US 20250257073A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2025/0257073 A1**

JO et al. (43) **Pub. Date: Aug. 14, 2025**

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

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(21) Appl. No.: **19/097,337**

(22) Filed: **Apr. 1, 2025**

Related U.S. Application Data

(62) Division of application No. 17/316,580, filed on May 10, 2021, now Pat. No. 12,286,441.

(30) **Foreign Application Priority Data**

May 13, 2020 (KR) 10-2020-0057193

Publication Classification

(51) **Int. Cl.**

C07D 498/16	(2006.01)
C07D 519/00	(2006.01)
H10K 50/15	(2023.01)
H10K 50/16	(2023.01)
H10K 50/17	(2023.01)
H10K 50/18	(2023.01)
H10K 50/85	(2023.01)
H10K 85/60	(2023.01)

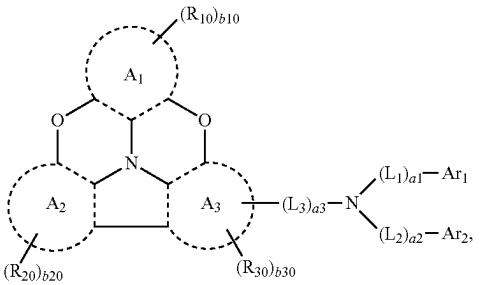
(52) **U.S. Cl.**

CPC ***C07D 498/16*** (2013.01); ***C07D 519/00*** (2013.01); ***H10K 85/615*** (2023.02); ***H10K 85/633*** (2023.02); ***H10K 85/636*** (2023.02); ***H10K 85/656*** (2023.02); ***H10K 85/6574*** (2023.02); ***H10K 85/6576*** (2023.02); *H10K 50/15* (2023.02); *H10K 50/16* (2023.02); *H10K 50/171* (2023.02); *H10K 50/18* (2023.02); *H10K 50/181* (2023.02); *H10K 50/85* (2023.02)

(57) **ABSTRACT**

A light-emitting device includes a heterocyclic compound represented by Formula 1:

Formula 1



The heterocyclic compound represented by Formula 1 may have a high glass transition temperature (T_g) and/or melting point for excellent thermal resistance, and excellent hole injectability and/or transportability. Accordingly, the light-emitting device may have excellent luminance, luminescence efficiency, lifespan, and/or driving voltage.

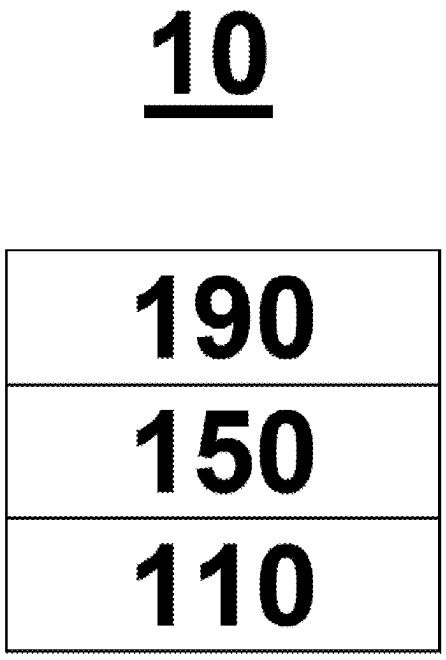


FIG. 1

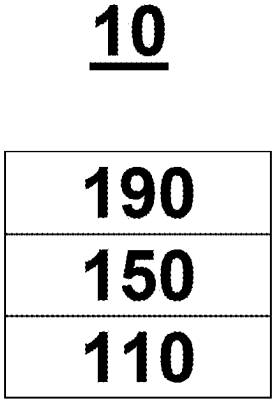


FIG. 2

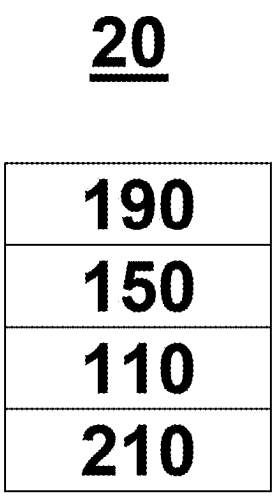


FIG. 3

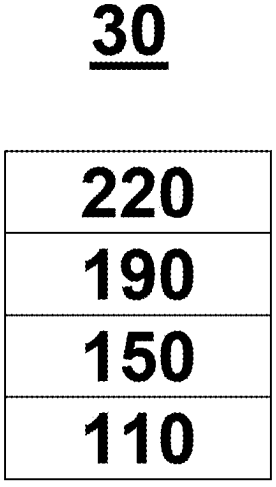
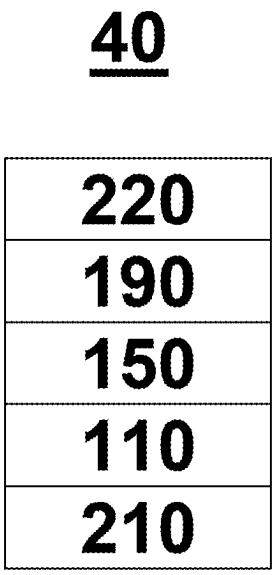


FIG. 4



HETEROCYCLIC COMPOUND, LIGHT-EMITTING DEVICE INCLUDING HETEROCYCLIC COMPOUND, AND APPARATUS INCLUDING LIGHT-EMITTING DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a divisional of U.S. patent application Ser. No. 17/316,580, filed on May 10, 2021, which claims priority to and the benefit of Korean Patent Application No. 10-2020-0057193, filed on May 13, 2020, in the Korean Intellectual Property Office, the entire contents of both of which are incorporated herein by reference.

BACKGROUND

1. Field

[0002] One or more aspects of embodiments of the present disclosure relate to a heterocyclic compound, a light-emitting device including the heterocyclic compound, and an apparatus including the light-emitting device.

2. Description of Related Art

[0003] Organic light-emitting devices (OLEDs) are self-emissive devices that, compared with devices in the related art, may have wide viewing angles, high contrast ratios, short response times, and/or excellent characteristics in terms of brightness, driving voltage, and/or response speed, and may produce full-color images.

[0004] OLEDs may include a first electrode on a substrate, and a hole transport region, an emission layer, an electron transport region, and a second electrode sequentially stacked on the first electrode. Holes provided from the first electrode may move toward the emission layer through the hole transport region, and electrons provided from the second electrode may move toward the emission layer through the electron transport region. Carriers (such as the holes and the electrons) may recombine in the emission layer to produce excitons. These excitons transition from an excited state to the ground state to thereby generate light.

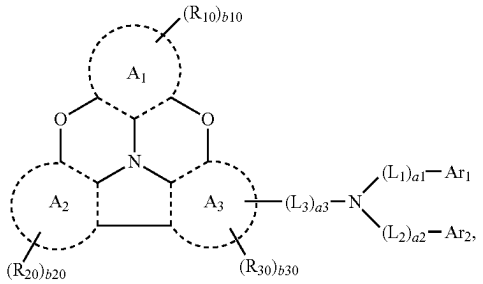
SUMMARY

[0005] One or more aspects of embodiments of the present disclosure are directed toward a heterocyclic compound and a light-emitting device including the heterocyclic compound.

[0006] 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 presented embodiments of the disclosure.

[0007] One or more example embodiments of the present disclosure provide a heterocyclic compound represented by Formula 1:

Formula 1



[0008] wherein, in Formula 1,

[0009] A_1 to A_3 may each independently be selected from a C_5-C_{60} carbocyclic group and a C_1-C_{60} heterocyclic group,

[0010] L_1 to L_3 may each independently be selected from a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, a substituted or unsubstituted C_1-C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0011] a1, a2, and a3 may each independently be an integer from 0 to 5,

[0012] Ar_1 and Ar_2 may each independently be selected from a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group,

[0013] R_{10}, R_{20}, and R_{30} may each independently be selected from hydrogen, deuterium, —F —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_2-C_{60} alkenyl group, a substituted or unsubstituted C_2-C_{60} alkynyl group, a substituted or unsubstituted C_1-C_{60} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic

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

[0014] b10, b20, and b30 may each independently be an integer from 1 to 8,

[0015] * and *' each indicate a binding site to an adjacent atom, and

[0016] at least one substituent of the substituted C_3-C_{10} cycloalkylene group, the substituted C_1-C_{10} heterocycloalkylene group, the substituted C_3-C_{10} cycloalkenylene group, the substituted C_1-C_{10} heterocycloalkenylene group, the substituted C_6-C_{60} arylene group, the substituted C_1-C_{60} heteroarylene group, the substituted divalent non-aromatic condensed polycyclic group, the substituted divalent non-aromatic condensed heteropolycyclic group, the substituted C_1-C_{60} alkyl group, the substituted C_2-C_{60} alkenyl group, the substituted C_2-C_{60} alkynyl group, the substituted C_1-C_{60} alkoxy group, the substituted C_3-C_{10} cycloalkyl group, the substituted C_1-C_{10} heterocycloalkyl group, the substituted C_3-C_{10} cycloalkenyl group, the substituted C_1-C_{10} heterocycloalkenyl group, the substituted C_6-C_{60} aryl group, the substituted C_6-C_{60} aryloxy group, the substituted C_6-C_{60} arylthio group, the substituted C_1-C_{60} heteroaryl group, the substituted monovalent non-aromatic condensed polycyclic group, and the substituted monovalent non-aromatic condensed heteropolycyclic group may be selected from:

[0017] deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group,

[0018] a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, 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_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic 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}), and —P(=O)(Q_{11})(Q_{12}),

[0019] 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_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group,

[0020] 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_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono 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_{10} cycloalkyl group, a C_1-C_1 heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_1 heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic 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}), and —P(=O)(Q_{21})(Q_{22}), and

[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}), and —P(=O)(Q_{31})(Q_{32}),

[0022] wherein 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 selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono 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_{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, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl group.

[0023] One or more example embodiments of the present disclosure provide a light-emitting device including 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 at least one of the heterocyclic compound.

[0024] One or more example embodiments of the present disclosure provide an apparatus including the light-emitting device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] The above and other aspects, features, and advantages of certain embodiments of the disclosure will be more apparent from the following description taken in conjunction with the accompanying drawings, in which:

[0026] FIG. **1** is a schematic cross-sectional view illustrating a light-emitting device according to an embodiment;

[0027] FIG. **2** is a schematic cross-sectional view illustrating a light-emitting device according to an embodiment;

[0028] FIG. **3** is a schematic cross-sectional view illustrating a light-emitting device according to an embodiment; and

[0029] FIG. **4** is a schematic cross-sectional view illustrating a light-emitting device according to an embodiment.

DETAILED DESCRIPTION

[0030] Reference will now be made in more detail to embodiments, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to like elements throughout, and duplicative descriptions thereof may not be provided. In this regard, the present embodiments may have different forms and should not be construed as being limited to the descriptions set forth herein. Accordingly, the embodiments are merely described below, by referring to the drawings, to explain aspects of the present description. As used herein, the term "and/or" includes any and all combinations of one or more of the

associated listed items. Throughout the disclosure, the expression "at least one of a, b or c" may refer to only a, only b, only c, both a and b, both a and c, both b and c, all of a, b, and c, or variations thereof.

[0031] The present disclosure allows for various changes and numerous embodiments, and selected embodiments will be illustrated in the drawings and described in detail in the written description. Effects, features, and a method of achieving the present disclosure will be obvious by referring to the example embodiments of the present disclosure with reference to the attached drawings. The present disclosure may, however, be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein.

[0032] In the embodiments described in the present specification, an expression used in the singular encompasses the expression of the plural, unless it has a clearly different meaning in the context.

[0033] In the present specification, it is to be understood that the terms such as "having," "includes," "including," "comprises," and "comprising" are intended to indicate the existence of the features or components disclosed in the specification, and are not intended to preclude the possibility that one or more other features or components may exist or may be added.

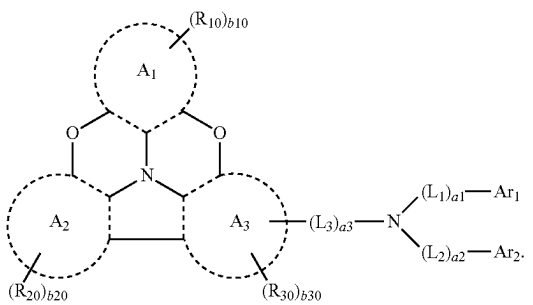
[0034] As used herein, expressions such as "at least one of," "one of," and "selected from," when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list. Further, the use of "may" when describing embodiments of the present disclosure refers to "one or more embodiments of the present disclosure".

[0035] It will be understood that when a layer, region, or component is referred to as being "on" or "onto" another layer, region, or component, it may be directly or indirectly formed over the other layer, region, or component. That is, for example, intervening layers, regions, or components may be present. When an element is referred to as being "directly on," "directly connected to," or "directly coupled to" another element, there are no intervening elements present.

[0036] The sizes of components in the drawings may be exaggerated for convenience of explanation. In other words, because sizes and thicknesses of components in the drawings are arbitrarily illustrated for convenience of explanation, the following embodiments are not limited thereto.

[0037] A heterocyclic compound according to one or more embodiments may be represented by Formula 1:

Formula 1



[0038] In Formula 1, A_1 to A_3 may each independently be selected from a C_5-C_{60} carbocyclic group and a C_1-C_{60} heterocyclic group.

[0039] In some embodiments, A_1 to A_3 may each independently be selected from 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 1,2,3,4-tetrahydronaphthalene 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 indenopyridine group, an indolopyridine group, a benzofuropyridine group, a benzothienopyridine group, a benzosilolopyridine group, an indenopyrimidine group, an indolopyrimidine group, a benzofuropyrimidine group, a benzothienopyrimidine group, a benzosilolopyrimidine group, a dihydropyridine 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 2,3-dihydroimidazole group, a triazole group, a 2,3-dihydrotriazole group, an oxazole group, an iso-oxazole group, a thiazole group, an isothiazole group, an oxadiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a 2,3-dihydrobenzimidazole group, an imidazopyridine group, a 2,3-dihydroimidazopyridine group, an imidazopyrimidine group, a 2,3-dihydroimidazopyrimidine group, an imidazopyrazine group, a 2,3-dihydroimidazopyrazine group, a benzoxazole group, a benzothiazole group, a benzoxadiazole group, a benzothiadiazole group, a 5,6,7,8-tetrahydroisoquinoline group, and a 5,6,7,8-tetrahydroquinoline group.

[0040] In some embodiments, A_1 to A_3 may each independently be selected from 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, and a quinazoline group.

[0041] In some embodiments, A_1 to A_3 may each independently be a benzene group or a naphthalene group.

[0042] In Formula 1, L_1 to L_3 may each independently be selected from a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, a substituted or unsubstituted C_1-C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group.

[0043] In some embodiments, L_1 to L_3 may each independently be selected from: a phenylene group, a pentalenylene group, an indenylene group, a naphthylene group, an azulenylene group, a heptalenylene group, an indacenylene group, an acenaphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a spiro-fluorene-benzofluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenalenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a naphthacenylene group, a picenylene group, a

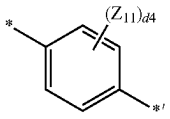
perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a rubicenylene group, a coronenylene group, an ovalenylene group, a pyrrolylene group, a thiophenylene group, a furanylene group, an imidazolylene group, a pyrazolylene group, a thiazolylene group, an isothiazolylene group, an oxazolylene group, an isoxazolylene group, a pyridinylene group, a pyrazinylene group, a pyrimidinylene group, a pyridazinylene group, an isoindolylene group, an indolylene group, an indazolylene group, a purinylene group, a quinolinylene group, an isoquinolinylene group, a benzoquinolinylene group, a phthalazinylene group, a naphthyridinylene group, a quinoxalinylene group, a quinazolinylene group, a cinnolinylene group, a carbazolylene group, a phenanthridinylene group, an acridinylene group, a phenanthrolinylene group, a phenazinylene group, a benzimidazolylene group, a benzofuranylene group, a benzothiophenylene group, an isobenzothiazolylene group, a benzoxazolylene group, an isobenzoxazolylene group, a triazolylene group, a tetrazolylene group, an oxadiazolylene group, a triazinylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a dibenzosilolylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a thiadiazolylene group, an imidazopyridinylene group, and an imidazopyrimidinylene group; and

[0044] a phenylene group, a pentalenylene group, an indenylene group, a naphthylene group, an azulenylene group, a heptalenylene group, an indacenylene group, an acenaphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a spiro-fluorene-benzofluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenalenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a naphthacenylene group, a picenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a rubicenylene group, a coronenylene group, an ovalenylene group, a pyrrolylene group, a thiophenylene group, a furanylene group, an imidazolylene group, a pyrazolylene group, a thiazolylene group, an isothiazolylene group, an oxazolylene group, an isoxazolylene group, a pyridinylene group, a pyrazinylene group, a pyrimidinylene group, a pyridazinylene group, an isoindolylene group, an indolylene group, an indazolylene group, a purinylene group, a quinolinylene group, an isoquinolinylene group, a benzoquinolinylene group, a phthalazinylene group, a naphthyridinylene group, a quinoxalinylene group, a quinazolinylene group, a cinnolinylene group, a carbazolylene group, a phenanthridinylene group, an acridinylene group, a phenanthrolinylene group, a phenazinylene group, a benzimidazolylene group, a benzofuranylene group, a benzothiophenylene group, an isobenzothiazolylene group, a benzoxazolylene group, an isobenzoxazolylene group, a triazolylene group, a tetrazolylene group, an oxadiazolylene group, a triazinylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a dibenzosilolylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a thiadiazolylene group, an imidazopyridinylene group, and an imidazopyrimidinylene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono 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 cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a naphthacenyl group, a picenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl 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 phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolylene group, a benzocarbazolyl group, a dibenzocarbazolyl group, a thiadiazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$,

[0045] wherein Q_{31} to Q_{33} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a phenyl group substituted with a C_1-C_{10} alkyl group, a biphenyl group, a terphenyl group, a naphthyl group, a pyridinyl group, a pyrimidyl group, a triazinyl group, a quinolinyl group, and an isoquinolinyl group.

[0046] In some embodiments, L_1 to L_3 may each independently be represented by any one of Formulae 3-1 to 3-26:

3-1



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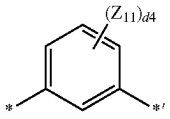

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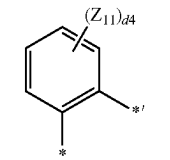

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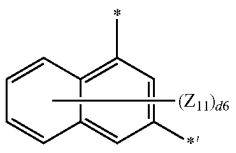

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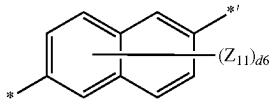

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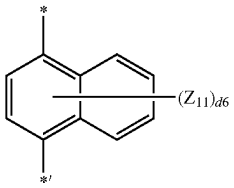

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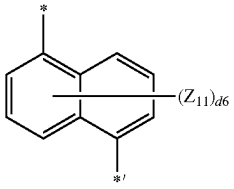

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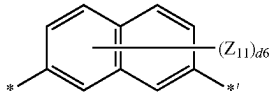

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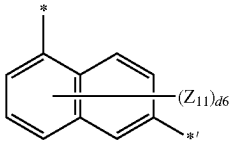

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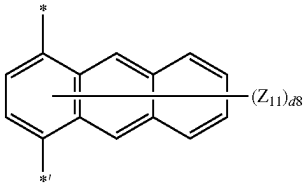

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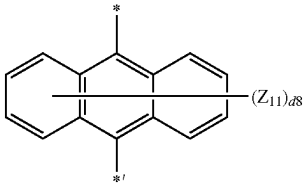

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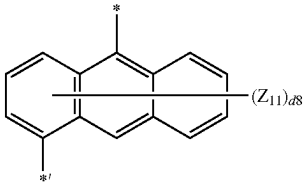

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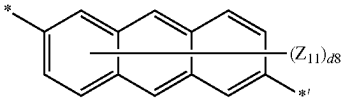

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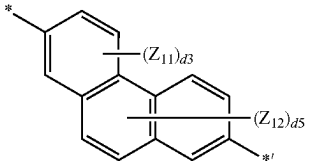

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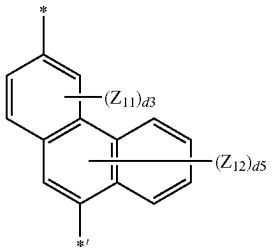

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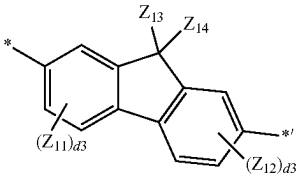

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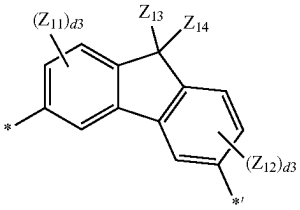

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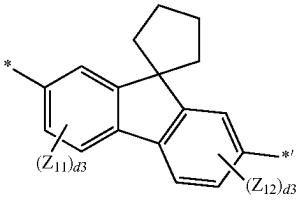

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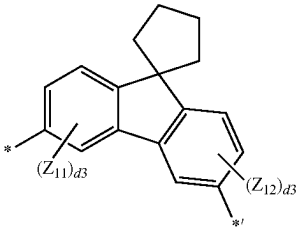

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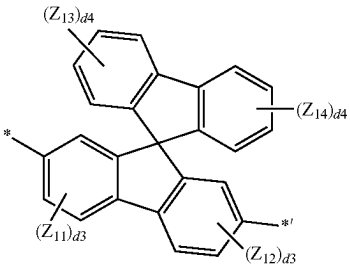

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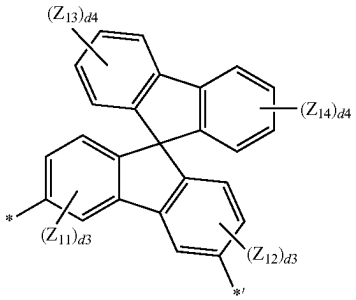
3-21



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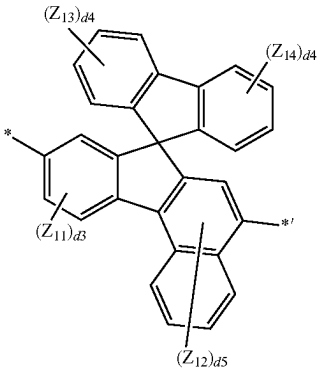
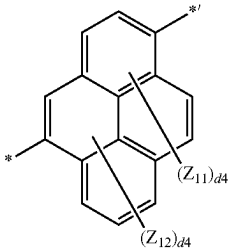
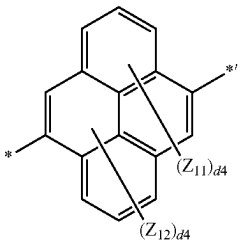


3-23



3-24



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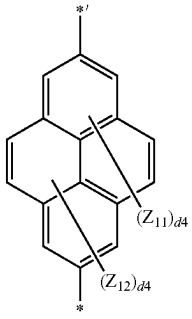

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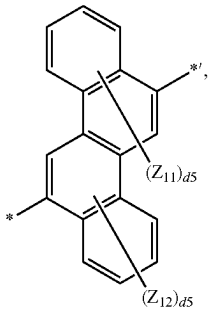
3-26



[0047] wherein, in Formulae 3-1 to 3-26,

[0048] Z_{11} to Z_{14} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spirobifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a triazinyl group, a benzimidazolyl group, a phenanthrolinyl group, and —$Si(Q_{31})(Q_{32})(Q_{33})$,

[0049] wherein Q_{31} to Q_{33} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group,

[0050] d2 may be an integer from 0 to 2,

[0051] d3 may be an integer from 0 to 3,

[0052] d4 may be an integer from 0 to 4,

[0053] d5 may be an integer from 0 to 5,

[0054] d6 may be an integer from 0 to 6,

[0055] d8 may be an integer from 0 to 8, and

[0056] * and *' each indicate a binding site to an adjacent atom.

[0057] In Formula 1, a1, a2, and a3 may each independently be an integer from 0 to 5.

[0058] In some embodiments, a1, a2, and a3 may each independently be 0, 1, or 2.

[0059] In some embodiments, a1, a2, and a3 may each independently be 0 or 1.

[0060] In some embodiments, a1 and a2 may each be 0, and a3 may be 0 or 1.

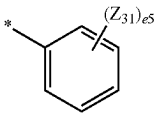
[0061] In some embodiments, a3 may be 0.

[0062] In some embodiments, a1, a2, and a3 may each be 0.

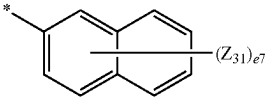
[0063] In Formula 1, Ar_1 and Ar_2 may each independently be selected from a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group.

[0064] In some embodiments, Ar_1 and Ar_2 may each independently be selected from groups represented by Formulae 5-1 to 5-26 and Formulae 6-1 to 6-55:

5-1



5-2



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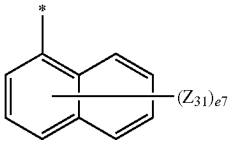

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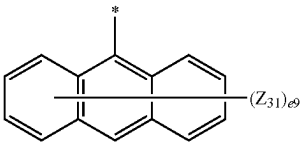
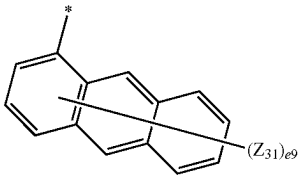


5-5



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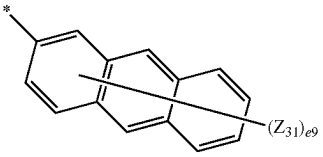
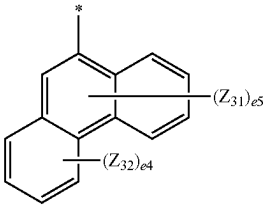


5-7



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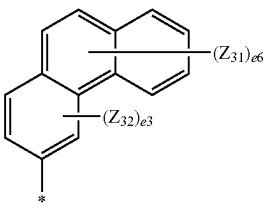

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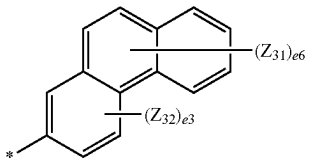
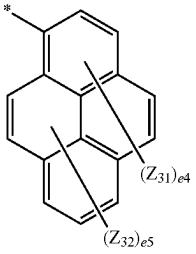
5-9



5-10



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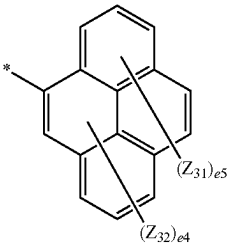

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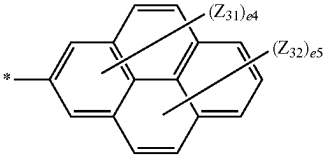

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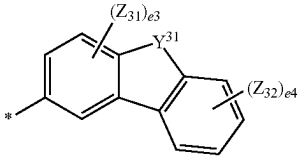

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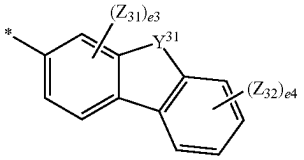

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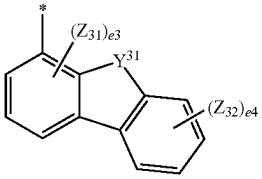

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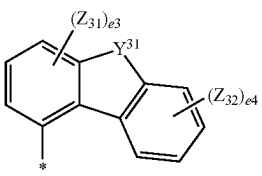

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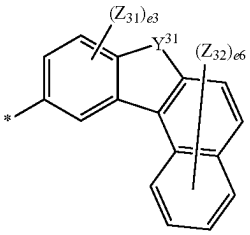

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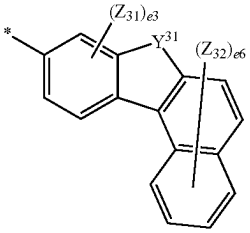

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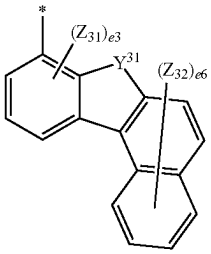

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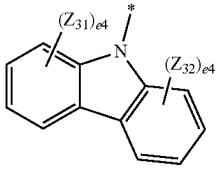

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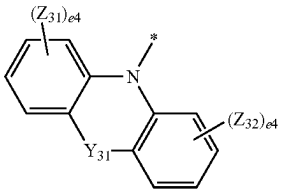

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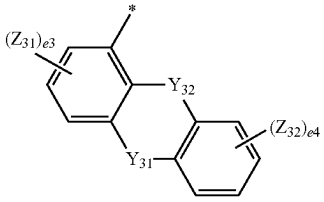

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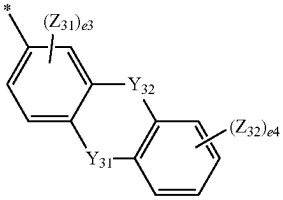

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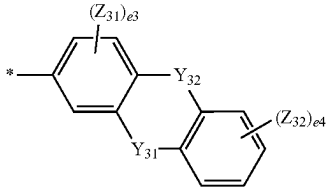

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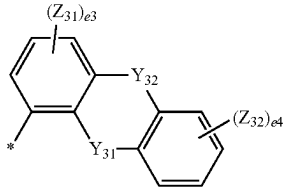

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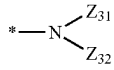

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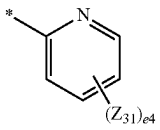

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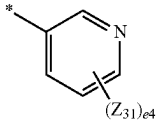

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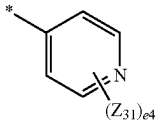

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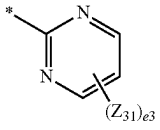

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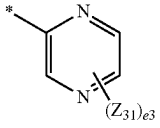

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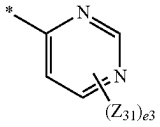

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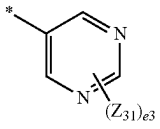

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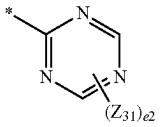

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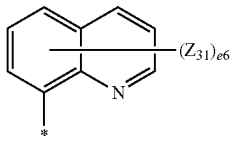

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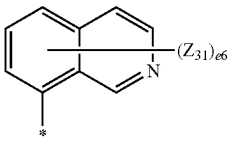

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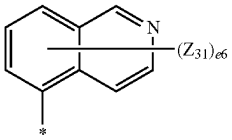

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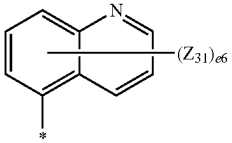

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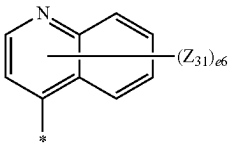

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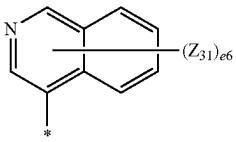

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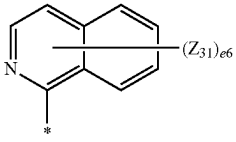

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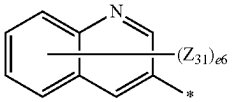

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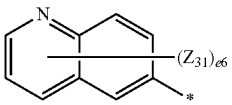

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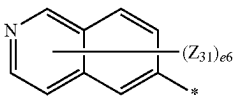

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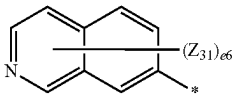

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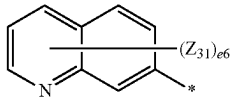

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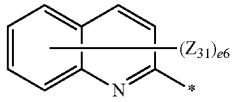

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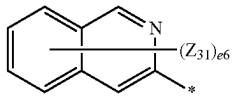

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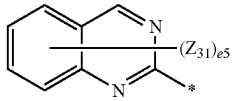

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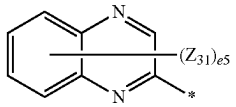

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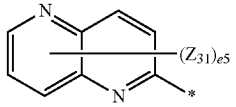

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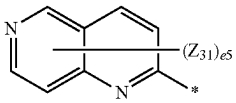

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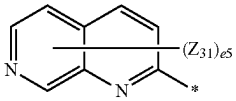

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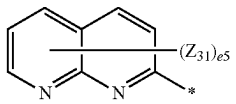

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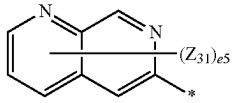

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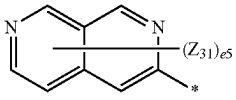

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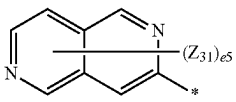

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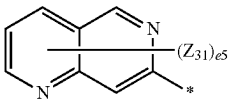

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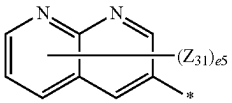

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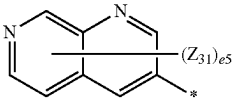

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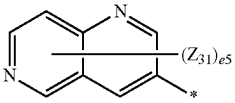

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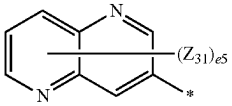

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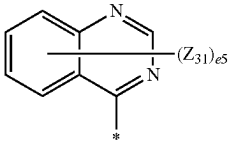

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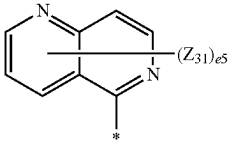

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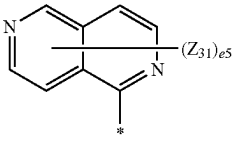

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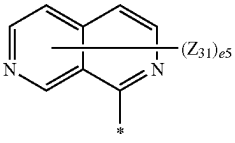

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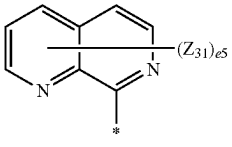

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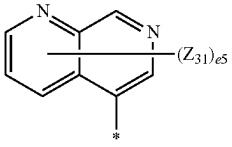

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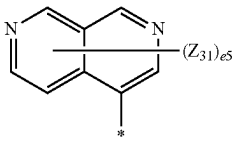

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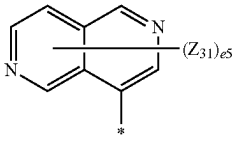

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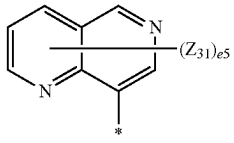

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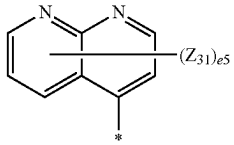

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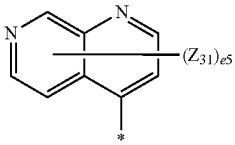

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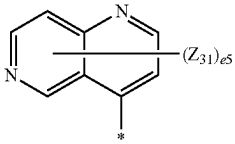

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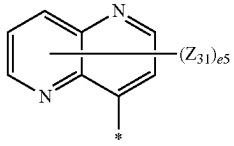

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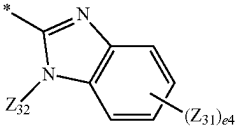

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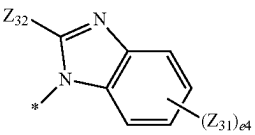

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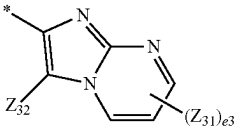

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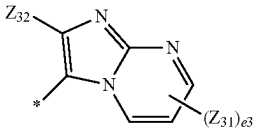

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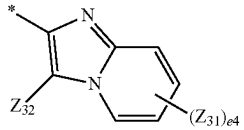

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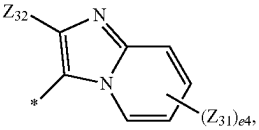


[0065] wherein, in Formulae 5-1 to 5-26 and Formulae 6-1 to 6-55,

[0066] Y_{31} and Y_{32} may each independently be O, S, $C(Z_{33})(Z_{34})$, $N(Z_{33})$, or $Si(Z_{33})(Z_{34})$,

[0067] Z_{31} to Z_{34} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkenyl group, a C_1-C_{20} alkynyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a phenanthrenyl group, an anthracenyl group, a triphenylenyl group, a pyridinyl group, a pyrimidinyl group, a carbazolyl group, and a triazinyl group,

[0068] e2 may be 1 or 2,

[0069] e3 may be an integer from 1 to 3,

[0070] e4 may be an integer from 1 to 4,

[0071] e5 may be an integer from 1 to 5,

[0072] e6 may be an integer from 1 to 6,

[0073] e7 may be an integer from 1 to 7,

[0074] e9 may be an integer from 1 to 9, and

[0075] * indicates a binding site to an adjacent atom.

[0076] In some embodiments, Ar_1 and Ar_2 may each independently be selected from groups represented by Formulae 5-1 to 5-25.

[0077] In some embodiments, Ar_1 and Ar_2 may each independently be selected from a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, and a dibenzocarbazolyl group.

[0078] In Formula 1, R_{10}, R_{20}, and R_{30} may each independently be selected from hydrogen, deuterium, —F —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_2-C_{60} alkenyl group, a substituted or unsubstituted C_2-C_{60} alkynyl group, a substituted or unsubstituted C_1-C_{60} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, $—Si(Q_1)(Q_2)(Q_3)$, $—B(Q_1)(Q_2)$, $—C(=O)(Q_1)$, $—S(=O)_2(Q_1)$, and $—P(=O)(Q_1)(Q_2)$.

[0079] In some embodiments, R_{10}, R_{20}, and R_{30} may each independently be selected from:

[0080] hydrogen, deuterium, —F —Cl, —Br, —I, a hydroxyl group, and a cyano group;

[0081] a C_1-C_{20} alkyl group, a C_2-C_{20} alkenyl group, a C_2-C_{20} alkynyl group, and a C_1-C_{20} alkoxy group;

[0082] a C_1-C_{20} alkyl group, a C_2-C_{20} alkenyl group, a C_2-C_{20} alkynyl group, and a C_1-C_{20} alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono 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 naphthyl group, a pyridinyl group, a pyrimidinyl group, $—Si(Q_{31})(Q_{32})(Q_{33})$, $—N(Q_{31})(Q_{32})$, $—B(Q_{31})(Q_{32})$, $—C(=O)(Q_{31})$, $—S(=O)_2(Q_{31})$, and $—P(=O)(Q_{31})(Q_{32})$;

[0083] 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 pentalenyl group, an indenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a furanyl group, a thiophenyl 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 phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzothiazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl 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, and an imidazopyrimidinyl group; and

[0084] 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 pentalenyl group, an indenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a furanyl group, a thiophenyl 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 phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzothiazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl 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, and an imidazopyrimidinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_2-C_{20} alkenyl group, a C_2-C_{20} alkynyl 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 pentalenyl group, an indenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a furanyl group, a thiophenyl 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 phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, a benzothiazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl 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, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$,

[0085] wherein Q_{31} to Q_{33} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a C_1-C_{20} alkyl group, a C_2-C_{20} alkenyl group, a C_2-C_{20} alkynyl group, a C_1-C_{20} alkoxy group, 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_{20} aryl group, a C_1-C_{20} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl group.

[0086] In some embodiments, R_{10}, R_{20}, and R_{30} may each independently be selected from:

[0087] hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a C_1-C_{20} alkyl group, and a C_1-C_{20} alkoxy group;

[0088] a C_1-C_{20} alkyl group and a C_1-C_{20} alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a cyano group, a phenyl group, and a biphenyl group;

[0089] a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, and a dibenzocarbazolyl group; and

[0090] a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, and a dibenzocarbazolyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a cyano group, a phenyl group, and a biphenyl group.

[0091] In some embodiments, R_{10} may be hydrogen.

[0092] In some embodiments, R_{20} and R_{30} may each be hydrogen.

[0093] In some embodiments, the heterocyclic compound may include one amine group.

[0094] In Formula 1, b10 and b30 may each independently be an integer from 1 to 7, and b20 and b40 may each independently be an integer from 1 to 8.

[0095] In some embodiments, b10 and b30 may each independently be 1, 2, or 3.

[0096] In some embodiments, b20 and b40 may each independently be 1, 2, 3, or 4.

[0097] * and *' each indicate a binding site to an adjacent atom.

[0098] At least one substituent of the substituted C_5-C_{60} carbocyclic group, the substituted C_1-C_{60} heterocyclic group, the substituted C_1-C_{60} alkyl group, the substituted C_2-C_{60} alkenyl group, the substituted C_2-C_{60} alkynyl group, the substituted C_1-C_{60} alkoxy group, the substituted C_3-C_{10} cycloalkyl group, the substituted C_1-C_{10} heterocycloalkyl group, the substituted C_3-C_{10} cycloalkenyl group, the substituted C_1-C_{10} heterocycloalkenyl group, the substituted C_6-C_{60} aryl group, the substituted C_6-C_{60} aryloxy group, the

substituted C_6-C_{60} arylthio group, the substituted C_1-C_{60} heteroaryl group, the substituted monovalent non-aromatic condensed polycyclic group, and the substituted monovalent non-aromatic condensed heteropolycyclic group may be selected from:

[0099] deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group;

[0100] a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_3-C_{10} cycloalkyl group, a C_1-C_1 heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_1 heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —$Si(Q_{11})(Q_{12})(Q_{13})$, —$N(Q_{11})(Q_{12})$, —$B(Q_{11})(Q_{12})$, —$C(=O)(Q_{11})$, —$S(=O)_2(Q_{11})$, and —$P(=O)(Q_{11})(Q_{12})$;

[0101] 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_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group;

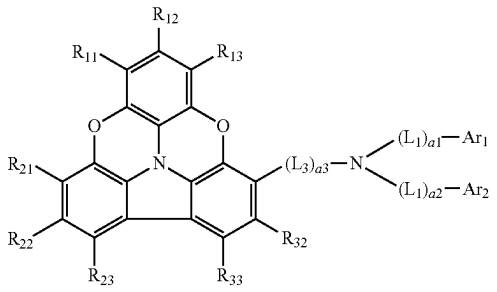
[0102] a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono 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_{10} cycloalkyl group, a C_1-C_1 heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_1 heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —$Si(Q_{21})(Q_{22})(Q_{23})$, —$N(Q_{21})(Q_{22})$, —$B(Q_{21})(Q_{22})$, —$C(=O)(Q_{21})$, —$S(=O)_2(Q_{21})$, and —$P(=O)(Q_{21})(Q_{22})$; and

[0103] —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$,

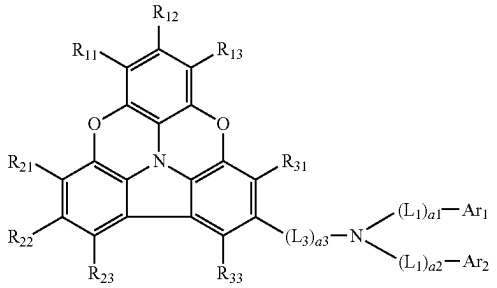
[0104] wherein Q_1 to Q_3, Q_{11} to Q_{13}, Q_{21} to Q_{23}, and Q_{31} to Q_{33} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_1 heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_1 heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl group.

[0105] The heterocyclic compound according to one or more embodiments may be represented by any one of Formulae 10^{-1} to 10^{-3}:

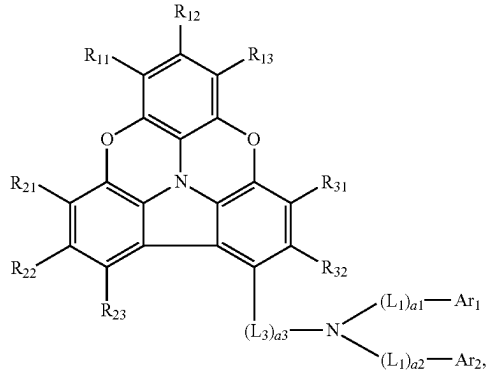
Formula 10-1



Formula 10-2



Formula 10-3



[0106] wherein, in Formulae 10^{-1} to 10^{-3},

[0107] L_1 to L_3, a1, a2, a3, Ar_1, and Ar_2 may each independently be the same as described above,

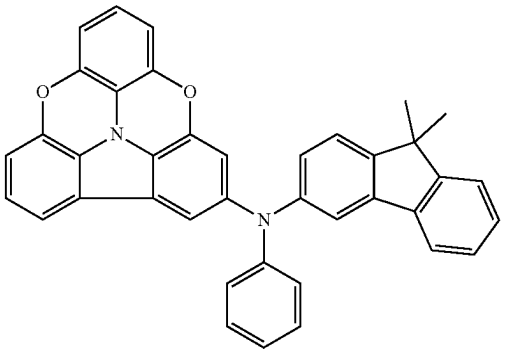
[0108] R_{11} to R_{13} may each independently be the same as described in connection with R_{10},

[0109] R_{21} to R_{23} may each independently be the same as described in connection with R_{20}, and

[0110] R_{31} to R_{33} may each independently be the same as described in connection with R_{30}.

[0111] In some embodiments, the heterocyclic compound may be selected from Compounds 1 to 123:

1



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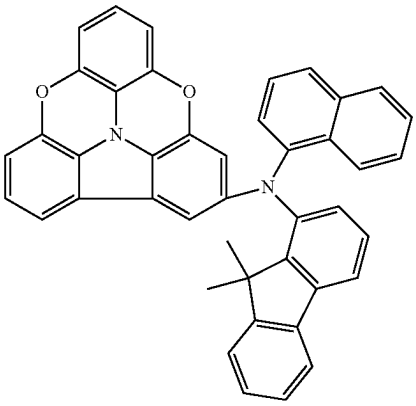

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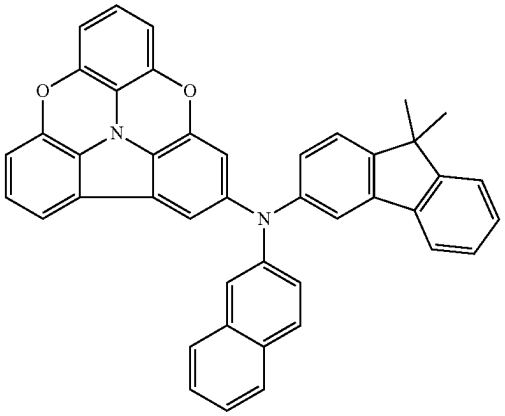

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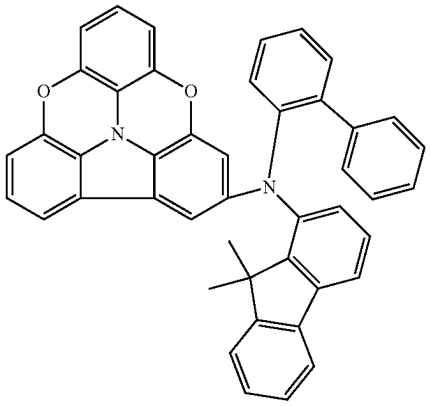

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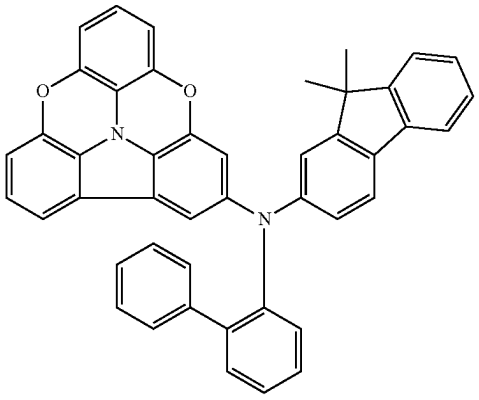

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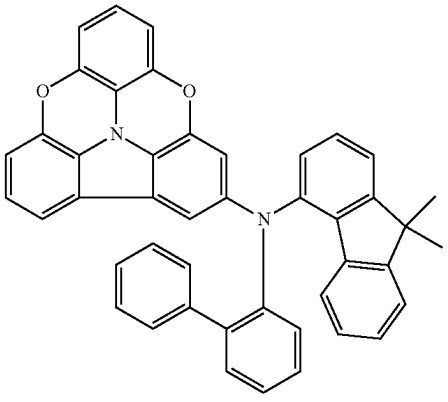

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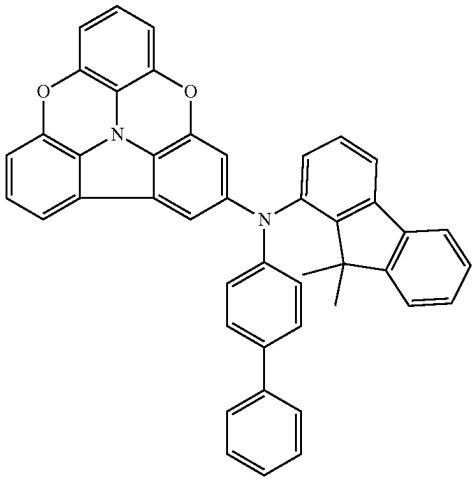

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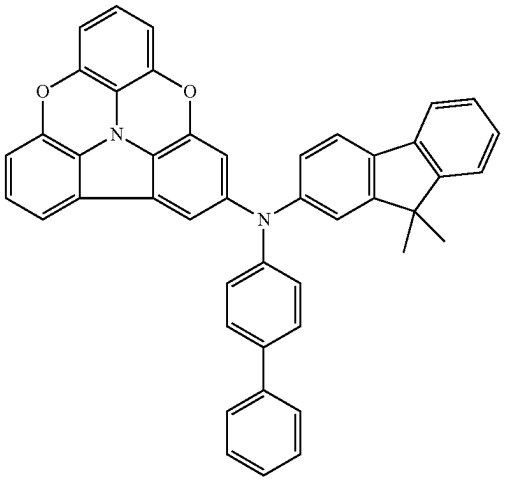

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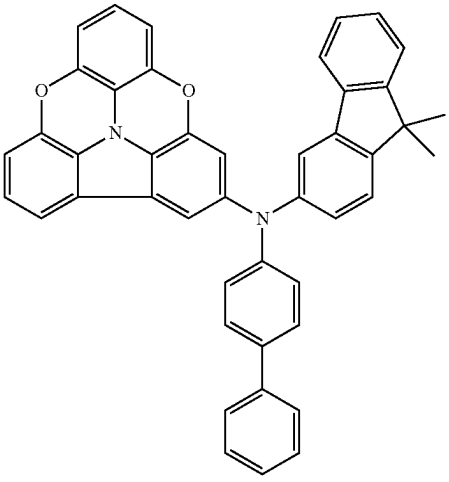

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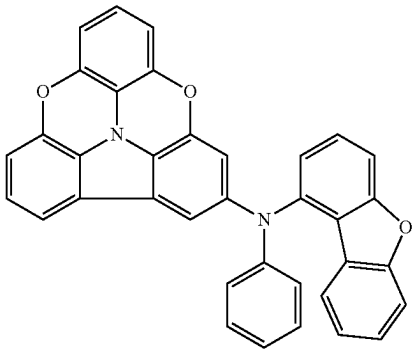

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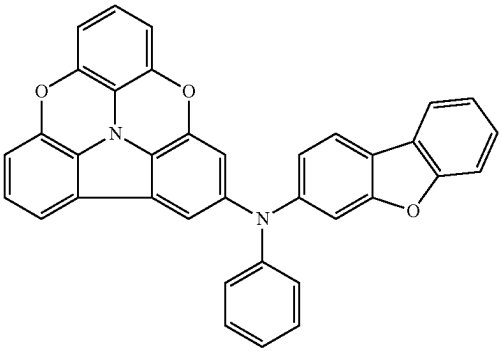

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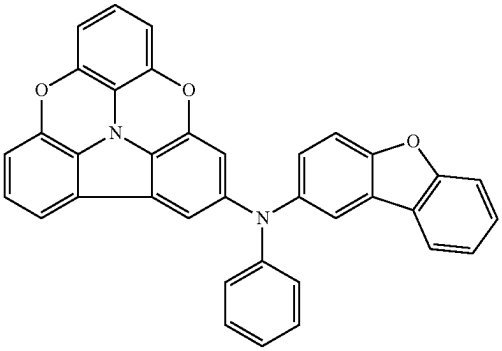

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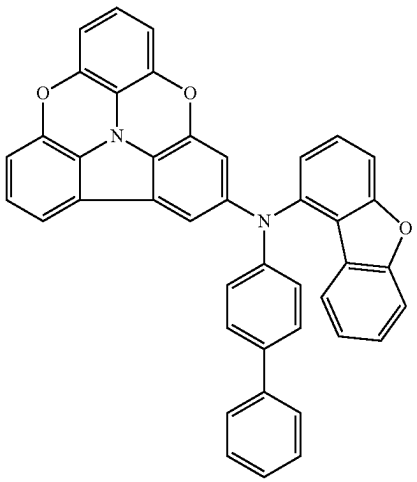

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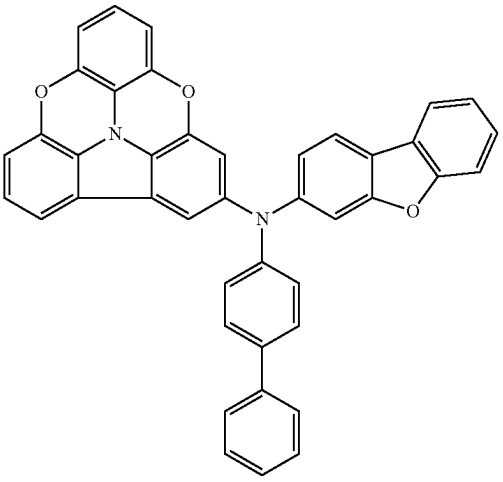

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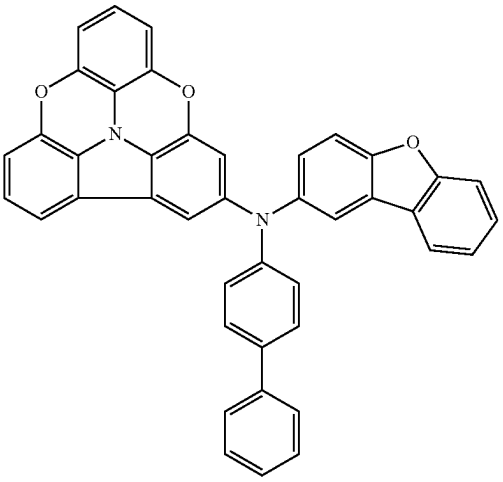

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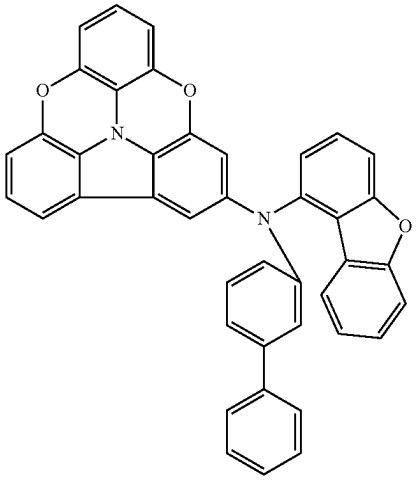

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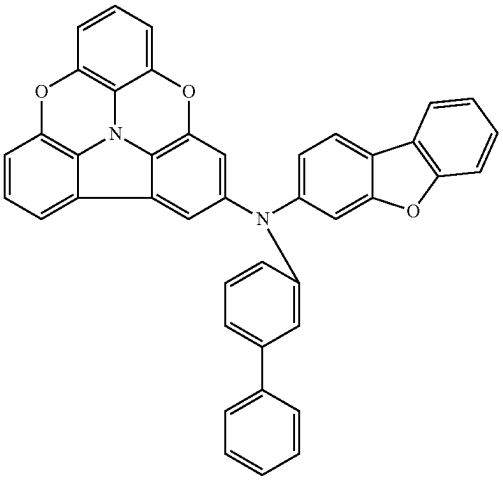

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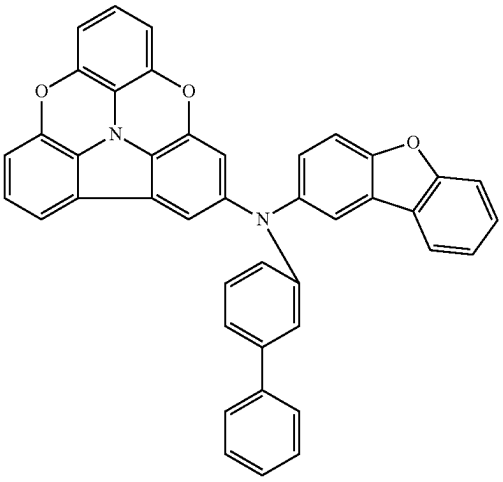

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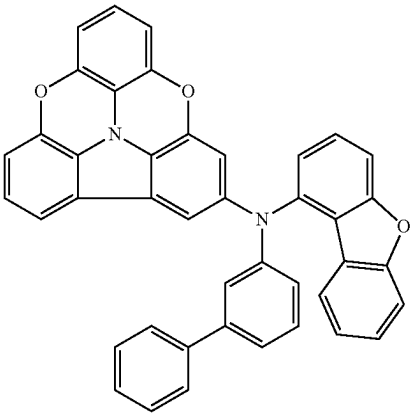

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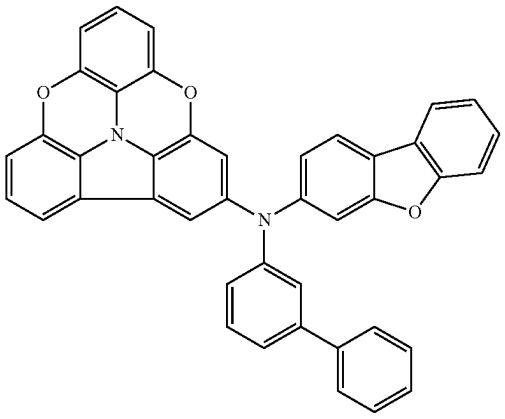

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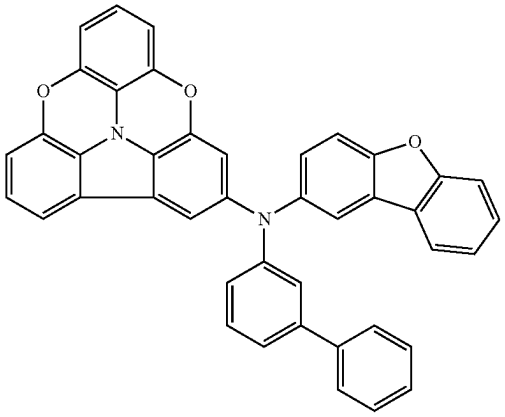

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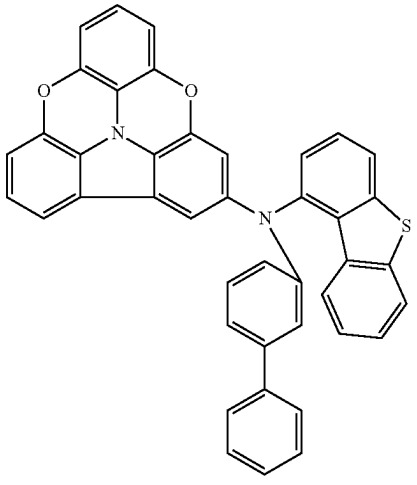

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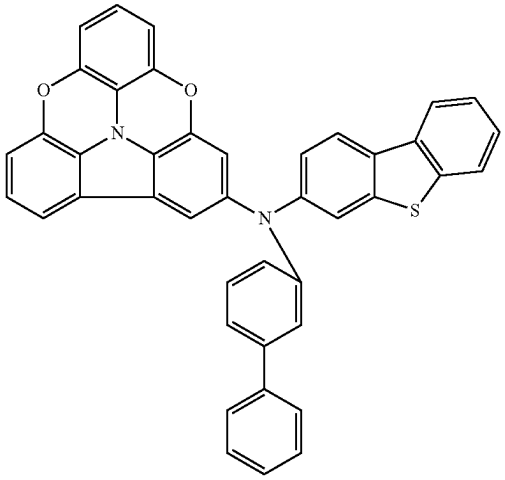

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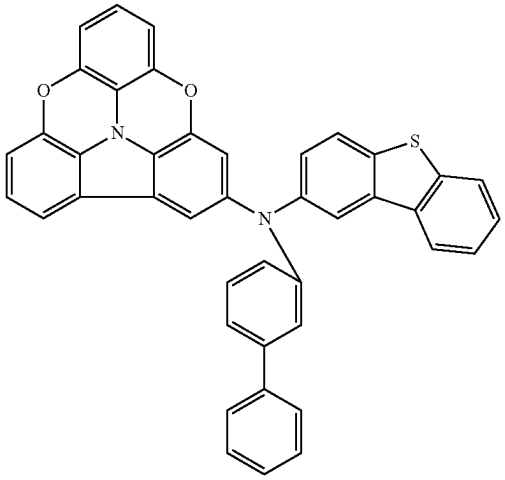

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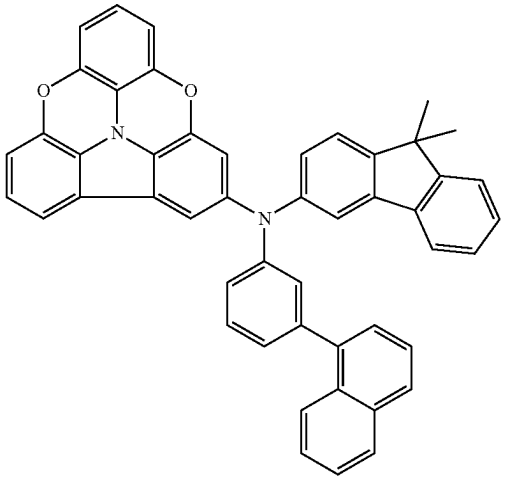

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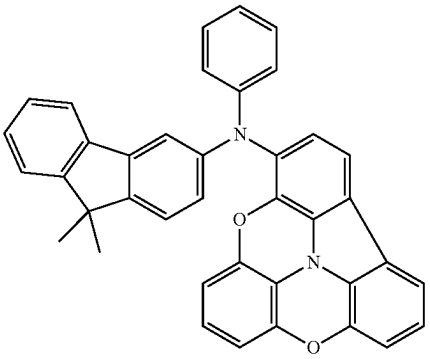

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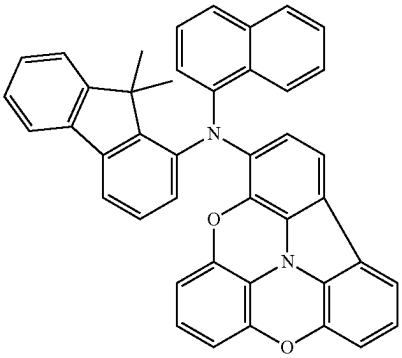

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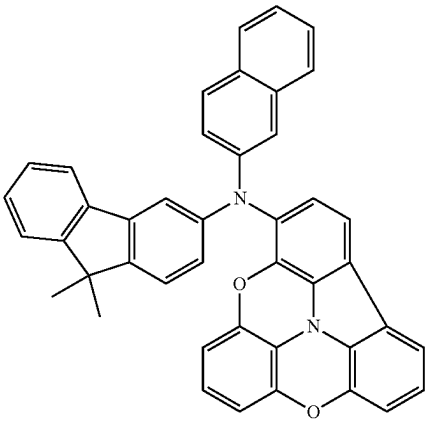

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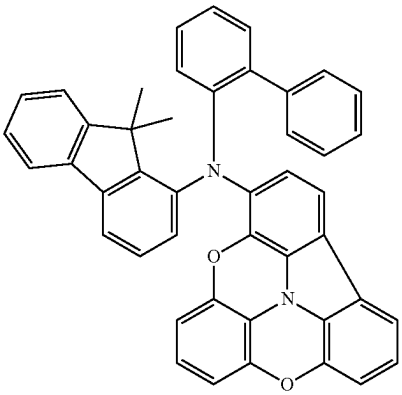

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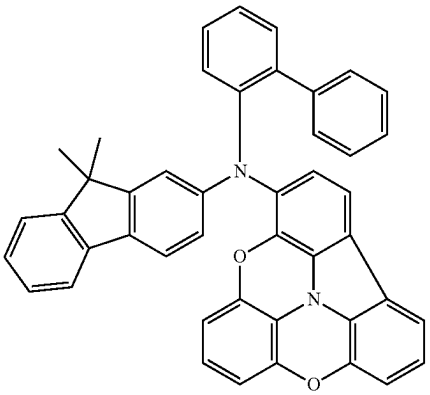

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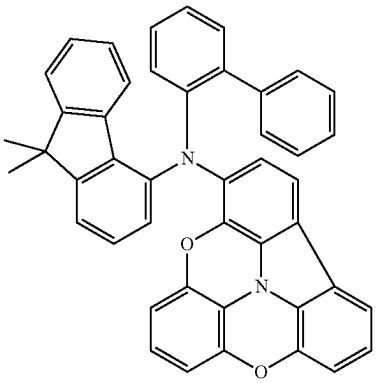

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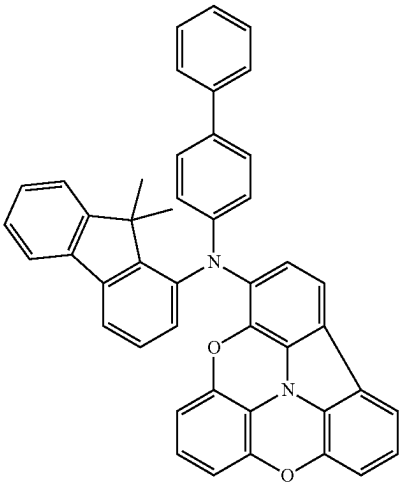

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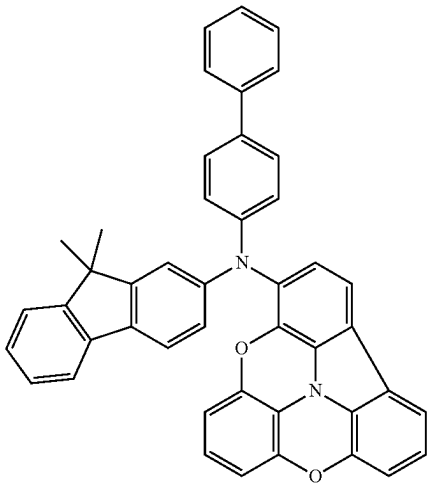

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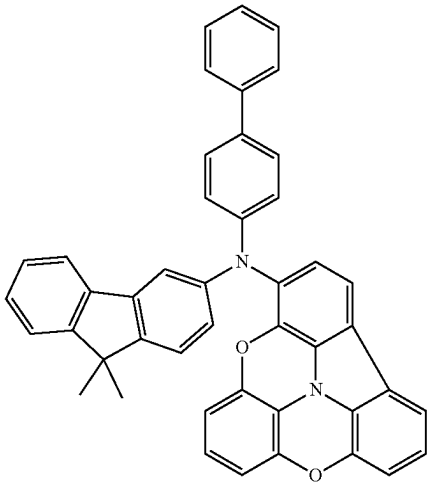

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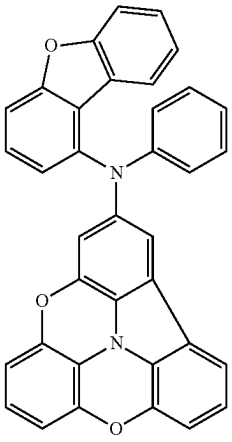

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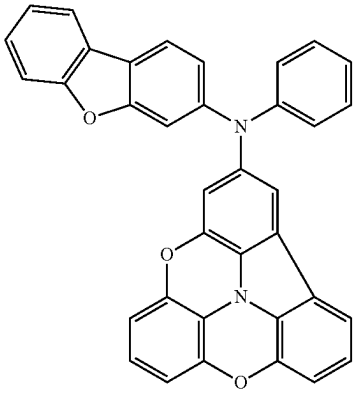

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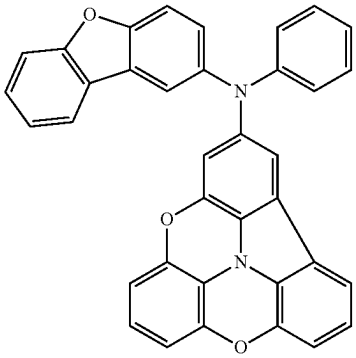

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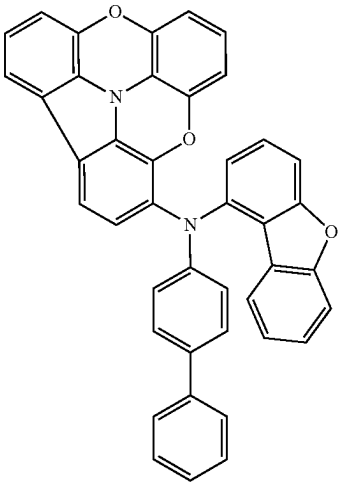

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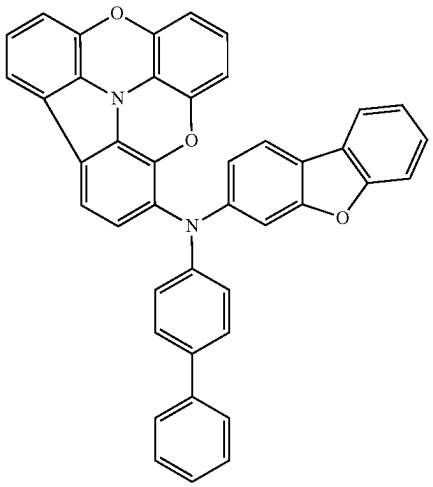

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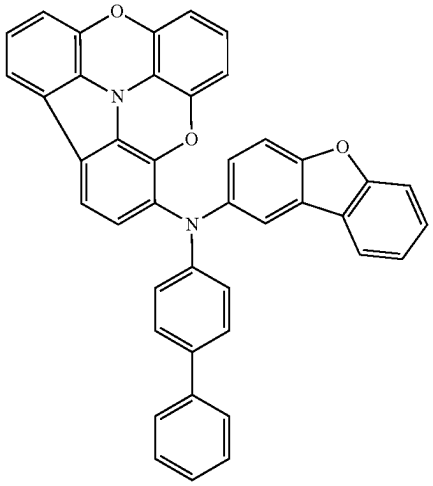

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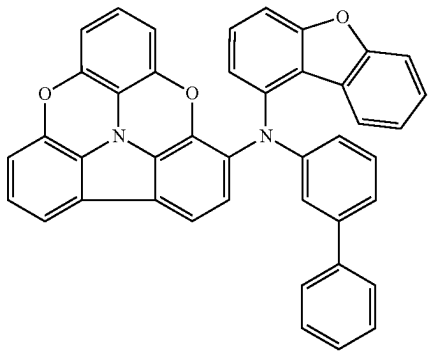

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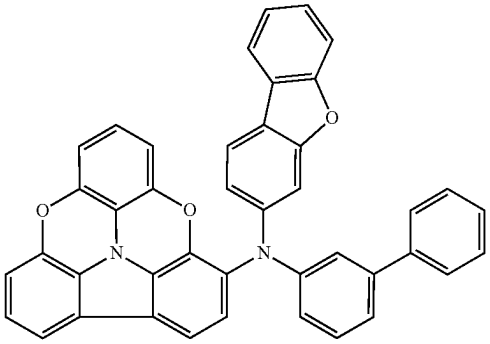

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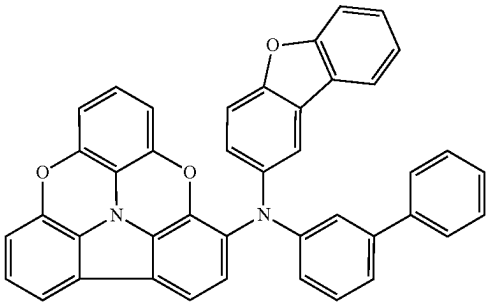

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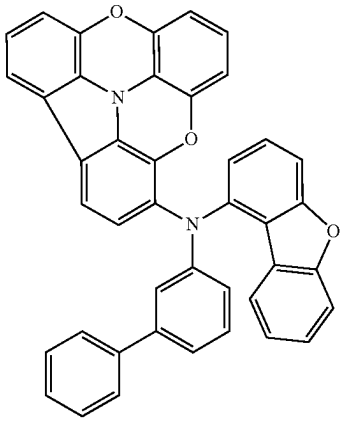

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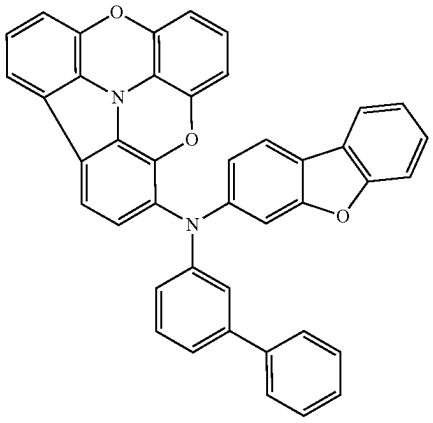

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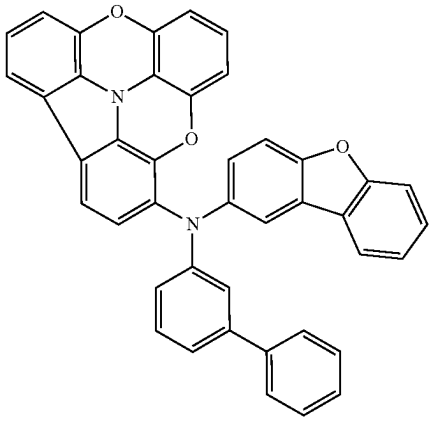

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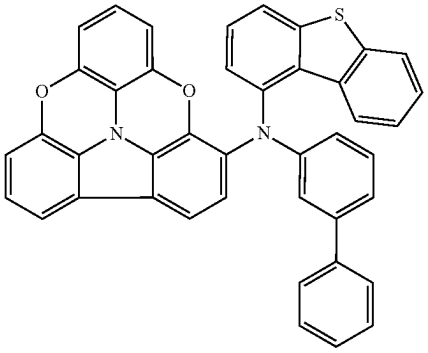

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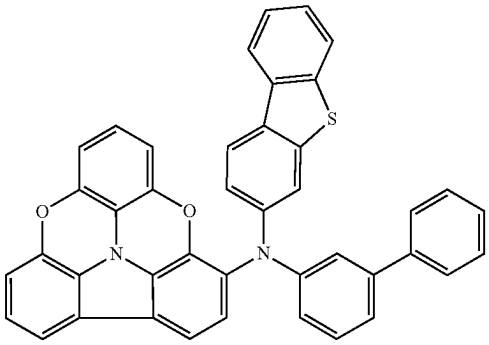

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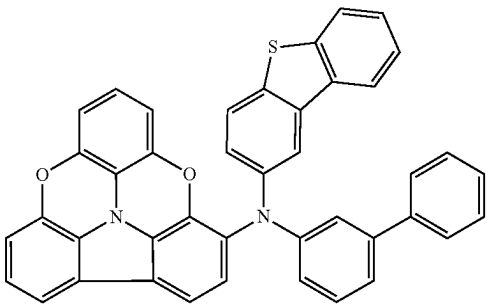

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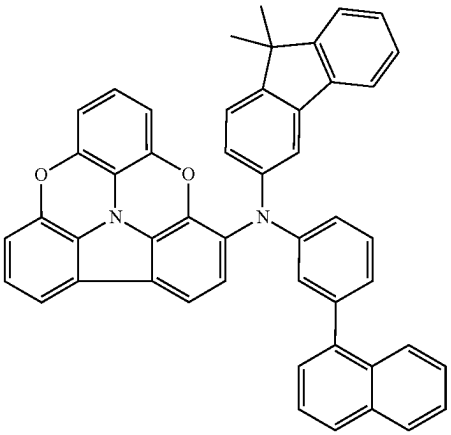

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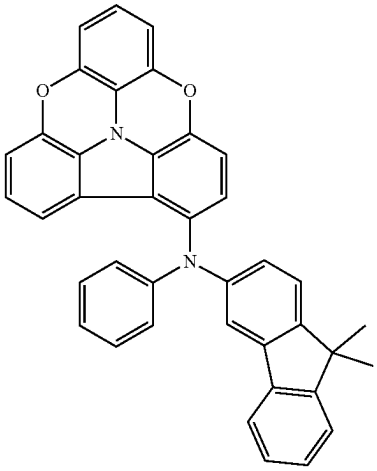

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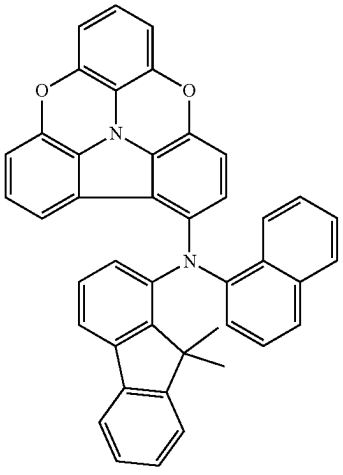

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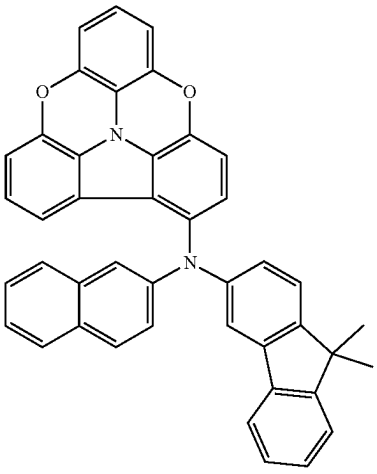

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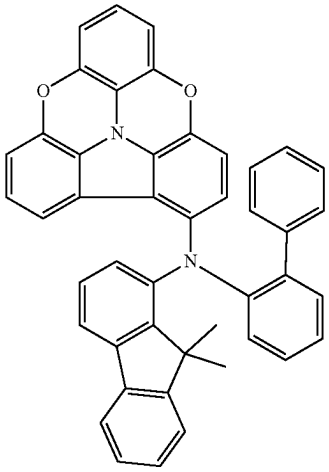

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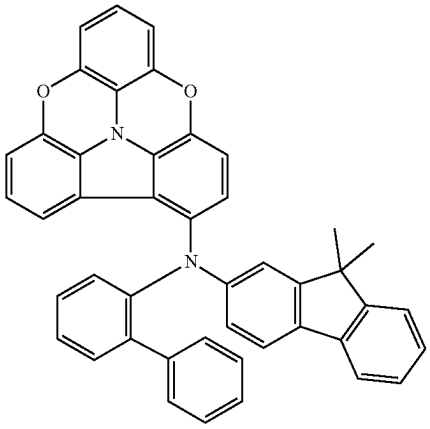

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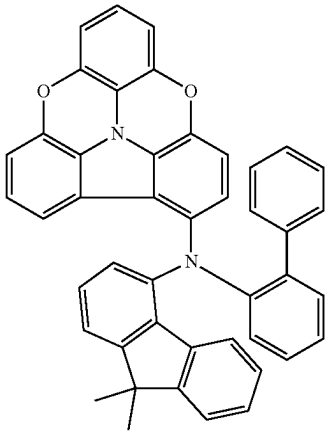

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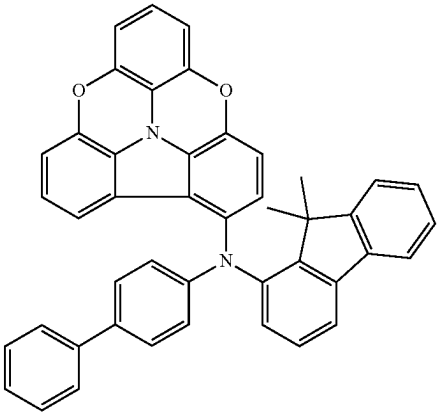

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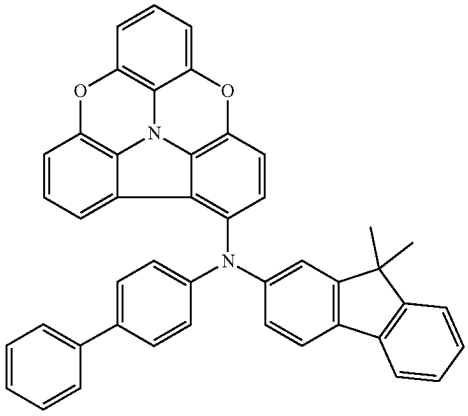

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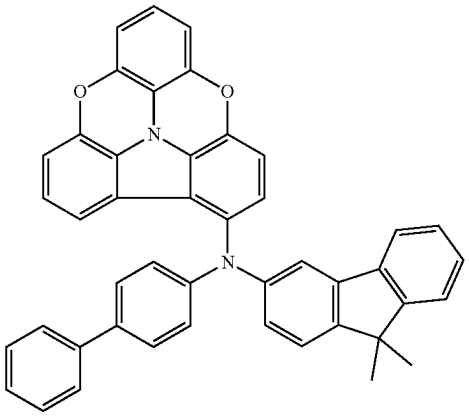

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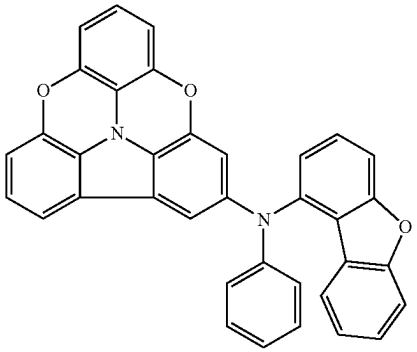

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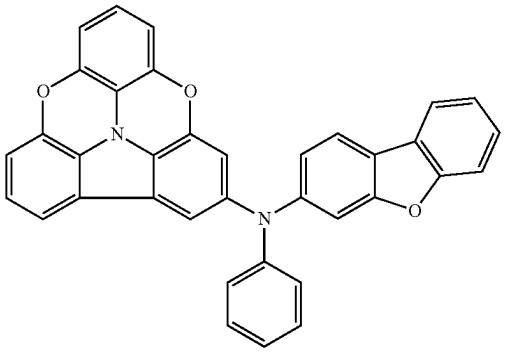

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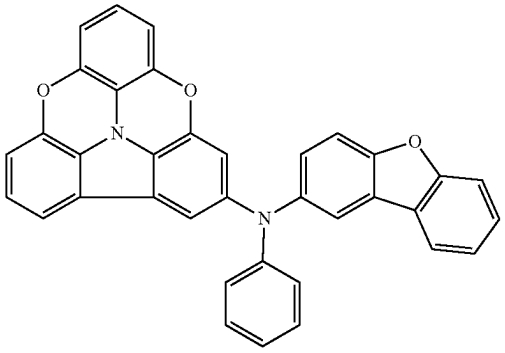

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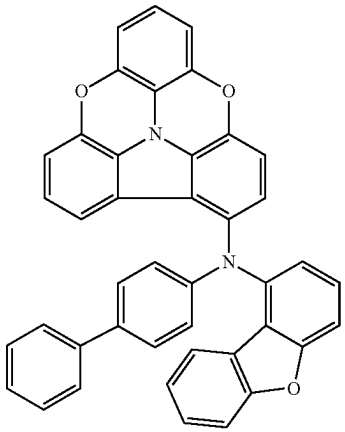

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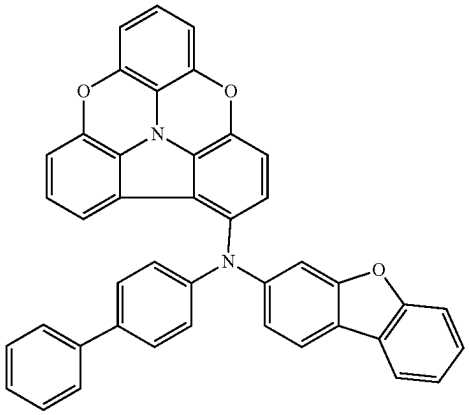

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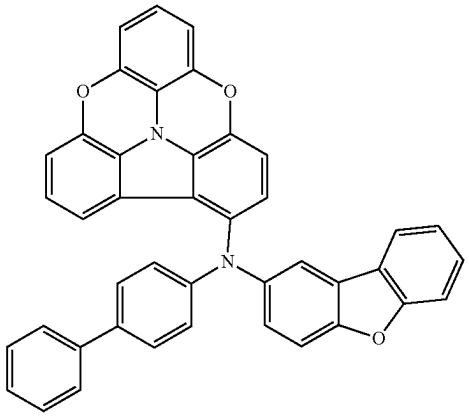

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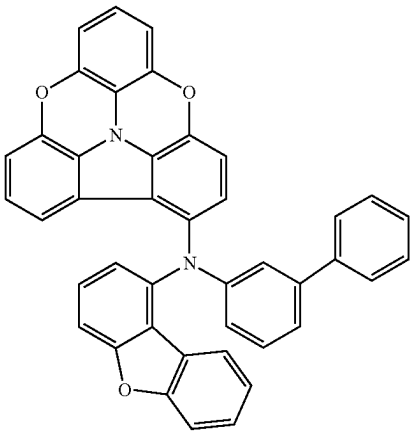

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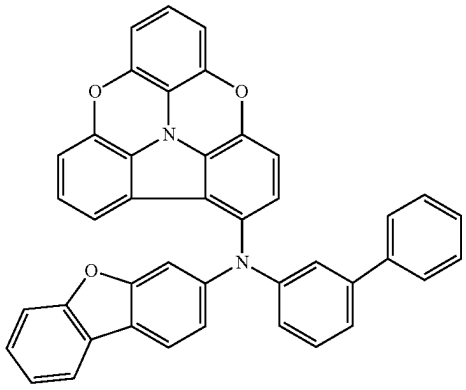

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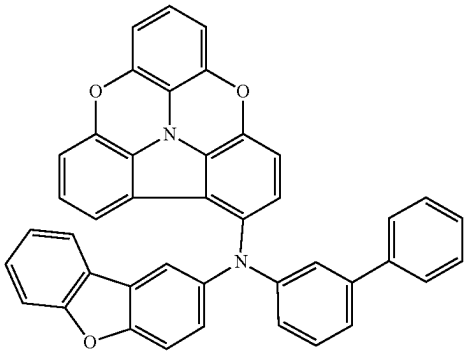

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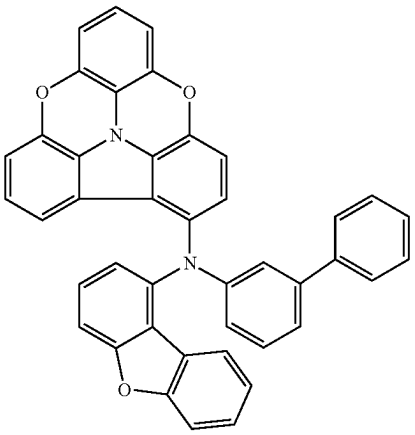

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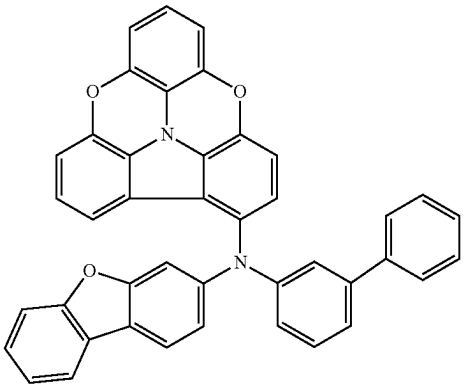

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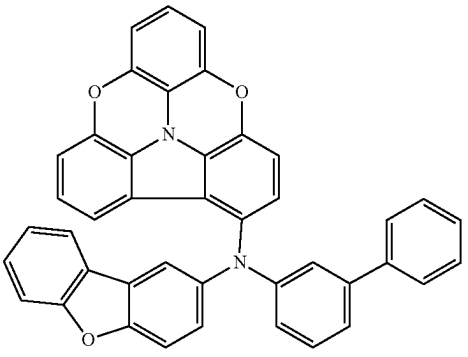

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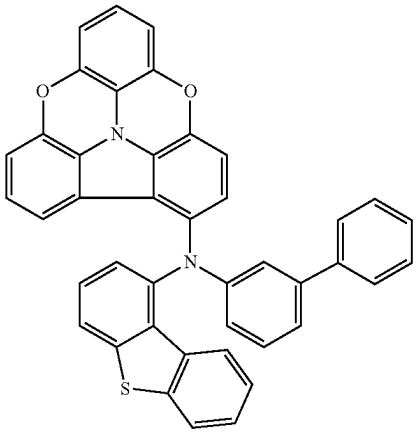

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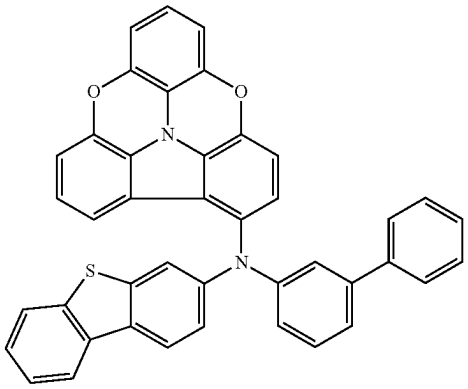

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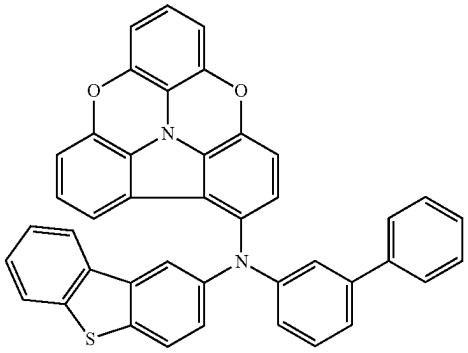

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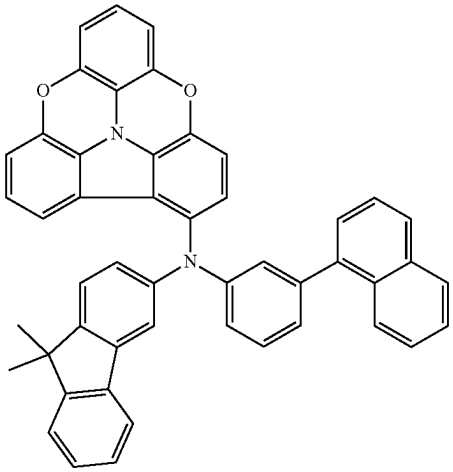

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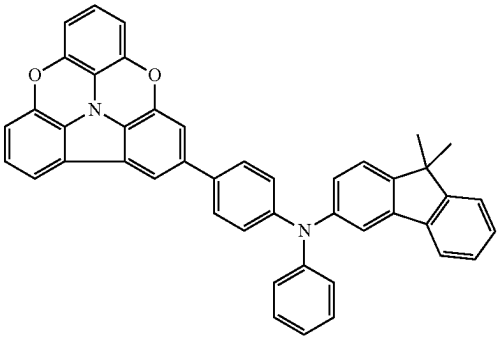

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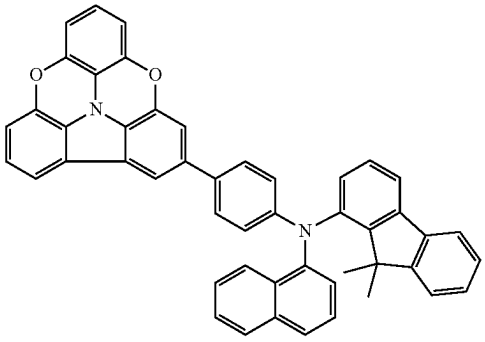

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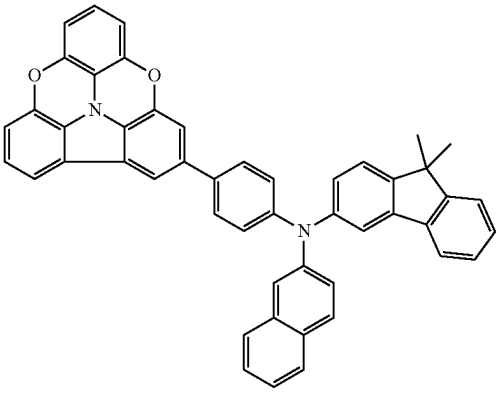

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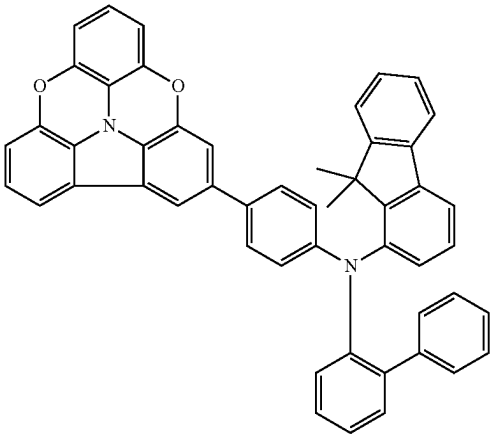

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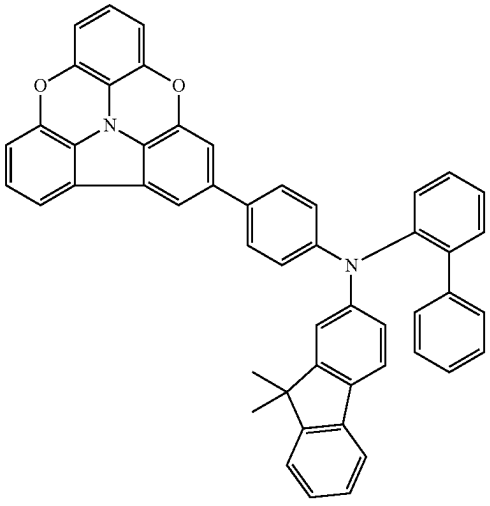

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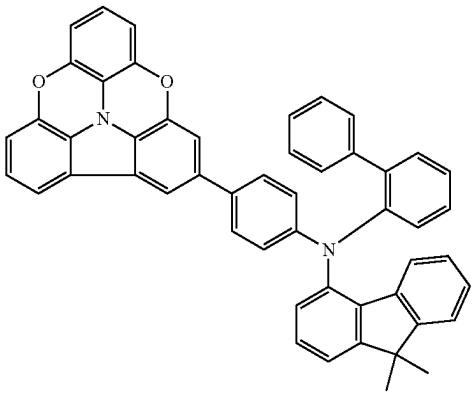

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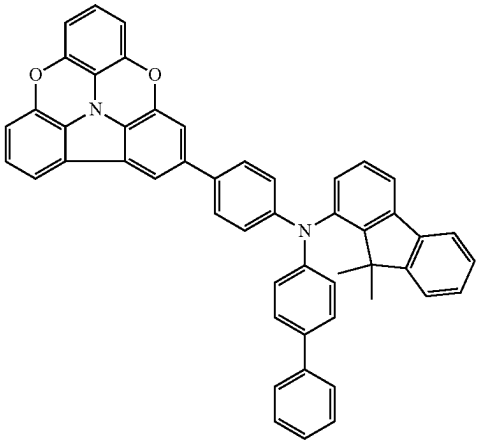

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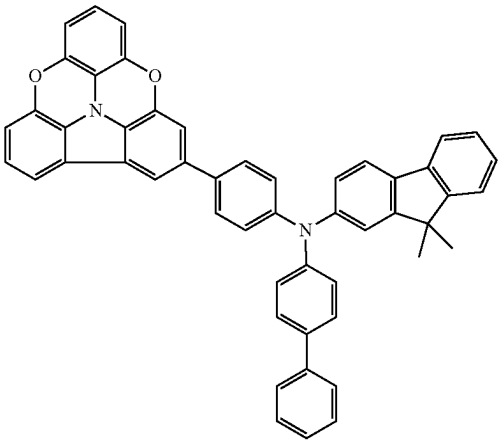

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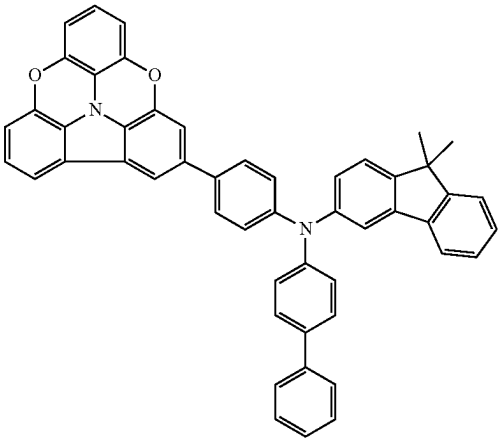

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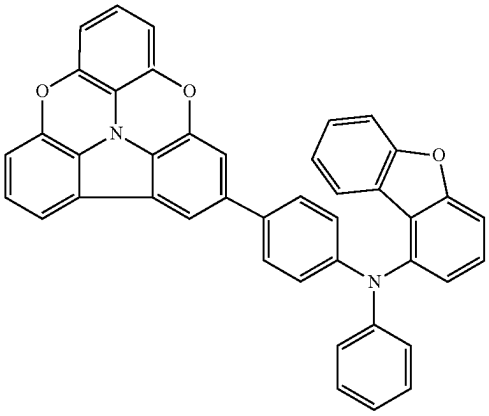

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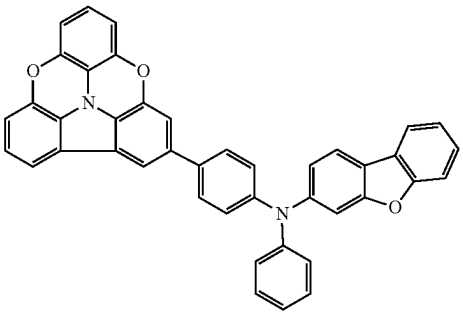

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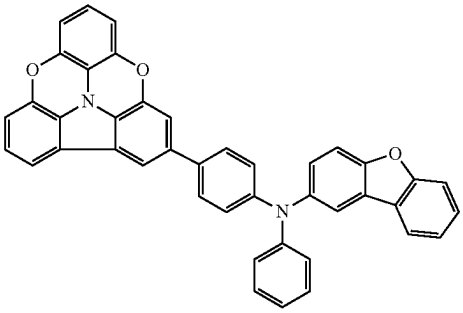

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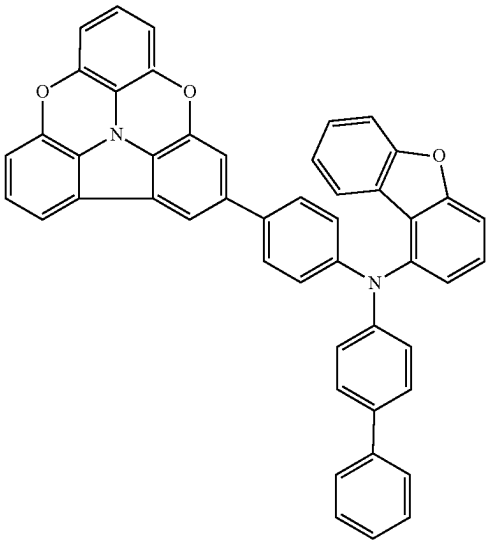

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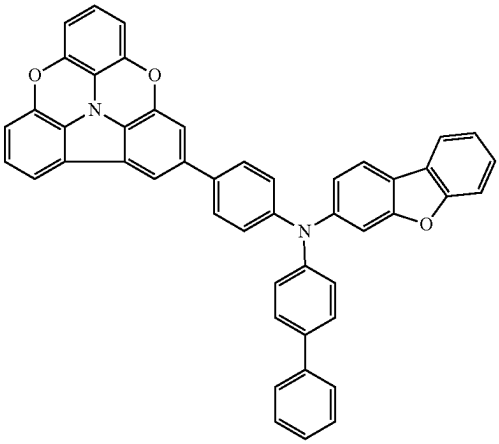

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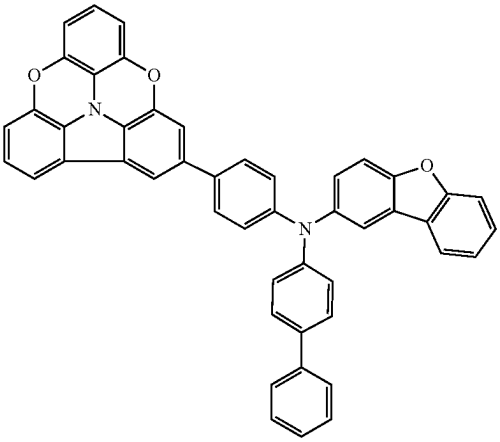

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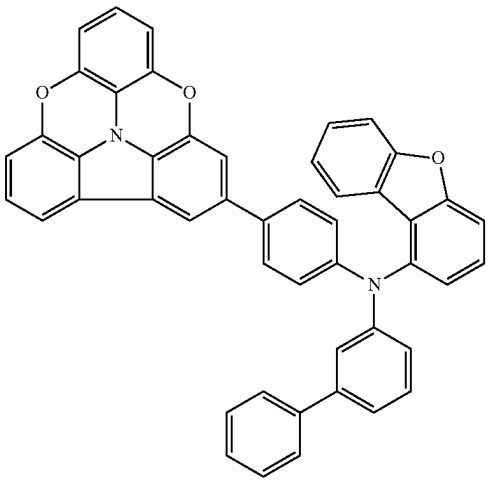

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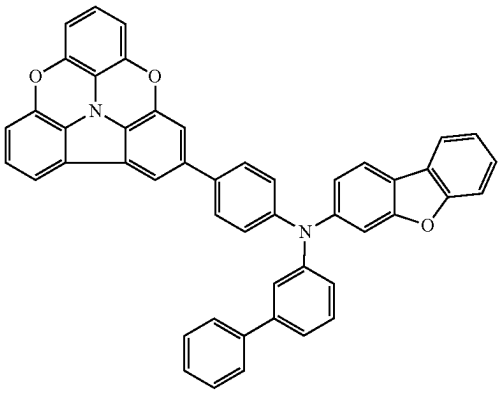

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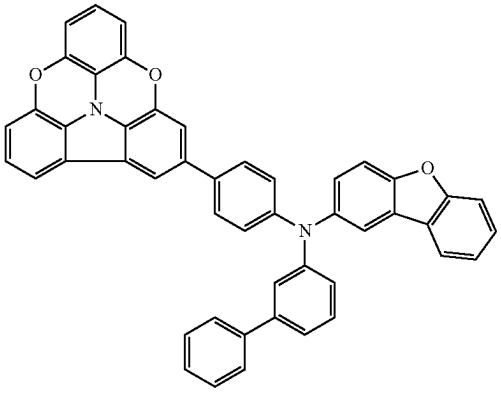

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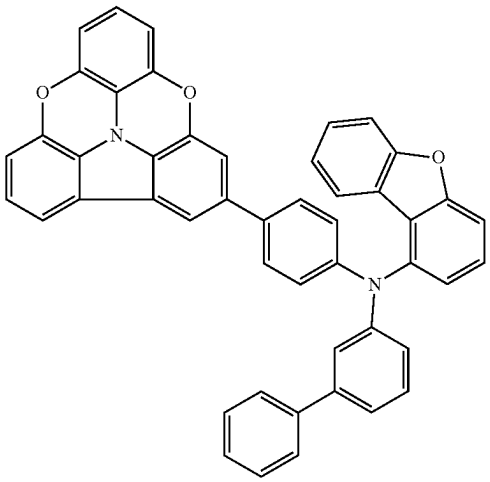

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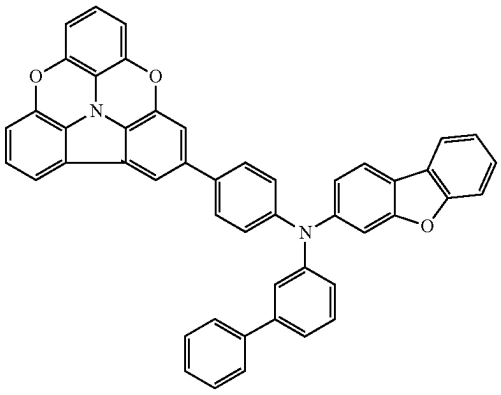

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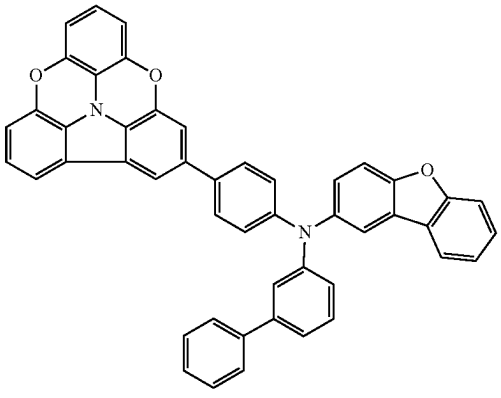

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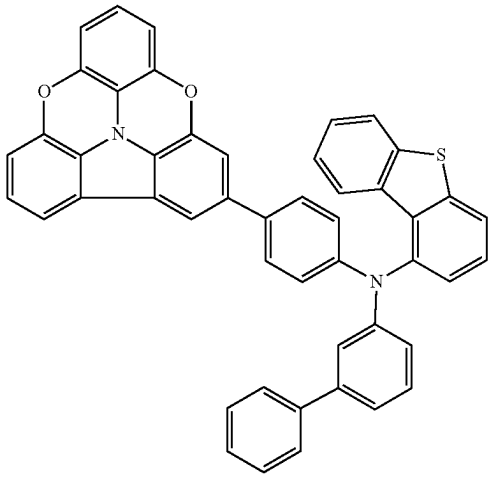

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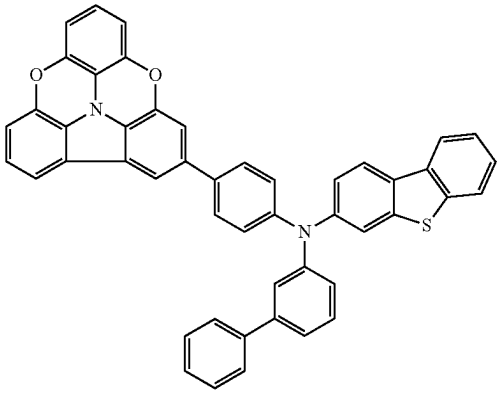

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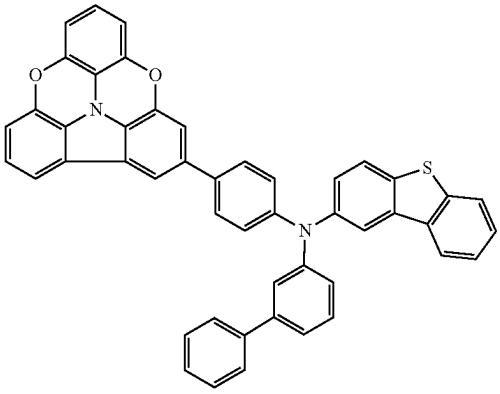

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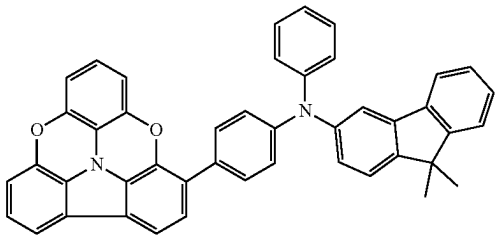

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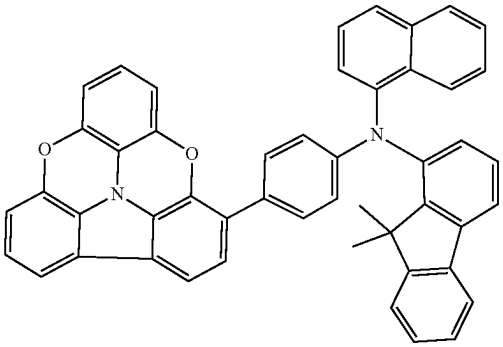

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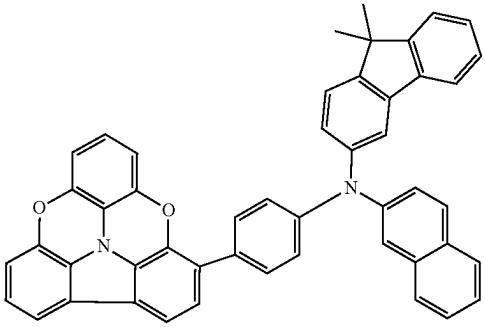

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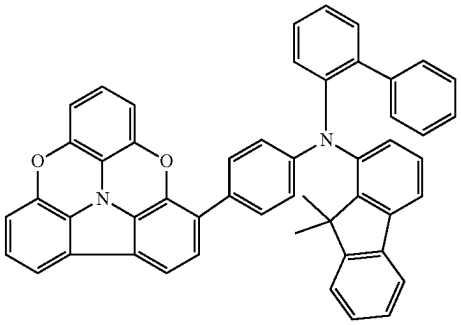

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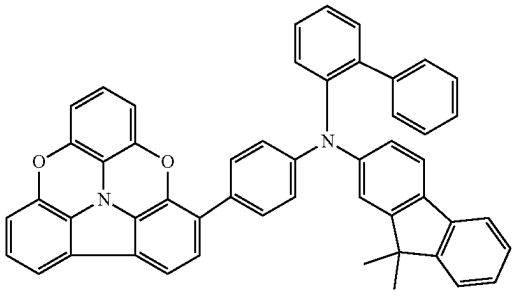

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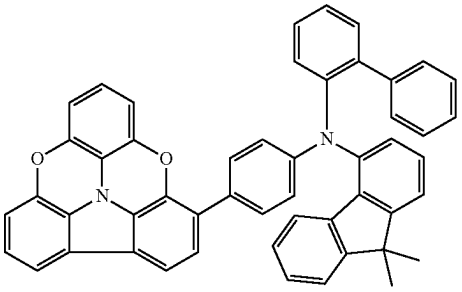

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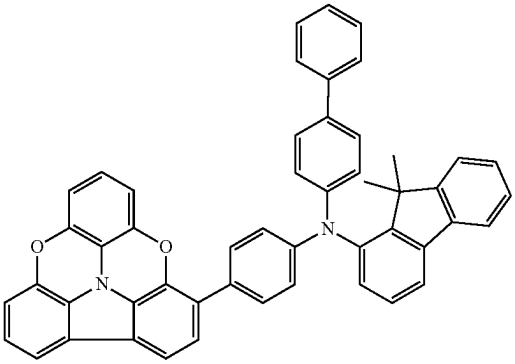

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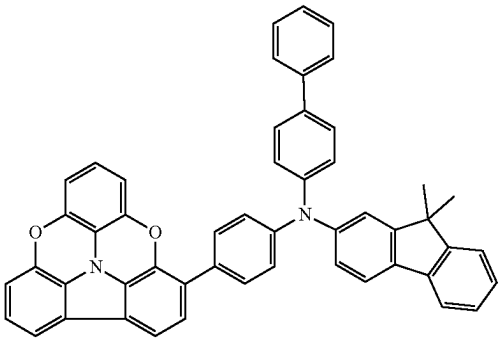

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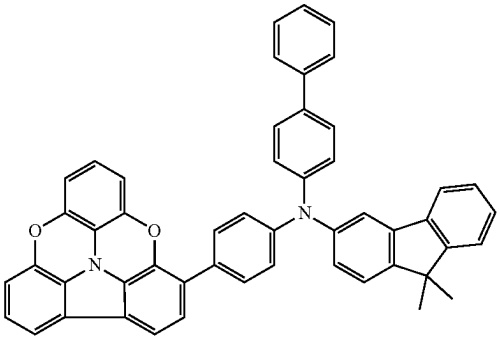

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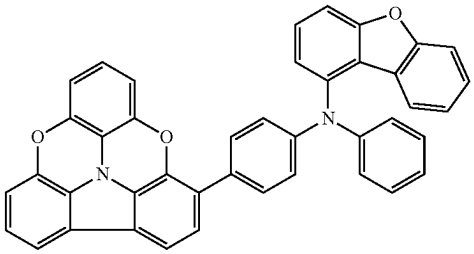

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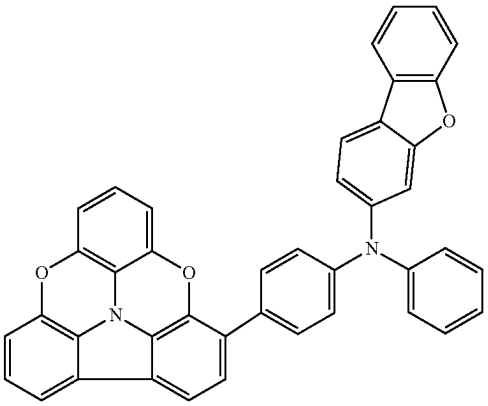

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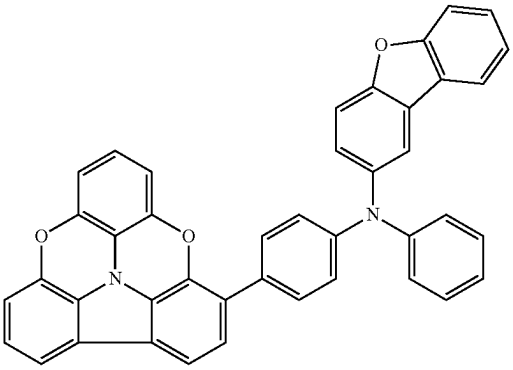

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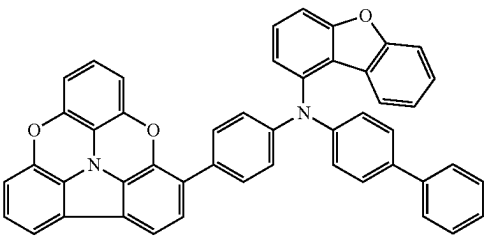

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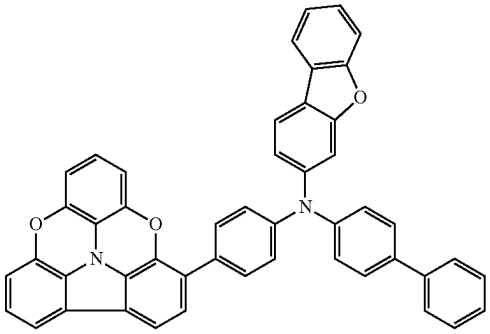

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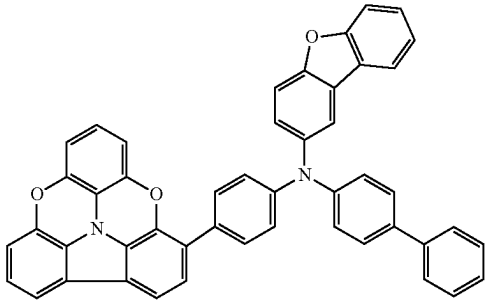

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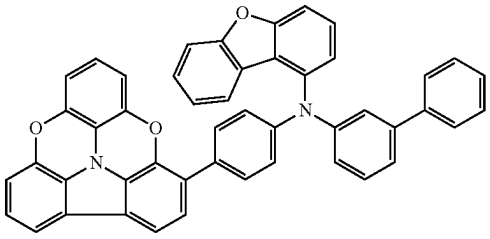

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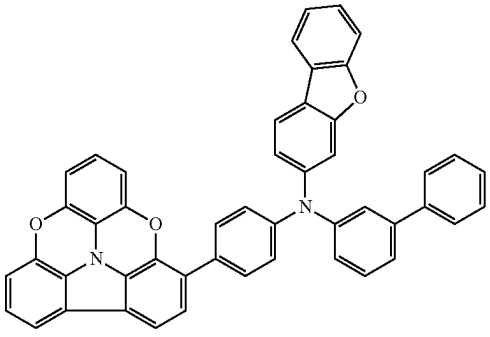

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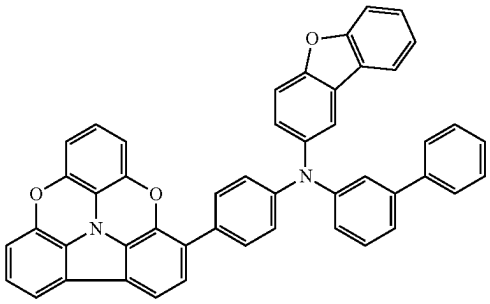

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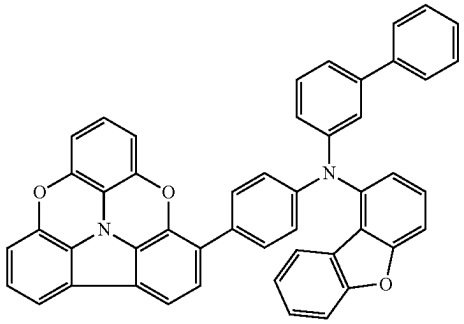

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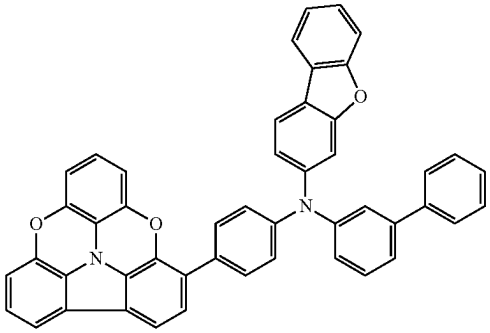

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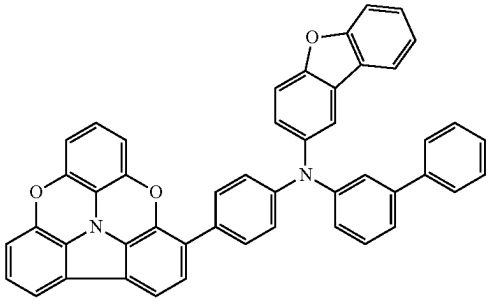

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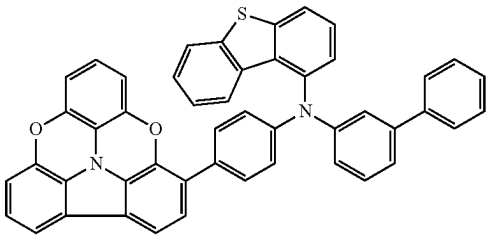

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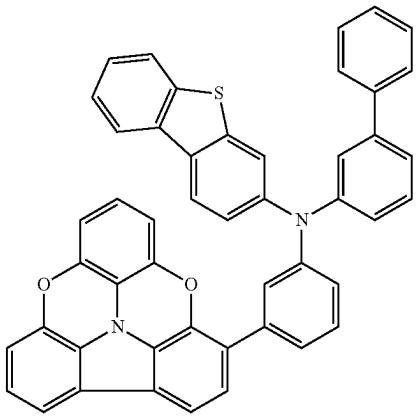

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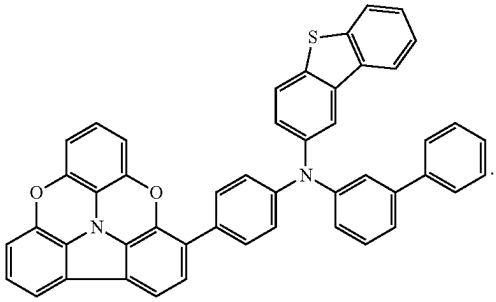


[0112] The heterocyclic compound represented by Formula 1 according to one or more embodiments may have a high glass transition temperature (T_g) and/or a high melting point, and may thus have excellent thermal resistance.

[0113] In addition, the heterocyclic compound represented by Formula 1 may have excellent hole injectability and/or transportability. As a result of its structure, the heterocyclic compound may provide improved hole mobility in the light-emitting device, thereby facilitating improved control of change balance in the light-emitting device and improving its lifespan and/or efficiency.

[0114] Accordingly, when the heterocyclic compound is used as a material for a light-emitting device, the light-emitting device may have excellent durability during storage and/or may have excellent driving voltage, and thus, the light-emitting device may have high efficiency, low driving voltage, high luminance, and/or long lifespan.

[0115] Methods of synthesizing the heterocyclic compound represented by Formula 1 should be readily understood by those of ordinary skill in the art by referring to Examples described herein.

[0116] At least one heterocyclic compound represented by Formula 1 may be included between a pair of electrodes in a light-emitting device. In some embodiments, the heterocyclic compound may be included in at least one selected from a hole transport region, an electron transport region, and an emission layer.

[0117] In some embodiments, the heterocyclic compound represented by Formula 1 may be used as a material for forming a capping layer on at least one outer side of the pair of electrodes in the light-emitting device (e.g., on a side of the cathode facing away from the anode and/or on a side of the anode facing away from the cathode).

[0118] Accordingly, there is provided a light-emitting device including 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 at least one heterocyclic compound represented by Formula 1.

[0119] In an embodiment, the first electrode may be an anode, and the second electrode may be a cathode,

[0120] the interlayer may include the heterocyclic compound, and

[0121] 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,

[0122] wherein 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

[0123] the electron transport region may include a hole blocking layer, an electron transport layer, an electron injection layer, or a combination thereof.

[0124] In some embodiments, the hole transport region of the light-emitting device may include the heterocyclic compound.

[0125] In some embodiments, the hole transport region of the light-emitting device may include a hole injection layer, and the hole injection layer may include the heterocyclic compound. In some embodiments, the hole transport region of the light-emitting device may include a hole transport layer, and the hole transport layer may include the heterocyclic compound.

[0126] In some embodiments, the emission layer of the light-emitting device may include a host and a dopant. In some embodiments, the emission layer may include at least one of a phosphorescent dopant and a fluorescent dopant as a dopant. In some embodiments, the emission layer may include a fluorescent dopant.

[0127] In some embodiments, the emission layer of the light-emitting device may be to emit blue light having a maximum emission wavelength of about 420 nanometers (nm) to about 490 nm.

[0128] An emission layer of the light-emitting device may include quantum dots.

[0129] The term "interlayer" as used herein refers to a single layer and/or a plurality of all layers between a first electrode and a second electrode in a light-emitting device.

[0130] The materials included in the "interlayer" are not limited to being an organic material.

Description of FIG. **1**

[0131] FIG. **1** is a schematic view of a light-emitting device **10** according to an embodiment. The light-emitting

device **10** may include a first electrode **110**, an interlayer **150**, and a second electrode **190**.

[0132] Hereinafter, the structure of the light-emitting device **10** according to an embodiment and a method of manufacturing the near-infrared light-emitting diode **10** according to an embodiment will be described in connection with FIG. **1**.

First Electrode **110**

[0133] In FIG. **1**, a substrate may be additionally located under the first electrode **110** and/or above the second electrode **190**. The substrate may be a glass substrate and/or a plastic substrate, each having excellent mechanical strength, thermal stability, transparency, surface smoothness, ease of handling, and/or water resistance.

[0134] The first electrode **110** may be formed by depositing or sputtering a material for forming the first electrode **110** onto the substrate. When the first electrode **110** is an anode, the material for forming the first electrode **110** may be selected from materials with a high work function to facilitate hole injection.

[0135] 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, the material for forming the first electrode **110** may be selected from indium tin oxide (ITO), indium zinc oxide (IZO), tin oxide (SnO_2), zinc oxide (ZnO), and any combination thereof, but embodiments are not limited thereto. In some embodiments, when the first electrode **110** is a semi-transmissive electrode or a reflective electrode, at least one of magnesium (Mg), silver (Ag), aluminum (Al), aluminum-lithium (Al—Li), calcium (Ca), magnesium-indium (Mg—In), magnesium-silver (Mg—Ag), or any combination thereof may be used as the material for forming the first electrode **110**, but embodiments are not limited thereto.

[0136] The first electrode **110** may have a single-layered structure, or a multi-layered structure including two or more layers. In some embodiments, the first electrode **110** may have a triple-layered structure of ITO/Ag/ITO, but embodiments are not limited thereto.

Interlayer **150**

[0137] The interlayer **150** may be on the first electrode **110**. The interlayer **150** may include an emission layer.

[0138] The interlayer **150** 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 **190**.

Hole Transport Region in Interlayer **150**

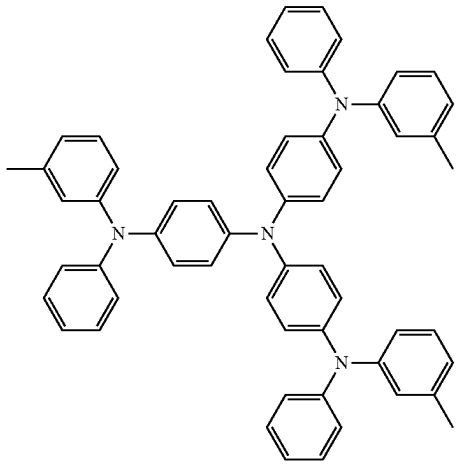
[0139] The hole transport region may have i) a single-layered structure including (e.g., consisting of) a single material, ii) a single-layered structure including a plurality of different materials, or iii) a multi-layered structure having a plurality of layers including a plurality of different materials.

[0140] The hole transport region may include at least one selected from a hole injection layer, a hole transport layer, an emission auxiliary layer, and an electron blocking layer.

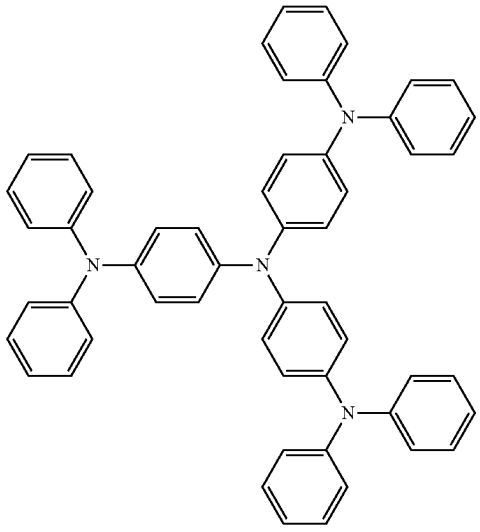
[0141] For example, the hole transport region may have a single-layered structure including a plurality of different materials or a multi-layered structure, e.g., a hole injection layer/hole transport layer structure, a hole injection layer/hole transport layer/emission auxiliary layer structure, a hole 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 constituting layers of each structure are sequentially stacked on the first electrode **110** in each stated order, but embodiments are not limited thereto.

[0142] The hole transport region may include the heterocyclic compound.

[0143] In some embodiments, the hole transport region may additionally include at least one selected from m-MTDATA, TDATA, 2-TNATA, NPB (NPD), p-NPB, TPD, a spiro-TPD, a spiro-NPB, methylated-NPB, TAPC, HMTPD, 4,4',4"-tris(N-carbazolyl)triphenylamine (TCTA), polyaniline/dodecylbenzene sulfonic acid (PANI/DBSA), poly(3,4-ethylene dioxythiophene)/poly(4-styrene sulfonate) (PEDOT/PSS), polyaniline/camphor sulfonic acid (PANI/CSA), polyaniline/poly(4-styrene sulfonate) (PANI/PSS), a compound represented by Formula 201, and a compound represented by Formula 202:



m-MTDATA



TDATA

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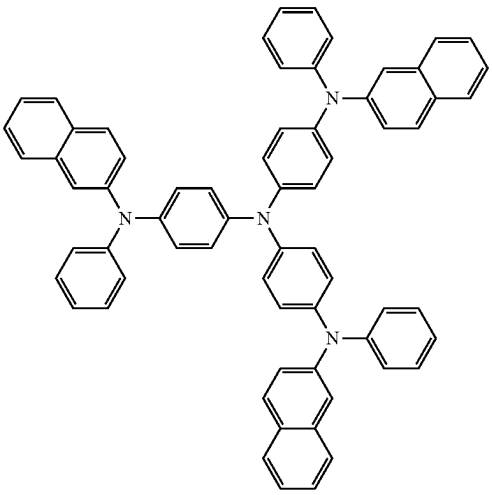
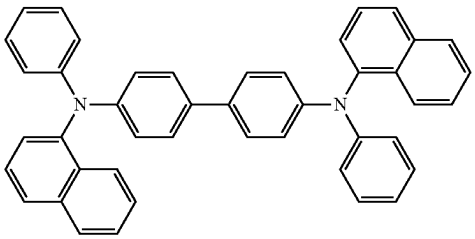
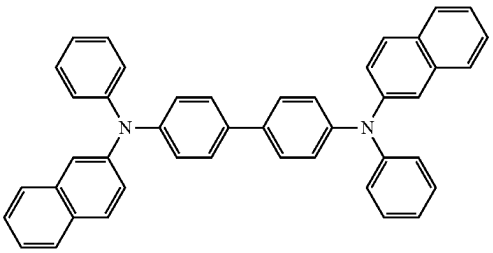


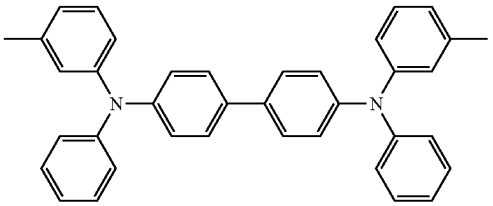
2-TNATA



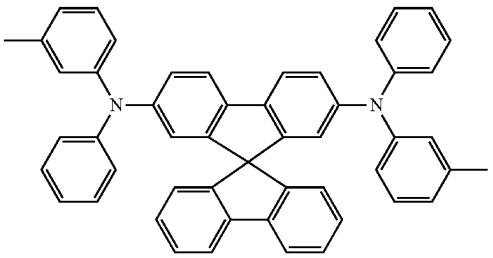
NPB



β-NPB



TPD



Spiro-TPD

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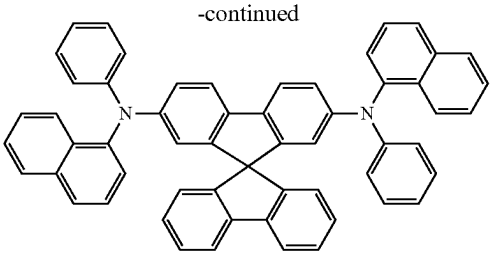

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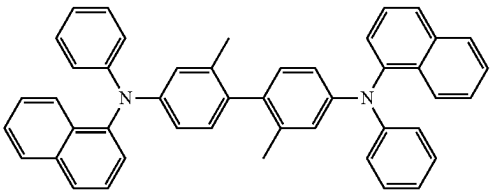
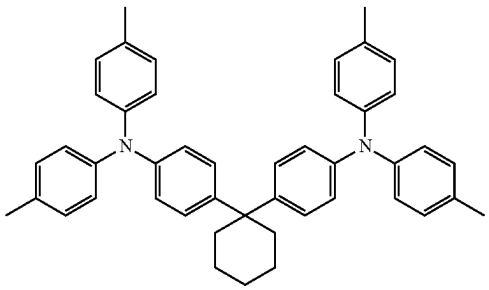
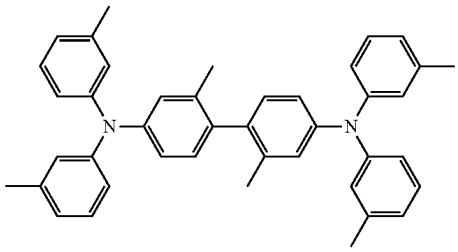


methylated-NPB

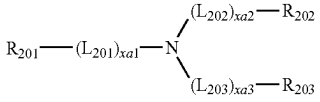


TAPC

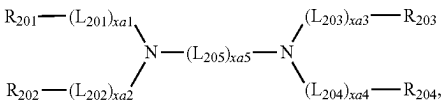


HMTPD

Formula 201



Formula 202



[0144] wherein, in Formulae 201 and 202,

[0145] L_{201} to L_{204} may each independently be selected from a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, a substituted or unsubstituted C_1-C_{60} heteroarylene group, a substituted or unsubstituted divalent non-

aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0146] L_{205} may be selected from *—O—*', *—S—*', *—N(Q_{201})—*', a substituted or unsubstituted C_1-C_{20} alkylene group, a substituted or unsubstituted C_2-C_{20} alkenylene group, a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, a substituted or unsubstituted C_1-C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0147] xa1 to xa4 may each independently be an integer from 0 to 3,

[0148] xa5 may be an integer from 1 to 10, and

[0149] R_{201} to R_{204} and Q_{201} may each independently be selected from a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group.

[0150] In some embodiments, in Formula 202, R_{201} and R_{202} may optionally be bound via a single bond, a dimethyl-methylene group, or a diphenyl-methylene group, and R_{203} and R_{204} may optionally be bound via a single bond, a dimethyl-methylene group, or a diphenyl-methylene group.

[0151] In some embodiments, in Formulae 201 and 202,

[0152] L_{201} to L_{205} may each independently be selected from:

[0153] a phenylene group, a pentalenylene group, an indenylene group, a naphthylene group, an azulenylene group, a heptalenylene group, an indacenylene group, an acenaphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenalenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a naphthacenylene group, a picenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a rubicenylene group, a coronenylene group, an ovalenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, and a pyridinylene group; and

[0154] a phenylene group, a pentalenylene group, an indenylene group, a naphthylene group, an azulenylene group, a heptalenylene group, an indacenylene group, an acenaphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenalenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a naphthacenylene group, a picenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a rubicenylene group, a coronenylene group, an ovalenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, and a pyridinylene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono 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 cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a phenyl group substituted with a C_1-C_{10} alkyl group, a phenyl group substituted with —F, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a naphthacenyl group, a picenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, —Si(Q_{31})(Q_{32})(Q_{33}), and —N(Q_{31})(Q_{32}),

[0155] wherein Q_{31} to Q_{33} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0156] In one or more embodiments, xa1 to xa4 may each independently be 0, 1, or 2.

[0157] In one or more embodiments, xa5 may be 1, 2, 3, or 4.

[0158] In one or more embodiments, R_{201} to R_{204} and Q_{201} may each independently be selected from: a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a naphthacenyl group, a picenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl

group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, and a pyridinyl group; and

[0159] a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a naphthacenyl group, a picenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, and a pyridinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono 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 cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a phenyl group substituted with a C_1-C_{10} alkyl group, a phenyl group substituted with —F, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a naphthacenyl group, a picenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, and —$N(Q_{31})(Q_{32})$,

[0160] wherein Q_{31} to Q_{33} may each independently be the same as described above.

[0161] In one or more embodiments, in Formula 201, at least one of R_{201} to R_{203} may be selected from:

[0162] a fluorenyl group, a spiro-bifluorenyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

[0163] a fluorenyl group, a spiro-bifluorenyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono 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 cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a phenyl group substituted with a C_1-C_{10} alkyl group, a phenyl group substituted with —F, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group,

[0164] but embodiments are not limited thereto.

[0165] In one or more embodiments, in Formula 202, i) R_{201} and R_{202} may be bound via a single bond, and/or ii) R_{203} and R_{204} may be bound via a single bond.

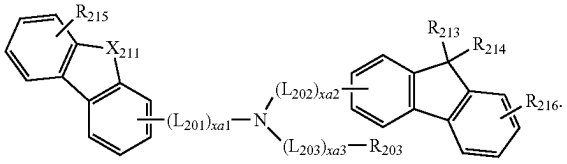
[0166] In one or more embodiments, in Formula 202, at least one of R_{201} to R_{204} may be selected from:

[0167] a carbazolyl group; and

[0168] a carbazolyl group substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono 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 cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a phenyl group substituted with a C_1-C_{10} alkyl group, a phenyl group substituted with —F, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group,

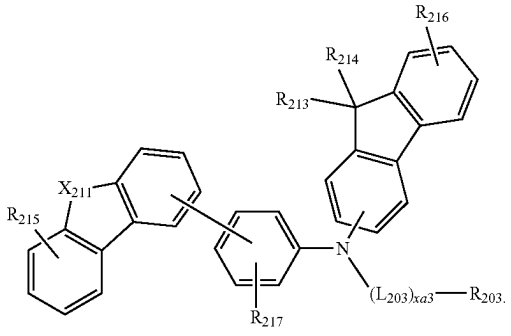
[0169] but embodiments are not limited thereto.

Formula 201-1



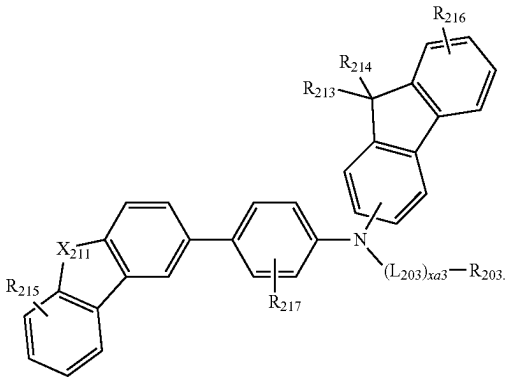
[0170] In some embodiments, the compound represented by Formula 201 may be represented by Formula 201-2, but embodiments are not limited thereto:

Formula 201-2



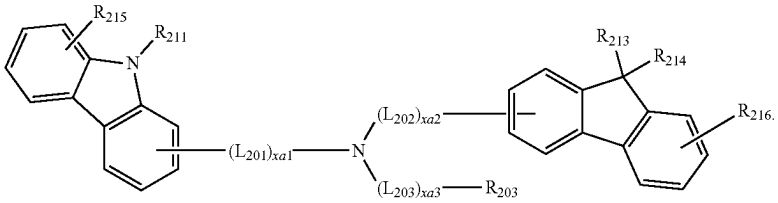
[0171] In some embodiments, the compound represented by Formula 201 may be represented by Formula 201-2(1), but embodiments are not limited thereto:

Formula 201-2(1)



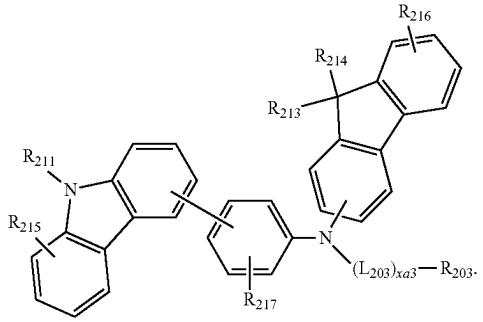
[0172] The compound represented by Formula 201 may be represented by Formula 201A:

Formula 201A



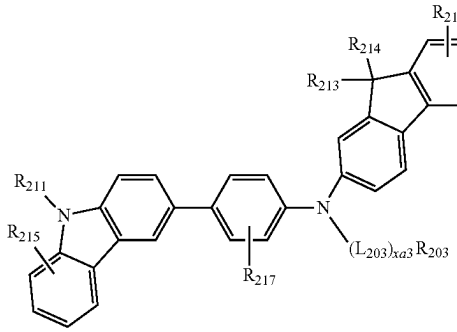
[0173] In some embodiments, the compound represented by Formula 201 may be represented by Formula 201A(1), but embodiments are not limited thereto:

Formula 201A(1)



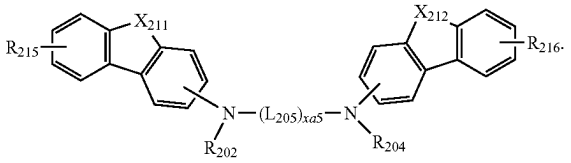
[0174] In some embodiments, the compound represented by Formula 201 may be represented by Formula 201A-1, but embodiments are not limited thereto:

Formula 201A-1



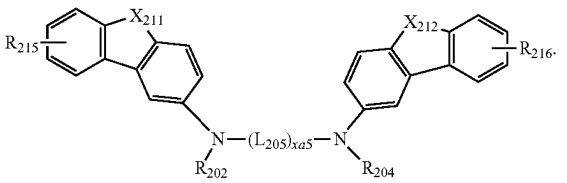
[0175] In some embodiments, the compound represented by Formula 202 may be represented by Formula 202-1:

Formula 202-1



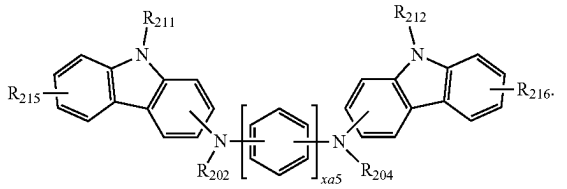
[0176] In one or more embodiments, the compound represented by Formula 202 may be represented by Formula 202-1(1):

Formula 202-1(1)



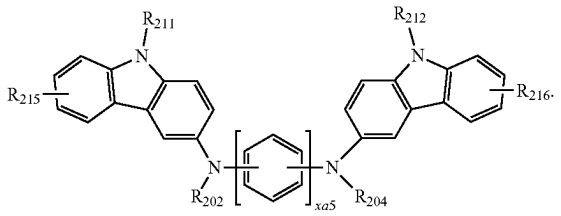
[0177] In some embodiments, the compound represented by Formula 202 may be represented by Formula 202A:

Formula 202A



[0178] In some embodiments, the compound represented by Formula 202 may be represented by Formula 202A-1:

Formula 202A-1



[0179] In Formulae 201-1, 201-2, 201-2(1), 201A, 201A (1), 201A-1, 202-1, 202-1(1), 202A, and 202A-1,

[0180] L_{201} to L_{203}, xa1 to xa3, xa5, and R_{202} to R_{204} may each independently be the same as described above,

[0181] L_{205} may be selected from a phenylene group and a fluorenylene group,

[0182] X_{211} may be selected from O, S, and $N(R_{211})$,

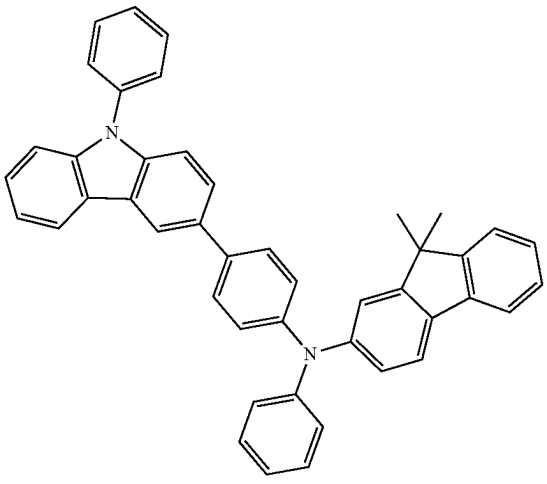
[0183] X_{212} may be selected from O, S, and $N(R_{212})$,

[0184] R_{211} and R_{212} may each independently be the same described in connection with R_{203}, and

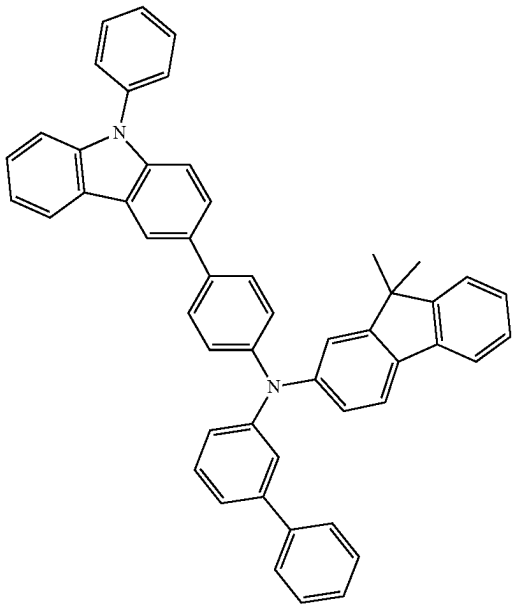
[0185] R_{213} to R_{217} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a phenyl group substituted with a C_1-C_1 alkyl group, a phenyl group substituted with —F, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a naphthacenyl group, a picenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, and a pyridinyl group.

[0186] The hole transport region may include at least one compound selected from Compounds HT1 to HT48, but embodiments are not limited thereto:

HT1



HT2



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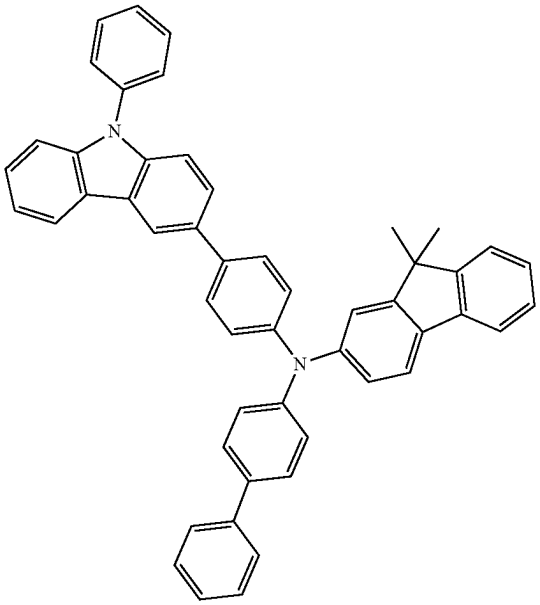
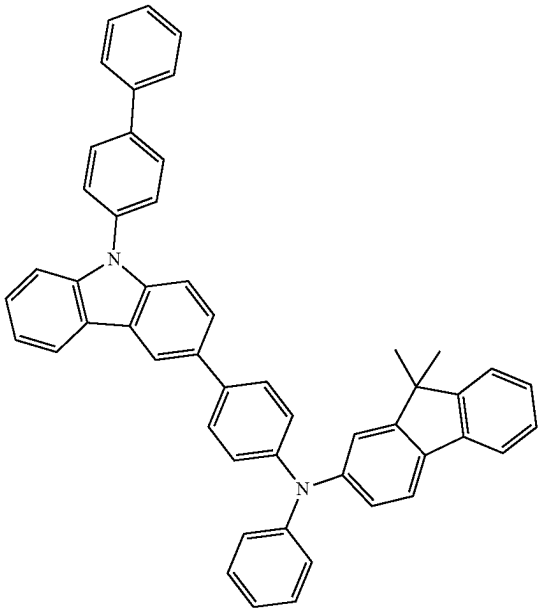
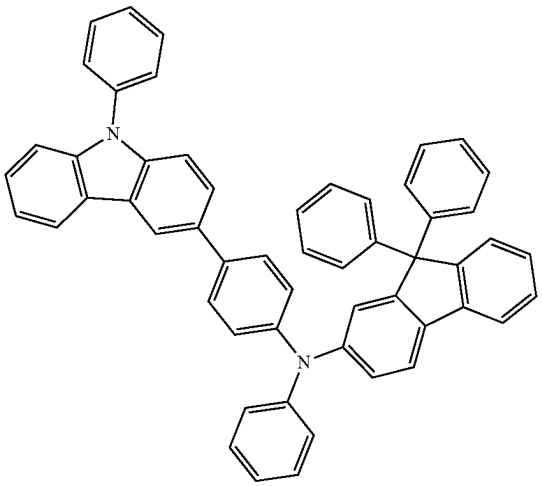
HT3



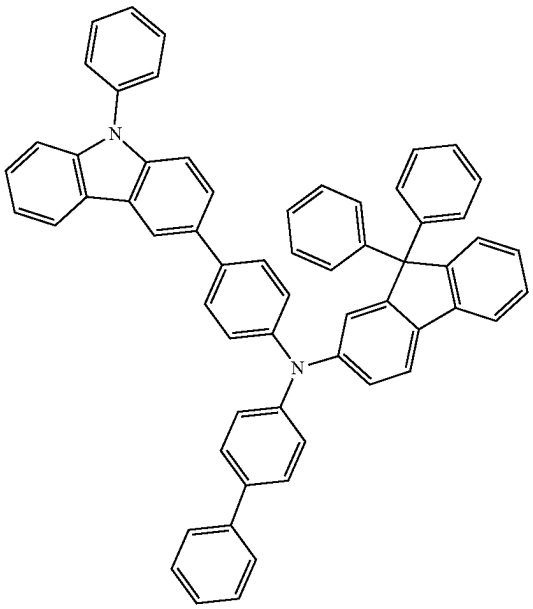
HT4



HT5



HT6



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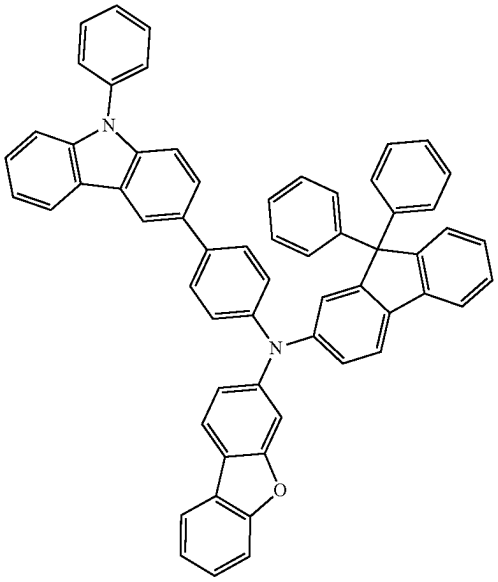
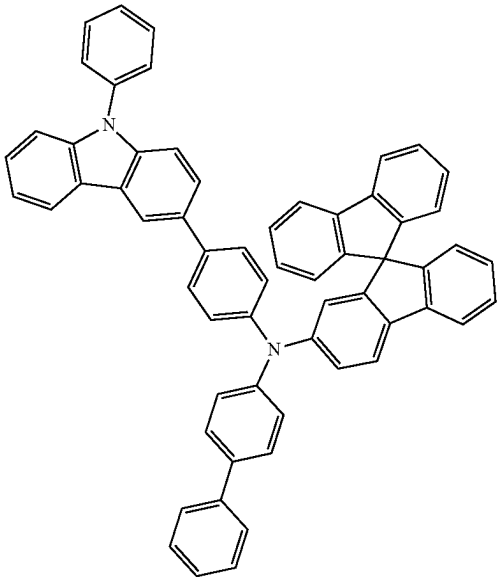
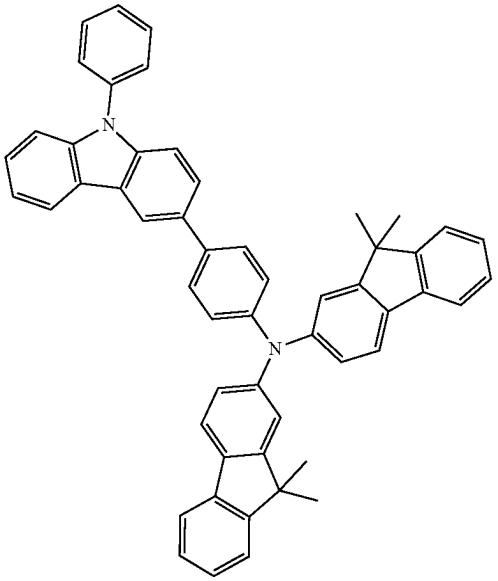
HT7



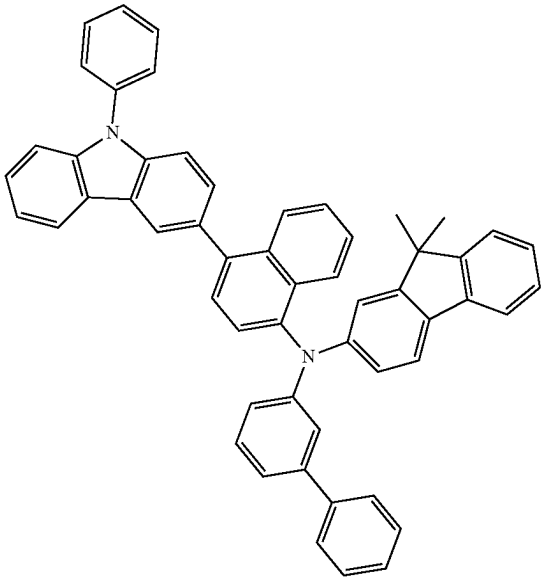
HT8



HT9



HT10



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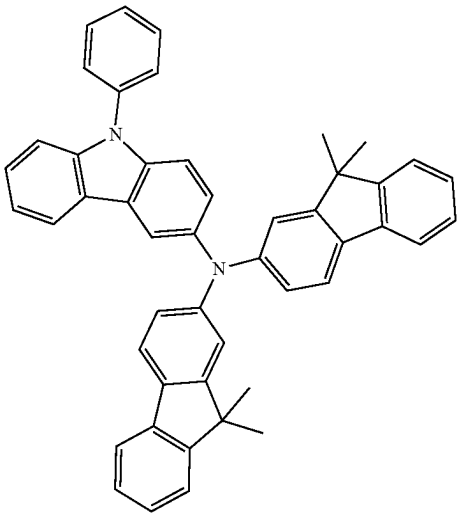
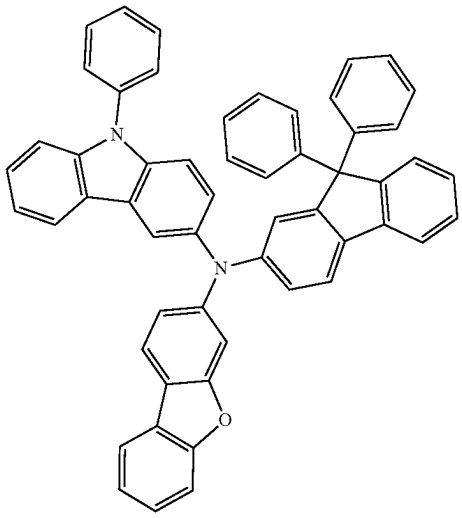
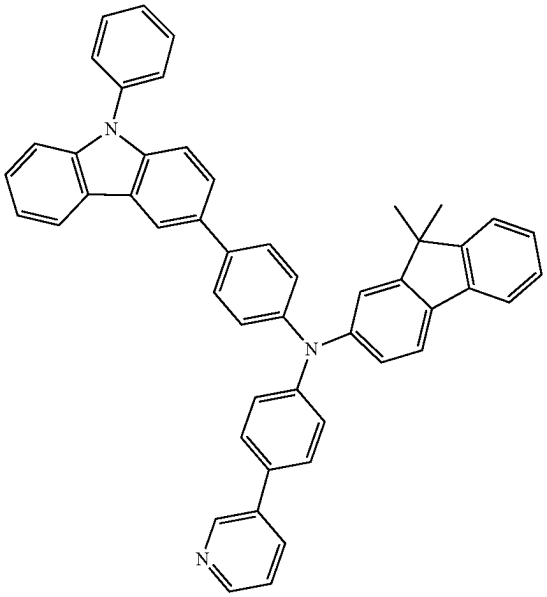
HT11



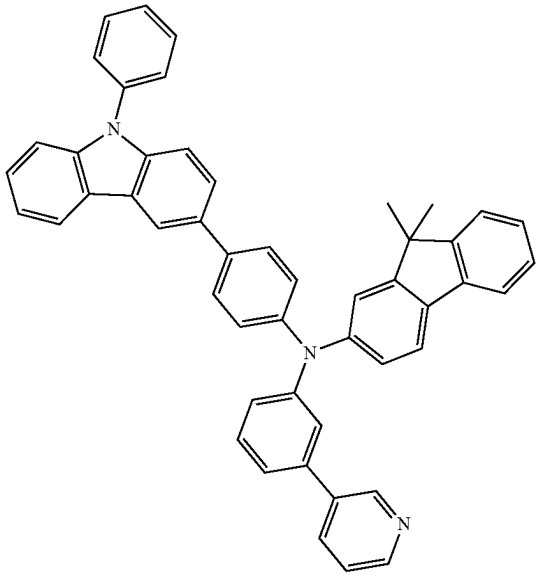
HT12



HT13



HT14



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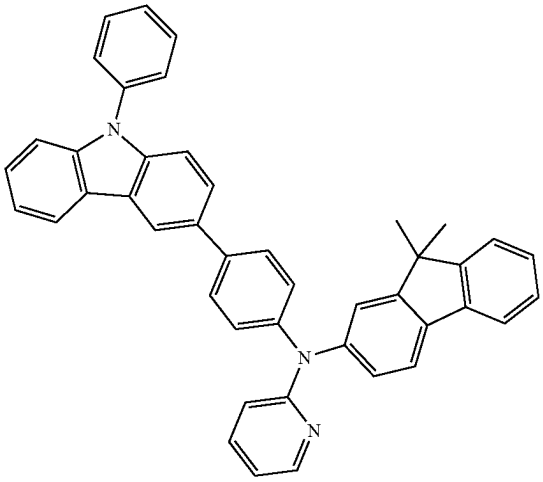
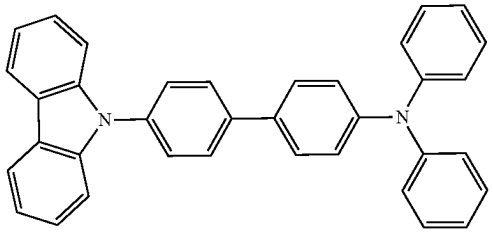
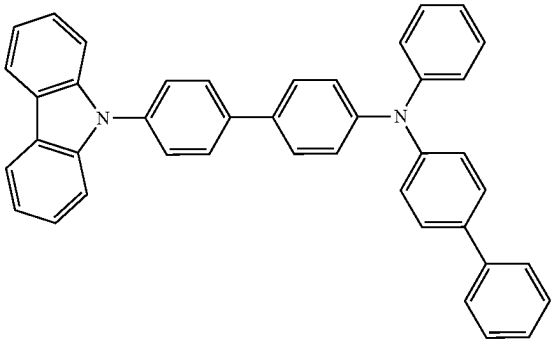
HT15



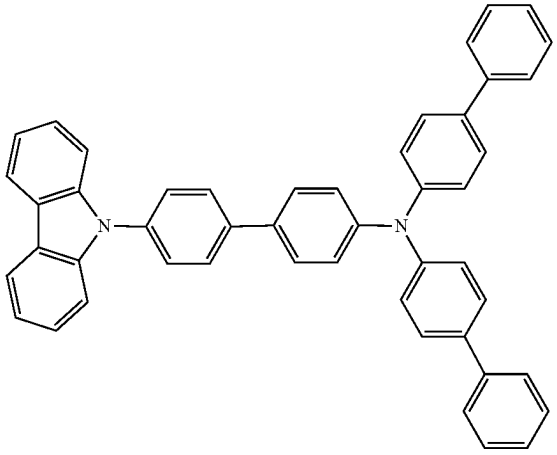
HT16



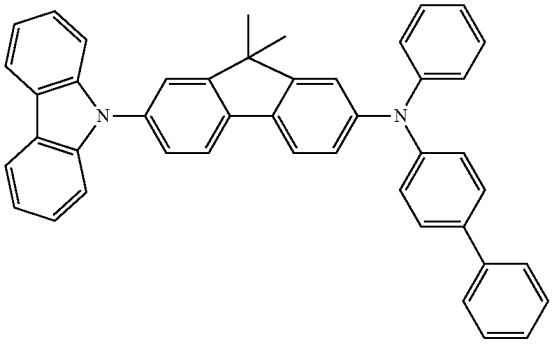
HT17



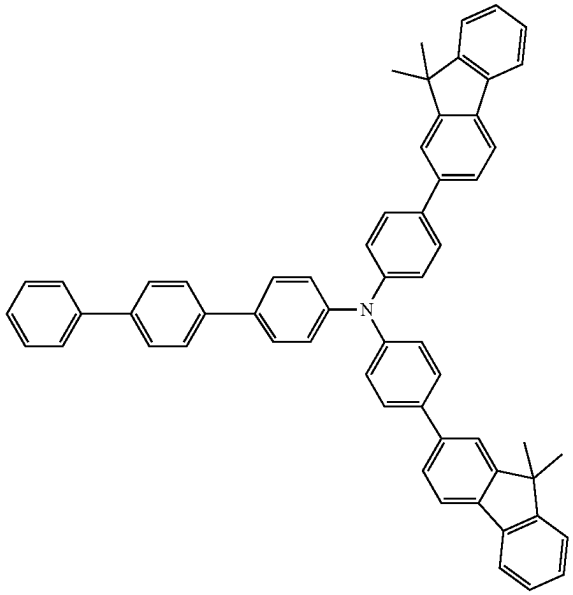
HT18



HT19



HT20



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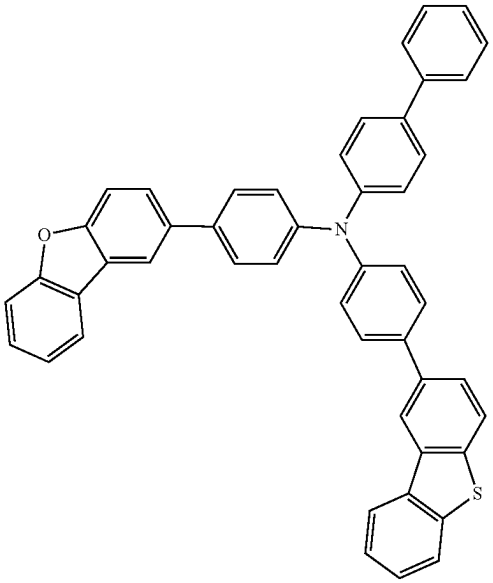
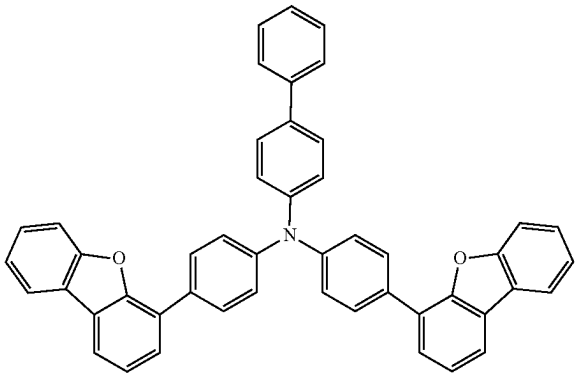
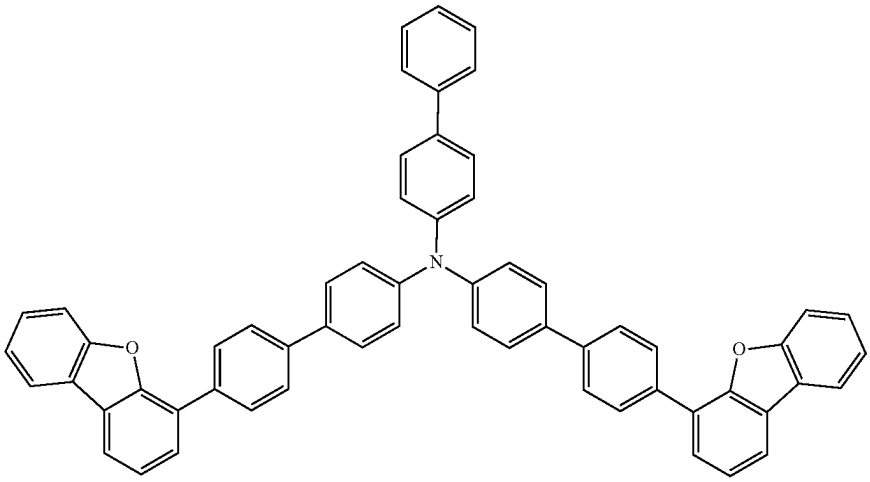
HT21



HT22



HT23



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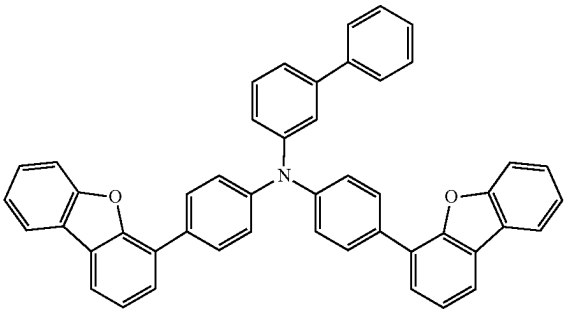
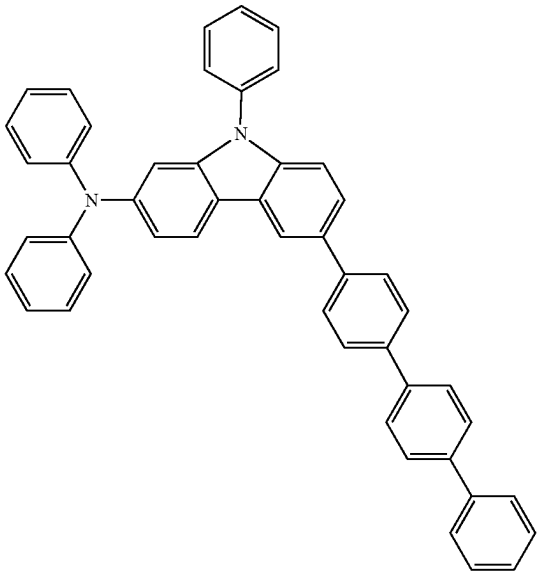
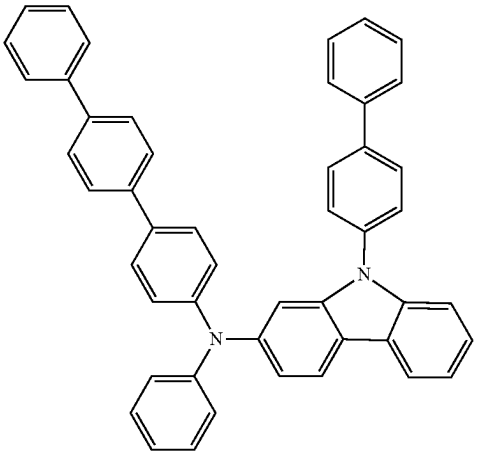
HT24



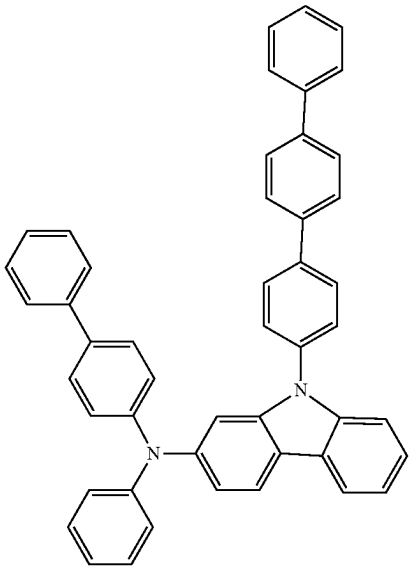
HT25



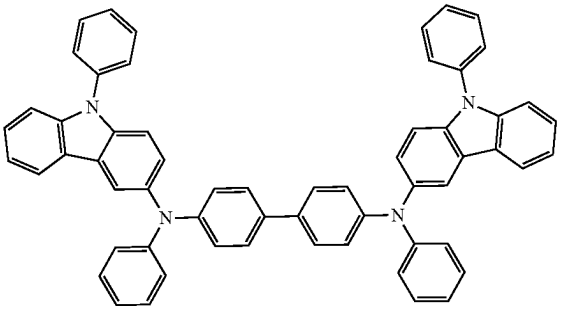
HT26



HT27



HT28



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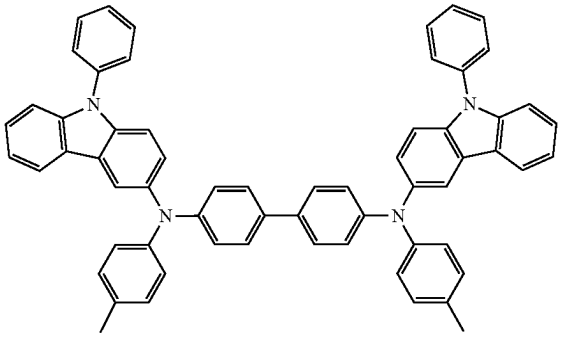

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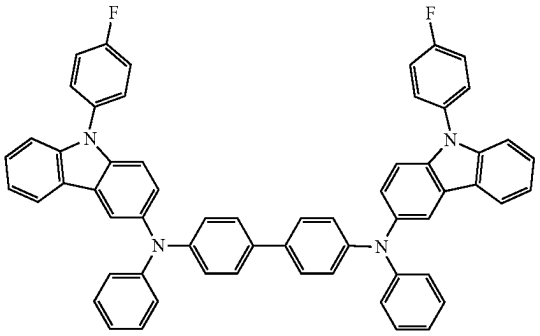

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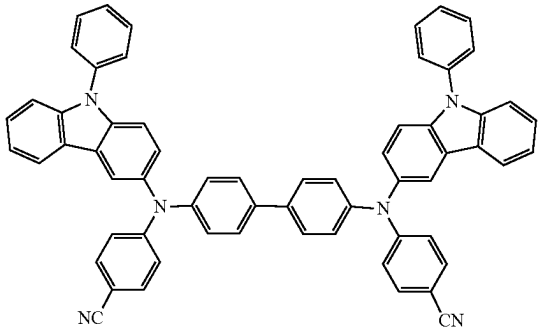

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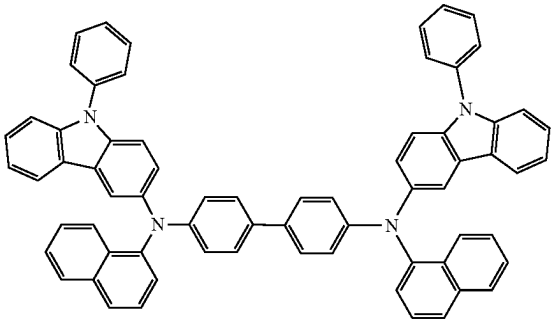

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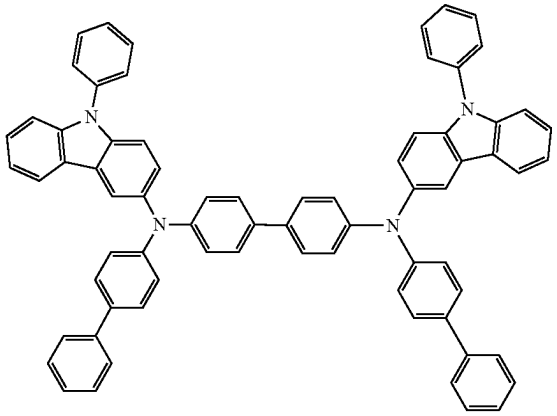

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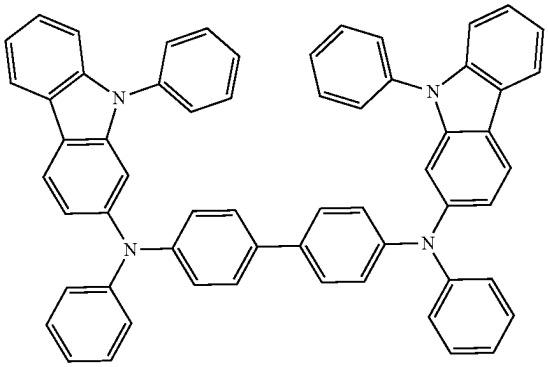

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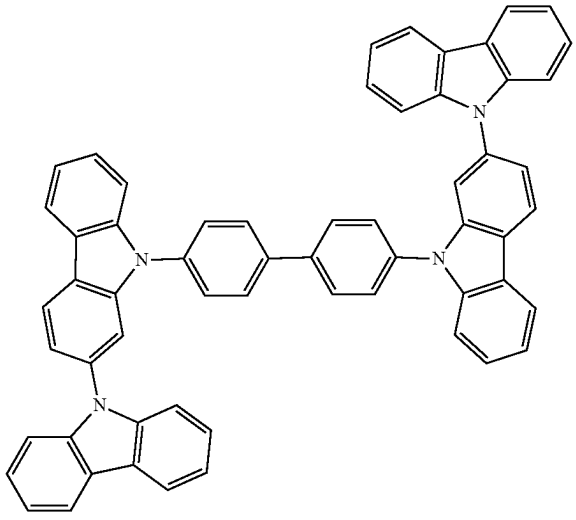

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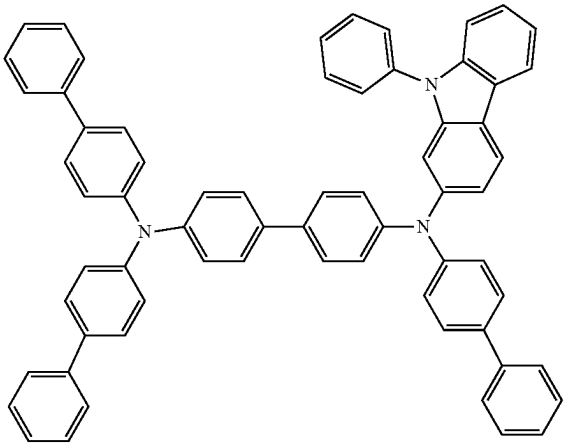

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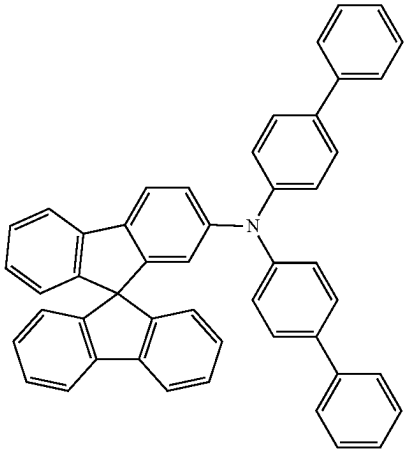

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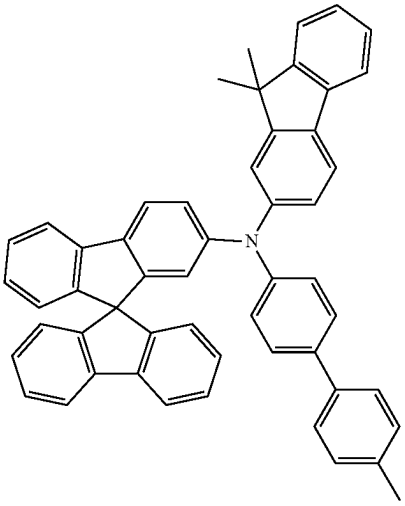

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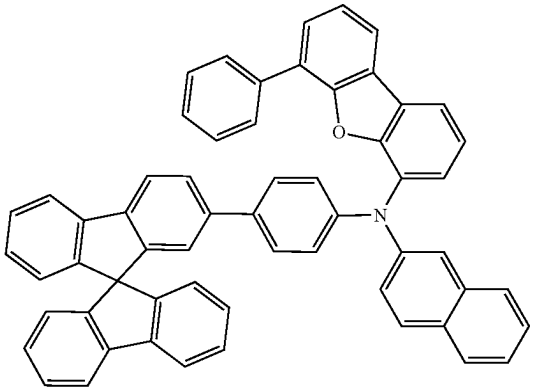

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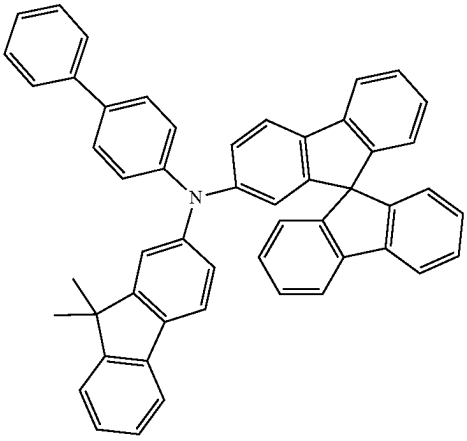

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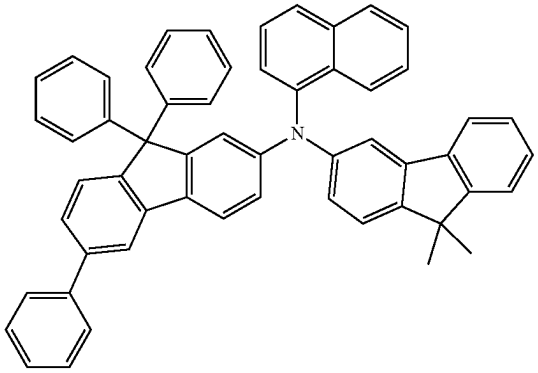

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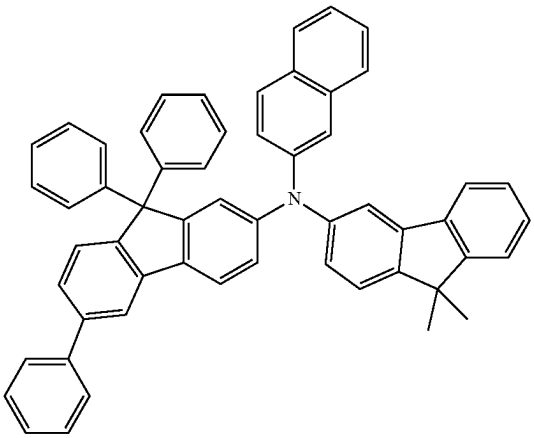

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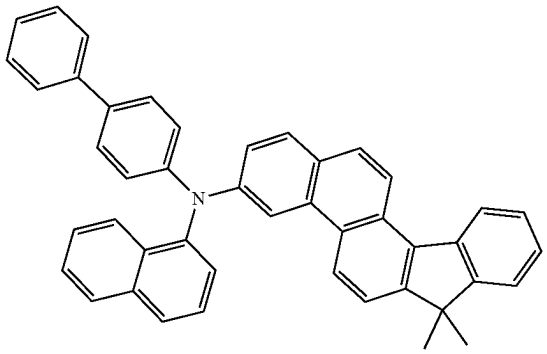

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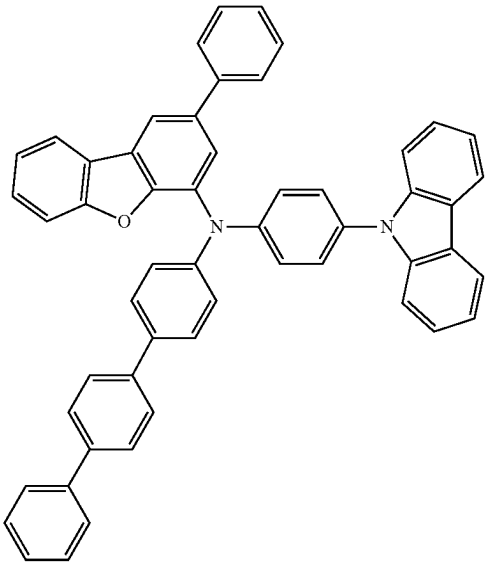

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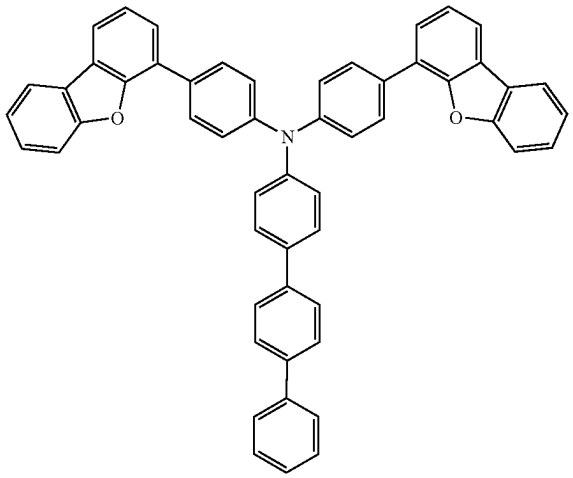

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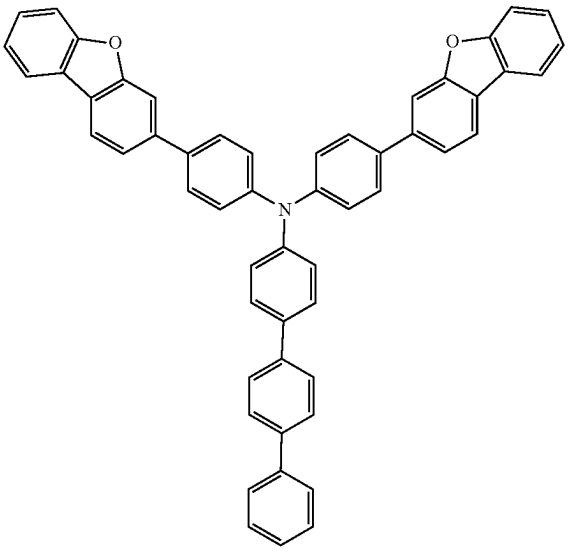

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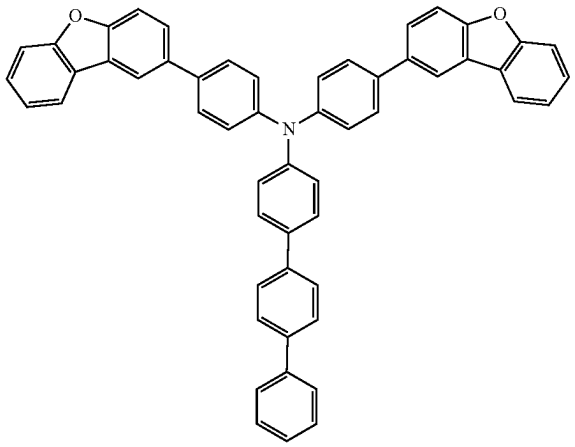

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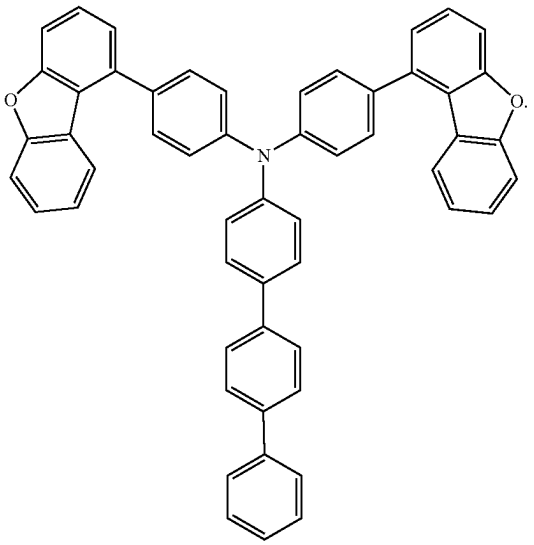


[0187] The thickness of the hole transport region may be about 100 (Angstroms)Å to about 10,000 Å, and in some embodiments, about 100 Å to about 1,000 Å. When the hole transport region includes at least one selected from a hole injection layer and a hole transport layer, the thickness of the hole injection layer may be about 100 Å to about 9,000 Å, and in some embodiments, about 100 Å to about 1,000 Å, and the thickness of the hole transport layer may be about 50 Å to about 2,000 Å, and in some embodiments, 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 any of these ranges, excellent hole transport characteristics may be obtained without a substantial increase in driving voltage.

[0188] The emission auxiliary layer may increase the light emission efficiency of the device by compensating for an optical resonance distance of the wavelength of light emitted by an emission layer. The electron blocking layer may reduce or eliminate the flow of electrons from an electron transport region. The emission auxiliary layer and the electron blocking layer may each include the materials described above.

p-Dopant

[0189] The hole transport region may include a charge generating material in addition to the above-described materials, to improve the conductive properties of the hole transport region. The charge generating material may be substantially homogeneously or non-homogeneously dispersed in the hole transport region.

[0190] The charge generating material may include, for example, a p-dopant.

[0191] In some embodiments, the lowest unoccupied molecular orbital (LUMO) energy level of the p-dopant may be −3.5 eV or less.

[0192] The p-dopant may include at least one selected from a quinone derivative, a metal oxide, and a cyano group-containing compound, but embodiments are not limited thereto.

[0193] In some embodiments, the p-dopant may include:

[0194] a quinone derivative (such as tetracyanoquinodimethane (TCNQ) and/or 2,3,5,6-tetrafluoro-7,7,8,8-tetracyanoquinodimethane (F4-TCNQ));

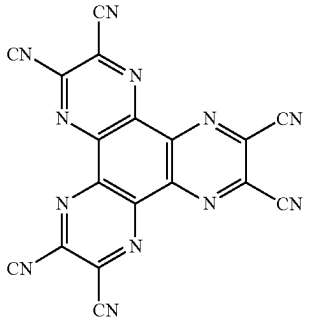
[0195] a metal oxide (such as tungsten oxide and/or molybdenum oxide);

[0196] 1,4,5,8,9,12-hexaazatriphenylene-hexacarbonitrile (HAT-CN); and

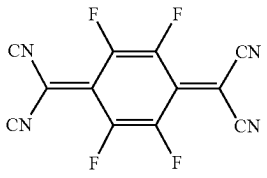
[0197] a compound represented by Formula 221,

[0198] but embodiments are not limited thereto:

HAT-CN



F4-TCNQ



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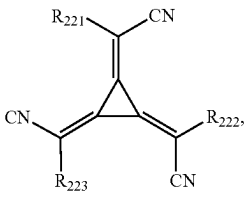
Formula 221



[0199] wherein, in Formula 221,

[0200] R_{221} to R_{223} may each independently be selected from a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_1 heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, wherein at least one selected from R_{221} to R_{223} may include at least one substituent selected from a cyano group, —F, —Cl, —Br, —I, a C_1-C_{20} alkyl group substituted with —F, a C_1-C_{20} alkyl group substituted with —C_1, a C_1-C_{20} alkyl group substituted with —Br, and a C_1-C_{20} alkyl group substituted with —I.

Emission Layer in Interlayer **150**

[0201] 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 a blue emission layer, according to a sub-pixel. In one or more embodiments, the emission layer may have a stacked structure. The stacked structure may include two or more layers selected from a red emission layer, a green emission layer, and a blue emission layer. In some embodiments, the two or more layers may be in direct contact with each other. In some embodiments, the two or more layers may be separated from each other. In one or more embodiments, the emission layer may include two or more materials. The two or more materials may each independently include a red light-emitting material, a green light-emitting material, or a blue light-emitting material. The two or more materials may be mixed with each other in a single layer. In some embodiments, the two or more materials mixed with each other in the single layer may be to emit white light.

[0202] The emission layer may include a host and a dopant. The dopant may include at least one of a fluorescent dopant and a phosphorescent dopant.

[0203] The amount of the dopant in the emission layer may be about 0.01 parts to about 15 parts by weight based on 100 parts by weight of the host, but embodiments are not limited thereto.

[0204] The thickness of the emission layer may be about 100 Å to about 1,000 Å, and in some embodiments, about 200 Å to about 600 Å. When the thickness of the emission layer is within any of these ranges, improved luminescence characteristics may be obtained without a substantial increase in driving voltage.

Host in Emission Layer

[0205] The host may include a compound represented by Formula 301:

$$[Ar_{301}]_{xb11}—[(L_{301})_{xb1}—R_{301}]_{xb21},$$ Formula 301

[0206] wherein, in Formula 301,

[0207] Ar_{301} may be selected from a substituted or unsubstituted C_5-C_{60} carbocyclic group and a substituted or unsubstituted C_1-C_{60} heterocyclic group,

[0208] xb11 may be 1, 2, or 3,

[0209] L_{301} may be selected from a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, a substituted or unsubstituted C_1-C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0210] xb1 may be an integer from 0 to 5,

[0211] R_{301} may be selected from deuterium, —F, —CI, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_2-C_{60} alkenyl group, a substituted or unsubstituted C_2-C_{60} alkynyl group, a substituted or unsubstituted C_1-C_{60} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, —$Si(Q_{301})(Q_{302})(Q_{303})$, —$N(Q_{301})(Q_{302})$, —$B(Q_{301})(Q_{302})$, —$C(=O)(Q_{301})$, —$S(=O)_2(Q_{301})$, and —$P(=O)(Q_{301})(Q_{302})$, and

[0212] xb21 may be an integer from 1 to 5,

[0213] wherein Q_{301} to Q_{303} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group, but embodiments are not limited thereto.

[0214] In some embodiments, in Formula 301, Ar_{301} may be selected from:

[0215] a naphthalene group, a fluorene group, a spirobifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, a dibenzofuran group, and a dibenzothiophene group; and

[0216] a naphthalene group, a fluorene group, a spirobifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene

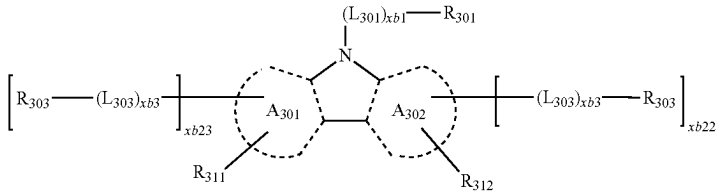
group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, a dibenzofuran group, and a dibenzothiophene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, $—Si(Q_{31})(Q_{32})(Q_{33})$, $—N(Q_{31})(Q_{32})$, $—B(Q_{31})(Q_{32})$, $—C(=O)(Q_{31})$, $—S(=O)_2(Q_{31})$, and $—P(=O)(Q_{31})(Q_{32})$,

[0217] wherein Q_{31} to Q_{33} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group, but embodiments are not limited thereto.

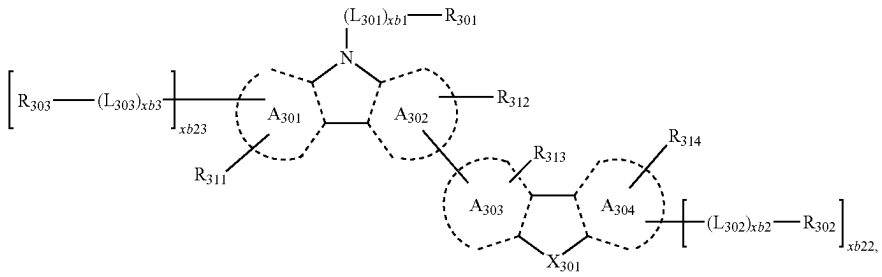
[0218] When xb11 in Formula 301 is 2 or greater, at least two Ar_{301}(s) may be bound via a single bond.

[0219] In one or more embodiments, the compound represented by Formula 301 may be represented by Formula 301-1 or 301-2:

Formula 301-1



Formula 301-2



[0220] wherein, in Formulae 301-1 to 301-2,

[0221] A_{301} to A_{304} may each independently be selected from a benzene group, a naphthalene group, a phenanthrene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a pyridine group, a pyrimidine group, an indene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, an indole group, a carbazole group, a benzocarbazole group, a dibenzocarbazole group, a furan group, a benzofuran group, a dibenzofuran group, a naphthofuran group, a benzonaphthofuran group, a dinaphthofuran group, a thiophene group, a benzothiophene group, a dibenzothiophene group, a naphthothiophene group, a benzonaphthothiophene group, and a dinaphthothiophene group,

[0222] X_{301} may be O, S, or $N—[(L_{304})_{xb4}—R_{304}]$,

[0223] R_{311} to R_{314} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group $—Si(Q_{31})(Q_{32})(Q_{33})$, $—N(Q_{31})(Q_{32})$, $—B(Q_{31})(Q_{32})$, $—C(=O)(Q_{31})$, $—S(=O)_2(Q_{31})$, and $—P(=O)(Q_{31})(Q_{32})$,

[0224] xb22 and xb23 may each independently be 0, 1, or 2,

[0225] L_{301}, xb1, R_{301}, and Q_{31} to Q_{33} may each independently be the same as described above,

[0226] L_{302} to L_{304} may each independently be the same as described herein in connection with L_{301},

[0227] xb2 to xb4 may each independently be the same as described herein in connection with xb1, and

[0228] R_{302} to R_{304} may each independently be the same as described herein in connection with R_{301}.

[0229] In some embodiments, in Formulae 301, 301-1, and 301-2, L_{301} to L_{304} may each independently be selected from:

[0230] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, a pyridinylene group, an imidazolylene group, a pyrazolylene group, a thiazolylene group, an isothiazolylene group, an oxazolylene group, an isoxazolylene group, a thiadiazolylene group, an oxadiazolylene group, a pyrazinylene

group, a pyrimidinylene group, a pyridazinylene group, a triazinylene group, a quinolinylene group, an isoquinolinylene group, a benzoquinolinylene group, a phthalazinylene group, a naphthyridinylene group, a quinoxalinylene group, a quinazolinylene group, a cinnolinylene group, a phenanthridinylene group, an acridinylene group, a phenanthrolinylene group, a phenazinylene group, a benzimidazolylene group, an isobenzothiazolylene group, a benzoxazolylene group, an isobenzoxazolylene group, a triazolylene group, a tetrazolylene group, an imidazopyridinylene group, an imidazopyrimidinylene group, and an azacarbazolylene group; and

[0231] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, a pyridinylene group, an imidazolylene group, a pyrazolylene group, a thiazolylene group, an isothiazolylene group, an oxazolylene group, an isoxazolylene group, a thiadiazolylene group, an oxadiazolylene group, a pyrazinylene group, a pyrimidinylene group, a pyridazinylene group, a triazinylene group, a quinolinylene group, an isoquinolinylene group, a benzoquinolinylene group, a phthalazinylene group, a naphthyridinylene group, a quinoxalinylene group, a quinazolinylene group, a cinnolinylene group, a phenanthridinylene group, an acridinylene group, a phenanthrolinylene group, a phenazinylene group, a benzimidazolylene group, an isobenzothiazolylene group, a benzoxazolylene group, an isobenzoxazolylene group, a triazolylene group, a tetrazolylene group, an imidazopyridinylene group, an imidazopyrimidinylene group, and an azacarbazolylene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl 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 hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an azacarbazolyl group, $—Si(Q_{31})(Q_{32})(Q_{33})$, $—N(Q_{31})(Q_{32})$, $—B(Q_{31})(Q_{32})$, $—C(=O)(Q_{31})$, $—S(=O)_2(Q_{31})$, and $—P(=O)(Q_{31})(Q_{32})$,

[0232] wherein Q_{31} to Q_{33} may each independently be the same as described above.

[0233] In some embodiments, in Formulae 301, 301-1, and 301-2, R_{301} to R_{304} may each independently be selected from:

[0234] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl 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 hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group; and

[0235] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl 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 hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzo-

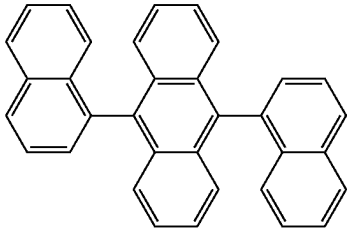
carbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl 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 hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an azacarbazolyl group, $—Si(Q_{31})(Q_{32})(Q_{33})$, $—N(Q_{31})(Q_{32})$, $—B(Q_{31})(Q_{32})$, $—C(=O)(Q_{31})$, $—S(=O)_2(Q_{31})$, and $—P(=O)(Q_{31})(Q_{32})$,

[0236] wherein Q_{31} to Q_{33} may each independently be the same as described above.

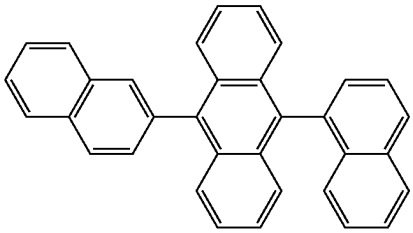
[0237] In some embodiments, the host may include an alkaline earth metal complex. For example, the host may include a beryllium (Be) complex, e.g., Compound H55, or a magnesium (Mg) complex. In some embodiments, the host may be or include a zinc (Zn) complex.

[0238] The host may include at least one selected from 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), and Compounds H1 to H55, but embodiments are not limited thereto:

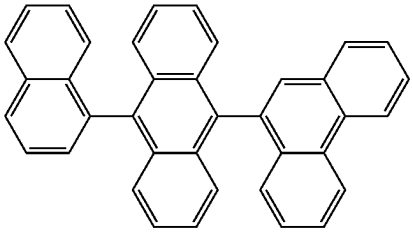
H1



H2



H3



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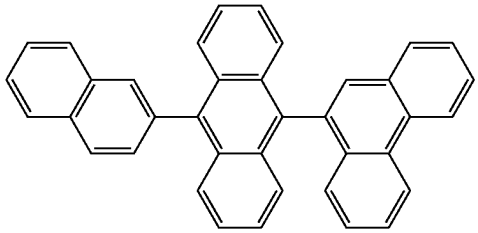

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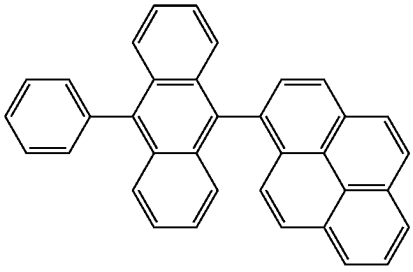

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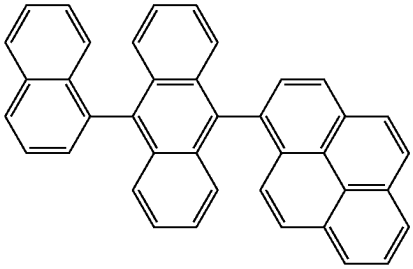

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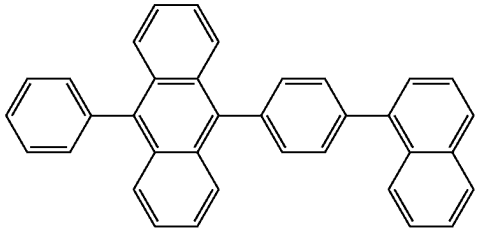

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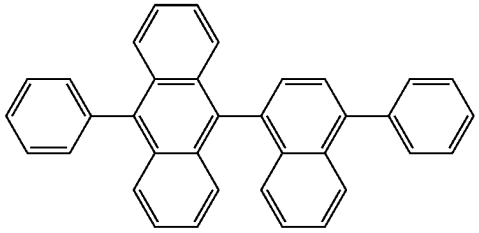

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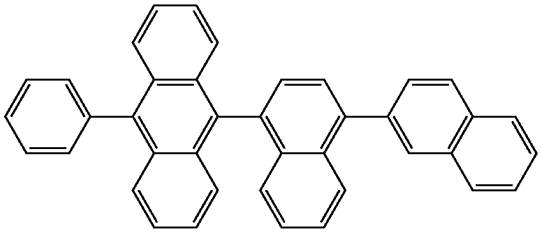

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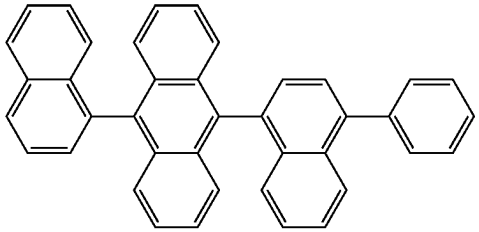

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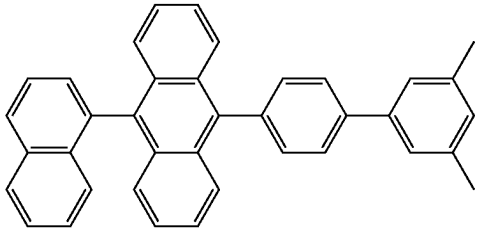

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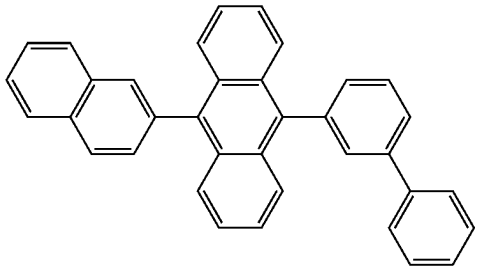

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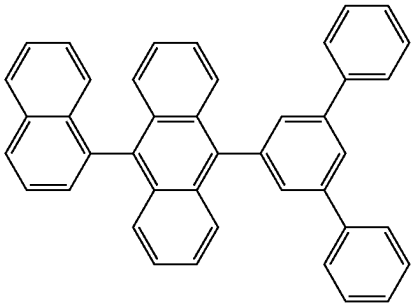

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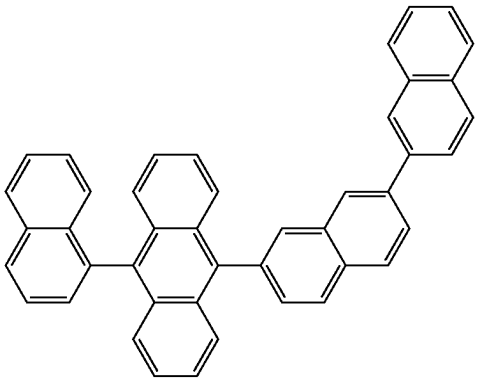

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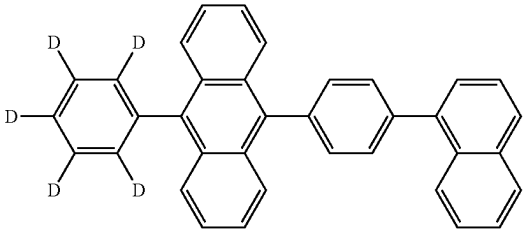

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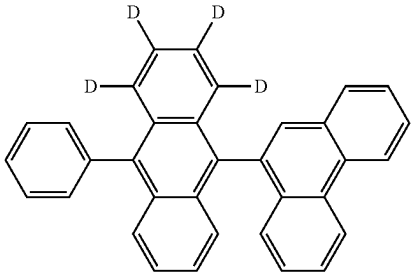

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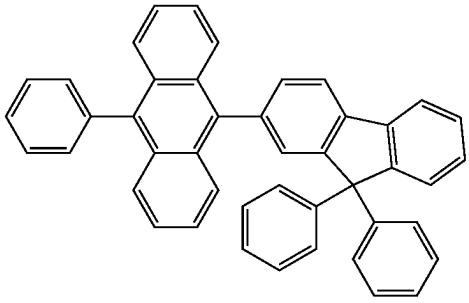

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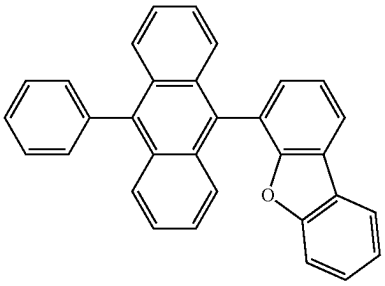

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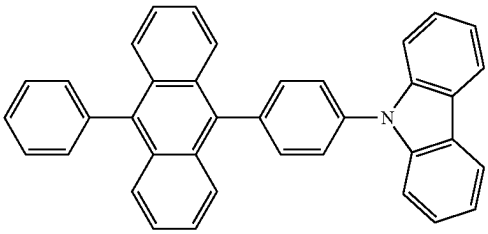

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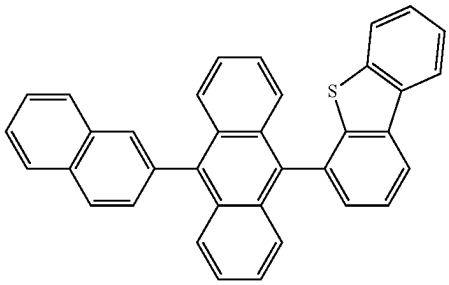

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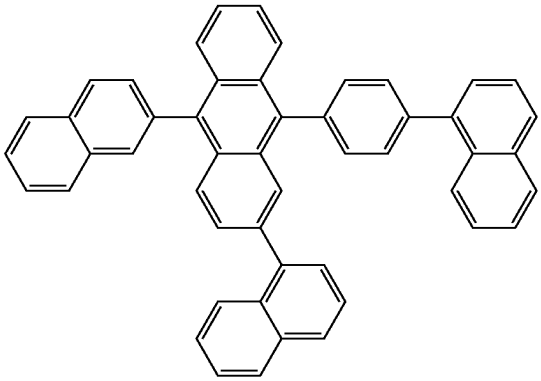

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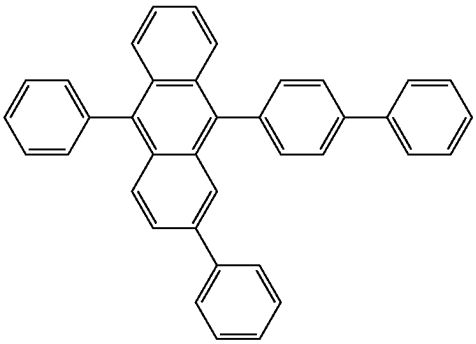

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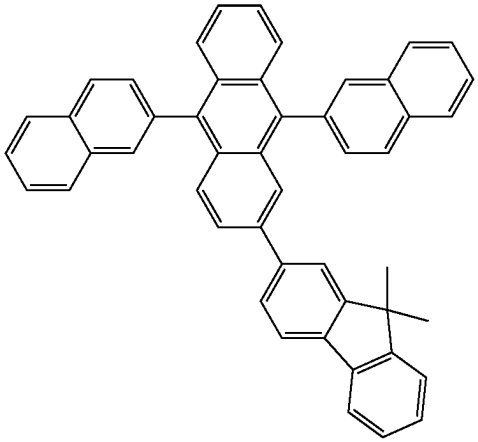

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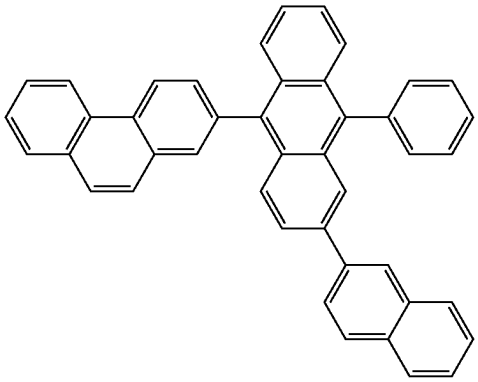

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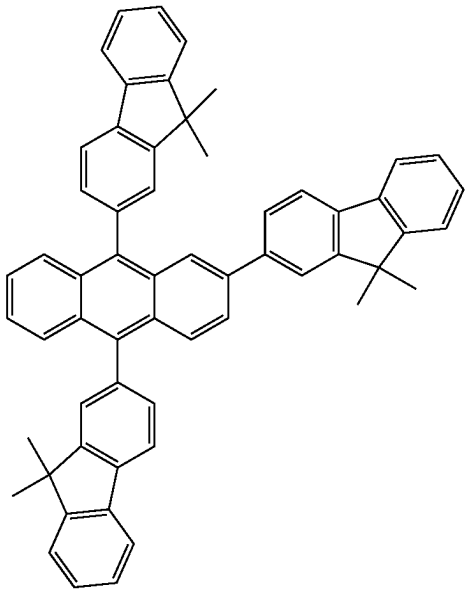

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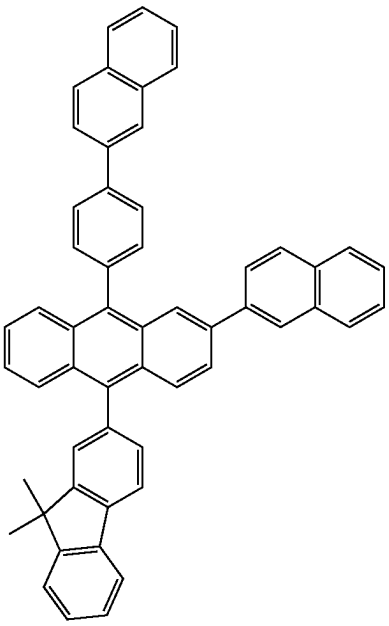

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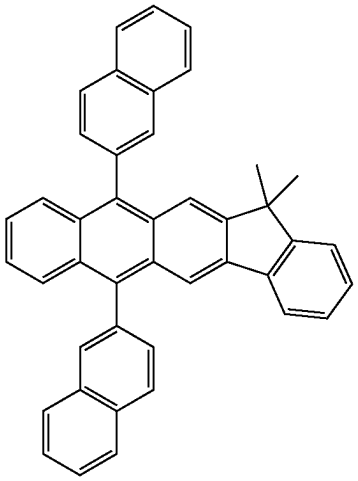

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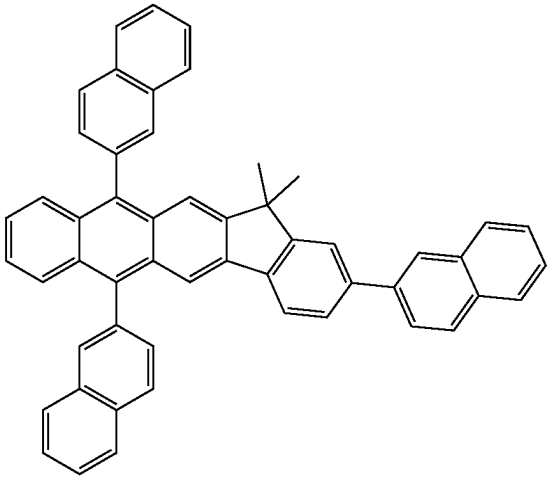

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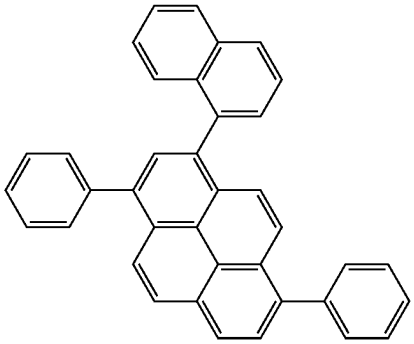

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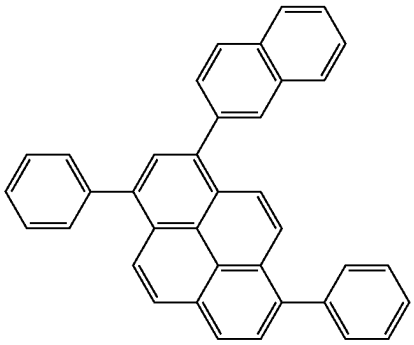

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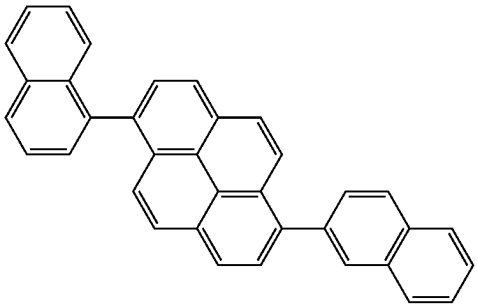

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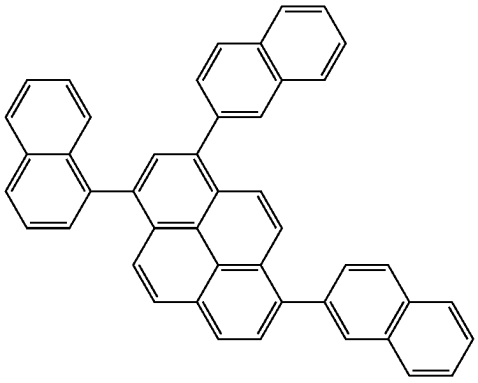

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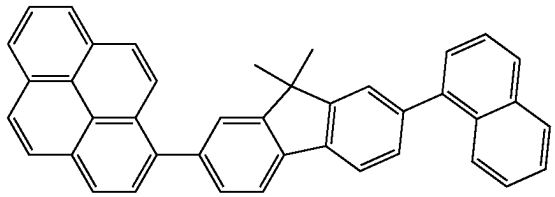

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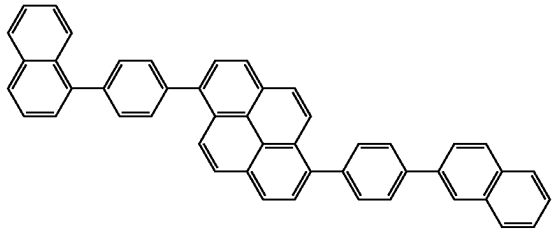

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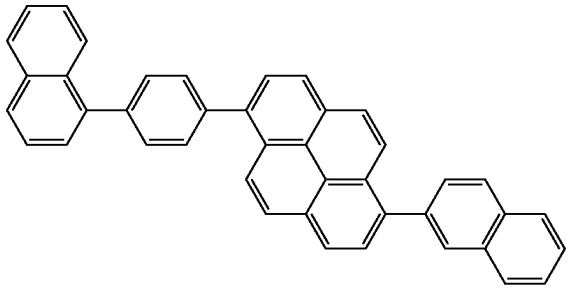

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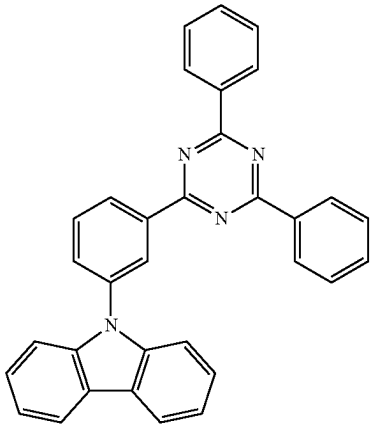

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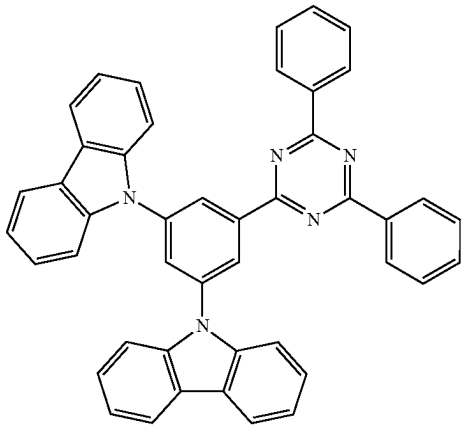

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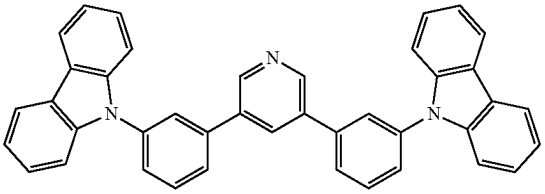

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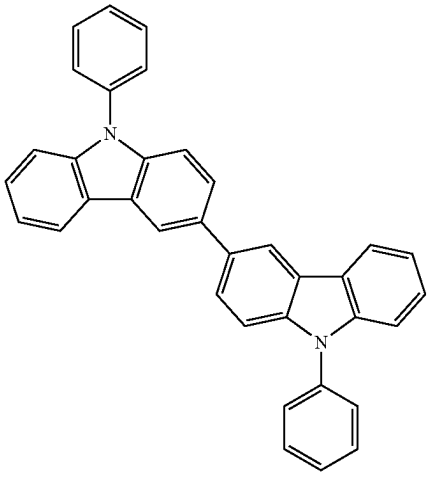

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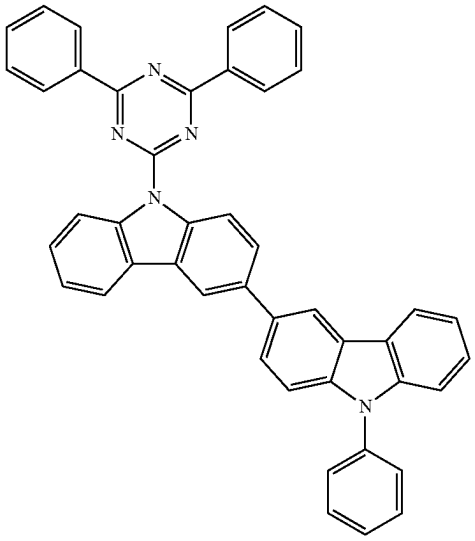

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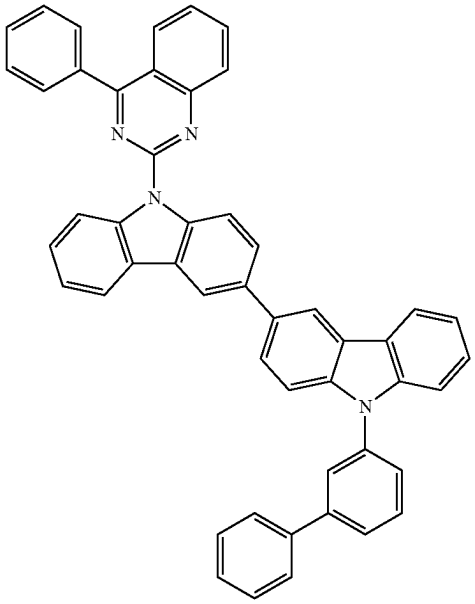

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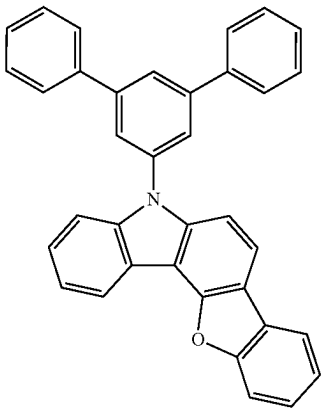

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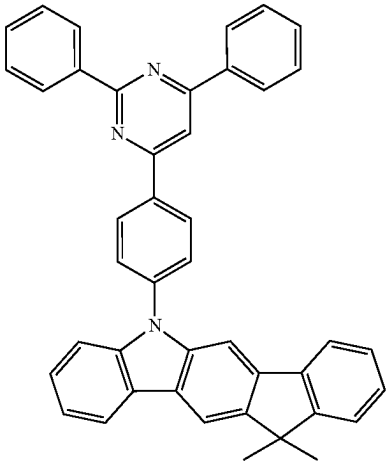

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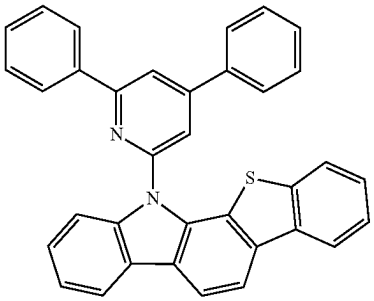

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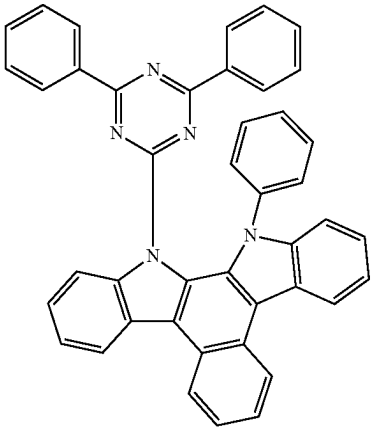

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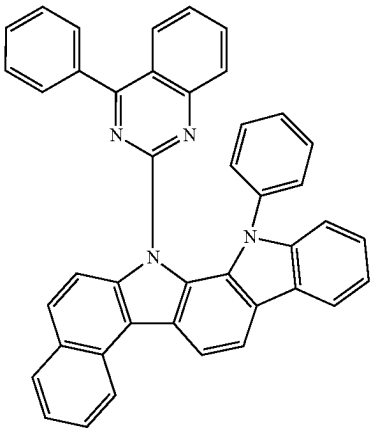

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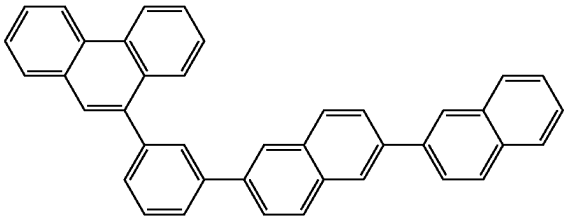

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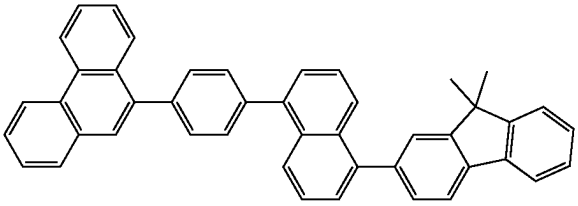

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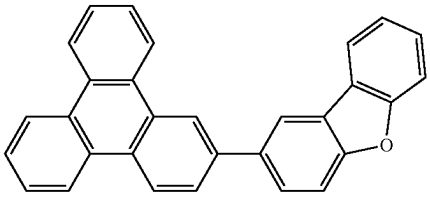

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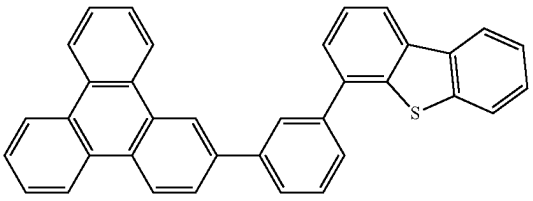

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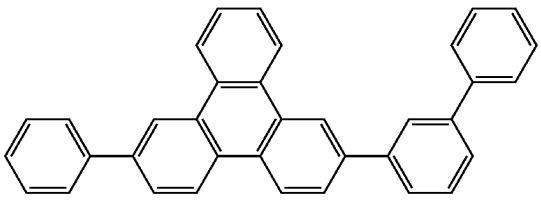

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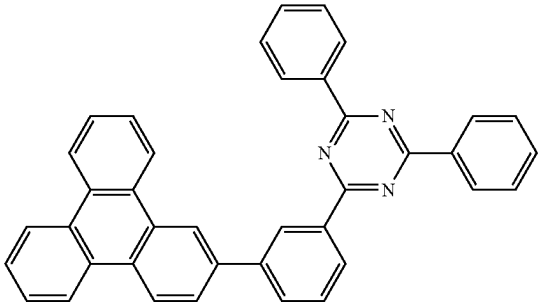

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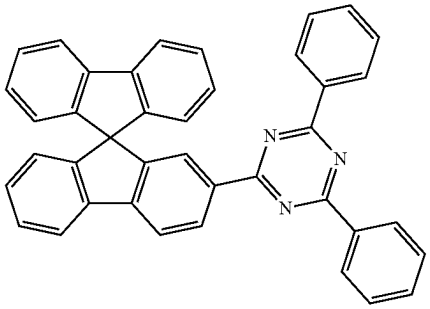

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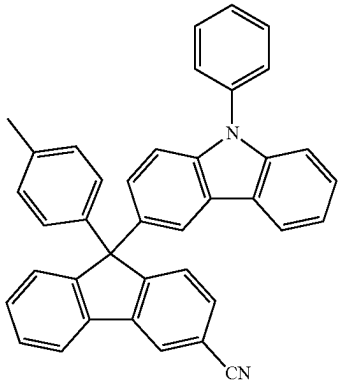

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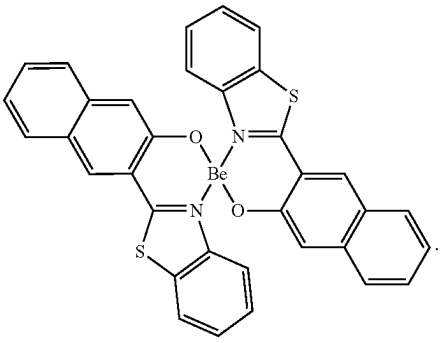


[0239] In some embodiments, the emission layer may include quantum dots.

[0240] A quantum dot is a particle having a crystal structure of several to tens of nanometers in size. The quantum dot may include hundreds to thousands of atoms.

[0241] Because the quantum dot is very small in size, quantum confinement effects may occur. "Quantum confinement" is a phenomenon in which a band gap of an object (e.g., of a crystal or particle) becomes larger when the object becomes smaller in size and approaches the above-described nanometer scale. Accordingly, when light having an energy larger than the band gap of the quantum dot is incident on the quantum dot, the quantum dot absorbs the light so that an electron is excited and then falls to the ground state, such that light (e.g., a photon) having a particular wavelength is emitted.

[0242] In this case, the wavelength of the emitted light may have a value corresponding to the band gap of the quantum dot.

[0243] A core of the quantum dot may include a II-VI compound, a III-VI compound, a III-V compound, a IV-VI compound, a Group IV element or compound, a I-III-VI compound, or a combination thereof.

[0244] The II-VI compound may be selected from: a binary compound selected from the group consisting of CdS, CdSe, CdTe, ZnS, ZnSe, ZnTe, ZnO, HgS, HgSe, HgTe, MgSe, MgS, and mixtures thereof; a ternary compound selected from the group consisting of CdSeS, CdSeTe, CdSTe, ZnSeS, ZnSeTe, ZnSTe, HgSeS, HgSeTe, HgSTe, CdZnS, CdZnSe, CdZnTe, CdHgS, CdHgSe, CdHgTe, HgZnS, HgZnSe, HgZnTe, MgZnSe, MgZnS, and mixtures thereof; and a quaternary compound selected from the group consisting of CdZnSeS, CdZnSeTe, CdZnSTe, CdHgSeS, CdHgSeTe, CdHgSTe, HgZnSeS, HgZnSeTe, HgZnSTe, and mixtures thereof.

[0245] The III-VI compound may include a binary compound such as In_2S_3 or In_2Se_3; a ternary compound such as $InGaS_3$ or $InGaSe_3$; or any combination thereof.

[0246] The III-V compound may be selected from: a binary compound selected from the group consisting of GaN, GaP, GaAs, GaSb, AlN, AlP, AlAs, AlSb, InN, InP, InAs, InSb and mixtures thereof; a ternary compound selected from the group consisting of GaNP, GaNAs, GaNSb, GaPAs, GaPSb, AlNP, AlNAs, AlNSb, AlPAs, AlPSb, InGaP, InAlP, InNP, InNAs, InNSb, InPAs, InPSb, GaAlNP, and mixtures thereof; and a quaternary compound selected from the group consisting of GaAlNAs, GaAlNSb, GaAlPAs, GaAlPSb, GaInNP, GaInNAs, GaInNSb, GaInPAs, GaInPSb, InAlNP, InAlNAs, InAlNSb, InAlPAs, InAlPSb, and mixtures thereof. The III-V semiconductor compound may further include a Group II metal (e.g., InZnP).

[0247] The IV-VI compound may be selected from: a binary compound selected from the group consisting of SnS, SnSe, SnTe, PbS, PbSe, PbTe, and mixtures thereof; a ternary compound selected from the group consisting of SnSeS, SnSeTe, SnSTe, PbSeS, PbSeTe, PbSTe, SnPbS, SnPbSe, SnPbTe, and mixtures thereof; and a quaternary compound selected from the group consisting of SnPbSSe, SnPbSeTe, SnPbSTe, and mixtures thereof. The Group IV element may be selected from the group consisting of Si, Ge, and mixtures thereof. The IV compound may be a binary compound selected from the group consisting of SiC, SiGe, and mixtures thereof.

[0248] The I-III-VI semiconductor compound may include a ternary compound such as AgInS, $AgInS_2$, CuInS, $CuInS_2$, $CuGaO_2$, $AgGaO_2$, $AgAlO_2$, or any combination thereof.

[0249] In some embodiments, the binary compound, the ternary compound, and/or the quaternary compound may be present in each particle at a substantially uniform concentration. or may be included at varying concentrations within each particle (e.g., to form a gradient within each particle). In some embodiments, for example, a quantum dot may have a core-shell structure. An interface between the core and the shell may have a concentration gradient, in which the concentration of elements present in the shell decreases toward the center (e.g., is decreased or absent in the core).

[0250] In some embodiments, for example, the quantum dot may have a core-shell structure, including a core as the nanocrystal described above and a shell surrounding the core. The shell of the quantum dot may serve as a protective layer to prevent or reduce chemical denaturation of the core to maintain its semiconductor characteristics, and/or as a charging layer for imparting electrophoretic characteristics to the quantum dot. The shell may be a monolayer or a multilayer structure. The interface between the core and the shell may have a concentration gradient where a concentration of elements present in the shell decreases toward the center. Non-limiting examples of materials that may be included in the shell of the quantum dot include metal or nonmetal oxide, a semiconductor compound, or a combination thereof.

[0251] In some embodiments, the metal or nonmetal oxide may be 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, and/or NiO), or a ternary compound (such as $MgAl_2O_4$, $CoFe_2O_4$, $NiFe_2O_4$, and/or $CoMn_2O_4$), but embodiments are not limited thereto.

[0252] In addition, the semiconductor compound may be CdS, CdSe, CdTe, ZnS, ZnSe, ZnTe, ZnSeS, ZnTeS, GaAs, GaP, GaSb, HgS, HgSe, HgTe, InAs, InP, InGaP, InSb, AlAs, AlP, or AlSb, but embodiments are not limited thereto.

[0253] The quantum dot may have a spectral full width at half maximum (FWHM) of an emission wavelength of about 45 nm or less, about 40 nm or less, or about 30 nm or less. When the FWHM of the quantum dot is within this range, color purity and/or color reproducibility may be improved. In addition, because light emitted by the quantum dot is emitted in all directions, an optical viewing angle of a device including the organic light emitting device including the quantum dot may be improved.

[0254] The form (format or shape) of the quantum dot may have any suitable form available in the art, and is not particularly limited. For example, the quantum dot may have a spherical form, a pyramidal form, or a multi-armed form, or may have the shape of a cubic nanoparticle, a nanotube, a nanowire, a nanofiber, a nano-plate particle, and/or the like.

[0255] The quantum dot may control color of emitted light according to the particle size. Accordingly, the quantum dot may have various emission colors such as blue, red, or green.

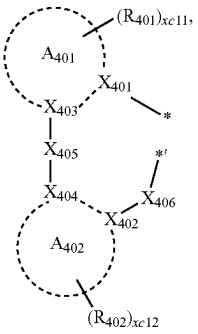
Phosphorescent Dopant Included in Emission Layer of Interlayer **150**

[0256] The phosphorescent dopant may include an organometallic complex represented by Formula 401:

Formula 401

$$M(L401)_{xc1}(L402)_{xc2}$$

Formula 402



[0257] wherein, in Formulae 401 and 402,

[0258] M may be selected from iridium (Ir), platinum (Pt), palladium (Pd), osmium (Os), titanium (Ti), zirconium (Zr), hafnium (Hf), europium (Eu), terbium (Tb), rhodium (Rh), and thulium (Tm),

[0259] L_{401} may be selected from ligands represented by Formula 402, and xc1 may be 1, 2, or 3; and when xc1 is 2 or greater, at least two L_{401}(s) may be identical to or different from each other,

[0260] L_{402} may be an organic ligand, and xc2 may be an integer selected from 0 to 4; and when xc2 is 2 or greater, at least two L_{402}(s) may be identical to or different from each other,

[0261] X_{401} to X_{404} may each independently be a nitrogen or a carbon,

[0262] X_{401} and X_{403} may be bound to each other via a single bond or a double bond, and X_{402} and X_{404} may be bound to each other via a single bond or a double bond,

[0263] A_{401} and A_{402} may each independently be a C_5-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group,

[0264] X_{405} 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═*', wherein Q_{411} and Q_{412} 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, or a naphthyl group,

[0265] X_{406} may be a single bond, O, or S,

[0266] R_{401} and R_{402} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a substituted or unsubstituted C_1-C_{20} alkyl group, a substituted or unsubstituted C_1-C_{20} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_1 heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, —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}), and —P(═O)(Q_{401})(Q_{402}), wherein Q_{401} to Q_{403} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a C_6-C_{20} aryl group, and a C_1-C_{20} heteroaryl group,

[0267] xc11 and xc12 may each independently be an integer from 0 to 10, and

[0268] * and *' in Formula 402 each indicate a binding site to M in Formula 401.

[0269] In some embodiments, in Formula 402, A_{401} and A_{402} may each independently be selected from a benzene group, a naphthalene group, a fluorene group, a spirobifluorene group, an indene group, a pyrrole group, a thiophene group, a furan group, an imidazole group, a pyrazole group, a thiazole group, an isothiazole group, an oxazole group, an isoxazole group, a pyridine group, a pyrazine group, a pyrimidine group, a pyridazine group, a quinoline group, an isoquinoline group, a benzoquinoline group, a quinoxaline group, a quinazoline group, a carbazole group, a benzimidazole group, a benzofuran group, a benzothiophene group, an isobenzothiophene group, a benzoxazole group, an isobenzoxazole group, a triazole group, a tetrazole group, an oxadiazole group, a triazine group, a dibenzofuran group, and a dibenzothiophene group.

[0270] In one or more embodiments, in Formula 402, i) X_{401} may be nitrogen, and X_4O_2 may be carbon, or ii) X_{401} and X_{402} may each be nitrogen.

[0271] In an embodiment, in Formula 402, R_{401} and R_{402} may each independently be selected from:

[0272] hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, and a C_1-C_{20} alkoxy group;

[0273] a C_1-C_{20} alkyl group and a C_1-C_{20} alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a phenyl group, a naphthyl group, a cyclopentyl group, a cyclohexyl group, an adamantyl group, a norbornanyl group, and a norbornenyl group;

[0274] a cyclopentyl group, a cyclohexyl group, an adamantyl group, a norbornanyl group, a norbornenyl group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group;

[0275] a cyclopentyl group, a cyclohexyl group, an adamantyl group, a norbornanyl group, a norbornenyl group a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl

group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, an adamantyl group, a norbornanyl group, a norbornenyl group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

[0276] —$Si(Q_{401})(Q_{402})(Q_{403})$, —$N(Q_{401})(Q_{402})$, —$B(Q_{401})(Q_{402})$, —$C(=O)(Q_{401})$, —$S(=O)_2(Q_{401})$, and —$P(=O)(Q_{401})(Q_{402})$,

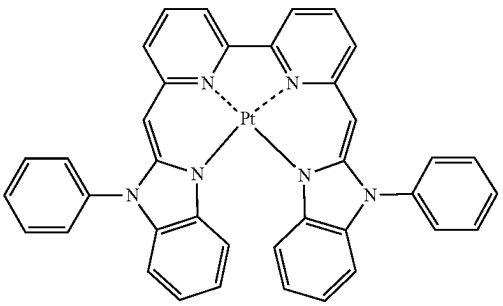
[0277] wherein Q_{401} to Q_{403} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a biphenyl group, and a naphthyl group, but embodiments are not limited thereto.

[0278] In one or more embodiments, when xc1 in Formula 401 is 2 or greater, two A_{401} (s) of the at least two L_{401} (s) may optionally be linked via X_{407} as a linking group; and/or two A_{402}(s) may optionally be linked via X_4O_8 as a linking group (see Compounds PD1 to PD4 and PD7). X_{407} and X_{408} may each independently be selected from a single bond, *—O—*', *—S—*, *—C(=O)—*', *—$N(Q_{413})$—*, *—$C(Q_{413})(Q_{414})$—*', and *—$C(Q_{413})$=$C(Q_{414})$—*', wherein Q_{413} and Q_{414} 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, or a naphthyl group, but embodiments are not limited thereto.

[0279] L_{402} in Formula 401 may be any suitable monovalent, divalent, or trivalent organic ligand. For example, L_{402} may be selected from a halogen, a diketone (e.g., acetylacetonate), a carboxylic acid (e.g., picolinate), —C(=O), an isonitrile, —CN, and a phosphorus-based group (e.g., phosphine or phosphite), but embodiments are not limited thereto.

[0280] In some embodiments, the phosphorescent dopant may include, for example, at least one selected from Compounds PD1 to PD25, but embodiments are not limited thereto:

PD1



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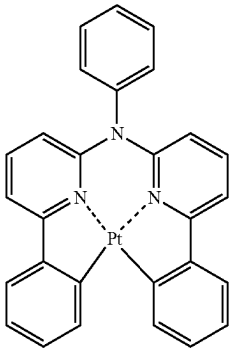
PD2



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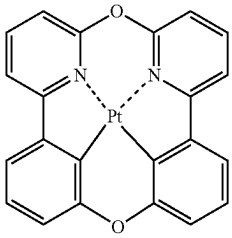

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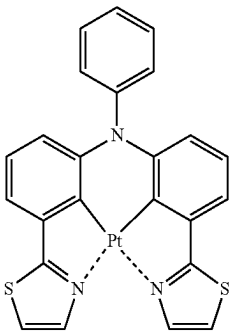

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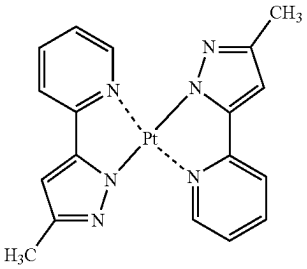

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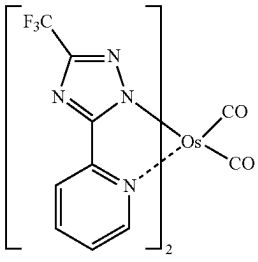

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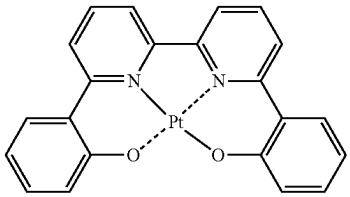

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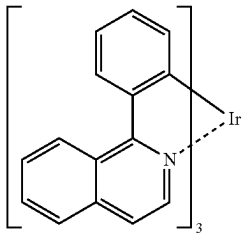

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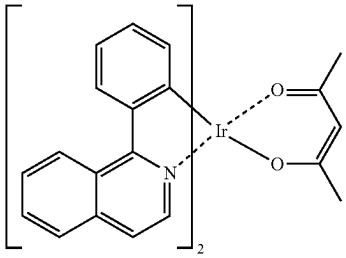

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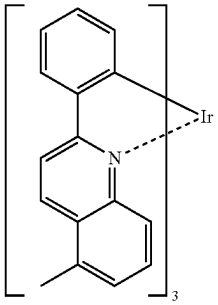

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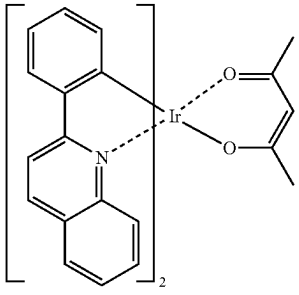

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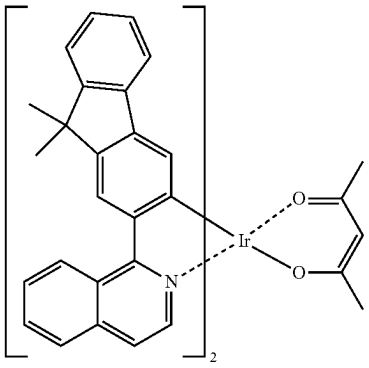

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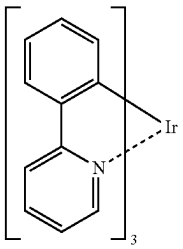

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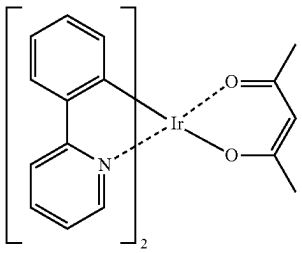

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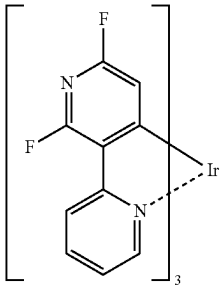

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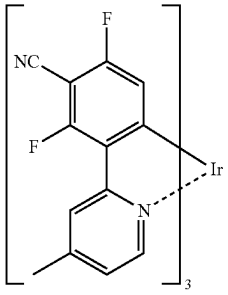

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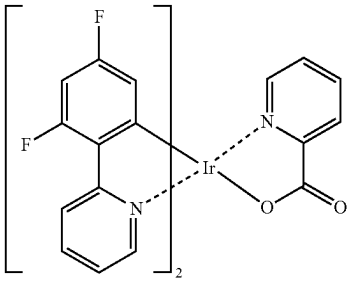

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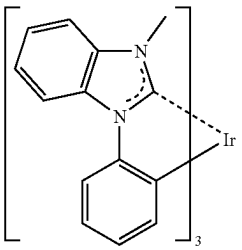

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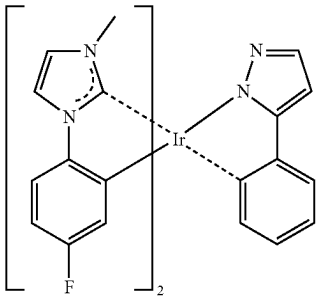

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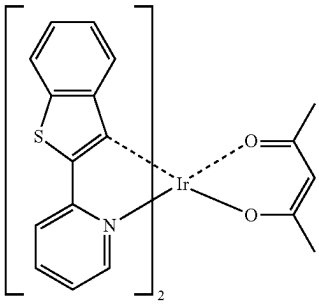

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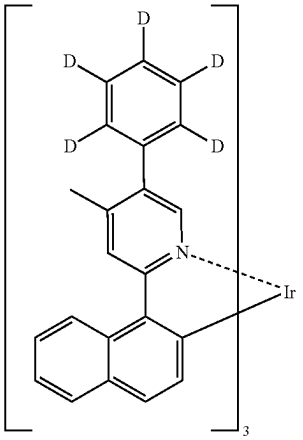

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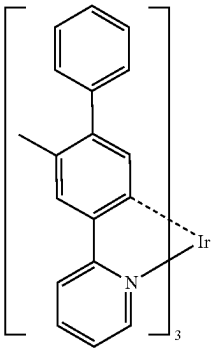

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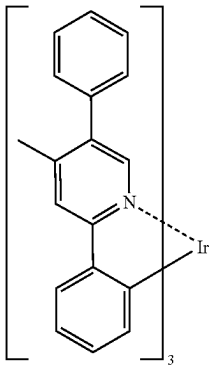

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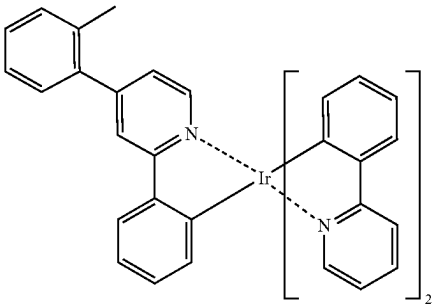

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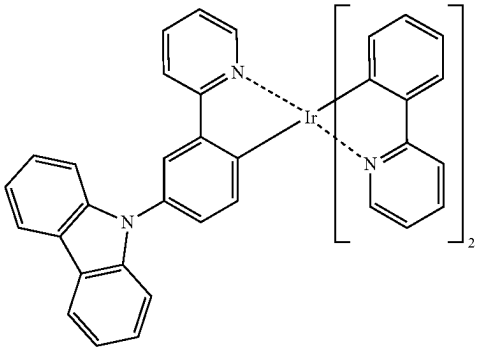
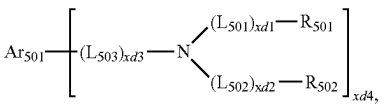


Fluorescent Dopant in Emission Layer

[0281] The fluorescent dopant may include an arylamine compound or a styrylamine compound.

[0282] In some embodiments, the fluorescent dopant may include a compound represented by Formula 501:

Formula 501



[0283] wherein, in Formula 501,

[0284] Ar_{501} may be selected from a substituted or unsubstituted C_5-C_{60} carbocyclic group and a substituted or unsubstituted C_1-C_{60} heterocyclic group,

[0285] L_{501} to L_{503} may each independently be selected from a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, a substituted or unsubstituted C_1-C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0286] xd1 to xd3 may each independently be an integer from 0 to 3,

[0287] R_{501} and R_{502} may each independently be selected from a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_1 heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, and

[0288] xd4 may be an integer from 1 to 6.

[0289] In some embodiments, in Formula 501, Ar_{501} may be selected from:

[0290] a naphthalene group, a heptalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, and an indenophenanthrene group; and

[0291] a naphthalene group, a heptalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, and an indenophenanthrene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0292] In an embodiment, in Formula 501, L_{501} and L_{503} may each independently be selected from:

[0293] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, and a pyridinylene group; and

[0294] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, and a pyridinylene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl 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 hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, and a pyridinyl group.

[0295] In an embodiment, in Formula 501, R_{501} and R_{502} may each independently be selected from:

[0296] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl 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 hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, and a pyridinyl group; and

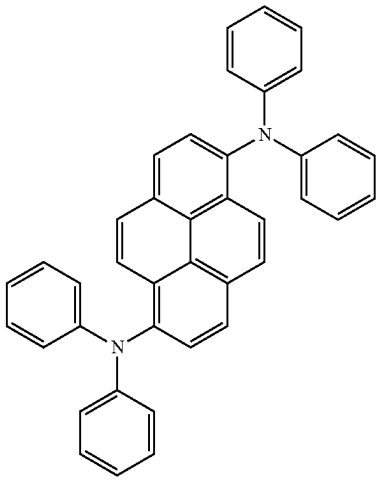
[0297] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spirobifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, and a pyridinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spirobifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl 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 hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, and —Si(Q_{31})(Q_{32})(Q_{33}),

[0298] wherein Q_{31} to Q_{33} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0299] In one or more embodiments, xd4 in Formula 501 may be 2, but embodiments are not limited thereto.

[0300] In some embodiments, the fluorescent dopant may be selected from Compounds FD1 to FD22:

FD1



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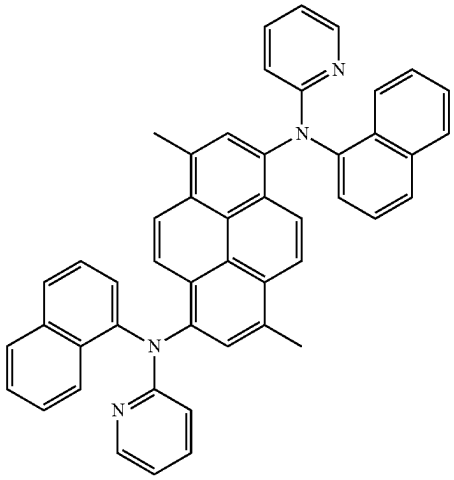
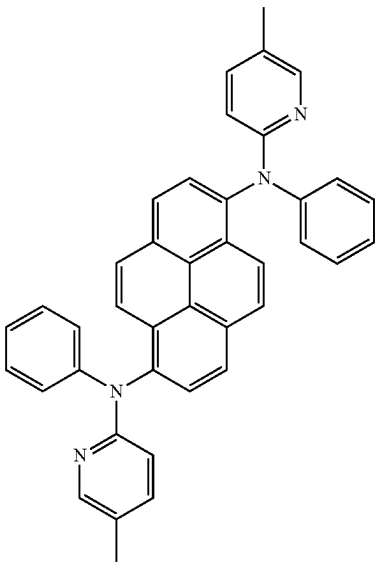
FD2



FD3



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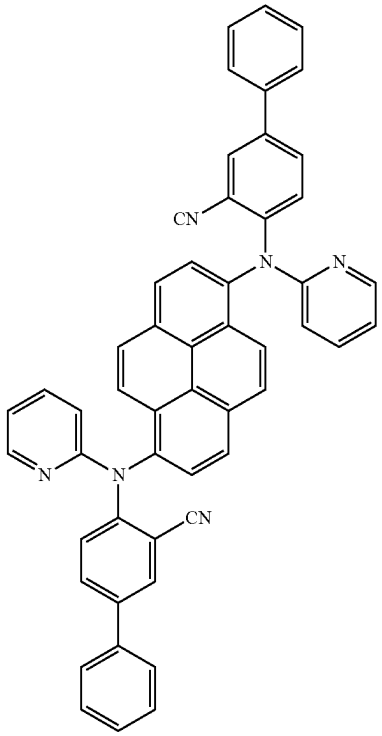
FD4



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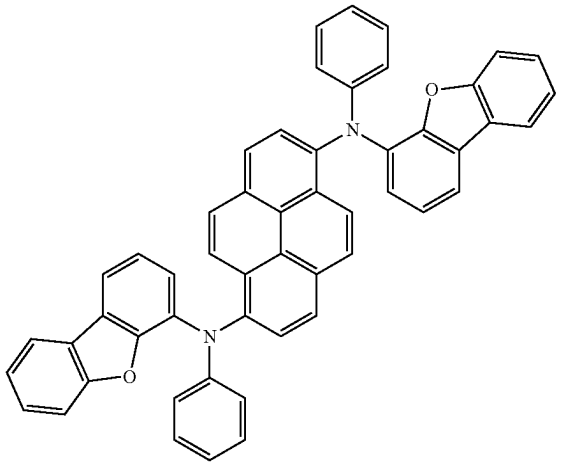

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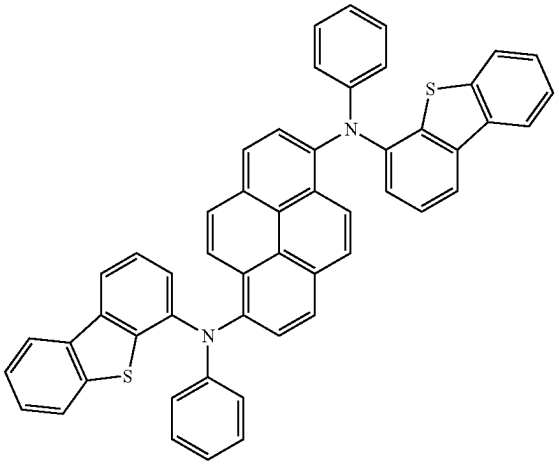
FD6



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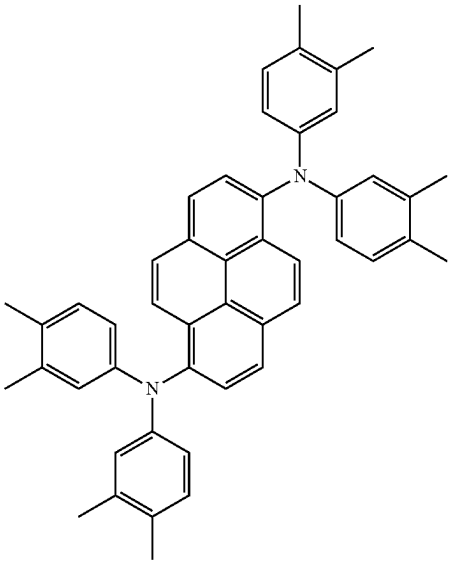

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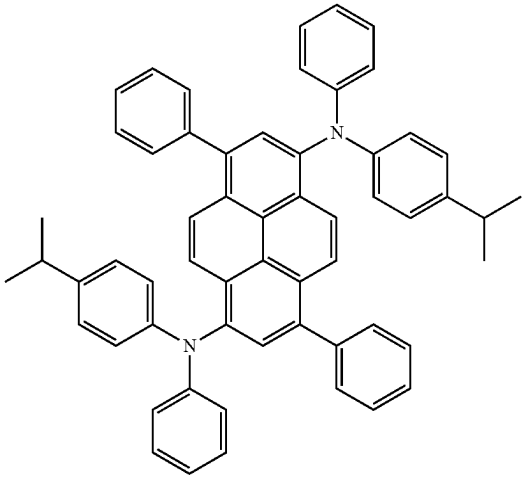

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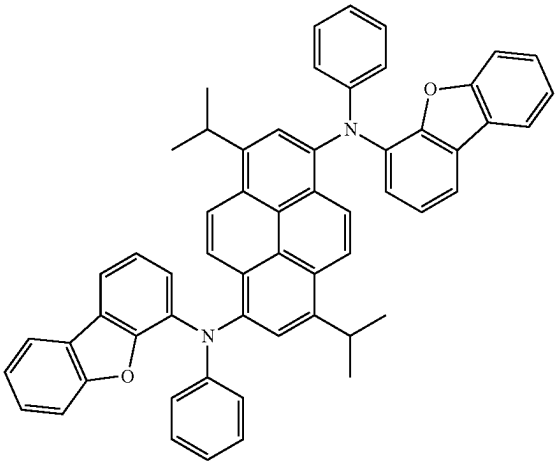

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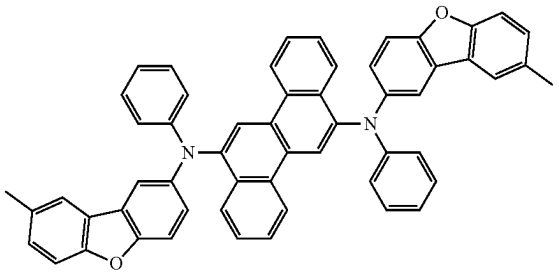

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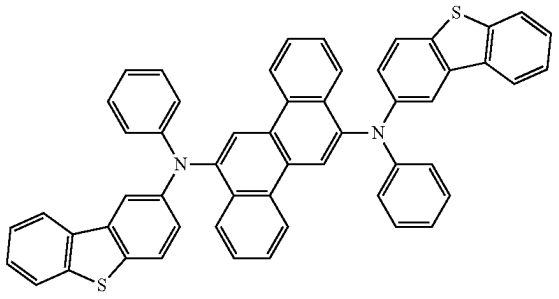

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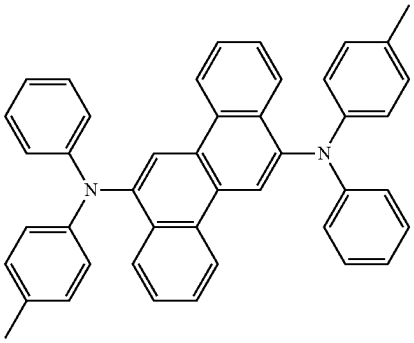

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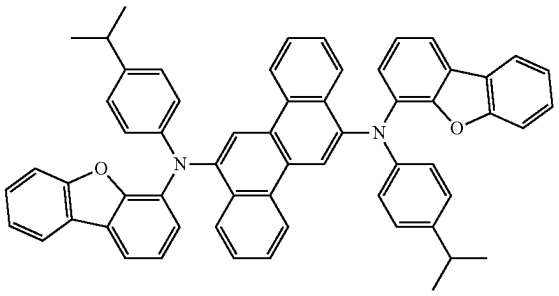
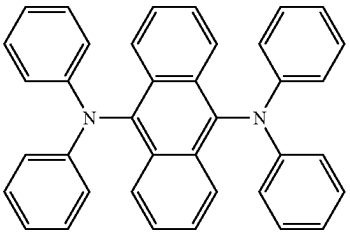
FD13



FD14



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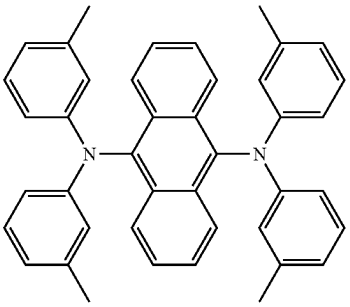

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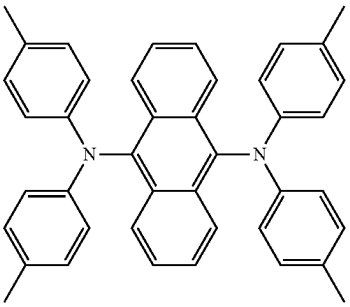

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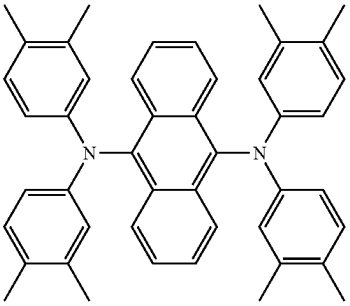

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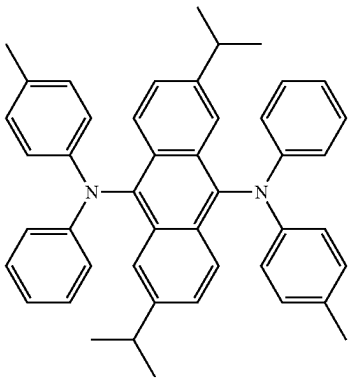

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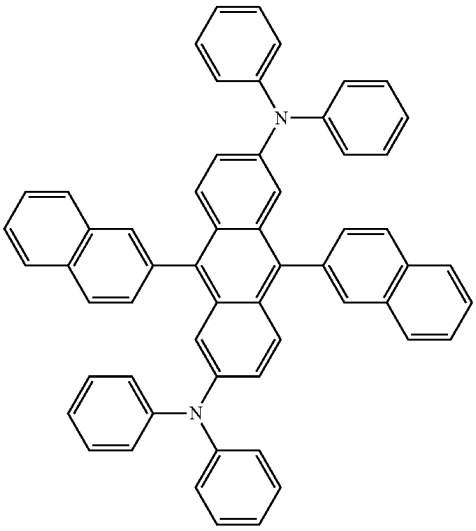

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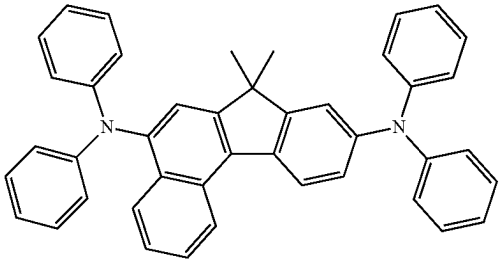

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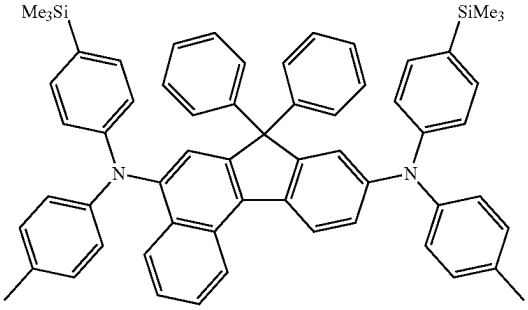

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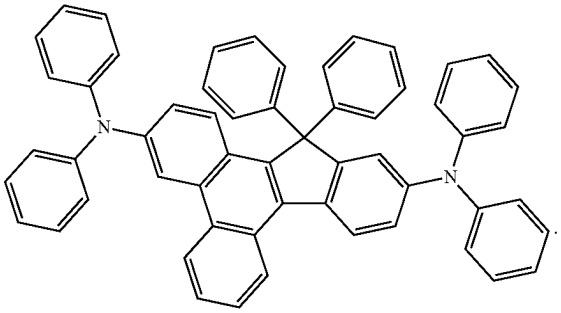
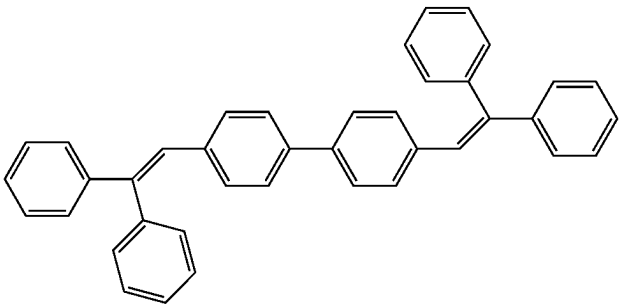


[0301] In some embodiments, the fluorescent dopant may be selected from the following compounds, but embodiments are not limited thereto:



DPVBi

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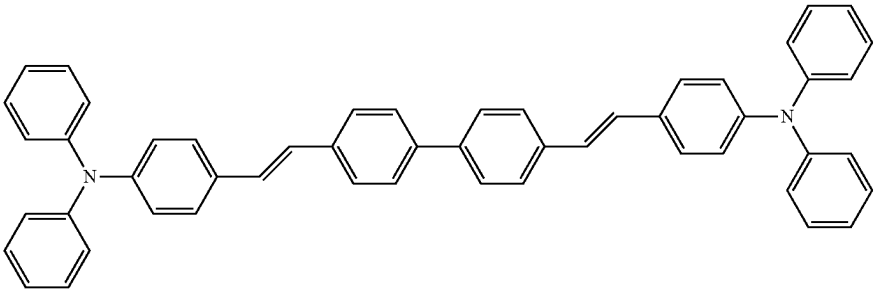
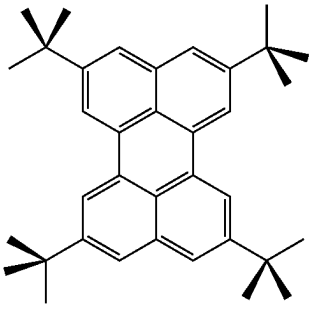
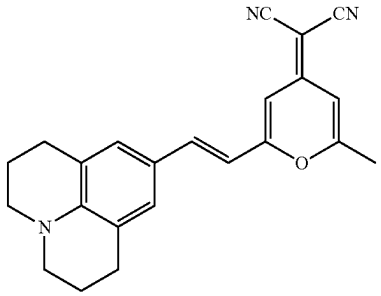


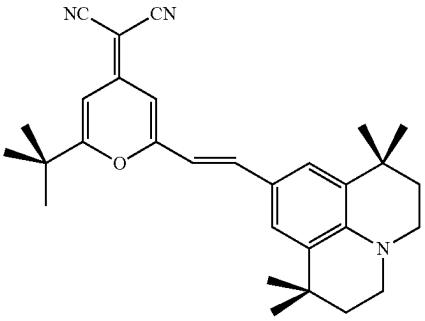
DPAVBi



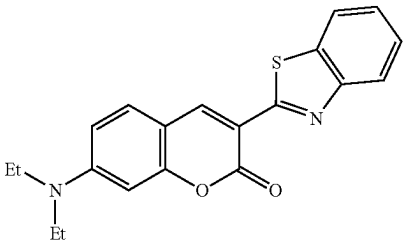
TBPe



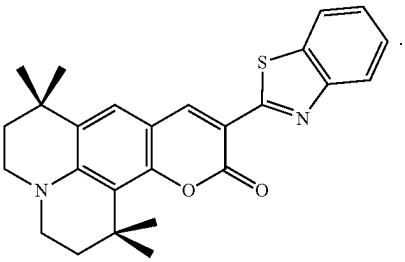
DCM



DCJTB



Coumarin 6



C545T

Electron Transport Region in Interlayer **150**

[0302] The electron transport region may have i) a single-layered structure including (e.g., consisting of) a single material, ii) a single-layered structure including a plurality of different materials, or iii) a multi-layered structure each having a plurality of layers, each having a plurality of different materials.

[0303] The electron transport region may include at least one selected from a buffer layer, a hole blocking layer, an electron control layer, an electron transport layer, and an electron injection layer, but embodiments are not limited thereto.

[0304] In some 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 constituting layers of each structure are sequentially stacked on the emission layer in each stated order, but embodiments are not limited thereto.

[0305] The electron transport region (for example, the buffer layer, the hole blocking layer, the electron control layer, or the electron transport layer in the electron transport

region) may include a metal-free compound including at least one π electron-depleted nitrogen-containing ring.

[0306] The term "π electron-depleted nitrogen-containing ring" as used herein refers to a C_1-C_{60} heterocyclic group having at least one *—N=*' moiety as a ring-forming moiety.

[0307] For example, the "π electron-depleted nitrogen-containing ring" may be i) a 5-membered to 7-membered heteromonocyclic group having at least one *—N=*' moiety, ii) a heteropolycyclic group in which at least two 5-membered to 7-membered heteromonocyclic groups, each having at least one *—N=*' moiety, are condensed, or iii) a heteropolycyclic group in which at least one of a 5-membered to 7-membered heteromonocyclic group, each having at least one *—N=*' moiety, is condensed with at least one C_5-C_{60} carbocyclic group.

[0308] Examples of the π electron-depleted nitrogen-containing ring include imidazole, pyrazole, thiazole, isothiazole, oxazole, isoxazole, pyridine, pyrazine, pyrimidine, pyridazine, indazole, purine, quinoline, isoquinoline, benzoquinoline, phthalazine, naphthyridine, quinoxaline, quinazoline, cinnoline, phenanthridine, acridine, phenanthroline, phenazine, benzimidazole, isobenzothiazole, benzoxazole, isobenzoxazole, triazole, tetrazole, oxadiazole, triazine, thiadiazole, imidazopyridine, imidazopyrimidine, and azacarbazole, but embodiments are not limited thereto.

[0309] In some embodiments, the electron transport region may include a compound represented by Formula 601:

$$[Ar_{601}]_{xe11}—[(L_{601})_{xe1}—R_{601}]_{xe21}, \quad \text{Formula 601}$$

[0310] wherein, in Formula 601,

[0311] Ar_{601} may be selected from a substituted or unsubstituted C_5-C_{60} carbocyclic group and a substituted or unsubstituted C_1-C_{60} heterocyclic group,

[0312] xe11 may be 1, 2, or 3,

[0313] L_{601} may be selected from a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, a substituted or unsubstituted C_1-C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0314] xe1 may be an integer from 0 to 5,

[0315] R_{601} may be selected from a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, $—Si(Q_{601})(Q_{602})(Q_{603})$, $—C(=O)(Q_{601})$, $—S(=O)_2(Q_{601})$, and $—P(=O)(Q_{601})(Q_{602})$,

[0316] wherein Q_{601} to Q_{603} may each independently be a C_1-C_1 alkyl group, a C_1-C_1 alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, or a naphthyl group, and

[0317] xe21 may be an integer from 1 to 5.

[0318] In some embodiments, at least one selected from the xe11 Ar_{601}(s) and the xe21 R_{601}(s) (i.e., Ar_{601}(s) in the number of xe11 and R_{601}(s) in the number of xe21) may include the π electron-depleted nitrogen-containing ring.

[0319] In some embodiments, in Formula 601, ring Ar_{601} may be selected from:

[0320] a benzene group, a naphthalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, a dibenzofuran group, a dibenzothiophene group, a carbazole group, an imidazole group, a pyrazole group, a thiazole group, an isothiazole group, an oxazole group, an isoxazole group, a pyridine group, a pyrazine group, a pyrimidine group, a pyridazine group, an indazole group, a purine group, a quinoline group, an isoquinoline group, a benzoquinoline group, a phthalazine group, a naphthyridine group, a quinoxaline group, a quinazoline group, a cinnoline group, a phenanthridine group, an acridine group, a phenanthroline group, a phenazine group, a benzimidazole group, an isobenzothiazole group, a benzoxazole group, an isobenzoxazole group, a triazole group, a tetrazole group, an oxadiazole group, a triazine group, a thiadiazole group, an imidazopyridine group, an imidazopyrimidine group, and an azacarbazole group; and

[0321] a benzene group, a naphthalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, a dibenzofuran group, a dibenzothiophene group, a carbazole group, an imidazole group, a pyrazole group, a thiazole group, an isothiazole group, an oxazole group, an isoxazole group, a pyridine group, a pyrazine group, a pyrimidine group, a pyridazine group, an indazole group, a purine group, a quinoline group, an isoquinoline group, a benzoquinoline group, a phthalazine group, a naphthyridine group, a quinoxaline group, a quinazoline group, a cinnoline group, a phenanthridine group, an acridine group, a phenanthroline group, a phenazine group, a benzimidazole group, an isobenzothiazole group, a benzoxazole group, an isobenzoxazole group, a triazole group, a tetrazole group, an oxadiazole group, a triazine group, a thiadiazole group, an imidazopyridine group, an imidazopyrimidine group, and an azacarbazole group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group,

a terphenyl group, a naphthyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$,

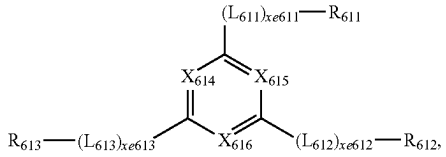
[0322] wherein Q_{31} to Q_{33} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0323] When xe11 in Formula 601 is 2 or greater, at least two Ar_{601}(s) may be bound via a single bond.

[0324] In one or more embodiments, Ar_{601} in Formula 601 may be an anthracene group.

[0325] In some embodiments, the compound represented by Formula 601 may be represented by Formula 601-1:

Formula 601-1



[0326] wherein, in Formula 601-1,

[0327] X_{614} may be N or $C(R_{614})$, X_{615} may be N or $C(R_{615})$, X_{616} may be N or $C(R_{616})$, at least one selected from X_{614} to X_{616} may be N,

[0328] L_{611} to L_{613} may each independently be the same as described in connection with L_{601},

[0329] xe611 to xe613 may each independently be the same as described in connection with xe1,

[0330] R_{611} to R_{613} may each independently be the same as described in connection with R_{601}, and

[0331] R_{614} to R_{616} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0332] In some embodiments, in Formulae 601 and 601-1, L_{601} and L_{611} to L_{613} may each independently be selected from:

[0333] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, a pyridinylene group, an imidazolylene group, a pyrazolylene group, a thiazolylene group, an isothiazolylene group, an oxazolylene group, an isoxazolylene group, a thiadiazolylene group, an oxadiazolylene group, a pyrazinylene group, a pyrimidinylene group, a pyridazinylene group, a triazinylene group, a quinolinylene group, an isoquinolinylene group, a benzoquinolinylene group, a phthalazinylene group, a naphthyridinylene group, a quinoxalinylene group, a quinazolinylene group, a cinnolinylene group, a phenanthridinylene group, an acridinylene group, a phenanthrolinylene group, a phenazinylene group, a benzimidazolylene group, an isobenzothiazolylene group, a benzoxazolylene group, an isobenzoxazolylene group, a triazolylene group, a tetrazolylene group, an imidazopyridinylene group, an imidazopyrimidinylene group, and an azacarbazolylene group; and

[0334] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, a pyridinylene group, an imidazolylene group, a pyrazolylene group, a thiazolylene group, an isothiazolylene group, an oxazolylene group, an isoxazolylene group, a thiadiazolylene group, an oxadiazolylene group, a pyrazinylene group, a pyrimidinylene group, a pyridazinylene group, a triazinylene group, a quinolinylene group, an isoquinolinylene group, a benzoquinolinylene group, a phthalazinylene group, a naphthyridinylene group, a quinoxalinylene group, a quinazolinylene group, a cinnolinylene group, a phenanthridinylene group, an acridinylene group, a phenanthrolinylene group, a phenazinylene group, a benzimidazolylene group, an isobenzothiazolylene group, a benzoxazolylene group, an isobenzoxazolylene group, a triazolylene group, a tetrazolylene group, an imidazopyridinylene group, an imidazopyrimidinylene group, and an azacarbazolylene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl 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 hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a

quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group,

[0335] but embodiments are not limited thereto.

[0336] In one or more embodiments, in Formulae 601 and 601-1, xe1 and xe611 to xe613 may each independently be 0, 1, or 2.

[0337] In one or more embodiments, in Formulae 601 and 601-1, R_{601} and R_{611} to R_{613} may each independently be selected from:

[0338] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl 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 hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group;

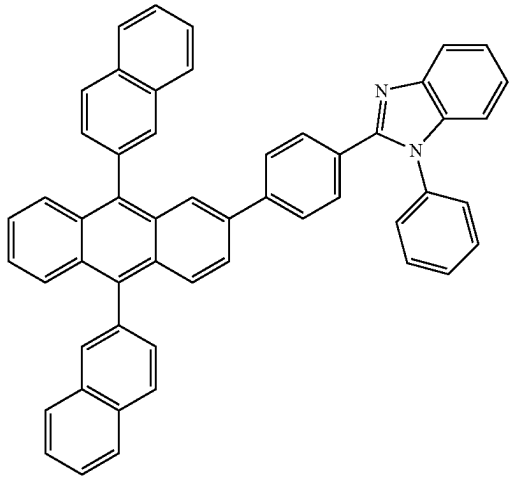
[0339] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl 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 hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group; and

[0340] —$S(=O)_2(Q_{601})$ and —$P(=O)(Q_{601})(Q_{602})$,

[0341] wherein Q_{601} and Q_{602} may each independently be the same as described above.

[0342] The electron transport region may include at least one compound selected from Compounds ET1 to ET36, but embodiments are not limited thereto:

ET1



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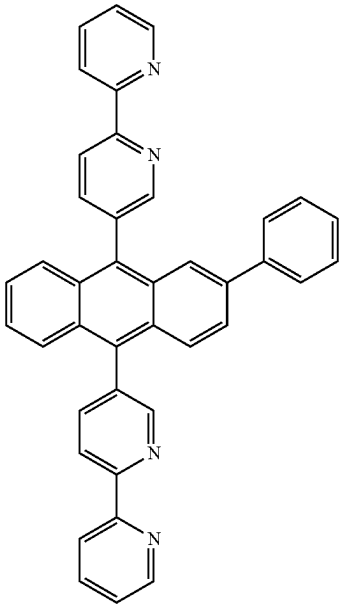
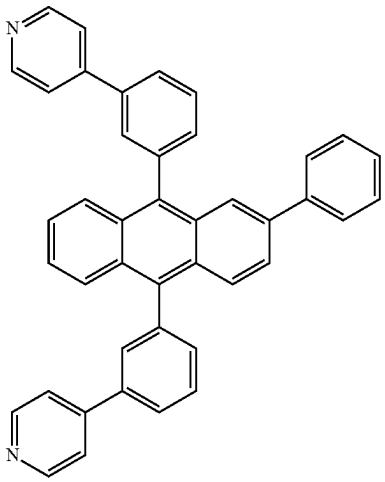
ET2



ET3



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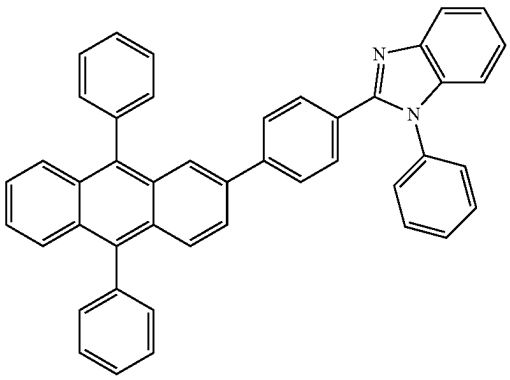

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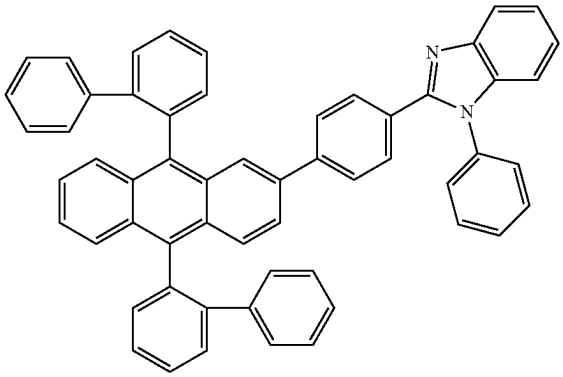
ET5



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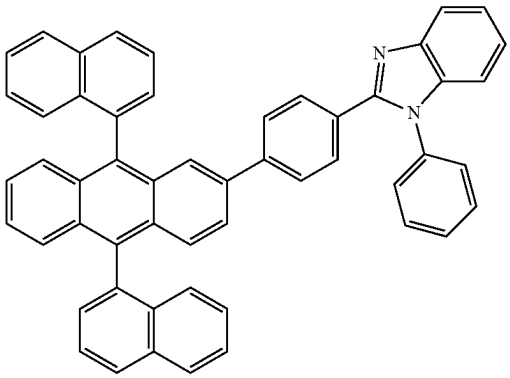

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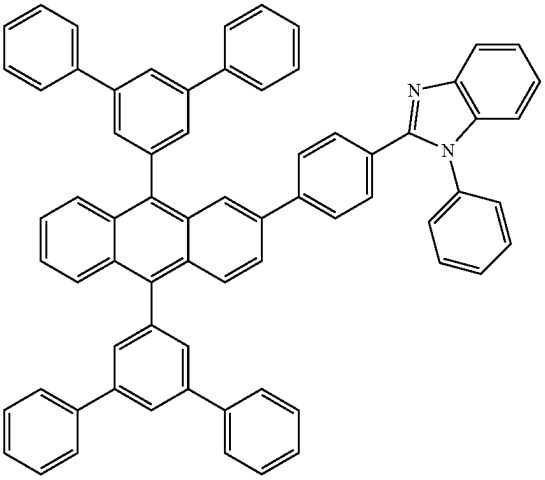

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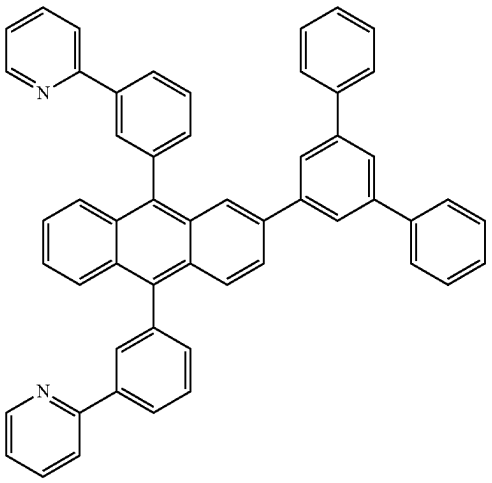

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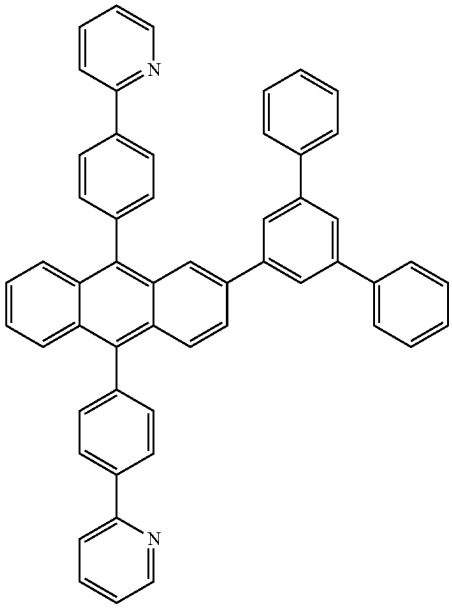

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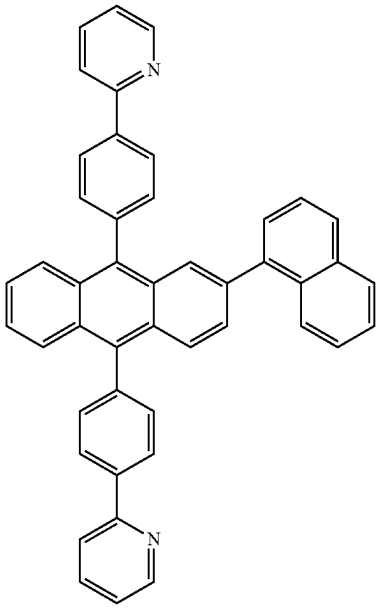

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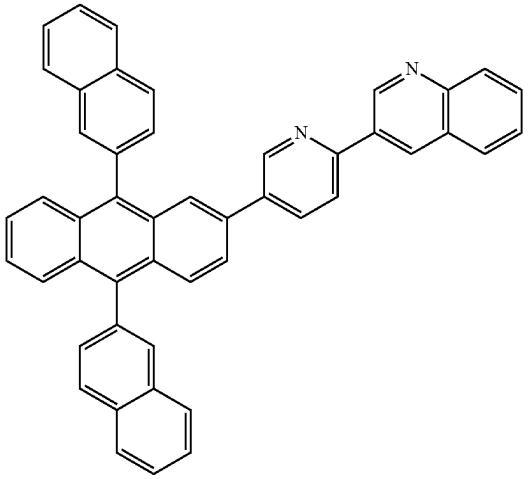

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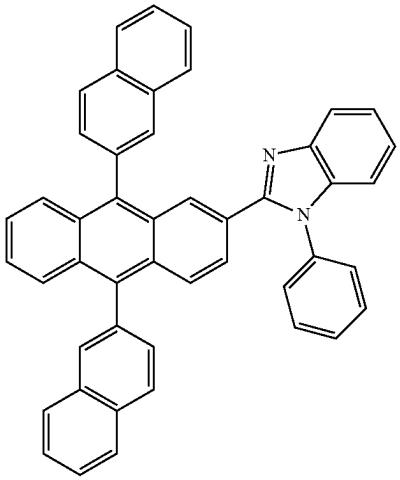

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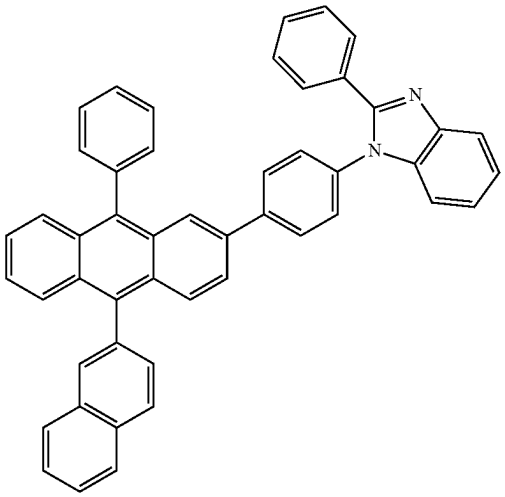

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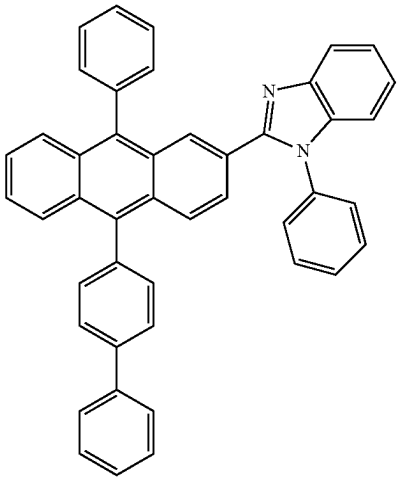

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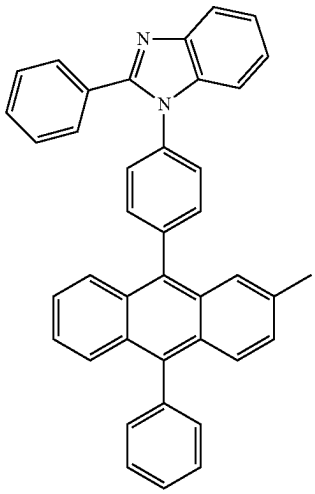

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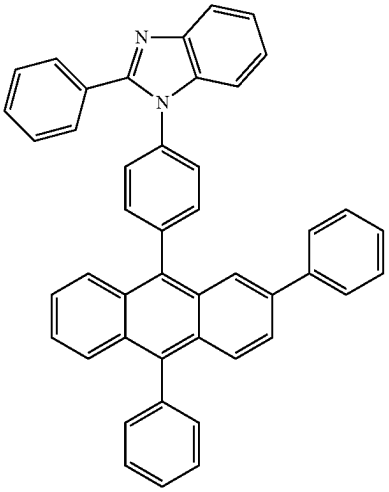

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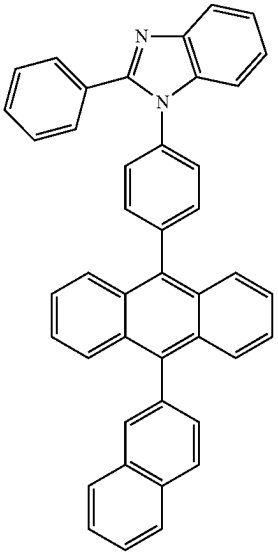

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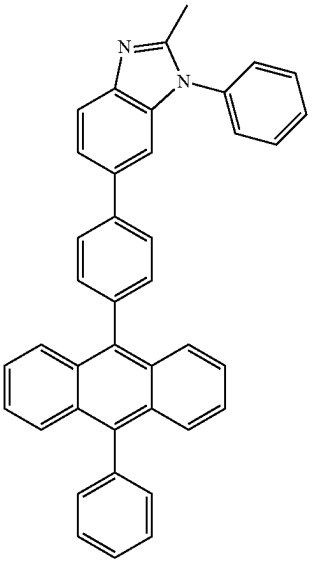

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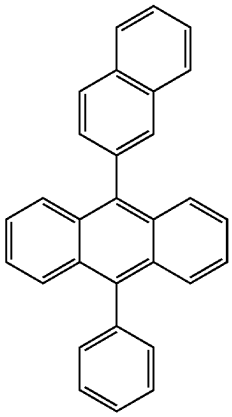

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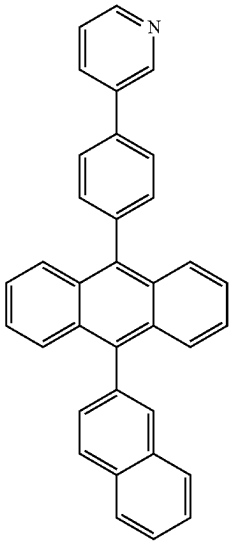

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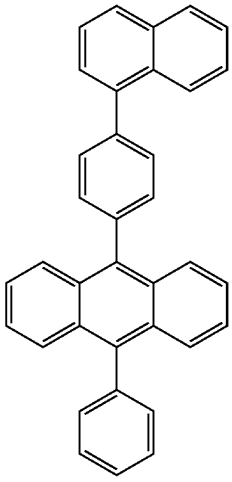

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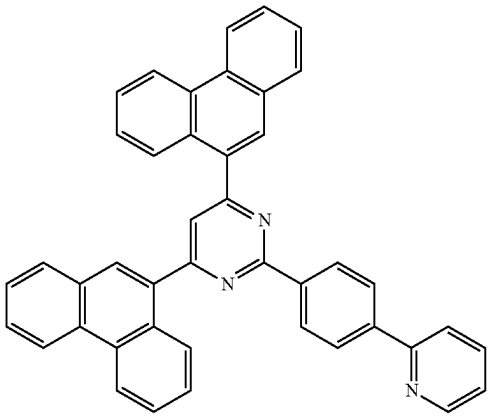

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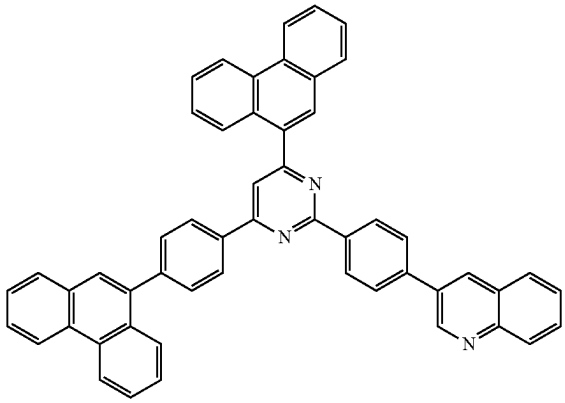

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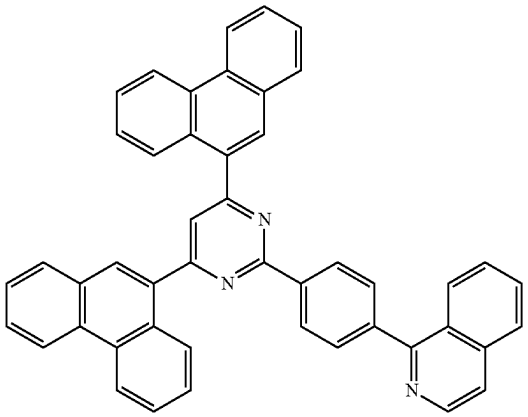

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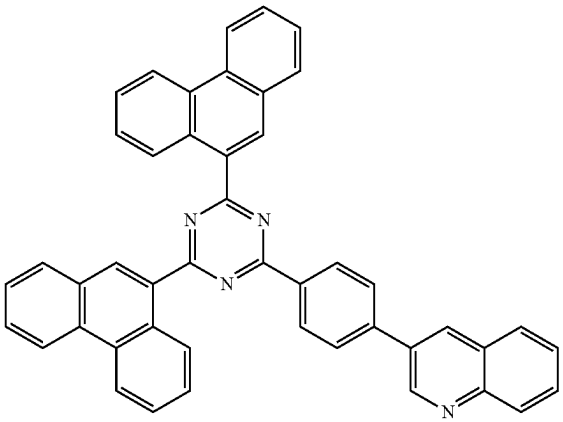

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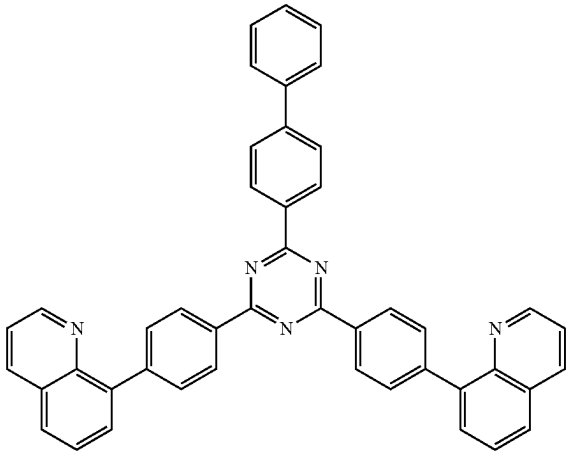

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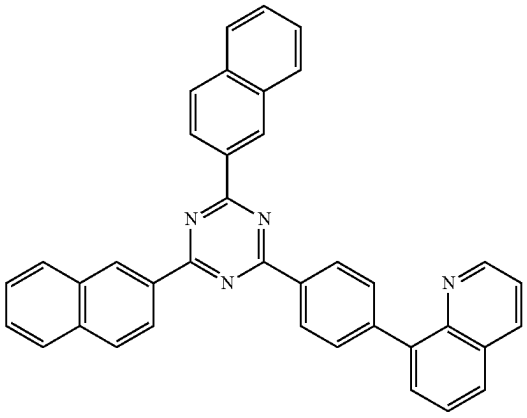

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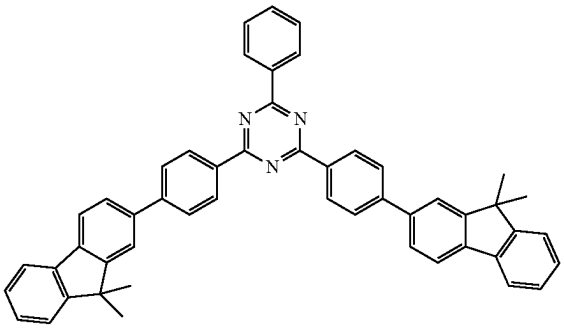

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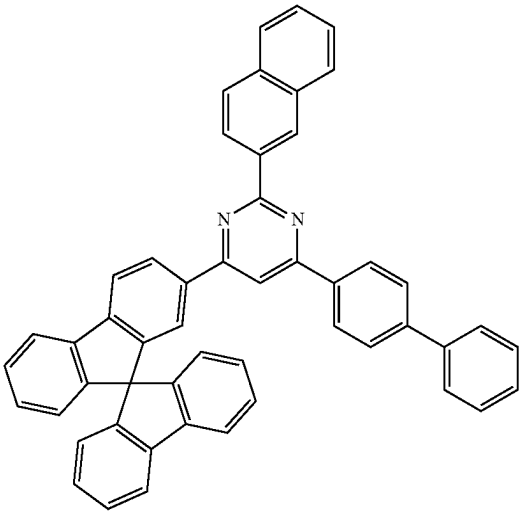

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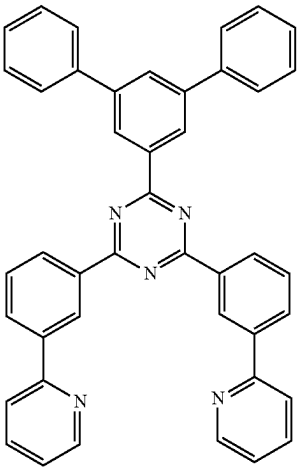

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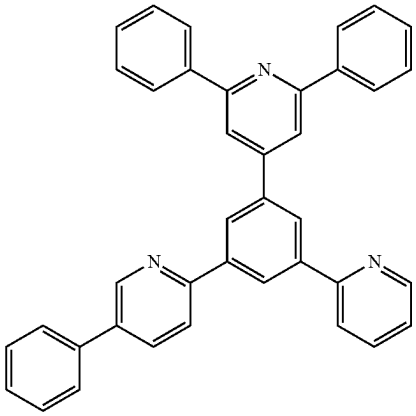

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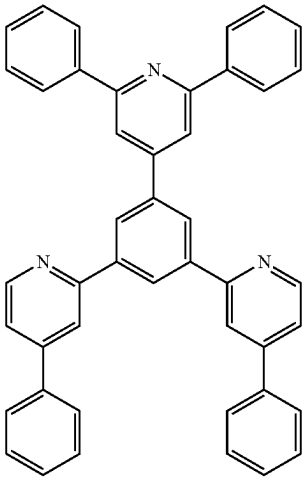

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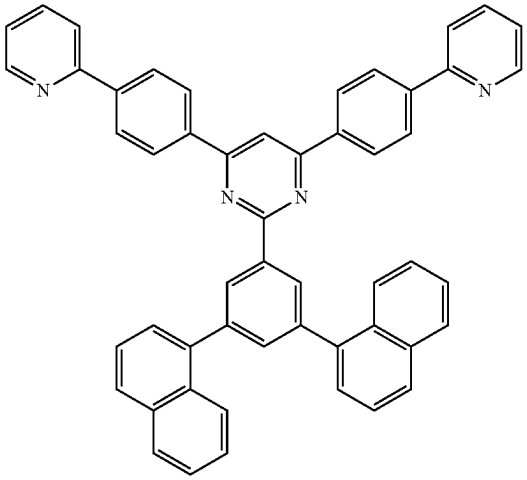

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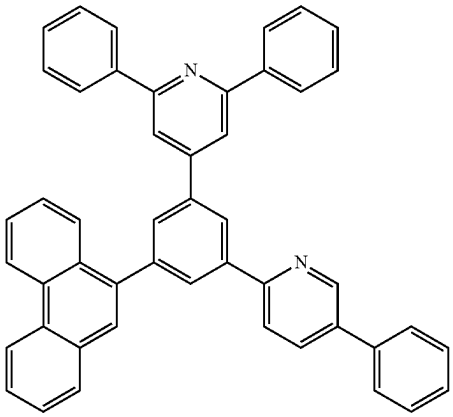
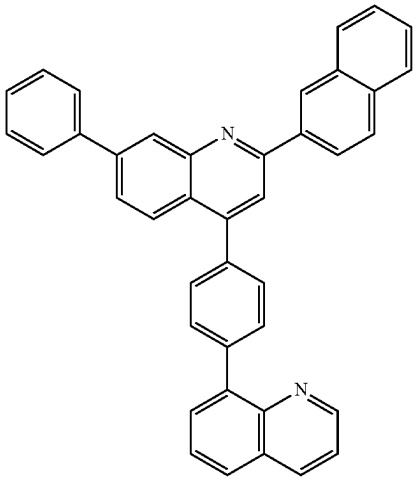
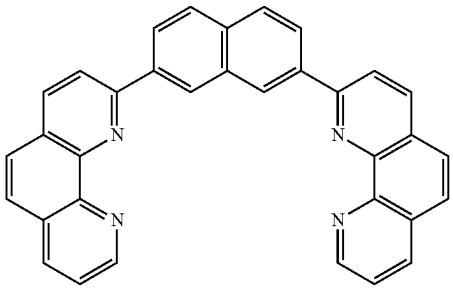
ET34



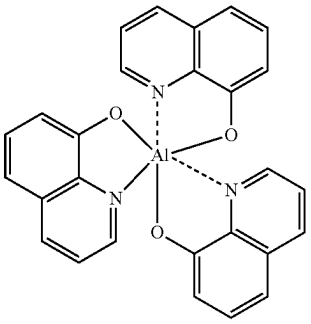
ET35



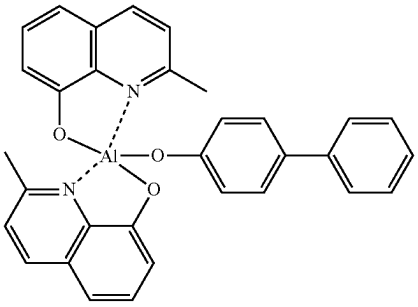
ET36



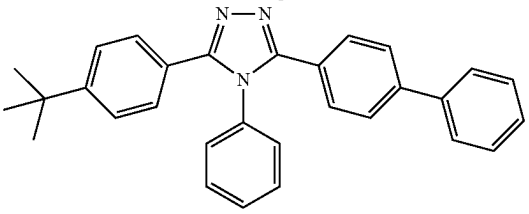
[0343] In some embodiments, the electron transport region may include at least one compound selected from 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP), 4,7-diphenyl-1,10-phenanthroline (Bphen), Alq_3, BAlq, 3-(biphenyl-4-yl)-5-(4-tert-butylphenyl)-4-phenyl-4H-1,2,4-triazole (TAZ), and NTAZ:



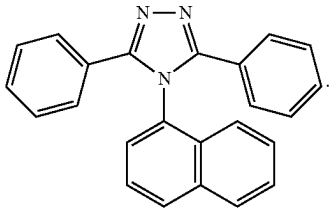
Alq_3



BAlq



TAZ



NTAZ

[0344] The thicknesses of the buffer layer, the hole blocking layer, and/or the electron control layer may each independently be about 20 Å to about 1,000 Å, and in some embodiments, about 30 Å to about 300 Å. When the thicknesses of the buffer layer, the hole blocking layer, and/or the electron control layer are within any of these ranges, excellent hole blocking characteristics or excellent electron controlling characteristics may be obtained without a substantial increase in driving voltage.

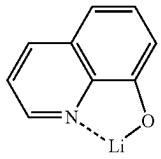
[0345] The thickness of the electron transport layer may be about 100 Å to about 1,000 Å, and in some embodiments, about 150 Å to about 500 Å. When the thickness of the electron transport layer is within any of these ranges, excellent electron transport characteristics may be obtained without a substantial increase in driving voltage.

[0346] The electron transport region (for example, the electron transport layer in the electron transport region) may further include, in addition to the materials described above, a metal-containing material.

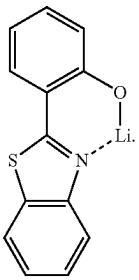
[0347] The metal-containing material may include at least one selected from an alkali metal complex and an alkaline earth metal complex. The alkali metal complex may include a metal ion selected from a lithium (Li) ion, a sodium (Na) ion, a potassium (K) ion, a rubidium (Rb) ion, and a cesium (Cs) ion. The alkaline earth metal complex may include a metal ion selected from a beryllium (Be) ion, a magnesium (Mg) ion, a calcium (Ca) ion, a strontium (Sr) ion, and a barium (Ba) ion. Each ligand coordinated with the metal ion of the alkali metal complex and the alkaline earth metal complex may independently be selected from hydroxyquinoline, hydroxyisoquinoline, hydroxybenzoquinoline, hydroxyacridine, hydroxyphenanthridine, hydroxyphenyloxazole, hydroxyphenylthiazole, hydroxyphenyloxadiazole, hydroxyphenylthiadiazole, hydroxyphenylpyridine, hydroxyphenylbenzimidazole, hydroxyphenylbenzothiazole, bipyridine, phenanthroline, and cyclopentadiene, but embodiments are not limited thereto.

[0348] For example, the metal-containing material may include a Li complex. The Li complex may include, e.g., Compound ET-D1 (LiQ) or Compound ET-D2:

ET-D1



ET-D2



[0349] The electron transport region may include an electron injection layer that facilitates injection of electrons from the second electrode **190**. The electron injection layer may be in direct contact with the second electrode **190**.

[0350] The electron injection layer may have i) a single-layered structure including (e.g., consisting of) a single material, ii) a single-layered structure including a plurality of different materials, or iii) a multi-layered structure having a plurality of layers, each including a plurality of different materials.

[0351] The electron injection layer may include an alkali metal, an alkaline earth metal, a rare earth metal, an alkali metal compound, an alkaline earth metal compound, a rare earth metal compound, an alkali metal complex, an alkaline earth metal complex, a rare earth metal complex, or a combination thereof.

[0352] The alkali metal may be selected from lithium (Li), sodium (Na), potassium (K), rubidium (Rb), and cesium

(Cs). In some embodiments, the alkali metal may be Li, Na, or Cs. In one or more embodiments, the alkali metal may be Li or Cs, but embodiments are not limited thereto.

[0353] The alkaline earth metal may be selected from magnesium (Mg), calcium (Ca), strontium (Sr), and barium (Ba).

[0354] The rare earth metal may be selected from scandium (Sc), yttrium (Y), cerium (Ce), terbium (Tb), ytterbium (Yb), and gadolinium (Gd).

[0355] The alkali metal compound, the alkaline earth metal compound, and the rare earth metal compound may each independently be selected from oxides and halides (e.g., fluorides, chlorides, bromides, and/or iodines) of the alkali metal, the alkaline earth metal, and the rare earth metal, respectively.

[0356] The alkali metal compound may be selected from alkali metal oxides (such as Li_2O, Cs_2O, and/or K_2O), and alkali metal halides (such as LiF, NaF, CsF, KF, LiI, NaI, CsI, and/or KI). In some embodiments, the alkali metal compound may be selected from LiF, Li_2O, NaF, LiI, NaI, CsI, and KI, but embodiments are not limited thereto.

[0357] The alkaline earth-metal compound may be selected from alkaline earth-metal compounds (such as BaO, SrO, CaO, $Ba_xSr_{1-x}O$ (wherein $0<x<1$), and/or $Ba_xCa_{1-x}O$ (wherein $0<x<1$)). In some embodiments, the alkaline earth metal compound may be selected from BaO, SrO, and CaO, but embodiments are not limited thereto.

[0358] The rare earth metal compound may be selected from YbF_3, ScF_3, ScO_3, Y_2O_3, Ce_2O_3, GdF_3, and TbF_3. In some embodiments, the rare earth metal compound may be selected from YbF_3, ScF_3, TbF_3, YbI_3, ScI_3, and TbI_3, but embodiments are not limited thereto.

[0359] The alkali metal complex, the alkaline earth metal complex, and the rare earth metal complex may respectively include an ion of the above-described alkali metal, alkaline earth metal, and rare earth metal. Each ligand coordinated with the metal ion of the alkali metal complex, the alkaline earth metal complex, and the rare earth metal complex may independently be selected from hydroxyquinoline, hydroxyisoquinoline, hydroxybenzoquinoline, hydroxyacridine, hydroxyphenanthridine, hydroxyphenyloxazole, hydroxyphenylthiazole, hydroxyphenyloxadiazole, hydroxyphenylthiadiazole, hydroxyphenylpyridine, hydroxyphenylbenzimidazole, hydroxyphenylbenzothiazole, bipyridine, phenanthroline, and cyclopentadiene, but embodiments are not limited thereto.

[0360] The electron injection layer may include (e.g., consist of) an alkali metal, an alkaline earth metal, a rare earth metal, an alkali metal compound, an alkaline earth metal compound, a rare earth metal compound, an alkali metal complex, an alkaline earth metal complex, a rare earth metal complex, or any combination thereof, as described above. In some embodiments, the electron injection layer may further include an organic material. When the electron injection layer further includes an organic material, the alkali metal, the alkaline earth metal, the rare earth metal, the alkali metal compound, the alkaline earth metal compound, the rare earth metal compound, the alkali metal complex, the alkaline earth metal complex, the rare earth metal complex, or a combination thereof may be substantially homogeneously or non-homogeneously dispersed in a matrix including the organic material.

[0361] The thickness of the electron injection layer may be about 1 Å to about 100 Å, and in some embodiments, about 3 Å to about 90 Å. When the thickness of the electron injection layer is within any of these ranges, excellent electron injection characteristics may be obtained without a substantial increase in driving voltage.

Second Electrode **190**

[0362] The second electrode **190** may be on the interlayer **150**. In an embodiment, the second electrode **190** may be a cathode, which is an electron injection electrode. In this embodiment, a material for forming the second electrode **190** may be a material having a low work function, for example, a metal, an alloy, an electrically conductive compound, or a combination thereof.

[0363] The second electrode **190** may include at least one selected from lithium (Li), silver (Ag), magnesium (Mg), aluminum (Al), aluminum-lithium (Al—Li), calcium (Ca), magnesium-indium (Mg—In), magnesium-silver (Mg—Ag), ITO, and IZO, but embodiments are not limited thereto. The second electrode **190** may be a transmissive electrode, a semi-transmissive electrode, or a reflective electrode.

[0364] The second electrode **190** may have a single-layered structure, or a multi-layered structure including two or more layers.

Description of FIGS. **2** to **4**

[0365] As shown in FIG. **2**, a light-emitting device **20** has structure including a first capping layer **210**, the first electrode **110**, the interlayer **150**, and the second electrode **190**, wherein the layers are sequentially stacked in this stated order. As shown in FIG. **3**, a light-emitting device **30** has the first electrode **110**, the interlayer **150**, the second electrode **190**, and a second capping layer **220** structure, wherein the layers are sequentially stacked in this stated order. As shown in FIG. **4**, a light-emitting device **40** has the first capping layer **210**, the first electrode **110**, the interlayer **150**, the second electrode **190**, and the second capping layer **220** structure, wherein the layers are sequentially stacked in this stated order.

[0366] The first electrode **110**, the interlayer **150**, and the second electrode **190** illustrated in FIGS. **2** to **4** may respectively be understood by referring to the descriptions of the first electrode **110**, the interlayer **150**, and the second electrode **190** illustrated in FIG. **1**.

[0367] In the light-emitting devices **20** and **40**, light emitted from the emission layer in the interlayer **150** may pass through the first electrode **110** (which may be a semi-transmissive electrode or a transmissive electrode) and through the first capping layer **210** to the outside. In the light-emitting devices **30** and **40**, light emitted from the emission layer in the interlayer **150** may pass through the second electrode **190** (which may be a semi-transmissive electrode or a transmissive electrode) and through the second capping layer **220** to the outside.

[0368] The first capping layer **210** and the second capping layer **220** may improve the external luminescence efficiency based on the principle of constructive interference.

[0369] The first capping layer **210** and the second capping layer **220** may each independently be a capping layer including an organic material, an inorganic capping layer including an inorganic material, or a composite capping layer including an organic material and an inorganic material.

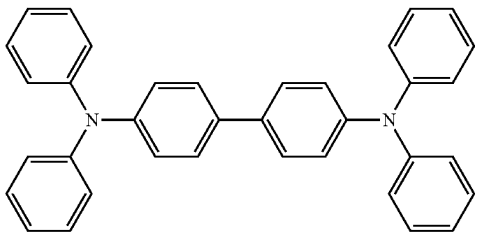
[0370] At least one of the first capping layer **210** and the second capping layer **220** may each independently include at least one material selected from carbocyclic compounds, heterocyclic compounds, amine-based compounds, porphyrin derivatives, phthalocyanine derivatives, naphthalocyanine derivatives, alkali metal complexes, and alkaline earth metal complexes. The carbocyclic compound, the heterocyclic compound, and the amine group-containing compound may optionally be substituted with a substituent containing at least one element selected from O, N, S, Se, Si, F, Cl, Br, and I.

[0371] In some embodiments, at least one of the first capping layer **210** and the second capping layer **220** may each independently include an amine-based compound.

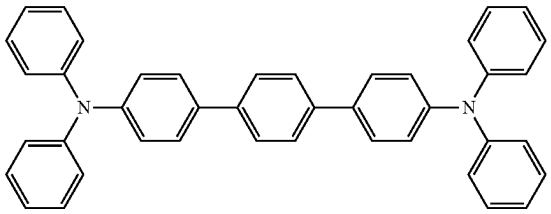
[0372] In one or more embodiments, at least one of the first capping layer **210** and the second capping layer **220** may each independently include a compound represented by Formula 201 or a compound represented by **202**.

[0373] In one or more embodiments, at least one of the first capping layer **210** and the second capping layer **220** may each independently include a compound selected from Compounds HT28 to HT33 and Compound CP1 to CP5, but embodiments are not limited thereto:

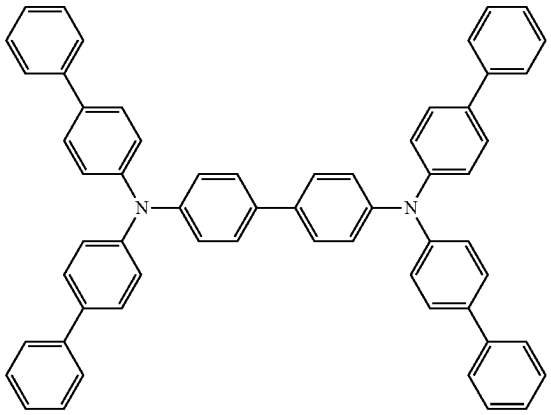
CP1



CP2

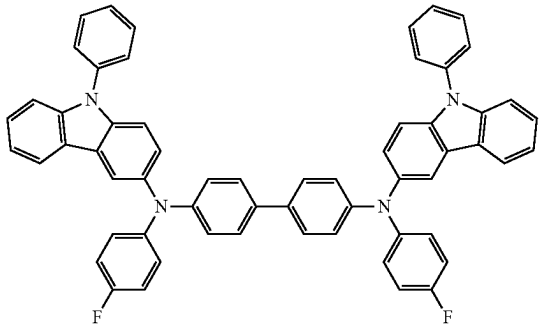


CP3

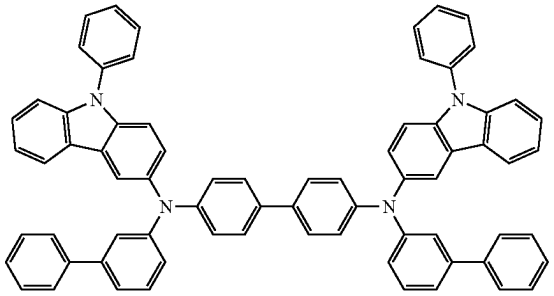


-continued

CP4



CP5



[0374] Hereinbefore, the light-emitting devices have been described with reference to FIGS. **1** to **4**, but embodiments are not limited thereto.

[0375] The layers constituting the hole transport region, the emission layer, and the layers constituting the electron transport region may each be formed in a set or predetermined region using one or more suitable methods (such as vacuum deposition, spin coating, casting, Langmuir-Blodgett (LB) deposition, ink-jet printing, laser printing, and/or laser-induced thermal imaging).

[0376] When the layers constituting the hole transport region, the emission layer, and the layers constituting the electron transport region are each formed by vacuum deposition, the vacuum deposition may be performed at a deposition temperature of about 100° C. to about 500° C., at a vacuum degree of about 10^{-8} torr to about 10^{-3} torr, and at a deposition rate of about 0.01 Angstroms per second (Å/sec) to about 100 Å/see, depending on the material to be included and the structure of each layer to be formed.

[0377] When the layers constituting the hole transport region, the emission layer, and the layers constituting the electron transport region are each formed by spin coating, the spin coating may be performed at a coating rate of about 2,000 revolutions per minute (rpm) to about 5,000 rpm and at a heat treatment temperature of about 80° C. to about 200° C., depending on the material to be included and the structure of each layer to be formed.

Apparatus

[0378] The light-emitting device described above may be applied to or integrated within various devices.

[0379] Accordingly, according to one or more embodiments, a device (apparatus) may include the above-described light-emitting device.

[0380] For example, the apparatus may be a light-emitting apparatus, an authentication apparatus, or an electronic apparatus, but embodiments are not limited thereto.

[0381] The emission apparatus may be used in any suitable display, light source, and/or the like.

[0382] The authentication apparatus may be, for example, a biometric authentication apparatus that identifies an individual according their biometric information (e.g., a fingertip, a pupil, or the like).

[0383] The authentication apparatus may further include a biometric information collecting unit, in addition to the light-emitting device described above.

[0384] The electronic apparatus may be applied to or integrated within a personal computer (e.g., a mobile personal computer), a cellphone, a digital camera, an electronic note, an electronic dictionary, an electronic game console, a medical device (e.g., an electronic thermometer, a blood pressure meter, a glucometer, a pulse measuring device, a pulse wave measuring device, an electrocardiograph recorder, an ultrasonic diagnosis device, an endoscope display device), a fish finder, various measurement devices, gauges (e.g., gauges of an automobile, an airplane, a ship), a projector, but embodiments are not limited thereto.

[0385] The apparatus may further include a thin-film transistor, in addition to the light-emitting device. In this embodiment, the thin-film transistor may include a source electrode, an activation layer, and a drain electrode, and the first electrode of the light-emitting device may be electrically connected to one of the source electrode and the drain electrode of the thin-film transistor.

General Definitions of Substituents

[0386] The term "C_1-C_{60} alkyl group" as used herein refers to a linear or branched aliphatic hydrocarbon monovalent group having 1 to 60 carbon atoms. Non-limiting examples thereof include a methyl group, an ethyl group, a propyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a pentyl group, an iso-amyl group, and a hexyl group. The term "C_1-C_{60} alkylene group" as used herein refers to a divalent group having substantially the same structure as the C_1-C_{60} alkyl group.

[0387] The term "C_2-C_{60} alkenyl group" as used herein refers to a hydrocarbon group having at least one carbon-carbon double bond in the middle or at the terminus of the C_2-C_{60} alkyl group. Non-limiting examples thereof include an ethenyl group, a propenyl group, and a butenyl group. The term "C_2-C_{60} alkenylene group" as used herein refers to a divalent group having substantially the same structure as the C_2-C_{60} alkenyl group.

[0388] The term "C_2-C_{60} alkynyl group" as used herein refers to a hydrocarbon group having at least one carbon-carbon triple bond in the middle or at the terminus of the C_2-C_{60} alkyl group. Non-limiting examples thereof include an ethynyl group and a propynyl group. The term "C_2-C_{60} alkynylene group" as used herein refers to a divalent group having substantially the same structure as the C_2-C_{60} alkynyl group.

[0389] The term "C_1-C_{60} alkoxy group" as used herein refers to a monovalent group represented by —OA_{101} (wherein A_{101} is a C_1-C_{60} alkyl group). Non-limiting examples thereof include a methoxy group, an ethoxy group, and an isopropyloxy group.

[0390] The term "C_3-C_{10} cycloalkyl group" as used herein refers to a monovalent monocyclic saturated hydrocarbon group including 3 to 10 carbon atoms. Non-limiting examples thereof include a cyclopropyl group, a cyclobutyl group, a cyclopentyl group, a cyclohexyl group, and a cycloheptyl group. The term "C_3-C_{10} cycloalkylene group" as used herein refers to a divalent group having substantially the same structure as the C_3-C_{10} cycloalkyl group.

[0391] The term "C_1-C_{10} heterocycloalkyl group" as used herein refers to a monovalent monocyclic group including at least one heteroatom selected from N, O, Si, P, and S as a ring-forming atom, and 1 to 10 carbon atoms. Non-limiting examples thereof 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 refers to a divalent group having substantially the same structure as the C_1-C_{10} heterocycloalkyl group.

[0392] The term "C_3-C_{10} cycloalkenyl group" as used herein refers to a monovalent monocyclic group that has 3 to 10 carbon atoms and at least one double bond in its ring, and is not aromatic. Non-limiting examples thereof include a cyclopentenyl group, a cyclohexenyl group, and a cycloheptenyl group. The term "C_3-C_{10} cycloalkenylene group" as used herein refers to a divalent group having substantially the same structure as the C_3-C_{10} cycloalkenyl group.

[0393] The term "C_1-C_{10} heterocycloalkenyl group" as used herein refers to a monovalent monocyclic group including at least one heteroatom selected from N, O, Si, P, and S as a ring-forming atom, 1 to 10 carbon atoms, and at least one double bond in its ring. Non-limiting examples of the C_1-C_{10} heterocycloalkenyl group 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} heterocycloalkylene group" as used herein refers to a divalent group having substantially the same structure as the C_1-C_{10} heterocycloalkyl group.

[0394] The term "C_6-C_{60} aryl group" as used herein refers to a monovalent group having a carbocyclic aromatic system having 6 to 6 carbon atoms. The term "C_6-C_{60} arylene group" as used herein refers to a divalent group having a carbocyclic aromatic system having 6 to 60 carbon atoms. Non-limiting examples of the C_6-C_{60} aryl group include a phenyl group, a naphthyl group, an anthracenyl group, a phenanthrenyl group, a pyrenyl group, a fluorenyl group, and a chrysenyl group. When the C_6-C_{60} aryl group and the C_6-C_{60} arylene group each independently include two or more rings, the respective rings may be fused.

[0395] The term "C_1-C_{60} heteroaryl group" as used herein refers to a monovalent group having a heterocyclic aromatic system having at least one heteroatom selected from N, O, Si, P, and S as a ring-forming atom, and 1 to 60 carbon atoms. The term "C_1-C_{60} heteroarylene group" as used herein refers to a divalent group having a heterocyclic aromatic system having at least one heteroatom selected from N, O, Si, P, and S as a ring-forming atom and 1 to 60 carbon atoms. Non-limiting examples of the C_1-C_{60} heteroaryl group include a pyridinyl group, a pyrimidinyl group, a pyrazinyl group, a pyridazinyl group, a triazinyl group, a carbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a quinolinyl group, and an isoquinolinyl group.

[0396] When the C_1-C_{60} heteroaryl group and the C_1-C_{60} heteroarylene group each independently include two or more rings, the respective rings may be fused.

[0397] The term "C_6-C_{60} aryloxy group" as used herein is represented by —OA_{102} (wherein A_{102} is s C_6-C_{60} aryl

group). The term "C_6-C_{60} arylthio group" as used herein is represented by —SA_{103} (wherein A_{103} is a C_6-C_{60} aryl group).

[0398] The term "monovalent non-aromatic condensed polycyclic group" as used herein refers to a monovalent group that has two or more rings condensed and only carbon atoms as ring forming atoms (e.g., 8 to 60 carbon atoms), wherein the entire molecular structure is non-aromatic. Non-limiting examples of the monovalent non-aromatic condensed polycyclic group may include an adamantyl group. The term "divalent non-aromatic condensed polycyclic group" as used herein refers to a divalent group having substantially the same structure as the monovalent non-aromatic condensed polycyclic group.

[0399] The term "monovalent non-aromatic condensed heteropolycyclic group" as used herein refers to a monovalent group that has two or more condensed rings and at least one heteroatom selected from N, O, Si, P, and S, in addition to carbon atoms (e.g., 1 to 60 carbon atoms), as a ring-forming atom, wherein the entire molecular structure is non-aromatic. Non-limiting examples of the monovalent non-aromatic condensed heteropolycyclic group may include an azaadamantyl group. The term "divalent non-aromatic condensed heteropolycyclic group" as used herein refers to a divalent group having substantially the same structure as the monovalent non-aromatic condensed heteropolycyclic group.

[0400] The term "C_5-C_{60} carbocyclic group" as used herein refers to a monocyclic or polycyclic group having 5 to 60 carbon atoms only as ring-forming atoms. The C_5-C_{60} carbocyclic group may be an aromatic carbocyclic group or a non-aromatic carbocyclic group. The term "C_5-C_{60} carbocyclic group" as used herein refers to a ring (e.g., a benzene group), a monovalent group (e.g., a phenyl group), or a divalent group (e.g., a phenylene group). Also, depending on the number of substituents connected to the C_5-C_{60} carbocyclic group, the C_5-C_{60} carbocyclic group may be a trivalent group or a quadrivalent group.

[0401] The term "C_1-C_{60} heterocyclic group" as used herein refers to a group having substantially the same structure as the C_5-C_{60} carbocyclic group, except that at least one heteroatom selected from N, O, Si, P, and S is used as a ring-forming atom, in addition to carbon atoms (e.g., 1 to 60 carbon atoms).

[0402] In the present specification, at least one substituent of the substituted C_5-C_{60} carbocyclic group, the substituted C_1-C_{60} heterocyclic group, the substituted C_3-C_{10} cycloalkylene group, the substituted C_1-C_{10} heterocycloalkylene group, the substituted C_3-C_{10} cycloalkenylene group, the substituted C_1-C_{10} heterocycloalkenylene group, the substituted C_6-C_{60} arylene group, the substituted C_1-C_{60} heteroarylene group, the substituted divalent non-aromatic condensed polycyclic group, the substituted divalent non-aromatic condensed heteropolycyclic group, the substituted C_1-C_{60} alkyl group, the substituted C_2-C_{60} alkenyl group, the substituted C_2-C_{60} alkynyl group, the substituted C_1-C_{60} alkoxy group, the substituted C_3-C_{10} cycloalkyl group, the substituted C_1-C_{10} heterocycloalkyl group, the substituted C_3-C_{10} cycloalkenyl group, the substituted C_1-C_{10} heterocycloalkenyl group, the substituted C_6-C_{60} aryl group, the substituted C_6-C_{60} aryloxy group, the substituted C_6-C_{60} arylthio group, the substituted C_1-C_{60} heteroaryl group, the substituted monovalent non-aromatic condensed polycyclic group, and the substituted monovalent non-aromatic condensed heteropolycyclic group may be selected from:

[0403] deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group;

[0404] a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, 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_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —$Si(Q_{11})(Q_{12})(Q_{13})$, —$N(Q_{11})(Q_{12})$, —$B(Q_{11})(Q_{12})$, —$C(=O)(Q_{11})$, —$S(=O)_2(Q_{11})$, and —$P(=O)(Q_{11})(Q_{12})$;

[0405] 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_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group;

[0406] 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_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono 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_{10} cycloalkyl group, a C_1-C_1 heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_1 heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —$Si(Q_{21})(Q_{22})(Q_{23})$, —$N(Q_{21})(Q_{22})$, —$B(Q_{21})(Q_{22})$, —$C(=O)(Q_{21})$, —$S(=O)_2(Q_{21})$, and —$P(=O)(Q_{21})(Q_{22})$; and

[0407] —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, and

[0408] $P(=O)(Q_{31})(Q_{32})$,

[0409] wherein Q_{11} to Q_{13}, Q_{21} to Q_{23}, and Q_{31} to Q_{33} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono 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_{10} cycloalkyl group, a C_1-C_1 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, a monova-

lent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl group.

[0410] The term "Ph" as used herein refers to a phenyl group. The term "Me" as used herein refers to a methyl group. The term "Et" as used herein refers to an ethyl group. The term "ter-Bu" or "But" as used herein refers to a tert-butyl group. The term "OMe" as used herein refers to a methoxy group.

[0411] The term "biphenyl group" as used herein refers to a phenyl group substituted with a phenyl group. The "biphenyl group" may be a substituted phenyl group having a C_6-C_{60} aryl group as a substituent.

[0412] The term "terphenyl group" as used herein refers to a phenyl group substituted with a biphenyl group. The "terphenyl group" may be a substituted phenyl group having a C_6-C_{60} aryl group substituted with a C_6-C_{60} aryl group as a substituent.

[0413] The symbols * and *' as used herein, unless defined otherwise, refer to a binding site to an adjacent atom in a corresponding formula.

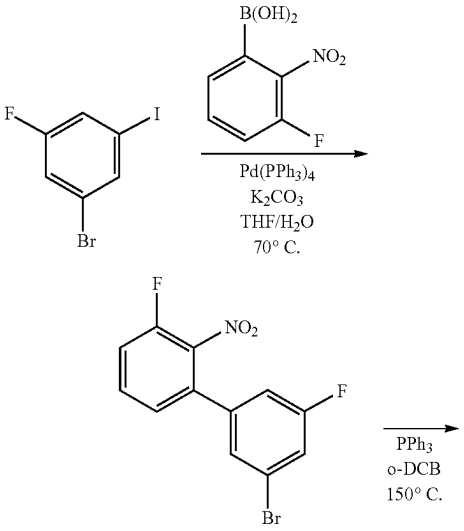
[0414] Hereinafter, compounds and a light-emitting device according to one or more embodiments will be described in more detail with reference to Synthesis Examples and Examples. The wording "B was used instead of A" used in describing Synthesis Examples refers to that an identical number of molar equivalents of B was used in place of A.

EXAMPLES

Synthesis Example

Synthesis of Intermediates T1 and T2

[0415] Intermediates T1 and T2 were respectively synthesized according to the following synthesis scheme:



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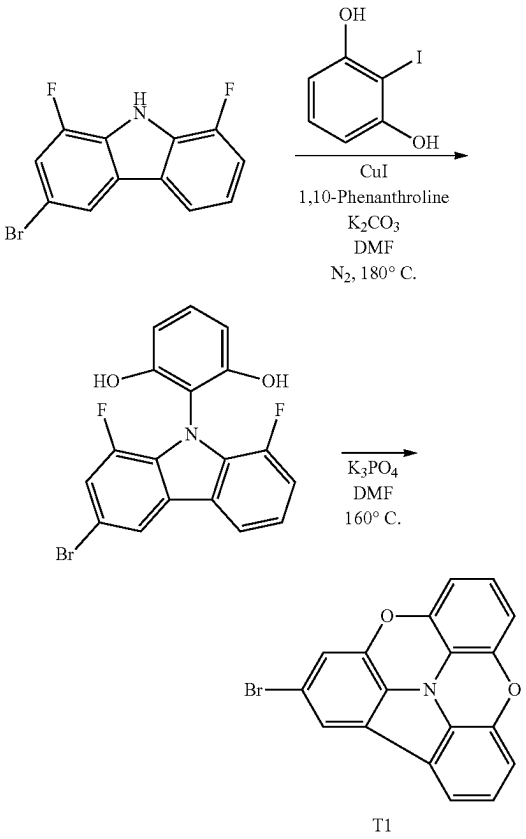
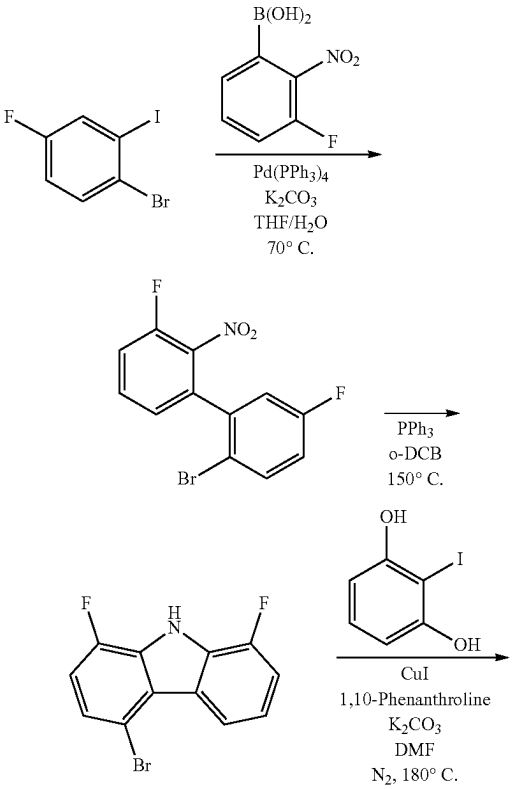


T1



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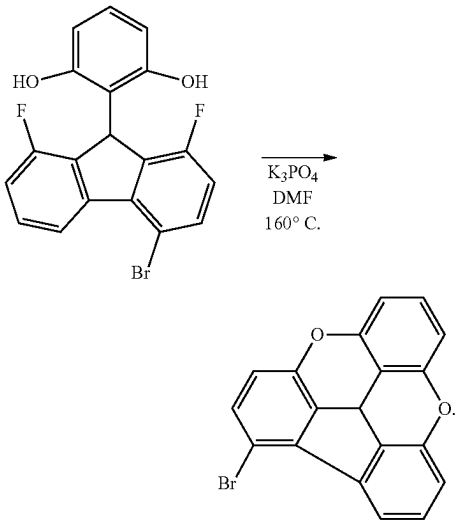
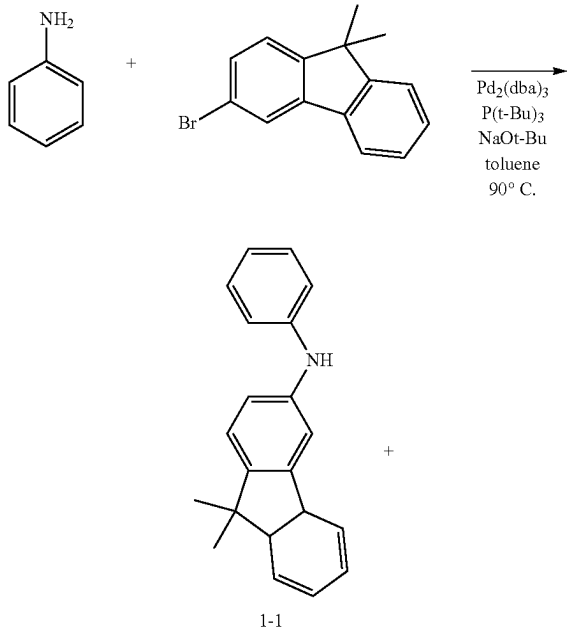


T2

Synthesis Example 1: Synthesis of Compound 1



T1

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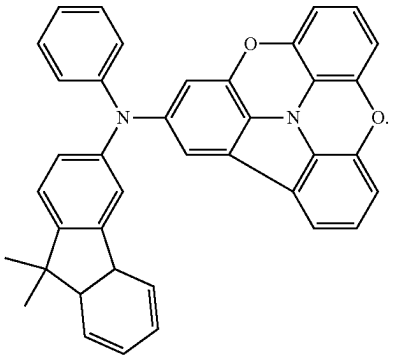


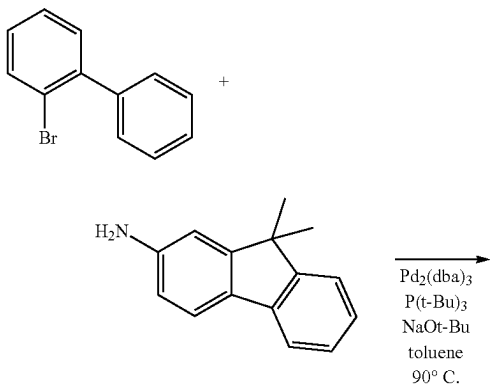
1

[0416] 2.2 grams (g) of aniline (reactant), 5.4 g of 3-bromo-9,9-dimethyl-9H-fluorene, 0.2 g of $Pd_2(dba)_3$, 0.30 g of $P(t\text{-}Bu)_3$, and 5.7 g of NaOt-Bu were dissolved in 200 milliliters (mL) of toluene and stirred at a temperature of 90° C. for 2 hours. The reaction solution was cooled to room temperature, and the reaction was terminated by using water. Then an extraction process was performed three times using ethyl ether.

[0417] The separated organic layer was dried using anhydrous magnesium sulfate and distilled under reduced pressure. The residue obtained therefrom was separated and purified through column chromatography to thereby obtain 3.9 g of Intermediate 1-1 (yield: 69%).

[0418] 2.1 g of Compound 1 was obtained in substantially the same manner as in the Synthesis of Intermediate 1-1, except that Intermediate T1 was used instead of 3-bromo-9,9-dimethyl-9H-fluorene, and 3.38 g of Intermediate 1-1 was reacted with 5.7 g of Intermediate T1 (yield: 26%). The molecular weight of Compound 1 measured by fast-atom bombardment mass spectrometry (FAB-MS) was 557.67. Accordingly, the resulting compound was identified as Compound 1.

Synthesis Example 2: Synthesis of Compound 5



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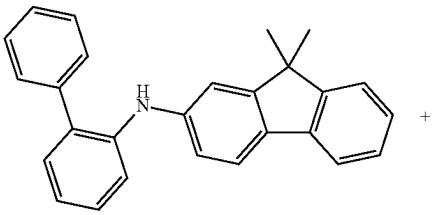
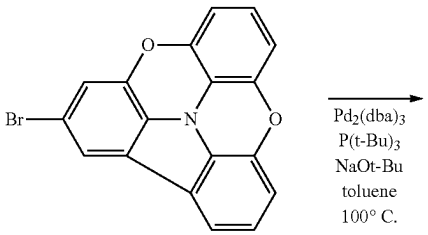
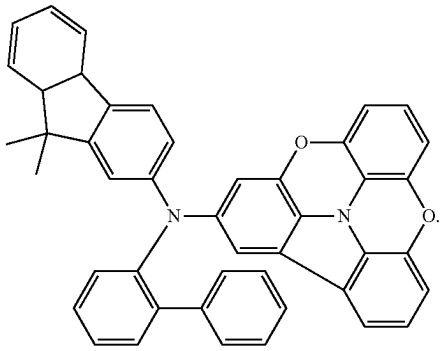


5-1



T1



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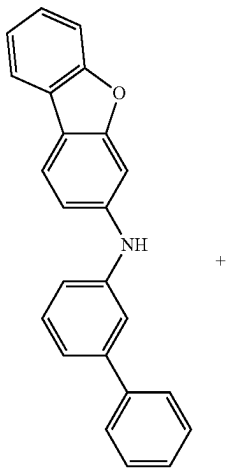
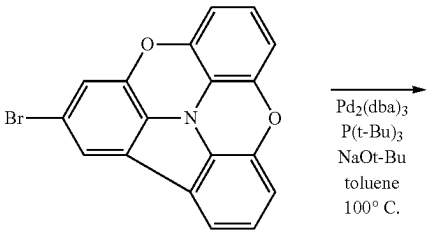
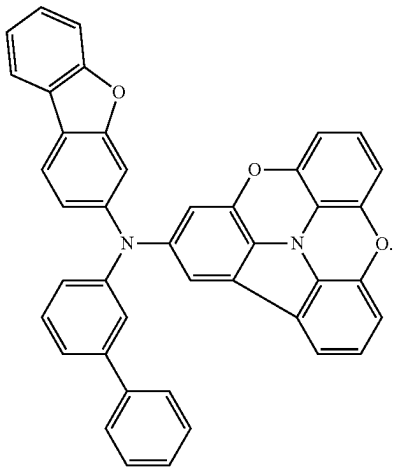


20-1



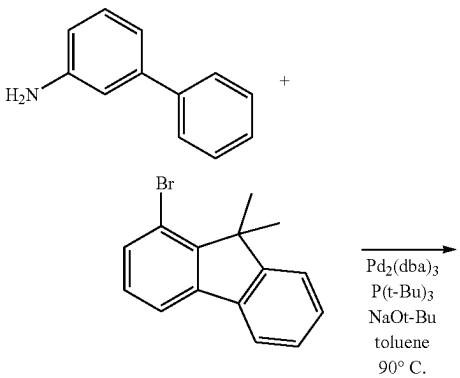
T1



20

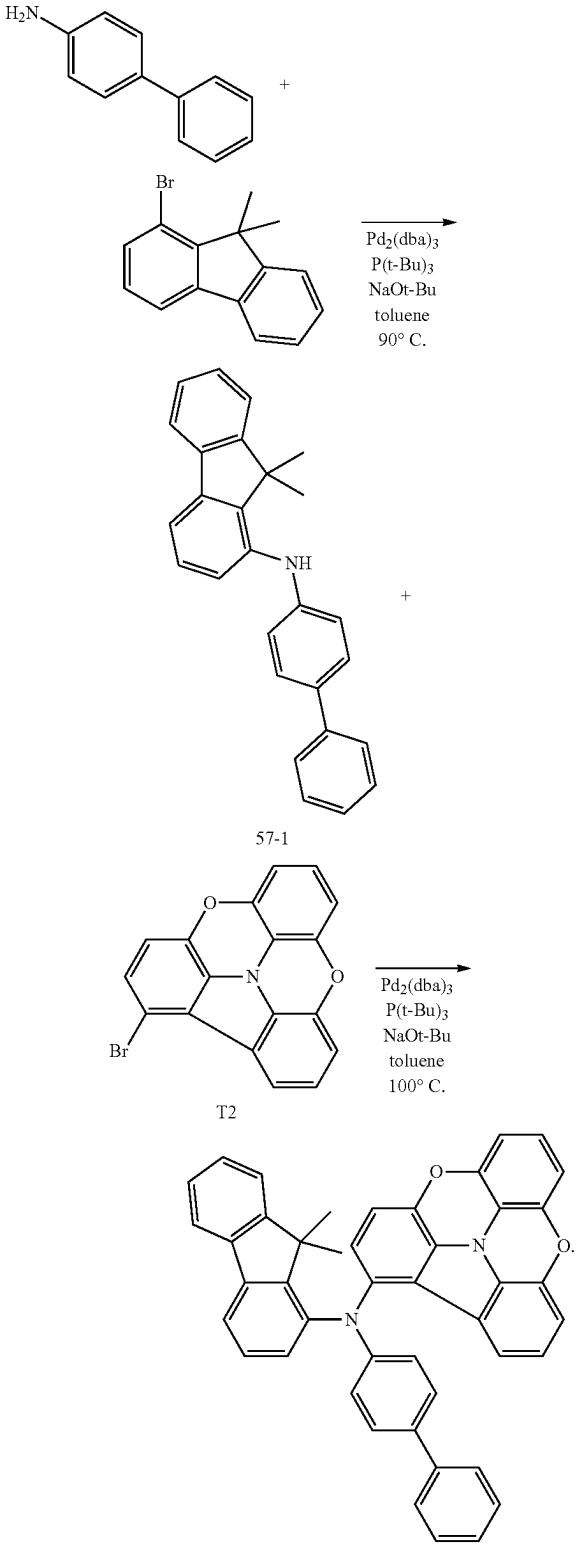
[0419] 2.5 g of Compound 5 was obtained in substantially the same manner as in the Synthesis of Compound 1, except that, as reactants, 2-bromo-1,1-biphenyl and 2-amino-9,9-dimethyl-9H-fluorene were used instead of aniline and 3-bromo-9,9-dimethyl-9H-fluorene, respectively (yield: 20%).

Synthesis Example 3: Synthesis of Compound 20



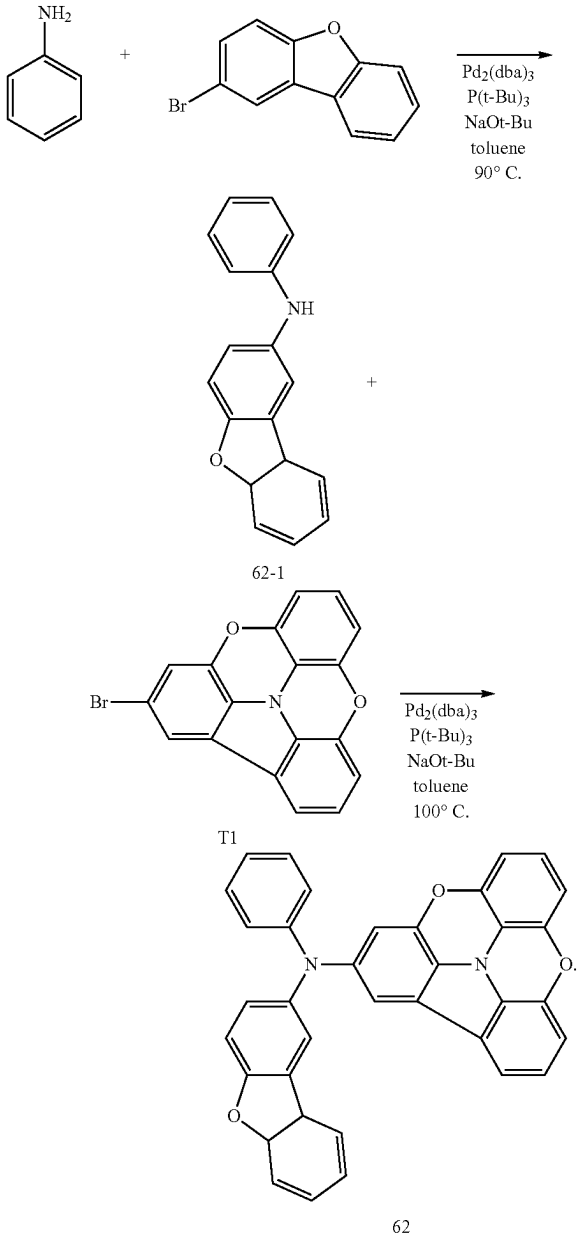
[0420] 2.3 g of Compound 20 was obtained in substantially the same manner as in the Synthesis of Compound 1, except that, as reactants, 3-aminobiphenyl and 3-bromodibenzofuran were used instead of aniline and 3-bromo-9,9-dimethyl-9H-fluorene, respectively (yield: 19%).

Synthesis Example 4: Synthesis of Compound 57



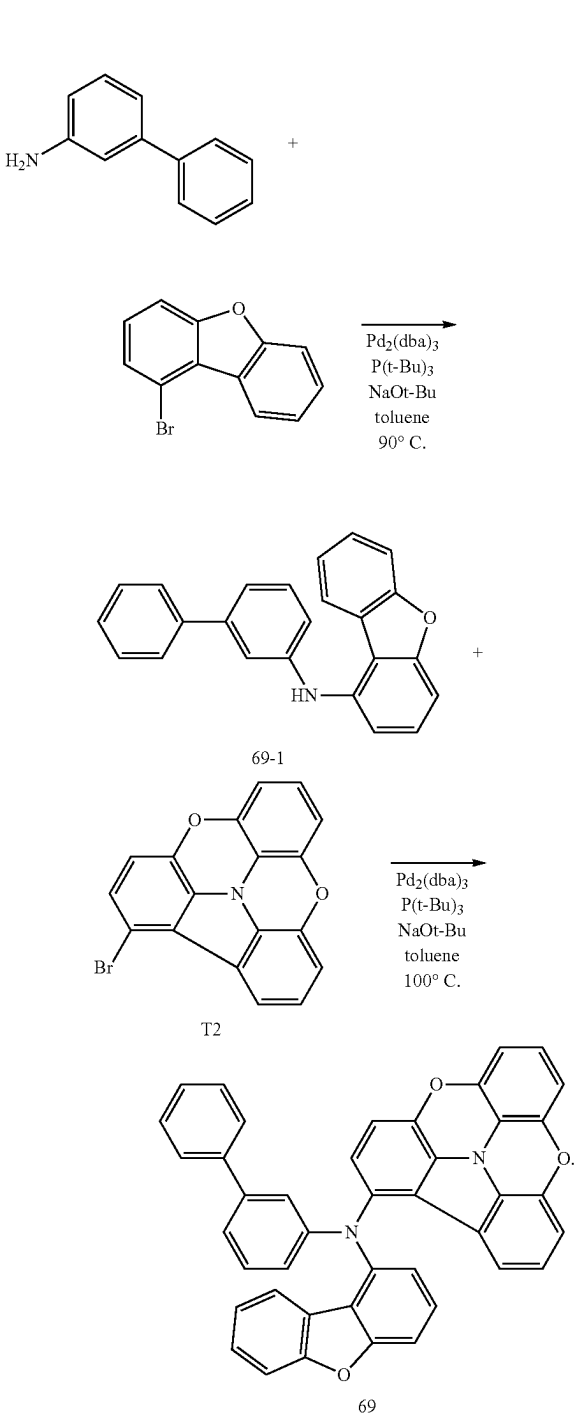
[0421] 2.0 g of Compound 57 was obtained in substantially the same manner as in the Synthesis of Compound 1, except that, as reactants, 4-aminobiphenyl and 1-bromo-9,9-dimethyl-9H-fluorene were used instead of aniline and 3-bromo-9,9-dimethyl-9H-fluorene, respectively, and Intermediate T2 was used instead of Intermediate T1 (yield: 16%).

Synthesis Example 5: Synthesis of Compound 62

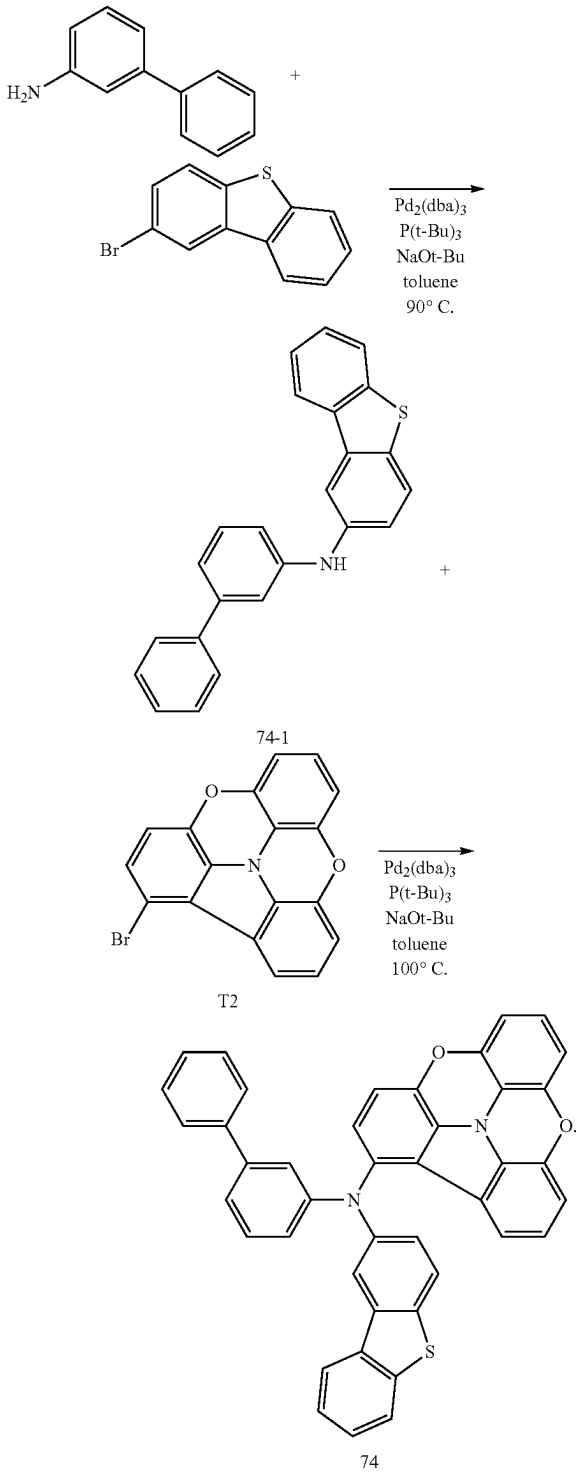


[0422] 2.1 g of Compound 62 was obtained in substantially the same manner as in the Synthesis of Compound 1, except that, as a reactant, 2-bromodibenzofuran was used instead of 3-bromo-9,9-dimethyl-9H-fluorene (yield: 20%).

Synthesis Example 6: Synthesis of Compound 69



Synthesis Example 7: Synthesis of Compound 74



[0423] 2.3 g of Compound 69 was obtained in substantially the same manner as in the Synthesis of Compound 1, except that, as reactants, 3-aminobiphenyl and 1-bromodibenzofuran were used instead of aniline and 3-bromo-9,9-dimethyl-9H-fluorene, respectively, and Intermediate T2 was used instead of Intermediate T1 (yield: 19%).

[0424] 2.1 g of Compound 74 was obtained in substantially the same manner as in the Synthesis of Compound 1, except that, as reactants, 3-aminobiphenyl and 2-bromodibenzothiophene were used instead of aniline and 3-bromo-

9,9-dimethyl-9H-10 fluorene, respectively, and Intermediate T2 was used instead of Intermediate Ti (yield: 17%).

[0425] The compounds synthesized in the Synthesis Examples were identified by ^{1}H nuclear magnetic resonance (NMR) and mass spectroscopy/fast atom bombardment (MS/FAB). The results are shown in Table 1.

TABLE 1

Compound No.	^{1}H NMR ($CDCl_3$, 400 MHz)	MS/FAB found	MS/FAB calc.
1	7.91(d, 1H), 7.73(s, 1H), 7.29-6.98(m, 19H), 6.86(d, 2H), 6.79(s, 1H), 5.80(m, 2H), 3.62(t, 1H), 2.55(t, 1H)	557.67	556.67
5	8.10(d, 1H), 7.91(d, 1H), 7.08(S, 1H), 7.73-7.08(m, 12H), 6.98(d, 1H), 6.86(d, 2H), 6.79(s, 1H), 6.64(t, 1H), 3.62(t, 1H), 2.55(t, 1H)	633.76	632.76
20	8.03(s, 1H), 7.91-7.98(m, 2H), 7.73-7.80(m, 4H), 7.17-7.55(m, 12H), 6.86-6.91(m, 2H), 6.52(s, 1H)	605.67	604.67
57	7.91-7.90(m, 2H), 7.75(d, 2H), 7.14-7.56(m, 15H), 7.06(d, 1H), 6.86(d, 2H), 6.73(d, 1H), 6.36(d, 1H), 1.67(s, 6H)	631.75	630.75
62	7.91(d, 1H), 7.73(s, 1H), 7.40(s, 1H), 7.29-7.00(m, 11H), 6.86(d, 2H), 6.76-6.64(m, 2H), 6.52(s, 1H), 5.80(m, 2H), 4.73(t, 1H), 3.93(t, 1H)	531.58	530.58
69	7.98-7.91(m, 1H), 7.75(m, 2H), 7.17-7.54(m, 16H), 6.86-6.91(m, 3H), 6.73(d, 1H), 6.36(d, 1H)	605.67	604.67

TABLE 1-continued

Compound No.	^{1}H NMR ($CDCl_3$, 400 MHz)	MS/FAB found	MS/FAB calc.
74	8.45(d, 1H), 7.95-7.85(m, 4H), 7.75(d, 2H), 7.17-7.56(m, 13H) 6.86(d, 2H), 6.73(d, 1H), 6.36(d, 1H)	621.73	620.73

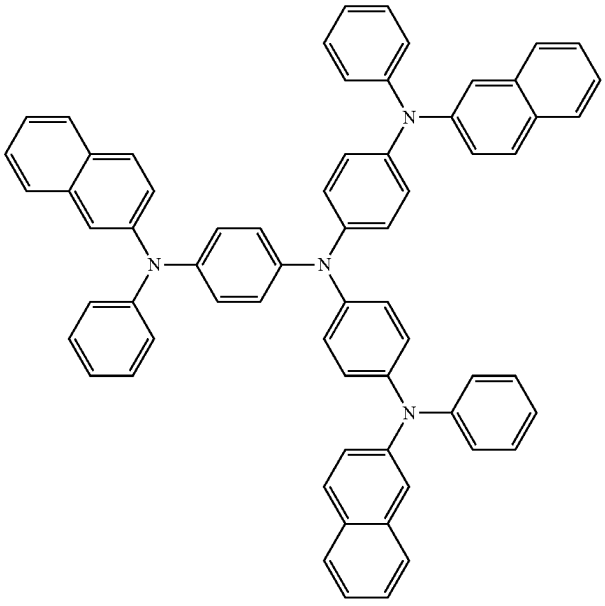
[0426] Methods of synthesizing compounds other than those shown in Table 1 may be easily understood by those skilled in the art by referring to the synthesis schemes and raw materials described above.

Comparative Example 1

[0427] A 15 Ohms per square centimeter (Ω/cm_2) (1,200 Å) ITO glass substrate from Corning was cut to a size of 50 millimeters (mm)×50 mm×0.7 mm, sonicated in isopropyl alcohol and pure water for 5 minutes in each solvent, and cleaned by exposure to ultraviolet rays with ozone to prepare the glass substrate as an anode. Then, the glass substrate was mounted to a vacuum-deposition apparatus.

[0428] 2-TNATA was vacuum-deposited on the glass substrate to form a hole injection layer having a thickness of 600 Å. Thereafter, 4,4'-bis[N—(1-naphthyl)-N-phenylamino]biphenyl (hereinafter referred to as "NPB") as a hole transporting compound was vacuum-deposited on the hole injection layer to form a hole transport layer having a thickness of 300 Å.

[0429] 9,10-di(naphthalen-2-yl)anthracene (hereinafter referred to as "DNA") as a blue fluorescent host, and 4,4'-bis[2-(4-(N,N-diphenylamino)phenyl)vinyl]biphenyl (hereinafter referred to as "DPAVBi") as a blue fluorescent dopant, were co-deposited on the hole transport layer in a weight ratio of about 98:2 to form an emission layer having a thickness of 300 Å.



2-TNATA

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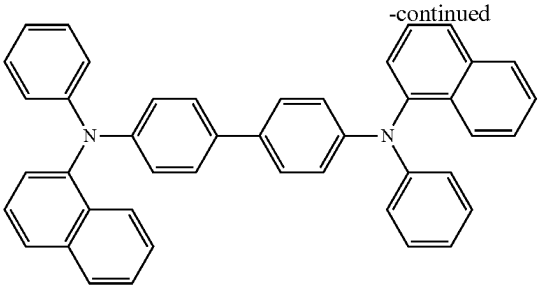
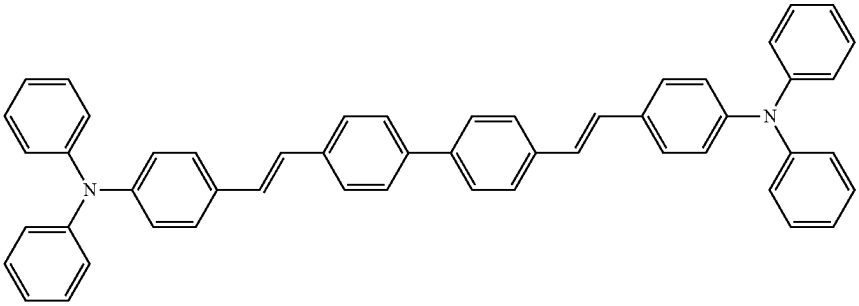
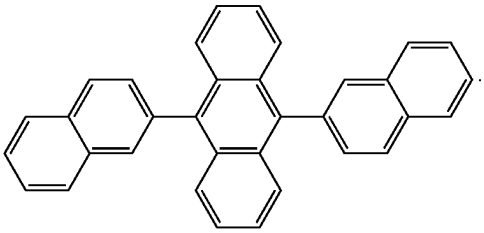


NPB



DPAVBi



DNA

Examples 1 to 7 and Comparative Examples 2 to 4

[0430] Light-emitting devices were manufactured in substantially the same manner as in Comparative Example 1, except that the Compounds shown in Table 2 were used instead of NPB when forming a hole transport layer.

Evaluation Example 1

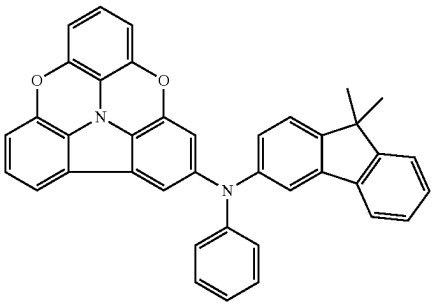
[0431] The external quantum efficiency, driving voltage, half lifespan, emission color, and emission wavelength of each of the light-emitting devices manufactured in Examples 1 to 7 and Comparative Examples 1 to 4 were measured using a Keithley source-measure unit (SMU) 236 and a luminance meter PR650. The results thereof are shown in Table 2:

TABLE 2

	Hole transport layer Material	Driving voltage (V)	Current density (mA/cm^2)	Luminance (cd/m^2)	Efficiency (cd/A)	Emission color	Half lifespan (hr @ 100 mA/cm^2)
Example 1	Compound 1	4.46	50	3700	7.40	Blue	361
Example 2	Compound 5	4.43	50	3715	7.43	Blue	367
Example 3	Compound 20	4.45	50	3710	7.42	Blue	371
Example 4	Compound 57	4.47	50	3675	7.35	Blue	368
Example 5	Compound 62	4.42	50	3685	7.37	Blue	365
Example 6	Compound 69	4.41	50	3720	7.44	Blue	373
Example 7	Compound 74	4.52	50	3725	7.45	Blue	370

TABLE 2-continued

	Hole transport layer Material	Driving voltage (V)	Current density (mA/cm^2)	Luminance (cd/m^2)	Efficiency (cd/A)	Emission color	Half lifespan (hr @ 100 mA/cm^2)
Comparative Example 1	NPB	7.01	50	2645	5.29	Blue	258
Comparative Example 2	Compound A	5.65	50	3010	6.02	Blue	315
Comparative Example 3	Compound B	5.14	50	3045	6.09	Blue	322
Comparative Example 4	Compound C	5.33	50	3055	6.11	Blue	309



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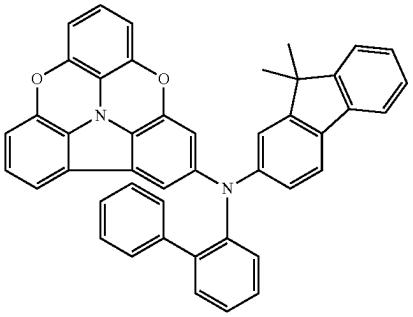

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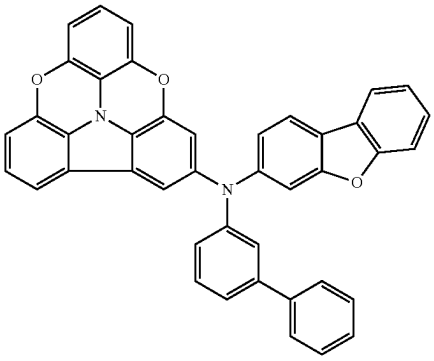

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TABLE 2-continued

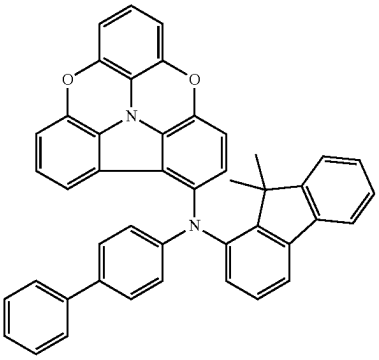
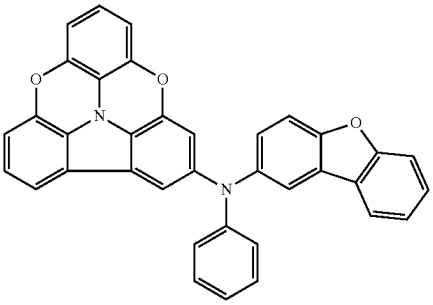
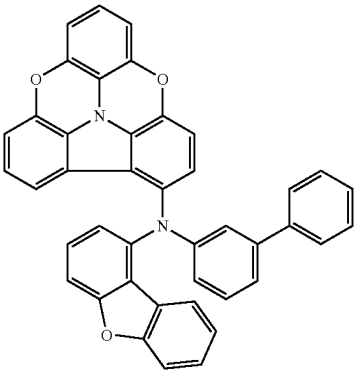
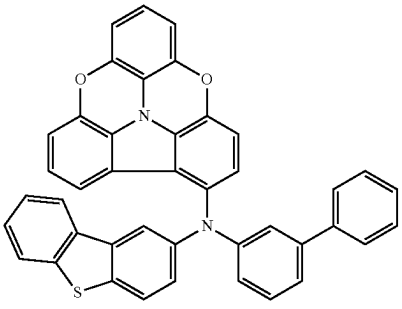
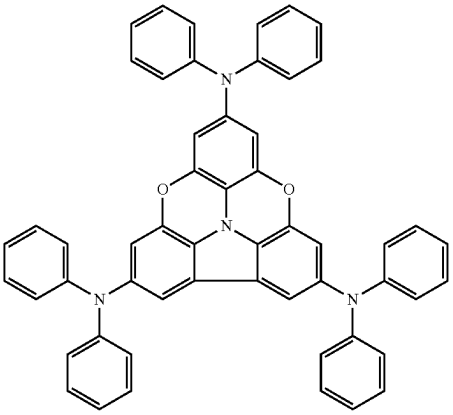
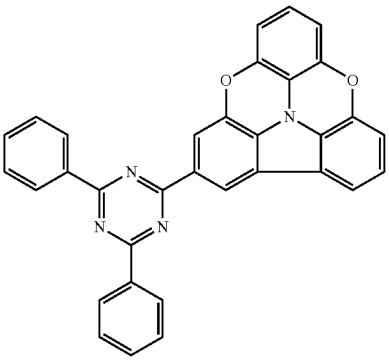
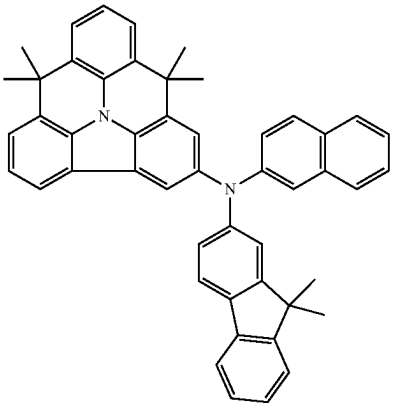
Hole transport layer Material	Driving voltage (V)	Current density (mA/cm^2)	Luminance (cd/m^2)	Efficiency (cd/A)	Emission color	Half lifespan (hr @ 100 mA/cm^2)
 57						
 62						
 69						
 74						

TABLE 2-continued

Hole transport layer Material	Driving voltage (V)	Current density (mA/cm^2)	Luminance (cd/m^2)	Efficiency (cd/A)	Emission color	Half lifespan (hr @ 100 mA/cm^2)
 A						
 B						
 C						

[0432] Referring to the results shown in Table 2, the light-emitting devices of Examples 1 to 7 were found to have excellent luminance, luminescence efficiency, and lifespan characteristics, and low driving voltage. In addition, the light-emitting devices of Examples 1 to 7 were found to have excellent luminance, luminescence efficiency, and lifespan characteristics, and low driving voltage, compared with the light-emitting devices of Comparative Examples 1 to 4.

[0433] In other words, when the compounds according to one or more embodiments are used in a light-emitting device, the light-emitting device may have excellent luminance, luminescence efficiency, lifespan, and/or driving voltage.

[0434] As apparent from the foregoing description, a light-emitting device including the heterocyclic compound may have low driving voltage, excellent luminance, excellent efficiency, and/or long lifespan.

[0435] As used herein, the terms "substantially," "about," and similar terms are used as terms of approximation and not as terms of degree, and are intended to account for the inherent deviations in measured or calculated values that would be recognized by those of ordinary skill in the art.

[0436] Any numerical range recited herein is intended to include all sub-ranges of the same numerical precision subsumed within the recited range. For example, a range of "1.0 to 10.0" is intended to include all subranges between (and including) the recited minimum value of 1.0 and the recited maximum value of 10.0, that is, having a minimum value equal to or greater than 1.0 and a maximum value equal to or less than 10.0, such as, for example, 2.4 to 7.6. Any maximum numerical limitation recited herein is intended to include all lower numerical limitations subsumed therein and any minimum numerical limitation recited in this specification is intended to include all higher numerical limitations subsumed therein. Accordingly, Applicant reserves the right to amend this specification, including the claims, to expressly recite any sub-range subsumed within the ranges expressly recited herein.

[0437] It should be understood that embodiments described herein should be considered in a descriptive sense only and not for purposes of limitation. Descriptions of features or aspects within each embodiment should typically be considered as available for other similar features or aspects in other embodiments. While one or more embodiments have been described with reference to the drawings, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope as defined by the following claims and equivalents thereof.

What is claimed is:

1. A light-emitting device comprising:

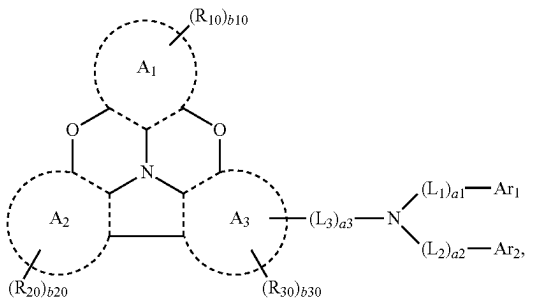
a first electrode;

a second electrode facing the first electrode;

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

at least one of a heterocyclic compound represented by Formula 1:

Formula 1



wherein, in Formula 1,

A_1 to A_3 are each independently selected from a C_5-C_{60} carbocyclic group and a C_1-C_{60} heterocyclic group,

L_1 to L_3 are each independently selected from a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, a substituted or unsubstituted C_1-C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

a1, a2, and a3 are each independently an integer from 0 to 5,

Ar_1 and Ar_2 are each independently selected from a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group,

R_{10}, R_{20}, and R_{30} are each independently selected from hydrogen, deuterium, —F —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_2-C_{60} alkenyl group, a substituted or unsubstituted C_2-C_{60} alkynyl group, a substituted or unsubstituted C_1-C_{60} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, —$Si(Q_1)(Q_2)(Q_3)$, —$B(Q_1)(Q_2)$, —$C(=O)(Q_1)$, —$S(=O)_2(Q_1)$, and —$P(=O)(Q_1)(Q_2)$,

b10, b20, and b30 are each independently an integer from 1 to 8,

* and *' each indicate a binding site to an adjacent atom, and

at least one substituent of the substituted C_3-C_1 cycloalkylene group, the substituted C_1-C_{10} heterocycloalkylene group, the substituted C_3-C_1 cycloalkenylene group, the substituted C_1-C_{10} heterocycloalkenylene group, the substituted C_6-C_{60} arylene group, the substituted C_1-C_{60} heteroarylene group, the substituted divalent non-aromatic condensed polycyclic group, the substituted divalent non-aromatic condensed heteropolycyclic group, the substituted C_1-C_{60} alkyl group, the substituted C_2-C_{60} alkenyl group, the substituted C_2-C_{60} alkynyl group, the substituted C_1-C_{60} alkoxy group, the substituted C_3-C_{10} cycloalkyl group, the substituted C_1-C_{10} heterocycloalkyl group, the substituted C_3-C_{10} cycloalkenyl group, the substituted C_1-C_{10} heterocycloalkenyl group, the substituted C_6-C_{60} aryl group, the substituted C_6-C_{60} aryloxy group, the substituted C_6-C_{60} arylthio group, the substituted C_1-C_{60} heteroaryl group, the substituted mon-

ovalent non-aromatic condensed polycyclic group, and the substituted monovalent non-aromatic condensed heteropolycyclic group is selected from:

deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group;

a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_3-C_{10} cycloalkyl group, a C_1-C_1 heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_1 heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic 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}), and —P(=O)(Q_{11})(Q_{12});

a C_3-C_1 cycloalkyl group, a C_1-C_1 heterocycloalkyl group, a C_3-C_1 cycloalkenyl group, a C_1-C_1 heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group;

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_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono 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_{10} cycloalkyl group, a C_1-C_1 heterocycloalkyl group, a C_3-C_1 cycloalkenyl group, a C_1-C_1 heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic 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}), and —P(=O)(Q_{21})(Q_{22}); and

—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}), and —P(=O)(Q_{31})(Q_{32}), and

wherein Q_1 to Q_3, Q_{11} to Q_{13}, Q_{21} to Q_{23}, and Q_{31} to Q_{33} are each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono 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_1 cycloalkyl group, a C_1-C_1 heterocycloalkyl group, a C_3-C_1 cycloalkenyl group, a C_1-C_1 heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl group.

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

the first electrode is an anode,

the second electrode is a cathode,

the interlayer comprises the at least one of the heterocyclic compound, and

the interlayer further comprises 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, and

wherein the hole transport region comprises a hole injection layer, a hole transport layer, an emission auxiliary layer, an electron blocking layer, or any combination thereof, and

the electron transport region comprises a hole blocking layer, an electron transport layer, an electron injection layer, or any combination thereof.

3. The light-emitting device of claim **2**, wherein the hole transport region comprises the at least one of the heterocyclic compound.

4. The light-emitting device of claim **2**, wherein the hole transport region comprises the hole transport layer, and

the hole transport layer comprises the at least one heterocyclic compound.

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

6. The light-emitting device of claim **5**, wherein the emission layer is to emit blue light having a maximum emission wavelength of about 420 nanometers (nm) to about 490 nm.

7. The light-emitting device of claim **1**, wherein the emission layer comprises quantum dots.

8. The light-emitting device of claim **2**, wherein the at least one of the heterocyclic compound is used as a material for a capping layer on a side of the cathode facing away from the anode and/or on a side of the anode facing away from the cathode.

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

10. The apparatus of claim **9**, 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 the source electrode or the drain electrode of the thin-film transistor.

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