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(54) **LIGHT-EMITTING DEVICE INCLUDING HETEROCYCLIC COMPOUND, ELECTRONIC APPARATUS AND ELECTRONIC EQUIPMENT INCLUDING THE LIGHT-EMITTING DEVICE, AND THE HETEROCYCLIC COMPOUND**

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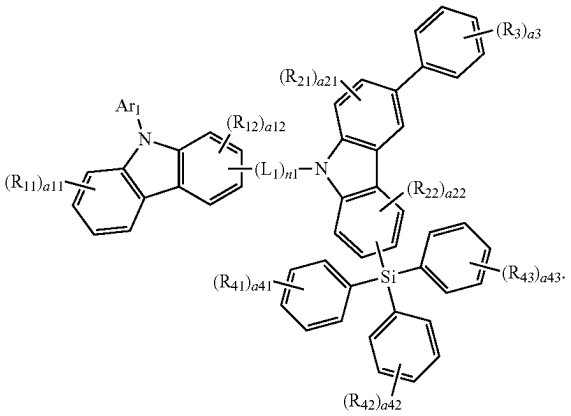
(57) **ABSTRACT**

Embodiments provide a heterocyclic compound, a light-emitting device including the heterocyclic compound, an electronic apparatus including the light-emitting device, and an electronic equipment including the light-emitting device. The heterocyclic compound is represented by Formula 1, which is explained in the specification:

[Formula 1]



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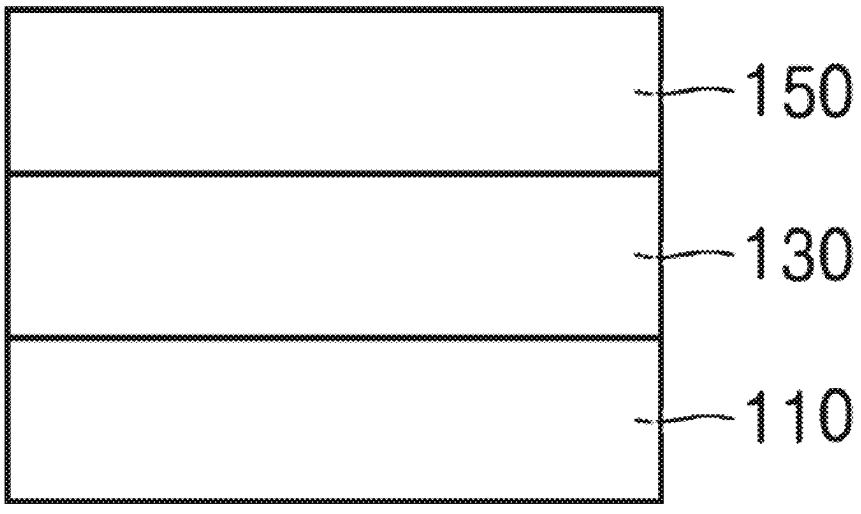

FIG. 1

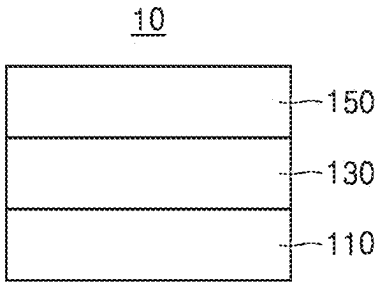

FIG. 2

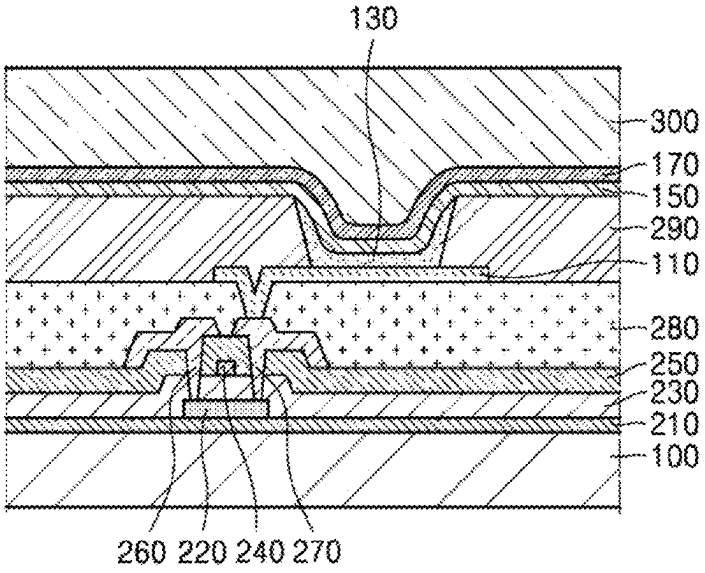
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FIG. 3

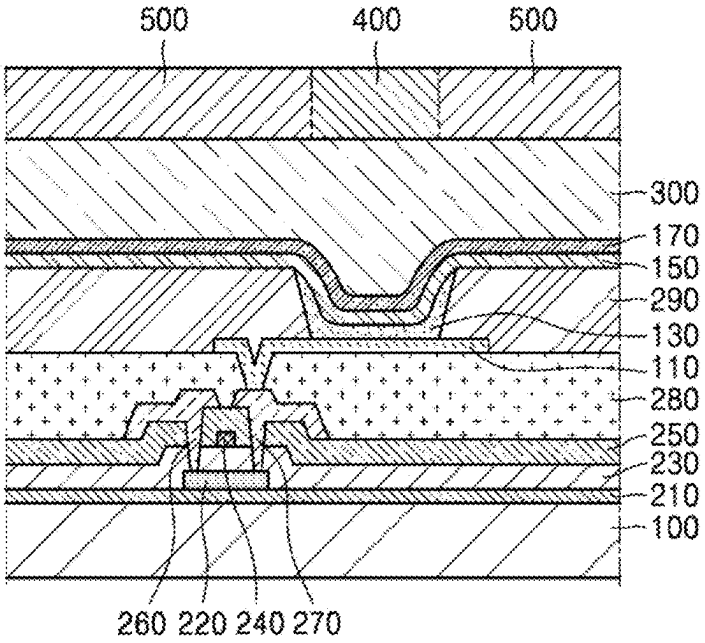
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FIG. 4

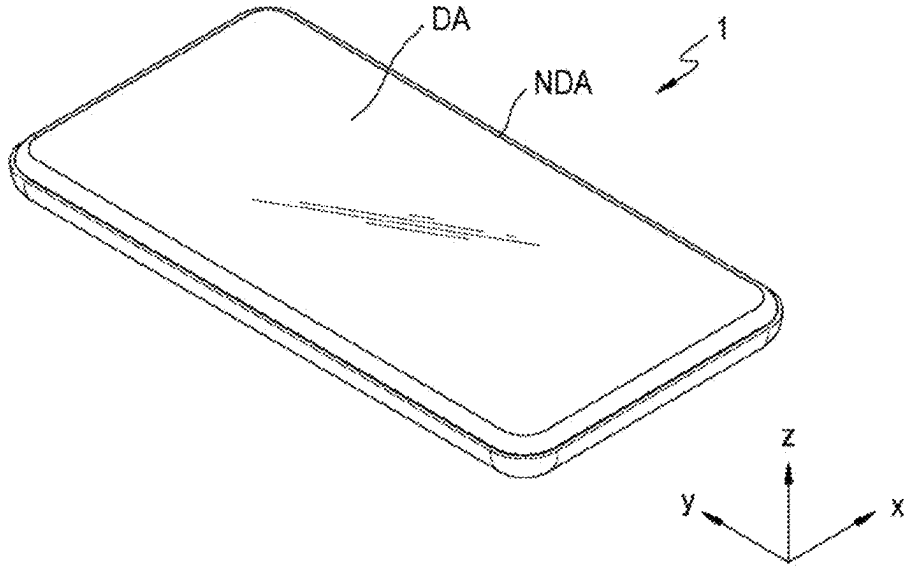

FIG. 5

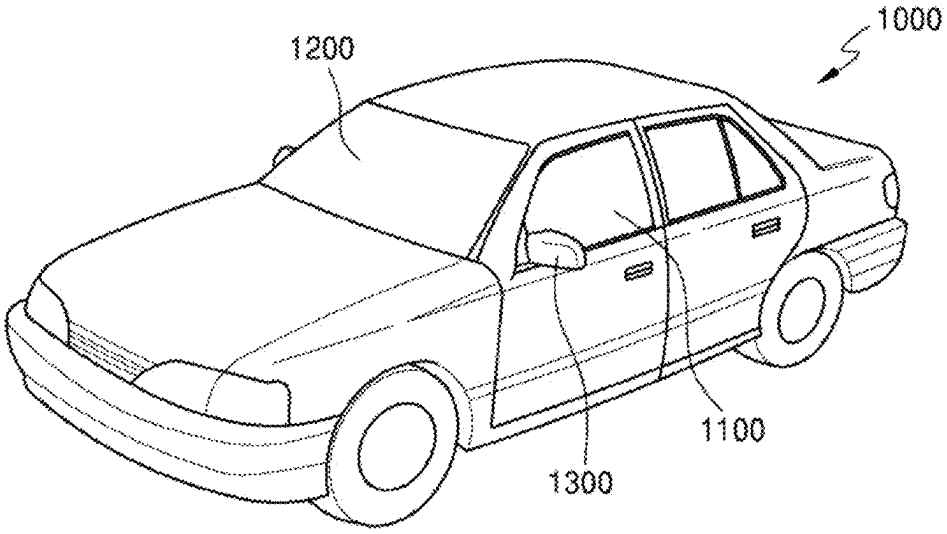

FIG. 6A

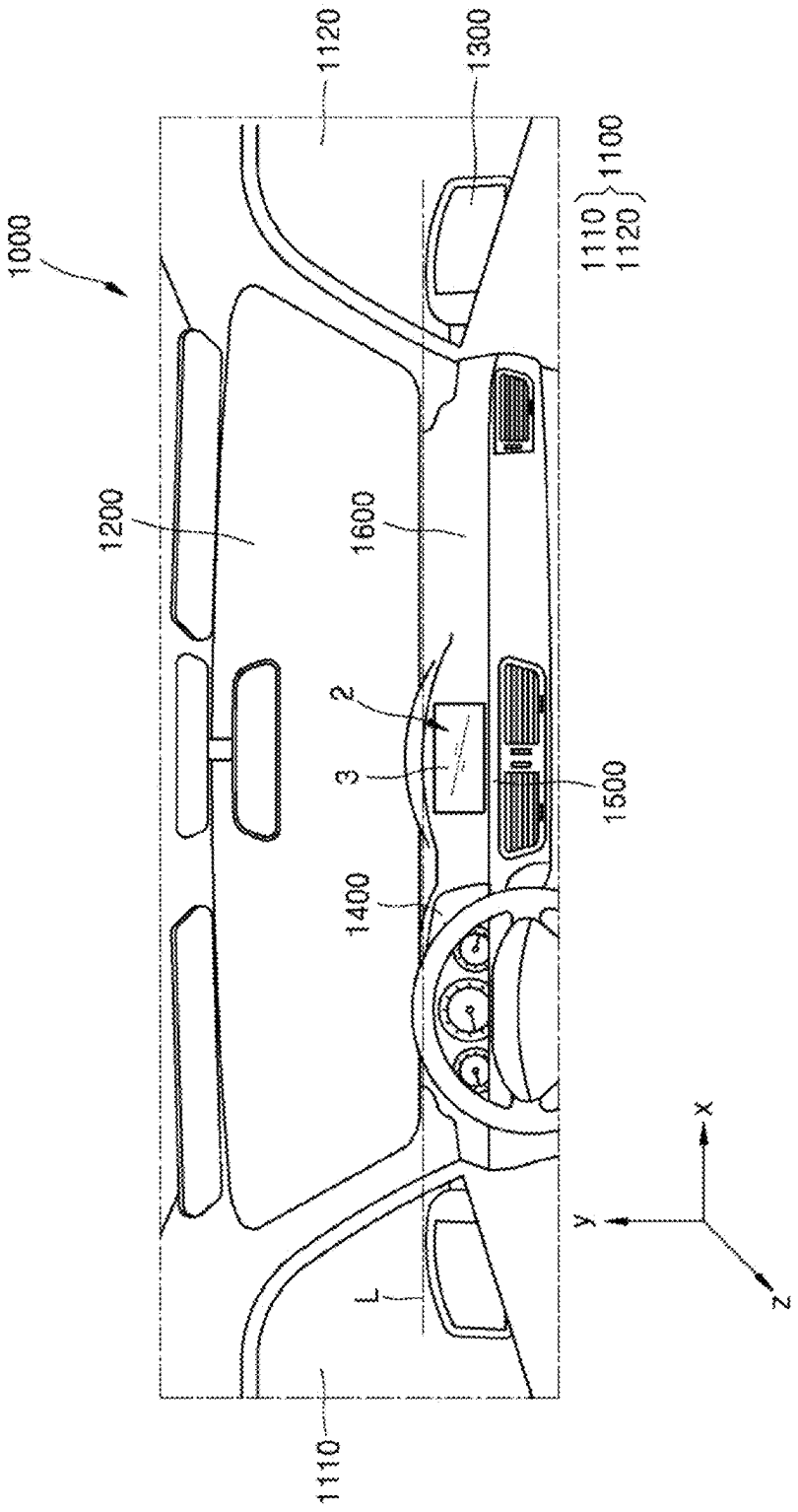
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FIG. 6B

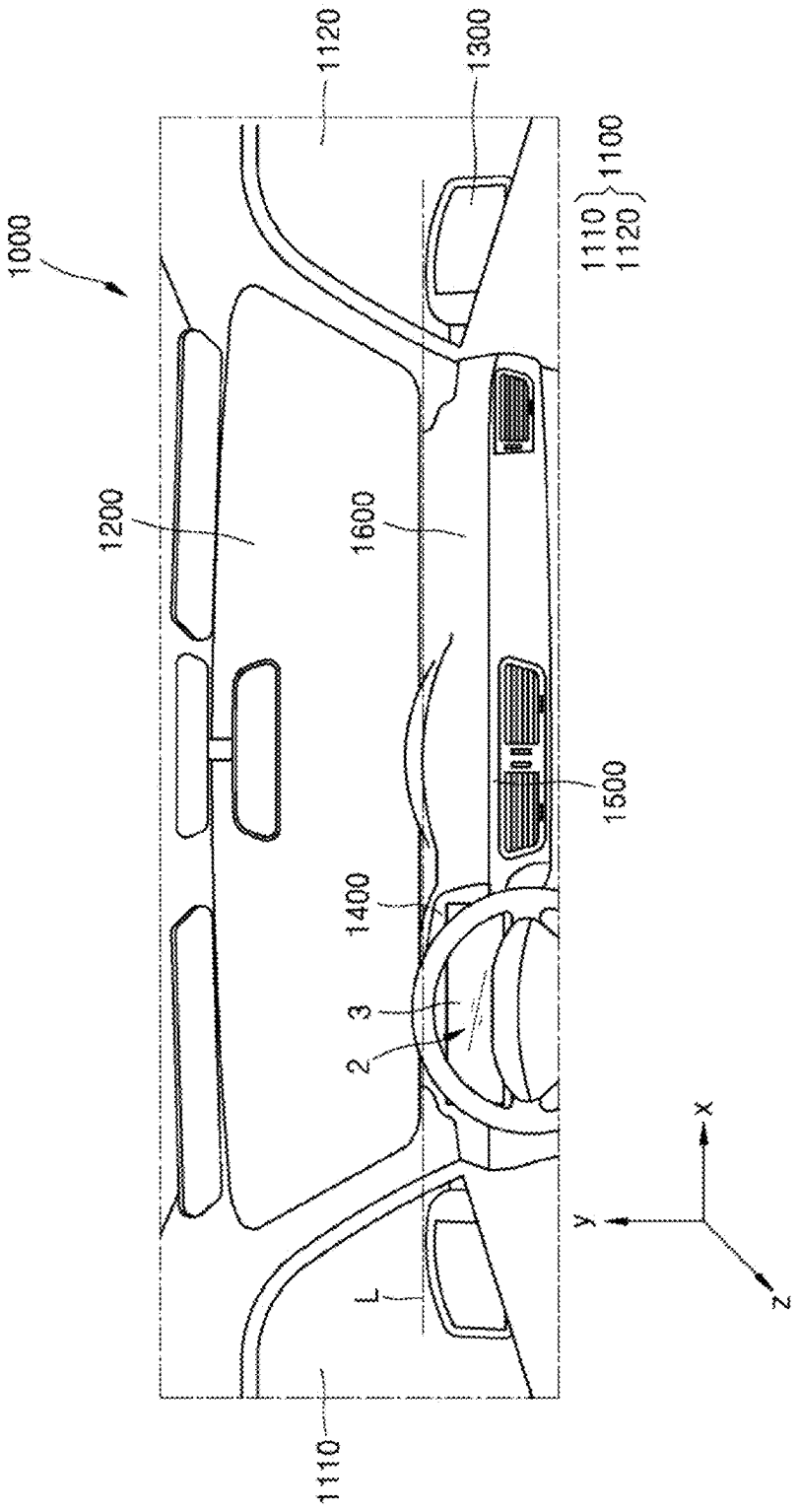
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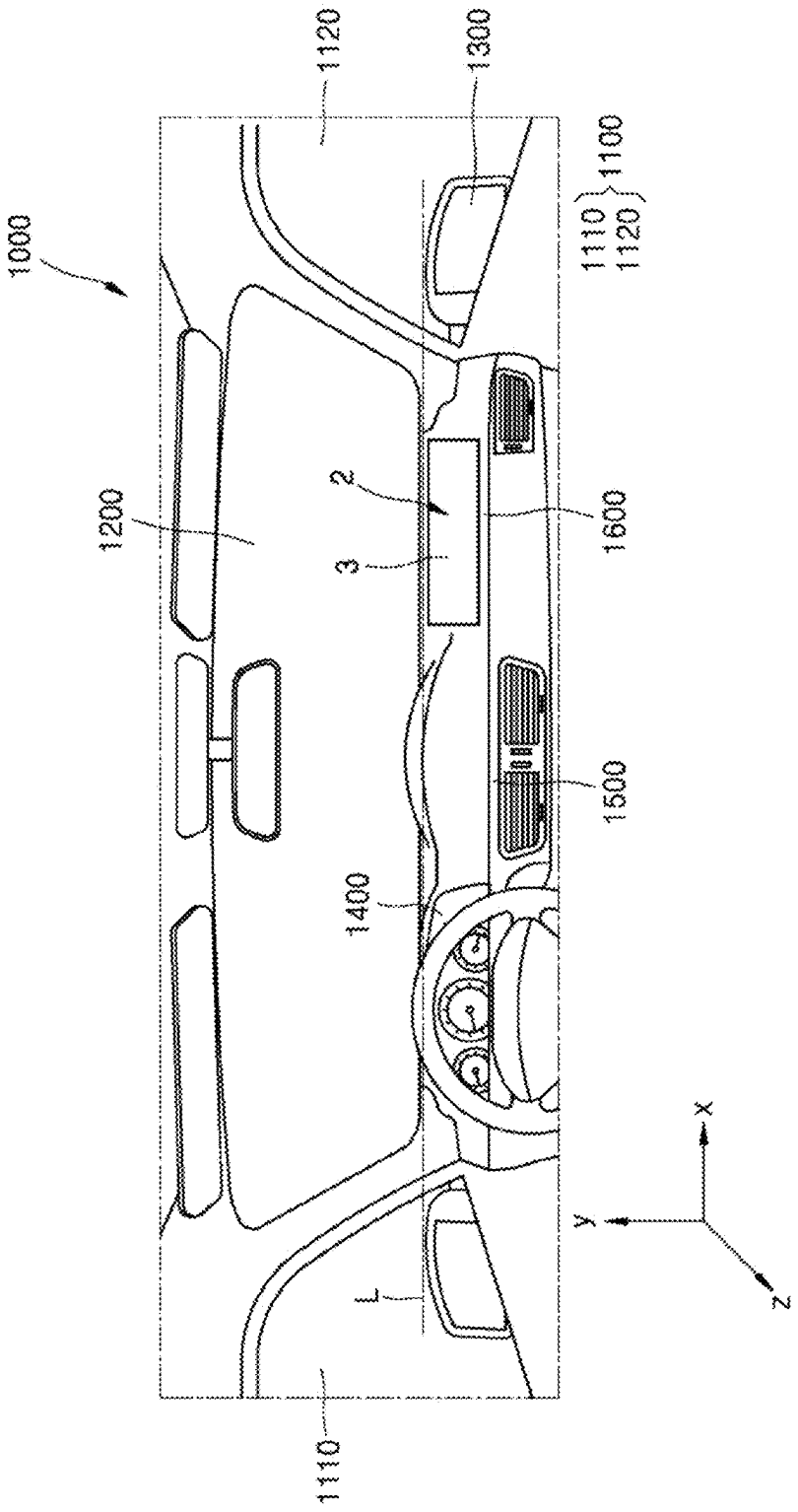
FIG. 6C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LIGHT-EMITTING DEVICE INCLUDING HETEROCYCLIC COMPOUND, ELECTRONIC APPARATUS AND ELECTRONIC EQUIPMENT INCLUDING THE LIGHT-EMITTING DEVICE, AND THE HETEROCYCLIC COMPOUND

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims priority to and benefits of Korean Patent Application No. 10-2024-0020667 under 35 U.S.C. § 119, filed on Feb. 13, 2024, in the Korean Intellectual Property Office, the entire contents of which are incorporated herein by reference.

BACKGROUND

1. Technical Field

[0002] Embodiments relate to a light-emitting device including a heterocyclic compound, an electronic apparatus including the light-emitting device, an electronic equipment including the light-emitting device, and the heterocyclic compound.

2. Description of the Related Art

[0003] Light-emitting devices are self-emissive devices that have wide viewing angles, high contrast ratios, short response times, and excellent characteristics in terms of luminance, driving voltage, and response speed.

[0004] In a light-emitting device, a first electrode may be located on a substrate, and a hole transport region, an emission layer, an electron transport region, and a second electrode may be sequentially arranged on the first electrode. Holes provided from the first electrode move toward the emission layer through the hole transport region, and electrons provided from the second electrode move toward the emission layer through the electron transport region. Carriers, such as holes and electrons, recombine in the emission layer to produce excitons. These excitons transition from an excited state to a ground state to thereby generate light.

[0005] It is to be understood that this background of the technology section is, in part, intended to provide useful background for understanding the technology. However, this background of the technology section may also include ideas, concepts, or recognitions that were not part of what was known or appreciated by those skilled in the pertinent art prior to a corresponding effective filing date of the subject matter disclosed herein.

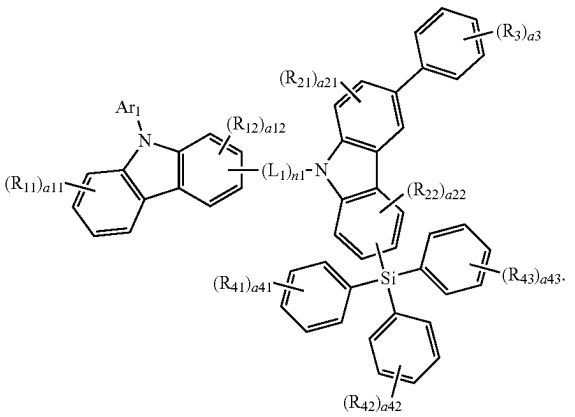
SUMMARY

[0006] Embodiments include a light-emitting device including a heterocyclic compound, an electronic apparatus and electronic equipment each including the light-emitting device, and the heterocyclic compound.

[0007] Additional aspects will be set forth in part in the description which follows and, in part, will be apparent from the description, or may be learned by practice of the embodiments of the disclosure.

[0008] According to embodiments, a light-emitting device may include a first electrode, a second electrode facing the first electrode, an interlayer between the first electrode and the second electrode and including an emission layer, and a heterocyclic compound represented by Formula 1:

[Formula 1]



[0009] In Formula 1,

[0010] R_{11}, R_{12}, R_{21}, R_{22}, R_3, and R_{41} to R_{43} may each independently be hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{60} alkyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} alkenyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} alkynyl group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} alkoxy group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} alkylthio group unsubstituted or substituted with at least one R_{10a}, a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}, a C_6-C_{60} aryloxy group unsubstituted or substituted with at least one R_{10a}, a C_6-C_{60} arylthio group unsubstituted or substituted with at least one R_{10a}, $—C(Q_1)(Q_2)(Q_3)$, $—Si(Q_1)(Q_2)(Q_3)$, $—N(Q_1)(Q_2)$, $—B(Q_1)(Q_2)$, $—C(=O)(Q_1)$, $—S(=O)_2(Q_1)$, or $—P(=O)(Q_1)(Q_2)$,

[0011] a11 may be an integer from 1 to 4,

[0012] a12, a21, and a22 may each independently be an integer from 1 to 3,

[0013] a3 and a41 to a43 may each independently be an integer from 1 to 5,

[0014] L_1 may be a single bond, a C_5-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, or a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a},

[0015] n1 may be an integer from 1 to 3,

[0016] Ar_1 may be a C_5-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}, $—C(Q_1)(Q_2)(Q_3)$, $—Si(Q_1)(Q_2)(Q_3)$, $—N(Q_1)(Q_2)$, or $—B(Q_1)(Q_2)$,

[0017] R_{10a} may be:

[0018] deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, or a nitro group;

[0019] a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, or a C_1-C_{60} alkoxy group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_5-C_{60} carbocyclic group, a C_1-C_{60} heterocyclic group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, $—Si(Q_{11})(Q_{12})(Q_{13})$, $—N(Q_{11})(Q_{12})$, $—B(Q_{11})$

(Q_{12}), —C(=O)(Q_{11}), —S(=O)$_2$(Q_{11}), —P(=O)(Q_{11})(Q_{12}), or any combination thereof;

[0020] a C_3-C_{60} carbocyclic group, a C_1-C_{60} heterocyclic group, a C_6-C_{60} aryloxy group, or a C_6-C_{60} arylthio group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_5-C_{60} carbocyclic group, a C_1-C_{60} heterocyclic group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, —Si(Q_{21})(Q_{22})(Q_{23}), —N(Q_{21})(Q_{22}), —B(Q_{21})(Q_{22}), —C(=O)(Q_{21}), —S(=O)$_2$(Q_{21}), —P(=O)(Q_{21})(Q_{22}), or any combination thereof; or

[0021] —Si(Q_{31})(Q_{32})(Q_{33}), —N(Q_{31})(Q_{32}), —B(Q_{31})(Q_{32}), —C(=O)(Q_{31}), —S(=O)$_2$(Q_{31}), or —P(=O)(Q_{31})(Q_{32}), and

[0022] Q_1 to Q_3, Q_{11} to Q_{13}, Q_{21} to Q_{23}, and Q_{31} to Q_{33} may each independently be: hydrogen; deuterium; —F; —Cl; —Br; —I; a hydroxyl group; a cyano group; a nitro group; a C_1-C_{60} alkyl group; a C_2-C_{60} alkenyl group; a C_2-C_{60} alkynyl group; a C_1-C_{60} alkoxy group; or a C_3-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group, each unsubstituted or substituted with deuterium, —F, a cyano group, a C_1-C_{60} alkyl group, a C_1-C_{60} alkoxy group, a phenyl group, a biphenyl group, or any combination thereof.

[0023] In an embodiment, the emission layer may include the heterocyclic compound; the emission layer may further include a transition metal-containing compound, a delayed fluorescence compound, or any combination thereof; and the heterocyclic compound, the transition metal-containing compound, and the delayed fluorescence compound may be different from each other.

[0024] In an embodiment, the emission layer may include the heterocyclic compound; the emission layer may further include a second compound including at least one TT electron-deficient nitrogen-containing C_1-C_{60} heterocyclic group; and the second compound may be different from the heterocyclic compound.

[0025] In an embodiment, the emission layer may include a host and a dopant, and the host may include the heterocyclic compound.

[0026] In an embodiment, the emission layer may emit blue light.

[0027] According to embodiments, an electronic apparatus may include the light-emitting device.

[0028] In an embodiment, the electronic apparatus may further include a thin-film transistor, wherein the thin-film transistor may include a source electrode and a drain electrode, and the first electrode of the light-emitting device may be electrically connected to at least one of the source electrode and the drain electrode.

[0029] In an embodiment, the electronic apparatus may further include a color filter, a color conversion layer, a touch screen layer, a polarizing layer, or any combination thereof.

[0030] According to embodiments, an electronic equipment may include the light-emitting device.

[0031] In an embodiment, the electronic equipment may be a flat panel display, a curved display, a computer monitor, a medical monitor, a television, a billboard, an indoor light, an outdoor light, a signal light, a head-up display, a fully transparent display, a partially transparent display, a flexible display, a rollable display, a foldable display, a stretchable display, a laser printer, a telephone, a mobile phone, a tablet computer, a phablet, a personal digital assistant (PDA), a wearable device, a laptop computer, a digital camera, a camcorder, a viewfinder, a micro display, a three-dimensional (3D) display, a virtual reality display, an augmented reality display, a vehicle, a video wall with multiple displays tiled together, a theater screen, a stadium screen, a phototherapy device, or a signboard.

[0032] According to embodiments, a heterocyclic compound may be represented by Formula 1, which is explained herein.

[0033] In an embodiment, R_{11}, R_{12}, R_{21}, R_{22}, R_3, and R_{41} to R_{43} may each independently be:

[0034] hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, or a C_1-C_{20} alkoxy group;

[0035] a C_1-C_{20} alkyl group or a C_1-C_{20} alkoxy group, each substituted with deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{10} alkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, or any combination thereof;

[0036] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azafluorenyl group, or an azadibenzosilolyl group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl

group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzosilolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, $—O(Q_{31})$, $—S(Q_{31})$, $—Si(Q_{31})(Q_{32})(Q_{33})$, $—N(Q_{31})(Q_{32})$, $—B(Q_{31})(Q_{32})$, $—P(Q_{31})(Q_{32})$, $—C(=O)(Q_{31})$, $—S(=O)_2(Q_{31})$, $—P(=O)(Q_{31})(Q_{32})$, or any combination thereof; or

[0037] $—C(Q_1)(Q_2)(Q_3)$, $—Si(Q_1)(Q_2)(Q_3)$, $—N(Q_1)(Q_2)$, $—B(Q_1)(Q_2)$, $—C(=O)(Q_1)$, $—S(=O)_2(Q_1)$, or $—P(=O)(Q_1)(Q_2)$, wherein Q_1 to Qs and Q_{31} to Q_{33} are explained below.

[0038] In an embodiment, at least one of R_{11}, R_{12}, R_{21}, R_{22}, R_3, and R_{41} to R_{43} may include at least one deuterium.

[0039] In an embodiment, R_{11}, R_{12}, R_{21}, R_{22}, R_3, and R_{41} to R_{43} may each include at least one deuterium.

[0040] In an embodiment, L_1 may be:

[0041] a single bond; or

[0042] a benzene group, a naphthalene group, an anthracene group, a phenanthrene group, a triphenylene group, a pyrene group, a chrysene group, a cyclopentadiene group, a furan group, a thiophene group, a silole group, an indene group, a fluorene group, an indole group, a carbazole group, a benzofuran group, a dibenzofuran group, a benzothiophene group, a dibenzothiophene group, a benzosilole group, a dibenzosilole group, an azafluorene group, an azacarbazole group, an azadibenzofuran group, an azadibenzothiophene group, an azadibenzosilole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a quinoxaline group, a quinazoline group, a phthalazine group, a phenanthroline group, a pyrrole group, a pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, a thiazole group, an isothiazole group, an oxadiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a benzoxazole group, a benzothiazole group, a benzoxadiazole group, a benzothiadiazole group, a dibenzooxasiline group, a dibenzothiasiline group, a dibenzodihydroazasiline group, a dibenzodihydrodisiline group, a dibenzodihydrosiline group, a dibenzodioxine group, a dibenzooxathiine group, a dibenzooxazine group, a dibenzopyran group, a dibenzodithiine group, a dibenzothiazine group, a dibenzothiopyran group, a dibenzocyclohexadiene group, a dibenzodihydropyridine group, or a dibenzodihydropyrazine group, each unsubstituted or substituted with at least one R_{10a}, which is explained herein.

[0043] In an embodiment, L_1 may be:

[0044] a single bond; or

[0045] a group represented by one of Formulae L(1) to L(24), which are explained below.

[0046] In an embodiment, Ar_1 may be a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzosilolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, $—O(Q_{31})$, $—S(Q_{31})$, $—Si(Q_{31})(Q_{32})(Q_{33})$, $—N(Q_{31})(Q_{32})$, $—B(Q_{31})(Q_{32})$, $—P(Q_{31})(Q_{32})$, $—C(=O)(Q_{31})$, $—S(=O)_2(Q_{31})$, $—P(=O)(Q_{31})(Q_{32})$, or any combination thereof, wherein Q_{31} to Q_{33} are explained below.

[0047] In an embodiment, Ar_1 may include at least one deuterium.

[0048] In an embodiment, the heterocyclic compound represented by Formula 1 may be represented by one of Formulae 1-1 to 1-8, which are explained below.

[0049] In an embodiment, the heterocyclic compound may be one of Compounds 1 to 153, which are explained below.

[0050] It is to be understood that the embodiments above are described in a generic and explanatory sense only and not for the purposes of limitation, and the disclosure is not limited to the embodiments described above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0051] The accompanying drawings are included to provide a further understanding of the embodiments, and are incorporated in and constitute a part of this specification. The drawings illustrate embodiments of the disclosure and principles thereof. The above and other aspects and features of the disclosure will become more apparent by describing in detail embodiments thereof with reference to the accompanying drawings, in which:

[0052] FIG. **1** is a schematic cross-sectional view of a light-emitting device according to an embodiment;

[0053] FIG. **2** is a schematic cross-sectional view of an electronic apparatus according to an embodiment;

[0054] FIG. **3** is a schematic cross-sectional view of an electronic apparatus according to another embodiment;

[0055] FIG. **4** is a schematic perspective view of an electronic equipment including a light-emitting device according to an embodiment;

[0056] FIG. **5** is a schematic perspective view of an exterior of a vehicle as an electronic equipment including a light-emitting device according to an embodiment; and

[0057] FIGS. **6**A, **6**B, and **6**C are each a schematic diagram of an interior of a vehicle according to embodiments.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0058] The disclosure will now be described more fully hereinafter with reference to the accompanying drawings, in which embodiments are shown. This disclosure may, however, be embodied in different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the disclosure to those skilled in the art.

[0059] In the drawings, the sizes, thicknesses, ratios, and dimensions of the elements may be exaggerated for ease of description and for clarity. Like reference numbers and reference characters refer to like elements throughout.

[0060] In the specification, it will be understood that when an element (or region, layer, part, etc.) is referred to as being "on", "connected to", or "coupled to" another element, it can be directly on, connected to, or coupled to the other element, or one or more intervening elements may be present therebetween. In a similar sense, when an element (or region, layer, part, etc.) is described as "covering" another element, it can directly cover the other element, or one or more intervening elements may be present therebetween.

[0061] In the specification, when an element is "directly on", "directly connected to", or "directly coupled to" another element, there are no intervening elements present. For example, "directly on" may mean that two layers or two elements are disposed without an additional element such as an adhesion element therebetween.

[0062] In the specification, the expressions used in the singular such as "a", "an", and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise.

[0063] In the specification, the term "and/or" includes any and all combinations of one or more of the associated listed items. For example, "A and/or B" may be understood to mean "A, B, or A and B". The terms "and" and "or" may be used in the conjunctive or disjunctive sense and may be understood to be equivalent to "and/or".

[0064] In the specification and the claims, the term "at least one of" is intended to include the meaning of "at least one selected from the group consisting of" for the purpose of its meaning and interpretation. For example, "at least one of A, B, and C" may be understood to mean A only, B only, C only, or any combination of two or more of A, B, and C, such as ABC, ACC, BC, or CC. When preceding a list of elements, the term, "at least one of", modifies the entire list of elements and does not modify the individual elements of the list.

[0065] It will be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another element. Thus, a first element could be termed a second element without departing from the teachings of the disclosure. Similarly, a second element could be termed a first element, without departing from the scope of the disclosure.

[0066] The spatially relative terms "below", "beneath", "lower", "above", "upper", or the like, may be used herein for ease of description to describe the relations between one element or component and another element or component as illustrated in the drawings. It will be understood that the spatially relative terms are intended to encompass different orientations of the device in use or operation, in addition to the orientation depicted in the drawings. For example, in the case where a device illustrated in the drawing is turned over, the device positioned "below" or "beneath" another device may be placed "above" another device. Accordingly, the illustrative term "below" may include both the lower and upper positions. The device may also be oriented in other directions and thus the spatially relative terms may be interpreted differently depending on the orientations.

[0067] The terms "about" or "approximately" as used herein is inclusive of the stated value and means within an acceptable range of deviation for the recited value as determined by one of ordinary skill in the art, considering the measurement in question and the error associated with measurement of the recited quantity (i.e., the limitations of the measurement system). For example, "about" may mean within one or more standard deviations, or within +20%, +10%, or +5% of the stated value.

[0068] It should be understood that the terms "comprises", "comprising", "includes", "including", "have", "having", "contains", "containing", and the like are intended to specify the presence of stated features, integers, steps, operations, elements, components, or combinations thereof in the disclosure, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, or combinations thereof.

[0069] Unless otherwise defined or implied herein, all terms (including technical and scientific terms) used have the same meaning as commonly understood by those skilled in the art to which this disclosure pertains. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and should not be interpreted in an ideal or excessively formal sense unless clearly defined in the specification.

[0070] According to embodiment, a light-emitting device may include:

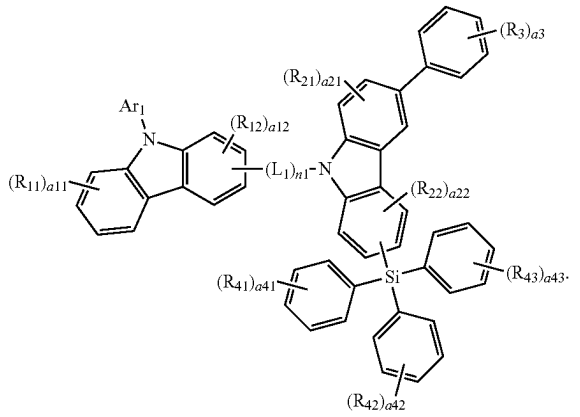
[0071] a first electrode;

[0072] a second electrode facing the first electrode;

[0073] an interlayer between the first electrode and the second electrode and including an emission layer; and

[0074] a heterocyclic compound represented by Formula 1:

[Formula 1]



[0075] Formula 1 is further described in the specification below.

[0076] In an embodiment, the first electrode of the light-emitting device may be an anode,

[0077] the second electrode of the light-emitting device may be a cathode,

[0078] the interlayer may further include a hole transport region between the first electrode and the emission layer, and an electron transport region between the emission layer and the second electrode,

[0079] the hole transport region may include a hole injection layer, a hole transport layer, an emission auxiliary layer, an electron blocking layer, or any combination thereof, and

[0080] the electron transport region may include a hole blocking layer, an electron transport layer, an electron injection layer, or any combination thereof.

[0081] In embodiments, the electron transport region of the light-emitting device may include a hole blocking layer, and the hole blocking layer may include a phosphine oxide-containing compound, a silicon-containing compound, or any combination thereof. In an embodiment, the hole blocking layer may contact (for example, directly contact) the emission layer.

[0082] In an embodiment, the interlayer may include the heterocyclic compound.

[0083] In an embodiment, the emission layer may include the heterocyclic compound.

[0084] In an embodiment, the emission layer may further include a transition metal-containing compound, a delayed fluorescence compound, or any combination thereof. In the emission layer, the heterocyclic compound, the transition metal-containing compound, and the delayed fluorescence compound may be different from each other.

[0085] In an embodiment, the emission layer may further include a second compound including at least one π electron-deficient nitrogen-containing C_1-C_{60} heterocyclic group. In the emission layer, the second compound may be different from the heterocyclic compound.

[0086] In an embodiment, the emission layer may further include, in addition to the heterocyclic compound, the transition metal-containing compound, the delayed fluorescence compound, and the second compound. In the emission layer, the heterocyclic compound, the transition metal-containing compound, the delayed fluorescence compound, and the second compound may be different from each other.

[0087] In an embodiment, the emission layer may further include a light-emitting material.

[0088] In an embodiment, the light-emitting material may include a transition metal-containing compound, a delayed fluorescence compound, or any combination thereof. In the light-emitting material, the heterocyclic compound, the transition metal-containing compound, and the delayed fluorescence compound may be different from each other.

[0089] In an embodiment, the light-emitting material may further include a second compound including at least one IT electron-deficient nitrogen-containing C_1-C_{60} heterocyclic group. In the light-emitting material, the second compound may be different from the heterocyclic compound.

[0090] In an embodiment, the light-emitting material may further include, in addition to the heterocyclic compound, the transition metal-containing compound, the delayed fluorescence compound, and the second compound. In the light-emitting material, the heterocyclic compound, the transition metal-containing compound, the delayed fluorescence compound, and the second compound may be different from each other.

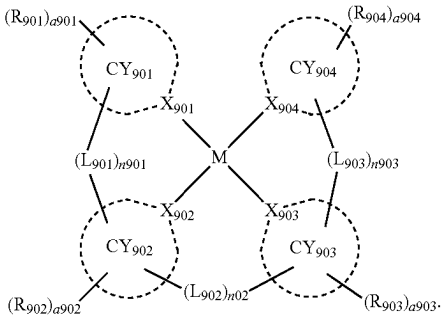
[0091] In an embodiment, the transition metal-containing compound may include platinum (Pt).

[0092] In an embodiment, the transition metal-containing compound may include platinum (Pt) and a tetradentate ligand bonded to the platinum, and the platinum and one of carbon atoms of the tetradentate ligand may be bonded via a coordinate bond.

[0093] In an embodiment, the transition metal-containing compound may be a carbene-containing compound.

[0094] In an embodiment, the transition metal-containing compound may be represented by Formula 3:

[Formula 3]



[0095] Formula 3 is further described in the specification below.

[0096] In an embodiment, the delayed fluorescence compound may be a compound including at least one cyclic group including boron (B) and nitrogen (N) as ring-forming atoms. The delayed fluorescence compound may improve color purity, luminescence efficiency, and lifespan characteristics of the light-emitting device.

[0097] In an embodiment, a difference between a triplet energy level (eV) of the delayed fluorescence compound and a singlet energy level (eV) of the delayed fluorescence compound may be in a range of about 0 eV to about 0.5 eV (for example, in a range of about 0 eV to about 0.3 eV).

[0098] In embodiments, the delayed fluorescence compound may be a C_8-C_{60} polycyclic group-containing compound in which two or more cyclic groups are condensed while sharing boron (B).

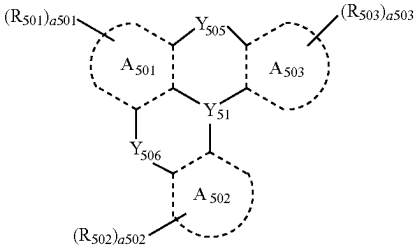
[0099] In embodiments, the delayed fluorescence compound may include a condensed cyclic moiety in which at least one third ring is condensed with at least one fourth ring,

[0100] the third ring may be a cyclopentane group, a cyclohexane group, a cycloheptane group, a cyclooctane group, a cyclopentene group, a cyclohexene group, a cycloheptene group, a cyclooctene group, an adamantane group, a norbornene group, a norbornane group, a bicyclo[1.1.1]pentane group, a bicyclo[2.1.1]hexane group, a bicyclo[2.2.2]octane group, a benzene group, a pyridine group, a pyrimidine group, a pyridazine group, a pyrazine group, or a triazine group, and

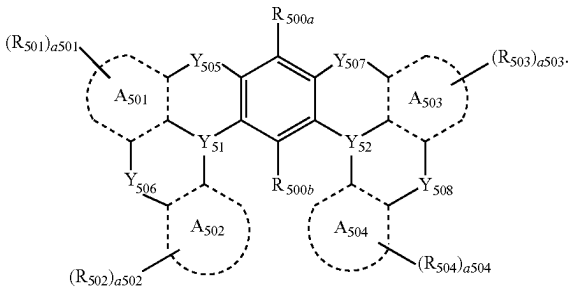
[0101] the fourth ring may be a 1,2-azaborinine group, a 1,3-azaborinine group, a 1,4-azaborinine group, a 1,2-dihydro-1,2-azaborinine group, a 1,4-oxaborinine group, a 1,4-thiaborinine group, or a 1,4-dihydroborinine group.

[0102] In an embodiment, the delayed fluorescence compound may include a compound represented by Formula 502, a group represented by Formula 503, or any combination thereof:

[Formula 502]



[Formula 503]



[0103] In Formulae 502 and 503,

[0104] ring A_{501} to ring A_{504} may each independently be a C_3-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group,

[0105] Y_{505} may be O, S, $N(R_{505})$, $B(R_{505})$, $C(R_{505a})(R_{505b})$, or $Si(R_{505a})(R_{505b})$,

[0106] Y_{506} may be O, S, $N(R_{506})$, $B(R_{506})$, $C(R_{506a})(R_{506b})$, or $Si(R_{506a})(R_{506b})$,

[0107] Y_{507} may be O, S, $N(R_{507})$, $B(R_{507})$, $C(R_{507a})(R_{507b})$, or $Si(R_{507a})(R_{507b})$,

[0108] Y_{508} may be O, S, $N(R_{508})$, $B(R_{508})$, $C(R_{508a})(R_{508b})$, or $Si(R_{508a})(R_{508b})$,

[0109] Y_{51} and Y_{52} may each independently be B, P(=O), or S(=O),

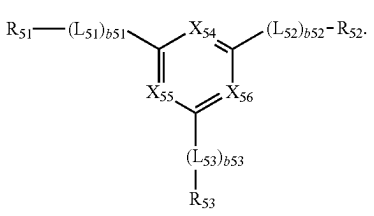
[0110] R_{500a}, R_{500b}, R_{501} to R_{508}, R_{505a}, R_{505b}, R_{506a}, R_{506b}, R_{507a}, R_{507b}, R_{508a}, and R_{508b} are each the same as described in the specification, and

[0111] a501 to a504 may each independently be an integer from 0 to 20.

[0112] In an embodiment, the second compound may include a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, or any combination thereof.

[0113] In embodiments, the second compound may include a compound represented by Formula 2:

[Formula 2]



[0114] In Formula 2,

[0115] L_{51} to L_{53} may each independently be a single bond, a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, or a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a},

[0116] b51 to b53 may each independently be an integer from 1 to 5,

[0117] X_{54} may be N or $C(R_{54})$, X_{55} may be N or $C(R_{55})$, X_{56} may be N or $C(R_{56})$, and at least one of X_{54} to X_{56} may each be N, and

[0118] R_{51} to R_{56} and R_{10a} are respectively the same as described in the specification.

[0119] The heterocyclic compound, the transition metal-containing compound, and the delayed fluorescence compound, and the second compound are each as described herein.

[0120] In an embodiment, the heterocyclic compound, the transition metal-containing compound, the delayed fluorescence compound, the second compound, or any combination thereof may each independently include at least one deuterium.

[0121] For example, the heterocyclic compound may include at least one deuterium.

[0122] For example, the transition metal-containing compound, the delayed fluorescence compound, the second compound, or any combination thereof may each include at least one deuterium.

[0123] In an embodiment, the heterocyclic compound may include at least one silicon.

[0124] In an embodiment, the second compound may include at least one silicon.

[0125] In an embodiment, the light-emitting device (e.g., an emission layer in the light-emitting device) may further include the transition metal-containing compound, in addition to the heterocyclic compound. At least one of the heterocyclic compound and the transition metal-containing compound may each independently include at least one deuterium.

[0126] In an embodiment, the light-emitting device (e.g., an emission layer in the light-emitting device) may further include the delayed fluorescence compound, in addition to the heterocyclic compound, and at least one of the heterocyclic compound and the transition metal-containing compound may each independently include at least one deuterium.

[0127] In an embodiment, the light-emitting device (e.g., an emission layer in the light-emitting device) may further include the transition metal-containing compound and the delayed fluorescence compound, in addition to the heterocyclic compound, and at least one of the heterocyclic compound, the transition metal-containing compound, and the delayed fluorescence compound may each independently include at least one deuterium.

[0128] In an embodiment, the light-emitting device (e.g., an emission layer in the light-emitting device) may further include the second compound, in addition to the heterocyclic compound, and at least one of the heterocyclic compound and the second compound may each independently include at least one deuterium.

[0129] In an embodiment, the light-emitting device (e.g., an emission layer in the light-emitting device) may further include the transition metal-containing compound, the delayed fluorescence compound, and the second compound, in addition to the heterocyclic compound, and at least one of the heterocyclic compound, the transition metal-containing compound, the delayed fluorescence compound, and the second compound may each independently include at least one deuterium.

[0130] In an embodiment, the heterocyclic compound and the second compound may form an exciplex. The heterocyclic compound and the second compound may each independently include at least one deuterium.

[0131] In an embodiment, the emission layer of the light-emitting device may include: the heterocyclic compound and the second compound; and the transition metal-containing compound or the delayed fluorescence compound.

[0132] In an embodiment, the emission layer may include a host and a dopant, and the host may include the heterocyclic compound. For example, the heterocyclic compound may serve as a host.

[0133] In an embodiment, the emission layer may emit blue light. The blue light may have a maximum emission wavelength in a range of, for example, about 430 nm to about 480 nm.

[0134] In an embodiment, the light emitted from the emission layer may have a maximum emission wavelength in a range of about 400 nm to about 500 nm. For example, the light emitted from the emission layer may have a maximum emission wavelength in a range of about 410 nm to about 490 nm, a range of about 420 nm to about 480 nm, a range of about 430 nm to about 475 nm, a range of about 440 nm to about 475 nm, a range of about 450 nm to about 475 nm, a range of about 430 nm to about 470 nm, a range of about 440 nm to about 470 nm, a range of about 450 nm to about 470 nm, a range of about 430 nm to about 465 nm, a range of about 440 nm to about 465 nm, a range of about 450 nm to about 465 nm, a range of about 430 nm to about 460 nm, a range of about 440 nm to about 460 nm, or a range of about 450 nm to about 460 nm.

[0135] In embodiments, the light-emitting device may satisfy at least one of Conditions 1 to 4:

[Condition 1]

[0136] lowest unoccupied molecular orbital (LUMO) energy level (eV) of heterocyclic compound >LUMO energy level (eV) of transition metal-containing compound;

[Condition 2]

[0137] LUMO energy level (eV) of transition metal-containing compound >LUMO energy level (eV) of second compound;

[Condition 3]

[0138] highest occupied molecular orbital (HOMO) energy level (eV) of transition metal-containing compound >HOMO energy level (eV) of heterocyclic compound; and

[Condition 4]

[0139] HOMO energy level (eV) of heterocyclic compound >HOMO energy level (eV) of second compound.

[0140] The HOMO energy level and the LUMO energy level of each of the heterocyclic compound, the second compound, and the transition metal-containing compound

may each be a negative value and may be measured according to a method of the related art.

[0141] In embodiments, an absolute value of a difference between a LUMO energy level of the transition metal-containing compound and a LUMO energy level of the second compound may be at least 0.1 eV but not more than to 1.0 eV; or an absolute value of a difference between a LUMO energy level of the transition metal-containing compound and a LUMO energy level of the heterocyclic compound may be at least 0.1 eV but not more than 1.0 eV. In embodiments, an absolute value of a difference between a HOMO energy level of the transition metal-containing compound and a HOMO energy level of the second compound may be equal to or less than 1.25 eV (e.g., at least 0.2 eV but not more than 1.25 eV); or an absolute value of a difference between a HOMO energy level of the transition metal-containing compound and a HOMO energy level of the heterocyclic compound may be equal to or less than 1.25 eV (e.g., at least 0.2 eV but not more than 1.25 eV).

[0142] When the relationships between LUMO energy level and HOMO energy level satisfy the conditions as described above, a balance between holes and electrons injected into the emission layer can be achieved.

[0143] The light-emitting device may have a structure according to a first embodiment or a second embodiment.

First Embodiment

[0144] According to a first embodiment, the heterocyclic compound may be included in the emission layer of the light-emitting device, wherein the emission layer may further include the transition metal-containing compound, and the emission layer may emit phosphorescence or fluorescence emitted from the transition metal-containing compound. Thus, according to the first embodiment, the heterocyclic compound may be a host, and the transition metal-containing compound may be a dopant or an emitter. For example, the transition metal-containing compound may be a phosphorescent dopant or a phosphorescent emitter.

[0145] The phosphorescence or fluorescence emitted from the transition metal-containing compound may be blue light.

[0146] The emission layer may further include an auxiliary dopant. The auxiliary dopant may improve luminescence efficiency by effectively transferring energy from the first compound to the transition metal-containing compound as a dopant or an emitter.

[0147] The auxiliary dopant may be different from the transition metal-containing compound and different from the heterocyclic compound.

[0148] In embodiments, the auxiliary dopant may be a delayed fluorescence-emitting compound.

[0149] In embodiments, the auxiliary dopant may be a compound including at least one cyclic group including boron (B) and nitrogen (N) as ring-forming atoms.

[0150] The emission layer may further include at least one host that is different from the heterocyclic compound, the transition metal-containing compound, and the auxiliary dopant. For example, the emission layer may further include the second compound as a host.

Second Embodiment

[0151] According to a second embodiment, the heterocyclic compound may be included in the emission layer of the light-emitting device, and the emission layer may further include a transition metal-containing compound and a dopant, wherein the heterocyclic compound, the transition metal-containing compound, and the dopant may be different from each other, and the emission layer may emit phosphorescence or fluorescence (e.g., delayed fluorescence) emitted from the dopant. Thus, according to the second embodiment, the heterocyclic compound may be a host, and the transition metal-containing compound may serve as an auxiliary dopant (rather than as a dopant), which transmits energy to a dopant (or emitter).

[0152] For example, in the second embodiment, the heterocyclic compound may be a host, and the transition metal-containing compound may serve as an emitter and may serve as an auxiliary dopant that transmits energy to a dopant (or emitter).

[0153] For example, phosphorescence or fluorescence emitted from the dopant (or the emitter) in the second embodiment may be blue phosphorescence or blue fluorescence (e.g., blue delayed fluorescence).

[0154] In the second embodiment, the dopant (or emitter) may be a phosphorescent dopant material (for example, the transition metal-containing compound as described herein) or a fluorescent dopant material (for example, a compound represented by Formula 501, a compound represented by Formula 502, a compound represented by Formula 503, or any combination thereof).

[0155] The emission layer may further include at least one host that is different from the heterocyclic compound, the transition metal-containing compound, and the dopant (or emitter). For example, the emission layer may further include the second compound as a host.

[0156] In the first and second embodiments, the blue light may have a maximum emission wavelength in a range of about 400 nm to about 500 nm. For example, the blue light may have a maximum emission wavelength in a range of about 410 nm to about 490 nm, in a range of about 420 nm to about 480 nm, in a range of about 430 nm to about 475 nm, in a range of about 440 nm to about 475 nm, in a range of about 450 nm to about 475 nm, in a range of about 430 nm to about 470 nm, in a range of about 440 nm to about 470 nm, in a range of about 450 nm to about 470 nm, in a range of about 430 nm to about 465 nm, in a range of about 440 nm to about 465 nm, in a range of about 450 nm to about 465 nm, in a range of about 430 nm to about 460 nm, in a range of about 440 nm to about 460 nm, or in a range of about 450 nm to about 460 nm.

[0157] The auxiliary dopant in the first embodiment may include, for example, the delayed fluorescence compound represented by Formula 502 or Formula 503.

[0158] The host in the first and second embodiments may further include any host material (for example, a compound represented by Formula 301, a compound represented by 301-1, a compound represented by Formula 301-2, or any combination thereof).

[0159] In an embodiment, the light-emitting device may further include a capping layer located outside the first electrode and/or outside the second electrode.

[0160] In embodiments, the light-emitting device may further include at least one of a first capping layer arranged outside the first electrode and a second capping layer arranged outside the second electrode, and the heterocyclic compound represented by Formula 1 may be included in at least one of the first capping layer and the second capping

layer. The first capping layer and the second capping layer are the same as described in the specification.

[0161] In an embodiment, the light-emitting device may further include:

[0162] a first capping layer located outside the first electrode and including the heterocyclic compound represented by Formula 1;

[0163] a second capping layer located outside the second electrode and including the heterocyclic compound represented by Formula 1; or

[0164] the first capping layer and the second capping layer.

[0165] The expression "(an interlayer and/or a capping layer) includes a heterocyclic compound represented by Formula 1" as used herein may include a case in which "(an interlayer and/or a capping layer) each includes an identical heterocyclic compound represented by Formula 1" and a case in which "(an interlayer and/or a capping layer) includes two or more different heterocyclic compounds each independently represented by Formula 1."

[0166] For example, the interlayer and/or the capping layer may include, as the heterocyclic compound, Compound 1 only. In this regard, Compound 1 may be present in the emission layer of the light-emitting device. In embodiments, the interlayer may include, as the heterocyclic compound, Compounds 1 and 2. In this regard, Compound 1 and Compound 2 may be present in a same layer (e.g., both Compound 1 and Compound 2 may be present in the emission layer), or may be present in different layers (e.g., Compound 1 may be present in the emission layer, and Compound 2 may be present in the electron transport region).

[0167] The term "interlayer" as used herein may refer to a single layer and/or all layers between the first electrode and the second electrode of the light-emitting device.

[0168] According to an embodiment, an electronic apparatus may include the light-emitting device. In an embodiment, the electronic apparatus may further include a thin-film transistor. In another embodiment, the electronic apparatus may further include a thin-film transistor including a source electrode and a drain electrode, and the first electrode of the light-emitting device may be electrically connected to at least one of the source electrode and the drain electrode. In an embodiment, the electronic apparatus may further include a color filter, a color conversion layer, a touch screen layer, a polarizing layer, or any combination thereof. The electronic apparatus may be as further described herein.

[0169] According to an embodiment, an electronic equipment may include the light-emitting device.

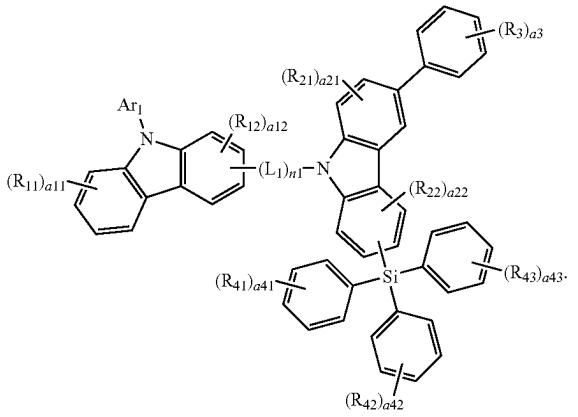
[0170] In an embodiment, the electronic equipment may be a flat panel display, a curved display, a computer monitor, a medical monitor, a television, a billboard, an indoor light, an outdoor light, a signal light, a head-up display, a fully transparent display, a partially transparent display, a flexible display, a rollable display, a foldable display, a stretchable display, a laser printer, a telephone, a mobile phone, a tablet computer, a phablet, a personal digital assistant (PDA), a wearable device, a laptop computer, a digital camera, a camcorder, a viewfinder, a micro display, a three-dimensional (3D) display, a virtual reality display, an augmented reality display, a vehicle, a video wall with multiple displays tiled together, a theater screen, a stadium screen, a phototherapy device, or a signboard.

[0171] According to an embodiment, a heterocyclic compound may be represented by Formula 1, which will be described below.

[0172] Synthesis methods of the heterocyclic compound may be recognizable by one of ordinary skill in the art by referring to the Synthesis Examples and/or the Examples below.

[Description of Formula 1]

[Formula 1]



[0173] In Formula 1, R_{11}, R_{12}, R_{21}, R_{22}, R_3, and R_{41} to R_{43} may each independently be hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{60} alkyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} alkenyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} alkynyl group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} alkoxy group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} alkylthio group unsubstituted or substituted with at least one R_{10a}, a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}, a C_6-C_{60} aryloxy group unsubstituted or substituted with at least one R_{10a}, a C_6-C_{60} arylthio group unsubstituted or substituted with at least one R_{10a}, $—C(Q_1)(Q_2)(Q_3)$, $—Si(Q_1)(Q_2)(Q_3)$, $—N(Q_1)(Q_2)$, $—B(Q_1)(Q_2)$, $—C(=O)(Q_1)$, $—S(=O)_2(Q_1)$, or $—P(=O)(Q_1)(Q_2)$.

[0174] In an embodiment, R_{11}, R_{12}, R_{21}, R_{22}, R_3, and R_{41} to R_{43} may each independently be:

[0175] hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, or a C_1-C_{20} alkoxy group;

[0176] a C_1-C_{20} alkyl group or a C_1-C_{20} alkoxy group, each substituted with deuterium, —F, —Cl, —Br, —I, $—CD_3$, $—CD_2H$, $—CDH_2$, $—CF_3$, $—CF_2H$, $—CFH_2$, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{10} alkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, or any combination thereof;

[0177] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl

group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azafluorenyl group, or an azadibenzosilolyl group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzosilolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, —$O(Q_{31})$, —$S(Q_{31})$, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$P(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, —$P(=O)(Q_{31})(Q_{32})$, or any combination thereof; or

[0178] —$C(Q_1)(Q_2)(Q_3)$, —$Si(Q_1)(Q_2)(Q_3)$, —$N(Q_1)(Q_2)$, —$B(Q_1)(Q_2)$, —$C(=O)(Q_1)$, —$S(=O)_2(Q_1)$, or —$P(=O)(Q_1)(Q_2)$, and

[0179] Q_1 to Q_3 and Q_{31} to Q_{33} may each independently be: hydrogen; deuterium; —F; —Cl; —Br; —I; a hydroxyl group; a cyano group; a nitro group; a C_1-C_{60} alkyl group; a C_2-C_{60} alkenyl group; a C_2-C_{60} alkynyl group; a C_1-C_{60} alkoxy group; or a C_3-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group, each unsubstituted or substituted with deuterium, —F, a cyano group, a C_1-C_{60} alkyl group, a C_1-C_{60} alkoxy group, a phenyl group, a biphenyl group, or any combination thereof.

[0180] In an embodiment, R_{11}, R_{12}, R_{21}, R_{22}, R_3, and R_{41} to R_{43} may each independently be:

[0181] hydrogen, deuterium, a cyano group, or a C_1-C_{20} alkyl group;

[0182] a C_1-C_{20} alkyl group unsubstituted or substituted with deuterium, a cyano group, —CD_3, —CD_2H, —CDH_2, a C_1-C_{10} alkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, or any combination thereof;

[0183] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a triazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, or an imidazopyrimidinyl group, each unsubstituted or substituted with deuterium, a cyano group, —CD_3, —CD_2H, —CDH_2, a C_1-C_{20} alkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a triazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, or any combination thereof; or

[0184] —$C(Q_1)(Q_2)(Q_3)$, —$Si(Q_1)(Q_2)(Q_3)$, or —$N(Q_1)(Q_2)$, and

[0185] Q_1 to Q_3 and Q_{31} to Q_{33} may each independently be: hydrogen; deuterium; a C_1-C_{10} alkyl group; a C_2-C_{10} alkenyl group; or a C_5-C_{20} carbocyclic group or a C_1-C_{20} heterocyclic group, each unsubstituted or substituted with deuterium, a C_1-C_{60} alkyl group, a phenyl group, a biphenyl group, or any combination thereof.

[0186] In an embodiment, at least one of R_{11}, R_{12}, R_{21}, R_{22}, R_3, and R_{41} to R_{43} may include at least one deuterium.

[0187] In an embodiment, R_{11}, R_{12}, R_{21}, R_{22}, R_3, and R_{41} to R_{43} may each include at least one deuterium.

[0188] In an embodiment, at least one of R_{11}, R_{12}, R_{21}, R_{22}, R_3, and R_{41} to R_{43} may each independently be:

[0189] deuterium;

[0190] a C_1-C_{20} alkyl group or a C_1-C_{20} alkoxy group substituted with at least one deuterium; or

[0191] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azafluorenyl group, or an azadibenzosilolyl group, each substituted with at least one deuterium.

[0192] In an embodiment, at least one of R_{11}, R_{12}, R_{21}, R_{22}, R_3, and R_{41} to R_{43} may each independently be:

[0193] deuterium;

[0194] a C_1-C_{20} alkyl group substituted with at least one deuterium; or

[0195] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a triazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, or an imidazopyrimidinyl group, each substituted with at least one deuterium.

[0196] In Formula 1, a11 indicates the number of R_{11}, and a11 may be an integer from 1 to 4.

[0197] In Formula 1, a12, a21, and a22 respectively indicate the numbers of R_{12}, R_{21}, and R_{22}, and a12, a21, and a22 may each independently be an integer from 1 to 3.

[0198] In Formula 1, a3 and a41 to a43 respectively indicate the numbers of R_3 and R_{41} to R_{43}, and a3 and a41 to a43 may each independently be an integer from 1 to 5.

[0199] In Formula 1, L_1 may be a single bond, a C_5-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, or a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}.

[0200] In an embodiment, L_1 may be:

[0201] a single bond; or

[0202] a benzene group, a naphthalene group, an anthracene group, a phenanthrene group, a triphenylene group, a pyrene group, a chrysene group, a cyclopentadiene group, a furan group, a thiophene group, a silole group, an indene group, a fluorene group, an indole group, a carbazole group, a benzofuran group, a dibenzofuran group, a benzothiophene group, a dibenzothiophene group, a benzosilole group, a dibenzosilole group, an azafluorene group, an azacarbazole group, an azadibenzofuran group, an azadibenzothiophene group, an azadibenzosilole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a quinoxaline group, a quinazoline group, a phthalazine group, a phenanthroline group, a pyrrole group, a pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, a thiazole group, an isothiazole group, an oxadiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a benzoxazole group, a benzothiazole group, a benzoxadiazole group, a benzothiadiazole group, a dibenzooxasiline group, a dibenzothiasiline group, a dibenzodihydroazasiline group, a dibenzodihydrodisiline group, a dibenzodihydrosiline group, a dibenzodioxine group, a dibenzooxathiine group, a dibenzooxazine group, a dibenzopyran group, a dibenzodithiine group, a dibenzothiazine group, a dibenzothiopyran group, a dibenzocyclohexadiene group, a dibenzodihydropyridine group, or a dibenzodihydropyrazine group, each unsubstituted or substituted with at least one R_{10a}.

[0203] In an embodiment, L_1 may be:

[0204] a single bond; or

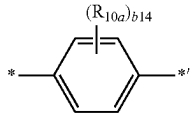
[0205] a benzene group, a naphthalene group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a quinoxaline group, a quinazoline group, or a phthalazine group, each unsubstituted or substituted with at least one R_{10a}.

[0206] In an embodiment, L_1 may be:

[0207] a single bond; or

[0208] a group represented by one of Formulae L(1) to L(24):

L(1)



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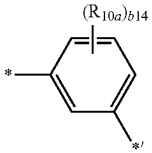

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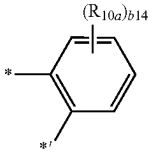

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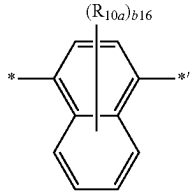

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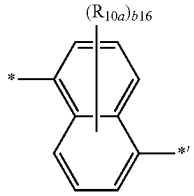

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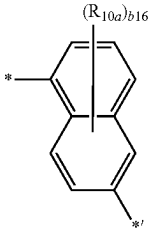

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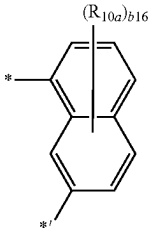

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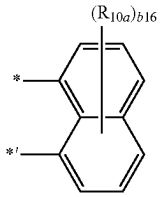

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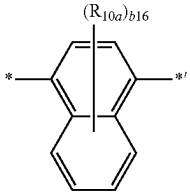

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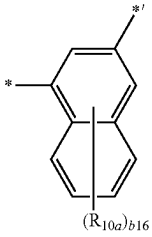

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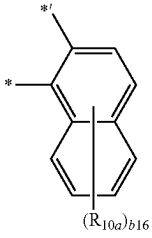

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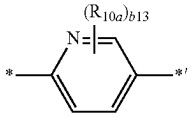

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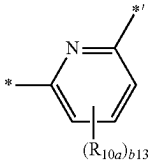

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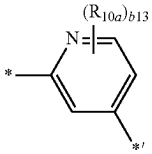

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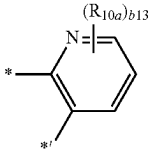

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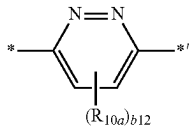

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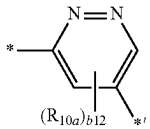

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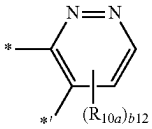

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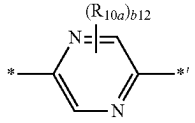

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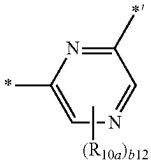
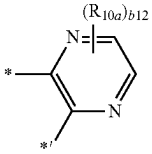
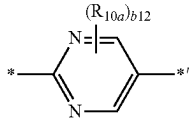


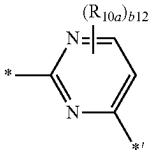
L(21)



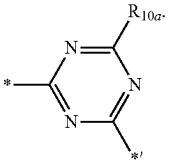
L(22)



L(23)



L(24)



[0209] In Formulae L(1) to L(24),

[0210] R_{10a} is the same as described herein,

[0211] b12 may be 1 or 2,

[0212] b13 may be an integer from 1 to 3,

[0213] b14 may be an integer from 1 to 4,

[0214] b16 may be an integer from 1 to 6, and

[0215] * and *' each indicate a binding site to a neighboring atom.

[0216] In Formula 1, n1 indicates the number of L_1, and n1 may be an integer from 1 to 3.

[0217] In an embodiment, n1 may be 1.

[0218] In Formula 1, Ar_1 may be a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}, —$C(Q_1)(Q_2)(Q_3)$, —$Si(Q_1)(Q_2)(Q_3)$, —$N(Q_1)(Q_2)$, or —$B(Q_1)(Q_2)$.

[0219] In an embodiment, Ar_1 may be a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzosilolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group,

—$O(Q_{31})$, —$S(Q_{31})$, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$P(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, —$P(=O)(Q_{31})(Q_{32})$, or any combination thereof, and

[0220] Q_{31} to Q_{33} may each independently be: hydrogen; deuterium; —F; —Cl; —Br; —I; a hydroxyl group; a cyano group; a nitro group; a C_1-C_{60} alkyl group; a C_2-C_{60} alkenyl group; a C_2-C_{60} alkynyl group; a C_1-C_{60} alkoxy group; or a C_3-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group, each unsubstituted or substituted with deuterium, —F, a cyano group, a C_1-C_{60} alkyl group, a C_1-C_{60} alkoxy group, a phenyl group, a biphenyl group, or any combination thereof.

[0221] In an embodiment, Ar_1 may be a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a triazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, or an imidazopyrimidinyl group, each unsubstituted or substituted with deuterium, a cyano group, —CD_3, —CD_2H, —CDH_2, a C_1-C_{20} alkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a triazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, or any combination thereof, and

[0222] Q_{31} to Q_{33} may each independently be: hydrogen; deuterium; a C_1-C_{10} alkyl group; a C_2-C_{10} alkenyl group; or a C_5-C_{20} carbocyclic group or a C_1-C_{20} heterocyclic group, each unsubstituted or substituted with deuterium, a C_1-C_{60} alkyl group, a phenyl group, a biphenyl group, or any combination thereof.

[0223] In an embodiment, Ar_1 may include at least one deuterium.

[0224] In an embodiment, Ar_1 may be:

[0225] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azafluorenyl group, or an azadibenzosilolyl group, each substituted with at least one deuterium; or

[0226] —$Si(Q_{31})(Q_{32})(Q_{33})$, and

[0227] Q_{31} to Q_{33} may each independently be: deuterium; or a C_3-C_{20} carbocyclic group or a C_1-C_{20} heterocyclic group, each substituted with at least one deuterium.

[0228] In an embodiment, Ar_1 may be:

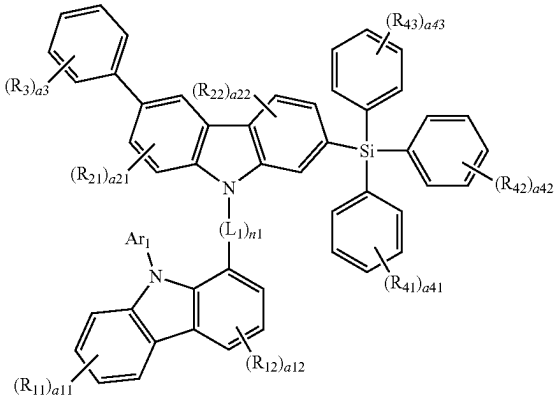
[0229] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a benzoimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a triazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, or an imidazopyrimidinyl group, each substituted with at least one deuterium; or

[0230] $Si(Q_{31})(Q_{32})(Q_{33})$, and

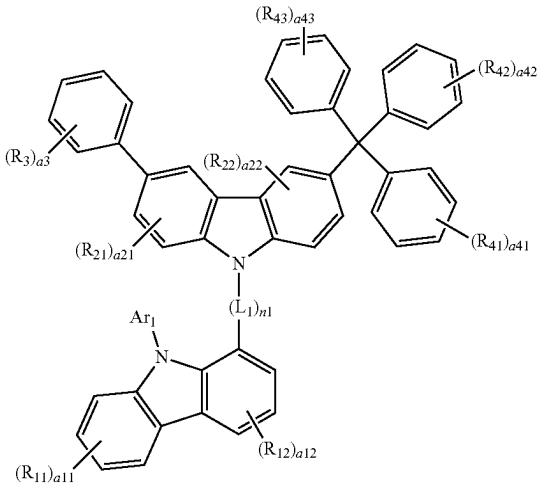
[0231] Q_{31} to Q_{33} may each independently be a C_3-C_{20} carbocyclic group or a C_1-C_{20} heterocyclic group, each substituted with at least one deuterium.

[0232] In an embodiment, the heterocyclic compound represented by Formula 1 may be represented by one of Formulae 1-1 to 1-8:

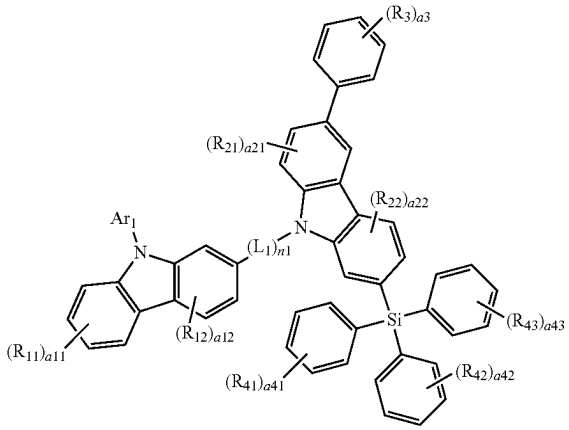
1-1



1-2



1-3



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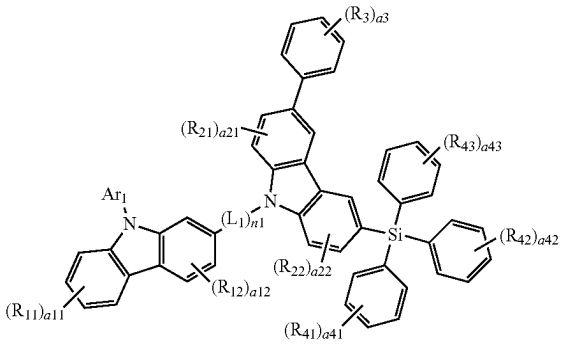
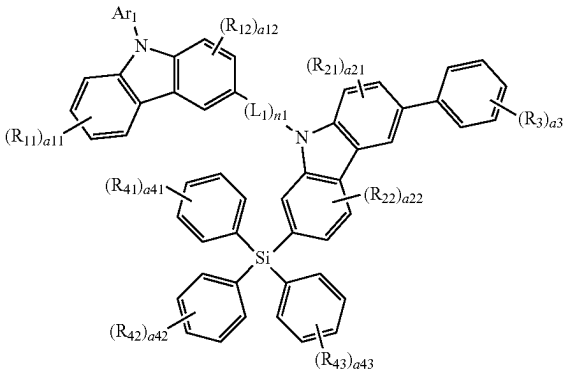
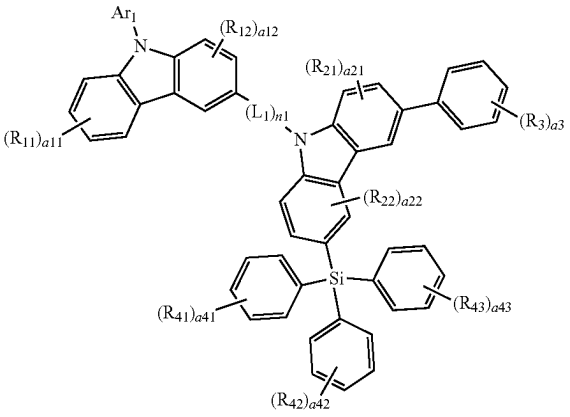
1-4



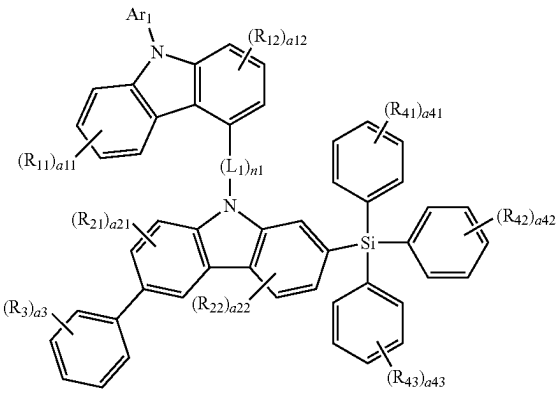
1-5



1-6



1-7



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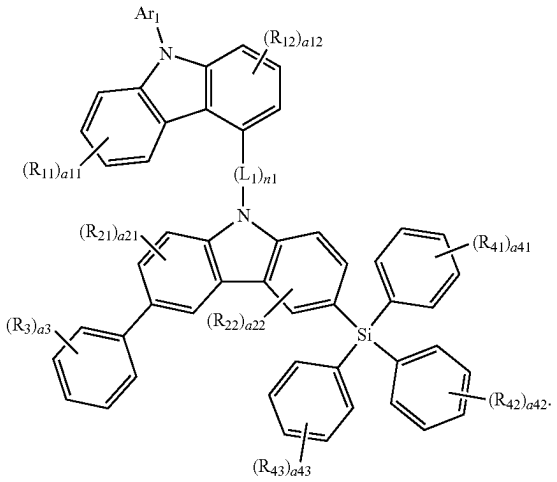
1-8



[0233] In Formulae 1-1 to 1-8,

[0234] R_{11}, R_{12}, R_{21}, R_{22}, R_3, R_{41} to R_{43}, a11, a12, a21, a22, a3, a41 to a43, L_1, n1, and Ar_1 are the same as described herein.

[0235] In Formula 1, unless otherwise defined, R_{10a} may be:

[0236] deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, or a nitro group;

[0237] a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, or a C_1-C_{60} alkoxy group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_5-C_{60} carbocyclic group, a C_1-C_{60} heterocyclic group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, —$Si(Q_{11})(Q_{12})(Q_{13})$, —$N(Q_{11})(Q_{12})$, —$B(Q_{11})(Q_{12})$, —$C(=O)(Q_{11})$, —$S(=O)_2(Q_{11})$, —$P(=O)(Q_{11})(Q_{12})$, or any combination thereof;

[0238] a C_3-C_{60} carbocyclic group, a C_1-C_{60} heterocyclic group, a C_6-C_{60} aryloxy group, or a C_6-C_{60} arylthio group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{60} carbocyclic group, a C_1-C_{60} heterocyclic group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, —$Si(Q_{21})(Q_{22})(Q_{23})$, —$N(Q_{21})(Q_{22})$, —$B(Q_{21})(Q_{22})$, —$C(=O)(Q_{21})$, —$S(=O)_2(Q_{21})$, —$P(=O)(Q_{21})(Q_{22})$, or any combination thereof; or

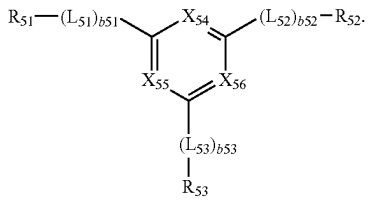
[0239] —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, or —$P(=O)(Q_{31})(Q_{32})$.

[0240] In Formula 1, unless otherwise defined, Q_1 to Q_3, Q_{11} to Q_{13}, Q_{21} to Q_{23}, and Q_{31} to Q_{33} may each independently be: hydrogen; deuterium; —F; —Cl; —Br; —I; a hydroxyl group; a cyano group; a nitro group; a C_1-C_{60} alkyl group; a C_2-C_{60} alkenyl group; a C_2-C_{60} alkynyl group; a C_1-C_{60} alkoxy group; or a C_5-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group, each unsubstituted or substituted with deuterium, —F, a cyano group, a C_1-C_{60} alkyl group, a C_1-C_{60} alkoxy group, a phenyl group, a biphenyl group, or any combination thereof.

[0241] The heterocyclic compound represented by Formula 1 may have a structure in which a bicarbazole moiety includes a triphenylsilyl substituent and a phenyl substituent. The phenyl substituent may be bonded to the bicarbazole moiety at a para position to a nitrogen atom thereof, which is a HOMO-rich site of the carbazole moiety, to make the HOMO energy level shallow, thereby facilitating hole injection and suppressing an increase in driving voltage due to the bulkiness of the triphenylsilyl substituent. As the steric effect of molecules is enhanced by the inclusion of the triphenylsilyl substituent, a dihedral angle between atoms may increase, and expansion of conjugation may be suppressed, resulting in high triplet energy. Thus, the heterocyclic compound according to embodiments may be used as a blue phosphorescence and TADF-emitting host and may have high luminescence efficiency. In the heterocyclic compound, the increased bulkiness may hinder the interaction with other molecules (such as with a dopant) and may suppress the formation of an exciplex, which may lead to improved glass transition temperature and thermal stability of molecules. Accordingly, by applying the heterocyclic compound as a blue phosphorescence and TADF host, an electronic device (for example, an organic light-emitting device) may have a low driving voltage and high efficiency.

[Descriptions of Formulae 2, 3, 502, and 503]

[Formula 2]



[0242] In Formula 2, b51 to b53 respectively indicate the numbers of L_{51} to L_{53}, and b51 to b53 may each independently be an integer from 1 to 5. When b51 is 2 or more, two or more of L_{51} may be identical to or different from each other, when b52 is 2 or more, two or more of L_{52} may be identical to or different from each other, and when b53 is 2 or more, two or more of L_{53} may be identical to or different from each other. In an embodiment, b51 to b53 may each independently be 1 or 2.

[0243] In an embodiment, in Formula 2, L_{51} to L_{53} may each independently be:

[0244] a single bond; or

[0245] a benzene group, a naphthalene group, an anthracene group, a phenanthrene group, a triphenylene group, a pyrene group, a chrysene group, a cyclopentadiene group, a furan group, a thiophene group, a silole group, an indene group, a fluorene group, an indole group, a carbazole group, a benzofuran group, a dibenzofuran group, a benzothiophene group, a dibenzothiophene group, a benzosilole group, a dibenzosilole group, an azafluorene group, an azacarbazole group, an azadibenzofuran group, an azadibenzothiophene group, an azadibenzosilole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a quinoxaline group, a quinazoline group, a phenanthroline group, a pyrrole group, a pyrazole

group, an imidazole group, a triazole group, an oxazole group, an isooxazole group, a thiazole group, an isothiazole group, an oxadiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a benzoxazole group, a benzothiazole group, a benzoxadiazole group, a benzothiadiazole group, a dibenzooxacilline group, a dibenzothiacilline group, a dibenzodihydroazacilline group, a dibenzodihydrodicilline group, a dibenzodihydrocilline group, a dibenzodioxane group, a dibenzooxathiene group, a dibenzooxazine group, a dibenzopyran group, a dibenzodithiine group, a dibenzothiazine group, a dibenzothiopyran group, a dibenzocyclohexadiene group, a dibenzodihydropyridine group, or a dibenzodihydropyrazine group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a triazinyl group, a fluorenyl group, a dimethylfluorenyl group, a diphenylfluorenyl group, a carbazolyl group, a phenylcarbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a dimethyldibenzosilolyl group, a diphenyldibenzosilolyl group, —$O(Q_{31})$, —$S(Q_{31})$, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$P(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, —$P(=O)(Q_{31})(Q_{32})$, or any combination thereof, and

[0246] Q_{31} to Q_{33} may each independently be hydrogen, deuterium, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a pyridinyl group, a pyrimidinyl group, a pyridazinyl group, a pyrazinyl group, or a triazinyl group.

[0247] In an embodiment, in Formula 2, a bond between L_{51} and R_{51}, a bond between L_{52} and R_{52}, a bond between L_{53} and R_{53}, a bond between two or more L_{51}, a bond between two or more L_{52}, a bond between two or more L_{53}, a bond between L_{51} and a carbon between X_{54} and X_{55}, a bond between L_{52} and a carbon between X_{54} and X_{56}, and a bond between L_{53} and a carbon between X_{55} and X_{56} may each be a "carbon-carbon single bond".

[0248] In Formula 2, X_{54} may be N or $C(R_{54})$, X_{55} may be N or $C(R_{55})$, X_{56} may be N or $C(R_{56})$, and at least one of X_{54} to X_{56} may each be N. R_{54} to R_{56} are the same as described herein. In an embodiment, two or three of X_{54} to X_{56} may each be N.

[0249] In Formula 2, a group represented by $*\text{-}(L_{51})_{b51}\text{-}R_{51}$ and a group represented by $*\text{-}(L_{52})_{b52}\text{—}R_{52}$ may each not be a phenyl group.

[0250] In an embodiment, a group represented by $*\text{-}(L_{51})_{b51}\text{-}R_{51}$ and a group represented by $*\text{-}(L_{52})_{b52}\text{-}R_{52}$ in Formula 2 may be identical to each other.

[0251] In an embodiment, a group represented by $*\text{-}(L_{51})_{b51}\text{-}R_{51}$ and a group represented by $*\text{-}(L_{52})_{b52}\text{-}R_{52}$ in Formula 2 may be different from each other.

[0252] In an embodiment, in Formula 2, b51 and b52 may each independently be 1, 2, or 3, and L_{51} and L_{52} may each independently be a benzene group, a pyridine group, a pyrimidine group, a pyridazine group, a pyrazine group, or a triazine group, each unsubstituted or substituted with at least one R_{10a}.

[0253] In an embodiment, in Formula 2, R_{51} and R_{52} may each independently be a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}, a C_6-C_{60} aryloxy group unsubstituted or substituted with at least one R_{10a}, a C_6-C_{60} arylthio group unsubstituted or substituted with at least one R_{10a}, —$C(Q_1)(Q_2)(Q_3)$, or —$Si(Q_1)(Q_2)(Q_3)$, and

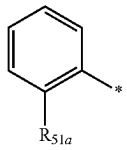
[0254] Q_1 to Q_3 may each independently be a C_3-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group, each unsubstituted or substituted with deuterium, —F, a cyano group, a C_1-C_{60} alkyl group, a C_1-C_{60} alkoxy group, a phenyl group, a biphenyl group, or any combination thereof.

[0255] In an embodiment, in Formula 2, a group represented by $*\text{-}(L_{51})_{b51}\text{-}R_{51}$ may be a group represented by one of Formulae CY51-1 to CY51-26, and/or

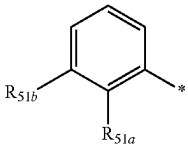
[0256] a group represented by $*\text{-}(L_{52})_{b52}\text{-}R_{52}$ may be a group represented by one of Formulae CY52-1 to CY52-26, and/or

[0257] a group represented by $*\text{-}(L_{53})_{b53}\text{-}R_{53}$ may be a group represented by one of Formulae CY53-1 to CY53-27, —$C(Q_1)(Q_2)(Q_3)$, or —$Si(Q_1)(Q_2)(Q_3)$:

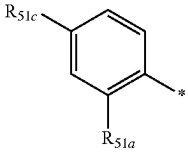
CY51-1



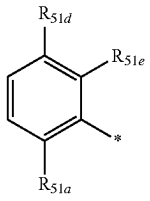
CY51-2



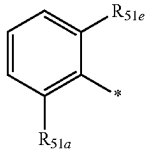
CY51-3



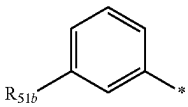
CY51-4



CY51-5



CY51-6



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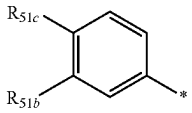
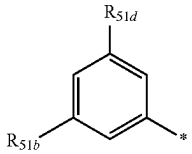
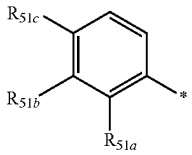
CY51-7



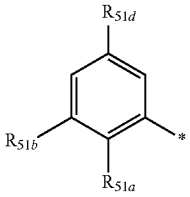
CY51-8



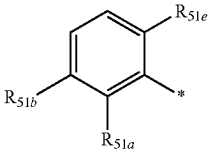
CY51-9



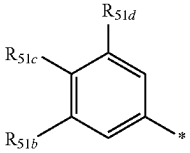
CY51-10



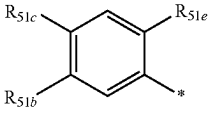
CY51-11



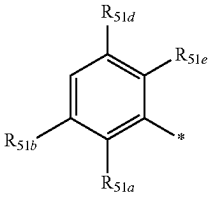
CY51-12



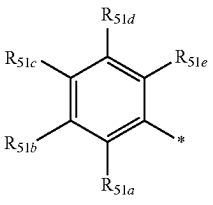
CY51-13



CY51-14



CY51-15



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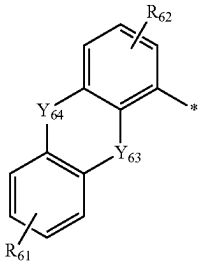
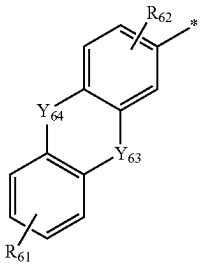
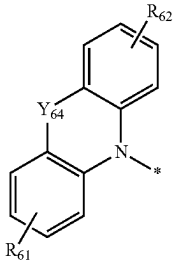
CY51-16



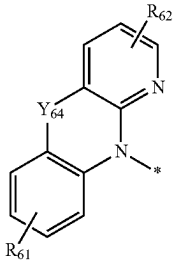
CY51-17



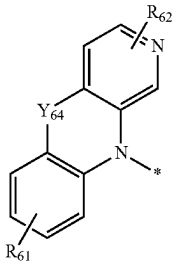
CY51-18



CY51-19



CY51-20



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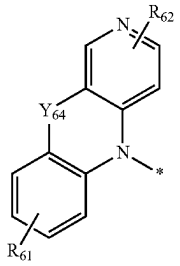
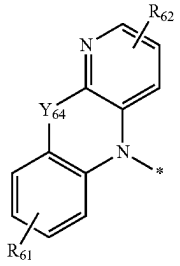
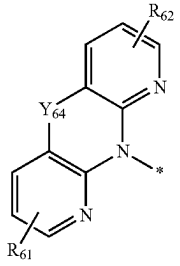
CY51-21



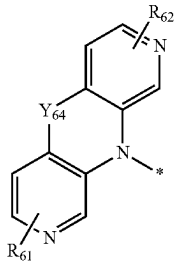
CY51-22



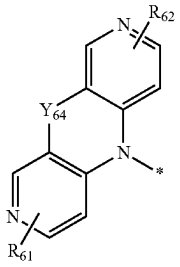
CY51-23



CY51-24



CY51-25



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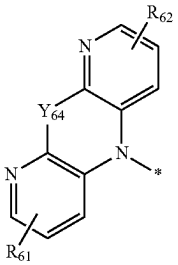
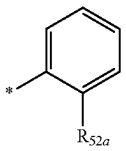
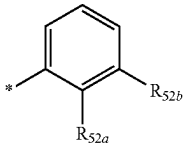
CY51-26



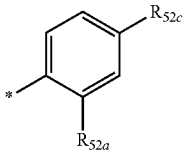
CY52-1



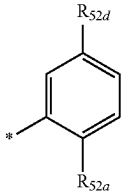
CY52-2



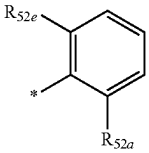
CY52-3



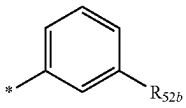
CY52-4



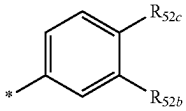
CY52-5



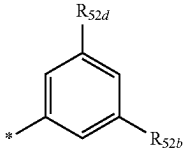
CY52-6



CY52-7



CY52-8



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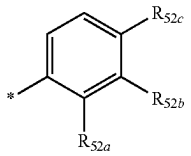
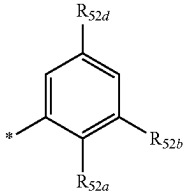
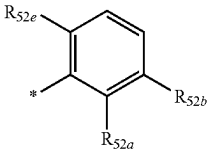
CY52-9



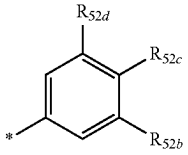
CY52-10



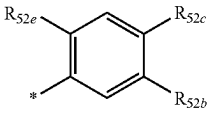
CY52-11



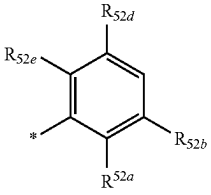
CY52-12



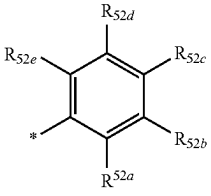
CY52-13



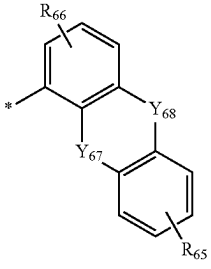
CY52-14



CY52-15



CY52-16



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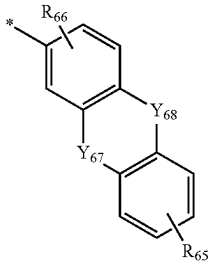
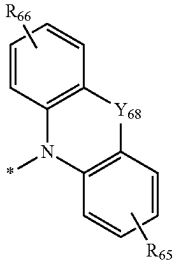
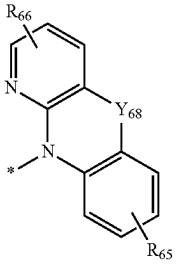
CY52-17



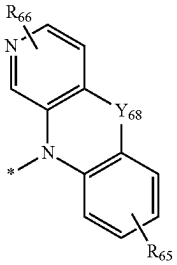
CY52-18



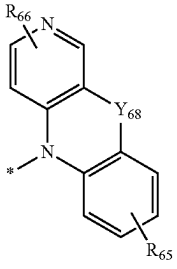
CY52-19



CY52-20



CY52-21



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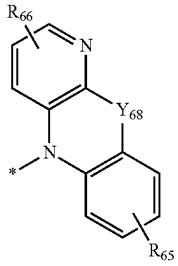
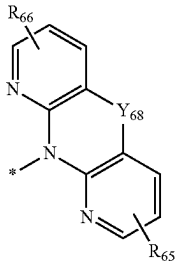
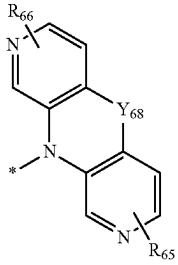
CY52-22



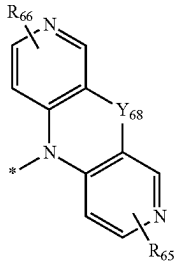
CY52-23



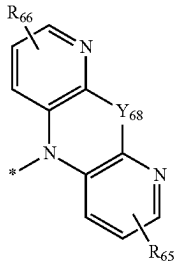
CY52-24



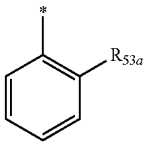
CY52-25



CY52-26



CY53-1



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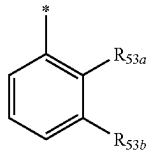
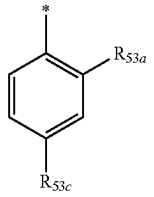
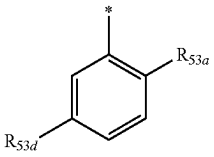
CY53-2



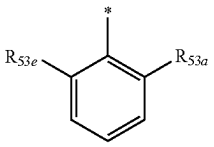
CY53-3



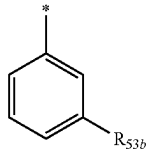
CY53-4



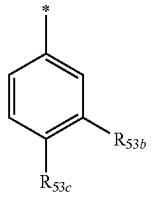
CY53-5



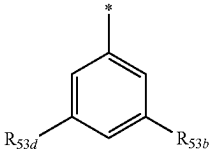
CY53-6



CY53-7



CY53-8



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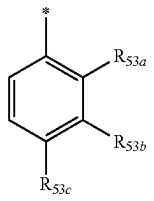

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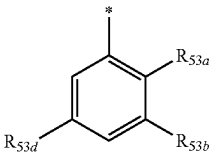

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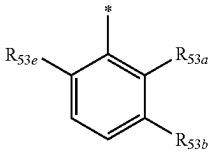

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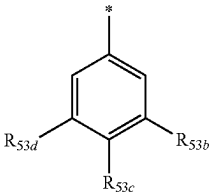

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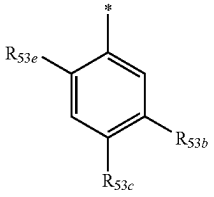

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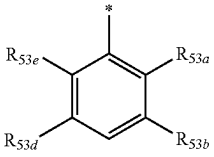

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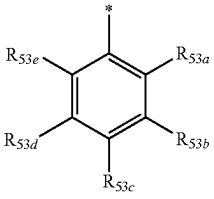

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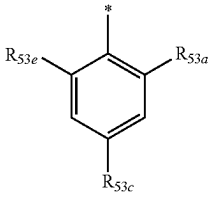

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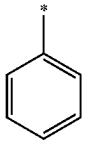

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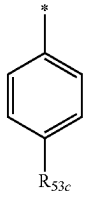

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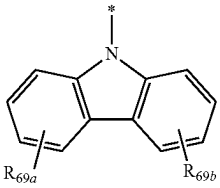

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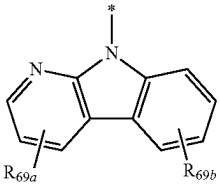

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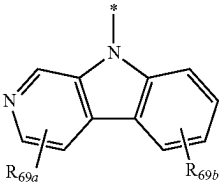

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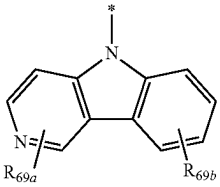

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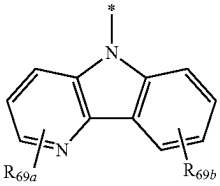

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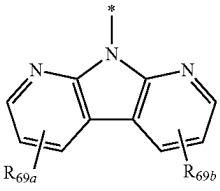

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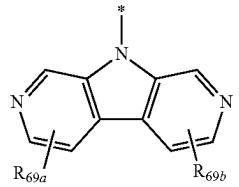
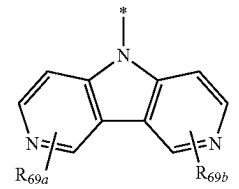
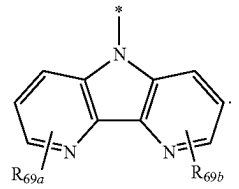


CY53-26



CY53-27



[0258] In Formulae CY51-1 to CY51-26, CY52-1 to CY52-26, and CY53-1 to CY53-27,

[0259] Y_{63} may be a single bond, O, S, $N(R_{63})$, $B(R_{63})$, $C(R_{63a})(R_{63b})$, or $Si(R_{63a})(R_{63b})$,

[0260] Y_{64} may be a single bond, O, S, $N(R_{64})$, $B(R_{64})$, $C(R_{64a})(R_{64b})$, or $Si(R_{64a})(R_{64b})$,

[0261] Y_{67} may be a single bond, O, S, $N(R_{67})$, $B(R_{67})$, $C(R_{67a})(R_{67b})$, or $Si(R_{67a})(R_{67b})$,

[0262] Y_{68} may be a single bond, O, S, $N(R_{68})$, $B(R_{68})$, $C(R_{68a})(R_{68b})$, or $Si(R_{68a})(R_{68b})$,

[0263] Y_{63} and Y_{64} in Formulae CY51-16 and CY51-17 may each not be a single bond at the same time,

[0264] Y_{67} and Y_{68} in Formulae CY52-16 and CY52-17 may each not be a single bond at the same time,

[0265] R_{51a} to R_{51e}, R_{61} to R_{64}, R_{63a}, R_{63b}, R_{64a}, and R_{64b} may each independently be the same as described in connection with R_{51} as described herein, except that R_{51a} to R_{51e} may not each be hydrogen,

[0266] R_{52a} to R_{52e}, R_{65} to R_{68}, R_{67a}, R_{67b}, R_{68a}, and R_{68b} may each independently be the same as described in connection with R_{52} as described herein, except that R_{52a} to R_{52e} may not each be hydrogen,

[0267] R_{53a} to R_{53e}, R_{69a}, and R_{69e} may each independently be the same as described in connection with R_{53} as described herein, except that R_{53a} to R_{53e} may not each be hydrogen, and

[0268] * indicates a binding site to an adjacent atom.

[0269] In embodiments, in Formulae CY51-1 to CY51-26 and CY52-1 to 52-26, R_{51a} to R_{51e} and R_{52a} to R_{52e} may each independently be:

[0270] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azafluorenyl group, or an azadibenzosilolyl group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, $—CD_3$, $—CD_2H$, $—CDH_2$, $—CF_3$, $—CF_2H$, $—CFH_2$, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, or any combination thereof; or

[0271] $—C(Q_1)(Q_2)(Q_3)$ or $—Si(Q_1)(Q_2)(Q_3)$,

[0272] Q_1 to Q_3 may each independently be a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a pyridazinyl group, a pyrazinyl group, or a triazinyl group, each unsubstituted or substituted with deuterium, a C_1-C_{10} alkyl group, a phenyl group, a biphenyl group, a pyridinyl group, a pyrimidinyl group, a pyridazinyl group, a pyrazinyl group, a triazinyl group, or any combination thereof,

[0273] in Formulae CY51-16 and CY51-17, Y_{63} may be O or S and Y_{64} may be $Si(R_{64a})(R_{64b})$, or Y_{63} may be $Si(R_{63a})(R_{63b})$ and Y_{64} may be O or S, and

[0274] in Formulae CY52-16 and CY52-17, Y_{67} may be O or S, and Y_{68} may be $Si(R_{68a})(R_{68b})$, or Y_{67} may be $Si(R_{67a})(R_{67b})$, and Y_{68} may be O or S.

[0275] In the specification, in Formula 2, R_{51} to R_{56} may each independently be hydrogen, deuterium, —F, —Cl,

—Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{60} alkyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} alkenyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} alkynyl group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} alkoxy group unsubstituted or substituted with at least one R_{10a}, a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}, a C_6-C_{60} aryloxy group unsubstituted or substituted with at least one R_{10a}, a C_6-C_{60} arylthio group unsubstituted or substituted with at least one R_{10a}, a C_7-C_{60} arylalkyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} heteroarylalkyl group unsubstituted or substituted with at least one R_{10a}, —$C(Q_1)(Q_2)(Q_3)$, —$Si(Q_1)(Q_2)(Q_3)$, —$N(Q_1)(Q_2)$, —$B(Q_1)(Q_2)$, —$C(=O)(Q_1)$, —$S(=O)_2(Q_1)$, or —$P(=O)(Q_1)(Q_2)$. Q_1 to Q_3 may each be the same as described in the specification.

[0276] For example, in Formula 2, R_{51} to R_{56} may each independently be:

[0277] hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, or a C_1-C_{20} alkoxy group;

[0278] a C_1-C_{20} alkyl group or a C_1-C_{20} alkoxy group, each substituted with deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{10} alkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, or any combination thereof;

[0279] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azafluorenyl group, or an azadibenzosilolyl group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, —$O(Q_{31})$, —$S(Q_{31})$, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$P(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, —$P(=O)(Q_{31})(Q_{32})$, or any combination thereof; or

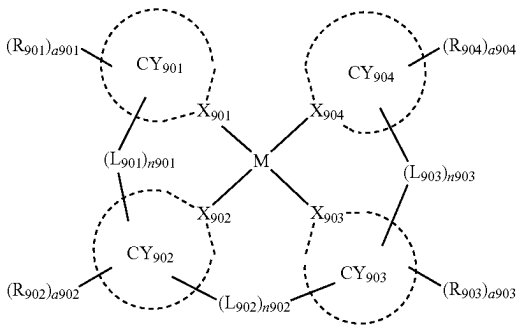
[0280] —$C(Q_1)(Q_2)(Q_3)$, —$Si(Q_1)(Q_2)(Q_3)$, —$N(Q_1)(Q_2)$, —$B(Q_1)(Q_2)$, —$C(=O)(Q_1)$, —$S(=O)_2(Q_1)$, or —$P(=O)(Q_1)(Q_2)$, and

[0281] Q_1 to Q_3 and Q_{31} to Q_{33} may each independently be:

[0282] —CH_3, —CD_3, —CD_2H, —CDH_2, —CH_2CH_3, —CH_2CD3, —CH_2CD2H, —CH_2CDH_2, —$CHDCH_3$, —$CHDCD_2H$, —$CHDCDH_2$, —$CHDCD_3$, —CD_2CD_3, —CD_2CD_2H, or —CD_2CDH_2; or

[0283] an n-propyl group, an iso-propyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an isopentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a pyridazinyl group, a pyrazinyl group, or a triazinyl group, each unsubstituted or substituted with deuterium, a C_1-C_{10} alkyl group, a phenyl group, a biphenyl group, a pyridinyl group, a pyrimidinyl group, a pyridazinyl group, a pyrazinyl group, a triazinyl group, or any combination thereof.

[Formula 3]



[0284] In Formula 3, M may be platinum (Pt), palladium (Pd), copper (Cu), silver (Ag), gold (Au), rhodium (Rh), ruthenium (Ru), osmium (Os), titanium (Ti), zirconium (Zr), hafnium (Hf), europium (Eu), terbium (Tb), or thulium (Tm).

[0285] In an embodiment, M may be Pt.

[0286] In Formula 3, X_{901} to X_{904} may each independently be C or N.

[0287] In an embodiment, X_{901} may be C. For example, in Formula 3, X_{901} may be a carbon atom of a carbene moiety.

[0288] In embodiments, in Formula 3, X_{901} may be N.

[0289] In an embodiment, X_{902} and X_{903} may each be C, and X_{904} may be N.

[0290] In Formula 3, a bond between X_{901} and M may be a coordinate bond, and one of a bond between X_{902} and M, a bond between X_{903} and M, and a bond between X_{904} and M may be a coordinate bond, and the other two bonds may each be a covalent bond.

[0291] For example, a bond between X_{901} and M and a bond between X_{904} and M may each be a coordinate bond, and a bond between X_{902} and M and a bond between X_{903} and M may each be a covalent bond.

[0292] In an embodiment, X_{901} may be C, and a bond between X_{901} and M may be a coordinate bond.

[0293] In Formula 3, ring CY901 to ring CY904 may each independently be a C_5-C_{30} carbocyclic group or a C_1-C_{30} heterocyclic group.

[0294] For example, ring CY_{901} may be a nitrogen-containing C_1-C_{60} heterocyclic group.

[0295] In an embodiment, in Formula 3, ring CY_{901} may be an X_{901}-containing 5-membered ring, an X_{901}-containing 5-membered ring to which at least one 6-membered ring is condensed, or an X_{901}-containing 6-membered ring. In an embodiment, in Formula 3, ring CY_{901} may be an X_{901}-containing 5-membered ring or an X_{901}-containing 5-membered ring to which at least one 6-membered ring is condensed. For example, in Formula 3, ring CY_{901} may include a 5-membered ring bonded to M via X_{901}. For example, the X_{901}-containing 5-membered ring may be a pyrrole group, a pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, a thiazole group, an isothiazole group, an oxadiazole group, or a thiadiazole group, and the X_{901}-containing 6-membered ring or the 6-membered ring which may be optionally condensed to the X_{901}-containing 5-membered ring may be a benzene group, a pyridine group, or a pyrimidine group.

[0296] In embodiments, ring CY_{901} may be an X_{901}-containing 5-membered ring, and the X_{901}-containing 5-membered ring may be an imidazole group or a triazole group.

[0297] In embodiments, ring CY_{901} may be an X_{901}-containing 5-membered ring condensed to at least one 6-membered ring, and the X_{901}-containing 5-membered ring condensed to the at least one 6-membered ring may be a benzimidazole group or an imidazopyridine group.

[0298] In an embodiment, ring CY_{901} may be an imidazole group, a triazole group, a benzimidazole group, or an imidazopyridine group.

[0299] In embodiments, X_{901} may be C, and ring CY_{901} may be an imidazole group, a triazole group, a benzimidazole group, a naphthoimidazole group, or an imidazopyridine group.

[0300] In an embodiment, ring CY_{902} may be a benzene group, a pyridine group, a pyrimidine group, a naphthalene group, a dibenzofuran group, a dibenzothiophene group, a carbazole group, a fluorene group, a dibenzosilole group, a naphthobenzofuran group, a naphthobenzothiophene group, a benzocarbazole group, a benzofluorene group, a naphthobenzosilole group, a dinaphthofuran group, a dinaphthothiophene group, a dibenzocarbazole group, a dibenzofluorene group, a dinaphthosilole group, an azadibenzofuran group, an azadibenzothiophene group, an azacarbazole group, an azafluorene group, an azadibenzosilole group, an azanaphthobenzofuran group, an azanaphthobenzothiophene group, an azabenzocarbazole group, an azabenzofluorene group, an azanaphthobenzosilole group, an azadinaphthofuran group, an azadinaphthothiophene group, an azadibenzocarbazole group, an azadibenzofluorene group, or an azadinaphthosilole group.

[0301] In an embodiment, ring CY_{902} may be a benzene group, a pyridine group, a pyrimidine group, a naphthalene group, a dibenzofuran group, a dibenzothiophene group, a carbazole group, a fluorene group, or a dibenzosilole group.

[0302] In an embodiment, in Formula 3, ring CY_{903} may be: a C_2-C_8 monocyclic group; or a C_4-C_{20} polycyclic group in which two or three C_2-C_8 monocyclic groups are condensed with each other.

[0303] For example, in Formula 3, ring CY_{903} may be: a C_4-C_6 monocyclic group; or a C_4-C_8 polycyclic group in which two or three C_4-C_6 monocyclic groups are condensed with each other.

[0304] In the specification, the term "C_2-C_8 monocyclic group" may refer to a non-condensed ring group and may be, for example, a cyclopentadiene group, a pyrrole group, a pyrazole group, an imidazole group, a triazole group, an oxazole group, an isooxazole group, a thiazole group, an isothiazole group, an oxadiazole group, a thiadiazole group, a benzene group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a cycloheptadiene group, a cyclooctadiene group, etc.

[0305] For example, ring CY_{903} may be a benzene group, a pyridine group, a pyrimidine group, a naphthalene group, a dibenzofuran group, a dibenzothiophene group, a carbazole group, a fluorene group, a dibenzosilole group, an azadibenzofuran group, an azadibenzothiophene group, an azacarbazole group, an azafluorene group, or an azadibenzosilole group.

[0306] In an embodiment, in Formula 3, ring CY_{904} may be a nitrogen-containing C_1-C_{60} heterocyclic group.

[0307] For example, ring CY_{904} may be a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a quinoxaline group, a quinazoline group, a phenanthroline group, a pyrrole group, a pyrazole group, an imidazole group, a triazole group, a benzopyrazole group, a benzimidazole group, or a benzothiazole group.

[0308] In Formula 3, L_{901} to L_{903} may each independently be a single bond, *—$C(R_{1a})(R_{1b})$—*, *—$C(R_{1a})$=**, *=$C(R_{1a})$—**, *—$C(R_{1a})$=$C(R_{1b})$—*, *—C(=O)—*, *—C(=S)—*, *—C≡C—**, *—$B(R_{1a})$—**, *—$N(R_{1a})$—**, *—O—**, *—$P(R_{1a})$—**, *—$Si(R_{1a})(R_{1b})$—**, * —P(=O)(R_{1a})—**, *—S—**, *—S(=O)—**, *—$S(=O)_2$—**, or *—$Ge(R_{1a})(R_{1b})$—*', and * and *' each indicate a binding site to a neighboring atom.

[0309] R_{1a} and R_{1b} are each the same as described herein.

[0310] In an embodiment, L_{901} and L_{903} may each independently be a single bond, and L_{902} may be *—C(Ra)

(R_{1b})—**, *—B(R_{1a})—**, *—N(R_{1a})—**, *—O—**, *—P(R_{1a})—**, *—Si(R_{1a})(R_{1b})—**, or *—S—**.

[0311] In an embodiment, L_{902} may be *—O—*' or *—S—*'.

[0312] In Formula 3, n901 to n903 respectively indicate the numbers of L_{901} to L_{903}, and n901 to n903 may each independently be an integer from 1 to 5. When n901 to n903 are each 2 or more, two or more L_{901} to L_{903} may be identical to or different from each other.

[0313] In an embodiment, n902 may be 1.

[0314] In the specification, in Formula 3, R_{901} to R_{904}, R_{1a}, and R_{1b} may each independently be hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{60} alkyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} alkenyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} alkynyl group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} alkoxy group unsubstituted or substituted with at least one R_{10a}, a C_5-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}, a C_6-C_{60} aryloxy group unsubstituted or substituted with at least one R_{10a}, a C_6-C_{60} arylthio group unsubstituted or substituted with at least one R_{10a}, —C(Q_1)(Q_2)(Q_3), —Si(Q_1)(Q_2)(Q_3), —N(Q_1)(Q_2), —B(Q_1)(Q_2), —C(=O)(Q_1), —S(=O)$_2$(Q_1), or —P(=O)(Q_1)(Q_2).

[0315] R_{10a}, Q_1, Q_2, and Q_3 are each the same as described herein.

[0316] In an embodiment, R_{901} to R_{904}, R_{1a}, and R_{1b} may each independently be:

[0317] hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, or a C_1-C_{20} alkoxy group;

[0318] a C_1-C_{20} alkyl group or a C_1-C_{20} alkoxy group, each substituted with deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{10} alkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, or any combination thereof;

[0319] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azafluorenyl group, or an azadibenzosilolyl group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, —O(Q_{31}), —S(Q_{31}), —Si(Q_{31})(Q_{32})(Q_{33}), —N(Q_{31})(Q_{32}), —B(Q_{31})(Q_{32}), —P(Q_{31})(Q_{32}), —C(=O)(Q_{31}), —S(=O)$_2$(Q_{31}), —P(=O)(Q_{31})(Q_{32}), or any combination thereof; or

[0320] —C(Q_1)(Q_2)(Q_3), —Si(Q_1)(Q_2)(Q_3), —N(Q_1)(Q_2), —B(Q_1)(Q_2), —C(=O)(Q_1), —S(=O)$_2$(Q_1), or —P(=O)(Q_1)(Q_2).

[0321] Q_1 to Q_3 and Q_{31} to Q_{33} may each be the same as described in the specification.

[0322] In an embodiment, R_{901} to R_{904}, R_{1a}, and R_{1b} may each independently be:

[0323] hydrogen, deuterium, —F, —Cl, —Br, —I, or a C_1-C_{20} alkyl group;

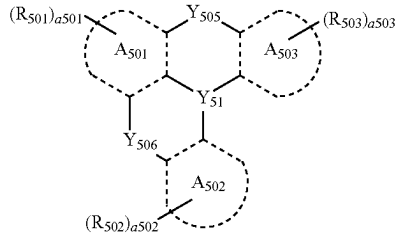
[0324] a C_1-C_{20} alkyl group unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{10} alkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, or any combination thereof; or

[0325] a phenyl group, a biphenyl group, a terphenyl group, a C_1-C_{10} alkylphenyl group, or a naphthyl group, each unsubstituted or substituted with deute-

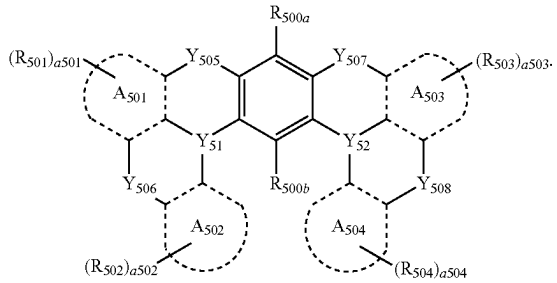
rium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a C_1-C_{20} alkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a C_1-C_{10} alkylphenyl group, or any combination thereof.

[0326] In Formula 3, a901 to a904 respectively indicate the numbers of R_{901} to R_{904}, and a901 to a904 may each independently be an integer from 1 to 10. When a901 to a904 are each 2 or more, two or more R_{901} to R_{904} may be identical to or different from each other.

[Formula 502]



[Formula 503]



[0327] In Formulae 502 and 503,

[0328] ring A_{501} to ring A_{504} may each independently be a C_3-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group,

[0329] Y_{505} may be O, S, $N(R_{505})$, $B(R_{505})$, $C(R_{505a})(R_{505b})$, or $Si(R_{505a})(R_{505b})$,

[0330] Y_{506} may be O, S, $N(R_{506})$, $B(R_{506})$, $C(R_{506a})(R_{506b})$, or $Si(R_{506a})(R_{506b})$,

[0331] Y_{507} may be O, S, $N(R_{507})$, $B(R_{507})$, $C(R_{507a})(R_{507b})$, or $Si(R_{507a})(R_{507b})$,

[0332] Y_{508} may be O, S, $N(R_{508})$, $B(R_{508})$, $C(R_{508a})(R_{508b})$, or $Si(R_{508a})(R_{508b})$,

[0333] Y_{51} and Y_{52} may each independently be B, P(═O), or S(═O), and

[0334] R_{500a}, R_{500b}, R_{501} to R_{508}, R_{505a}, R_{505b}, R_{506a}, R_{506b}, R_{507a}, R_{507b}, R_{508a}, and R_{508b} are each the same as described in the specification.

[0335] In Formulae 502 and 503, a501 to a504 respectively indicate the numbers of R_{501} to R_{504}, and a501 to a504 may each independently be an integer from 0 to 20. When a501 is 2 or more, two or more of R_{501} may be identical to or different from each other, when a502 is 2 or more, two or more of R_{502} may be identical to or different from each other, when a503 is 2 or more, two or more of R_{503} may be identical to or different from each other, and when a504 is 2 or more, two or more of R_{504} may be identical to or different from each other. In an embodiment, a501 to a504 may each independently be an integer from 0 to 8.

[0336] In the specification, in Formulae 502 and 503, R_{500a}, R_{500b}, R_{501} to R_{508}, R_{505a}, R_{505b}, R_{506a}, R_{506b}, R_{507a}, R_{507b}, R_{508a}, and R_{508b} may each independently be hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{60} alkyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} alkenyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} alkynyl group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} alkoxy group unsubstituted or substituted with at least one R_{10a}, a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}, a C_6-C_{60} aryloxy group unsubstituted or substituted with at least one R_{10a}, a C_6-C_{60} arylthio group unsubstituted or substituted with at least one R_{10a}, a C_7-C_{60} arylalkyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} heteroarylalkyl group unsubstituted or substituted with at least one R_{10a}, $—C(Q_1)(Q_2)(Q_3)$, $—Si(Q_1)(Q_2)(Q_3)$, $—N(Q_1)(Q_2)$, $—B(Q_1)(Q_2)$, $—C(═O)(Q_1)$, $—S(═O)_2(Q_1)$, or $—P(═O)(Q_1)(Q_2)$. Q_1 to Q_3 may each be the same as described in the specification.

[0337] For example, in Formulae 502 and 503, R_{500a}, R_{500b}, R_{501} to R_{508}, R_{505a}, R_{505b}, R_{506a}, R_{506b}, R_{507a}, R_{507b}, R_{508a}, and R_{508b} may each independently be:

[0338] hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, or a C_1-C_{20} alkoxy group;

[0339] a C_1-C_{20} alkyl group or a C_1-C_{20} alkoxy group, each substituted with deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{10} alkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, or any combination thereof;

[0340] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imida-

zopyrimidinyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azafluorenyl group, or an azadibenzosilolyl group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, —$O(Q_{31})$, —$S(Q_{31})$, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$P(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, —$P(=O)(Q_{31})(Q_{32})$, or any combination thereof; or

[0341] —$C(Q_1)(Q_2)(Q_3)$, —$Si(Q_1)(Q_2)(Q_3)$, —$N(Q_1)(Q_2)$, —$B(Q_1)(Q_2)$, —$C(=O)(Q_1)$, —$S(=O)_2(Q_1)$, or —$P(=O)(Q_1)(Q_2)$, and

[0342] Q_1 to Q_3 and Q_{31} to Q_{33} may each independently be:

[0343] —CH_3, —CD_3, —CD_2H, —CDH_2, —CH_2CH_3, —CH_2CD_3, —CH_2CD_2H, —CH_2CDH_2, —$CHDCH_3$, —$CHDCD_2H$, —$CHDCDH_2$, —$CHDCD_3$, —CD_2CD_3, —CD_2CD_2H, or —CD_2CDH_2; or

[0344] an n-propyl group, an iso-propyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an isopentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a pyridazinyl group, a pyrazinyl group, or a triazinyl group, each unsubstituted or substituted with deuterium, a C_1-C_{10} alkyl group, a phenyl group, a biphenyl group, a pyridinyl group, a pyrimidinyl group, a pyridazinyl group, a pyrazinyl group, a triazinyl group, or any combination thereof.

[0345] In embodiments, in the specification, R_{10a} may be:

[0346] hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, or a C_1-C_{20} alkoxy group;

[0347] a C_1-C_{20} alkyl group or a C_1-C_{20} alkoxy group, each substituted with deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{10} alkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, or any combination thereof;

[0348] a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azafluorenyl group, or an azadibenzosilolyl group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, —$O(Q_{31})$, —$S(Q_{31})$, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$P(Q_{31})$

(Q_{32}), —C(=O)(Q_{31}), —S(=O)$_2$(Q_{31}), —P(=O)(Q_{31})(Q_{32}), or any combination thereof; or

[0349] —C(Q_1)(Q_2)(Q_3), —Si(Q_1)(Q_2)(Q_3), —N(Q_1)(Q_2), —B(Q_1)(Q_2), —C(=O)(Q_1), —S(=O)$_2$(Q_1), or —P(=O)(Q_1)(Q_2), and

[0350] Q_1 to Q_3 and Q_{31} to Q_{33} may each independently be:

[0351] —CH_3, —CD_3, —CD_2H, —CDH_2, —CH_2CH_3, —CH_2CD_3, —CH_2CD_2H, —CH_2CDH_2, —$CHDCH_3$, —$CHDCD_2H$, —$CHDCDH_2$, —$CHDCD_3$, —CD_2CD_3, —CD_2CD_2H, or —CD_2CDH_2; or

[0352] an n-propyl group, an iso-propyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an isopentyl group, a sec-pentyl group, a tert-pentyl group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a pyridazinyl group, a pyrazinyl group, or a triazinyl group, each unsubstituted or substituted with deuterium, a C_1-C_{10} alkyl group, a phenyl group, a biphenyl group, a pyridinyl group, a pyrimidinyl group, a pyridazinyl group, a pyrazinyl group, a triazinyl group, or any combination thereof.

[0353] In an embodiment, R_{11}, R_{12}, R_{21}, R_{22}, R_3, and R_{41} to R_{43} in Formula 1, R_{51} to R_{56} in Formula 2, R_{901} to R_{904}, R_{1a}, and R_{1b} in Formula 3, R_{500a}, R_{500b}, R_{501} to R_{508}, R_{505a}, R_{505b}, R_{506a}, R_{506b}, R_{507a}, R_{507b}, R_{508a}, and R_{508b} in Formulae 502 and 503, and R_{10a} may each independently be hydrogen, deuterium, —F, a cyano group, a nitro group, —CH_3, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a group represented by one of Formulae 9-1 to 9-19, a group represented by one of Formulae 10-1 to 10-246, —C(Q_1)(Q_2)(Q_3), —Si(Q_1)(Q_2)(Q_3), or —P(=O)(Q_1)(Q_2), wherein Q_1 to Q_3 are each the same as described herein:

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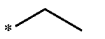

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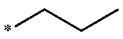

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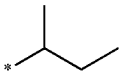

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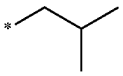

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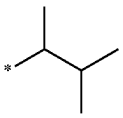

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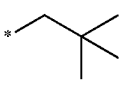

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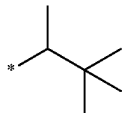

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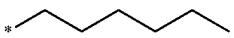

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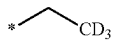

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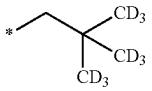

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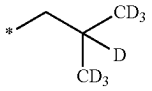

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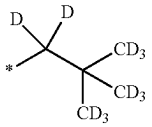

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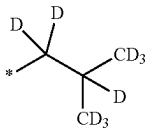

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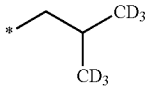

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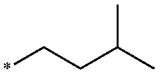

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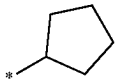

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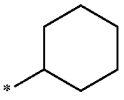

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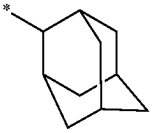

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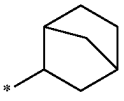

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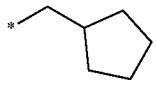

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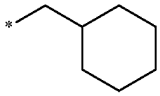

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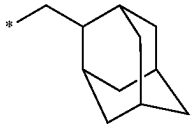

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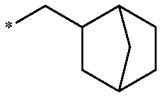

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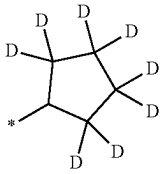

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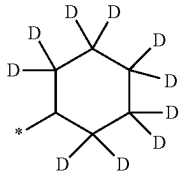

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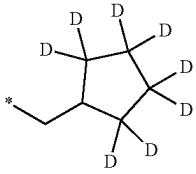

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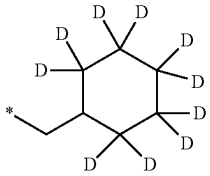

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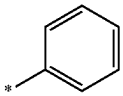

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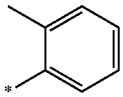

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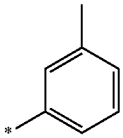

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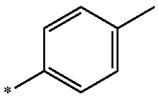

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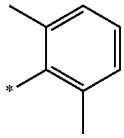

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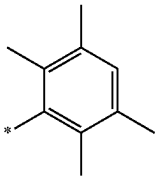

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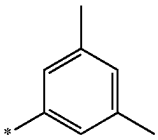

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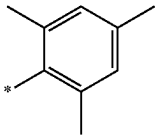

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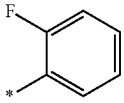

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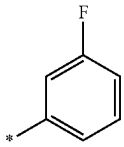

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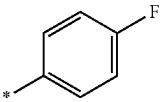

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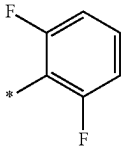

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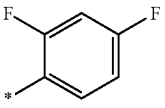

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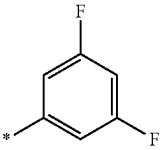

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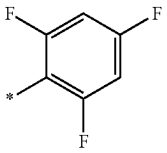

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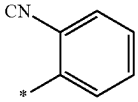

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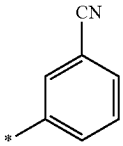

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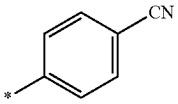

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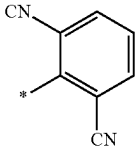

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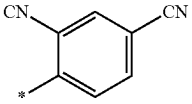

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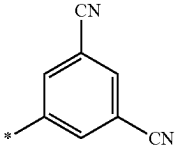

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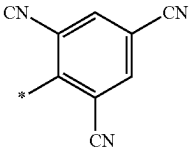

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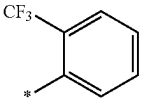

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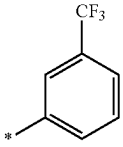

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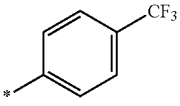

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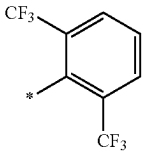

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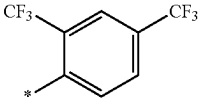

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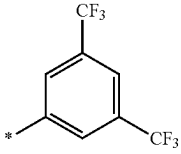

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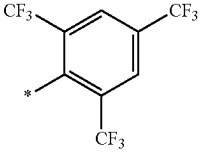

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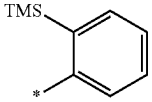

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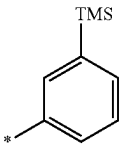

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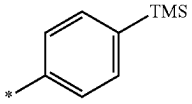

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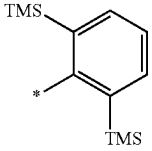

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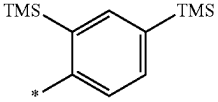

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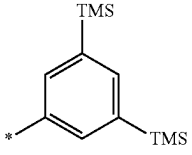

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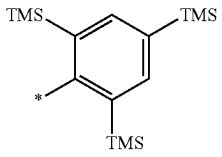

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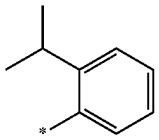

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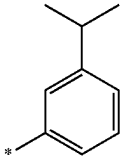

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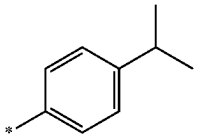

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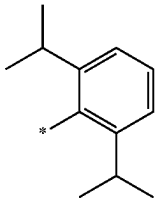

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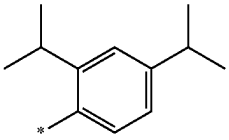

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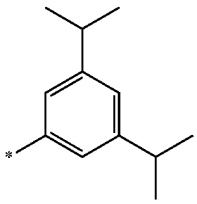

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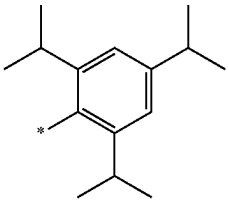

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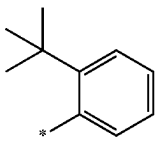

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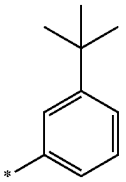

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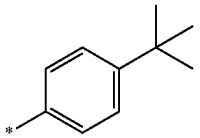

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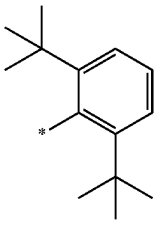

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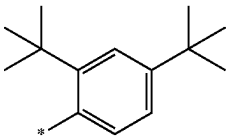

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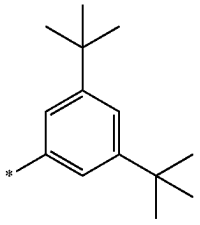

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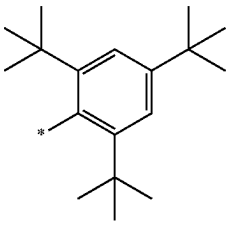

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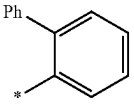

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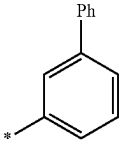

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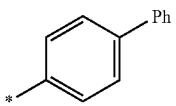

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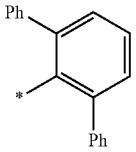

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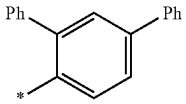

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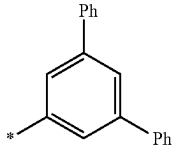

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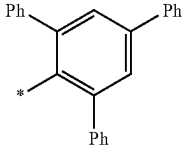

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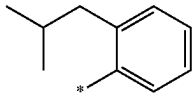

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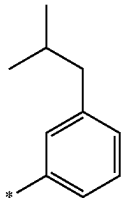

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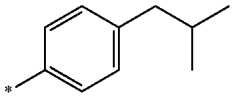

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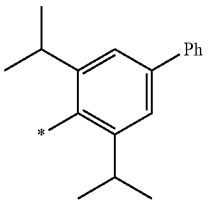

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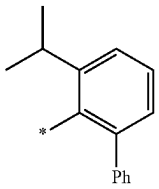

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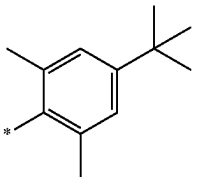

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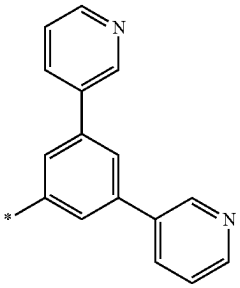

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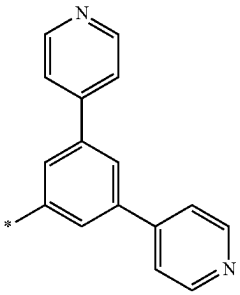

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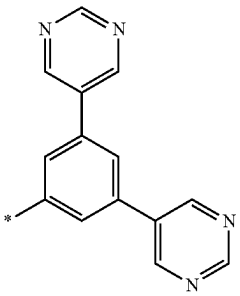

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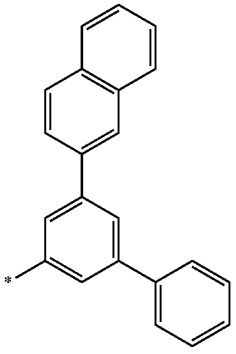

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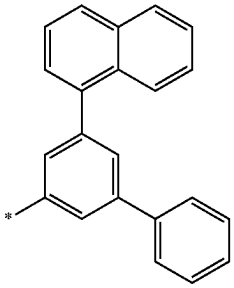

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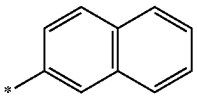

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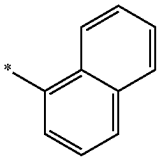

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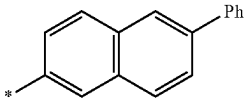

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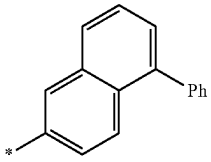

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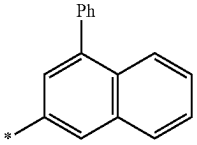

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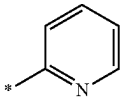

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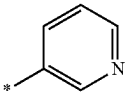

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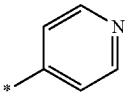

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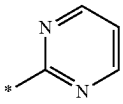

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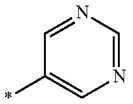

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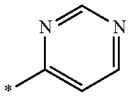

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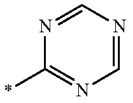

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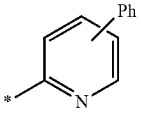

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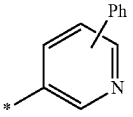

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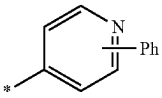

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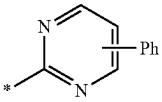

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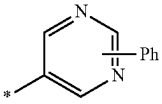

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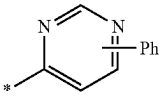

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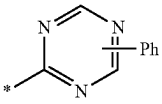

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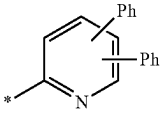

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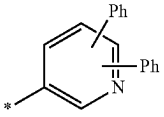

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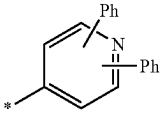

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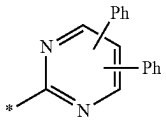

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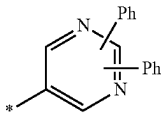

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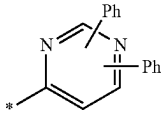

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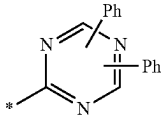

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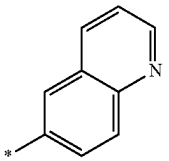

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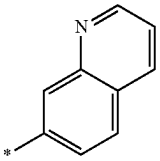

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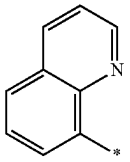

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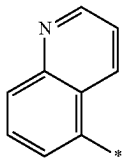

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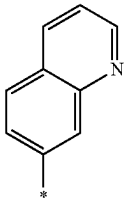

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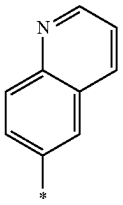

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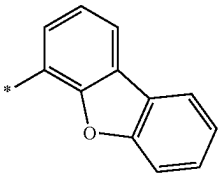

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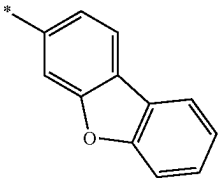

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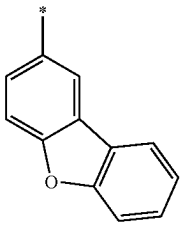

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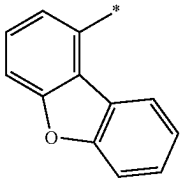

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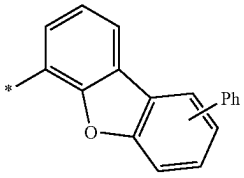

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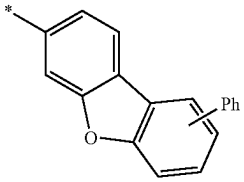

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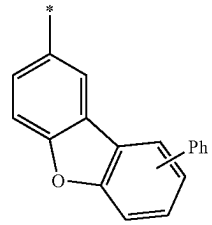

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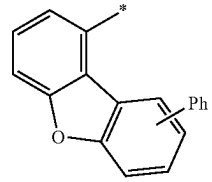

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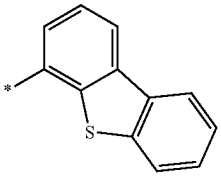

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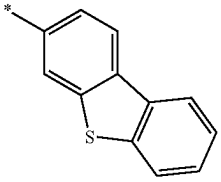

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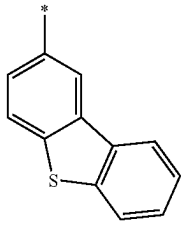

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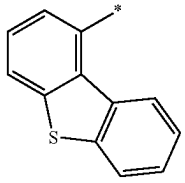

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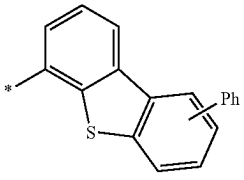

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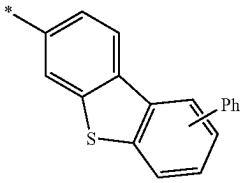

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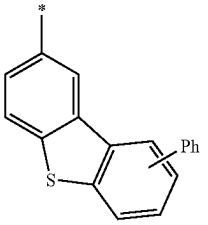

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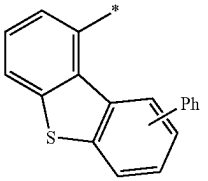

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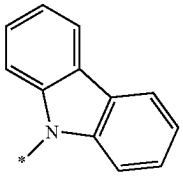

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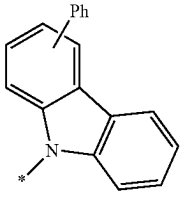

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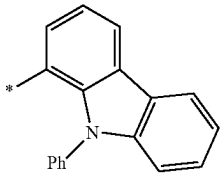

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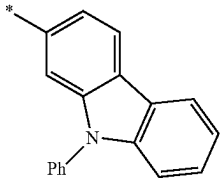

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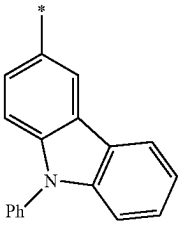

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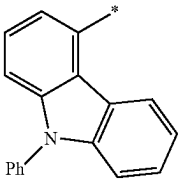

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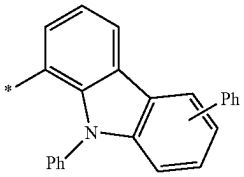

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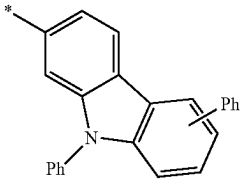

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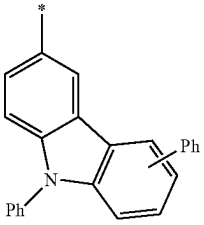

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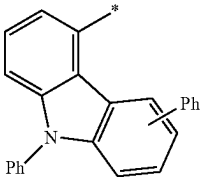

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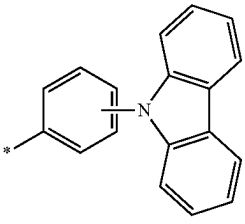

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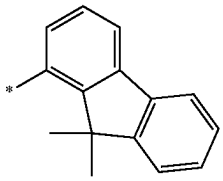

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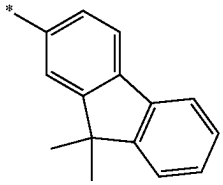

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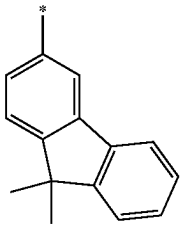

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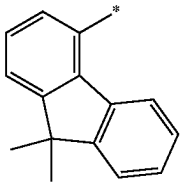

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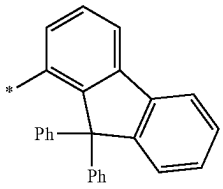

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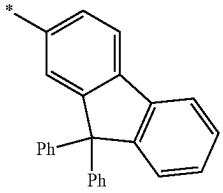

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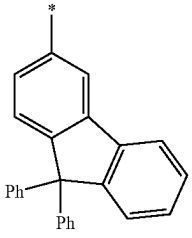

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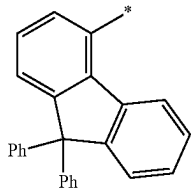

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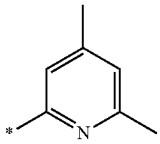

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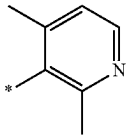

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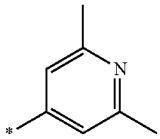

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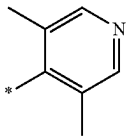

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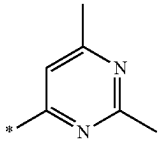

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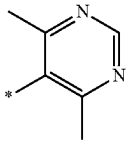

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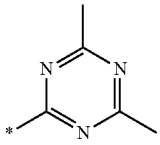

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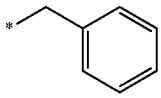

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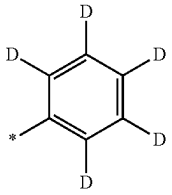

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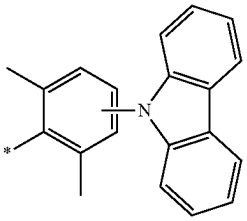

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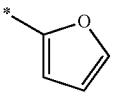

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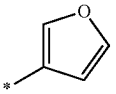

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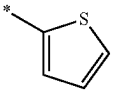

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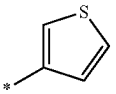

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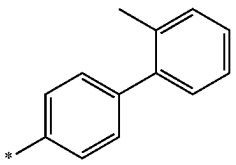

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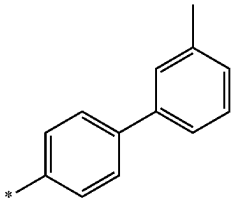

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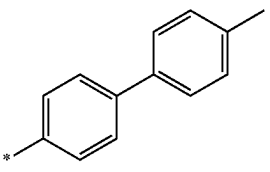

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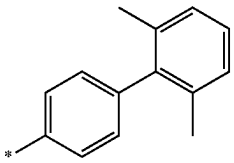

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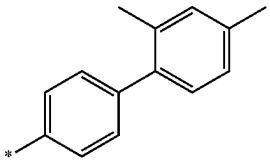

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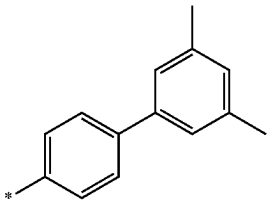

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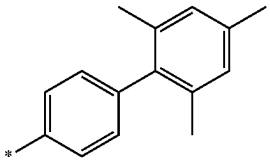

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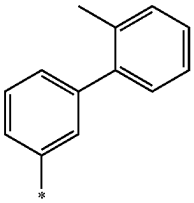

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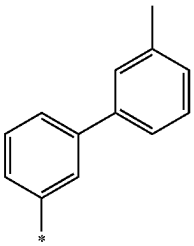

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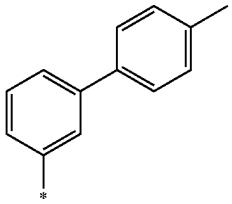

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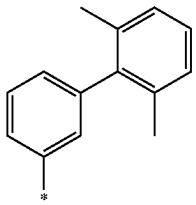

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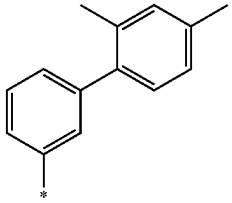

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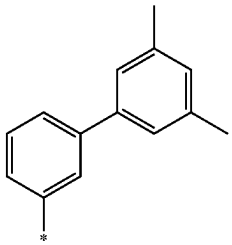

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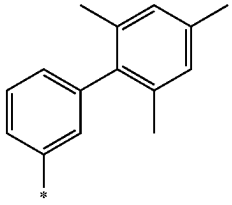

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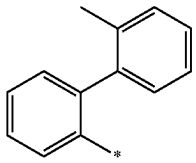

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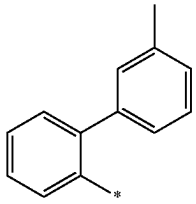

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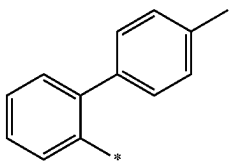

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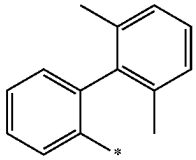

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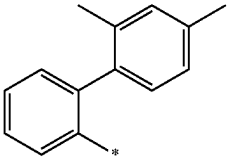

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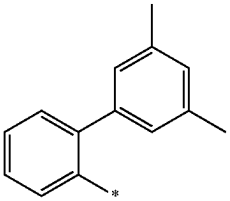

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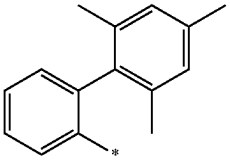

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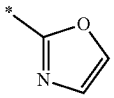

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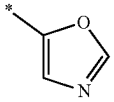

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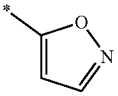

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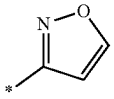

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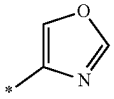

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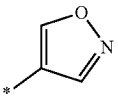

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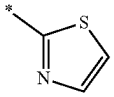

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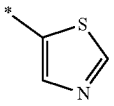

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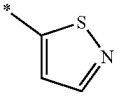

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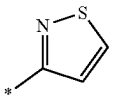

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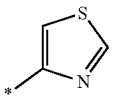

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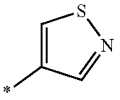

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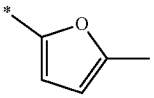

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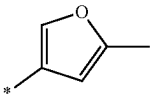

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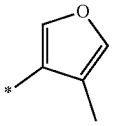

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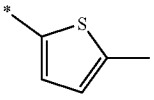

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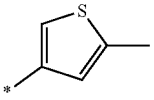

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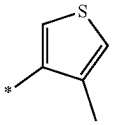

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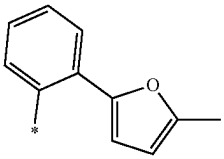

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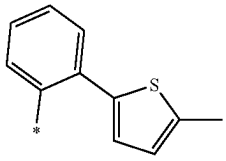

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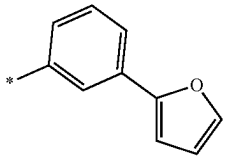

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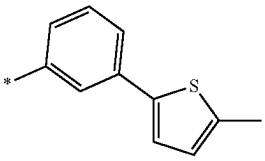

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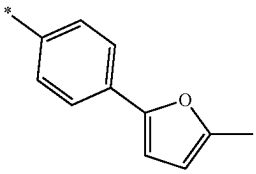

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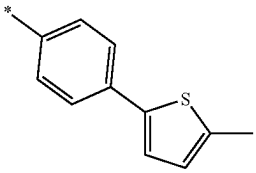

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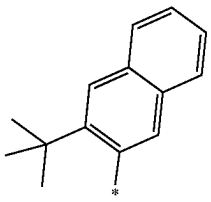

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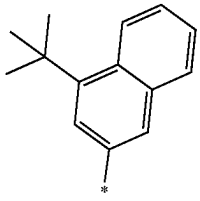

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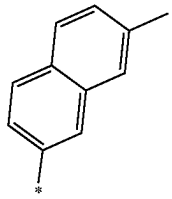

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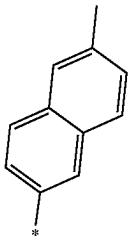

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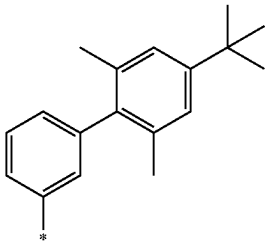

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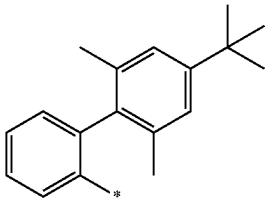

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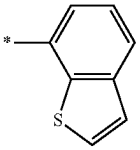

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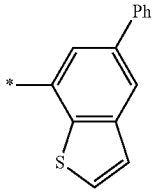

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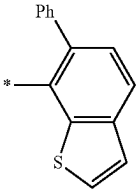

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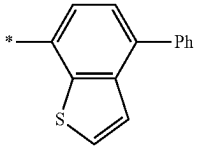

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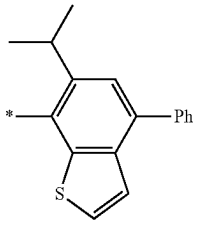

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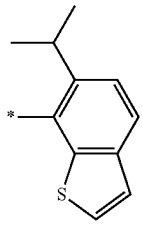

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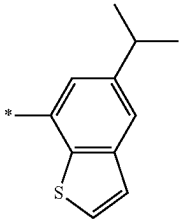

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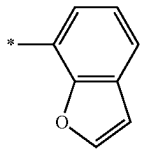

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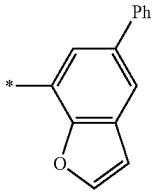

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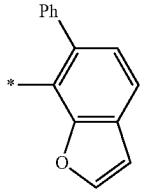

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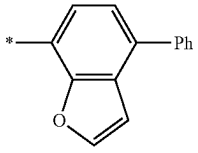

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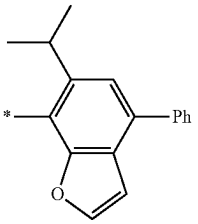

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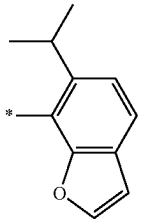

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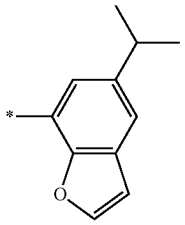

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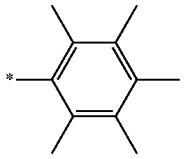

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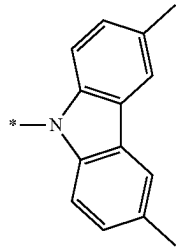

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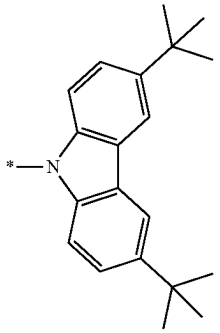

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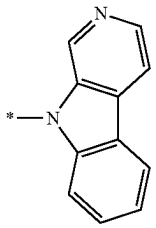

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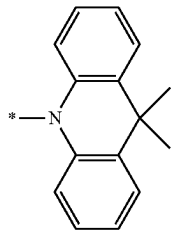

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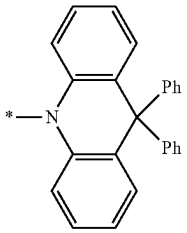

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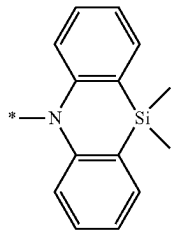

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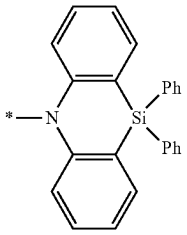

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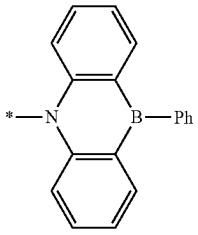

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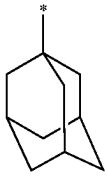
10-237



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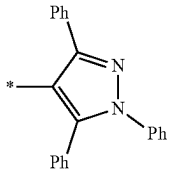

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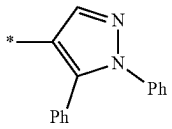

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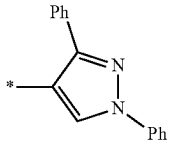

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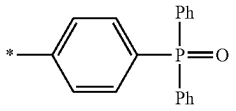

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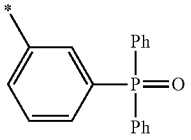

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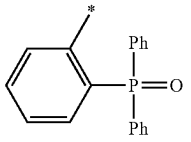

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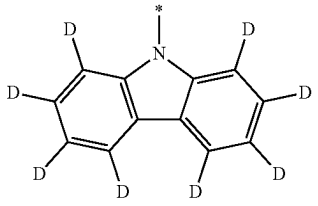

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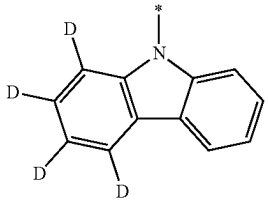

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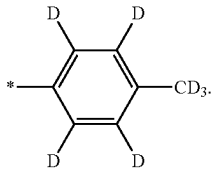
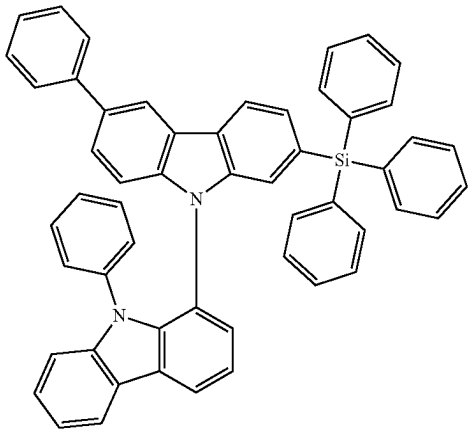


[0354] In Formulae 9-1 to 9-19 and 10-1 to 10-246, * indicates a binding site to an adjacent atom, Ph represents a phenyl group, and TMS represents a trimethylsilyl group.

Examples of Compounds

[0355] In an embodiment, the heterocyclic compound represented by Formula 1 may be one of Compounds 1 to 153:

1



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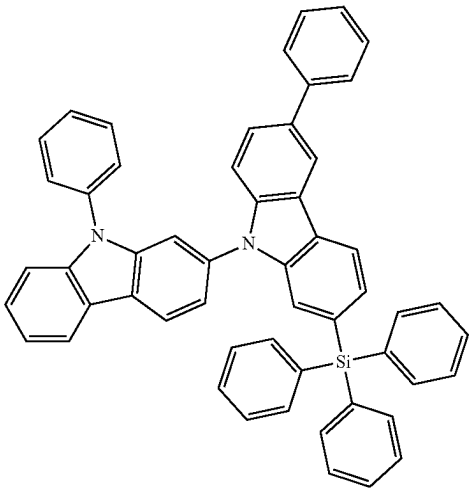

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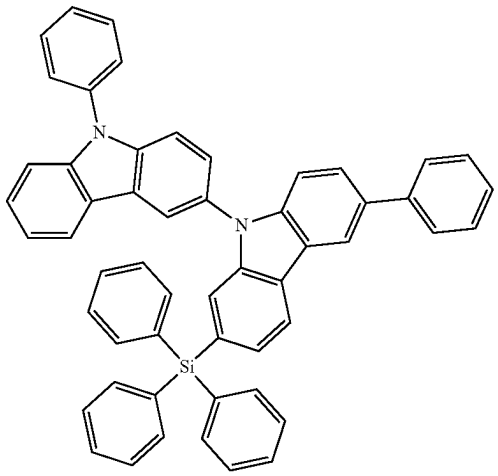

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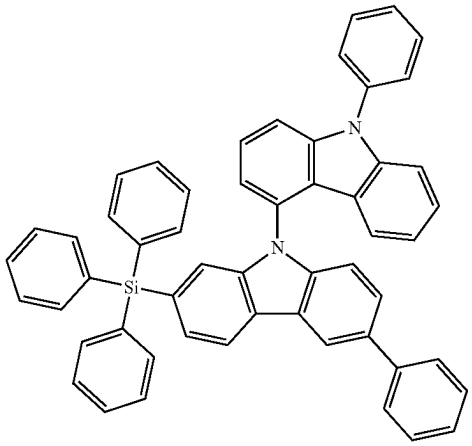

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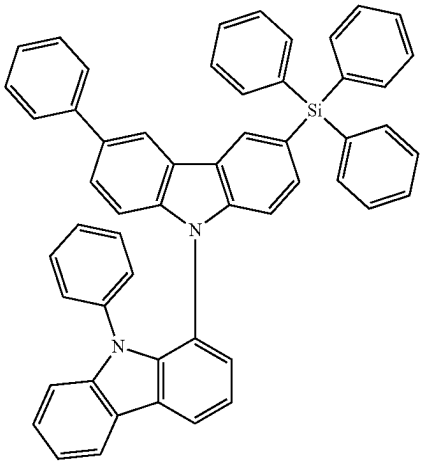

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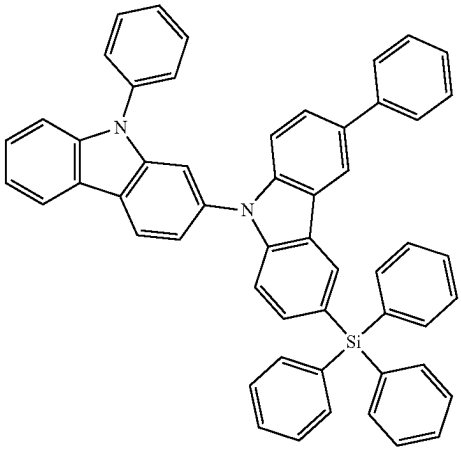

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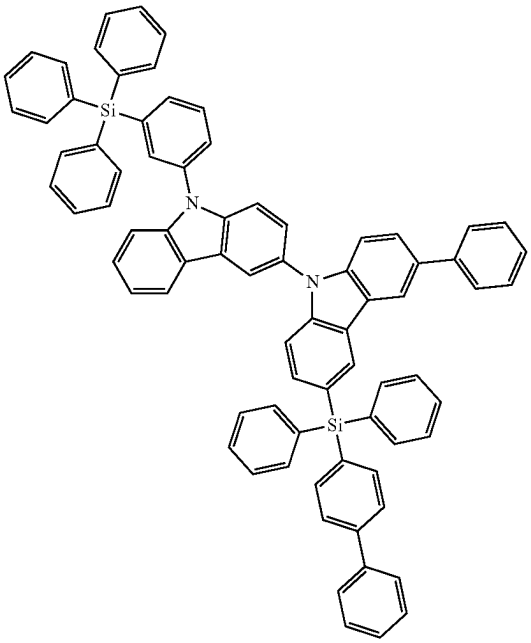

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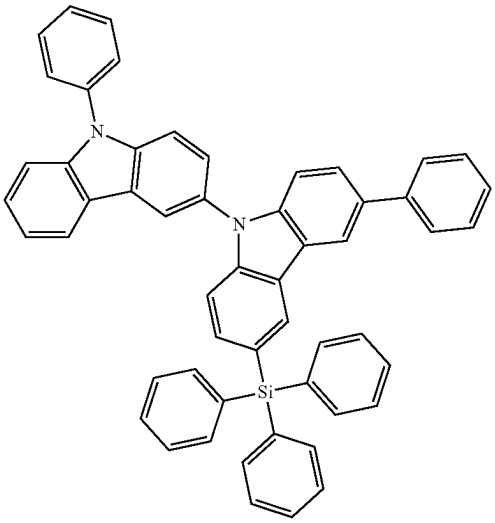

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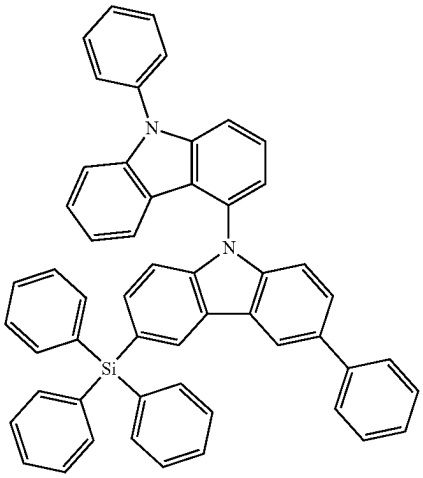

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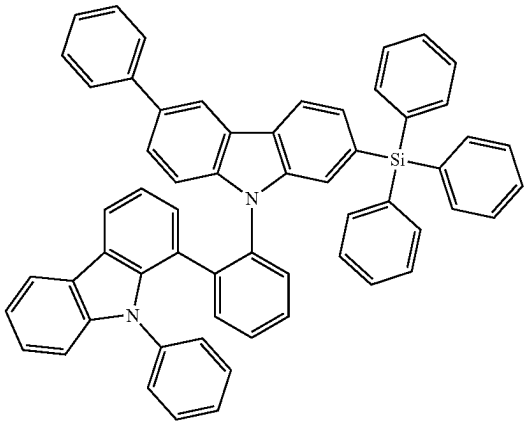

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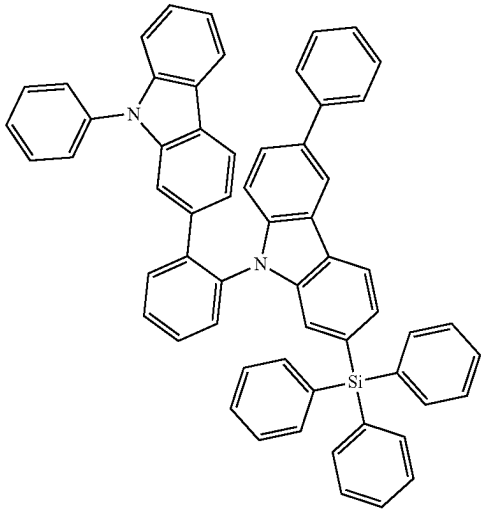

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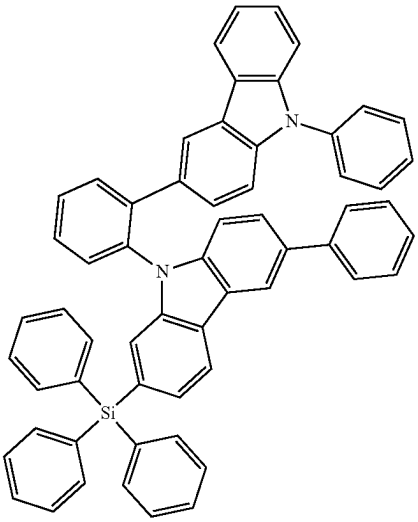

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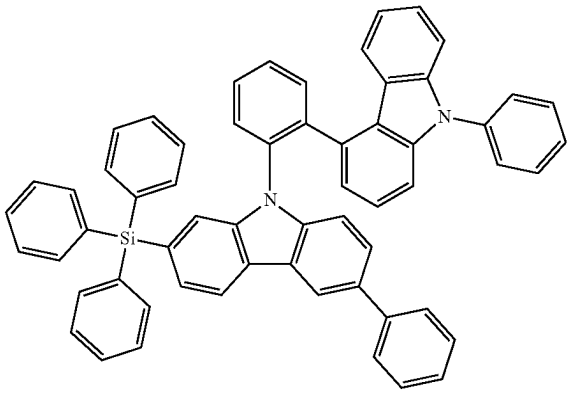

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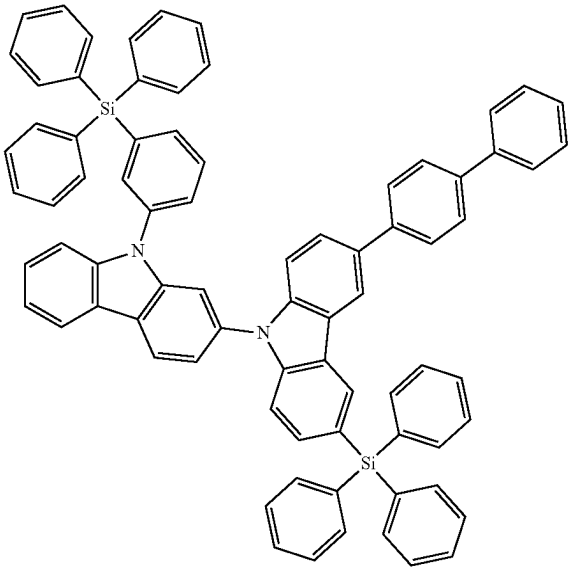

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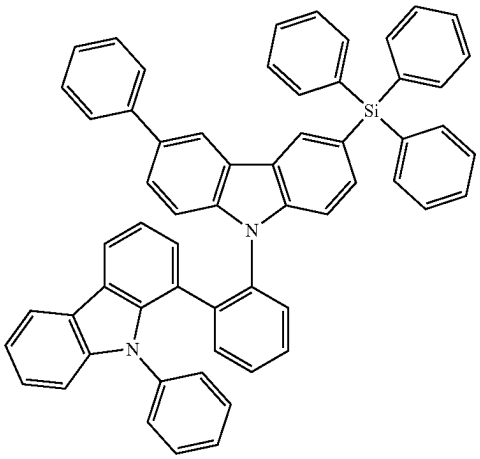

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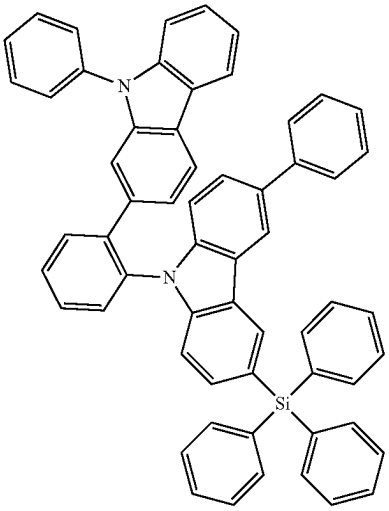

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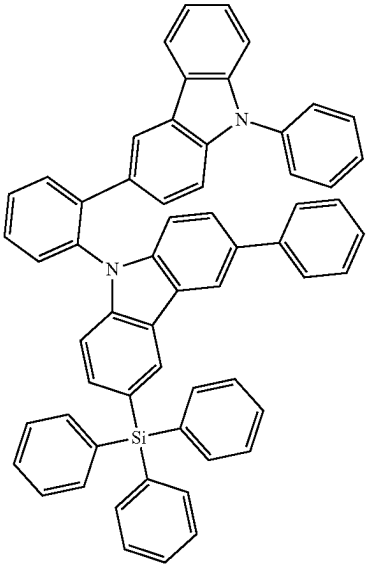

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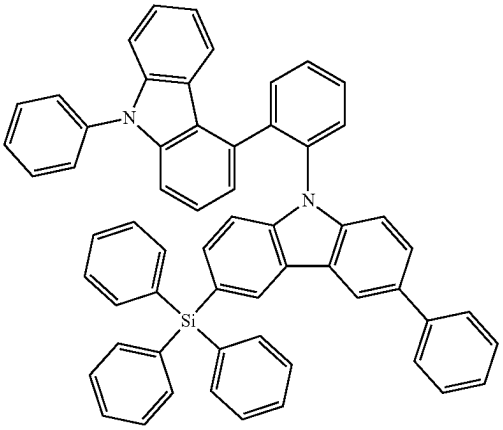

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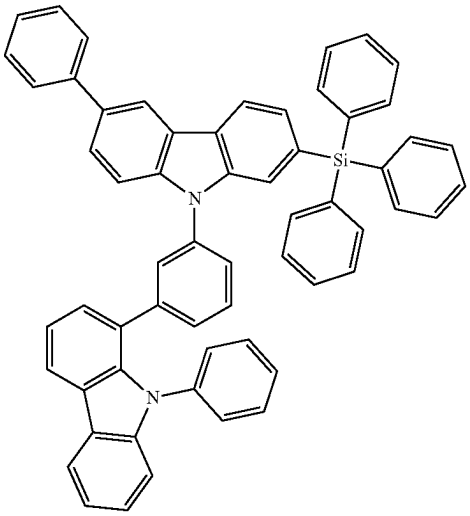

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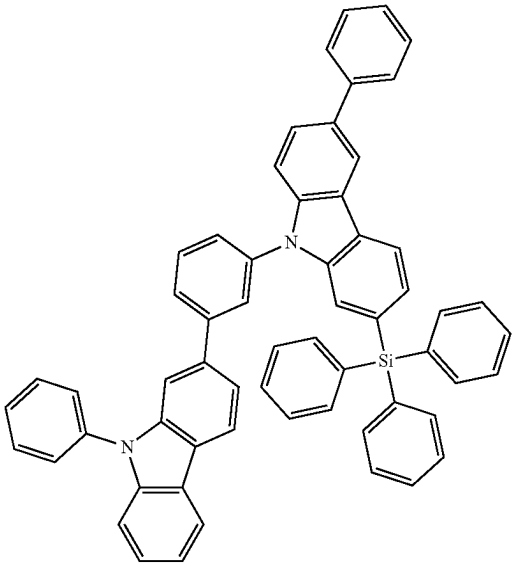

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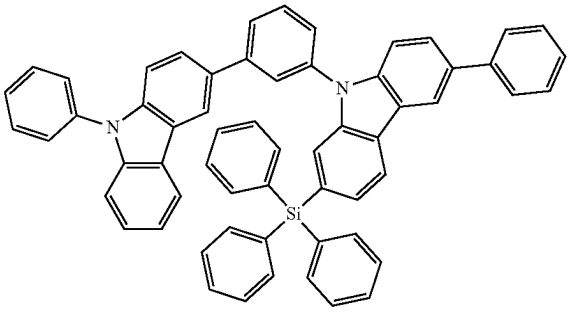

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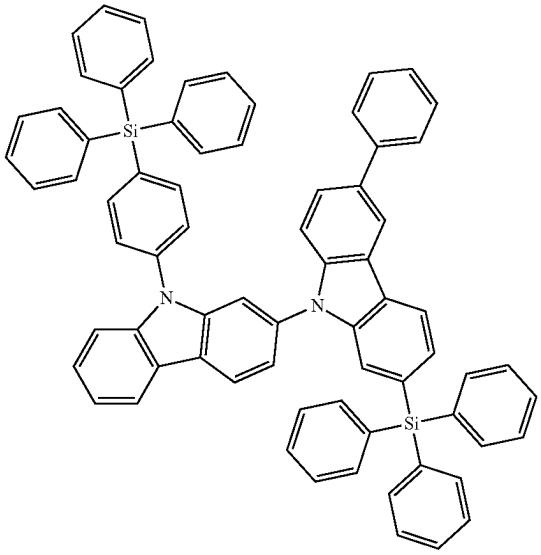

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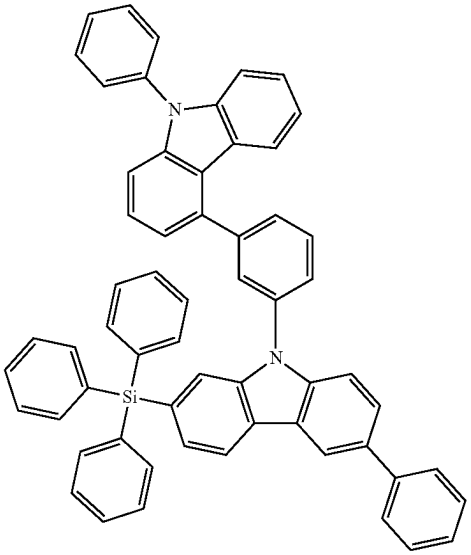

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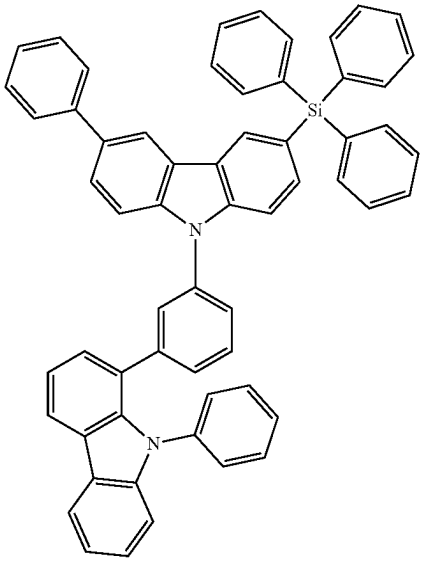

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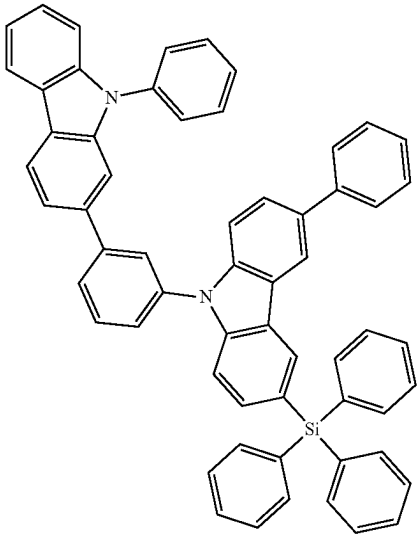

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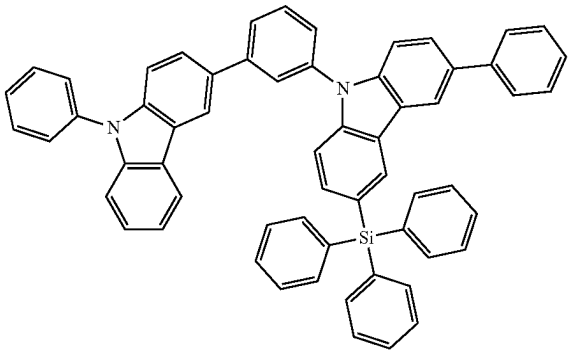

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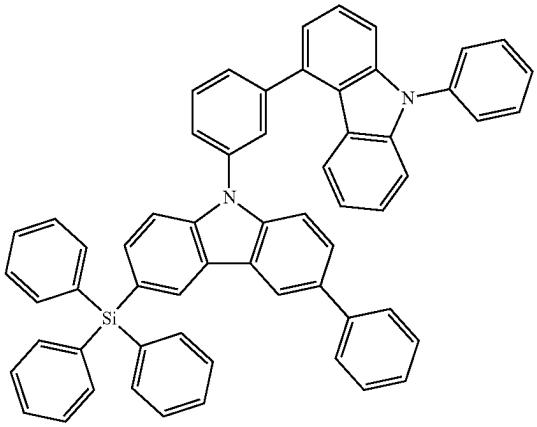

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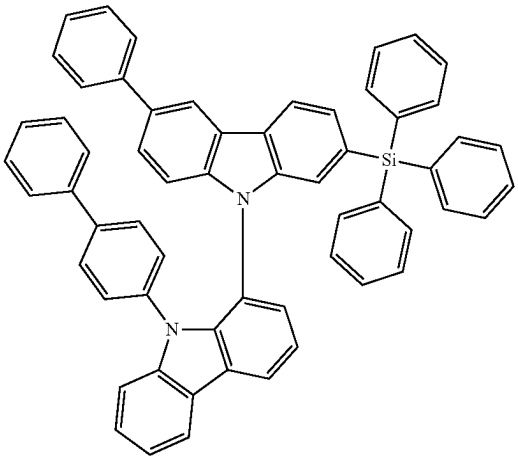

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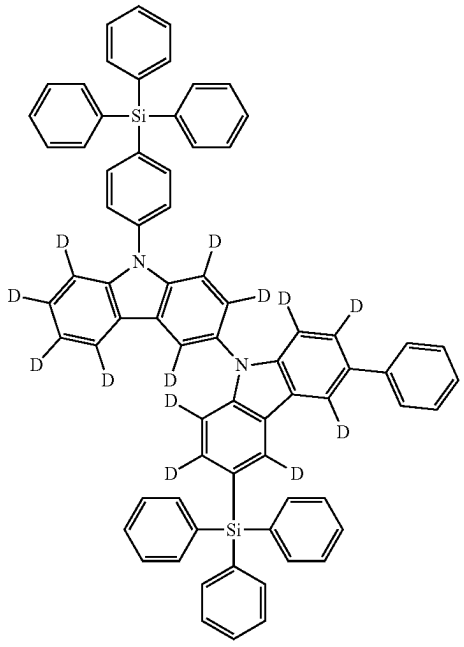

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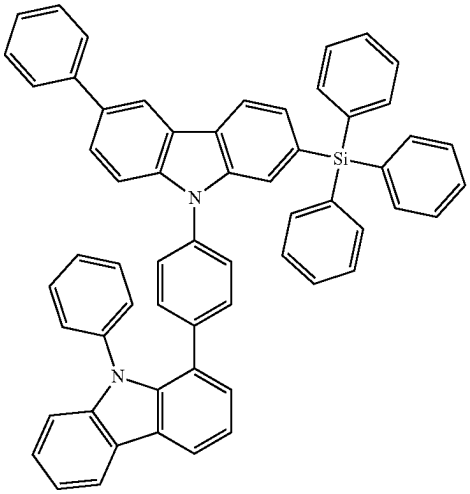

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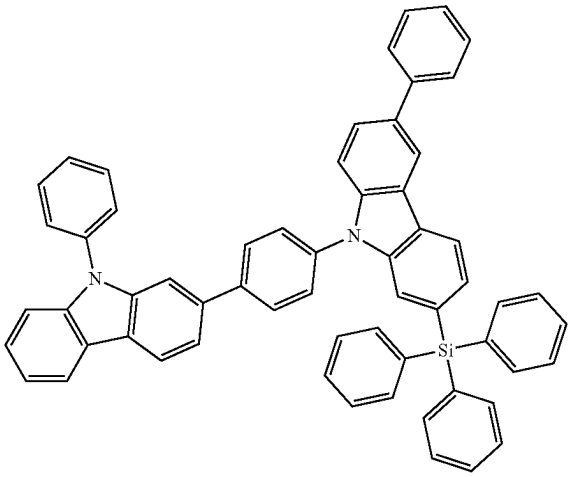

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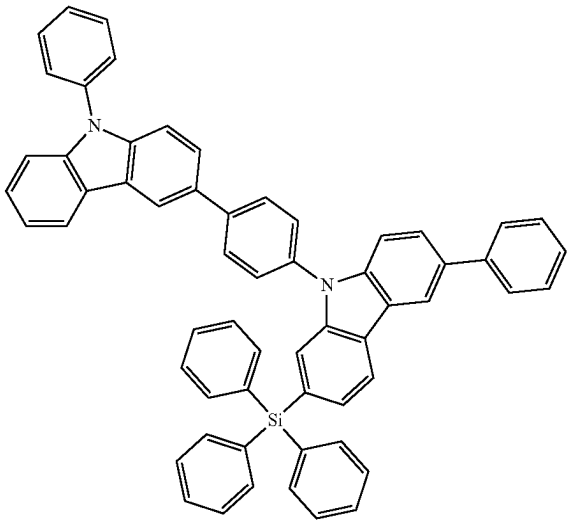

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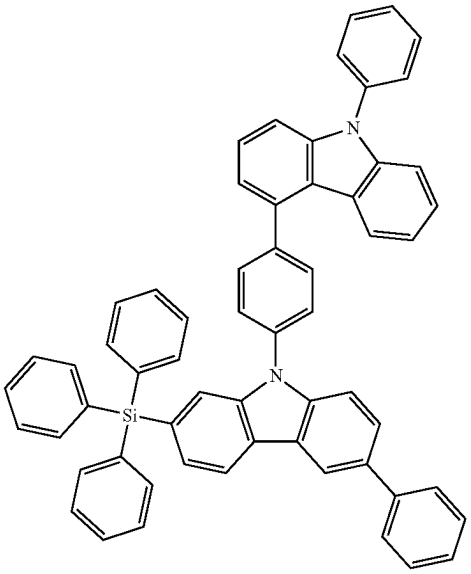

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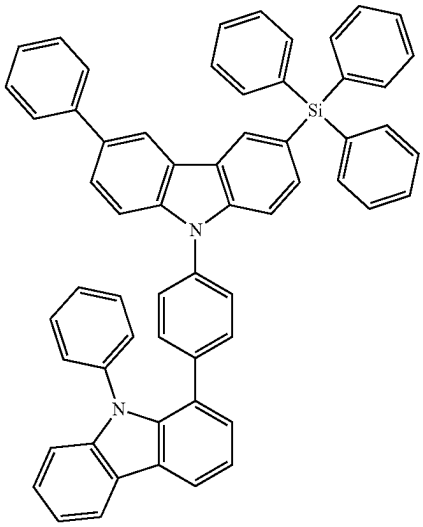

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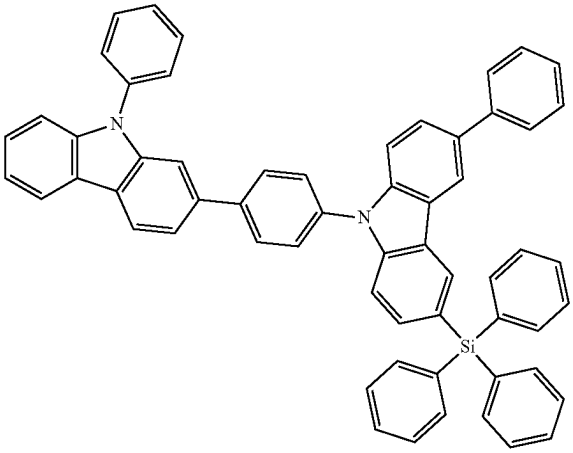

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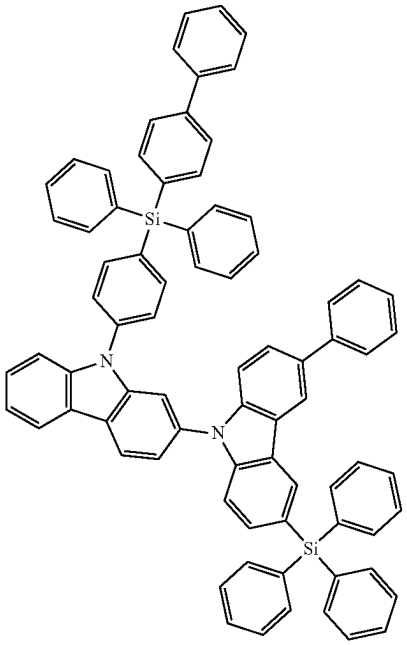

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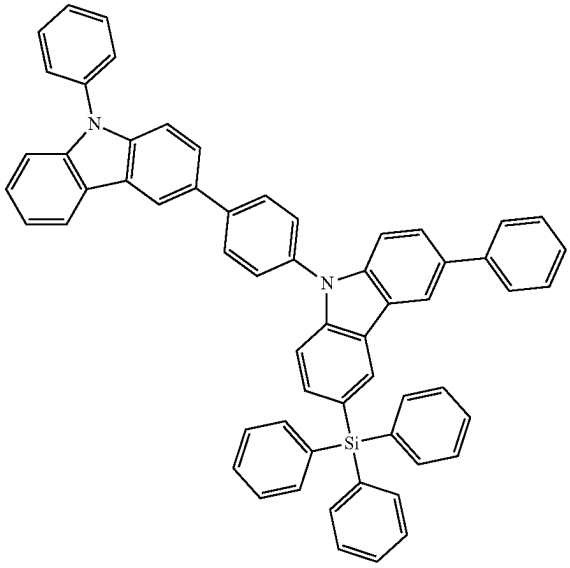

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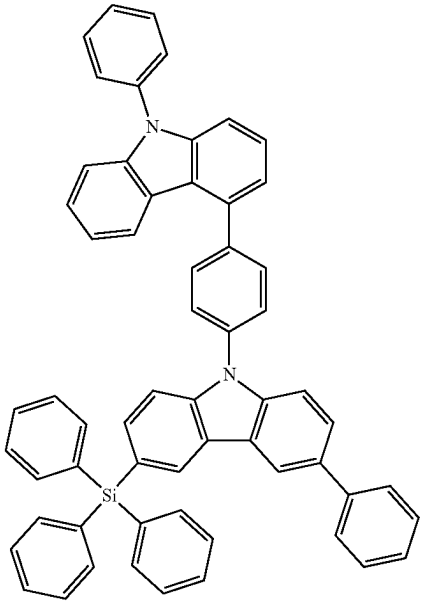

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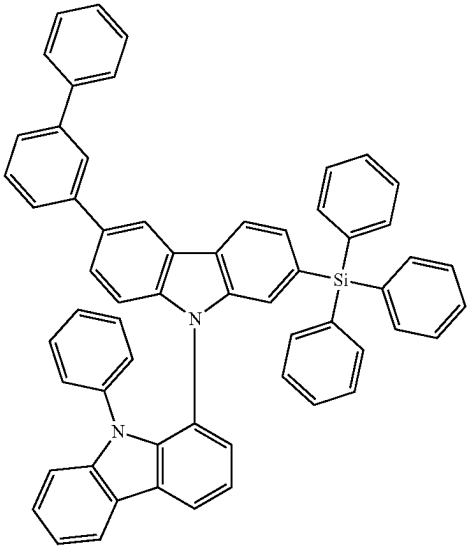

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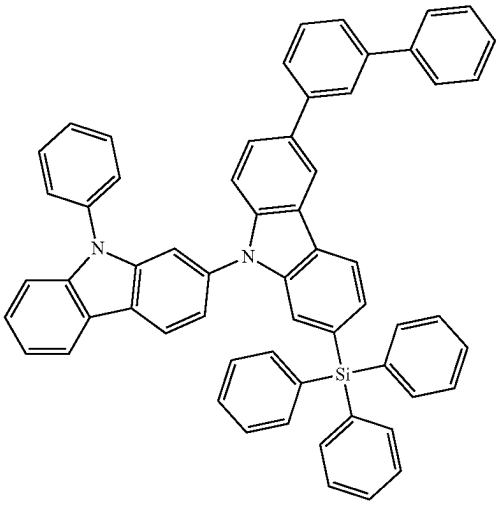

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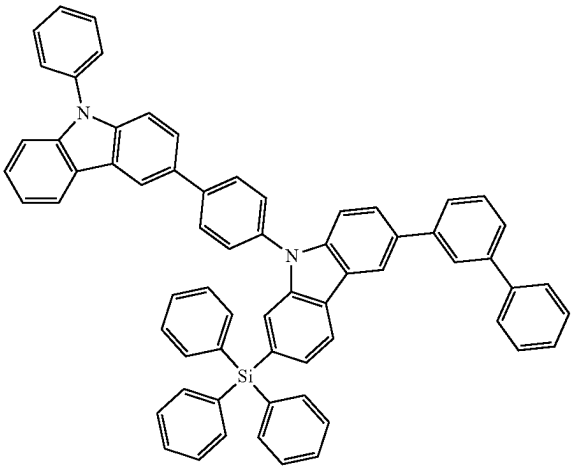

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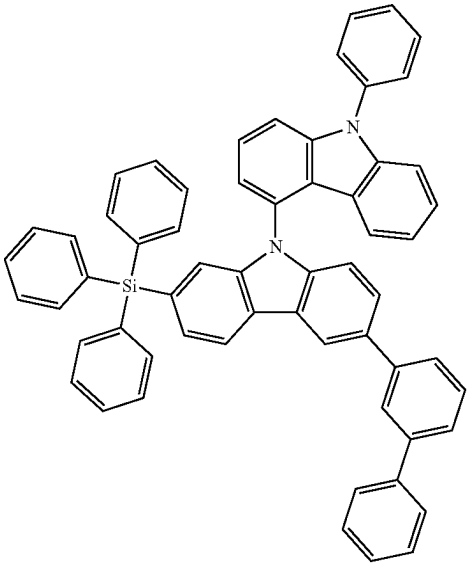

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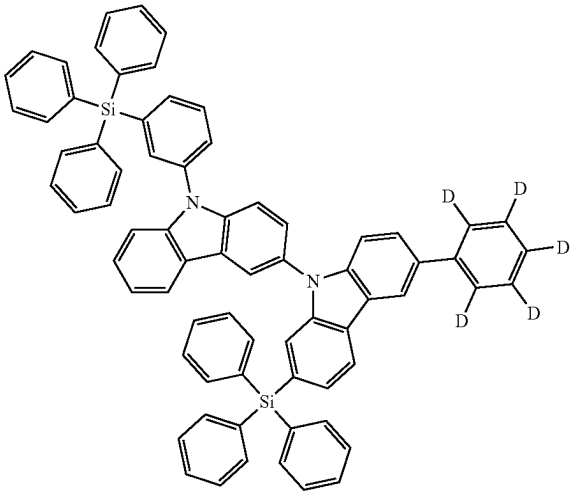

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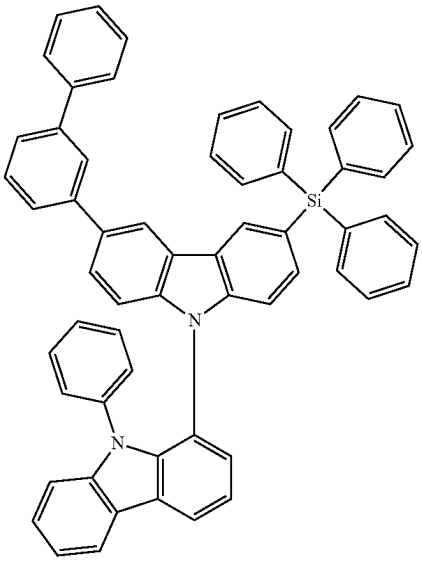

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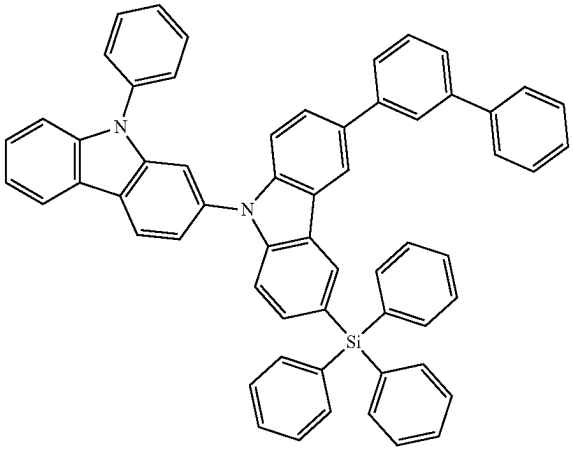

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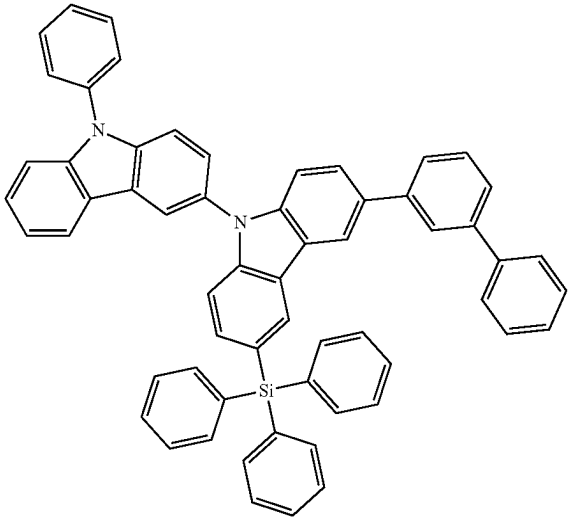

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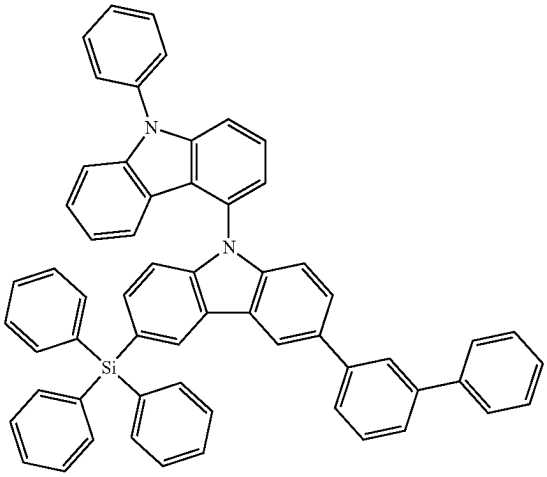

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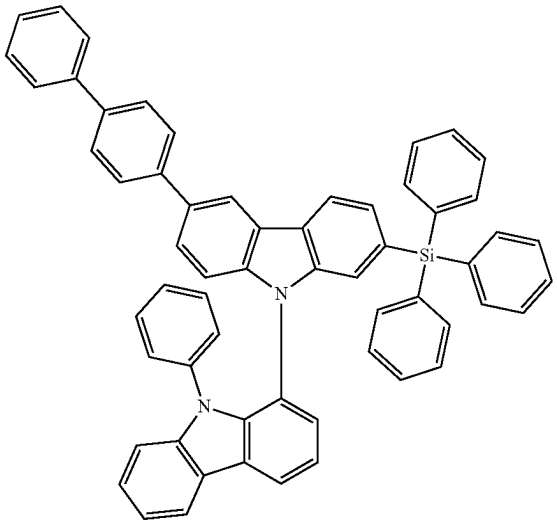

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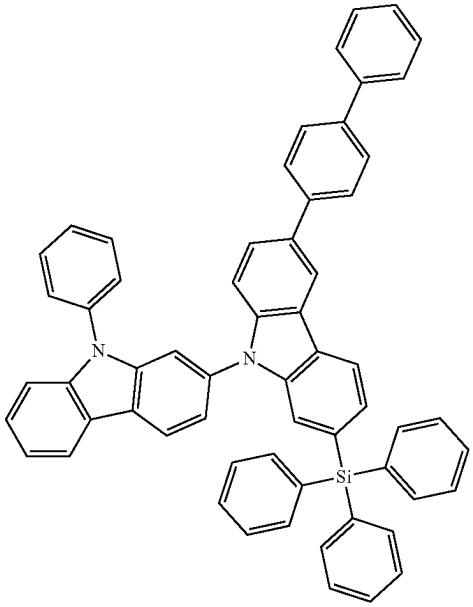

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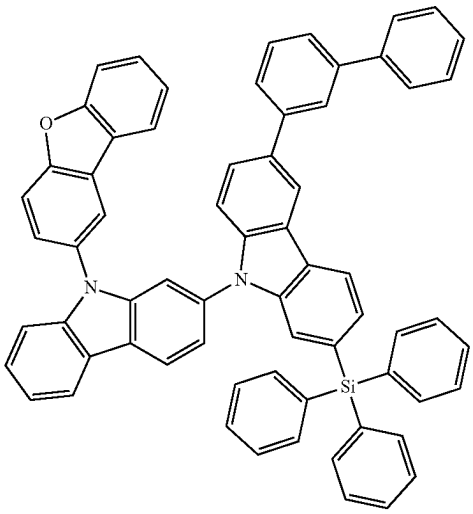

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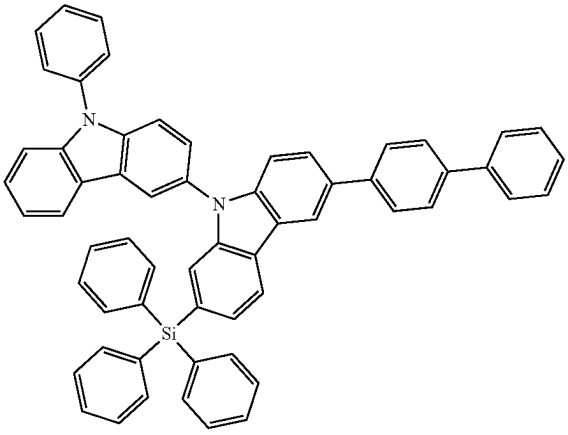

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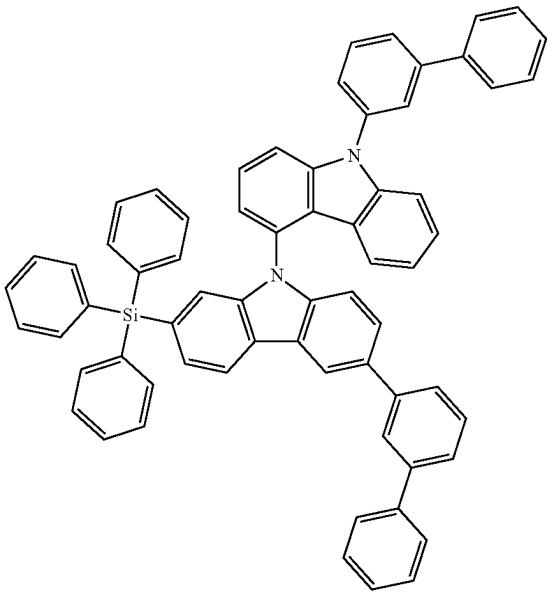

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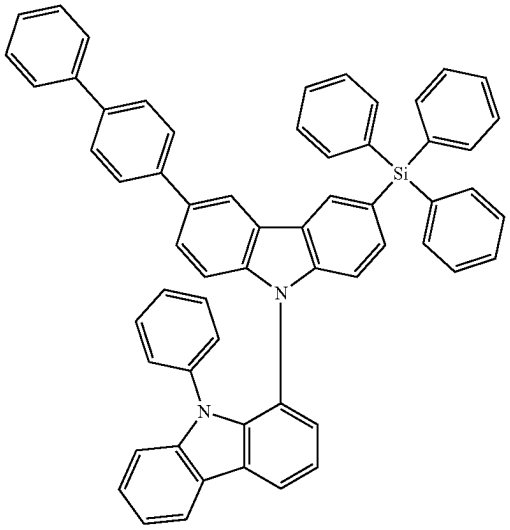

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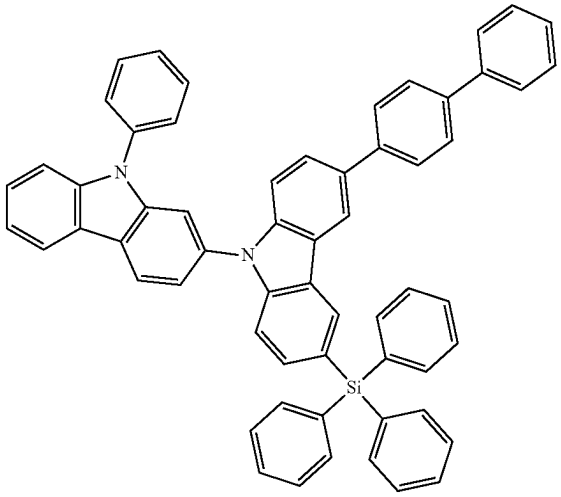

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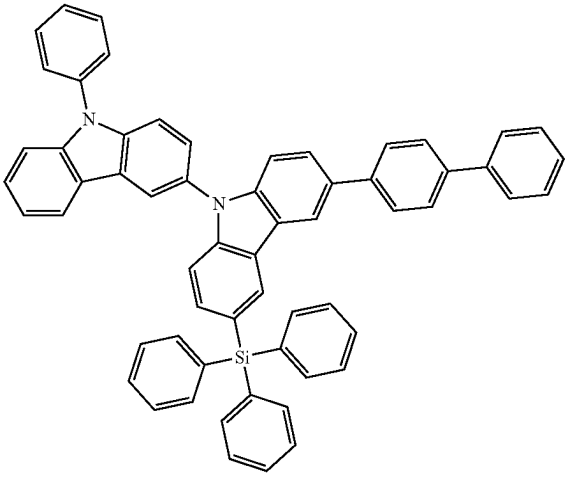

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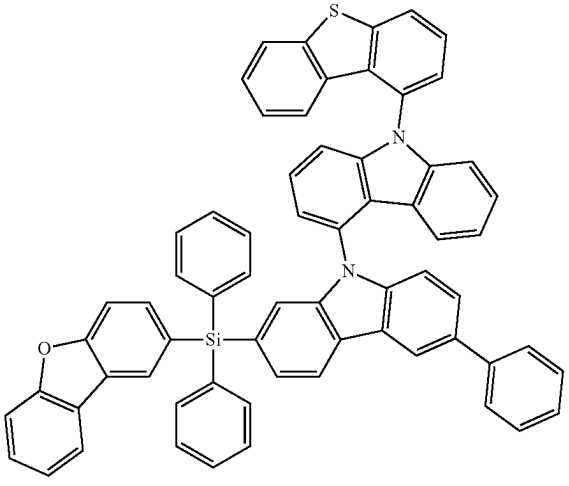

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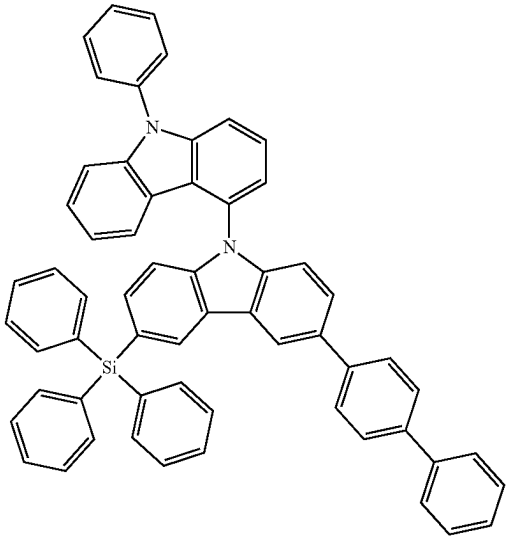

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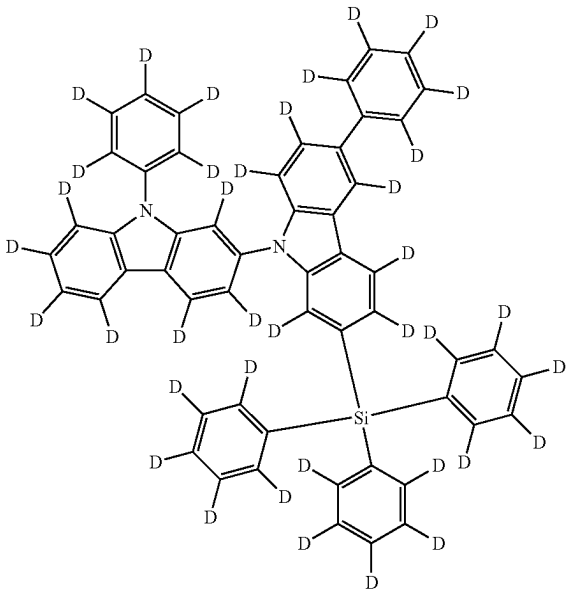

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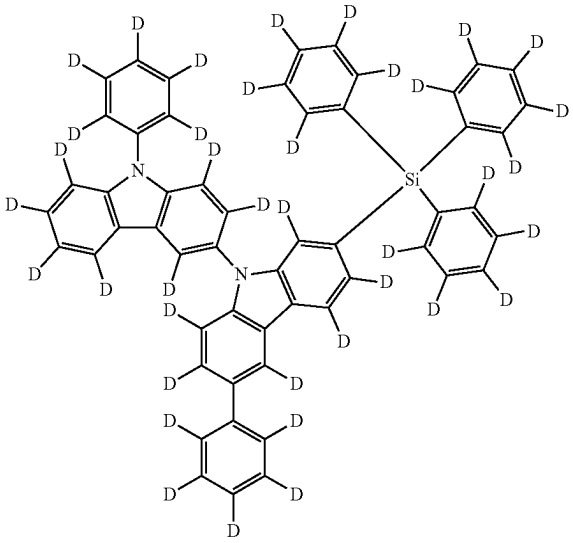

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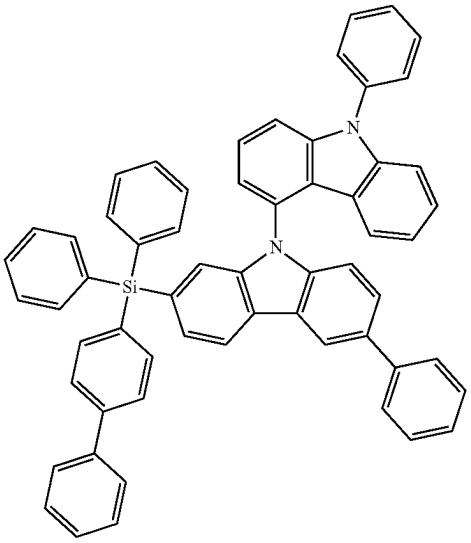

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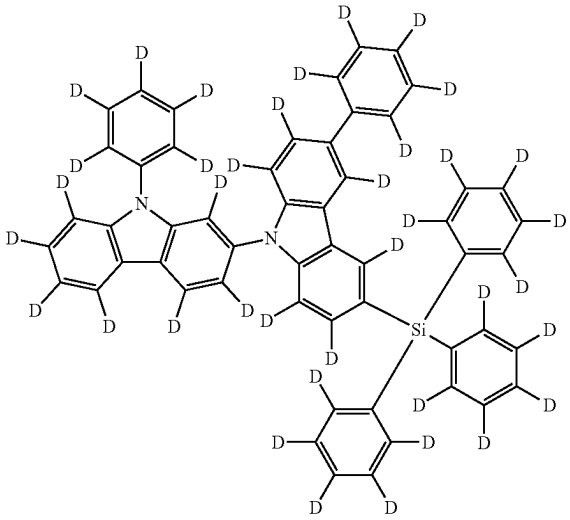

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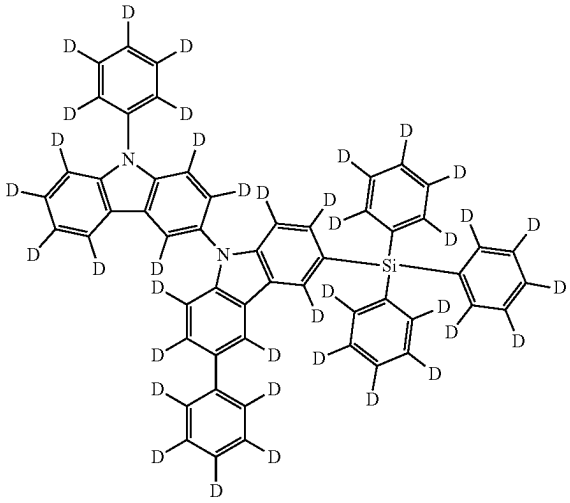

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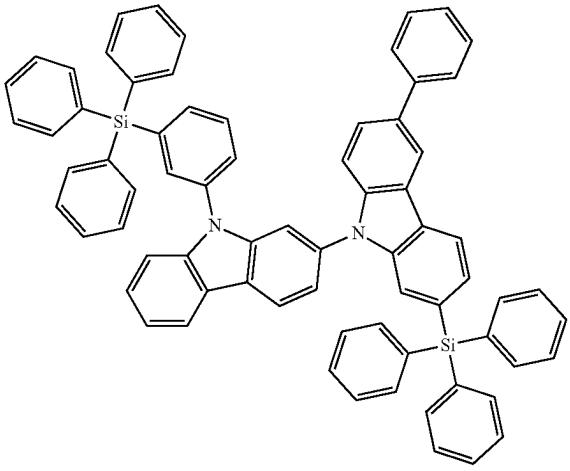

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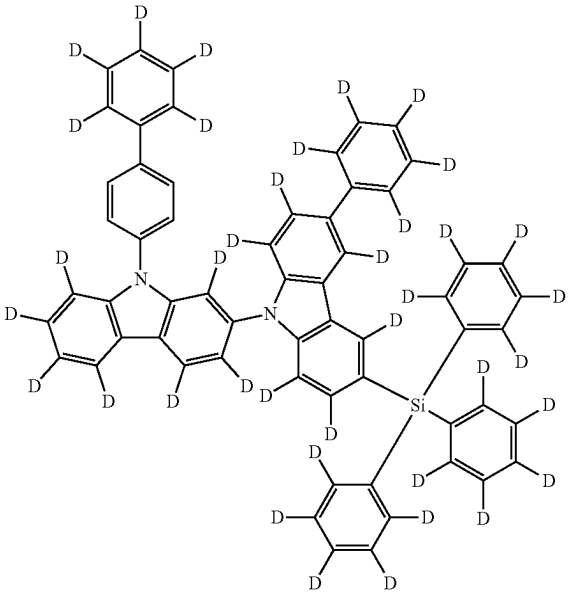

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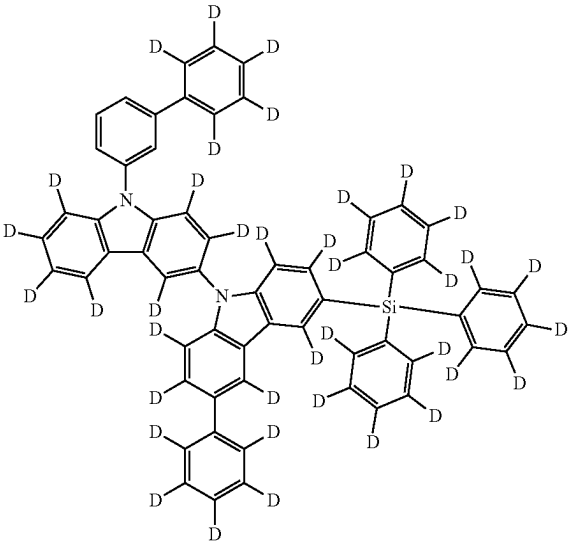

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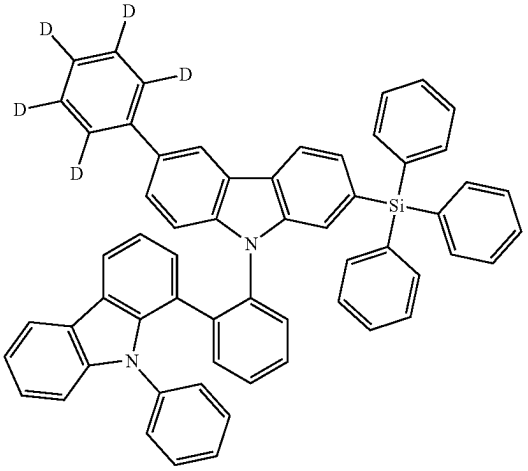

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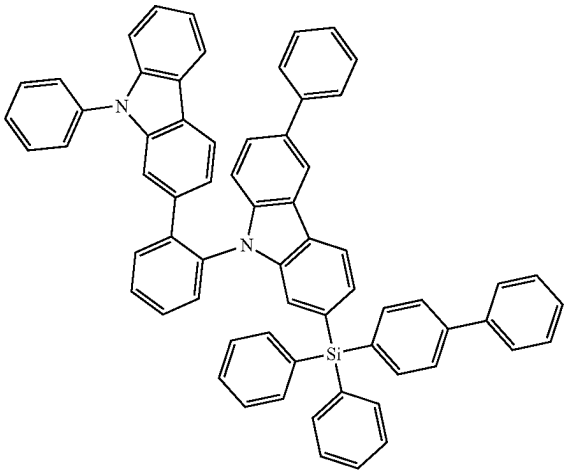

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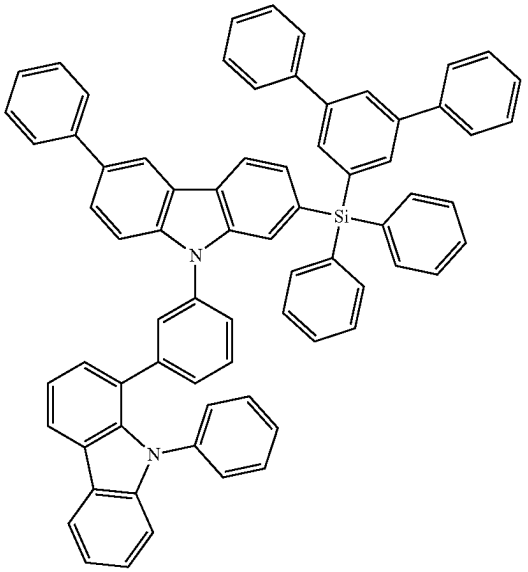

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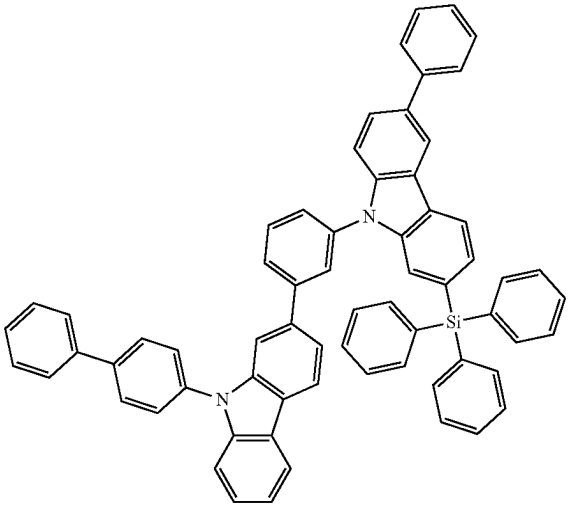

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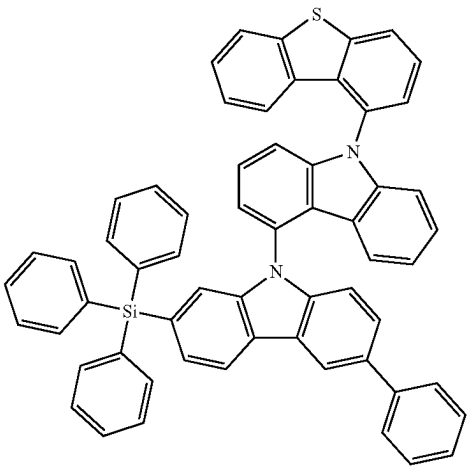

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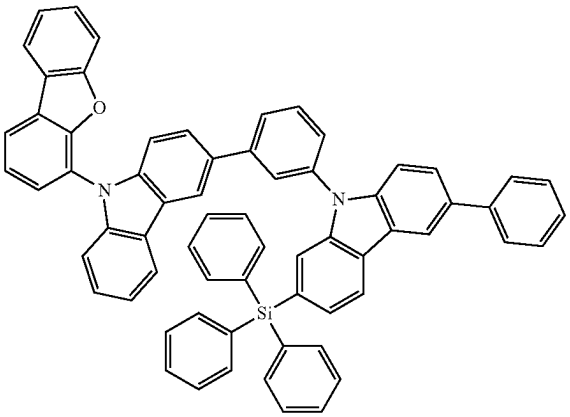

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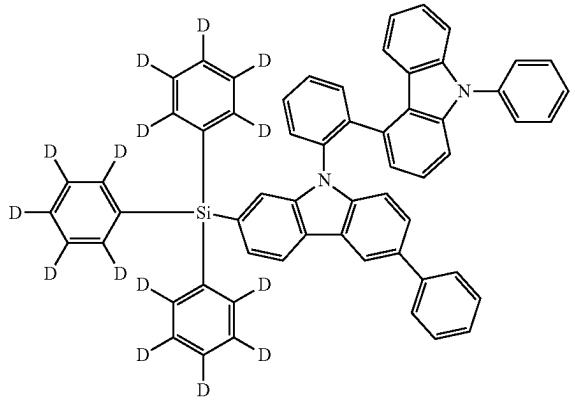

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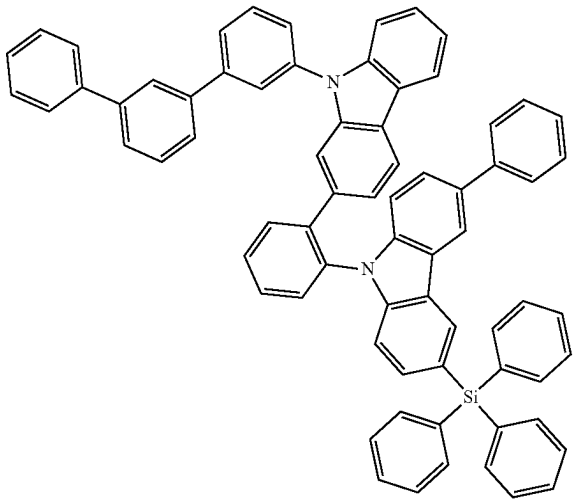

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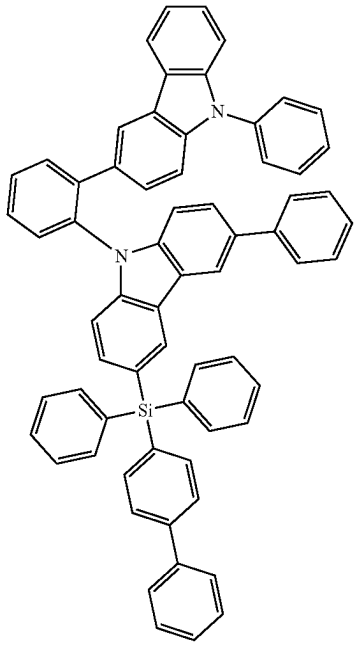

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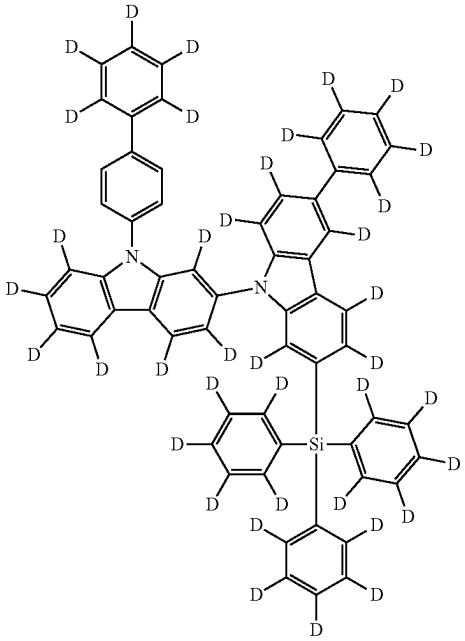

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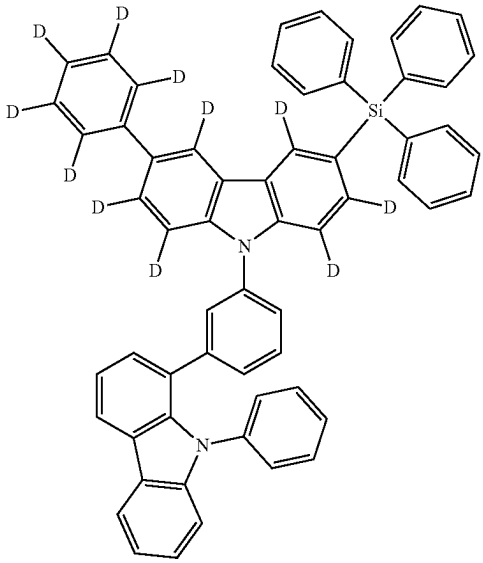

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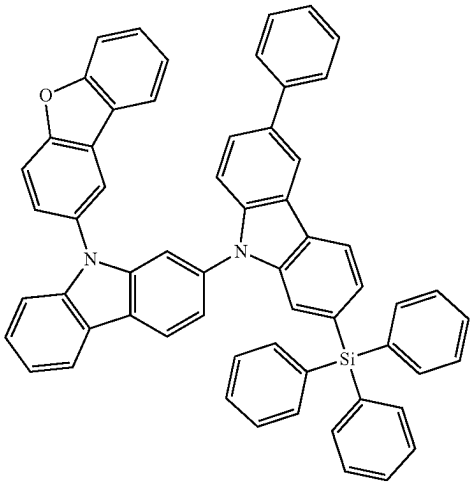

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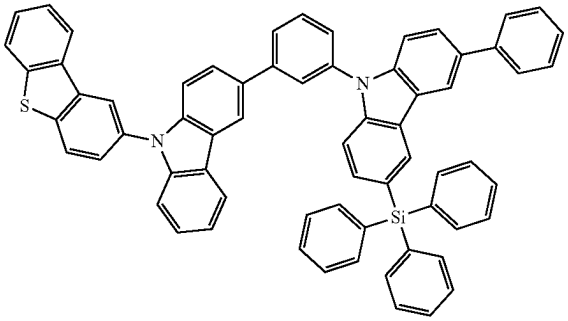

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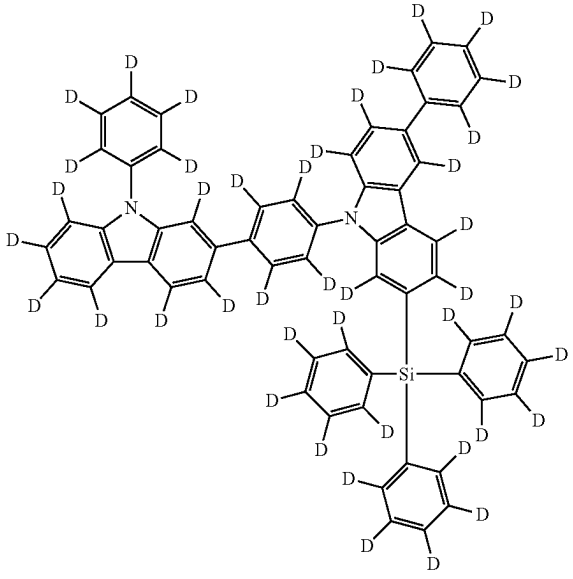

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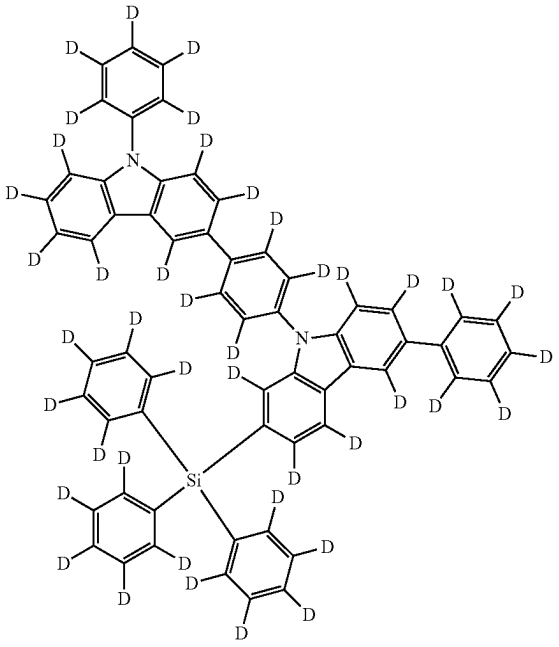

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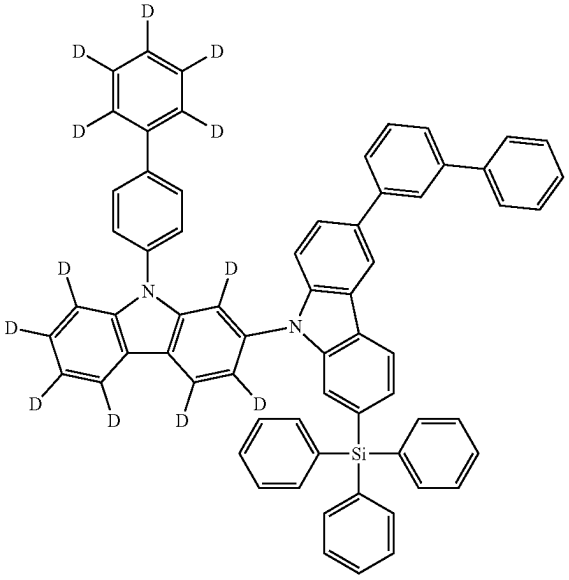

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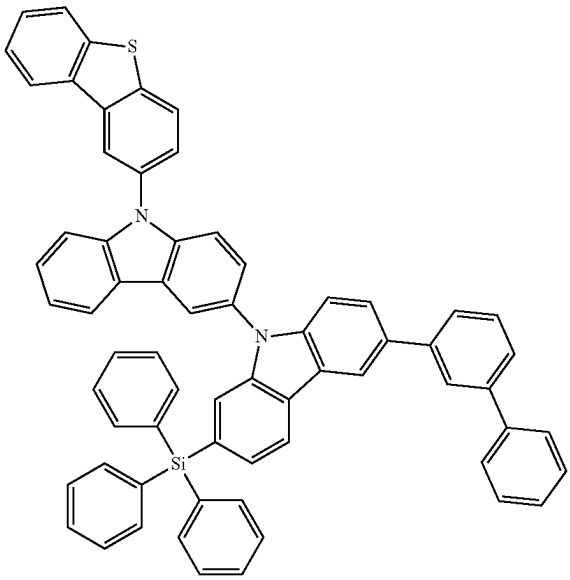

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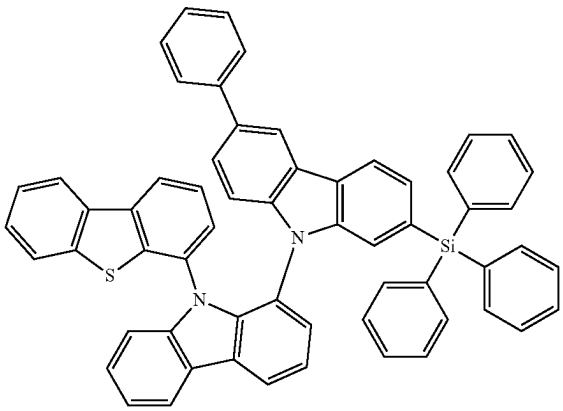

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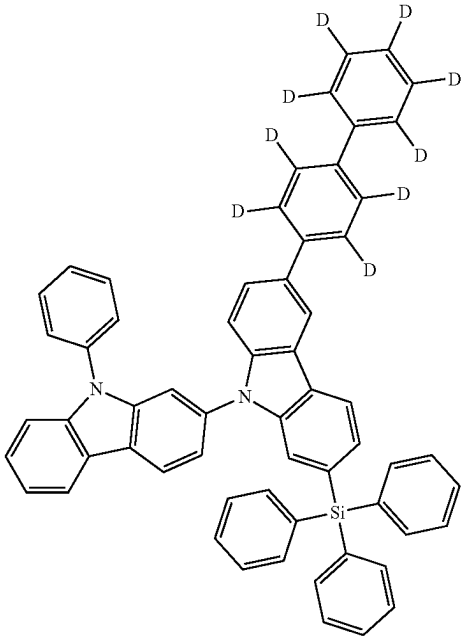

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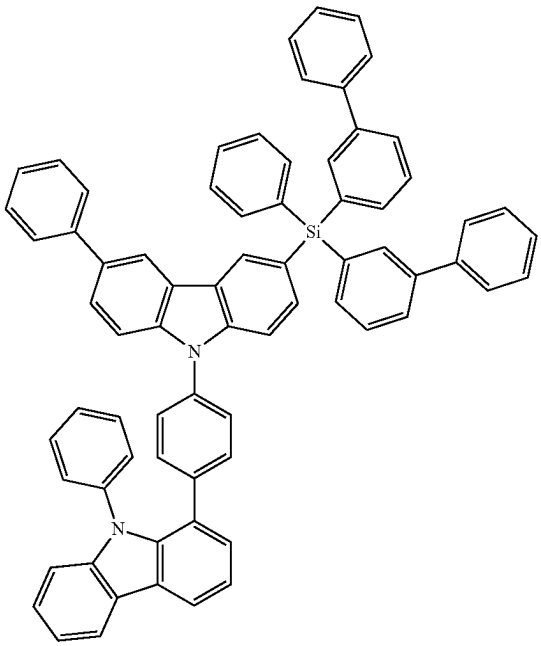

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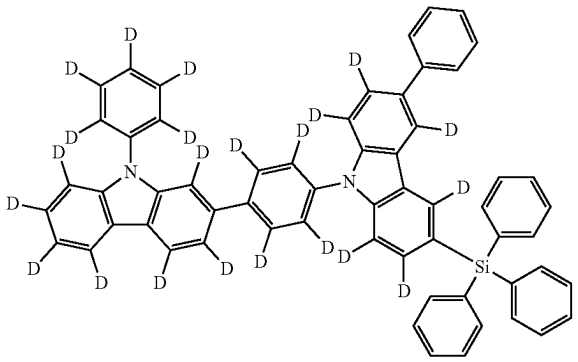

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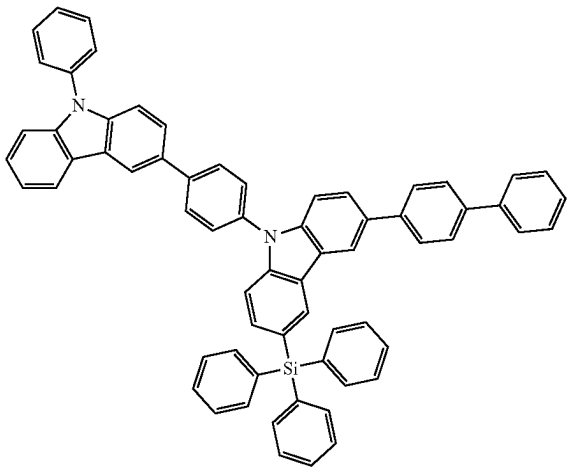

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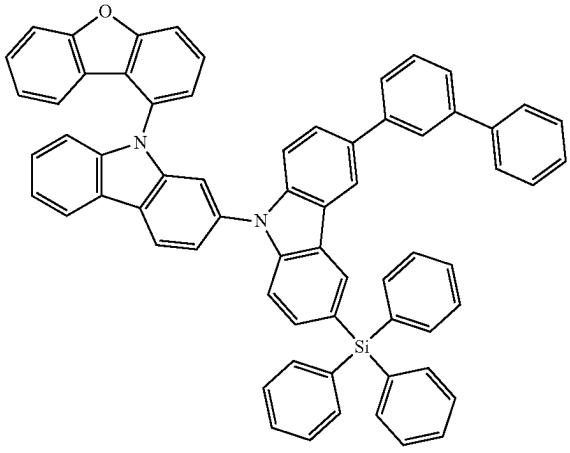

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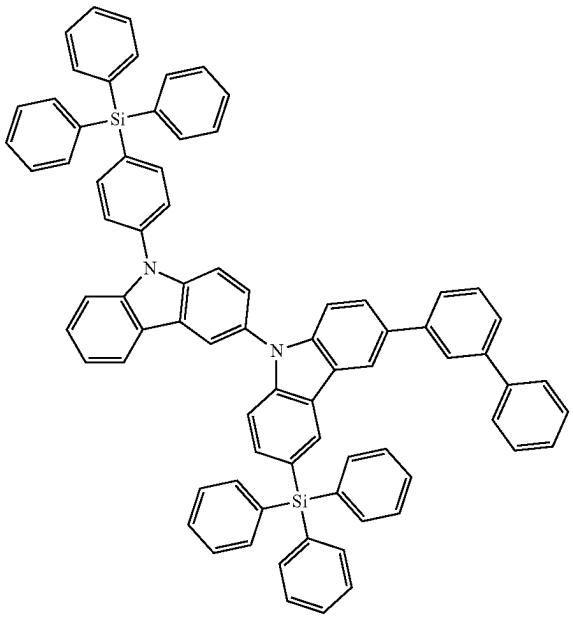

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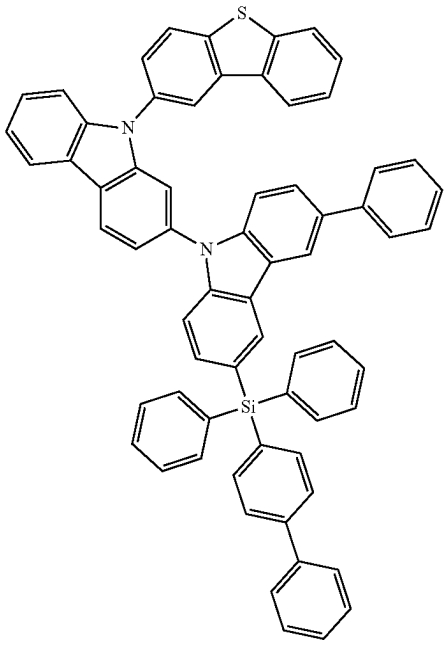

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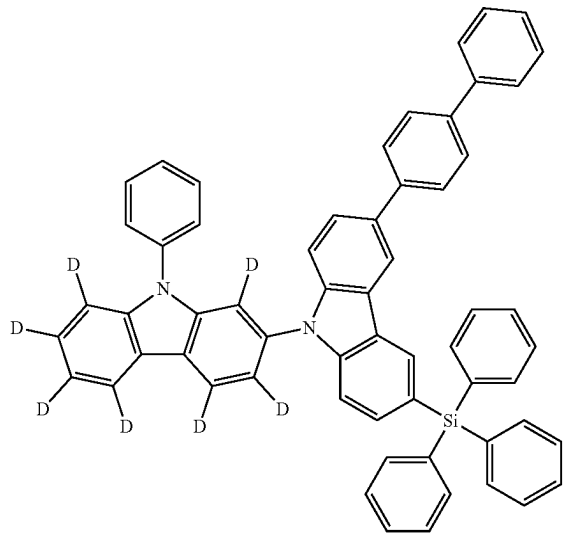

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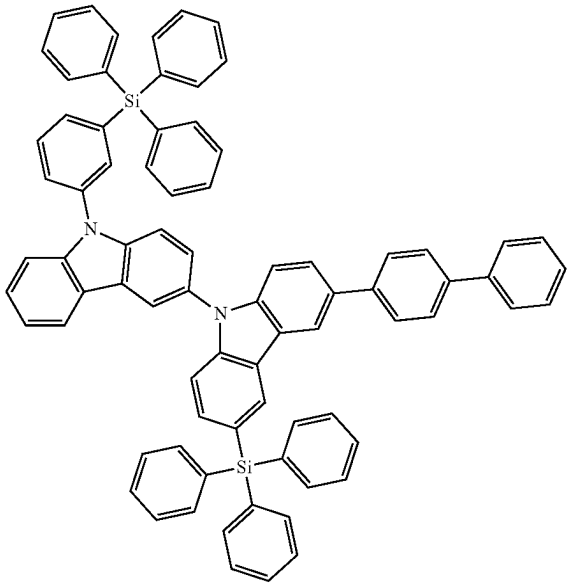

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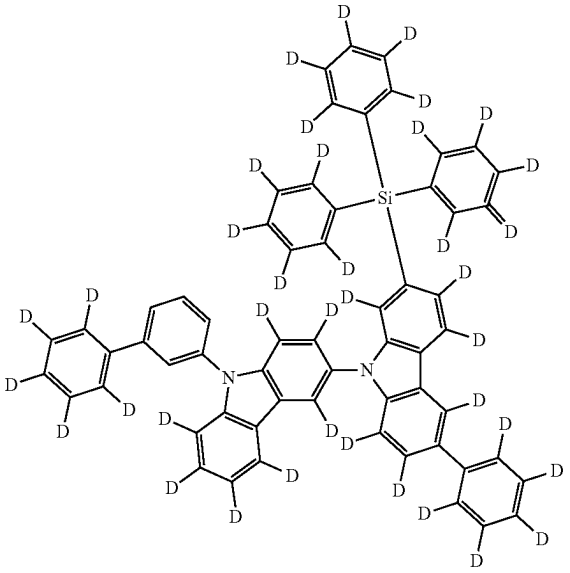

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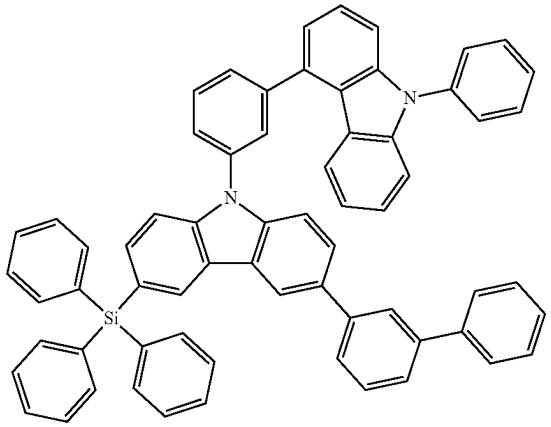

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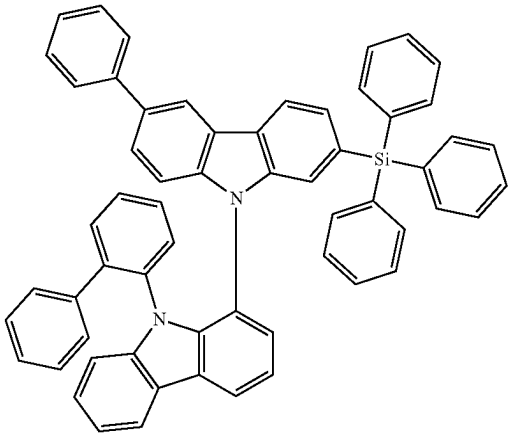

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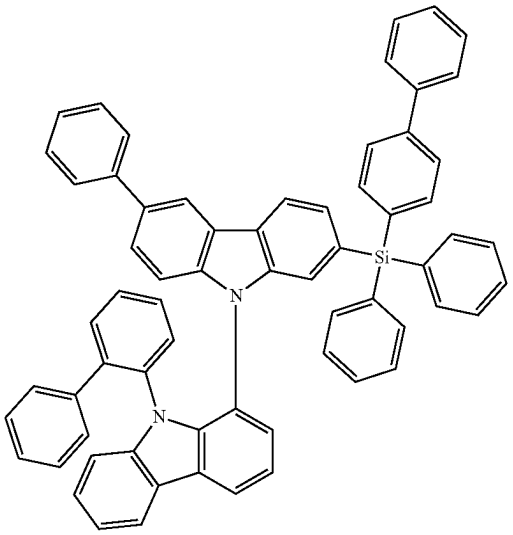

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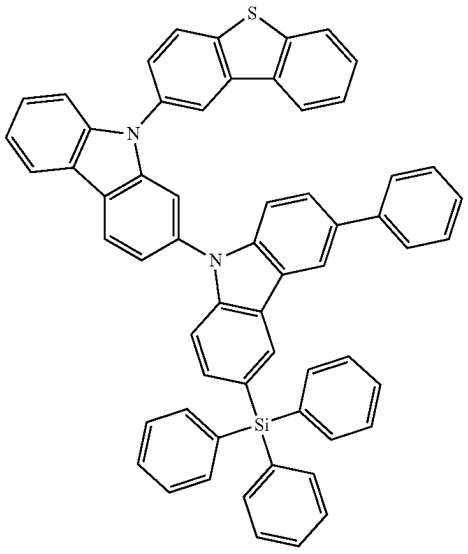

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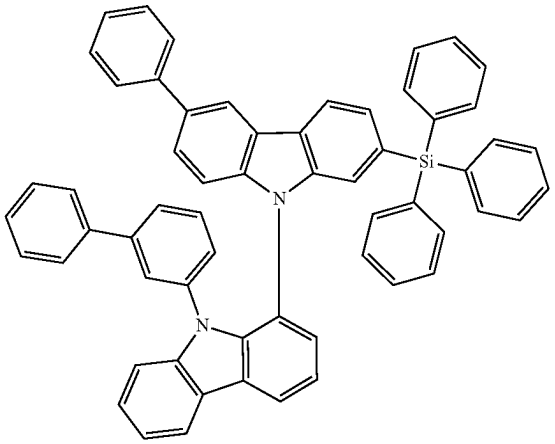

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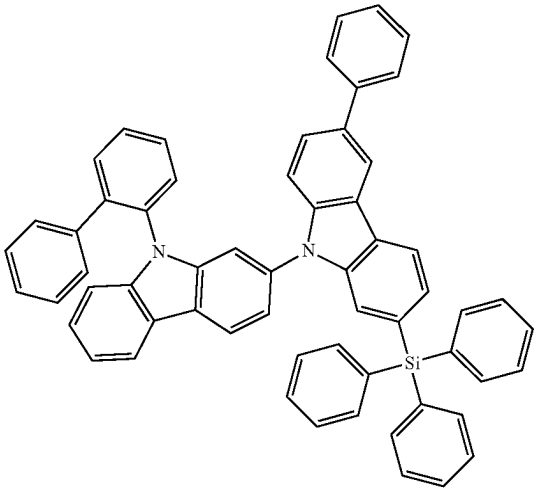

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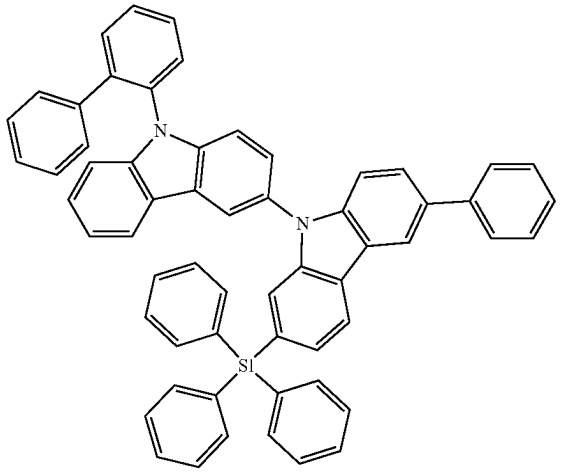

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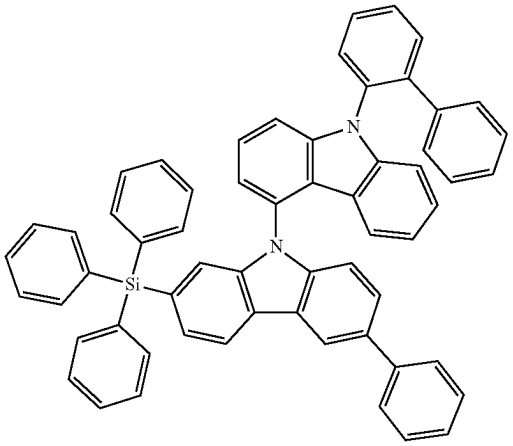

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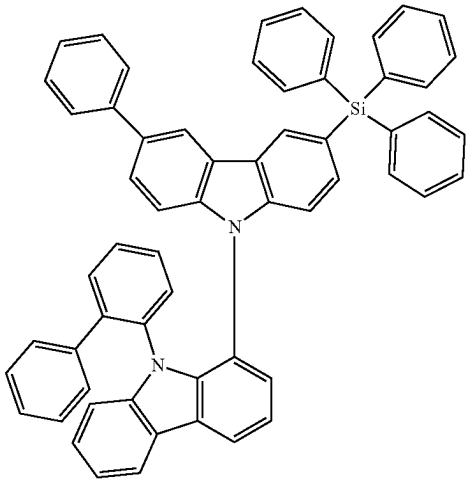

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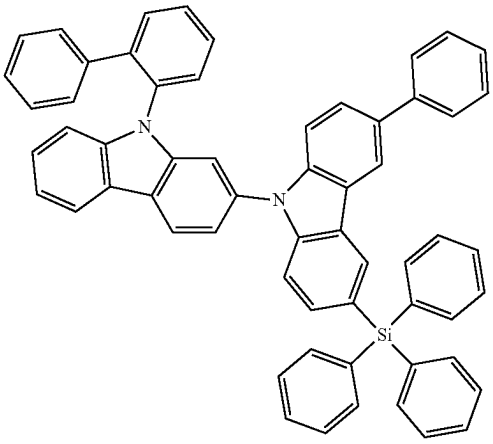

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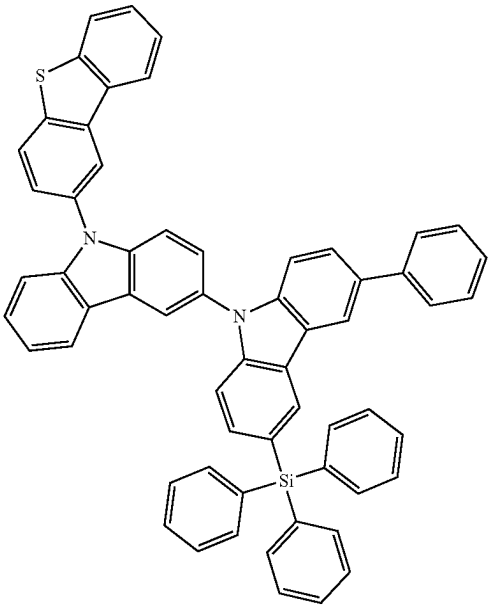

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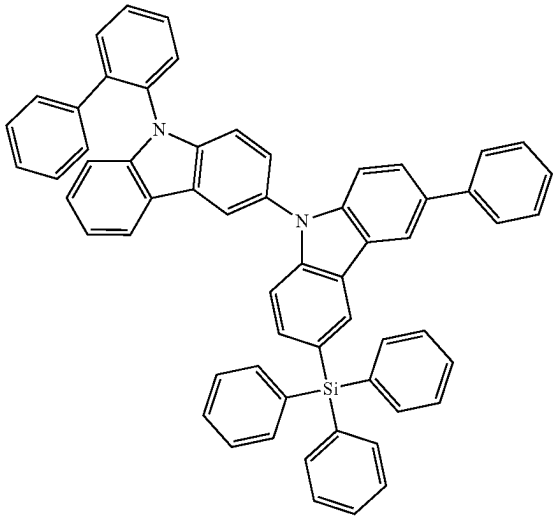

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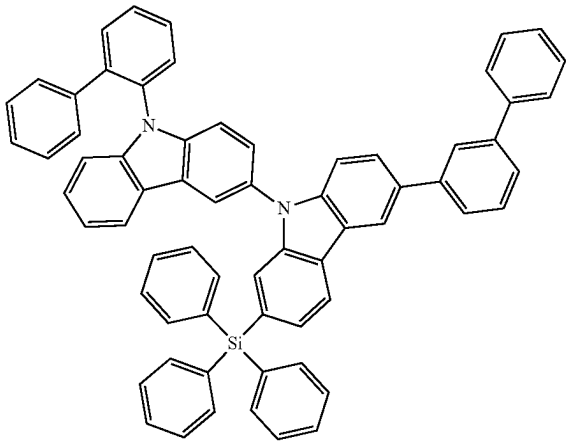

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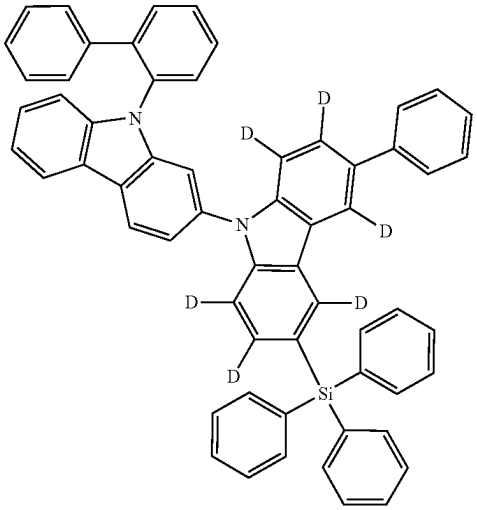

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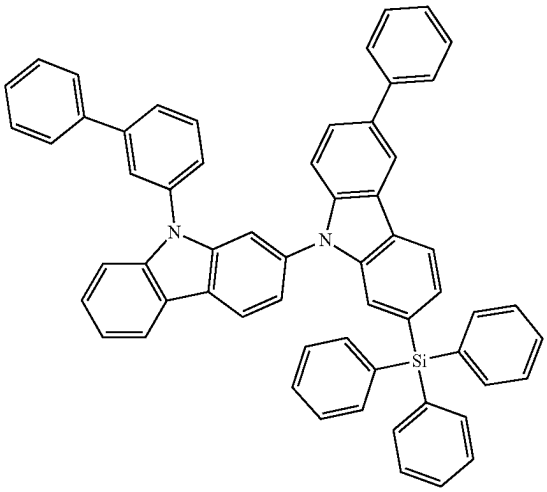

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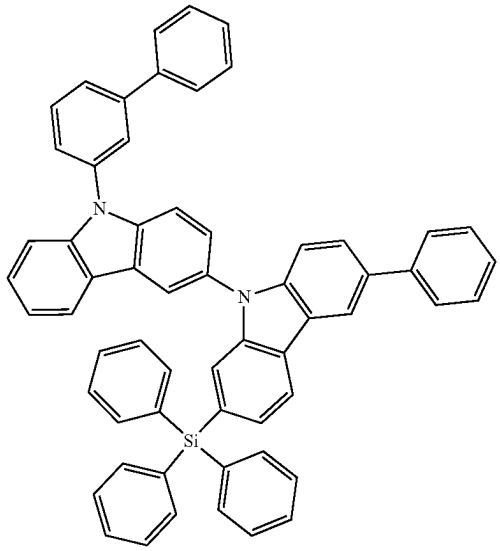

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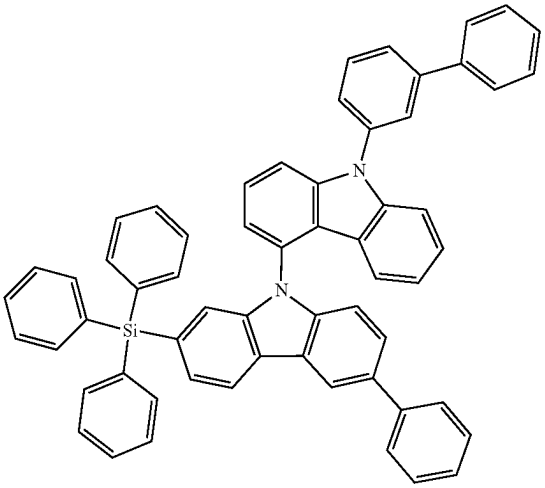

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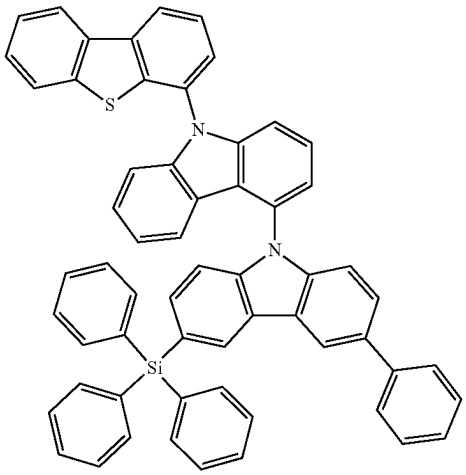

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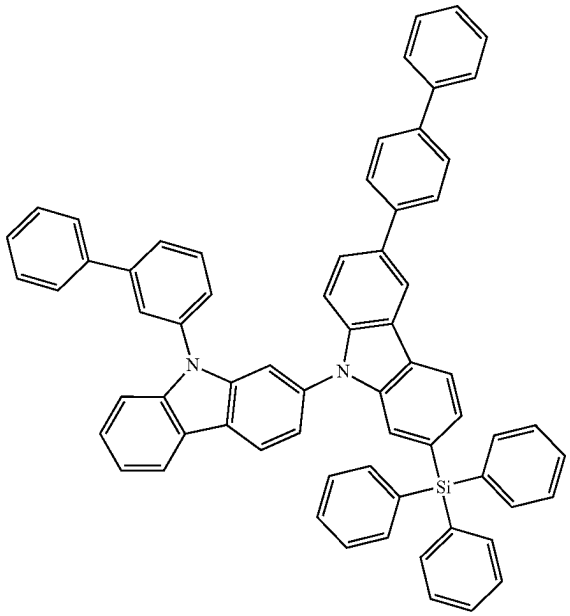

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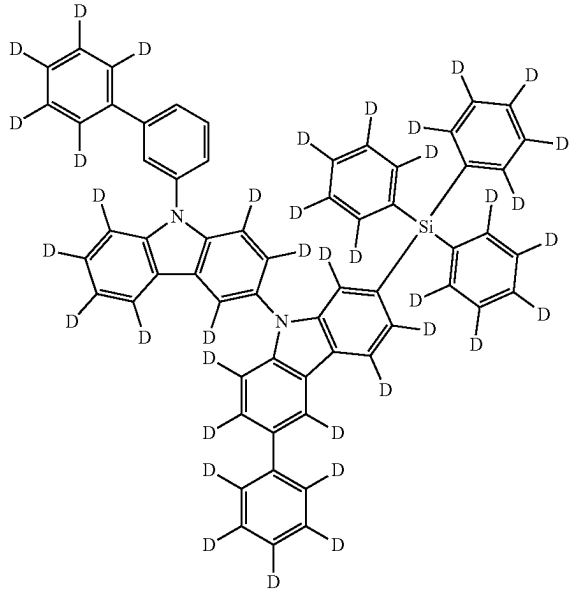

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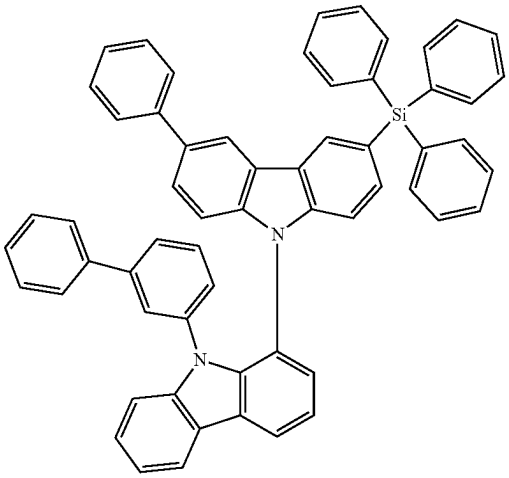

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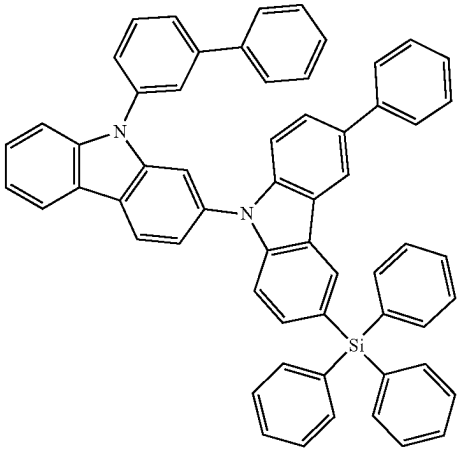

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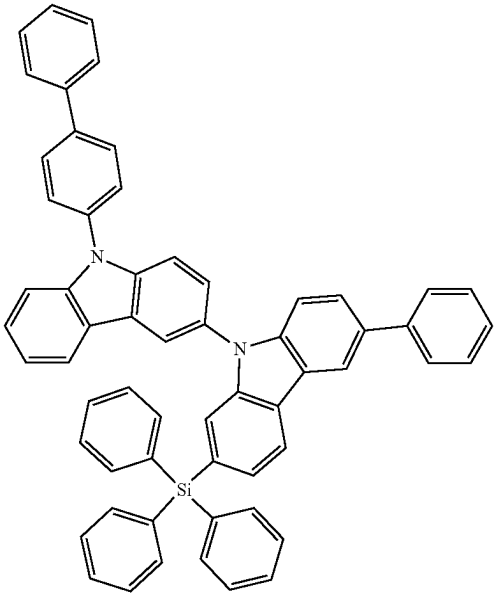

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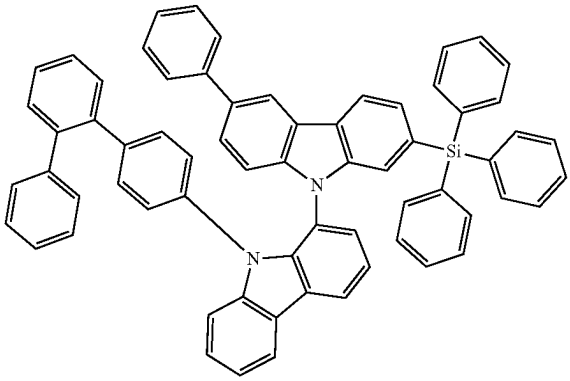

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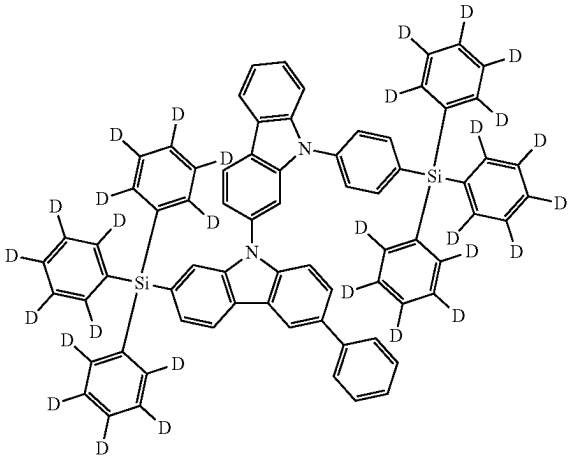

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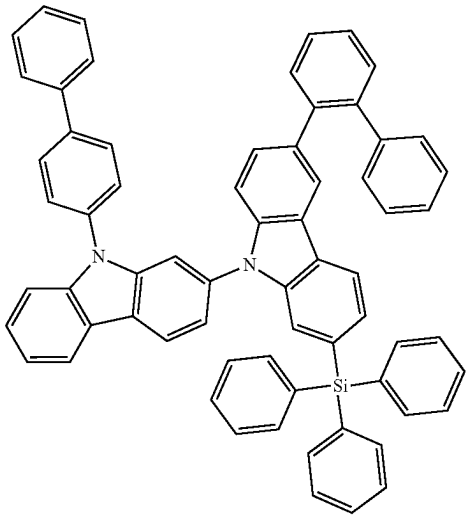

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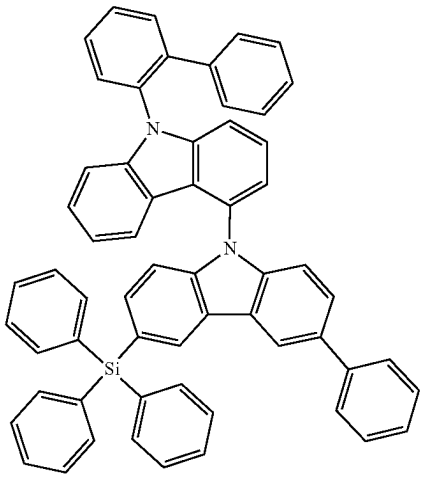

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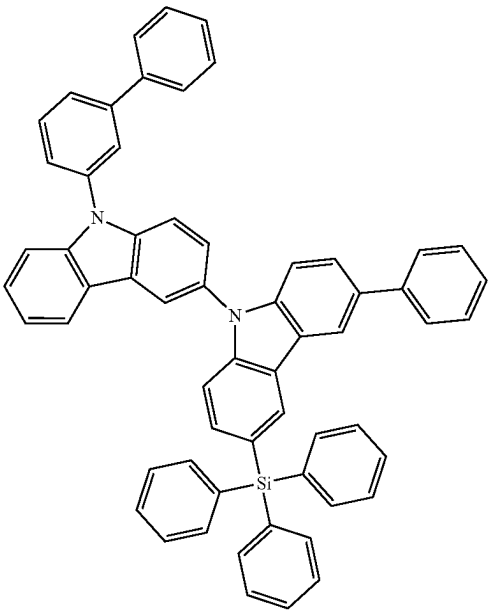

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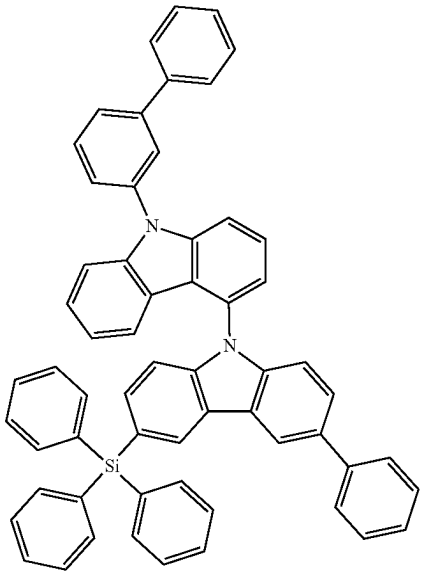

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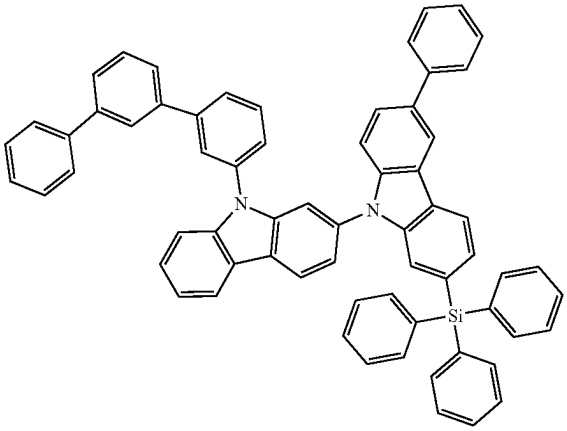

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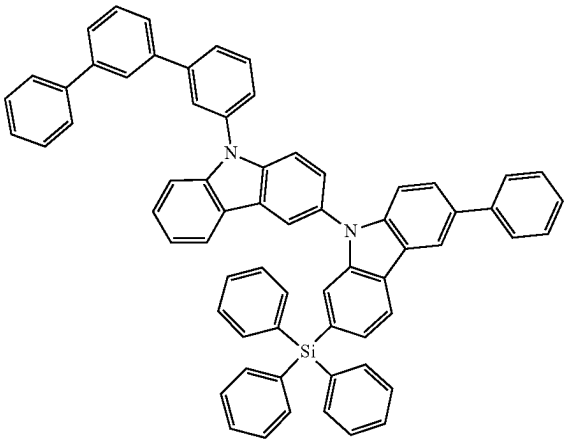

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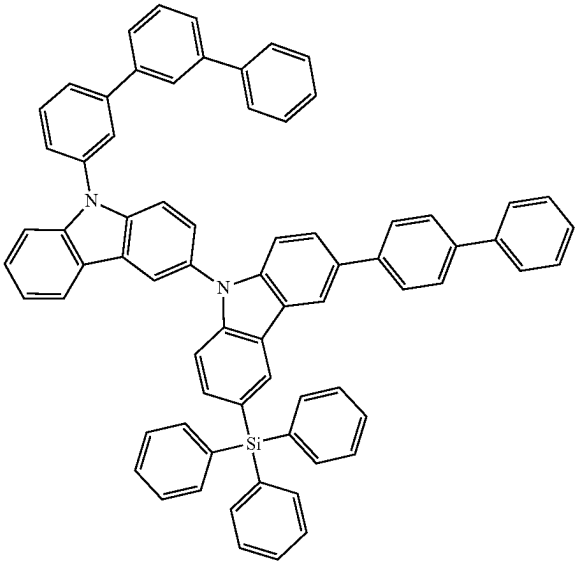

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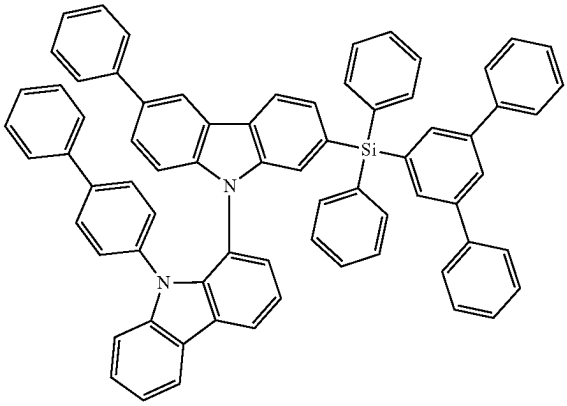

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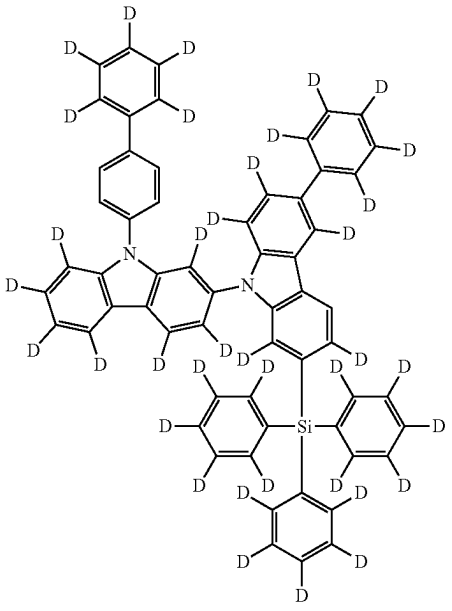

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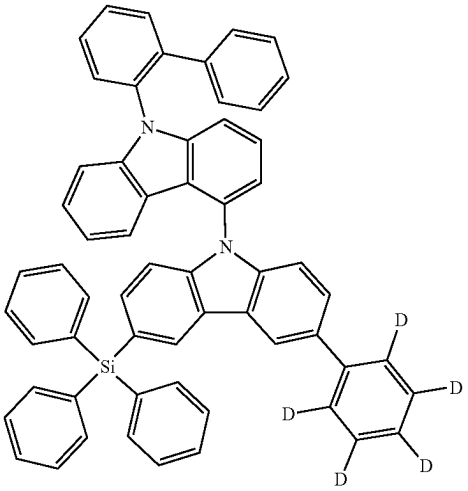

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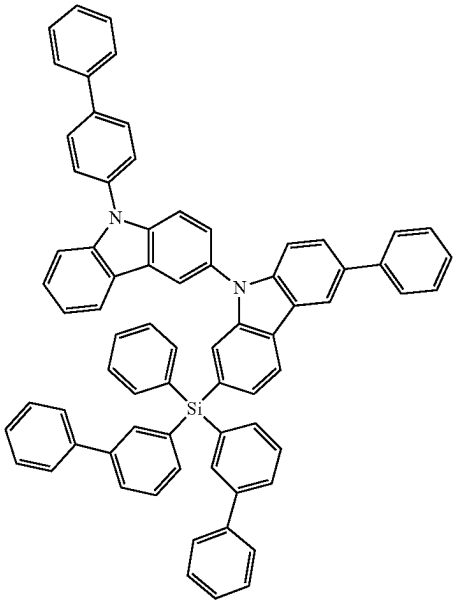

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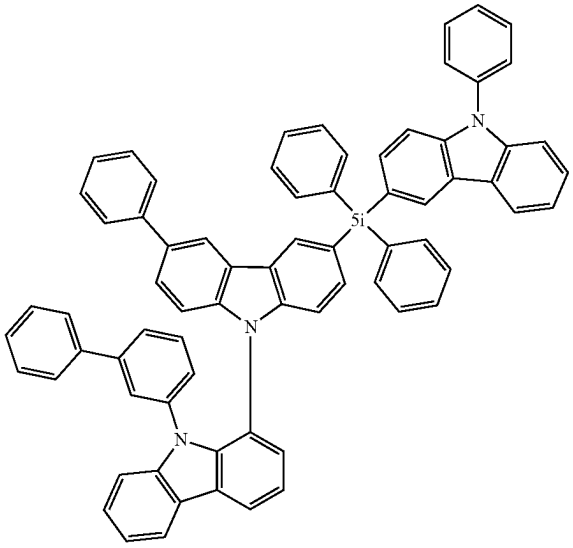

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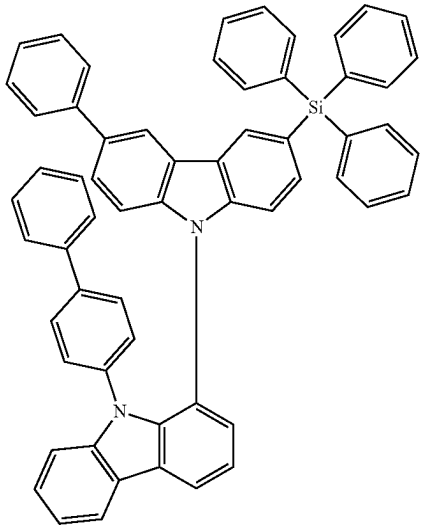

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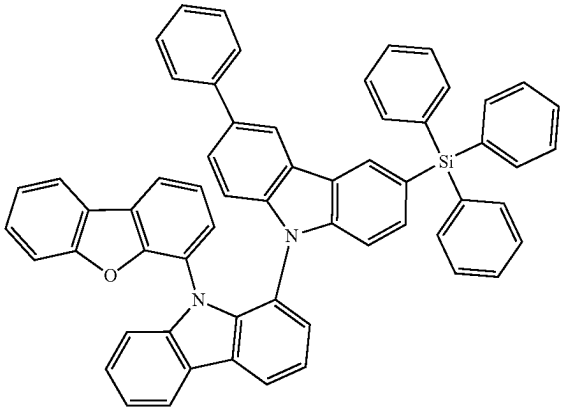

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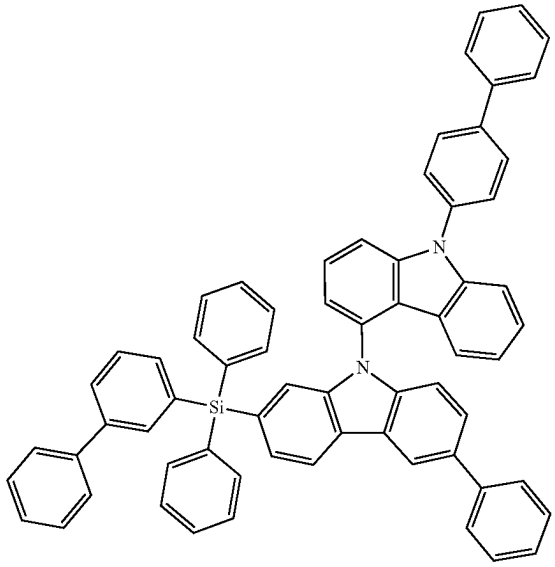

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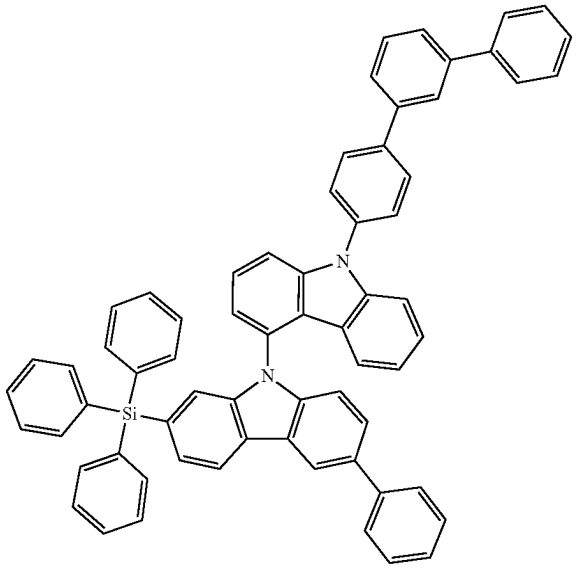

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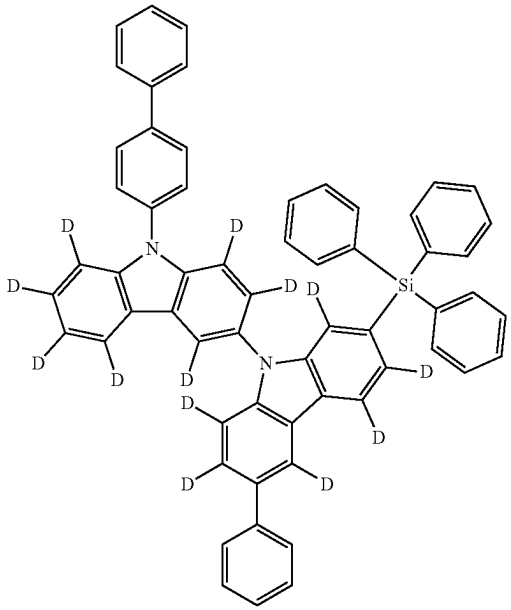

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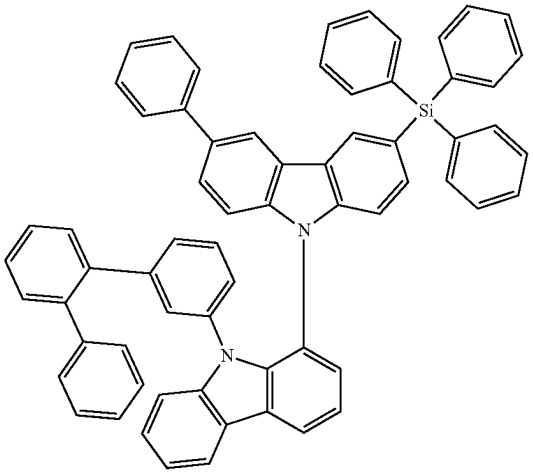

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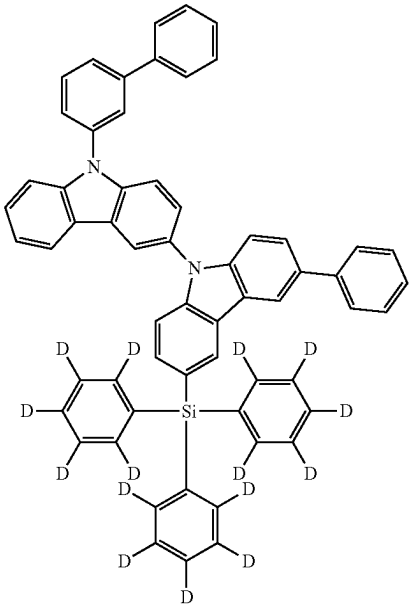

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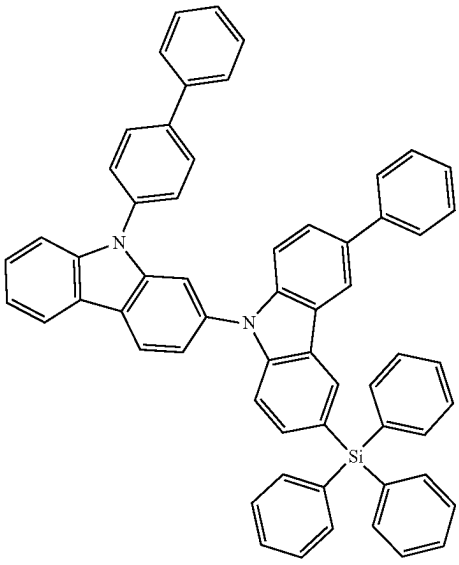

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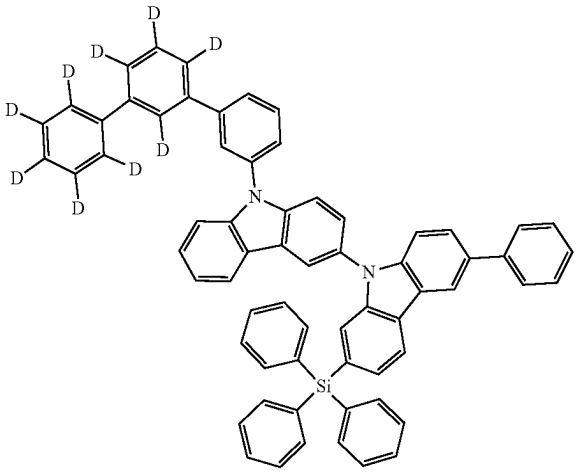

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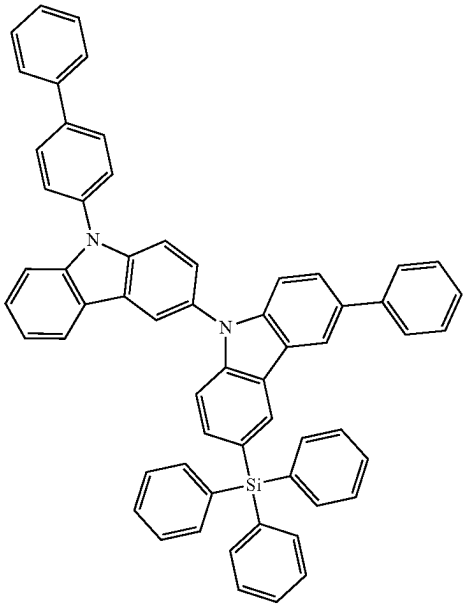

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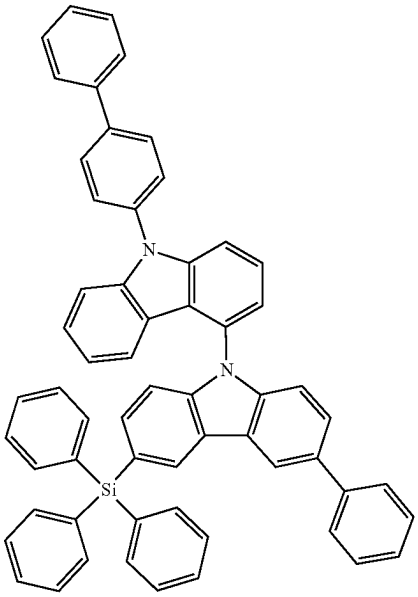

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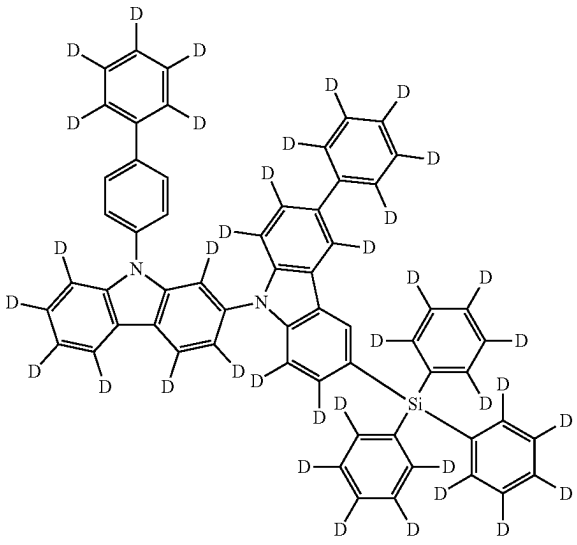

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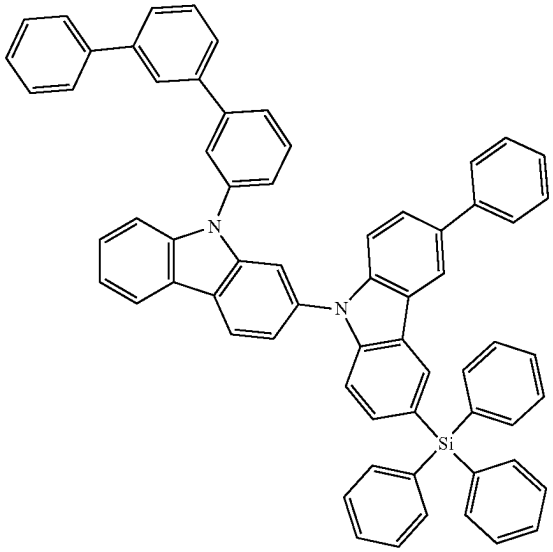

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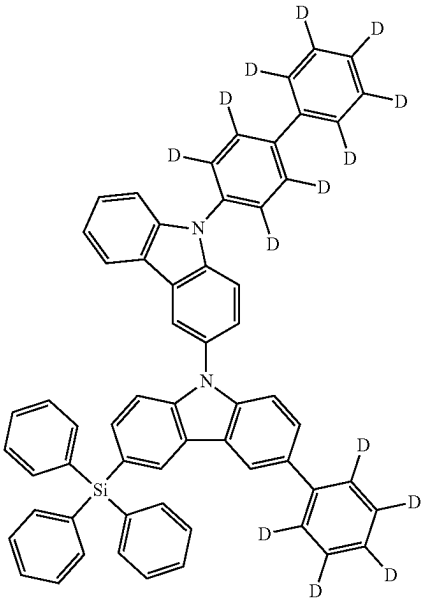

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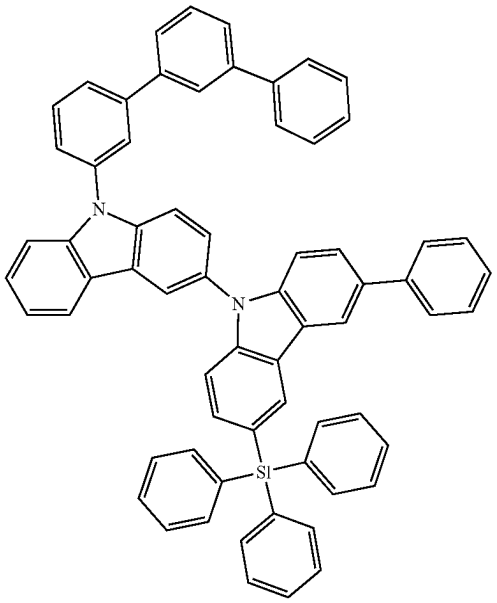

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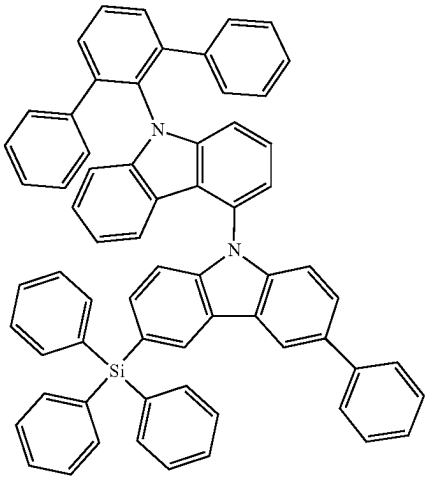

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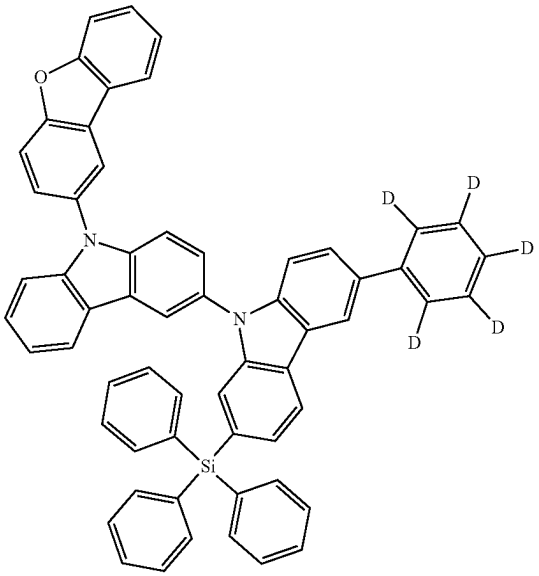

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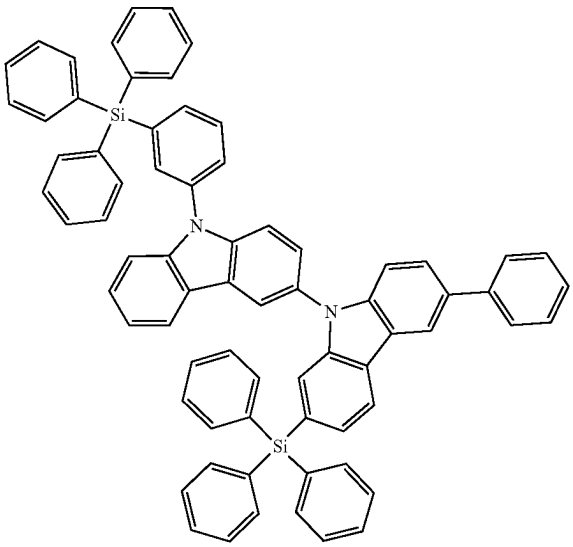

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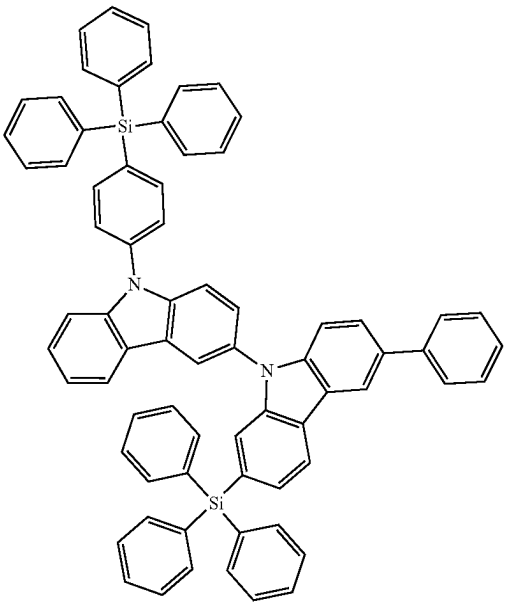

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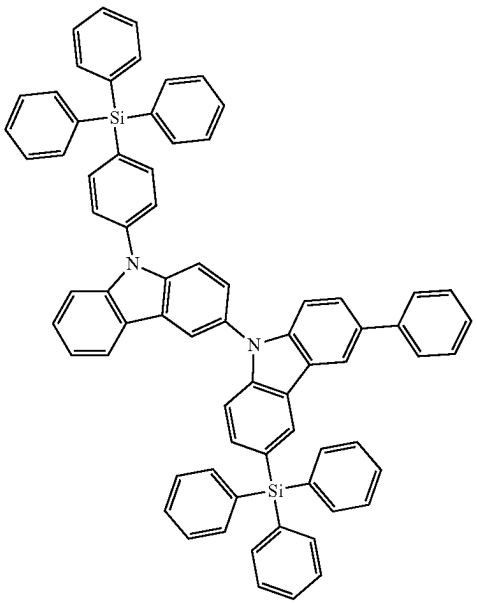

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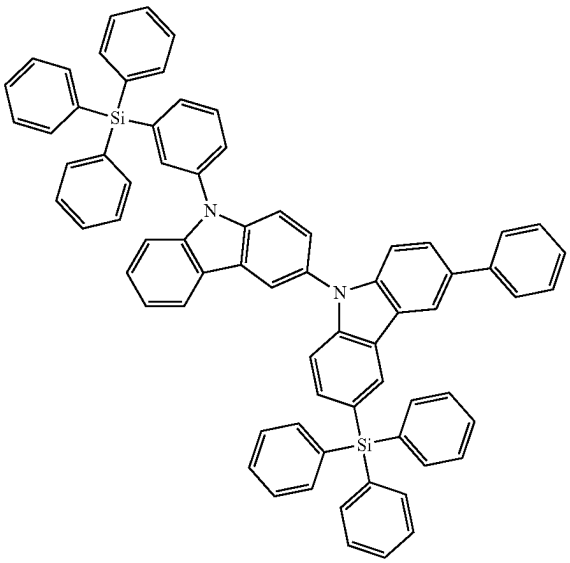

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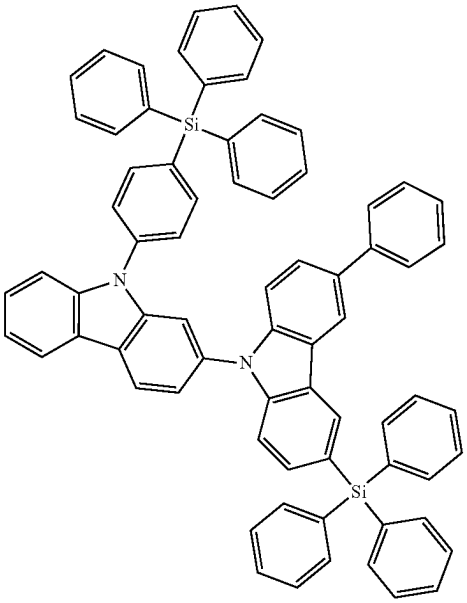

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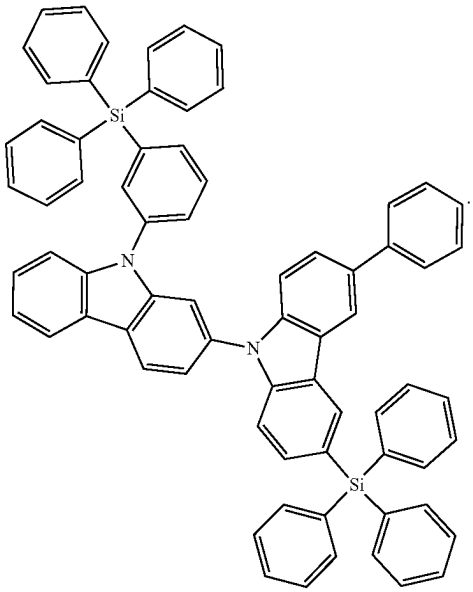


[Description of FIG. **1**]

[0356] FIG. **1** is a schematic cross-sectional view of a light-emitting device **10** according to an embodiment. The light-emitting device **10** includes a first electrode **110**, an interlayer **130**, and a second electrode **150**.

[0357] Hereinafter, the structure of the light-emitting device **10** according to an embodiment and a method of manufacturing the light-emitting device **10** will be described with reference to FIG. **1**.

[First Electrode **110**]

[0358] In FIG. **1**, a substrate may be further included under the first electrode **110** or on the second electrode **150**. The substrate may be a glass substrate or a plastic substrate. In embodiments, the substrate may be a flexible substrate, and may include plastics with excellent heat resistance and durability, such as polyimide, polyethylene terephthalate (PET), polycarbonate, polyethylene naphthalate, polyarylate (PAR), polyetherimide, or any combination thereof.

[0359] The first electrode **110** may be formed by, for example, depositing or sputtering a material for forming the first electrode **110** on the substrate. When the first electrode **110** is an anode, a material for forming the first electrode **110** may be a high-work function material that facilitates injection of holes.

[0360] The first electrode **110** may be a reflective electrode, a semi-transmissive electrode, or a transmissive electrode. When the first electrode **110** is a transmissive electrode, a material for forming the first electrode **110** may include indium tin oxide (ITO), indium zinc oxide (IZO), tin oxide (SnO_2), zinc oxide (ZnO), or any combination thereof. In embodiments, when the first electrode **110** is a semi-transmissive electrode or a reflective electrode, a material for forming the first electrode **110** may include magnesium (Mg), silver (Ag), aluminum (AI), aluminum-lithium (Al—L_1), calcium (Ca), magnesium-indium (Mg—In), magnesium-silver (Mg—Ag), or any combination thereof.

[0361] The first electrode **110** may have a structure consisting of a single layer or a structure including multiple layers. For example, the first electrode **110** may have a three-layered structure of ITO/Ag/ITO.

[Interlayer **130**]

[0362] The interlayer **130** may be located on the first electrode **110**. The interlayer **130** may include an emission layer.

[0363] The interlayer **130** may further include a hole transport region between the first electrode **110** and the emission layer, and an electron transport region between the emission layer and the second electrode **150**.

[0364] The interlayer **130** may further include, in addition to various organic materials, a metal-containing compound such as an organometallic compound, an inorganic material such as quantum dots, or the like.

[0365] In embodiments, the interlayer **130** may include two or more emitting units stacked between the first electrode **110** and the second electrode **150**, and at least one charge generation layer between adjacent units among the two or more emitting units. When the interlayer **130** includes the two or more emitting units and the at least one charge generation layer as described above, the light-emitting device **10** may be a tandem light-emitting device.

[Hole Transport Region in Interlayer **130**]

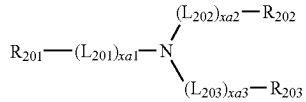
[0366] The hole transport region may have a structure consisting of a layer consisting of a single material, a structure consisting of a layer including different materials, or a structure including multiple layers including different materials.

[0367] The hole transport region may include a hole injection layer, a hole transport layer, an emission auxiliary layer, an electron blocking layer, or any combination thereof.

[0368] In embodiments, the hole transport region may have a multi-layered structure including a hole injection layer/hole transport layer structure, a hole injection layer/hole transport layer/emission auxiliary layer structure, a hole injection layer/emission auxiliary layer structure, a hole transport layer/emission auxiliary layer structure, or a hole injection layer/hole transport layer/electron blocking layer structure, wherein the layers of each structure may be stacked from the first electrode **110** in its respective stated order, but the structure of the hole transport region is not limited thereto.

[0369] In embodiments, the hole transport region may include a compound represented by Formula 201, a compound represented by Formula 202, or any combination thereof:

[Formula 201]



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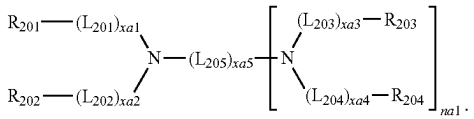
[Formula 202]



[0370] In Formulae 201 and 202,

[0371] L_{201} to L_{204} may each independently be a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a} or a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a},

[0372] L_{205} may be *—O—**, *—S—**, *—N(Q_{201})—*', a C_1-C_{20} alkylene group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{20} alkenylene group unsubstituted or substituted with at least one R_{10a}, a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, or a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a},

[0373] xa1 to xa4 may each independently be an integer from 0 to 5,

[0374] xa5 may be an integer from 1 to 10,

[0375] R_{201} to R_{204} and Q_{201} may each independently be a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a} or a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a},

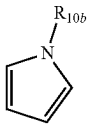
[0376] R_{201} and R_{202} may optionally be linked to each other via a single bond, a C_1-C_5 alkylene group unsubstituted or substituted with at least one R_{10a}, or a C_2-C_5 alkenylene group unsubstituted or substituted with at least one R_{10a}, to form a C_8-C_{60} polycyclic group (for example, a carbazole group or the like) unsubstituted or substituted with at least one R_{10a} (for example, Compound HT16),

[0377] R_{203} and R_{204} may optionally be linked to each other via a single bond, a C_1-C_5 alkylene group unsubstituted or substituted with at least one R_{10a}, or a C_2-C_5 alkenylene group unsubstituted or substituted with at least one R_{10a}, to form a C_8-C_{60} polycyclic group unsubstituted or substituted with at least one R_{10a}, and

[0378] na1 may be an integer from 1 to 4.

[0379] In embodiments, the compound represented by Formula 201 and the compound represented by Formula 202 may each independently include at least one of groups represented by Formulae CY_{201} to CY_{217}:

CY201



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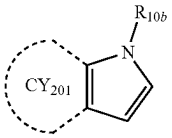
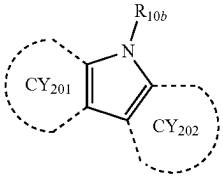
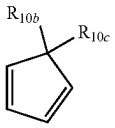
CY202



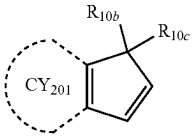
CY203



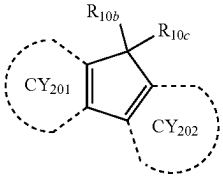
CY204



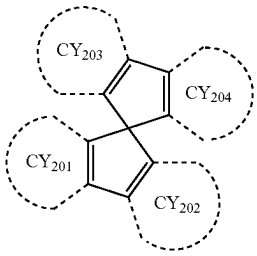
CY205



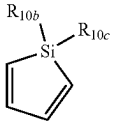
CY206



CY207



CY208



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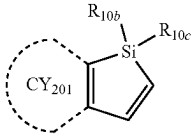

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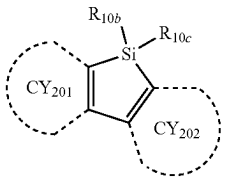
CY210



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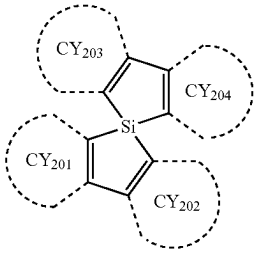
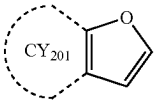


CY212

CY213



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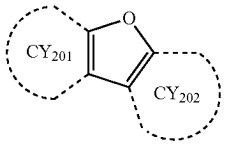
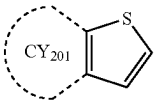


CY215

CY216



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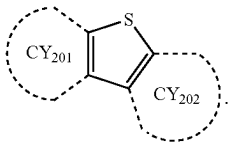
CY217



[0380] In Formulae CY_{201} to CY_{217}, R_{10b} and R_{10c} may each independently be the same as described with respect to R_{10a}, ring CY_{201} to ring CY_{204} may each independently be a C_5-C_{20} carbocyclic group or a C_1-C_{20} heterocyclic group, and at least one hydrogen in Formulae CY_{201} to CY_{217} may be unsubstituted or substituted with R_{10a} as described herein.

[0381] In an embodiment, in Formulae CY_{201} to CY_{217}, ring CY_{201} to ring CY_{204} may each independently be a benzene group, a naphthalene group, a phenanthrene group, or an anthracene group.

[0382] In embodiments, the compound represented by Formula 201 and the compound represented by Formula 202 may each independently include at least one of groups represented by Formulae CY_{201} to CY_{203}.

[0383] In embodiments, the compound represented by Formula 201 may include at least one of groups represented by Formulae CY_{201} to CY_{203} and at least one of groups represented by Formulae CY_{204} to CY_{217}.

[0384] In embodiments, in Formula 201, xa1 may be 1, R_{201} may be a group represented by one of Formulae CY_{201} to CY_{203}, xa2 may be 0, and R_{202} may be a group represented by one of Formulae CY_{204} to CY_{207}.

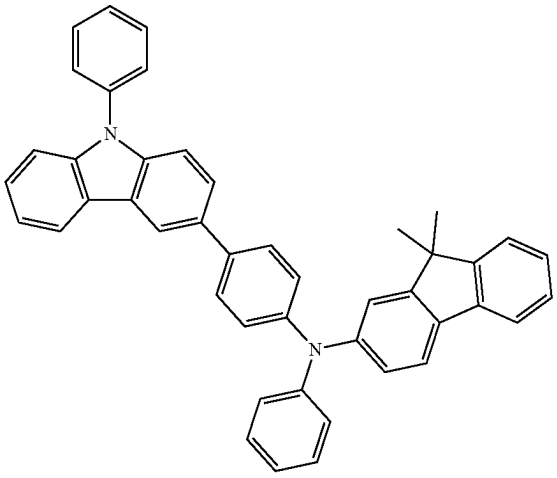
[0385] In embodiments, the compound represented by Formula 201 and the compound represented by Formula 202 may each not include a group represented by one of Formulae CY_{201} to CY_{203}.

[0386] In embodiments, the compound represented by Formula 201 and the compound represented by Formula 202 may each not include a group represented by one of Formulae CY_{201} to CY_{203}, and may each independently include at least one of groups represented by Formulae CY_{204} to CY_{217}.

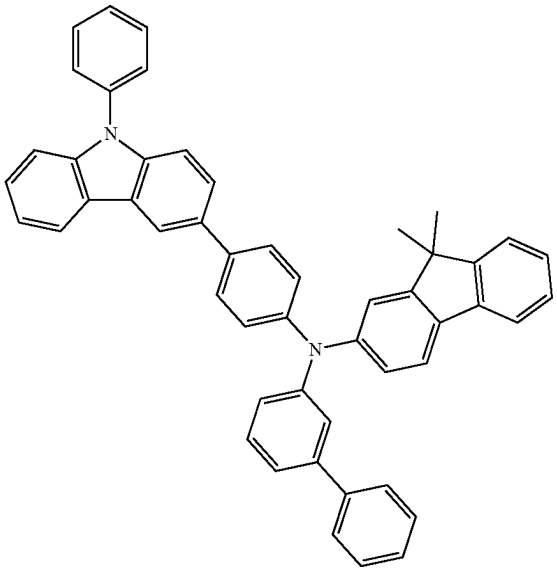
[0387] In embodiments, the compound represented by Formula 201 and the compound represented by Formula 202 may each not include a group represented by one of Formulae CY_{201} to CY_{217}.

[0388] In an embodiment, the hole transport region may include one of Compounds HT1 to HT46, m-MTDATA, TDATA, 2-TNATA, NPB (NPD), β-NPB, TPD, Spiro-TPD, Spiro-NPB, methylated NPB, TAPC, HMTPD, 4,4',4"-tris (N-carbazolyl)triphenylamine (TCTA), polyaniline/dodecylbenzenesulfonic acid (PANI/DBSA), poly(3,4-ethylenedioxythiophene)/poly(4-styrenesulfonate) (PEDOT/PSS), polyaniline/camphor sulfonic acid (PANI/CSA), polyaniline/poly(4-styrenesulfonate) (PANI/PSS), or any combination thereof:

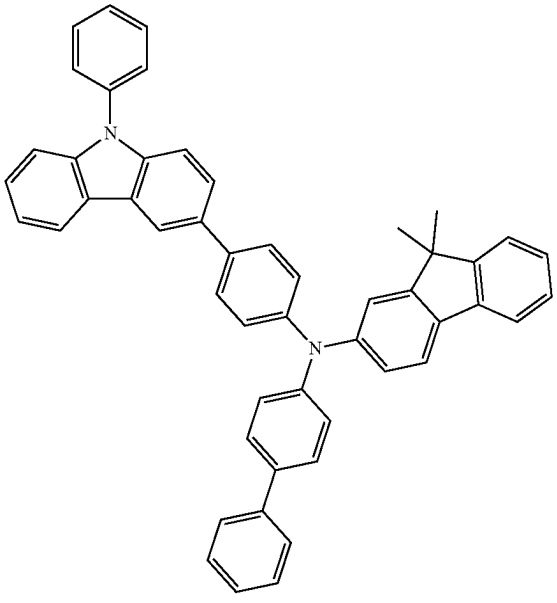
HT1



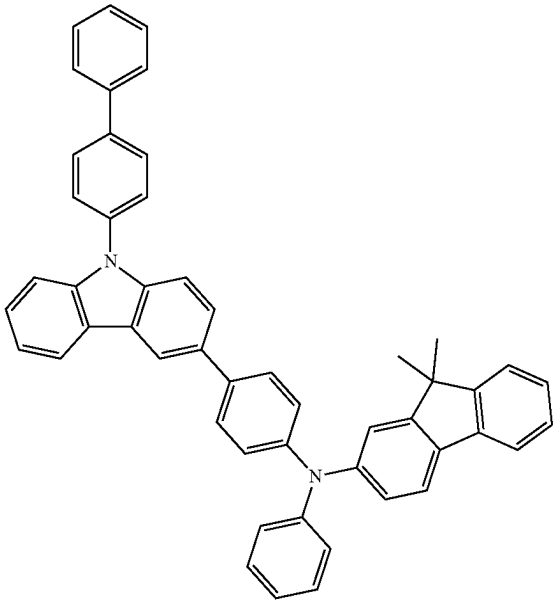
HT2



HT3



HT4



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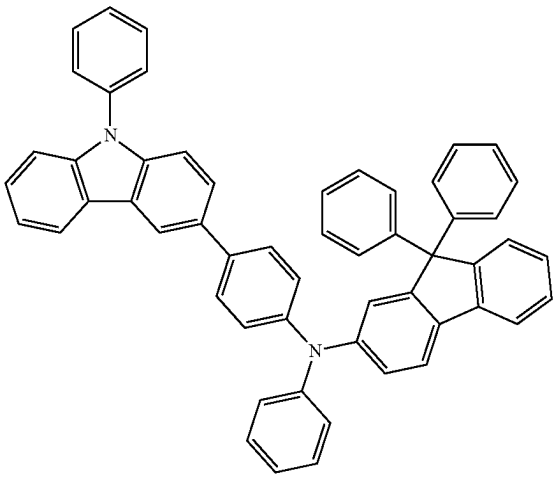
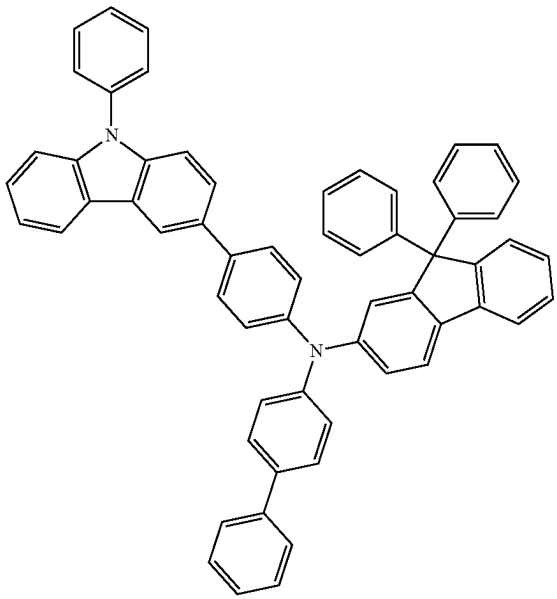
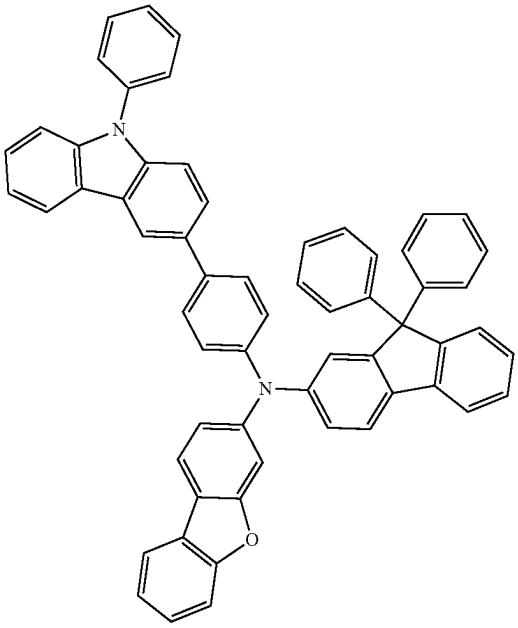
HT5



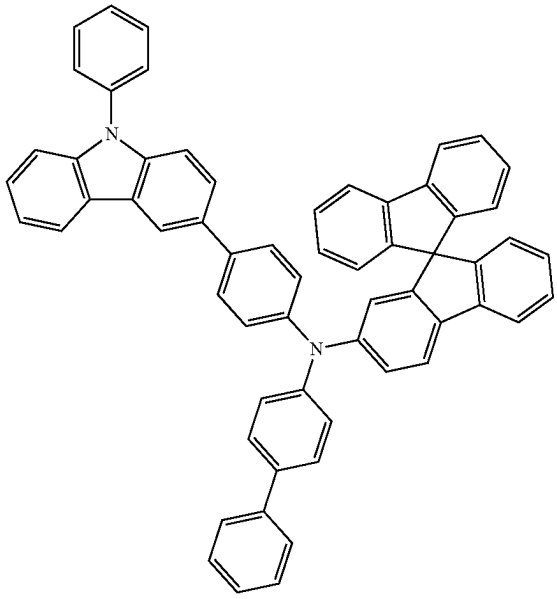
HT6



HT7



HT8



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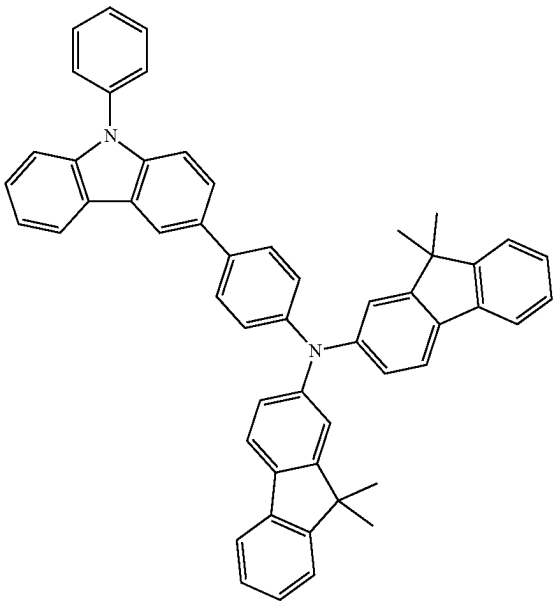
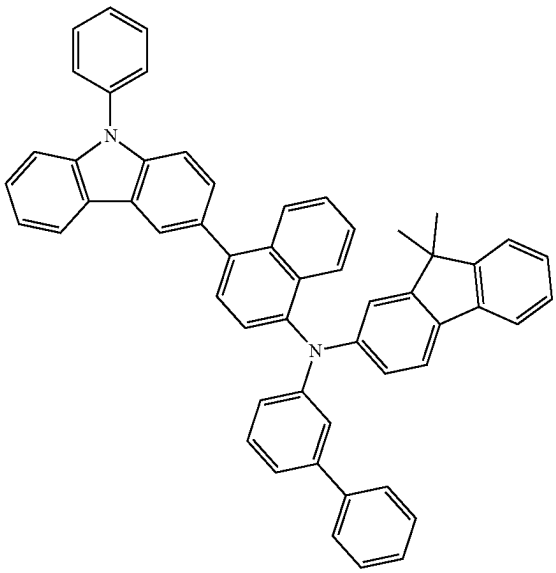
HT9



HT10



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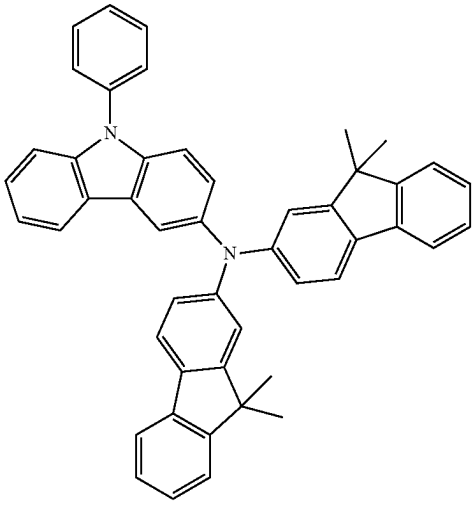

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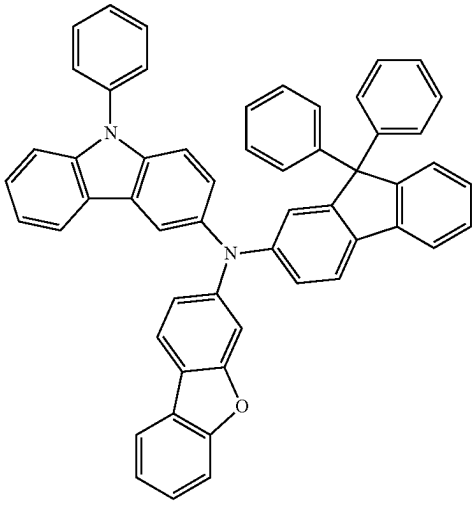

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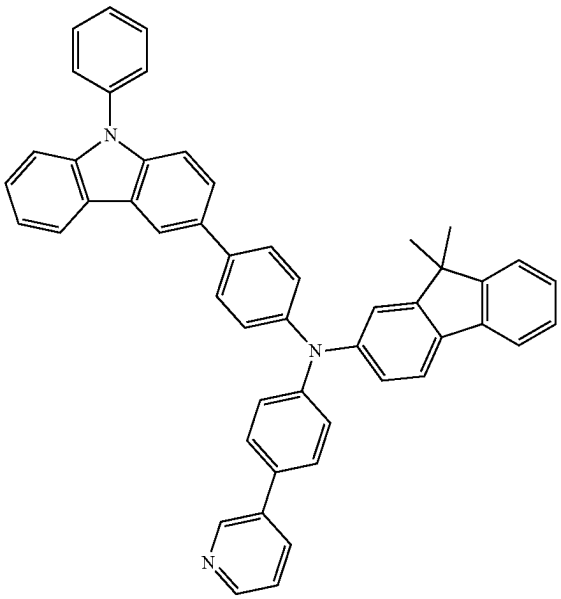
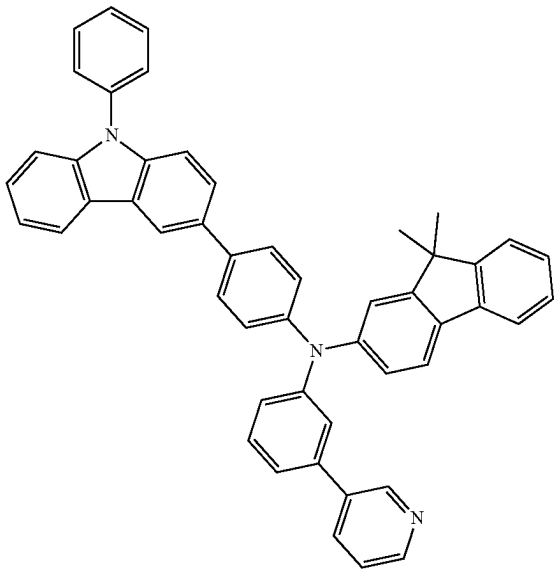
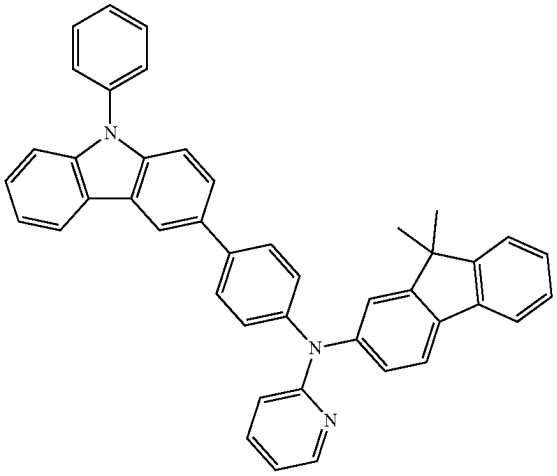
HT13



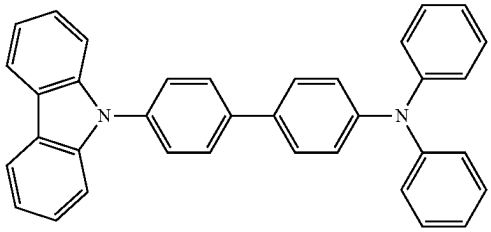
HT14



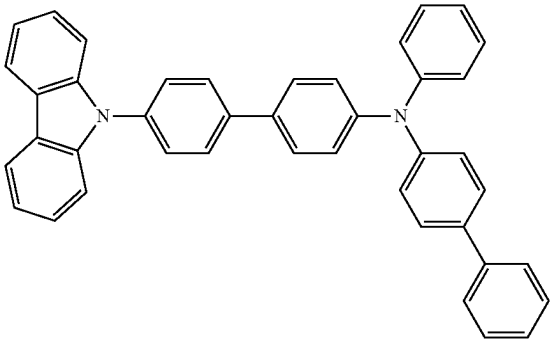
HT15



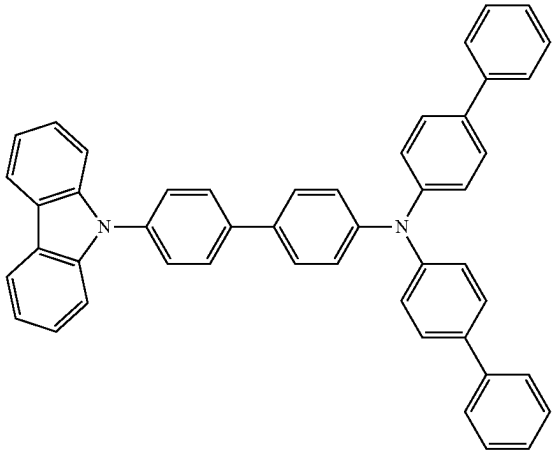
HT16



HT17



HT18



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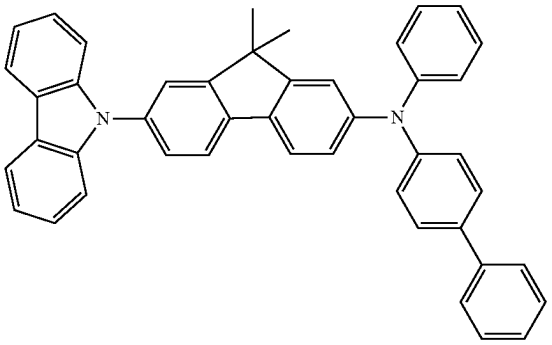

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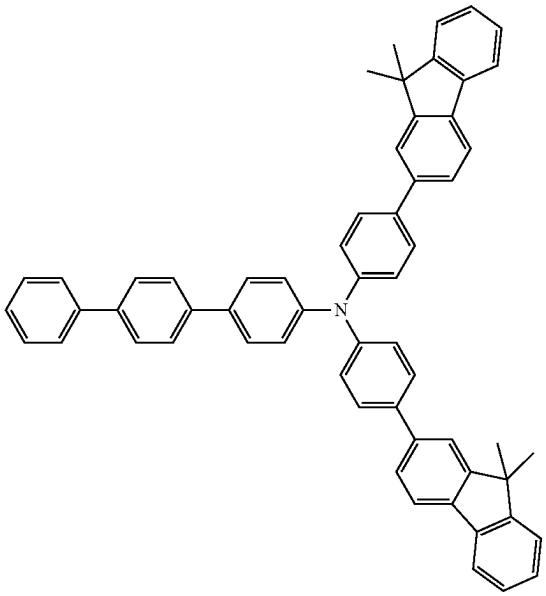

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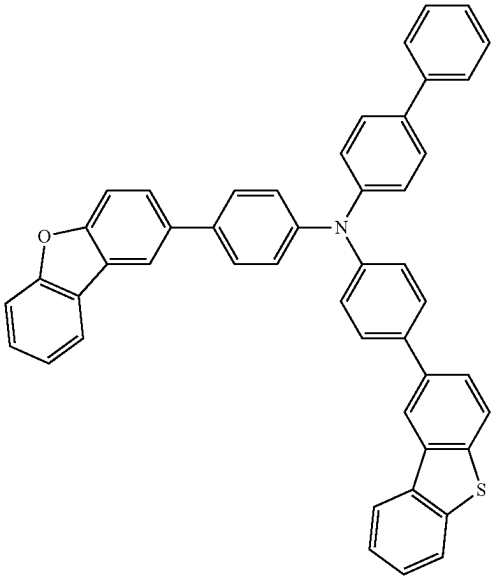

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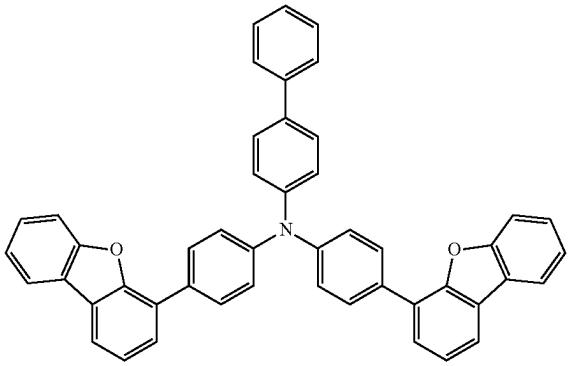

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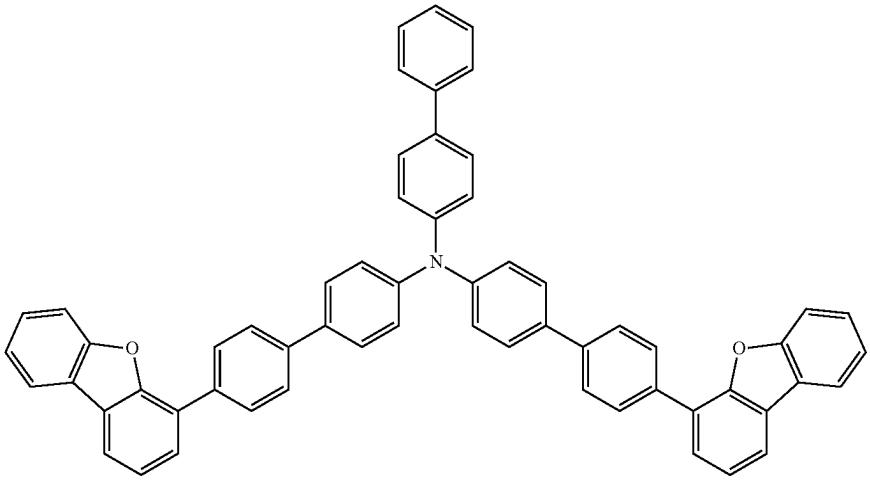

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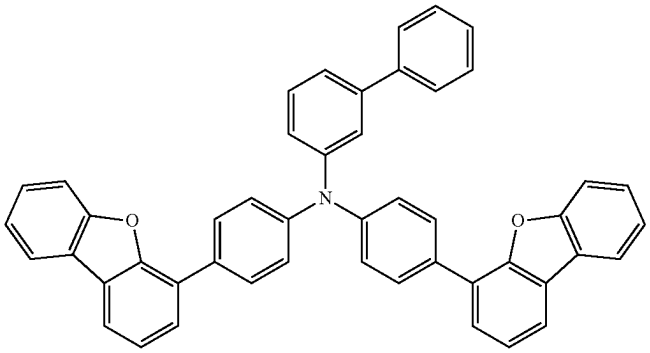

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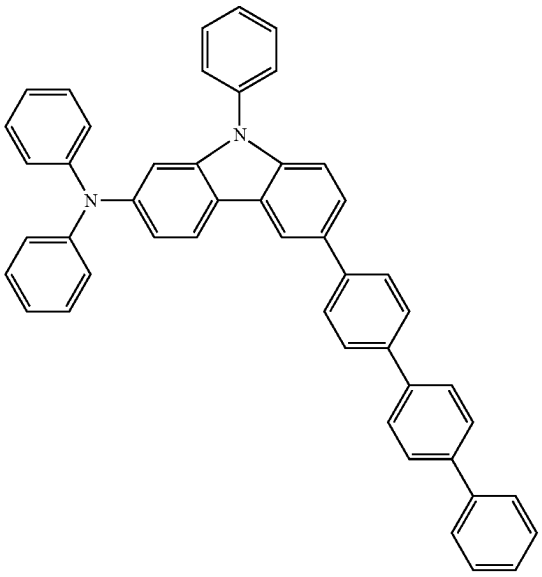

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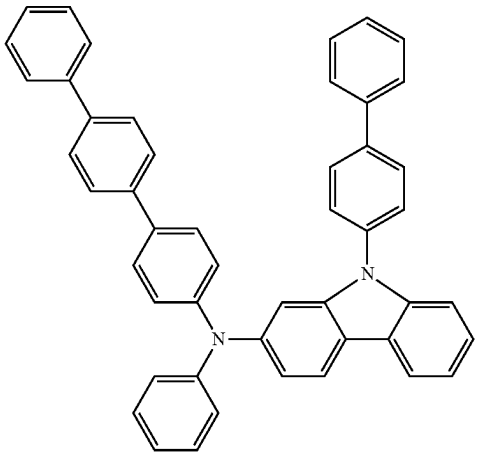

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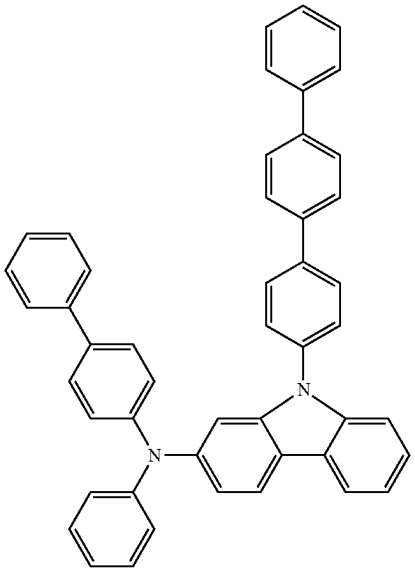

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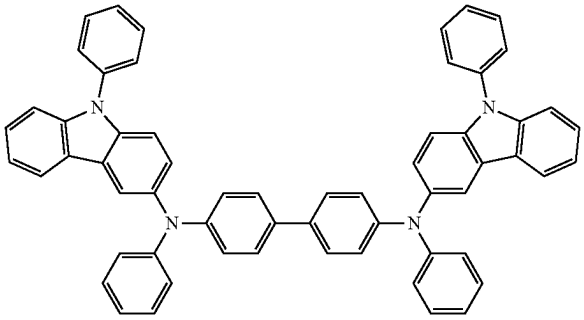

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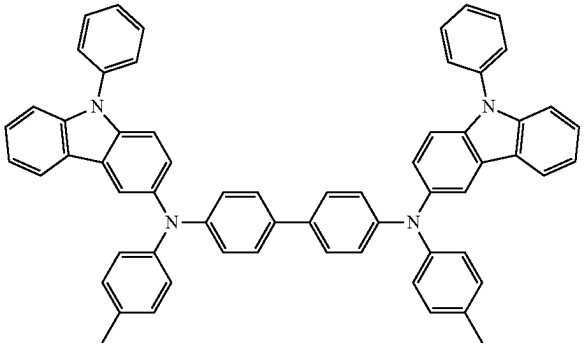

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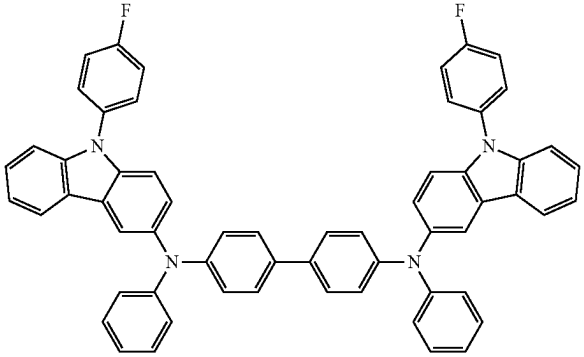

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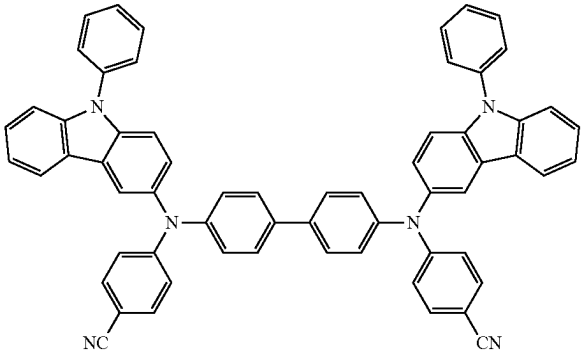

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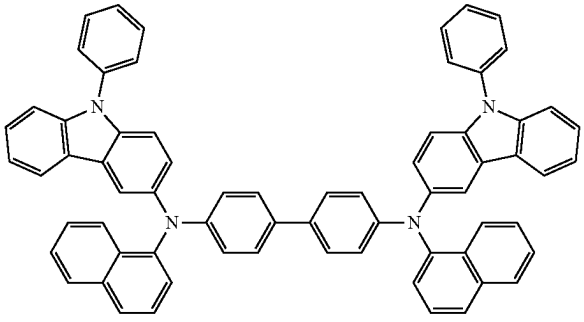

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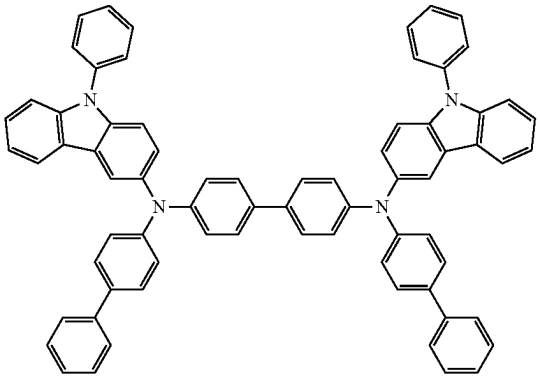

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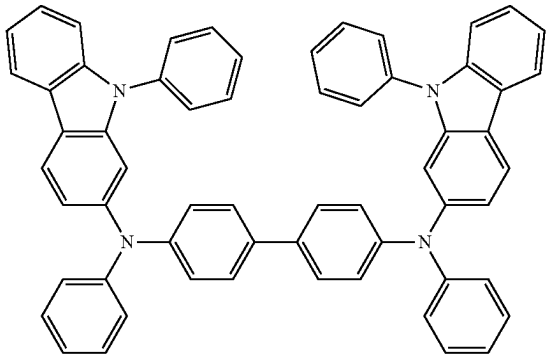

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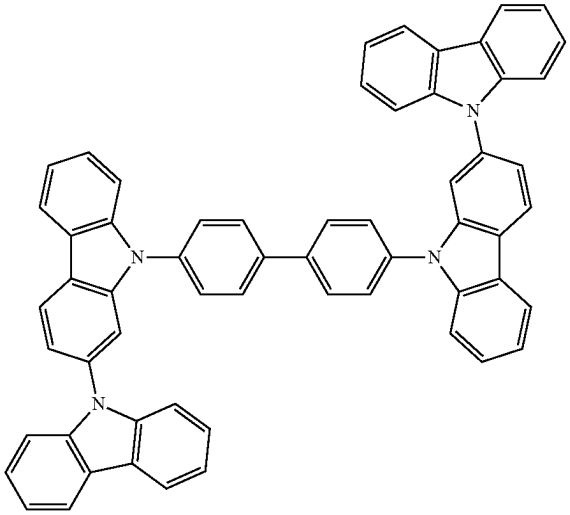

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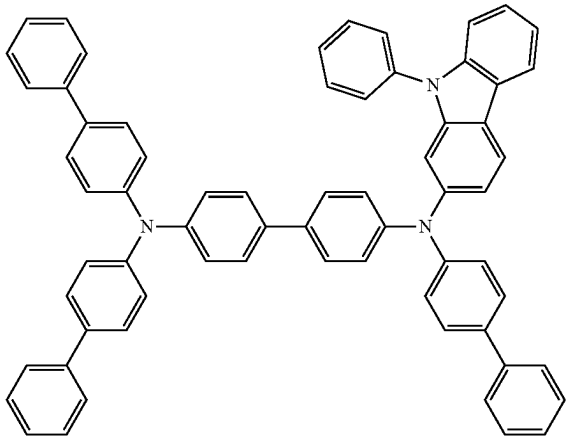

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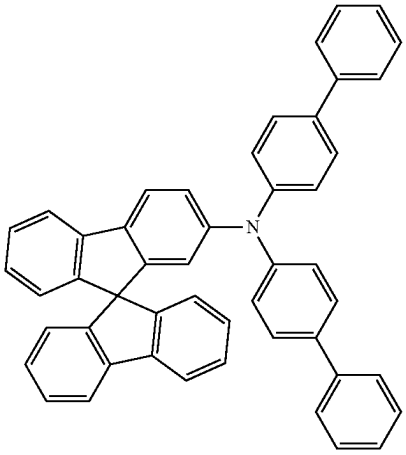

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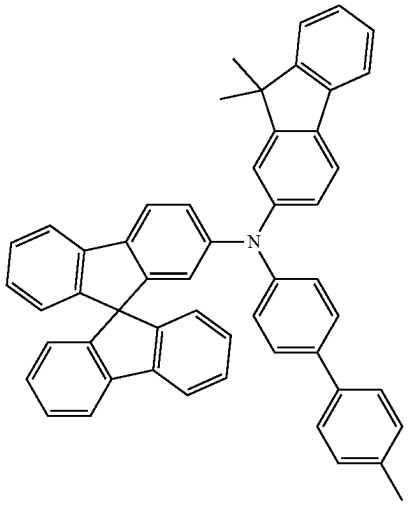

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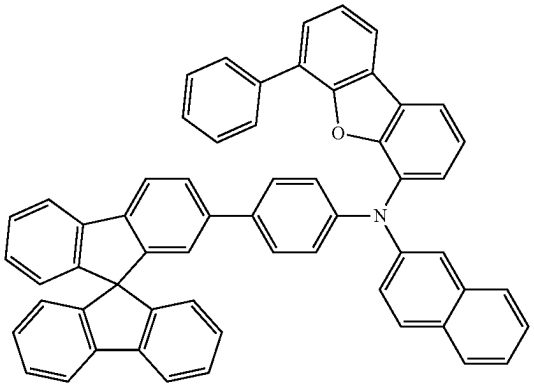

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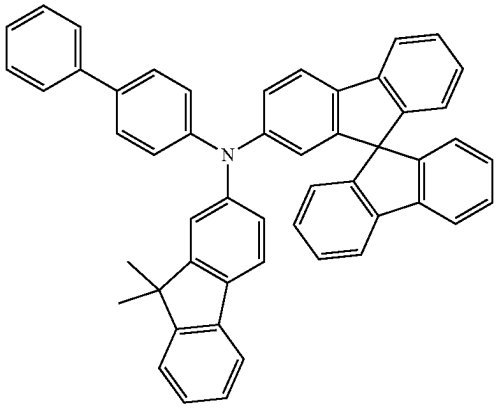

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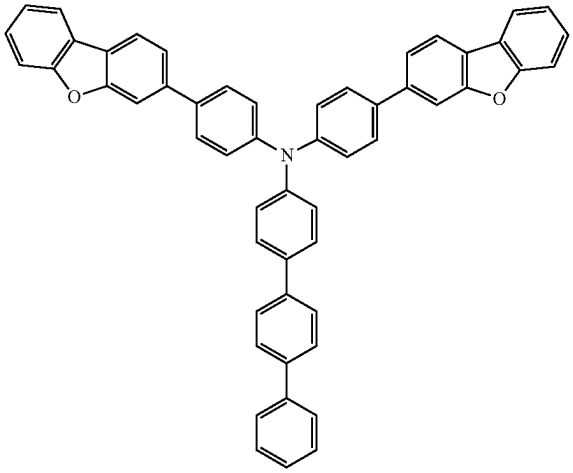

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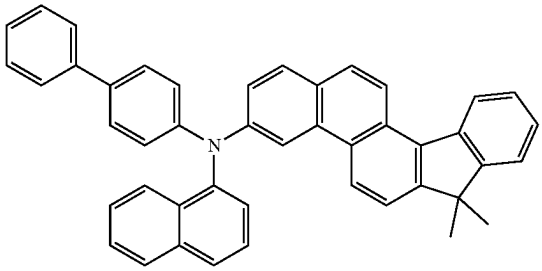

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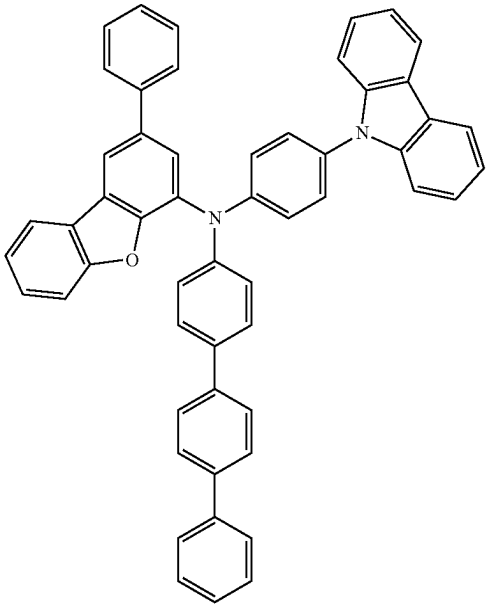

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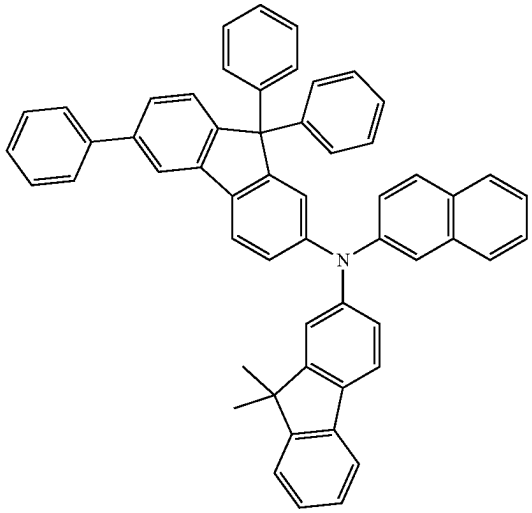

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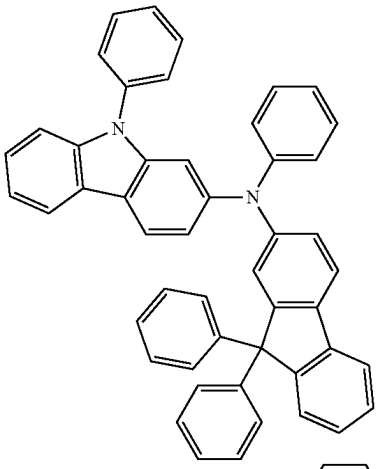

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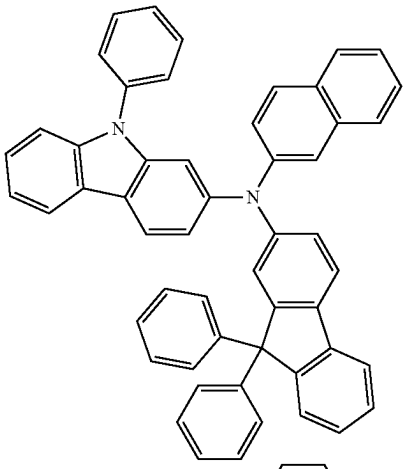

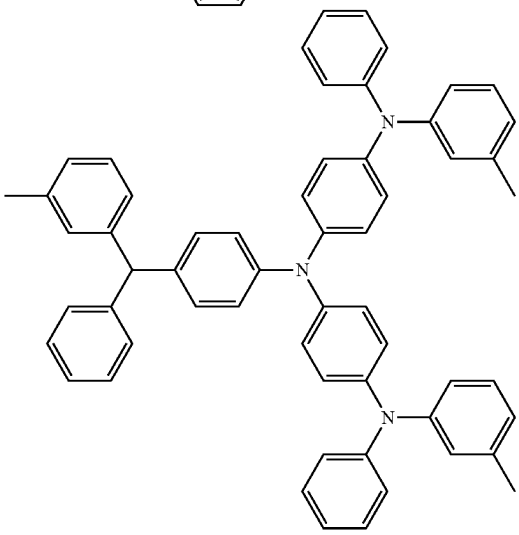

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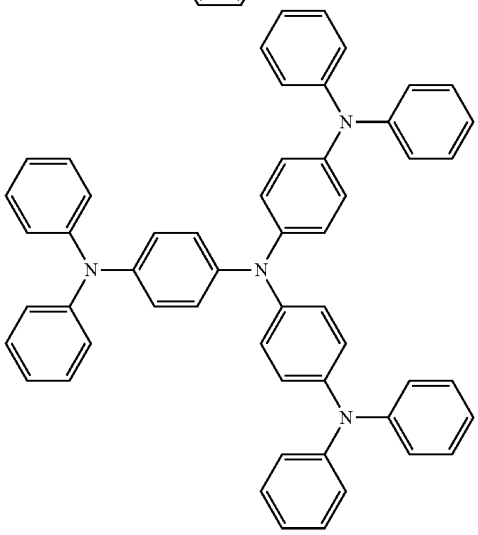
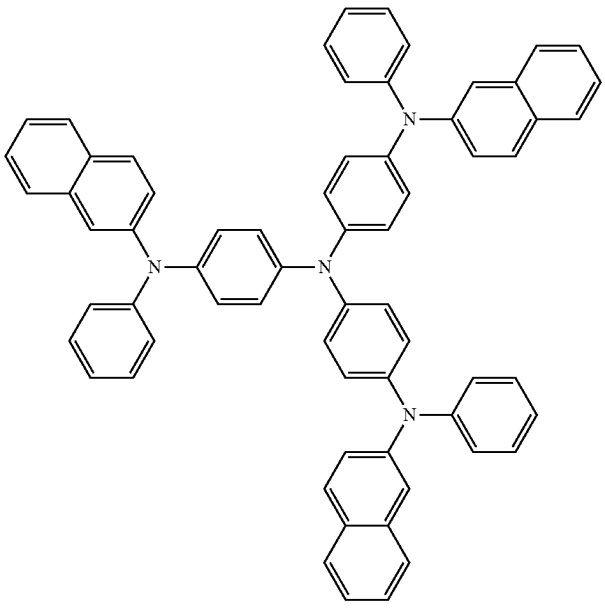


TDATA



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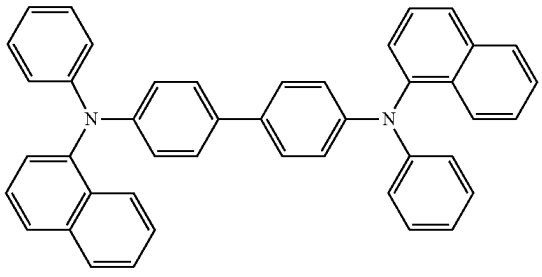

NPB

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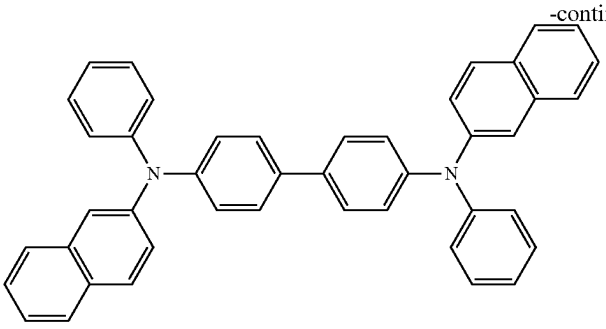
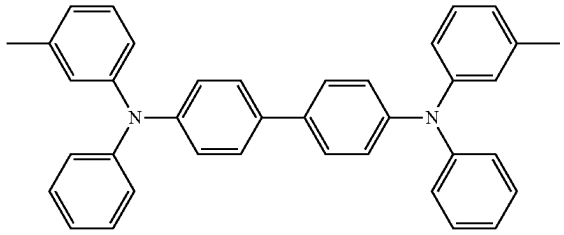
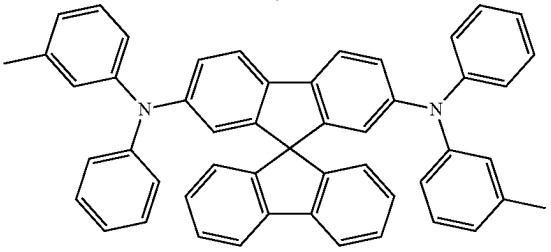


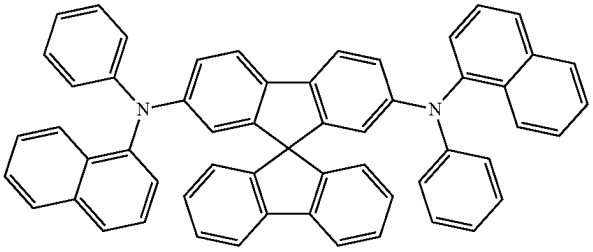
β-NPB



TPD



Spiro-TPD



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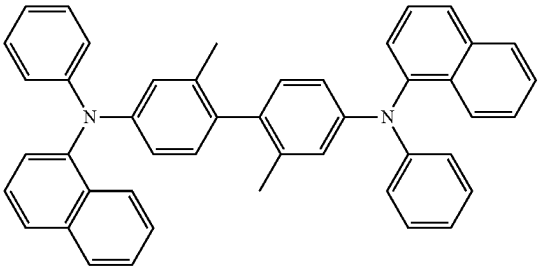
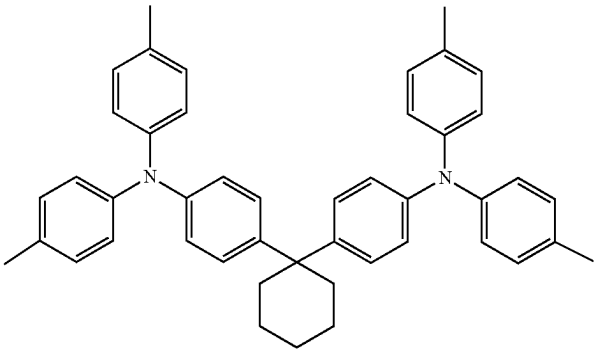
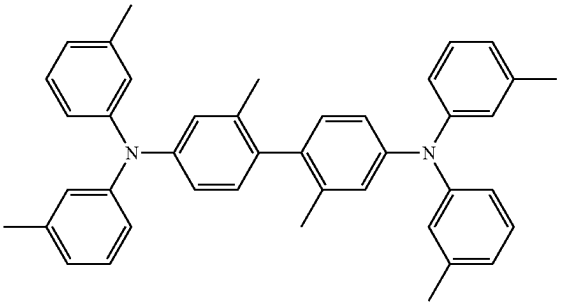


methylated-NPB



TAPC



HMTPD

[0389] A thickness of the hole transport region may be in a range of about 50 Å to about 10,000 Å. For example, the thickness of the hole transport region may be in a range of about 100 Å to about 4,000 Å. When the hole transport region includes a hole injection layer, a hole transport layer, or any combination thereof, a thickness of the hole injection layer may be in a range of about 100 Å to about 9,000 Å, and a thickness of the hole transport layer may be in a range of about 50 Å to about 2,000 Å. For example, the thickness of the hole injection layer may be in a range of about 100 Å to about 1,000 Å. For example, the thickness of the hole transport layer may be in a range of about 100 Å to about 1,500 Å. When the thicknesses of the hole transport region, the hole injection layer, and the hole transport layer are within these ranges, satisfactory hole transporting characteristics may be obtained without a substantial increase in driving voltage.

[0390] The emission auxiliary layer may increase light-emission efficiency by compensating for an optical resonance distance according to a wavelength of light emitted by an emission layer, and the electron blocking layer may block

the leakage of electrons from an emission layer to a hole transport region. Materials that may be included in the hole transport region may be included in the emission auxiliary layer and the electron blocking layer.

[p-dopant]

[0391] The hole transport region may further include, in addition to these materials, a charge-generation material for the improvement of conductive properties. The charge-generation material may be uniformly or non-uniformly dispersed in the hole transport region (for example, in the form of a single layer consisting of a charge-generation material).

[0392] The charge-generation material may be, for example, a p-dopant.

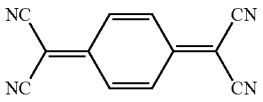
[0393] A lowest unoccupied molecular orbital (LUMO) energy level of the p-dopant may be equal to or less than about-3.5 eV.

[0394] In embodiments, the p-dopant may include a quinone derivative, a cyano group-containing compound, a compound including element EL1 and element EL2, or any combination thereof.

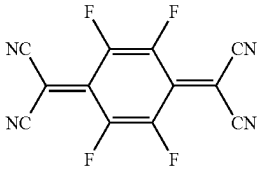
[0395] Examples of a quinone derivative may include TCNQ, F4-TCNQ, etc.

[0396] Examples of a cyano group-containing compound may include HAT-CN, and a compound represented by Formula 221:

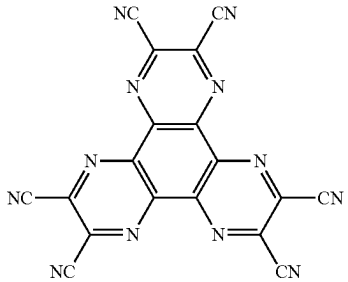
TCNQ



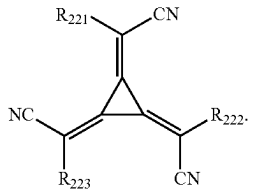
F4-TCNQ



HAT-CN



[Formula 221]



[0397] In Formula 221,

[0398] R_{221} to R_{223} may each independently be a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a} or a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}, and

[0399] at least one of R_{221} to R_{223} may each independently be a C_3-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group, each substituted with: a cyano group; —F; —Cl; —Br; —I; a C_1-C_{20} alkyl group that is substituted with a cyano group, —F, —Cl, —Br, —I, or any combination thereof; or any combination thereof.

[0400] In the compound including element EL1 and element EL2, element EL1 may be a metal, a metalloid, or any combination thereof, and element EL2 may be a non-metal, a metalloid, or any combination thereof.

[0401] Examples of a metal may include: an alkali metal (for example, lithium (L_1), sodium (Na), potassium (K), rubidium (Rb), cesium (Cs), etc.); an alkaline earth metal (for example, beryllium (Be), magnesium (Mg), calcium (Ca), strontium (Sr), barium (Ba), etc.); a transition metal (for example, titanium (Ti), zirconium (Zr), hafnium (Hf), vanadium (V), niobium (Nb), tantalum (Ta), chromium (Cr), molybdenum (Mo), tungsten (W), manganese (Mn), technetium (Tc), rhenium (Re), iron (Fe), ruthenium (Ru), osmium (Os), cobalt (Co), rhodium (Rh), iridium (Ir), nickel (Ni), palladium (Pd), platinum (Pt), copper (Cu), silver (Ag), gold (Au), etc.); a post-transition metal (for example, zinc (Zn), indium (In), tin (Sn), etc.); and a lanthanide metal (for example, lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu), etc.).

[0402] Examples of a metalloid may include silicon (Si), antimony (Sb), and tellurium (Te).

[0403] Examples of a non-metal may include oxygen (O) and a halogen (for example, F, Cl, Br, I, etc.).

[0404] Examples of a compound including element EL1 and element EL2 may include a metal oxide, a metal halide (for example, a metal fluoride, a metal chloride, a metal bromide, or a metal iodide), a metalloid halide (for example, a metalloid fluoride, a metalloid chloride, a metalloid bromide, or a metalloid iodide), a metal telluride, or any combination thereof.

[0405] Examples of a metal oxide may include a tungsten oxide (for example, WO, W_2O_3, WO_2, WO_3, W_2O_5, etc.), a vanadium oxide (for example, VO, V_2O_3, VO_2, V_2O_5, etc.), a molybdenum oxide (MoO, Mo_2O_3, MoO_2, MoO_3, Mo_2O_5, etc.), and a rhenium oxide (for example, ReO_3, etc.).

[0406] Examples of a metal halide may include an alkali metal halide, an alkaline earth metal halide, a transition metal halide, a post-transition metal halide, and a lanthanide metal halide.

[0407] Examples of an alkali metal halide may include LiF, NaF, KF, RbF, CsF, LiCl, NaCl, KCl, RbCl, CsCl, LiBr, NaBr, KBr, RbBr, CsBr, LiI, NaI, KI, RbI, and CsI.

[0408] Examples of an alkaline earth metal halide may include BeF_2, MgF_2, CaF_2, SrF_2, BaF_2, $BeCl_2$, $MgCl_2$, $CaCl_2$, $SrCl_2$, $BaCl_2$, $BeBr_2$, $MgBr_2$, $CaBr_2$, $SrBr_2$, $BaBr_2$, BeI_2, MgI_2, CaI_2, SrI_2, and BaI_2.

[0409] Examples of a transition metal halide may include a titanium halide (for example, TiF_4, $TiCl_4$, $TiBr_4$, TiI_4, etc.), a zirconium halide (for example, ZrF_4, $ZrCl_4$, $ZrBr_4$, ZrI_4, etc.), a hafnium halide (for example, HfF_4, $HfCl_4$, $HfBr_4$, HfI_4, etc.), a vanadium halide (for example, VF_3, VCl_3, VBr_3, VI_3, etc.), a niobium halide (for example, NbF_3, $NbCl_3$, $NbBr_3$, NbI_3, etc.), a tantalum halide (for example, TaF_3, $TaCl_3$, $TaBr_3$, TaI_3, etc.), a chromium halide (for example, CrF_3, $CrCl_3$, $CrBr_3$, CrI_3, etc.), a molybdenum halide (for example, MoF_3, $MoCl_3$, $MoBr_3$, MoI_3, etc.), a tungsten halide (for example, WF_3, WCl_3, WBr_3, WI_3, etc.), a manganese halide (for example, MnF_2, $MnCl_2$, $MnBr_2$, MnI_2, etc.), a technetium halide (for example, TcF_2, $TcCl_2$, $TcBr_2$, TcI_2, etc.), a rhenium halide (for example, ReF_2, $ReCl_2$, $ReBr_2$, ReI_2, etc.), an iron halide (for example, FeF_2, $FeCl_2$, $FeBr_2$, FeI_2, etc.), a ruthenium halide (for example, RuF_2, $RuCl_2$, $RuBr_2$, RuI_2, etc.), an osmium halide (for example, OsF_2, $OsCl_2$, $OsBr_2$, OsI_2, etc.), a cobalt halide (for example, CoF_2, $CoCl_2$, $CoBr_2$, CoI_2, etc.), a rhodium halide (for example, RhF_2, $RhCl_2$, $RhBr_2$, RhI_2, etc.), an iridium halide (for example, IrF_2, $IrCl_2$, $IrBr_2$, IrI_2, etc.), a nickel halide (for example, NiF_2, $NiCl_2$, $NiBr_2$, NiI_2, etc.), a palladium halide (for example, PdF_2, $PdCl_2$, $PdBr_2$, PdI_2, etc.), a platinum halide (for example, PtF_2, $PtCl_2$, $PtBr_2$, PtI_2, etc.), a copper halide (for example, CuF, CuCl, CuBr, CuI, etc.), a silver halide (for example, AgF, AgCl, AgBr, AgI, etc.), and a gold halide (for example, AuF, AuCl, AuBr, AuI, etc.).

[0410] Examples of a post-transition metal halide may include a zinc halide (for example, ZnF_2, $ZnCl_2$, $ZnBr_2$, ZnI_2, etc.), an indium halide (for example, InI_3, etc.), and a tin halide (for example, SnI_2, etc.).

[0411] Examples of a lanthanide metal halide may include YbF, YbF_2, YbF_3, SmF_3, YbCl, $YbCl_2$, $YbCl_3$ $SmCl_3$, YbBr, $YbBr_2$, $YbBr_3$, $SmBr_3$, YbI, YbI_2, YbI_3, SmI_3, and the like.

[0412] Examples of a metalloid halide may include an antimony halide (for example, $SbCl_5$ and the like) and the like.

[0413] Examples of a metal telluride may include an alkali metal telluride (for example, Li_2Te, Na_2Te, K_2Te, Rb_2Te, Cs_2Te, etc.), an alkaline earth metal telluride (for example, BeTe, MgTe, CaTe, SrTe, BaTe, etc.), a transition metal telluride (for example, $TiTe_2$, $ZrTe_2$, $HfTe_2$, V_2Te_3, Nb_2Te_3, Ta_2Te_3, Cr_2Te_3, Mo_2Te_3, W_2Te_3, MnTe, TcTe, ReTe, FeTe, RuTe, OsTe, CoTe, RhTe, IrTe, NiTe, PdTe, PtTe, Cu_2Te, CuTe, Ag_2Te, AgTe, Au_2Te, etc.), a post-transition metal telluride (for example, ZnTe, etc.), and a lanthanide metal telluride (for example, LaTe, CeTe, PrTe, NdTe, PmTe, EuTe, GdTe, TbTe, DyTe, HoTe, ErTe, TmTe, YbTe, LuTe, etc.).

[Emission Layer in Interlayer **130**]

[0414] When the light-emitting device **10** is a full-color light-emitting device, the emission layer may be patterned into a red emission layer, a green emission layer, and/or a blue emission layer, according to a subpixel. In embodiments, the emission layer may have a stacked structure of two or more layers of a red emission layer, a green emission layer, and a blue emission layer, in which the two or more layers may contact each other or may be separated from each other to emit white light. In embodiments, the emission layer may include two or more materials of a red light-emitting material, a green light-emitting material, and a blue light-emitting material, in which the two or more materials may be mixed with each other in a single layer to emit white light.

[0415] The emission layer may include a host and a dopant. The dopant may include a phosphorescent dopant, a fluorescent dopant, or any combination thereof.

[0416] An amount of the dopant in the emission layer may be in a range of about 0.01 parts by weight to about 15 parts by weight, based on 100 parts by weight of the host.

[0417] In embodiments, the emission layer may include a quantum dot.

[0418] In an embodiment, the emission layer may include a delayed fluorescence material. The delayed fluorescence material may serve as a host or as a dopant in the emission layer.

[0419] A thickness of the emission layer may be in a range of about 100 Å to about 1,000 Å. For example, the thickness of the emission layer may be in a range of about 200 Å to about 600 Å. When the thickness of the emission layer is within any of these ranges, excellent light-emission characteristics may be obtained without a substantial increase in driving voltage.

[Host]

[0420] In embodiments, the host may include a compound represented by Formula 301:

$$[Ar_{301}]_{xb11}\text{-}[(L_{301})_{xb1}\text{-}R_{301}]_{xb21} \quad \text{[Formula 301]}$$

[0421] In Formula 301,

[0422] Ar_{301} and L_{301} may each independently be a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a} or a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a},

[0423] xb11 may be 1, 2, or 3,

[0424] xb1 may be an integer from 0 to 5,

[0425] R_{301} may be hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{60} alkyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} alkenyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} alkynyl group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} alkoxy group unsubstituted or substituted with at least one R_{10a}, a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}, —$Si(Q_{301})(Q_{302})(Q_{303})$, —$N(Q_{301})(Q_{302})$, —$B(Q_{301})(Q_{302})$, —$C(=O)(Q_{301})$, —$S(=O)_2(Q_{301})$, or —$P(=O)(Q_{301})(Q_{302})$,

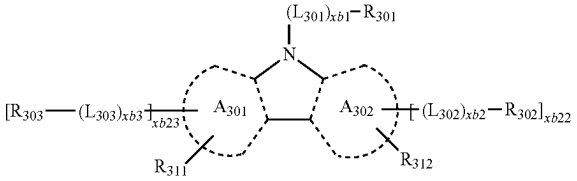
[0426] xb21 may be an integer from 1 to 5, and

[0427] Q_{301} to Q_{303} may each independently be the same as described with respect to Q_1.

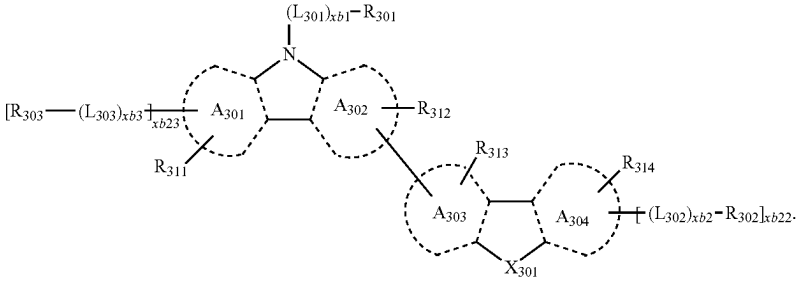
[0428] In an embodiment, in Formula 301, when xb11 is 2 or more, two or more of Ar_{301} may be linked to each other via a single bond.

[0429] In embodiments, the host may include a compound represented by Formula 301-1, a compound represented by Formula 301-2, or any combination thereof:

[Formula 301-1]



[Formula 301-2]



[0430] In Formula 301-1 and 301-2,

[0431] ring A_{301} to ring A_{304} may each independently be a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a} or a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a},

[0432] X_{301} may be O, S, N—$[(L_{304})_{xb4}$-$R_{304}]$, $C(R_{304})(R_{305})$, or $Si(R_{304})(R_{305})$,

[0433] xb22 and xb23 may each independently be 0, 1, or 2,

[0434] L_{301}, xb1, and R_{301} may each be the same as described herein,

[0435] L_{302} to L_{304} may each independently be the same as described with respect to with L_{301},

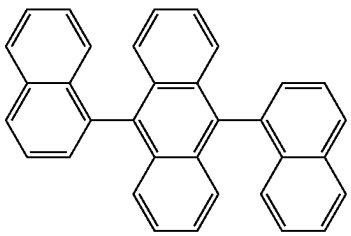
[0436] xb2 to xb4 may each independently be the same as described with respect to xb1, and

[0437] R_{302} to R_{305} and R_{311} to R_{314} may each independently be the same as described with respect to R_{301}.

[0438] In embodiments, the host may include an alkali earth metal complex, a post-transition metal complex, or any combination thereof. For example, the host may include a Be complex (for example, Compound H55), an Mg complex, a Zn complex, or any combination thereof.

[0439] In embodiments, the host may include one of Compounds H1 to H128, 9,10-di(2-naphthyl) anthracene (ADN), 2-methyl-9,10-bis(naphthalen-2-yl) anthracene (MADN), 9,10-di-(2-naphthyl)-2-t-butyl-anthracene (TBADN), 4,4'-bis(N-carbazolyl)-1,1'-biphenyl (CBP), 1,3-di-9-carbazolylbenzene (mCP), 1,3,5-tri (carbazol-9-yl)benzene (TCP), or any combination thereof:

H1



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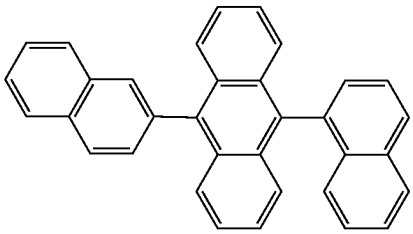
H2



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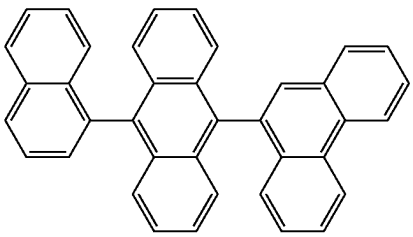

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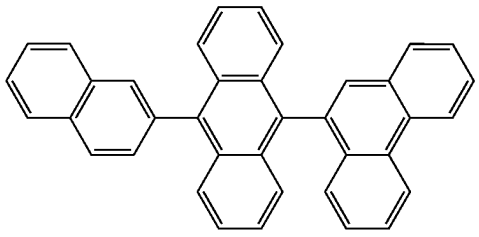

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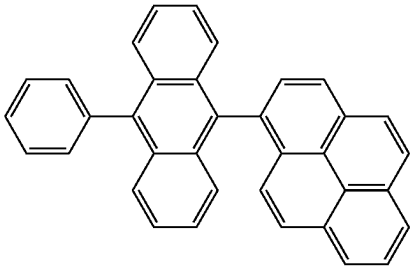

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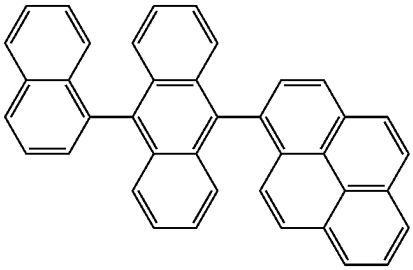

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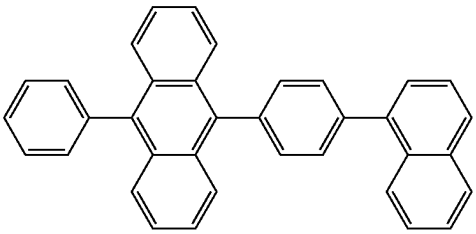

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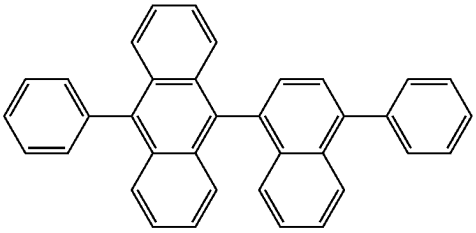

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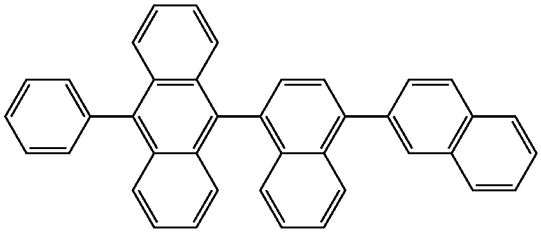

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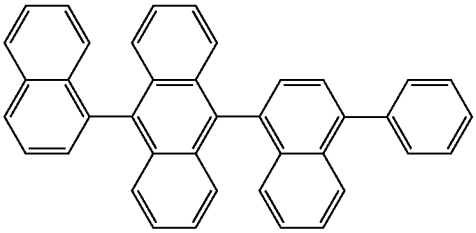

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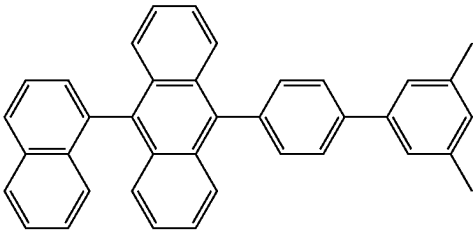

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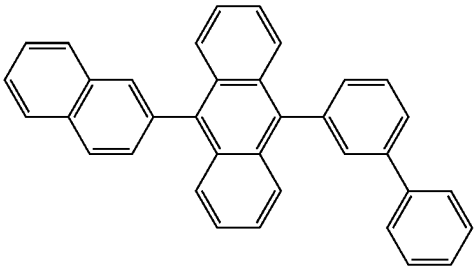

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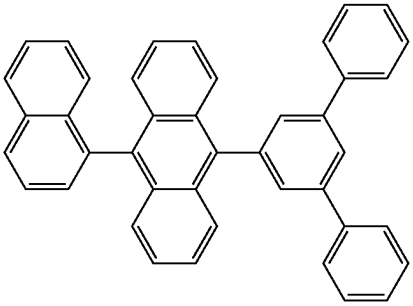

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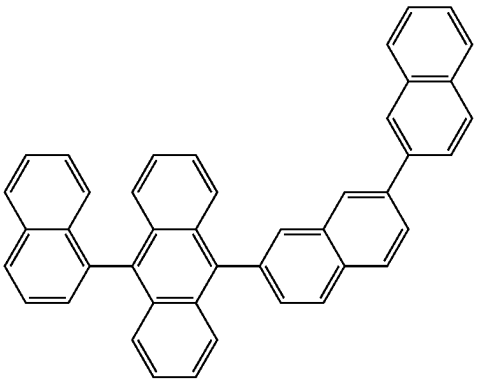

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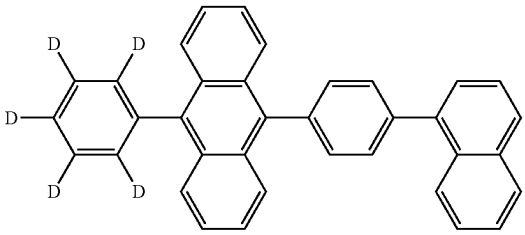

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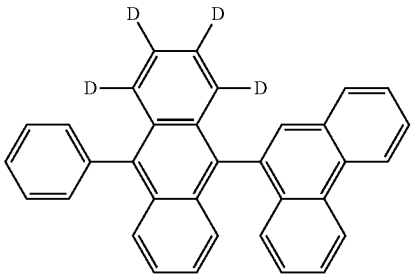

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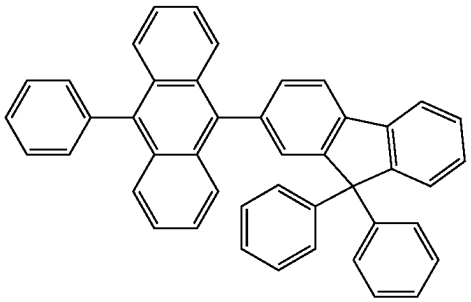

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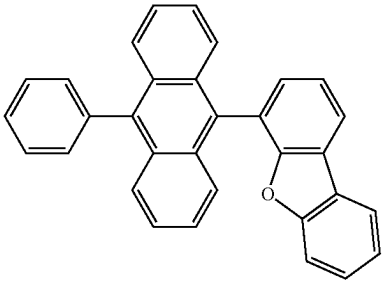

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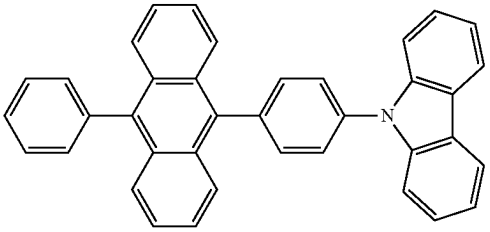

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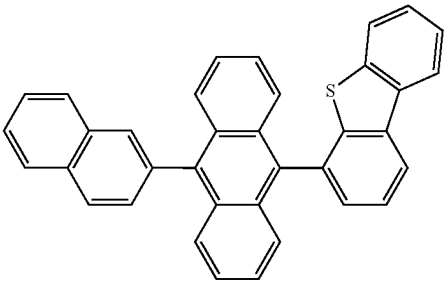

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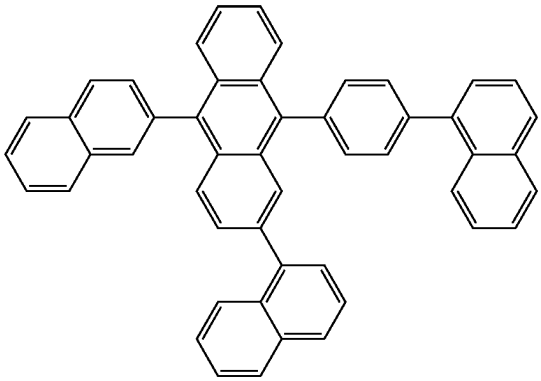

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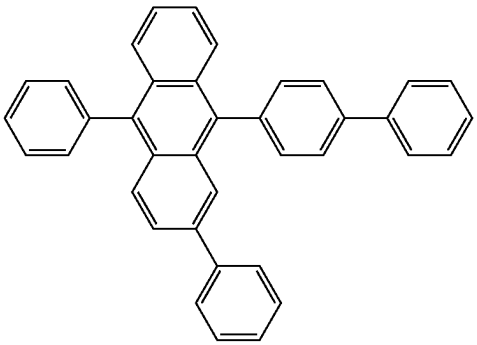

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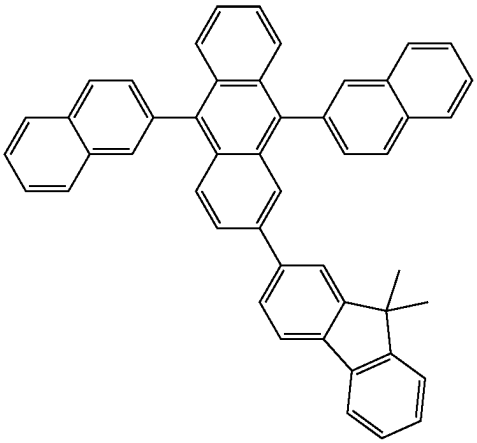

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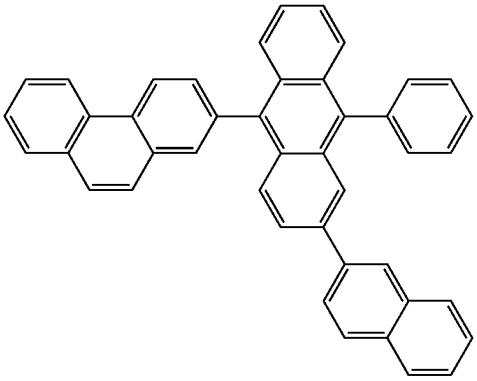

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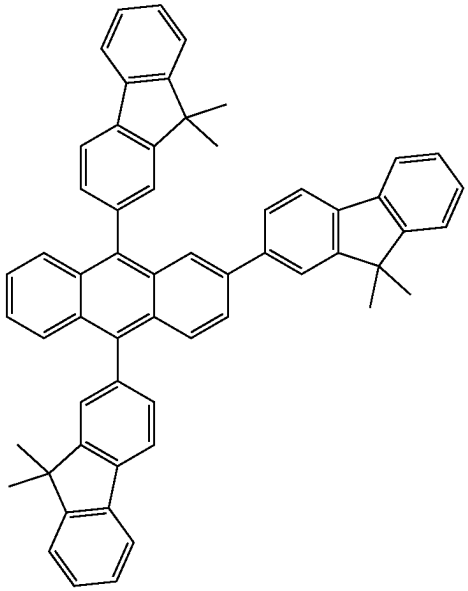

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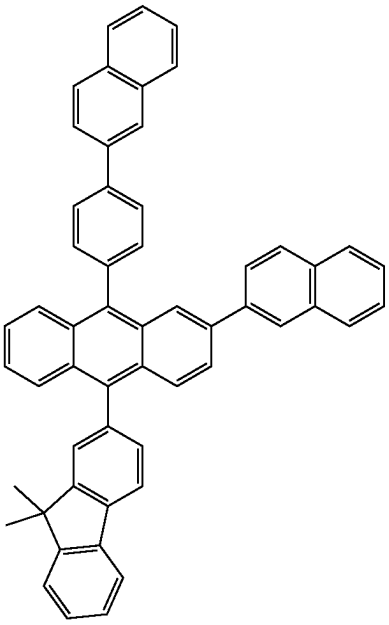

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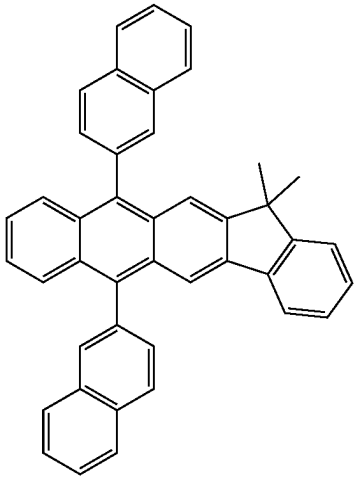

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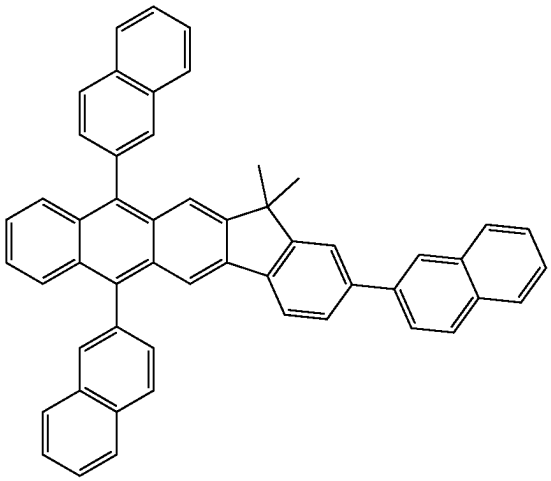

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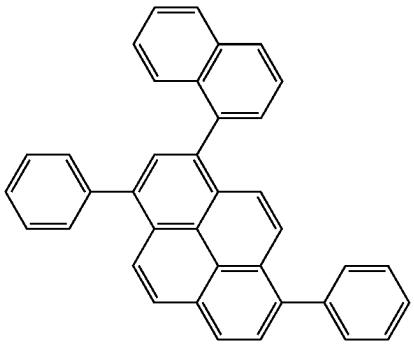

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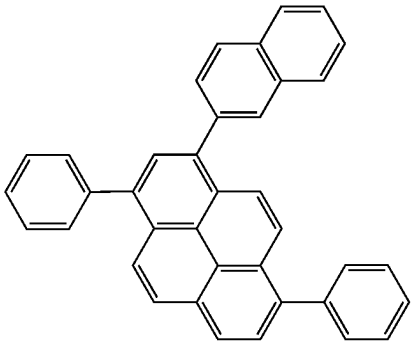
H30



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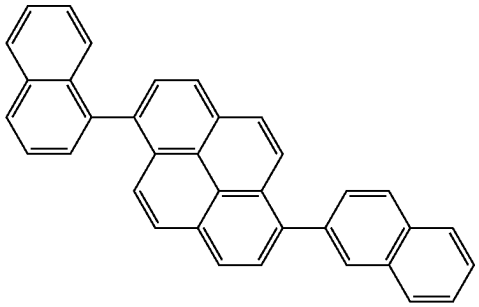

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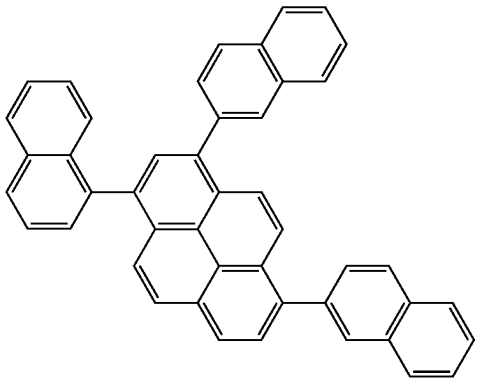

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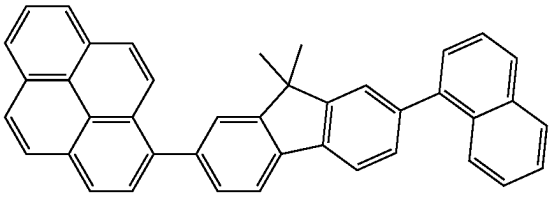

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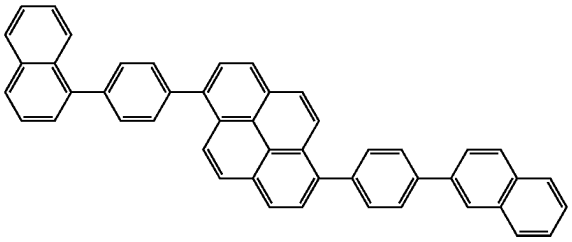

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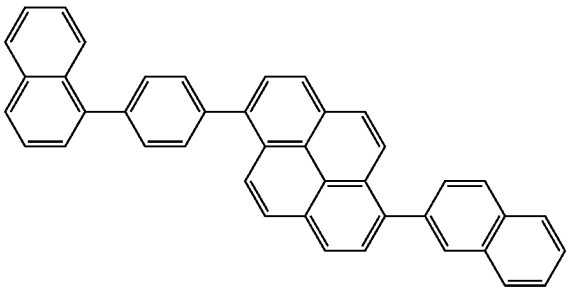

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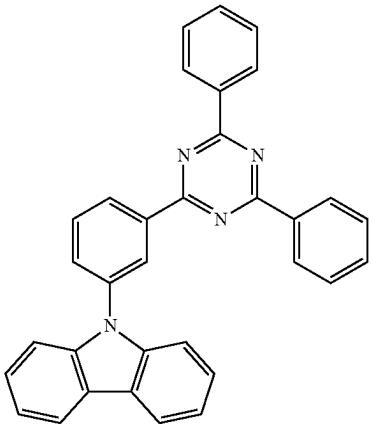

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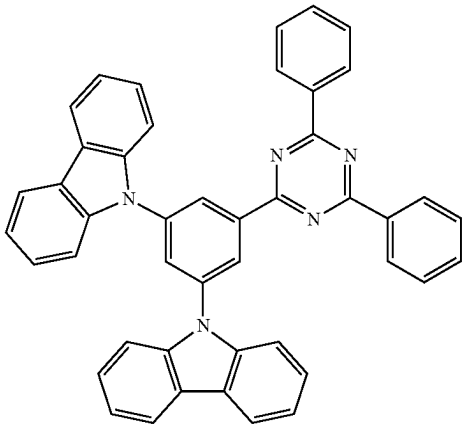

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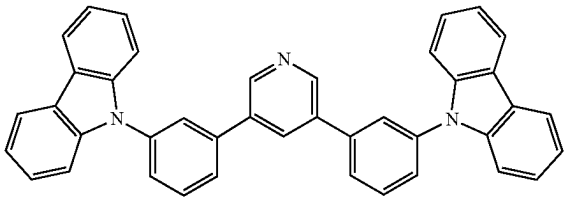

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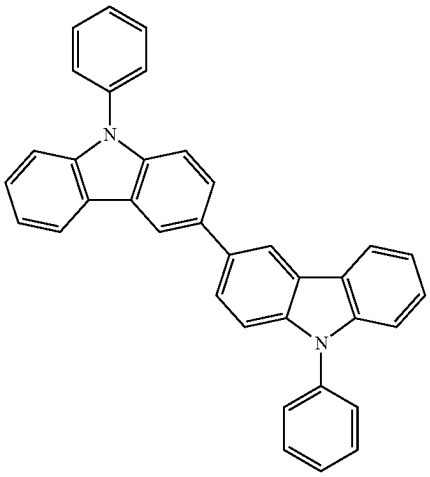

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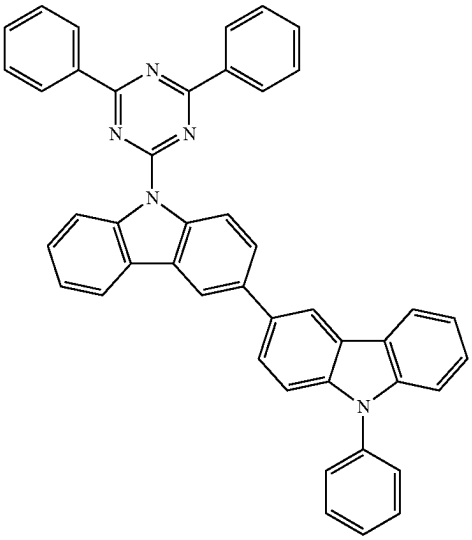

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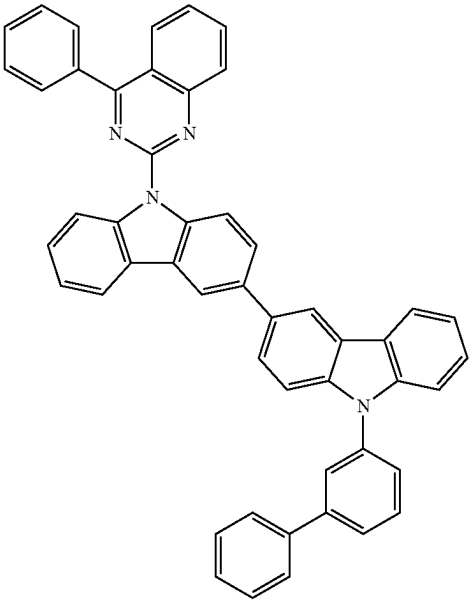

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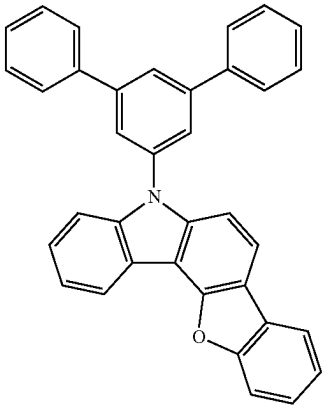

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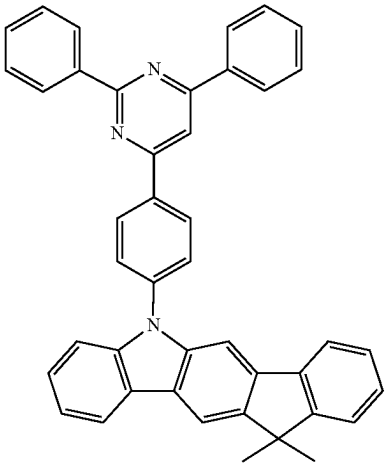

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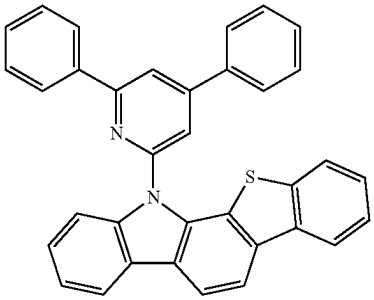

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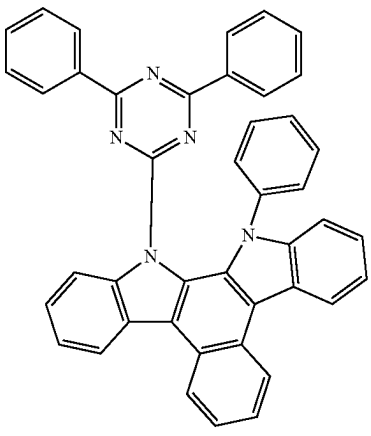

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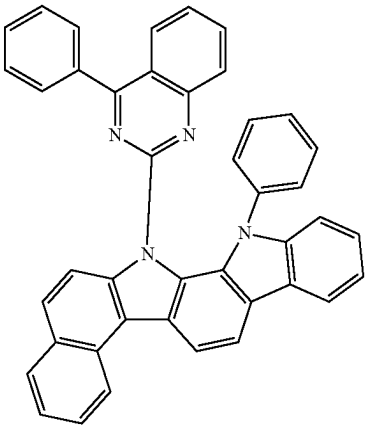

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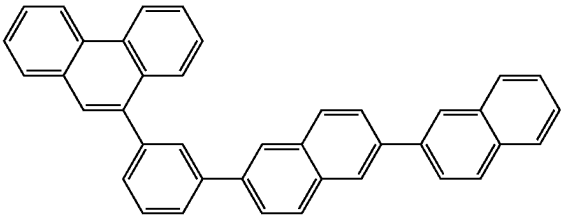

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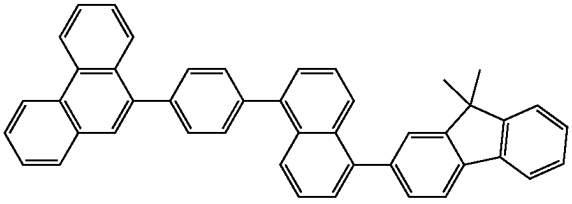

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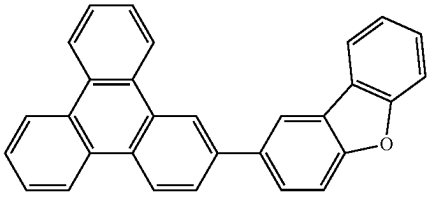

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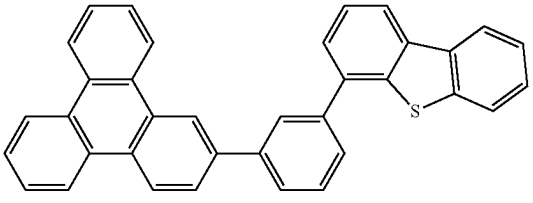

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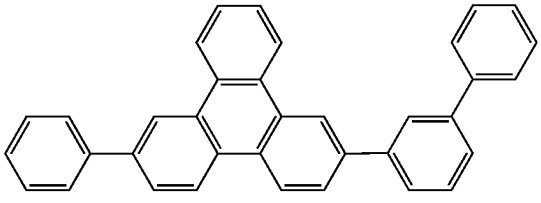

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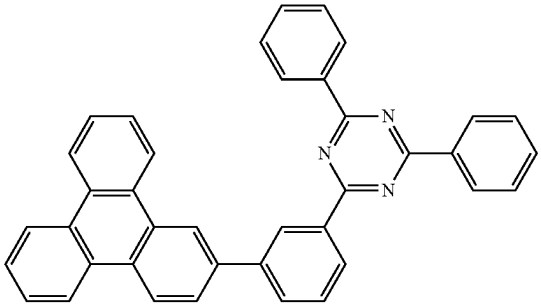

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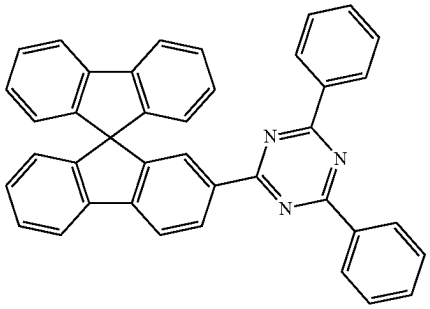

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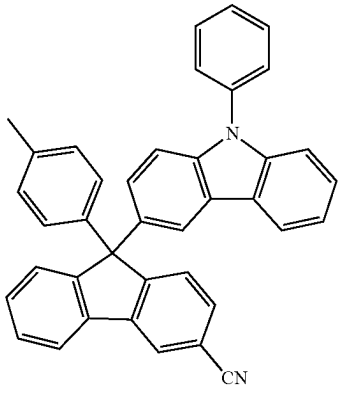

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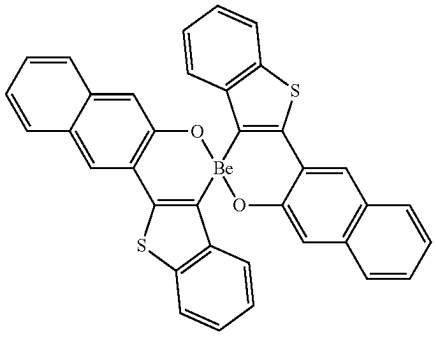

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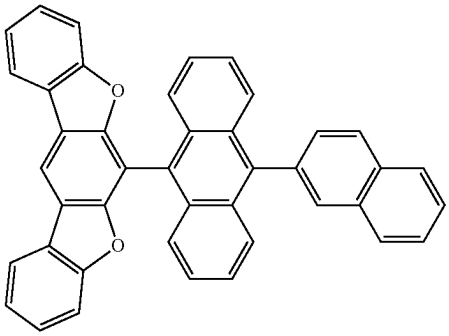

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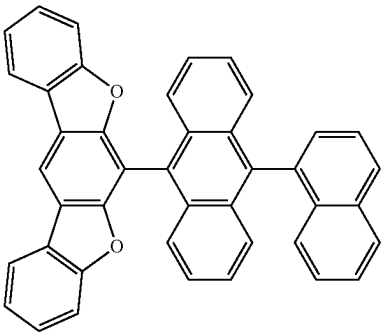

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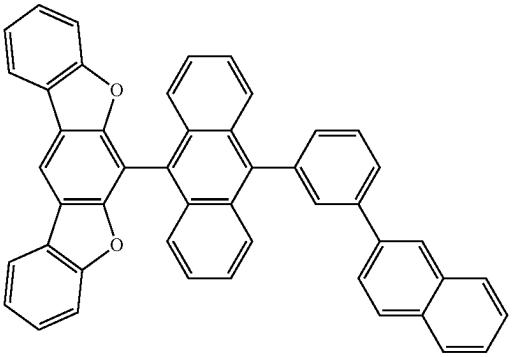

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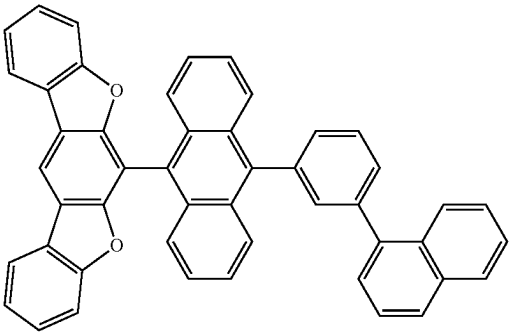

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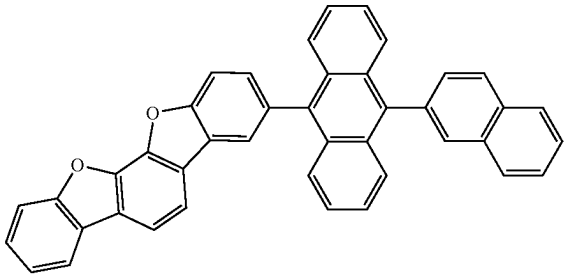

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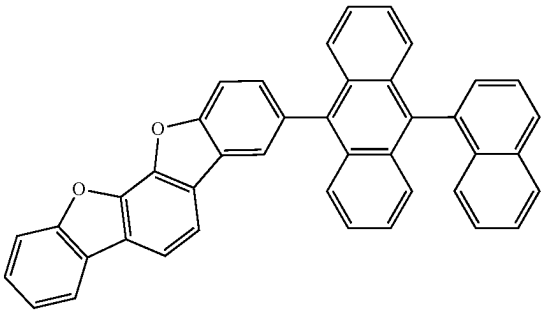

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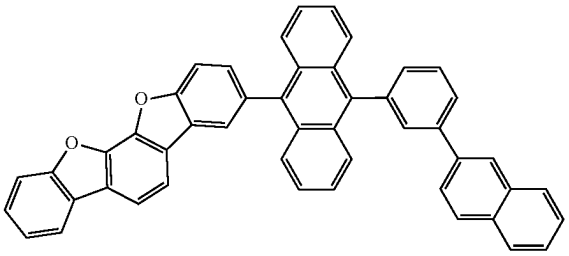

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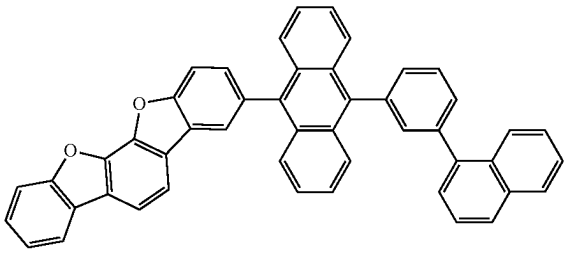

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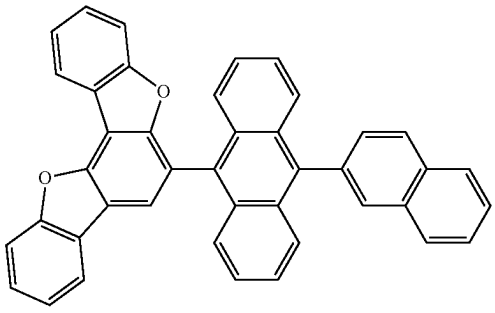

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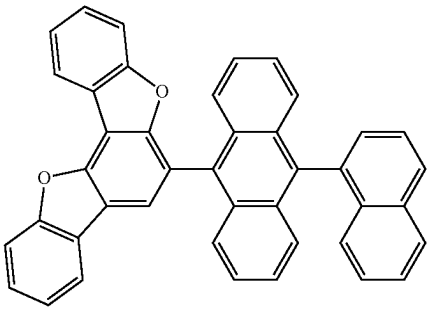

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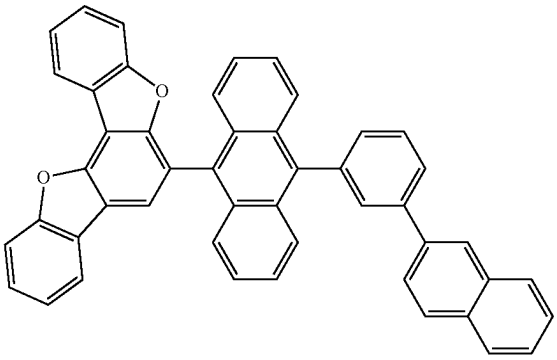

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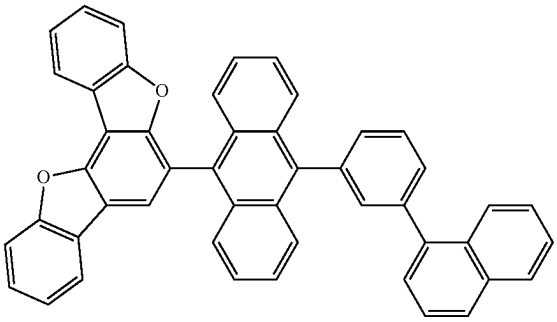

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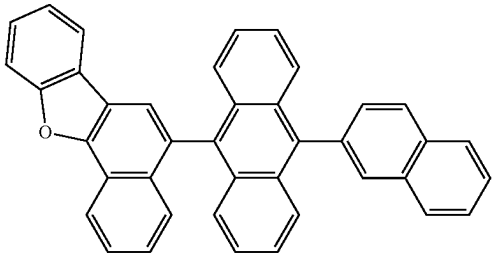

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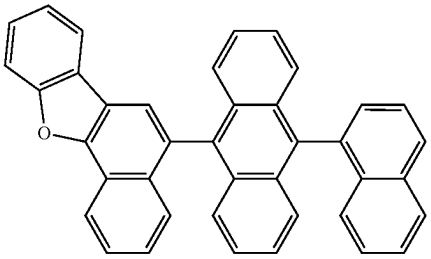

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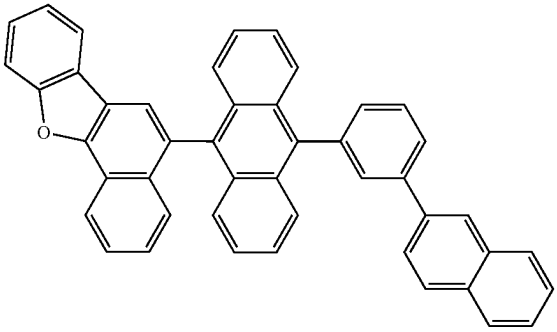

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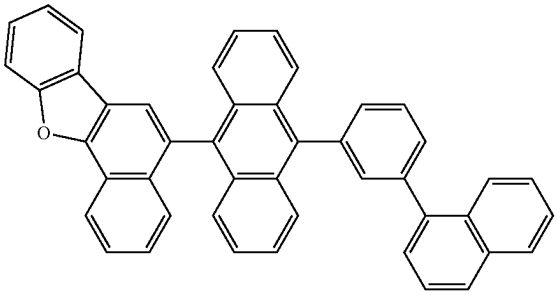

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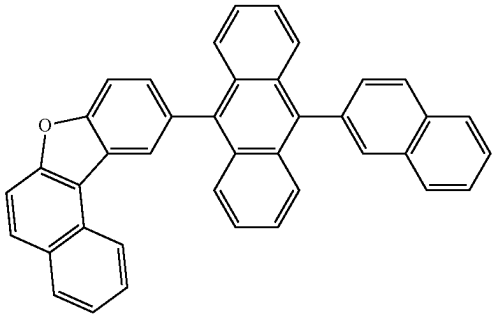

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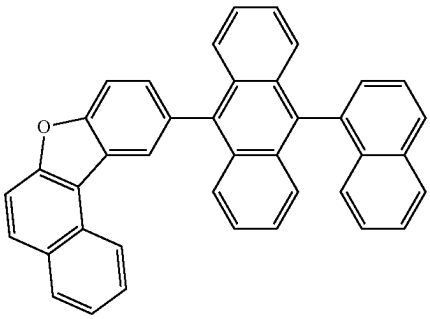

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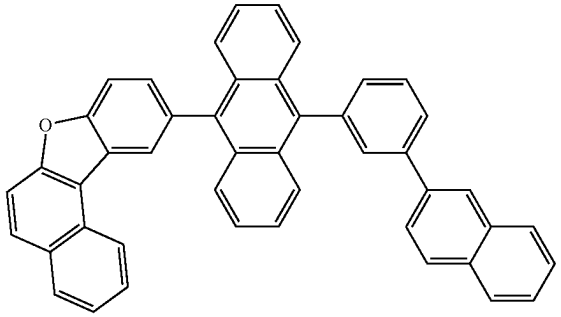

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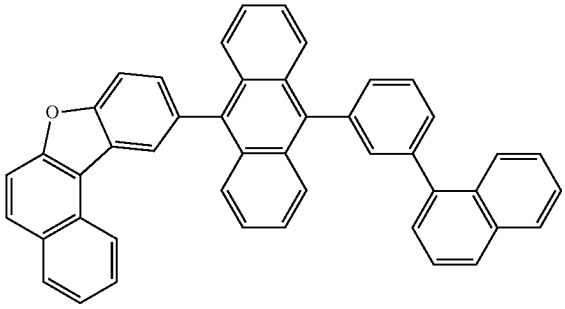

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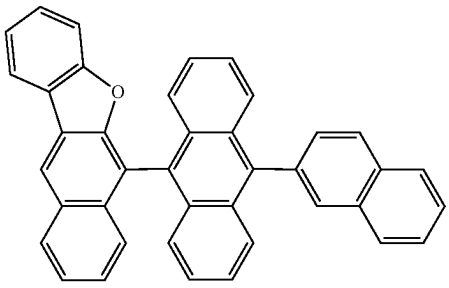

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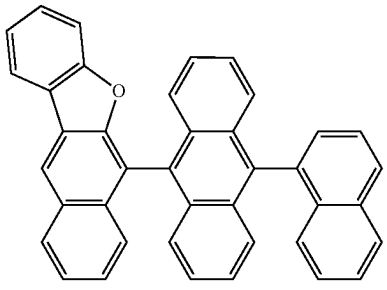

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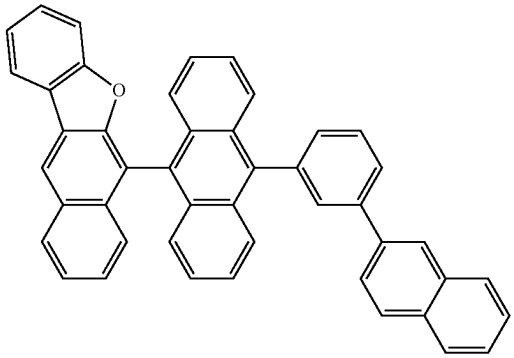

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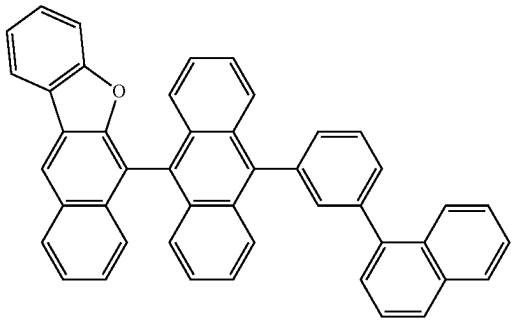

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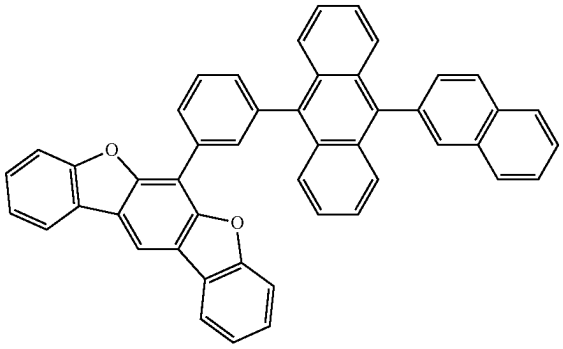

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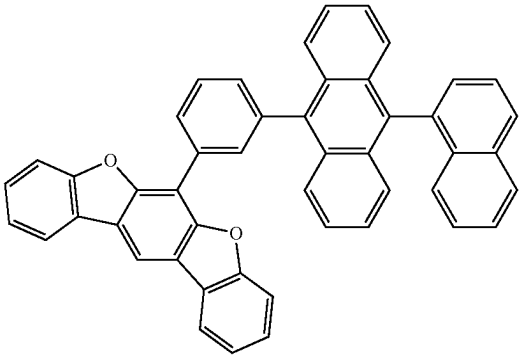

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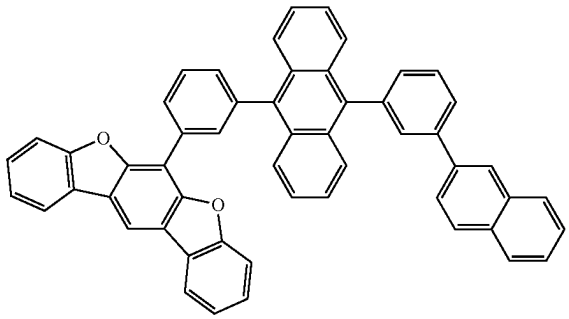

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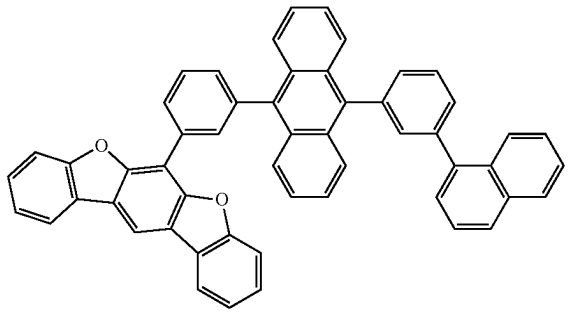

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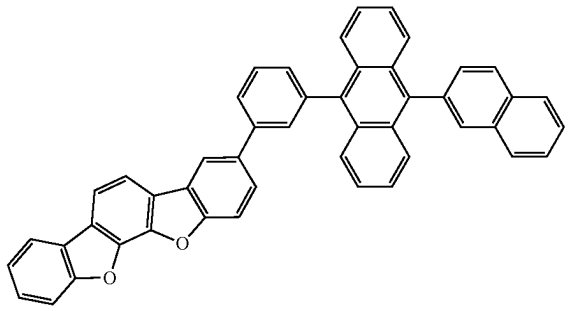

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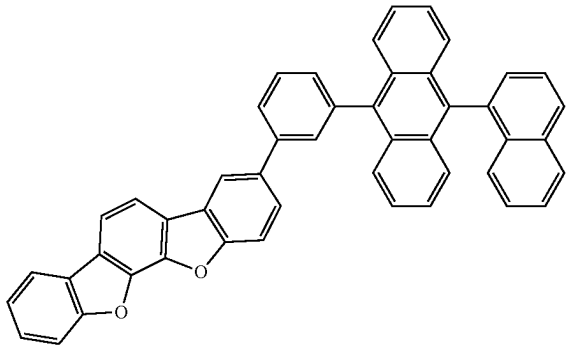

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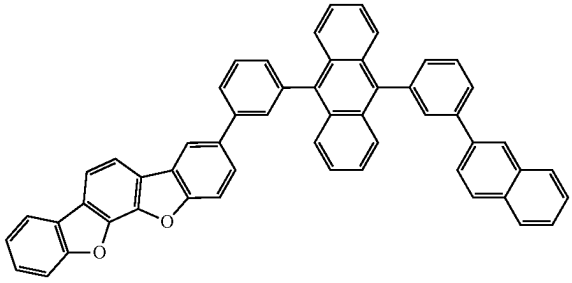

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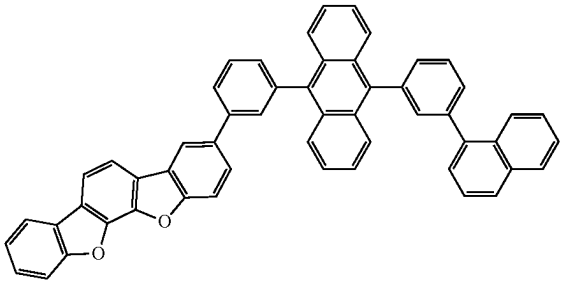

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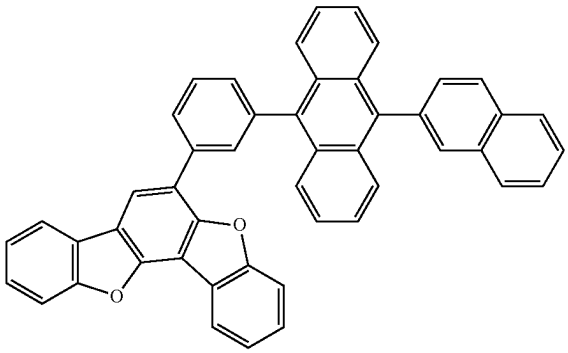

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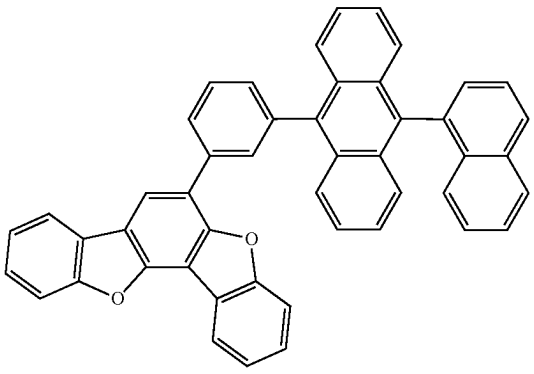

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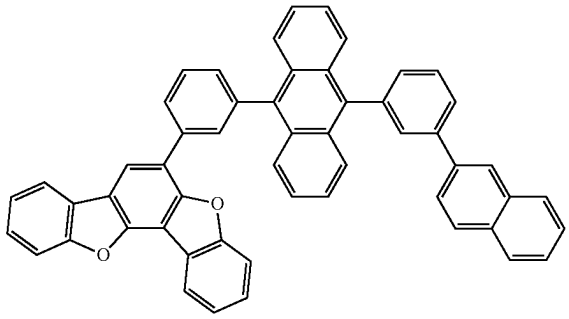

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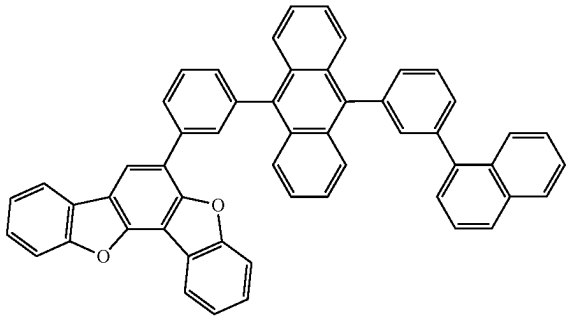

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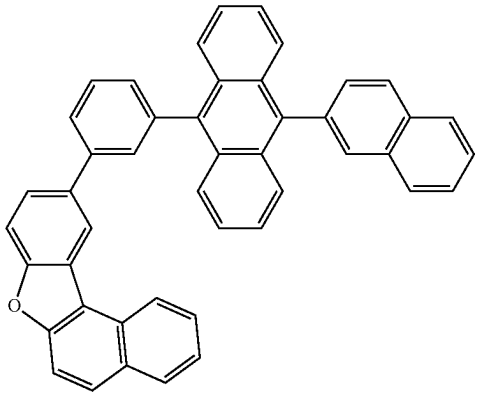

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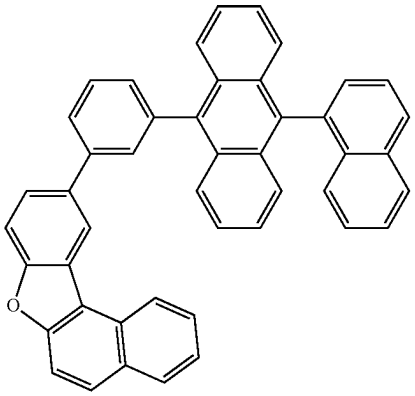

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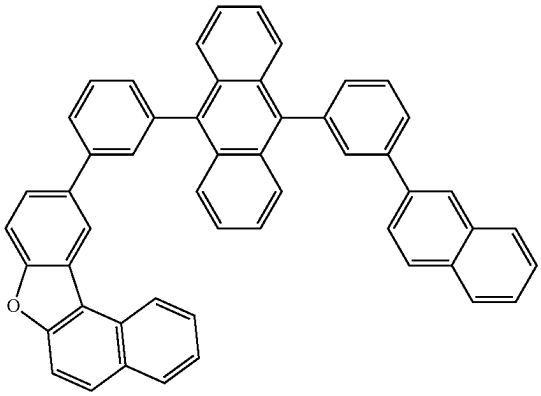

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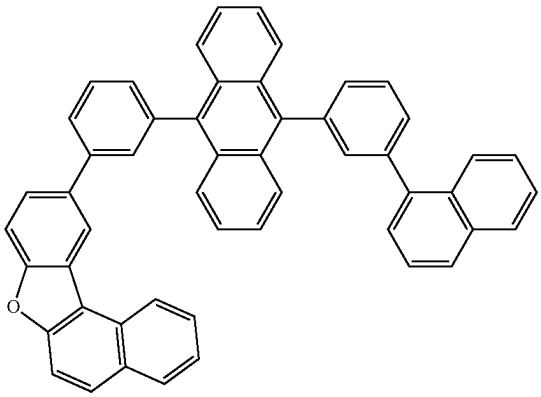

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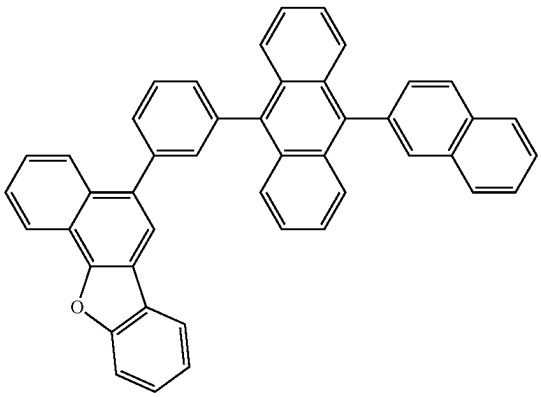

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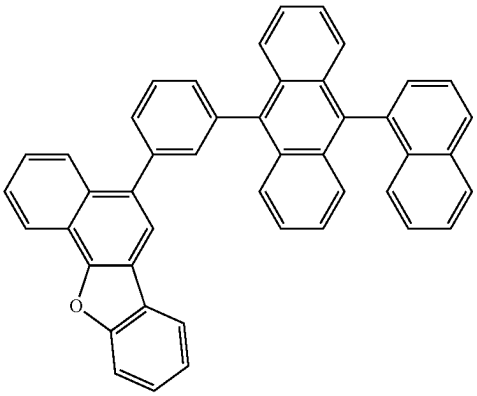

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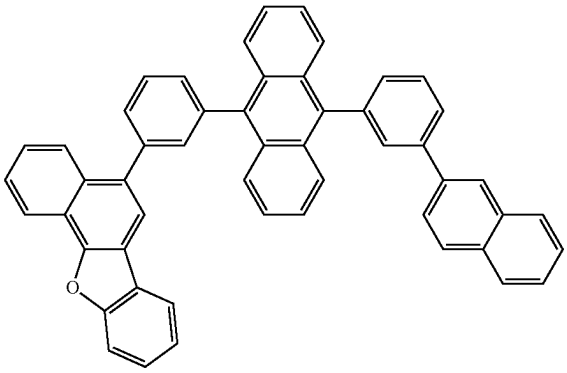

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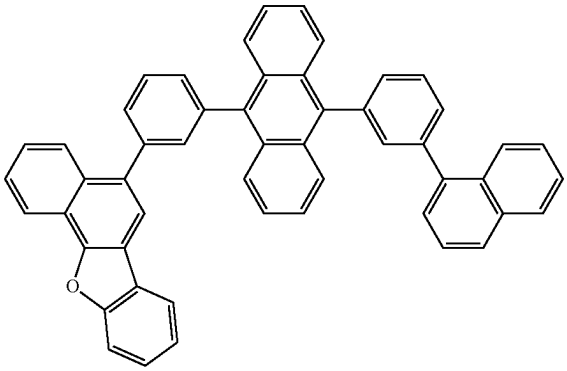

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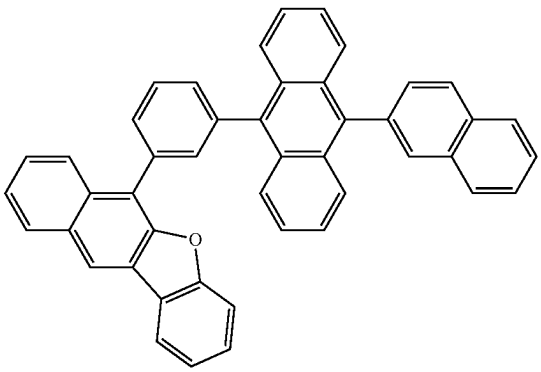

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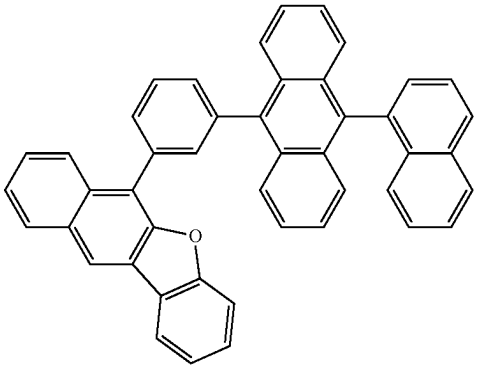

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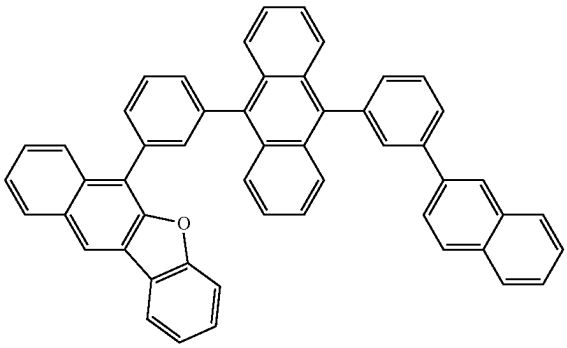

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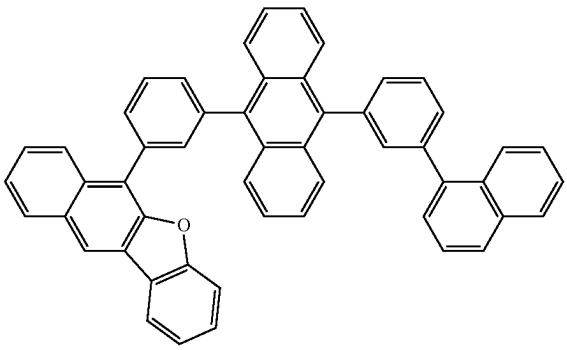

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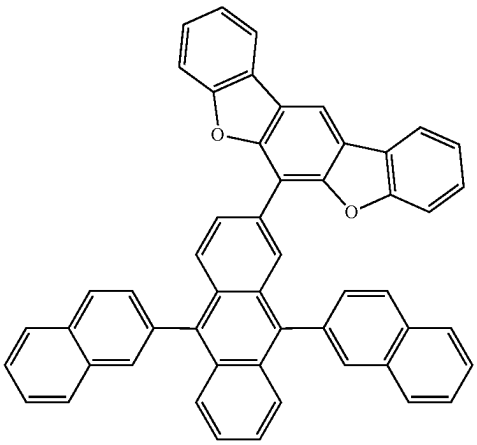

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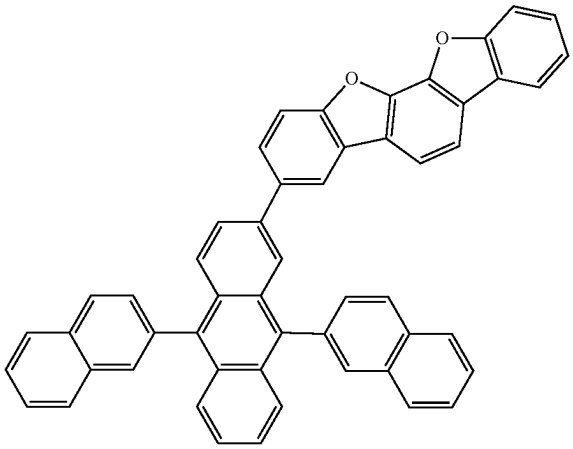

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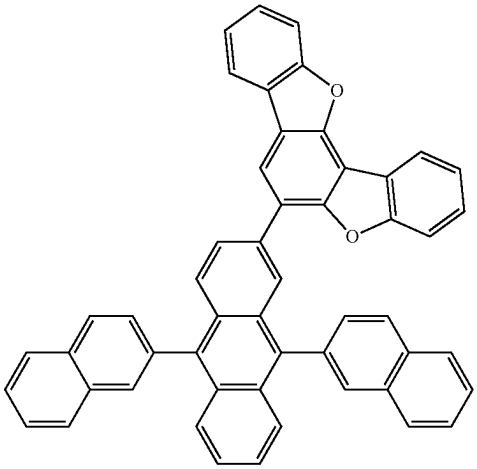

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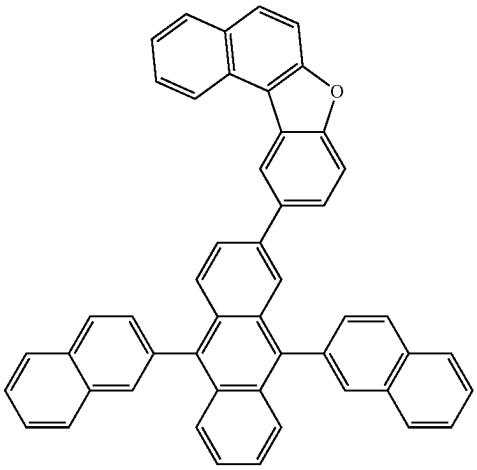

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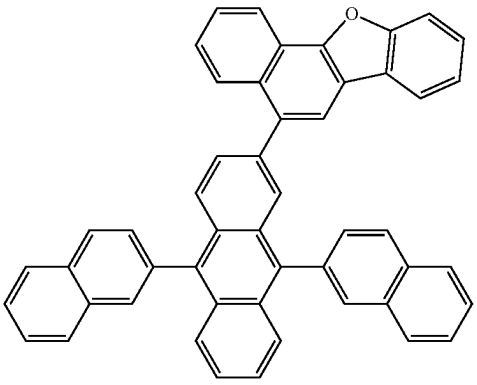

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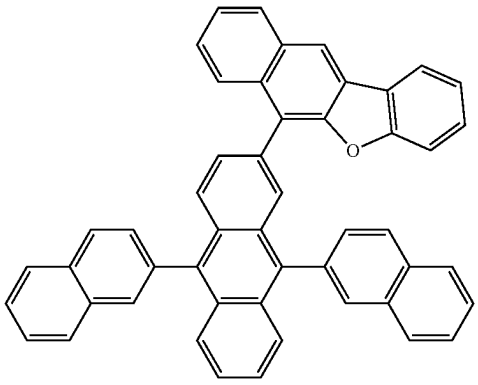

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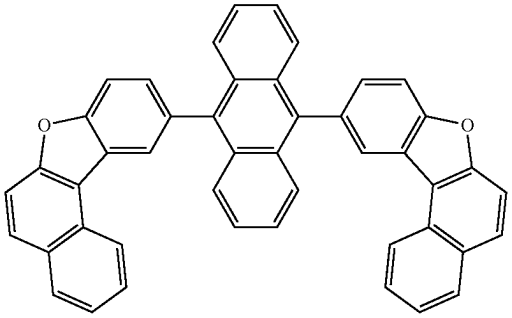

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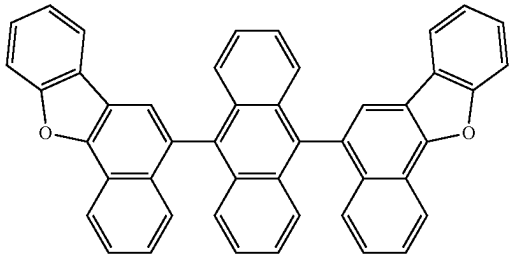

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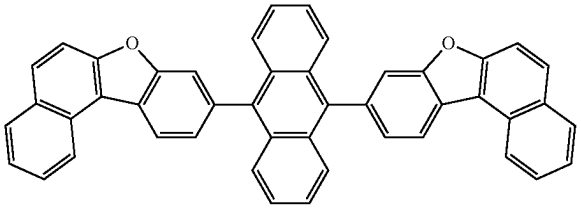

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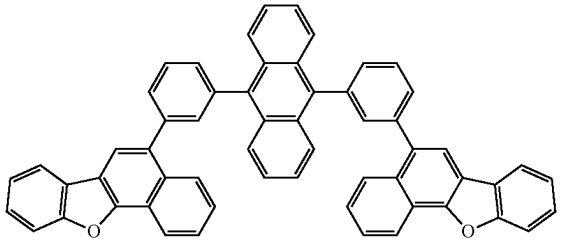

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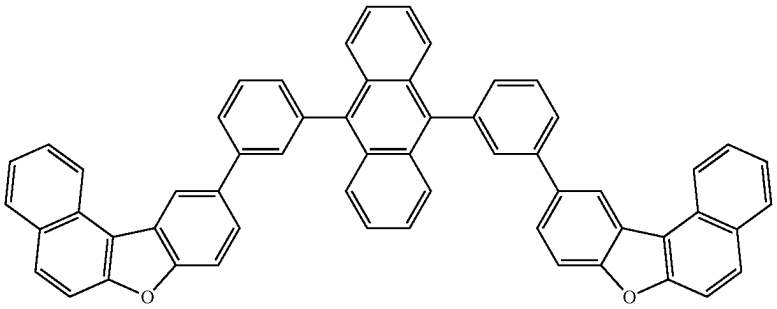

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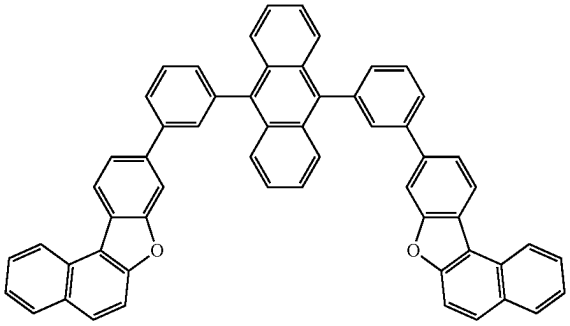

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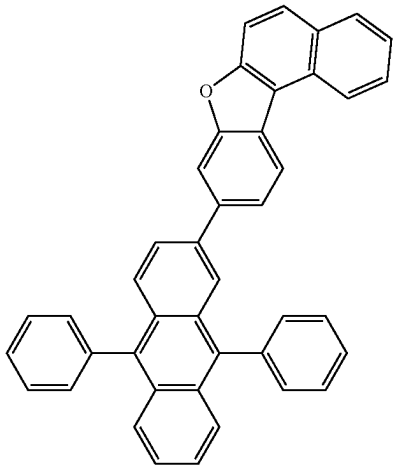

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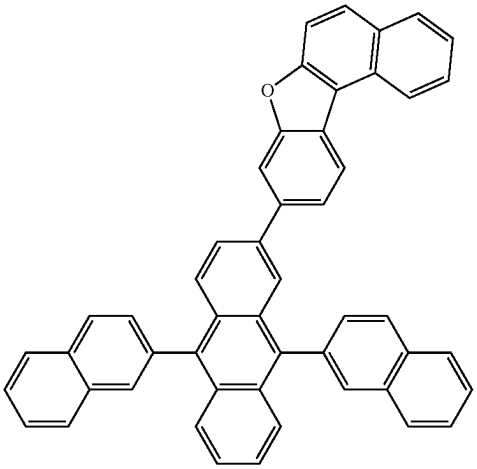

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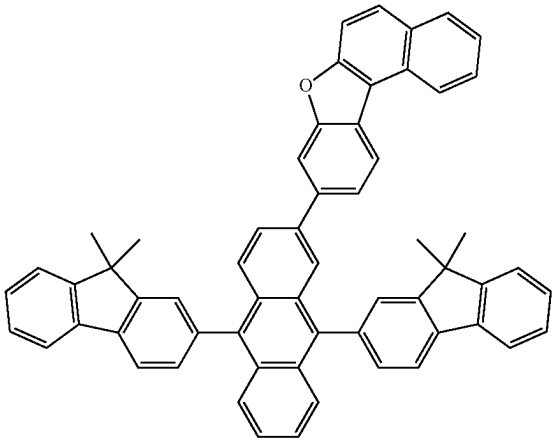

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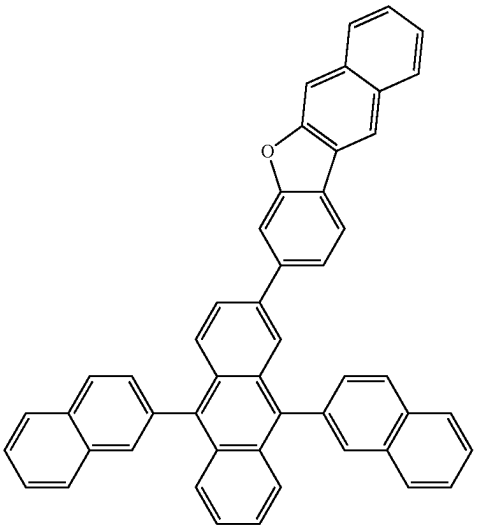

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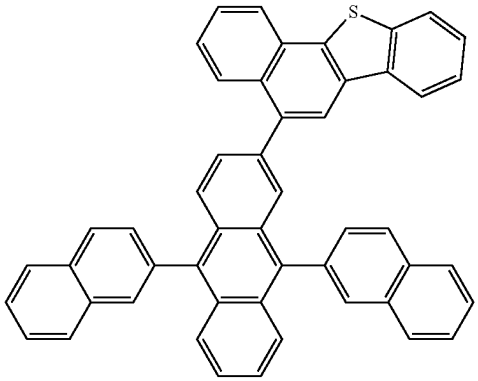

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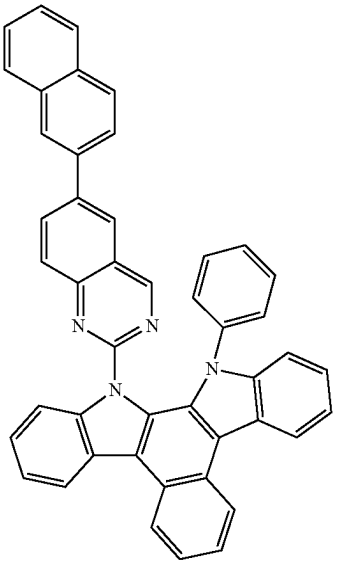

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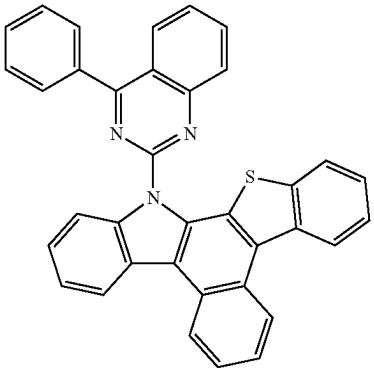

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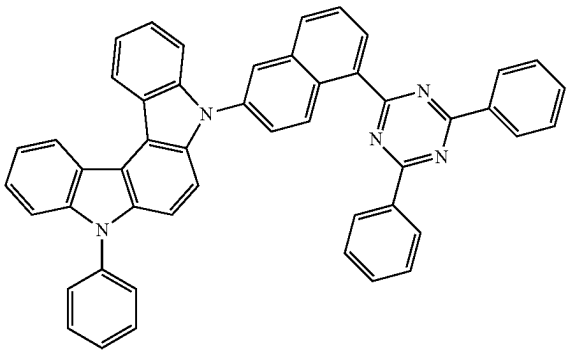

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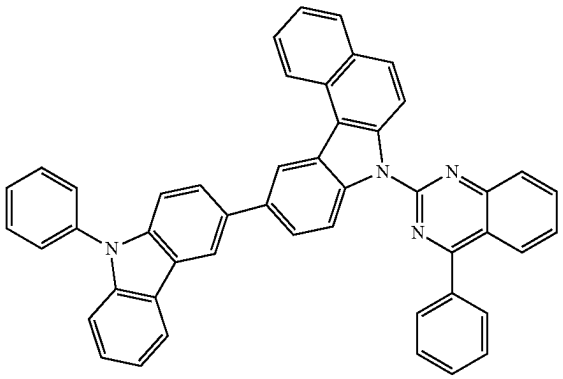

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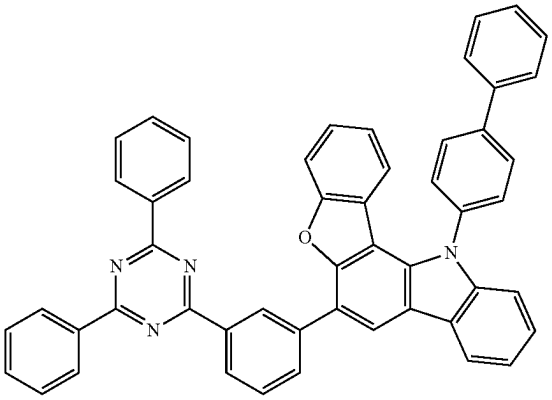

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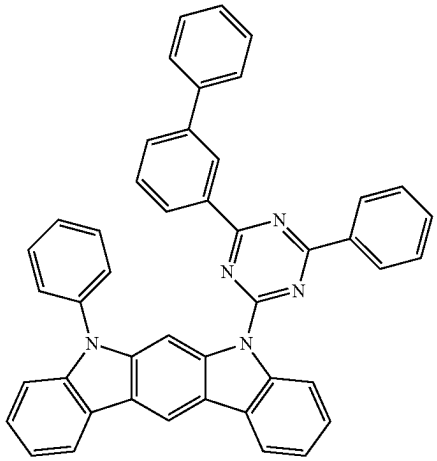

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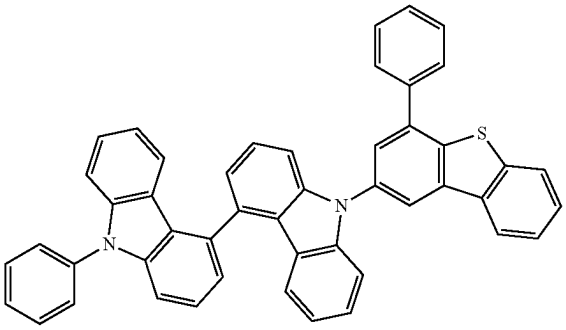

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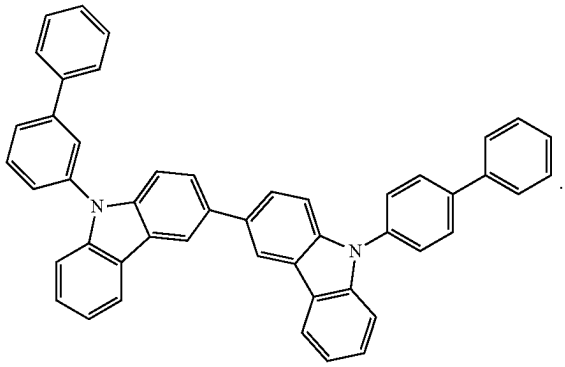


[Phosphorescent Dopant]

[0440] In embodiments, the phosphorescent dopant may include at least one transition metal as a central metal.

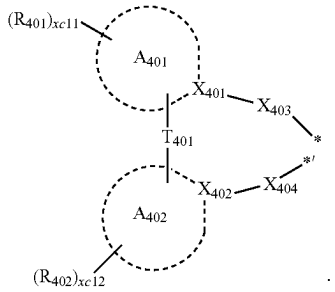
[0441] The phosphorescent dopant may include a monodentate ligand, a bidentate ligand, a tridentate ligand, a tetradentate ligand, a pentadentate ligand, a hexadentate ligand, or any combination thereof.

[0442] The phosphorescent dopant may be electrically neutral.

[0443] In an embodiment, the phosphorescent dopant may include an organometallic compound represented by Formula 401:

$$M(L_{401})_{xc1}(L_{402})_{xc2} \quad \text{[Formula 401]}$$

[Formula 402]



[0444] In Formulae 401 and 402,

[0445] M may be a transition metal (for example, iridium (Ir), platinum (Pt), palladium (Pd), osmium (Os), titanium (Ti), gold (Au), hafnium (Hf), europium (Eu), terbium (Tb), rhodium (Rh), rhenium (Re), or thulium (Tm)),

[0446] L_{401} may be a ligand represented by Formula 402, and xc1 may be 1, 2, or 3, wherein when xc1 is two or more, two or more of L_{401} may be identical to or different from each other,

[0447] L_{402} may be an organic ligand, and xc2 may be 0, 1, 2, 3, or 4, wherein when xc2 is 2 or more, two or more of L_{402} may be identical to or different from each other,

[0448] X_{401} and X_{402} may each independently be nitrogen or carbon,

[0449] ring A_{401} and ring A_{402} may each independently be a C_3-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group,

[0450] T_{401} may be a single bond, *—O—**, *—S—*', *—C(═O)—**, *—N(Q_{411})—**, *—C(Q_{411})(Q_{412})—*, *—C(Q_{411})═C(Q_{412})—*, *—C(Q_{411})═*, or *═C═*,

[0451] X_{403} and X_{404} may each independently be a chemical bond (for example, a covalent bond or a coordination bond), O, S, N (Q_{413}), B(Q_{413}), P(Q_{413}), C(Q_{413})(Q_{414}), or Si(Q_{413})(Q_{414}),

[0452] Q_{411} to Q_{414} may each independently be the same as described with respect to Q_1,

[0453] R_{401} and R_{402} may each independently be hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{20} alkoxy group unsubstituted or substituted with at least one R_{10a}, a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}, —Si(Q_{401})(Q_{402})(Q_{403}), —N(Q_{401})(Q_{402}), —B(Q_{401})(Q_{402}), —C(═O)(Q_{401}), —S(═O)$_2$(Q_{401}), or —P(═O)(Q_{401})(Q_{402}),

[0454] Q_{401} to Q_{403} may each independently be the same as described with respect to Q_1,

[0455] xc11 and xc12 may each independently be an integer from 0 to 10, and

[0456] * and *' in Formula 402 each indicate a binding site to M in Formula 401.

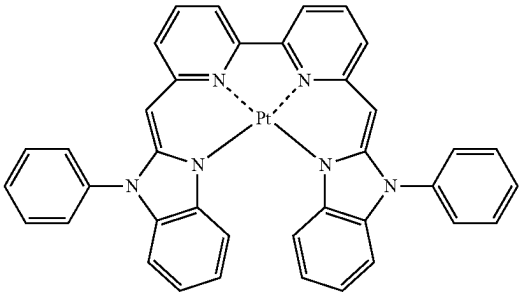
[0457] For example, in Formula 402, X_{401} may be nitrogen and X_{402} may be carbon, or X_{401} and X_{402} may each be nitrogen.

[0458] In an embodiment, in Formula 401, when xc1 is 2 or more, two ring A_{401} among two or more of L_{401} may optionally be bonded to each other via T_{402}, which is a linking group, and two ring A_{402} among two or more of L_{401} may optionally be bonded to each other via T_{403}, which is a linking group (see Compounds PD1 to PD4 and PD7). T_{402} and T_{403} may each independently be the same as described with respect to T_{401}.

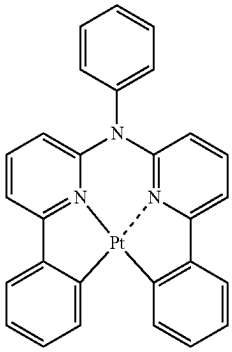
[0459] In Formula 401, L_{402} may be an organic ligand. For example, L_{402} may include a halogen group, a diketone group (for example, an acetylacetonate group), a carboxylic acid group (for example, a picolinate group), —C(═O), an isonitrile group, —CN group, a phosphorus group (for example, a phosphine group, a phosphite group, etc.), or any combination thereof.

[0460] In an embodiment, the phosphorescent dopant may include, for example, one of Compounds PD1 to PD39, or any combination thereof:

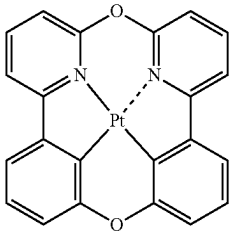
PD1



PD2



PD3



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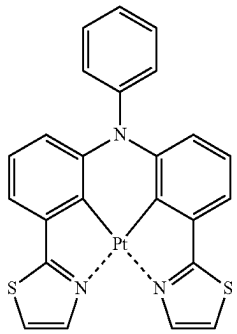
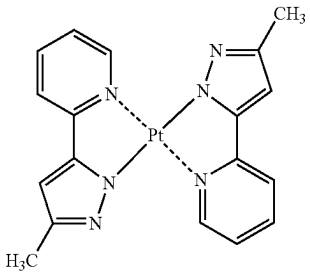
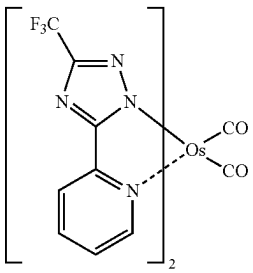
PD4



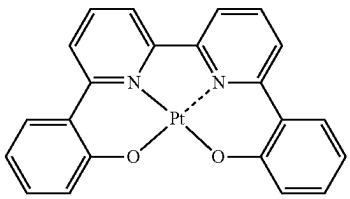
PD5



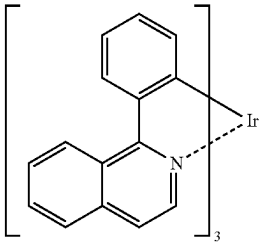
PD6



PD7



PD8



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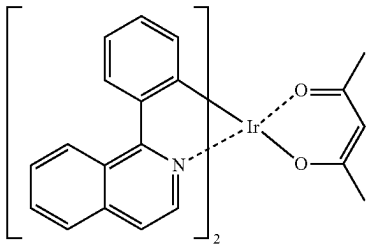
PD9



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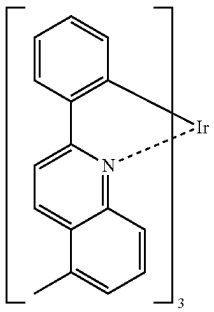

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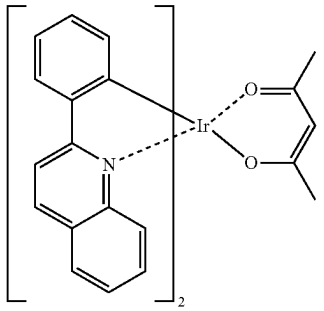

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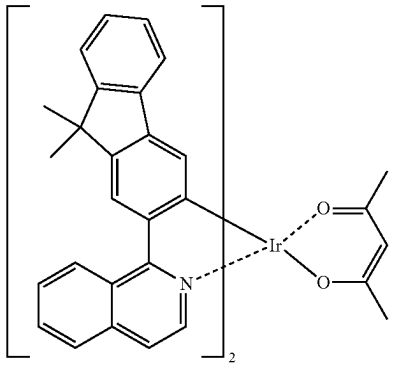

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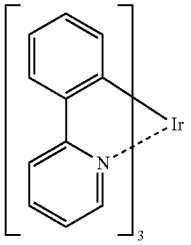

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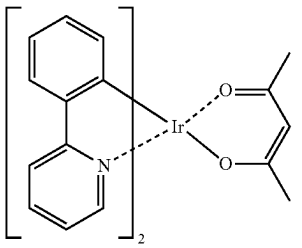

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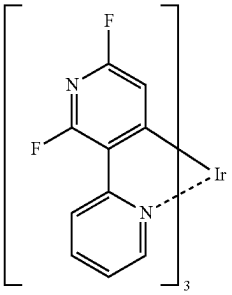
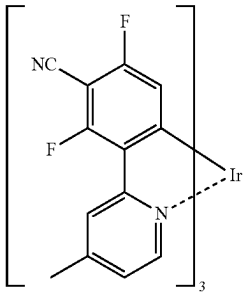


PD16



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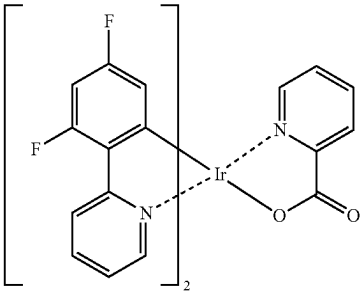

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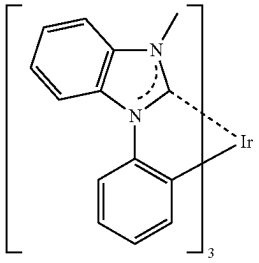

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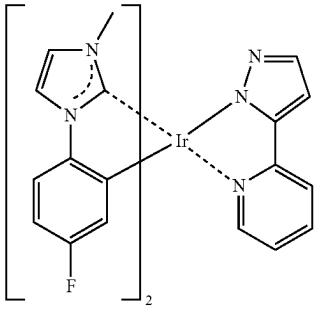
PD19



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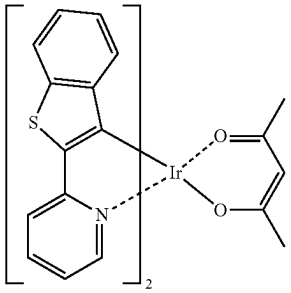
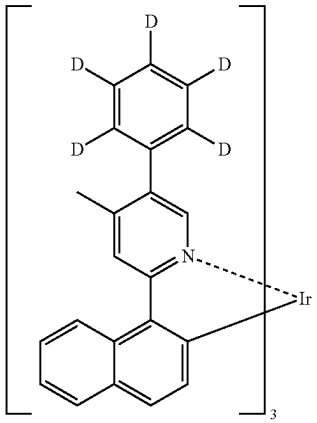


PD21



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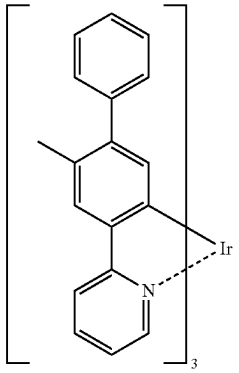

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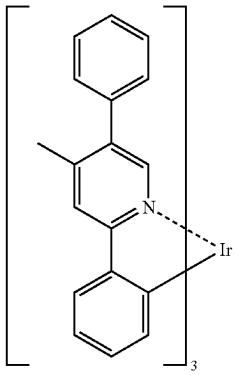

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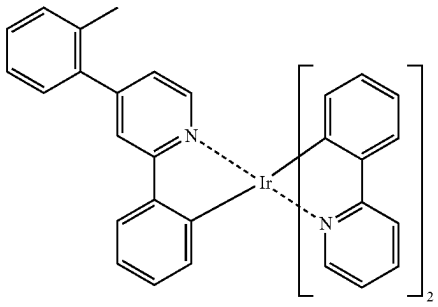

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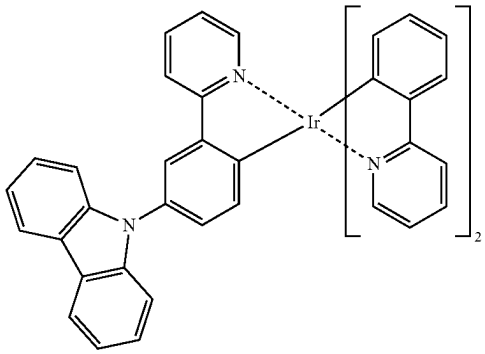

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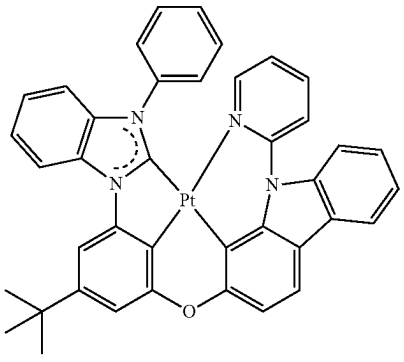

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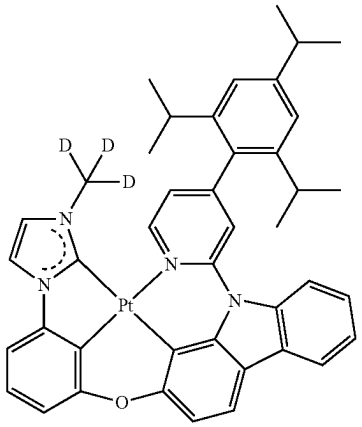

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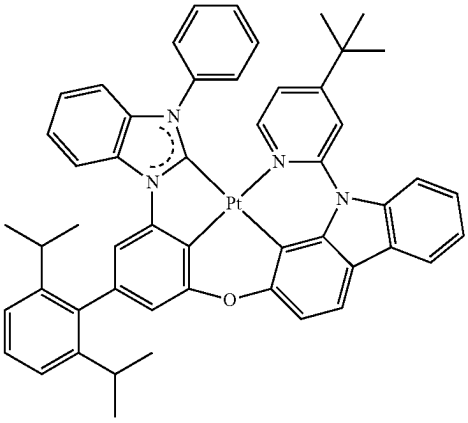

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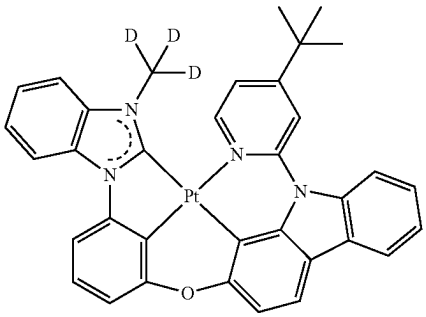

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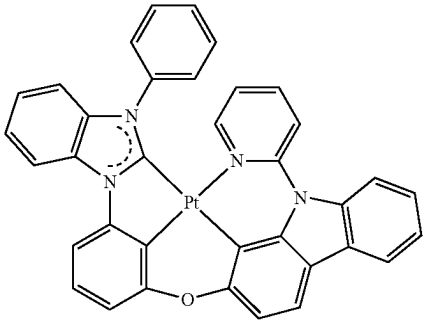

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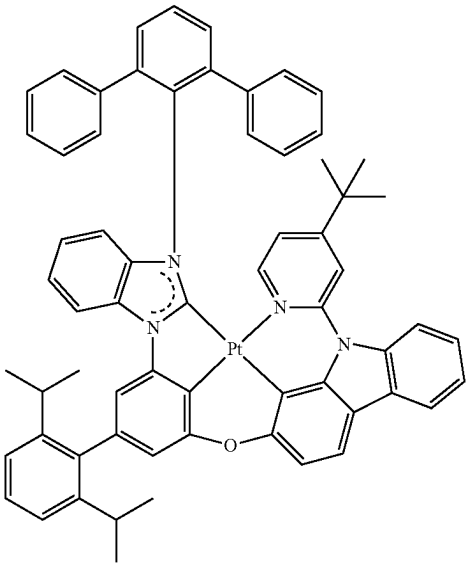

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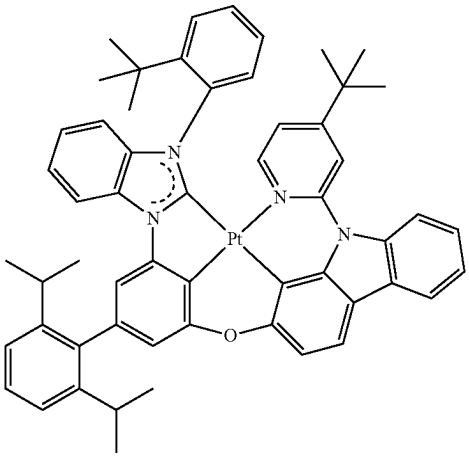

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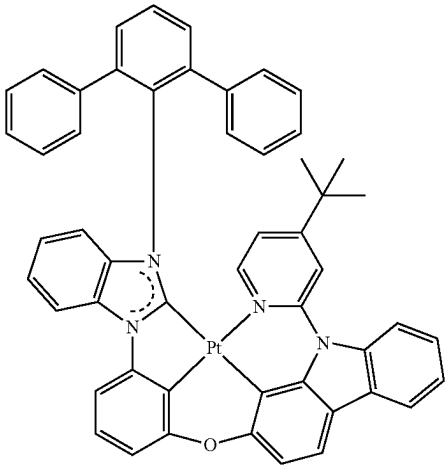

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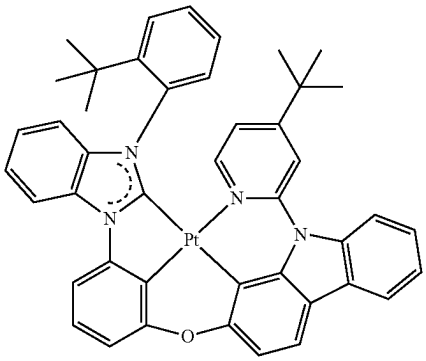

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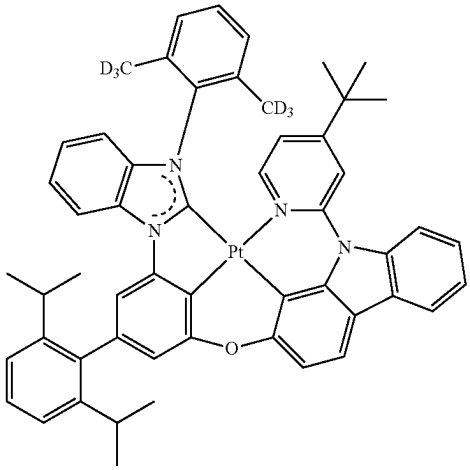

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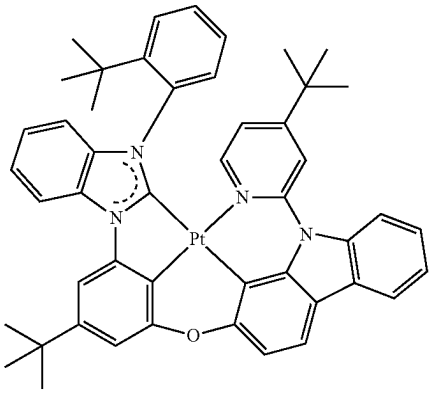

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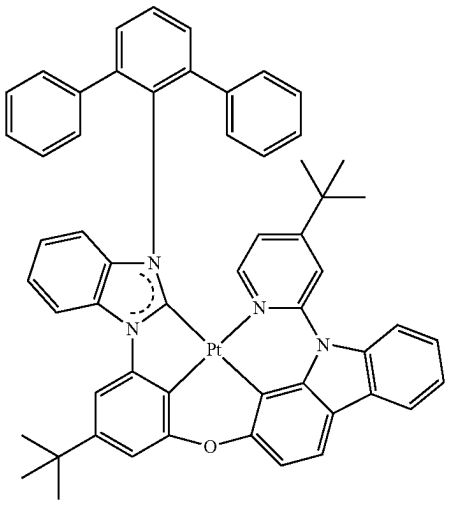

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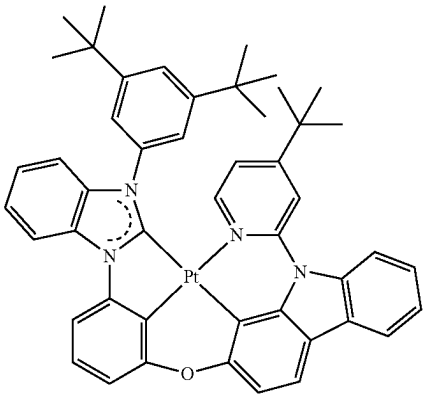

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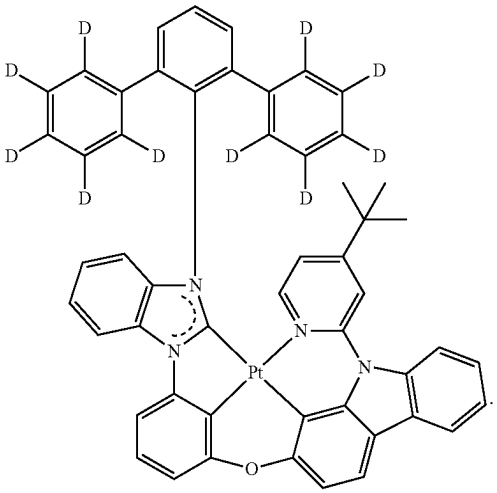
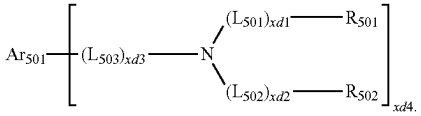


[Fluorescent Dopant]

[0461] The fluorescent dopant may include an amine group-containing compound, a styryl group-containing compound, or any combination thereof.

[0462] In an embodiment, the fluorescent dopant may include a compound represented by Formula 501:

[Formula 501]



[0463] In Formula 501,

[0464] Ar_{501}, L_{501} to L_{503}, R_{501}, and R_{502} may each independently be a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a} or a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a},

[0465] xd1 to xd3 may each independently be 0, 1, 2, or 3, and

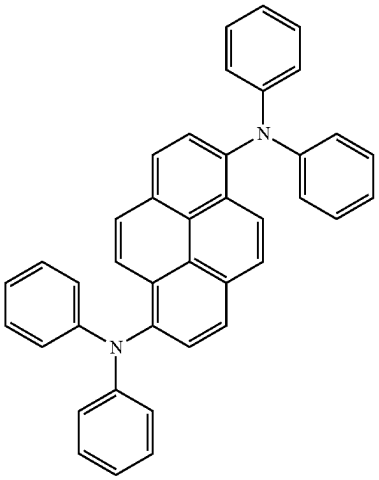
[0466] xd4 may be 1, 2, 3, 4, 5, or 6.

[0467] In an embodiment, in Formula 501, Ar_{501} may be a condensed cyclic group (for example, an anthracene group, a chrysene group, or a pyrene group) in which three or more monocyclic groups are condensed together.

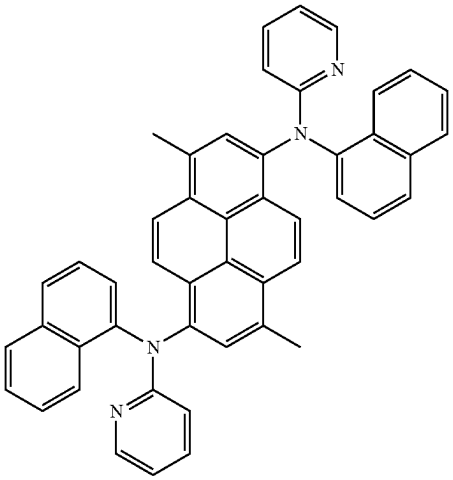
[0468] In embodiments, in Formula 501, xd4 may be 2.

[0469] In an embodiment, the fluorescent dopant may include: one of Compounds FD1 to FD37; DPVBi; DPAVBi; or any combination thereof:

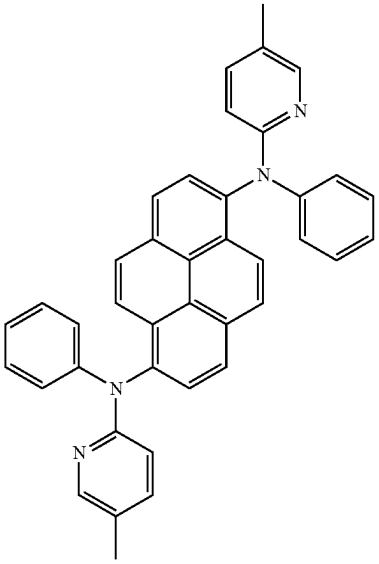
FD1



FD2



FD3



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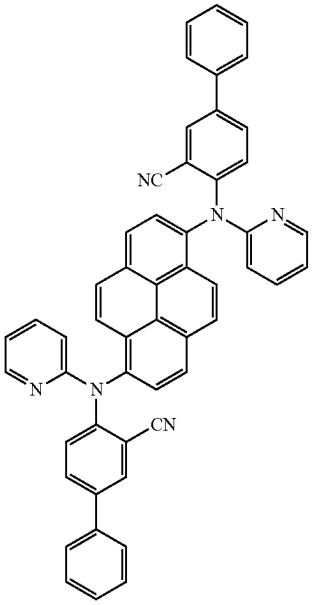
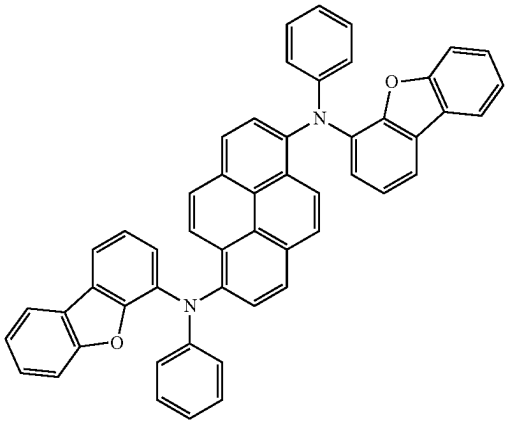


FD5



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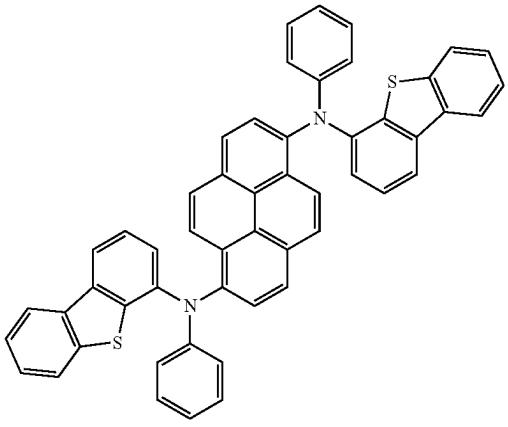

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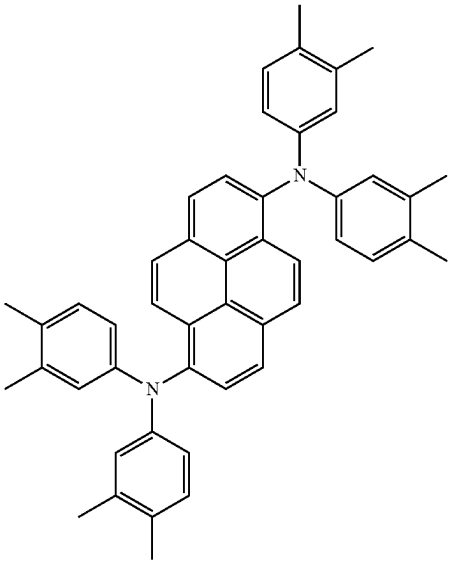

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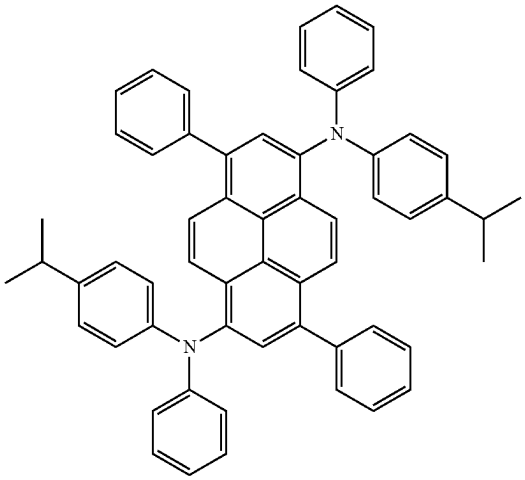

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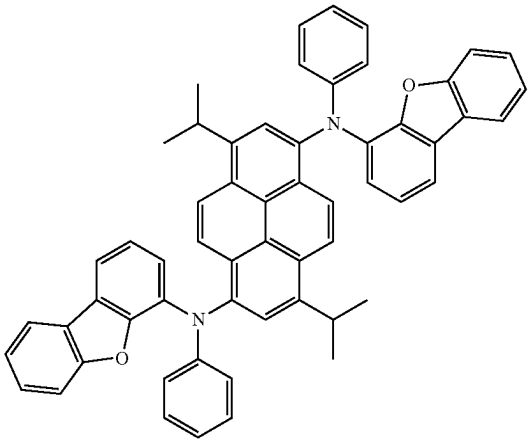

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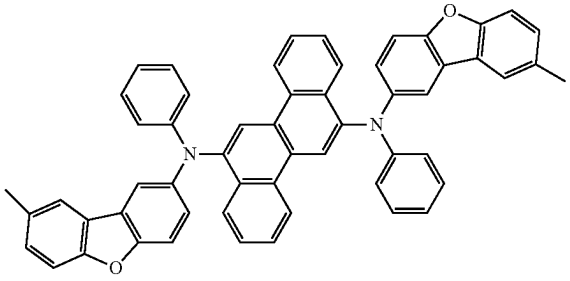

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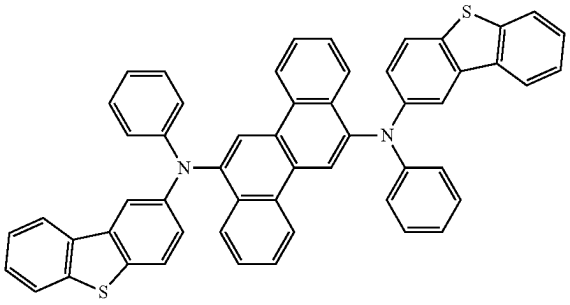

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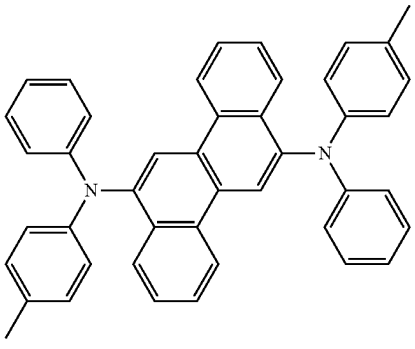

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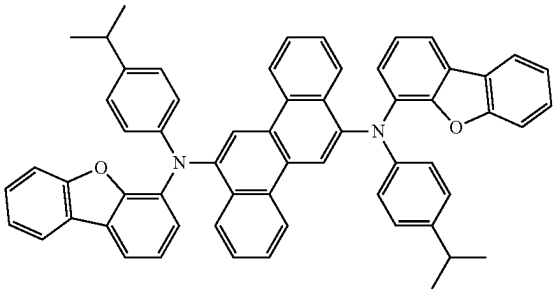

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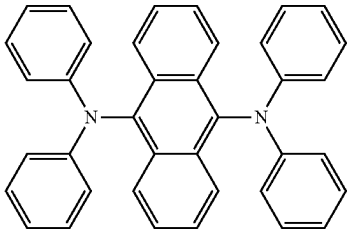

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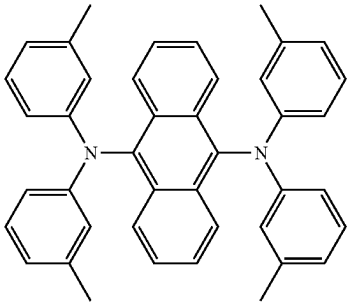

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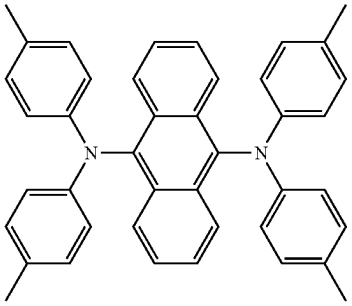

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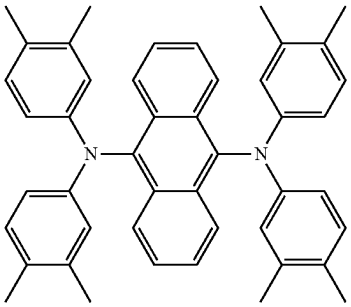

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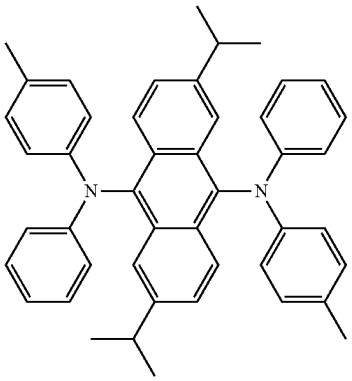

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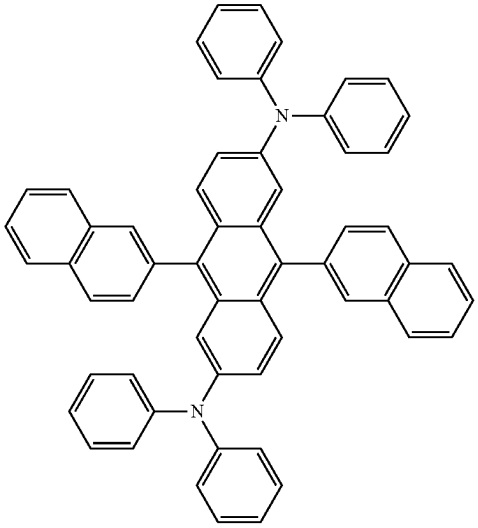

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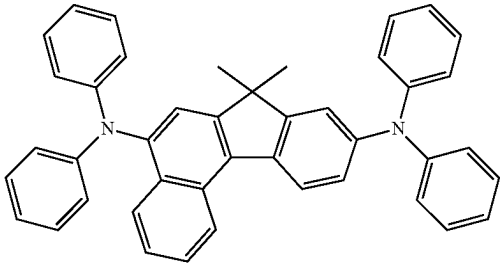

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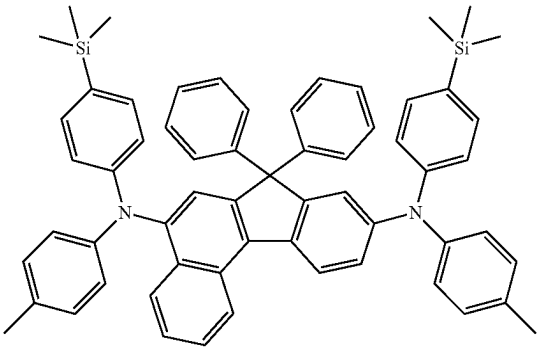

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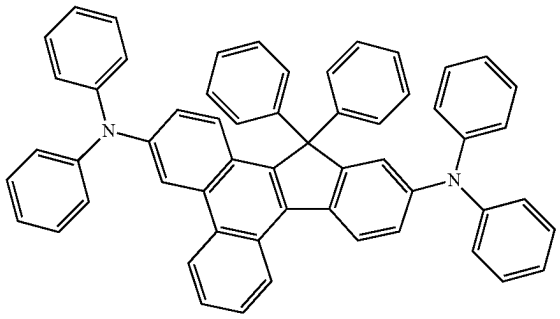

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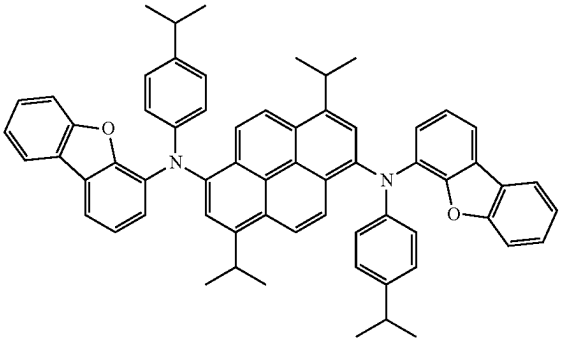

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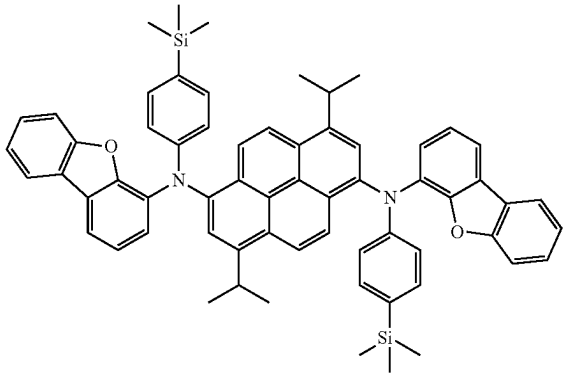

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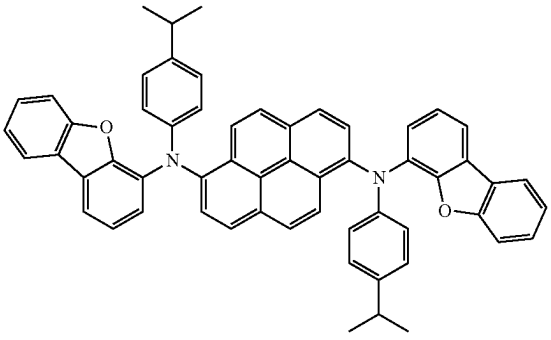

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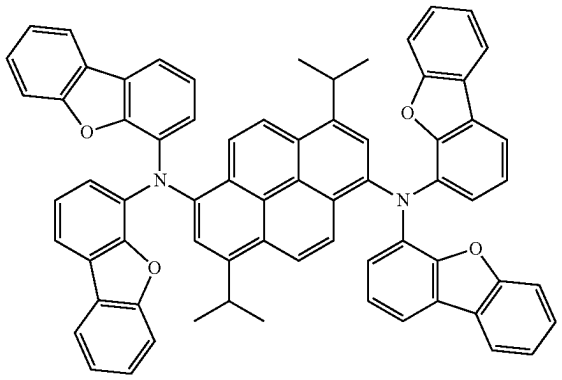

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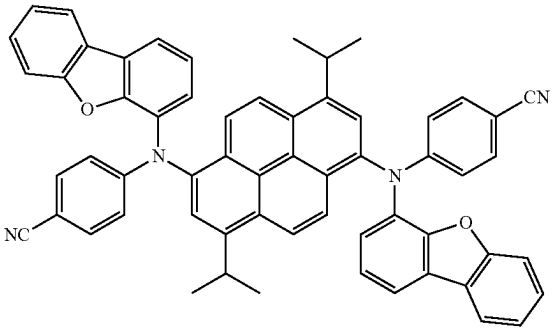

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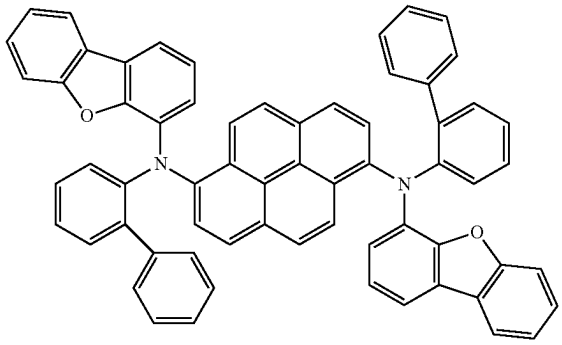

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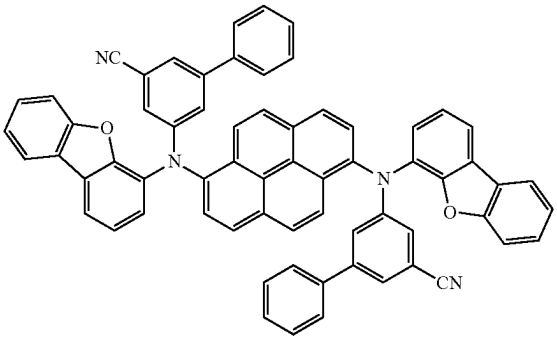

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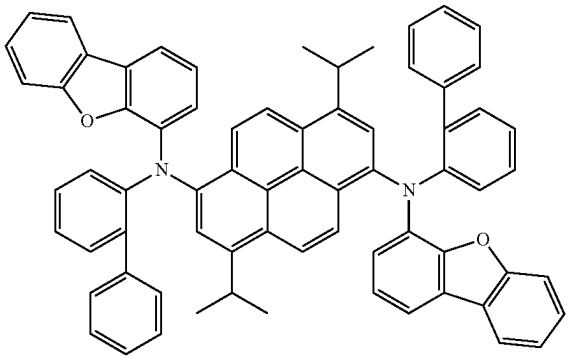

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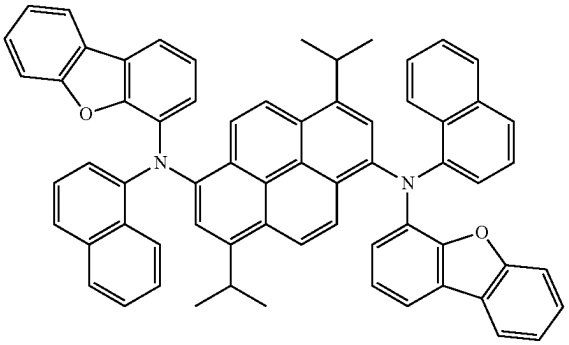

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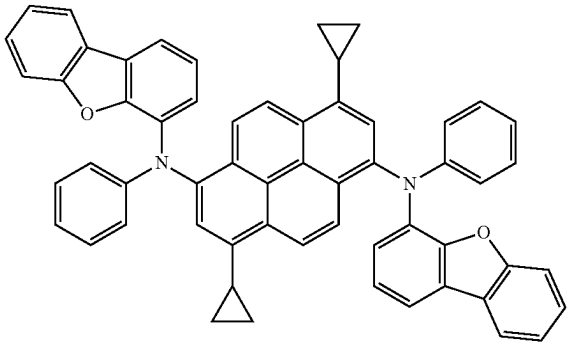

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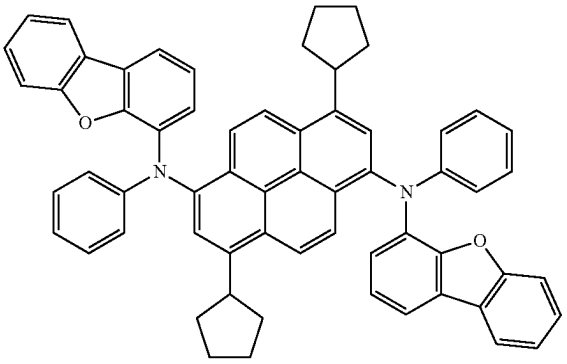

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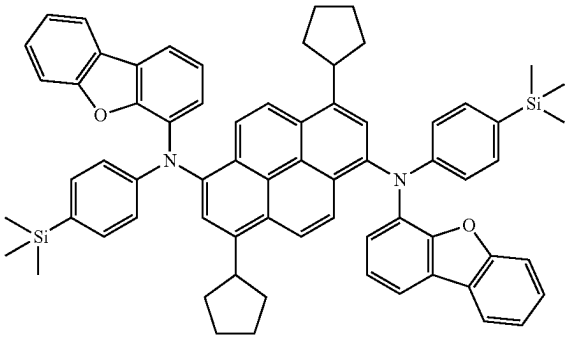

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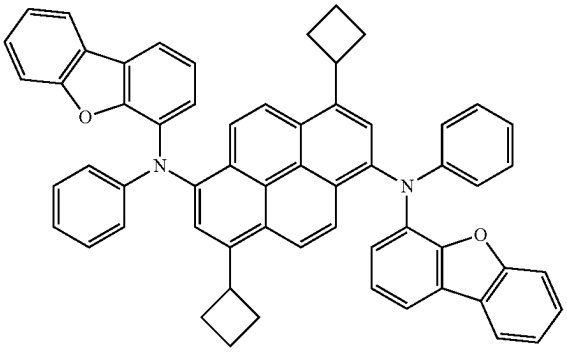

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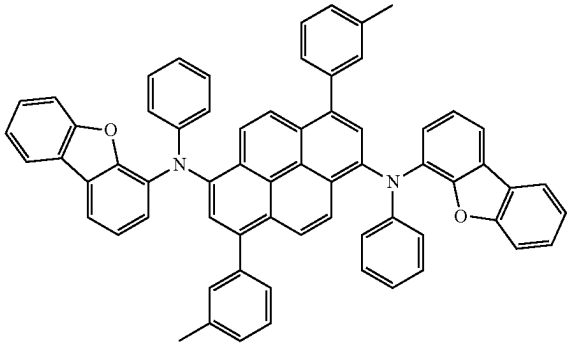

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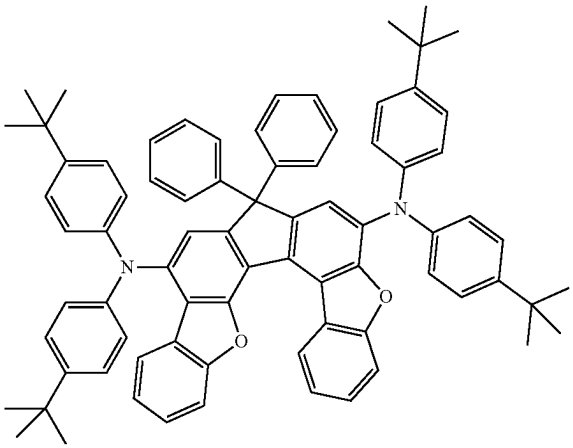
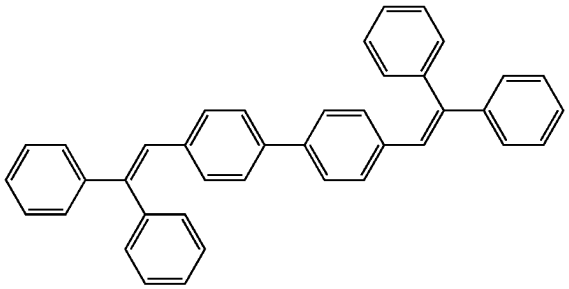
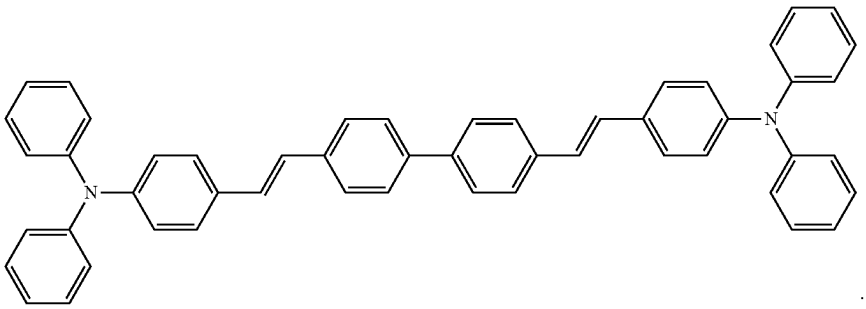
FD37





DPVBi



DPAVBi

[Delayed Fluorescence Material]

[0470] The emission layer may include a delayed fluorescence material.

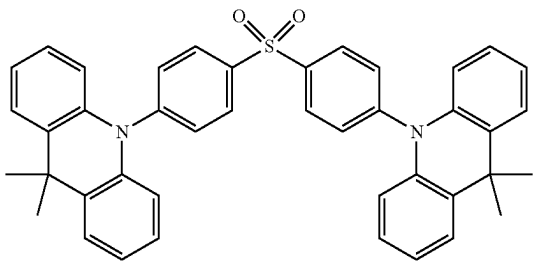
[0471] In the specification, a delayed fluorescence material may be any compound that is capable of emitting delayed fluorescence, based on a delayed fluorescence emission mechanism.

[0472] The delayed fluorescence material included in the emission layer may serve as a host or as a dopant, depending on the types of other materials included in the emission layer.

[0473] In an embodiment, a difference between a triplet energy level (eV) of the delayed fluorescence material and a singlet energy level (eV) of the delayed fluorescence material may be at least 0 eV but not more than 0.5 eV. When a difference between the triplet energy level (eV) of the delayed fluorescence material and the singlet energy level (eV) of the delayed fluorescence material is within the range described above, up-conversion from a triplet state to a singlet state of the delayed fluorescence material may effectively occur, and thus, the light-emitting device **10** may have improved luminescence efficiency.

[0474] In an embodiment, the delayed fluorescence material may include: a material including at least one electron donor (for example, a π electron-rich C_3-C_{60} cyclic group, such as a carbazole group) and at least one electron acceptor (for example, a sulfoxide group, a cyano group, or a π electron-deficient nitrogen-containing C_1-C_{60} cyclic group); or a material including a C_8-C_{60} polycyclic group in which two or more cyclic groups are condensed while sharing boron (B).

[0475] In an embodiment, the delayed fluorescence material may include at least one of Compounds DF1 to DF14:



DF1(DMAC-DPS)

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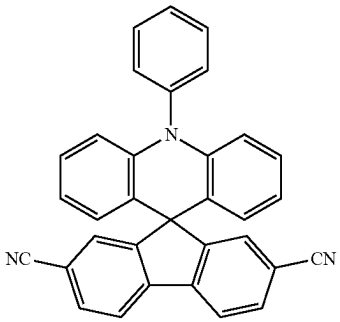
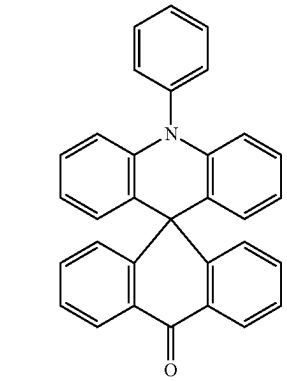
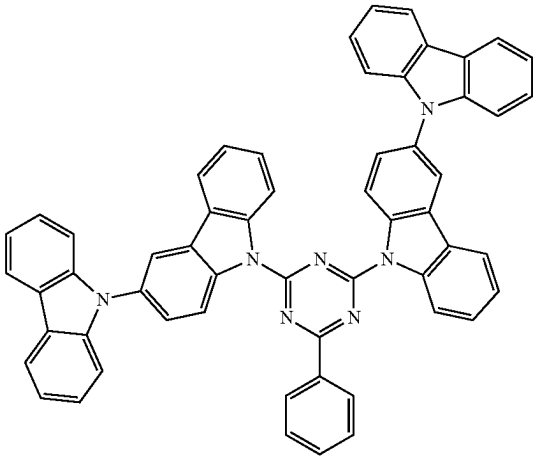


DF2(ACRFLCN)



DF3(ACRSA)



DF4(CC2TA)

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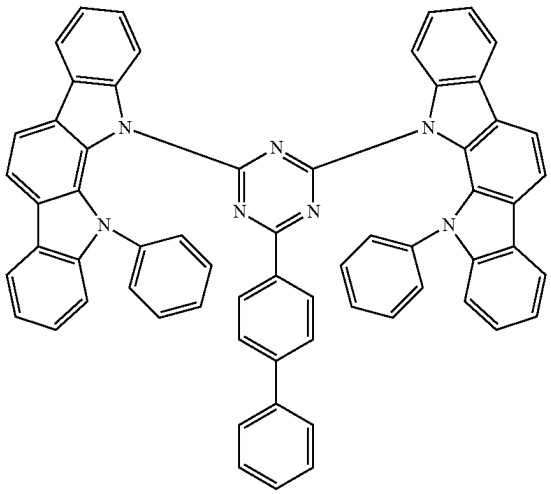
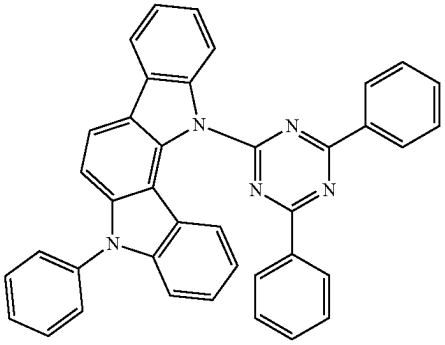


DF5(PIC-TRZ)



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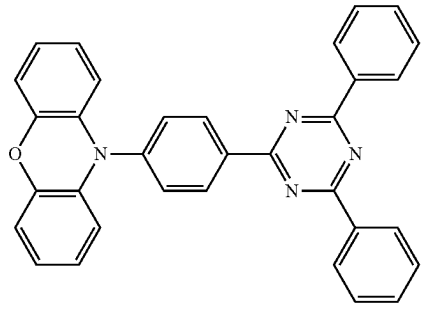
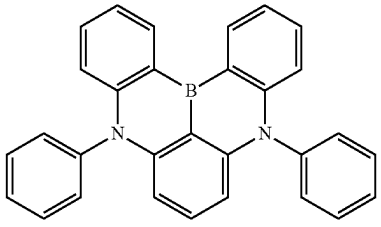


DF7(PXZ-TRZ)



DF8(DABNA-1)

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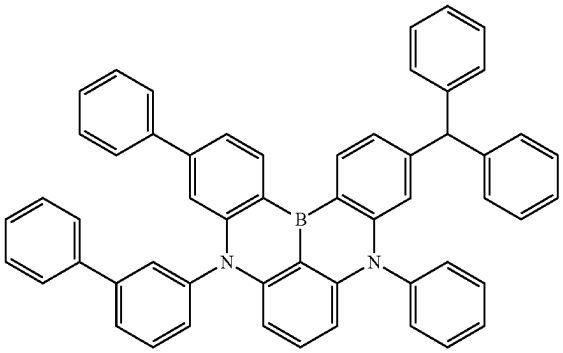
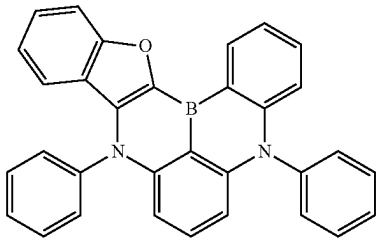
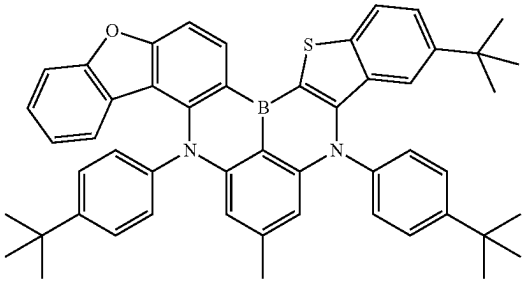


DF9(DABNA-2)



DF10



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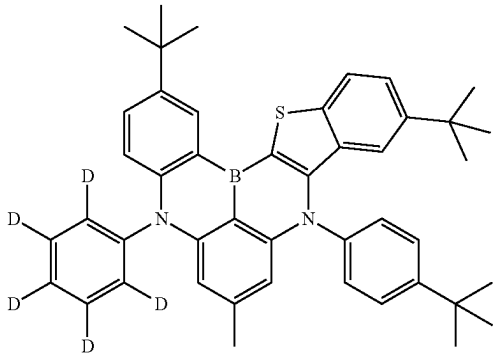

DF12

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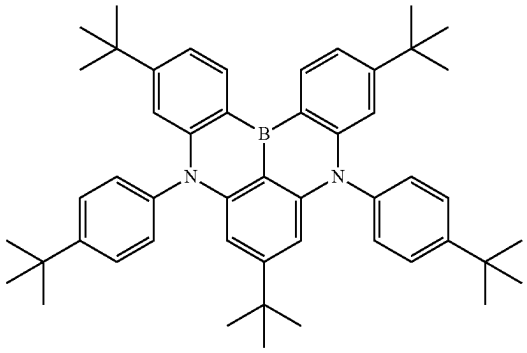
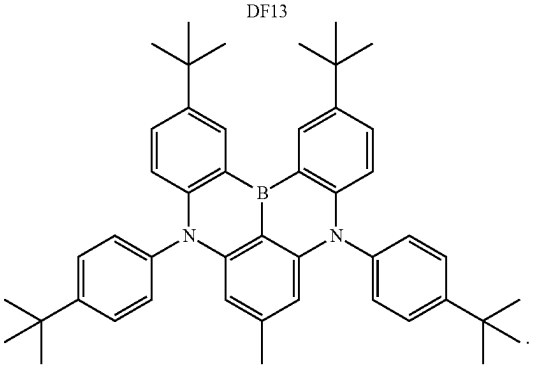


DF13



DF14

[Quantum Dot]

[0476] The emission layer may include a quantum dot.

[0477] In the specification, a quantum dot may be a crystal of a semiconductor compound, and may include any material capable of emitting light of various emission wavelengths according to a size of the crystal.

[0478] A diameter of a quantum dot may be, for example, in a range of about 1 nm to about 10 nm.

[0479] The quantum dot may be synthesized by a wet chemical process, a metal organic chemical vapor deposition process, a molecular beam epitaxy process, or any process similar thereto.

[0480] The wet chemical process is a method that includes mixing a precursor material with an organic solvent and growing a quantum dot particle crystal. When the crystal grows, the organic solvent naturally serves as a dispersant coordinated on the surface of the quantum dot crystal and controls the growth of the crystal so that the growth of quantum dot particles can be controlled through a process which costs less, and may be more readily performed than vapor deposition methods, such as metal organic chemical vapor deposition (MOCVD) or molecular beam epitaxy (MBE),

[0481] A quantum dot may include a Group II-VI semiconductor compound, a Group III-V semiconductor compound, a Group III-VI semiconductor compound, a Group I-III-VI semiconductor compound, a Group IV-VI semiconductor compound, a Group IV element or compound, or any combination thereof.

[0482] Examples of a Group II-VI semiconductor compound may include: a binary compound, such as CdS, CdSe, CdTe, ZnS, ZnSe, ZnTe, ZnO, HgS, HgSe, HgTe, MgSe, or MgS; a ternary compound, such as CdSeS, CdSeTe, CdSTe, ZnSeS, ZnSeTe, ZnSTe, HgSeS, HgSeTe, HgSTe, CdZnS, CdZnSe, CdZnTe, CdHgS, CdHgSe, CdHgTe, HgZnS, HgZnSe, HgZnTe, MgZnSe, or MgZnS; a quaternary compound, such as CdZnSeS, CdZnSeTe, CdZnSTe, CdHgSeS, CdHgSeTe, CdHgSTe, HgZnSeS, HgZnSeTe, or HgZnSTe; and any combination thereof.

[0483] Examples of a Group III-V semiconductor compound may include: a binary compound, such as GaN, GaP, GaAs, GaSb, AlN, AlP, AlAs, AlSb, InN, InP, InAs, or InSb; a ternary compound, such as GaNP, GaNAs, GaNSb, GaPAs, GaPSb, AlNP, AlNAs, AlNSb, AlPAs, AlPSb, InGaP, InNP, InAlP, InNAs, InNSb, InPAs, or InPSb; a quaternary compound, such as GaAlNP, GaAlNAs, GaAlNSb, GaAlPAs, GaAlPSb, GaInNP, GaInNAs, GaInNSb, GaInPAs, GaInPSb, InAlNP, InAlNAs, InAlNSb, InAlPAs, or InAlPSb; and any combination thereof. In an embodiment, a Group III-V semiconductor compound may further include a Group II element. Examples of a Group III-V semiconductor compound further including a Group II element may include InZnP, InGaZnP, InAlZnP, etc.

[0484] Examples of a Group III-VI semiconductor compound may include: a binary compound, such as GaS, GaSe, GazSes, GaTe, InS, InSe, In_2S_3, In_2Se_3, or InTe; a ternary compound, such as $InGaS_3$ or $InGaSe_3$; and any combination thereof.

[0485] Examples of a Group I-III-VI semiconductor compound may include: a ternary compound, such as AgInS, $AgInS_2$, CuInS, $CuInS_2$, $CuGaO_2$, $AgGaO_2$, or $AgAlO_2$; and any combination thereof.

[0486] Examples of a Group IV-VI semiconductor compound may include: a binary compound, such as SnS, SnSe, SnTe, PbS, PbSe, or PbTe; a ternary compound, such as SnSeS, SnSeTe, SnSTe, PbSeS, PbSeTe, PbSTe, SnPbS, SnPbSe, or SnPbTe; a quaternary compound, such as SnPbSSe, SnPbSeTe, or SnPbSTe; and any combination thereof.

[0487] Examples of a Group IV element or compound may include: a single element material, such as Si or Ge; a binary compound, such as SiC or SiGe; and any combination thereof.

[0488] Each element included in a compound, such as a binary compound, a ternary compound, or a quaternary compound, may be present in a particle at a uniform concentration or at a non-uniform concentration.

[0489] In an embodiment, a quantum dot may have a single structure in which the concentration of each element in the quantum dot is uniform, or a quantum dot may have a core-shell structure. For example, when a quantum dot has a core-shell structure, a material included in the core and a material included in the shell may be different from each other.

[0490] The shell of a quantum dot may serve as a protective layer that prevents chemical degeneration of the core to maintain semiconductor characteristics, and/or may serve as a charging layer that imparts electrophoretic characteristics to the quantum dot. The shell may be single-layered or multilayered. An interface between the core and the shell may have a concentration gradient in which the concentration of an element that is present in the shell decreases toward the core.

[0491] A shell of a quantum dot may include a metal oxide, a metalloid oxide, a non-metal oxide, a semiconductor compound, or any combination thereof. Examples of a metal oxide, a metalloid oxide, or a non-metal oxide may include: a binary compound, such as SiO_2, Al_2O_3, TiO_2, ZnO, MnO, Mn_2O_3, Mn_3O_4, CuO, FeO, Fe_2O_3, Fe_3O_4, CoO, Co_3O_4, or NiO; a ternary compound, such as $MgAl_2O_4$, $CoFe_2O_4$, $NiFe_2O_4$, or $CoMn_2O_4$; and any combination thereof.

[0492] Examples of a semiconductor compound may include, as described herein: a Group II-VI semiconductor compound; a Group III-V semiconductor compound; a Group III-VI semiconductor compound; a Group I-III-VI semiconductor compound; a Group IV-VI semiconductor compound; and any combination thereof. For example, the semiconductor compound may include CdS, CdSe, CdTe, ZnS, ZnSe, ZnTe, ZnSeS, ZnTeS, GaAs, GaP, GaSb, HgS, HgSe, HgTe, InAs, InP, InGaP, InSb, AlAs, AlP, AlSb, or any combination thereof.

[0493] A full width at half maximum (FWHM) of an emission spectrum of a quantum dot may be equal to or less than about 45 nm. For example, a FWHM of an emission spectrum of a quantum dot may be equal to or less than about 40 nm. For example, a FWHM of an emission spectrum of a quantum dot may be equal to or less than about 30 nm. Within these ranges, color purity or color reproducibility may be increased. Light emitted through a quantum dot may be emitted in all directions, so that a wide viewing angle may be improved.

[0494] In embodiments, a quantum dot may be in the form of a spherical particle, a pyramidal particle, a multi-arm particle, a cubic nanoparticle, a nanotube particle, a nanowire particle, a nanofiber particle, or a nanoplate particle.

[0495] Since an energy band gap may be adjusted by controlling a size of the quantum dot, light having various wavelength bands may be obtained from a quantum dot emission layer. Accordingly, by using quantum dots of different sizes, a light-emitting device that emits light of various wavelengths may be implemented. In embodiments, the size of the quantum dot may be adjusted to emit red light, green light, and/or blue light. In an embodiments, the size of the quantum dot may be configured to emit white light by a combination of light of various colors.

[Electron Transport Region in Interlayer **130**]

[0496] The electron transport region may have a structure consisting of a layer consisting of a single material, a structure consisting of a layer including different materials, or a structure including multiple layers including different materials.

[0497] The electron transport region may include a buffer layer, a hole blocking layer, an electron control layer, an electron transport layer, an electron injection layer, or any combination thereof.

[0498] In embodiments, the electron transport region may have an electron transport layer/electron injection layer structure, a hole blocking layer/electron transport layer/electron injection layer structure, an electron control layer/electron transport layer/electron injection layer structure, or a buffer layer/electron transport layer/electron injection

layer structure, wherein the layers of each structure may be stacked from an emission layer in its respective stated order, but the structure of the electron transport region is not limited thereto.

[0499] In an embodiment, the electron transport region (for example, a buffer layer, a hole blocking layer, an electron control layer, or an electron transport layer in the electron transport region) may include a metal-free compound including at least one IT electron-deficient nitrogen-containing C_1-C_{60} cyclic group.

[0500] In an embodiment, the electron transport region may include a compound represented by Formula 601:

$$[Ar_{601}]xe_{11}\text{-}[(L_{601})_{xe1}\text{-}R_{601}]_{xe21} \quad \text{[Formula 601]}$$

[0501] In Formula 601,

[0502] Ar_{601} and L_{601} may each independently be a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a} or a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a},

[0503] xe11 may be 1, 2, or 3,

[0504] xe1 may be 0, 1, 2, 3, 4, or 5,

[0505] R_{601} may be a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}, —$Si(Q_{601})(Q_{602})(Q_{603})$, —$C(=O)(Q_{601})$, —$S(=O)_2(Q_{601})$, or —$P(=O)(Q_{601})(Q_{602})$,

[0506] Q_{601} to Q_{603} may each independently be the same as described with respect to Q_1,

[0507] xe21 may be 1, 2, 3, 4, or 5, and

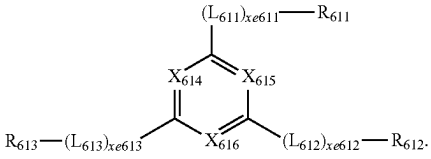
[0508] at least one of Ar_{601}, L_{601}, and R_{601} may each independently be a IT electron-deficient nitrogen-containing C_1-C_{60} cyclic group unsubstituted or substituted with at least one R_{10a}.

[0509] In an embodiment, in Formula 601, when xe11 is 2 or more, two or more of Ar_{601} may be linked to each other via a single bond.

[0510] In embodiments, in Formula 601, Ar_{601} may be an anthracene group unsubstituted or substituted with at least one R_{10a}.

[0511] In embodiments, the electron transport region may include a compound represented by Formula 601-1:

[Formula 601-1]



[0512] In Formula 601-1,

[0513] X_{614} may be N or $C(R_{614})$, X_{615} may be N or $C(R_{615})$, X_{616} may be N or $C(R_{616})$, and at least one of X_{614} to X_{616} may each be N,

[0514] L_{611} to L_{613} may each independently be the same as described with respect to L_{601},

[0515] xe611 to xe613 may each independently be the same as described with respect to xe1,

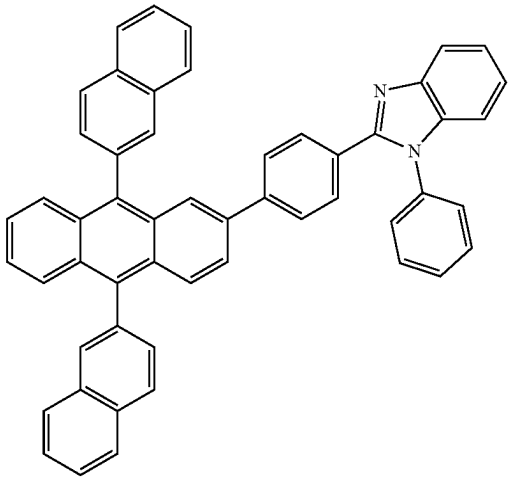
[0516] R_{611} to R_{613} may each independently be the same as described with respect to R_{601}, and

[0517] R_{614} to R_{616} may each independently be hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, or a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}.

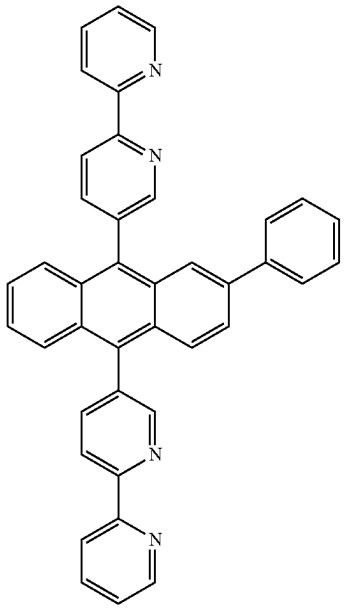
[0518] In an embodiment, in Formulae 601 and 601-1, xe1 and xe611 to xe613 may each independently be 0, 1, or 2.

[0519] In an embodiment, the electron transport region may include one of Compounds ET1 to ET45, 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP), 4,7-diphenyl-1,10-phenanthroline (Bphen), Alq_3, BAlq, TAZ, NTAZ, or any combination thereof:

ET1



ET2



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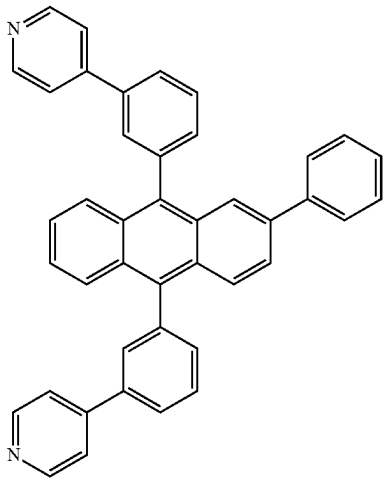
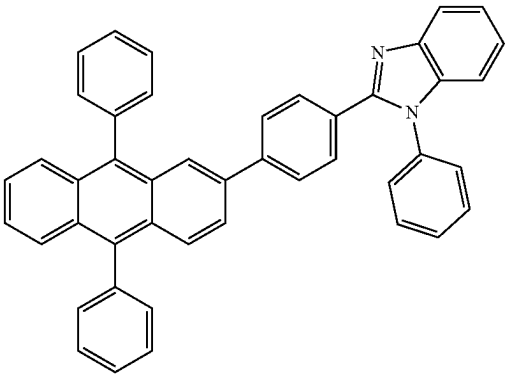
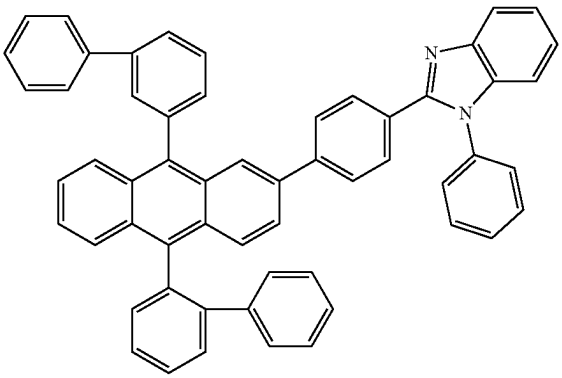
ET3



ET4



ET5



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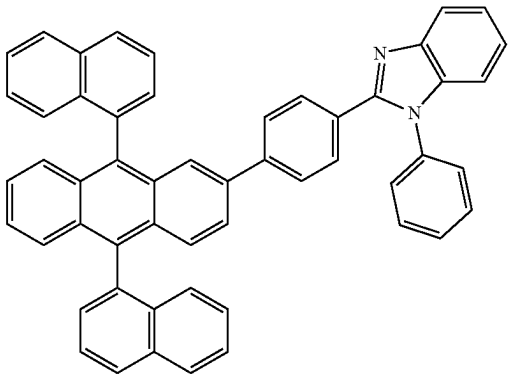
ET6



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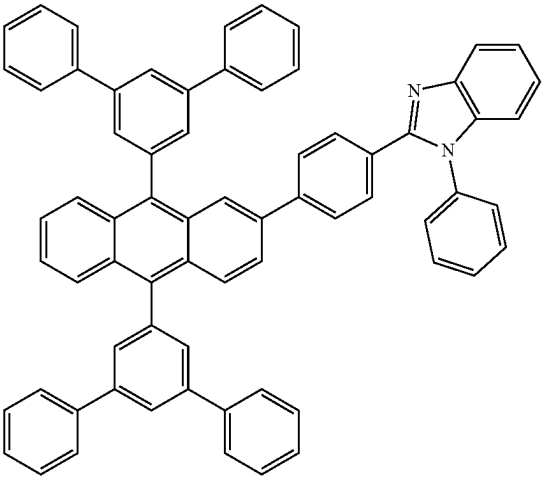

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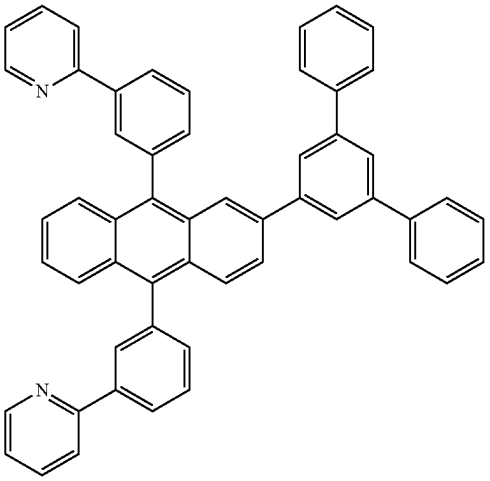

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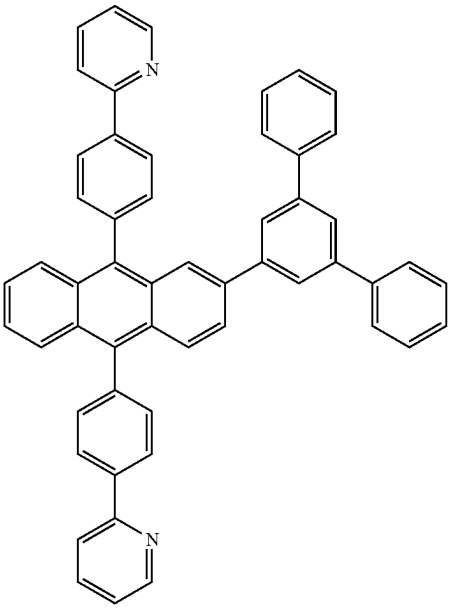
ET9



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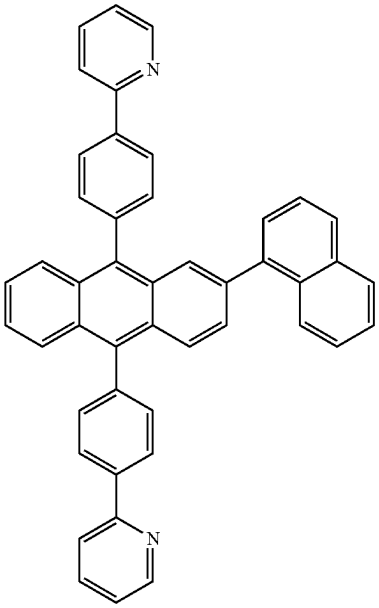

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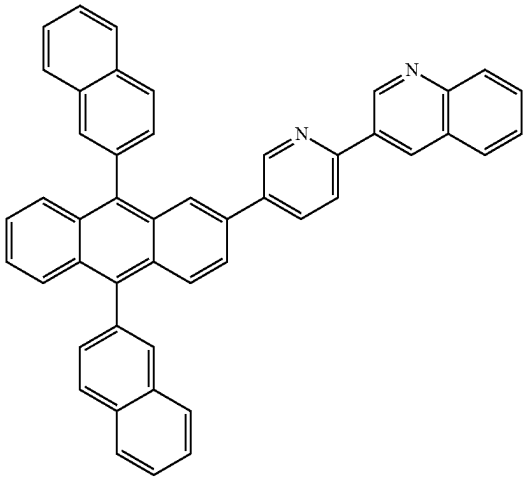
ET11



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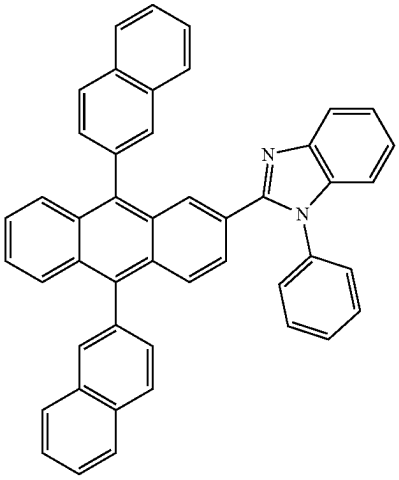

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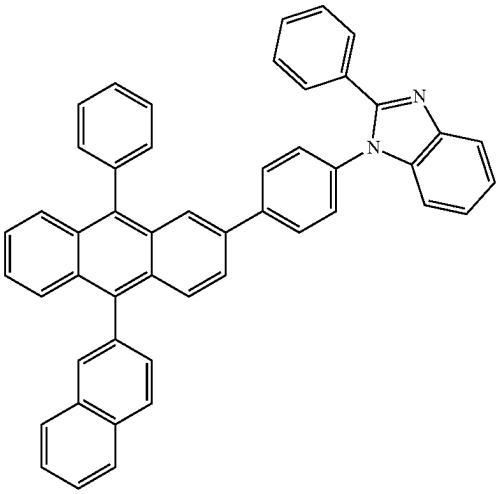

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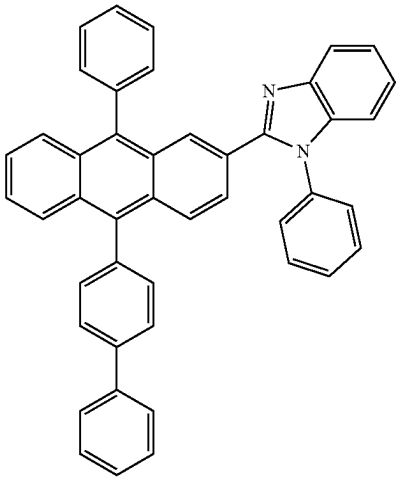
ET14



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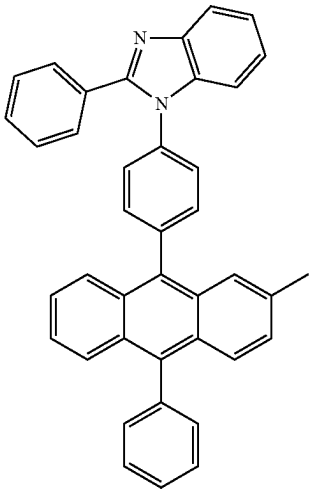

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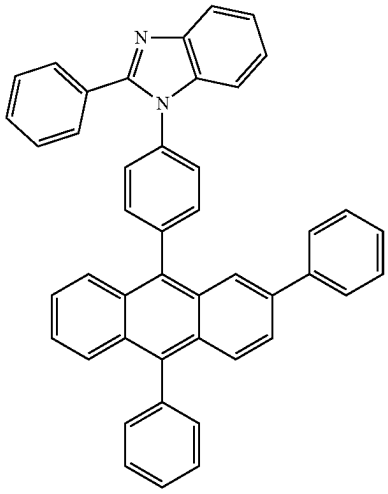

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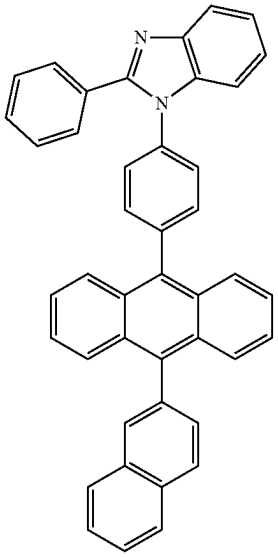
ET17



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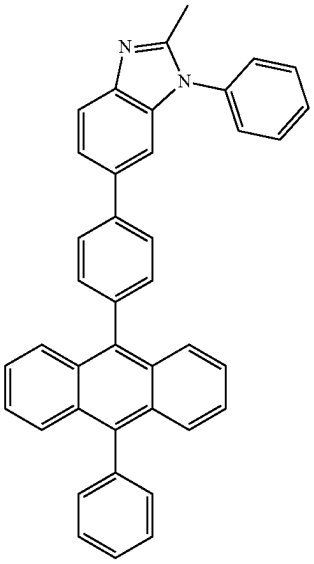

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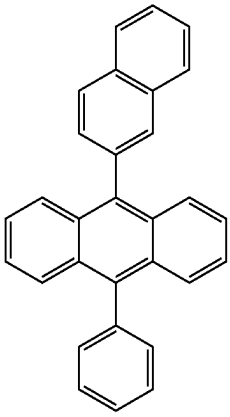

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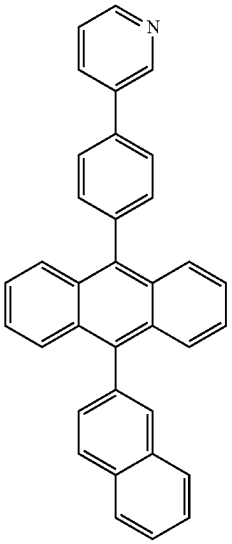

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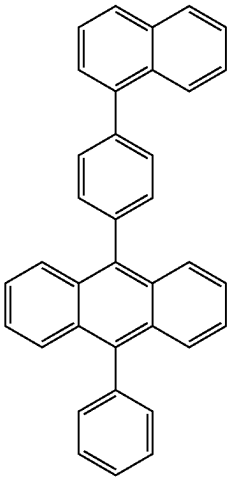

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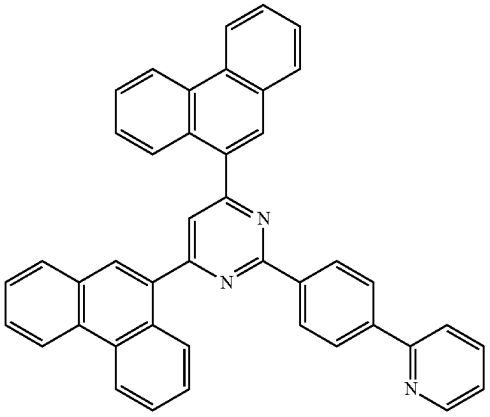

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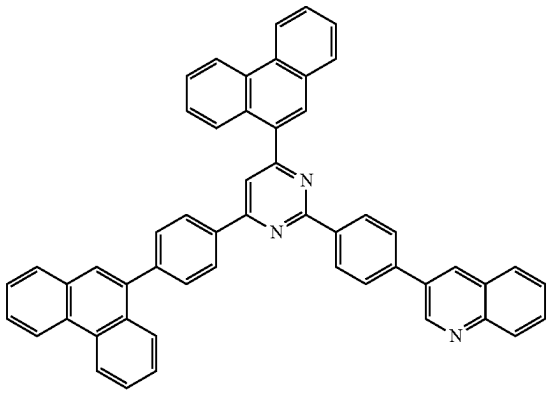

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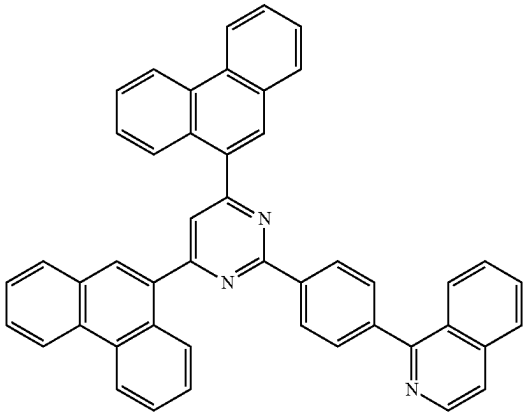

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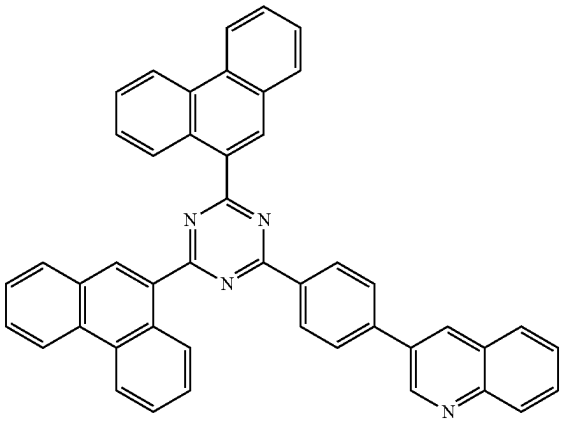

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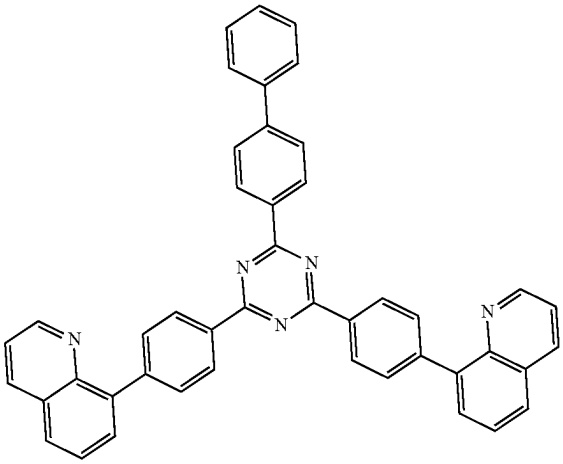

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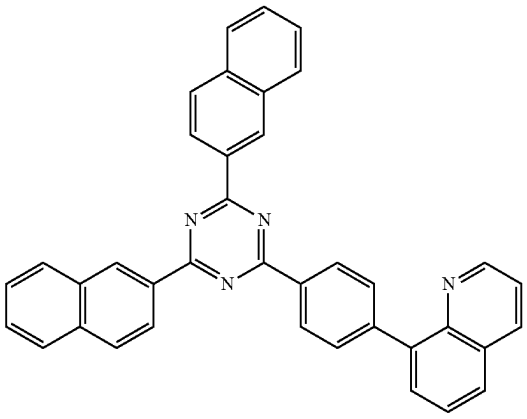

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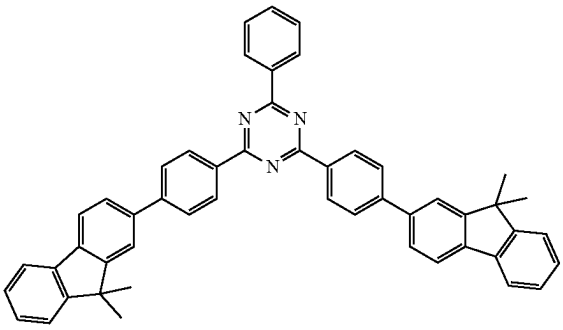

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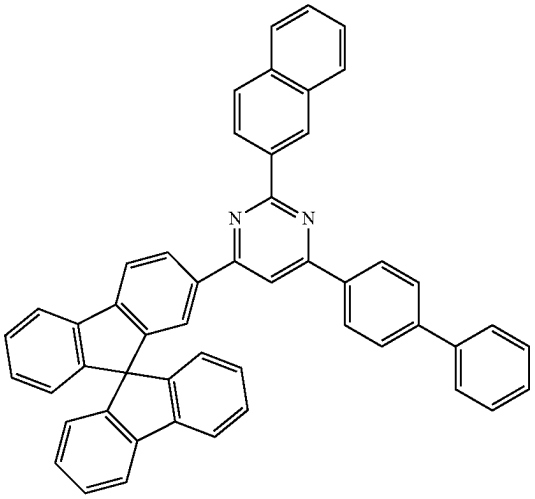

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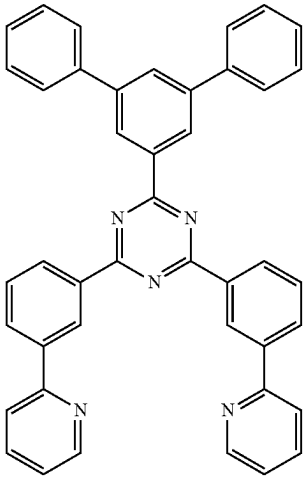

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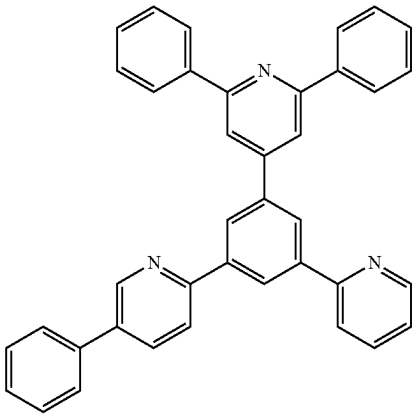

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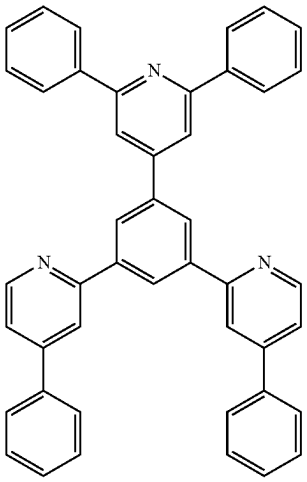

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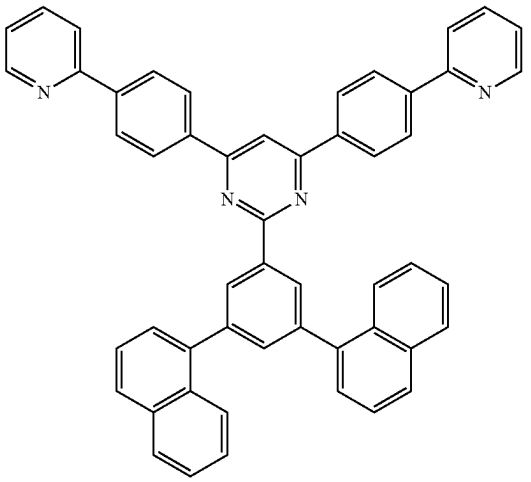

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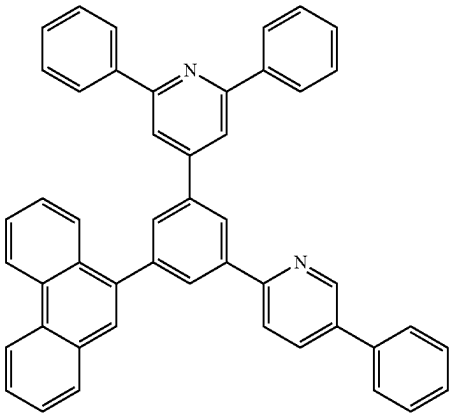

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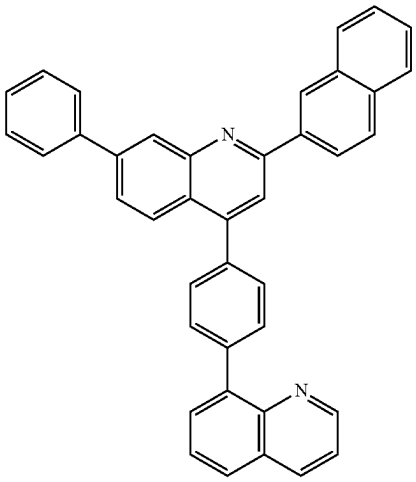

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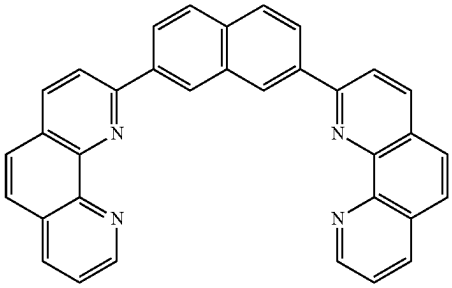

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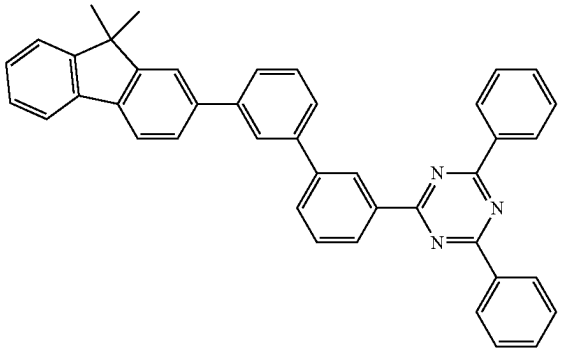

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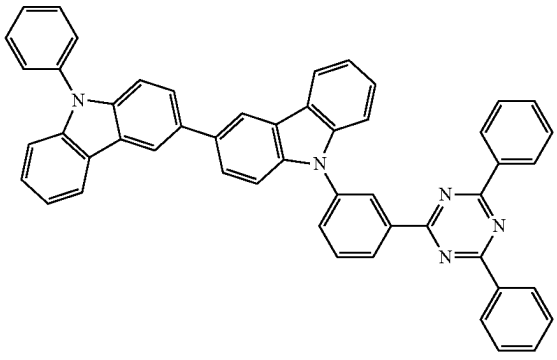

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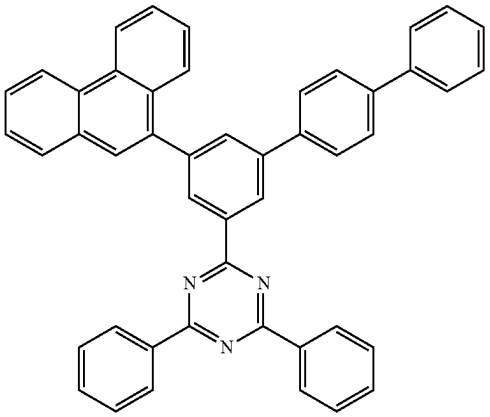

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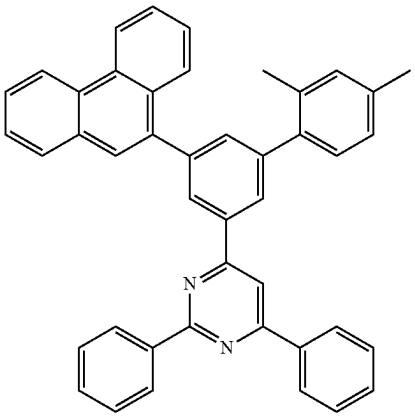

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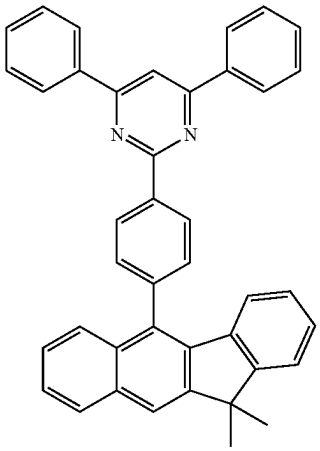

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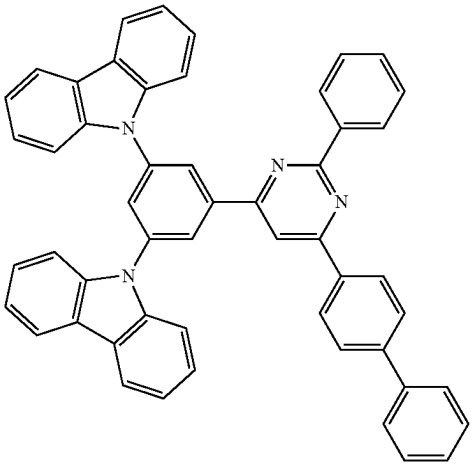

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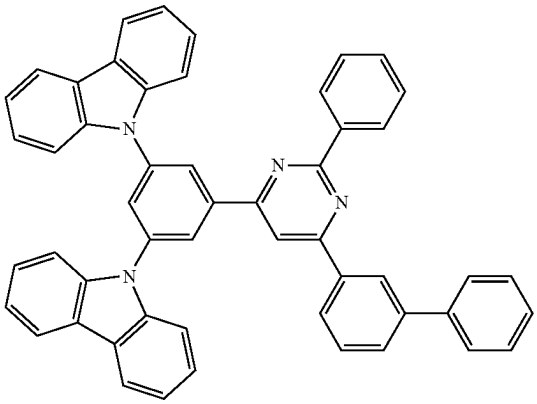

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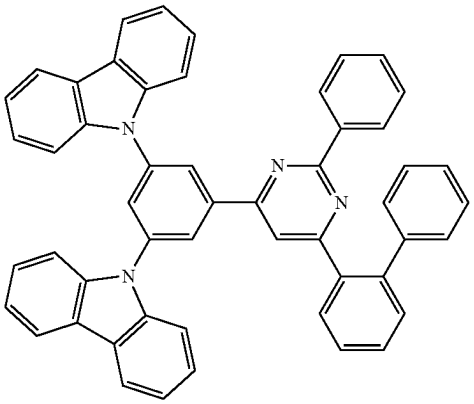

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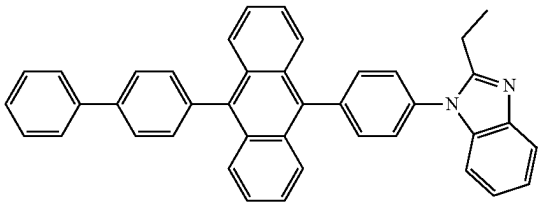

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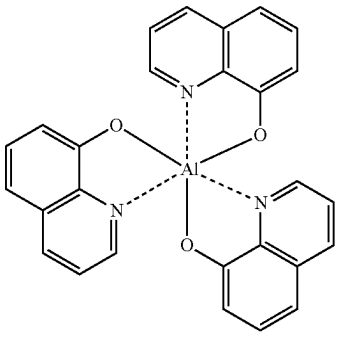
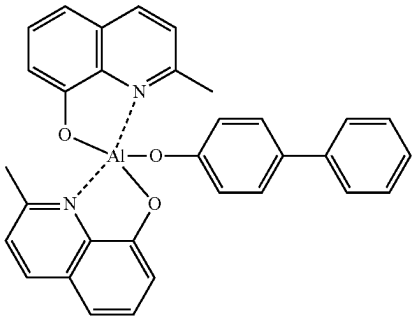
Alq3



BAlq



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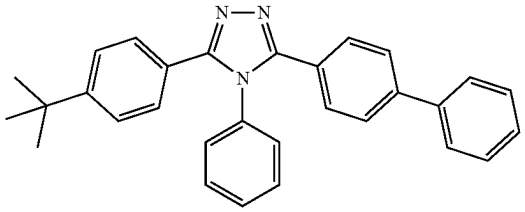

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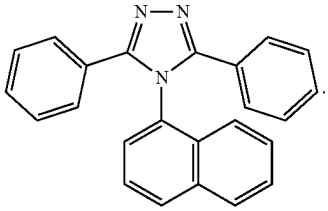


[0520] A thickness of the electron transport region may be in a range of about 100 Å to about 5,000 Å. For example, the thickness of the electron transport region may be in a range of about 160 Å to about 4,000 Å. When the electron transport region includes a buffer layer, a hole blocking layer, an electron control layer, an electron transport layer, or any combination thereof, a thickness of the buffer layer, the hole blocking layer, or the electron control layer may each independently be in a range of about 20 Å to about 1,000 Å, and a thickness of the electron transport layer may be in a range of about 100 Å to about 1,000 Å. For example, the thickness of the buffer layer, the hole blocking layer, or the electron control layer may each independently be in a range of about 30 Å to about 300 Å. For example, the thickness of the electron transport layer may be in a range of about 150 Å to about 500 Å. When the thickness of the buffer layer, the hole blocking layer, the electron control layer, the electron transport layer, and/or the electron transport region are within these ranges, satisfactory electron transporting characteristics may be obtained without a substantial increase in driving voltage.

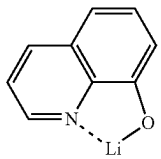
[0521] The electron transport region (for example, an electron transport layer in the electron transport region) may further include, in addition to the materials described above, a metal-containing material.

[0522] The metal-containing material may include an alkali metal complex, an alkaline earth metal complex, or any combination thereof. A metal ion of an alkali metal complex may be a Li ion, a Na ion, a K ion, a Rb ion, or a Cs ion, and a metal ion of an alkaline earth metal complex may be a Be ion, a Mg ion, a Ca ion, a Sr ion, or a Ba ion.

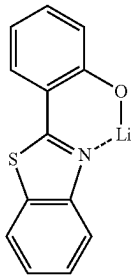
[0523] A ligand coordinated with a metal ion of an alkali metal complex or an alkaline earth-metal complex may each independently include a hydroxyquinoline, a hydroxyisoquinoline, a hydroxybenzoquinoline, a hydroxyacridine, a hydroxyphenanthridine, a hydroxyphenyloxazole, a hydroxyphenylthiazole, a hydroxyphenyloxadiazole, a hydroxyphenylthiadiazole, a hydroxyphenylpyridine, a hydroxyphenylbenzimidazole, a hydroxyphenylbenzothiazole, a bipyridine, a phenanthroline, a cyclopentadiene, or any combination thereof.

[0524] In an embodiment, the metal-containing material may include a Li complex. The Li complex may include, for example, Compound ET-D1 (LiQ) or Compound ET-D2:

ET-D1



ET-D2



[0525] The electron transport region may include an electron injection layer that facilitates the injection of electrons from the second electrode **150**. The electron injection layer may directly contact the second electrode **150**.

[0526] The electron injection layer may have a structure consisting of a layer consisting of a single material, a structure consisting of a layer including different materials, or a structure including multiple layers including different materials.

[0527] The electron injection layer may include an alkali metal, an alkaline earth metal, a rare earth metal, an alkali metal-containing compound, an alkaline earth metal-containing compound, a rare earth metal-containing compound, an alkali metal complex, an alkaline earth metal complex, a rare earth metal complex, or any combination thereof.

[0528] The alkali metal may include Li, Na, K, Rb, Cs, or any combination thereof. The alkaline earth metal may

include Mg, Ca, Sr, Ba, or any combination thereof. The rare earth metal may include Sc, Y, Ce, Tb, Yb, Gd, or any combination thereof.

[0529] The alkali metal-containing compound, the alkaline earth metal-containing compound, and the rare earth metal-containing compound may include oxides, halides (for example, fluorides, chlorides, bromides, or iodides), or tellurides of the alkali metal, the alkaline earth metal, and the rare earth metal, or any combination thereof.

[0530] The alkali metal-containing compound may include: an alkali metal oxide, such as Li_2O, Cs_2O, or K_2O; an alkali metal halide, such as LiF, NaF, CsF, KF, LiI, NaI, CsI, or KI; or any combination thereof. The alkaline earth metal-containing compound may include an alkaline earth metal oxide, such as BaO, SrO, CaO, $Ba_xSr_{1-x}O$ (wherein x is a real number satisfying the condition of $0<x<1$), $Ba_xCa_{1-x}O$ (wherein x is a real number satisfying the condition of $0<x<1$), or the like. The rare earth metal-containing compound may include YbF_3, ScF_3, Sc_2O_3, Y_2O_3, Ce_2O_3, GdF_3, TbF_3, YbI_3, ScI_3, TbI_3, or any combination thereof. In embodiments, the rare earth metal-containing compound may include a lanthanide metal telluride. Examples of a lanthanide metal telluride are LaTe, CeTe, PrTe, NdTe, PmTe, SmTe, EuTe, GdTe, TbTe, DyTe, HoTe, ErTe, TmTe, YbTe, LuTe, La_2Te_3, Ce_2Te_3, Pr_2Te_3, Nd_2Te_3, Pm_2Te_3, Sm_2Te_3, Eu_2Te_3, Gd_2Te_3, Tb_2Te_3, Dy_2Te_3, Ho_2Te_3, Er_2Te_3, Tm_2Te_3, Yb_2Te_3, and Lu_2Te_3.

[0531] The alkali metal complex, the alkaline earth-metal complex, and the rare earth metal complex may include; an alkali metal ion, an alkaline earth metal ion, or a rare earth metal ion; and a ligand bonded to the metal ion (for example, hydroxyquinoline, hydroxyisoquinoline, hydroxybenzoquinoline, hydroxyacridine, hydroxyphenanthridine, hydroxyphenyloxazole, hydroxyphenylthiazole, hydroxyphenyloxadiazole, hydroxyphenylthiadiazole, hydroxyphenylpyridine, hydroxyphenyl benzimidazole, hydroxyphenylbenzothiazole, bipyridine, phenanthroline, cyclopentadiene, or any combination thereof).

[0532] In an embodiment, the electron injection layer may consist of an alkali metal, an alkaline earth metal, a rare earth metal, an alkali metal-containing compound, an alkaline earth metal-containing compound, a rare earth metal-containing compound, an alkali metal complex, an alkaline earth metal complex, a rare earth metal complex, or any combination thereof, as described above. In embodiments, the electron injection layer may further include an organic material (for example, a compound represented by Formula 601).

[0533] In embodiments, the electron injection layer may consist of an alkali metal-containing compound (for example, an alkali metal halide); or the electron injection layer may consist of an alkali metal-containing compound (for example, an alkali metal halide), and an alkali metal, an alkaline earth metal, a rare earth metal, or any combination thereof. For example, the electron injection layer may be a KI:Yb co-deposited layer, an RbI:Yb co-deposited layer, a LiF:Yb co-deposited layer, or the like.

[0534] When the electron injection layer further includes an organic material, an alkali metal, an alkaline earth metal, a rare earth metal, an alkali metal-containing compound, an alkaline earth metal-containing compound, a rare earth metal-containing compound, an alkali metal complex, an alkaline earth-metal complex, a rare earth metal complex, or any combination thereof may be uniformly or non-uniformly dispersed in a matrix including the organic material.

[0535] A thickness of the electron injection layer may be in a range of about 1 Å to about 100 Å. For example, the thickness of the electron injection layer may be in a range of about 3 Å to about 90 Å. When the thickness of the electron injection layer is within any of the ranges described above, satisfactory electron injection characteristics may be obtained without a substantial increase in driving voltage.

[Second Electrode **150**]

[0536] The second electrode **150** may be located on the interlayer **130** having a structure as described above. The second electrode **150** may be a cathode, which is an electron injection electrode. When the second electrode **150** is a cathode, the second electrode **150** may include a material having a low-work function, such as a metal, an alloy, an electrically conductive compound, or any combination thereof.

[0537] The second electrode **150** may include lithium (L_1), silver (Ag), magnesium (Mg), aluminum (Al), aluminum-lithium (Al—Li), calcium (Ca), magnesium-indium (Mg—In), magnesium-silver (Mg—Ag), ytterbium (Yb), silver-ytterbium (Ag—Yb), ITO, IZO, or any combination thereof. The second electrode **150** may be a transmissive electrode, a semi-transmissive electrode, or a reflective electrode.

[0538] The second electrode **150** may have a single-layered structure or a multi-layered structure.

[Capping Layer]

[0539] The light-emitting device **10** may include a first capping layer located outside the first electrode **110**, and/or a second capping layer located outside the second electrode **150**. In embodiments, the light-emitting device **10** may have a structure in which the first capping layer, the first electrode **110**, the interlayer **130**, and the second electrode **150** are stacked in the stated order, a structure in which the first electrode **110**, the interlayer **130**, the second electrode **150**, and the second capping layer are stacked in the stated order, or a structure in which the first capping layer, the first electrode **110**, the interlayer **130**, the second electrode **150**, and the second capping layer are stacked in the stated order.

[0540] Light generated in an emission layer of the interlayer **130** of the light-emitting device **10** may be extracted through the first electrode **110**, which may be a semi-transmissive electrode or a transmissive electrode, and through the first capping layer to the outside. Light generated in an emission layer of the interlayer **130** of the light-emitting device **10** may be extracted through the second electrode **150**, which may be a semi-transmissive electrode or a transmissive electrode, and through the second capping layer to the outside.

[0541] The first capping layer and the second capping layer may each increase external emission efficiency according to the principle of constructive interference. Accordingly, light extraction efficiency of the light-emitting device **10** is increased, so that the luminescence efficiency of the light-emitting device **10** may be improved.

[0542] The first capping layer and the second capping layer may each include a material having a refractive index equal to or greater than about 1.6 (with respect to a wavelength of about 589 nm).

[0543] The first capping layer and the second capping layer may each independently be an organic capping layer including an organic material, an inorganic capping layer including an inorganic material, or an organic-inorganic composite capping layer including an organic material and an inorganic material.

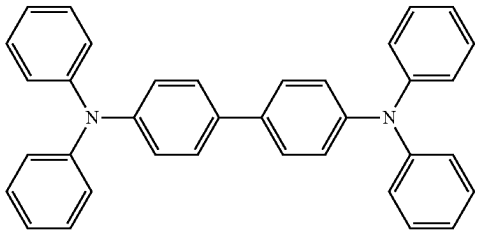
[0544] At least one of the first capping layer and the second capping layer may each independently include a carbocyclic compound, a heterocyclic compound, an amine group-containing compound, a porphine derivative, a phthalocyanine derivative, a naphthalocyanine derivative, an alkali metal complex, an alkaline earth metal complex, or any combination thereof. The carbocyclic compound, the heterocyclic compound, and the amine group-containing compound may be optionally substituted with a substituent including O, N, S, Se, Si, F, Cl, Br, I, or any combination thereof.

[0545] In embodiments, at least one of the first capping layer and the second capping layer may each independently include an amine group-containing compound.

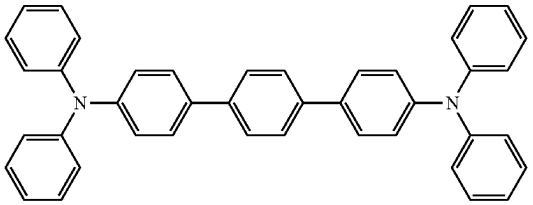
[0546] For example, at least one of the first capping layer and the second capping layer may each independently include a compound represented by Formula 201, a compound represented by Formula 202, or any combination thereof.

[0547] In embodiments, at least one of the first capping layer and the second capping layer may each independently include one of Compounds HT28 to HT33, one of Compounds CP1 to CP6, β-NPB, or any combination thereof:

CP1



CP2



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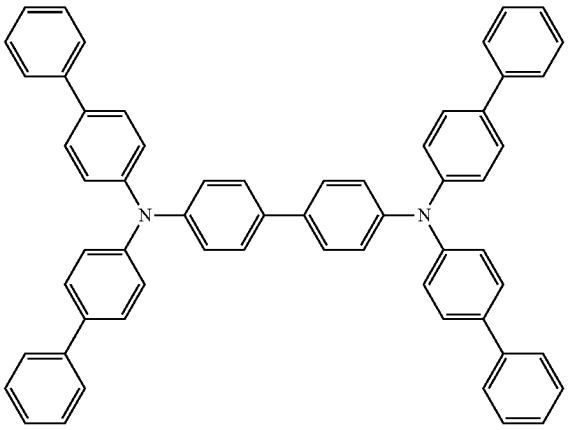
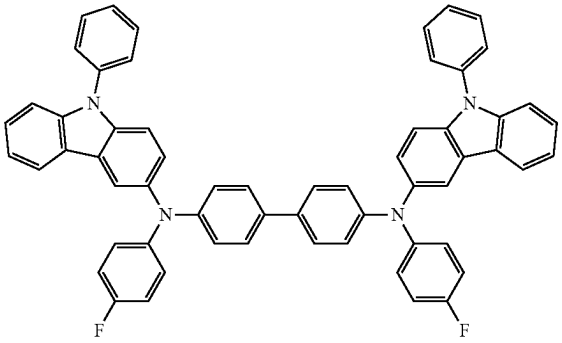
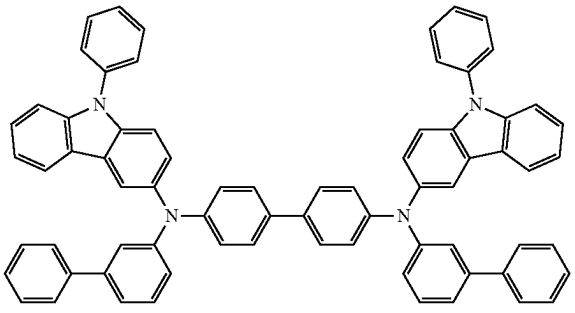
CP3



CP4

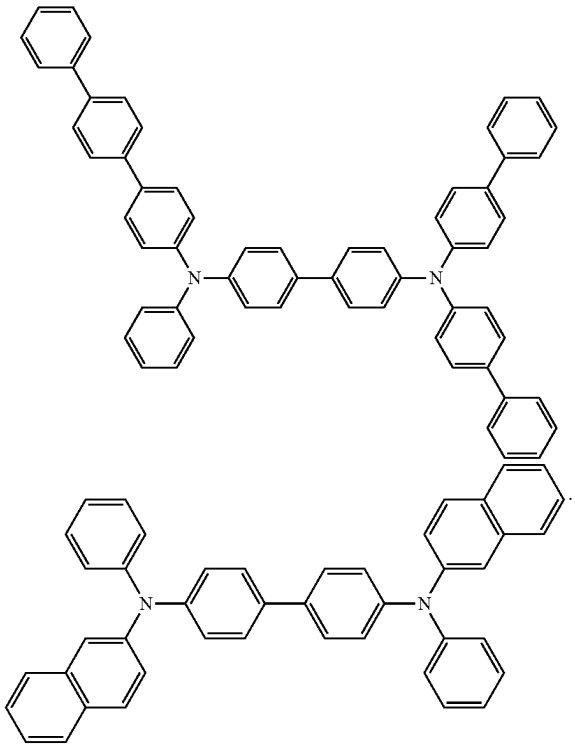


CP5



-continued

CP6



β-NPB

[Film]

[0548] The heterocyclic compound represented by Formula 1 may be included in various films. Accordingly, another embodiment provides a film including a heterocyclic compound represented by Formula 1. The film may be, for example, an optical member (or a light control means) (for example, a color filter, a color conversion member, a capping layer, a light extraction efficiency enhancement layer, a selective light absorbing layer, a polarizing layer, a quantum dot-containing layer, or like), a light blocking member (for example, a light reflective layer, a light absorbing layer, or the like), or a protective member (for example, an insulating layer, a dielectric layer, or the like).

[Electronic Apparatus]

[0549] The light-emitting device may be included in various electronic apparatuses. For example, an electronic apparatus including the light-emitting device may be a light-emitting apparatus, an authentication apparatus, or the like.

[0550] The electronic apparatus (for example, a light-emitting apparatus) may further include, in addition to the light-emitting device, a color filter, a color conversion layer, or a color filter and a color conversion layer. The color filter and/or the color conversion layer may be located in at least one direction in which light emitted from the light-emitting device travels. For example, the light emitted from the light-emitting device may be blue light or white light. Further details on the light-emitting device may be the same as described herein. In embodiments, the color conversion layer may include a quantum dot. The quantum dot may be, for example, a quantum dot as described herein.

[0551] The electronic apparatus may include a substrate. The substrate may include subpixels, the color filter may include color filter areas respectively corresponding to the subpixels, and the color conversion layer may include color conversion areas respectively corresponding to the subpixels.

[0552] A pixel-defining film may be located between the subpixels to define each subpixel.

[0553] The color filter may further include color filter areas and light-shielding patterns located between the color filter areas, and the color conversion layer may further include color conversion areas and light-shielding patterns located between the color conversion areas.

[0554] The color filter areas (or the color conversion areas) may include a first area emitting first color light, a second area emitting second color light, and/or a third area emitting third color light, wherein the first color light, the second color light, and/or the third color light may have different maximum emission wavelengths from one another. For example, the first color light may be red light, the second color light may be green light, and the third color light may be blue light. In an embodiment, the color filter areas (or the color conversion areas) may include quantum dots. For example, the first area may include a red quantum dot, the second area may include a green quantum dot, and the third area may not include a quantum dot. Further details on the quantum dot may be the same as described herein. The first area, the second area, and/or the third area may each further include a scatterer.

[0555] In an embodiment, the light-emitting device may emit first light, the first area may absorb the first light to emit first-first color light, the second area may absorb the first light to emit second-first color light, and the third area may absorb the first light to emit third-first color light. The first-first color light, the second-first color light, and the third-first color light may have different maximum emission wavelengths. For example, the first light may be blue light, the first-first color light may be red light, the second-first color light may be green light, and the third-first color light may be blue light.

[0556] The electronic apparatus may further include a thin-film transistor, in addition to the light-emitting device as described above. The thin-film transistor may include a source electrode, a drain electrode, and an active layer, wherein any one of the source electrode and the drain electrode may be electrically connected to any one of the first electrode and the second electrode of the light-emitting device.

[0557] The thin-film transistor may further include a gate electrode, a gate insulating film, or the like.

[0558] The active layer may include crystalline silicon, amorphous silicon, an organic semiconductor, an oxide semiconductor, or the like.

[0559] The electronic apparatus may further include a sealing portion for sealing the light-emitting device. The sealing portion may be located between the color filter and/or the color conversion layer and the light-emitting device. The sealing portion allows light from the light-emitting device to be extracted to the outside, and simultaneously prevents ambient air and moisture from penetrating into the light-emitting device. The sealing portion may be a sealing substrate that includes a transparent glass substrate

or a plastic substrate. The sealing portion may be a thin-film encapsulation layer that includes at least one of an organic layer and/or an inorganic layer. When the sealing portion is a thin film encapsulation layer, the electronic apparatus may be flexible.

[0560] Various functional layers may be further included on the sealing portion, in addition to the color filter and/or the color conversion layer, according to a use of the electronic apparatus. Examples of a functional layer may include a touch screen layer, a polarizing layer, and the like. The touch screen layer may be a pressure-sensitive touch screen layer, a capacitive touch screen layer, or an infrared touch screen layer. The authentication apparatus may be, for example, a biometric authentication apparatus that authenticates an individual by using biometric information of a living body (for example, fingertips, pupils, etc.).

[0561] The authentication apparatus may further include, in addition to the light-emitting device as described above, a biometric information collector.

[0562] The electronic apparatus may be applied to various displays, light sources, lighting, personal computers (for example, a mobile personal computer), mobile phones, digital cameras, electronic organizers, electronic dictionaries, electronic game machines, medical instruments (for example, electronic thermometers, sphygmomanometers, blood glucose meters, pulse measurement devices, pulse wave measurement devices, electrocardiogram displays, ultrasonic diagnostic devices, or endoscope displays), fish finders, various measuring instruments, meters (for example, meters for a vehicle, an aircraft, and a vessel), projectors, and the like.

[Electronic Equipment]

[0563] The light-emitting device may be included in various electronic equipment.

[0564] In embodiments, an electronic equipment including the light-emitting device may be a flat panel display, a curved display, a computer monitor, a medical monitor, a television, a billboard, an indoor light, an outdoor light, a signal light, a head-up display, a fully transparent display, a partially transparent display, a flexible display, a rollable display, a foldable display, a stretchable display, a laser printer, a telephone, a mobile phone, a tablet computer, a phablet, a personal digital assistant (PDA), a wearable device, a laptop computer, a digital camera, a camcorder, a viewfinder, a micro display, a three-dimensional (3D) display, a virtual reality display, an augmented reality display, a vehicle, a video wall with multiple displays tiled together, a theater screen, a stadium screen, a phototherapy device, or a signboard.

[0565] The light-emitting device may have excellent properties in terms of luminescence efficiency and long lifespan, and thus the electronic equipment including the light-emitting device may have characteristics such as high luminance, high resolution, and low power consumption.

[Description of FIGS. **2** and **3**]

[0566] FIG. **2** is a schematic cross-sectional view of an electronic apparatus according to an embodiment.

[0567] The electronic apparatus (for example, a light-emitting apparatus) of FIG. **2** includes a substrate **100**, a thin-film transistor (TFT), a light-emitting device, and an encapsulation portion **300** that seals the light-emitting device.

[0568] The substrate **100** may be a flexible substrate, a glass substrate, or a metal substrate. A buffer layer **210** may be located on the substrate **100**. The buffer layer **210** may prevent penetration of impurities through the substrate **100** and may provide a flat surface on the substrate **100**.

[0569] A TFT may be located on the buffer layer **210**. The TFT may include an active layer **220**, a gate electrode **240**, a source electrode **260**, and a drain electrode **270**.

[0570] The active layer **220** may include an inorganic semiconductor such as silicon or polysilicon, an organic semiconductor, or an oxide semiconductor, and may include a source region, a drain region, and a channel region.

[0571] A gate insulating film **230** for insulating the active layer **220** from the gate electrode **240** may be located on the active layer **220**, and the gate electrode **240** may be located on the gate insulating film **230**.

[0572] An interlayer insulating film **250** may be located on the gate electrode **240**. The interlayer insulating film **250** may be located between the gate electrode **240** and the source electrode **260** to insulate the gate electrode **240** from the source electrode **260** and between the gate electrode **240** and the drain electrode **270** to insulate the gate electrode **240** from the drain electrode **270**.

[0573] The source electrode **260** and the drain electrode **270** may be located on the interlayer insulating film **250**. The interlayer insulating film **250** and the gate insulating film **230** may be formed to expose a source region and a drain region of the active layer **220**, and the source electrode **260** and the drain electrode **270** may respectively contact the exposed portions of the source region and the drain region of the active layer **220**.

[0574] The TFT is electrically connected to a light-emitting device to drive the light-emitting device, and is covered and protected by a passivation layer **280**. The passivation layer **280** may include an inorganic insulating film, an organic insulating film, or any combination thereof. A light-emitting device is provided on the passivation layer **280**. The light-emitting device may include a first electrode **110**, an interlayer **130**, and a second electrode **150**.

[0575] The first electrode **110** may be located on the passivation layer **280**. The passivation layer **280** may not completely cover the drain electrode **270** and may expose a portion of the drain electrode **270**. The first electrode **110** may be connected (for example, electrically connected) to the exposed portion of the drain electrode **270**.

[0576] A pixel defining layer **290** including an insulating material may be located on the first electrode **110**. The pixel defining layer **290** may expose a region of the first electrode **110**, and an interlayer **130** may be formed on the exposed region of the first electrode **110**. The pixel defining layer **290** may be a polyimide or polyacrylic organic film. Although not shown in FIG. **2**, at least some layers of the interlayer **130** may extend beyond the upper portion of the pixel defining layer **290** to be provided in the form of a common layer.

[0577] The second electrode **150** may be located on the interlayer **130**, and a capping layer **170** may be further included on the second electrode **150**. The capping layer **170** may be formed to cover the second electrode **150**.

[0578] The encapsulation portion **300** may be located on the capping layer **170**. The encapsulation portion **300** may

be located on a light-emitting device to protect the light-emitting device from moisture and/or oxygen. The encapsulation portion **300** may include: an inorganic film including silicon nitride (SiN_x), silicon oxide (SiO_x), indium tin oxide, indium zinc oxide, or any combination thereof; an organic film including polyethylene terephthalate, polyethylene naphthalate, polycarbonate, polyimide, polyethylene sulfonate, polyoxymethylene, polyarylate, hexamethyldisiloxane, an acrylic resin (for example, polymethyl methacrylate, polyacrylic acid, or the like), an epoxy-based resin (for example, aliphatic glycidyl ether (AGE), or the like), or any combination thereof; or any combinations of the inorganic film and the organic film.

[0579] FIG. **3** is a schematic cross-sectional view of an electronic apparatus according to an embodiment.

[0580] The electronic apparatus (for example, a light-emitting apparatus) of FIG. **3** may differ from the electronic apparatus of FIG. **2**, at least in that a light-shielding pattern **500** and a functional region **400** are further included on the encapsulation portion **300**. The functional region **400** may be a color filter area, a color conversion area, or a combination of the color filter area and the color conversion area. In an embodiment, the light-emitting device included in the electronic apparatus of FIG. **3** may be a tandem light-emitting device.

[Description of FIG. **4**]

[0581] FIG. **4** is a schematic perspective view of electronic equipment **1** including a light-emitting device according to an embodiment.

[0582] The electronic equipment **1**, which may be a device that displays a moving image or a still image, may be not only a portable electronic equipment, such as a mobile phone, a smartphone, a tablet computer, a mobile communication terminal, an electronic notebook, an electronic book, a portable multimedia player (PMP), a navigation device, or an ultra-mobile PC (UMPC), but may also be various products, such as a television, a laptop computer, a monitor, a billboards, or an Internet of things (IoT). The electronic equipment **1** may be any product as described above or a part thereof.

[0583] In an embodiment, the electronic equipment **1** may be a wearable device, such as a smart watch, a watch phone, a glasses-type display, or a head mounted display (HMD), or a part of the wearable device. However, embodiments of the disclosure are not limited thereto.

[0584] Examples of the electronic equipment **1** may include an instrument panel of a dashboard of a vehicle, a center information display (CID) on a center fascia or on a dashboard of a vehicle, a room mirror display that replaces a side mirror of a vehicle, an entertainment display for a rear seat of a vehicle or a display located on the back of a front seat, a head up display (HUD) installed at the front of a vehicle or projected on a front window glass, or a computer generated hologram augmented reality head up display (CGH AR HUD). FIG. **4** illustrates an embodiment in which the electronic equipment **1** is a smartphone, for convenience of explanation.

[0585] The electronic equipment **1** may include a display area DA and a non-display area NDA outside the display area DA. A display device may implement an image through a two-dimensional array of pixels that are arranged in the display area DA.

[0586] The non-display area NDA is an area that does not display an image, and may surround (for example, entirely surround) the display area DA. A driver for providing electrical signals or power to display devices arranged in the display area DA may be arranged in the non-display area NDA. A pad, which is an area to which an electronic element or a printed circuit board may be electrically connected, may be arranged in the non-display area NDA.

[0587] In the electronic equipment **1**, a length in the x-axis direction and a length in the y-axis direction may be different from each other. For example, as shown in FIG. **4**, the length in the x-axis direction may be shorter than the length in the y-axis direction. In embodiments, the length in the x-axis direction may be the same as the length in the y-axis direction. In embodiments, the length in the x-axis direction may be longer than the length in the y-axis direction.

[Descriptions of FIGS. **5** and **6**A to **6**C]

[0588] FIG. **5** is a schematic perspective view of an exterior of a vehicle **1000** as an electronic equipment including a light-emitting device according to an embodiment. FIGS. **6**A to **6**C are each a schematic diagram of an interior of a vehicle **1000** according to embodiments.

[0589] Referring to FIGS. **5**, **6**A, **6**B, and **6**C, embodiments of a vehicle **1000** may include various apparatuses for moving a subject to be transported, such as a person, an object, or an animal, from a departure point to a destination. Examples of a vehicle **1000** may include a vehicle traveling on a road or a track, a vessel moving over a sea or river, an airplane flying in the sky using the action of air, and the like.

[0590] The vehicle **1000** may travel on a road or a track. The vehicle **1000** may move in a selected or given direction according to the rotation of at least one wheel. Examples of a vehicle **1000** may include a three-wheeled or four-wheeled vehicle, a construction machine, a two-wheeled vehicle, a prime mover device, a bicycle, and a train running on a track.

[0591] The vehicle **1000** may include a vehicle body having an interior and an exterior, and a chassis that is a portion excluding the vehicle body in which mechanical apparatuses necessary for driving are installed. The exterior of the vehicle body may include a front panel, a bonnet, a roof panel, a rear panel, a trunk, a pillar provided at a boundary between doors, and the like. The chassis of the vehicle **1000** may include a power generating device, a power transmitting device, a driving device, a steering device, a braking device, a suspension device, a transmission device, a fuel device, front and rear wheels, left and right wheels, and the like.

[0592] The vehicle **1000** may include a side window glass **1100**, a front window glass **1200**, a side mirror **1300**, a cluster **1400**, a center fascia **1500**, a passenger seat dashboard **1600**, and a display device **2**.

[0593] The side window glass **1100** and the front window glass **1200** may be partitioned by a pillar arranged between the side window glass **1100** and the front window glass **1200**.

[0594] The side window glass **1100** may be installed on a side of the vehicle **1000**. In an embodiment, the side window glass **1100** may be installed on a door of the vehicle **1000**. Multiple side window glasses **1100** may be provided and may face each other. In an embodiment, the side window glass **1100** may include a first side window glass **1110** and a second side window glass **1120**. In an embodiment, the

first side window glass **1110** may be arranged adjacent to the cluster **1400**, and the second side window glass **1120** may be arranged adjacent to the passenger seat dashboard **1600**.

[0595] In an embodiment, the side window glasses **1100** may be spaced apart from each other in the x-direction or the −x-direction. For example, the first side window glass **1110** and the second side window glass **1120** may be spaced apart from each other in the x direction or the −x direction. For example, a virtual straight line L connecting the side window glasses **1100** may extend in the x-direction or the −x-direction. In an embodiment, a virtual straight line L connecting the first side window glass **1110** and the second side window glass **1120** to each other may extend in the x direction or the −x direction.

[0596] The front window glass **1200** may be installed in the front of the vehicle **1000**. The front window glass **1200** may be arranged between the side window glasses **1100** facing each other.

[0597] The side mirror **1300** may provide a rear view of the vehicle **1000**. The side mirror **1300** may be installed on the exterior of the vehicle body. In an embodiment, multiple side mirrors **1300** may be provided. For example, one of the side mirrors **1300** may be arranged outside the first side window glass **1110**, and another of the side mirrors **1300** may be arranged outside the second side window glass **1120**.

[0598] The cluster **1400** may be arranged in front of the steering wheel. The cluster **1400** may include a tachometer, a speedometer, a coolant thermometer, a fuel gauge, a turn signal indicator, a high beam indicator, a warning light, a seat belt warning light, an odometer, a tachograph, an automatic shift selector indicator light, a door open warning light, an engine oil warning light, and/or a low fuel warning light.

[0599] The center fascia **1500** may include a control panel on which buttons for adjusting an audio device, an air conditioning device, and a seat heater are disposed. The center fascia **1500** may be arranged on a side of the cluster **1400**.

[0600] A passenger seat dashboard **1600** may be spaced apart from the cluster **1400**, and the center fascia **1500** may be arranged between the cluster **1400** and the passenger seat dashboard **1600**. In an embodiment, the cluster **1400** may be arranged to correspond to a driver seat (not shown), and the passenger seat dashboard **1600** may be disposed to correspond to a passenger seat (not shown). In an embodiment, the cluster **1400** may be adjacent to the first side window glass **1110**, and the passenger seat dashboard **1600** may be adjacent to the second side window glass **1120**.

[0601] In an embodiment, the display device **2** may include a display panel **3**, and the display panel **3** may display an image. The display device **2** may be arranged inside the vehicle **1000**. In an embodiment, the display device **2** may be arranged between the side window glasses **1100** facing each other. The display device **2** may be arranged on at least one of the cluster **1400**, the center fascia **1500**, and the passenger seat dashboard **1600**.

[0602] The display device **2** may include an organic light-emitting display device, an inorganic electroluminescent (EL) display device, a quantum dot display device, or the like. Hereinafter, an organic light-emitting display device including the light-emitting device according to an embodiment will be described as an example of the display device **2**. However, various types of display devices as described above may be used in embodiments.

[0603] Referring to FIG. **6**A, the display device **2** may be arranged on the center fascia **1500**. In an embodiment, the display device **2** may display navigation information. In an embodiment, the display device **2** may display information audio, video, or vehicle settings.

[0604] Referring to FIG. **6**B, the display device **2** may be arranged on the cluster **1400**. When the display device **2** is arranged on the cluster **1400**, the cluster **1400** may display driving information and the like through the display device **2**. For example, the cluster **1400** may digitally implement driving information and the like. The digital cluster **1400** may display vehicle information and driving information as images. For example, a needle and a gauge of a tachometer and various warning lights or icons may be displayed by a digital signal.

[0605] Referring to FIG. **6**C, the display device **2** may be arranged on the passenger seat dashboard **1600**. The display device **2** may be embedded in the passenger seat dashboard **1600** or arranged on the passenger seat dashboard **1600**. In an embodiment, the display device **2** arranged on the passenger seat dashboard **1600** may display an image related to information displayed on the cluster **1400** and/or information displayed on the center fascia **1500**. In an embodiment, the display device **2** arranged on the passenger seat dashboard **1600** may display information that is different from information displayed on the cluster **1400** and/or information displayed on the center fascia **1500**.

[Manufacturing Method]

[0606] Respective layers included in the hole transport region, the emission layer, and respective layers included in the electron transport region may be formed in a selected region by using one or more suitable methods such as vacuum deposition, spin coating, casting, Langmuir-Blodgett (LB) deposition, ink-jet printing, laser-printing, and laser-induced thermal imaging.

[0607] When layers constituting the hole transport region, an emission layer, and layers constituting the electron transport region are formed by vacuum deposition, the deposition may be performed at a deposition temperature of about 100° C. to about 500° C., a vacuum degree of about 10^{-8} torr to about 10^{-3} torr, and a deposition speed of about 0.01 Å/sec to about 100 Å/sec, depending on a material to be included in a layer to be formed and the structure of a layer to be formed.

[Definitions of Terms]

[0608] The term "C_3-C_{60} carbocyclic group" as used herein may be a cyclic group consisting of carbon atoms as the only ring-forming atoms and having three to sixty carbon atoms. The term "C_1-C_{60} heterocyclic group" as used herein may be a cyclic group that has one to sixty carbon atoms and further has, in addition to a carbon atom, at least one heteroatom as a ring-forming atom. The C_3-C_{60} carbocyclic group and the C_1-C_{60} heterocyclic group may each be a monocyclic group consisting of one ring or a polycyclic group in which two or more rings are condensed with each other. For example, a C_1-C_{60} heterocyclic group may have 3 to 61 ring-forming atoms.

[0609] The term "cyclic group" as used herein may be a C_3-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group.

[0610] The term "π electron-rich C_3-C_{60} cyclic group" as used herein may be a cyclic group that has three to sixty

carbon atoms and may not include *—N=*' as a ring-forming moiety. The term "π electron-deficient nitrogen-containing C_1-C_{60} cyclic group" as used herein may be a heterocyclic group that has one to sixty carbon atoms and may include *—N=*' as a ring-forming moiety.

[0611] In embodiments,

[0612] a C_3-C_{60} carbocyclic group may be a T1 group or a group in which two or more T1 groups are condensed with each other (for example, a cyclopentadiene group, an adamantane group, a norbornane group, a benzene group, a pentalene group, a naphthalene group, an azulene group, an indacene group, an acenaphthylene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a perylene group, a pentaphene group, a heptalene group, a naphthacene group, a picene group, a hexacene group, a pentacene group, a rubicene group, a coronene group, an ovalene group, an indene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, an indenophenanthrene group, or an indenoanthracene group),

[0613] a C_1-C_{60} heterocyclic group may be a T_2 group, a group in which two or more T_2 groups are condensed with each other, or a group in which at least one T_2 group and at least one T_1 group are condensed with each other (for example, a pyrrole group, a thiophene group, a furan group, an indole group, a benzoindole group, a naphthoindole group, an isoindole group, a benzoisoindole group, a naphthoisoindole group, a benzosilole group, a benzothiophene group, a benzofuran group, a carbazole group, a dibenzosilole group, a dibenzothiophene group, a dibenzofuran group, an indenocarbazole group, an indolocarbazole group, a benzofurocarbazole group, a benzothienocarbazole group, a benzosilolocarbazole group, a benzoindolocarbazole group, a benzocarbazole group, a benzonaphthofuran group, a benzonaphthothiophene group, a benzonaphthosilole group, a benzofurodibenzofuran group, a benzofurodibenzothiophene group, a benzothienodibenzothiophene group, a pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, an oxadiazole group, a thiazole group, an isothiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a benzoxazole group, a benzoisoxazole group, a benzothiazole group, a benzoisothiazole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a benzoquinoline group, a benzoisoquinoline group, a quinoxaline group, a benzoquinoxaline group, a quinazoline group, a benzoquinazoline group, a phenanthroline group, a cinnoline group, a phthalazine group, a naphthyridine group, an imidazopyridine group, an imidazopyrimidine group, an imidazotriazine group, an imidazopyrazine group, an imidazopyridazine group, an azacarbazole group, an azafluorene group, an azadibenzosilole group, an azadibenzothiophene group, an azadibenzofuran group, etc.),

[0614] a π electron-rich C_3-C_{60} cyclic group may be a T1 group, a group in which two or more T1 groups are condensed with each other, a T3 group, a group in which two or more T3 groups are condensed with each other, or a group in which at least one T3 group and at least one T1 group are condensed with each other (for example, a C_3-C_{60} carbocyclic group, a 1H-pyrrole group, a silole group, a borole group, a 2H-pyrrole group, a 3H-pyrrole group, a thiophene group, a furan group, an indole group, a benzoindole group, a naphthoindole group, an isoindole group, a benzoisoindole group, a naphthoisoindole group, a benzosilole group, a benzothiophene group, a benzofuran group, a carbazole group, a dibenzosilole group, a dibenzothiophene group, a dibenzofuran group, an indenocarbazole group, an indolocarbazole group, a benzofurocarbazole group, a benzothienocarbazole group, a benzosilolocarbazole group, a benzoindolocarbazole group, a benzocarbazole group, a benzonaphthofuran group, a benzonaphthothiophene group, a benzonaphthosilole group, a benzofurodibenzofuran group, a benzofurodibenzothiophene group, a benzothienodibenzothiophene group, etc.),

[0615] a π electron-deficient nitrogen-containing C_1-C_{60} cyclic group may be a T4 group, a group in which two or more T4 groups are condensed with each other, a group in which at least one T4 group and at least one T1 group are condensed with each other, a group in which at least one T4 group and at least one T3 group are condensed with each other, or a group in which at least one T4 group, at least one T1 group, and at least one T3 group are condensed with one another (for example, a pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, an oxadiazole group, a thiazole group, an isothiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a benzoxazole group, a benzoisoxazole group, a benzothiazole group, a benzoisothiazole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a benzoquinoline group, a benzoisoquinoline group, a quinoxaline group, a benzoquinoxaline group, a quinazoline group, a benzoquinazoline group, a phenanthroline group, a cinnoline group, a phthalazine group, a naphthyridine group, an imidazopyridine group, an imidazopyrimidine group, an imidazotriazine group, an imidazopyrazine group, an imidazopyridazine group, an azacarbazole group, an azafluorene group, an azadibenzosilole group, an azadibenzothiophene group, an azadibenzofuran group, etc.), wherein

[0616] a T1 group may be a cyclopropane group, a cyclobutane group, a cyclopentane group, a cyclohexane group, a cycloheptane group, a cyclooctane group, a cyclobutene group, a cyclopentene group, a cyclopentadiene group, a cyclohexene group, a cyclohexadiene group, a cycloheptene group, an adamantane group, a norbornane (or a bicyclo[2.2.1] heptane) group, a norbornene group, a bicyclo[1.1.1]pentane group, a bicyclo[2.1.1]hexane group, a bicyclo[2.2.2] octane group, or a benzene group,

[0617] a T2 group may be a furan group, a thiophene group, a 1H-pyrrole group, a silole group, a borole group, a 2H-pyrrole group, a 3H-pyrrole group, an imidazole group, a pyrazole group, a triazole group, a tetrazole group, an oxazole group, an isoxazole group, an oxadiazole group, a thiazole group, an isothiazole group, a thiadiazole group, an azasilole group, an azaborole group, a pyridine group, a pyrimidine group,

a pyrazine group, a pyridazine group, a triazine group, a tetrazine group, a pyrrolidine group, an imidazolidine group, a dihydropyrrole group, a piperidine group, a tetrahydropyridine group, a dihydropyridine group, a hexahydropyrimidine group, a tetrahydropyrimidine group, a dihydropyrimidine group, a piperazine group, a tetrahydropyrazine group, a dihydropyrazine group, a tetrahydropyridazine group, or a dihydropyridazine group,

[0618] a T3 group may be a furan group, a thiophene group, a 1H-pyrrole group, a silole group, or a borole group, and

[0619] a T4 group may be a 2H-pyrrole group, a 3H-pyrrole group, an imidazole group, a pyrazole group, a triazole group, a tetrazole group, an oxazole group, an isoxazole group, an oxadiazole group, a thiazole group, an isothiazole group, a thiadiazole group, an azasilole group, an azaborole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, or a tetrazine group.

[0620] The terms "cyclic group", "C_3-C_{60} carbocyclic group", "C_1-C_{60} heterocyclic group", "π electron-rich C_3-C_{60} cyclic group", and "π electron-deficient nitrogen-containing C_1-C_{60} cyclic group" as used herein may each be a group condensed to any cyclic group, a monovalent group, or a polyvalent group (for example, a divalent group, a trivalent group, a tetravalent group, etc.) according to the structure of a formula for which the corresponding term is used. For example, a "benzene group" may be a benzo group, a phenyl group, a phenylene group, or the like, which may be readily understood by one of ordinary skill in the art according to the structure of a formula including the "benzene group."

[0621] Examples of a monovalent C_3-C_{60} carbocyclic group or a monovalent C_1-C_{60} heterocyclic group may include a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group. Examples of a divalent C_3-C_{60} carbocyclic group or a divalent C_1-C_{60} heterocyclic group may include a C_3-C_{10} cycloalkylene group, a C_1-C_{10} heterocycloalkylene group, a C_3-C_{10} cycloalkenylene group, a C_1-C_{10} heterocycloalkenylene group, a C_6-C_{60} arylene group, a C_1-C_{60} heteroarylene group, a divalent non-aromatic condensed polycyclic group, and a divalent non-aromatic condensed heteropolycyclic group.

[0622] The term "C_1-C_{60} alkyl group" as used herein may be a linear or branched monovalent aliphatic hydrocarbon group that has one to sixty carbon atoms, and examples thereof may include a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, a sec-butyl group, an isobutyl group, a tert-butyl group, an n-pentyl group, a tert-pentyl group, a neopentyl group, an isopentyl group, a sec-pentyl group, a 3-pentyl group, a sec-isopentyl group, an n-hexyl group, an isohexyl group, a sec-hexyl group, a tert-hexyl group, an n-heptyl group, an isoheptyl group, a sec-heptyl group, a tert-heptyl group, an n-octyl group, an isooctyl group, a sec-octyl group, a tert-octyl group, an n-nonyl group, an isononyl group, a sec-nonyl group, a tert-nonyl group, an n-decyl group, an isodecyl group, a sec-decyl group, and a tert-decyl group. The term "C_1-C_{60} alkylene group" as used herein may be a divalent group having a same structure as the C_1-C_{60} alkyl group.

[0623] The term "C_2-C_{60} alkenyl group" as used herein may be a monovalent hydrocarbon group having at least one carbon-carbon double bond in the middle or at a terminus of a C_2-C_{60} alkyl group, and examples thereof may include an ethenyl group, a propenyl group, and a butenyl group. The term "C_2-C_{60} alkenylene group" as used herein may be a divalent group having a same structure as the C_2-C_{60} alkenyl group.

[0624] The term "C_2-C_{60} alkynyl group" as used herein may be a monovalent hydrocarbon group having at least one carbon-carbon triple bond in the middle or at a terminus of a C_2-C_{60} alkyl group, and examples thereof may include an ethynyl group and a propynyl group. The term "C_2-C_{60} alkynylene group" as used herein may be a divalent group having a same structure as the C_2-C_{60} alkynyl group.

[0625] The term "C_1-C_{60} alkoxy group" as used herein may be a monovalent group represented by —$O(A_{101})$ (wherein A_{101} may be a C_1-C_{60} alkyl group), and examples thereof may include a methoxy group, an ethoxy group, and an isopropyloxy group.

[0626] The term "C_5-C_{10} cycloalkyl group" as used herein may be a monovalent saturated hydrocarbon cyclic group having 3 to 10 carbon atoms, and examples thereof may include a cyclopropyl group, a cyclobutyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group (or bicyclo[2.2.1] heptyl group), a bicyclo[1.1.1] pentyl group, a bicyclo[2.1.1] hexyl group, and a bicyclo[2.2.2] octyl group. The term "C_3-C_{10} cycloalkylene group" as used herein may be a divalent group having a same structure as the C_3-C_{10} cycloalkyl group.

[0627] The term "C_1-C_{10} heterocycloalkyl group" as used herein may be a monovalent cyclic group having 1 to 10 carbon atoms, further including, in addition to carbon atoms, at least one heteroatom as ring-forming atoms, and examples thereof may include a 1,2,3,4-oxatriazolidinyl group, a tetrahydrofuranyl group, and a tetrahydrothiophenyl group. The term "C_1-C_{10} heterocycloalkylene group" as used herein may be a divalent group having a same structure as the C_1-C_{10} heterocycloalkyl group.

[0628] The term "C_3-C_{10} cycloalkenyl group" as used herein may be a monovalent cyclic group that has 3 to 10 carbon atoms and at least one carbon-carbon double bond in the cyclic structure thereof and no aromaticity, and examples thereof may include a cyclopentenyl group, a cyclohexenyl group, and a cycloheptenyl group. The term "C_3-C_{10} cycloalkenylene group" as used herein may be a divalent group having a same structure as the C_3-C_{10} cycloalkenyl group.

[0629] The term "C_1-C_{10} heterocycloalkenyl group" as used herein may be a monovalent cyclic group that has 1 to 10 carbon atoms, further including, in addition to carbon atoms, at least one heteroatom as ring-forming atoms, and having at least one carbon-carbon double bond in the cyclic structure thereof. Examples of a C_1-C_{10} heterocycloalkenyl group may include a 4,5-dihydro-1,2,3,4-oxatriazolyl group, a 2,3-dihydrofuranyl group, and a 2,3-dihydrothiophenyl group. The term "C_1-C_{10} heterocycloalkenylene group" as used herein may be a divalent group having a same structure as the C_1-C_{10} heterocycloalkenyl group.

[0630] The term "C_6-C_{60} aryl group" as used herein may be a monovalent group having a carbocyclic aromatic system of 6 to 60 carbon atoms, and the term "C_6-C_{60} arylene group" as used herein may be a divalent group having a carbocyclic aromatic system of 6 to 60 carbon atoms. Examples of a C_6-C_{60} aryl group may include a phenyl group, a pentalenyl group, a naphthyl group, an azulenyl group, an indacenyl group, an acenaphthyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a heptalenyl group, a naphthacenyl group, a picenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, and an ovalenyl group. When the C_6-C_{60} aryl group and the C_6-C_{60} arylene group each include two or more rings, the respective two or more rings may be condensed with each other.

[0631] The term "C_1-C_{60} heteroaryl group" as used herein may be a monovalent group having a heterocyclic aromatic system of 1 to 60 carbon atoms, further including, in addition to carbon atoms, at least one heteroatom as ring-forming atoms. The term "C_1-C_{60} heteroarylene group" as used herein may be a divalent group having a heterocyclic aromatic system of 1 to 60 carbon atoms, further including, in addition to carbon atoms, at least one heteroatom as ring-forming atoms. Examples of a C_1-C_{60} heteroaryl group may include a pyridinyl group, a pyrimidinyl group, a pyrazinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, a benzoquinolinyl group, an isoquinolinyl group, a benzoisoquinolinyl group, a quinoxalinyl group, a benzoquinoxalinyl group, a quinazolinyl group, a benzoquinazolinyl group, a cinnolinyl group, a phenanthrolinyl group, a phthalazinyl group, and a naphthyridinyl group. When the C_1-C_{60} heteroaryl group and the C_1-C_{60} heteroarylene group each include two or more rings, the respective two or more rings may be condensed with each other.

[0632] The term "monovalent non-aromatic condensed polycyclic group" as used herein may be a monovalent group (for example, having 8 to 60 carbon atoms) having two or more rings condensed to each other, only carbon atoms as ring-forming atoms, and no aromaticity in its molecular structure as a whole. Examples of a monovalent non-aromatic condensed polycyclic group may include an indenyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, an indenophenanthrenyl group, and an indeno anthracenyl group. The term "divalent non-aromatic condensed polycyclic group" as used herein may be a divalent group having a same structure as the monovalent non-aromatic condensed polycyclic group.

[0633] The term "monovalent non-aromatic condensed heteropolycyclic group" as used herein may be a monovalent group (for example, having 1 to 60 carbon atoms) having two or more rings condensed to each other, further including, in addition to carbon atoms, at least one heteroatom as ring-forming atoms, and having no aromaticity in its molecular structure as a whole. Examples of a monovalent non-aromatic condensed heteropolycyclic group may include a pyrrolyl group, a thiophenyl group, a furanyl group, an indolyl group, a benzoindolyl group, a naphthoindolyl group, an isoindolyl group, a benzoisoindolyl group, a naphthoisoindolyl group, a benzosilolyl group, a benzothiophenyl group, a benzofuranyl group, a carbazolyl group, a dibenzosilolyl group, a dibenzothiophenyl group, a dibenzofuranyl group, an azacarbazolyl group, an azafluorenyl group, an azadibenzosilolyl group, an azadibenzothiophenyl group, an azadibenzofuranyl group, a pyrazolyl group, an imidazolyl group, a triazolyl group, a tetrazolyl group, an oxazolyl group, an isoxazolyl group, a thiazolyl group, an isothiazolyl group, an oxadiazolyl group, a thiadiazolyl group, a benzopyrazolyl group, a benzimidazolyl group, a benzoxazolyl group, a benzothiazolyl group, a benzoxadiazolyl group, a benzothiadiazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an imidazotriazinyl group, an imidazopyrazinyl group, an imidazopyridazinyl group, an indeno carbazolyl group, an indolocarbazolyl group, a benzofurocarbazolyl group, a benzothienocarbazolyl group, a benzosilolocarbazolyl group, a benzoindolocarbazolyl group, a benzocarbazolyl group, a benzonaphthofuranyl group, a benzonaphthothiophenyl group, a benzonaphtho silolyl group, a benzofurodibenzofuranyl group, a benzofurodibenzothiophenyl group, and a benzothienodibenzothiophenyl group. The term "divalent non-aromatic condensed heteropolycyclic group" as used herein may be a divalent group having a same structure as the monovalent non-aromatic condensed heteropolycyclic group.

[0634] The term "C_6-C_{60} aryloxy group" as used herein may be a group represented by —O(A_{102}) (wherein A_{102} may be a C_6-C_{60} aryl group), and the term "C_6-C_{60} arylthio group" as used herein may be a group represented by —S(A_{103}) (wherein A_{103} may be a C_6-C_{60} aryl group).

[0635] The term "C_7-C_{60} aryl alkyl group" as used herein may be a group represented by —(A_{104}) (A_{105}) (wherein A_{104} may be a C_1-C_{54} alkylene group, and A_{105} may be a C_6-C_{59} aryl group), and the term C_2-C_{60} heteroaryl alkyl group" as used herein may be a group represented by —(A_{106}) (A_{107}) (wherein A_{106} may be a C_1-C_{59} alkylene group, and A_{107} may be a C_1-C_{59} heteroaryl group).

[0636] In the specification, the group R_{10a} may be:

[0637] deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, or a nitro group;

[0638] a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, or a C_1-C_{60} alkoxy group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_3-C_{60} carbocyclic group, a C_1-C_{60} heterocyclic group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_7-C_{60} aryl alkyl group, a C_2-C_{60} heteroaryl alkyl group, —Si(Q_{11})(Q_{12})(Q_{13}), —N(Q_{11})(Q_{12}), —B(Q_{11})(Q_{12}), —C(=O)(Q_{11}), —S(=O)$_2$(Q_{11}), —P(=O)(Q_{11})(Q_{12}), or any combination thereof;

[0639] a C_3-C_{60} carbocyclic group, a C_1-C_{60} heterocyclic group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_7-C_{60} aryl alkyl group, or a C_2-C_{60} heteroaryl alkyl group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{60} carbocyclic group, a C_1-C_{60} heterocyclic group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_7-C_{60} aryl alkyl group, a C_2-C_{60} heteroaryl alkyl group, —Si(Q_{21})(Q_{22})(Q_{23}), —N(Q_{21})(Q_{22}), —B(Q_{21})(Q_{22}), —C(=O)(Q_{21}), —S(=O)$_2$(Q_{21}), —P(=O)(Q_{21})(Q_{22}), or any combination thereof; or

[0640] —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, or —$P(=O)(Q_{31})(Q_{32})$.

[0641] In the specification, Q_1 to Q_3, Q_{11} to Q_{13}, Q_{21} to Q_{23}, and Q_{31} to Q_{33} may each independently be: hydrogen; deuterium; —F; —Cl; —Br; —I; a hydroxyl group; a cyano group; a nitro group; a C_1-C_{60} alkyl group; a C_2-C_{60} alkenyl group; a C_2-C_{60} alkynyl group; a C_1-C_{60} alkoxy group; a C_3-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group, each unsubstituted or substituted with deuterium, —F, a cyano group, a C_1-C_{60} alkyl group, a C_1-C_{60} alkoxy group, a phenyl group, a biphenyl group, or any combination thereof; a C_7-C_{60} aryl alkyl group; or a C_2-C_{60} heteroaryl alkyl group.

[0642] The term "heteroatom" as used herein may be any atom other than a carbon atom or a hydrogen atom. Examples of a heteroatom may include O, S, N, P, Si, B, Ge, Se, and any combinations thereof.

[0643] In the specification, examples of a "third-row transition metal" may include hafnium (Hf), tantalum (Ta), tungsten (W), rhenium (Re), osmium (Os), iridium (Ir), platinum (Pt), gold (Au), and the like.

[0644] In the specification, the term "Ph" refers to a phenyl group, the term "Me" refers to a methyl group, the term "Et" refers to an ethyl group, the terms "tert-Bu" and "But" each refers to a tert-butyl group, and the term "OMe" refers to a methoxy group.

[0645] The term "biphenyl group" as used herein may be a "phenyl group substituted with a phenyl group." For example, a "biphenyl group" may be a substituted phenyl group having a C_6-C_{60} aryl group as a substituent.

[0646] The term "terphenyl group" as used herein may be a "phenyl group substituted with a biphenyl group". For example, a "terphenyl group" may be a substituted phenyl group having, as a substituent, a C_6-C_{60} aryl group substituted with a C_6-C_{60} aryl group.

[0647] In the specification, the symbols * and *', unless defined otherwise, each refer to a binding site to a neighboring atom in a corresponding formula or moiety.

[0648] In the specification, the terms "x-axis", "y-axis", and "z-axis" are not limited to three axes in an orthogonal coordinate system (for example, a Cartesian coordinate system), and may be interpreted in a broader sense that the aforementioned three axes in an orthogonal coordinate system. For example, the x-axis, y-axis, and z-axis may describe exes that are orthogonal to each other, or may describe axes that are in different directions that are not orthogonal to each other.

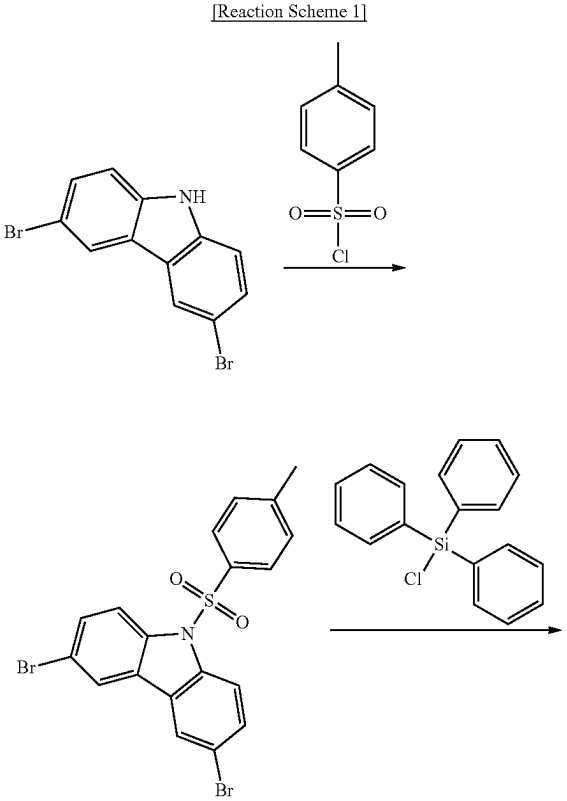
[0649] Hereinafter, compounds according to embodiments and light-emitting devices according to embodiments will be described in detail with reference to the following Synthesis Examples and Examples. The wording "B was used instead of A" used in describing Synthesis Examples means that an identical molar equivalent of B was used in place of A.

EXAMPLES

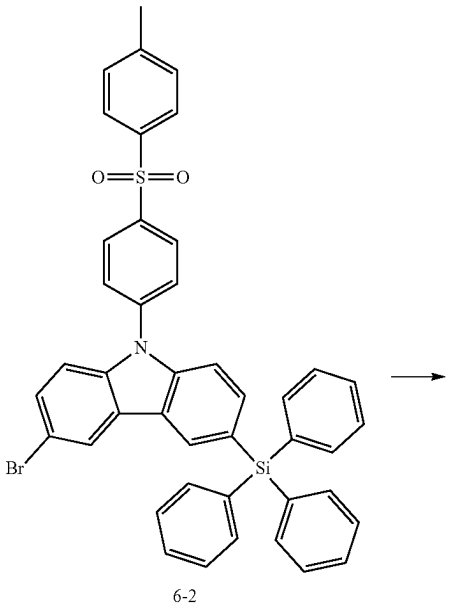
Synthesis Example 1: Synthesis of Compound 6

[0650] Compound 6 according to an embodiment may be synthesized according to, for example, Reaction Scheme 1.

[Reaction Scheme 1]



6-1



6-2

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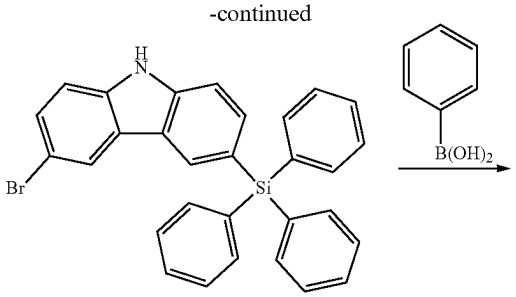

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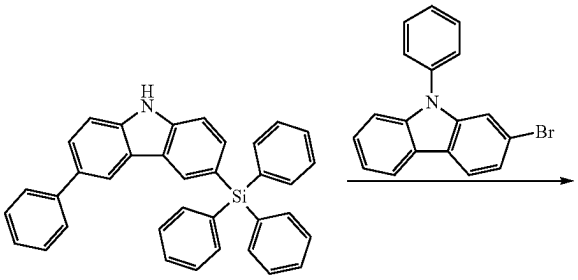
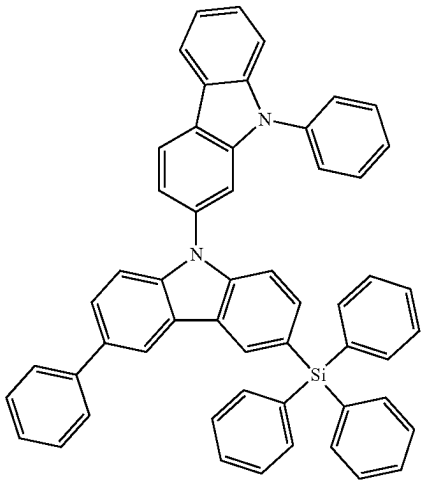


6-4



6

(Synthesis of Intermediate 6-1)

[0651] 3,6-dibromo-9H-carbazole (CAS No.: 6825-20-3), potassium hydroxide, 4-toluenesulfonylchloride (CAS No.: 98-59-9) were reacted to obtain Intermediate 6-1. With regard to Intermediate 6-1, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{19}H_{13}Br_2NO_2S$: M+1 477.90

(Synthesis of Intermediate 6-2)

[0652] Intermediate 6-1 was reacted with n-BuLi, and with chlorotriphenylsilane (CAS No.: 76-86-8) in sequence, and Intermediate 6-2 was obtained. With regard to Intermediate 6-2, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{37}H_{28}BrNO_2SSi$: M+1 658.10

(Synthesis of Intermediate 6-3)

[0653] Intermediate 6-2 and sodium hydroxide were reacted to obtain Intermediate 6-3. With regard to Intermediate 6-3, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{30}H_{22}BrNSi$: M+1 504.10

(Synthesis of Intermediate 6-4)

[0654] Intermediate 6-3 and phenylboronic acid (CAS No.: 98-80-6) were reacted in the presence of Pd catalyst to obtain Intermediate 6-4. With regard to Intermediate 6-4, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{30}H_{22}BrNSi$: M+1 502.20

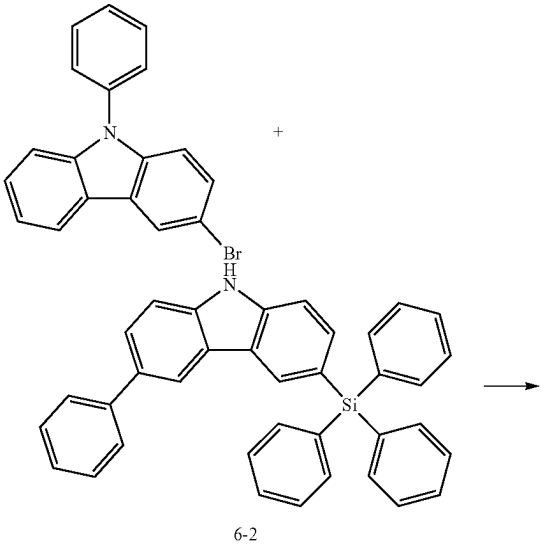
(Synthesis of Compound 6)

[0655] 5 g of 2-bromo-9-phenyl-9H-carbazole (CAS No.: 94994-62-4), 7.8 g of Intermediate 6-4, 2.3 g of sodium tert-butoxide, 0.57 g of tris(dibenzylidene acetone)dipalladium(0), 0.5 mL of tritert-butylphosphine, and 80 mL of toluene were added into a reaction vessel and refluxed for 24 hours. After the reaction was completed, the reaction solution was extracted with ethylacetate, the collected organic layer was dried with magnesium sulfate and a solvent was evaporated therefrom. The obtained residue was separated and purified by silica gel column chromatography to obtain 8 g (yield: 70%) of Compound 6. Compound 6 was identified by LC-MS and 1H-NMR.

Synthesis Example 2: Synthesis of Compound 8

[0656] Compound 8 according to an embodiment may be synthesized according to, for example, Reaction Scheme 2.

[Reaction Scheme 2]



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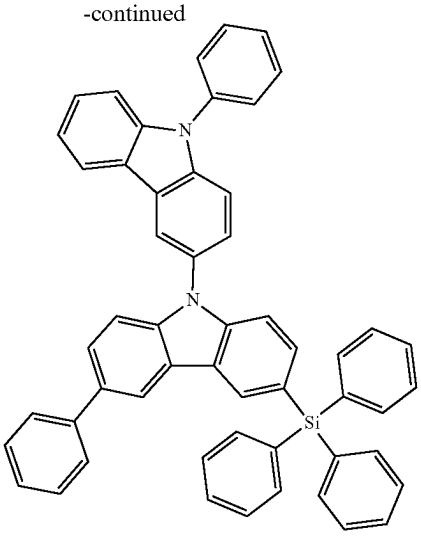


8

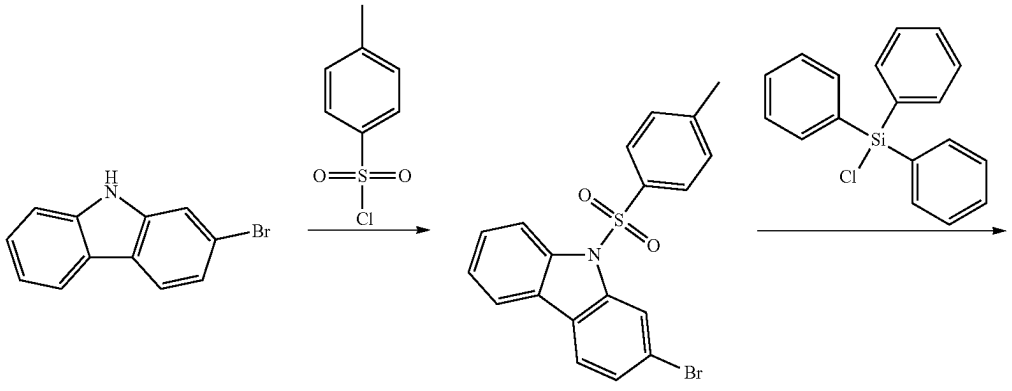
(Synthesis of Compound 8)

[0657] 4 g of 3-bromo-9-phenyl-9H-carbazole (CAS No.: 1153-85-1), 6.2 g of Intermediate 6-2, 1.8 g of sodium tert-butoxide, 0.45 g of tris(dibenzylidene acetone)dipalladium(0), 0.4 mL of tritert-butylphosphine, and 60 mL of toluene were added into a reaction vessel and refluxed for 24 hours. After the reaction was completed, the reaction solution was extracted with ethylacetate, the collected organic layer was dried with magnesium sulfate and a solvent was evaporated therefrom. The obtained residue was separated and purified by silica gel column chromatography to obtain 7 g (yield: 77%) of Compound 8. Compound 8 was confirmed by LC-MS and ^{1}H-NMR.

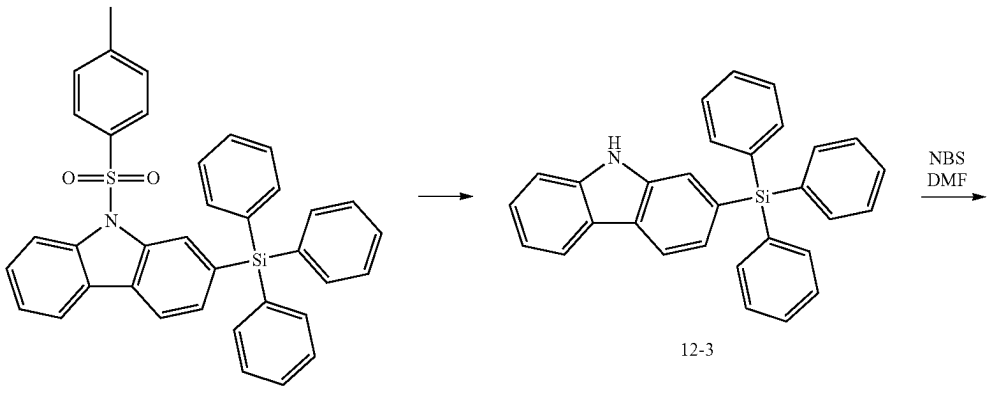
Synthesis Example 3: Synthesis of Compound 12

[0658] Compound 12 according to an embodiment may be synthesized according to, for example, Reaction Scheme 3.

[Reaction Scheme 3]



12-1



12-2

12-3

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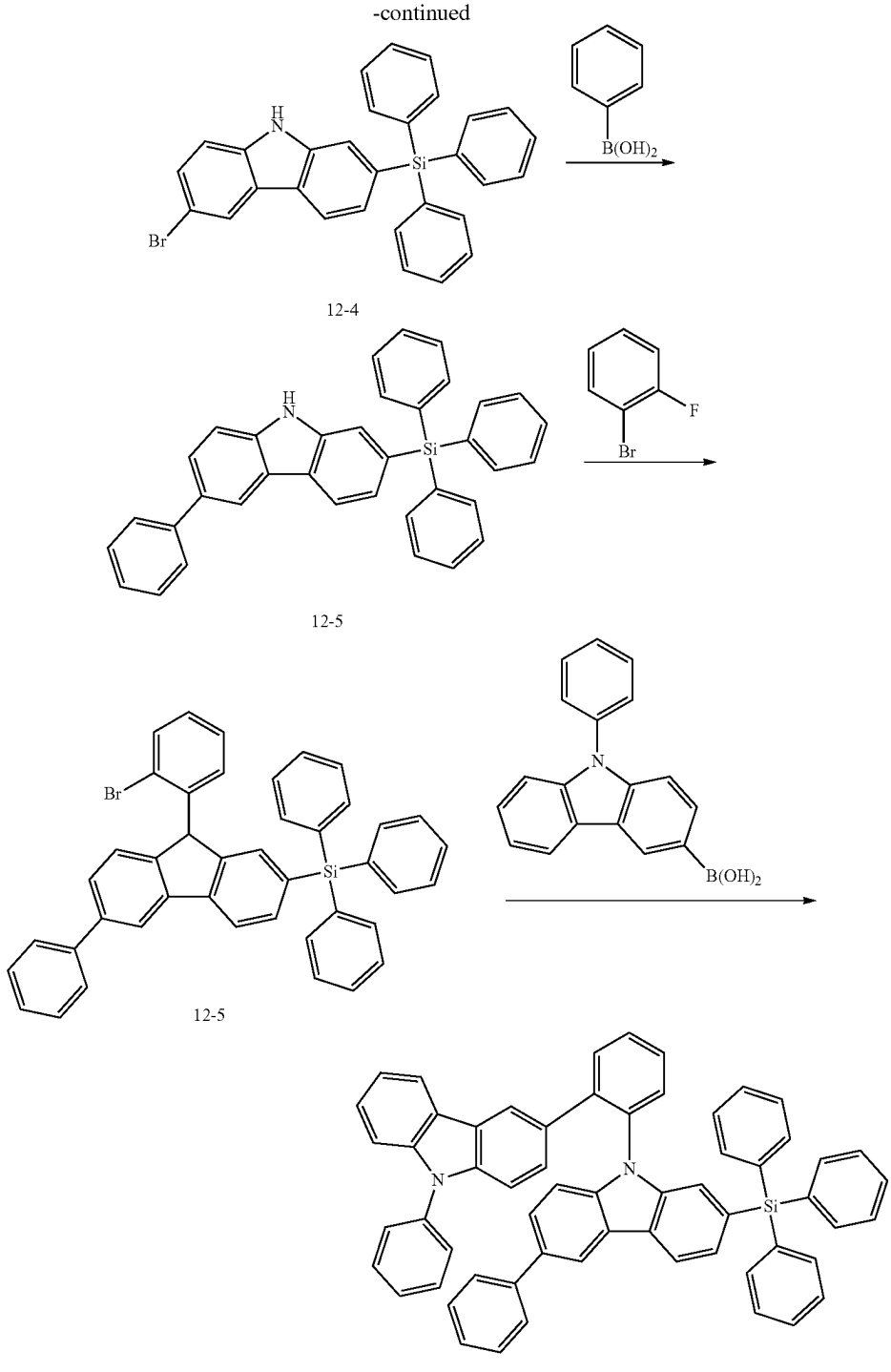


12-4

12-5

12-5

12

(Synthesis of Intermediate 12-1)

[0659] 2-bromo-9H-carbazole (CAS No.: 3652-90-2), potassium hydroxide, 4-toluenesulfonylchloride (CAS No.: 98-59-9) were reacted to obtain Intermediate 12-1. With regard to Intermediate 12-1, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{19}H_{14}BrNO_2S$: M+1 399.99

(Synthesis of Intermediate 12-2)

[0660] Intermediate 12-1 was reacted with n-BuLi, and with chlorotriphenylsilane (CAS No.: 76-86-8) in sequence, and Intermediate 12-2 was obtained. With regard to Intermediate 12-2, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{37}H_{29}NO_2SSi$: M+1 580.19

(Synthesis of Intermediate 12-3)

[0661] Intermediate 12-2 and sodium hydroxide were reacted to obtain Intermediate 12-3. With regard to Intermediate 12-3, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{30}H_{23}NSi$: M+1 426.16

(Synthesis of Intermediate 12-4)

[0662] Intermediate 12-3 and N-bromosuccinimide (CAS No.: 128-08-5) were reacted in the presence of dimethylformamide solvent to obtain Intermediate 12-4. With regard to Intermediate 12-4, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{30}H_{22}BrNSi$: M+1 504.10

(Synthesis of Intermediate 12-5)

[0663] Intermediate 12-4 and phenylboronic acid (CAS No.: 98-80-6) were reacted in the presence of Pd catalyst to obtain Intermediate 12-5. With regard to Intermediate 12-5, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{30}H_{22}BrNSi$: M+1 502.20

(Synthesis of Intermediate 12-6)

[0664] Intermediate 12-5 and 1-bromo-2-fluorobenzene (CAS No.: 1072-85-1) were reacted in the presence of dimethylformamide solvent to obtain Intermediate 12-6. With regard to Intermediate 12-6, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{42}H_{30}BrNSi$: M+1 656.13

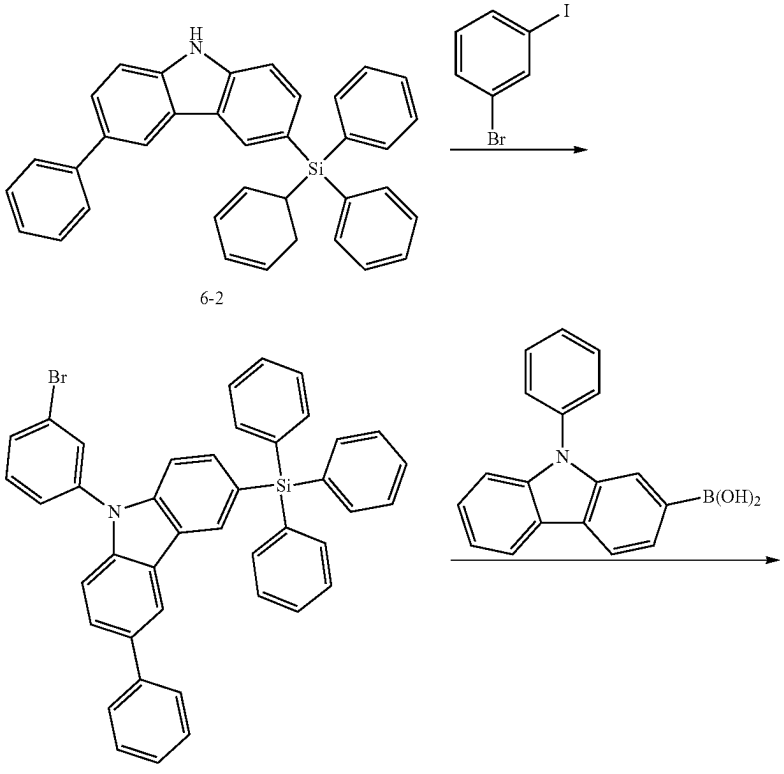
(Synthesis of Compound 12)

[0665] 4 g of Intermediate 12-6, 1.8 g of (9-phenyl-9H-carbazole-3-yl) boronic acid (CAS No.: 854952-58-2), 0.35 g of tetrakis(triphenylphosphine) palladium, and 2.1 g of potassium carbonate were added into a reaction vessel and dissolved in 32 mL of tetrahydrofuran and 8 mL of distilled water. The mixture was refluxed for 24 hours. After the reaction was completed, the reaction solution was extracted with ethylacetate, the collected organic layer was dried with magnesium sulfate and a solvent was evaporated therefrom. The obtained residue was separated and purified by silica gel column chromatography to obtain 3 g (yield: 60%) of Compound 12. Compound 12 was confirmed by LC-MS and ^{1}H-NMR.

Synthesis Example 4: Synthesis of Compound 25

[0666] Compound 25 according to an embodiment may be synthesized according to, for example, Reaction Scheme 4.

[Reaction Scheme 4]



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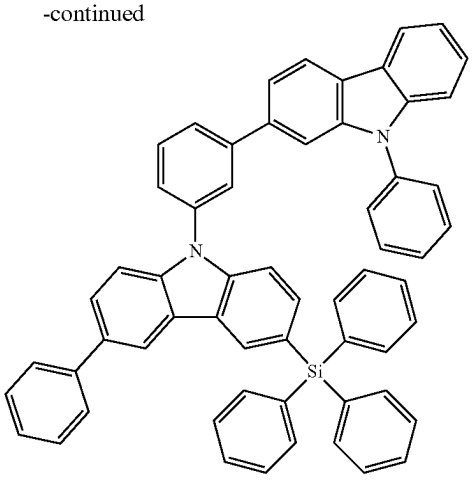


25

(Synthesis of Intermediate 25-1)

[0667] Intermediate 6-2 and 1-bromo-3-iodoa benzene (CAS No.: 591-18-4) were reacted in the presence of Cu catalyst to obtain Intermediate 25-1. With regard to Intermediate 25-1, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{42}H_{30}BrNSi$: M+1 656.13

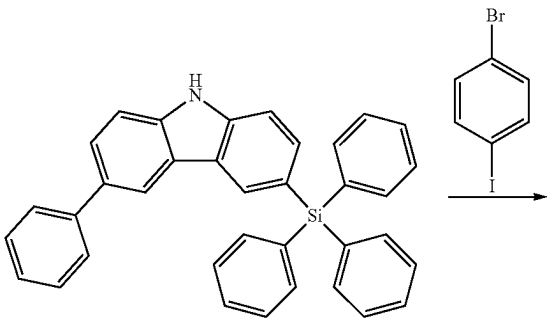
(Synthesis of Compound 25)

[0668] 6 g of Intermediate 25-1, 2.6 g of (9-phenyl-9H-carbazole-2-yl) boronic acid (CAS No.: 1001911-63-2), 0.53 g of tetrakis(triphenylphosphine) palladium, and 3.2 g of potassium carbonate were added into a reaction vessel and dissolved in 44 mL of tetrahydrofuran and 11 mL of distilled water. The mixture was refluxed for 24 hours. After the reaction was completed, the reaction solution was extracted with ethylacetate, the collected organic layer was dried with magnesium sulfate and a solvent was evaporated therefrom. The obtained residue was separated and purified by silica gel column chromatography to obtain 4.8 g (yield: 64%) of compound 25. Compound 25 was identified by LC-MS and ^{1}H-NMR.

Synthesis Example 5: Synthesis of Compound 37

[0669] Compound 37 according to an embodiment may be synthesized according to, for example, Reaction Scheme 5.

[Reaction Scheme 5]



6-2

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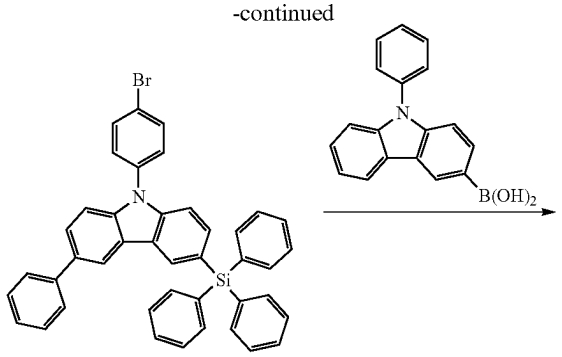
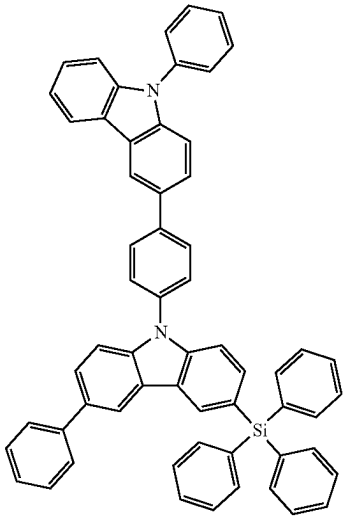


37-1



37

(Synthesis of Intermediate 37-1)

[0670] Intermediate 6-2 and 1-bromo-4-iodoa benzene (CAS No.: 589-87-7) were reacted in the presence of Cu catalyst to obtain Intermediate 37-1. With regard to Inter-

mediate 37-1, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{42}H_{30}BrNSi$: M+1 656.13

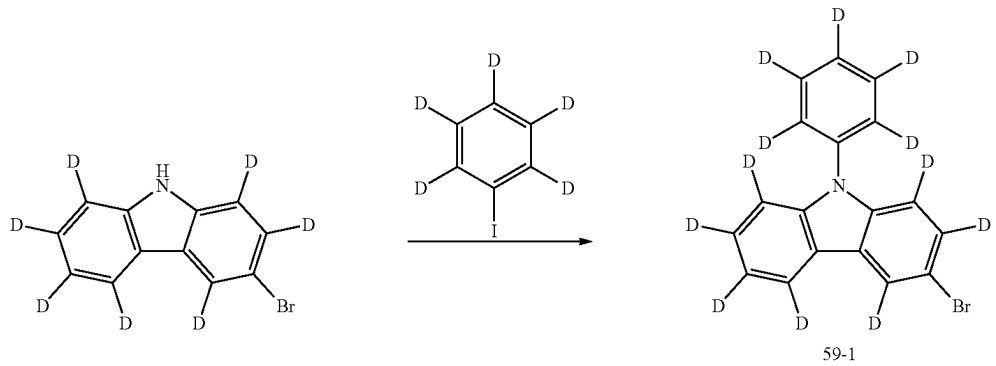
(Synthesis of Compound 37)

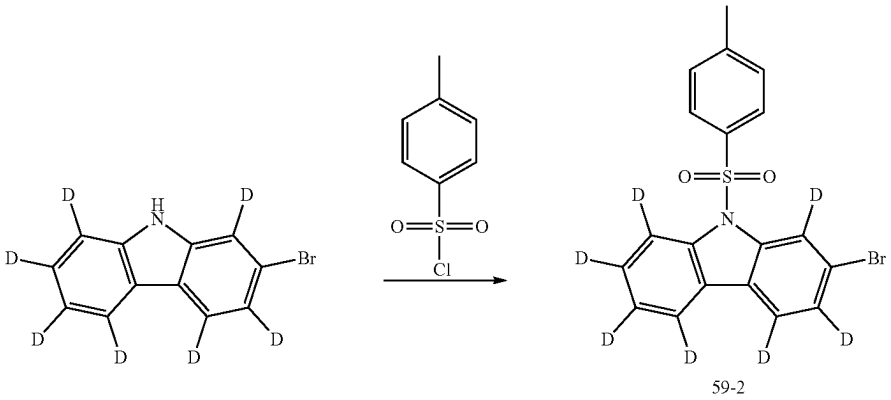
[0671] 4.8 g of Intermediate 37-1, 2.3 g of (9-phenyl-9H-carbazole-3-yl) boronic acid (CAS No.: 854952-58-2), 0.42 g of tetrakis(triphenylphosphine) palladium, and 2.5 g of potassium carbonate were added into a reaction vessel and dissolved in 40 mL of tetrahydrofuran and 10 mL of distilled water. The mixture was refluxed for 24 hours. After the reaction was completed, the reaction solution was extracted with ethylacetate, the collected organic layer was dried with magnesium sulfate and a solvent was evaporated therefrom. The obtained residue was separated and purified by silica gel column chromatography to 4.5 g (yield: 75%) of Compound 37. Compound 37 was confirmed by LC-MS and ^{1}H-NMR.

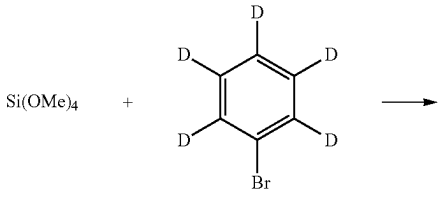
Synthesis Example 6: Synthesis of Compound 59

[0672] Compound 59 according to an embodiment may be synthesized according to, for example, Reaction Scheme 6.

[Reaction Scheme 6]







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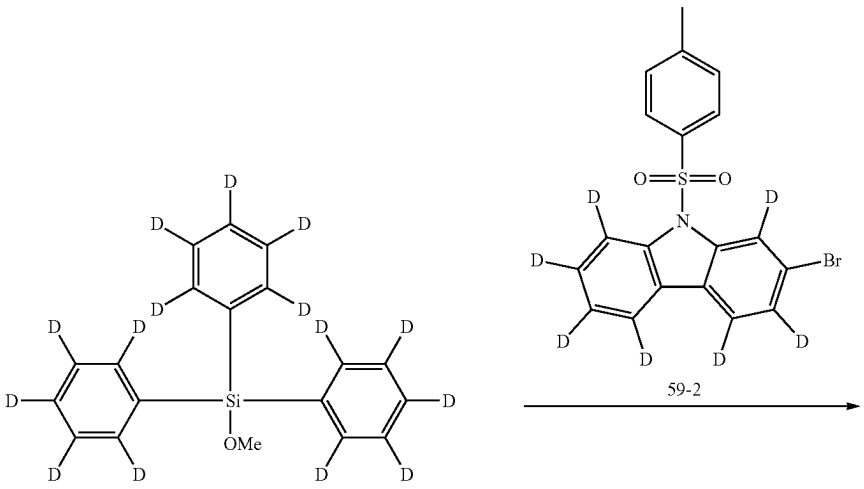
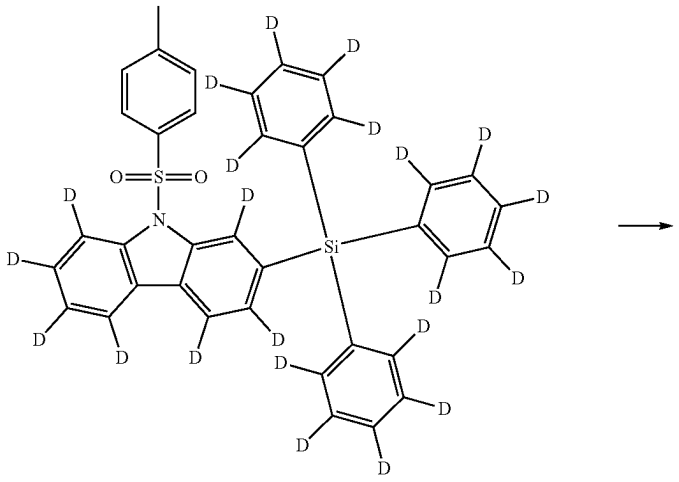
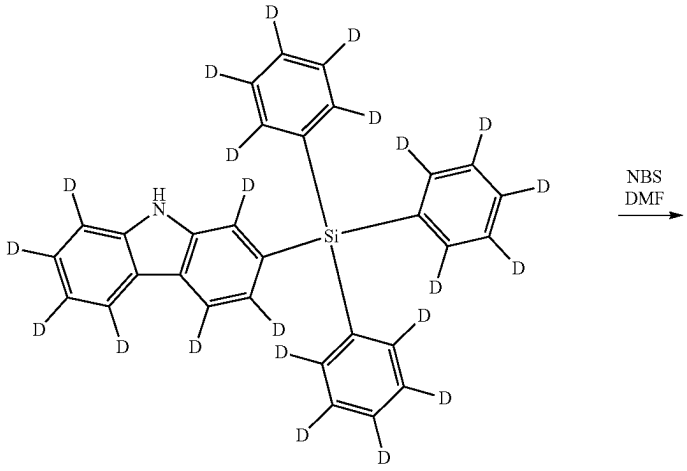


59-3

59-2



59-4



NBS
DMF

59-5

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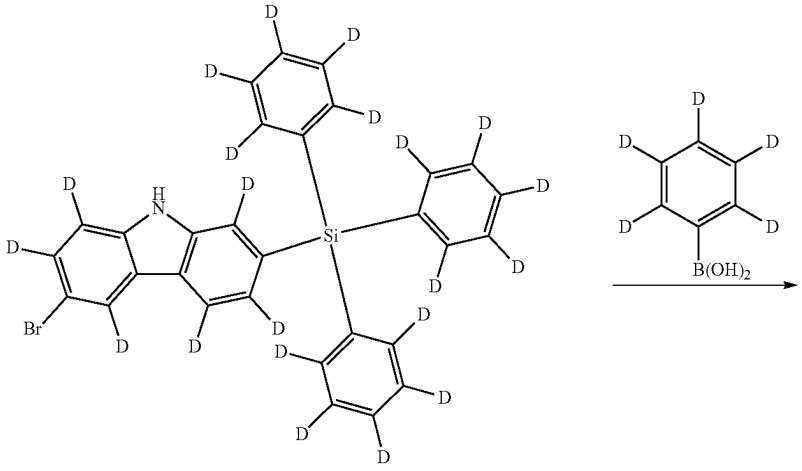
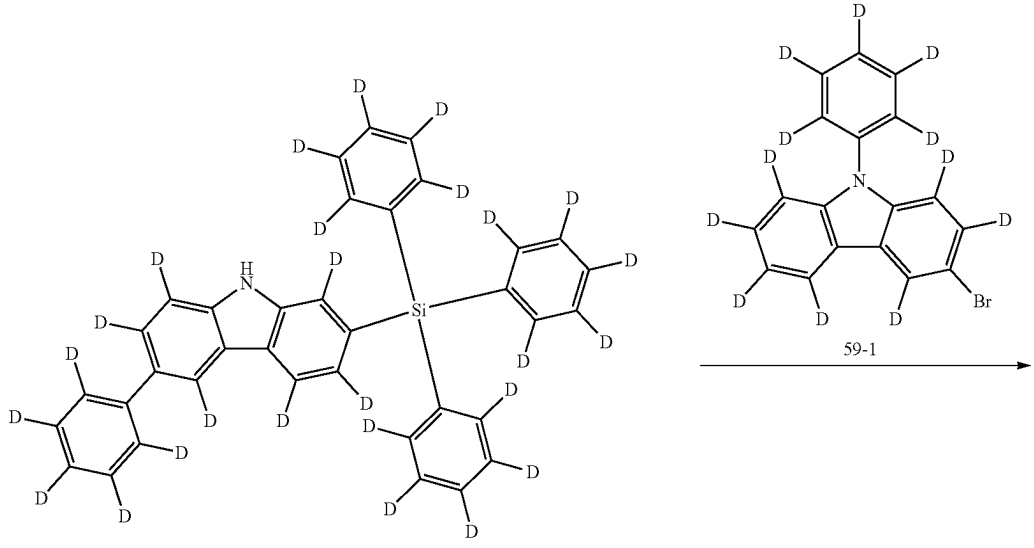


59-6



59-7

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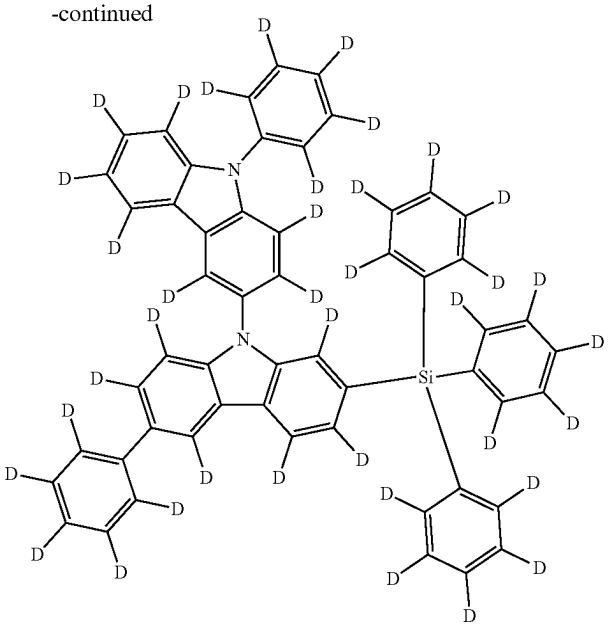


59

(Synthesis of Intermediate 59-1)

[0673] 3-bromo-9H-carbazole-1,2,4,5,6,7,8-d_7 (CAS No.: 1592-95-6) and iodobenzene-ds (CAS No.: 7379-67-1) were reacted in the presence of Cu catalyst to obtain Intermediate 59-1. With regard to Intermediate 59-1, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{18}D_{12}BrN$: M+1 334.08

(Synthesis of Intermediate 59-2)

[0674] 2-bromo-9-phenyl-9H-carbazole (CAS No.: 94994-62-4), potassium hydroxide, 4-toluenesulfonylchloride (CAS No.: 98-59-9) were reacted to obtain Intermediate 59-2. With regard to Intermediate 59-2, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{19}H_7D_7BrNO_2S$: M+1 407.03

(Synthesis of Intermediate 59-3)

[0675] Bromobenzene-d_5 (CAS No.: 4165-57-5) was reacted with n-BuLi, and with tetramethyl silicate (CAS No.: 681-84-5) to obtain Intermediate 59-3. With regard to Intermediate 59-3, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{19}H_3D_{15}OSi$: M+1 306.20

(Synthesis of Intermediate 59-4)

[0676] Intermediate 59-2 was reacted with n-BuLi, and with Intermediate 59-3 to obtain Intermediate 59-4. With regard to Intermediate 59-4, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{37}H_7D_{22}NO_2SSi$: M+1 602.30

(Synthesis of Intermediate 59-5)

[0677] Intermediate 59-4 and sodium hydroxide were reacted to obtain Intermediate 59-5. With regard to Intermediate 59-5, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{30}HD_{22}NSi$: M+1 448.30

(Synthesis of Intermediate 59-6)

[0678] Intermediate 59-5 and N-bromosuccinimide (CAS No.: 128-08-5) were reacted in the presence of dimethylformamide solvent to obtain Intermediate 59-6. With regard to Intermediate 59-6, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{30}HD_{21}BrNSi$: M+1 525.20

(Synthesis of Intermediate 59-7)

[0679] Intermediate 59-6 and (phenyl-d_5) boronic acid (CAS No.: 215527-70-1) were reacted in the presence of Pd catalyst to obtain Intermediate 59-7. With regard to Intermediate 59-7, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{36}HD_{26}NSi$: M+1 528.35

(Synthesis of Compound 59)

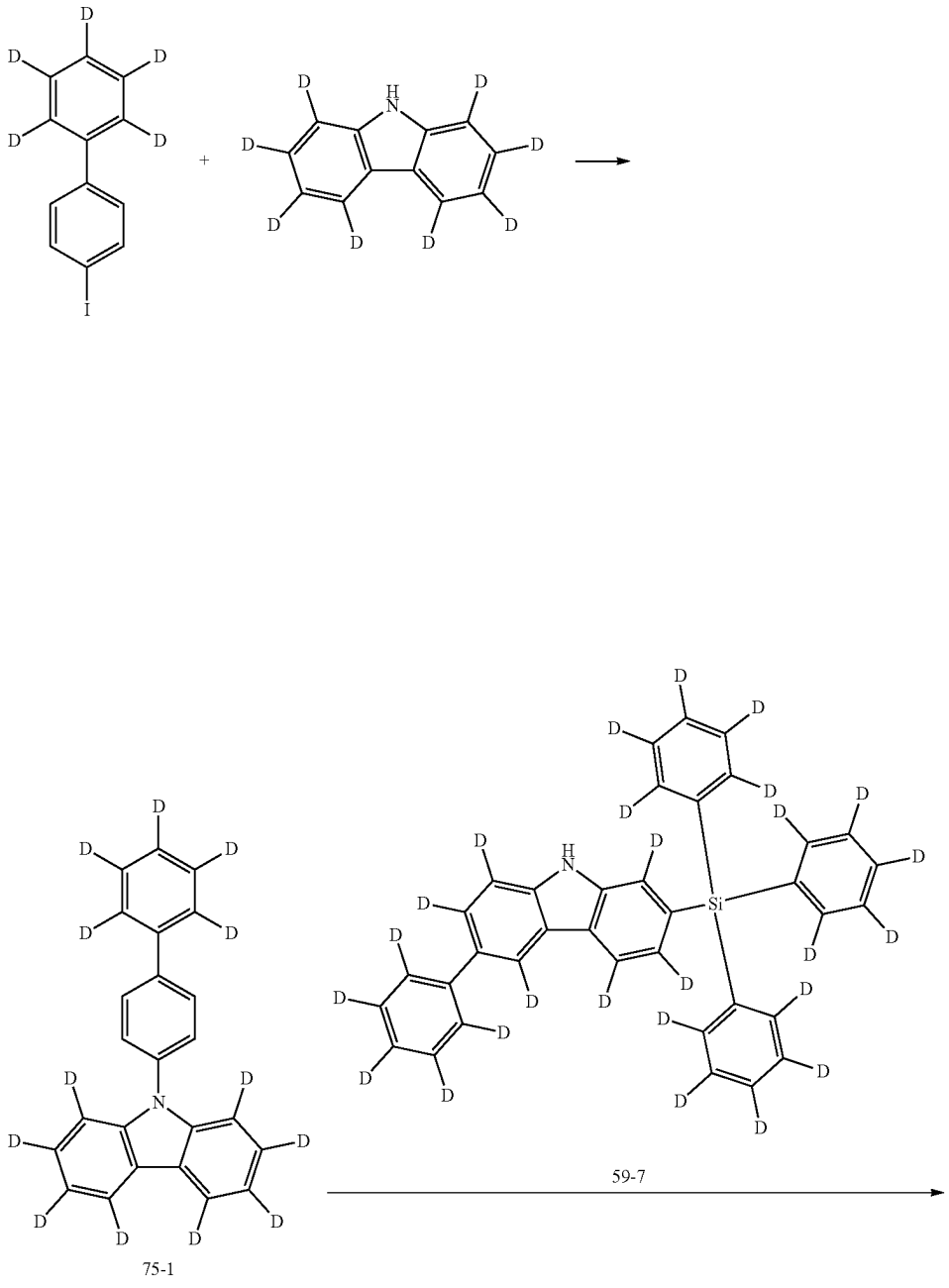
[0680] 2.4 g of Intermediate 59-1, 3.8 g of Intermediate 59-7, 1 g of sodium tert-butoxide, 0.26 g of tris(dibenzylideneacetone)dipalladium(0), 0.23 mL of tritert-butylphos-

phine, and 36 mL of toluene were added into a reaction vessel and refluxed for 24 hours. After the reaction was completed, the reaction solution was extracted with ethyl-acetate, the collected organic layer was dried with magnesium sulfate and a solvent was evaporated therefrom. The obtained residue was separated and purified by silica gel column chromatography to obtain 3.8 g (yield: 68%) of compound 59. Compound 59 was identified by LC-MS and ^{1}H-NMR.

Synthesis Example 7: Synthesis of Compound 75

[0681] Compound 75 according to an embodiment may be synthesized according to, for example, Reaction Scheme 7.

[Reaction Scheme 7]



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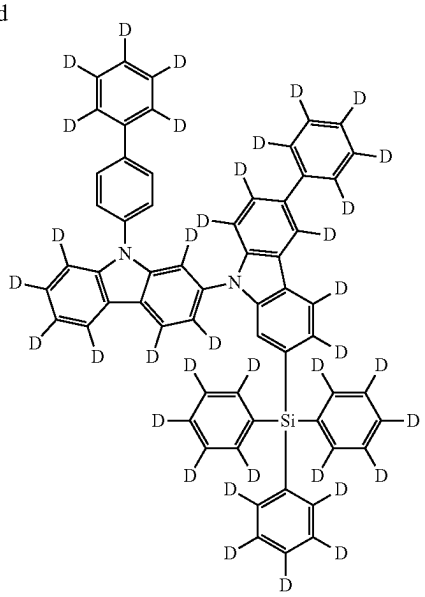


75

(Synthesis of Intermediate 75-1)

[0682] 4-iodo-1,1'-biphenyl-2',3',4',5',6'-d_5 (CAS No.: 1453088-17-9) and 2-bromo-9H-carbazole-1,3,4,5,6,7,8-d_7 (CAS No.: 2650519-97-2) were reacted in the presence of Cu catalyst to obtain Intermediate 75-1. With regard to Intermediate 75-1, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{24}H_4D_{12}BrN$: M+1 410.11

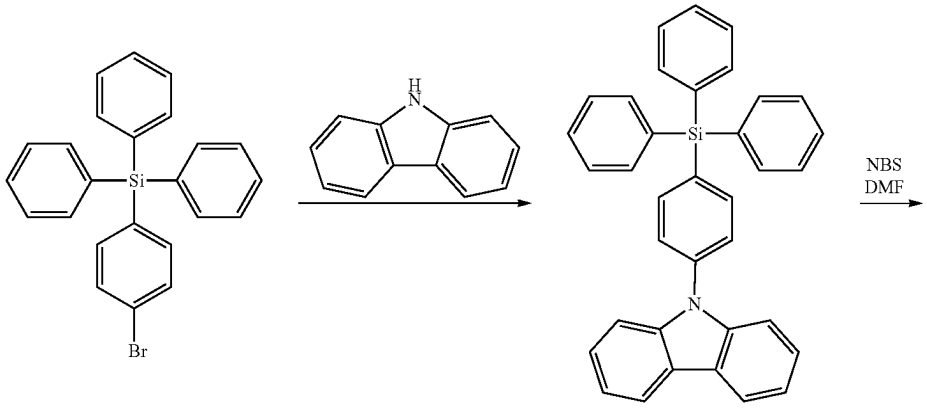
(Synthesis of Compound 75)

[0683] 2.6 g of Intermediate 75-1, 3.4 g of Intermediate 59-7, 0.92 g of sodium tert-butoxide, 0.23 g of tris(dibenzylideneacetone)dipalladium(0), 0.2 mL of tritert-butylphosphine, and 32 mL of toluene were added into a reaction vessel and refluxed for 24 hours. After the reaction was completed, the reaction solution was extracted with ethylacetate, the collected organic layer was dried with magnesium sulfate and a solvent was evaporated therefrom. The obtained residue was separated and purified by silica gel column chromatography to obtain 3 g (yield: 55%) of compound 75. Compound 75 was identified by LC-MS and ^{1}H-NMR.

Synthesis Example 8: Synthesis of Compound 149

[0684] Compound 149 according to an embodiment may be synthesized according to, for example, Reaction Scheme 8.

[Reaction Scheme 8]



149-1

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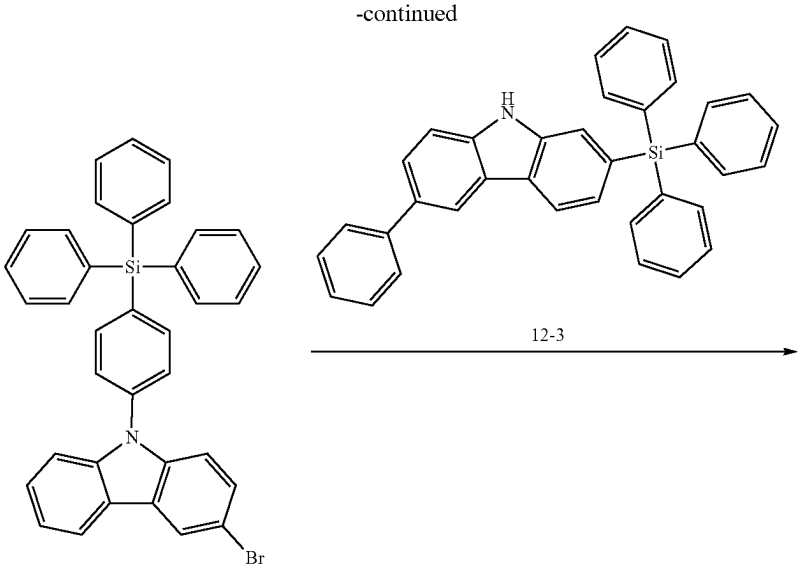
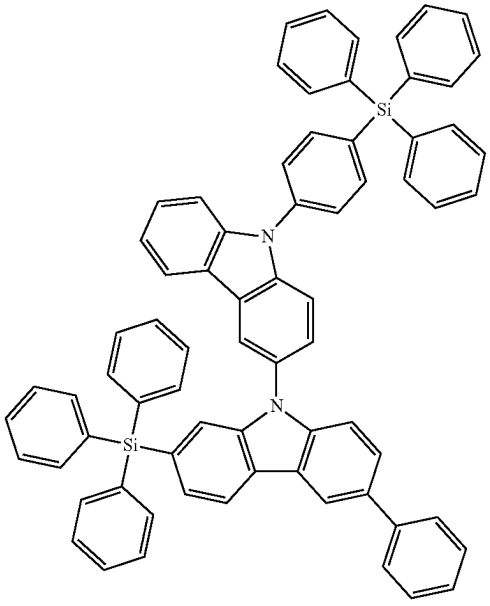


149-2



149

(Synthesis of Intermediate 149-1)

[0685] (4-bromophenyl)triphenylsilane (CAS No.: 18737-40-1) and 9H-carbazole (CAS No.: 86-74-8) were reacted in the presence of Pd catalyst to obtain Intermediate 149-1. With regard to Intermediate 149-1, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{36}H_{27}NSi$: M+1 502.20

(Synthesis of Intermediate 149-2)

[0686] Intermediate 149-1 and N-bromosuccinimide (CAS No.: 128-08-5) were reacted in the presence of dimethylformamide solvent to obtain Intermediate 149-2. With regard to Intermediate 149-2, the following M+1 peak value was confirmed by liquid chromatography mass spectrometry (LC-MS).

$C_{36}H_{26}BrNSi$: M+1 580.10

(Synthesis of Compound 149)

[0687] 3.4 g of Intermediate 149-2, 3 g of Intermediate 12-3, 0.85 g of sodium tert-butoxide, 0.22 g of tris(dibenzylideneacetone)dipalladium(0), 0.19 mL of tritert-butylphosphine, and 30 mL of toluene were added into a reaction vessel and refluxed for 24 hours. After the reaction was completed, the reaction solution was extracted with ethylacetate, the collected organic layer was dried with

magnesium sulfate and a solvent was evaporated therefrom. The obtained residue was separated and purified by silica gel column chromatography to obtain 4.3 g (yield: 73%) of Compound 149. Compound 149 was confirmed by LC-MS and ^{1}H-NMR.

[0688] MS/FAB of the compounds synthesized according to the Synthesis Examples are shown in Table 1. Synthesis methods of other compounds in addition to the compounds synthesized in the Synthesis Examples may be readily recognized by those skilled in the art by referring to the synthesis paths and source materials.

TABLE 1

Compound No.	MS/FAB found [M + 1]	MS/FAB calc.
6	743.3	742.28
8	743.3	742.28
12	819.3	818.31
25	819.3	818.31
37	819.3	818.31
59	781.5	780.52
75	857.5	856.55
149	1001.3	1000.37

Evaluation Example 1

[0689] The HOMO energy level (eV) and the LUMO energy level (eV) of Compounds 6, 8, 12, 25, 37, 59, 75, and 149 were evaluated by the DFT method of Gaussian program structurally optimized at a level of B3LYP/6-31G(d,p), and the results thereof are shown in Table 2.

TABLE 2

Compound No.	HOMO (eV)	LUMO (eV)
6	−5.42	−1.30
8	−5.38	−1.30
12	−5.41	−1.16
25	−5.47	−1.44
37	−5.41	−1.20
59	−5.35	−1.25
75	−5.40	−1.37
149	−5.35	−1.24

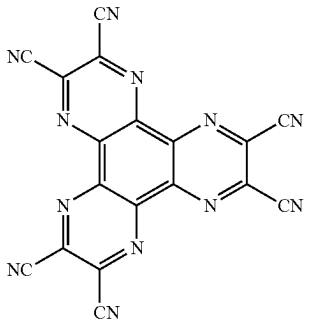
Example 1

[0690] As an anode, a Corning 15 Ω/cm^2 (1,200 Å) ITO glass substrate was cut to a size of 50 mm×50 mm×0.5 mm, sonicated with isopropyl alcohol and pure water each for 5 minutes, and cleaned by exposure to ultraviolet rays and ozone for 30 minutes. The ITO glass substrate was provided to a vacuum deposition apparatus.

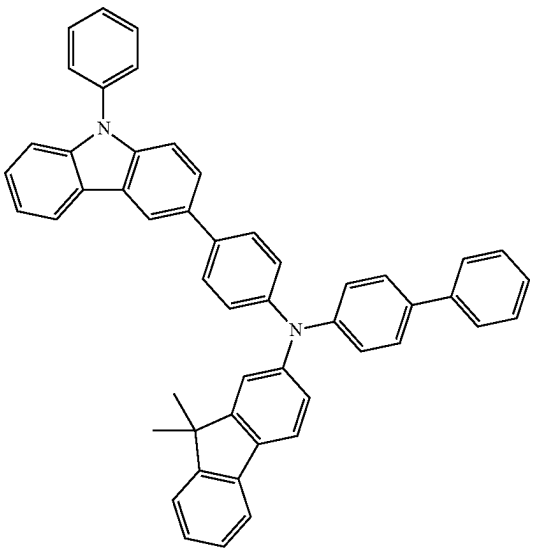
[0691] HATCN was formed on the substrate as a hole injection layer having a thickness of 100 Å, and BCFN, which is a first hole transport material, was vacuum-deposited thereon at a thickness of 600 Å. SiCzCz, which is a hole transport material, was vacuum-deposited as a second hole transporting compound to form a hole transport layer having a thickness of 50 Å.

[0692] SiTrzCz2 and Compound 6 as a host and PtON-TBBI as a phosphorescent dopant were co-deposited at a weight ratio of 60:27:13 on the hole transport layer to form an emission layer having a thickness of 350 Å.

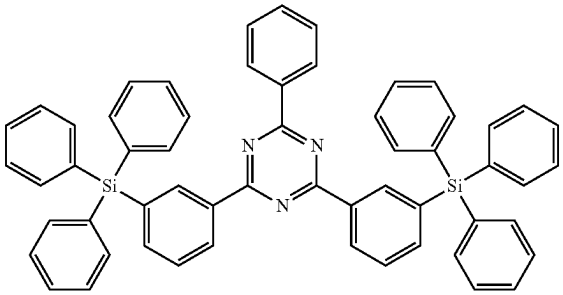
[0693] On the emission layer, mSiTrz was deposited as a first electron transport layer having a thickness of 50 Å, and mSiTrz and LiQ were co-deposited as a second electron transport layer at a weight ratio of 1:1 to form an electron transport layer having a thickness of 350 Å. LiF, which is a halogenated alkaline metal, was deposited on the electron transport layer to form an electron injection layer having a thickness of 15 Å, and Al was vacuum-deposited to form a LiF/Al electrode having a thickness of 80 Å, thereby completing the manufacture of an organic light-emitting device.



HATCN



BCFN



mSiTrz

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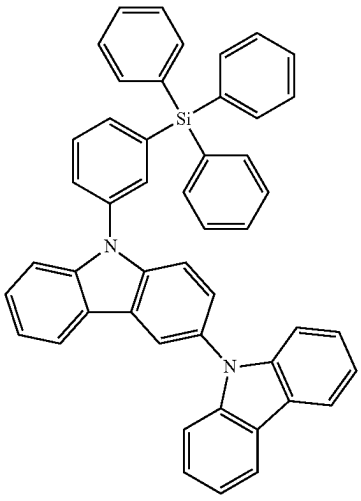
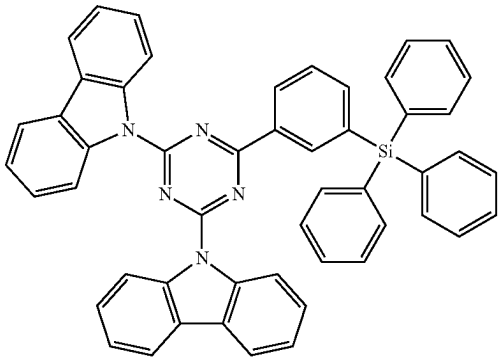


SiCzCz



SiTrzCz2

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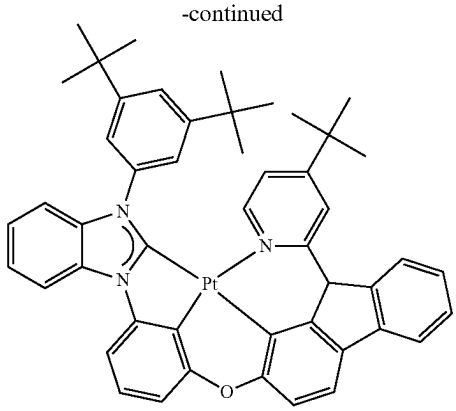

PtON-TBBI

Examples 2 to 8 and Comparative Examples 1 to 6

[0694] Organic light-emitting devices were manufactured in the same manner as in Example 1, except that, in forming an emission layer, Compound 6 as a host was changed as shown in Table 3.

Evaluation Example 2

[0695] To evaluate the characteristics of the organic light-emitting devices according to Examples 1 to 8 and Comparative Examples 1 to 6, driving voltage at a current density of 10 mA/cm^2, current density, and maximum quantum efficiency were measured.

[0696] The driving voltage and current density of the organic light-emitting devices were measured by using a source meter (Keithley Instrument Inc., 2400 series), and the maximum quantum efficiency was measured by using the external quantum efficiency measurement device C9920-2-12 of Hamamatsu Photonics Inc.

[0697] In evaluating the maximum quantum efficiency, the luminance/current density was measured by using a luminance meter that was calibrated for wavelength sensitivity, and the maximum quantum efficiency was converted by assuming an angular luminance distribution (Lambertian) which introduced a perfect reflecting diffuser.

[0698] Table 3 below shows the evaluation results of the characteristics of the organic light-emitting devices.

TABLE 3

Classification	Host in emission layer	Driving voltage (V)	Current density (mA/cm^2)	Maximum quantum efficiency (%)	Emission color
Example 1	Compound 6	4.8	10	26.5	Blue
Example 2	Compound 8	4.7	10	26.8	Blue
Example 3	Compound 12	4.6	10	27.3	Blue
Example 4	Compound 25	4.8	10	26.1	Blue
Example 5	Compound 37	4.6	10	25.3	Blue
Example 6	Compound 59	4.4	10	27.1	Blue
Example 7	Compound 75	4.5	10	27.8	Blue
Example 8	Compound 149	4.7	10	28.1	Blue
Comparative Example 1	C1	5.4	10	22.4	Blue
Comparative Example 2	C2	5.5	10	22.8	Blue
Comparative Example 3	C3	5.2	10	23.1	Blue
Comparative Example 4	C4	5.2	10	22.2	Blue
Comparative Example 5	C5	5.3	10	21.9	Blue

TABLE 3-continued

Classification	Host in emission layer	Driving voltage (V)	Current density (mA/cm^2)	Maximum quantum efficiency (%)	Emission color
Comparative Example 6	C6	5.5	10	22.1	Blue

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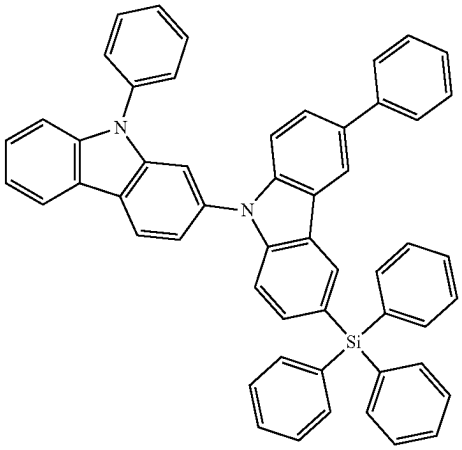

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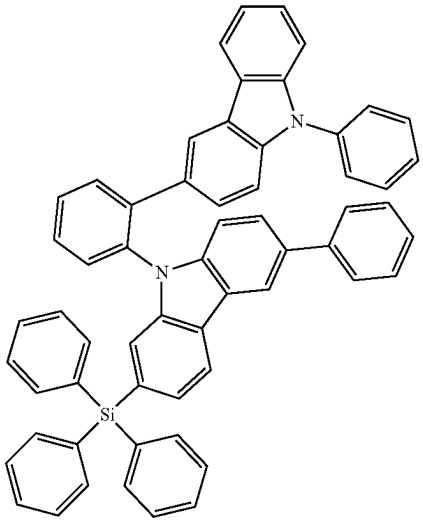

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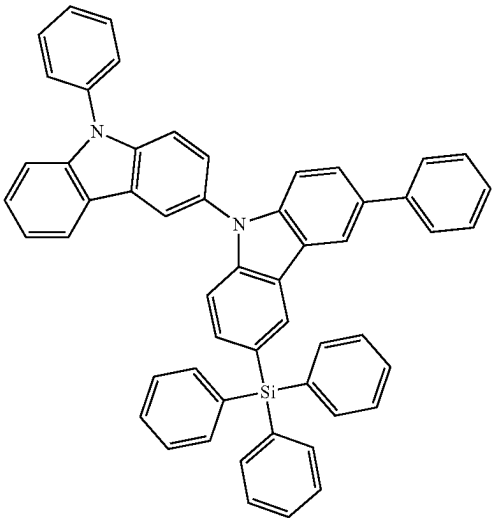

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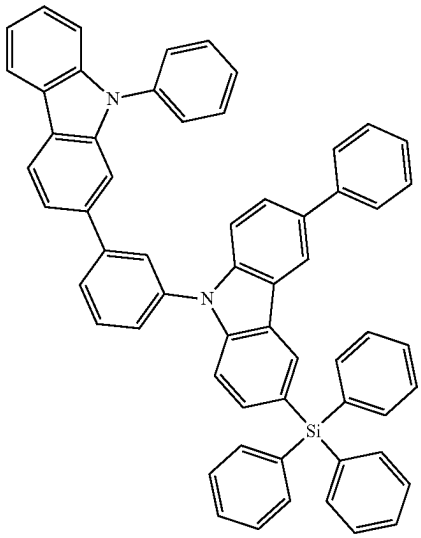

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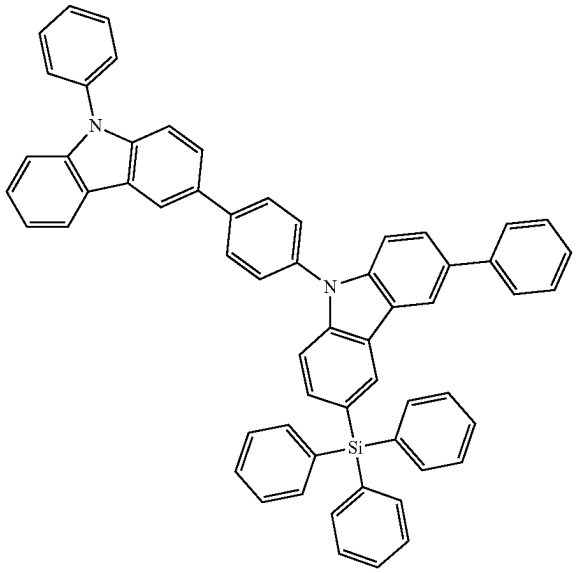

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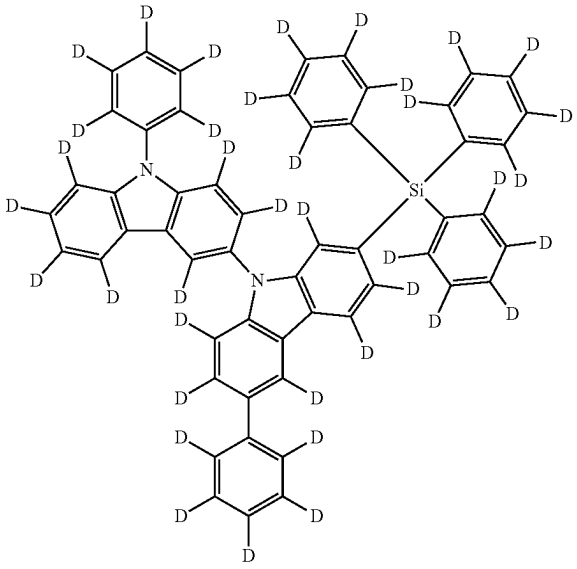

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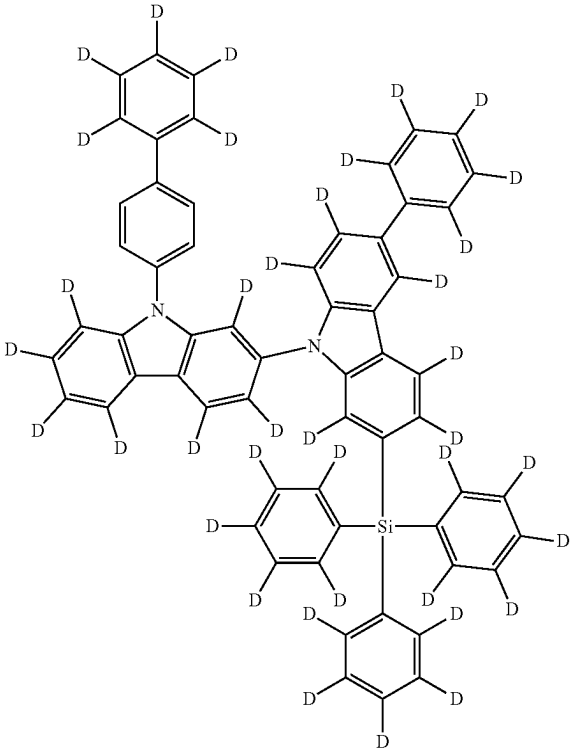

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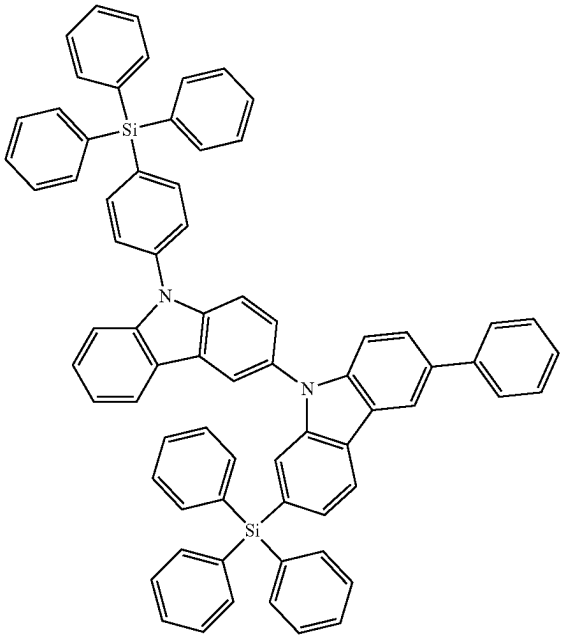

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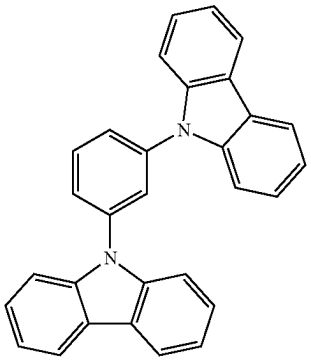
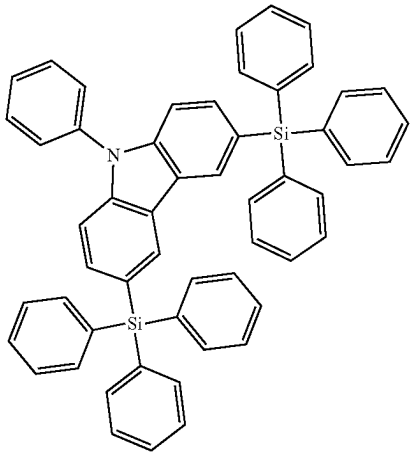
C1



C2



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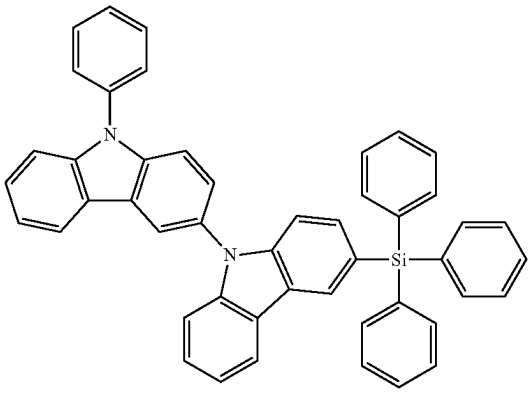

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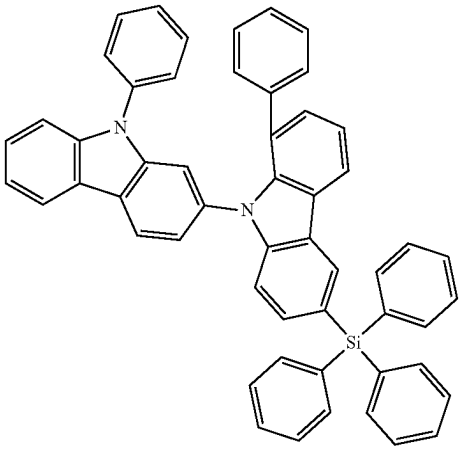
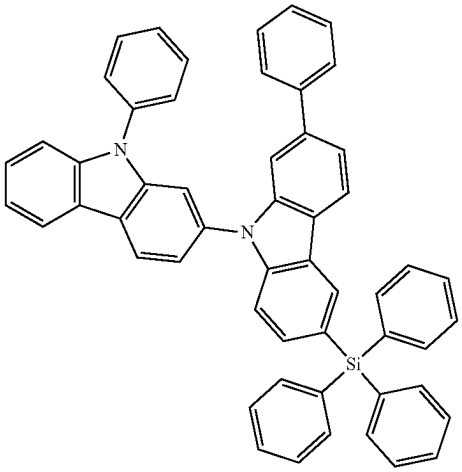
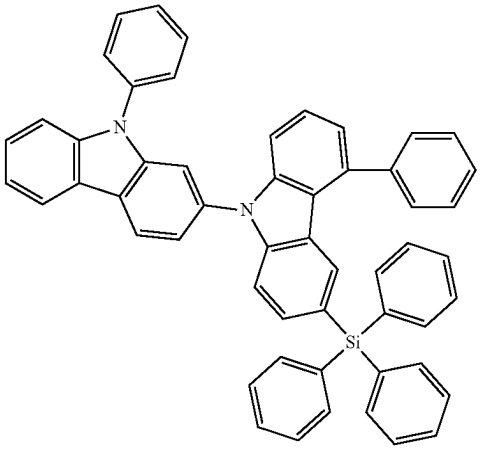
C4



C5



C6



[0699] From Table 3, it was confirmed that the organic light-emitting devices according to Examples 1 to 8 had a lower driving voltage and higher maximum quantum efficiency than the organic light-emitting devices according to Comparative Examples 1 to 6.

[0700] By using the heterocyclic compound, a light-emitting device having a lower driving voltage, higher efficiency,

and longer lifespan, and a high-quality electronic apparatus including the light-emitting device may be manufactured.

[0701] Embodiments have been disclosed herein, and although terms are employed, they are used and are to be interpreted in a generic and descriptive sense only and not for the purposes of limitation. In some instances, as would be apparent by one of ordinary skill in the art, features, characteristics, and/or elements described in connection with an embodiment may be used singly or in combination with features, characteristics, and/or elements described in connection with other embodiments unless otherwise specifically indicated. Accordingly, it will be understood by those of ordinary skill in the art that various changes in form and details may be made without departing from the spirit and scope of the disclosure as set forth in the claims.

What is claimed is:

1. A light-emitting device comprising:

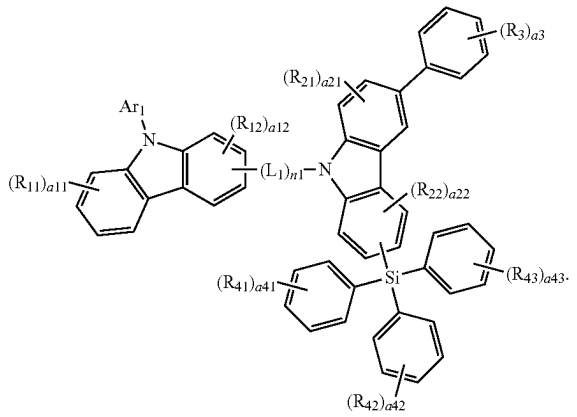
a first electrode;

a second electrode facing the first electrode;

an interlayer between the first electrode and the second electrode and comprising an emission layer; and

a heterocyclic compound represented by Formula 1:

[Formula 1]



wherein in Formula 1,

R_{11}, R_{12}, R_{21}, R_{22}, R_3, and R_{41} to R_{43} are each independently hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{60} alkyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} alkenyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} alkynyl group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} alkoxy group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} alkylthio group unsubstituted or substituted with at least one R_{10a}, a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}, a C_6-C_{60} aryloxy group unsubstituted or substituted with at least one R_{10a}, a C_6-C_{60} arylthio group unsubstituted or substituted with at least one R_{10a}, —$C(Q_1)(Q_2)(Q_3)$, —$Si(Q_1)(Q_2)(Q_3)$, —$N(Q_1)(Q_2)$, —$B(Q_1)(Q_2)$, —$C(=O)(Q_1)$, —$S(=O)_2(Q_1)$, or —$P(=O)(Q_1)(Q_2)$,

a11 is an integer from 1 to 4,

a12, a21, and a22 are each independently an integer from 1 to 3,

a3 and a41 to a43 are each independently an integer from 1 to 5,

L_1 is a single bond, a C_5-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, or a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a},

n1 is an integer from 1 to 3,

Ar_1 is a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}, —$C(Q_1)(Q_2)(Q_3)$, —$Si(Q_1)(Q_2)(Q_3)$, —$N(Q_1)(Q_2)$, or —$B(Q_1)(Q_2)$,

R_{10a} is:

deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, or a nitro group;

a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, or a C_1-C_{60} alkoxy group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_5-C_{60} carbocyclic group, a C_1-C_{60} heterocyclic group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, —$Si(Q_{11})(Q_{12})(Q_{13})$, —$N(Q_{11})(Q_{12})$, —$B(Q_{11})(Q_{12})$, —$C(=O)(Q_{11})$, —$S(=O)_2(Q_{11})$, —$P(=O)(Q_{11})(Q_{12})$, or a combination thereof;

a C_3-C_{60} carbocyclic group, a C_1-C_{60} heterocyclic group, a C_6-C_{60} aryloxy group, or a C_6-C_{60} arylthio group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{60} carbocyclic group, a C_1-C_{60} heterocyclic group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, —$Si(Q_{21})(Q_{22})(Q_{23})$, —$N(Q_{21})(Q_{22})$, —$B(Q_{21})(Q_{22})$, —$C(=O)(Q_{21})$, —$S(=O)_2(Q_{21})$, —$P(=O)(Q_{21})(Q_{22})$, or a combination thereof; or

—$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, or —$P(=O)(Q_{31})(Q_{32})$, and

Q_1 to Q_3, Q_{11} to Q_{13}, Q_{21} to Q_{23}, and Q_{31} to Q_{33} are each independently:

hydrogen; deuterium; —F; —Cl; —Br; —I; a hydroxyl group; a cyano group; a nitro group; a C_1-C_{60} alkyl group; a C_2-C_{60} alkenyl group; a C_2-C_{60} alkynyl group; a C_1-C_{60} alkoxy group; or a C_5-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group, each unsubstituted or substituted with deuterium, —F, a cyano group, a C_1-C_{60} alkyl group, a C_1-C_{60} alkoxy group, a phenyl group, a biphenyl group, or a combination thereof.

2. The light-emitting device of claim **1**, wherein

the emission layer comprises the heterocyclic compound,

the emission layer further comprises a transition metal-containing compound, a delayed fluorescence compound, or a combination thereof, and

the heterocyclic compound, the transition metal-containing compound, and the delayed fluorescence compound are different from each other.

3. The light-emitting device of claim **1**, wherein

the emission layer comprises the heterocyclic compound,

the emission layer further comprises a second compound comprising at least one IT electron-deficient nitrogen-containing C_1-C_{60} heterocyclic group, and

the second compound is different from the heterocyclic compound.

4. The light-emitting device of claim **1**, wherein the emission layer comprises a host and a dopant, and the host comprises the heterocyclic compound.

5. The light-emitting device of claim **1**, wherein the emission layer emits blue light.

6. An electronic apparatus comprising the light-emitting device of claim **1**.

7. The electronic apparatus of claim **6**, further comprising:

a thin-film transistor, wherein

the thin-film transistor comprises a source electrode and a drain electrode, and

the first electrode of the light-emitting device is electrically connected to at least one of the source electrode and the drain electrode.

8. The electronic apparatus of claim **7**, further comprising:

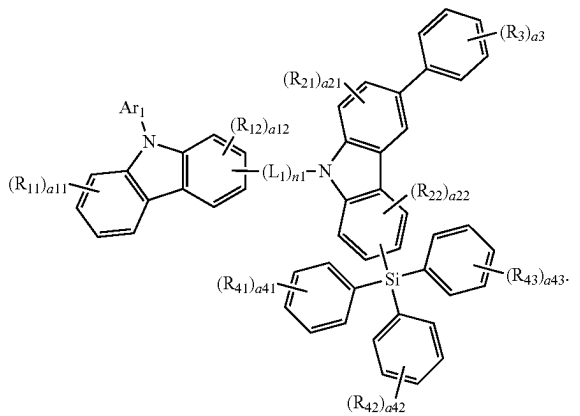
a color filter, a color conversion layer, a touch screen layer, a polarizing layer, or a combination thereof.

9. An electronic equipment comprising the light-emitting device of claim **1**.

10. The electronic equipment of claim **9**, wherein the electronic equipment is a flat panel display, a curved display, a computer monitor, a medical monitor, a television, a billboard, an indoor light, an outdoor light, a signal light, a head-up display, a fully transparent display, a partially transparent display, a flexible display, a rollable display, a foldable display, a stretchable display, a laser printer, a telephone, a mobile phone, a tablet computer, a phablet, a personal digital assistant (PDA), a wearable device, a laptop computer, a digital camera, a camcorder, a viewfinder, a micro display, a three-dimensional (3D) display, a virtual reality display, an augmented reality display, a vehicle, a video wall with multiple displays tiled together, a theater screen, a stadium screen, a phototherapy device, or a signboard.

11. A heterocyclic compound represented by Formula 1:

[Formula 1]



wherein in Formula 1,

R_{11}, R_{12}, R_{21}, R_{22}, R_3, and R_{41} to R_{43} are each independently hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{60} alkyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} alkenyl group unsubstituted or substituted with at least one R_{10a}, a C_2-C_{60} alkynyl group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} alkoxy group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} alkylthio group unsubstituted or substituted with at least one R_{10a}, a C_5-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}, a C_6-C_{60} aryloxy group unsubstituted or substituted with at least one R_{10a}, a C_6-C_{60} arylthio group unsubstituted or substituted with at least one R_{10a}, —$C(Q_1)(Q_2)(Q_3)$, —$Si(Q_1)(Q_2)(Q_3)$, —$N(Q_1)(Q_2)$, —$B(Q_1)(Q_2)$, —$C(=O)(Q_1)$, —$S(=O)_2(Q_1)$, or —$P(=O)(Q_1)(Q_2)$,

a11 is an integer from 1 to 4,

a12, a21, and a22 are each independently an integer from 1 to 3,

a3 and a41 to a43 are each independently an integer from 1 to 5,

L_1 is a single bond, a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, or a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a},

n1 is an integer from 1 to 3,

Ar_1 is a C_3-C_{60} carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C_1-C_{60} heterocyclic group unsubstituted or substituted with at least one R_{10a}, —$C(Q_1)(Q_2)(Q_3)$, —$Si(Q_1)(Q_2)(Q_3)$, —$N(Q_1)(Q_2)$, or —$B(Q_1)(Q_2)$,

R_{10a} is:

deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, or a nitro group;

a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, or a C_1-C_{60} alkoxy group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_5-C_{60} carbocyclic group, a C_1-C_{60} heterocyclic group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, —$Si(Q_{11})(Q_{12})(Q_{13})$, —$N(Q_{11})(Q_{12})$, —$B(Q_{11})(Q_{12})$, —$C(=O)(Q_{11})$, —$S(=O)_2(Q_{11})$, —$P(=O)(Q_{11})(Q_{12})$, or a combination thereof;

a C_3-C_{60} carbocyclic group, a C_1-C_{60} heterocyclic group, a C_6-C_{60} aryloxy group, or a C_6-C_{60} arylthio group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{60} carbocyclic group, a C_1-C_{60} heterocyclic group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, —$Si(Q_{21})(Q_{22})(Q_{23})$, —$N(Q_{21})(Q_{22})$, —$B(Q_{21})(Q_{22})$, —$C(=O)(Q_{21})$, —$S(=O)_2(Q_{21})$, —$P(=O)(Q_{21})(Q_{22})$, or a combination thereof; or

—$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, or —$P(=O)(Q_{31})(Q_{32})$, and

Q_1 to Q_3, Q_{11} to Q_{13}, Q_{21} to Q_{23}, and Q_{31} to Q_{33} are each independently: hydrogen; deuterium; —F; —Cl; —Br; —I; a hydroxyl group; a cyano group; a nitro group; a C_1-C_{60} alkyl group; a C_2-C_{60} alkenyl group; a C_2-C_{60} alkynyl group; a C_1-C_{60} alkoxy group; or a C_3-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group, each unsubstituted or substituted with deuterium, —F, a cyano group, a C_1-C_{60} alkyl group, a C_1-C_{60} alkoxy group, a phenyl group, a biphenyl group, or a combination thereof.

12. The heterocyclic compound of claim **11**, wherein R_1, R_{12}, R_{21}, R_{22}, R_3, and R_{41} to R_{43} are each independently:

hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, or a C_1-C_{20} alkoxy group;

a C_1-C_{20} alkyl group or a C_1-C_{20} alkoxy group, each substituted with deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{10} alkyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, or a combination thereof;

a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azafluorenyl group, or an azadibenzosilolyl group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzosilolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, —$O(Q_{31})$, —$S(Q_{31})$, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$P(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, —$P(=O)(Q_{31})(Q_{32})$, or a combination thereof; or

—$C(Q_1)(Q_2)(Q_3)$, —$Si(Q_1)(Q_2)(Q_3)$, —$N(Q_1)(Q_2)$, —$B(Q_1)(Q_2)$, —$C(=O)(Q_1)$, —$S(=O)_2(Q_1)$, or —$P(=O)(Q_1)(Q_2)$, and

Q_1 to Q_3 and Q_{31} to Q_{33} are each independently: hydrogen; deuterium; —F; —Cl; —Br; —I; a hydroxyl group; a cyano group; a nitro group; a C_1-C_{60} alkyl group; a C_2-C_{60} alkenyl group; a C_2-C_{60} alkynyl group; a C_1-C_{60} alkoxy group; or a C_5-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group, each unsubstituted or substituted with deuterium, —F, a cyano group, a C_1-C_{60} alkyl group, a C_1-C_{60} alkoxy group, a phenyl group, a biphenyl group, or a combination thereof.

13. The heterocyclic compound of claim **11**, wherein at least one of R_{11}, R_{12}, R_{21}, R_{22}, R_3, and R_{41} to R_{43} comprises at least one deuterium.

14. The heterocyclic compound of claim **11**, wherein R_{11}, R_{12}, R_{21}, R_{22}, R_3, and R_{41} to R_{43} each comprise at least one deuterium.

15. The heterocyclic compound of claim **11**, wherein L_1 is:

a single bond; or

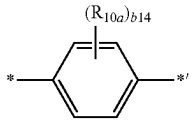
a benzene group, a naphthalene group, an anthracene group, a phenanthrene group, a triphenylene group, a pyrene group, a chrysene group, a cyclopentadiene group, a furan group, a thiophene group, a silole group, an indene group, a fluorene group, an indole group, a carbazole group, a benzofuran group, a dibenzofuran group, a benzothiophene group, a dibenzothiophene group, a benzosilole group, a dibenzosilole group, an azafluorene group, an azacarbazole group, an azadibenzofuran group, an azadibenzothiophene group, an azadibenzosilole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a quinoxaline group, a quinazoline group, a phthalazine group, a phenanthroline group, a pyrrole group, a pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, a thiazole group, an isothiazole group, an oxadiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a benzoxazole group, a benzothiazole group, a benzoxadiazole group, a benzothiadiazole group, a dibenzooxasiline group, a dibenzothiasiline group, a dibenzodihydroazasiline group, a dibenzodihydrodisiline group, a dibenzodihydrosiline group, a dibenzodioxine group, a dibenzooxathiine group, a dibenzooxazine group, a dibenzopyran group, a dibenzodithiine group, a dibenzothiazine group, a dibenzothiopyran group, a dibenzocyclohexadiene group, a dibenzodihydropyridine group, or a dibenzodihydropyrazine group, each unsubstituted or substituted with at least one R_{10a}.

16. The heterocyclic compound of claim **11**, wherein L_1 is:

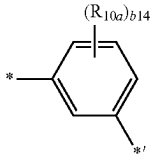
a single bond; or

a group represented by one of Formulae L(1) to L(24):

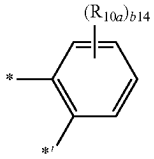
L(1)



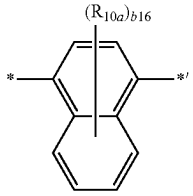
L(2)



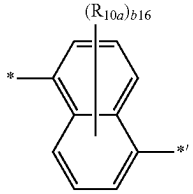
L(3)



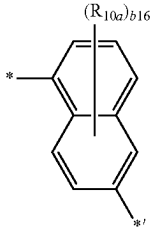
L(4)



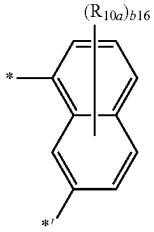
L(5)



L(6)



L(7)



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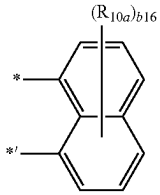
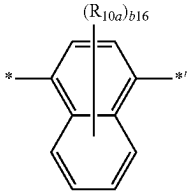
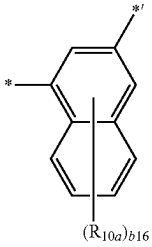
L(8)



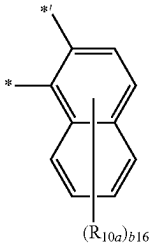
L(9)



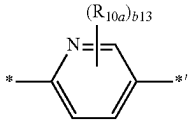
L(10)



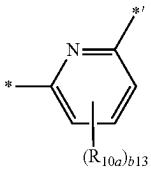
L(11)



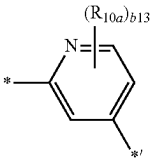
L(12)



L(13)



L(14)



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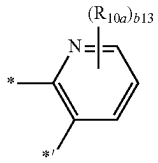
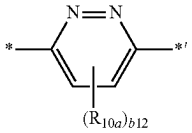
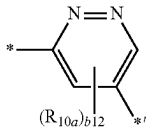
L(15)



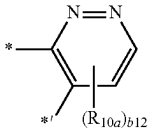
L(16)



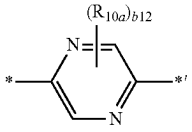
L(17)



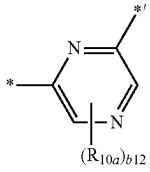
L(18)



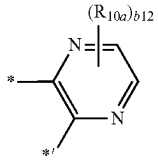
L(19)



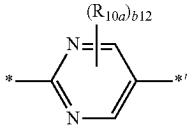
L(20)



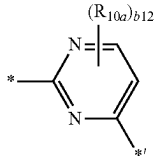
L(21)



L(22)



L(23)



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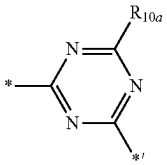
L(24)



wherein in Formulae L(1) to L(24),

R_{10a} is the same as described in Formula 1, b12 is 1 or 2,

b13 is an integer from 1 to 3,

b14 is an integer from 1 to 4,

b16 is an integer from 1 to 6, and

* and *' each indicate a binding site to a neighboring atom.

17. The heterocyclic compound of claim **11**, wherein Ar_1 is a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an azacarbazolyl group, an azadibenzofuranyl group, an azadibenzothiophenyl group, an azafluorenyl group, or an azadibenzosilolyl group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group, a norbornenyl group, a cyclopentenyl group, a cyclohexenyl group, a cycloheptenyl group, a phenyl group, a biphenyl group, a C_1-C_{10} alkylphenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzo-

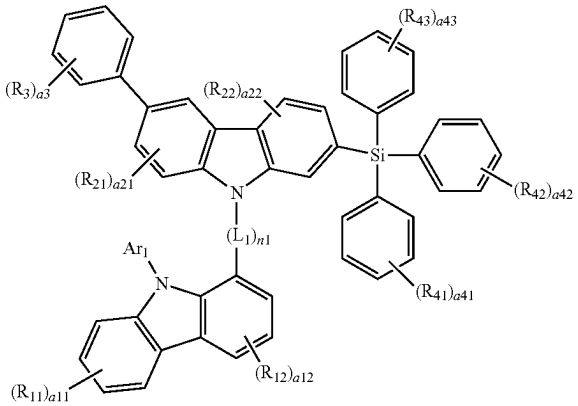
furanyl group, a benzothiophenyl group, a benzoisothiazolyl group, a benzoxazolyl group, a benzoisoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzosilolyl group, a dibenzocarbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, —$O(Q_{31})$, —$S(Q_{31})$, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$P(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, —$P(=O)(Q_{31})(Q_{32})$, or a combination thereof, and

Q_{31} to Q_{33} are each independently: hydrogen; deuterium; —F; —Cl; —Br; —I; a hydroxyl group; a cyano group; a nitro group; a C_1-C_{60} alkyl group; a C_2-C_{60} alkenyl group; a C_2-C_{60} alkynyl group; a C_1-C_{60} alkoxy group; or a C_5-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group, each unsubstituted or substituted with deuterium, —F, a cyano group, a C_1-C_{60} alkyl group, a C_1-C_{60} alkoxy group, a phenyl group, a biphenyl group, or a combination thereof.

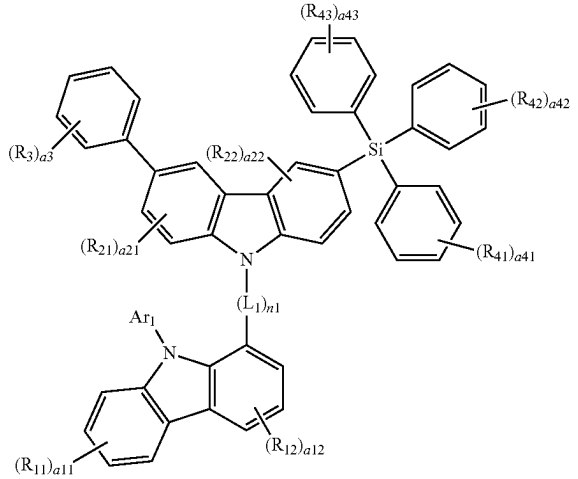
18. The heterocyclic compound of claim **11**, wherein Ar_1 comprises at least one deuterium.

19. The heterocyclic compound of claim **11**, wherein the heterocyclic compound represented by Formula 1 is represented by one of Formulae 1-1 to 1-8:

1-1



1-2



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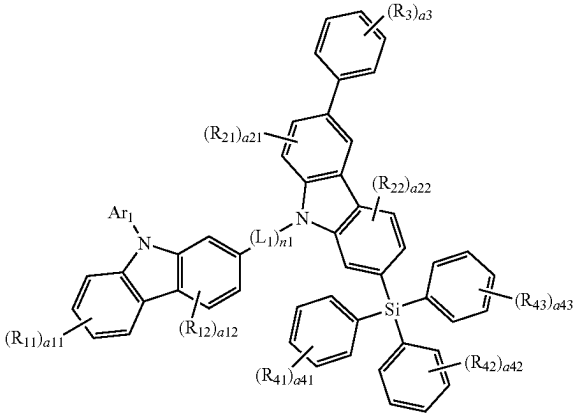
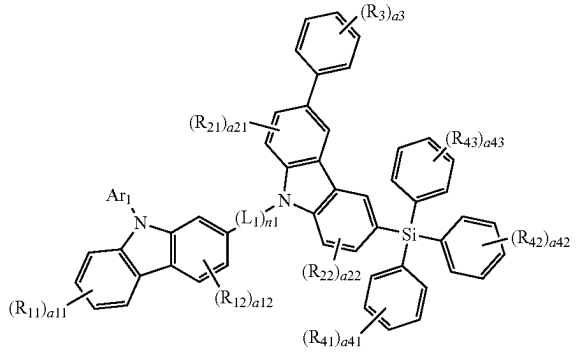
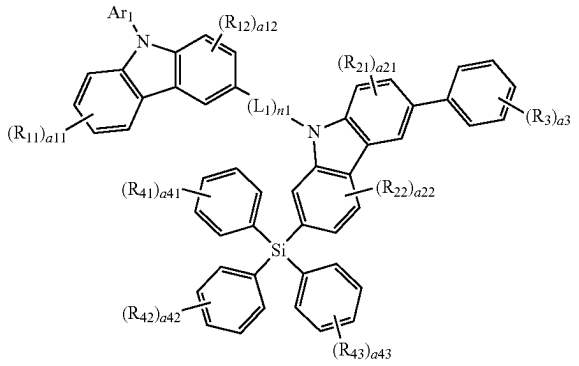
1-3



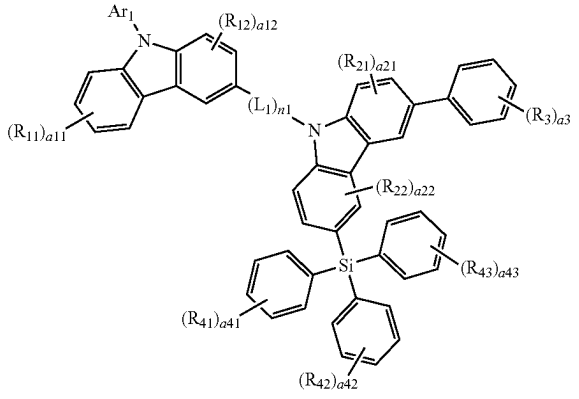
1-4



1-5



1-6



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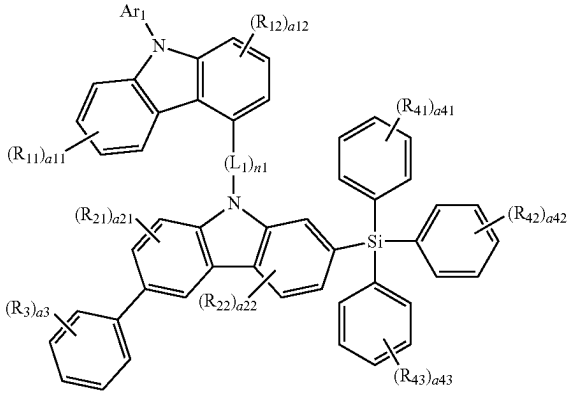
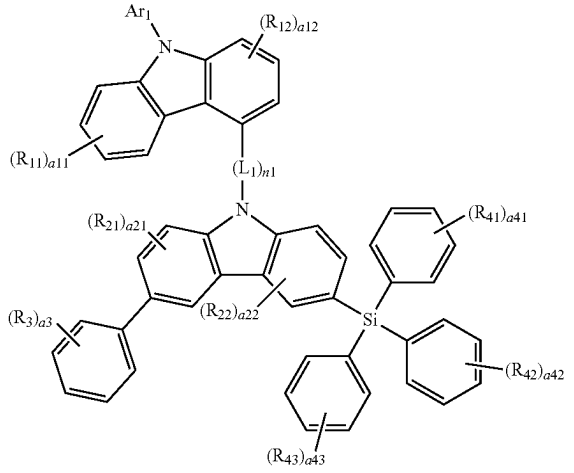
1-7



1-8

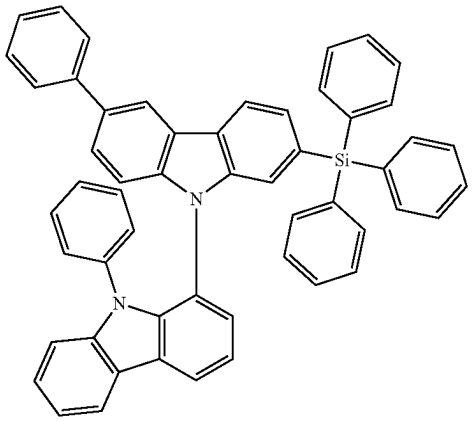


wherein in Formulae 1-1 to 1-8,

R_{11}, R_{12}, R_{21}, R_{22}, R_3, R_{41} to R_{43}, a11, a12, a21, a22, a3, a41 to a43, L_1, n1, and Ar_1 are each the same as described in Formula 1.

20. The heterocyclic compound of claim **11**, wherein the heterocyclic compound is one of Compounds 1 to 153:

1



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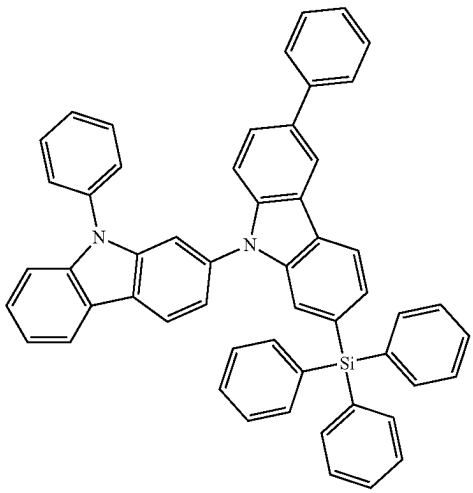

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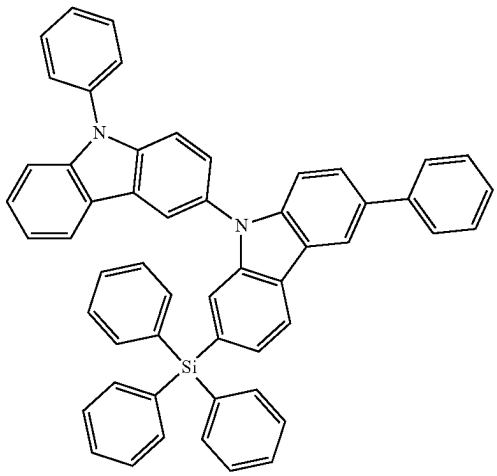

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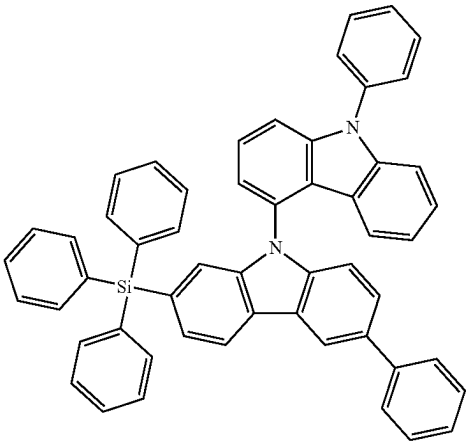

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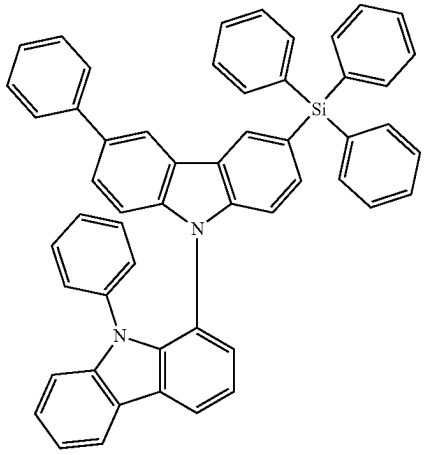

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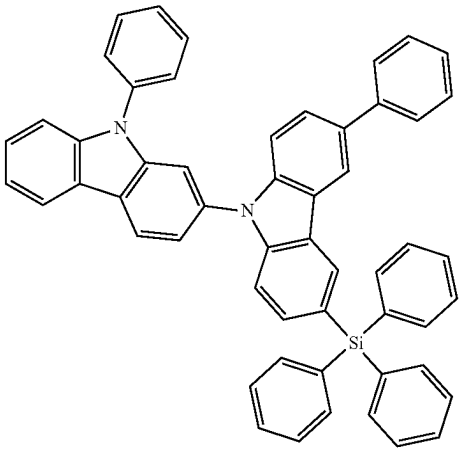

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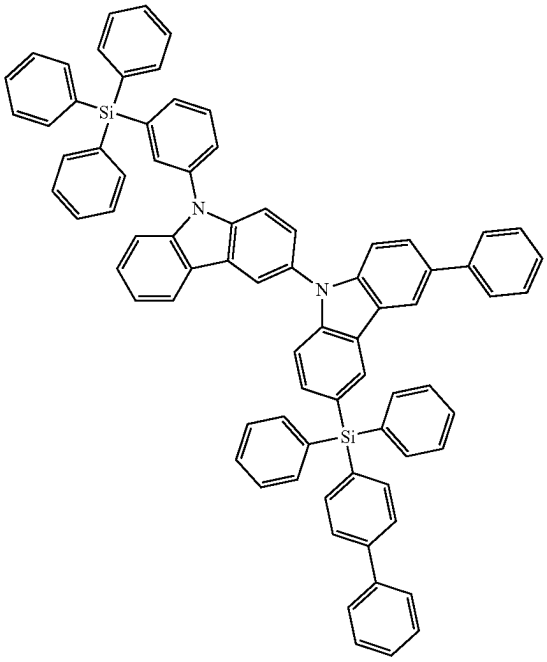

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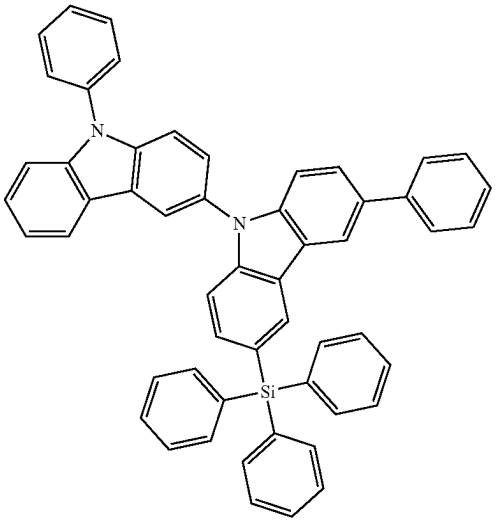

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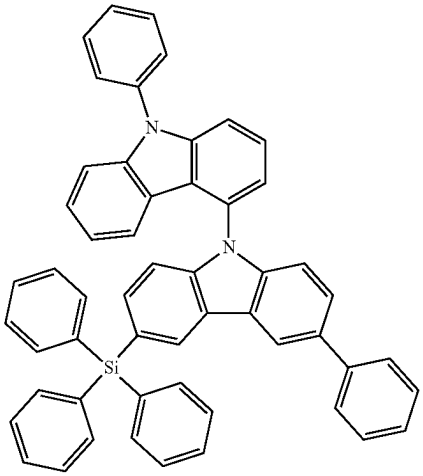

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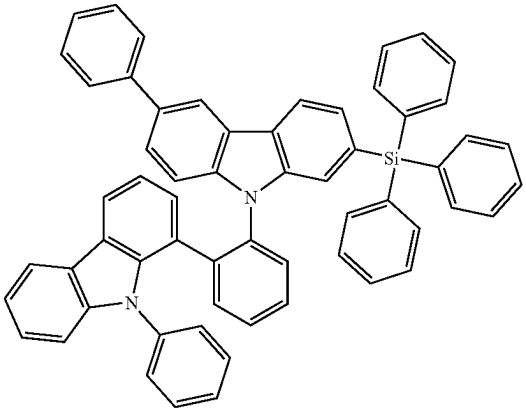

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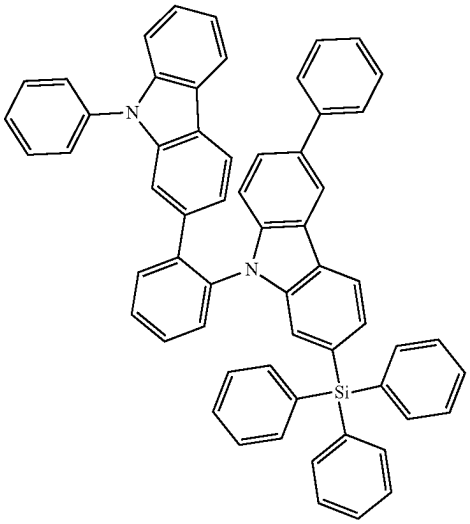

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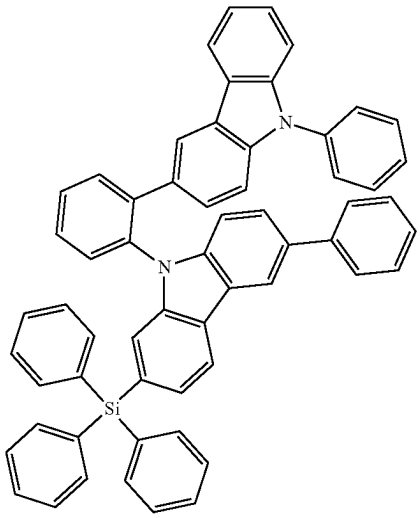

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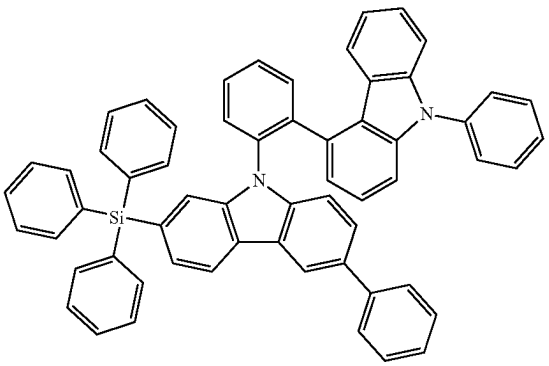

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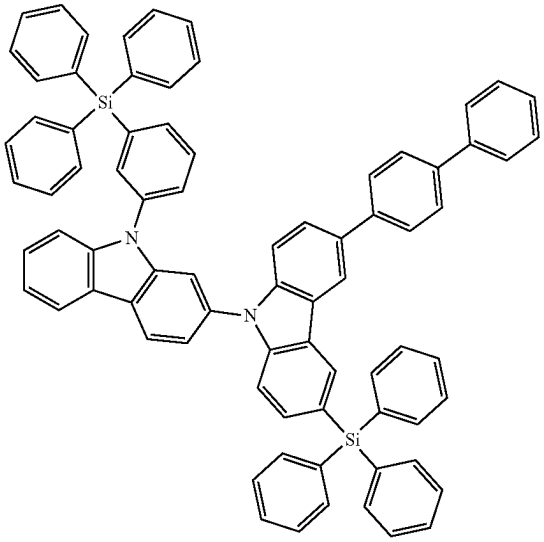

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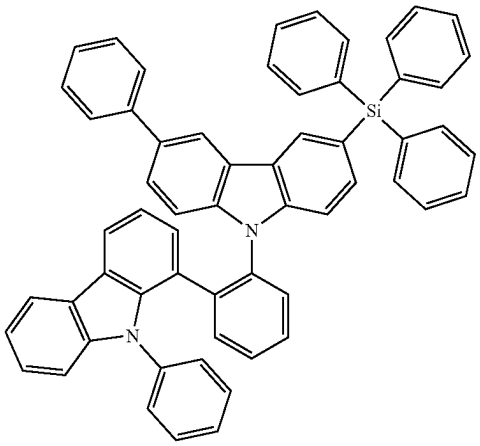

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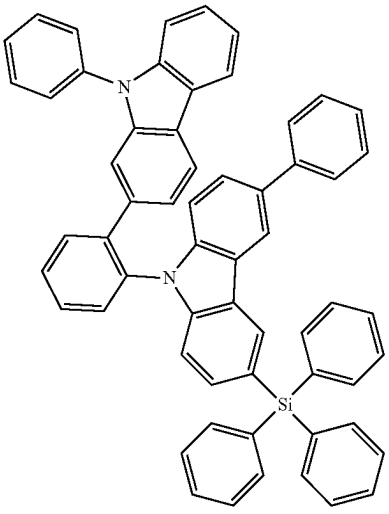

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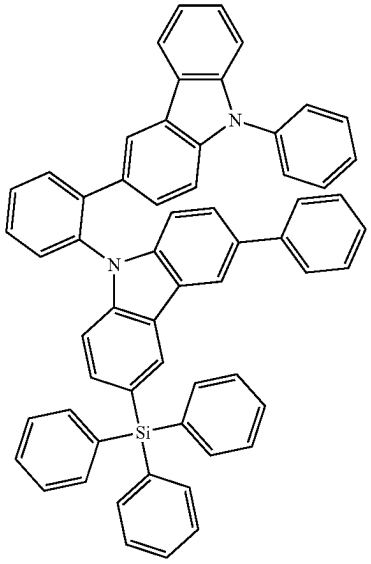

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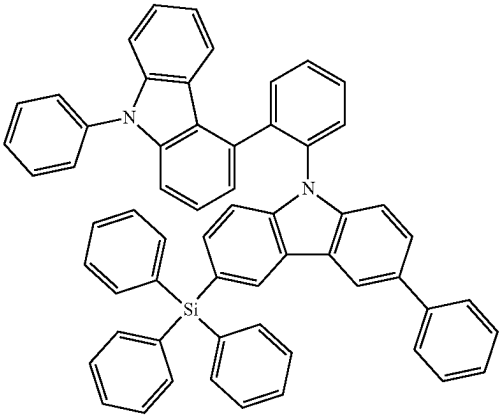

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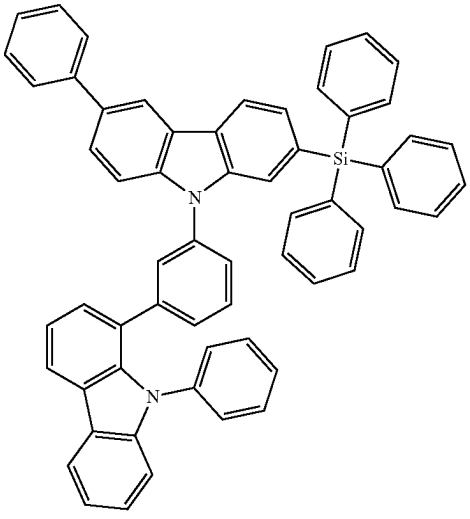

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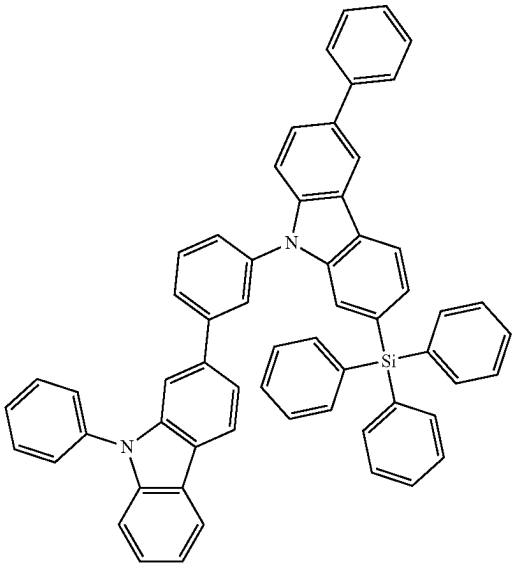

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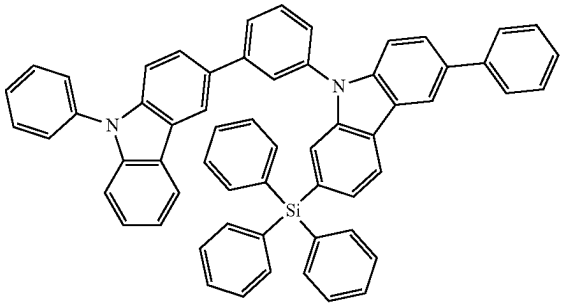

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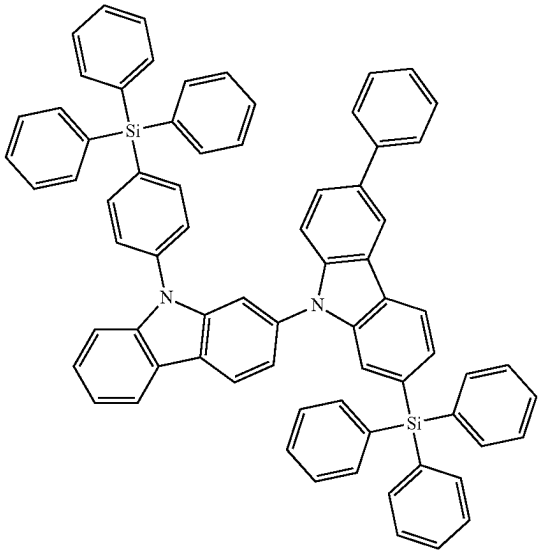

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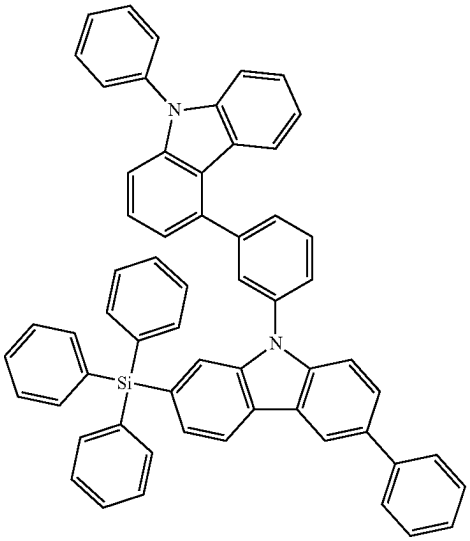

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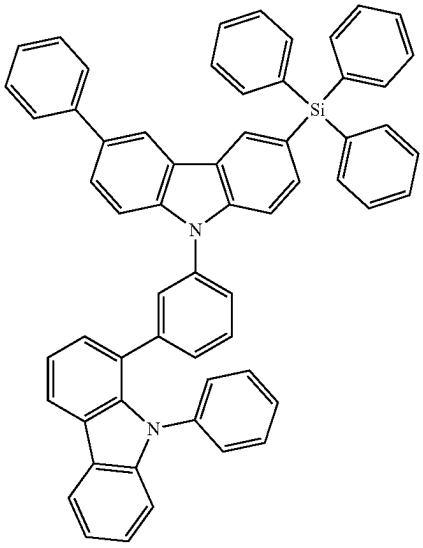

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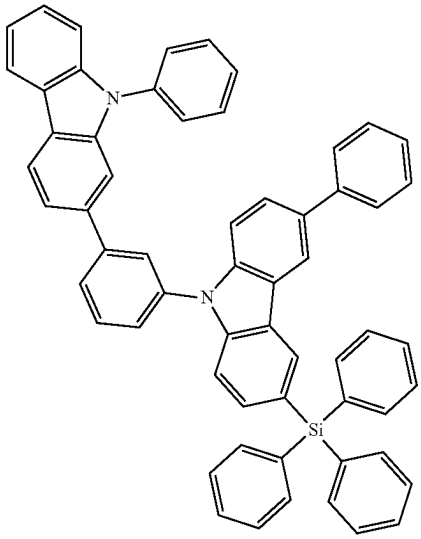

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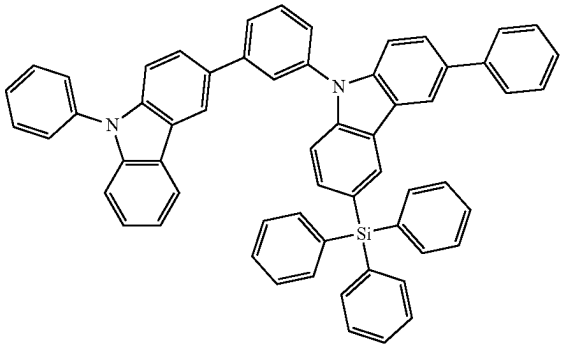

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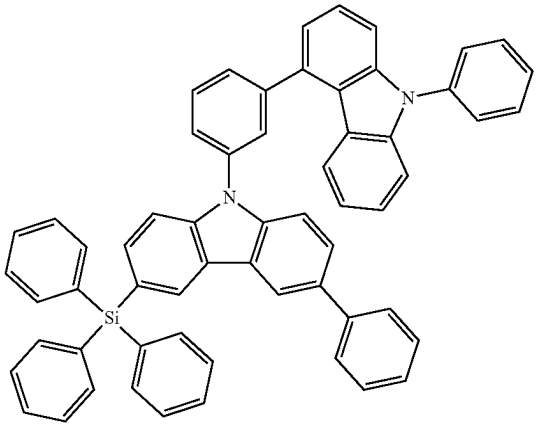

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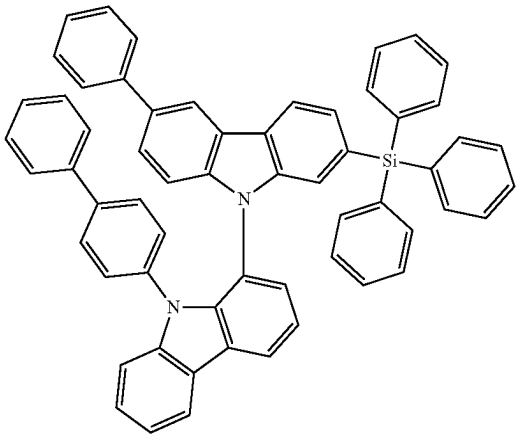

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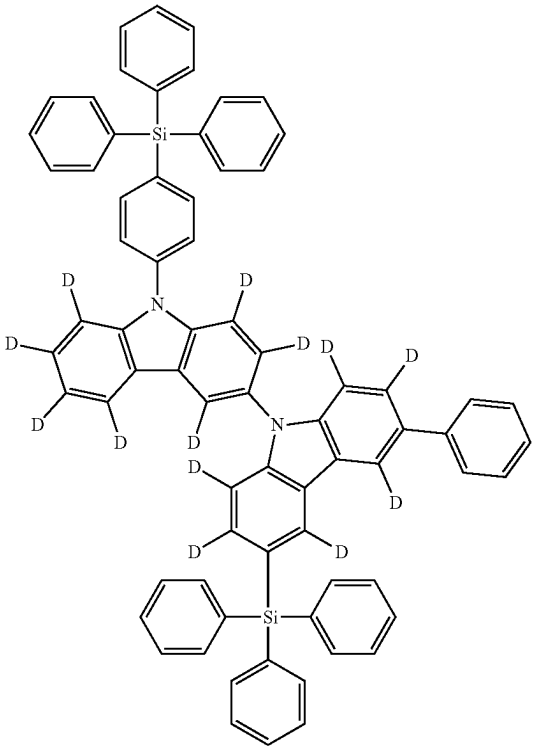

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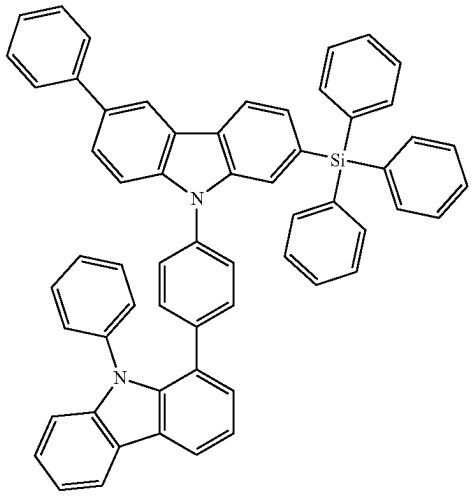

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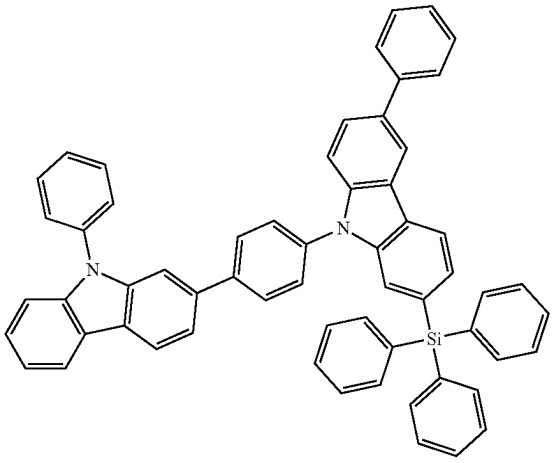

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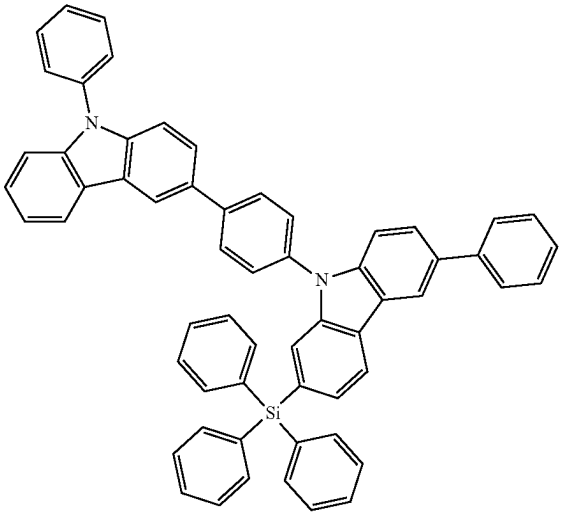

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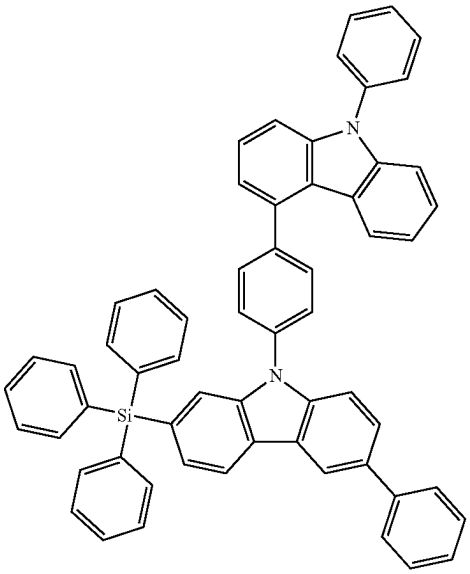

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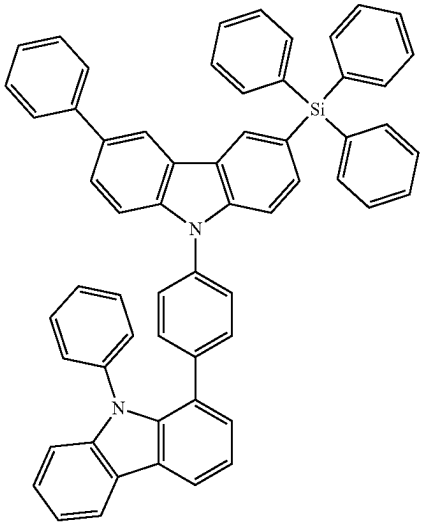

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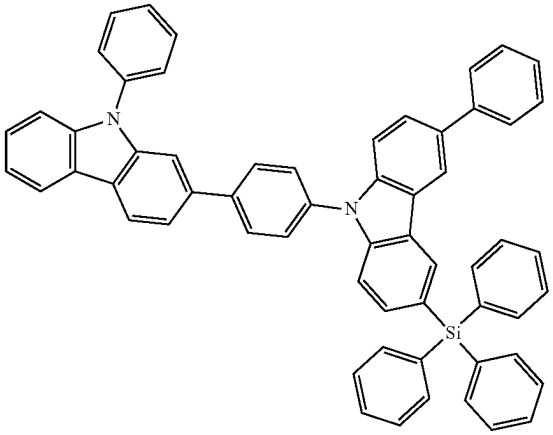

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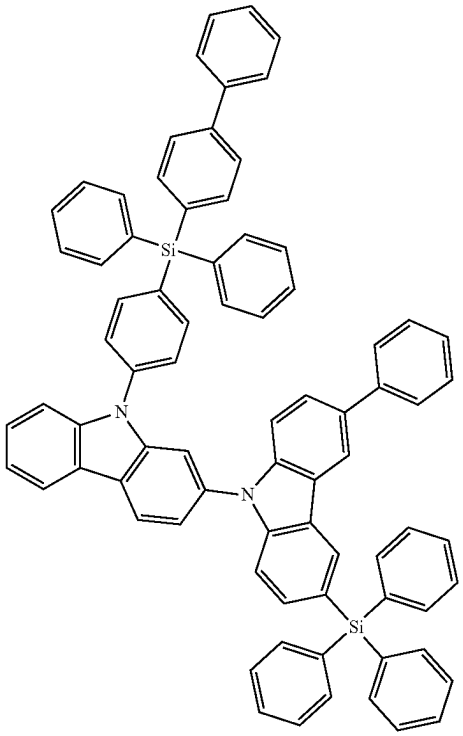

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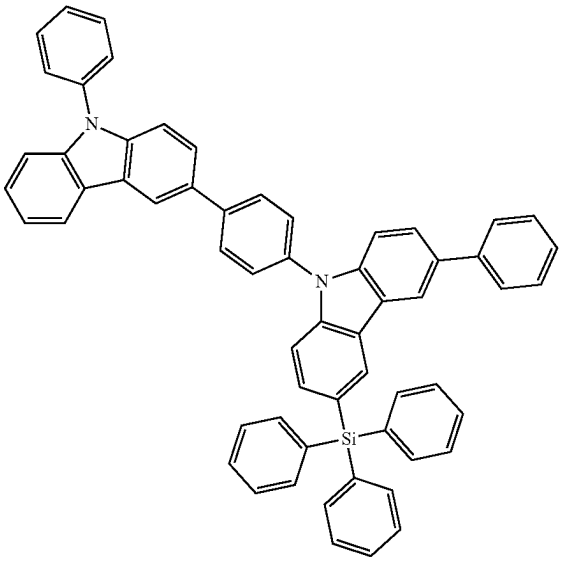

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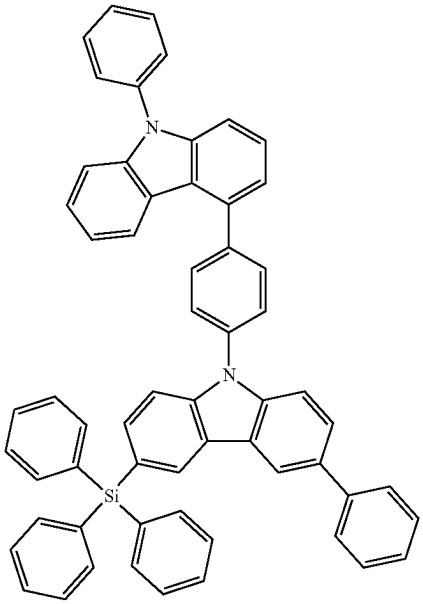

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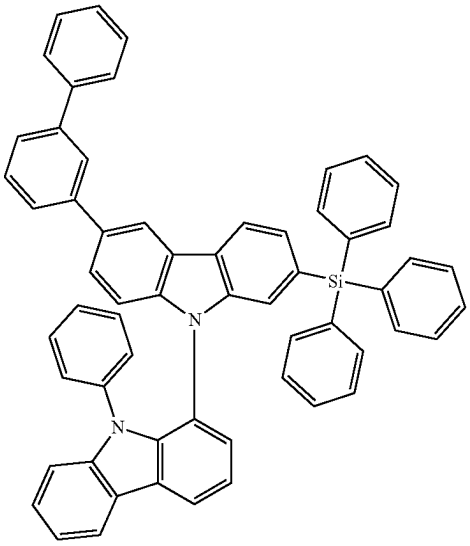

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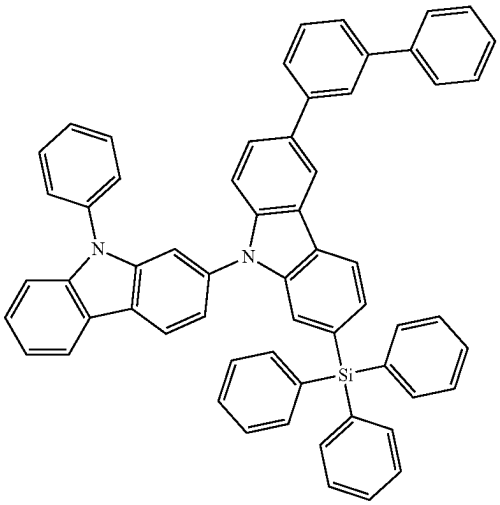

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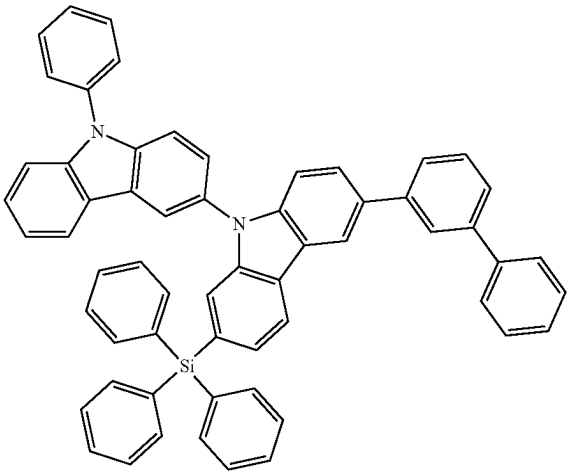

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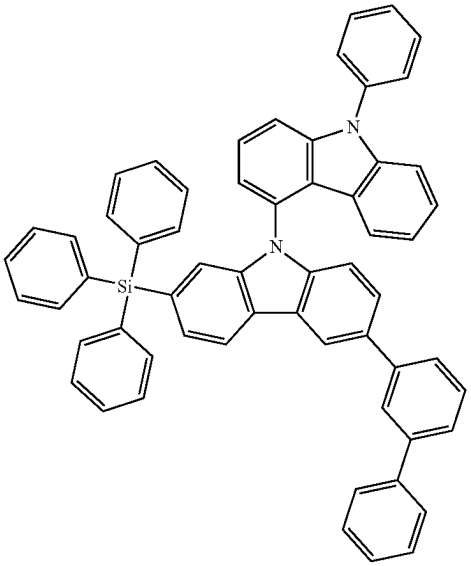

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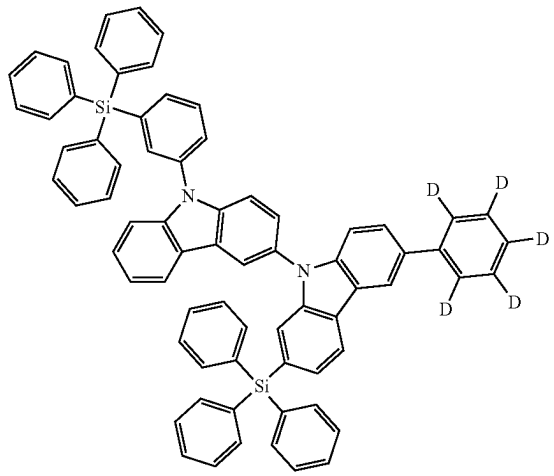

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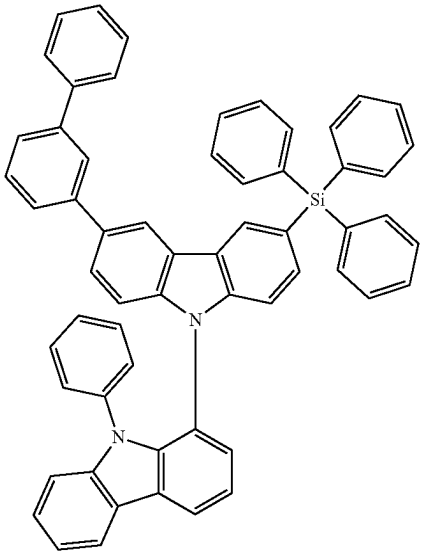

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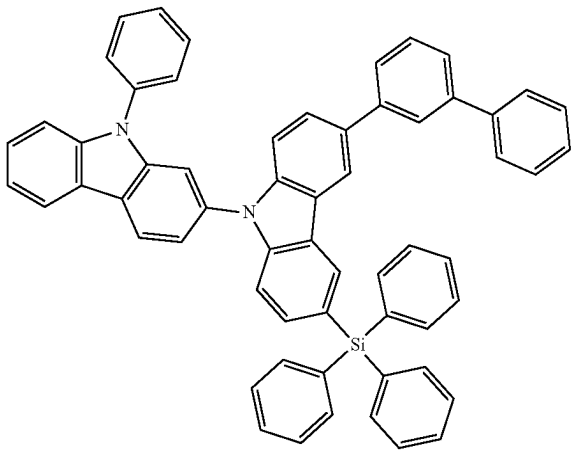

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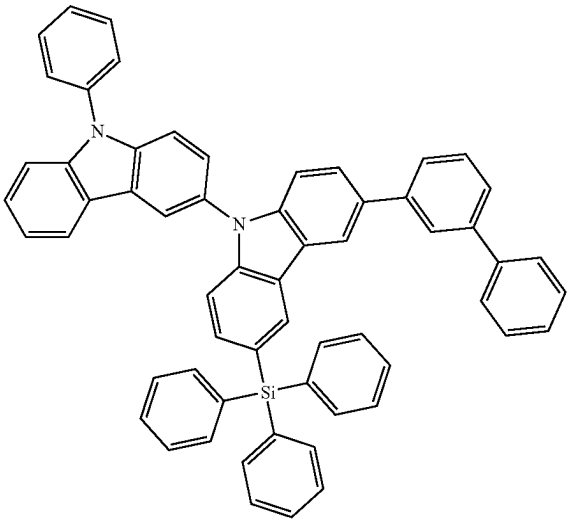

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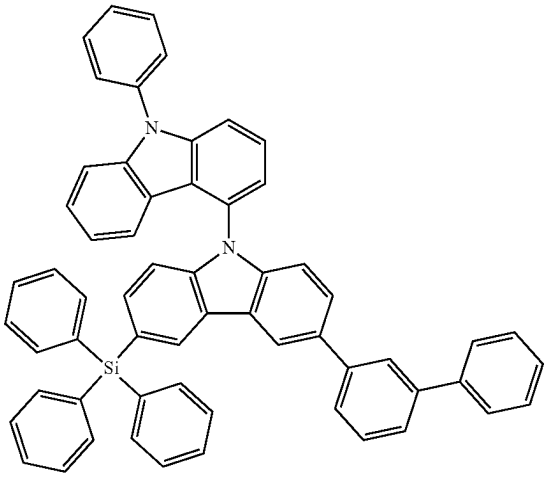

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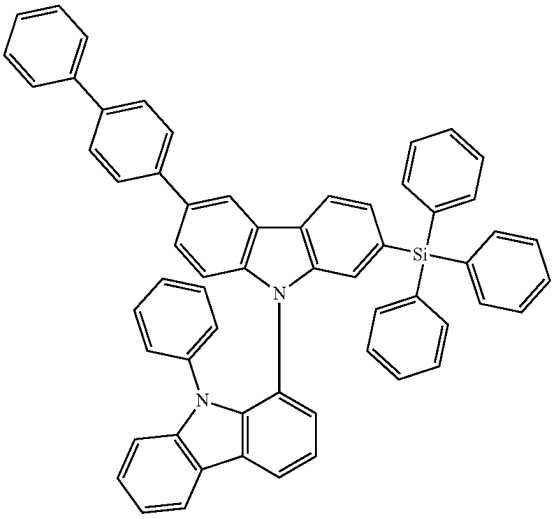

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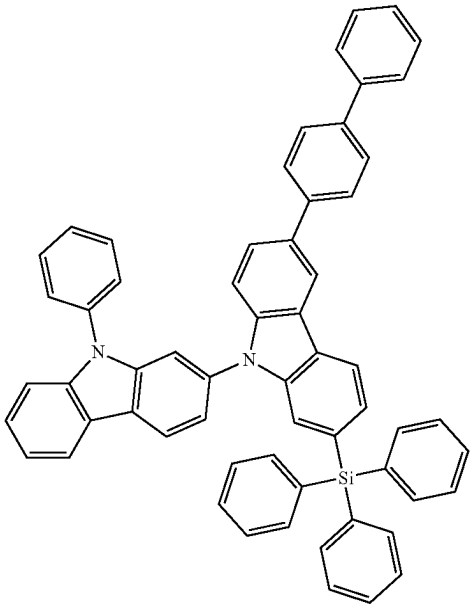

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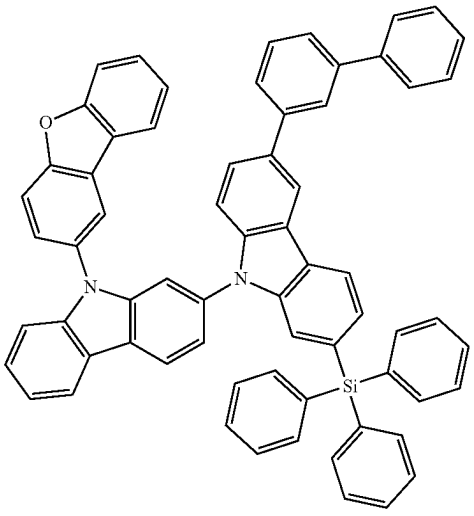

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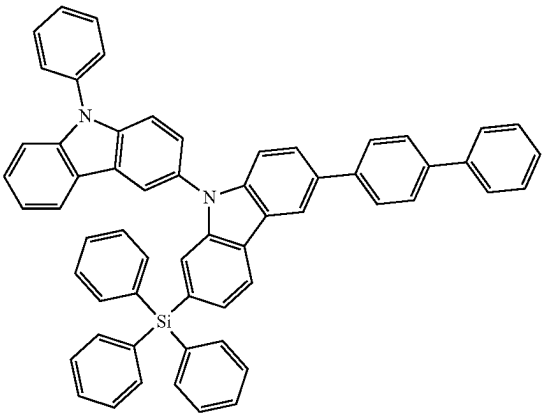

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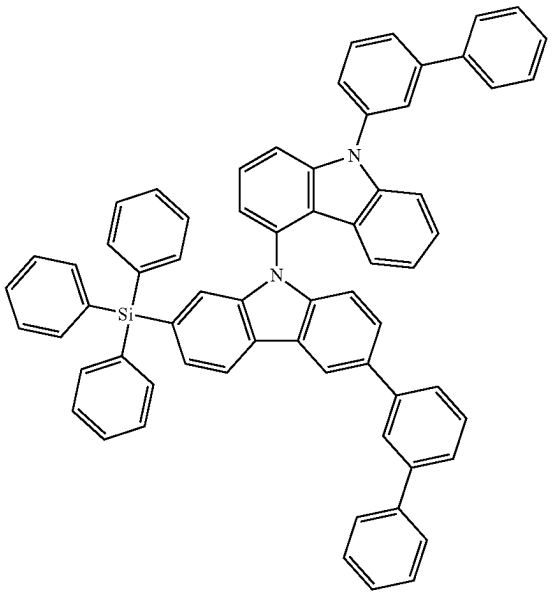

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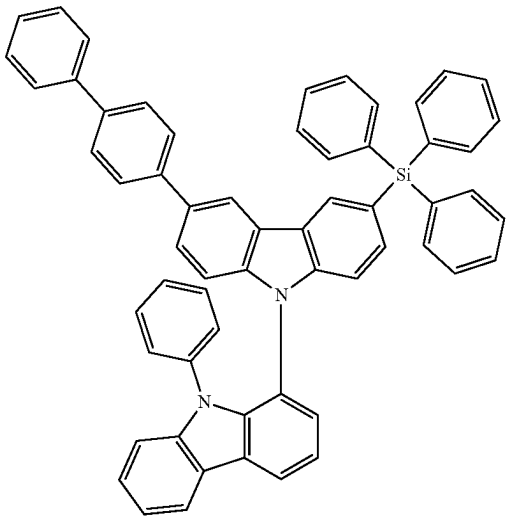

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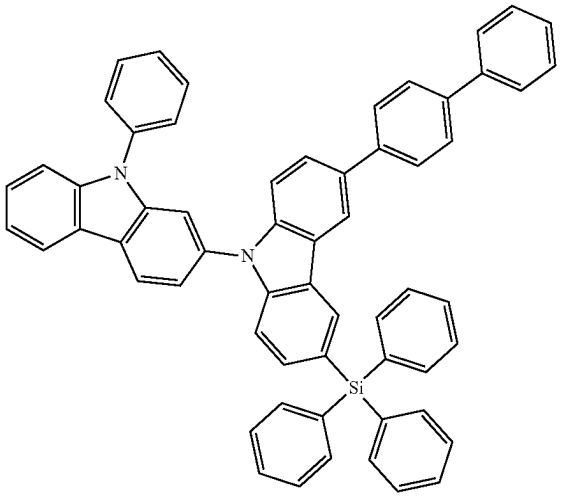

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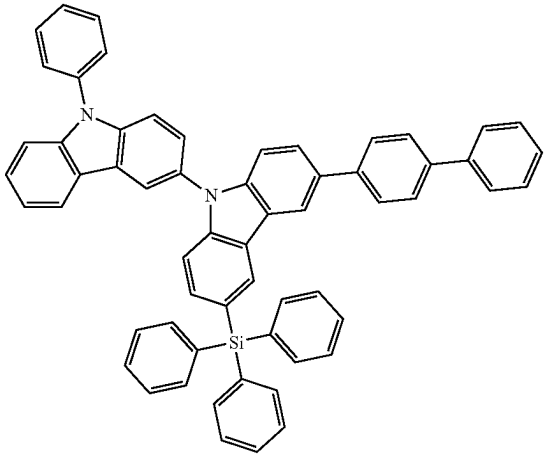

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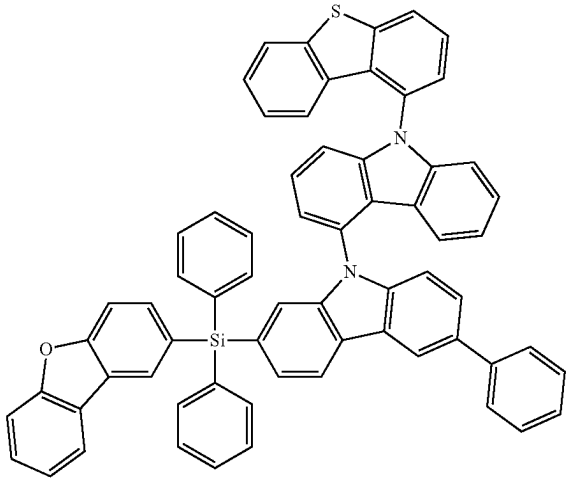

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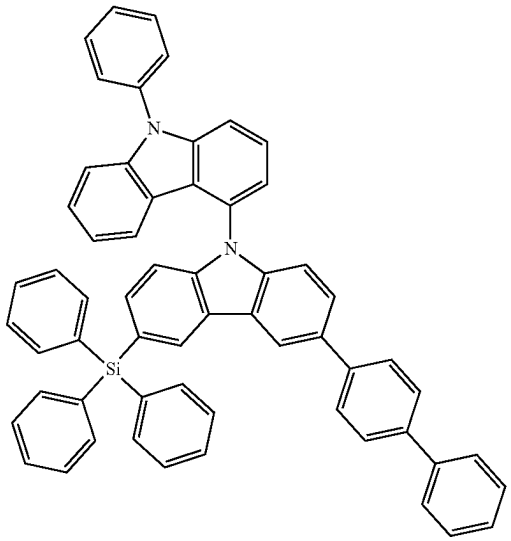

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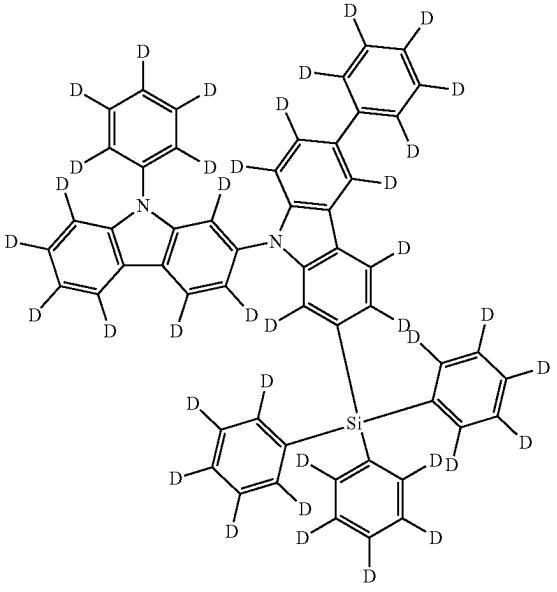

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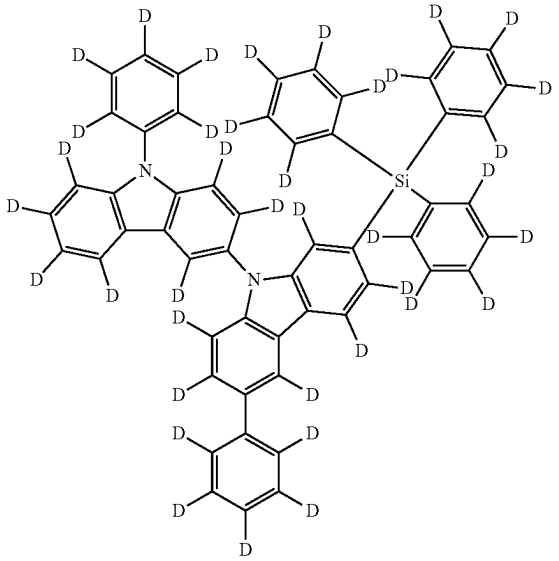

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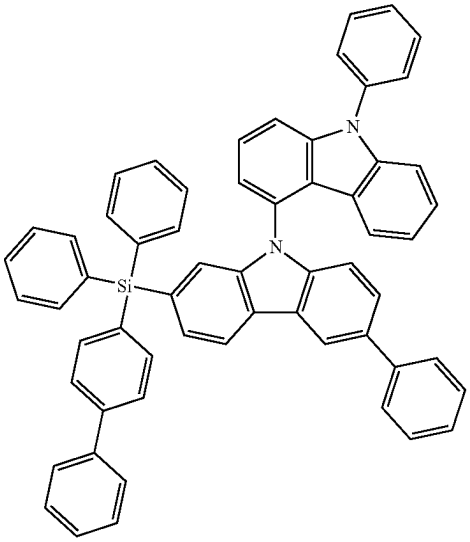

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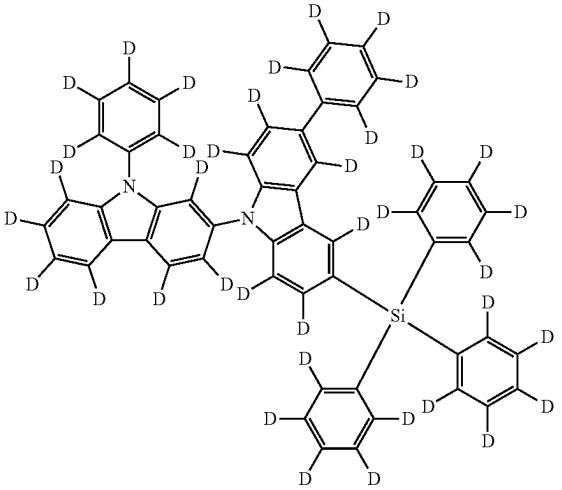

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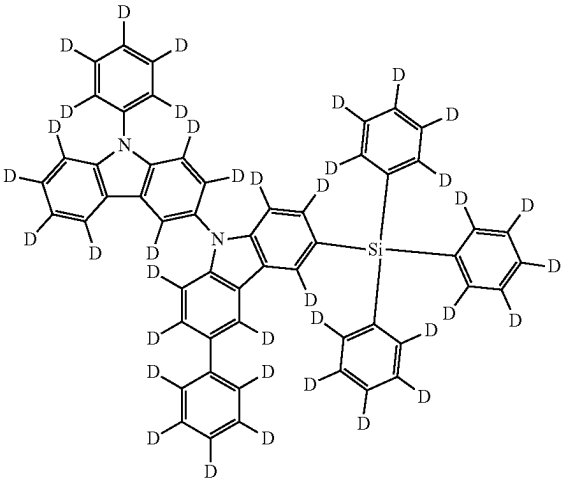

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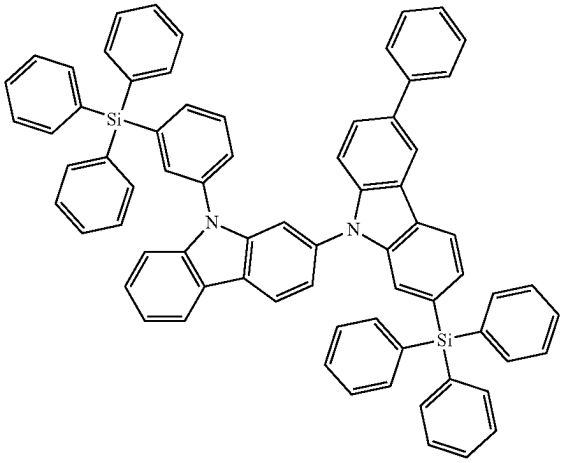

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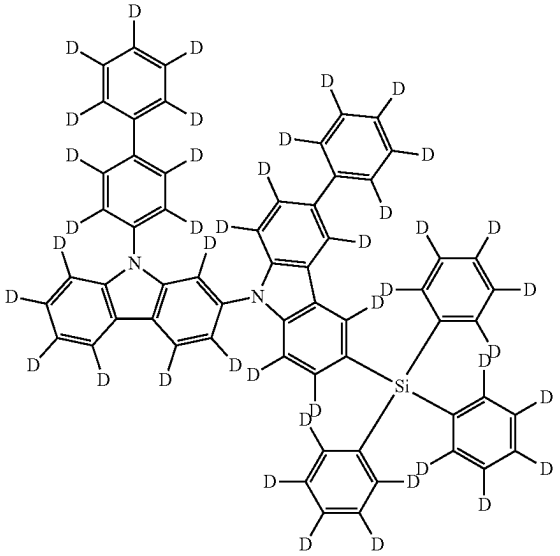

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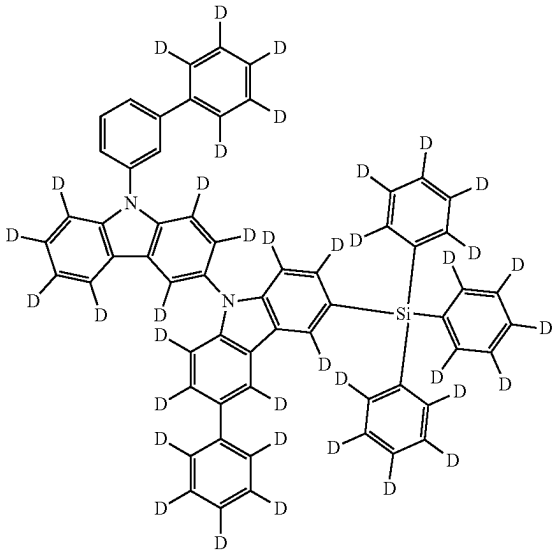

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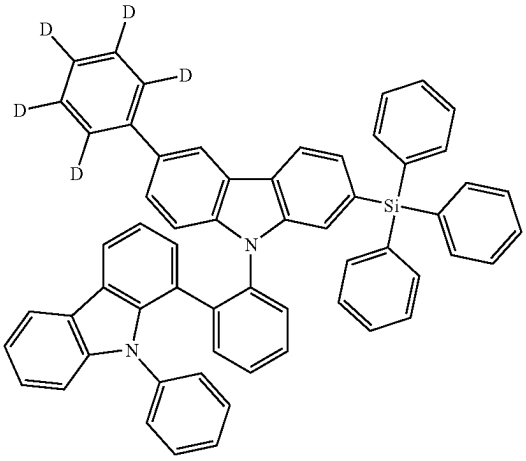

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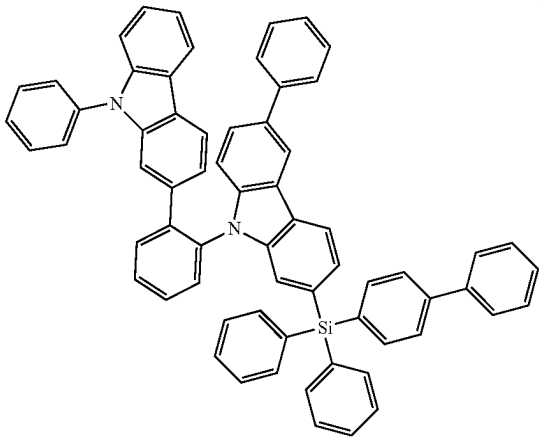

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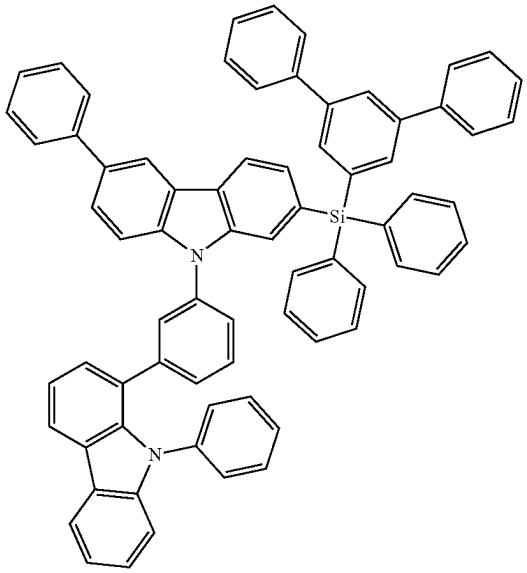

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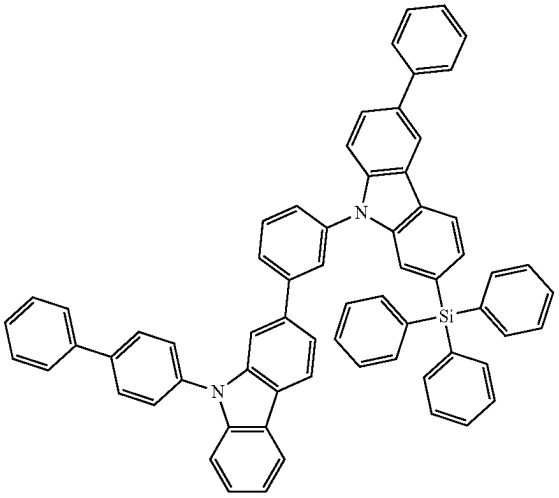

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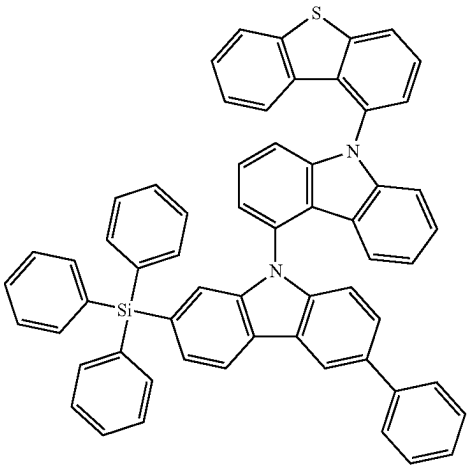

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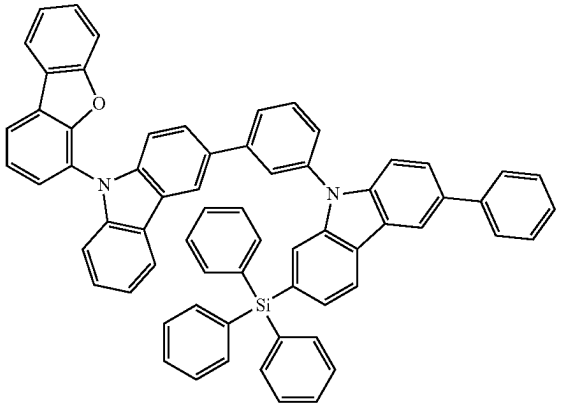

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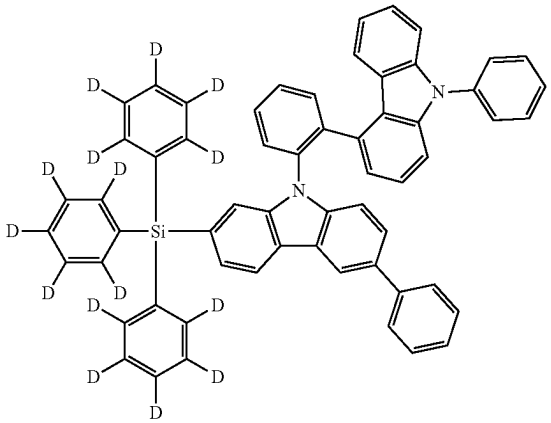

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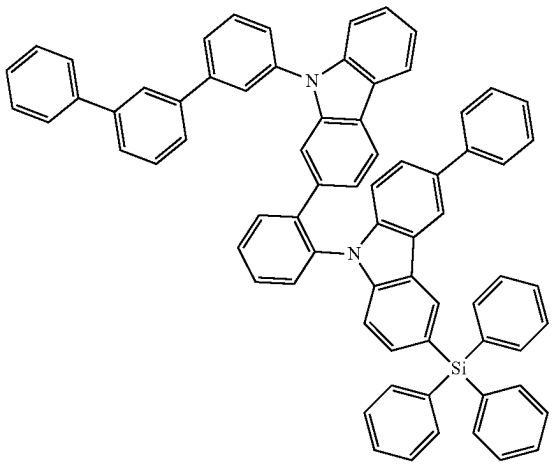

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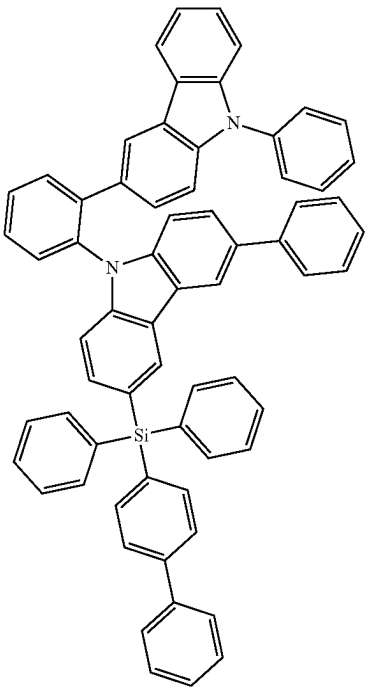

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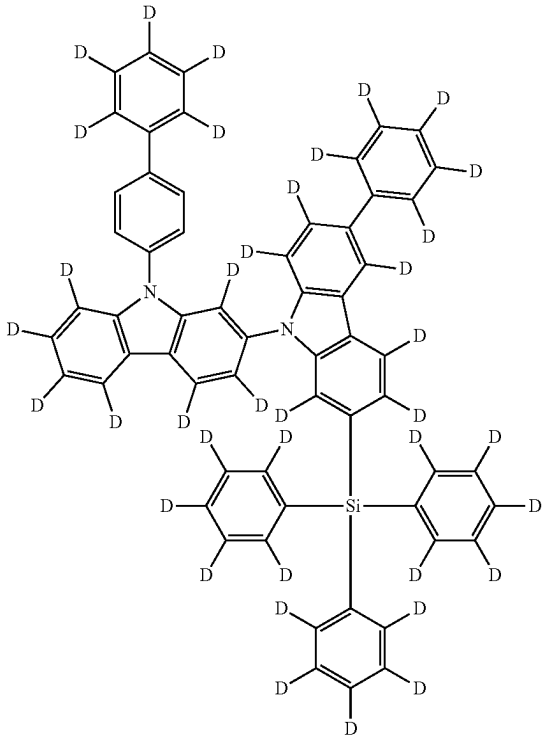

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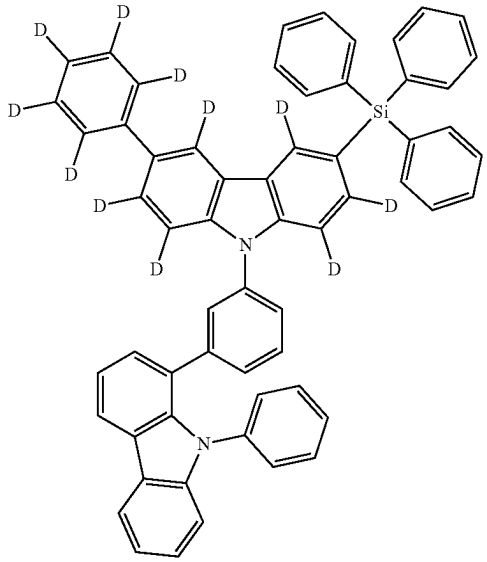

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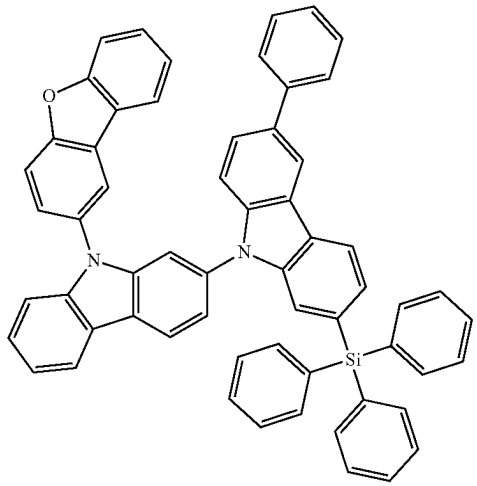

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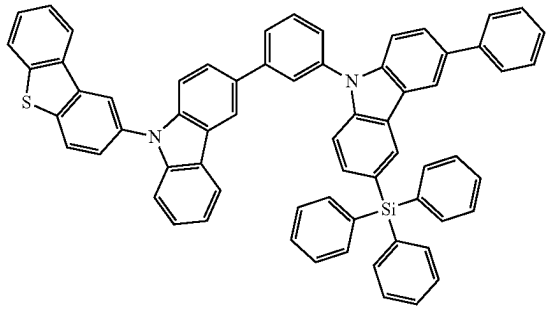

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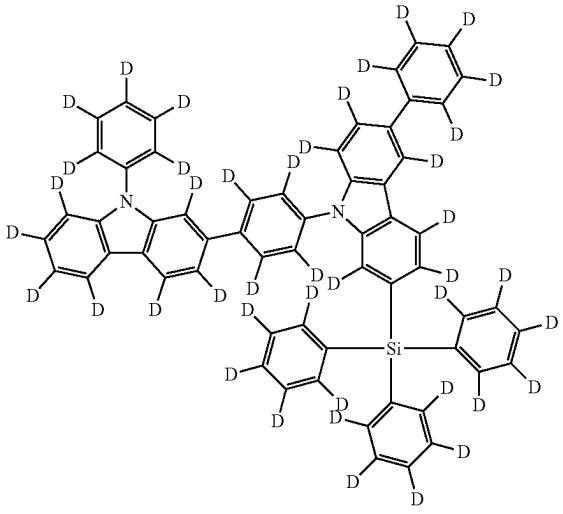

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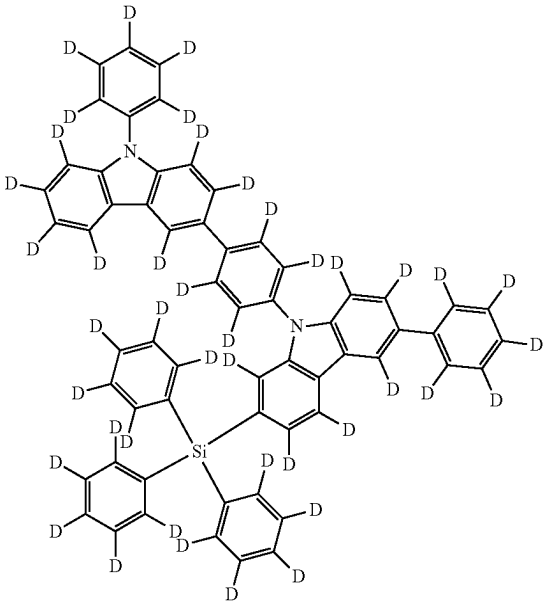

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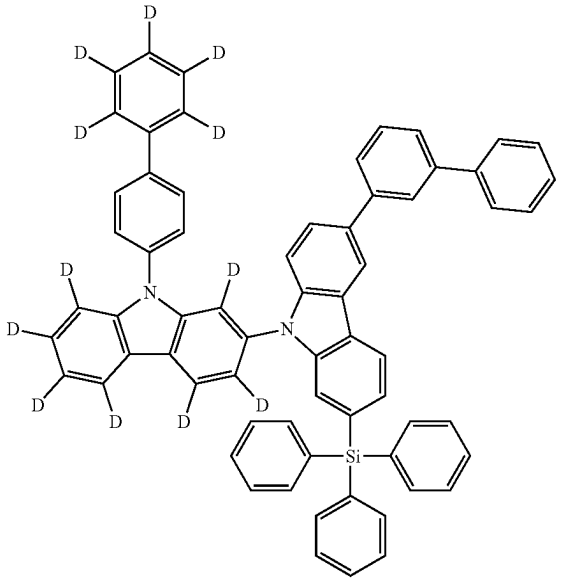

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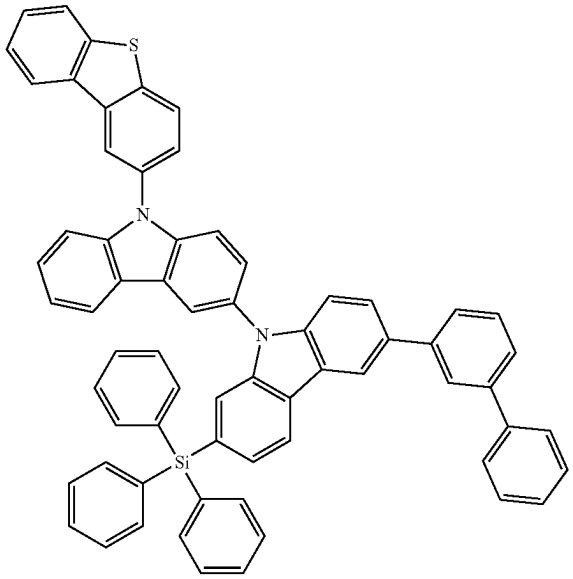

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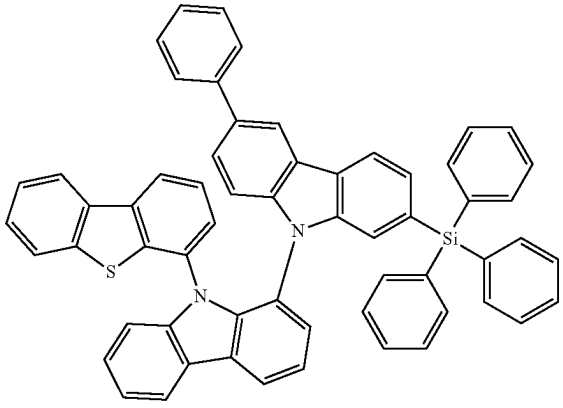

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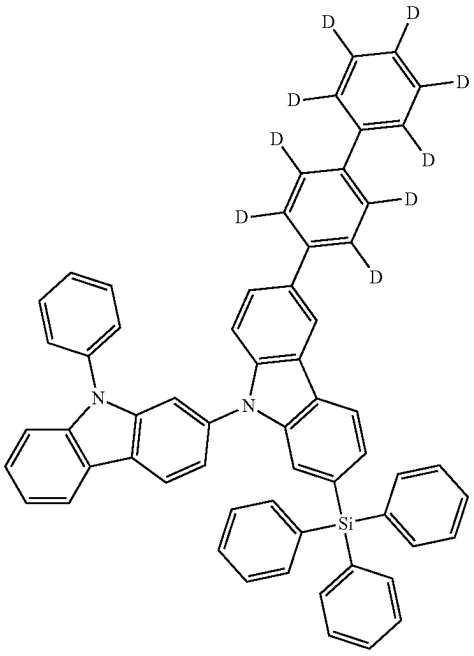

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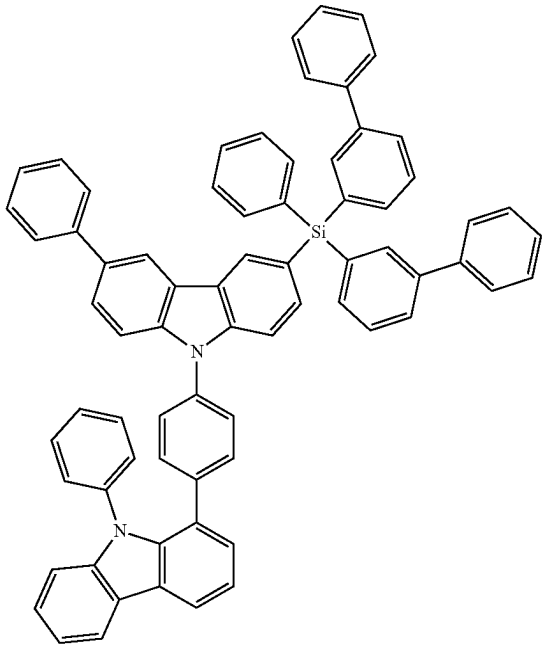

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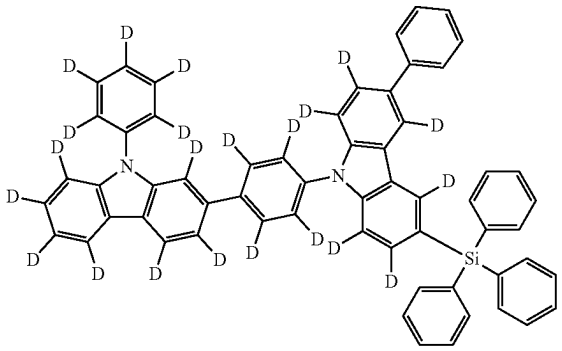

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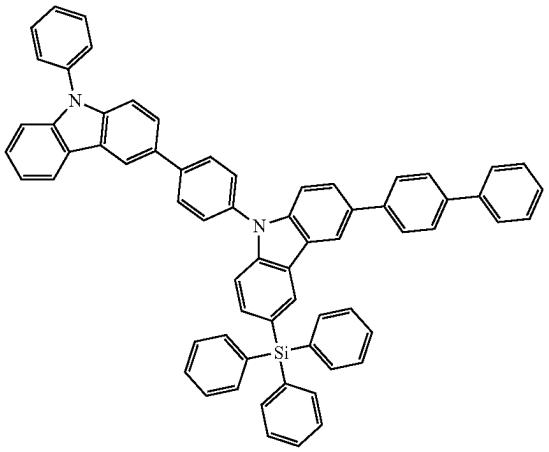

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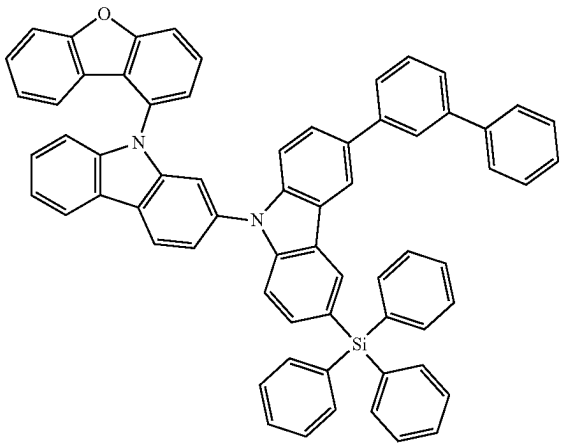

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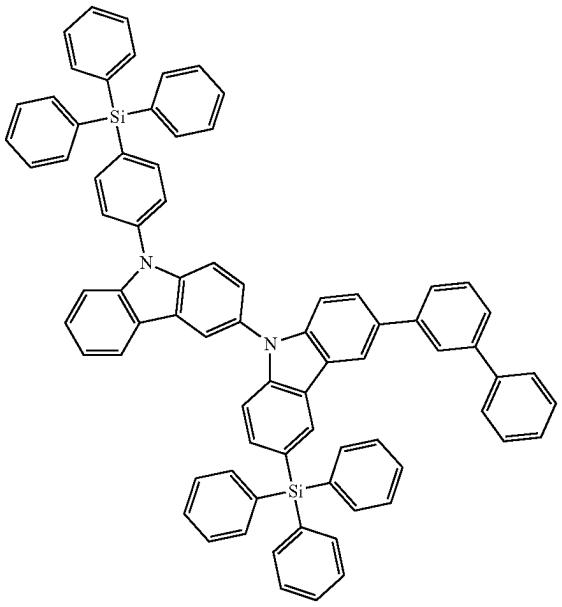

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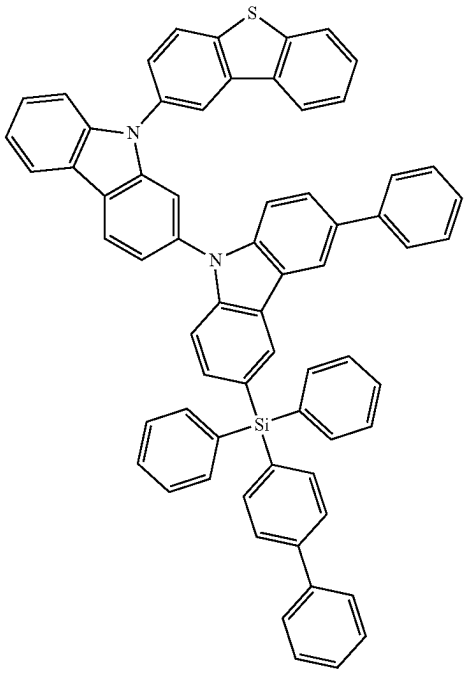

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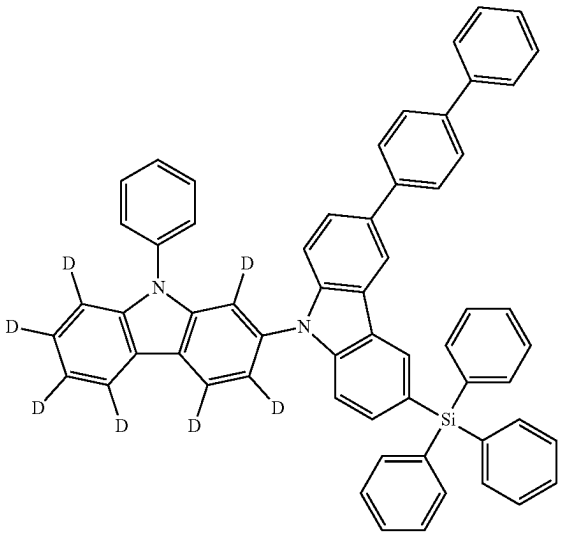

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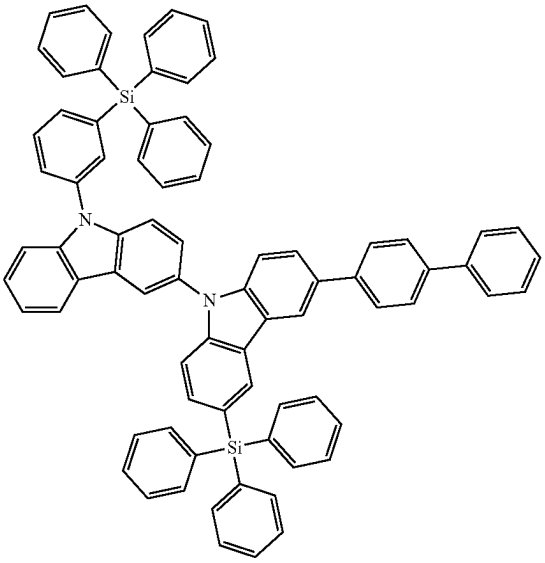

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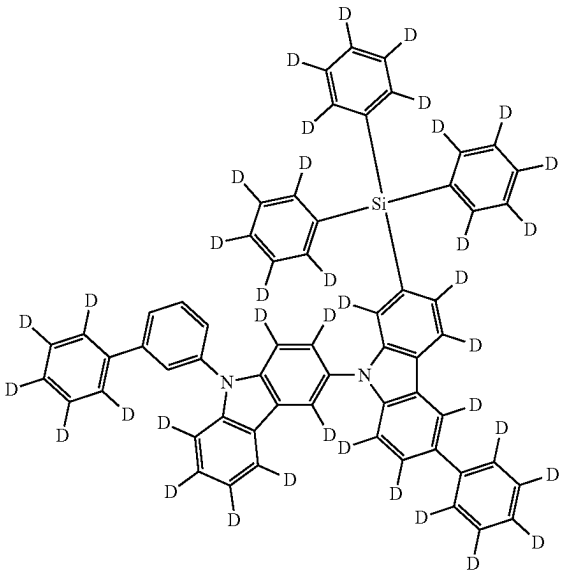

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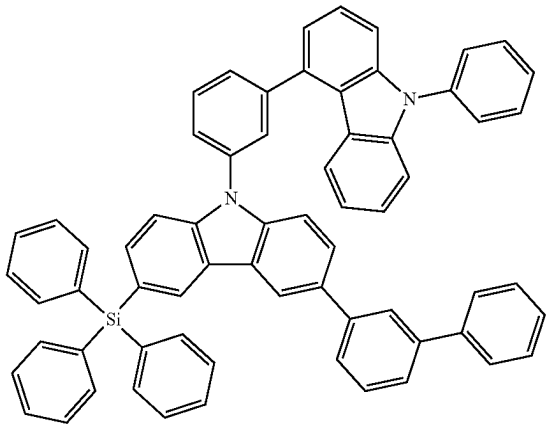

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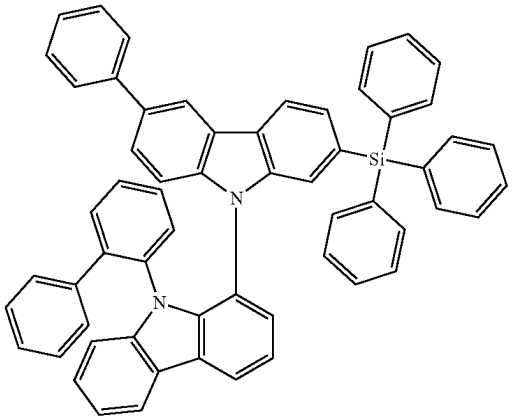

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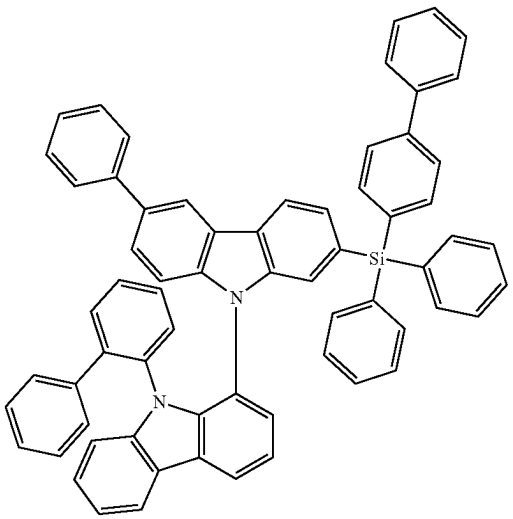

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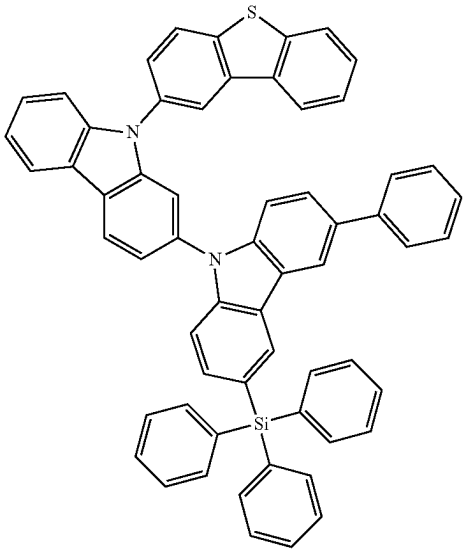

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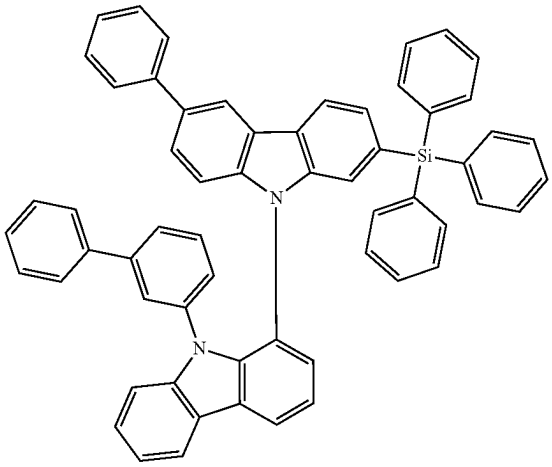

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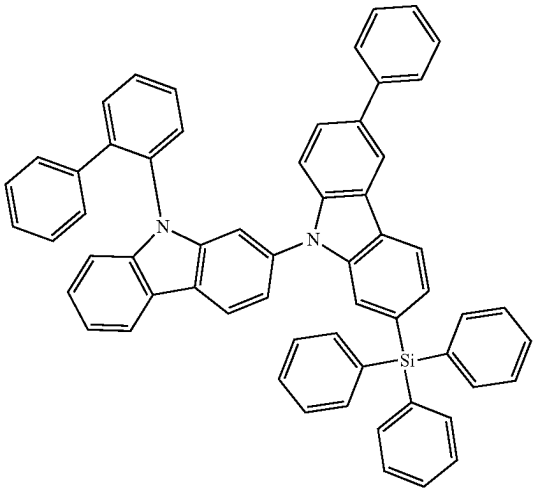

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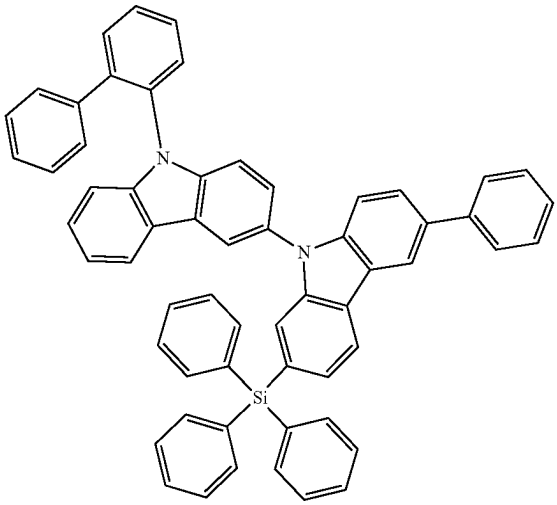

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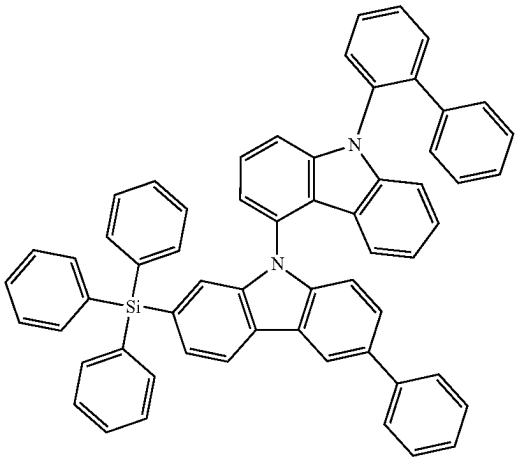

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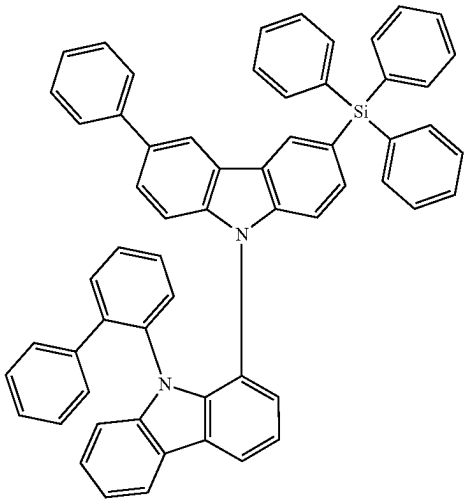

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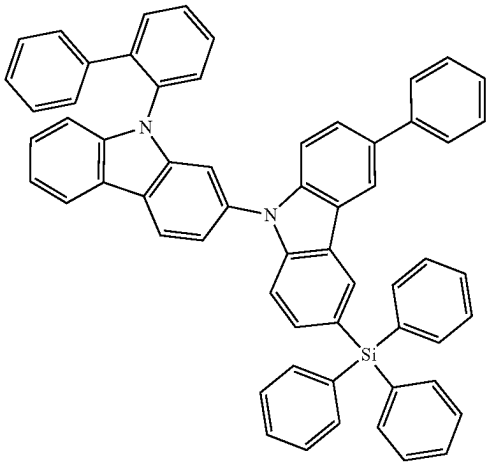

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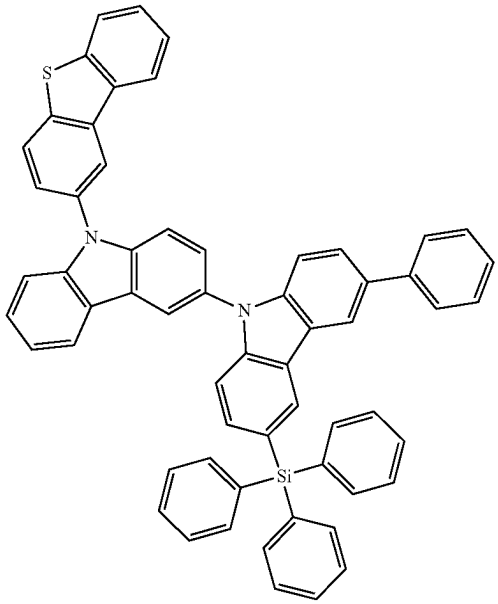

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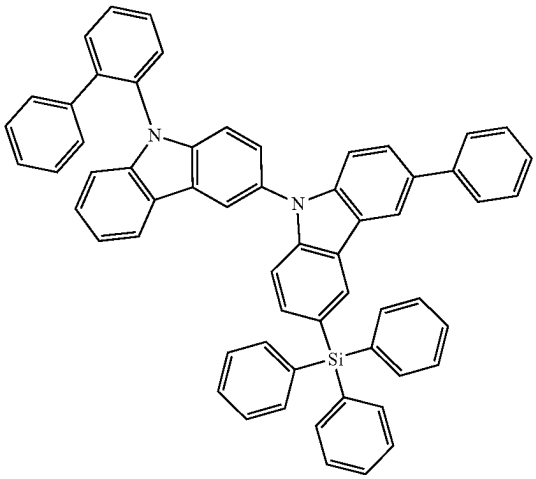

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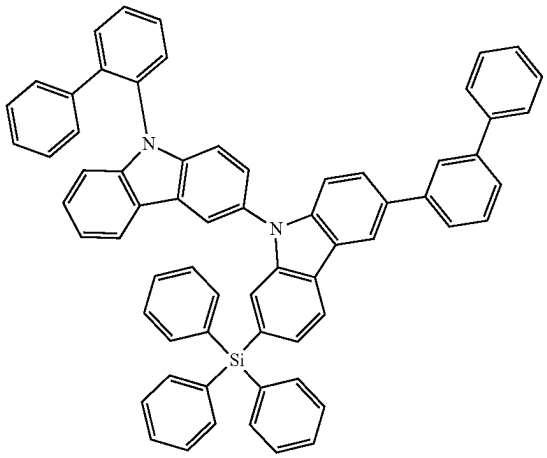

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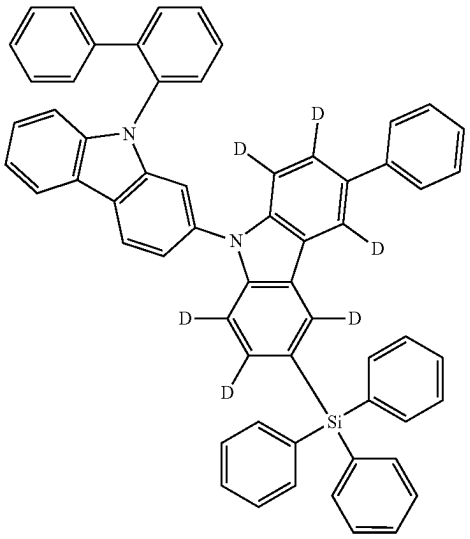

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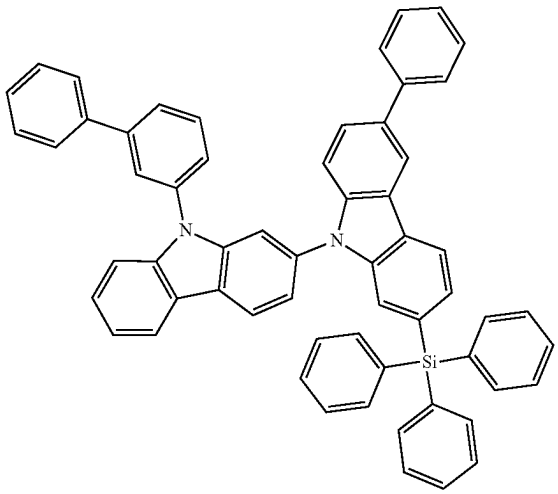

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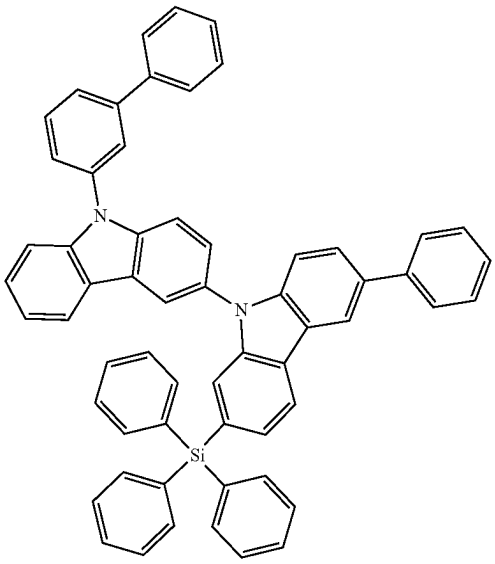

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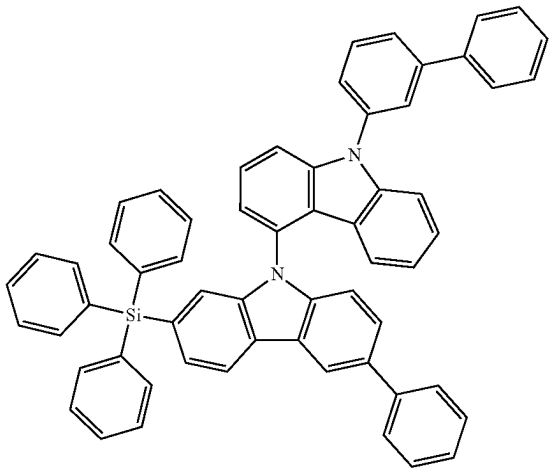

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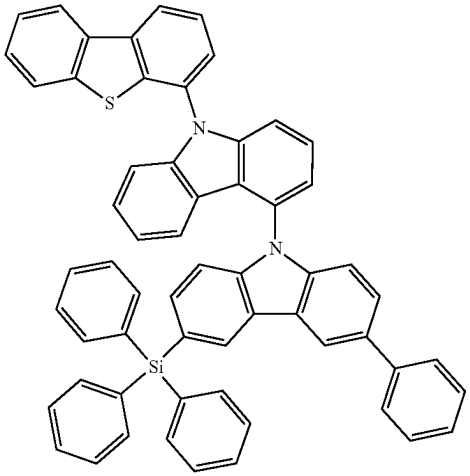

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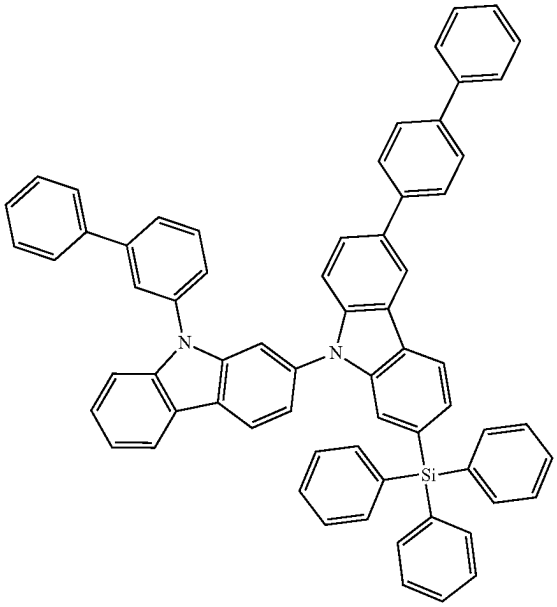

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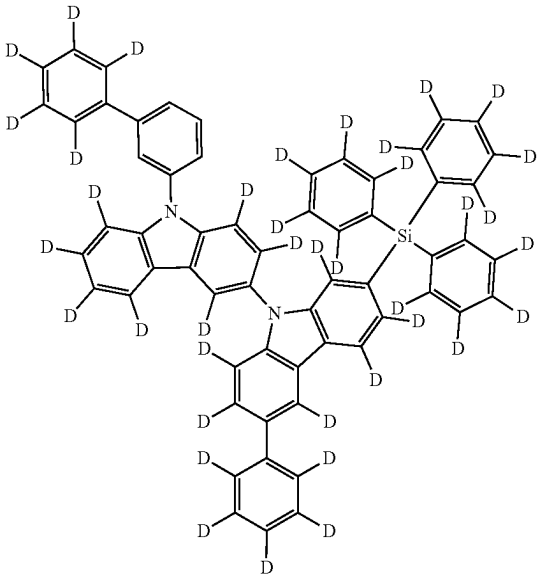

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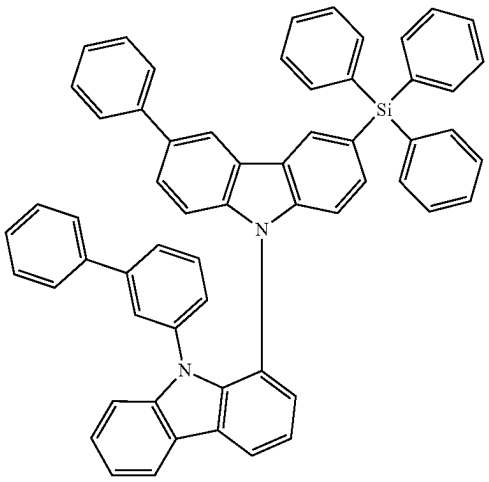

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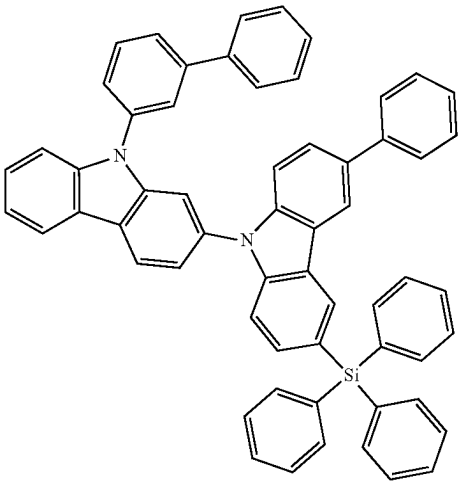

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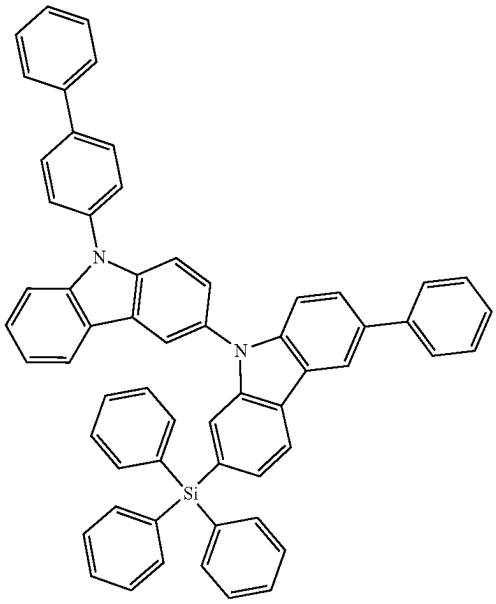

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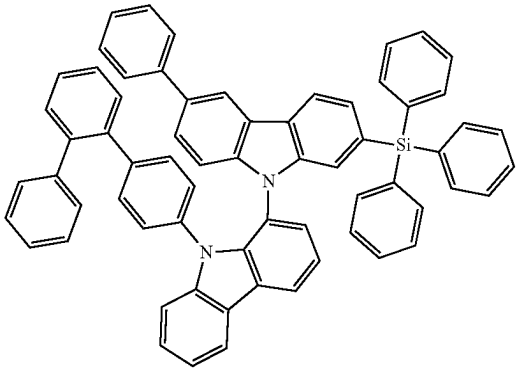

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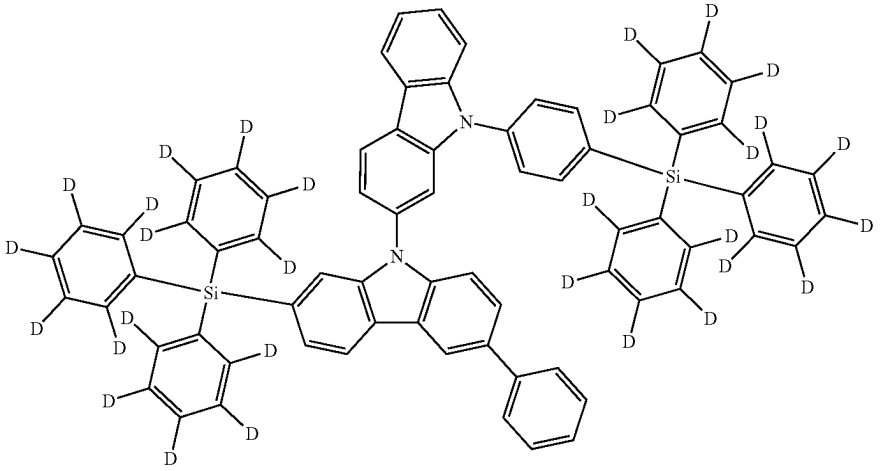

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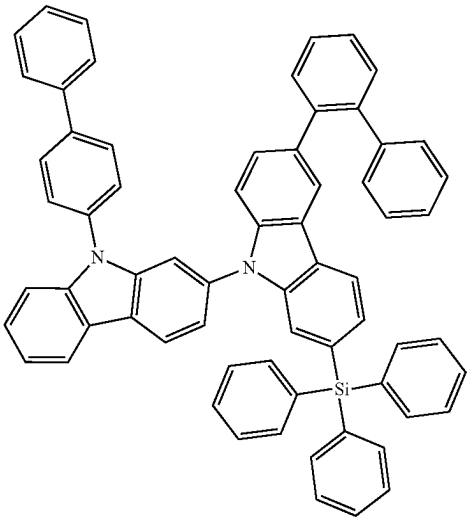

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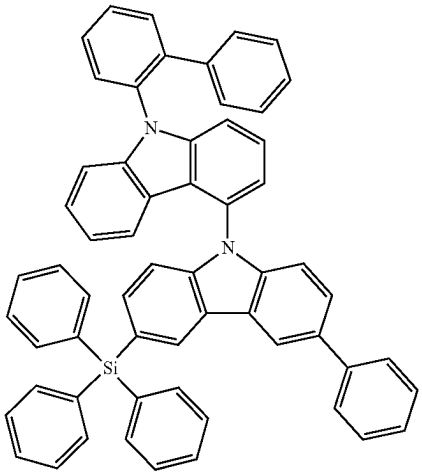

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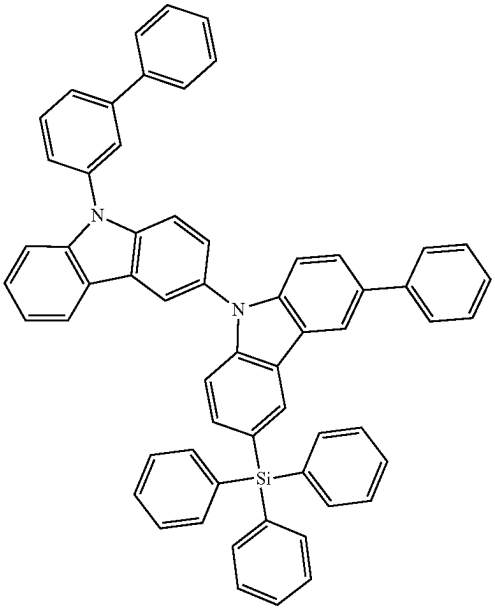

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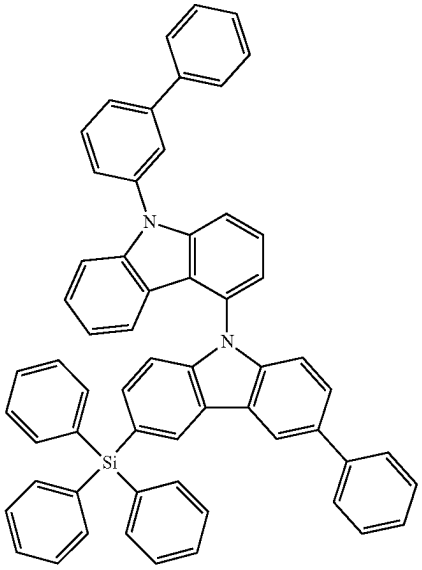

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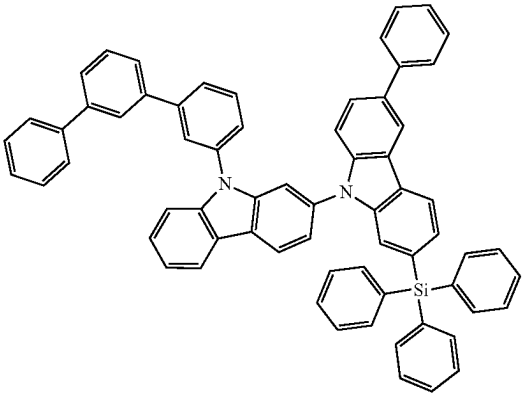

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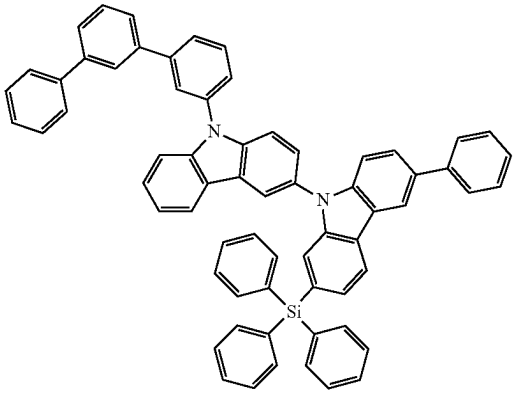

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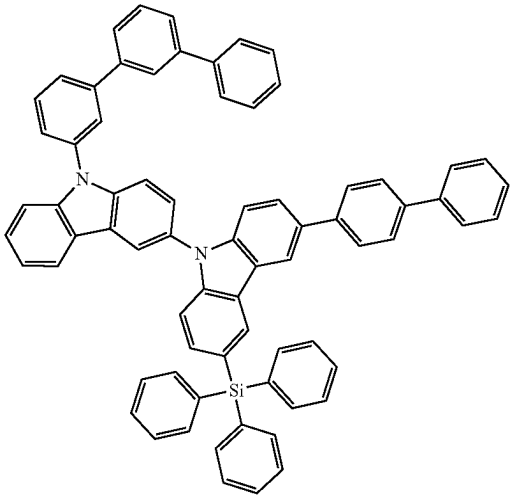

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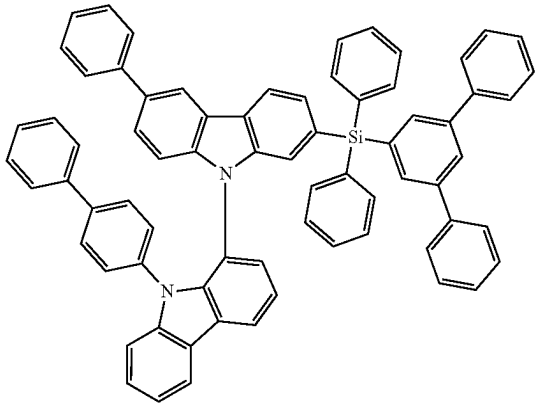

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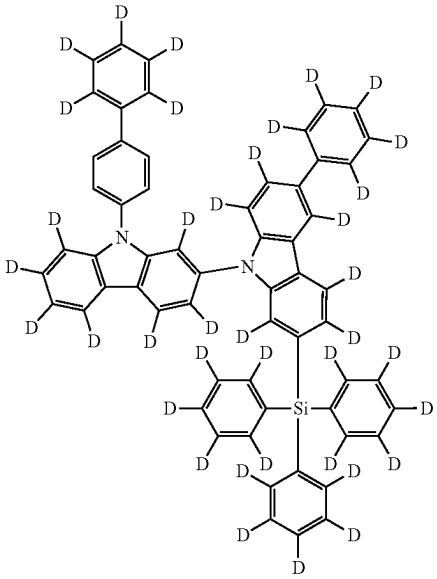

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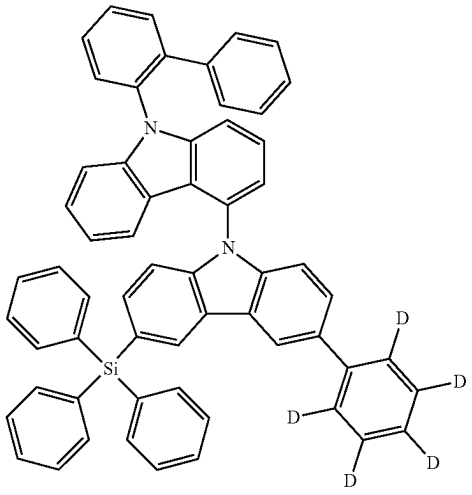

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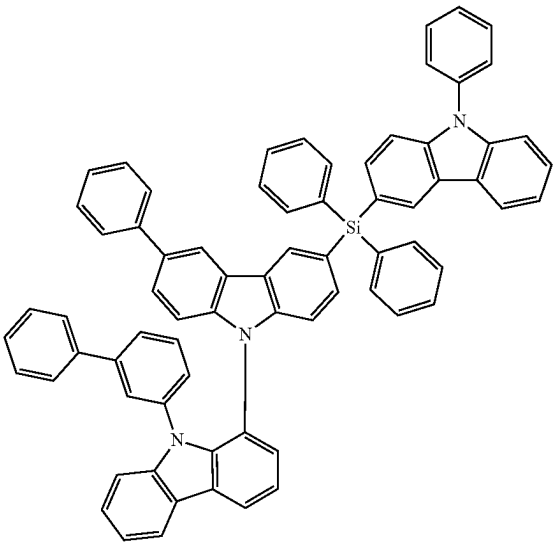

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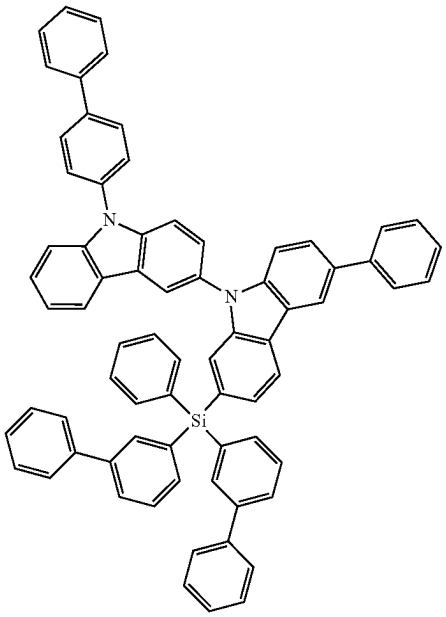

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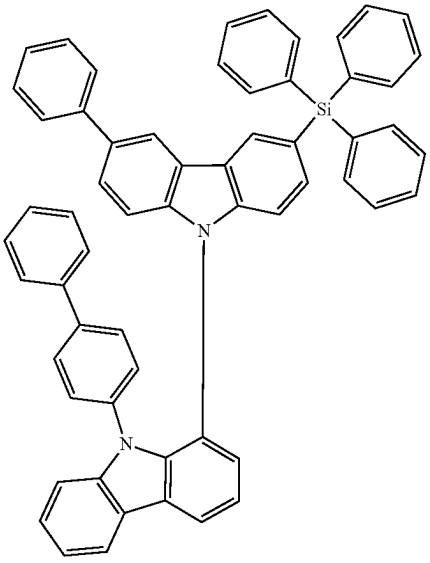

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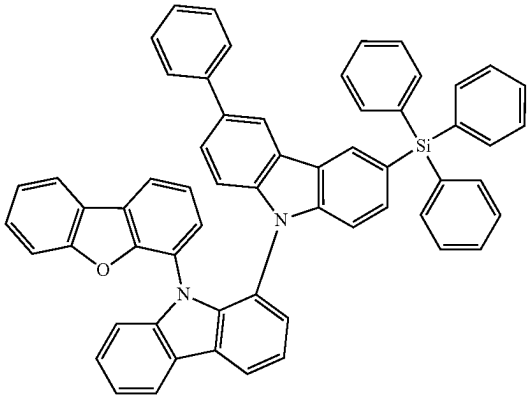

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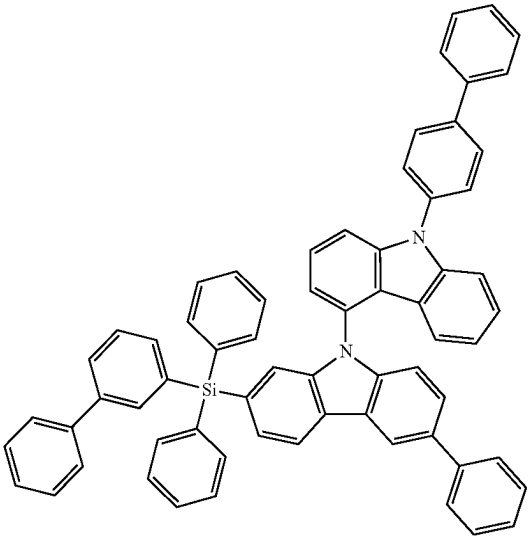

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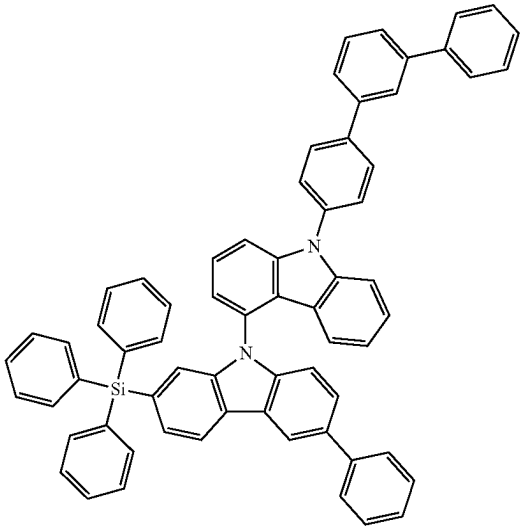

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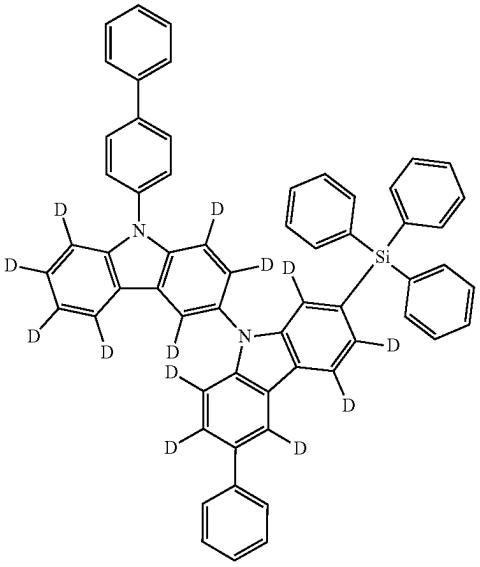

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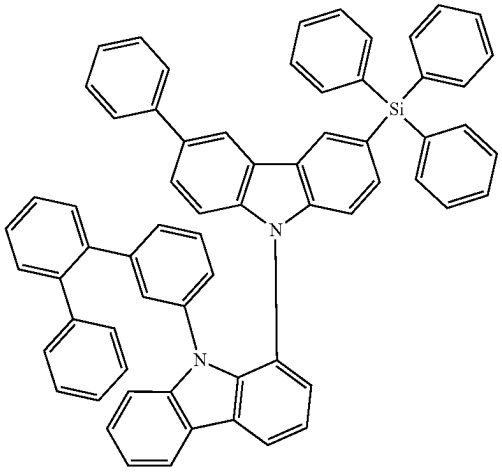

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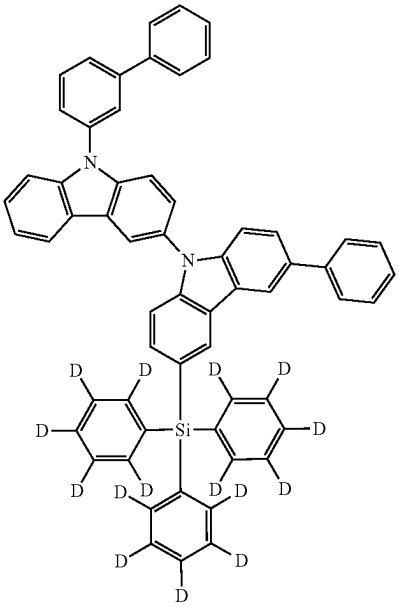

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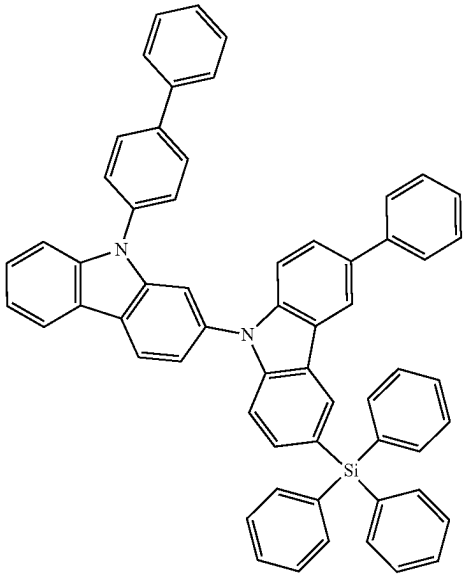

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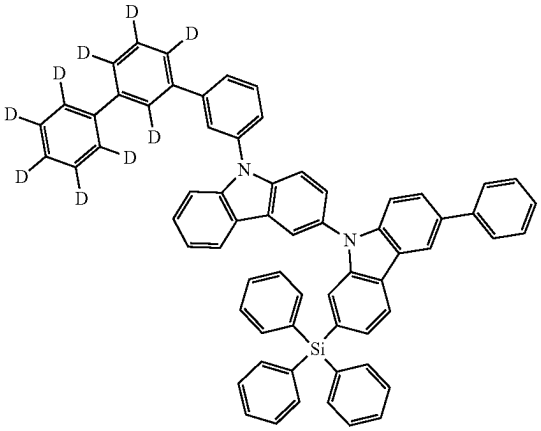

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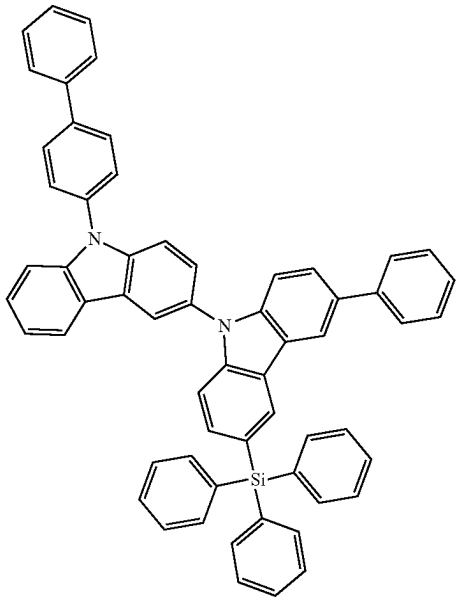

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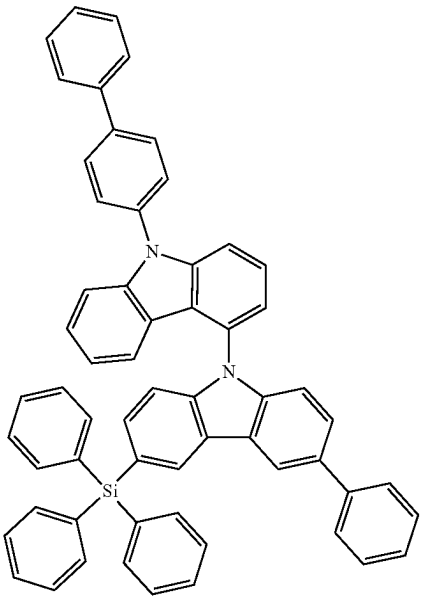

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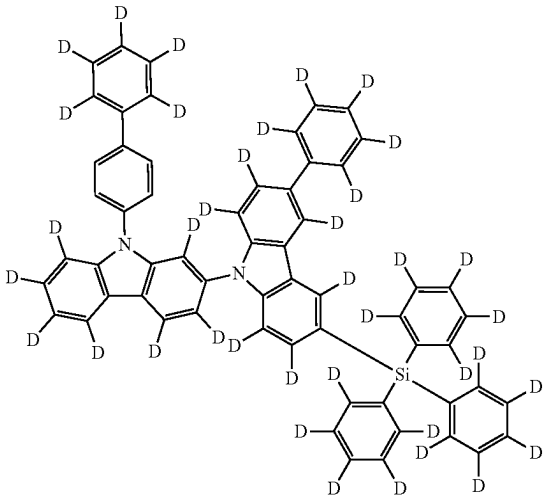

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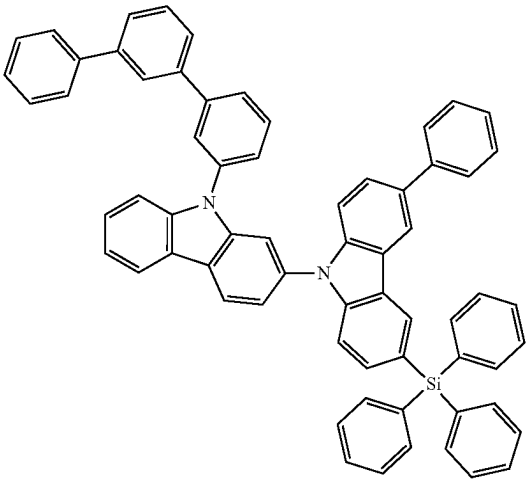

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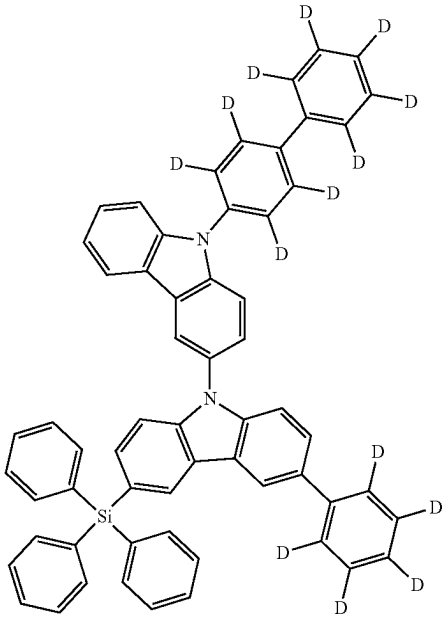

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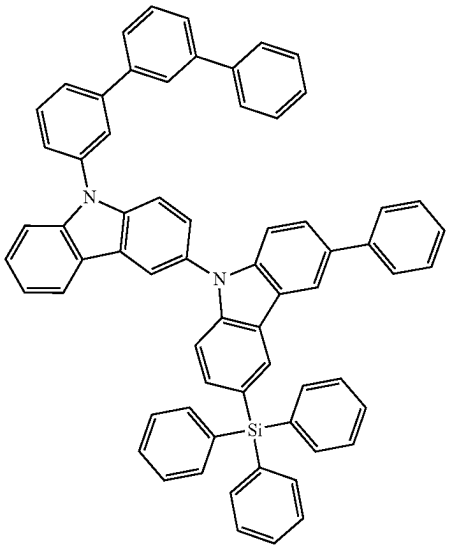

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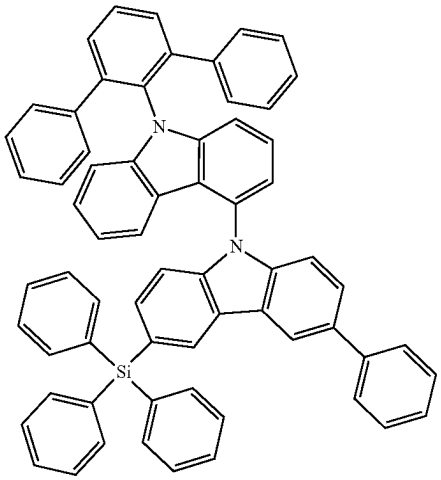

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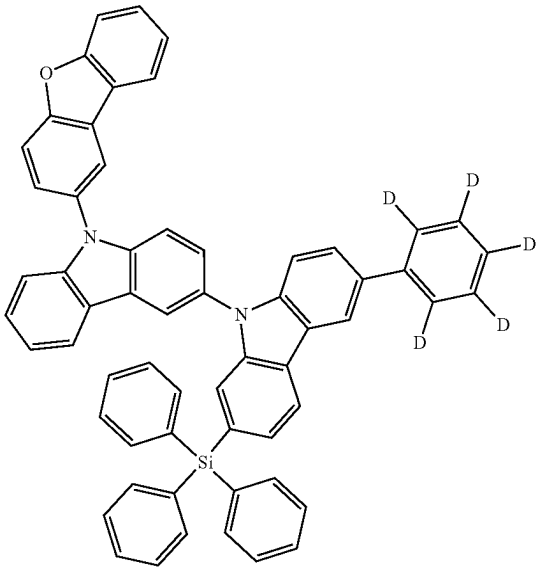

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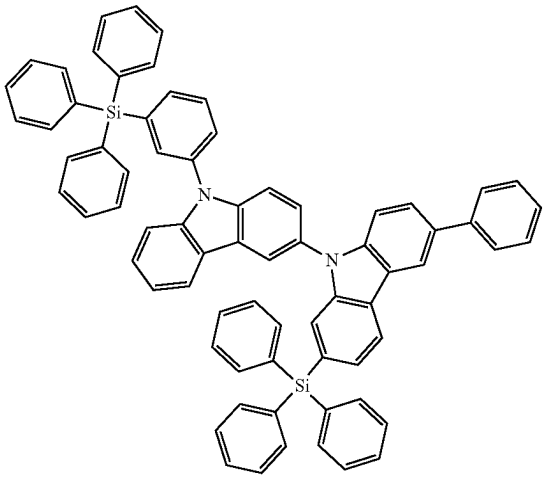

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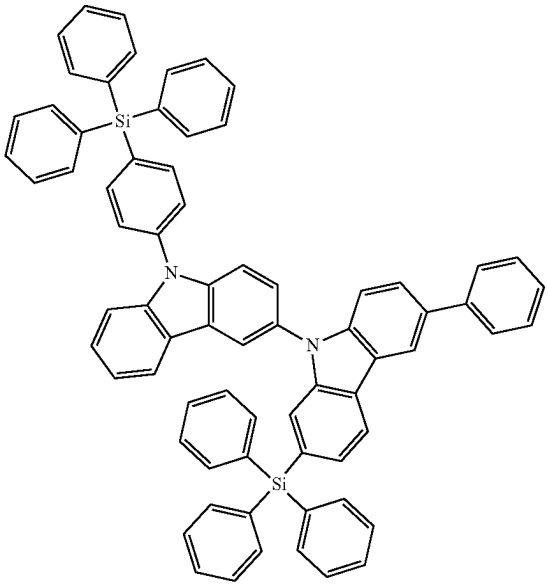

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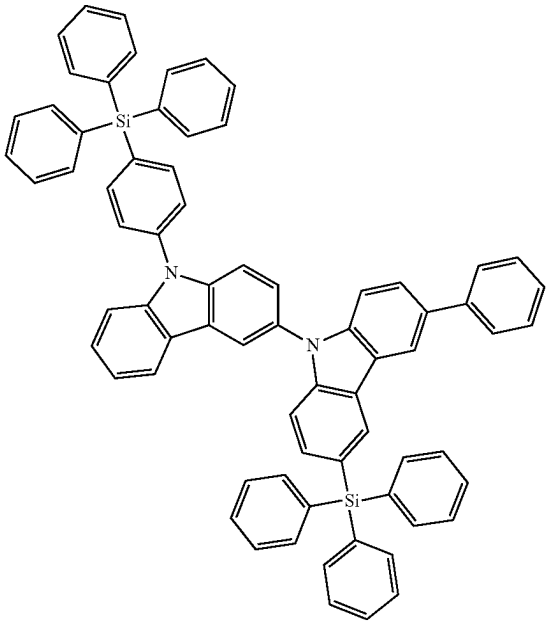

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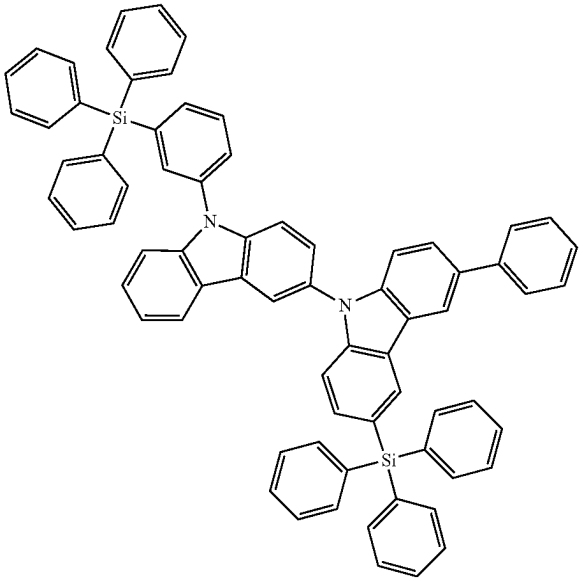

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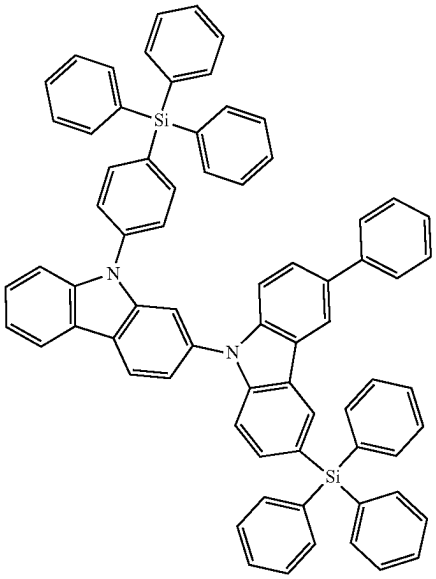

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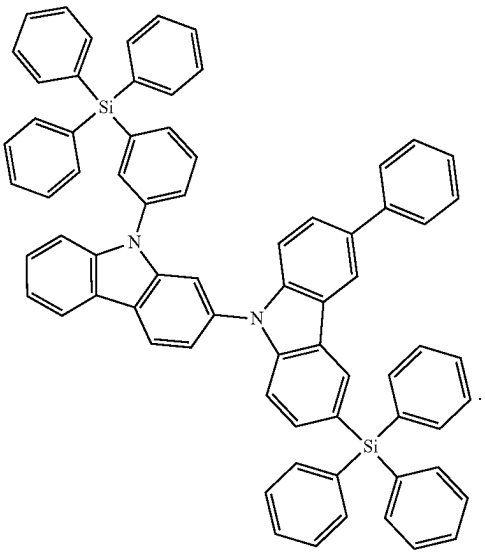

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