



US012391715B2

(12) **United States Patent**
Ahn et al.(10) **Patent No.:** US 12,391,715 B2
(45) **Date of Patent:** Aug. 19, 2025(54) **ORGANOMETALLIC COMPOUND,
LIGHT-EMITTING DEVICE INCLUDING
THE SAME, AND ELECTRONIC APPARATUS
INCLUDING THE LIGHT-EMITTING
DEVICE**(71) Applicant: **Samsung Display Co., Ltd.**, Yongin-si (KR)(72) Inventors: **Eunsoo Ahn**, Yongin-si (KR);
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Sungbum Kim, Yongin-si (KR);
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Jaesung Lee, Yongin-si (KR)(73) Assignee: **Samsung Display Co., Ltd.**, Yongin-si (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 686 days.

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(30) **Foreign Application Priority Data**

Dec. 3, 2020 (KR) 10-2020-0167831

(51) **Int. Cl.**
B82Y 20/00 (2011.01)
B82Y 30/00 (2011.01)
(Continued)(52) **U.S. Cl.**
CPC **C07F 15/0086** (2013.01); **H10K 85/1135** (2023.02); **H10K 85/324** (2023.02);
(Continued)(58) **Field of Classification Search**
CPC .. H10K 85/341; H10K 85/346; H10K 85/371;
C07F 1/08; C07F 1/10; C07F 1/12; C07F
15/006; C07F 15/0086; C07F 15/04
See application file for complete search history.(56) **References Cited**

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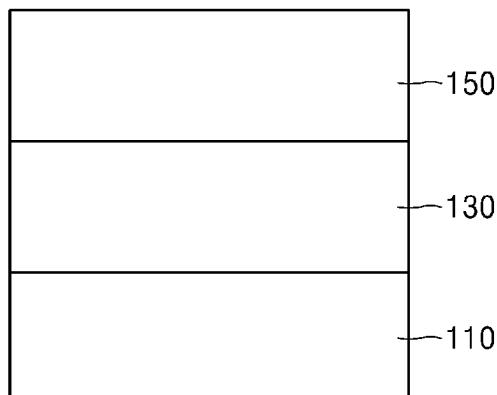
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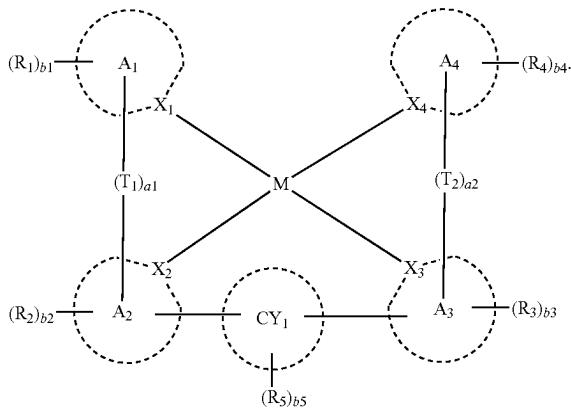
Prokhorov, Anton M. et al. "Triazines, Tetrazines, and Fused Ring Polyaza Systems", *Progress in Heterocyclic Chemistry*, vol. 23, 2011, pp. 403-425.*Primary Examiner* — Jennifer A Boyd*Assistant Examiner* — Rachel Simbana(74) *Attorney, Agent, or Firm* — Womble Bond Dickinson (US) LLP(57) **ABSTRACT**

A light-emitting device includes a first compound represented by Formula 1, for example, in an emission layer of the device as a dopant or emitter. An electronic apparatus includes the light-emitting device, and the first compound represented by Formula 1 is an organometallic compound, in which M is platinum (Pt), palladium (Pd), gold (Au), nickel (Ni), silver (Ag), or copper (Cu):

(Continued)

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Formula 1



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85/654 (2023.02); **H10K 85/6572** (2023.02);
H10K 85/6574 (2023.02); **H10K 85/6576**
(2023.02); **H10K 85/658** (2023.02); **B82Y
20/00** (2013.01); **H10K 50/11** (2023.02); **H10K
50/115** (2023.02); **H10K 50/12** (2023.02);
H10K 50/15 (2023.02); **H10K 2101/10**
(2023.02); **H10K 2101/40** (2023.02)

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FIG. 1

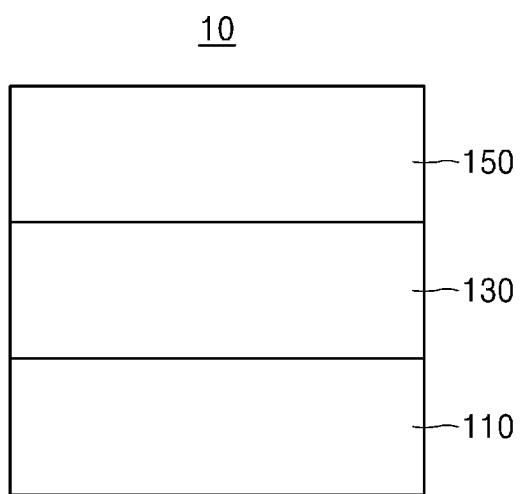


FIG. 2

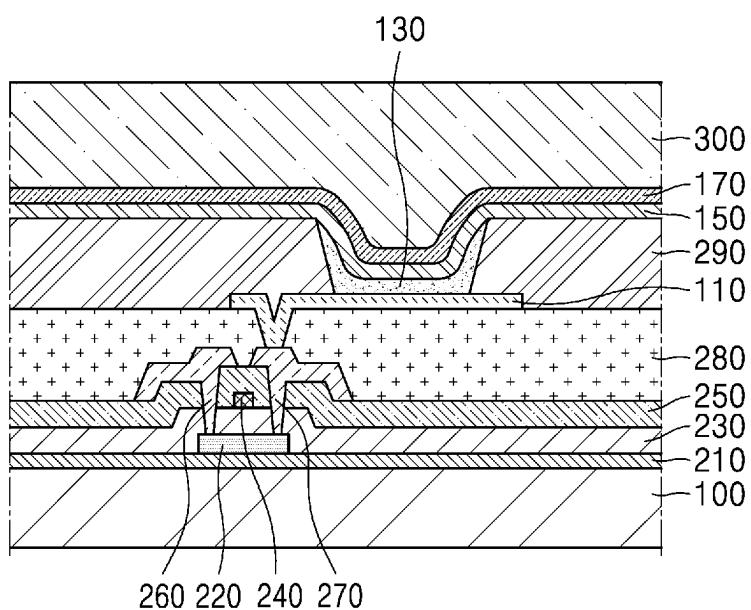
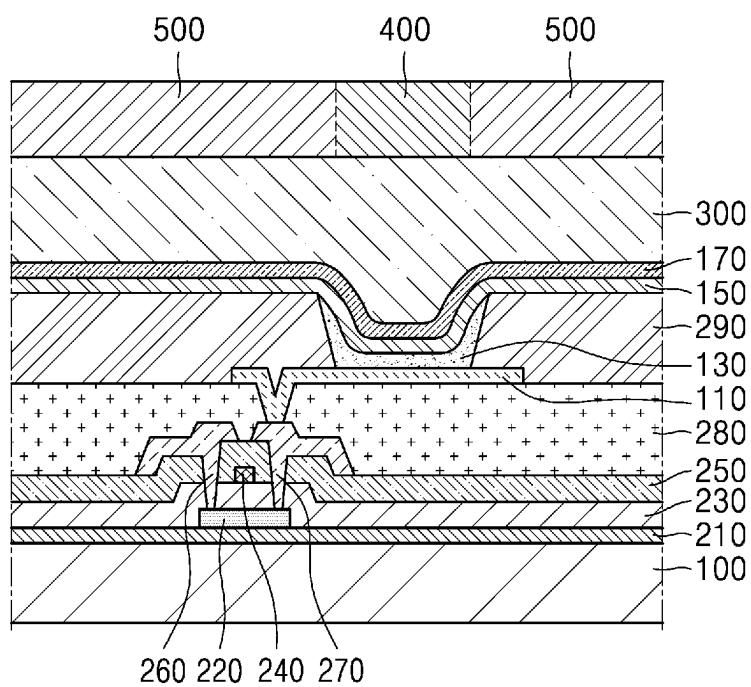


FIG. 3



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**ORGANOMETALLIC COMPOUND,
LIGHT-EMITTING DEVICE INCLUDING
THE SAME, AND ELECTRONIC APPARATUS
INCLUDING THE LIGHT-EMITTING
DEVICE**

**CROSS-REFERENCE TO RELATED
APPLICATION**

This application claims priority to and the benefit of Korean Patent Application No. 10-2020-0167831, filed on Dec. 3, 2020, in the Korean Intellectual Property Office, the entire content of which is hereby incorporated by reference. 15

BACKGROUND

1. Field

One or more aspects of embodiments of the present disclosure relate to an organometallic compound, a light-emitting device including the same, and an electronic apparatus including the light-emitting device. 25

2. Description of the Related Art

Self-emissive light-emitting devices may have wide viewing angles, excellent or suitable contrast, short response times, and/or excellent or suitable brightness, driving voltage, and/or response speed characteristics. 30

In a light-emitting device, a first electrode may be located on a substrate, and a hole transport region, an emission layer, an electron transport region, and a second electrode may be sequentially formed 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 holes and electrons) may recombine in the emission layer to produce excitons. These excitons may transition from an excited state to the ground state to thereby generate light. 35

SUMMARY

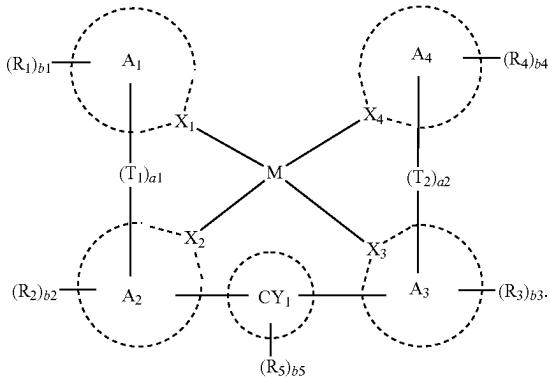
One or more aspects of embodiments of the present disclosure are directed toward a light-emitting device having high luminescence efficiency and/or long lifespan, an electronic apparatus including the same, and an organometallic compound (e.g., that is used in the same). 55

Additional aspects will be set forth in part in the description that follows, and will be apparent in part from the description, or may be learned by practice of the presented embodiments of the disclosure. 60

One or more embodiments of the present disclosure provide an organometallic compound represented by Formula 1:

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Formula 1



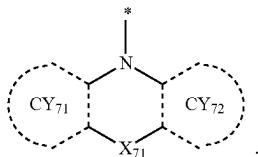
In Formula 1,
M may be platinum (Pt), palladium (Pd), gold (Au), nickel (Ni), silver (Ag), or copper (Cu),
X₁ to X₄ may each independently be C or N,
A₁ to A₄ may each independently be a C₃-C₆₀ carbocyclic group or a C₁-C₆₀ heterocyclic group,
CY₁ may be a π electron-deficient nitrogen-containing C₁-C₆₀ cyclic group,
T₁ and T₂ may each independently be a single bond, a double bond, *—N[(L₁)_{c1}(Z₁₁)]—*, *—B(Z₁₁)—*, *—P(Z₁₁)—*, *—C(Z₁₁)(Z₁₂)—*, *—Si(Z₁₁)(Z₁₂)—*, *—Ge(Z₁₁)(Z₁₂)—*, *—S*!, *—Se*!, *—O*!, *—C(=O)—*, *—S(=O)—*, *—S(=O)₂—*, *—C(Z₁₁)—*, *—C(Z₁₁)—*, *—C(Z₁₁)=C(Z₁₂)—*, *—C(=S)*!, or *—C≡C—*, where * and *! each indicate a binding site to a neighboring atom,
L₁ may be a single bond, a C₅-C₃₀ carbocyclic group unsubstituted or substituted with at least one R_{10a}, or a C₁-C₃₀ heterocyclic group unsubstituted or substituted with at least one R_{10a},
c1 may be an integer from 0 to 5,
a1 and a4 may each independently be an integer from 0 to 3,
R₁ to R₅, Z₁₁, and Z₁₂ may each independently be hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C₁-C₆₀ alkyl group unsubstituted or substituted with at least one R_{10a}, a C₂-C₆₀ alkenyl group unsubstituted or substituted with at least one R_{10a}, a C₂-C₆₀ alkynyl group unsubstituted or substituted with at least one R_{10a}, a C₁-C₆₀ alkoxy group unsubstituted or substituted with at least one R_{10a}, a C₃-C₆₀ carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C₁-C₆₀ heterocyclic group unsubstituted or substituted with at least one R_{10a}, a C₆-C₆₀ aryloxy group unsubstituted or substituted with at least one R_{10a}, a C₆-C₆₀ arylthio group unsubstituted or substituted with at least one R_{10a}, —Si(Q₁)(Q₂)(Q₃), —N(Q₁)(Q₂), —B(Q₁)(Q₂), —C(=O)(Q₁), —S(=O)₂(Q₁), or —P(=O)(Q₁)(Q₂), b1 to b5 may each independently be an integer from 0 to 10,
two or more groups of R₁ to R₅, Z₁₁, and Z₁₂ may optionally be linked to form a C₅-C₃₀ carbocyclic group unsubstituted or substituted with at least one R_{10a} or a C₂-C₃₀ heterocyclic group unsubstituted or substituted with at least one R_{10a},

R_{10a} may be:
deuterium (-D), —F, —Cl, —Br, —I, a hydroxyl group,
a cyano group, or a nitro group,
a $C_1\text{-}C_{60}$ alkyl group, a $C_2\text{-}C_{60}$ alkenyl group, a $C_2\text{-}C_{60}$
alkynyl group, or a $C_1\text{-}C_{60}$ alkoxy group, each unsub-
stituted or substituted with deuterium, —F, —Cl, —Br,
—I, a hydroxyl group, a cyano group, a nitro group, a
 $C_3\text{-}C_{60}$ carbocyclic group, a $C_1\text{-}C_{60}$ heterocyclic group,
a $C_6\text{-}C_{60}$ aryloxy group, a $C_6\text{-}C_{60}$ arylthio group, —Si
 $(Q_{11})(Q_{12})(Q_{13})$, —N($Q_{11})(Q_{12})$, —B($Q_{11})(Q_{12})$,
—C(=O)($Q_{11})$, —S(=O) $_2(Q_{11})$, —P(=O)($Q_{11})$
 (Q_{12}) , or any combination thereof,
a $C_3\text{-}C_{60}$ carbocyclic group, a $C_1\text{-}C_{60}$ heterocyclic group,
a $C_6\text{-}C_{60}$ aryloxy group, or a $C_6\text{-}C_{60}$ arylthio group,
each unsubstituted or substituted with deuterium, —F,
—I, a hydroxyl group, a cyano group, a
nitro group, a $C_1\text{-}C_{60}$ alkyl group, a $C_2\text{-}C_{60}$ alkenyl
group, a $C_2\text{-}C_{60}$ alkynyl group, a $C_1\text{-}C_{60}$ alkoxy group,
a $C_3\text{-}C_{60}$ carbocyclic group, a $C_1\text{-}C_{60}$ heterocyclic
group, a $C_6\text{-}C_{60}$ aryloxy group, a $C_6\text{-}C_{60}$ arylthio group,
—Si($Q_{21})(Q_{22})(Q_{23})$, —N($Q_{21})(Q_{22})$, —B($Q_{21})(Q_{22})$,
—C(=O)($Q_{21})$, —S(=O) $_2(Q_{21})$, —P(=O)($Q_{21})$
 (Q_{22}) , or any combination thereof, or
—Si($Q_{31})(Q_{32})(Q_{33})$, —N($Q_{31})(Q_{32})$, —B($Q_{31})(Q_{32})$,
—C(=O)($Q_{31})$, —S(=O) $_2(Q_{31})$, or —P(=O)($Q_{31})$
 (Q_{32}) ,
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 hydrogen, deuterium, —F,
—I, a hydroxyl group, a cyano group, a
nitro group, a $C_1\text{-}C_{60}$ alkyl group, a $C_2\text{-}C_{60}$ alkenyl
group, a $C_2\text{-}C_{60}$ alkynyl group, a $C_1\text{-}C_{60}$ alkoxy group,
or a $C_3\text{-}C_{60}$ carbocyclic group or a $C_1\text{-}C_{60}$ heterocyclic
group, each unsubstituted or substituted with deute-
rium, —F, a cyano group, a $C_1\text{-}C_{60}$ alkyl group, a
 $C_1\text{-}C_{60}$ alkoxy group, a phenyl group, a biphenyl group,
or any combination thereof.

One or more embodiments of the present disclosure
provide a light-emitting device including:

- a first electrode,
- a second electrode facing the first electrode, and
- an interlayer located between the first electrode and the
second electrode and including an emission layer,
wherein the interlayer includes:
 - i) a first compound which is the organometallic compound
as described above, and
 - ii) a second compound including at least one π electron-
deficient nitrogen-containing $C_1\text{-}C_{60}$ cyclic group, a
third compound including a group represented by For-
mula 3, a fourth compound capable of emitting delayed
fluorescence, or any combination thereof, and
- the first compound and the second compound, and the
third compound and the fourth compound are different
from each other.

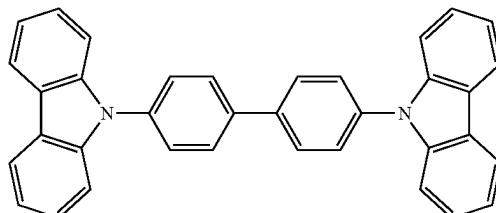
Formula 3



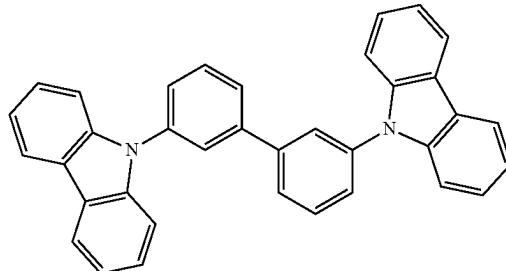
In Formula 3, ring CY₇₁ and ring CY₇₂ may each inde-
pendently be a π electron-rich $C_3\text{-}C_{60}$ cyclic group or a
pyridine group,

in Formula 3, X₇₁ may be a linking group including a
single bond, O, S, N, B, C, Si, or any combination
thereof,

in Formula 3, * indicates a binding site to a neighboring
atom in the third compound, and
the compounds below are excluded from being the third
compound.



CBP



mCBP

One or more embodiments of the present disclosure
provide an electronic apparatus including the light-emitting
device.

BRIEF DESCRIPTION OF THE DRAWINGS

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:

FIG. 1 is a schematic cross-sectional view of a light-
emitting device according to an embodiment; and

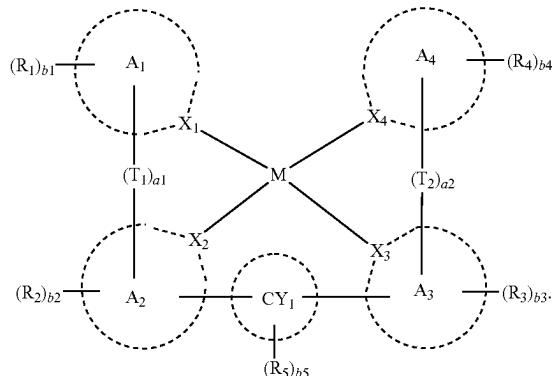
FIGS. 2 and 3 are each a cross-sectional view of a
light-emitting apparatus according to another embodiment.

DETAILED DESCRIPTION

Reference will now be made in more detail to embodi-
ments, examples of which are illustrated in the accompa-
nying drawings, wherein like reference numerals refer to like
elements throughout the specification, 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,
by referring to the drawings, to explain aspects of the present
description. As utilized 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" indicates only a, only b, only c, both
(e.g., simultaneously) a and b, both (e.g., simultaneously) a
and c, both (e.g., simultaneously) b and c, all of a, b, and c,
or variations thereof.

An organometallic compound is represented by Formula 1:

Formula 1



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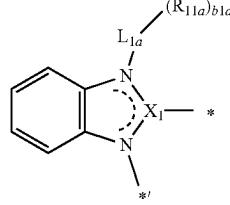
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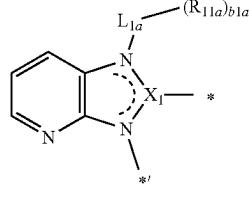
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in Formula 1 may be a group represented by one of Formulae A1(1) to A1(6):

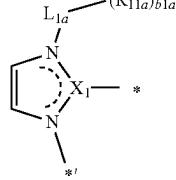
A1(1)



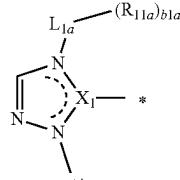
A1(2)



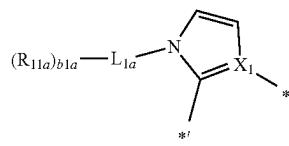
A1(3)



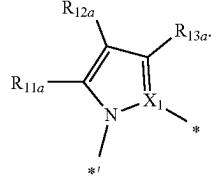
A1(4)



A1(5)



A1(6)



In Formulae A1(1) to A1(6), X₁ may be the same as described herein, L_{1a} and b1a may each independently be the same as described in connection with L₁ and b1, R_{11a} to R_{13a} may each independently be the same as described in connection with R₁, and each of R_{11a} to R_{13a} is not hydrogen, indicates a binding site to M in Formula 1, and ' is a binding site to a neighboring atom in Formula 1. CY₁ in Formula 1 may be a π electron-deficient nitrogen-containing C₁-C₆₀ cyclic group.

In an embodiment, CY₁ in Formula 1 may be an imidazole group, a pyrazole group, a thiazole group, an isothiazole group, an oxadiazole group, or a thiadiazole group.

In Formula 1, M may be platinum (Pt), palladium (Pd), gold (Au), nickel (Ni), silver (Ag), or copper (Cu).

X₁ to X₄ in Formula 1 may each independently be C or N.

In an embodiment, X₁ in Formula 1 may be C, and C may be carbon or a carbene moiety.

In an embodiment, in Formula 1, X₁ to X₃ may each be C, and X₄ may be N.

In an embodiment, in Formula 1, a bond between X₁ and M and a bond between X₄ and M may each be a coordinate bond, and a bond between X₂ and M and a bond between X₃ and M may each be a covalent bond.

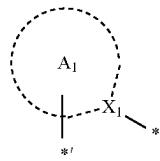
A₁ to A₄ in Formula 1 may each independently be a C₃-C₆₀ carbocyclic group or a C₁-C₆₀ heterocyclic group.

In an embodiment, in Formula 1, A₁ may be i) an X₁-containing 5-membered ring, ii) the X₁-containing 5-membered ring, to which at least one 6-membered ring is condensed, or iii) an X₁-containing 6-membered ring, and A₄ may be an X₄-containing 6-membered ring. In an embodiment, in Formula 1, A₁ may be i) the X₁-containing 5-membered ring or ii) the X₁-containing 5-membered ring to which at least one 6-membered ring is condensed, and A₄ may be a 6-membered ring. Thus, A₁ may include a 5-membered ring linked to M in Formula 1 via X₁ and A₄ may include a 6-membered ring linked to M in Formula 1 via X₄.

In an embodiment, the X₁-containing 5-membered ring in A₁ of Formula 1 may be a pyrrole group, a pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, a thiazole group, an isothiazole group, an oxadiazole group, or a thiadiazole group.

In an embodiment, the X₁-containing 6-membered ring, the 6-membered ring condensed to the X₁-containing 5-membered ring in A₁ the 6-membered ring in A₁, and/or the X₄-containing 6-membered ring in A₄ may each independently be a benzene group, a pyridine group, or a pyrimidine group.

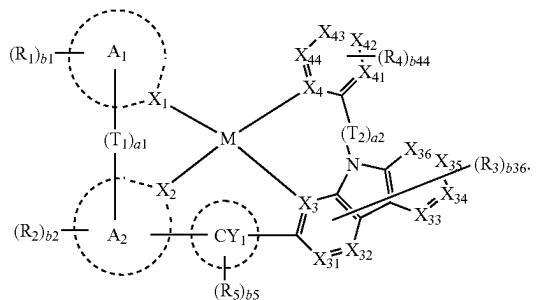
In one or more embodiments, a group represented by



unsubstituted or substituted with at least one $R_{10\alpha}$ or a C_2-C_{30} heterocyclic group unsubstituted or substituted with at least one $R_{10\alpha}$,

In an embodiment, Formula 1 may be a group represented by Formula 1-1:

Formula 1-1



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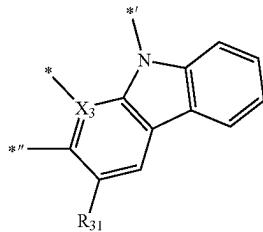
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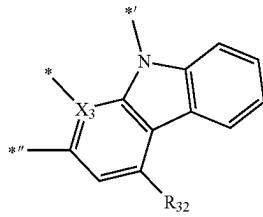
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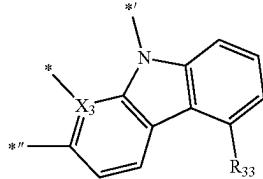
A3(2)



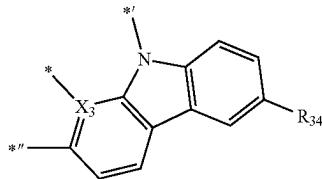
A3(3)



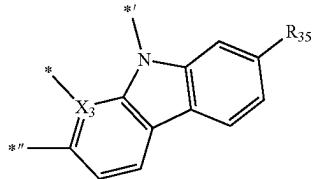
A3(4)



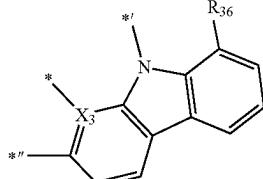
A3(5)



A3(6)



A3(7)



In Formula 1-1,

M, X_1 to X_4 , A_1 , A_2 , CY_1 , T_1 , T_2 , $a1$, $a2$, R_1 to R_5 , $b1$, $b2$, and $b5$ may each independently be the same as described herein,

X_{31} to X_{36} may each independently be the same as described in connection with X_3 ,

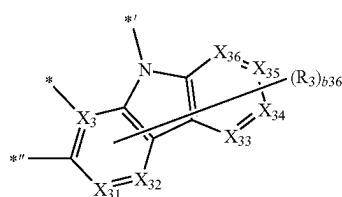
X_{43} to X_{44} may each independently be the same as described in connection with X_4 ,

$b36$ may be an integer from 0 to 6, and

$b44$ may be an integer from 0 to 4.

In an embodiment, X_{31} to X_{36} and X_{41} to X_{44} in Formula 1-1 may all (each) be C.

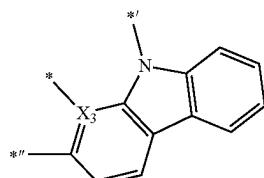
In an embodiment, a group represented by



in Formula 1-1 may be a group represented by one of 55 Formulae A3(1) to A3(7):

A3(1)

60



In Formulae A3(1) to A3(7), X_3 may be the same as described herein,

R_{31} to R_{36} may each independently be the same as described in connection with R_3 , and each of R_{31} to R_{36} may not be hydrogen,

indicates a binding site to M in Formula 1-1, and

' and '' may be a binding site to a neighboring atom in Formula 1-1.

In the organometallic compound represented by Formula 1, because CY_1 is a π electron-deficient nitrogen-containing C_1-C_{60} cyclic group, electron mobility may be improved, and thus low driving voltage may be decreased and/or a long lifespan effect may be obtained. In addition, the CY_1 moiety may correspond to the highest occupied molecular orbital

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(HOMO) of the organometallic compound, which may have (e.g., emit) deep blue light, and the moiety may sterically inhibit intermolecular accumulation (e.g., aggregation). Accordingly, formation of an excimer or an exciplex may be inhibited when the device is driven, so that the full width at half maximum (FWHM) value of the organometallic compound in photoluminescence (PL) or electroluminescence (EL) may be lowered.

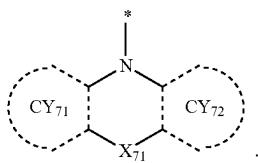
Accordingly, a light-emitting device including the organometallic compound represented by Formula 1 may have high color purity, high efficiency, low driving voltage, and/or long lifespan.

Suitable synthesis methods of the organometallic compound represented by Formula 1 may be recognizable by one of ordinary skill in the art by referring to the Synthesis Examples and/or Examples provided below.

In an embodiment, at least one organometallic compound represented by Formula 1 may be utilized in a light-emitting device (for example, an organic light-emitting device). Therefore, a light-emitting device may include:

- a first electrode;
- a second electrode facing the first electrode; and
- an interlayer located between the first electrode and the second electrode and including an emission layer, wherein the interlayer includes:
 - i) a first compound, the first compound being the organometallic compound represented by Formula 1; and
 - ii) a second compound including at least one π electron-deficient nitrogen-containing C_1 - C_{60} cyclic group, a third compound including a group represented by Formula 3, a fourth compound to emit delayed fluorescence, or any combination thereof, and
- the first compound and the second compound, and the third compound and the fourth compound different from each other;

Formula 3

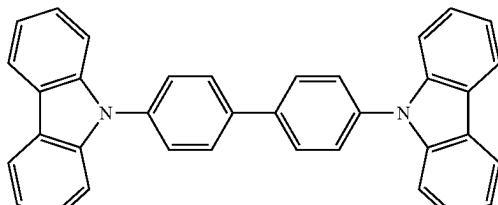


In Formula 3, ring CY₇₁ and ring CY₇₂ may each independently be a π electron-rich C_3 - C_{60} cyclic group or a pyridine group,

in Formula 3, X₇₁ may be a single bond, O, S, N, B, C, Si, or any combination thereof,

in Formula 3, * indicates a binding site to a neighboring atom in the third compound, and

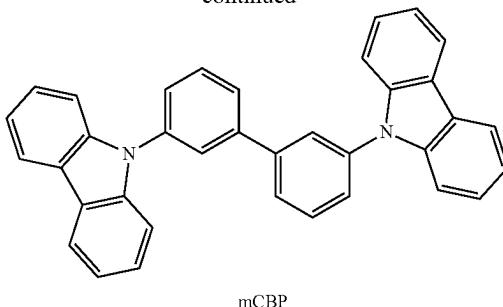
the third compound may exclude the compounds below.



CBP

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-continued



mCBP

Description of Second Compound and Fourth Compound

The second compound may include a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, or any combination thereof.

In an embodiment, the light emitting device may further include at least one of a second compound and a third compound in addition to the first compound.

In an embodiment, the light-emitting device may further include a fourth compound in addition to the first compound.

In an embodiment, the light-emitting device may include all of the first to fourth compounds.

In an embodiment, the interlayer may include the second compound. The interlayer may further include the third compound, the fourth compound, or a combination thereof, in addition to the first compound and the second compound.

The difference between a triplet energy level (eV) of the fourth compound and a singlet energy level (eV) of the fourth compound may be 0 eV or more and 0.5 eV or less (or for example, 0 eV or more and 0.3 eV or less).

In an embodiment, the fourth compound may be a compound including at least one cyclic group including a B (boron) atom and a N (nitrogen) atom each (e.g., simultaneously) as a ring-forming atom.

In an embodiment, the fourth compound may be a C_8 - C_{60} polycyclic group-containing compound including two or more condensed cyclic groups sharing a boron (B) atom.

In an embodiment, the fourth compound may include a condensed cyclic group, in which at least one third ring and at least one fourth ring are condensed with each other, where:

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

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

In an embodiment, the interlayer may include the fourth compound. The interlayer may further include the second compound, the third compound, or a combination thereof, in addition to the first compound and the fourth compound.

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In an embodiment, the interlayer may include the third compound. In an embodiment, the third compound may not include compounds represented by CBP and mCBP described herein.

- 5 i) The first compound; and ii) the second compound, the third compound, the fourth compound, or any combination thereof may be included in an emission layer in the interlayer.

The emission layer may be to emit phosphorescence or fluorescence, as emitted from the first compound. In an embodiment, the phosphorescence or fluorescence emitted from the first compound may be blue light.

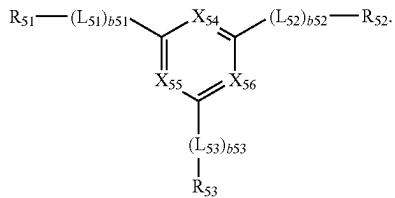
10 In an embodiment, the emission layer of the light-emitting device may include the first compound and the second compound, and the first compound and the second compound may be to form an exciplex.

15 In an embodiment, the emission layer of the light-emitting device may include the first compound, the second compound, and the third compound, and the first compound and the second compound may be to form an exciplex.

20 In an embodiment, the emission layer of the light-emitting device may include the first compound and the fourth compound, and the fourth compound may improve the color purity, emission efficiency, and/or lifespan characteristics of the light-emitting device.

25 In an embodiment, the second compound may be a compound represented by Formula 2:

30 Formula 2



35 In Formula 2,

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

45 $b51$ to $b53$ may each independently be an integer from 1 to 5,

50 X_{54} may be N or C(R_{54}), X_{55} may be N or C(R_{55}), X_{56} may be N or C(R_{56}), and at least one of X_{54} to X_{56} may be N,

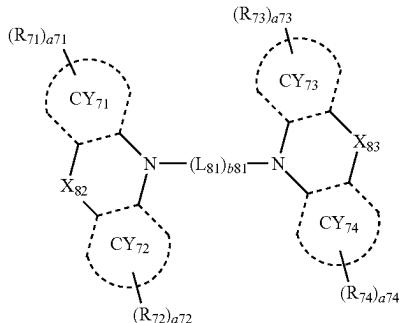
55 R_{51} to R_{56} may each independently be the same as described herein, and

60 R_{10a} may be the same as described herein.

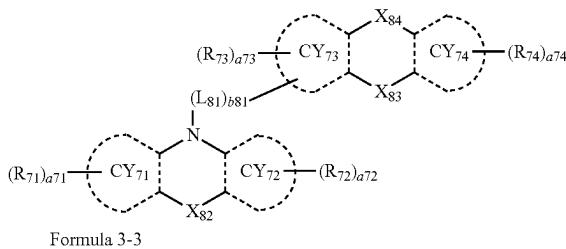
In an embodiment, the third compound may include a compound represented by Formula 3-1, a compound represented by Formula 3-2, a compound represented by Formula 3-3, a compound represented by Formula 3-4, a compound represented by Formula 3-5, or any combination thereof:

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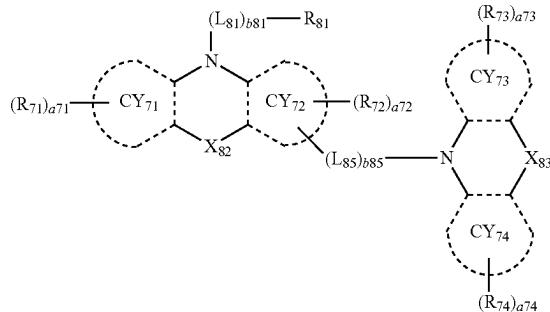
Formula 3-1



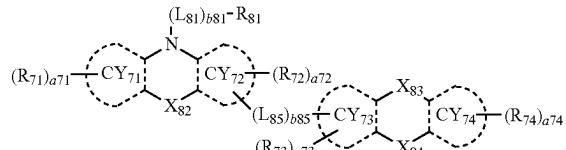
Formula 3-2



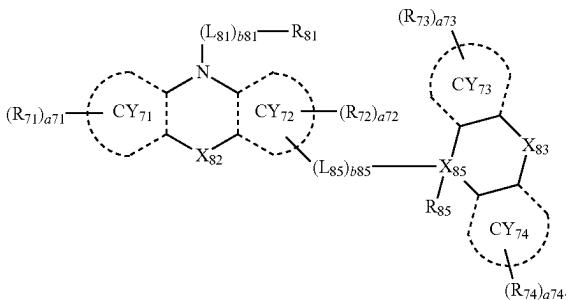
Formula 3-3



Formula 3-4



Formula 3-5



65 In Formulae 3-1 to 3-5,

ring CY₇₁ and ring CY₇₄ may each independently be a π electron-rich C_3 - C_{60} carbocyclic group or a pyridine group, X₈₂ may be a single bond, O, S, N-[$(L_{82})_{b82}$ -R₈₂], C(R_{82a}) (R_{82b}) , or Si(R_{82a}) (R_{82b}) ,

X₈₃ may be a single bond, O, S, N-[$(L_{83})_{b83}$ -R₈₃], C(R_{83a}) (R_{83b}) , or Si(R_{83a}) (R_{83b}) ,

15

X_{84} may be O, S, N—[(L_{84})_{b84}— R_{84}], C(R_{84a})(R_{84b}), or Si(R_{84a})(R_{84b}),

X_{85} may be C or Si,

L_{81} to L_{85} may each independently be a single bond,

—C(Q_4)(Q_5), *—Si(Q_4)(Q_5)*, a C_3 - C_{60} cyclic group unsubstituted or substituted with at least one R_{10a} , or a pyridine group unsubstituted or substituted with at least one R_{10a} , and Q_4 and Q_5 may each independently be the same as described in connection with Q_1 ,

$b81$ to $b85$ may each independently be an integer from 1 to 5,

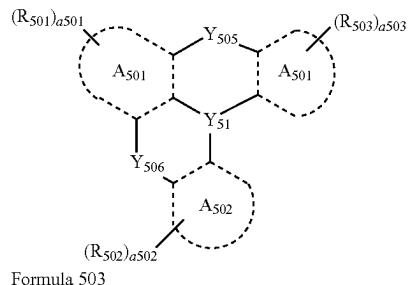
R_{71} to R_{74} , R_{81} to R_{85} , R_{82a} , R_{82b} , R_{83a} , R_{83b} , R_{84a} , and R_{84b} may each independently be the same as described herein,

$a71$ to $a74$ may each independently be an integer from 0 to 20, and

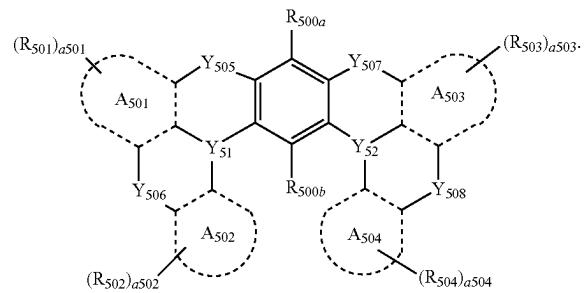
R_{10a} may be the same as described herein.

In an embodiment, the fourth compound may include a compound represented by Compound 502, a compound represented by Compound 503, or any combination thereof:

Formula 502



Formula 503



In Formulae 502 and 503,

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

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

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

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

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

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

R_{50a} , R_{50b} , R_{501} to R_{508} , R_{505a} , R_{505b} , R_{506a} , R_{506b} , R_{507a} , R_{507b} , R_{508a} , and R_{508b} may each independently be the same as described herein,

$a501$ to $a504$ may each independently be an integer from 0 to 20, and

R_{10a} may be the same as described herein.

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Description of Formulae 1 to 4

b51 to b53 in Formula 2 may each indicate the number of $L_{51}(s)$ to $L_{53}(s)$, and may each independently be an integer from 1 to 5. When b51 is 2 or more, the two or more $L_{51}(s)$ may be identical to or different from each other, and when b52 is 2 or more, the two or more $L_{52}(s)$ may be identical to or different from each other, and when b53 is 2 or more, the two or more $L_{53}(s)$ may be identical to or different from each other. In an embodiment, b51 to b53 may each independently be 1 or 2.

In Formulae 1 and 2, L_1 , L_7 , and L_{51} to L_{53} may each independently be:

a single bond; or

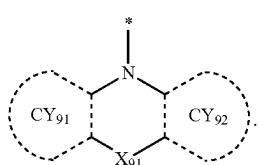
a benzene group, a naphthalene group, an anthracene group, a phenanthrene group, a triphenylene group, a pyrene group, a chrysene group, a cyclopentadiene group, a furan group, a thiophene group, a silole group, an indene group, a fluorene group, an indole group, a carbazole group, a benzofuran group, a dibenzofuran group, a benzothiophene group, a dibenzothiophene group, a benzosilole group, a dibenzosilole group, an azafuorene group, an azacarbazole group, an azadibenzofuran group, an azadibenzothiophene group, an azadibenzosilole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a quinoxaline group, a quinazoline group, a phenanthroline group, a pyrrole group, a pyrazole group, an imidazole group, a triazole group, an oxazole group, an isooxazole group, a thiazole group, an isothiazole group, an oxadiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a benzoxazole group, a benzothiazole group, a benzoxadiazole group, a benzothiadiazole group, a dibenzoxasiline group, a dibenzothiasilane group, a dibenzodihydroazasiline group, a dibenzodihydrodilysine group, a dibenzodihydrosyline group, a dibenzodioxine group, a dibenzooxathiane group, a dibenzooxazine group, a dibenzopyran group, a dibenzodithiine group, a dibenzothiazine group, a dibenzothiopyran group, a dibenzocyclohexadiene group, a dibenzodihydropyridine group, or a dibenzodihydropyrazine group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C_1 - C_{20} alkyl group, a C_1 - C_{20} alkoxy group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a triazinyl group, a fluorenyl group, a dimethylfluorenyl group, a diphenylfluorenyl group, a carbazolyl group, a phenylcarbazolyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a dibenzosilolyl group, a dimethylbibenzosilolyl group, a diphenyldibenzosilolyl group, —O(Q_{31}), —S(Q_{31}), —Si(Q_{31})(Q_{32})(Q_{33}), —N(Q_{31})(Q_{32}), —B(Q_{31})(Q_{32}), —P(Q_{31})(Q_{32}), —C(=O)(Q_{31}), —S(=O)₂(Q_{31}), —P(=O)(Q_{31})(Q_{32}), or any combination thereof,

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

In an embodiment, in Formula 2, a bond between L_{51} and R_{51} , a bond between L_{52} and R_{52} , a bond between L_{53} and R_{53} , a bond between two or more $L_{51}(s)$, a bond between two or more $L_{52}(s)$, a bond between two or more $L_{53}(s)$, a

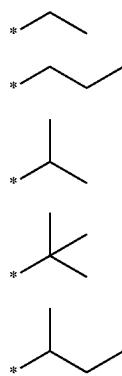
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Formula 91



In Formula 91,
ring CY₉₁ and ring CY₉₂ may each independently be a C₅-C₃₀ carbocyclic group unsubstituted or substituted with at least one R_{10a} or a C₁-C₃₀ heterocyclic group unsubstituted or substituted with at least one R_{10a},
X₉₁ may be a single bond, O, S, N(R₉₁), B(R₉₁), C(R_{91a}) (R_{91b}), or Si(R_{91a})(R_{91b}),
R₉₁, R_{91a}, and R_{91b} may each independently be the same as described in connection with R₈₂, R_{82a}, and R_{82b},
R_{10a} may be the same as described herein, and indicates a binding site to a neighboring atom.
For example, in Formula 91,
ring CY₉₁ and ring CY₉₂ may each independently be a benzene group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, or a triazine group, each unsubstituted or substituted with at least one R_{10a},
R₉₁, R_{91a}, and R_{91b} may each independently be selected from:
hydrogen or a C₁-C₂₀ alkyl group; or
a phenyl group, a pyridinyl group, a pyrimidinyl group, a pyridazinyl group, a pyrazinyl group, or a triazinyl group, each unsubstituted or substituted with deuterium, a C₁-C₁₀ alkyl group, a phenyl group, a biphenyl group, a pyridinyl group, a pyrimidinyl group, a pyridazinyl group, a pyrazinyl group, a triazinyl group, or any combination thereof.

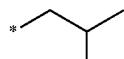
In an embodiment, i) R₁ to R₅, Z₁₁, and Z₁₂ in Formula 1, ii) R₅₁ to R₅₆, R₇₁ to R₇₄, R₈₁ to R₈₅, R_{82a}, R_{82b}, R_{83a}, R_{83b}, R_{84a}, R_{84b}, R_{500a}, R_{500b}, R₅₀₁ to R₅₀₈, R_{505a}, R_{505b}, R_{506a}, R_{506b}, R_{507a}, R_{507b}, R_{508a}, and R_{508b} in Formulae 2, 3-1 to 3-5, 502, and 503, and iii) R_{10a} may each independently be: hydrogen, deuterium, —F, a cyano group, a nitro group, —CH₃, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H, —CFH₂, a group represented by one of Formulae 9-1 to 9-19, a group represented by one of Formulae 10-1 to 10-246, —C(Q₁)(Q₂)(Q₃), —Si(Q₁)(Q₂)(Q₃), or —P(=O)(Q₁)(Q₂)(Q₁ to Q₃) may each independently be the same as described herein:



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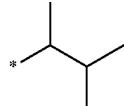
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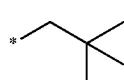
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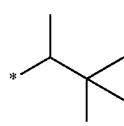
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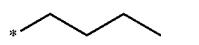
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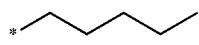
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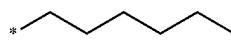
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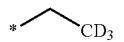
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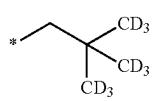
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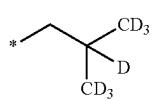
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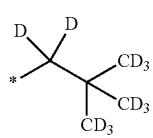
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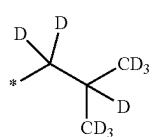
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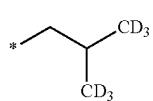
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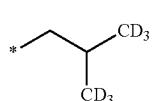
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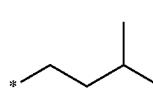
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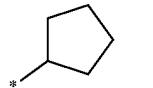
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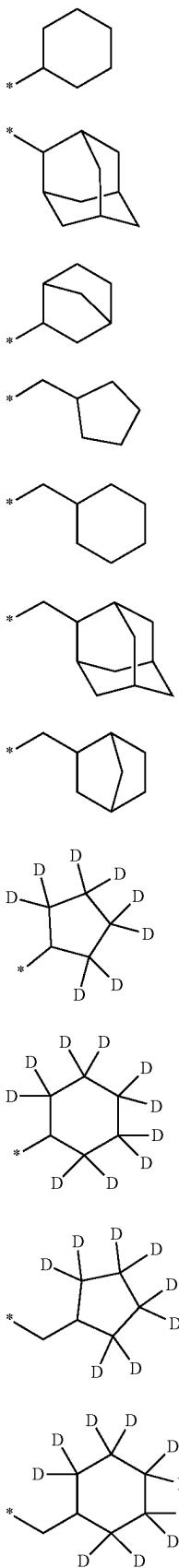
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10-1

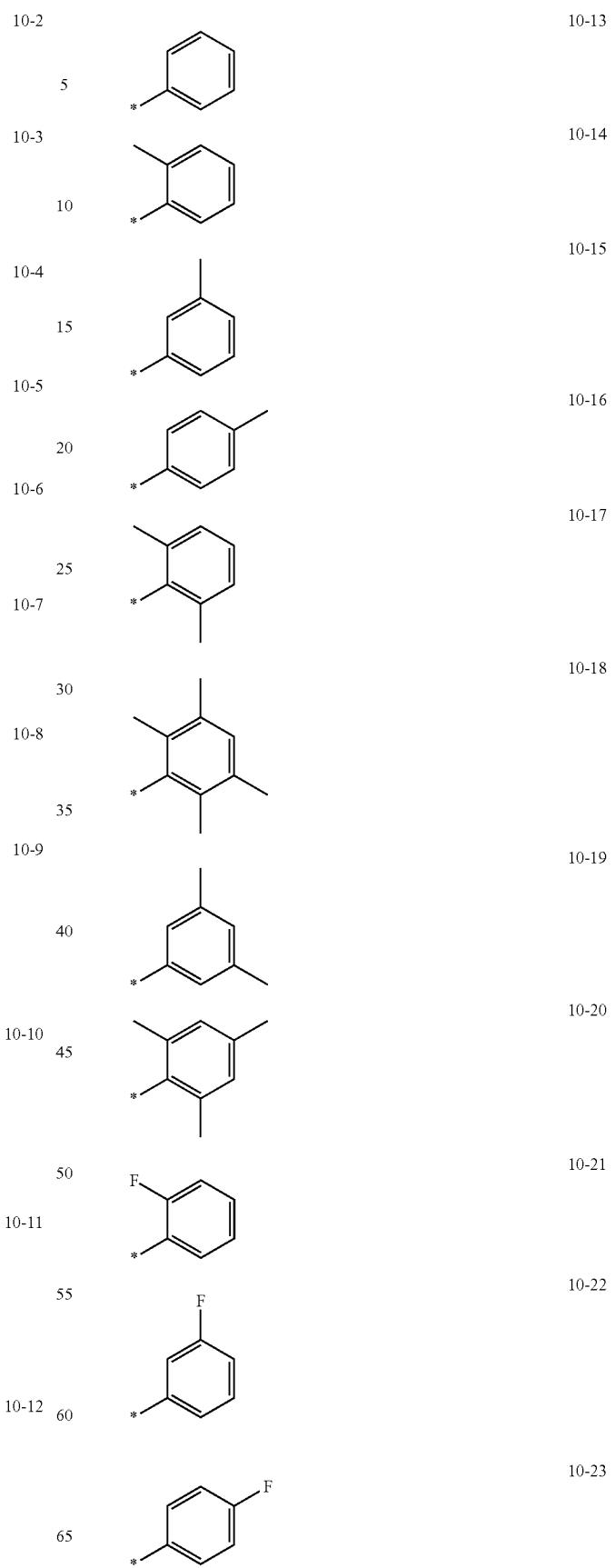


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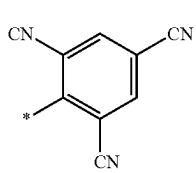
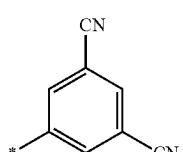
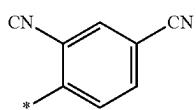
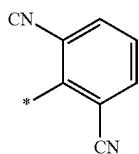
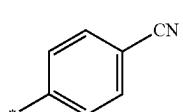
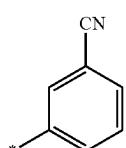
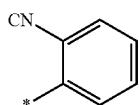
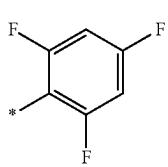
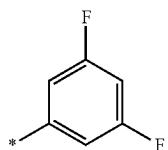
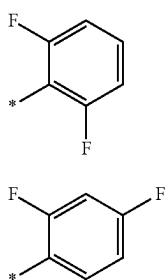


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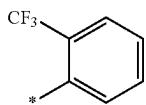
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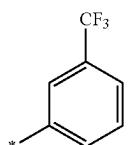


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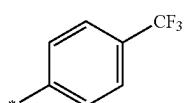
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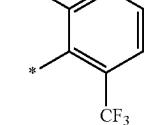
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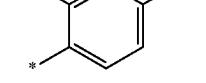
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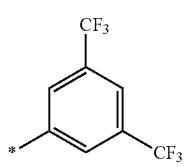
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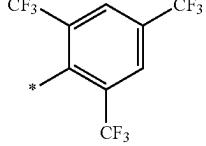
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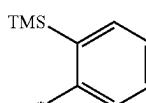
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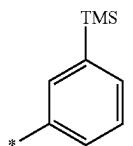
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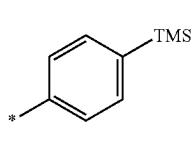
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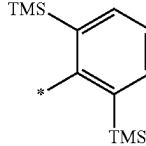
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10-33 10-44

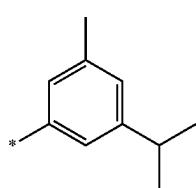
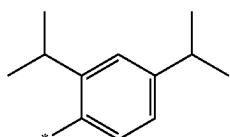
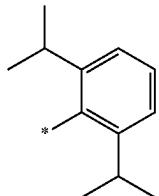
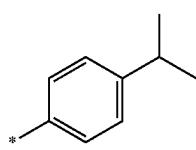
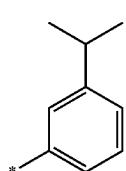
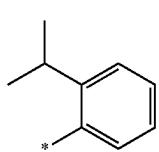
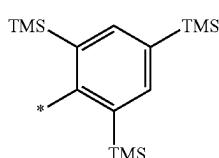
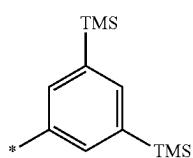
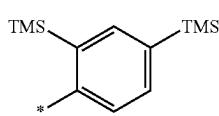


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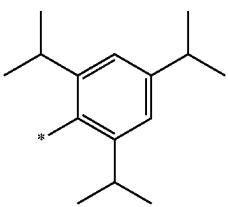
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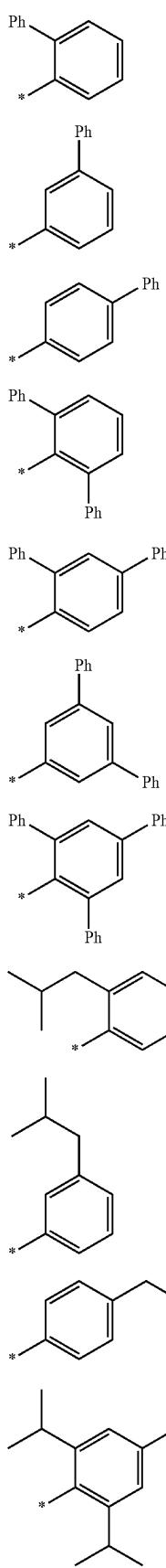
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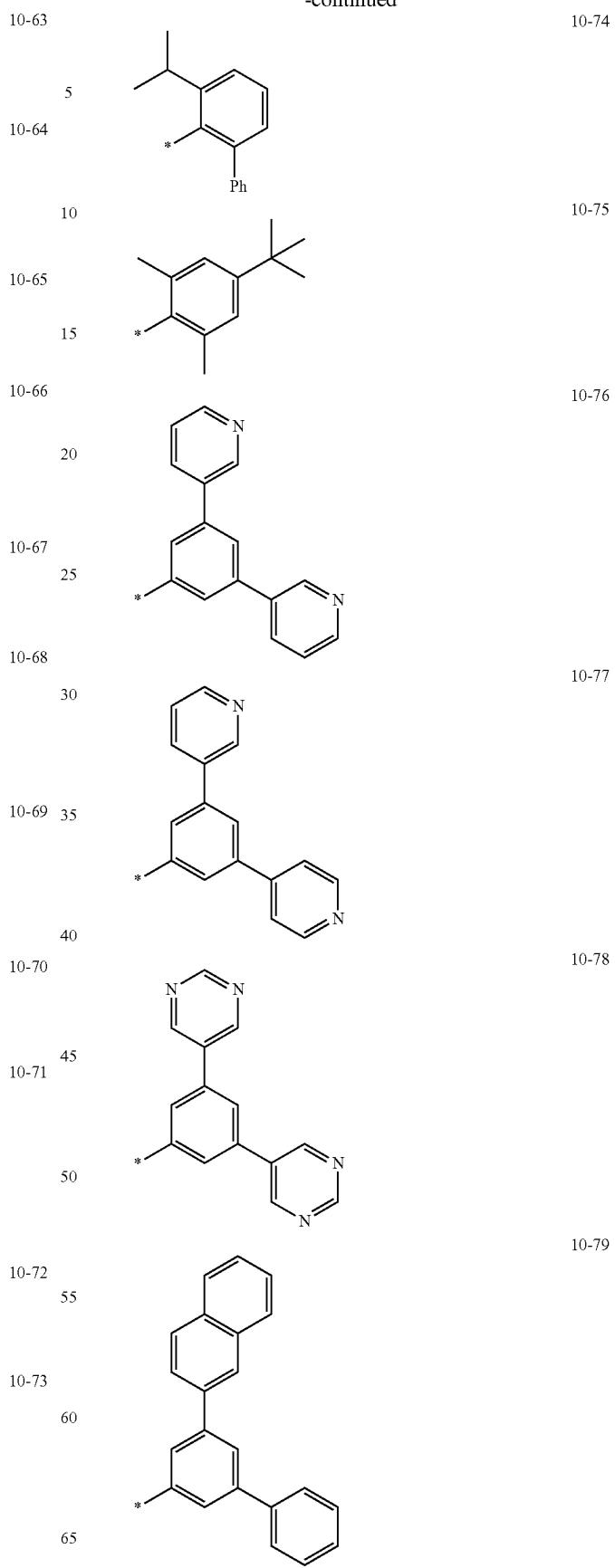
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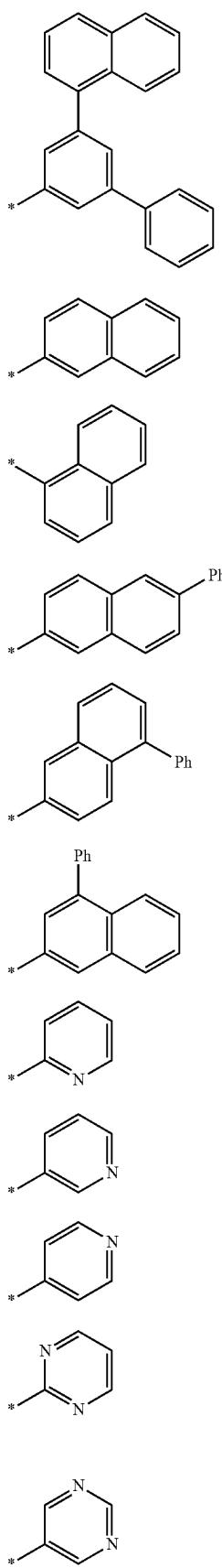
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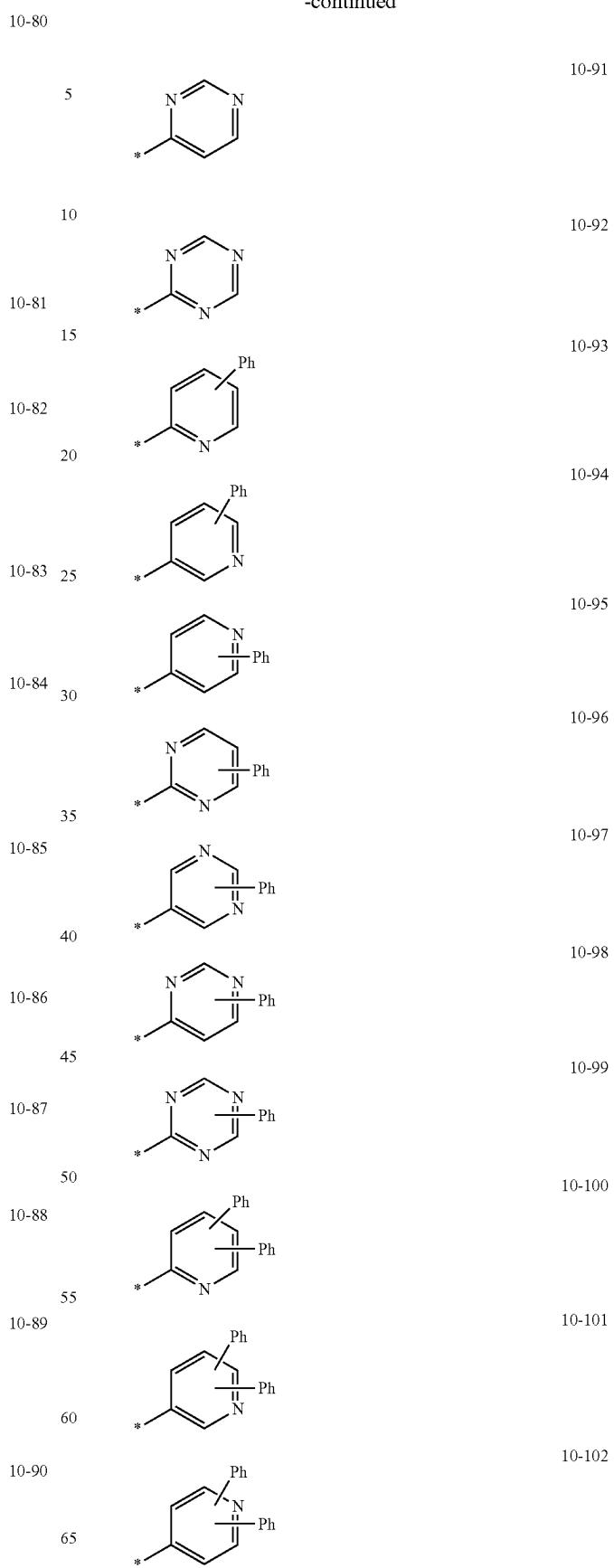
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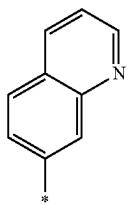
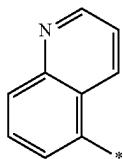
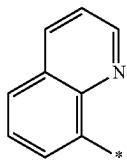
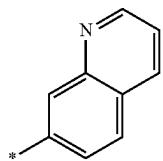
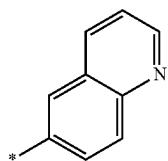
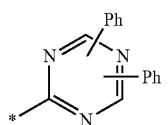
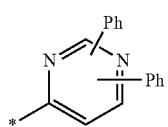
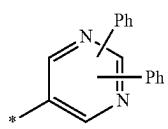
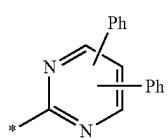


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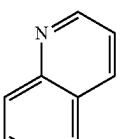
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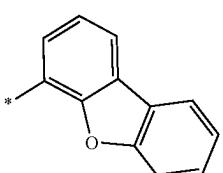


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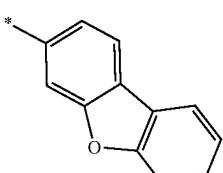
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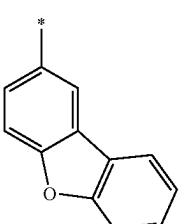
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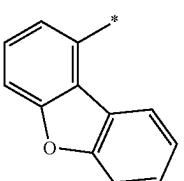
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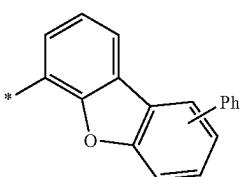
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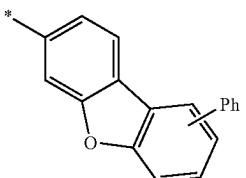
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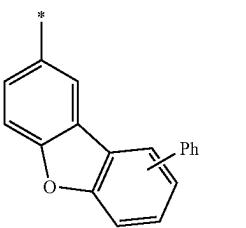
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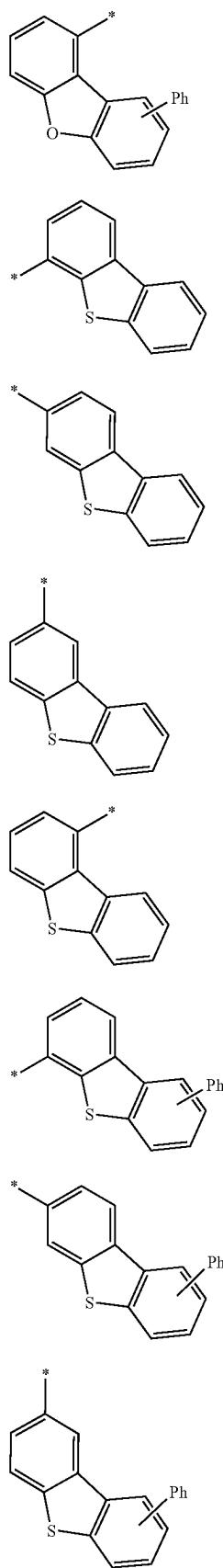
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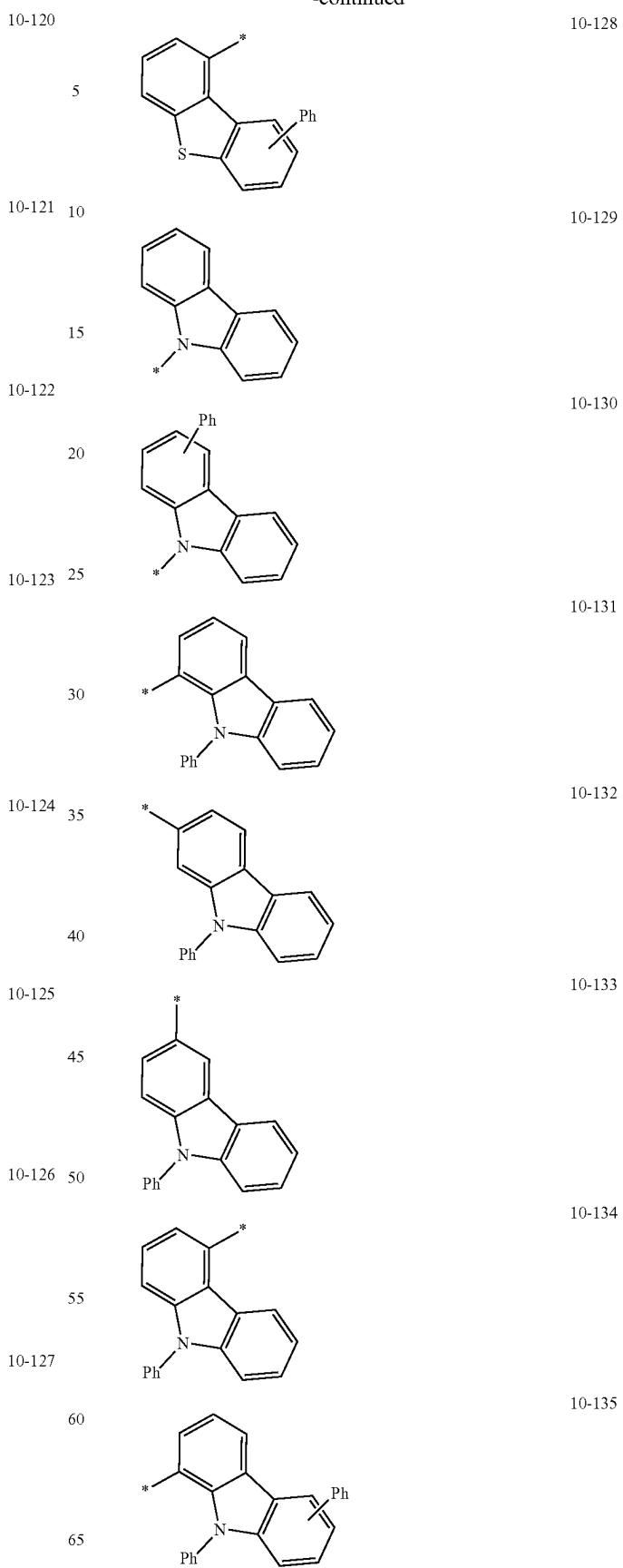
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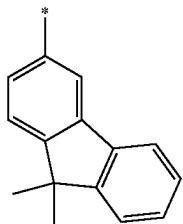
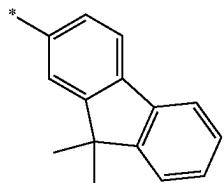
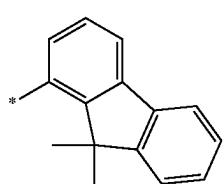
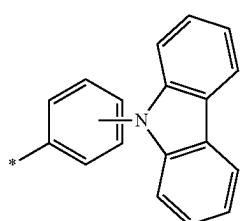
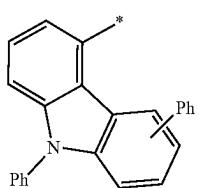
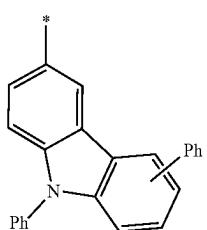
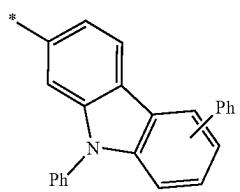


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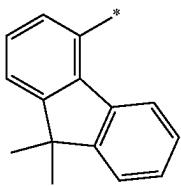
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**36**

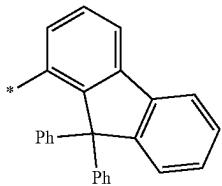
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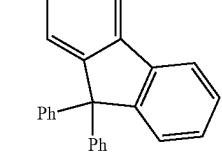
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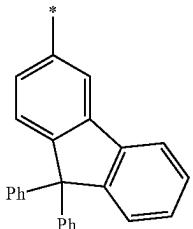
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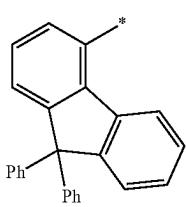
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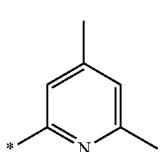
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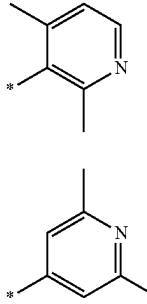
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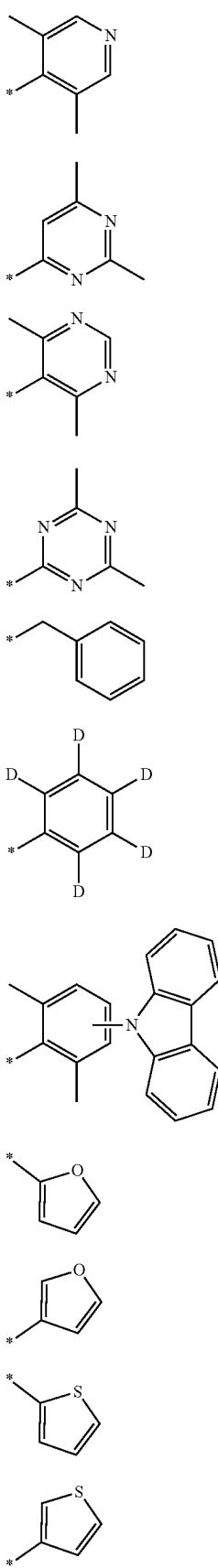
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10-149

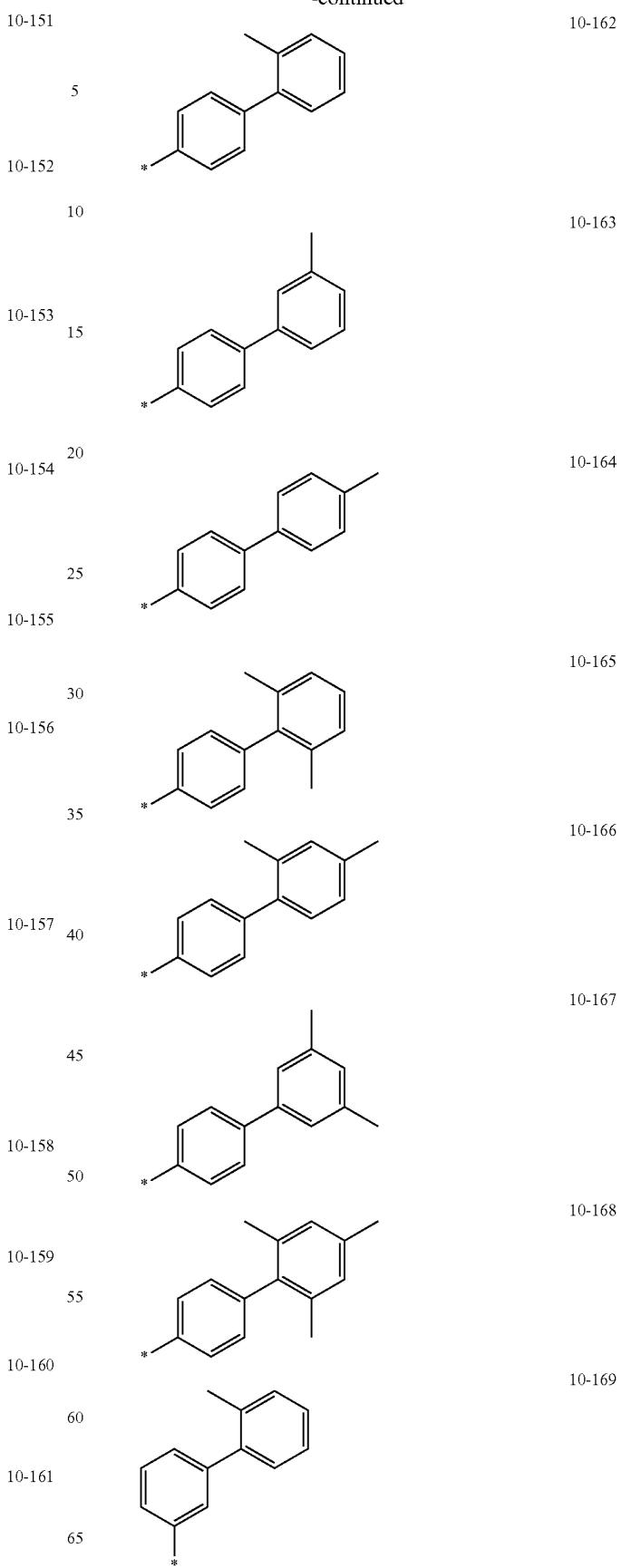
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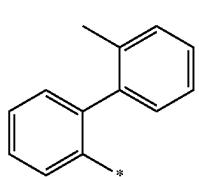
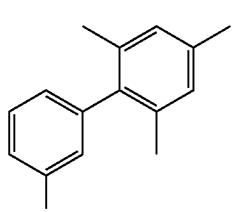
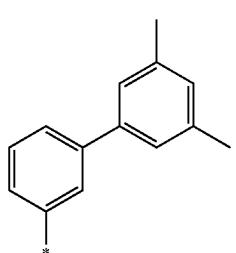
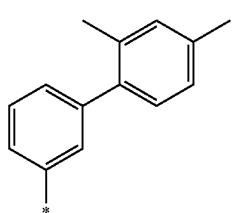
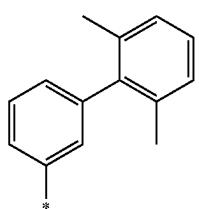
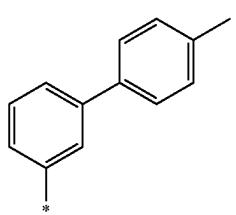
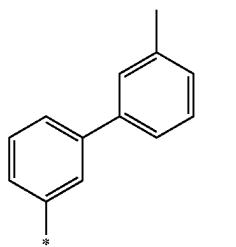
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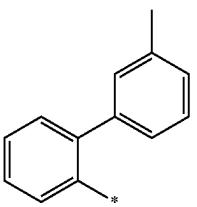


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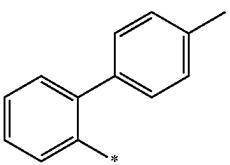
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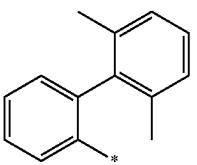
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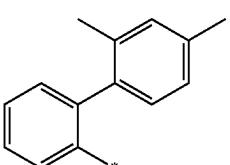
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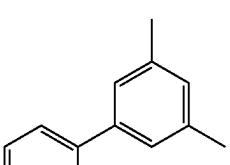
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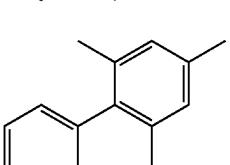
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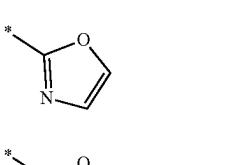
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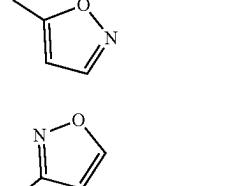


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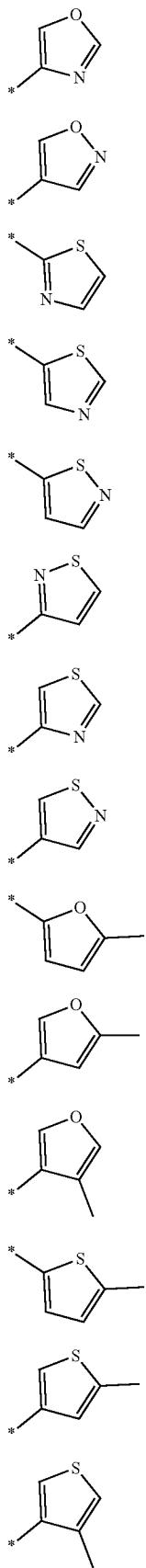
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10-185

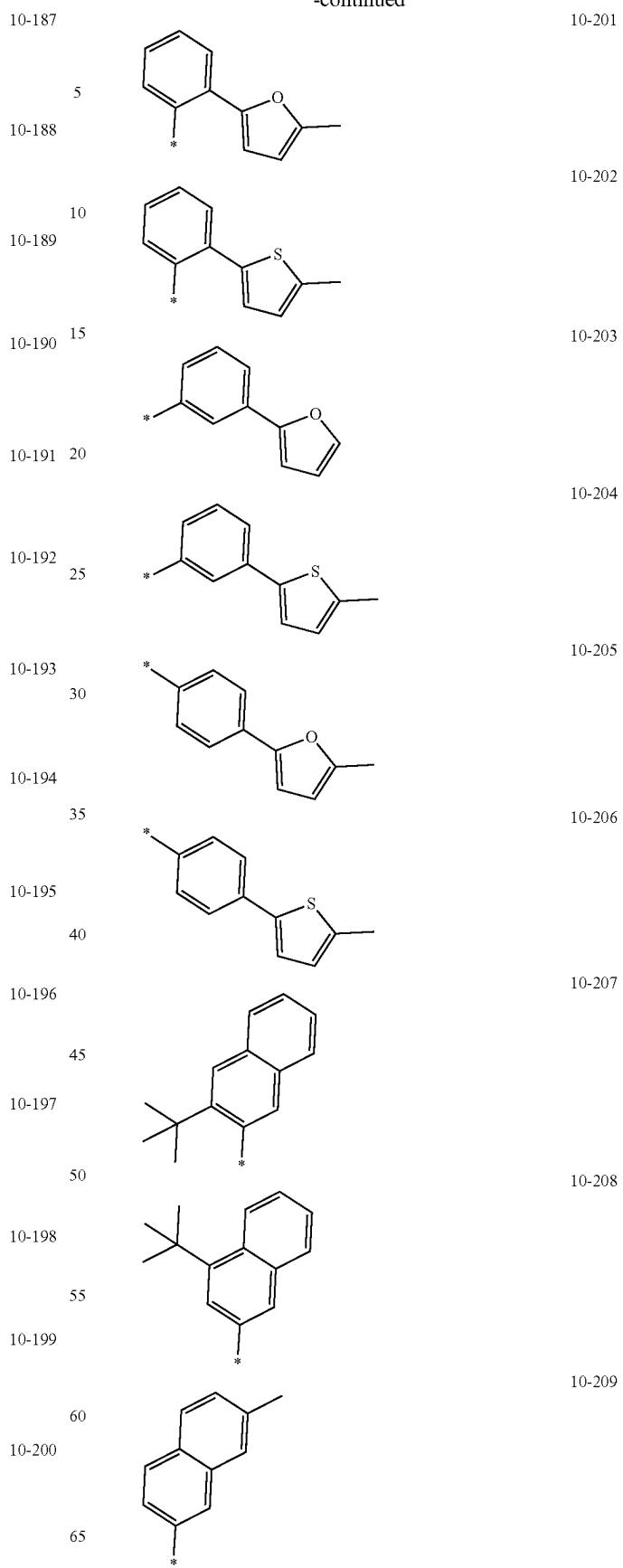
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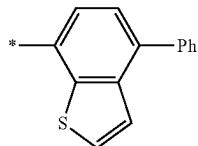
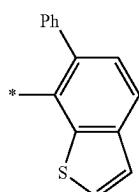
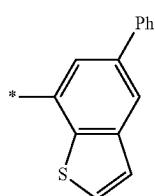
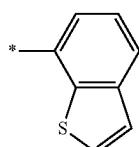
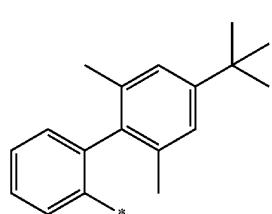
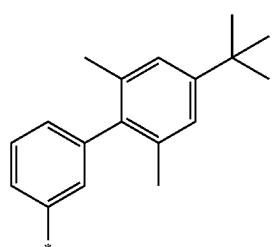
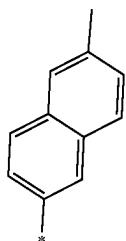


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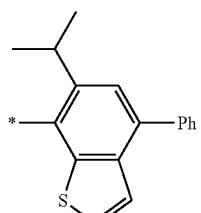
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43
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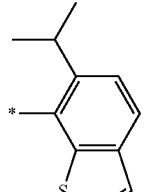
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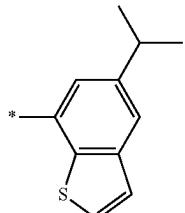
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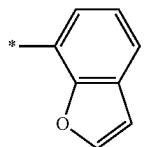
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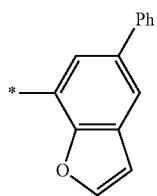
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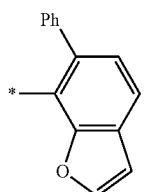
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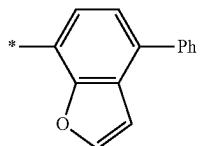


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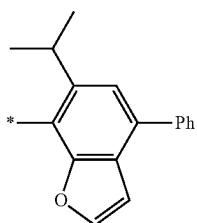


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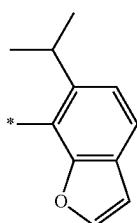
US 12,391,715 B2

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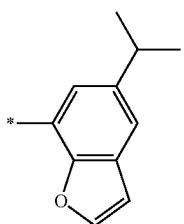
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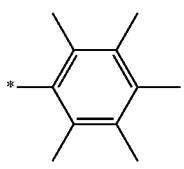
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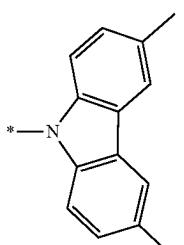
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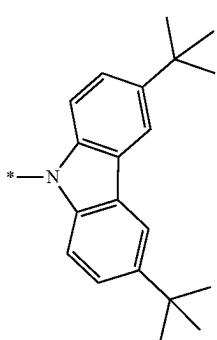
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10-228

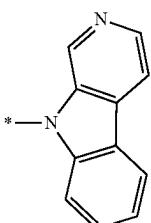


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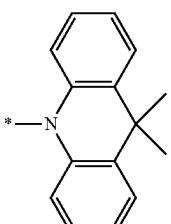
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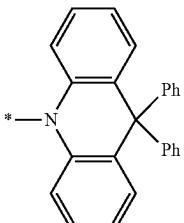
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10-231

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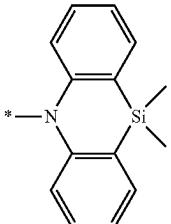
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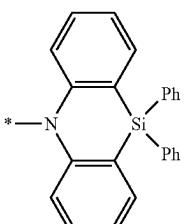
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10-233

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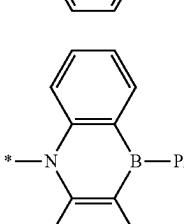
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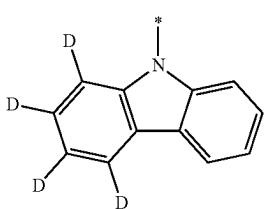
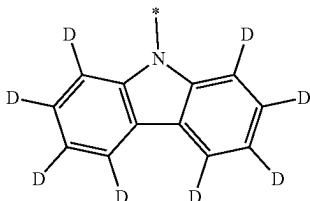
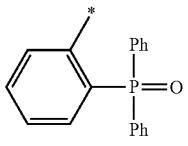
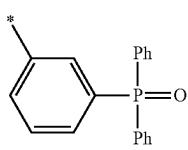
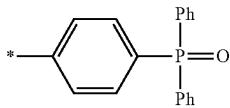
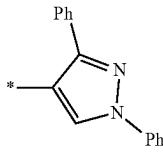
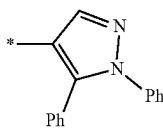
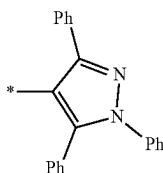
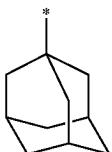
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10-236

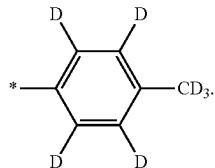
47

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**48**

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10-237



10-238 10

In Formulae 9-1 to 9-19 and 10-1 to 10-246, * indicates a binding site to a neighboring atom, Ph may be a phenyl group, and TMS may be a trimethylsilyl group.

In Formulae 3-1 to 3-5, 502, and 503, a71 to a74 and a501 to a504 each indicate the number of R₇₁(s) to R₇₄(s) and R₅₀₁(s) to R₅₀₄(s), and may each independently be an integer of 0 to 20. When a71 is 2 or more, two or more R₇₁(s) may be identical to or different from each other, when a72 is 2 or more, two or more R₇₁(s) may be identical to or different

10-239

from each other, when a73 is 2 or more, two or more R₇₃(s) may be identical to or different from each other, when a74 is 2 or more, two or more R₇₄(s) may be identical to or different from each other, when a501 is 2 or more, two or more R₅₀₁(s) may be identical to or different from each other, when a502 is 2 or more, two or more R₅₀₂(s) are identical to or different from each other, when a503 is 2 or more, two or more R₅₀₃(s) may be identical to or different from each other, and when a504 is 2 or more, two or more R₅₀₄(s) may be identical to or different from each other. a71 to a74 and a501 to a504 may each independently be an integer of 0 to 8.

10-240

In Formula 2, a group represented by *-(L₅₁)_{b51}-R₅₁ and a group represented by *-(L₅₂)_{b52}-R₅₂ may not be a phenyl group.

In an embodiment, in Formula 2, a group represented by *-(L₅₁)_{b51}-R₅₁ and a group represented by *-(L₅₂)_{b52}-R₅₂ may be identical to each other.

In an embodiment, in Formula 2, a group represented by *-(L₅₁)_{b51}-R₅₁ and a group represented by *-(L₅₂)_{b52}-R₅₂ may be different from each other.

10-243

In an embodiment, in Formula 2, b51 and b52 may be 1, 2 or 3, and L₅₁ and L₅₂ may each independently be a benzene group, a pyridine group, a pyrimidine group, a pyridazine group, a pyrazine group, or a triazine group, each unsubstituted or substituted with at least one R_{10a}.

10-244 50

In an embodiment, in Formula 2, R₅₁ and R₅₂ may each independently be a C₃-C₆₀ carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C₁-C₆₀ heterocyclic group unsubstituted or substituted with at least one R_{10a}, a C₆-C₆₀ aryloxy group unsubstituted or substituted with at least one R_{10a}, a C₆-C₆₀ arylthio group unsubstituted or substituted with at least one R_{10a}, —C(Q₁)(Q₂)(Q₃), or —Si(Q₁)(Q₂)(Q₃), and

Q₁ to Q₃ may each independently be a C₃-C₆₀ carbocyclic group or a C₁-C₆₀ heterocyclic group unsubstituted or substituted with deuterium, —F, a cyano group, a C₁-C₆₀ alkyl group, a C₁-C₆₀ alkoxy group, a phenyl group, a biphenyl group, or any combination thereof.

10-245

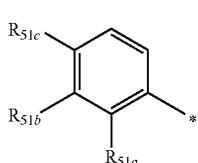
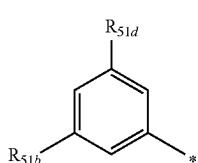
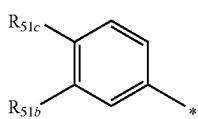
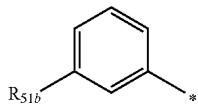
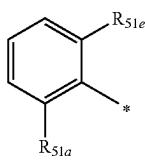
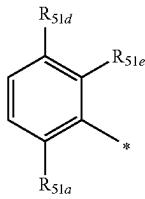
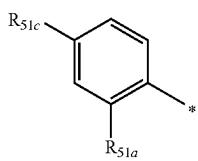
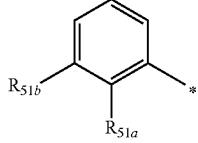
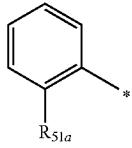
In an embodiment, the group represented by *-(L₅₁)_{b51}-R₅₁ in Formula 2 may be a group represented by one of Formulae CY51-1 to CY51-26, and/or

the group represented by *-(L₅₂)_{b52}-R₅₂ in Formula 2 may be a group represented by one of Formulae CY52-1 to CY52-26, and/or

10-246

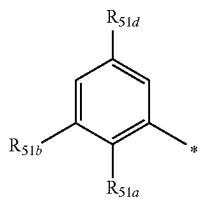
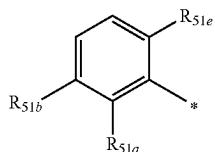
49

the group represented by $*-(L_{53})_{b53}-R_{53}$ in Formula 2 may be a group represented by one of Formulae CY53-1 to CY53-27, —C(Q₁)(O₂)(O₃), or —Si(Q₁)(Q₂)(Q₃):

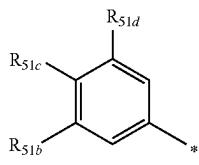
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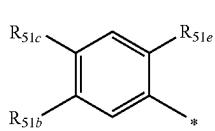
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CY51-110
CY51-2

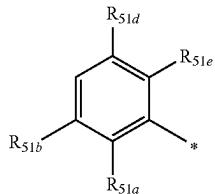
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CY51-3
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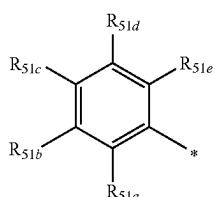
CY51-12

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CY51-4

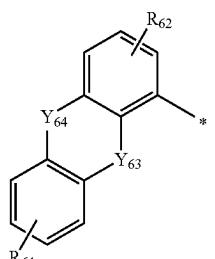
CY51-13

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CY51-5
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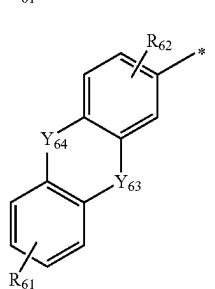
CY51-14

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CY51-6

CY51-15

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CY51-7

CY51-16

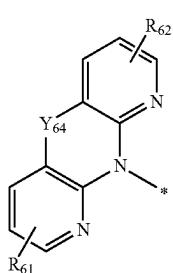
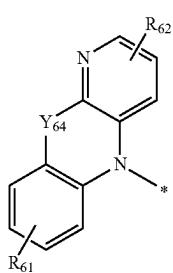
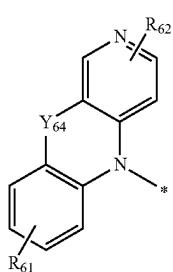
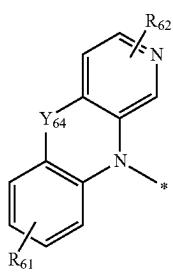
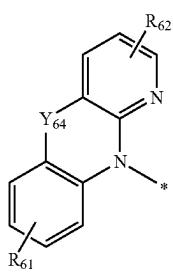
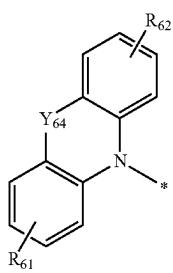
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CY51-17

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CY51-9
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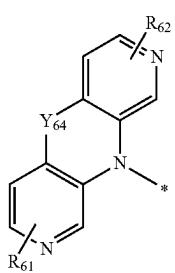
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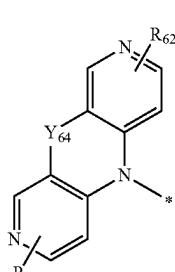


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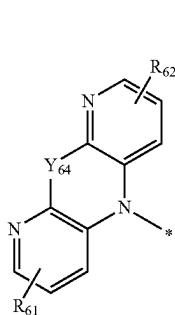
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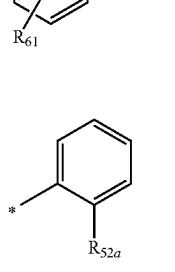
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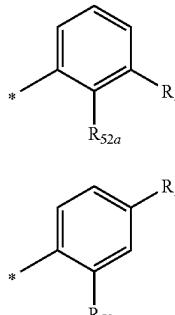
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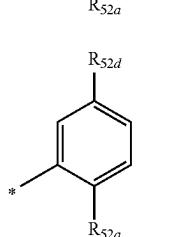
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CY51-22



CY51-23



CY51-24

CY51-25

CY51-26

CY52-1

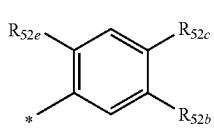
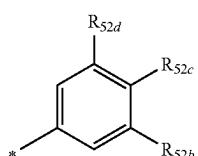
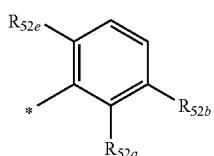
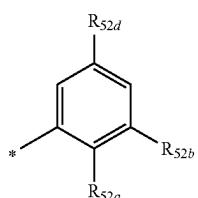
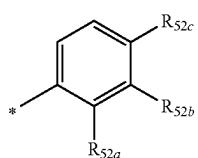
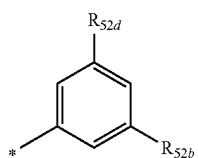
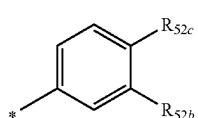
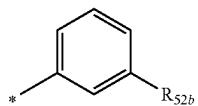
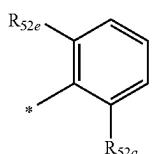
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CY52-3

CY52-4

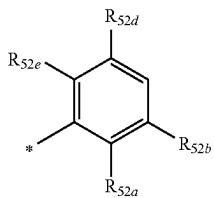
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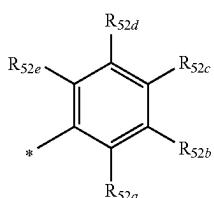


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CY52-5



CY52-6 10



CY52-7

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CY52-8

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CY52-9

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CY52-10

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CY52-11

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CY52-12

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CY52-13

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CY52-14

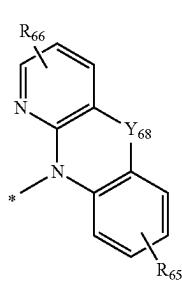
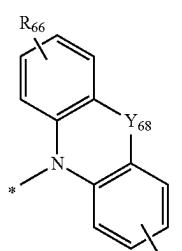
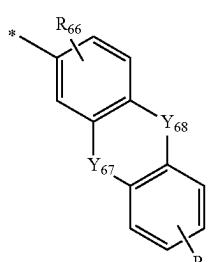
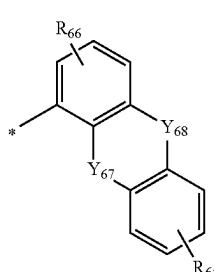
CY52-15

CY52-16

CY52-17

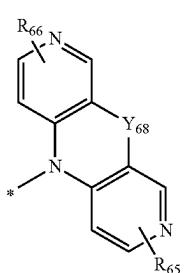
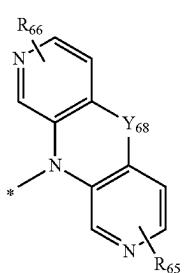
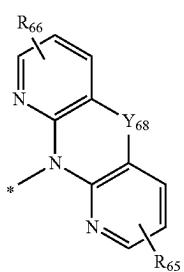
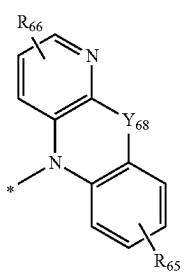
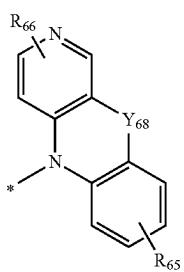
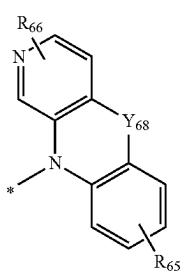
CY52-18

CY52-19



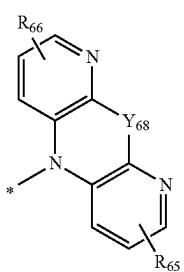
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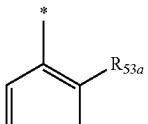


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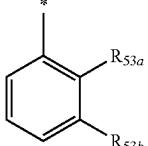
CY52-20



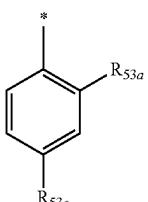
CY52-21



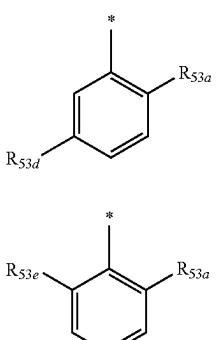
CY52-22



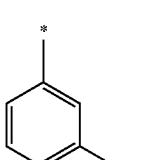
CY52-23



CY52-24



CY52-25



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CY52-26

CY53-1

CY53-2

CY53-3

CY53-4

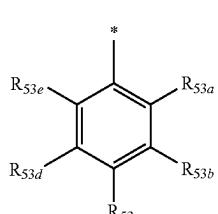
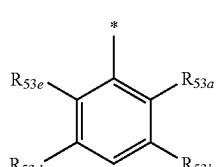
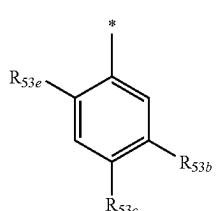
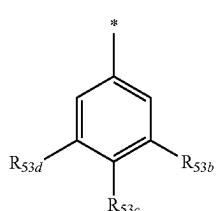
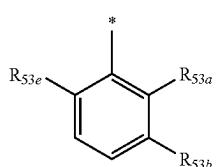
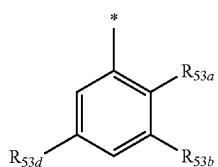
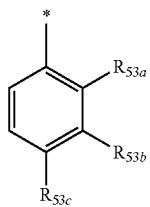
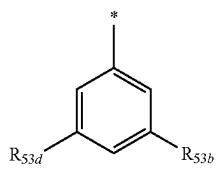
CY53-5

CY53-6

CY53-7

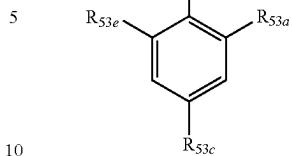
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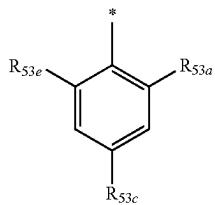


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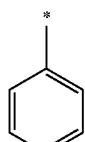
CY53-8



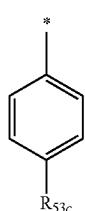
5 CY53-9 10



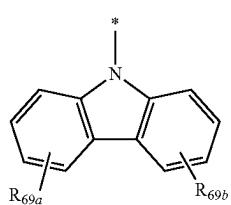
15 CY53-10



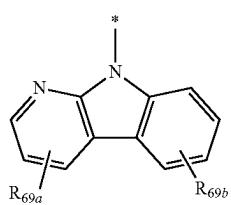
20 CY53-11 25



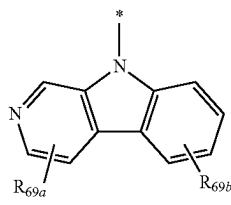
30 CY53-12 35



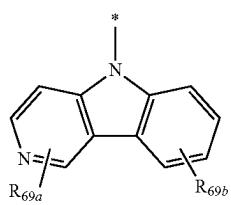
40 CY53-13



50 CY53-14



CY53-15



CY53-16

CY53-17

CY53-18

CY53-19

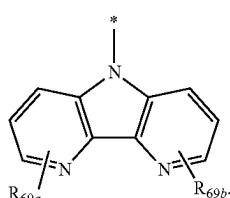
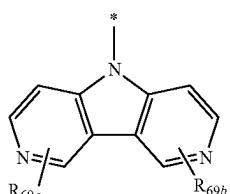
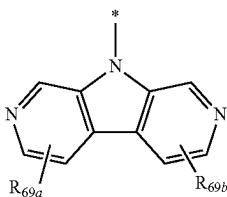
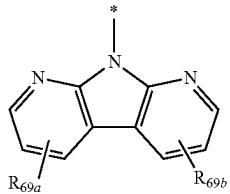
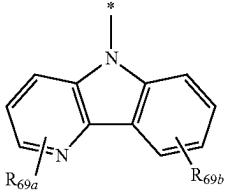
CY53-20

CY53-21

CY53-22

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

Y₆₃ may be a single bond, O, S, N(R₆₃), B(R₆₃), C(R₆₃)₂
(R_{63b}), or Si(R_{63a})(R_{63b}),

Y₆₄ may be a single bond, O, S, N(R₆₄), B(R₆₄), C(R₆₄)₂
(R_{64b}), or Si(R_{64a})(R_{64b}),

Y₆₇ may be a single bond, O, S, N(R₆₇), B(R₆₇), C(R_{67a})₂
(R_{67b}), or Si(R_{67a})(R_{67b}),

Y₆₈ may be a single bond, O, S, N(R₆₈), B(R₆₈), C(R_{68a})₂
(R_{68b}), or Si(R_{68a})(R_{68b}),

each of Y₆₃ and Y₆₄ in Formulae CY51-16 and CY51-17
may not be a single bond,

each of Y₆₇ and Y₆₈ in Formulae CY52-16 and CY52-17
may not be a single bond,

R_{51a} to R_{51e}, R₆₁ to R₆₄, R_{63a}, R_{63b}, R_{64a}, and R_{64b} may
each independently be the same as described in con-
nection with R₅₁, and each of R_{51a} to R_{51e} may not be
hydrogen,

R_{52a} to R_{52e}, R₆₅ to R₆₈, R_{67a}, R_{67b}, R_{68a}, and R_{68b} may
each independently be same as described in connection
with R₅₂, and each of R_{52a} to R_{52e} is not hydrogen,

CY53-23

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R_{53a} to R_{53e}, R_{69a} and R_{69b} may each independently be
the same as described in connection with R₅₃, and each
of R_{53a} to R_{53e} may not be hydrogen, and
indicates a binding site to a neighboring atom.

For example,

R_{51a} to R_{51e} and R_{52a} to R_{52e} in Formulae CY51-1 to
CY51-26 and Formulae CY52-1 to 52-26 may each
independently be:

a cyclopentyl group, a cyclohexyl group, a cycloheptyl
group, a cyclooctyl group, an adamantanyl group, a
norbornanyl group, a norbornenyl group, a cyclopentenyl
group, a cyclohexenyl group, a cycloheptenyl
group, a phenyl group, a biphenyl group, a C₁-C₁₀
alkylphenyl group, a naphthyl group, a fluorenyl group,
a phenanthrenyl group, an anthracenyl group, a fluo-
ranthenyl group, a triphenylenyl group, a pyrenyl
group, a chrysenyl group, a pyrrolyl group, a thiophe-
nyl group, a furanyl group, an imidazolyl group, a
pyrazolyl group, a thiazolyl group, an isothiazolyl
group, an oxazolyl group, an isoxazolyl group, a pyridi-
nyl group, a pyrazinyl group, a pyrimidinyl group, a
pyridazinyl group, an isoindolyl group, an indolyl
group, an indazolyl group, a purinyl group, a quinolinyl
group, an isoquinolinyl group, a benzoquinolinyl
group, a quinoxalinyl group, a quinazolinyl group, a
cinnolinyl group, a carbazolyl group, a phenanthrolinyl
group, a benzimidazolyl group, a benzofuranyl group,
a benzothiophenyl group, an isobenzothiazolyl group, a
benzoxazolyl group, an isobenzoxazolyl group, a tri-
azolyl group, a tetrazolyl group, an oxadiazolyl group,
a triazinyl group, a dibenzofuranyl group, a dibeno-
thiophenyl group, a benzocarbazolyl group, a dibeno-
carbazolyl group, an imidazopyridinyl group, an imi-
dazopyrimidinyl group, an azacarbazolyl group, an
azadibenzofuranyl group, an azadibenzothiophenyl
group, an azafluorenyl group, an azadibenzosilolyl
group, or a group represented by Formula 91, each
unsubstituted or substituted with deuterium, —F, —Cl,
—Br, —I, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H,
—CFH₂, a hydroxyl group, a cyano group, a nitro
group, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a
cyclopentyl group, a cyclohexyl group, a cycloheptyl
group, a cyclooctyl group, an adamantanyl group, a
norbornanyl group, a norbornenyl group, a cyclopentenyl
group, a cyclohexenyl group, a cycloheptenyl
group, a phenyl group, a biphenyl group, a C₁-C₁₀
alkylphenyl group, a naphthyl group, a fluorenyl group,
a phenanthrenyl group, an anthracenyl group, a fluo-
ranthenyl group, a triphenylenyl group, a pyrenyl
group, a chrysenyl group, a pyrrolyl group, a thiophe-
nyl group, a furanyl group, an imidazolyl group, a
pyrazolyl group, a thiazolyl group, an isothiazolyl
group, an oxazolyl group, an isoxazolyl group, a pyridi-
nyl group, a pyrazinyl group, a pyrimidinyl group, a
pyridazinyl group, an isoindolyl group, an indolyl
group, an indazolyl group, a purinyl group, a quinolinyl
group, an isoquinolinyl group, a benzoquinolinyl
group, a quinoxalinyl group, a quinazolinyl group, a
cinnolinyl group, a carbazolyl group, a phenanthrolinyl
group, a benzimidazolyl group, a benzofuranyl group,
a benzothiophenyl group, an isobenzothiazolyl group, a
benzoxazolyl group, an isobenzoxazolyl group, a tri-
azolyl group, a tetrazolyl group, an oxadiazolyl group,
a triazinyl group, a dibenzofuranyl group, a dibeno-
thiophenyl group, a benzocarbazolyl group, a dibeno-
carbazolyl group, an imidazopyridinyl group, an imi-
dazopyrimidinyl group, an azacarbazolyl group, an
azadibenzofuranyl group, an azadibenzothiophenyl
group, an azafluorenyl group, an azadibenzosilolyl
group, or a group represented by Formula 91, each
unsubstituted or substituted with deuterium, —F, —Cl,
—Br, —I, —CD₃, —CD₂H, —CDH₂, —CF₃, —CF₂H,
—CFH₂, a hydroxyl group, a cyano group, a nitro
group, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a

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benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzo-thiophenyl group, a benzocarbazolyl group, a dibenzo-carbazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, or any combination thereof; or —C(Q₁)(Q₂)(Q₃) or —Si(Q₁)(Q₂)(Q₃), wherein Q₁ to Q₃ may each independently be a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a pyridazinyl group, a pyrazinyl group, or triazinyl group, each unsubstituted or substituted with deuterium, a C₁-C₁₀ alkyl group, a phenyl group, a biphenyl group, a pyridinyl group, a pyrimidinyl group, a pyridazinyl group, a pyrazinyl group, a triazinyl group, or any combination thereof,

in Formulae CY51-16 and CY51-17, i) Y₆₃ may be O or S and Y₆₄ may be Si(R_{64a})(R_{64b}), or ii) Y₆₃ may be Si(R_{63a})(R_{63b}) and Y₆₄ may be O or S, and in Formulae CY52-16 and CY52-17, i) Y₆₇ may be O or S and Y₆₈ may be Si(R_{68a})(R_{68b}), or ii) Y₆₇ may be Si(R_{67a})(R_{67b}) and Y₆₈ may be O or S.

In Formulae 3-1 to 3-5, L₈₁ to L₈₅ may each independently be:

a single bond;

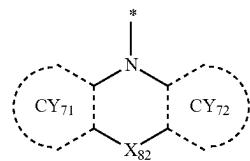
—C(Q₄)(Q₅)! or *—Si(Q₄)(Q₅)*!; or

a benzene group, a naphthalene group, an anthracene group, a phenanthrene group, a triphenylene group, a pyrene group, a chrysene group, cyclopentadiene group, a furan group, a thiophene group, a silole group, an indene group, a fluorene group, an indole group, a carbazole group, a benzofuran group, a dibenzofuran group, a benzo-thiophene group, a dibenzo-thiophene group, a benzosilole group, a dibenzosilole group, an azafluorene group, an azacarbazole group, an azadibenzofuran group, an azadibenzothiophene group, an azadibenzosilole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a quinoxaline group, a quinazoline group, a phenanthroline group, a pyrrole group, a pyrazole group, an imidazole group, a triazole group, an oxazole group, an isooxazole group, a thiazole group, an isothiazole group, an oxadiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a benzoxazole group, a benzothiazole group, a benzoxadiazole group, or a benzothiadiazole group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrimidinyl group, a triazinyl group, a fluorenyl group, a dimethylfluorenyl group, a diphenylfluorenyl group, a carbazolyl group, a phenylcarbazolyl group, a dibenzofuranyl group, a dibenzo-thiophenyl group, a dibenzosilolyl group, a dimethyldibenzosilolyl group, a diphenyldibenzosilolyl group, —O(Q₃₁), —S(Q₃₁), —Si(Q₃₁)(Q₃₂)(Q₃₃), —N(Q₃₁)(Q₃₂), —B(Q₃₁)(Q₃₂), —P(Q₃₁)(Q₃₂), —C(=O)(Q₃₁), —S(=O)₂(Q₃₁), —P(=O)(Q₃₁)(Q₃₂), or any combination thereof,

wherein Q₄, Q₅, and Q₃₁ to Q₃₃ may each independently be hydrogen, deuterium, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a pyridinyl group, a pyrimidinyl group, a pyridazinyl group, a pyrazinyl group, or a triazinyl group.

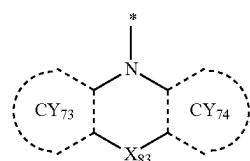
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In an embodiment, the group represented by



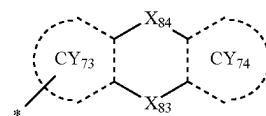
in Formulae 3-1 and 3-2 may be a group represented by one of Formulae CY71-1(1) to CY71-1(8), and/or

the group represented by



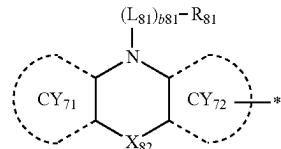
in Formulae 3-1 and 3-3 may be a group represented by one of Formulae CY71-2(1) to CY71-2(8),

the group represented by



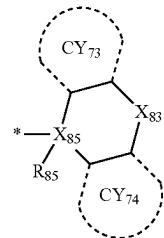
in Formulae 3-2 and 3-4 may be a group represented by one of Formulae CY71-3(1) to CY71-3(32), and/or

the group represented by



in Formulae 3-3 to 3-5 may be a group represented by one of Formulae CY71-4(1) to CY71-4(32), and/or

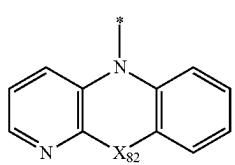
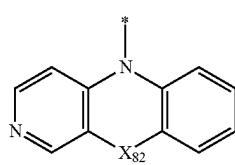
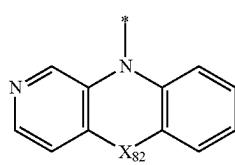
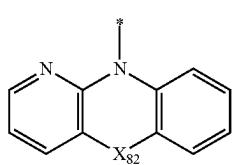
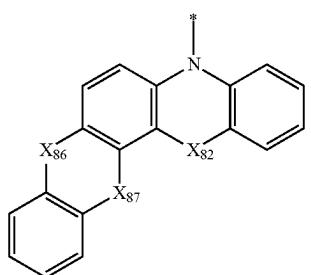
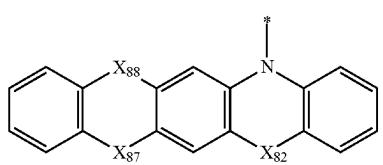
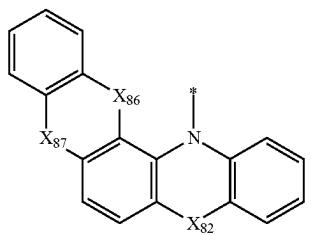
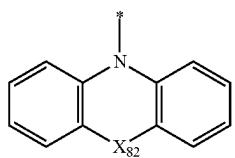
the group represented by



in Formula 3-5 may be a group represented by one of Formulae CY71-5(1) to CY71-5(8):

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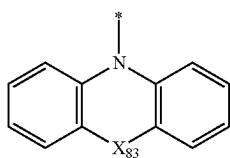
63



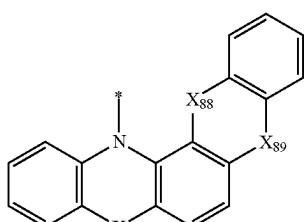
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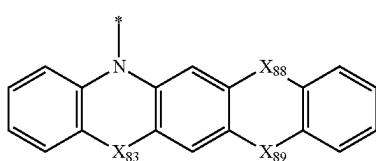
CY71-1(1)



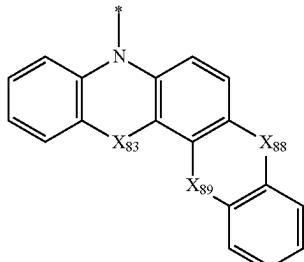
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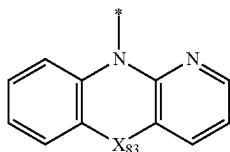
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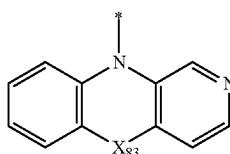
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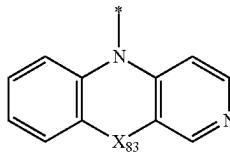
CY71-1(5)



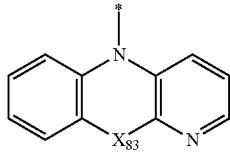
CY71-1(6)



CY71-1(7)



CY71-1(8) 60



CY71-2(1)

CY71-2(2)

CY71-2(3)

CY71-2(4)

CY71-2(5)

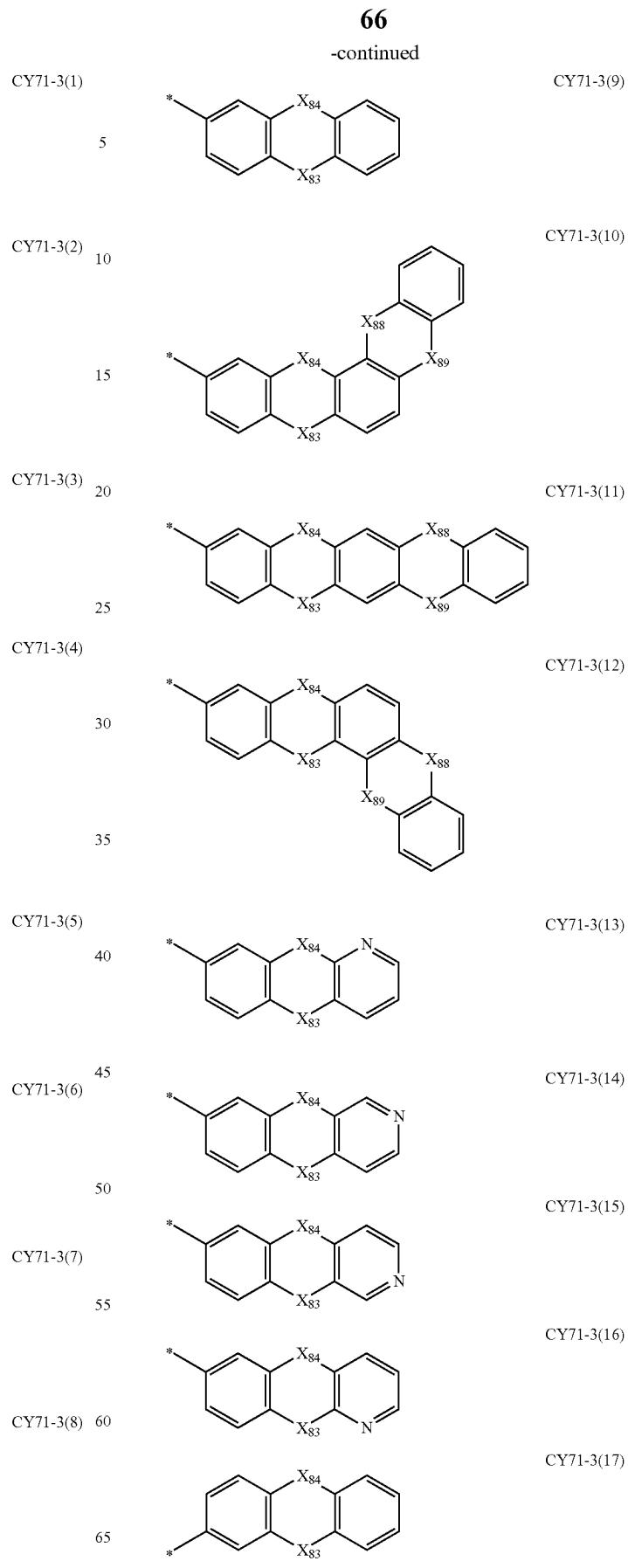
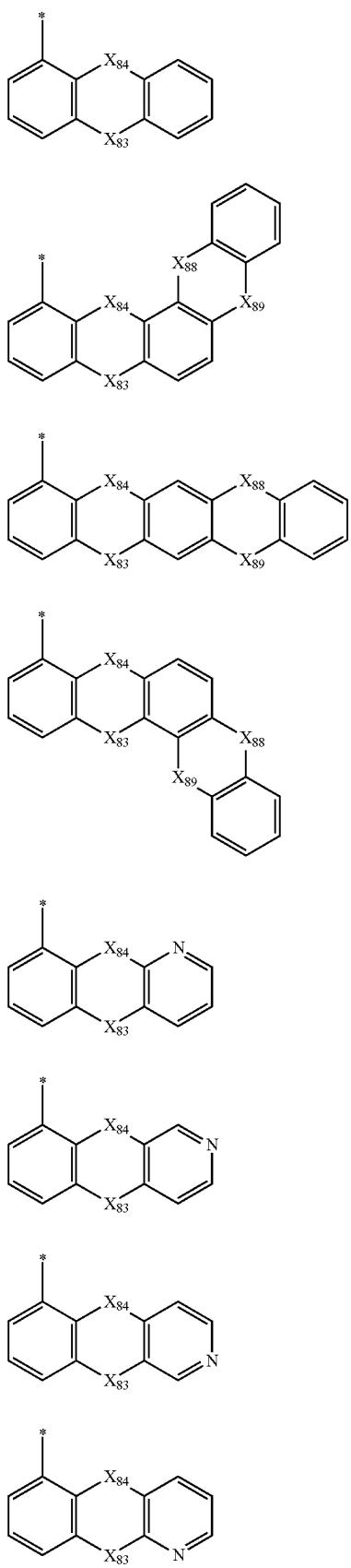
CY71-2(6)

CY71-2(7)

CY71-2(8)

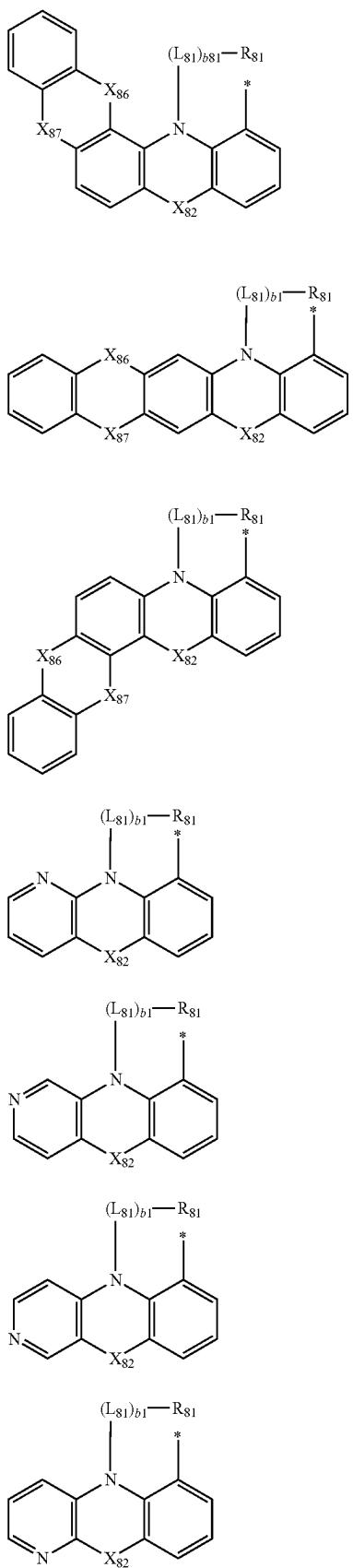
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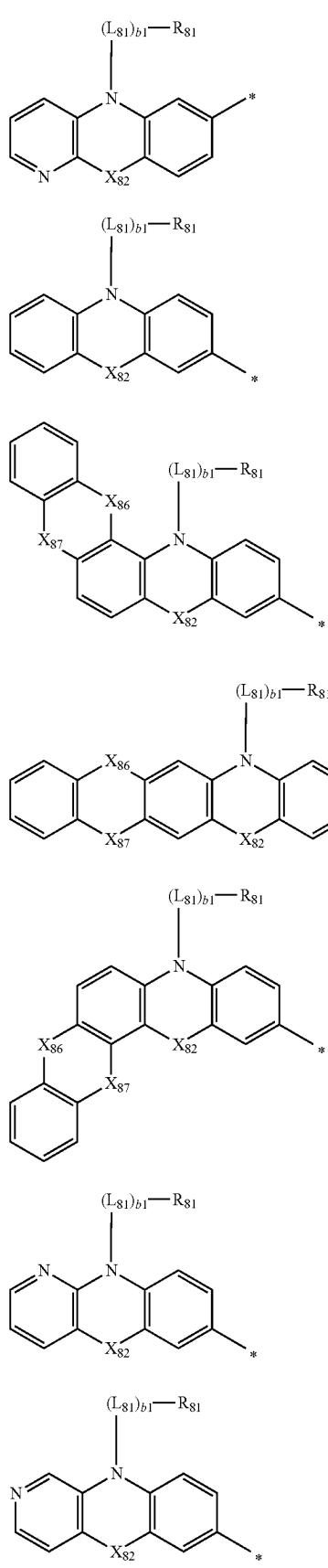
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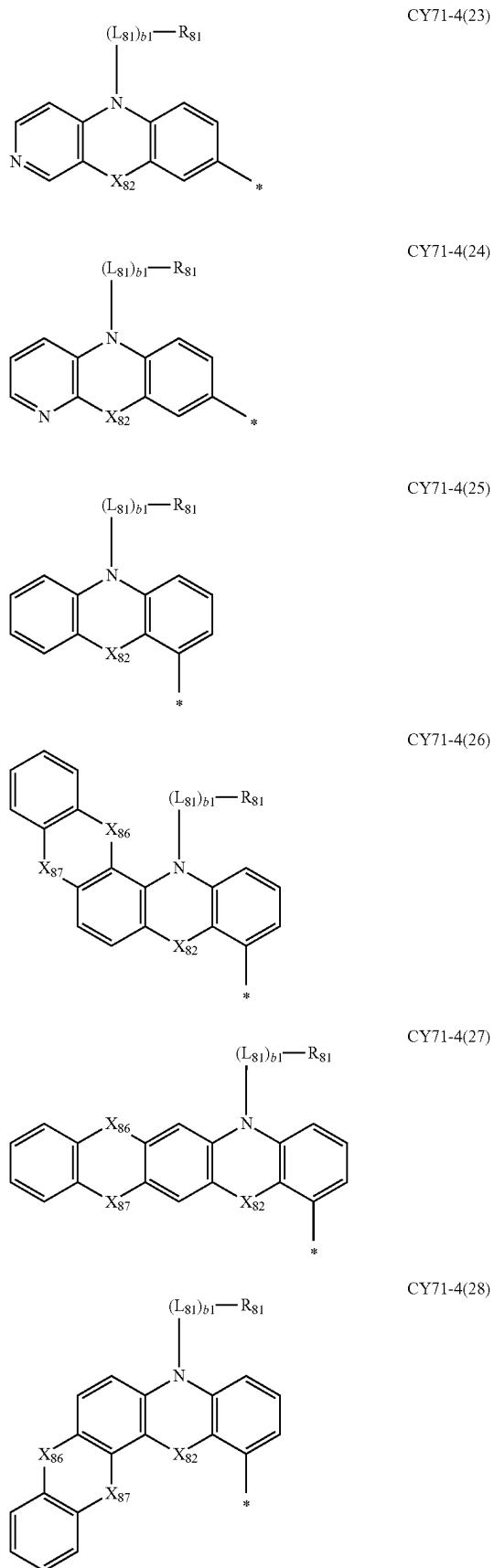


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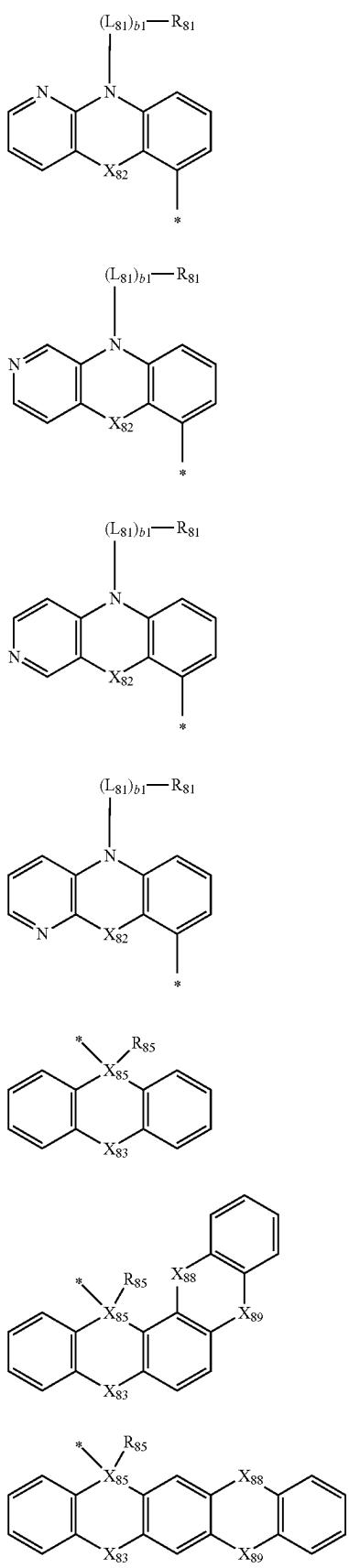
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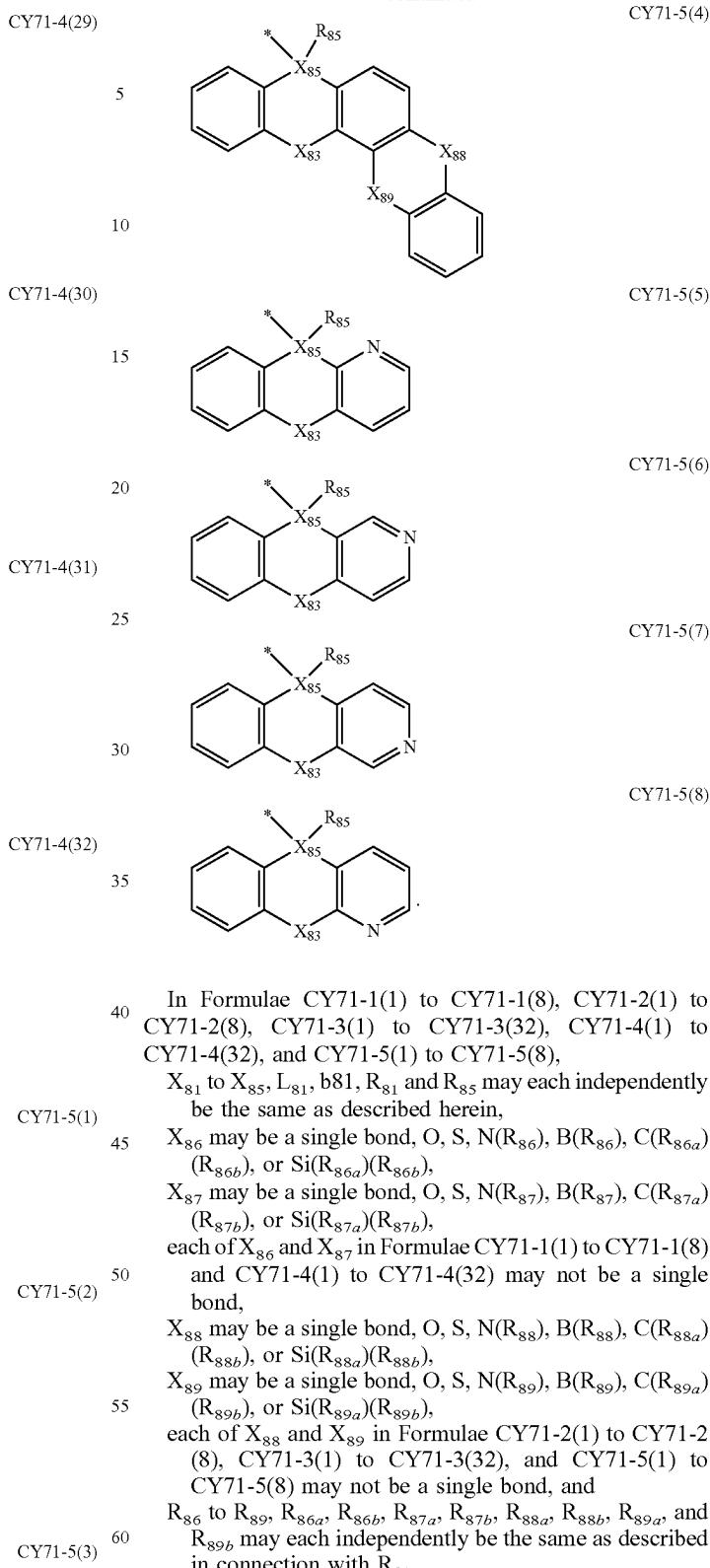
72
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73
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74
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40 In Formulae CY71-1(1) to CY71-1(8), CY71-2(1) to CY71-2(8), CY71-3(1) to CY71-3(32), CY71-4(1) to CY71-4(32), and CY71-5(1) to CY71-5(8),

X₈₁ to X₈₅, L₈₁, b81, R₈₁ and R₈₅ may each independently be the same as described herein,

X₈₆ may be a single bond, O, S, N(R₈₆), B(R₈₆), C(R_{86a}) (R_{86b}), or Si(R_{86a})(R_{86b}),

X₈₇ may be a single bond, O, S, N(R₈₇), B(R₈₇), C(R_{87a}) (R_{87b}), or Si(R_{87a})(R_{87b}),

each of X₈₆ and X₈₇ in Formulae CY71-1(1) to CY71-1(8) and CY71-4(1) to CY71-4(32) may not be a single bond,

X₈₈ may be a single bond, O, S, N(R₈₈), B(R₈₈), C(R_{88a}) (R_{88b}), or Si(R_{88a})(R_{88b}),

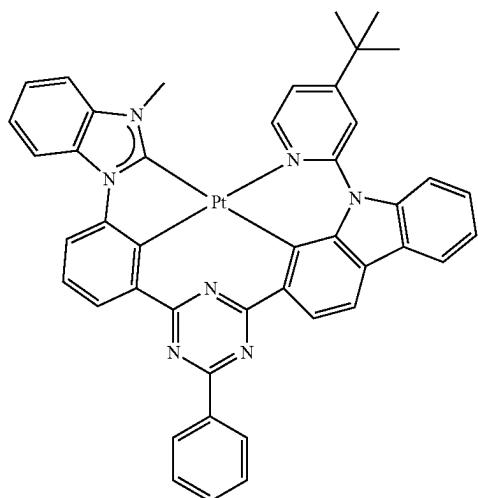
X₈₉ may be a single bond, O, S, N(R₈₉), B(R₈₉), C(R_{89a}) (R_{89b}), or Si(R_{89a})(R_{89b}),

each of X₈₈ and X₈₉ in Formulae CY71-2(1) to CY71-2(8), CY71-3(1) to CY71-3(32), and CY71-5(1) to CY71-5(8) may not be a single bond, and

R₈₆ to R₈₉, R_{86a}, R_{86b}, R_{87a}, R_{87b}, R_{88a}, R_{88b}, R_{89a}, and R_{89b} may each independently be the same as described in connection with R₈₁.

EXAMPLES OF COMPOUNDS

65 In an embodiment, the first compound (the organometallic compound represented by Formula 1) may be at least one of Compounds BD1 to BD55:

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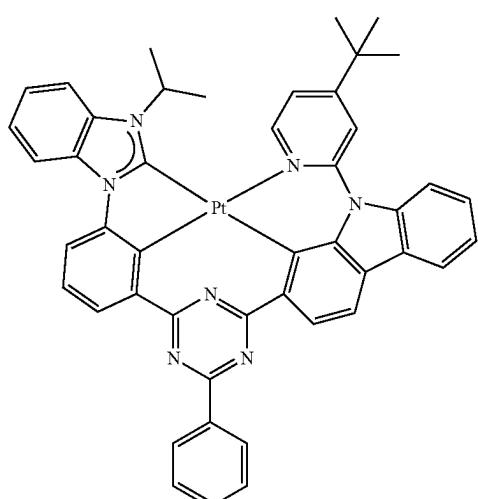
BD1

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BD2

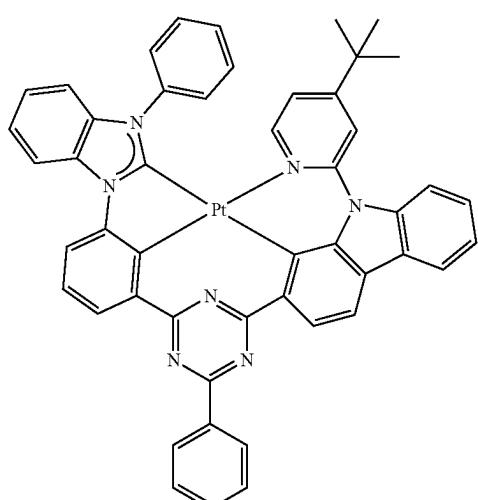
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BD3

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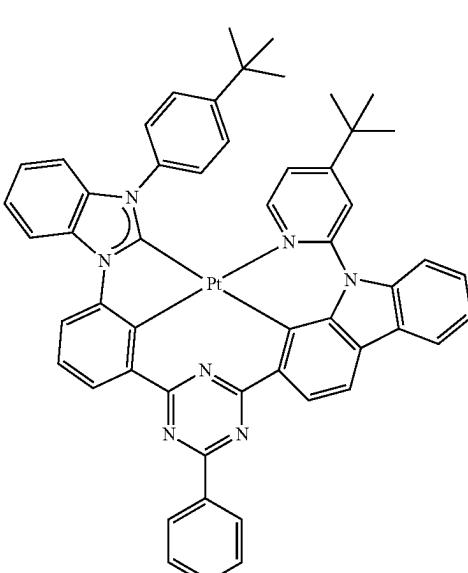
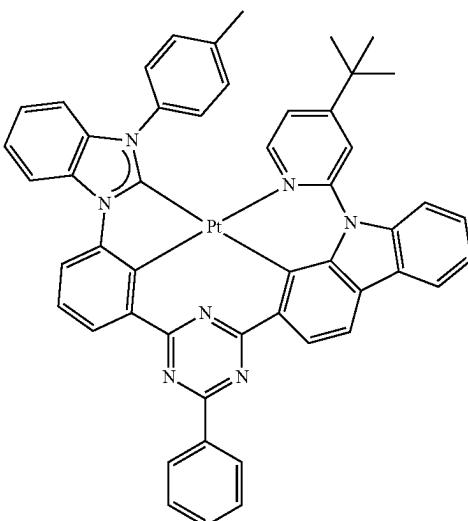
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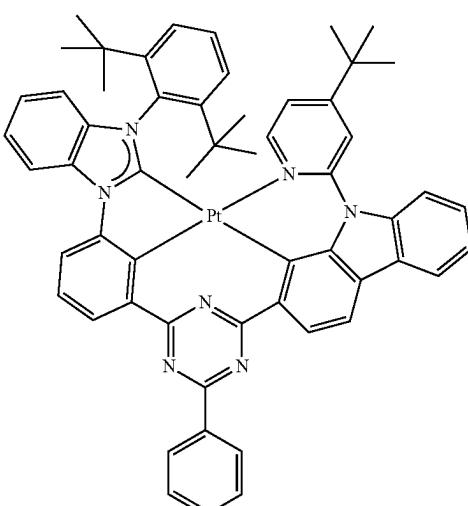
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BD4



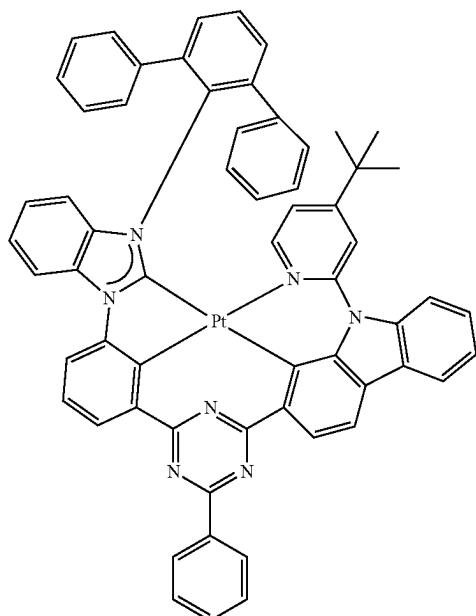
BD5



BD6

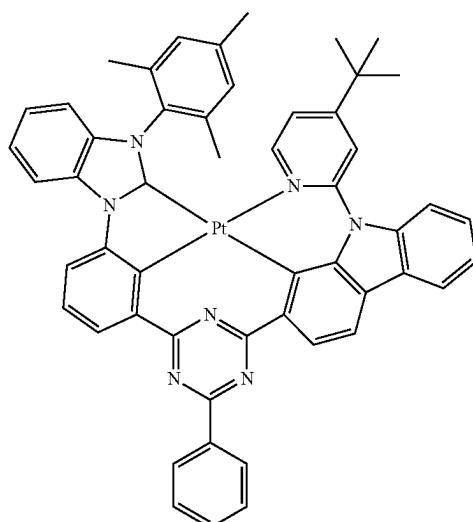
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BD7

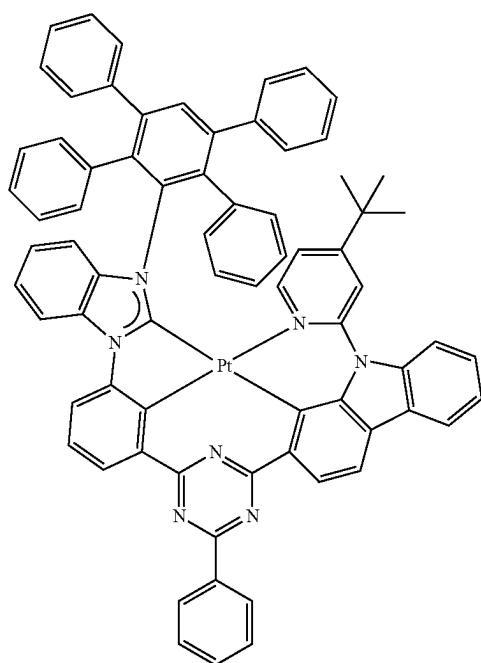


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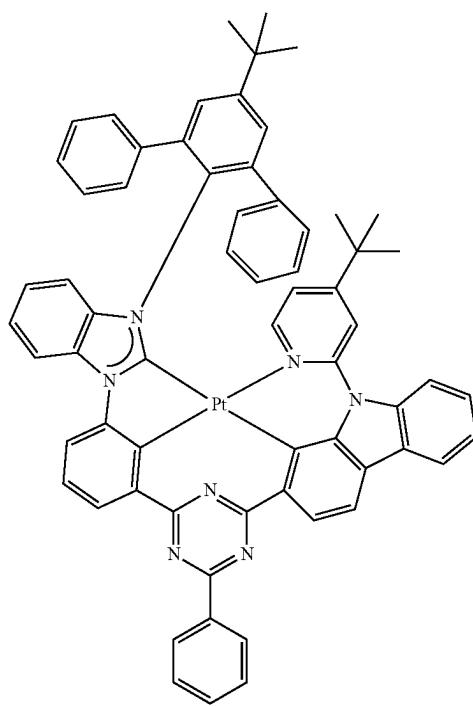
BD9



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BD8 40



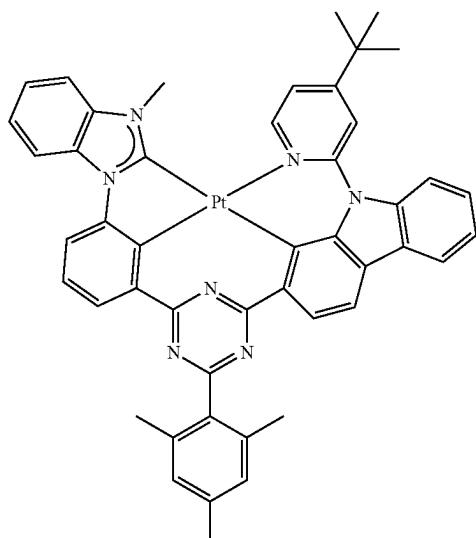
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BD10

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BD11



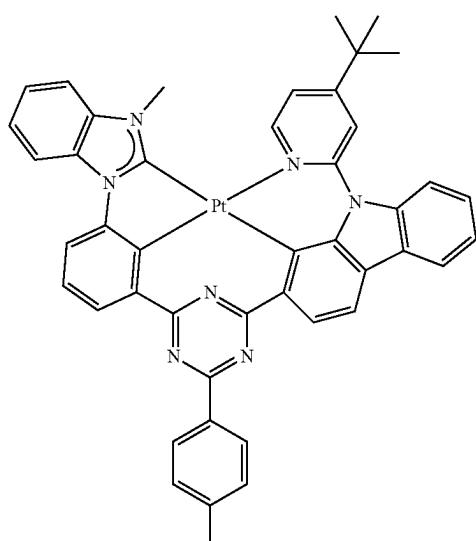
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BD12 25

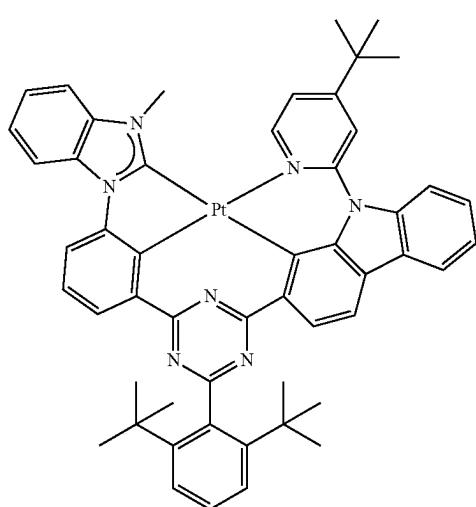


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BD13



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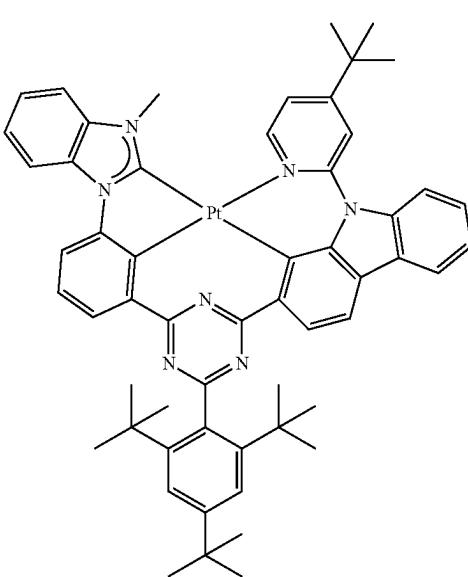
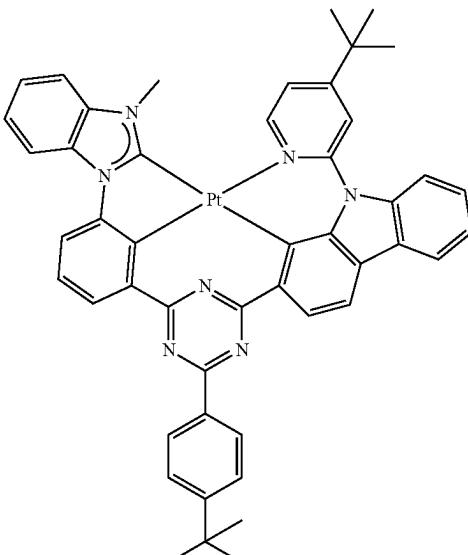
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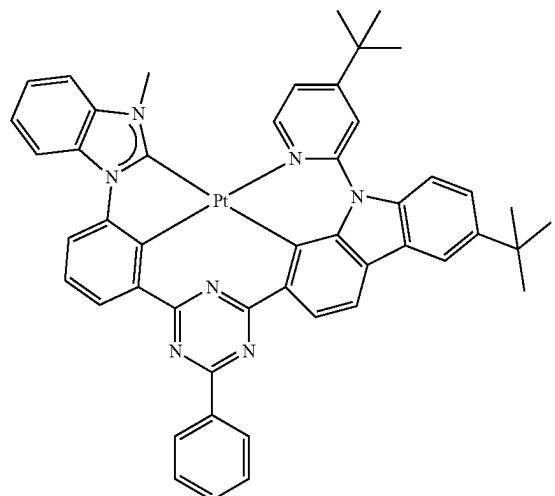
BD14



BD15

81
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BD16



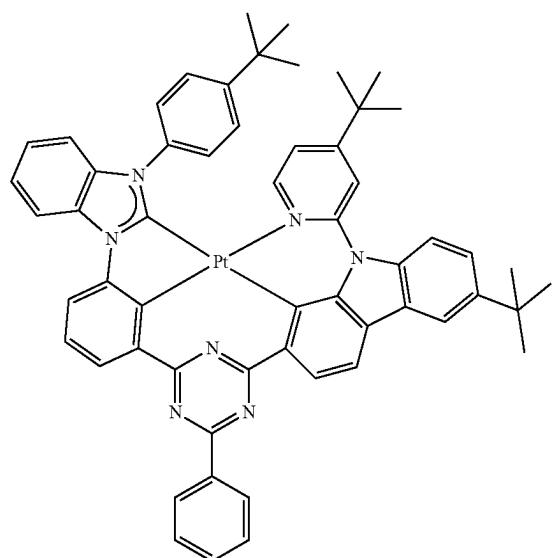
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BD17



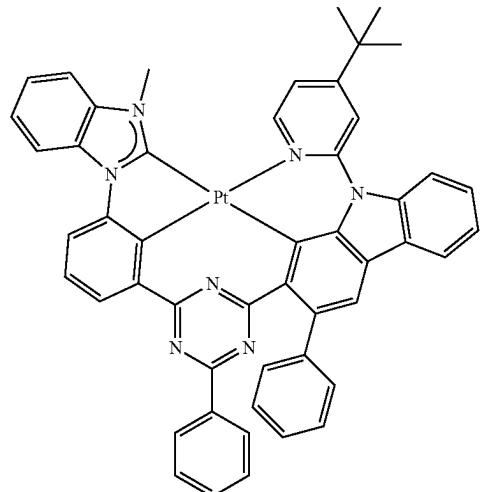
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BD18



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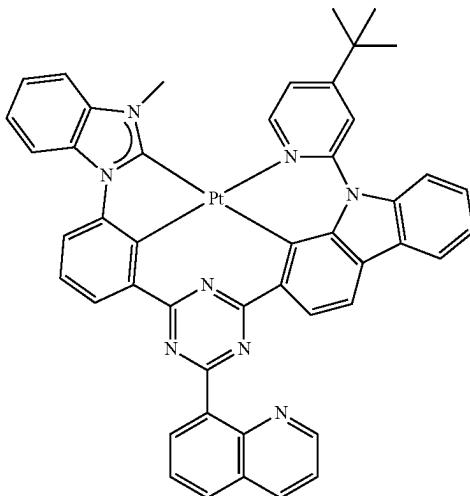
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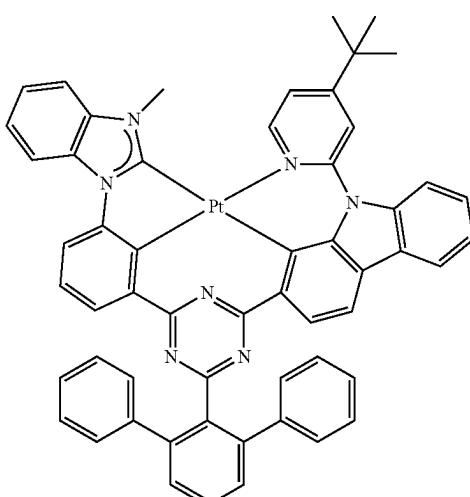
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82
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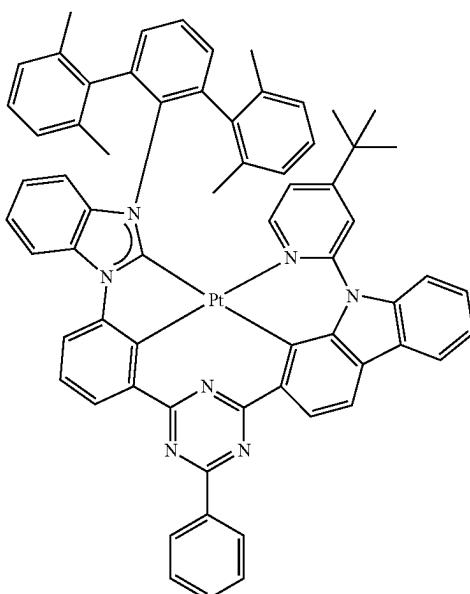
BD19



BD20



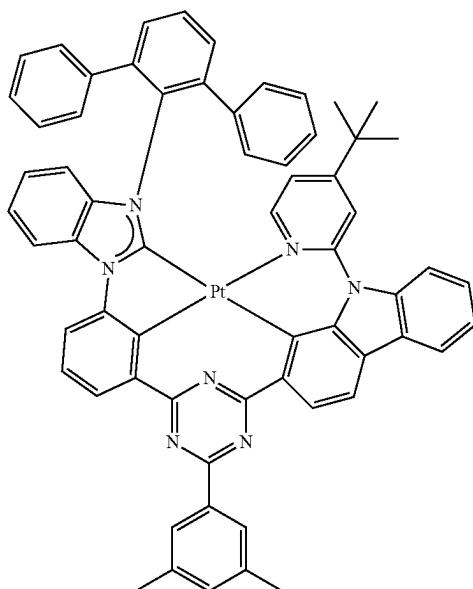
BD21



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83
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BD22



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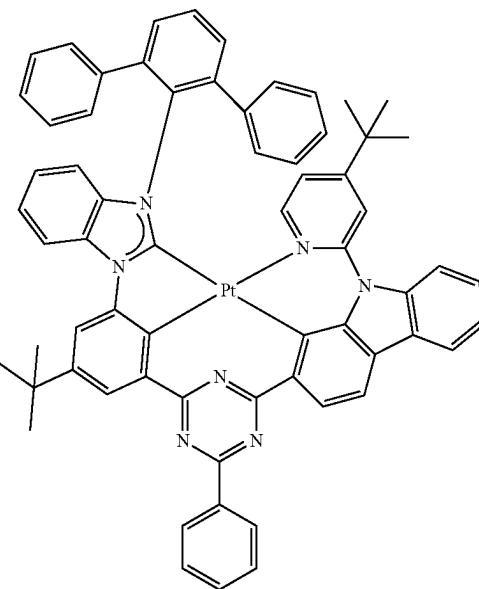
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BD23

BD24



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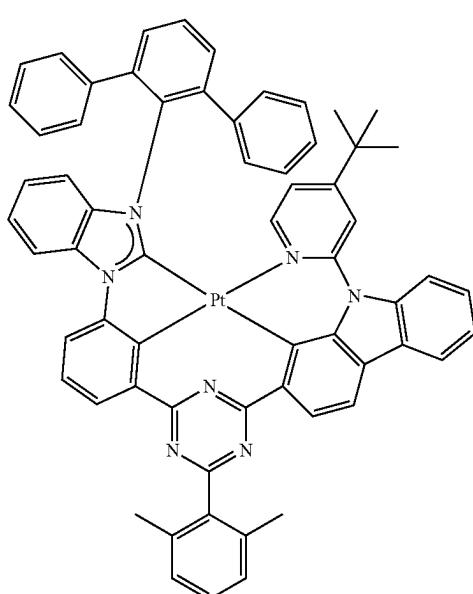
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BD23

BD25



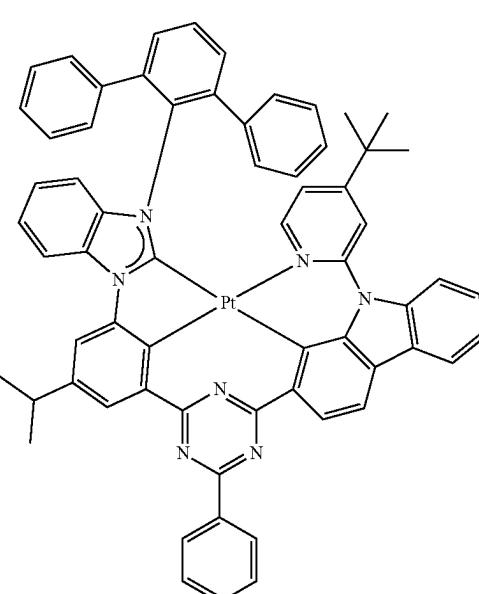
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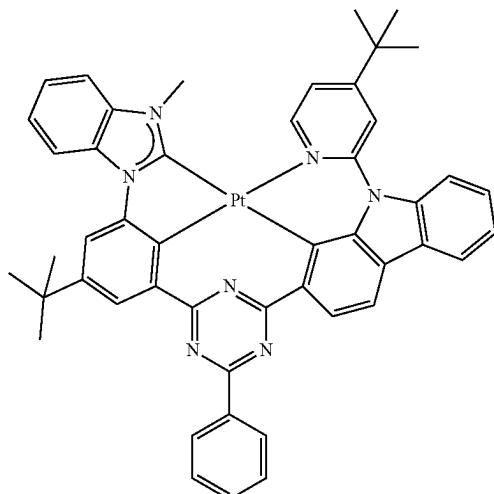
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85

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BD26



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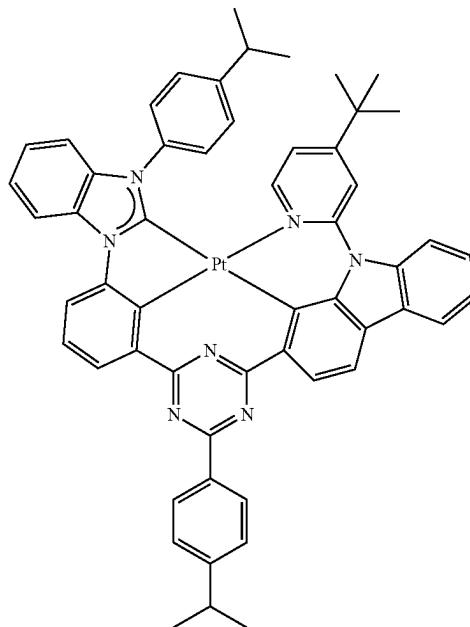
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86

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BD28



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BD29

BD27

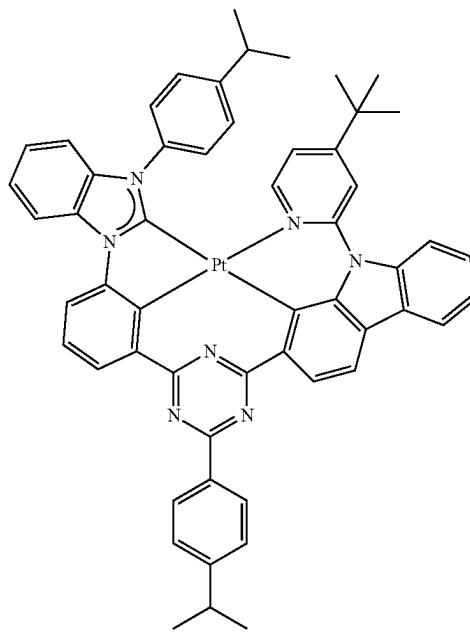
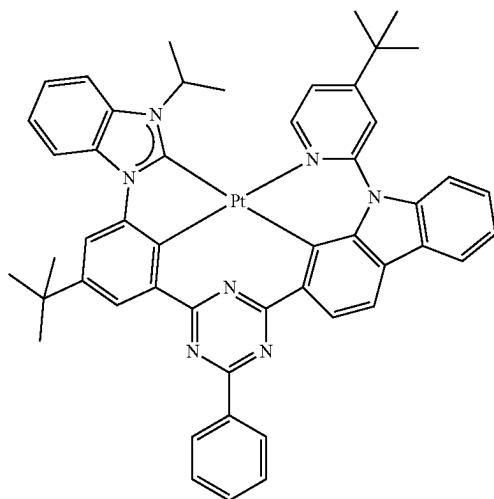
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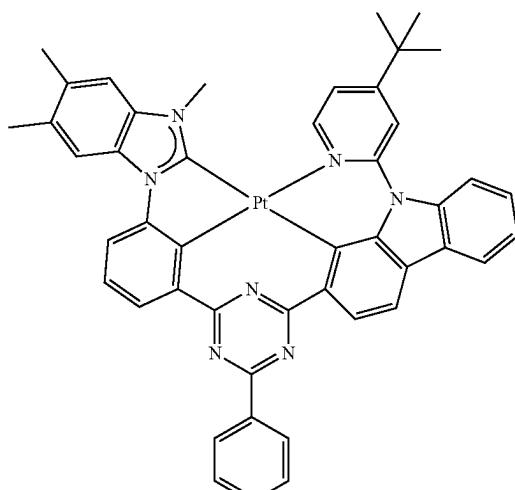
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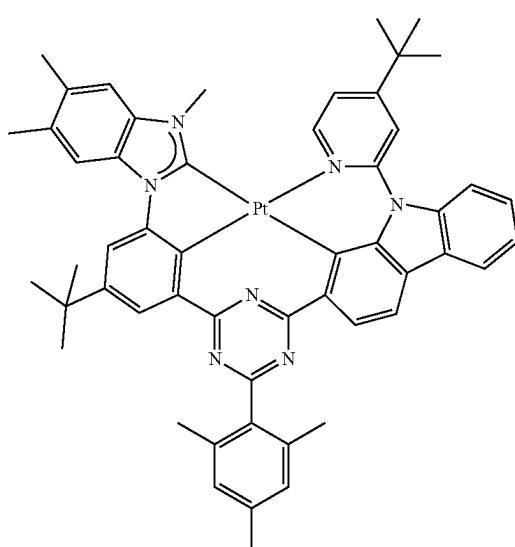


87
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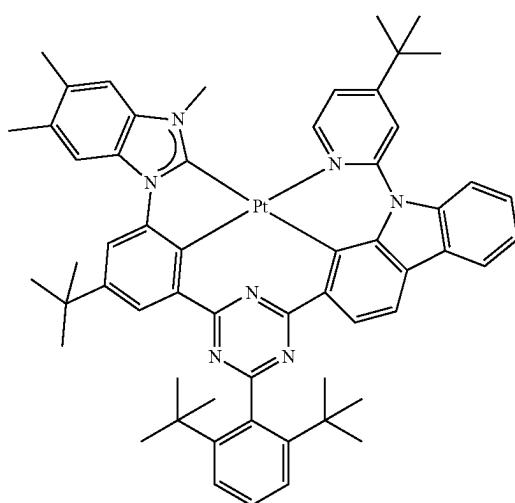
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BD31

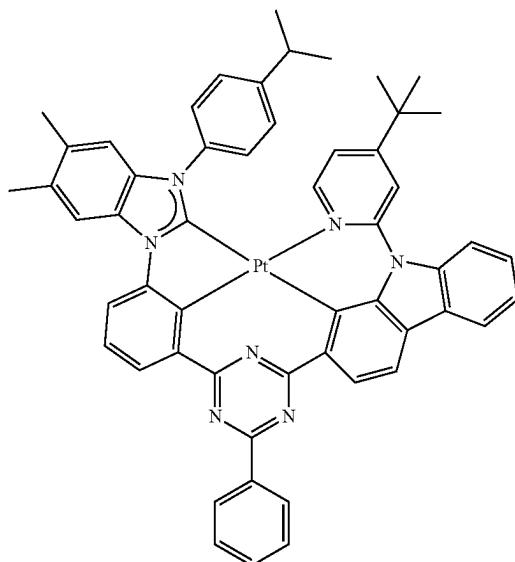
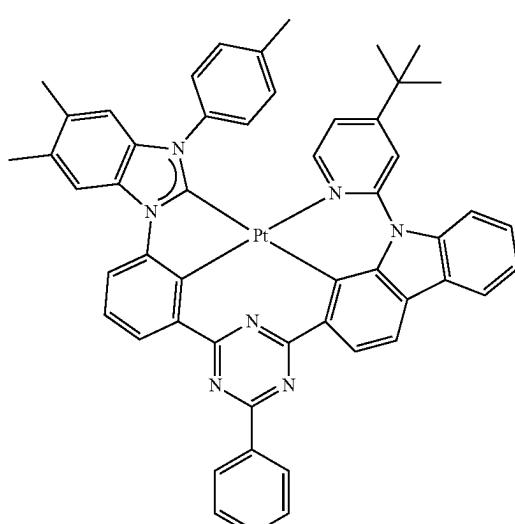


BD32



88
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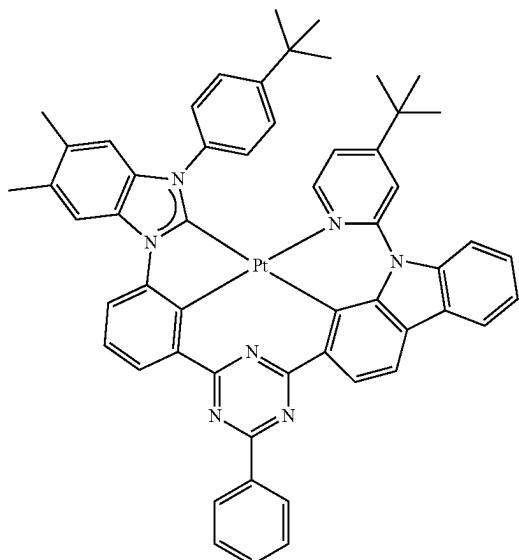
BD33



89

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BD35



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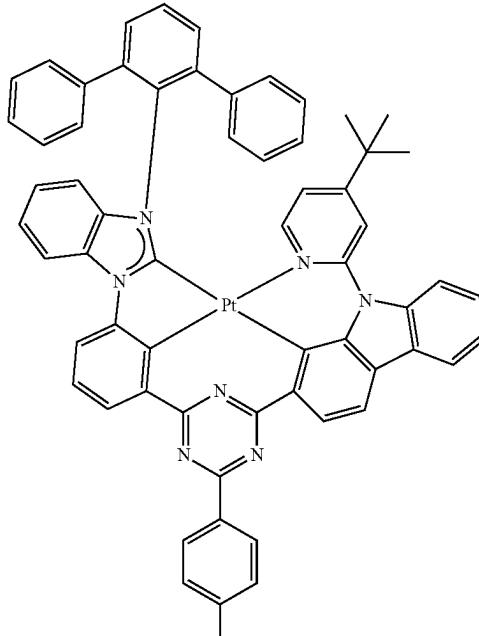
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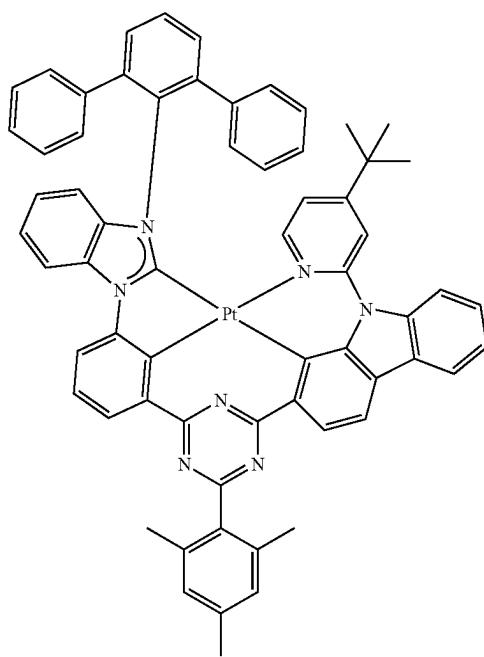
BD37



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BD36



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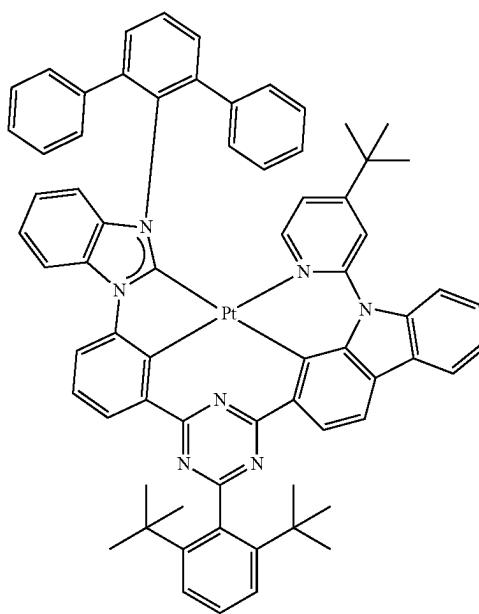
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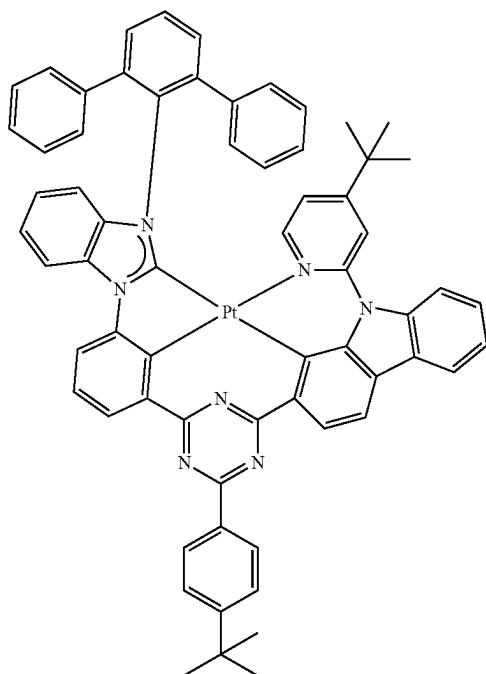
BD38



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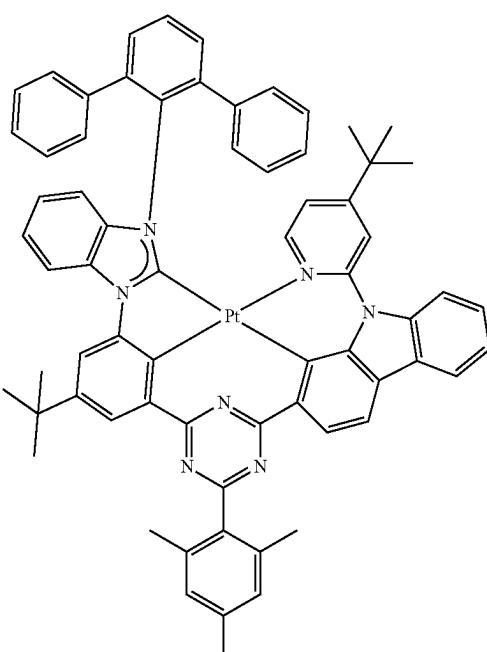
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BD39



92
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BD41

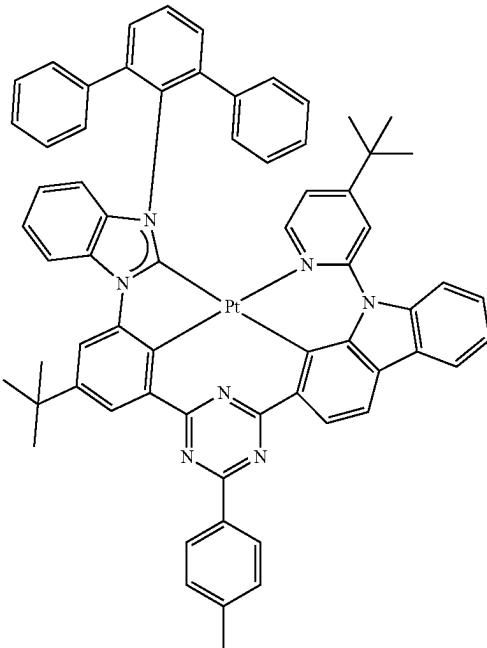
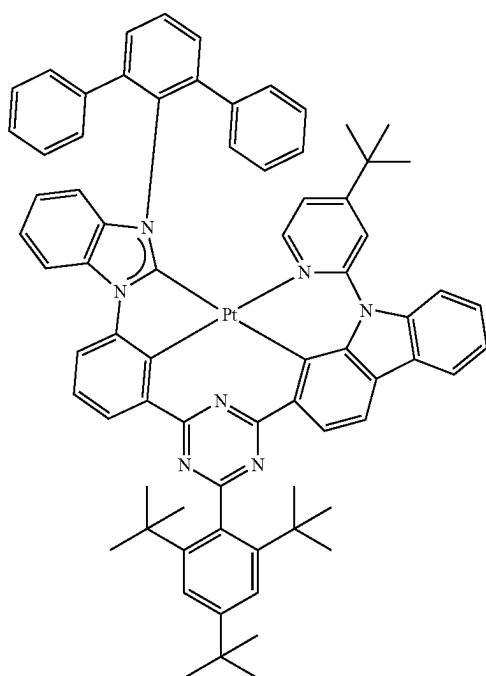


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BD40 40

BD42



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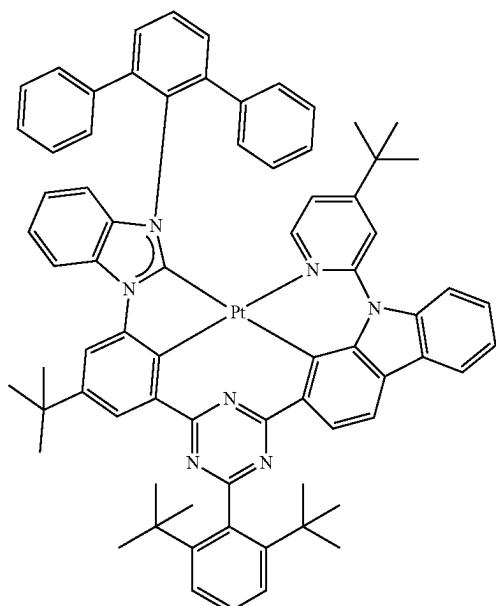
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93

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BD43



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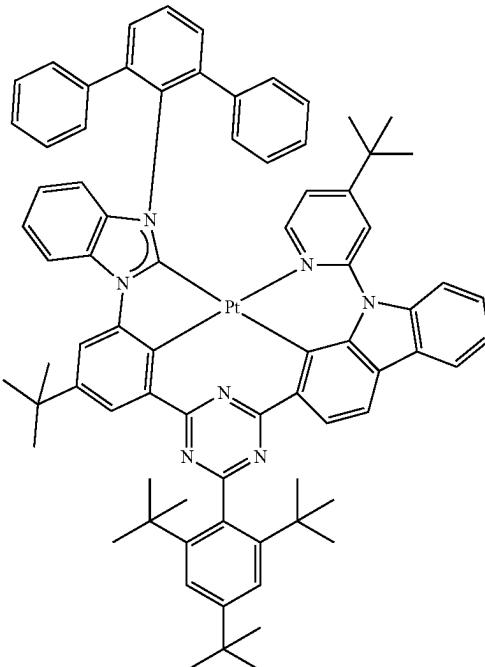
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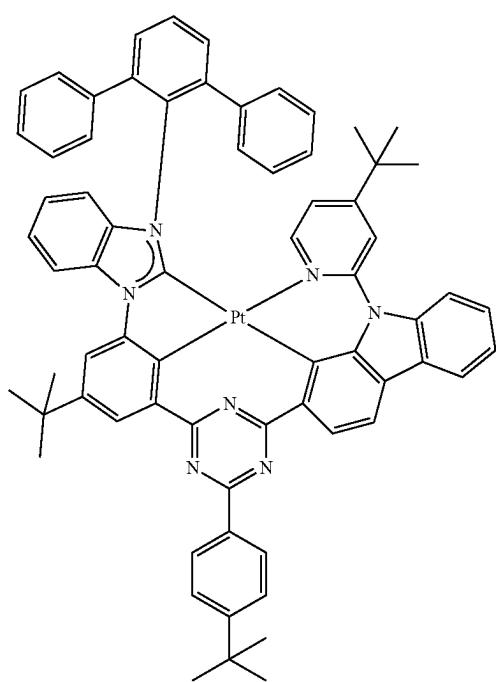
BD45



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BD44 40

BD46



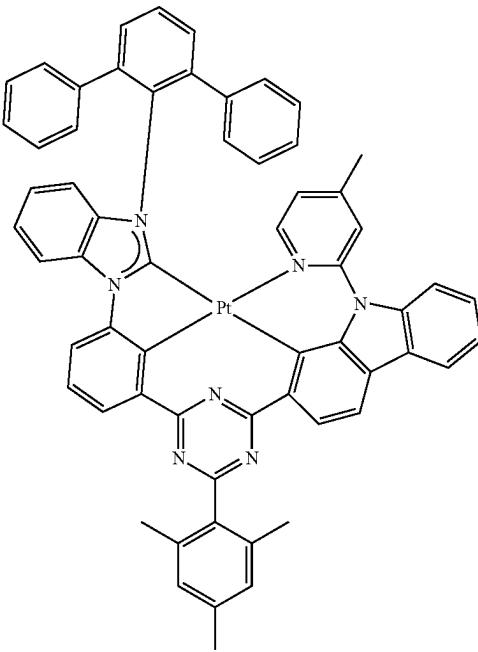
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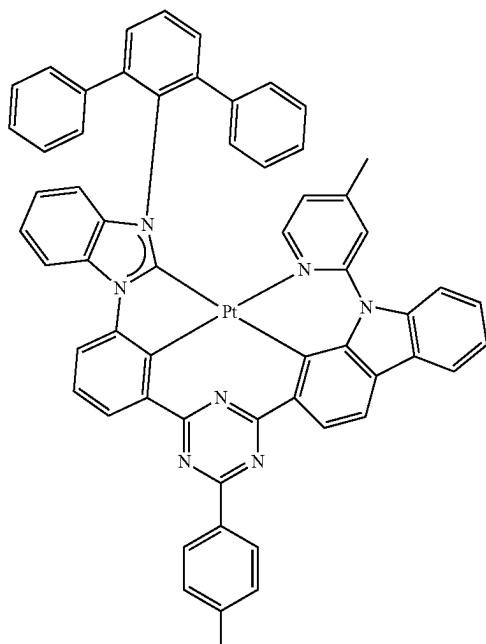
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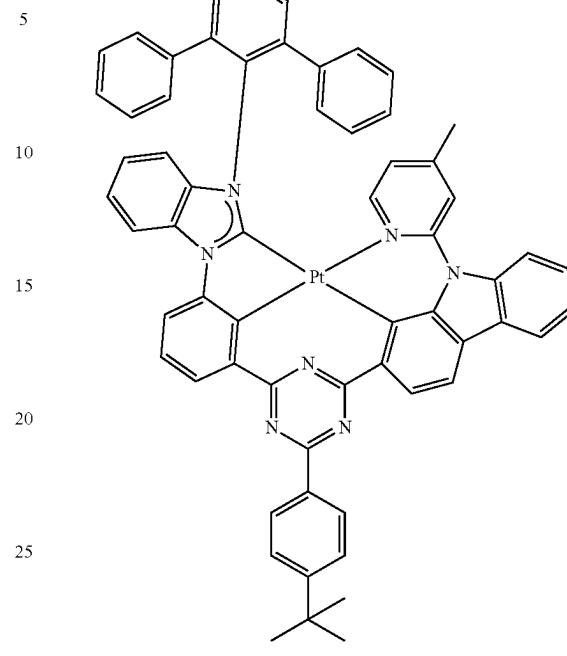
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BD47



96
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BD49

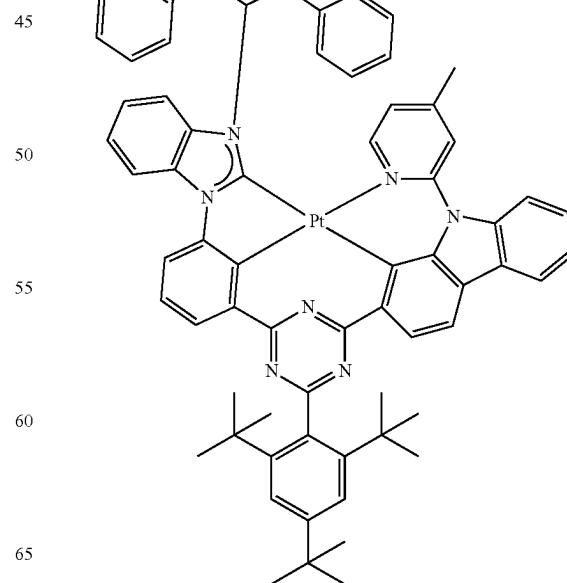
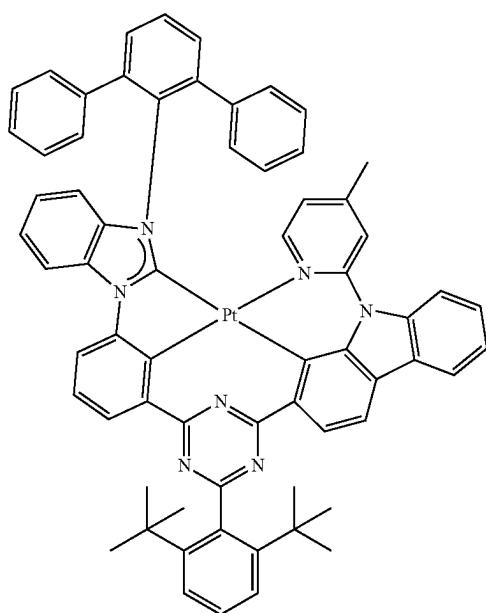


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BD50

BD48

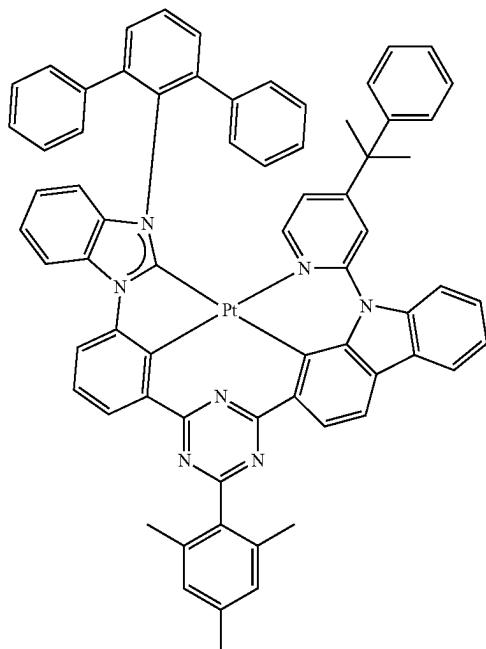


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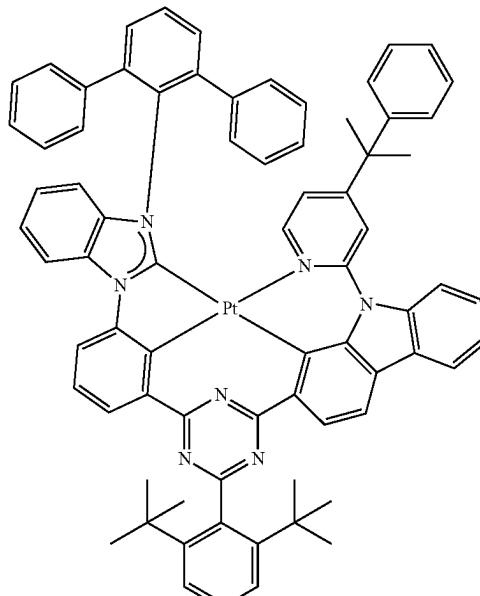
BD51



98

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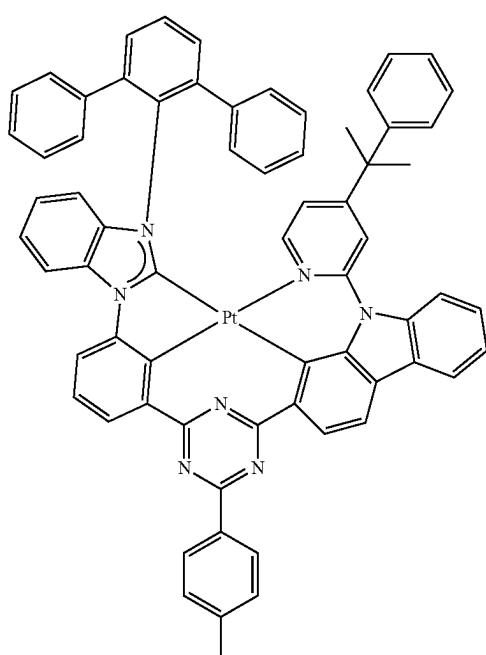
BD53



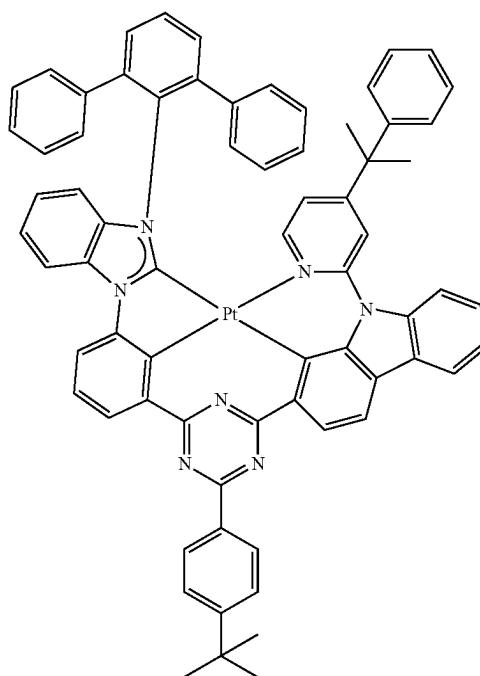
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BD52



BD54

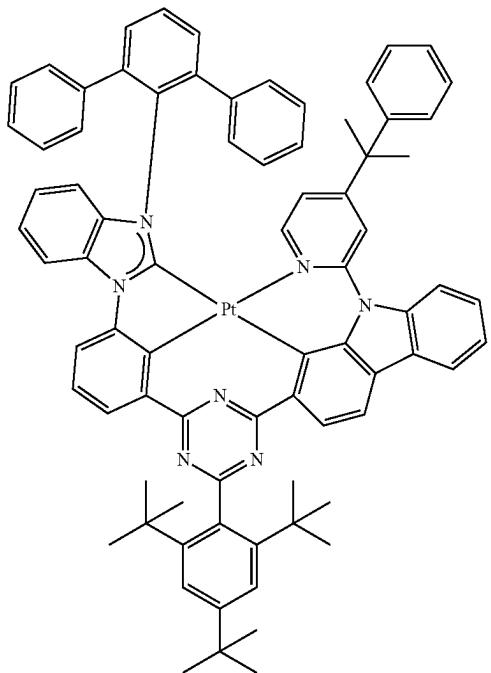


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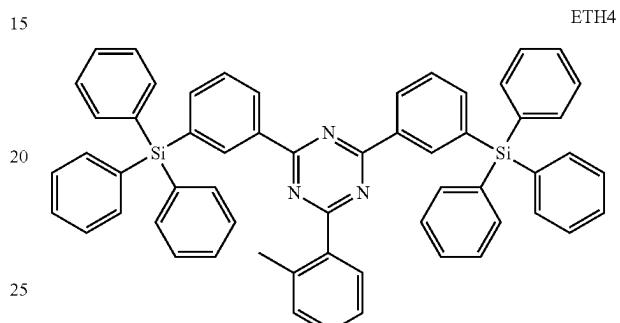
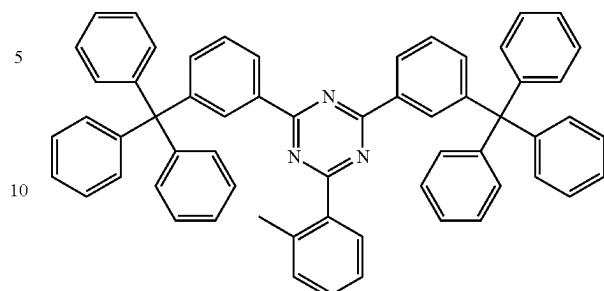
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BD55

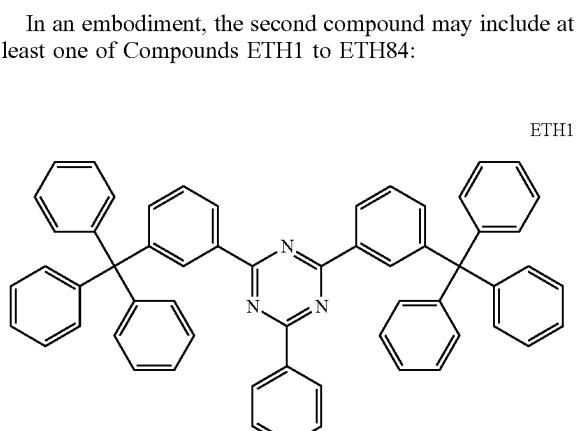
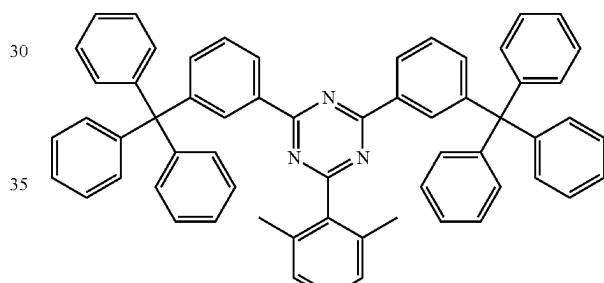


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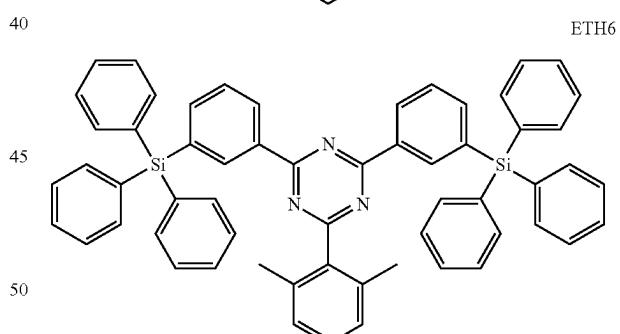
ETH3



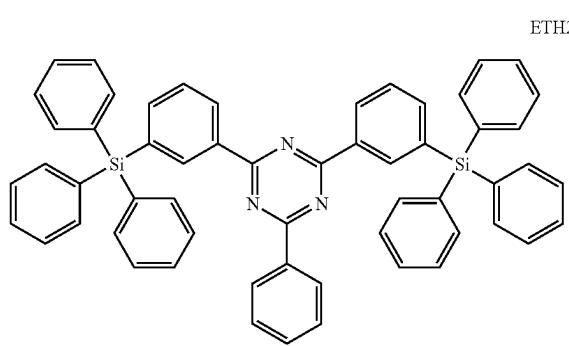
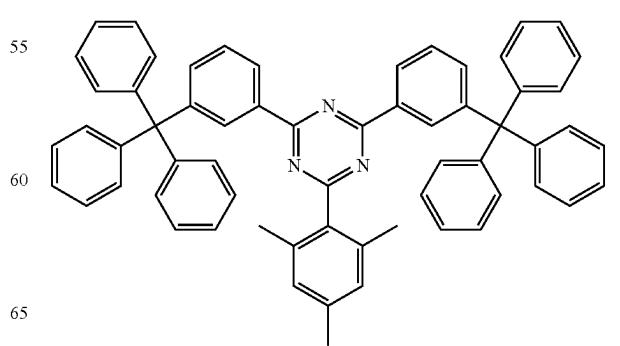
ETH4



ETH1



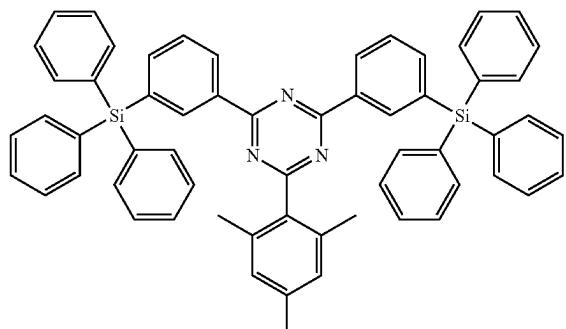
ETH6



101

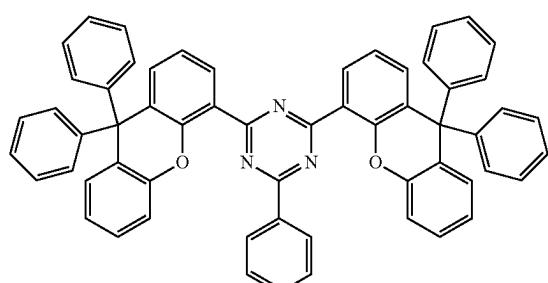
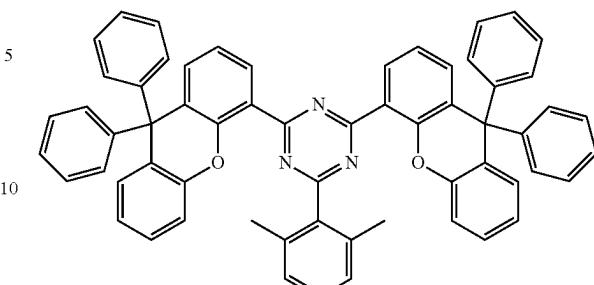
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ETH8



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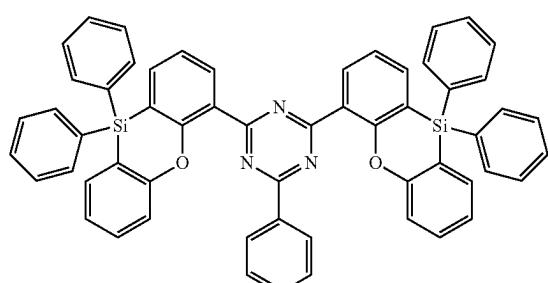
ETH9



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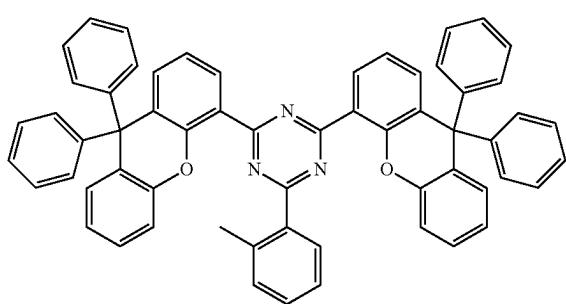
ETH10

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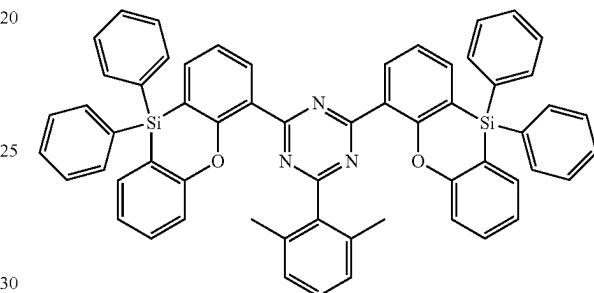
ETH11

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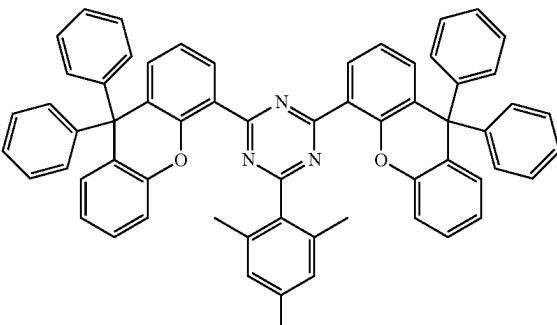


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ETH14

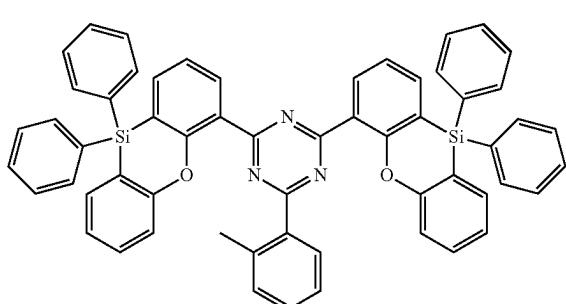


ETH15

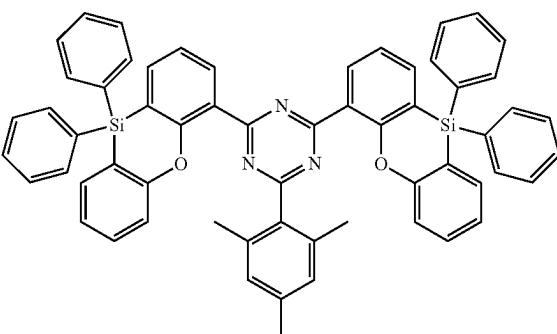


ETH16

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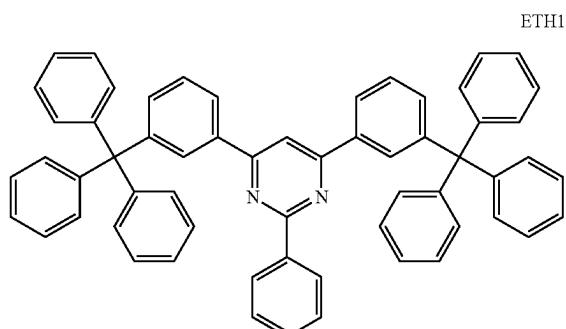
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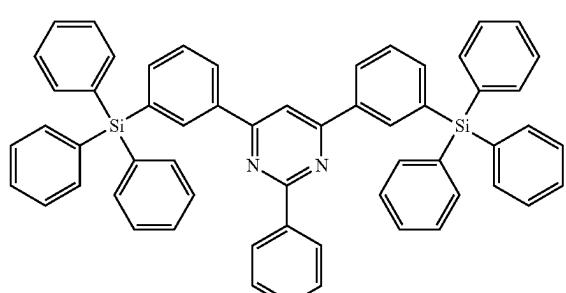
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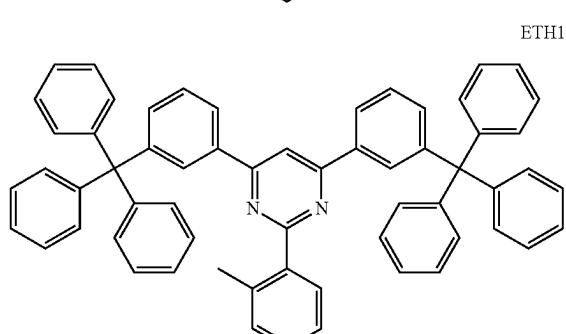
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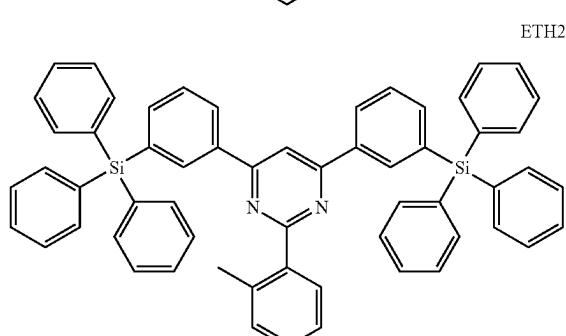
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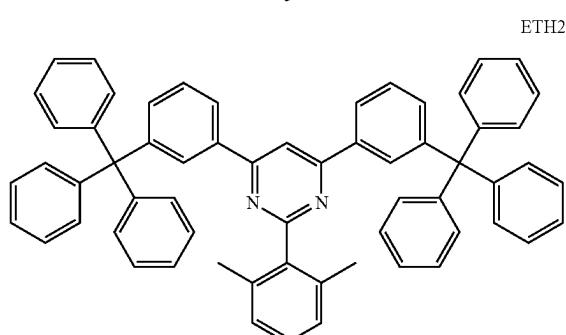
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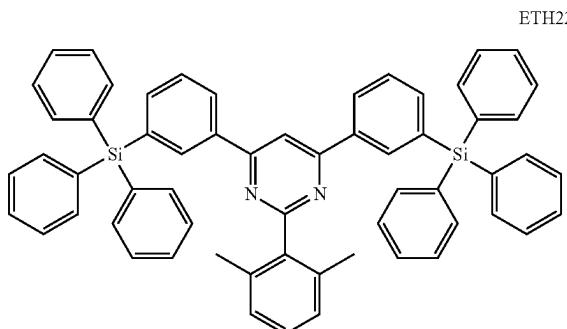
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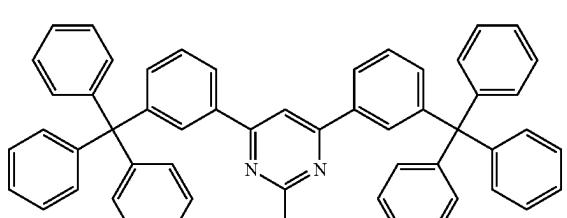
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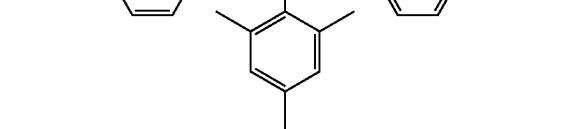
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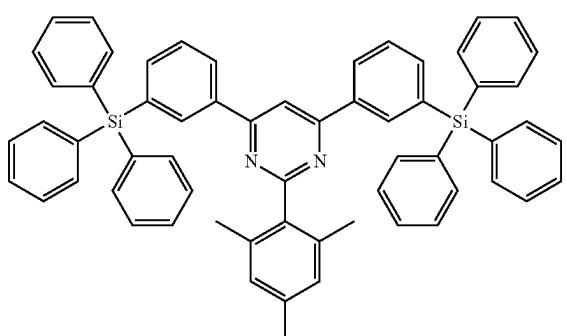


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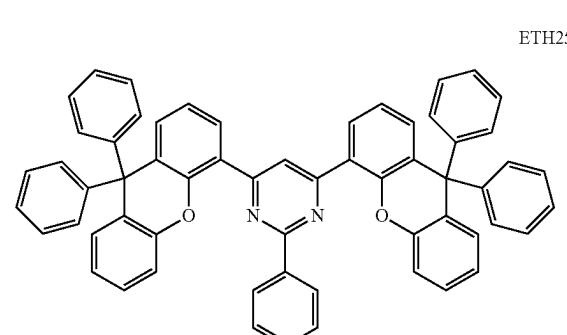
ETH19

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ETH20

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ETH25

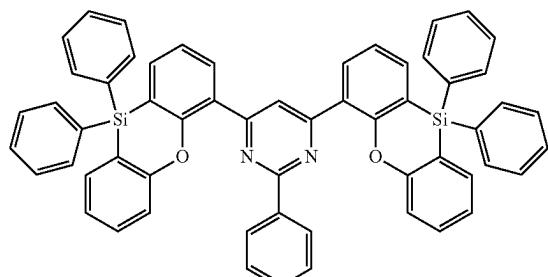
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105

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ETH26

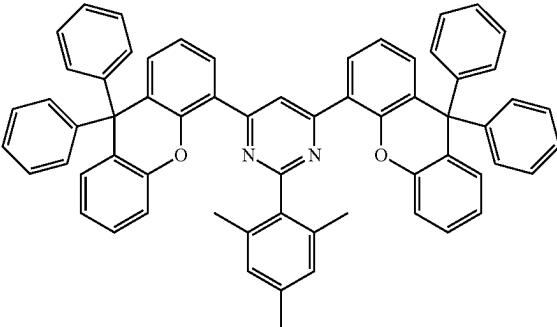


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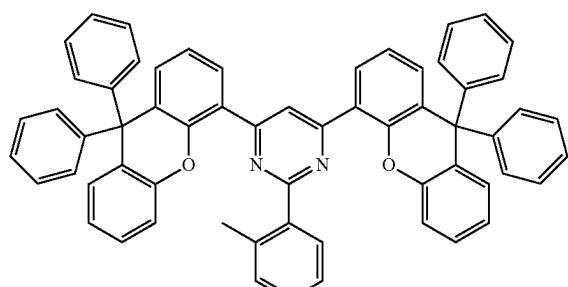
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ETH31

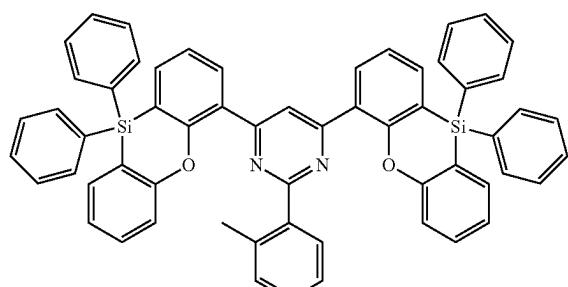


ETH27 15



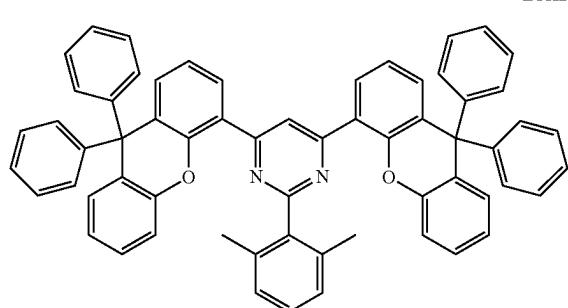
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ETH28



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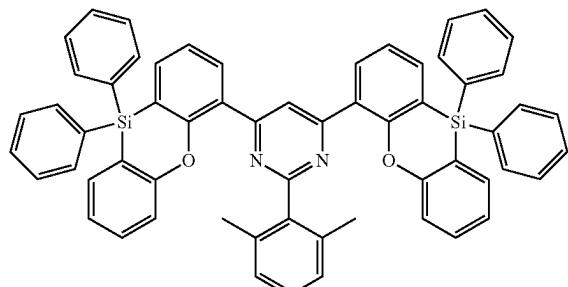
ETH29



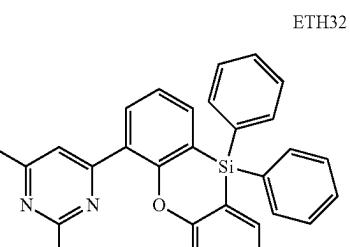
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ETH30

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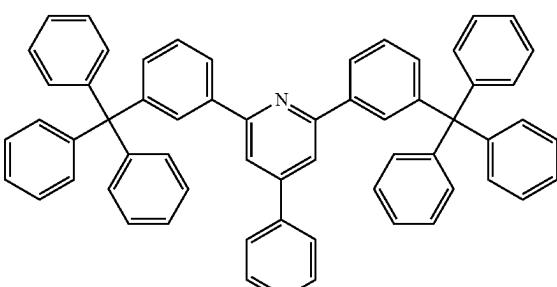


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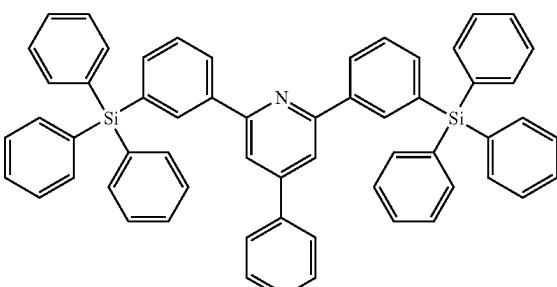
ETH32

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ETH33

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ETH34

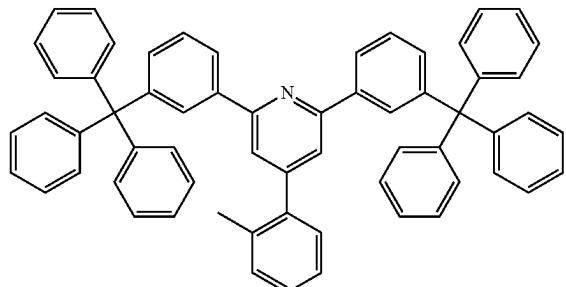
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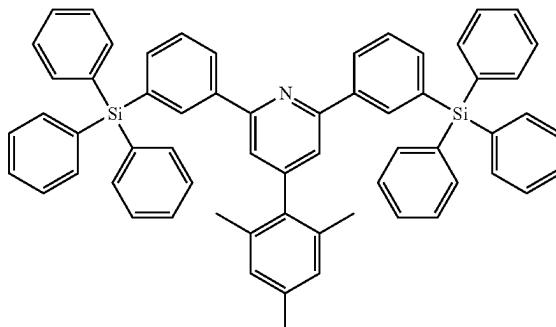
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ETH35

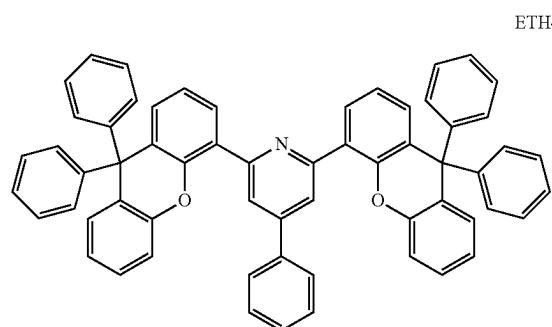
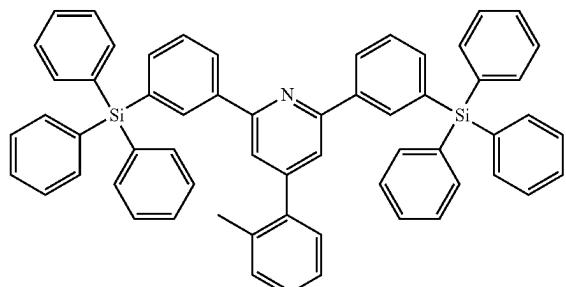
**108**

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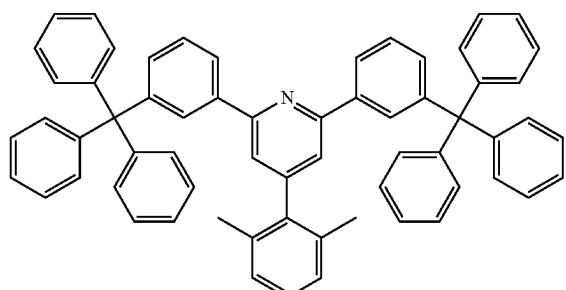
ETH40



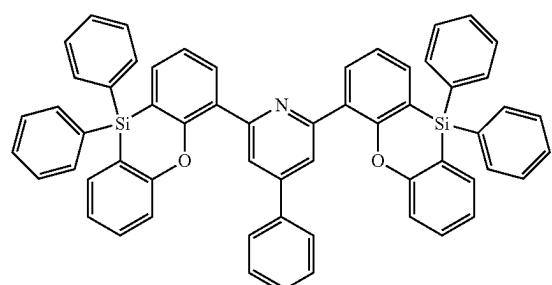
ETH36 15



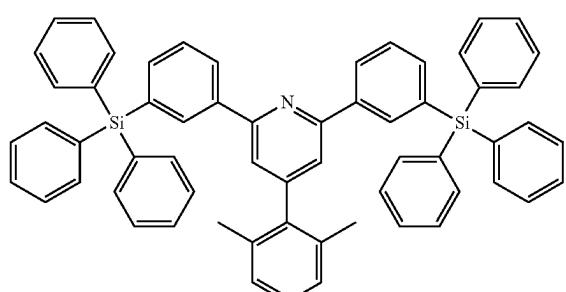
ETH37



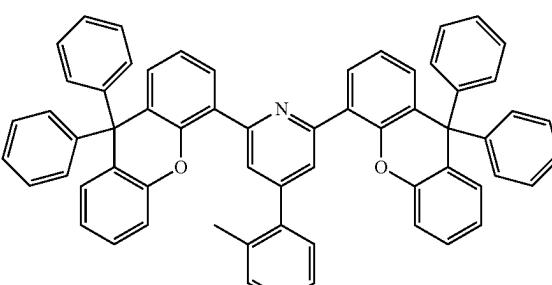
ETH42



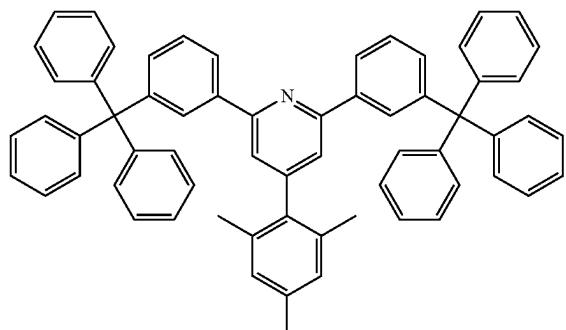
ETH38 40



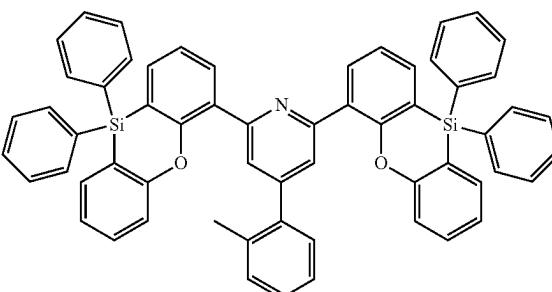
ETH43



ETH39



ETH44



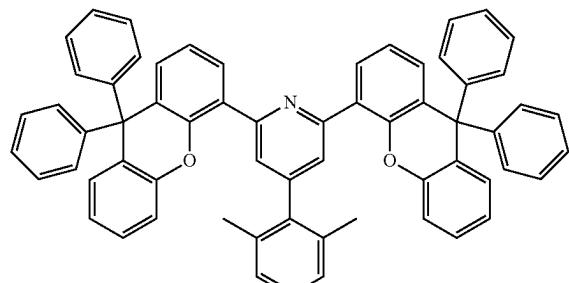
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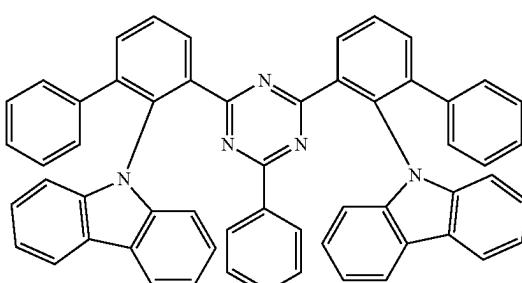
109

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ETH45



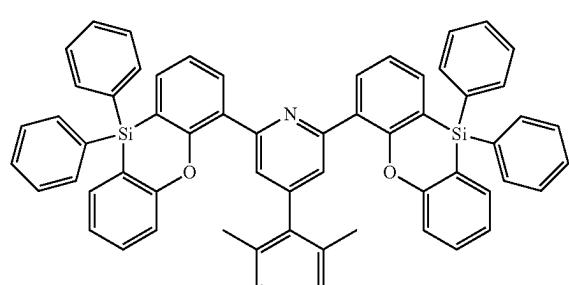
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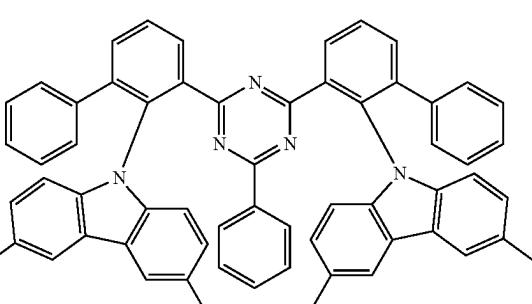
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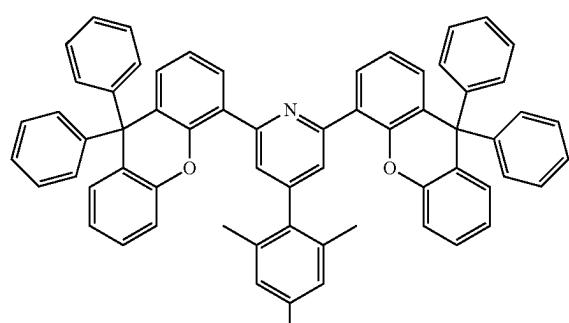
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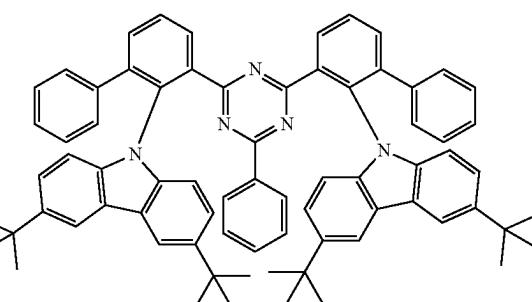
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ETH50



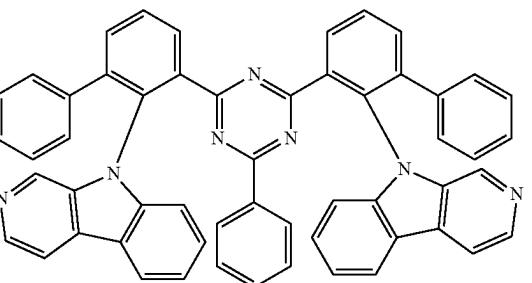
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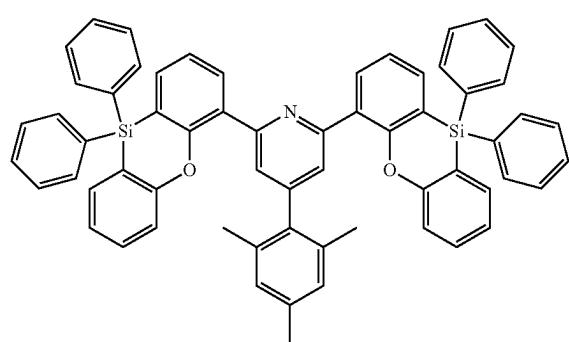
ETH51



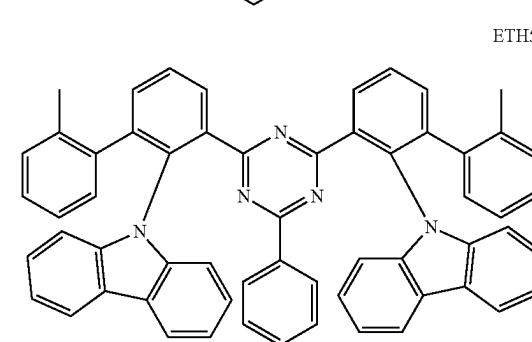
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ETH52



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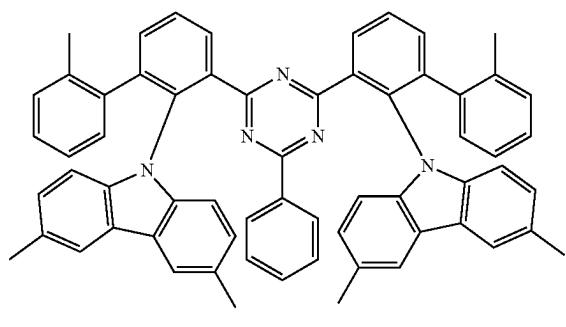


ETH53

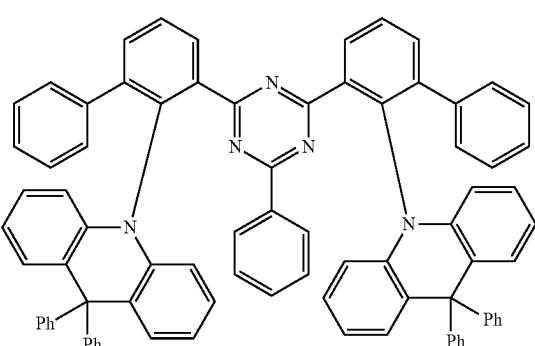
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111
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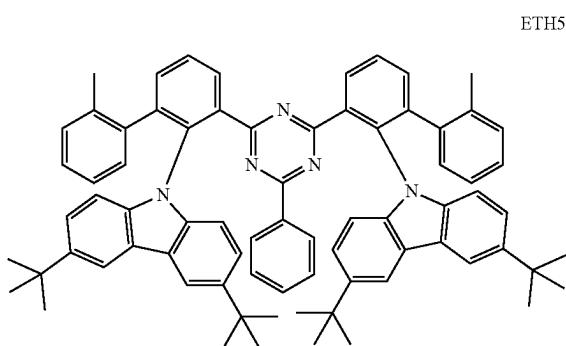
ETH54



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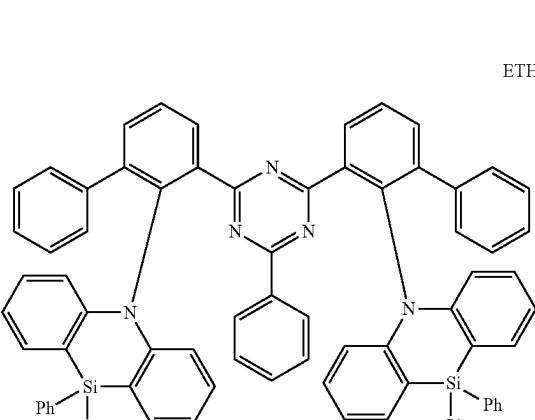


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ETH55

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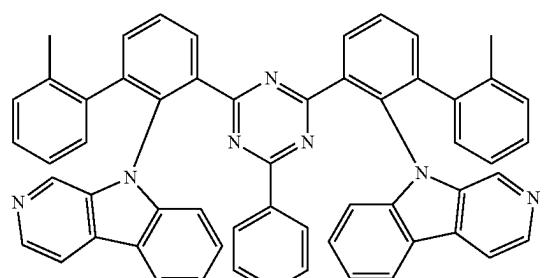


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ETH56

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ETH60

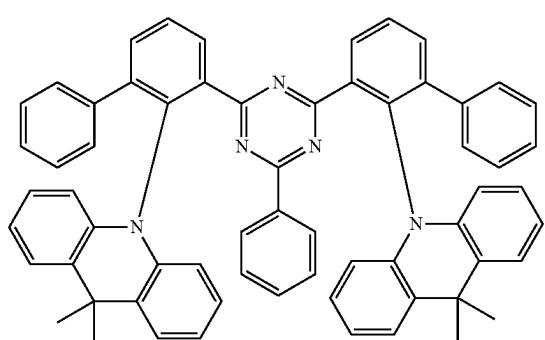
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ETH57

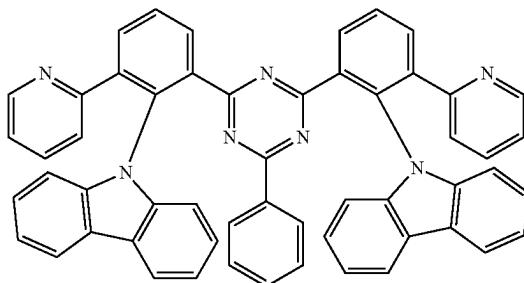
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ETH61

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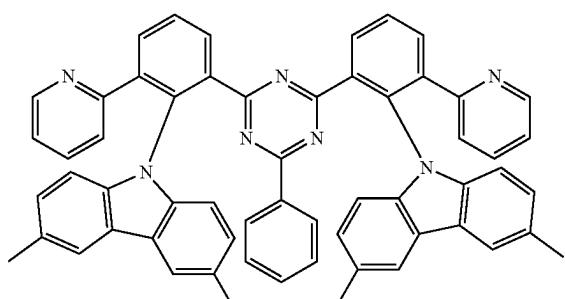


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113

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ETH62



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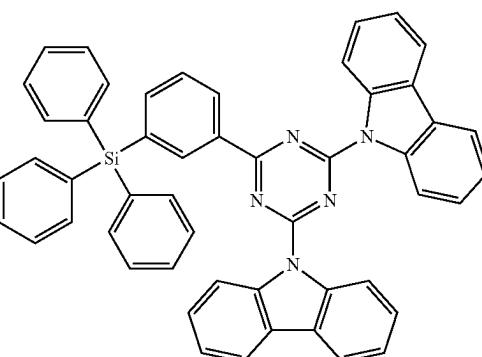
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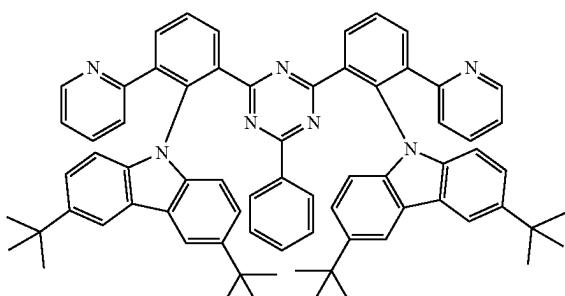
114

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ETH66



ETH63 20

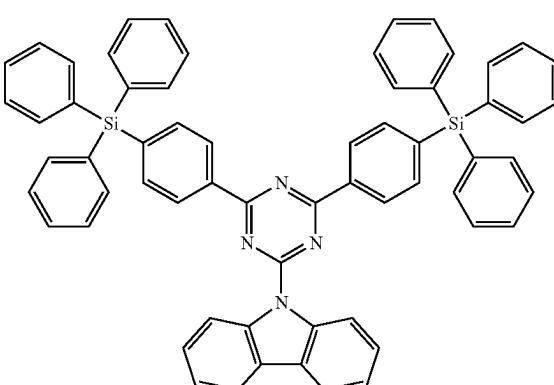


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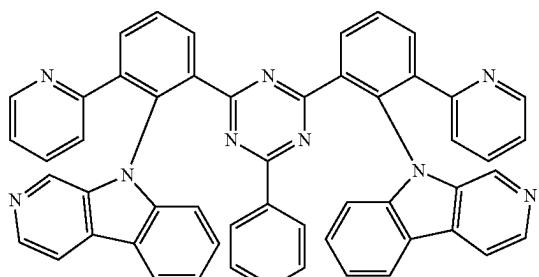
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ETH67



ETH64

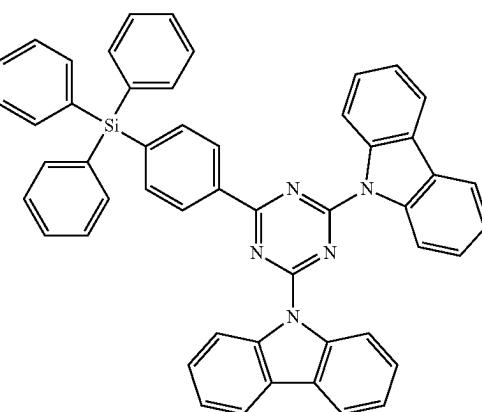


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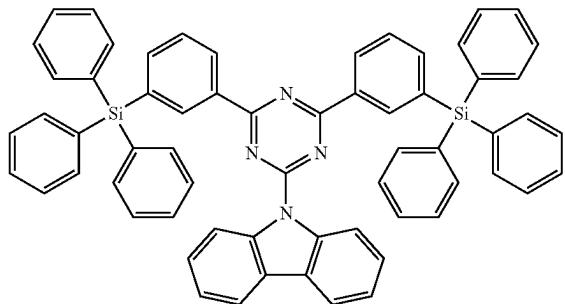
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ETH68



ETH65



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ETH69

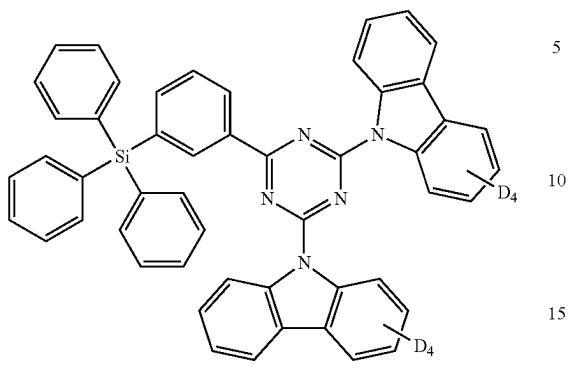
Chemical structure 114 is identical to the one shown above, labeled ETH66.

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115

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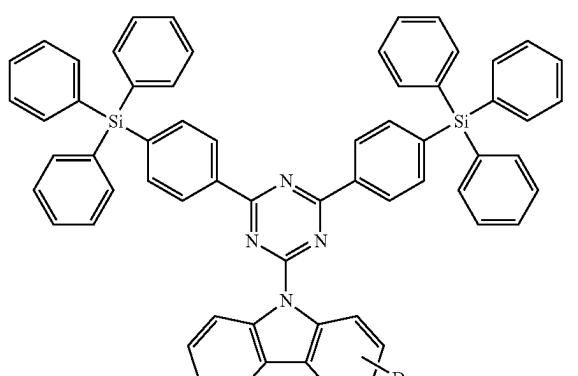
ETH70



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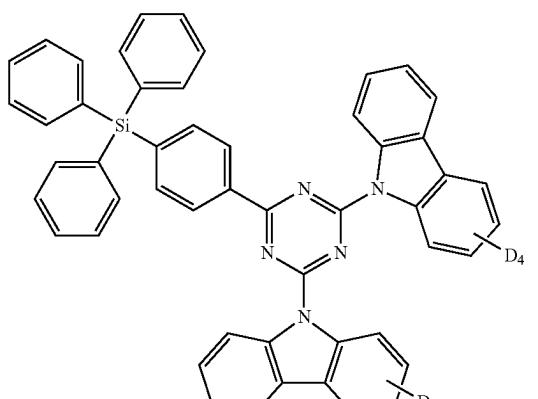
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ETH71



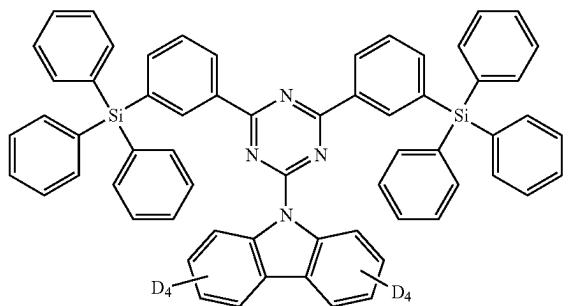
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ETH72



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ETH73



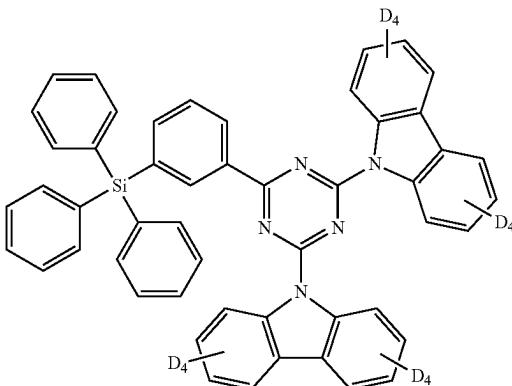
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116

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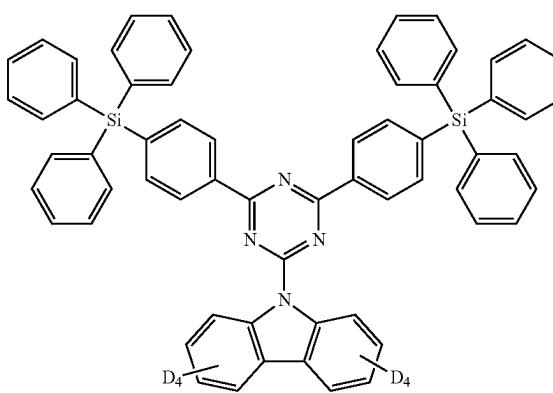
ETH74



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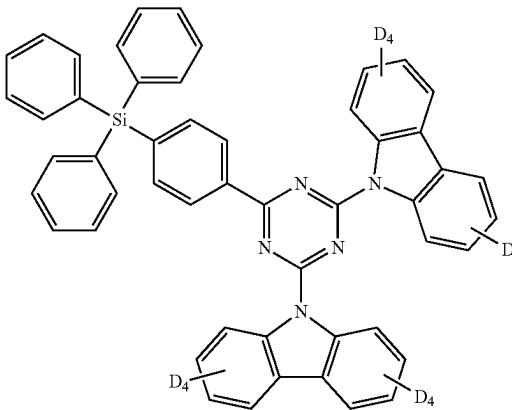
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ETH75



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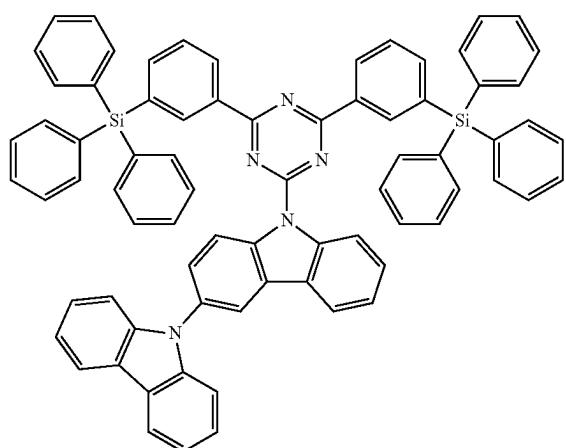
ETH76



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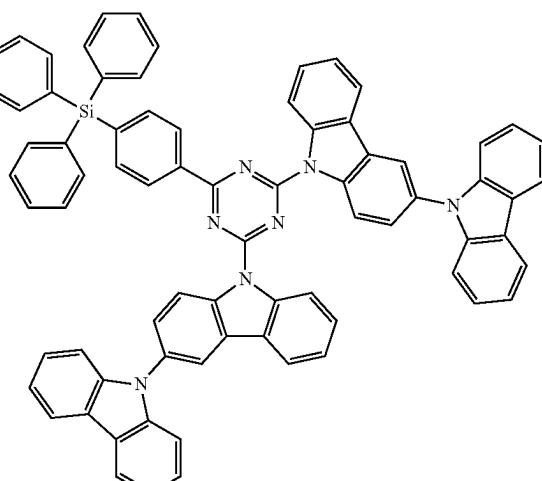
ETH77



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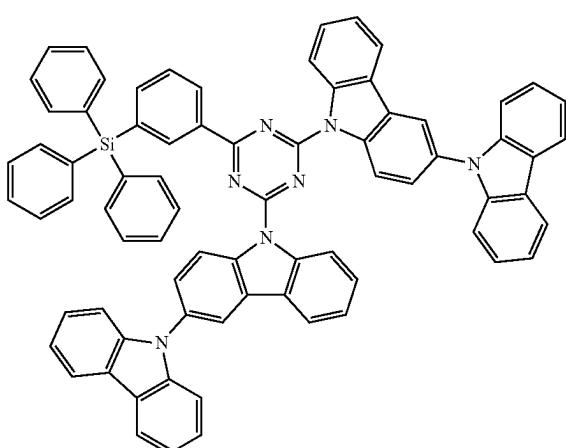
118
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ETH80

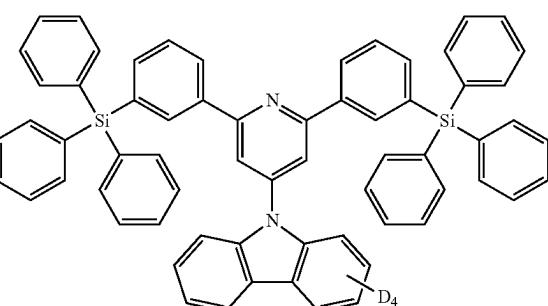


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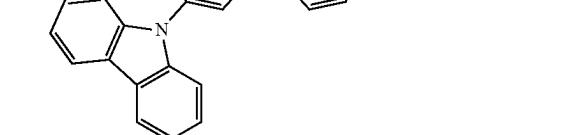
ETH81



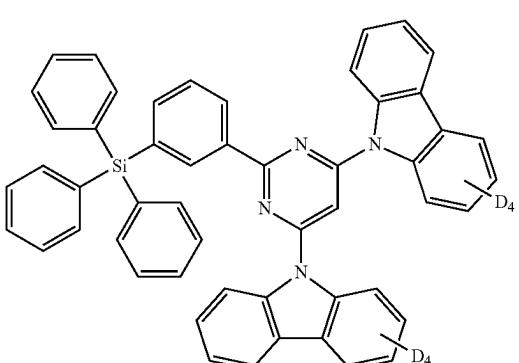
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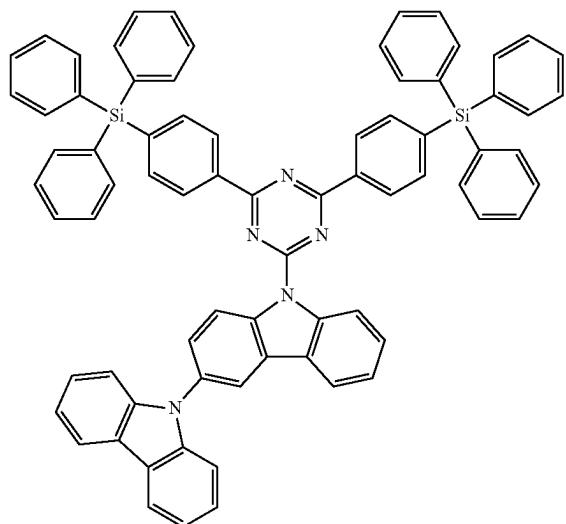
ETH82



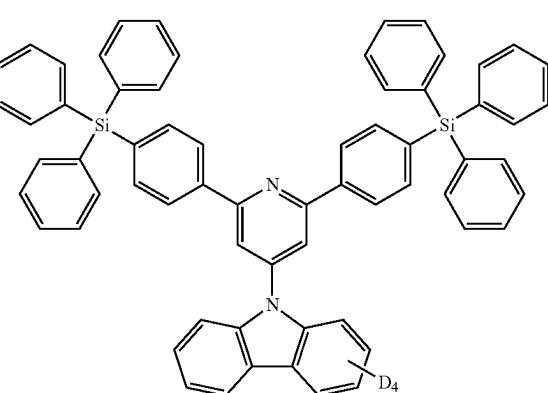
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ETH83

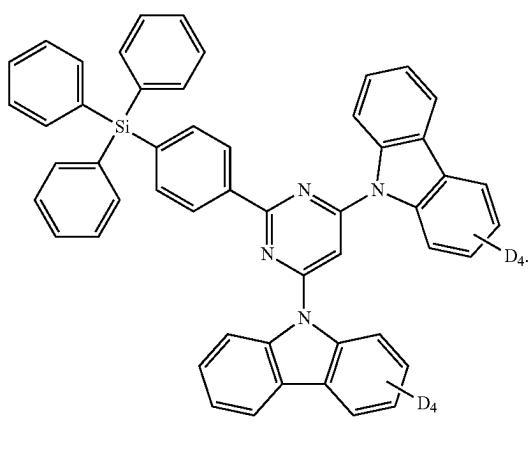


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119
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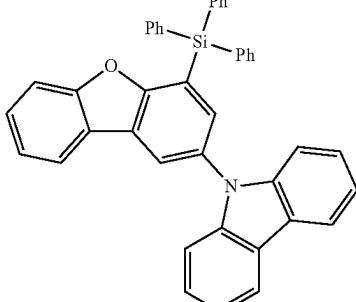
ETH84



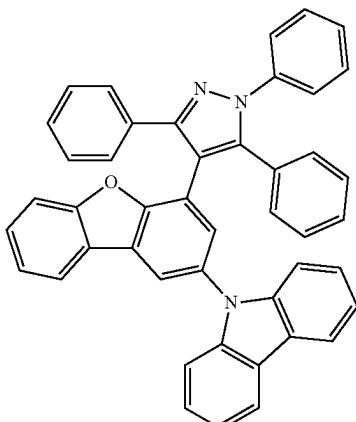
In an embodiment, the third compound may include at least one of Compounds HTH1 to HTH52:

120
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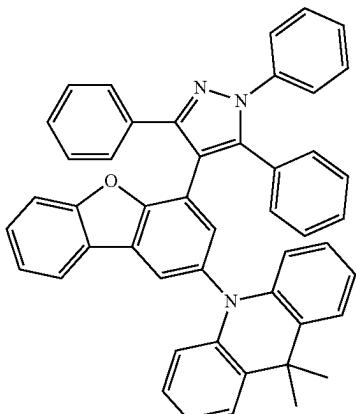
HTH4



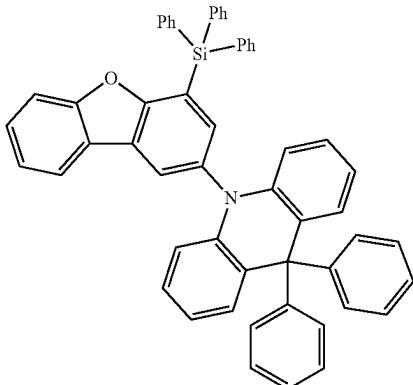
HTH5



HTH6



HTH7



HTH1 25

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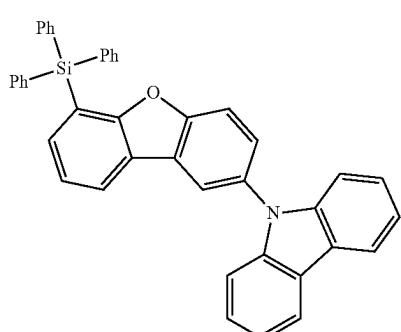
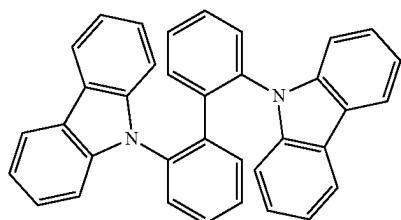
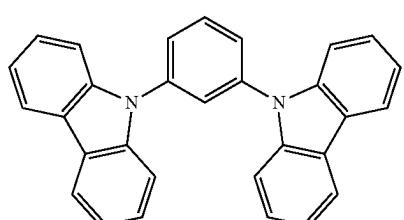
HTH2 40

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HTH3 55

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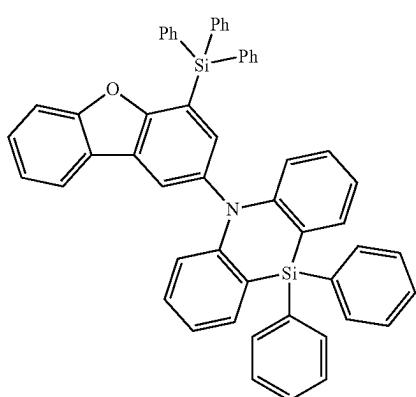
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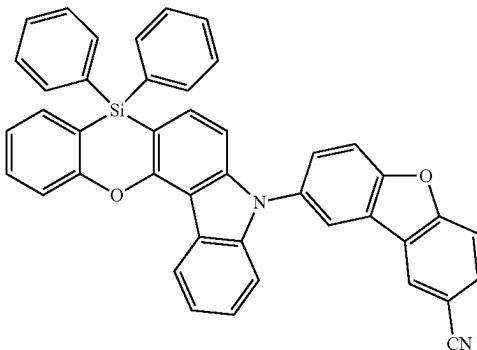


HTH8

122

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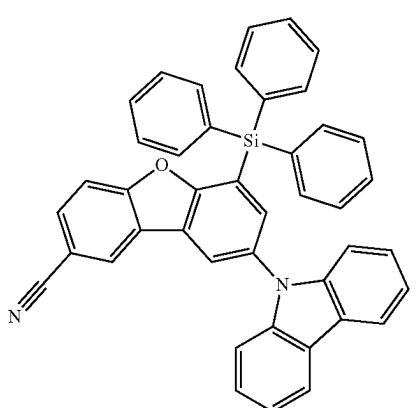
HTH12



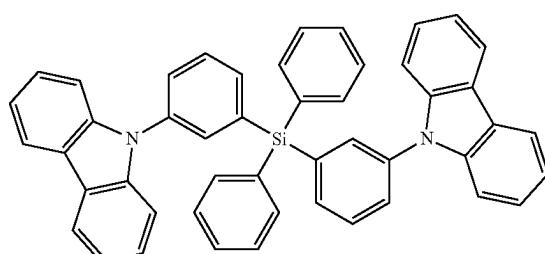
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HTH9 20

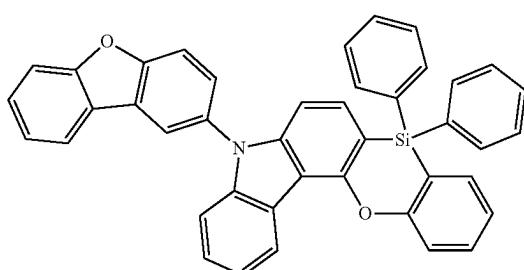
HTH13



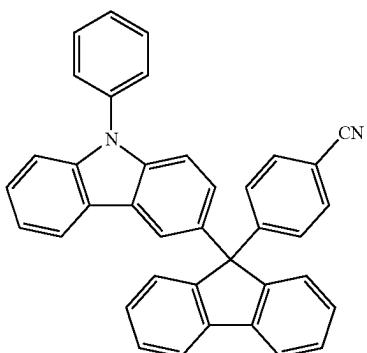
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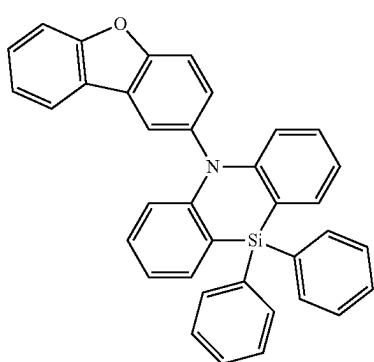
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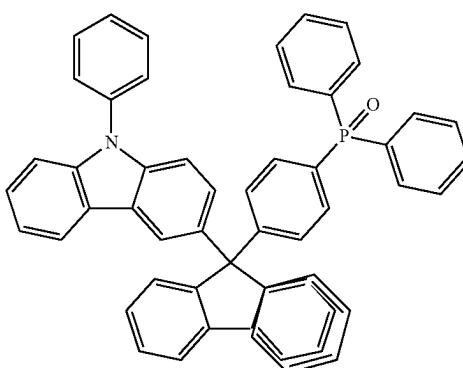


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HTH11

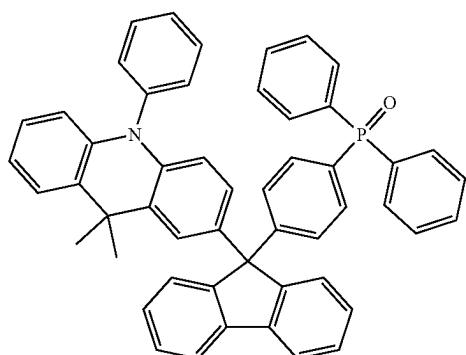
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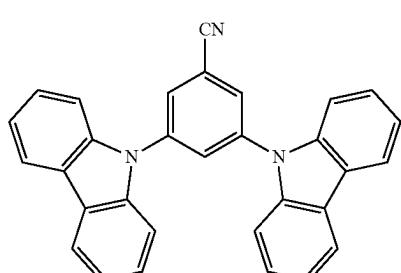
HTH16



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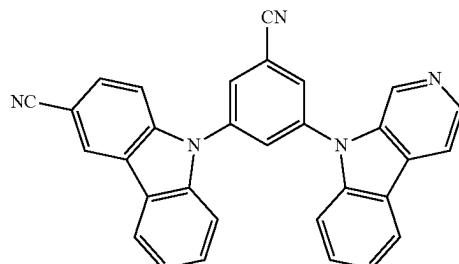


HTH17 20

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HTH22

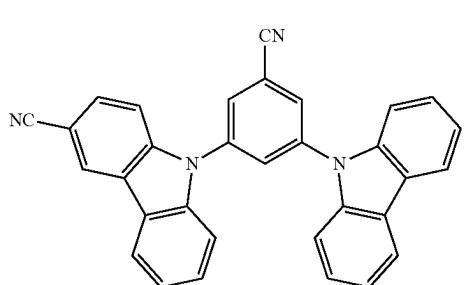


HTH18

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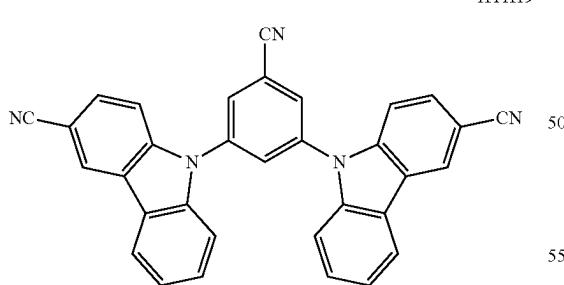
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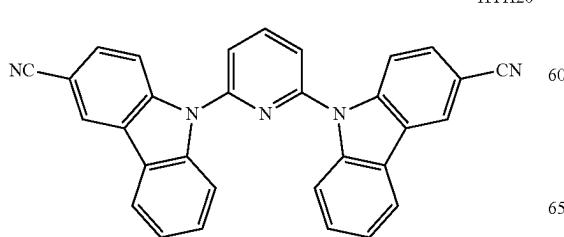
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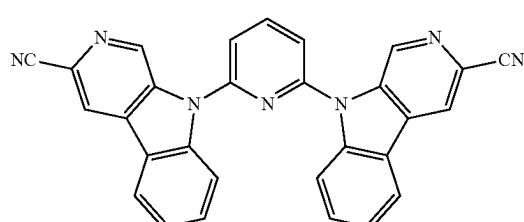
HTH24



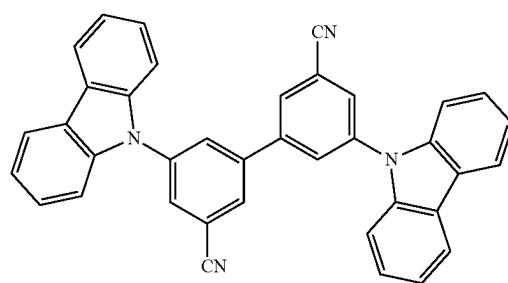
HTH20



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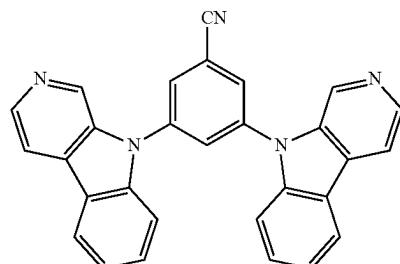


HTH25



124
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HTH21

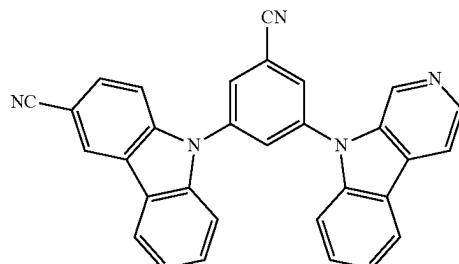


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HTH22

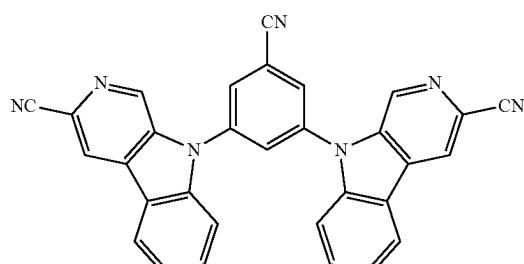


HTH17 20

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HTH23

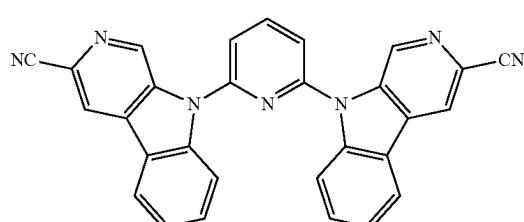


HTH18

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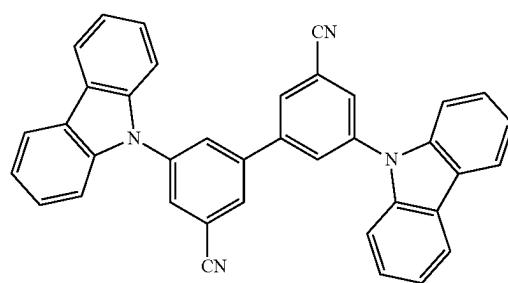
HTH24



HTH19 45

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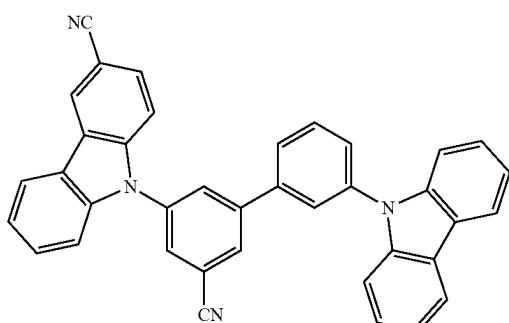
HTH25



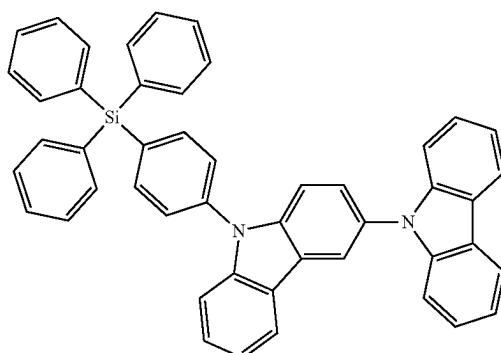
US 12,391,715 B2

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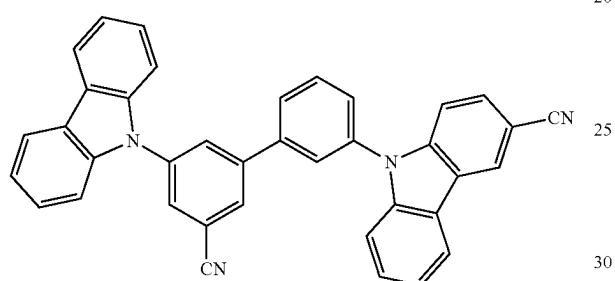
HTH26

**126**
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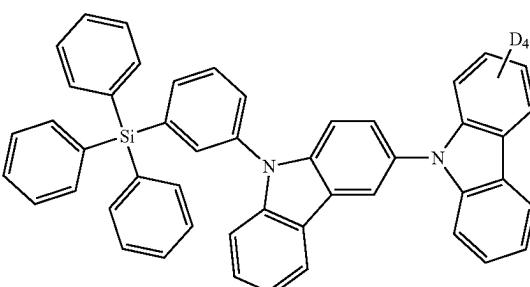
HTH30



HTH27 20

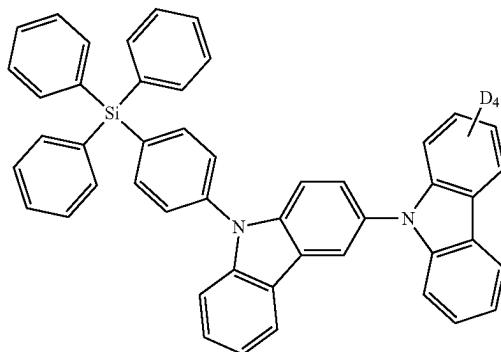
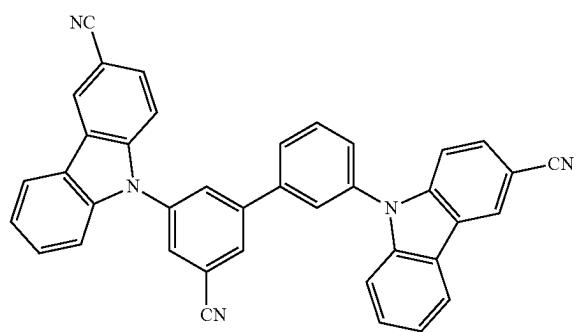


HTH31



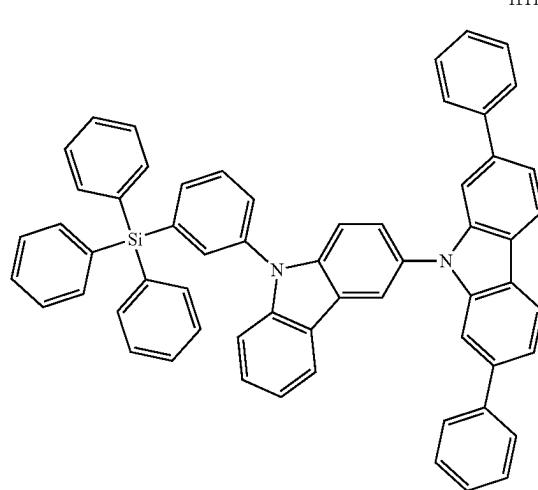
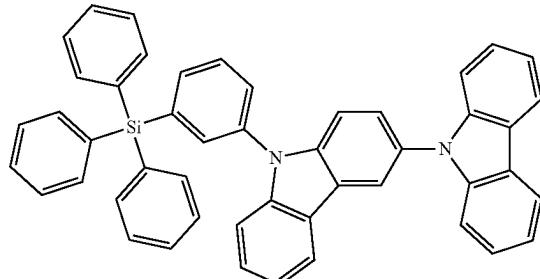
HTH32

HTH28 35



HTH33

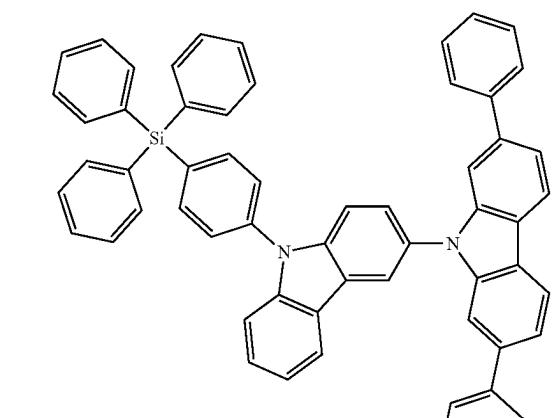
HTH29 55



127

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HTH34



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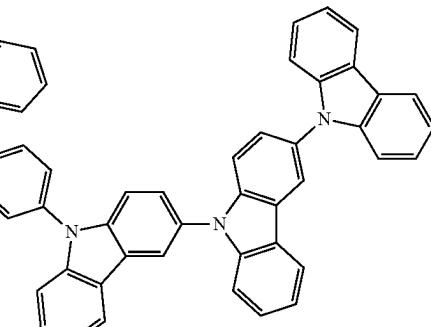
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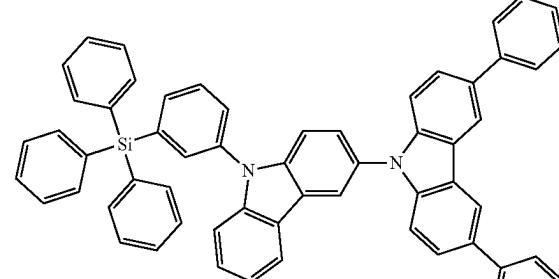
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HTH38



HTH35

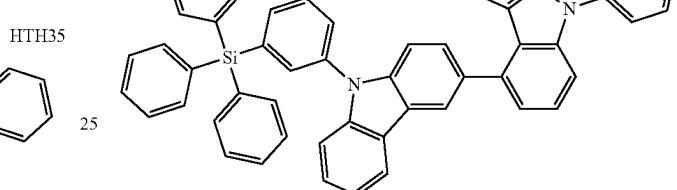


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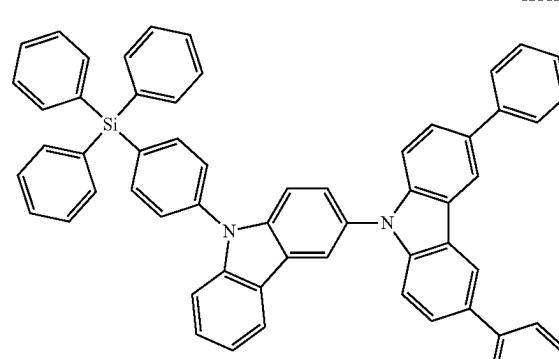
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HTH40

HTH36



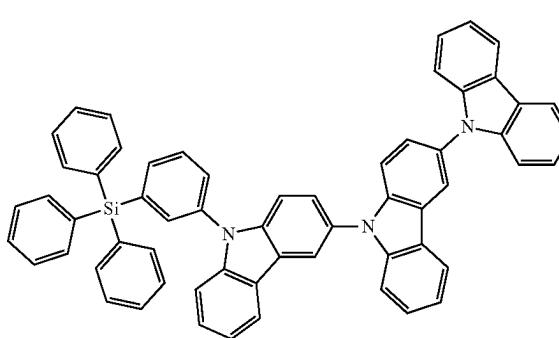
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HTH37

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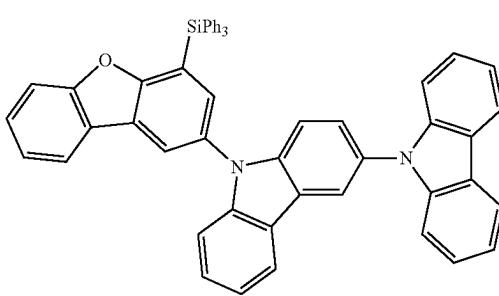
HTH41



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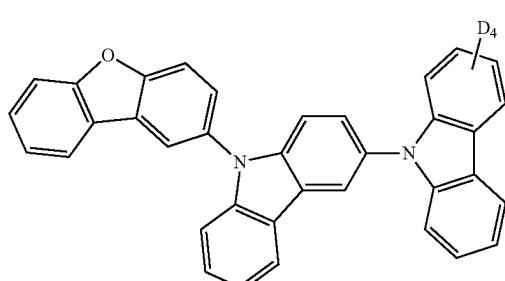
HTH42



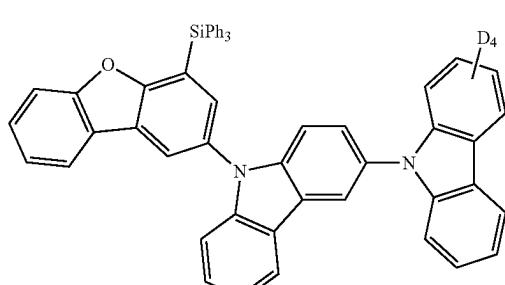
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HTH43

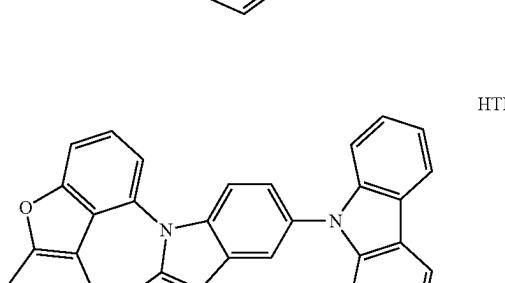


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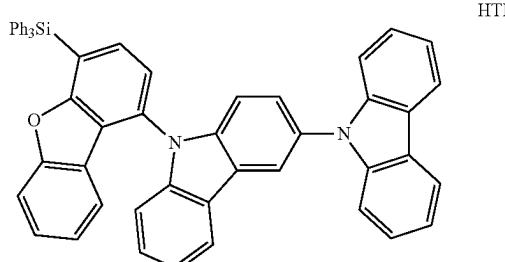
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HTH44



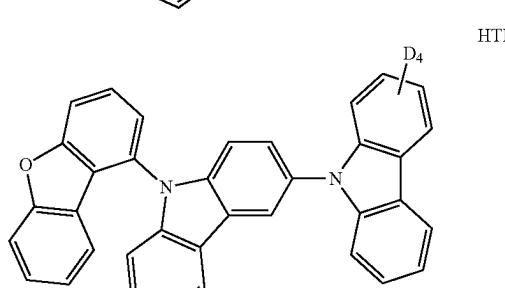
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HTH45



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HTH46



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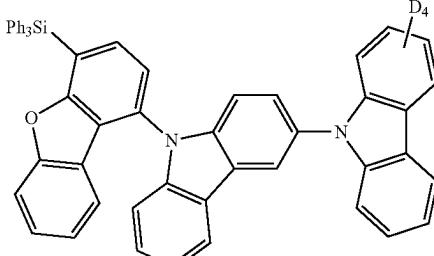
HTH47

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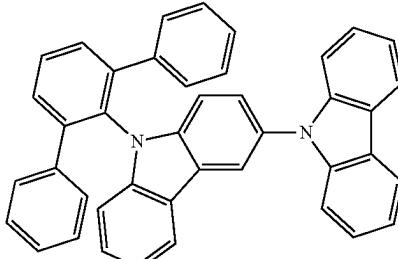
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HTH48

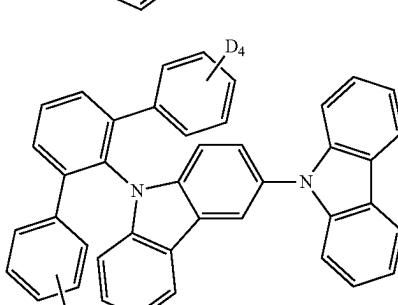


HTH49



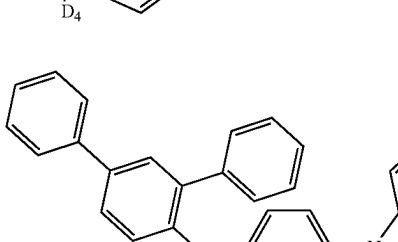
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HTH44



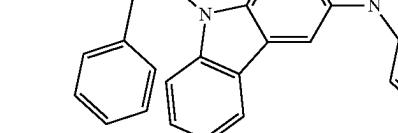
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HTH50



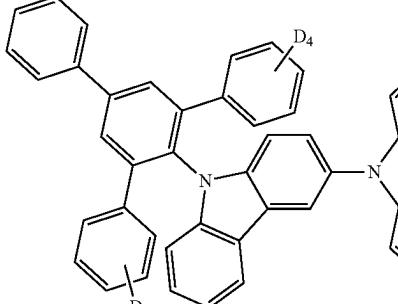
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HTH51



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HTH52



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HTH46

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HTH47

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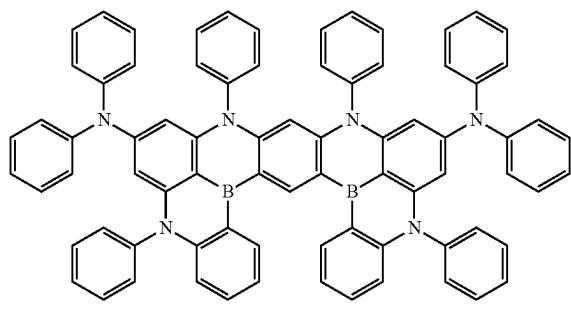
HTH47

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In an embodiment, the fourth compound may include at least one of Compounds DFD1 to DFD14:

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DFD1



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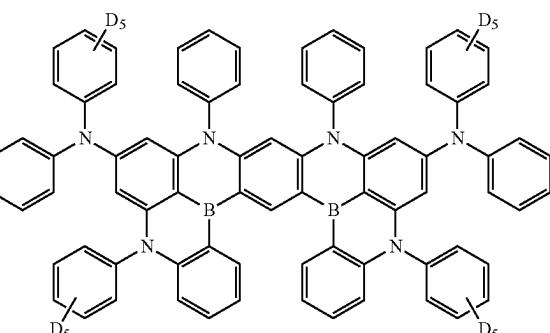
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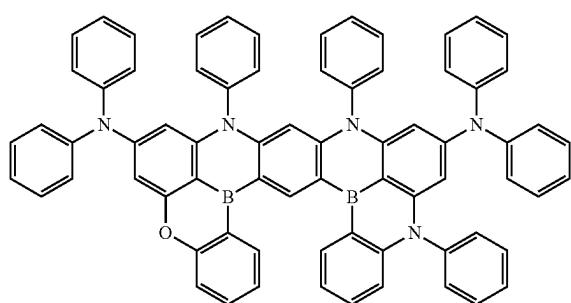
132

-continued

DFD5

D₅D₅D₅D₅

DFD2 20

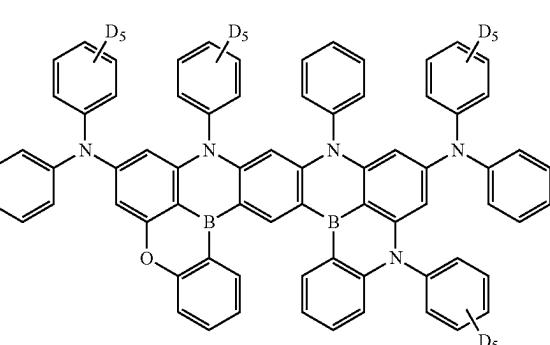


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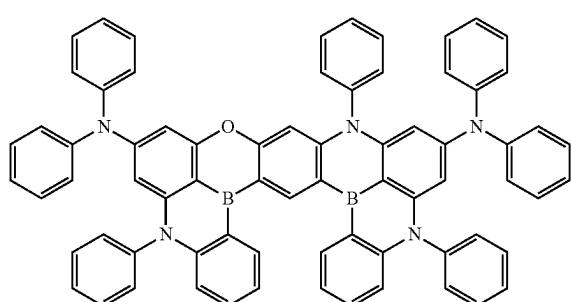
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DFD6

D₅D₅D₅D₅

DFD3

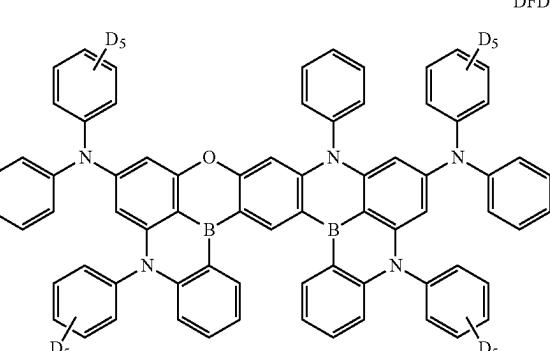


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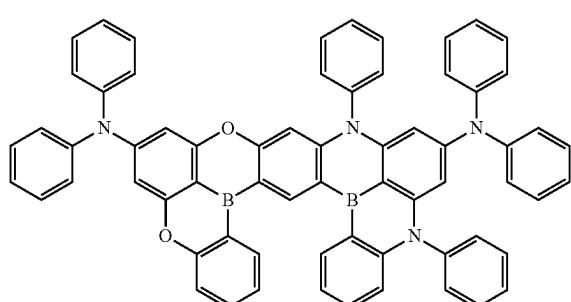
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DFD7

D₅D₅D₅D₅

DFD4

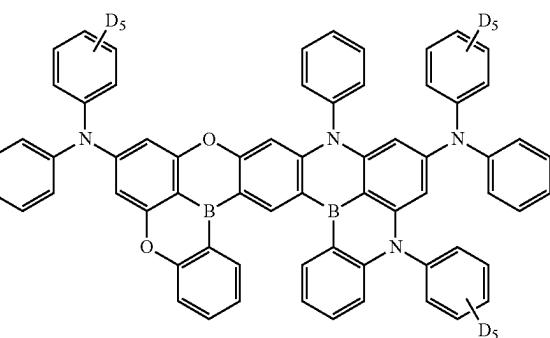


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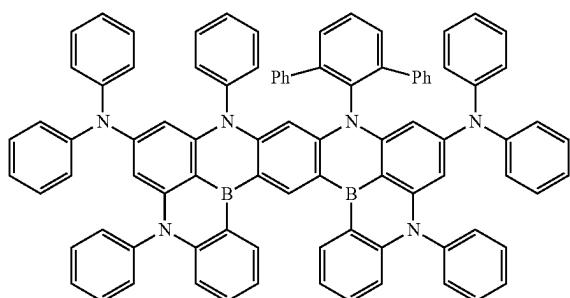
DFD8

D₅D₅D₅D₅

133

-continued

DFD9

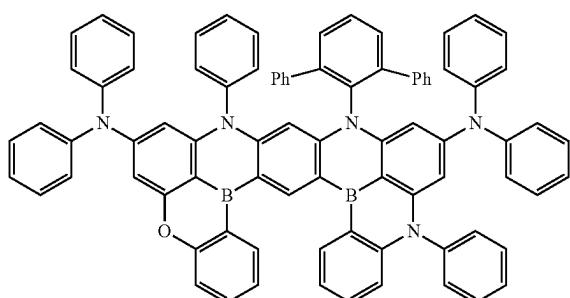


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DFD10

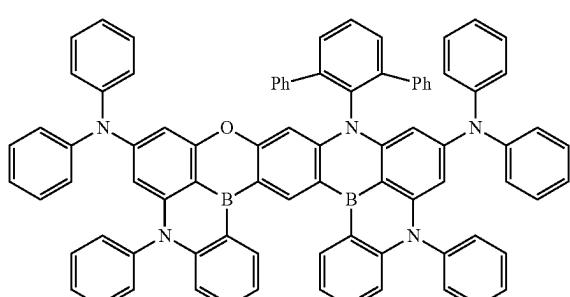


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DFD11

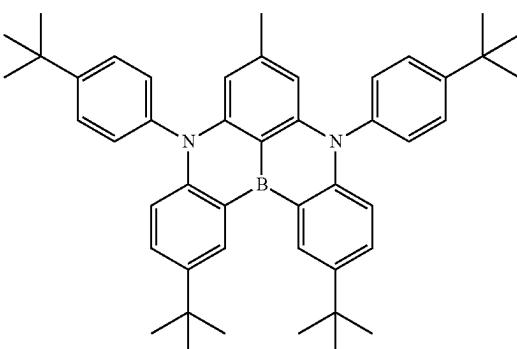


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134

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DF13

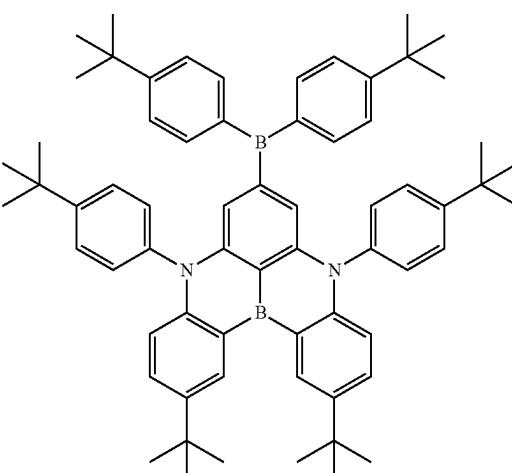


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DF14



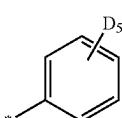
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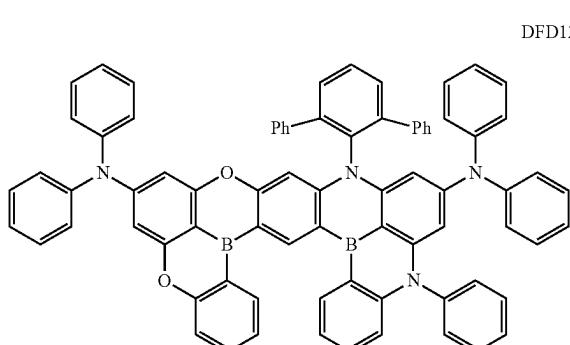
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DFD11

Among the compounds, Ph indicates a phenyl group, D₅ indicates a substitution with five deuteriums, and D₄ indicates a substitution with four deuteriums. For example, a group represented by

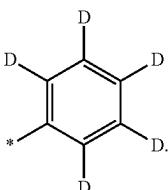


may be identical to a group represented by



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In an embodiment, the light-emitting device may satisfy at least one of Condition 1 to Condition 4:

Condition 1

lowest unoccupied molecular orbital (LUMO) energy level (eV) of the third compound > LUMO energy level (eV) of the first compound

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Condition 2

LUMO energy level (eV) of the first compound > LUMO
energy level (eV) of the second compound

Condition 3

HOMO energy level (eV) of the first compound > HOMO
energy level (eV) of the third compound

Condition 4

HOMO energy level (eV) of the first compound > HOMO
energy level (eV) of the third compound

The HOMO energy level and the LUMO energy level of each of the first compound, the second compound, and the third compound are negative values and may be measured according to any suitable method.

In an embodiment, the absolute value of the difference between the LUMO energy level of the first compound and the LUMO energy level of the second compound may be 0.1 eV or more and 1.0 eV or less, or the absolute value of the difference between the LUMO energy level of the first compound and the LUMO energy level of the third compound may be 0.1 eV or more and 1.0 eV or less, and the absolute value of the difference between the HOMO energy level of the first compound and the HOMO energy level of the second compound may be 1.25 eV or less (for example, 1.25 eV or less and 0.2 eV or more), or the absolute value of the difference between the HOMO energy level of the first compound and the HOMO energy level of the third compound may be 1.25 eV or less (for example, 1.25 eV or less and 0.2 eV or more).

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

The light-emitting device may have the structure of a first embodiment or a second embodiment:

Description of First Embodiment

According to the first embodiment, the first compound is included in the emission layer in the interlayer of the light-emitting device, the emission layer further includes a host, the first compound and the host are different from each other, and the emission layer may be to emit phosphorescence or fluorescence emitted from the first compound. Thus, according to the first embodiment, the first compound may be a dopant or an emitter. In an embodiment, the first compound may be a phosphorescent dopant or a phosphorescent emitter.

In an embodiment, the phosphorescence or fluorescence to be emitted from the first compound may be blue light.

In an embodiment, the emission layer may further include an auxiliary dopant. The auxiliary dopant may improve the emission efficiency of the first compound by effectively transferring energy to the first compound, which may be a dopant or an emitter.

The auxiliary dopant may be different from each of the first compound and the host.

In an embodiment, the auxiliary dopant may be a delayed fluorescence emission compound.

In an embodiment, the auxiliary dopant may be a compound including at least one cyclic group including B (boron) and N (nitrogen) each (e.g., simultaneously) as ring-forming atoms.

Description of Second Embodiment

According to the second embodiment, the first compound is included in an emission layer in an interlayer of the

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light-emitting device, the emission layer further includes a host and a dopant, each of the first compound, the host, and the dopant are different from each other, and the emission layer may be to emit phosphorescence or fluorescence (for example, delayed fluorescence) emitted from the dopant.

For example, in the second embodiment, the first compound may act as an auxiliary dopant that transfers energy to the dopant (or emitter), not as a dopant.

As another example, the first compound in the second embodiment may act as an emitter and may also act as an auxiliary dopant for transferring energy to a dopant (or emitter).

In the second embodiment, the phosphorescence or fluorescence to be emitted from the dopant (or emitter) may be blue phosphorescence or blue fluorescence (for example, blue delayed fluorescence).

In the second embodiment, the dopant (or emitter) may be a phosphorescent dopant material (for example, an organometallic compound represented by Formula 1, an organometallic compound represented by Formula 401, or any combination thereof) or any fluorescent dopant material (for example, a compound represented by Formula 501, a compound represented by Formula 502, a compound represented by Formula 503, or any combination thereof).

In the first and second embodiments, the blue light may be blue light having a maximum emission wavelength in the range of 390 nm to 500 nm, 410 nm to 490 nm, 430 nm to 480 nm, 440 nm to 475 nm, or 455 nm to 470 nm.

In the first embodiment, the auxiliary dopant may include, for example, a fourth compound represented by Formula 502 or 503.

In the first and second embodiments, the host may be any host material (for example, a compound represented by Formula 301, a compound represented by 301-1, a compound represented by Formula 301-2, or any combination thereof).

In some embodiments, among the first and second embodiments, the host may be the second compound, the third compound, or any combination thereof.

In an embodiment, the light-emitting device may further include at least one of a first capping layer located outside the first electrode and a second capping layer located outside the second electrode, and the organometallic compound represented by Formula 1 may be included in at least one of the first capping layer and the second capping layer. More details for the first capping layer and/or second capping layer may be the same as described herein.

In one or more embodiments, the light-emitting device may further include:

a first capping layer located outside the first electrode and containing the heterocyclic compound represented by Formula 1;

a second capping layer located outside the second electrode and containing the heterocyclic compound represented by Formula 1; or

the first capping layer and the second capping layer (e.g., simultaneously).

The wording “(an interlayer and/or capping layer) includes an organometallic compound represented by Formula 1” as utilized herein may be understood as “(an interlayer and/or capping layer) may include one kind of (e.g., the same) organometallic compound represented by Formula 1 or two different kinds of organometallic compounds, each represented by Formula 1.”

For example, the interlayer and/or capping layer may include Compound D1 only as the organometallic compound. For example, Compound D1 may exist in the emission layer of the light-emitting device. In an embodiment,

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the interlayer may include, as the organometallic compound, Compound D1 and Compound D2. In this regard, Compound D1 and Compound D2 may both exist in an identical (e.g., the same) layer (for example, Compound D1 and Compound D2 may both exist in an emission layer), or may exist in different layers (for example, Compound D1 may exist in an emission layer and Compound D2 may exist in an electron transport region).

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

Another aspect provides an electronic apparatus including the light-emitting device. The electronic apparatus may further include a thin-film transistor. In one or more embodiments, the electronic apparatus may further include a thin-film transistor including a source electrode and a drain electrode, and the first electrode of the light-emitting device may be electrically connected to the source electrode or the drain electrode. In an embodiment, the electronic apparatus may further include a color filter, a color conversion layer, a touch screen layer, a polarizing layer, or any combination thereof. The electronic apparatus may be the same as described herein.

In an embodiment, provided is an organometallic compound represented by Formula 1. The organometallic compound represented by Formula 1 may be the same as described herein.

In an embodiment, the organometallic compound represented by Formula 1 may be to emit blue light. For example, the organometallic compound represented by Formula 1 may be to emit blue light having a maximum emission wavelength in the range of 390 nm to 500 nm, 410 nm to 490 nm, 430 nm to 480 nm, 440 nm to 475 nm, or 455 nm to 470 nm.

In an embodiment, the organometallic compound represented by Formula 1 may have a color purity in which the bottom emission CIE_x coordinate is in the range of 0.12 to 0.15 or 0.13 to 0.14, and the bottom emission CIE_y coordinate is in the range of 0.06 to 0.25, 0.10 to 0.20 or 0.13 to 0.20.

Suitable synthesis methods of the organometallic compound represented by Formula 1 may be recognizable by one of ordinary skill in the art by referring to the Synthesis Examples and/or Examples provided below.

Description of FIG. 1

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

Hereinafter, the structure of the light-emitting device 10 according to an embodiment and a method of manufacturing the light-emitting device 10 will be described in connection with FIG. 1.

First Electrode 110

In FIG. 1, a substrate may be additionally located under the first electrode 110 and/or above the second electrode 150. As the substrate, a glass substrate or a plastic substrate may be utilized. In an embodiment, the substrate may be a flexible substrate, and may include plastics with excellent or suitable heat resistance and durability (such as polyimide, polyethylene terephthalate (PET), polycarbonate, polyethylene naphthalate, polyarylate (PAR), polyetherimide, or any combination thereof).

The first electrode 110 may be formed by, for example, depositing and/or sputtering a material for forming the first electrode 110 on the substrate. When the first electrode 110

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is an anode, a material for forming the first electrode 110 may be a high work function material that facilitates injection of holes.

The first electrode 110 may be a reflective electrode, a semi-transmissive electrode, or a transmissive electrode. When the first electrode 110 is a transmissive electrode, a material for forming the first electrode 110 may include indium tin oxide (ITO), indium zinc oxide (IZO), tin oxide (SnO_2), zinc oxide (ZnO), or any combination thereof. In an embodiment, when the first electrode 110 is a semi-transmissive electrode or a reflective electrode, 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 utilized as a material for forming a first electrode.

The first electrode 110 may have a single-layered structure including (e.g., consisting of) a single layer, or a multilayer structure including a plurality of layers. For example, the first electrode 110 may have a three-layered structure of ITO/Ag/ITO.

Interlayer 130

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

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

The interlayer 130 may further include metal-containing compounds (such as organometallic compounds), inorganic materials (such as quantum dots), and/or the like, in addition to one or more suitable organic materials.

In an embodiment, the interlayer 130 may include i) two or more emitting units sequentially stacked between the first electrode 110 and the second electrode 150 and ii) a charge generation layer located between the two emitting units. When the interlayer 130 includes the emitting unit and the charge generation layer as described above, the light-emitting device 10 may be a tandem light-emitting device.

Hole Transport Region in Interlayer 130

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

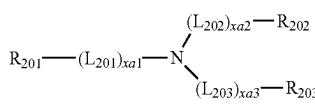
The hole transport region may include a hole injection layer (HIL), a hole transport layer (HTL), an emission auxiliary layer, an electron blocking layer (EBL), or any combination thereof.

For example, the hole transport region may have a multi-layered structure including a hole injection layer/hole transport layer structure, a hole injection layer/hole transport layer/emission auxiliary layer structure, a hole injection layer/emission auxiliary layer structure, a hole transport layer/emission auxiliary layer structure, or a hole injection layer/hole transport layer/electron blocking layer structure, wherein the constituting layers of each structure are stacked sequentially from the first electrode 110.

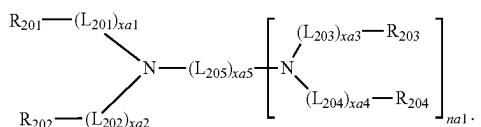
The hole transport region may include a compound represented by Formula 201, a compound represented by Formula 202, or any combination thereof:

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Formula 201



Formula 202



In Formulae 201 and 202,

L₂₀₁ to L₂₀₄ may each independently be a C₃-C₆₀ carbocyclic group unsubstituted or substituted with at least one R_{10a} or a C₁-C₆₀ heterocyclic group unsubstituted or substituted with at least one R_{10a}, 15

L₂₀₅ may be *—O—*, *—S—*, *—N(Q₂₀₁)—*, a C₁-C₂₀ alkylene group unsubstituted or substituted with at least one R_{10a}, a C₂-C₂₀ alkenylene group unsubstituted or substituted with at least one R_{10a}, a C₃-C₆₀ carbocyclic group unsubstituted or substituted with at least one R_{10a}, or a C₁-C₆₀ heterocyclic group unsubstituted or substituted with at least one R_{10a}, 20

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

xa5 may be an integer from 1 to 10,

R₂₀₁ to R₂₀₄ and O₂₀₁ may each independently be a C₃-C₆₀ carbocyclic group unsubstituted or substituted with at least one R_{10a} or a C₁-C₆₀ heterocyclic group unsubstituted or substituted with at least one R_{10a},

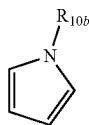
R₂₀₁ and R₂₀₂ may optionally be linked to each other via a single bond, a C₁-C₅ alkenylene group unsubstituted or substituted with at least one R_{10a}, or a C₂-C₅ alkenylene group unsubstituted or substituted with at least one R_{10a} to thereby form a C₈-C₆₀ polycyclic group (for example, a carbazole group and/or the like) 35

unsubstituted or substituted with at least one R_{10a} (see e.g., Compound HT16 and/or the like),

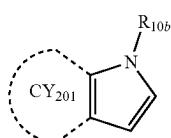
R₂₀₃ and R₂₀₄ may optionally be linked to each other via a single bond, a C₁-C₅ alkylene group unsubstituted or substituted with at least one R_{10a}, or a C₂-C₅ alkenylene 45 group unsubstituted or substituted with at least one R_{10a} to thereby form a C₈-C₆₀ polycyclic group unsubstituted or substituted with at least one R_{10a}, and

na1 may be an integer from 1 to 4.

In an embodiment, each of Formulae 201 and 202 may include at least one of the groups represented by Formulae CY201 to CY217:



CY201

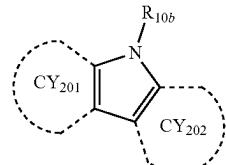


CY202

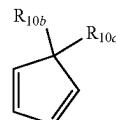
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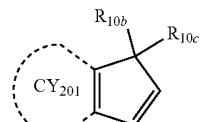
CY203



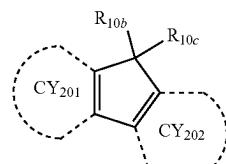
CY204



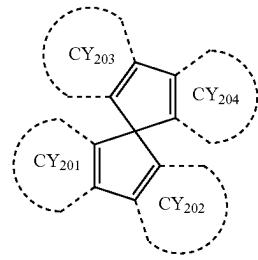
CY205



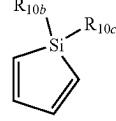
CY206



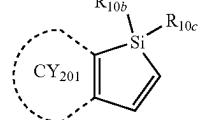
CY207



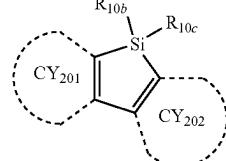
CY208



CY209

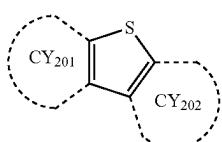
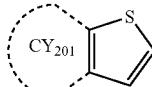
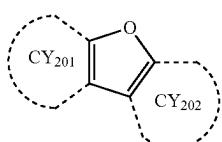
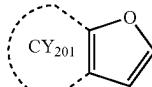
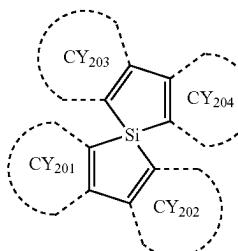


CY210



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R_{10b} and R_{10c} in Formulae CY201 to CY217 may each independently be the same as described in connection with R_{10a}, ring CY₂₀₁ to ring CY₂₀₄ may each independently be a C₃-C₂₀ carbocyclic group or a C₁-C₂₀ heterocyclic group, and at least one hydrogen in Formulae CY201 to CY217 may be unsubstituted or substituted with at least one R_{10a}.

In an embodiment, ring CY₂₀₁ to ring CY₂₀₄ in Formulae CY201 to CY217 may each independently be a benzene group, a naphthalene group, a phenanthrene group, or an anthracene group.

In one or more embodiments, each of Formulae 201 and 202 may include at least one of the groups represented by Formulae CY201 to CY203.

In one or more embodiments, Formula 201 may include at least one of the groups represented by Formulae CY201 to CY203 and at least one of the groups represented by Formulae CY204 to CY217.

In one or more embodiments, x_{a1} in Formula 201 may be 1, R₂₀₁ may be a group represented by one of Formulae CY201 to CY203, x_{a2} may be 0, and R₂₀₂ may be a group represented by one of Formulae CY204 to CY207.

In one or more embodiments, each of Formulae 201 and 202 may not include (e.g., may exclude) a group represented by one of Formulae CY201 to CY203.

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In one or more embodiments, each of Formulae 201 and 202 may not include a group represented by one of Formulae CY201 to CY203, and may include at least one of the groups represented by Formulae CY204 to CY217.

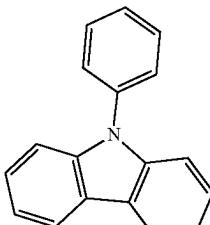
5 In an embodiment, each of Formulae 201 and 202 may not include a group represented by one of Formulae CY201 to CY217.

In an embodiment, the hole transport region may further 10 include one or more of Compounds HT1 to HT46, m-MT-DATA, TDATA, 2-TNATA, NPB(NPD), p-NPB, TPD, Spiro-TPD, Spiro-NPB, methylated NPB, TAPC, HMTPD, 4,4',4''-tris(N-carbazolyl)triphenylamine (TCTA), polyaniline/dodecylbenzene sulfonic acid (PANI/DBSA), poly(3,4-15 ethylene dioxythiophene)/poly(4-styrene sulfonate) (PEDOT/PSS), polyaniline/camphor sulfonic acid (PANI/CSA), polyaniline/poly(4-styrene sulfonate) (PANI/PSS), or any combination thereof:

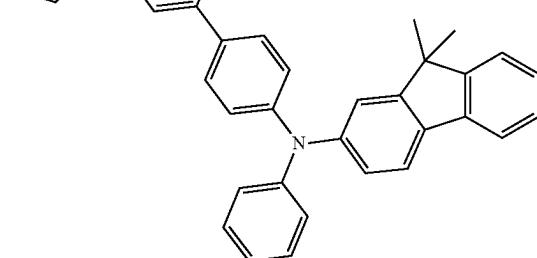
20 CY214

HT1

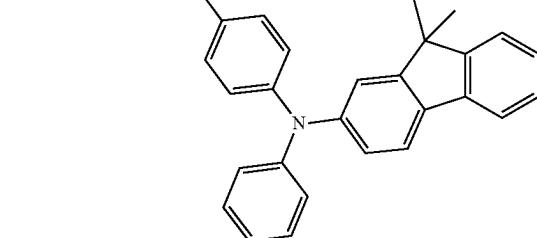
25 CY215



30 CY216

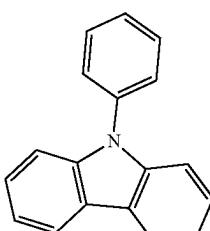


35 CY217



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HT2



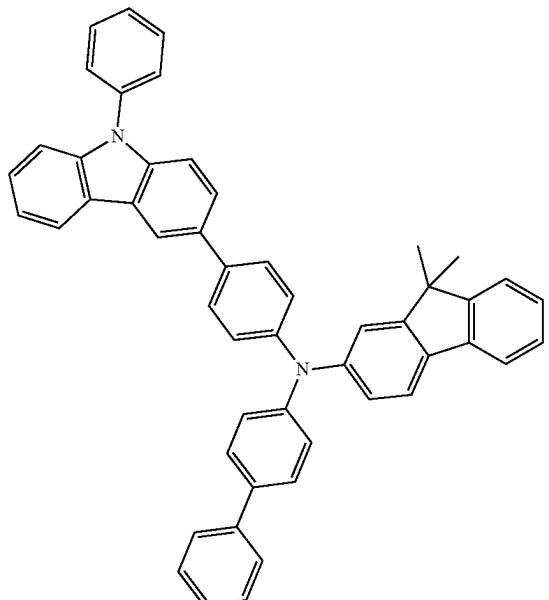
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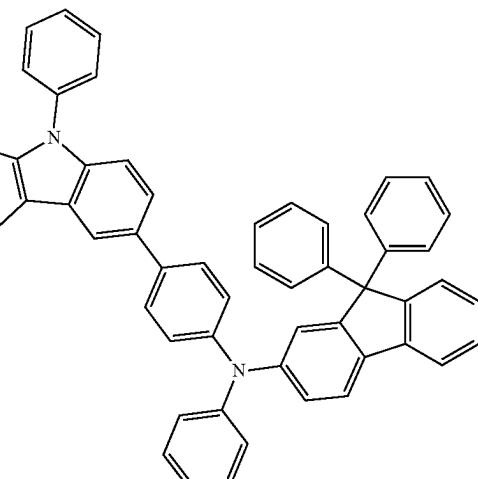
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HT4

HT5

144

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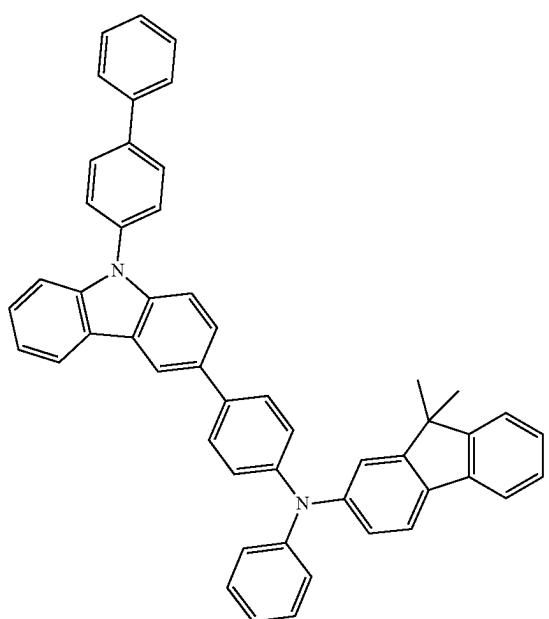
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HT6

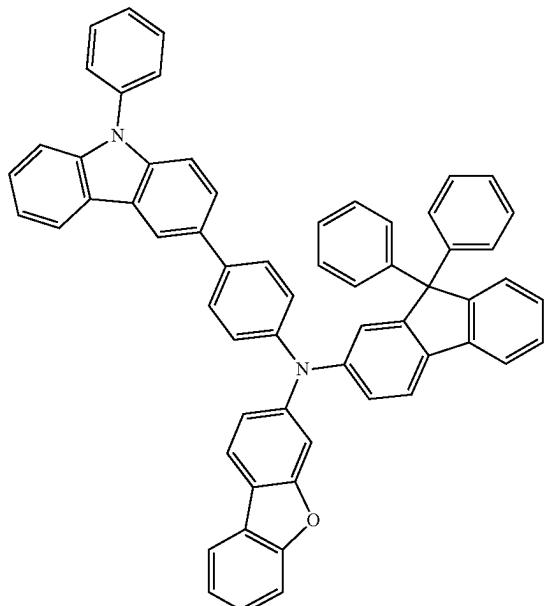


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HT7



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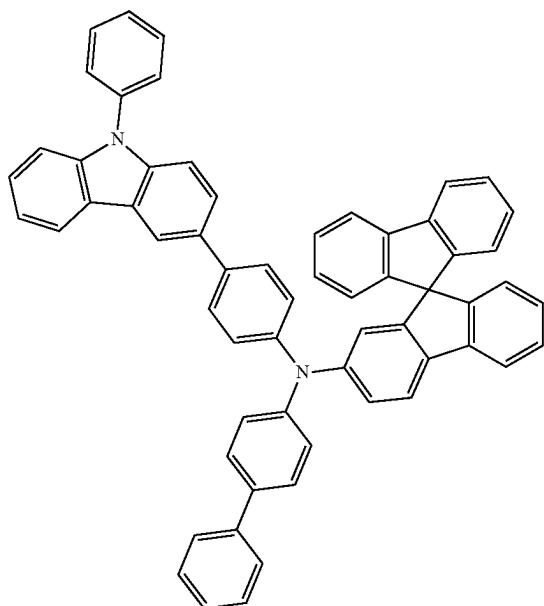
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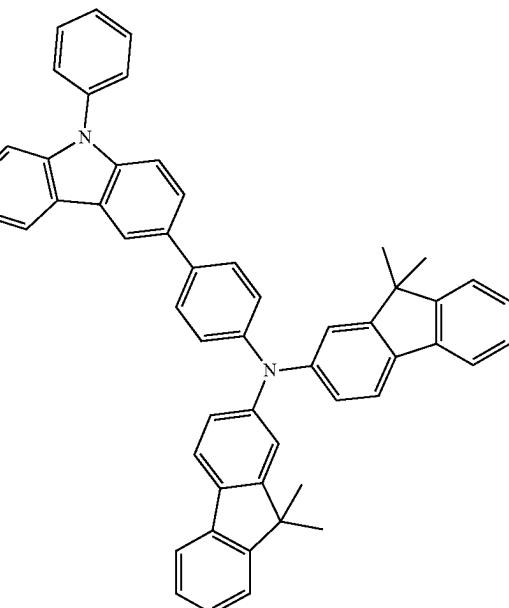
HT8



146

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HT9



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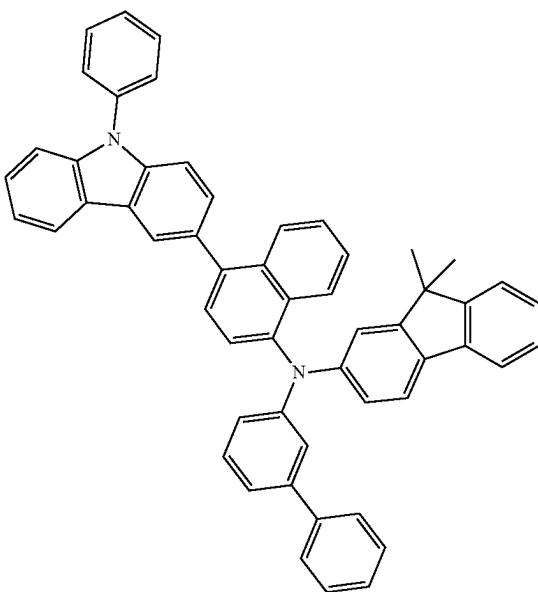
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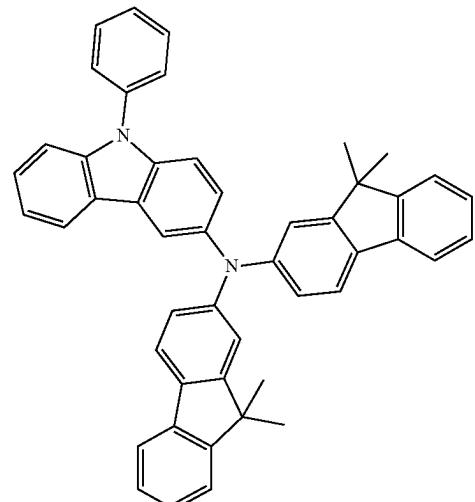
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HT10



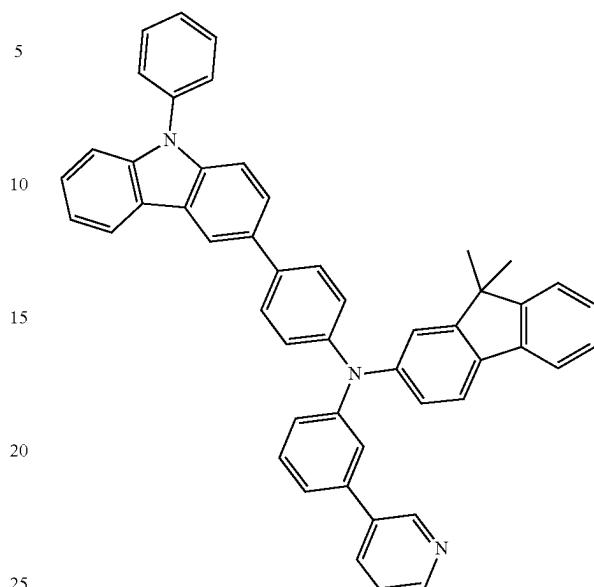
147
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HT11

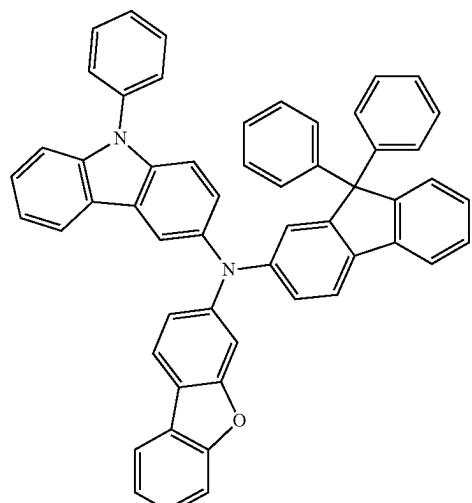


148
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HT14

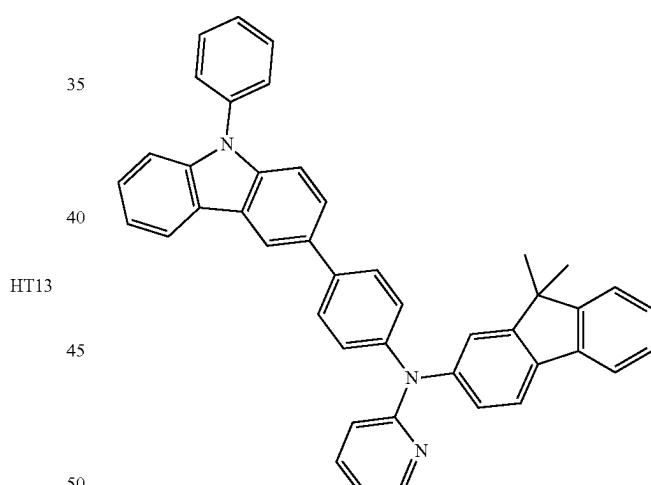


HT12

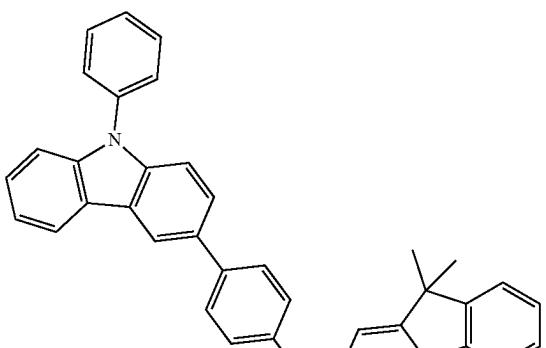


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HT15



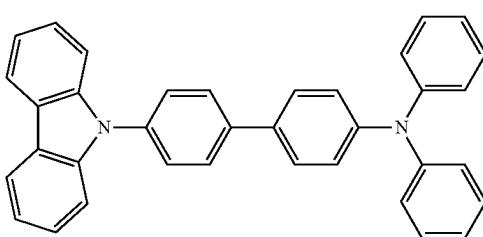
HT13



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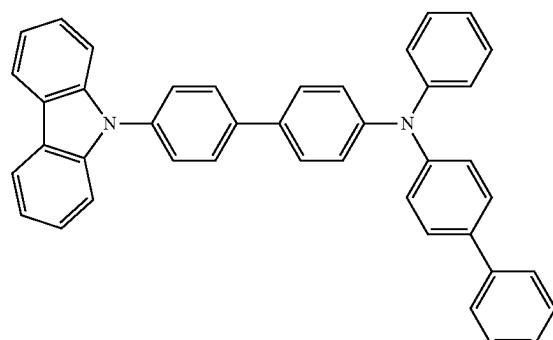
HT16



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149
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HT17



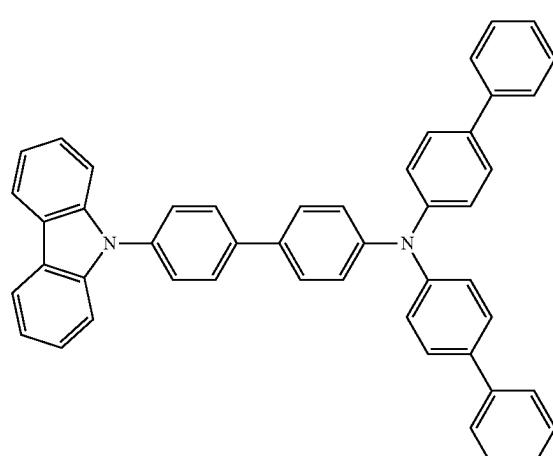
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HT18 25



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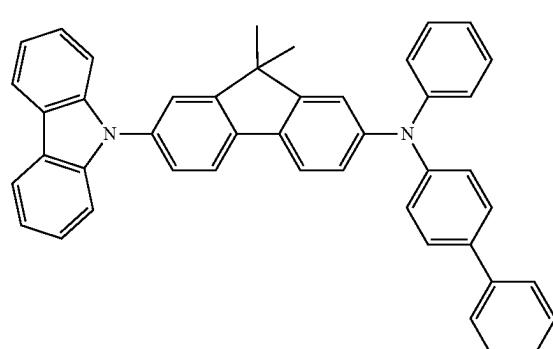
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HT19



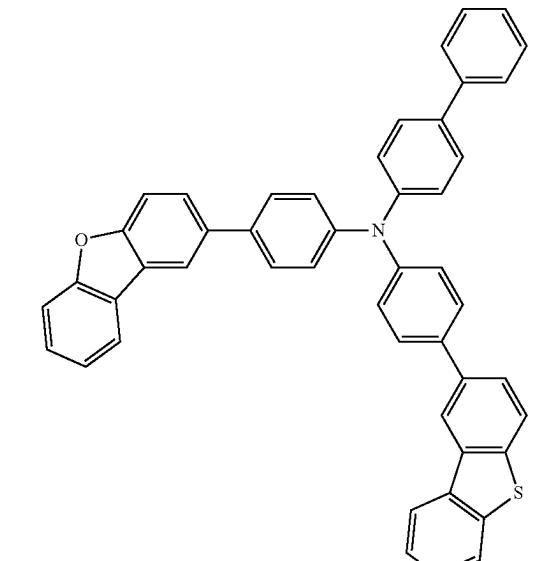
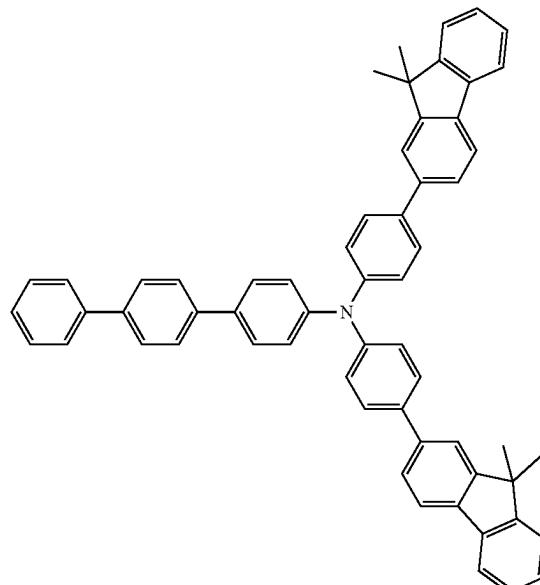
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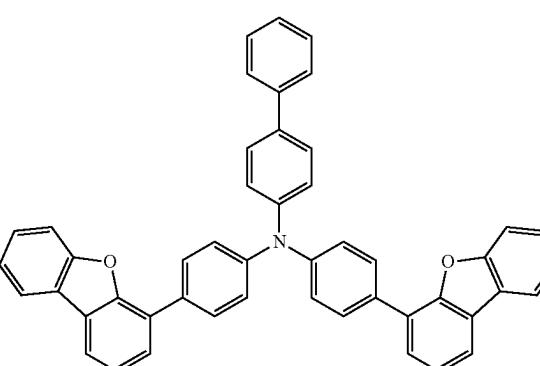
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HT20



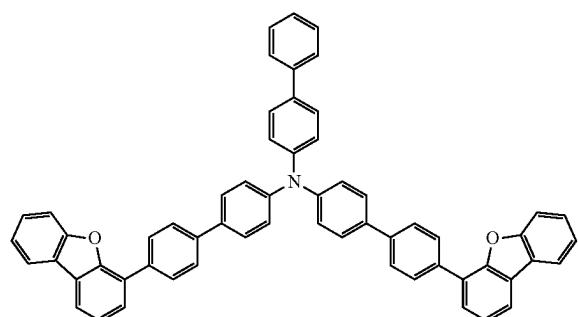
HT21



HT22

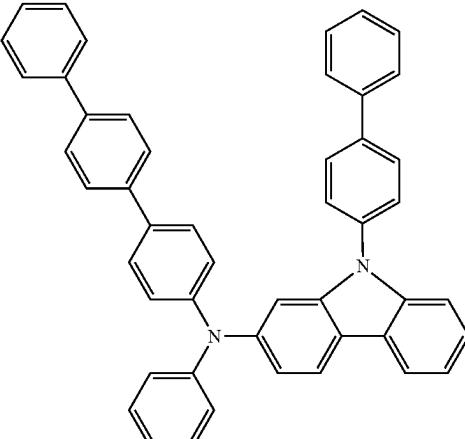
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HT23

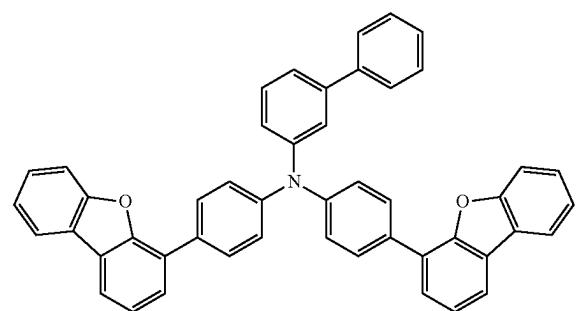
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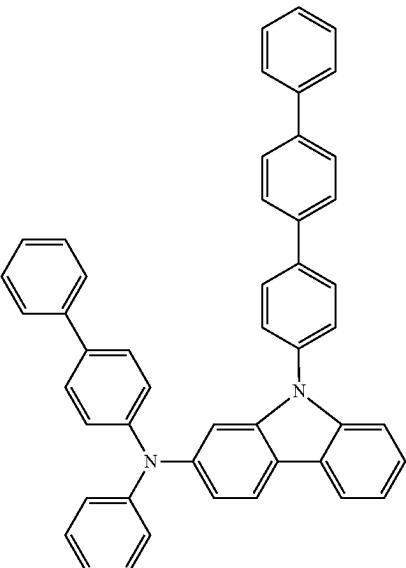
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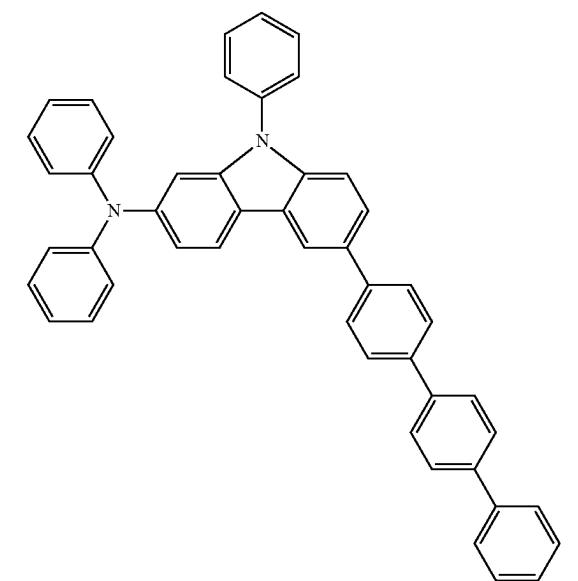
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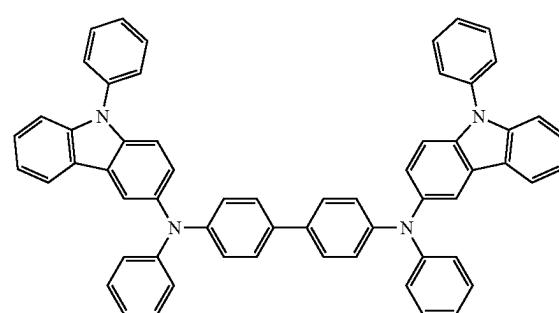
HT27

HT25
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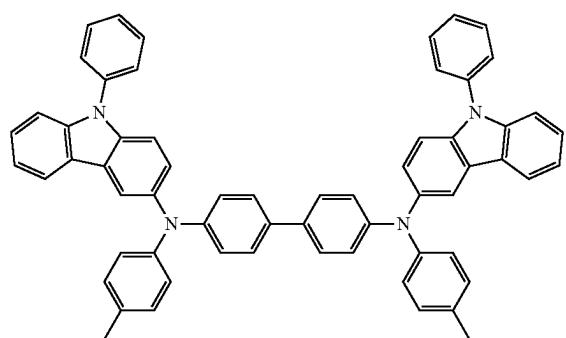
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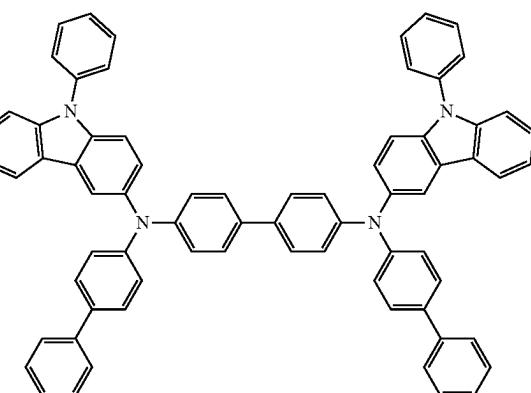
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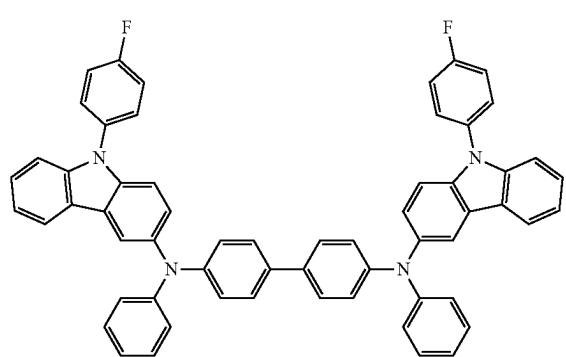
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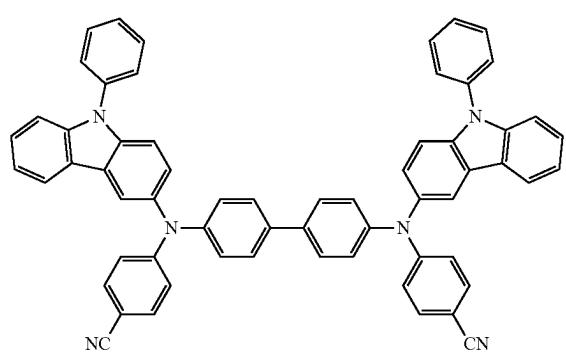


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HT30
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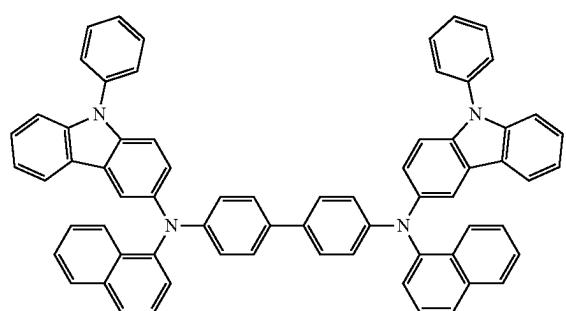
HT31



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HT32



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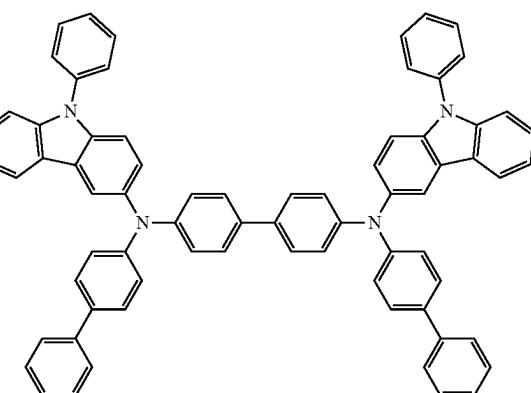
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HT33



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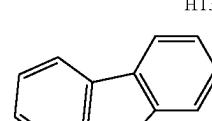
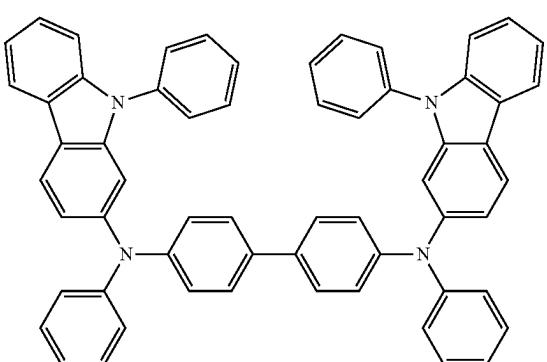
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HT34

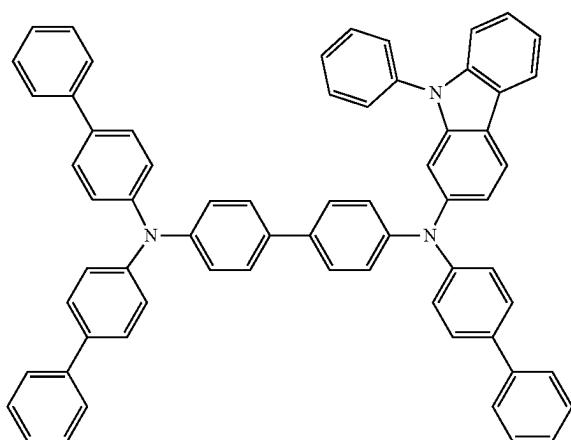


HT35

155

-continued

HT36



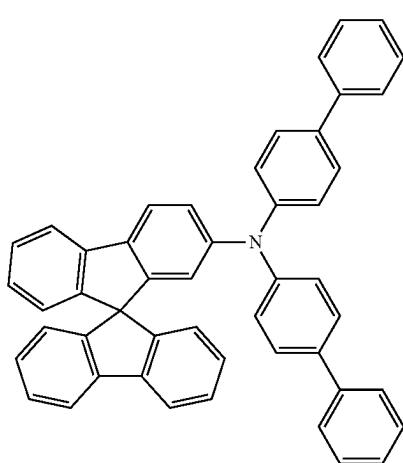
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HT37 25



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HT38

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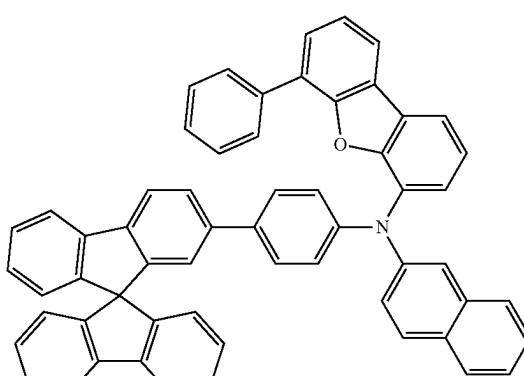
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156

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HT39



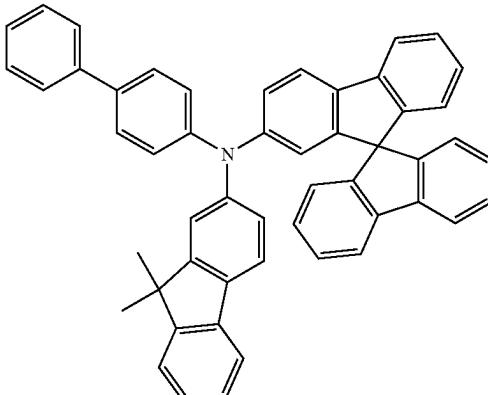
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HT40



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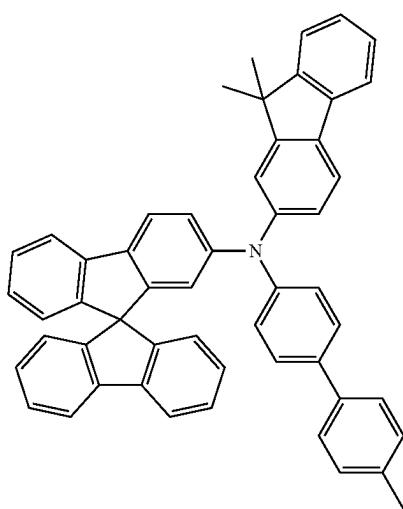
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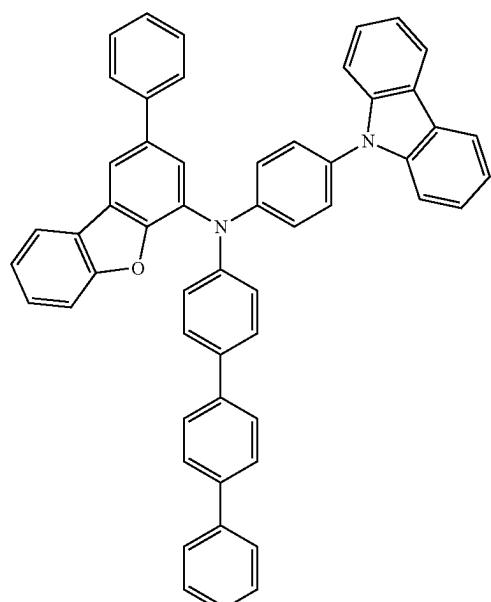
HT41

HT42



157
-continued

HT43



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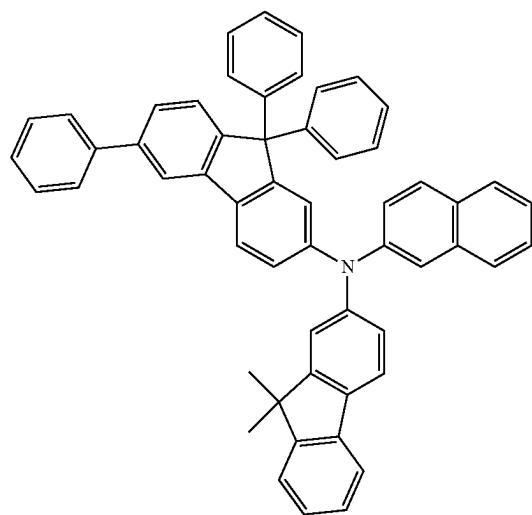
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HT44



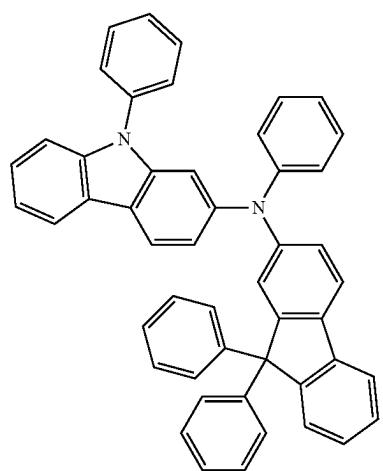
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HT45



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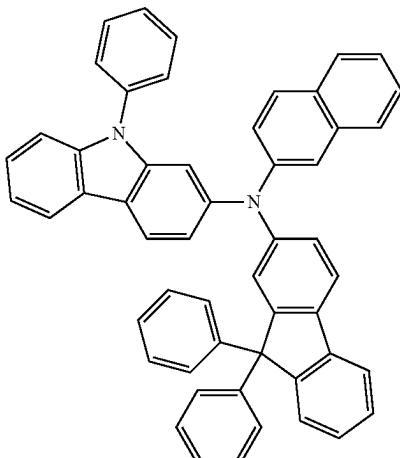
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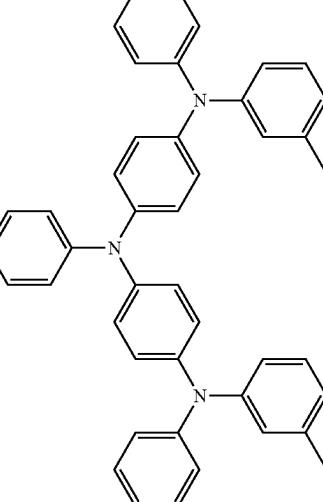
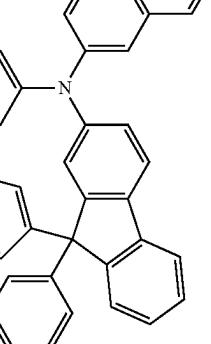
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158
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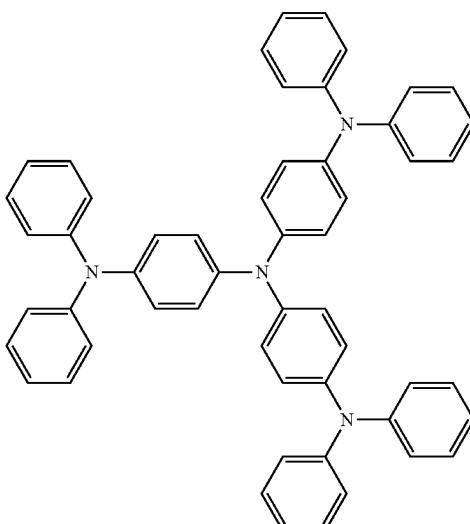
HT46



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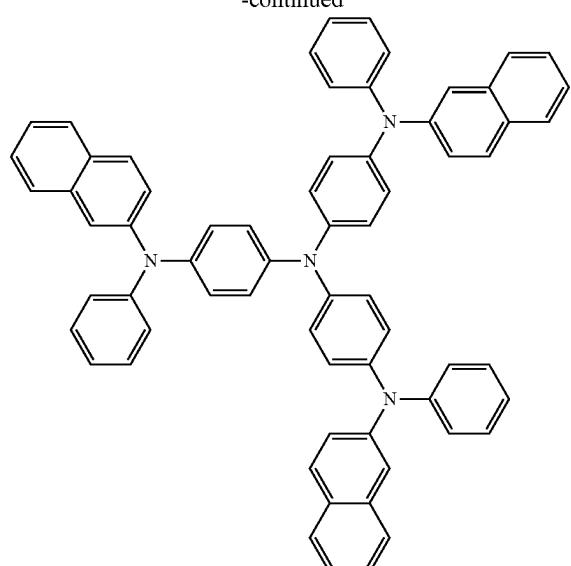
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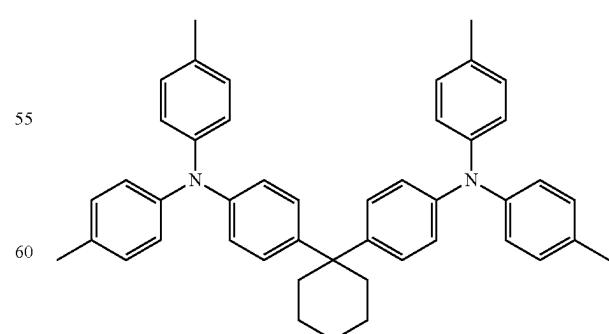
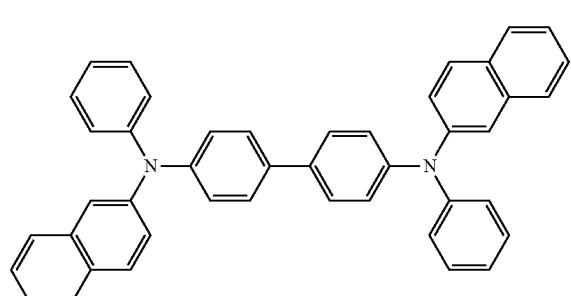
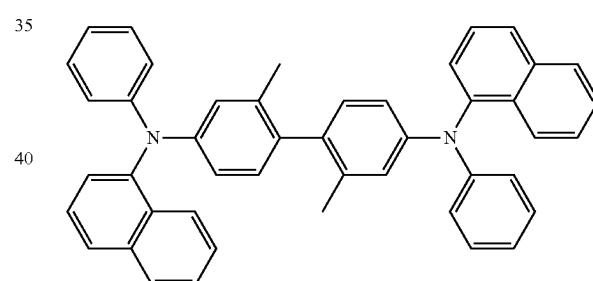
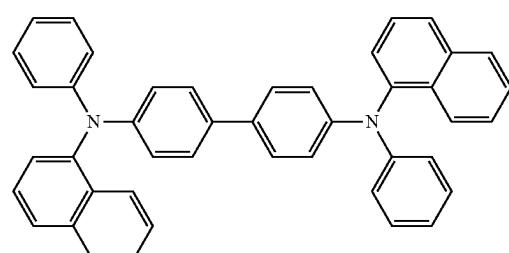
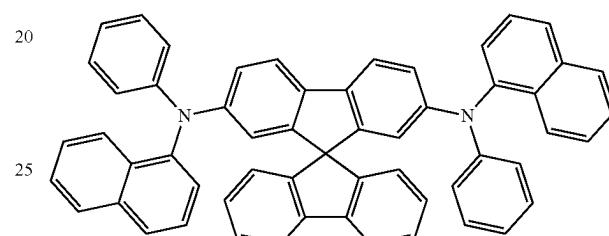
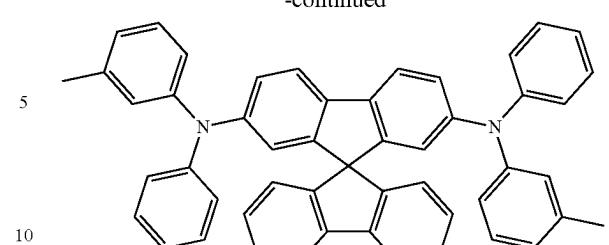
TDATA

159

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**160**

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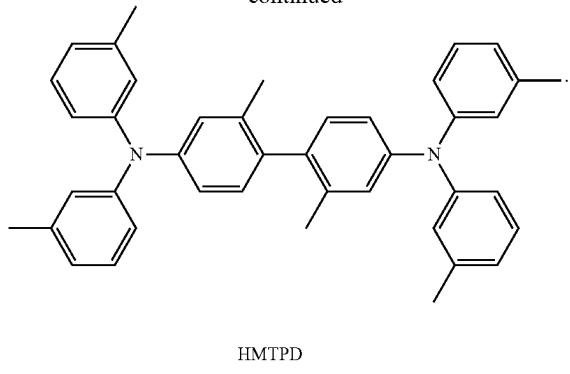


TPD

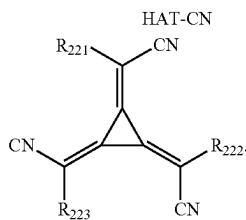
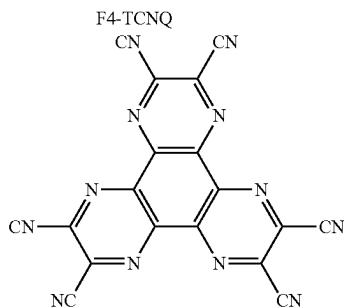
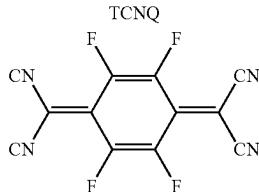
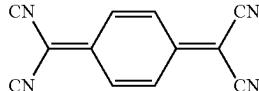
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**162**

Formula 221



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

The emission auxiliary layer may increase the light-emission efficiency of a device by compensating for an optical resonance distance of the wavelength of light emitted by an emission layer, and the electron-blocking layer may block or reduce the flow of electrons from an electron transport region. The emission auxiliary layer and the electron-blocking layer may include the materials as described above.

p-Dopant

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

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

In an embodiment, the lowest unoccupied molecular orbital (LUMO) energy level of the p-dopant may be -3.5 eV or less.

In an embodiment, the p-dopant may include a quinone derivative, a cyano group-containing compound, a compound containing an element EL1 and an element EL2, or any combination thereof.

Non-limiting examples of the quinone derivative include TCNQ, F4-TCNQ, etc.

Non-limiting examples of the cyano group-containing compound include HAT-CN, and a compound represented by Formula 221.

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In Formula 221, R₂₂₁ to R₂₂₃ may each independently be a C₃-C₆₀ carbocyclic group unsubstituted or substituted with at least one R_{10g} or a C₁-C₆₀ heterocyclic group unsubstituted or substituted with at least one R_{10g}, and at least one of R₂₂₁ to R₂₂₃ may each independently be a C₃-C₆₀ carbocyclic group or a C₁-C₆₀ heterocyclic group, each substituted with a cyano group; —F; —Cl; —Br; —I; a C₁-C₂₀ alkyl group substituted with a cyano group, —F, —Cl, —Br, —I, or any combination thereof; or any combination thereof.

In the compound containing the element EL1 and the element EL2, the element EL1 may be a metal, a metalloid, or a combination thereof, and the element EL2 may be a non-metal, a metalloid, or a combination thereof.

Non-limiting examples of the metal include an alkali metal (for example, lithium (Li), sodium (Na), potassium (K), rubidium (Rb), cesium (Cs), etc.); an alkaline earth metal (for example, beryllium (Be), magnesium (Mg), calcium (Ca), strontium (Sr), barium (Ba), etc.); a transition metal (for example, titanium (Ti), zirconium (Zr), hafnium (Hf), vanadium (V), niobium (Nb), tantalum (Ta), chromium (Cr), molybdenum (Mo), tungsten (W), manganese (Mn), technetium (Tc), rhenium (Re), iron (Fe), ruthenium (Ru), osmium (Os), cobalt (Co), rhodium (Rh), iridium (Ir), nickel (Ni), palladium (Pd), platinum (Pt), copper (Cu), silver (Ag), gold (Au), etc.); a post-transition metal (for example, zinc (Zn), indium (In), tin (Sn), etc.); and a lanthanide metal (for example, lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), euro-

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pium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), ruthenium (Lu), etc.).

Non-limiting examples of the metalloid include silicon (Si), antimony (Sb), and tellurium (Te).

Non-limiting examples of the non-metal include oxygen (O) and a halogen (for example, F, Cl, Br, I, etc.).

In an embodiment, non-limiting examples of the compound containing the element EL1 and the element EL2 are a metal oxide, a metal halide (for example, a metal fluoride, a metal chloride, a metal bromide, or a metal iodide), a metalloid halide (for example, a metalloid fluoride, a metalloid chloride, a metalloid bromide, or a metalloid iodide), a metal telluride, or any combination thereof.

Non-limiting examples of the metal oxide include a tungsten oxide (for example, WO, W₂O₃, WO₂, WO₃, W₂O₅, etc.), a vanadium oxide (for example, VO, V₂O₃, VO₂, V₂O₅, etc.), a molybdenum oxide (MoO₃, Mo₂O₃, MoO₂, MoO₃, Mo₂O₅, etc.), and a rhenium oxide (for example, ReO₃, etc.).

Non-limiting examples of the metal halide include an alkali metal halide, an alkaline earth metal halide, a transition metal halide, a post-transition metal halide, and a lanthanide metal halide.

Non-limiting examples of the alkali metal halide include LiF, NaF, KF, RbF, CsF, LiCl, NaCl, KCl, RbCl, CsCl, LiBr, NaBr, KBr, RbBr, CsBr, LiI, NaI, KI, RbI, and CsI.

Non-limiting examples of the alkaline earth metal halide include BeF₂, MgF₂, CaF₂, SrF₂, BaF₂, BeCl₂, MgCl₂, CaCl₂, SrCl₂, BaCl₂, BeBr₂, MgBr₂, CaBr₂, SrBr₂, BaBr₂, BeI₂, MgI₂, CaI₂, SrI₂, and BaI₂.

Non-limiting examples of the transition metal halide include a titanium halide (for example, TiF₄, TiCl₄, TiBr₄, TiI₄, etc.), a zirconium halide (for example, ZrF₄, ZrCl₄, ZrBr₄, ZrI₄, etc.), a hafnium halide (for example, HfF₄, HfCl₄, HfBr₄, HfI₄, etc.), a vanadium halide (for example, VF₃, VCl₃, VBr₃, VI₃, etc.), a niobium halide (for example, NbF₃, NbCl₃, NbBr₃, NbI₃, etc.), a tantalum halide (for example, TaF₃, TaCl₃, TaBr₃, TaI₃, etc.), a chromium halide (for example, CrF₃, CrCl₃, CrBr₃, CrI₃, etc.), a molybdenum halide (for example, MoF₃, MoCl₃, MoBr₃, MoI₃, etc.), a tungsten halide (for example, WF₃, WCl₃, WBr₃, WI₃, etc.), a manganese halide (for example, MnF₂, MnCl₂, MnBr₂, MnI₂, etc.), a technetium halide (for example, TcF₂, TcCl₂, TcBr₂, TcI₂, etc.), a rhenium halide (for example, ReF₂, ReCl₂, ReBr₂, ReI₂, etc.), an iron halide (for example, FeF₂, FeCl₂, FeBr₂, FeI₂, etc.), a ruthenium halide (for example, RuF₂, RuCl₂, RuBr₂, RuI₂, etc.), an osmium halide (for example, OsF₂, OsCl₂, OsBr₂, OsI₂, etc.), a cobalt halide (for example, CoF₂, CoCl₂, CoBr₂, CoI₂, etc.), a rhodium halide (for example, RhF₂, RhCl₂, RhBr₂, RhI₂, etc.), an iridium halide (for example, IrF₂, IrCl₂, IrBr₂, IrI₂, etc.), a nickel halide (for example, NiF₂, NiCl₂, NiBr₂, NiI₂, etc.), a palladium halide (for example, PdF₂, PdCl₂, PdBr₂, PdI₂, etc.), a platinum halide (for example, PtF₂, PtCl₂, PtBr₂, PtI₂, etc.), a copper halide (for example, CuF, CuCl, CuBr, CuI, etc.), a silver halide (for example, AgF, AgCl, AgBr, AgI, etc.), and a gold halide (for example, AuF, AuCl, AuBr, AuI, etc.).

Non-limiting examples of the post-transition metal halide include a zinc halide (for example, ZnF₂, ZnCl₂, ZnBr₂, ZnI₂, etc.), an indium halide (for example, InI₃, etc.), and a tin halide (for example, SnI₂, etc.).

Non-limiting examples of the lanthanide metal halide include YbF, YbF₂, YbF₃, SmF₃, YbCl, YbCl₂, YbCl₃, SmCl₃, YbBr, YbBr₂, YbBr₃, SmBr₃, YbI, YbI₂, YbI₃, and SmI₃.

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A non-limiting example of the metalloid halide is antimony halide (for example, SbCl₅, etc.).

Non-limiting examples of the metal telluride include an alkali metal telluride (for example, Li₂Te, Na₂Te, K₂Te, Rb₂Te, Cs₂Te, etc.), an alkaline earth metal telluride (for example, BeTe, MgTe, CaTe, SrTe, BaTe, etc.), a transition metal telluride (for example, TiTe₂, ZrTe₂, HfTe₂, V₂Te₃, Nb₂Te₃, Ta₂Te₃, Cr₂Te₃, Mo₂Te₃, W₂Te₃, MnTe, TcTe, ReTe, FeTe, RuTe, OsTe, CoTe, RhTe, IrTe, NiTe, PdTe, PtTe, Cu₂Te, CuTe, Ag₂Te, AgTe, Au₂Te, etc.), a post-transition metal telluride (for example, ZnTe, etc.), and a lanthanide metal telluride (for example, LaTe, CeTe, PrTe, NdTe, PmTe, EuTe, GdTe, TbTe, DyTe, HoTe, ErTe, TmTe, YbTe, LuTe, etc.).

15 Emission Layer in Interlayer 130

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

20 In an embodiment, the emission layer may include a host and a dopant (or emitter). In some embodiments, the emission layer may further include an auxiliary dopant for promoting energy transfer to the dopant (or emitter), in addition to the host and the dopant (or emitter). When the emission layer includes the dopant (or emitter) and the auxiliary dopant, the dopant (or emitter) and the auxiliary dopant may be different from each other.

The first compound described herein may serve as the dopant (or emitter) or the auxiliary dopant.

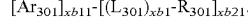
25 40 The amount of the dopant (or emitter) in the emission layer may be about 0.01 parts by weight to about 15 parts by weight based on 100 parts by weight of the host.

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

Host

35 50 The host in the emission layer may include the second compound, the third compound, or any combination thereof.

In an embodiment, the host may include a compound represented by Formula 301:



Formula 301

In Formula 301,

Ar_{301} and L_{301} may each independently be a C₃-C₆₀ carbocyclic group unsubstituted or substituted with at least one R_{10a} or a C₁-C₆₀ heterocyclic group unsubstituted or substituted with at least one R_{10a},

x_{b11} may be 1, 2, or 3,

x_{b1} may be an integer from 0 to 5,

R₃₀₁ may be hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C₁-C₆₀ alkyl group unsubstituted or substituted with at least one R_{10a}, a C₂-C₆₀ alkenyl group unsubstituted or substituted with at least one R_{10a}, a C₂-C₆₀ alkynyl

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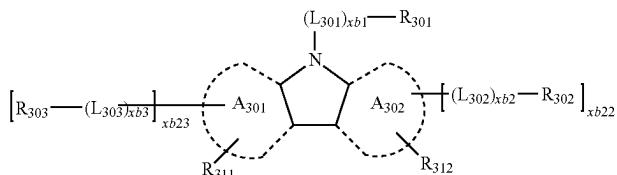
group unsubstituted or substituted with at least one R_{10a}, a C₁-C₆₀ alkoxy group unsubstituted or substituted with at least one R_{10a}, a C₃-C₆₀ carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C₁-C₆₀ heterocyclic group unsubstituted or substituted with at least one R_{10a}, —Si(Q₃₀₁)(Q₃₀₂)(Q₃₀₃), —N(Q₃₀₁)(Q₃₀₂), —B(Q₃₀₁)(Q₃₀₂), —C(=O)(Q₃₀₁), —S(=O)₂(Q₃₀₁), or —P(=O)(Q₃₀₁)(Q₃₀₂),

xb21 may be an integer from 1 to 5, and Q₃₀₁ to Q₃₀₃ may each independently be the same as described in connection with Q₁.

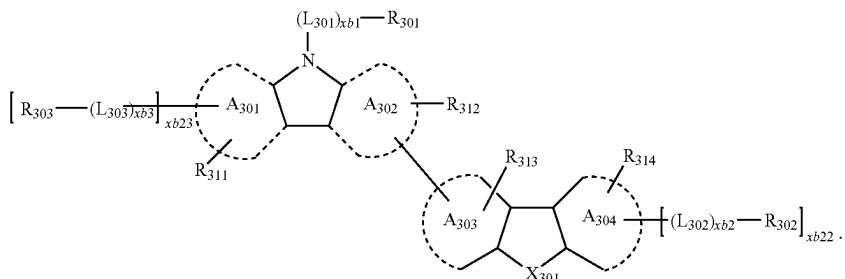
For example, when xb11 in Formula 301 is 2 or more, two or more Ar₃₀₁(S) may be linked to each other via a single bond.

In an embodiment, the host may include a compound represented by Formula 301-1, a compound represented by Formula 301-2, or any combination thereof:

Formula 301-1



Formula 301-2



In Formulae 301-1 to 301-2,

ring A₃₀₁ to ring A₃₀₄ may each independently be a C₃-C₆₀ carbocyclic group unsubstituted or substituted with at least one R_{10a} or a C₁-C₆₀ heterocyclic group unsubstituted or substituted with at least one R_{10a},

X₃₀₁ may be O, S, N-(L₃₀₄)_{xb4}-R₃₀₄, C(R₃₀₄)(R₃₀₅), or Si(R₃₀₄)(R₃₀₅),

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

L₃₀₁, xb1, and R₃₀₁ may each independently be the same as described herein,

L₃₀₂ to L₃₀₄ may each independently be substantially the same as described in connection with L₃₀₁,

xb2 to xb4 may each independently be substantially the same as described in connection with xb1, and

R₃₀₂ to R₃₀₅ and R₃₁₁ to R₃₁₄ may each independently be the same as described in connection with R₃₀₁.

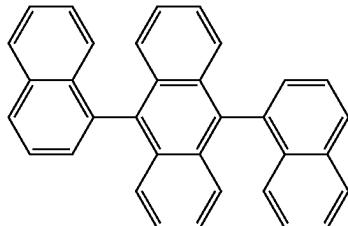
In an embodiment, the host may include an alkaline earth-metal complex. In an embodiment, the host may include a Be complex (for example, Compound H55), an Mg complex, a Zn complex, or a combination thereof.

In an embodiment, the host may include one of Compounds H1 to H124, 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'-

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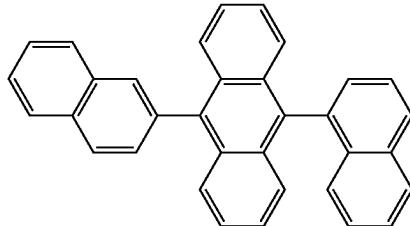
bis(N-carbazolyl)-1,1'-biphenyl (CBP), 1,3-di-9-carbazolylbenzene (mCP), 1,3,5-tri(carbazol-9-yl)benzene (TCP), or any combination thereof, but embodiments of the present disclosure are not limited thereto:

H1

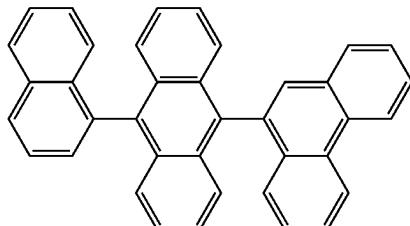


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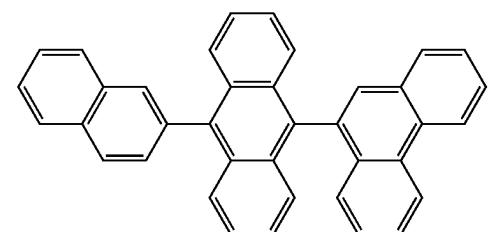
H2



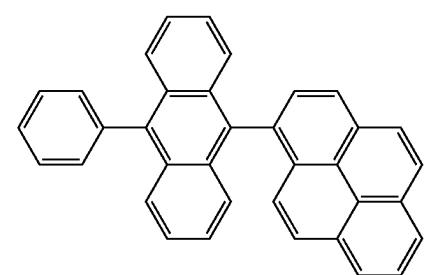
H3



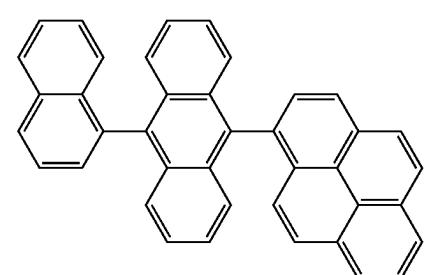
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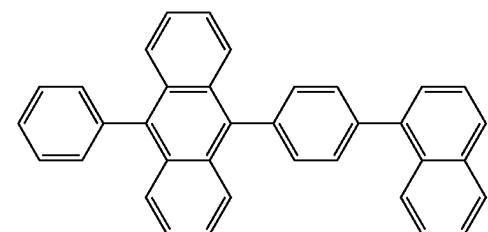
H4



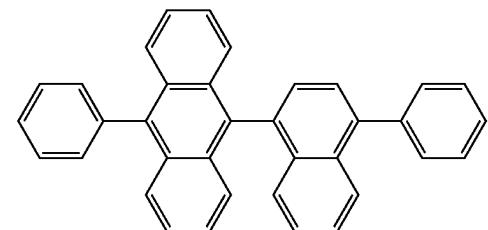
H5



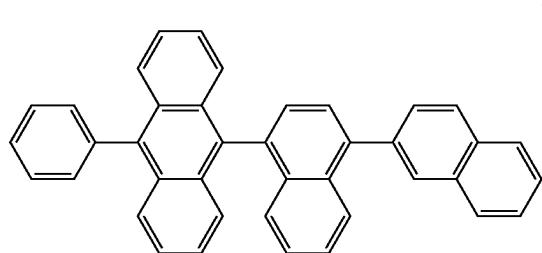
H6



H7

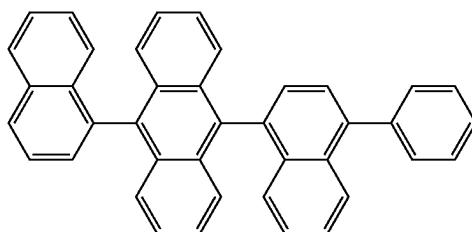


H8

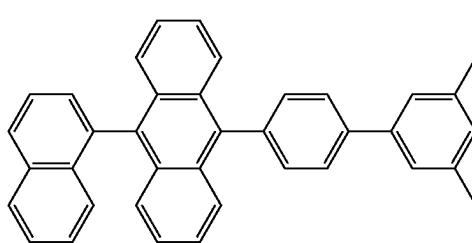


H9

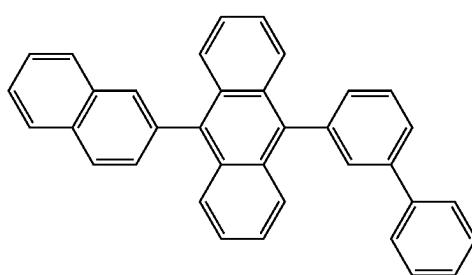
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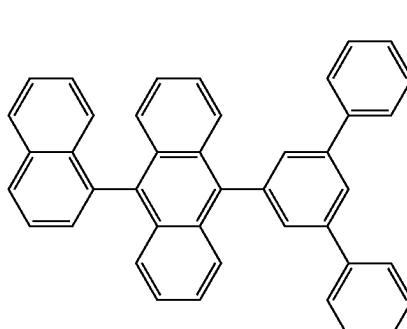
H10



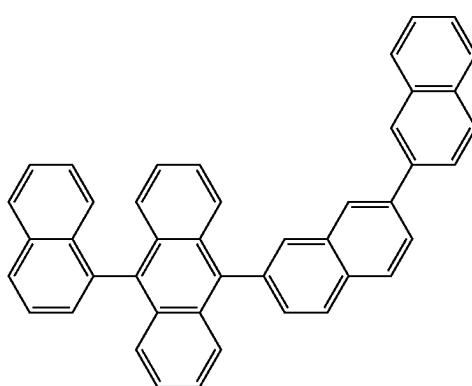
H11



H12



H13

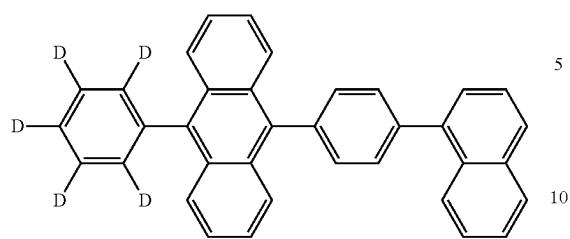


H14

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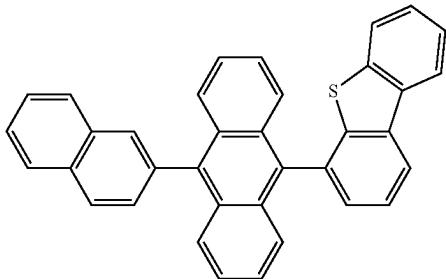
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H15

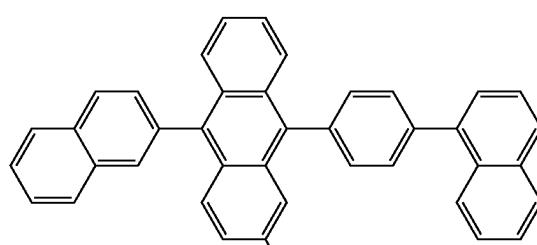
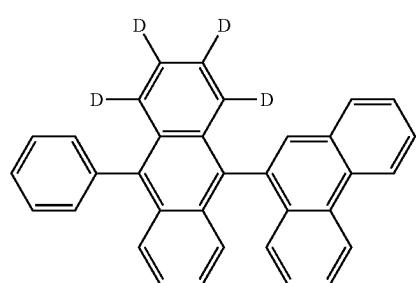
**170**

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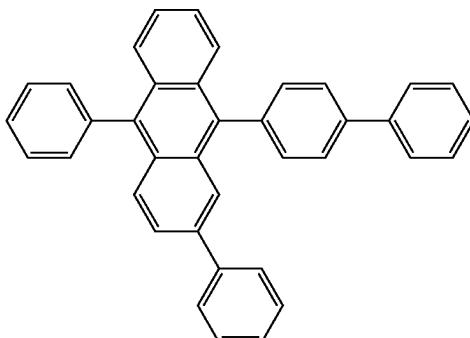
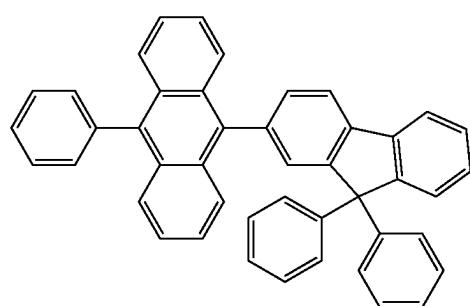
H20



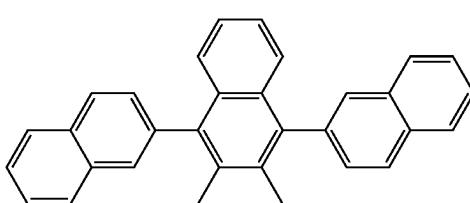
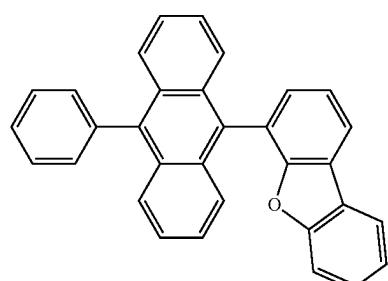
H16 15



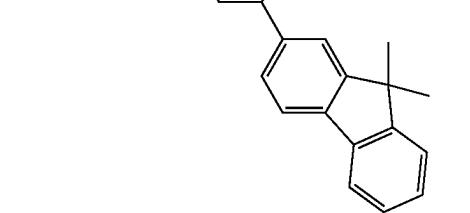
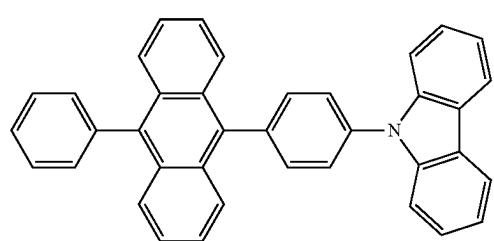
H17



H18

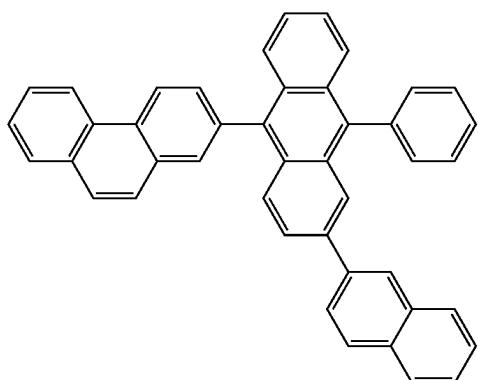


H19



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H24



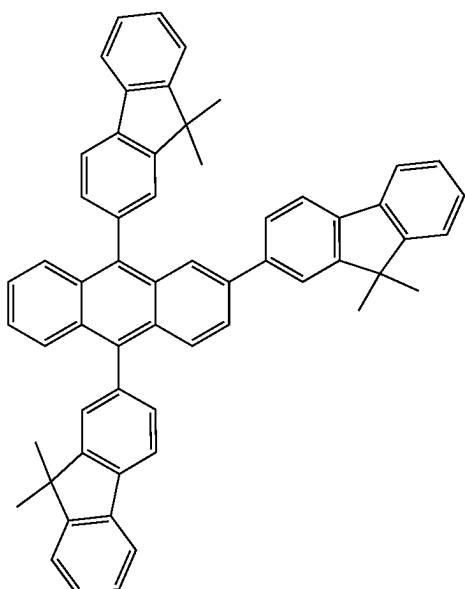
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H26

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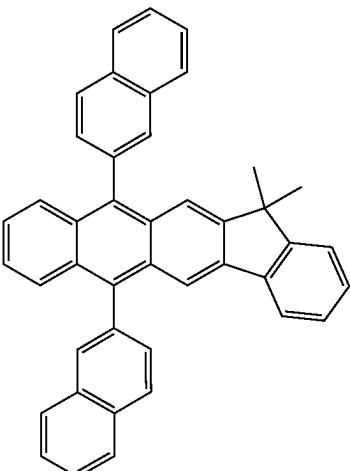
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172
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H27



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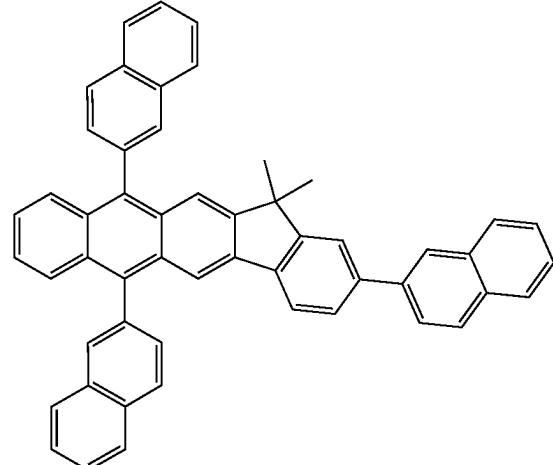
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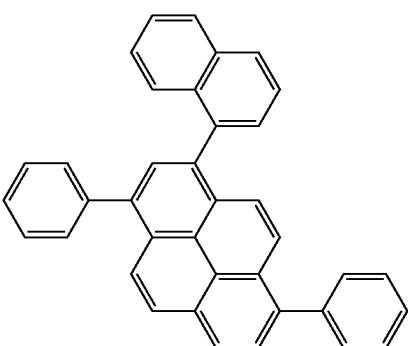
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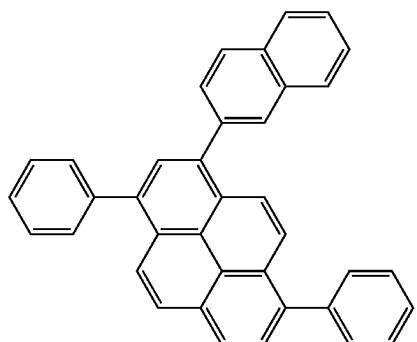
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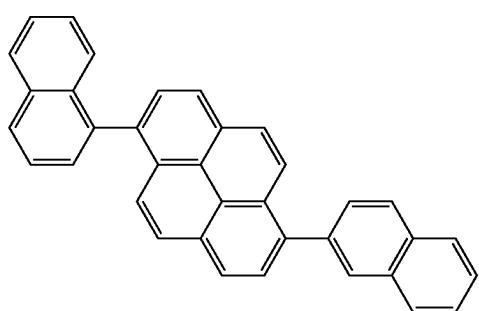
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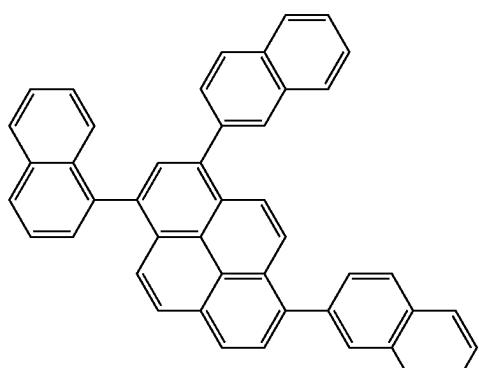
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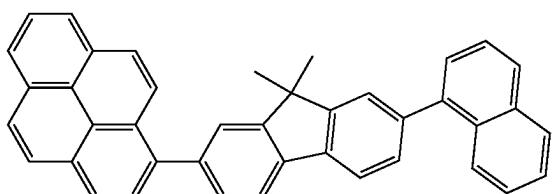
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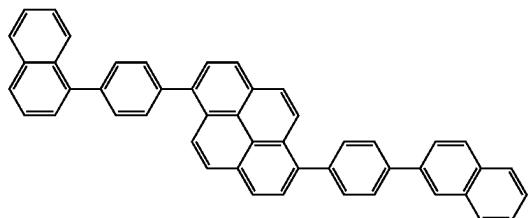
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H32

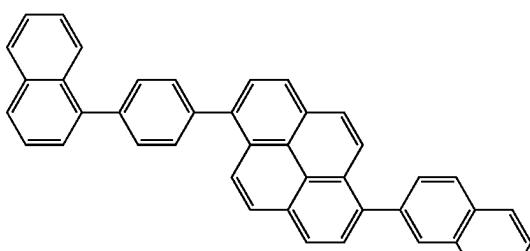


H33



H34

174
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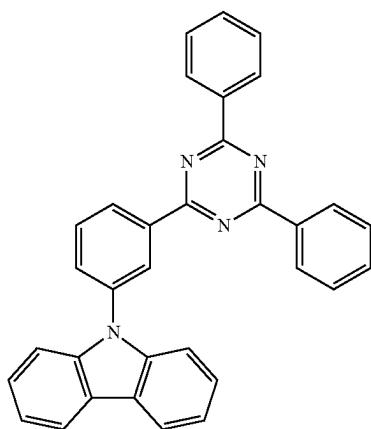


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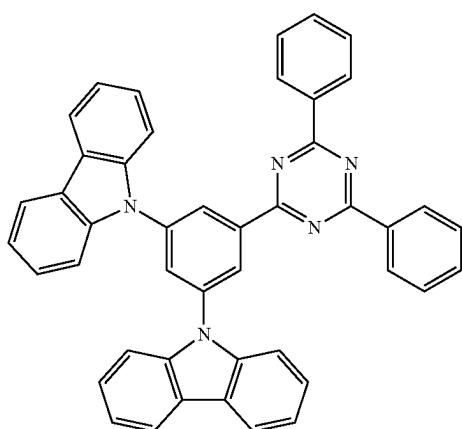
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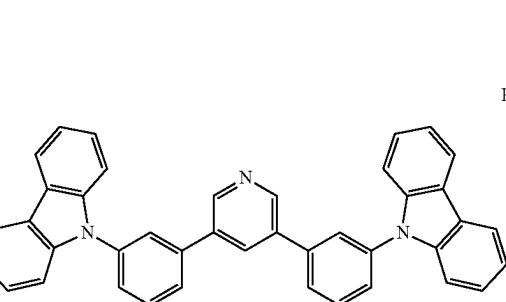
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H37



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H38

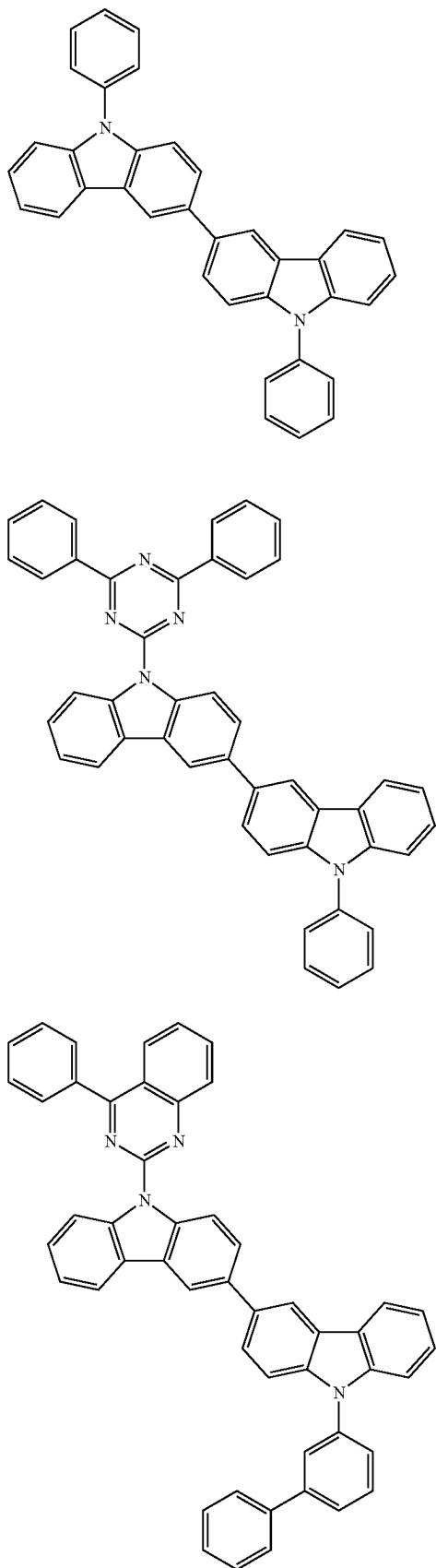
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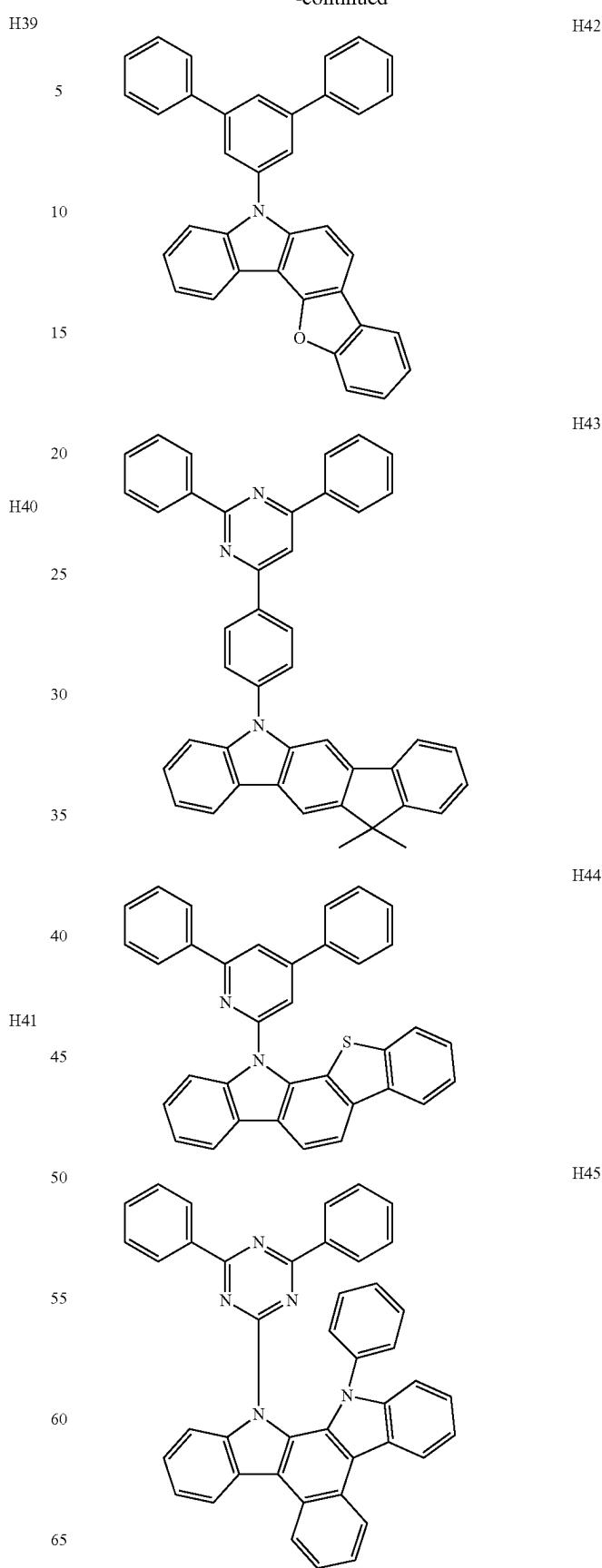
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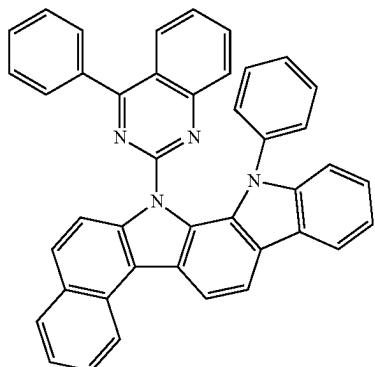


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177
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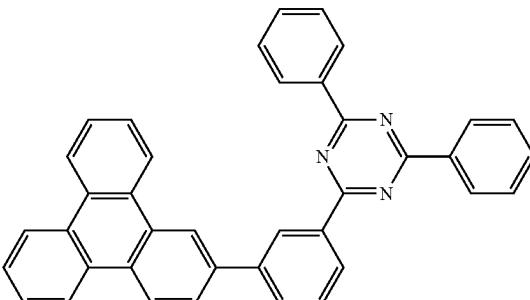
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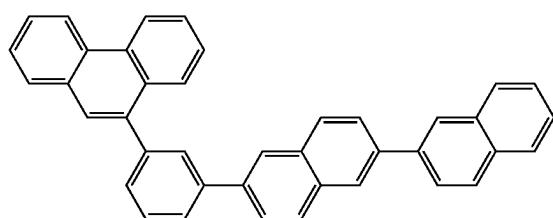
178
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H52

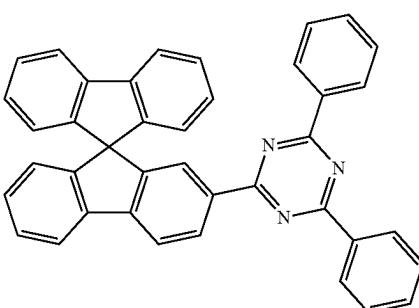


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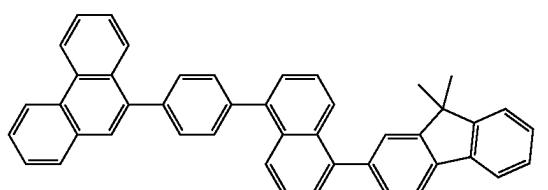
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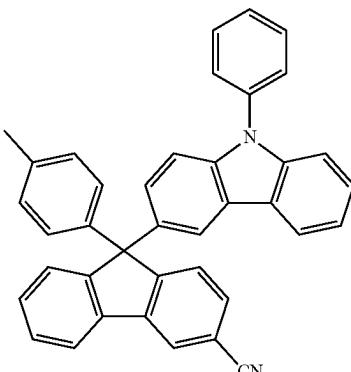


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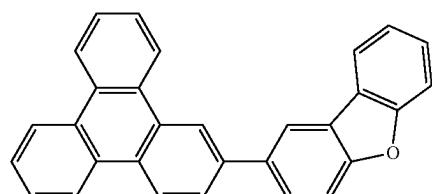


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H54

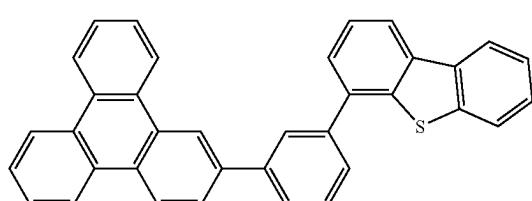


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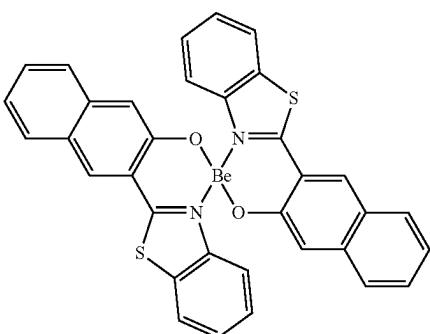
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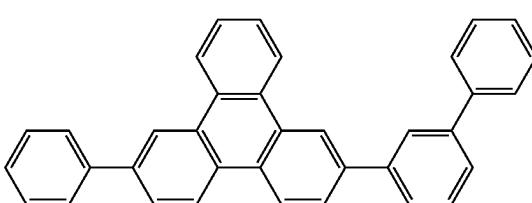


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H55



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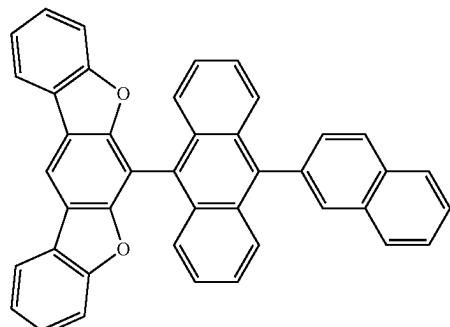


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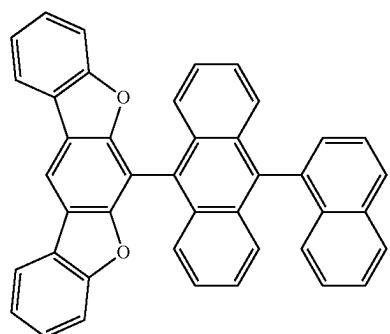
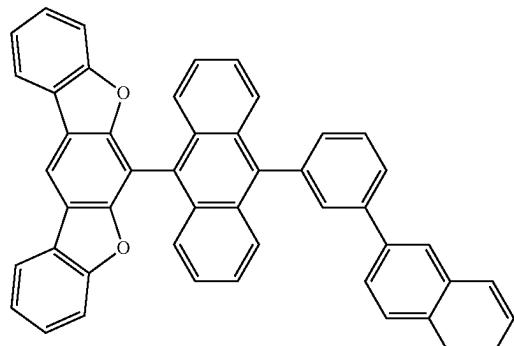
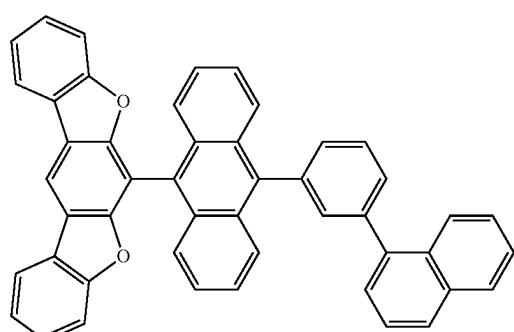
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179

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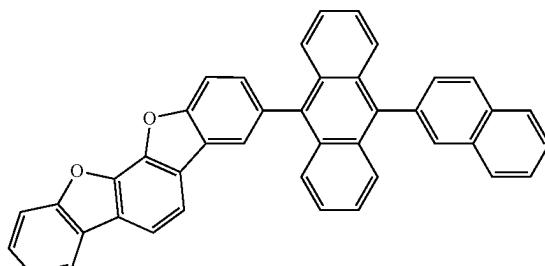


H56

H57
20H58
35H59
55**180**

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H60

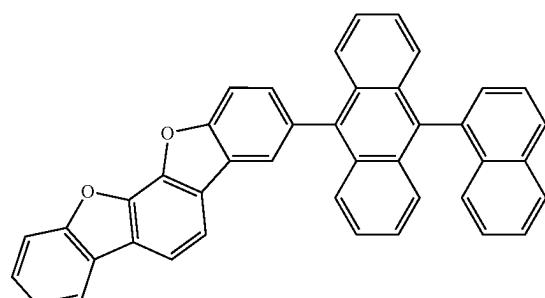


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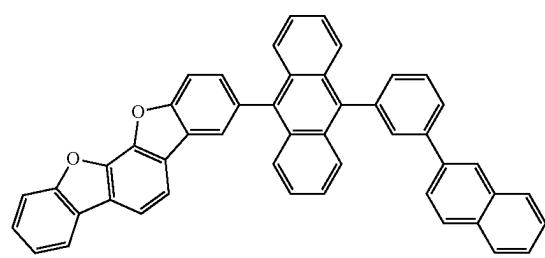
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H61



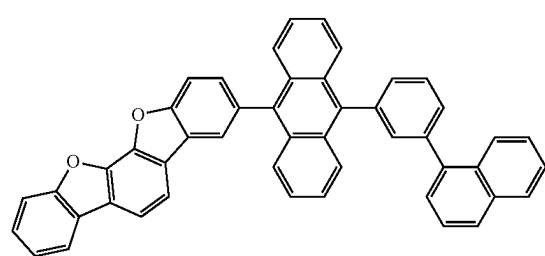
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H62



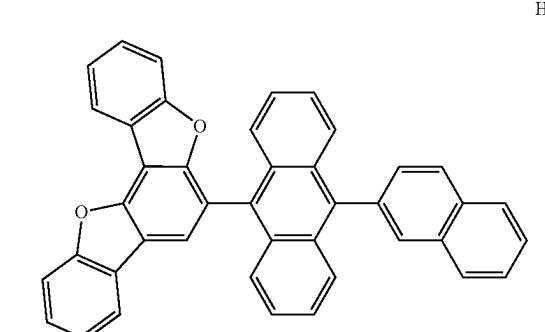
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H63



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H64



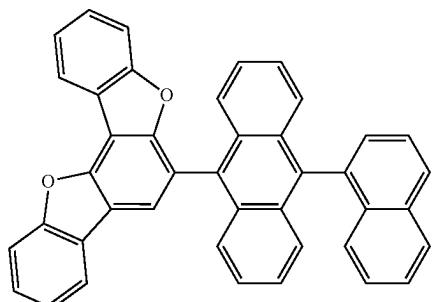
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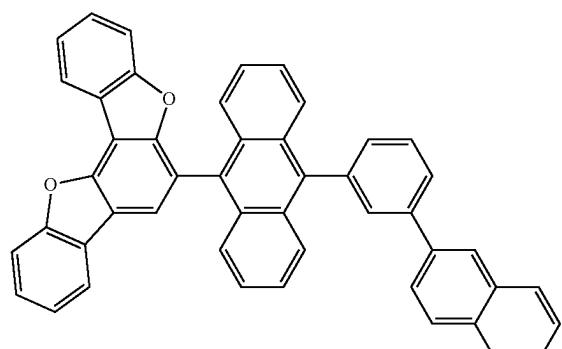
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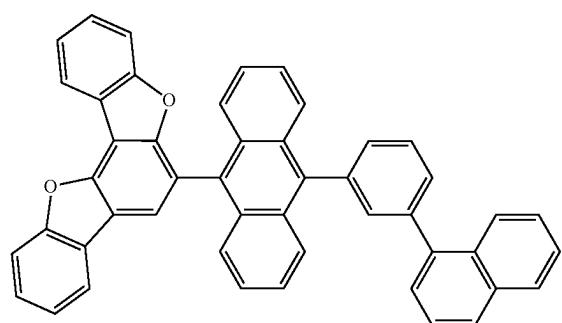
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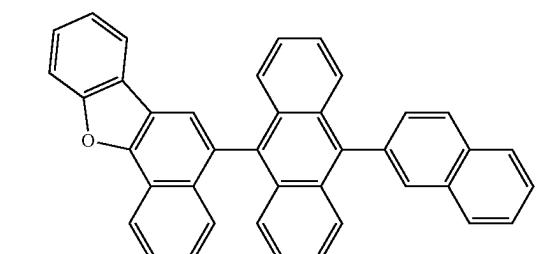
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H66

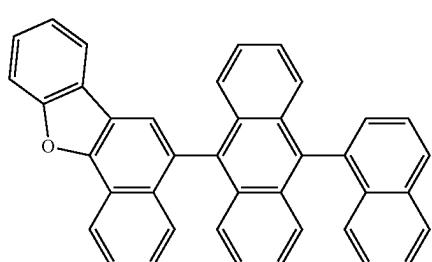


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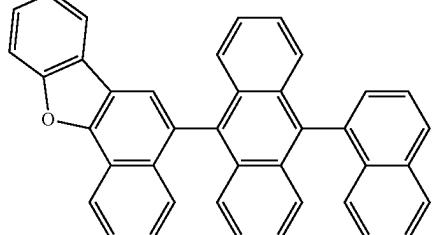
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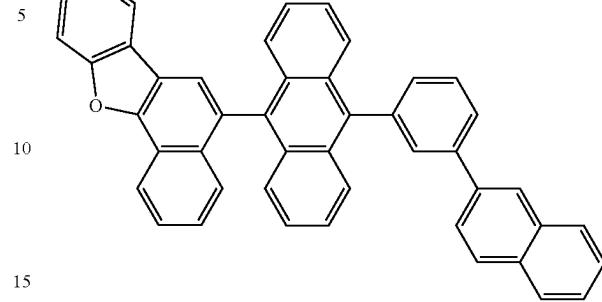
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182

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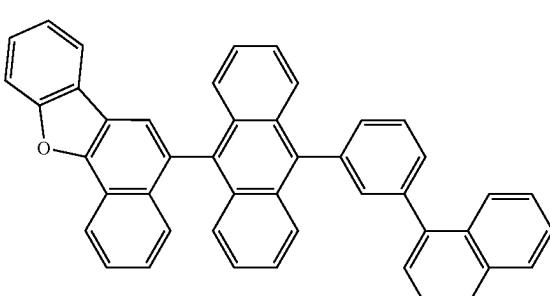
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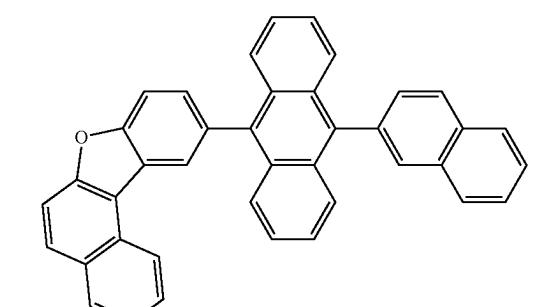
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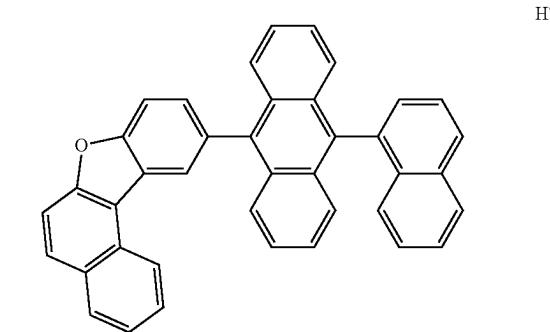
H70



H71



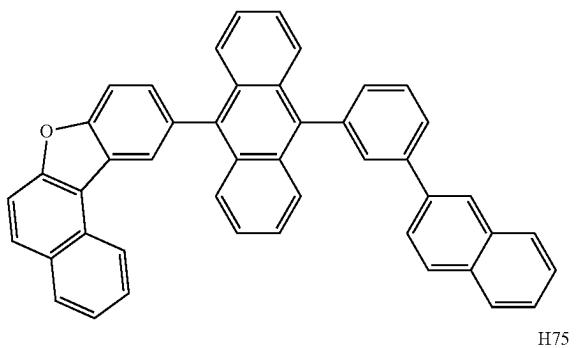
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H73

183

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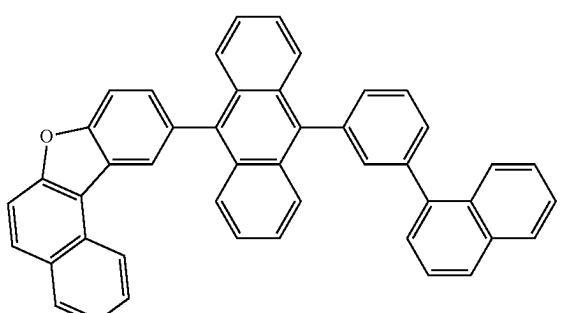


H74

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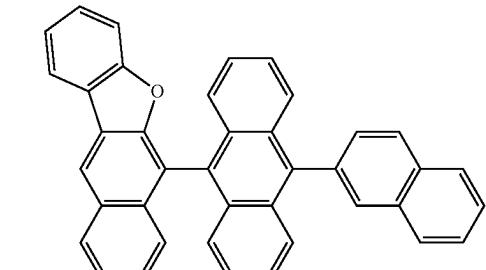
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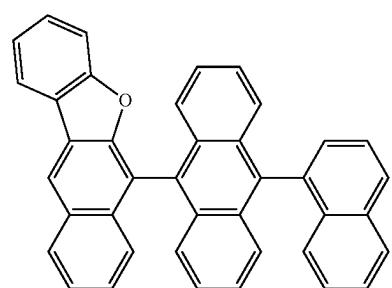
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H76 30



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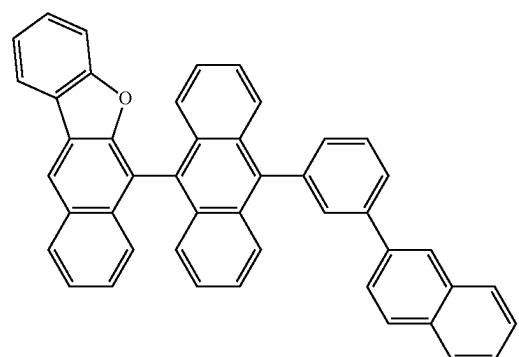
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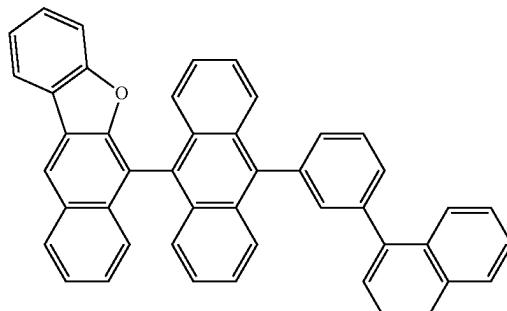
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H78

**184**

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H79



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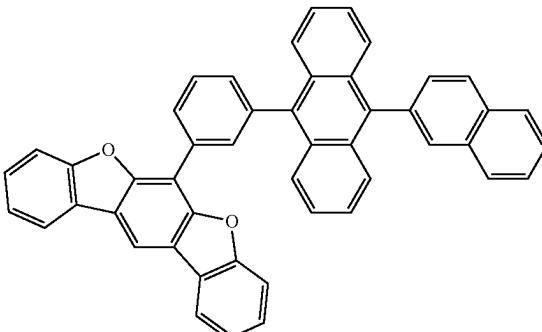
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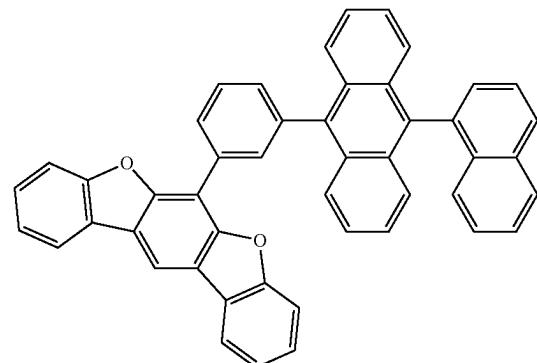
H76 30



H80

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H81



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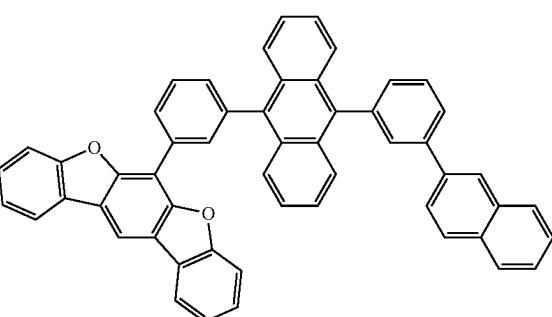
H78

H82

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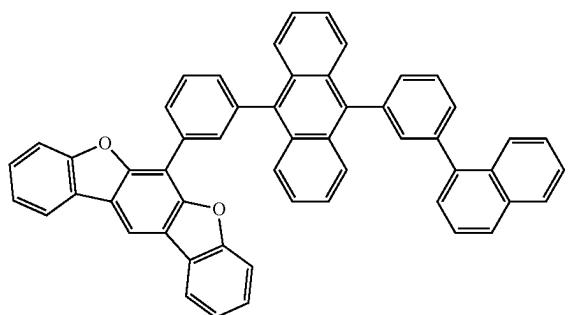
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185
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H83

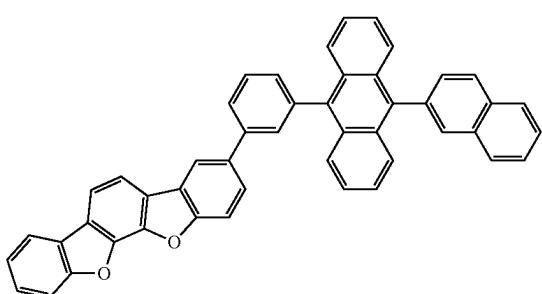


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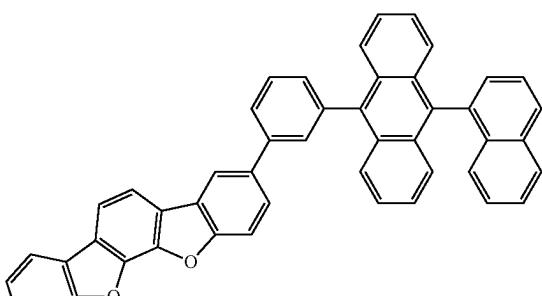
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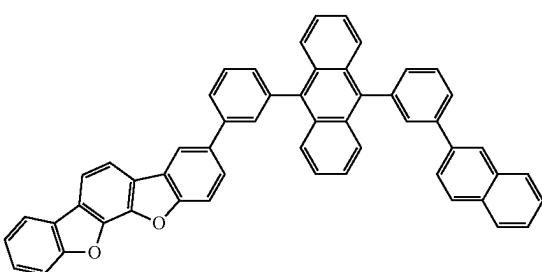
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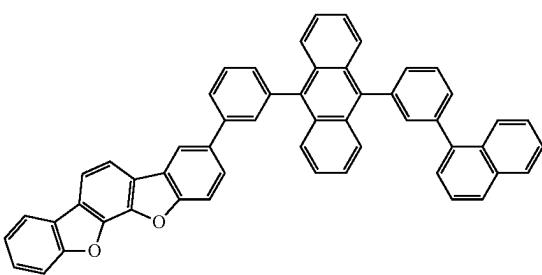
H86



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H87



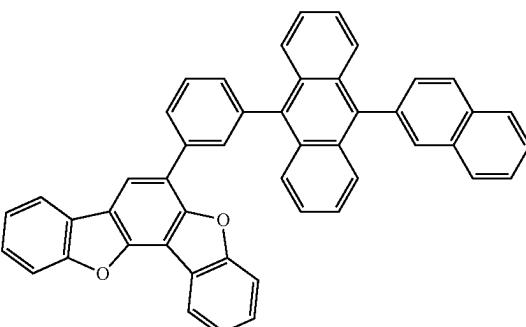
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186
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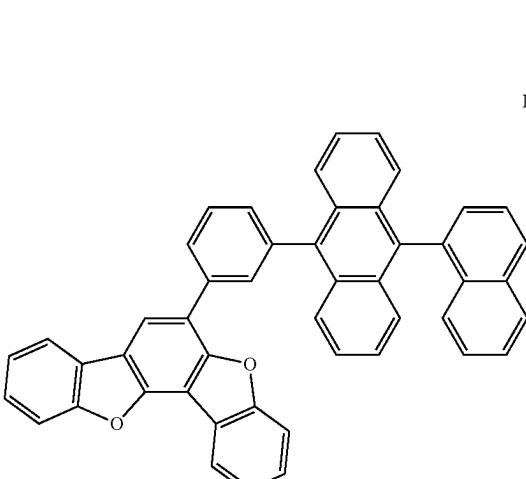
H88



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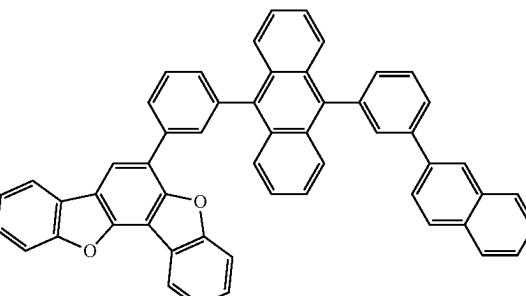
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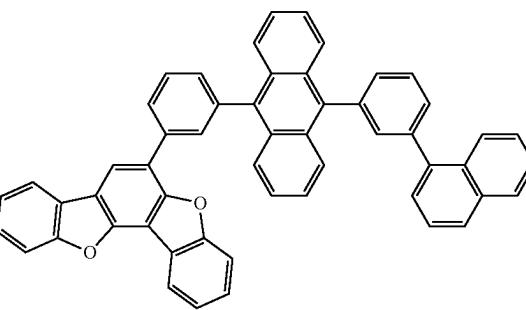
H89



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H90



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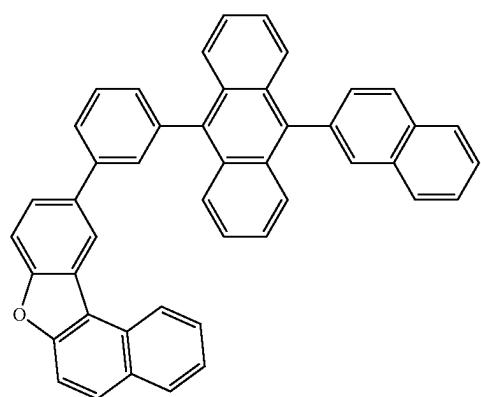
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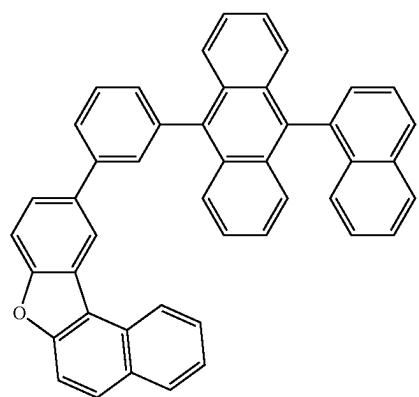
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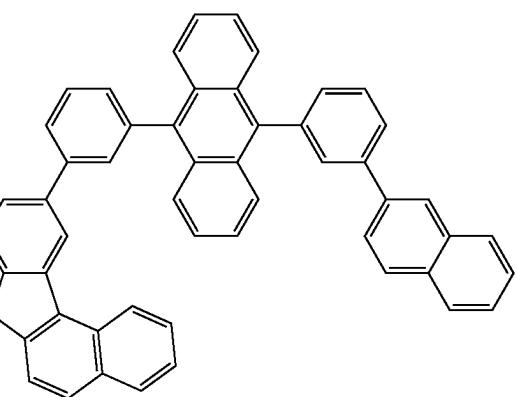
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187
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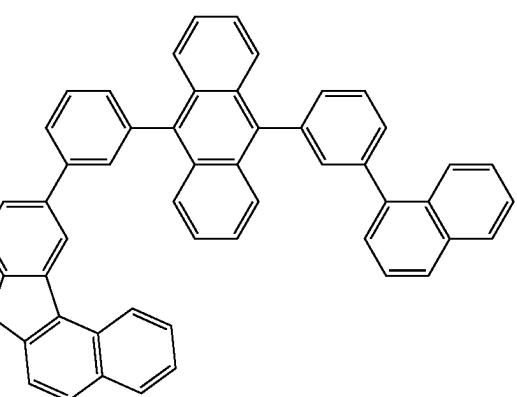
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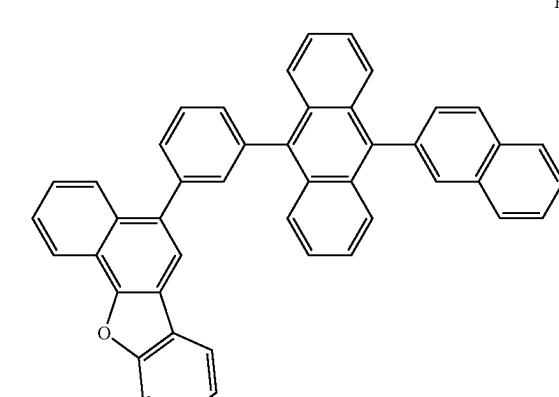
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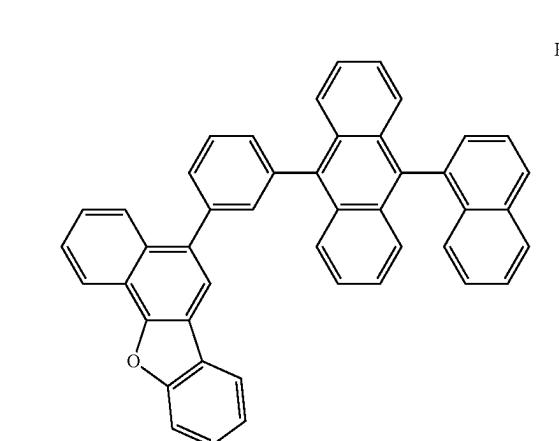
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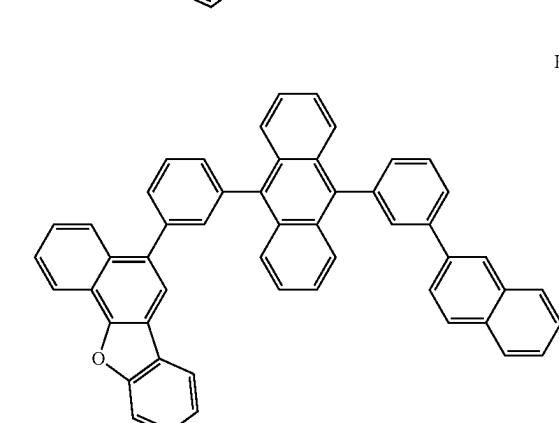
H95

188
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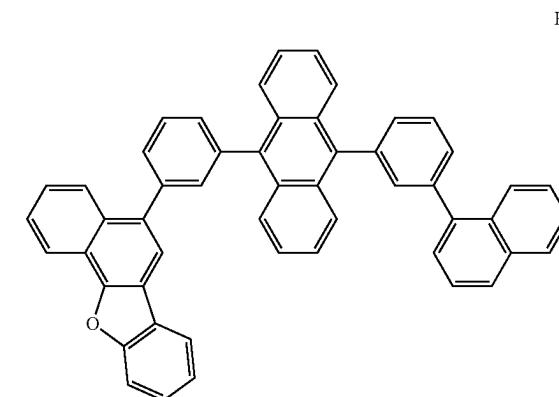
H96



H97



H98

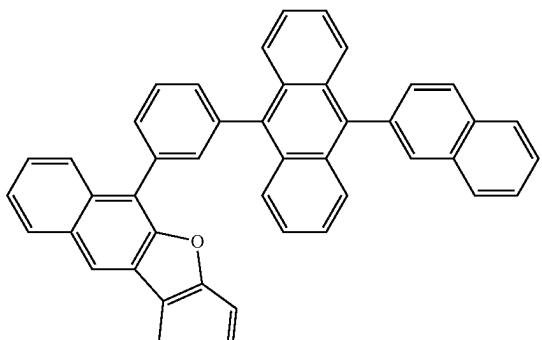


H99

189

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H100

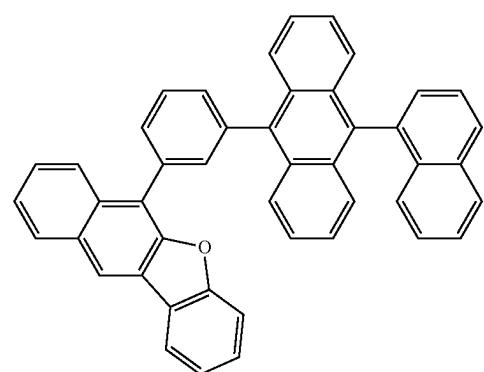


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H101 20

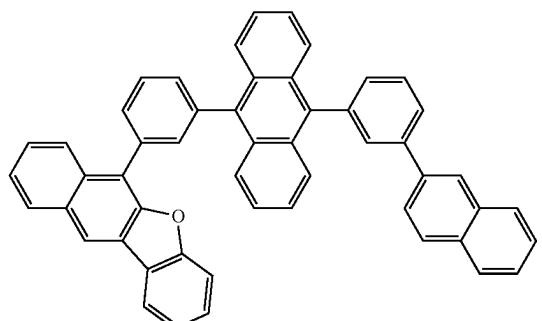


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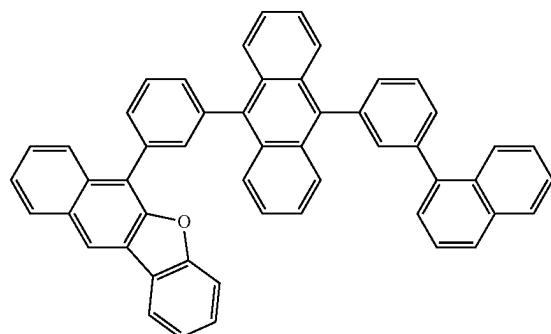
H102 40



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H103



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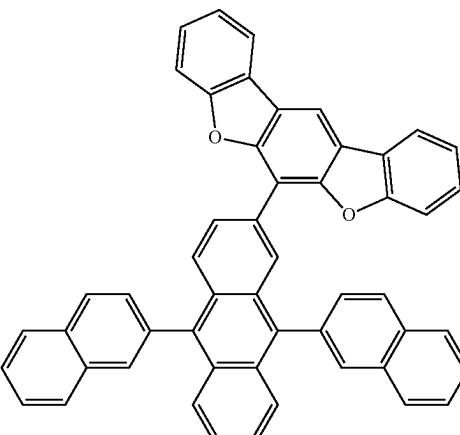
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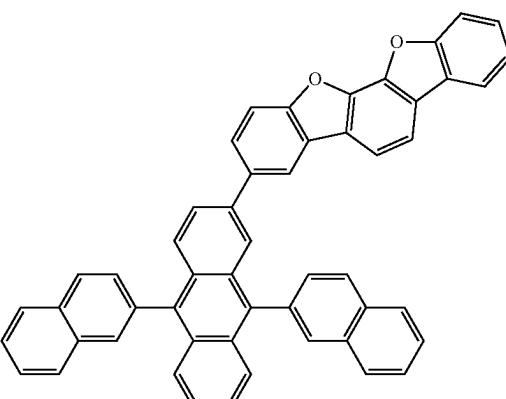
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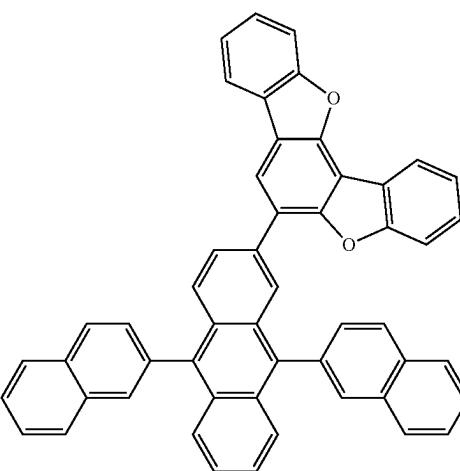
H104



H105



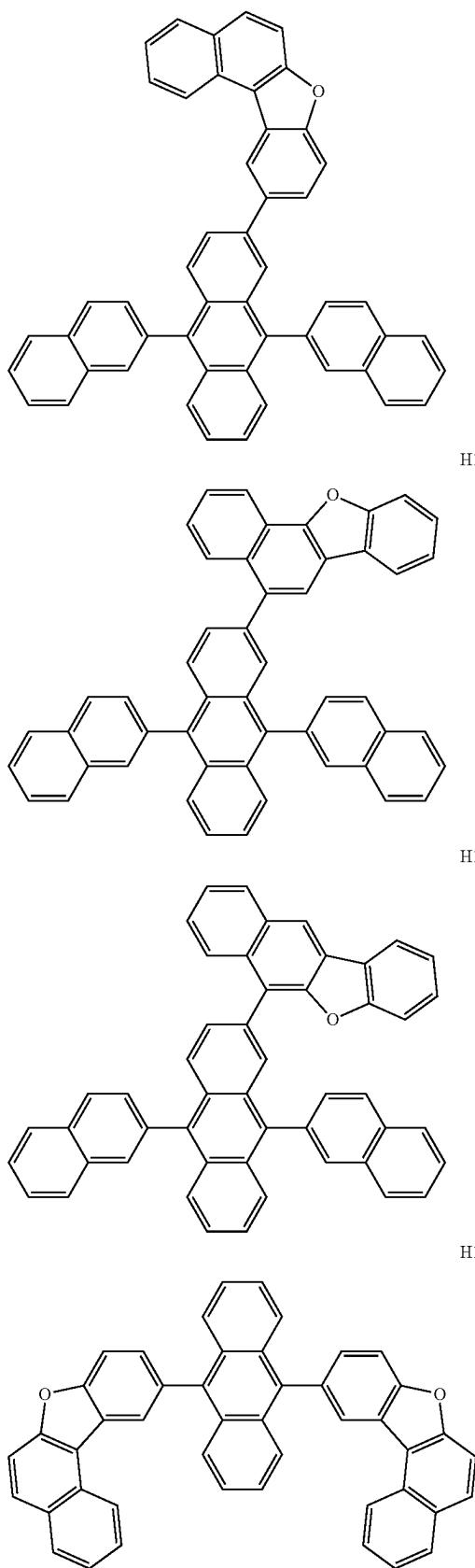
H106



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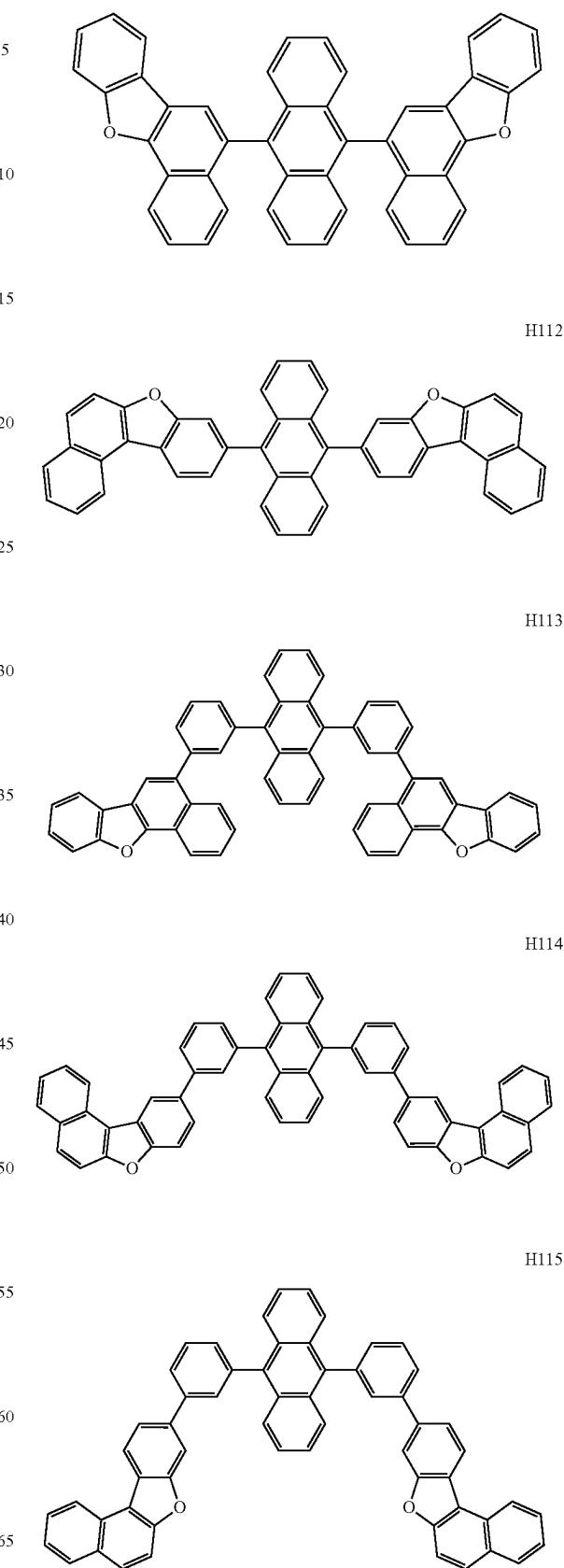
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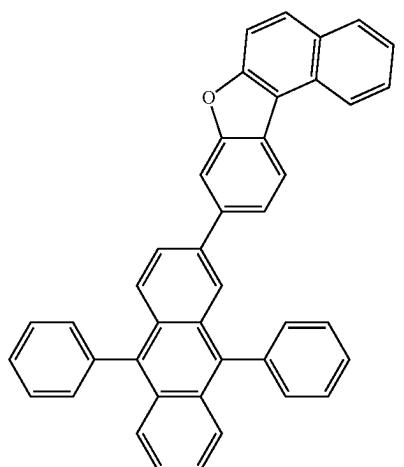
192

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193

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H116

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H117

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H118 50

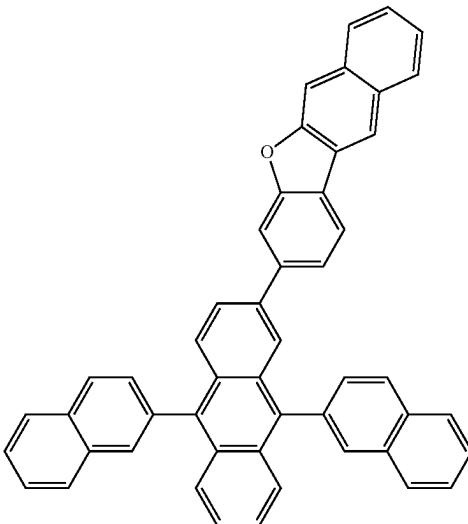
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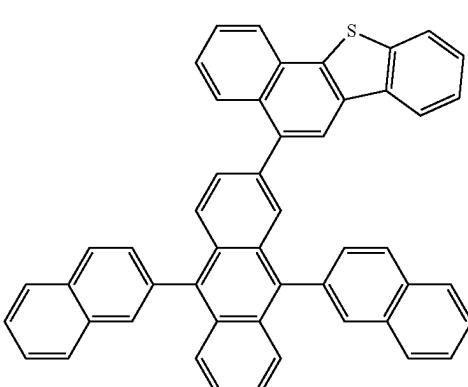
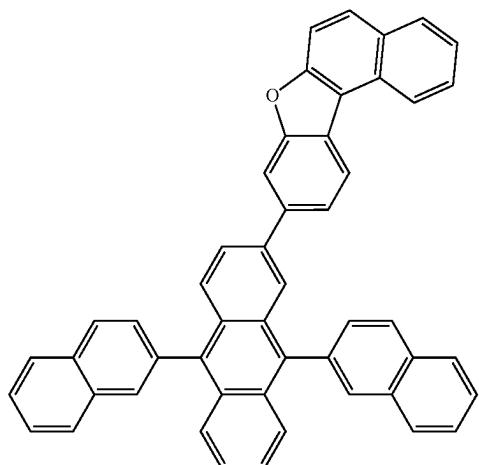
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194

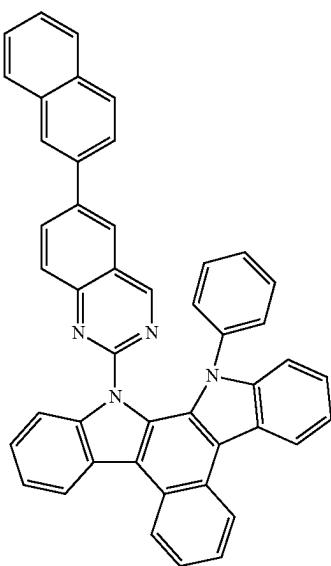
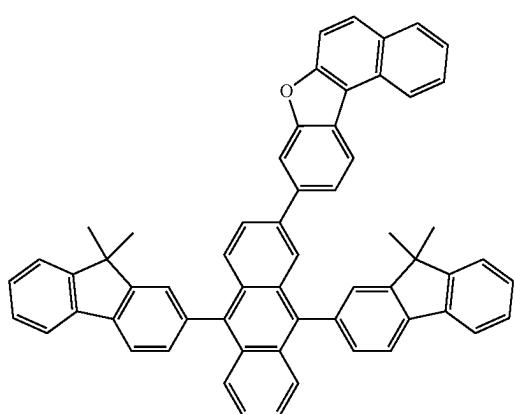
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H119



H120

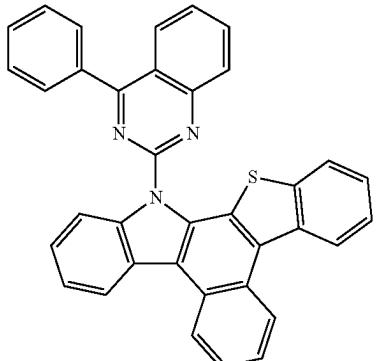


H121

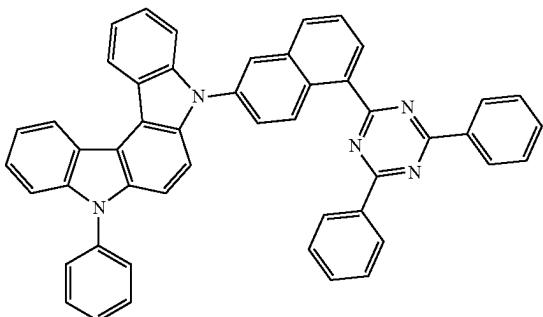
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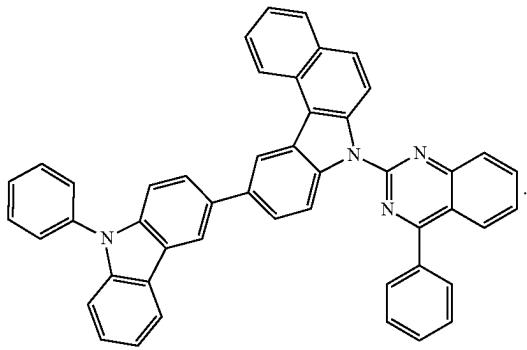
H122



H123



H124



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The host may include a silicon-containing compound, a phosphine oxide-containing compound, or any combination thereof.

The host may have one or more suitable modifications, 50 For example, the host may include only one kind of compound, or may include two or more kinds of different compounds.

Phosphorescent Dopant

The emission layer is a phosphorescent dopant and may 55 include the first compound as described herein.

In some embodiments, when the first compound is included in the emission layer, and the first compound acts as an auxiliary dopant, the emission layer may include a phosphorescent dopant.

In an embodiment, the phosphorescent dopant may include at least one transition metal as a central metal.

The phosphorescent dopant may include a monodentate ligand, a bidentate ligand, a tridentate ligand, a tetradeятate ligand, a pentadentate ligand, a hexadentate ligand, or any 65 combination thereof.

The phosphorescent dopant may be electrically neutral.

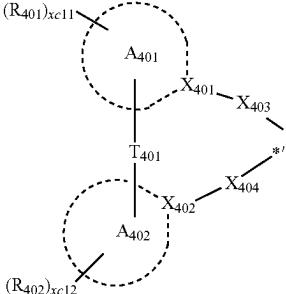
196

For example, the phosphorescent dopant may include an organometallic compound represented by Formula 401:

5 Formula 401

M(L₄₀₁)_{xc1}(L₄₀₂)_{xc2}

Formula 402



In Formulae 401 and 402,

M may be transition metal (for example, iridium (Ir), platinum (Pt), palladium (Pd), osmium (Os), titanium (Ti), gold (Au)hafnium (Hf), europium (Eu), terbium (Tb), rhodium (Rh), rhenium (Re), or thulium (Tm)), L₄₀₁ may be a ligand represented by Formula 402, and xc1 may be 1, 2, or 3, wherein when xc1 is two or more, two or more L₄₀₁(s) may be identical to or different from each other,

L₄₀₂ may be an organic ligand, and xc2 may be 0, 1, 2, 3, or 4, and when xc2 is 2 or more, two or more L₄₀₂(s) may be identical to or different from each other,

X₄₀₁ and X₄₀₂ may each independently be nitrogen or carbon,

ring A₄₀₁ and ring A₄₀₂ may each independently be a C₃-C₆₀ carbocyclic group or a C₁-C₆₀ heterocyclic group,

T₄₀₁ may be a single bond, *—O—*, *—S—*, *—C(=O)—*, *—N(Q₄₁₁)—*, *—C(Q₄₁₁)(Q₄₁₂)—*, *—C(Q₄₁₁)=C(Q₄₁₂)—*, *—C(Q₄₁₁)=—*, or *—C(Q₄₁₁)=—*,

X₄₀₃ and X₄₀₄ may each independently be a chemical bond (for example, a covalent bond or a coordination bond), O, S, N(Q₄₁₃), B(Q₄₁₃), P(Q₄₁₃), C(Q₄₁₃)(Q₄₁₄), or Si(Q₄₁₃)(Q₄₁₄),

Q₄₁₁ to Q₄₁₄ may each independently be the same as described in connection with Q₁,

R₄₀₁ and R₄₀₂ may each independently be hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C₁-C₂₀ alkyl group unsubstituted or substituted with at least one R_{10a}, a C₁-C₂₀ alkoxy group unsubstituted or substituted with at least one R_{10a}, a C₃-C₆₀ carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C₁-C₆₀ heterocyclic group unsubstituted or substituted with at least one R_{10a}, —Si(Q₄₀₁)(Q₄₀₂)(Q₄₀₃), —N(Q₄₀₁)(Q₄₀₂), —B(Q₄₀₁)(Q₄₀₂), —C(=O)(Q₄₀₁), —S(=O)₂(Q₄₀₁), or —P(=O)(Q₄₀₁)(Q₄₀₂),

Q₄₀₁ to Q₄₀₃ may each independently be the same as described in connection with Q₁,

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

and * in Formula 402 each indicate a binding site to M in Formula 401.

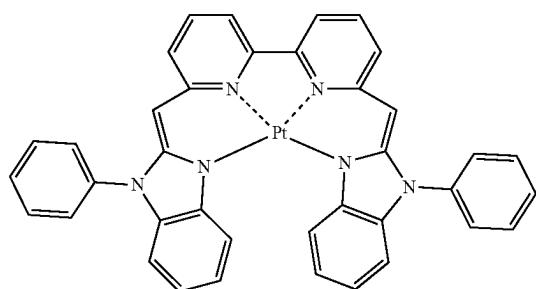
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For example, in Formula 402, i) X₄₀₁ is nitrogen, and X₄₀₂ is carbon, or ii) each of X₄₀₁ and X₄₀₂ is nitrogen.

In an embodiment, when xc1 in Formula 402 is 2 or more, two rings A₄₀₁ in two or more L₄₀₁(s) may be optionally linked to each other via T₄₀₂, which is a linking group, and two rings A₄₀₂ may optionally be linked to each other via T₄₀₃, which is a linking group (see Compounds PD1 to PD4 and PD7). T₄₀₂ and T₄₀₃ may each independently be the same as described in connection with T₄₀₁.

L₄₀₂ in Formula 401 may be an organic ligand. For example, L₄₀₂ may include a halogen group, a diketone group (for example, an acetylacetone group), a carboxylic acid group (for example, a picolinate group), —C(=O), an isonitrile group, —CN group, a phosphorus group (for example, a phosphine group, a phosphite group, etc.), or any combination thereof.

The phosphorescent dopant may include, for example, one of compounds PD1 to PD25, or any combination thereof:

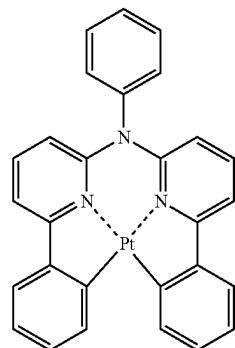


PD1

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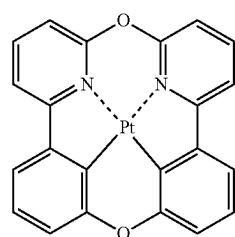
PD2

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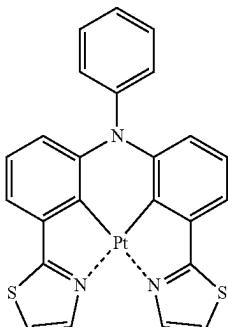
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PD3

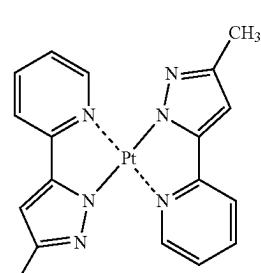
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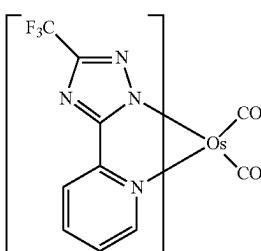
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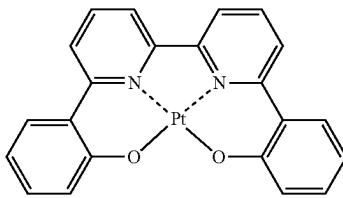
PD4



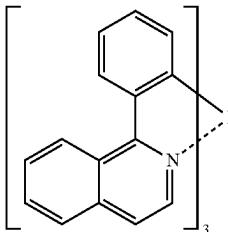
PD5



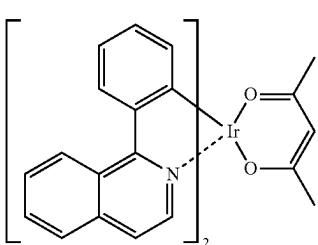
PD6



PD7

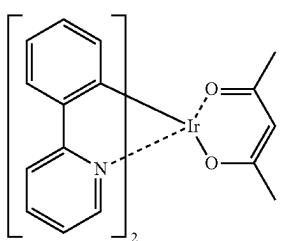
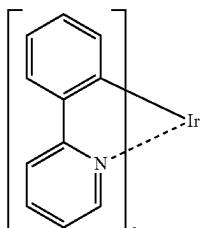
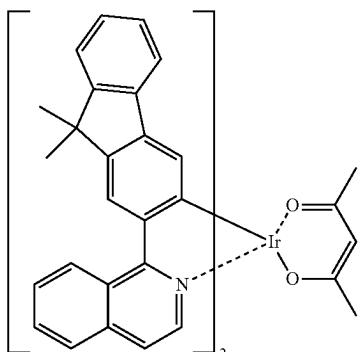
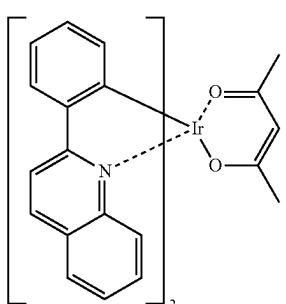
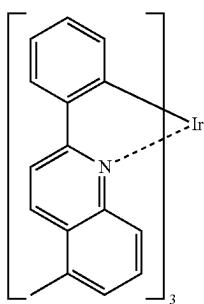


PD8



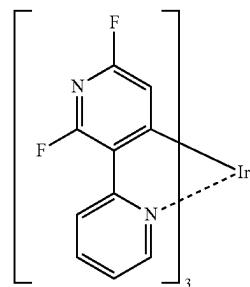
PD9

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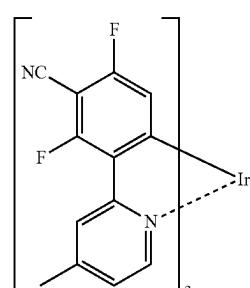
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PD10

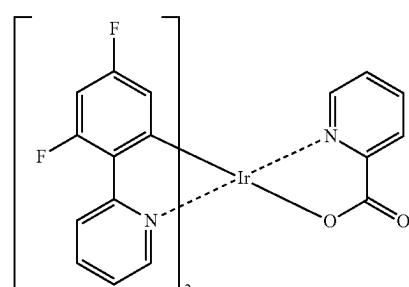


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PD11

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PD12

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PD15

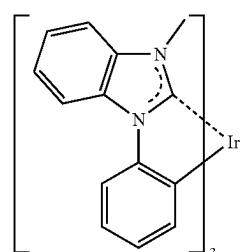
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PD17

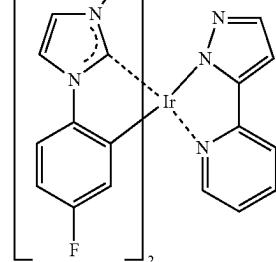
PD18

PD19

PD13

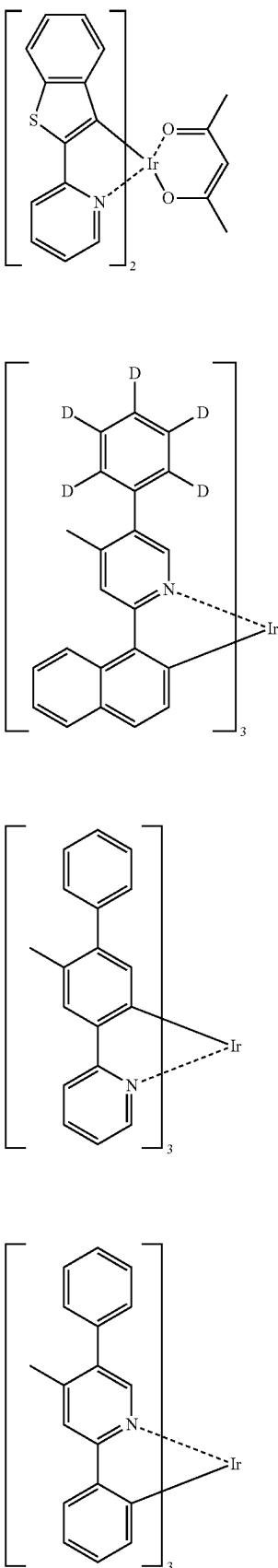
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PD14

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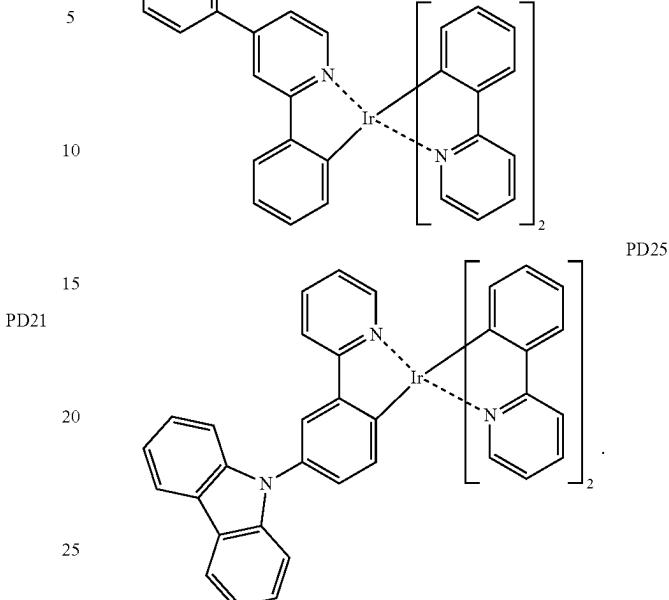
201

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**202**

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PD20 PD24



Fluorescent Dopant

30 When the first compound is included in the emission layer, and the first compound acts as an auxiliary dopant, the emission layer may further include a fluorescent dopant.

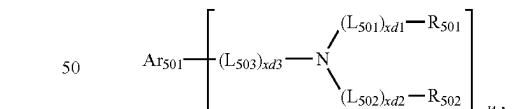
In some embodiments, when the first compound is included in the emission layer, and the first compound acts as a phosphorescent dopant, the emission layer may further include an auxiliary dopant.

35 The fluorescent dopant and auxiliary dopant may each independently include an arylamine compound, a styrylamine compound, a boron-containing compound, or any combination thereof.

40 For example, the fluorescent dopant and auxiliary dopant may each independently include a compound represented by Formula 501:

45

Formula 501



PD23

wherein, in Formula 501,

55 Ar_{501} , L_{501} to L_{503} , R_{501} , and R_{502} may each independently be a $\text{C}_3\text{-}\text{C}_{60}$ carbocyclic group unsubstituted or substituted with at least one R_{10a} or a $\text{C}_1\text{-}\text{C}_{60}$ heterocyclic group unsubstituted or substituted with at least one R_{10a} ,

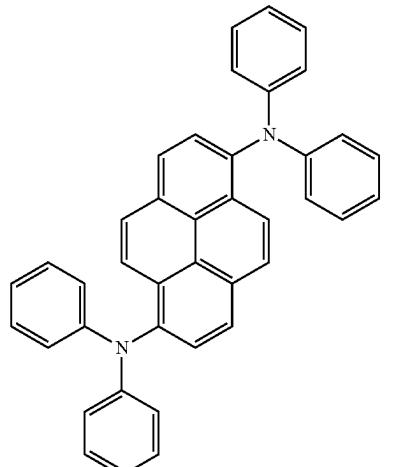
60 $xd1$ to $xd3$ may each independently be 0, 1, 2, or 3, and $xd4$ may be 1, 2, 3, 4, 5, or 6.

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

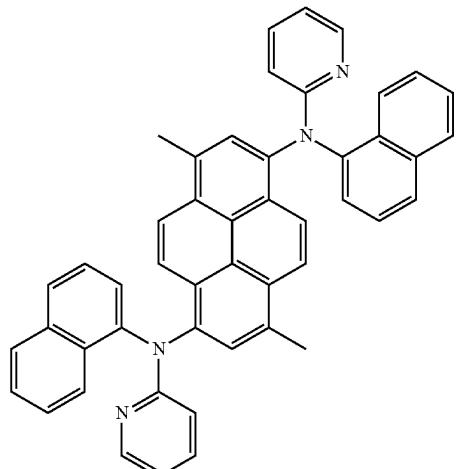
65 In one or more embodiments, $xd4$ in Formula 501 may be 2.

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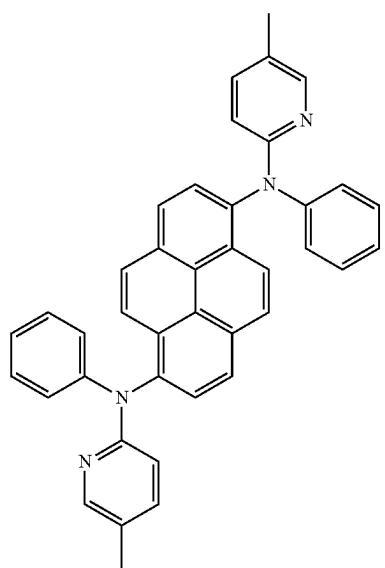
In an embodiment, the fluorescent dopant and auxiliary dopant may include: one of Compounds FD1 to FD36; DPVBi; DPAVBi; or any combination thereof:



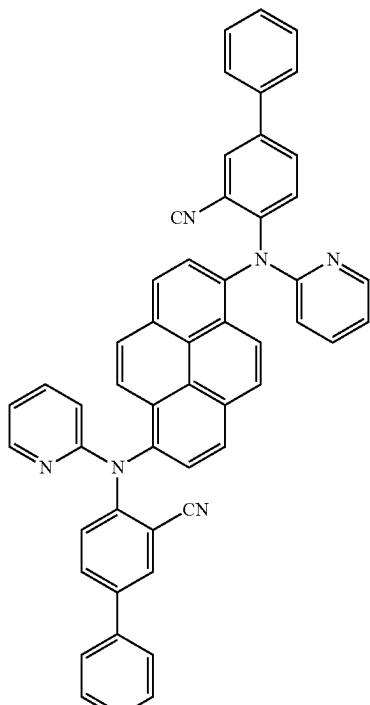
FD1



FD2

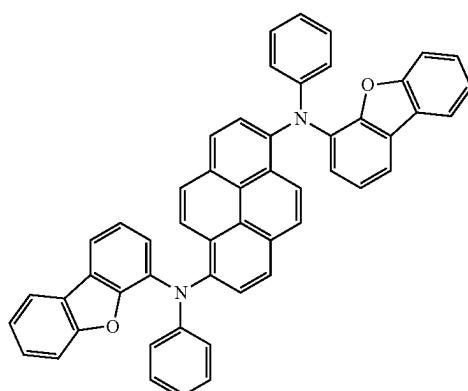


FD3

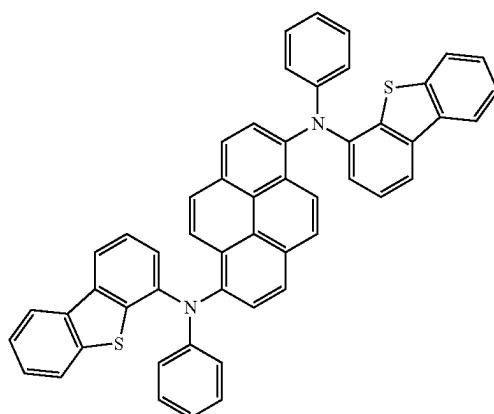
**204**

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FD4



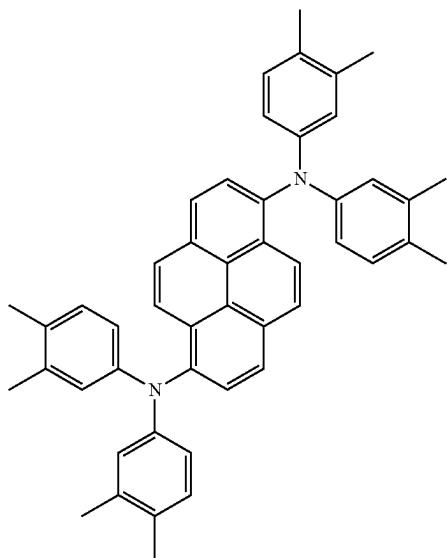
FD5



FD6

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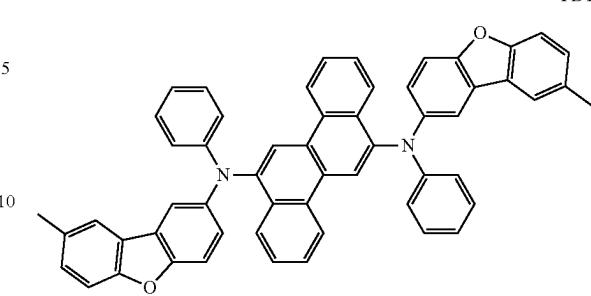
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FD7

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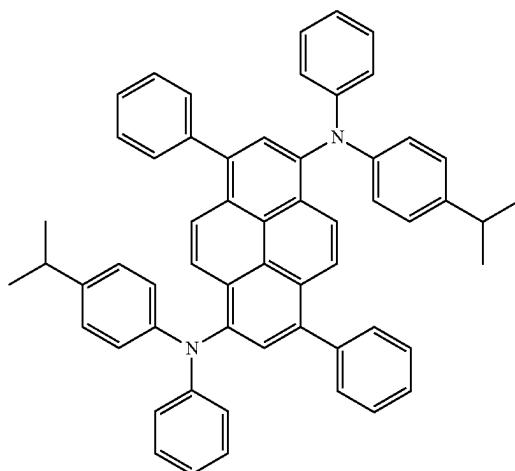
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FD10

FD11

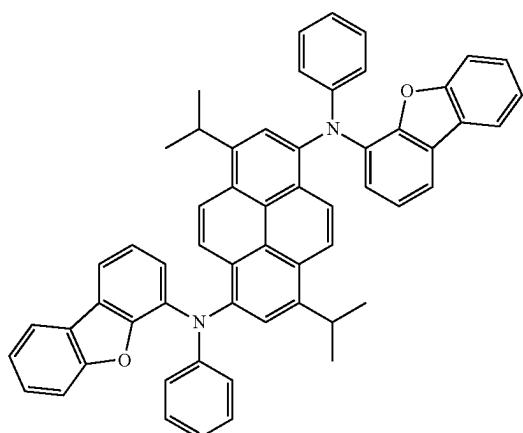
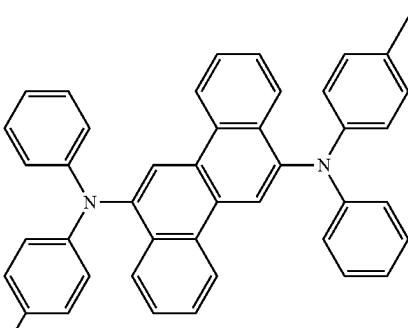


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FD12

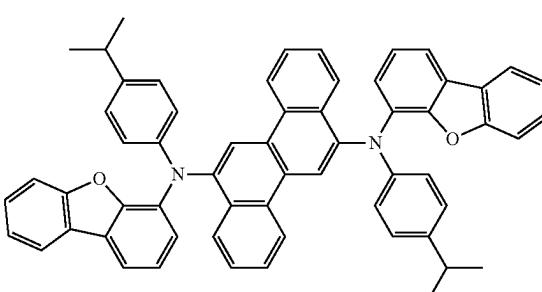


FD9

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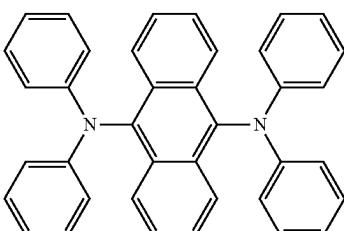
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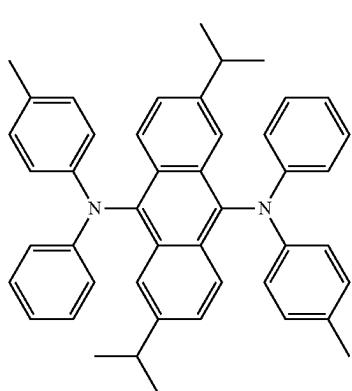
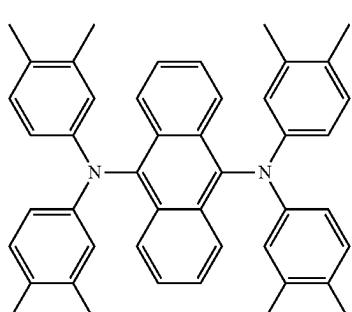
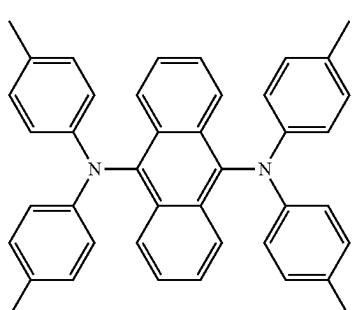
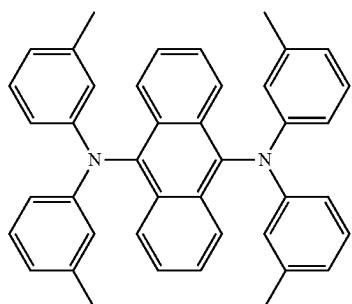


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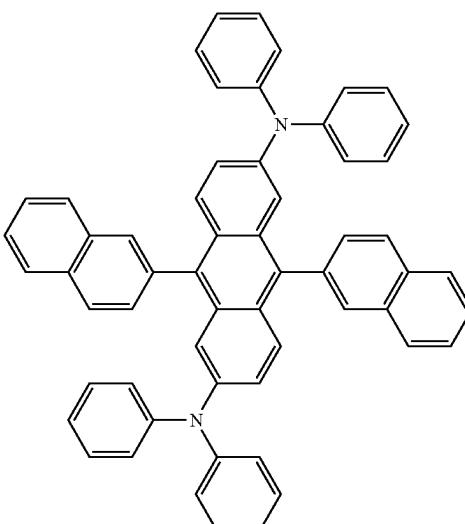
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FD14

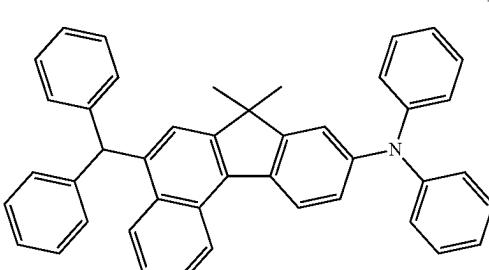


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-continued**208**
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FD15

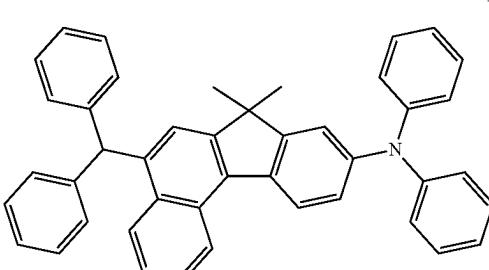


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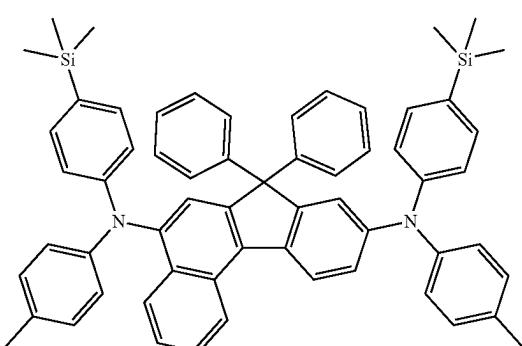


FD17

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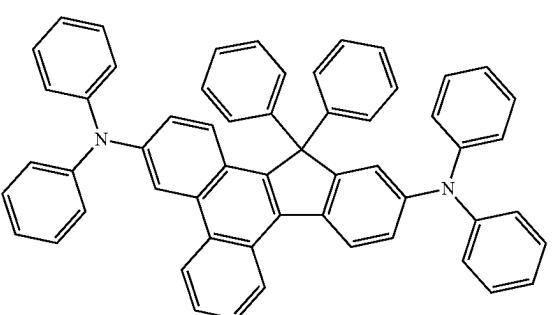


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FD18

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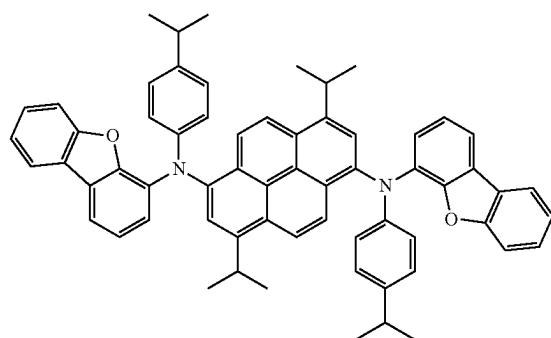
FD19

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FD23



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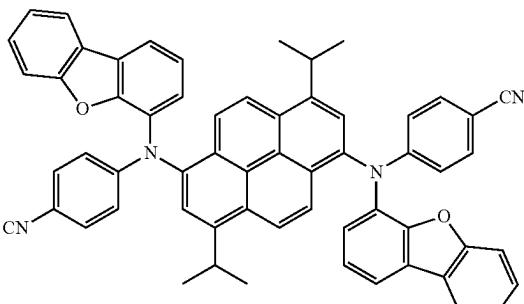
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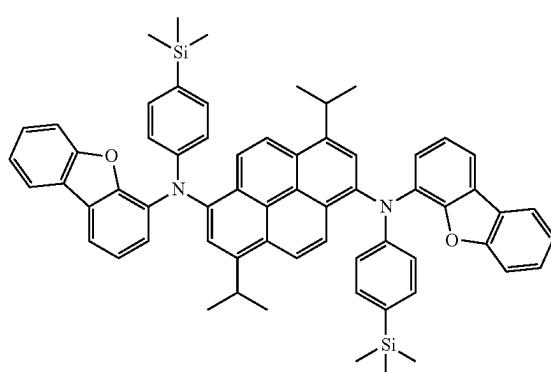
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FD27



FD24

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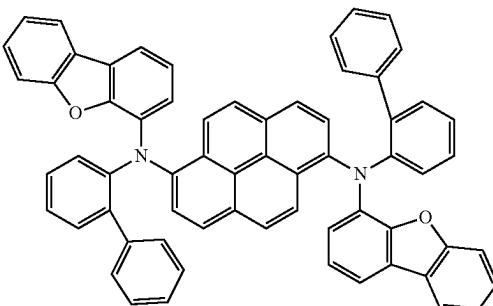


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FD28



FD25

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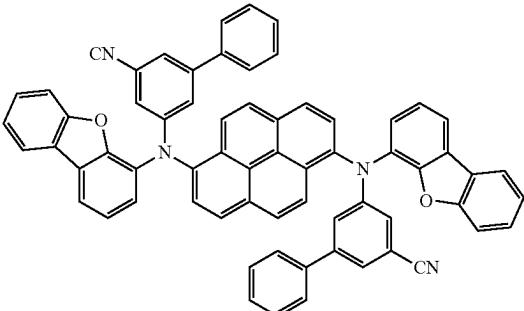
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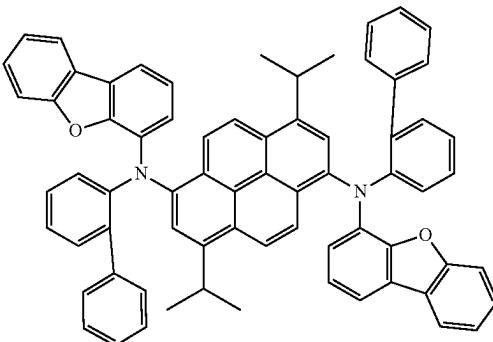
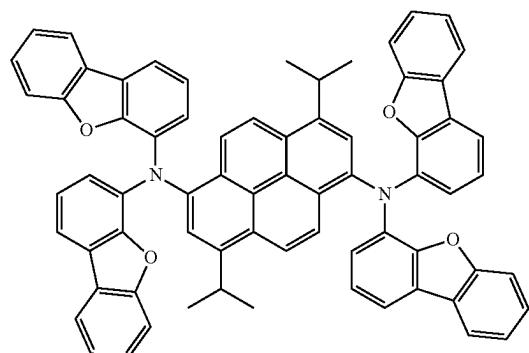
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FD29



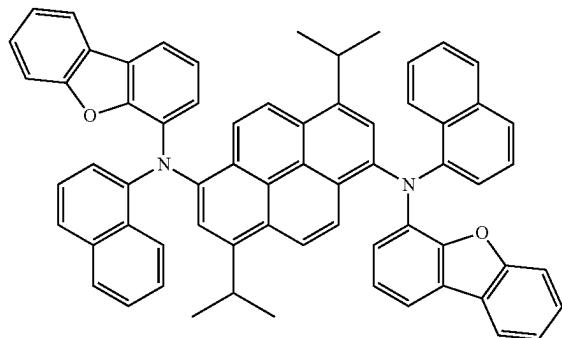
FD30



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FD31



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FD32

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FD33

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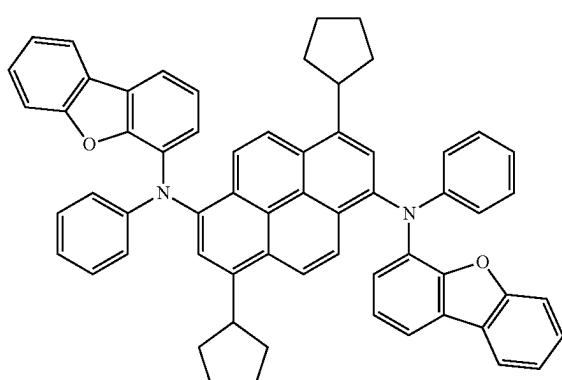
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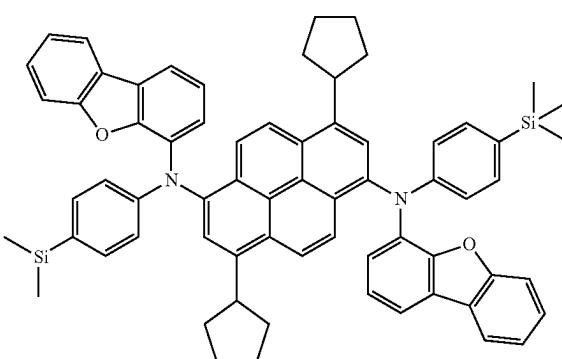
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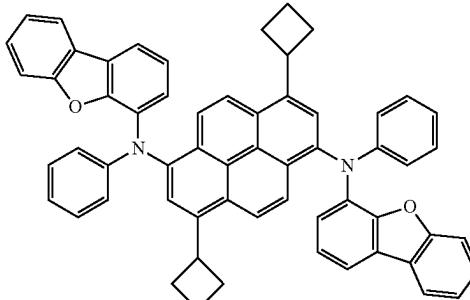


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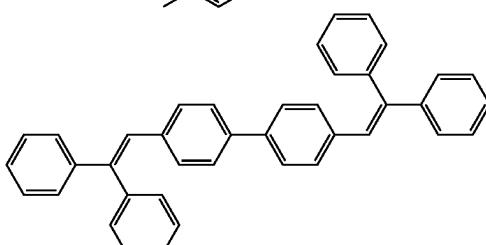
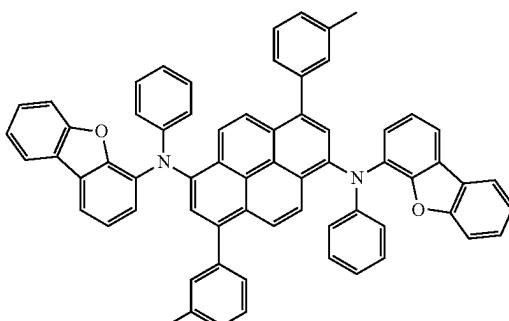
**212**

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FD35



FD36



DPVBi

DPAVBi

In some embodiments, the fluorescent dopant and auxiliary dopant may each independently include a fourth compound represented by Formula 502 or 503 as described herein.

Delayed Fluorescence Material

In an embodiment, the emission layer may include a delayed fluorescence material.

The delayed fluorescence material may be selected from compounds capable of emitting delayed fluorescence via a delayed fluorescence emission mechanism.

The delayed fluorescence material included in the emission layer may act as (e.g., be) a host or a dopant depending on the kind (e.g., type) of other materials included in the emission layer.

In an embodiment, the difference between the triplet energy level (eV) of the delayed fluorescence material and the singlet energy level (eV) of the delayed fluorescence material may be greater than or equal to 0 eV and less than

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or equal to 0.5 eV. When the difference between the triplet energy level (eV) of the delayed fluorescence material and the singlet energy level (eV) of the delayed fluorescence material satisfies the above-described range, up-conversion from the triplet state to the singlet state of the delayed fluorescence material may effectively occur, and thus, the emission efficiency of the light-emitting device **10** may be improved.

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

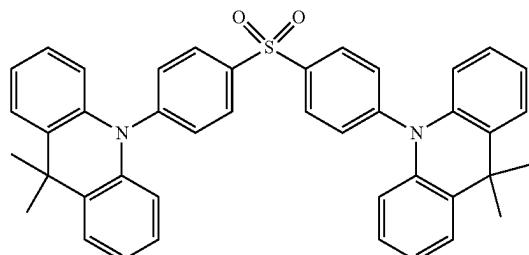
In an embodiment, the delayed fluorescence material may include at least one of the following Compounds DF1 to DF9:

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DF1



(DMAC-DPS)

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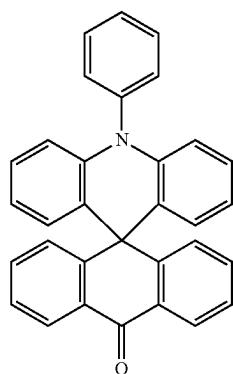
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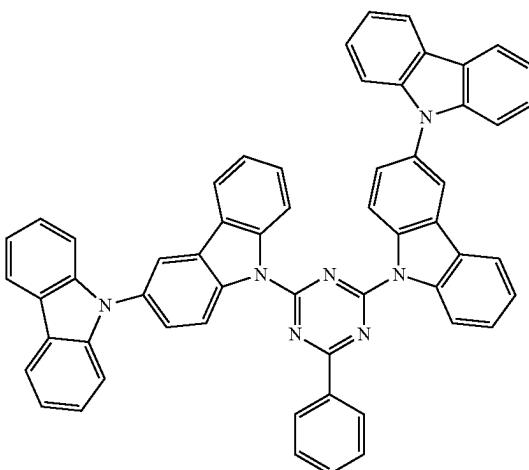


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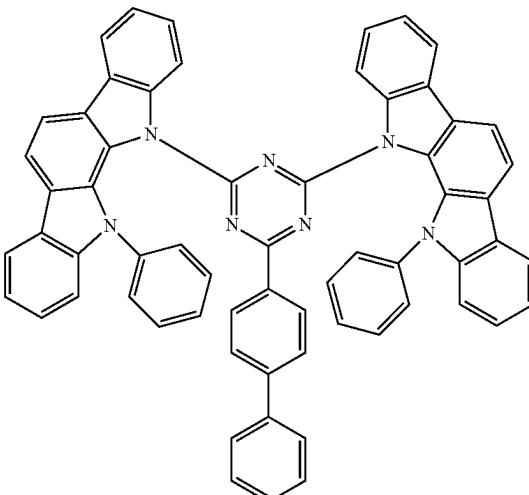
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DF4



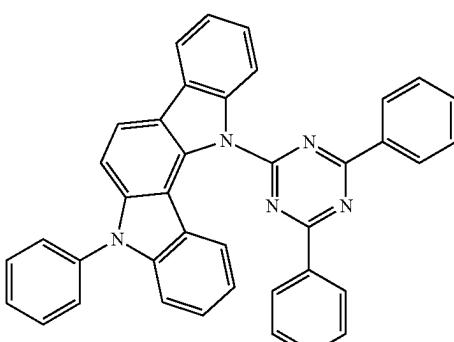
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DF5



(PIC-TRZ)

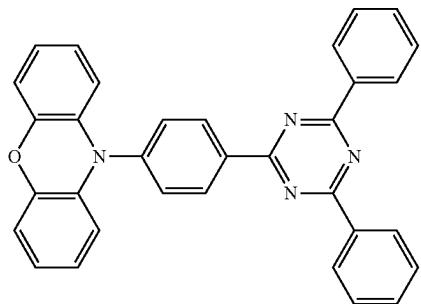
DF6



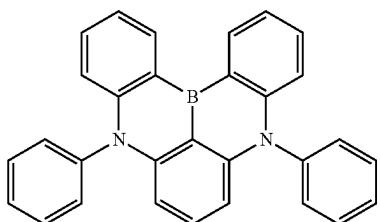
(PIC-TRZ2)

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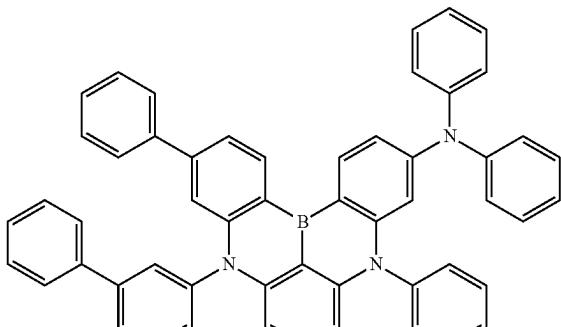
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(PXZ-TRZ)



(DABNA-1)



(DABNA-2)

Quantum Dot

The emission layer may include a quantum dot.

In the present specification, the term "quantum dot" refers to a crystal of a semiconductor compound, and may include any material capable of emitting light of various emission wavelengths according to the size (e.g., diameter) of the crystal.

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

The quantum dot may be synthesized by a wet chemical process, a metal organic (e.g., organometallic) chemical vapor deposition process, a molecular beam epitaxy process, or any suitable process similar thereto.

In the wet chemical process, a precursor material is mixed with an organic solvent to grow a quantum dot particle crystal. When the crystal grows, the organic solvent naturally acts as a dispersant coordinated on the surface of the quantum dot crystal and controls the growth of the crystal so that the growth of quantum dot particles can be controlled through a process that is more easily performed than vapor deposition methods, (such as metal organic chemical vapor deposition (MOCVD) and/or molecular beam epitaxy (MBE)), and which is a low cost process.

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DF7

The quantum dot may include a Group II-VI semiconductor compound, a Group III-V semiconductor compound, a Group III-VI semiconductor compound, a Group I-III-VI semiconductor compound, a Group IV-VI semiconductor compound, a Group IV element or compound; or any combination thereof.

Non-limiting examples of the Group II-VI semiconductor compound may include a binary compound (such as CdSe, CdTe, ZnS, ZnSe, ZnTe, ZnO, HgS, HgSe, HgTe, MgSe, and/or MgS); a ternary compound (such as CdSeS, CdSeTe, CdSTe, ZnSeS, ZnSeTe, ZnSTe, HgSeS, HgSeTe, HgSTE, CdZnS, CdZnSe, CdZnTe, CdHgS, CdHgSe, CdHgTe, HgZnS, HgZnSe, HgZnTe, MgZnSe, and/or MgZnS); a quaternary compound (such as CdZnSeS, CdZnSeTe, CdZnSeTe, CdHgSeS, CdHgSeTe, CdHgSTe, HgZnSeS, HgZnSeTe, and/or HgZnSTe); or any combination thereof.

Non-limiting examples of the Group III-V semiconductor compound may include a binary compound (such as GaN, GaP, GaAs, GaSb, AlN, AlP, AlAs, AlSb, InN, InP, InAs, InSb, and/or the like); a ternary compound (such as GaNP, GaNAs, GaNSb, GaPAs, GaPSb, AlNP, AlNAs, AlNSb, AlPAs, AlPSb, InGaP, InNP, InAlP, InNAS, InNSb, InPAs, InPSb, and/or the like); a quaternary compound (such as GaAlNAs, GaAlNSb, GaAlPAs, GaAlPSb, GaInNP, GaInNAs, GaInNSb, GaInPAs, GaInPSb, InAlNP, InAlNAs, InAlNSb, InAlPAs, InAlPSb, GaAlNP, and/or the like); or any combination thereof. The Group III-V semiconductor compound may further include a Group II element. Non-limiting examples of the Group III-V further including a Group II element are InZnP, InGaZnP, InAlZnP, etc.

Non-limiting examples of the Group III-VI semiconductor compound may include a binary compound (such as GaS, GaSe, Ga₂Se₃, GaTe, InS, InSe, In₂S₃, In₂Se₃, and/or InTe); a ternary compound (such as InGaS₃, and/or InGaSe₃); or any combination thereof.

Non-limiting examples of the Group I-III-VI semiconductor compound may include a ternary compound (such as AgInS, AgInS₂, CuInS, CuInS₂, CuGaO₂, AgGaO₂, and/or AgAlO₂); or any combination thereof.

Non-limiting examples of the Group IV-VI semiconductor compound may include a binary compound (such as SnS, SnSe, SnTe, PbS, PbSe, PbTe, and/or the like); a ternary compound (such as SnSeS, SnSeTe, SnSTe, PbSeS, PbSeTe, PbSTe, SnPbS, SnPbSe, SnPbTe, and/or the like); a quaternary compound (such as SnPbSSe, SnPbSeTe, SnPbSTe, and/or the like); or any combination thereof.

The Group IV element or compound may include a single element compound (such as Si and/or Ge); a binary compound (such as SiC and/or SiGe); or any combination thereof.

Each element included in a multi-element compound (such as the binary compound, the ternary compound, and/or the quaternary compound), may exist (e.g., be included) in a particle with a substantially uniform concentration (e.g., concentration distribution) or non-uniform concentration.

In one embodiment, the quantum dot may have a single structure or a dual core-shell structure. In the case of the quantum dot having a single structure, the concentration of each element included in the corresponding quantum dot may be substantially uniform. In an embodiment, in the dual core-shell structure, the material contained in the core and the material contained in the shell may be different from each other.

The shell of the quantum dot may act as (e.g., be) a protective layer to reduce or prevent chemical degeneration of the core to maintain semiconductor characteristics and/or as a charging layer to impart electrophoretic characteristics

to the quantum dot. The shell may be a single layer or a multi-layer. The interface between the core and the shell may have a concentration gradient in which the concentration of elements existing in the shell decreases toward the center of the core.

Non-limiting examples of the material in the shell of the quantum dot may include an oxide of a metal, a metalloid, or a non-metal; a semiconductor compound; or any combination thereof. Non-limiting examples of the oxide of a metal, a metalloid, or a non-metal may include a binary compound (such as SiO₂, Al₂O₃, TiO₂, ZnO, MnO, Mn₂O₃, Mn₃O₄, CuO, FeO, Fe₂O₃, Fe₃O₄, CoO, Co₃O₄, and/or NiO); a ternary compound (such as MgAl₂O₄, CoFe₂O₄, NiFe₂O₄, and/or CoMn₂O₄); or any combination thereof. Non-limiting examples of the semiconductor compound may include, as described herein, Group II-VI semiconductor compounds; Group III-V semiconductor compounds; Group III-VI semiconductor compounds; Group I-III-VI semiconductor compounds; or any combination thereof. In addition, the semiconductor compound may include CdS, CdSe, CdTe, ZnS, ZnSe, ZnTe, ZnSeS, ZnTeS, GaAs, GaP, GaSb, HgS, HgSe, HgTe, InAs, InP, InGaP, InSb, AlAs, AlP, AlSb, or any combination thereof.

A full width at half maximum (FWHM) of an emission wavelength spectrum of the quantum dot may be about 45 nm or less, for example, about 40 nm or less, for example, about 30 nm or less, and within these ranges, color purity or color gamut may be increased. In addition, because the light emitted through the quantum dot is emitted in all directions, the wide viewing angle can be improved.

In addition, the quantum dot may be or include a spherical particle, a pyramidal particle, a multi-arm particle, a cubic nanoparticle, a nanotube particle, a nanowire particle, a nanofiber particle, and/or a nanoplate particle.

Because the energy band gap can be adjusted by controlling the size of the quantum dot, light having various wavelength bands can be obtained from the quantum dot emission layer. Therefore, by utilizing quantum dots of different sizes, a light-emitting display to emit light of various suitable wavelengths may be implemented. In an embodiment, the size of the quantum dot may be selected to emit red, green and/or blue light. In addition, the size of the quantum dot may be configured to emit white light by combining light of various suitable colors.

Electron Transport Region in Interlayer 130

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

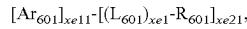
The electron transport region may include a buffer layer, a hole blocking layer, an electron control layer, an electron transport layer, an electron injection layer, or any combination thereof.

In an embodiment, 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 from an emission layer.

In an embodiment, the electron transport region (for example, the buffer layer, the hole blocking layer, the

electron control layer, and/or the electron transport layer in the electron transport region) may include a metal-free compound including at least one π electron-deficient nitrogen-containing C₁-C₆₀ cyclic group.

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



Formula 601

wherein, in Formula 601,

Ar_{601} and L_{601} may each independently be a C₃-C₆₀ carbocyclic group unsubstituted or substituted with at least one R_{10a} or a C₁-C₆₀ heterocyclic group unsubstituted or substituted with at least one R_{10a} ,

$xe11$ may be 1, 2, or 3,

$xe1$ may be 0, 1, 2, 3, 4, or 5,

R_{601} may be a C₃-C₆₀ carbocyclic group unsubstituted or substituted with at least one R_{10a} , a C₁-C₆₀ heterocyclic group unsubstituted or substituted with at least one R_{10a} , —Si(Q₆₀₁)(Q₆₀₂)(Q₆₀₃), —C(=O)(Q₆₀₁), —S(=O)₂(Q₆₀₁), or —P(=O)(Q₆₀₁)(Q₆₀₂),

Q₆₀₁ to Q₆₀₃ may each independently be the same as described in connection with Q₁,

$xe21$ may be 1, 2, 3, 4, or 5, and

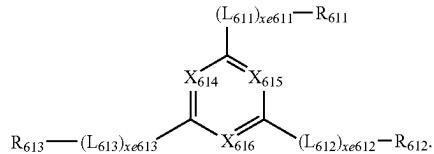
at least one of Ar_{601} , L_{601} , and R_{601} may each independently be a π electron-deficient nitrogen-containing C₁-C₆₀ cyclic group unsubstituted or substituted with at least one R_{10a} .

For example, when $xe11$ in Formula 601 is 2 or more, two or more $\text{Ar}_{601}(s)$ may be linked via a single bond.

In an embodiment, Ar_{601} in Formula 601 may be a substituted or unsubstituted anthracene group.

In an embodiment, the electron transport region may include a compound represented by Formula 601-1:

Formula 601-1



In Formula 601-1,

X₆₁₄ may be N or C(R₆₁₄), X₆₁₅ may be N or C(R₆₁₅), X₆₁₆ may be N or C(R₆₁₆), and at least one of X₆₁₄ to X₆₁₆ may be N,

L₆₁₁ to L₆₁₃ may each independently be the same as described in connection with L₆₀₁,

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

R₆₁₁ to R₆₁₃ may each independently be the same as described in connection with R₆₀₁, and

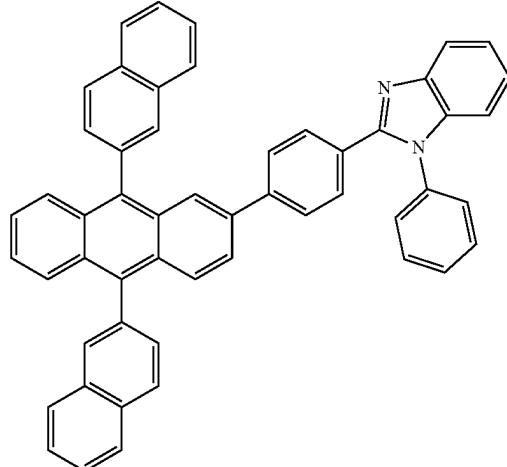
R₆₁₄ to R₆₁₆ may each independently be hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C₁-C₂₀ alkyl group, a C₁-C₂₀ alkoxy group, a C₃-C₆₀ carbocyclic group unsubstituted or substituted with at least one R_{10a} , or a C₁-C₆₀ heterocyclic group substituted or unsubstituted at least one R_{10a} .

For example, xe1 and xe611 to xe613 in Formulae 601 and 601-1 may each independently be 0, 1, or 2.

The electron transport region may include one of Compounds ET1 to ET45, 2,9-dimethyl-4,7-diphenyl-1,10-

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phenanthroline (BCP), 4,7-diphenyl-1,10-phenanthroline (Bphen), Alq₃, BAiq, TAZ, NTAZ, or any combination thereof:



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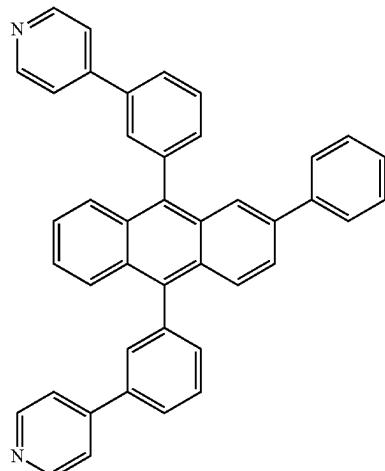
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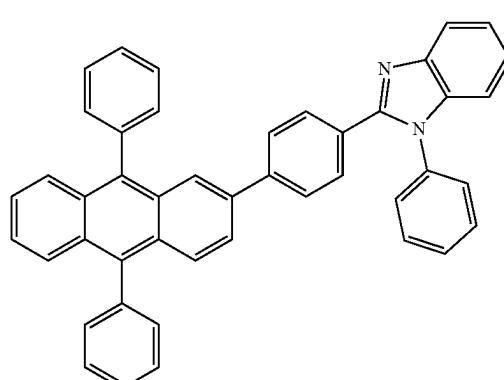
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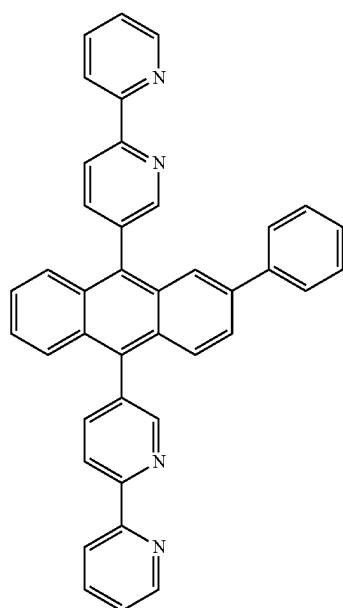
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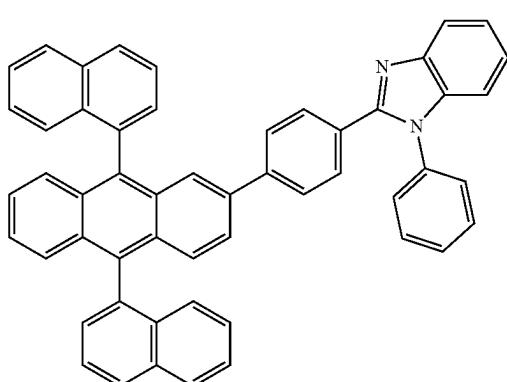
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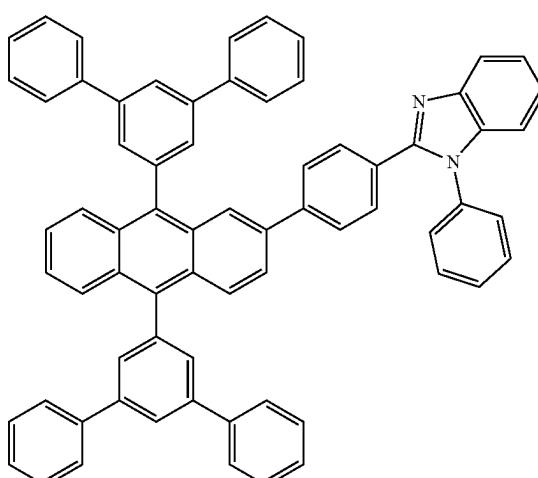
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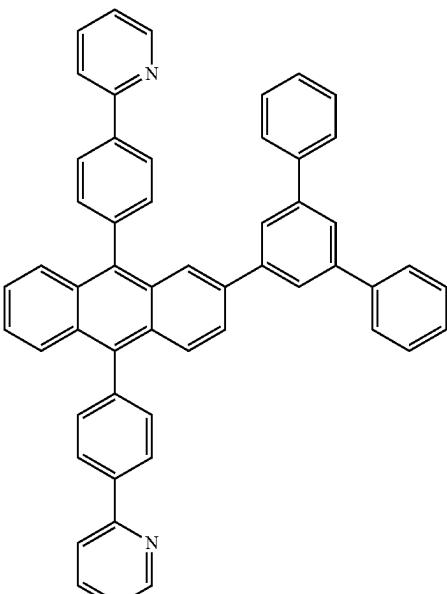
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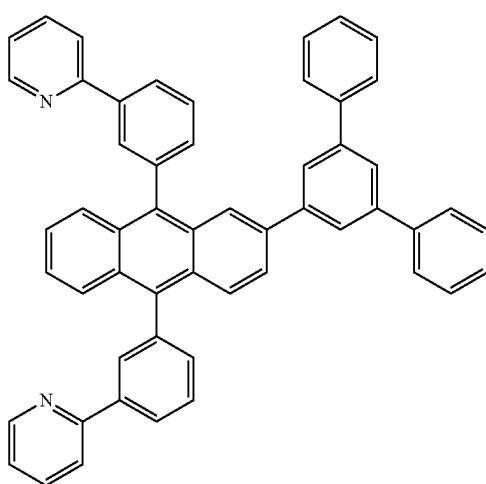
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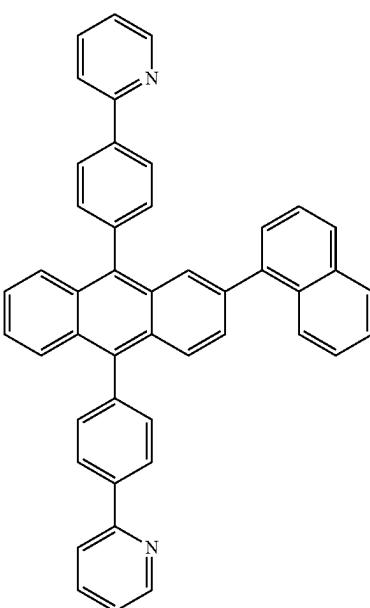
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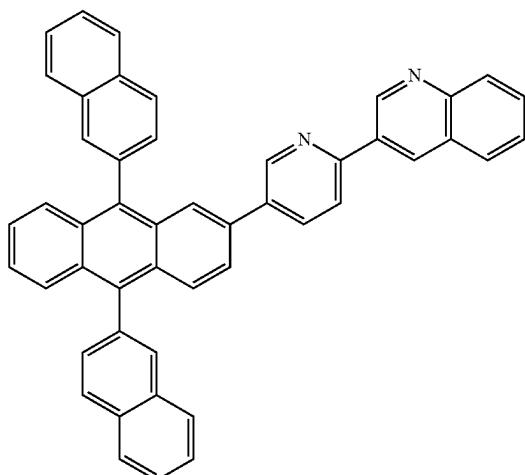


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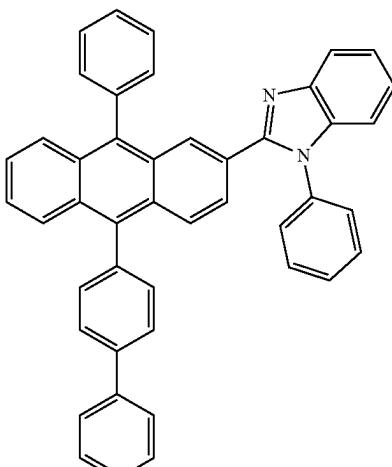
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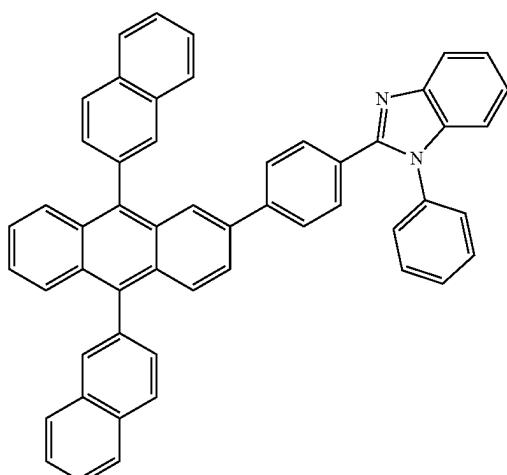
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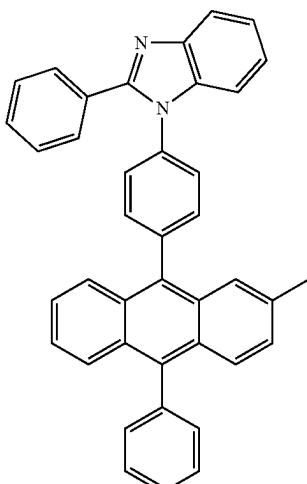
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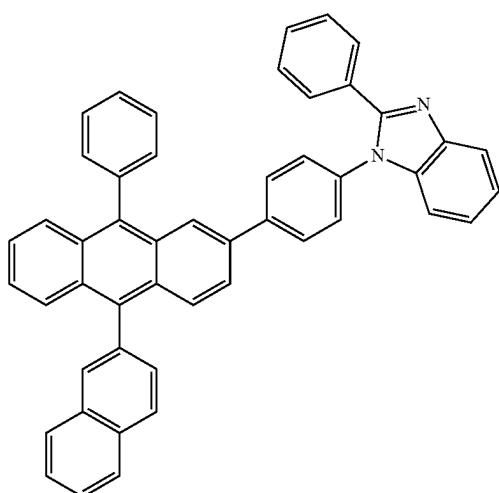
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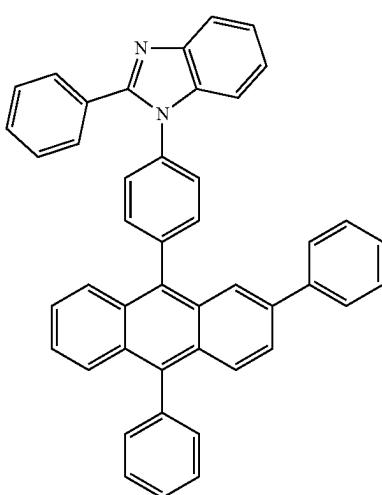
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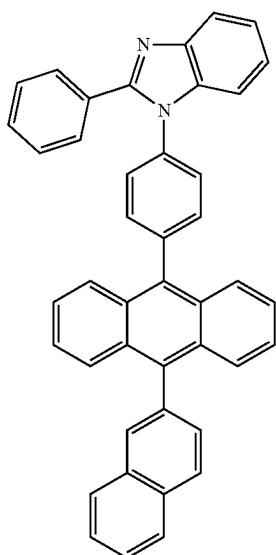
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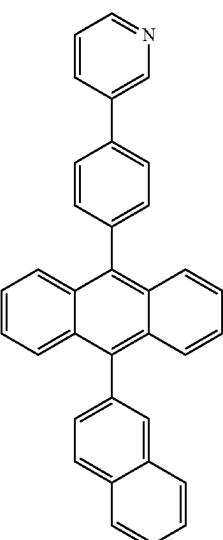


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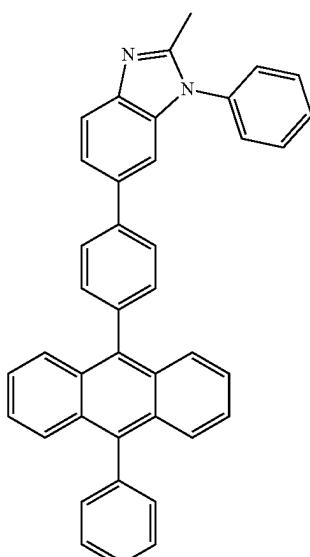


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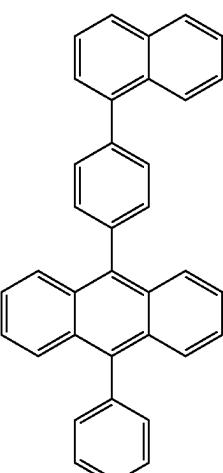
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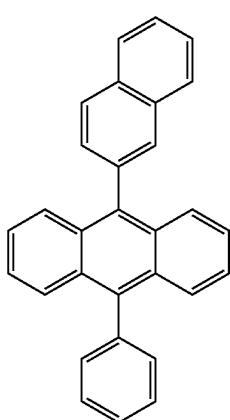
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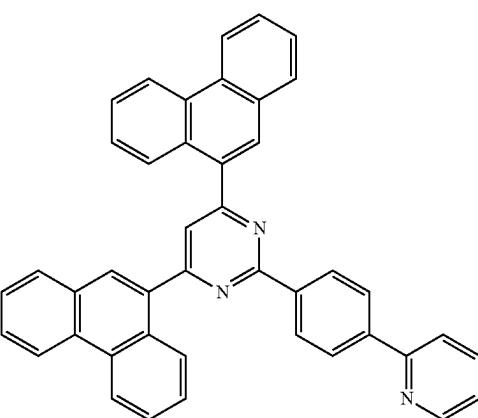
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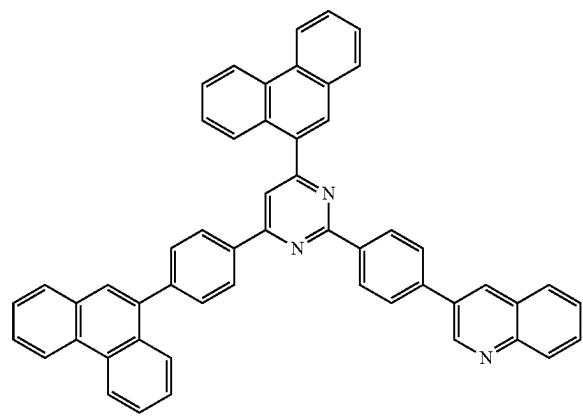
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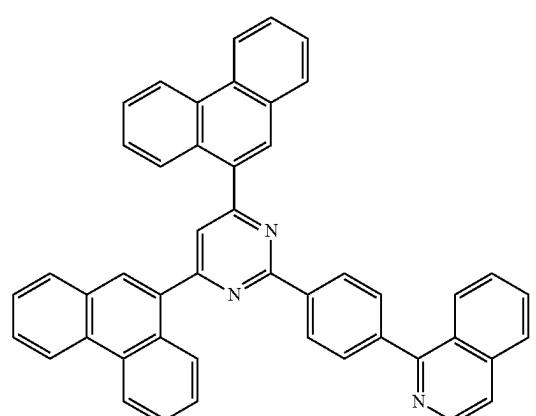
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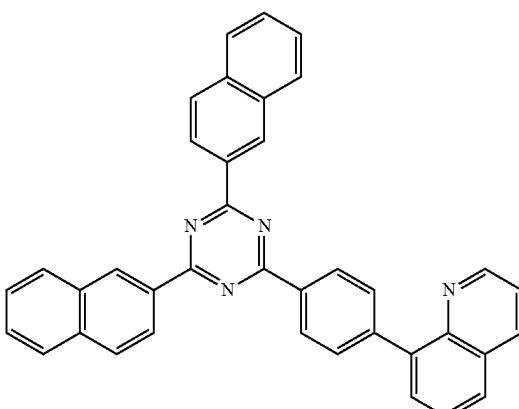
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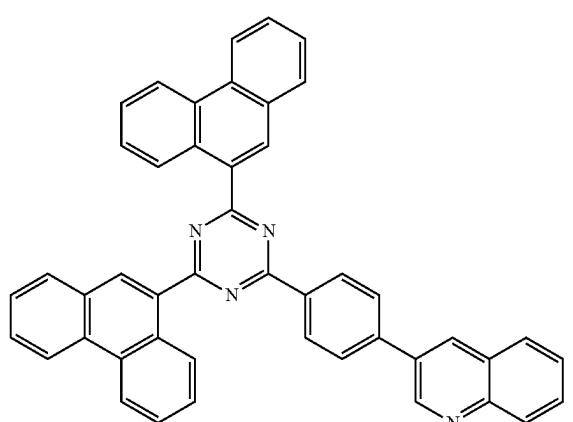
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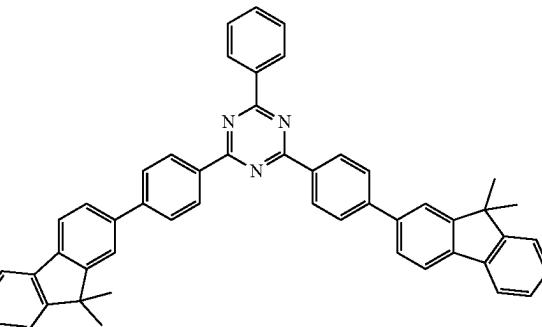


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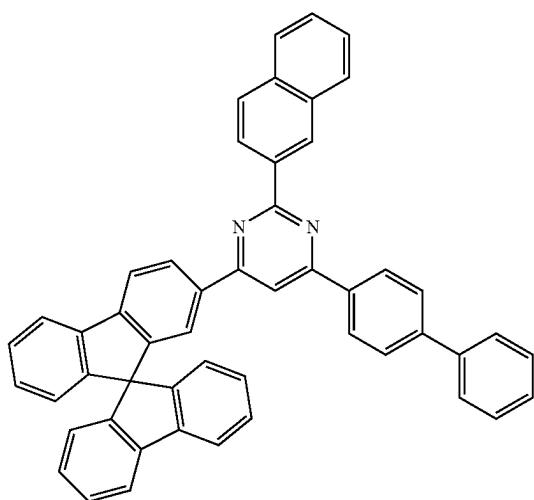
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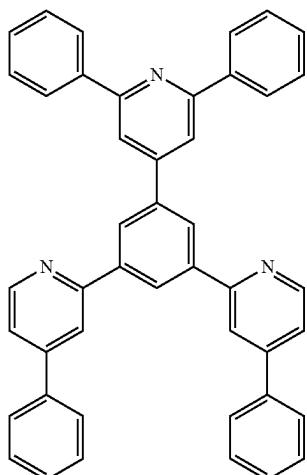
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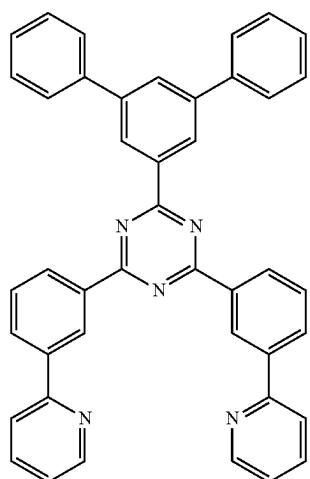
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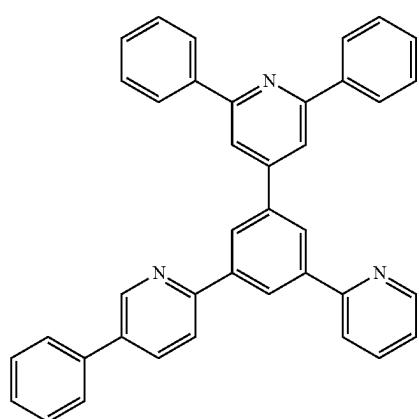
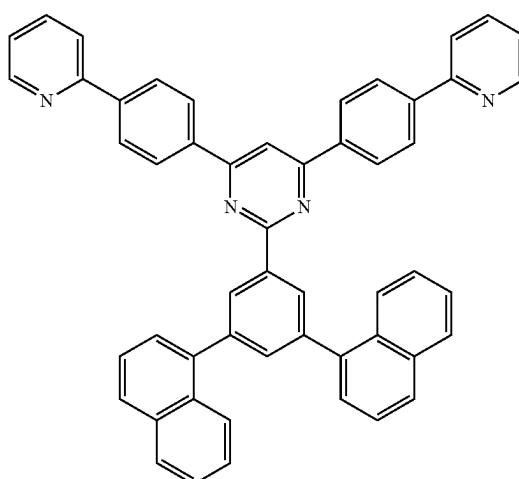
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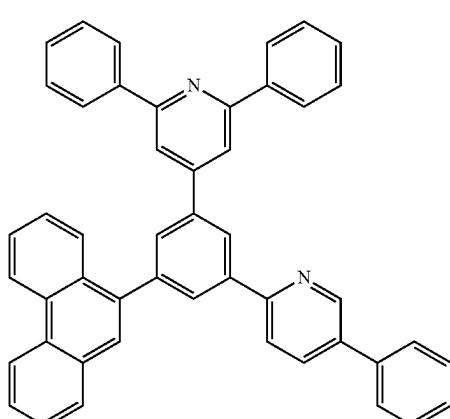
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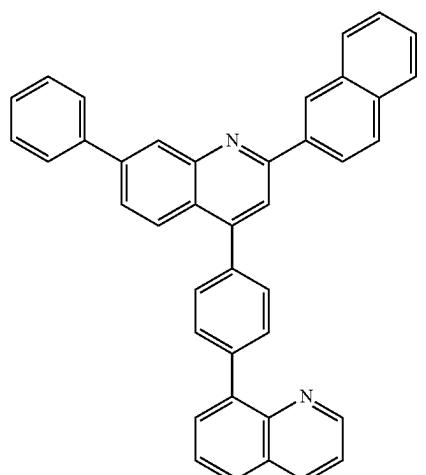
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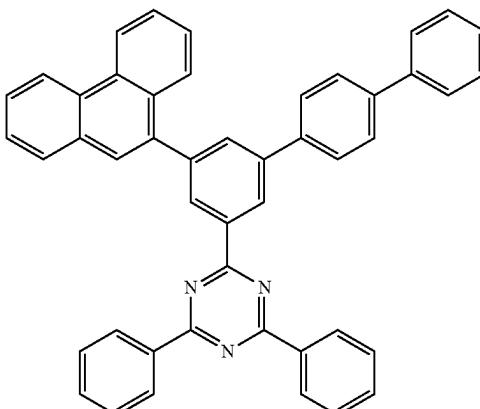
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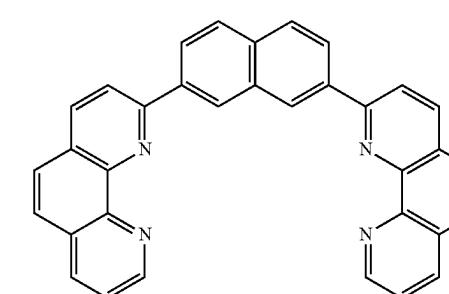
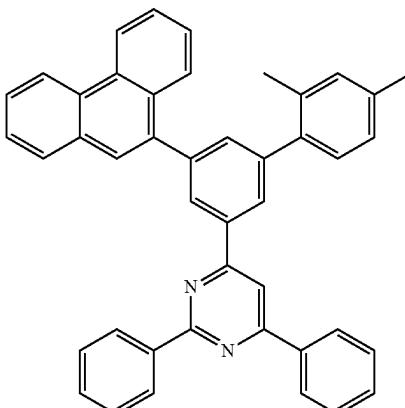


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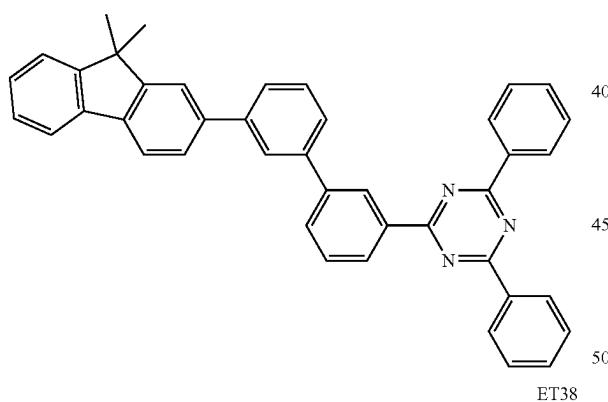
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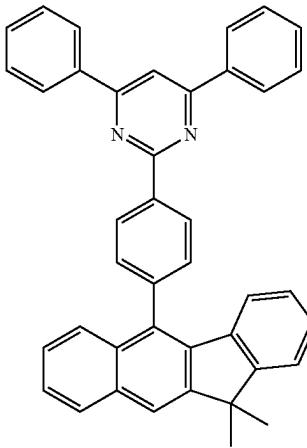
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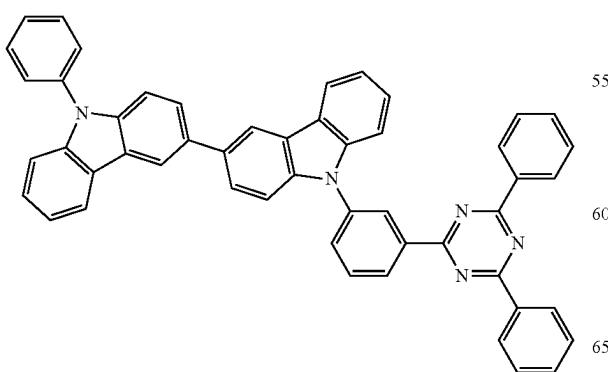
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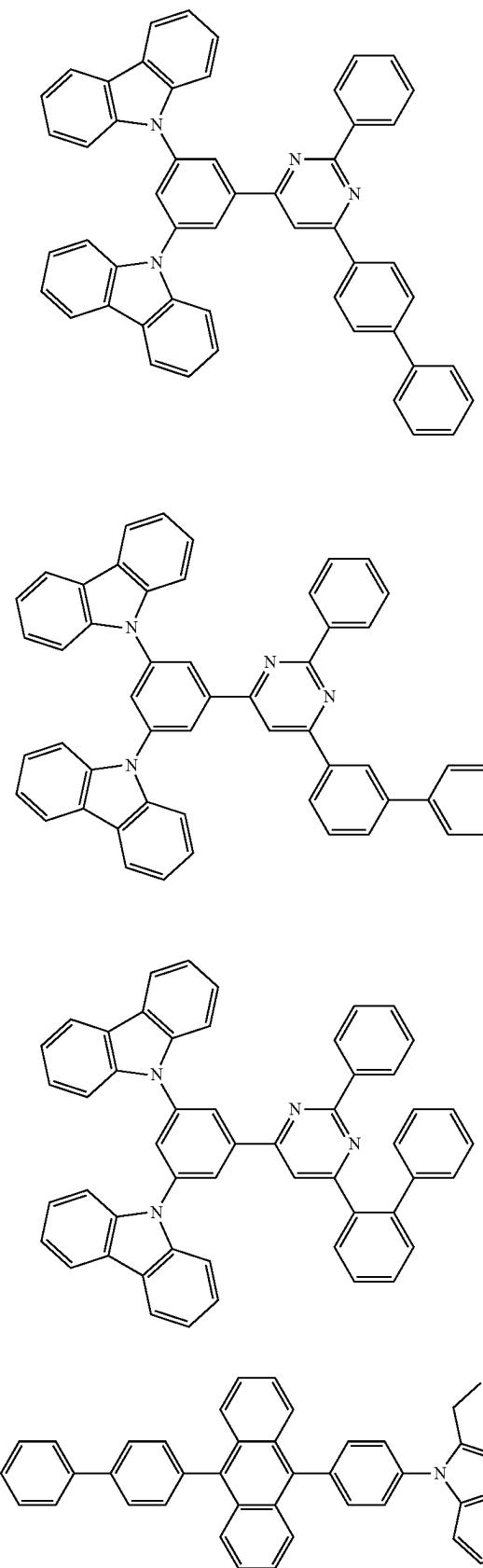
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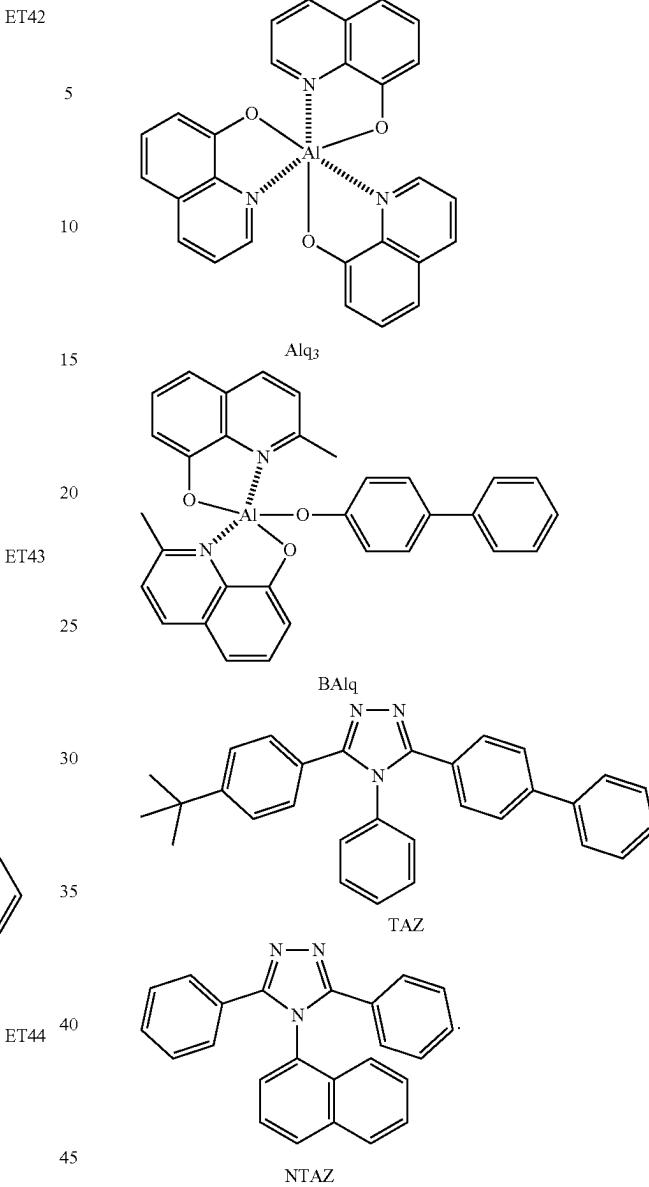
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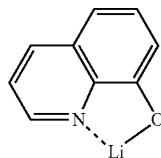
The thickness of the electron transport region may be about 160 Å to about 5,000 Å, for example, about 100 Å to about 4,000 Å. When the electron transport region includes a buffer layer, a hole blocking layer, an electron control layer, an electron transport layer, or any combination thereof, the thickness of the buffer layer, the hole blocking layer, or the electron control layer may each independently be about 20 Å to about 1000 Å, for example, about 30 Å to about 300 Å, and the thickness of the electron transport layer may be about 100 Å to about 1000 Å, for example, about 150 Å to about 500 Å. When the thicknesses of the buffer layer, hole blocking layer, electron control layer, electron transport layer and/or electron transport layer are within these ranges, satisfactory electron transporting characteristics may be obtained without a substantial increase in driving voltage.

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.

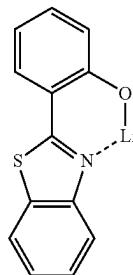
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The metal-containing material may include an alkali metal complex, an alkaline earth metal complex, or any combination thereof. The metal ion of the alkali metal complex may be a Li ion, a Na ion, a K ion, a Rb ion, or a Cs ion, and the metal ion of the alkaline earth metal complex may be a Be ion, a Mg ion, a Ca ion, a Sr ion, or a Ba ion. A ligand coordinated with the metal ion of the alkali metal complex or the alkaline earth-metal complex may include a hydroxyquinoline, a hydroxyisoquinoline, a hydroxybenzoquinoline, a hydroxyacridine, a hydroxyphenanthridine, a hydroxyphenyloxazole, a hydroxyphenylthiazole, a hydroxydiphenyloxadiazole, a hydroxydiphenylthiadiazole, a hydroxyphenylpyridine, a hydroxyphenylbenzimidazole, a hydroxyphenylbenzothiazole, a bipyridine, a phenanthroline, a cyclopentadiene, or any combination thereof.

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



ET-D1



ET-D2

The electron transport region may include an electron injection layer to facilitate the injection of electrons from the second electrode 150. The electron injection layer may directly contact the second electrode 150.

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

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

The alkali metal may include Li, Na, K, Rb, Cs, or any combination thereof. The alkaline earth metal may include Mg, Ca, Sr, Ba, or any combination thereof. The rare earth metal may include Sc, Y, Ce, Tb, Yb, Gd, or any combination thereof.

The alkali metal-containing compound, the alkaline earth metal-containing compound, and the rare earth metal-containing compound may be oxides, halides (for example, fluorides, chlorides, bromides, and/or iodides), and/or tellu-

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rides of the alkali metal, the alkaline earth metal, and the rare earth metal, or any combination thereof.

The alkali metal-containing compound may include alkali metal oxides, such as Li_2O , Cs_2O , or K_2O , alkali metal halides, such as LiF, NaF, CsF, KF, LiI, NaI, CsI, or KI, or any combination thereof. The alkaline earth metal-containing compound may include an alkaline earth metal compound, such as BaO , SrO , CaO , $\text{Ba}_x\text{Sr}_{1-x}\text{O}$ (x is a real number satisfying the condition of $0 < x < 1$), $\text{Ba}_x\text{Ca}_{1-x}\text{O}$ (x is a real number satisfying the condition of $0 < x < 1$), and/or the like. The rare earth metal-containing compound may include YbF_3 , ScF_3 , Sc_2O_3 , Y_2O_3 , Ce_2O_3 , GdF_3 , TbF_3 , YbI_3 , ScI_3 , TbI_3 , or any combination thereof. In an embodiment, the rare earth metal-containing compound may include a lanthanide metal telluride. Non-limiting examples of the lanthanide metal telluride include LaTe, CeTe, PrTe, NdTe, PmTe, SmTe, EuTe, GdTe, TbTe, DyTe, HoTe, ErTe, TmTe, YbTe, LuTe, La_2Te_3 , Ce_2Te_3 , Pr_2Te_3 , Nd_2Te_3 , Pm_2Te_3 , Sm_2Te_3 , Eu_2Te_3 , Gd_2Te_3 , Tb_2Te_3 , Dy_2Te_3 , Ho_2Te_3 , Er_2Te_3 , Tm_2Te_3 , Yb_2Te_3 , and Lu_2Te_3 .

The alkali metal complex, the alkaline earth-metal complex, and the rare earth metal complex may include i) one ion of the alkali metal, the alkaline earth metal, and the rare earth metal, and ii) a ligand bonded to the metal ion, for example, hydroxyquinoline, hydroxyisoquinoline, hydroxybenzoquinoline, hydroxyacridine, hydroxyphenanthridine, hydroxyphenyloxazole, hydroxyphenylthiazole, hydroxydiphenyloxadiazole, hydroxydiphenylthiadiazole, hydroxyphenylpyridine, hydroxyphenylbenzimidazole, hydroxyphenylbenzothiazole, bipyridine, phenanthroline, cyclopentadiene, or any combination thereof.

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

In an embodiment, the electron injection layer may include (e.g., consist of) i) an alkali metal-containing compound (for example, an alkali metal halide), ii) a) an alkali metal-containing compound (for example, an alkali metal halide); and b) an alkali metal, an alkaline earth metal, a rare earth metal, or any combination thereof. In an embodiment, the electron injection layer may be a KI:Yb co-deposited layer, an RbI:Yb co-deposited layer, and/or the like.

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

A thickness of the electron injection layer may be in a range of about 1 Å to about 100 Å, and, for example, about 3 Å to about 90 Å. When the thickness of the electron injection layer is within the range described above, the electron injection layer may have satisfactory electron injection characteristics without a substantial increase in driving voltage.

65 Second Electrode 150

The second electrode 150 may be located on the interlayer 130 having such a structure. The second electrode 150 may

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be a cathode, which is an electron injection electrode, and as the material for the second electrode **150**, a metal, an alloy, an electrically conductive compound, or any combination thereof, each having a low work function, may be utilized.

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

The second electrode **150** may have a single-layered structure or a multi-layered structure including two or more layers.

Capping Layer

A first capping layer may be located outside the first electrode **110**, and/or a second capping layer may be located outside the second electrode **150**. In detail, the light-emitting device **10** may have a structure in which the first capping layer, the first electrode **110**, the interlayer **130**, and the second electrode **150** are sequentially stacked in this stated order, a structure in which the first electrode **110**, the interlayer **130**, the second electrode **150**, and the second capping layer are sequentially stacked in this stated order, or a structure in which the first capping layer, the first electrode **110**, the interlayer **130**, the second electrode **150**, and the second capping layer are sequentially stacked in this stated order.

Light generated in an emission layer of the interlayer **130** of the light-emitting device **10** may be extracted toward the outside of the device through the first electrode **110** (which is a semi-transmissive electrode or a transmissive electrode) and the first capping layer, and/or light generated in an emission layer of the interlayer **130** of the light-emitting device **10** may be extracted toward the outside through the second electrode **150** (which is a semi-transmissive electrode or a transmissive electrode) and the second capping layer.

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

Each of the first capping layer and second capping layer may include a material having a refractive index (at 589 nm) of 1.6 or more.

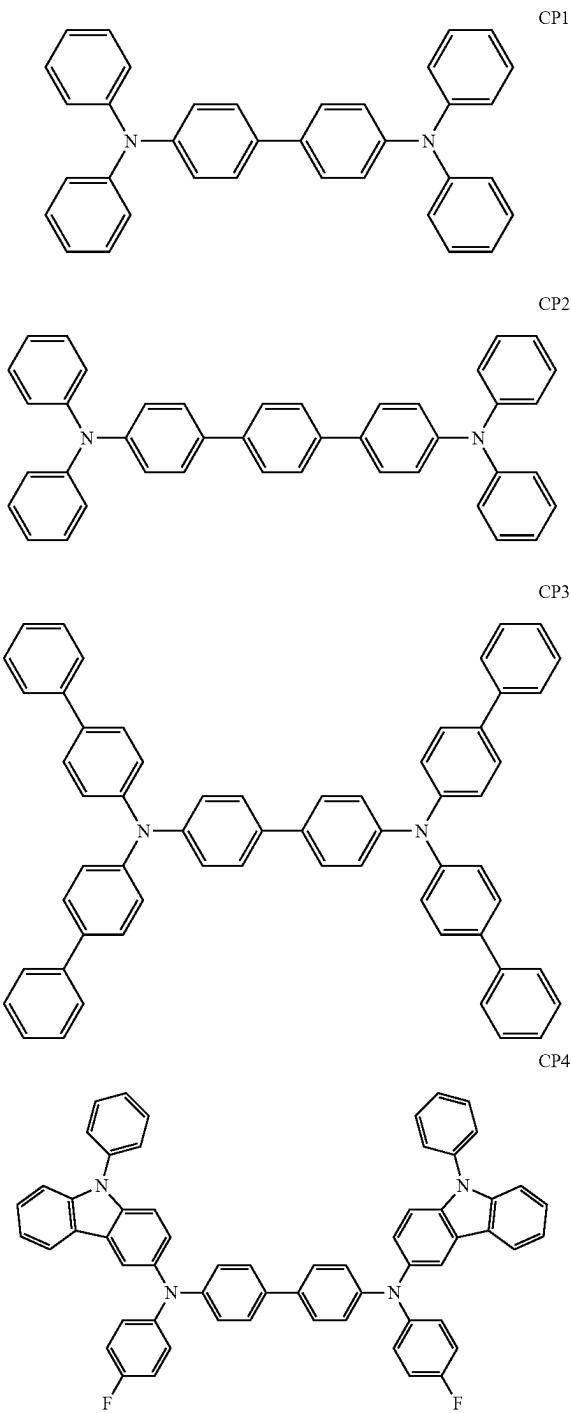
The first capping layer and the second capping layer may each independently be an organic capping layer including an organic material, an inorganic capping layer including an inorganic material, or a composite capping layer including an organic material and an inorganic material.

At least one selected from the first capping layer and the second capping layer may each independently include one or more carbocyclic compounds, heterocyclic compounds, amine group-containing compounds, porphyrin derivatives, phthalocyanine derivatives, naphthalocyanine derivatives, alkali metal complexes, alkaline earth metal complexes, or any combination thereof. The carbocyclic compound, the heterocyclic compound, and the amine group-containing compound may be optionally substituted with a substituent containing O, N, S, Se, Si, F, Cl, Br, I, or any combination thereof. In an embodiment, at least one of the first capping layer and the second capping layer may each independently include an amine group-containing compound.

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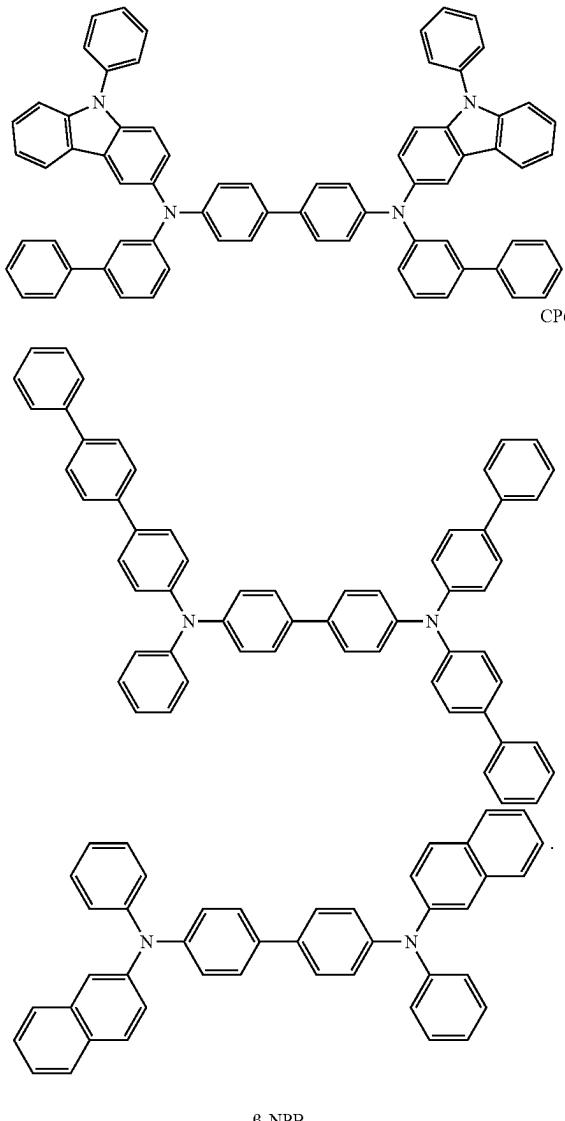
In an embodiment, at least one of the first capping layer and the second capping layer may each independently include a compound represented by Formula 201, a compound represented by Formula 202, or any combination thereof.

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



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-continued



CP5

5 respectively corresponding to the subpixel areas, and the color conversion layer may include a plurality of color conversion areas respectively corresponding to the subpixel areas.

5 A pixel-defining film may be located among the subpixel areas to define each of the subpixel areas.

The color filter may further include a plurality of color filter areas and light-blocking patterns located among the color filter areas, and the color conversion layer may include 10 a plurality of color conversion areas and light-blocking patterns located among the color conversion areas.

The color filter areas (and/or the color conversion areas) may include a first area emitting first color light, a second area emitting second color light, and/or a third area emitting third color light, and the first color light, the second color light, and/or the third color light may have different maximum emission wavelengths from one another. In an embodiment, the first color light may be red light, the second color light may be green light, and the third color light may be 15 blue light. In an embodiment, the color filter areas (or the color conversion areas) may include quantum dots. In detail, the first area may include a red quantum dot, the second area may include a green quantum dot, and the third area may not include a quantum dot. The quantum dot may be the same as 20 described herein. The first area, the second area, and/or the third area may each include a scatter.

In an embodiment, the light-emitting device may be to emit a first (e.g., initial) light, the first area may be to absorb the first light to emit first first-color light, the second area 30 may be to absorb the first light to emit second first-color light, and the third area may be to absorb the first light to emit third first-color light. In this regard, the first first-color light, the second first-color light, and the third first-color light may have different maximum emission wavelengths. In 35 detail, the first light may be blue light, the first first-color light may be red light, the second first-color light may be green light, and the third first-color light may be blue light.

The electronic apparatus may further include a thin-film transistor in addition to the light-emitting device 1 as 40 described above. The thin-film transistor may include a source electrode, a drain electrode, and an activation layer, wherein any one of the source electrode and the drain electrode may be electrically connected to any one of the first electrode and the second electrode of the light-emitting device.

The thin-film transistor may further include a gate electrode, a gate insulating film, etc.

The activation layer may include crystalline silicon, an amorphous silicon, an organic semiconductor, an oxide semiconductor, and/or the like.

The electronic apparatus may further include a sealing portion for sealing the light-emitting device. The sealing portion and/or the color conversion layer may be placed between the color filter and the light-emitting device. The 55 sealing portion allows light from the light-emitting device to be extracted to the outside, while concurrently (e.g., simultaneously) preventing or reducing ambient air and/or moisture from penetrating into the light-emitting device. The sealing portion may be a sealing substrate including a transparent glass substrate and/or a plastic substrate. The sealing portion may be a thin-film encapsulation layer including at least one layer of an organic layer and/or an inorganic layer. When the sealing portion is a thin film encapsulation layer, the electronic apparatus may be flexible.

Various suitable functional layers may be additionally located on the sealing portion, in addition to the color filter

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respectively corresponding to the subpixel areas, and the color conversion layer may include a plurality of color conversion areas respectively corresponding to the subpixel areas.

5 A pixel-defining film may be located among the subpixel areas to define each of the subpixel areas.

The color filter may further include a plurality of color filter areas and light-blocking patterns located among the color filter areas, and the color conversion layer may include 10 a plurality of color conversion areas and light-blocking patterns located among the color conversion areas.

The color filter areas (and/or the color conversion areas) may include a first area emitting first color light, a second area emitting second color light, and/or a third area emitting third color light, and the first color light, the second color light, and/or the third color light may have different maximum emission wavelengths from one another. In an embodiment, the first color light may be red light, the second color light may be green light, and the third color light may be 15 blue light. In an embodiment, the color filter areas (or the color conversion areas) may include quantum dots. In detail, the first area may include a red quantum dot, the second area may include a green quantum dot, and the third area may not include a quantum dot. The quantum dot may be the same as 20 described herein. The first area, the second area, and/or the third area may each include a scatter.

In an embodiment, the light-emitting device may be to emit a first (e.g., initial) light, the first area may be to absorb the first light to emit first first-color light, the second area 30 may be to absorb the first light to emit second first-color light, and the third area may be to absorb the first light to emit third first-color light. In this regard, the first first-color light, the second first-color light, and the third first-color light may have different maximum emission wavelengths. In 35 detail, the first light may be blue light, the first first-color light may be red light, the second first-color light may be green light, and the third first-color light may be blue light.

The electronic apparatus may further include a thin-film transistor in addition to the light-emitting device 1 as 40 described above. The thin-film transistor may include a source electrode, a drain electrode, and an activation layer, wherein any one of the source electrode and the drain electrode may be electrically connected to any one of the first electrode and the second electrode of the light-emitting device.

The thin-film transistor may further include a gate electrode, a gate insulating film, etc.

The activation layer may include crystalline silicon, an amorphous silicon, an organic semiconductor, an oxide semiconductor, and/or the like.

The electronic apparatus may further include a sealing portion for sealing the light-emitting device. The sealing portion and/or the color conversion layer may be placed between the color filter and the light-emitting device. The 55 sealing portion allows light from the light-emitting device to be extracted to the outside, while concurrently (e.g., simultaneously) preventing or reducing ambient air and/or moisture from penetrating into the light-emitting device. The sealing portion may be a sealing substrate including a transparent glass substrate and/or a plastic substrate. The sealing portion may be a thin-film encapsulation layer including at least one layer of an organic layer and/or an inorganic layer. When the sealing portion is a thin film encapsulation layer, the electronic apparatus may be flexible.

Various suitable functional layers may be additionally located on the sealing portion, in addition to the color filter

Electronic Apparatus

The light-emitting device may be included in one or more suitable electronic apparatuses. In an embodiment, the electronic apparatus including the light-emitting device may be a light-emitting apparatus, an authentication apparatus, or the like.

The electronic apparatus (for example, light-emitting apparatus) may further include, in addition to the light-emitting device, i) a color filter, ii) a color conversion layer, or iii) a color filter and a color conversion layer. The color filter and/or the color conversion layer may be located in at least one traveling direction of light emitted from the light-emitting device. In an embodiment, the light emitted from the light-emitting device may be blue light or white light. The light-emitting device may be substantially the same as described above. In an embodiment, the color conversion layer may include quantum dots.

The electronic apparatus may include a first substrate. The first substrate may include a plurality of subpixel areas, the color filter may include a plurality of color filter areas

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and/or the color conversion layer, according to the use of the electronic apparatus. The functional layers may include a touch screen layer, a polarizing layer, and/or the like. The touch screen layer may be a pressure-sensitive touch screen layer, a capacitive touch screen layer, or an infrared touch screen layer. The authentication apparatus may be, for example, a biometric authentication apparatus that authenticates an individual by utilizing biometric information of a living body (for example, fingertips, pupils, etc.).

The authentication apparatus may further include, in addition to the light-emitting device, a biometric information collector.

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

Description of FIGS. 2 and 3

FIG. 2 is a cross-sectional view showing a light-emitting apparatus according to an embodiment of the present disclosure.

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

The substrate 100 may be a flexible substrate, a glass substrate, or a metal substrate. A buffer layer 210 may be formed on the substrate 100. The buffer layer 210 may prevent or reduce penetration of impurities through the substrate 100 and may provide a flat surface on the substrate 100.

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

The activation layer 220 may include an inorganic semiconductor such as silicon or polysilicon, an organic semiconductor, or an oxide semiconductor, and may include a source region, a drain region and a channel region.

A gate insulating film 230 for insulating the activation layer 220 from the gate electrode 240 may be located on the activation layer 220, and the gate electrode 240 may be located on the gate insulating film 230.

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

The source electrode 260 and the drain electrode 270 may be located on the interlayer insulating film 250. The interlayer insulating film 250 and the gate insulating film 230 may be formed to expose the source region and the drain region of the activation layer 220, and the source electrode 260 and the drain electrode 270 may be in contact with the exposed portions of the source region and the drain region of the activation layer 220.

The TFT is electrically connected to a light-emitting device to drive the light-emitting device, and is covered by a passivation layer 280. The passivation layer 280 may

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include an inorganic insulating film, an organic insulating film, or a combination thereof. A light-emitting device may be provided on the passivation layer 280. The light-emitting device may include a first electrode 110, an interlayer 130, and a second electrode 150.

The first electrode 110 may be formed on the passivation layer 280. The passivation layer 280 does not completely cover the drain electrode 270 and may expose a portion of the drain electrode 270, and the first electrode 110 is connected to the exposed portion of the drain electrode 270.

A pixel defining layer 290 containing an insulating material may be located on the first electrode 110. The pixel defining layer 290 exposes a region of the first electrode 110, and an interlayer 130 may be formed in the exposed region of the first electrode 110. The pixel defining layer 290 may be a polyimide or polyacrylic organic film. In some embodiments, at least some layers of the interlayer 130 may extend beyond the upper portion of the pixel defining layer 290 to be located in the form of a common layer.

The second electrode 150 may be located on the interlayer 130, and a capping layer 170 may be additionally formed on the second electrode 150. The capping layer 170 may be formed to cover the second electrode 150.

The encapsulation portion 300 may be located on the capping layer 170. The encapsulation portion 300 may be located on a light-emitting device to protect the light-emitting device from moisture or oxygen. The encapsulation portion 300 may include: an inorganic film including silicon nitride (SiN_x), silicon oxide (SiO_x), indium tin oxide, indium zinc oxide, or any combination thereof; an organic film including polyethylene terephthalate, polyethylene naphthalate, polycarbonate, polyimide, polyethylene sulfonate, polyoxymethylene, polyarylate, hexamethyldisiloxane, an acrylic resin (for example, polymethyl methacrylate, polyacrylic acid, and/or the like), an epoxy-based resin (for example, aliphatic glycidyl ether (AGE), and/or the like), or a combination thereof; or a combination of the inorganic film and the organic film.

FIG. 3 shows a cross-sectional view showing a light-emitting apparatus according to an embodiment of the present disclosure.

The light-emitting apparatus of FIG. 3 is substantially the same as the light-emitting apparatus of FIG. 2, except that a light-blocking pattern 500 and a functional region 400 are additionally located on the encapsulation portion 300. The functional region 400 may be a combination of i) a color filter area, ii) a color conversion area, or iii) a combination of the color filter area and the color conversion area. In an embodiment, the light-emitting device included in the light-emitting apparatus of FIG. 3 may be a tandem light-emitting device.

Manufacture Method

The layers included in the hole transport region, the emission layer, and the layers included in the electron transport region may be formed in a set or predetermined region by utilizing one or more suitable methods selected from vacuum deposition, spin coating, casting, Langmuir-Blodgett (LB) deposition, ink-jet printing, laser-printing, and laser-induced thermal imaging.

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

Definition of Terms

The term “C₃-C₆₀ carbocyclic group” as utilized herein refers to a cyclic group including (e.g., consisting of) three to sixty carbon atoms, and the term “C₁-C₆₀ heterocyclic group” as utilized herein refers to a cyclic group that has one to sixty carbon atoms and further has, in addition to carbon, a heteroatom. The C₃-C₆₀ carbocyclic group and the C₁-C₆₀ heterocyclic group may each be a monocyclic group including (e.g., consisting of) one ring, or a polycyclic group in which two or more rings are condensed with each other. For example, the number of ring-forming atoms of the C₁-C₆₀ heterocyclic group may be from 3 to 61.

The term “cyclic group” as utilized herein may include the C₃-C₆₀ carbocyclic group, and the C₁-C₆₀ heterocyclic group.

The term “Tr electron-rich C₃-C₆₀ cyclic group” as utilized herein refers to a cyclic group that has three to sixty carbon atoms and does not include *—N—* as a ring-forming moiety, and the term “Tr electron-deficient nitrogen-containing C₁-C₆₀ cyclic group” as utilized herein refers to a heterocyclic group that has one to sixty carbon atoms and includes *—N—* as a ring-forming moiety.

For example,

the C₃-C₆₀ carbocyclic group may be i) a group T1 or ii) a condensed cyclic group in which two or more groups T1 are condensed with each other (for example, a cyclopentadiene group, an adamantane group, a norbornane group, a benzene group, a pentalene group, a naphthalene group, an azulene group, an indacene group, acenaphthylene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a perylene group, a pentaphene group, a heptalene group, a naphthacene group, a picene group, a hexacene group, a pentacene group, a rubicene group, a coronene group, an ovalene group, an indene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, an indenophenanthrene group, or an indenoanthracene group),

the C₁-C₆₀ heterocyclic group may be i) a group T2, ii) a condensed cyclic group in which two or more groups T2 are condensed with each other, or iii) a condensed cyclic group in which at least one group T2 and at least one group T1 are condensed with each other (for example, a pyrrole group, a thiophene group, a furan group, an indole group, a benzoindole group, a naphthoisoindole group, a naphthoisoindole group, a benzosilole group, a benzothiophene group, a benzofuran group, a carbazole group, a dibenzosilole group, a dibenzothiophene group, a dibenzofuran group, an indenocarbazole group, a benzofurocarbazole group, a benzothienocarbazole group, a benzosilolocarbazole group, a benzoindolocarbazole group, a benzocarbazole group, a benzonaphthofuran group, a benzonaphthosilole group, a benzofurodibenzofuran group, a benzofurodibenzothiophene group, a benzothienodibenzothiophene group, a pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, an oxadiazole group, a thiazole group, an isothiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a benzoxazole group, a benzoisoxazole group, a benzothiazole group, a benzoisothiazole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a benzoquinoline group, a benzoquinazoline group, a quinazoline group, a benzoquinazoline group, a phenanthroline group, a cinnoline group, a phthalazine group, a naphthyridine group, an imidazopyridine group, an imidazopyrimidine group, an imidazotriazine group, an imidazopyrazine group, an imidazopyridazine group, an azacarbazole group, an azafluorene group, an azadibenzosilole group, an azadibenzothiophene group, an azadibenzofuran group, etc.).

an isoquinoline group, a benzoquinoline group, a benzoisoquinoline group, a quinoxaline group, a benzoquinoxaline group, a quinazoline group, a benzoquinazoline group, a phenanthroline group, a cinnoline group, a phthalazine group, a naphthyridine group, an imidazopyridine group, an imidazopyrimidine group, an imidazotriazine group, an imidazopyrazine group, an imidazopyridazine group, an azacarbazole group, an azafluorene group, an azadibenzosilole group, an azadibenzothiophene group, an azadibenzofuran group, etc.),

the π electron-rich C₃-C₆₀ cyclic group may be i) a group T1, ii) a condensed cyclic group in which two or more groups T1 are condensed with each other, iii) a group T3, iv) a condensed cyclic group in which two or more groups T3 are condensed with each other, or v) a condensed cyclic group in which at least one group T3 and at least one group T1 are condensed with each other (for example, the C₃-C₆₀ carbocyclic group, a pyrrole group, a thiophene group, a furan group, an indole group, a benzoindole group, a naphthoisindole group, a naphthoisindole group, a benzosilole group, a benzothiophene group, a benzofuran group, a carbazole group, a dibenzosilole group, a dibenzothiophene group, a dibenzofuran group, an indenocarbazole group, an indolocarbazole group, a benzofurocarbazole group, a benzothienocarbazole group, a benzosilolocarbazole group, a benzoindolocarbazole group, a benzocarbazole group, a benzonaphthofuran group, a benzonaphthosilole group, a benzofurodibenzofuran group, a benzofurodibenzothiophene group, a benzothienodibenzothiophene group, etc.),

the π electron-deficient nitrogen-containing C₁-C₆₀ cyclic group may be i) a group T4, ii) a condensed cyclic group in which two or more group T4 are condensed with each other, iii) a condensed cyclic group in which at least one group T4 and at least one group T1 are condensed with each other, iv) a condensed cyclic group in which at least one group T4 and at least one group T3 are condensed with each other, or v) a condensed cyclic group in which at least one group T4, at least one group T1, and at least one group T3 are condensed with one another (for example, a pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, an oxadiazole group, a thiazole group, an isothiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a benzoxazole group, a benzoisoxazole group, a benzothiazole group, a benzoisothiazole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a benzoquinoline group, a benzoquinazoline group, a quinazoline group, a benzoquinazoline group, a phenanthroline group, a cinnoline group, a phthalazine group, a naphthyridine group, an imidazopyridine group, an imidazopyrimidine group, an imidazotriazine group, an imidazopyrazine group, an imidazopyridazine group, an azacarbazole group, an azafluorene group, an azadibenzosilole group, an azadibenzothiophene group, an azadibenzofuran group, etc.).

the group T1 may be a cyclopropane group, a cyclobutane group, a cyclopentane group, a cyclohexane group, a cycloheptane group, a cyclooctane group, a

cyclobutene group, a cyclopentene group, a cyclopentadiene group, a cyclohexene group, a cyclohexadiene group, a cycloheptene group, an adamantane group, a norbornane (or a bicyclo[2.2.1]heptane) group, a norbornene group, a bicyclo[1.1.1]pentane group, a bicyclo[2.1.1]hexane group, a bicyclo[2.2.2]octane group, or a benzene group, the group T2 may be a furan group, a thiophene group, a 1H-pyrrole group, a silole group, a borole group, a 2H-pyrrole group, a 3H-pyrrole group, an imidazole group, a pyrazole group, a triazole group, a tetrazole group, an oxazole group, an isoxazole group, an oxadiazole group, a thiazole group, an isothiazole group, a thiadiazole group, an azasilole group, an azaborole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, or a tetrazine group, the group T3 may be a furan group, a thiophene group, a 1H-pyrrole group, a silole group, or a borole group, and the group T4 may be a 2H-pyrrole group, a 3H-pyrrole group, an imidazole group, a pyrazole group, a triazole group, a tetrazole group, an oxazole group, an isoxazole group, an oxadiazole group, a thiazole group, an isothiazole group, a thiadiazole group, an azasilole group, an azaborole group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, or a tetrazine group.

The terms “the cyclic group”, “the $C_3\text{-}C_{60}$ carbocyclic group”, “the $C_1\text{-}C_{60}$ heterocyclic group”, “the Tr electron-rich $C_3\text{-}C_{60}$ cyclic group”, and/or “the π electron-deficient nitrogen-containing $C_1\text{-}C_{60}$ cyclic group” as utilized herein may refer to a group condensed to any cyclic group or a polyvalent group (for example, a divalent group, a trivalent group, a tetravalent group, etc.), depending on the context e.g., the structure of a formula in connection with which the terms are utilized). In an embodiment, “a benzene group” may be a benzo group, a phenyl group, a phenylen group, and/or the like, which may be easily understood by one of ordinary skill in the art according to the structure of a formula including the “benzene group.”

Non-limiting examples of the monovalent $C_3\text{-}C_{60}$ carbocyclic group and the monovalent $C_1\text{-}C_{60}$ heterocyclic group are a $C_3\text{-}C_{10}$ cycloalkyl group, a $C_1\text{-}C_{10}$ heterocycloalkyl group, a $C_3\text{-}C_{10}$ cycloalkenyl group, a $C_1\text{-}C_{10}$ heterocycloalkenyl group, a $C_6\text{-}C_{60}$ aryl group, a $C_1\text{-}C_{60}$ heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, and non-limiting examples of the divalent $C_3\text{-}C_{60}$ carbocyclic group and the divalent $C_1\text{-}C_{60}$ heterocyclic group are a $C_3\text{-}C_{10}$ cycloalkenylene group, a $C_1\text{-}C_{10}$ heterocycloalkenylene group, a $C_6\text{-}C_{60}$ arylene group, a $C_1\text{-}C_{60}$ heteroarylene group, a divalent non-aromatic condensed polycyclic group, and a divalent non-aromatic condensed heteropolycyclic group.

The term “ $C_1\text{-}C_{60}$ alkyl group” as utilized herein refers to a linear or branched aliphatic hydrocarbon monovalent group that has one to sixty carbon atoms, and non-limiting examples thereof include a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, a sec-butyl group, an isobutyl group, a tert-butyl group, an n-pentyl group, a tert-pentyl group, neopentyl group, an isopentyl group, a sec-pentyl group, 3-pentyl group, a sec-isopentyl group, an n-hexyl group, an isoheptyl group, a sec-hexyl group, a tert-heptyl group, an n-heptyl group, an isoheptyl group, a sec-heptyl group, a tert-heptyl group, an n-octyl group, an isoctyl group, a sec-octyl group, a tert-octyl group, an n-nonyl group, an isononyl group, a sec-

nonyl group, a tert-nonyl group, an n-decyl group, an isodecyl group, a sec-decyl group, and a tert-decyl group. The term “ $C_1\text{-}C_{60}$ alkylene group” as utilized herein refers to a divalent group having substantially the same structure as the $C_1\text{-}C_{60}$ alkyl group.

The term “ $C_2\text{-}C_{60}$ alkenyl group” as utilized herein refers to a monovalent hydrocarbon group having at least one carbon-carbon double bond in the middle or at the terminus of the $C_2\text{-}C_{60}$ alkyl group, and non-limiting examples thereof include an ethenyl group, a propenyl group, and a butenyl group. The term “ $C_2\text{-}C_{60}$ alkynylene group” as utilized herein refers to a divalent group having substantially the same structure as the $C_2\text{-}C_{60}$ alkenyl group.

The term “ $C_2\text{-}C_{60}$ alkynyl group” as utilized herein refers to a monovalent hydrocarbon group having at least one carbon-carbon triple bond in the middle or at the terminus of the $C_2\text{-}C_{60}$ alkyl group, and non-limiting examples thereof include an ethynyl group and a propynyl group. The term “ $C_1\text{-}C_{60}$ alkynylene group” as utilized herein refers to a divalent group having substantially the same structure as the $C_1\text{-}C_{60}$ alkynyl group.

The term “ $C_1\text{-}C_{60}$ alkoxy group” as utilized herein refers to a monovalent group represented by $-\text{OA}_{101}$ (wherein A_{101} is the $C_1\text{-}C_{60}$ alkyl group), and non-limiting examples thereof include a methoxy group, an ethoxy group, and an isopropoxy group.

The term “ $C_3\text{-}C_{10}$ cycloalkyl group” as utilized herein refers to a monovalent saturated hydrocarbon cyclic group having 3 to 10 carbon atoms, and non-limiting examples thereof include a cyclopropyl group, a cyclobutyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclooctyl group, an adamantanyl group, a norbornanyl group (or bicyclo[2.2.1]heptyl group), a bicyclo[1.1.1]pentyl group, a bicyclo[2.1.1]hexyl group, and a bicyclo[2.2.2]octyl group. The term “ $C_3\text{-}C_{10}$ cycloalkylene group” as utilized herein refers to a divalent group having substantially the same structure as the $C_3\text{-}C_{10}$ cycloalkyl group.

The term “ $C_1\text{-}C_{10}$ heterocycloalkyl group” as utilized herein refers to a monovalent cyclic group that further includes, in addition to a carbon atom, at least one heteroatom as a ring-forming atom and has 1 to 10 carbon atoms, and non-limiting examples thereof include a 1,2,3,4-oxatriazolidinyl group, a tetrahydrofuran group, and a tetrahydrothiophenyl group. The term “ $C_1\text{-}C_{10}$ heterocycloalkylene group” as utilized herein refers to a divalent group having substantially the same structure as the $C_1\text{-}C_{10}$ heterocycloalkyl group.

The term “ $C_3\text{-}C_{10}$ cycloalkenyl group” utilized herein refers to a monovalent cyclic group that has three to ten carbon atoms, at least one carbon-carbon double bond in the ring thereof, and no aromaticity, and non-limiting examples thereof include a cyclopentenyl group, a cyclohexenyl group, and a cycloheptenyl group. The term “ $C_3\text{-}C_{10}$ cycloalkenylene group” as utilized herein refers to a divalent group having substantially the same structure as the $C_3\text{-}C_{10}$ cycloalkenyl group.

The term “ $C_1\text{-}C_{10}$ heterocycloalkenyl group” as utilized herein refers to a monovalent cyclic group that has, in addition to a carbon atom, at least one heteroatom as a ring-forming atom, 1 to 10 carbon atoms, and at least one carbon-carbon double bond in the cyclic structure thereof. Non-limiting examples of the $C_1\text{-}C_{10}$ heterocycloalkenyl group include a 4,5-dihydro-1,2,3,4-oxatriazolyl group, a 2,3-dihydrofuran group, and a 2,3-dihydrothiophenyl group. The term “ $C_1\text{-}C_{10}$ heterocycloalkenylene group” as utilized herein refers to a divalent group having substantially the same structure as the $C_1\text{-}C_{10}$ heterocycloalkenyl group.

The term “C₆-C₆₀ aryl group” as utilized herein refers to a monovalent group having a carbocyclic aromatic system having six to sixty carbon atoms, and the term “C₆-C₆₀ arylene group” as utilized herein refers to a divalent group having a carbocyclic aromatic system having six to sixty carbon atoms. Non-limiting examples of the C₆-C₆₀ aryl group include a phenyl group, a pentalenyl group, a naphthyl group, an azulenyl group, an indacenyl group, an acenaphthyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysanyl group, a perylényl group, a pentaphenyl group, a heptalenyl group, a naphthacenyl group, a picenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, and an ovalenyl group. When the C₆-C₆₀ aryl group and the C₆-C₆₀ arylene group each include two or more rings, the rings may be condensed with each other.

The term “C₁-C₆₀ heteroaryl group” as utilized herein refers to a monovalent group having a heterocyclic aromatic system that has, in addition to a carbon atom, at least one heteroatom as a ring-forming atom, and 1 to 60 carbon atoms. The term “C₁-C₆₀ heteroarylene group” as utilized herein refers to a divalent group having a heterocyclic aromatic system that has, in addition to a carbon atom, at least one heteroatom as a ring-forming atom, and 1 to 60 carbon atoms. Non-limiting examples of the C₁-C₆₀ heteroaryl group include a pyridinyl group, a pyrimidinyl group, a pyrazinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, a benzoquinolinyl group, an isoquinolinyl group, a benzoisoquinolinyl group, a quinoxalinyl group, a benzoquinoxalinyl group, a quinazolinyl group, a benzoquinazolinyl group, a cinnolinyl group, a phenanthrolinyl group, a phthalazinyl group, and a naphthyridinyl group. When the C₁-C₆₀ heteroaryl group and the C₁-C₆₀ heteroarylene group each include two or more rings, the rings may be condensed with each other.

The term “monovalent non-aromatic condensed polycyclic group” as utilized herein refers to a monovalent group (for example, having 8 to 60 carbon atoms) having two or more rings condensed to each other, only carbon atoms as ring-forming atoms, and no aromaticity in its entire molecular structure. Non-limiting examples of the monovalent non-aromatic condensed polycyclic group include an indenyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, an indenophenanthrenyl group, and an indenoanthracenyl group. The term “divalent non-aromatic condensed polycyclic group” as utilized herein refers to a divalent group having substantially the same structure as a monovalent non-aromatic condensed polycyclic group.

The term “monovalent non-aromatic condensed heteropolycyclic group” as utilized herein refers to a monovalent group (for example, having 1 to 60 carbon atoms) having two or more rings condensed to each other, at least one heteroatom other than carbon atoms, as a ring-forming atom, and no aromaticity in its entire molecular structure. Non-limiting examples of the monovalent non-aromatic condensed heteropolycyclic group include a pyrrolyl group, a thiophenyl group, a furanyl group, an indolyl group, a benzoindolyl group, a naphthoindolyl group, an isoindolyl group, a benzoisoindolyl group, a naphthoisoindolyl group, a benzosilolyl group, a benzothiophenyl group, a benzofuranyl group, a carbazolyl group, a dibenzosilolyl group, a dibenzothiophenyl group, a dibenzofuranyl group, an azacarbazolyl group, an azafluorenyl group, an azadibenzosilolyl group, an azadibenzothiophenyl group, an azadibenzofuranyl group, a pyrazolyl group, an imidazolyl group, a triazolyl group, a tetrazolyl group, an oxazolyl group, an isoxa-

zolyl group, a thiazolyl group, an isothiazolyl group, an oxadiazolyl group, a thiadiazolyl group, a benzopyrazolyl group, a benzimidazolyl group, a benzoaxazolyl group, a benzothiazolyl group, a benzoaxadiazolyl group, a benzothiadiazolyl group, an imidazopyridinyl group, an imidazotriazinyl group, an imidazopyrazinyl group, an imidazopyridazinyl group, an indenocarbazolyl group, an indolocarbazolyl group, a benzofurocarbazolyl group, a benzothienocarbazolyl group, a benzosilolocarbazolyl group, a benzoindolocarbazolyl group, a benzocarbazolyl group, a benzonaphthofuranyl group, a benzonaphthothiophenyl group, a benzonaphthosilolyl group, a benzofurodibenzofuranyl group, a benzofurodibenzothiophenyl group, and a benzothienodibenzothiophenyl group. The term “divalent non-aromatic heterocondensed polycyclic group” as utilized herein refers to a divalent group having substantially the same structure as a monovalent non-aromatic heterocondensed polycyclic group.

The term “C₆-C₆₀ aryloxy group” as utilized herein refers to —OA₁₀₂ (wherein A₁₀₂ is a C₆-C₆₀ aryl group), and the term “C₆-C₆₀ arylthio group” as utilized herein indicates —SA₁₀₃ (wherein A₁₀₃ is a C₆-C₆₀ aryl group).

The term “R₁₀₂” as utilized herein refers to: deuterium (-D), —F, —Cl, —Br, —I, a hydroxyl group,

a cyano group, or a nitro group, a C₁-C₆₀ alkyl group, a C₂-C₆₀ alkenyl group, a C₂-C₆₀ alkynyl group, or a C₁-C₆₀ alkoxy group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C₃-C₆₀ carbocyclic group, a C₁-C₆₀ heterocyclic group, a C₆-C₆₀ aryloxy group, a C₆-C₆₀ arylthio group, —Si(Q₁₁)(Q₁₂)(Q₁₃), —N(Q₁₁)(Q₁₂), —B(Q₁₁)(Q₁₂), —C(=O)(Q₁₁), —S(=O)₂(Q₁₁), —P(=O)(Q₁₁)(Q₁₂), or any combination thereof,

a C₃-C₆₀ carbocyclic group, a C₁-C₆₀ heterocyclic group, a C₆-C₆₀ aryloxy group, or a C₆-C₆₀ arylthio group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C₁-C₆₀ alkyl group, a C₂-C₆₀ alkenyl group, a C₂-C₆₀ alkynyl group, a C₁-C₆₀ alkoxy group, a C₃-C₆₀ carbocyclic group, a C₁-C₆₀ heterocyclic group, a C₆-C₆₀ aryloxy group, a C₆-C₆₀ arylthio group, —Si(Q₂₁)(Q₂₂)(Q₂₃), —N(Q₂₁)(Q₂₂), —B(Q₂₁)(Q₂₂), —C(=O)(Q₂₁), —S(=O)₂(Q₂₁), —P(=O)(Q₂₁)(Q₂₂), or any combination thereof, or —Si(Q₃₁)(Q₃₂)(Q₃₃), —N(Q₃₁)(Q₃₂), —B(Q₃₁)(Q₃₂), —C(=O)(Q₃₁), —S(=O)₂(Q₃₁), or —P(=O)(Q₃₁)(Q₃₂),

Q₁ to Q₃, Q₁₁ to Q₁₃, Q₂₁ to Q₂₃ and Q₃₁ to Q₃₃ utilized herein may each independently be: hydrogen; deuterium; —F; —Cl; —Br; —I; a hydroxyl group; a cyano group; a nitro group; C₁-C₆₀ alkyl group; C₂-C₆₀ alkenyl group; C₂-C₆₀ alkynyl group; C₁-C₆₀ alkoxy group; or a C₃-C₆₀ carbocyclic group or a C₁-C₆₀ heterocyclic group, each unsubstituted or substituted with deuterium, —F, a cyano group, a C₁-C₆₀ alkyl group, a C₁-C₆₀ alkoxy group, a phenyl group, a biphenyl group, or any combination thereof.

The term “hetero atom” as utilized herein refers to any atom other than a carbon atom. Non-limiting examples of the heteroatom include O, S, N, P, Si, B, Ge, Se, and any combination thereof.

The term “Ph” as utilized herein refers to a phenyl group, the term “Me” as utilized herein refers to a methyl group, the term “Et” as utilized herein refers to an ethyl group, the term

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"ter-Bu" or "Bu" as utilized herein refers to a tert-butyl group, and the term "OMe" as utilized herein refers to a methoxy group.

The term "biphenyl group" as utilized herein refers to "a phenyl group substituted with a phenyl group." In other words, the "biphenyl group" is a substituted phenyl group having a C₆-C₆₀ aryl group as a substituent.

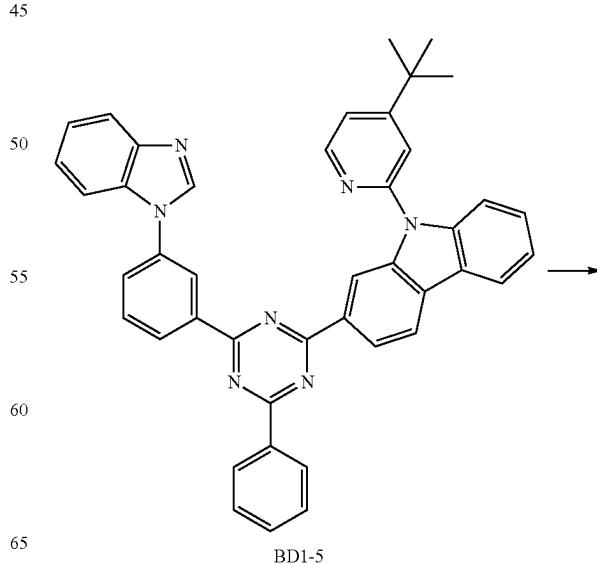
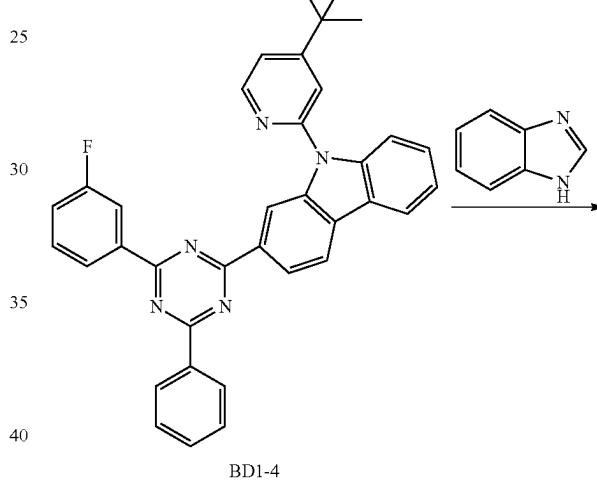
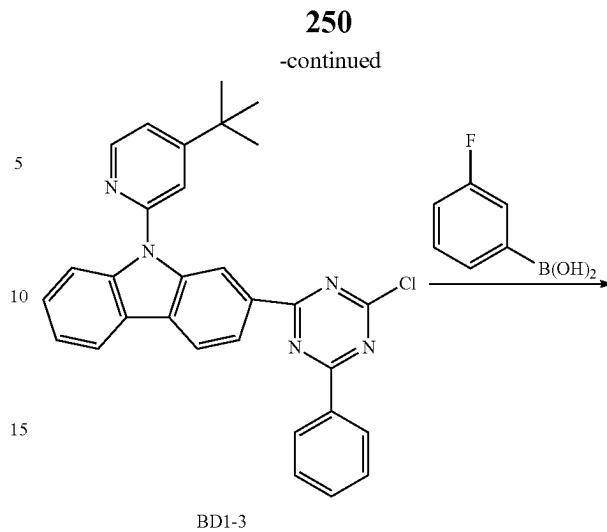
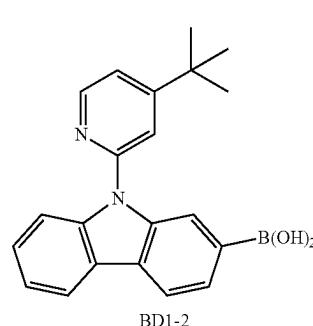
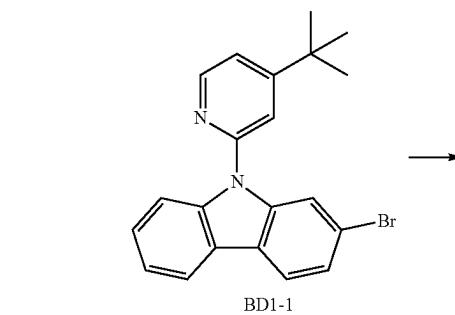
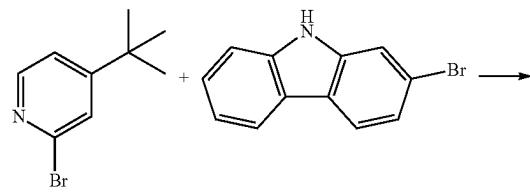
The term "terphenyl group" as utilized herein refers to "a phenyl group substituted with a biphenyl group". In other words, the "terphenyl group" is a substituted phenyl group having, as a substituent, a C₆-C₆₀ aryl group substituted with a C₆-C₆₀ aryl group.

* and * as utilized herein, unless defined otherwise, each refer to a binding site to a neighboring atom in a corresponding formula.

Hereinafter, a compound according to embodiments and a light-emitting device according to embodiments will be described in more detail with reference to Synthesis Examples and Examples. The wording "B" was utilized instead of "A" utilized in describing Synthesis Examples indicates that an identical molar equivalent of B was utilized in place of A.

EXAMPLES

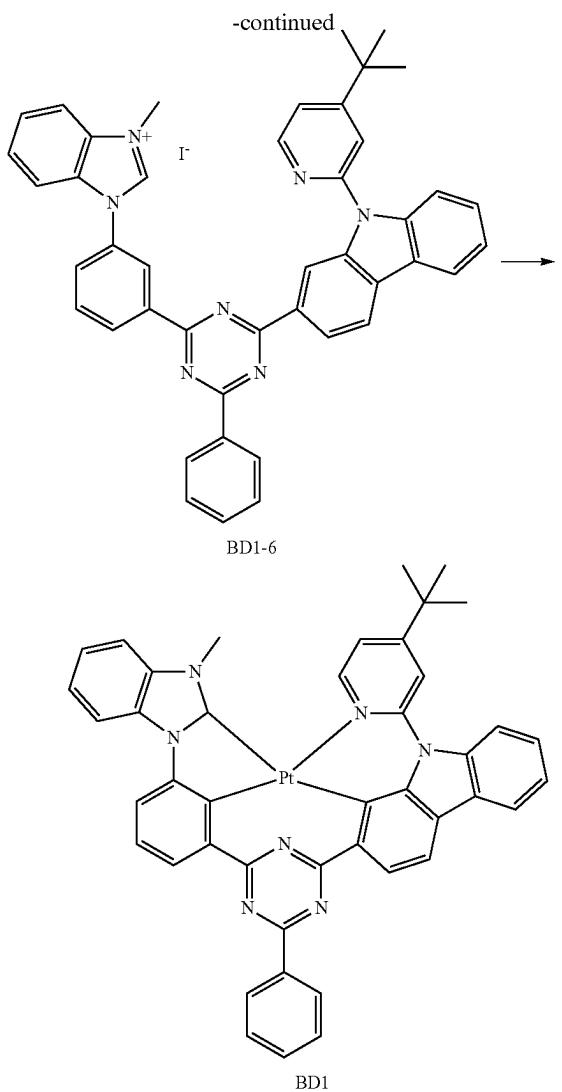
Synthesis Example 1: Synthesis of Compound BD1

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1) Synthesis of Intermediate Compound BD1-1

2-bromo-4-(tert-butyl)pyridine (1.0 eq), 2-bromo-9H-carbazole (1.2 eq), CuI (0.01 eq), K₂CO₃ (2.0 eq), and L-proline (0.02 eq) were dissolved in dimethyl sulfoxide (0.1M) and stirred at a temperature of 130° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD1-1 (yield: 65%).

2) Synthesis of Intermediate BD1-2

Intermediate compound BD1-1 was dissolved in THF (0.1M), n-butyllithium (2.5M in Hexane, 1.2 eq) was slowly added dropwise thereto at a temperature of -78° C., and stirred for 1 hour. Trimethyl borate (1.2 eq) was added to the reactants and stirred at room temperature for 24 hours. 2M HCl was added to the resultant, was stirred for 30 minutes, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic

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layer. The obtained organic layer was dried utilizing magnesium sulfate, concentrated, and recrystallized utilizing hexane to synthesize Intermediate compound BD1-2 (yield: 80%).

3) Synthesis of Intermediate Compound BD1-3

Intermediate compound BD1-2 (1.2 eq), 2,4-dichloro-6-phenyl-1,3,5-triazine (1.0 eq), Ph(PPh₃)₄ (0.02 eq), and K₂CO₃ (2.0 eq) were dissolved in toluene and stirred at a temperature of 120° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate BD1-3 (yield: 85%).

4) Synthesis of Intermediate Compound BD1-4

Intermediate compound BD1-3 (1.0 eq), 3-fluorophenylboronic acid (1.2 eq), Ph(PPh₃)₄ (0.02 eq), and K₂CO₃ (2.0 eq) were dissolved in toluene and stirred at a temperature of 120° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate BD1-4 (yield: 90%).

3) Synthesis of Intermediate Compound BD1-5

Intermediate compound BD1-4 (1.0 eq), 1H-benzo[d]imidazole (2.5 eq), and K₃PO₄ (2.0 eq) were dissolved in dimethyl sulfoxide (0.1M) and stirred at a temperature of 160° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD1-5 (yield: 67%).

3) Synthesis of Intermediate Compound BD1-6

Intermediate compound BD1-5 (1.0 eq) and iodomethane (3.0 eq) were dissolved in THF (1.0 M) and stirred at a temperature of 70° C. for 12 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate BD1-6 (yield: 75%).

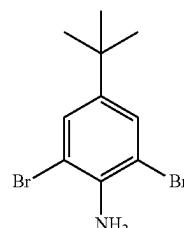
(5) Synthesis of Compound BD1

Intermediate compound BD1-6 (1.0 eq), dichloro(1,2-dicyclooctadiene)platinum (Pt(COD)Cl₂) (1.1 eq), and sodium acetate (2.0 eq) were dissolved in dioxane (0.1 M) and stirred at a temperature of 120° C. for 72 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium

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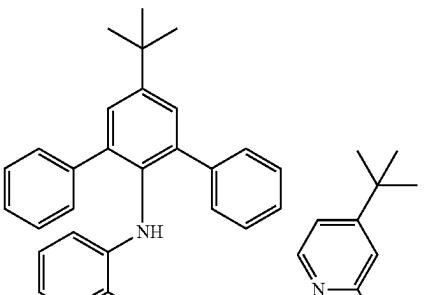
sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate BD1 (yield: 21%).

Synthesis Example 2: Synthesis of Compound BD10



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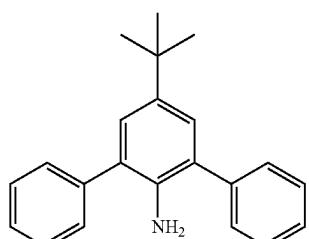
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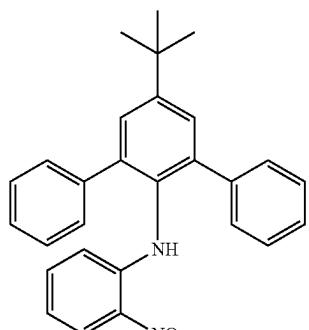
BD10-4

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BD10-1

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BD10-2

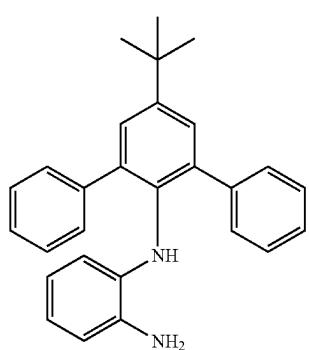
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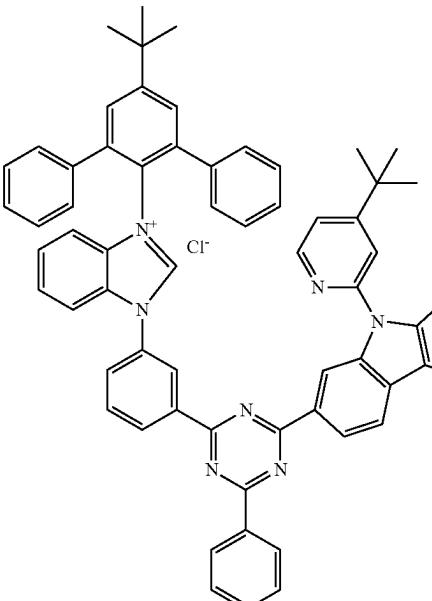
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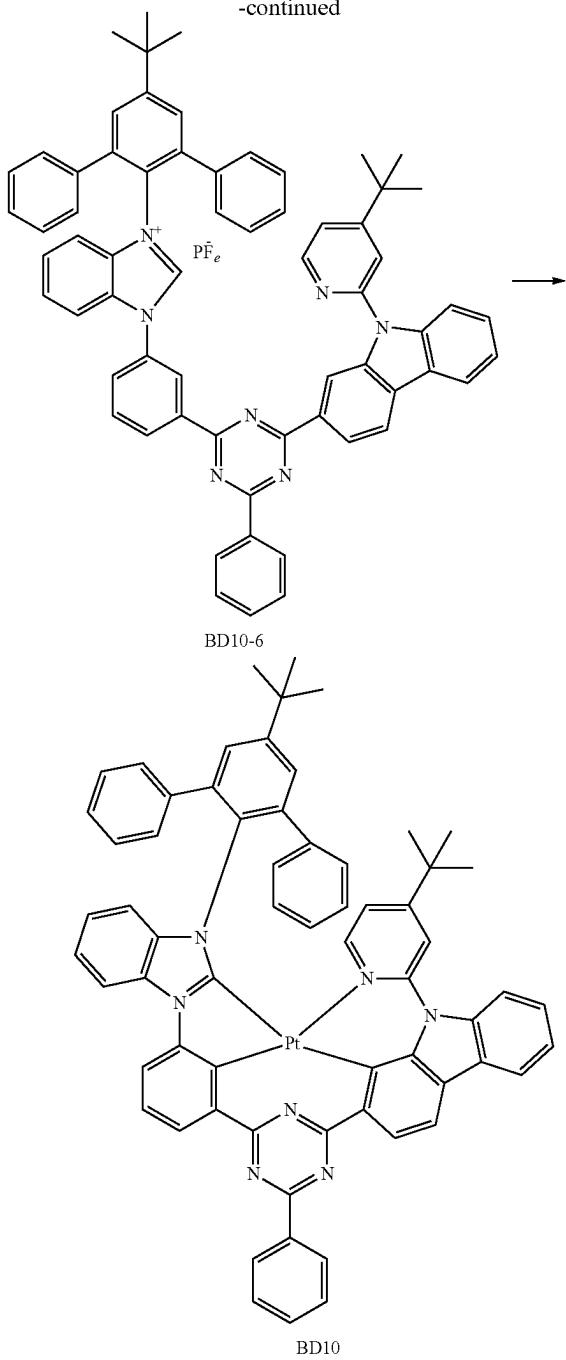
BD10-3



BD10-5

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1) Synthesis of Intermediate Compound BD0-1

2,6-dibromo-4-(tert-butyl)aniline, (1.0 eq), phenyl boronic acid (3.0 eq), $\text{Ph}(\text{PPh}_3)_4$ (0.02 eq), and K_2CO_3 (2.0 eq) were dissolved in toluene and stirred at a temperature of 120° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD10-4 (yield: 90%).

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2) Synthesis of Intermediate Compound BD10-2

Intermediate compound BD10-1 (1.0 eq), 1-iodo-2-nitrobenzene (1.2 eq), $\text{Pd}_2(\text{dba})_3$ (0.05 eq), Sphos (0.05 eq), and sodium tert-butoxide (2.0 eq) were dissolved in toluene (0.05 M) and stirred at a temperature of 120° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD10-2 (yield: 81%).

3) Synthesis of Intermediate Compound BD10-3

Intermediate compound BD10-2, Sn (2.5 eq), and HCl (2.0 eq) were dissolved in EtOH and stirred at a temperature of 80° C. for 12 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD10-3 (yield: 90%).

4) Synthesis of Intermediate Compound BD10-4

Intermediate compound BD10-3 (2.5 eq), and K_3PO_4 (2.0 eq) were dissolved in dimethyl sulfoxide (0.1M) and stirred at a temperature of 160° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD10-4 (yield: 77%).

3) Synthesis of Intermediate Compound BD10-5

Intermediate compound BD10-4 (1.0 eq), triethylorthoformate (50 eq), and HCl (25 eq) were dissolved and stirred at a temperature of 80° C. for 12 hours. The reaction mixture was cooled at room temperature, triethylorthoformate was removed, and then the mixture was subjected to an extraction process three times utilizing ethyl acetate and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD10-4 (yield: 92%).

5) Synthesis of Intermediate Compound BD10-6

Intermediate compound BD10-5 was dissolved in methanol (0.1M), distilled water was slowly added thereto and stirred, and then NH_4PF_6 (1.2 eq) was added thereto and stirred at room temperature for 12 hours. The resultant solid was filtered, washed three times with diethyl ether, and dried to synthesize Intermediate compound BD10-5 (yield: 94%).

6) Synthesis of Compound BD10

Intermediate compound BD10-6 (1.0 eq), dichloro(1,2-dicyclooctadiene)platinum ($\text{Pt}(\text{COD})\text{Cl}_2$) (1.1 eq), and

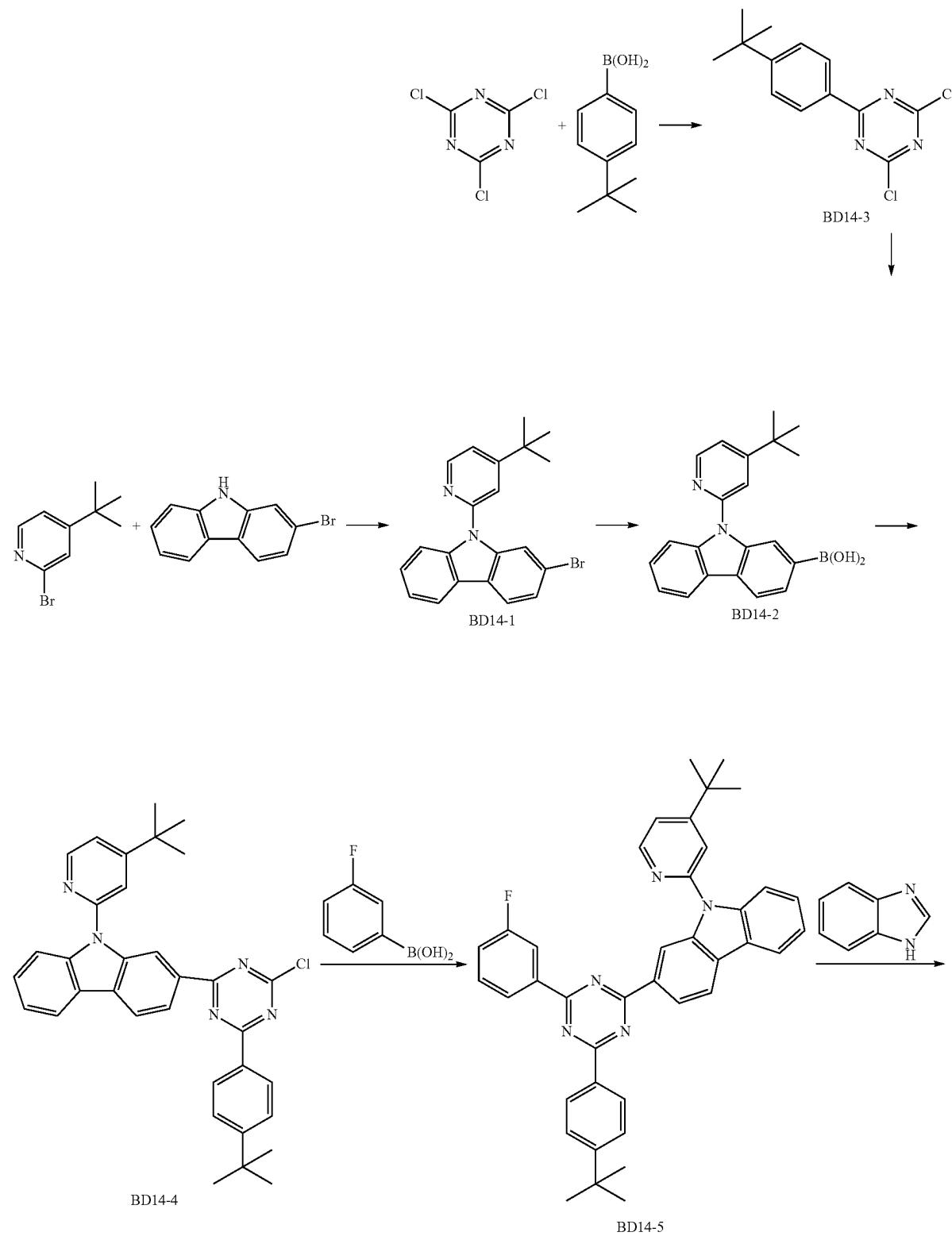
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sodium acetate (2.0 eq) were dissolved in dioxane (0.1 M) and stirred at a temperature of 120° C. for 72 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium

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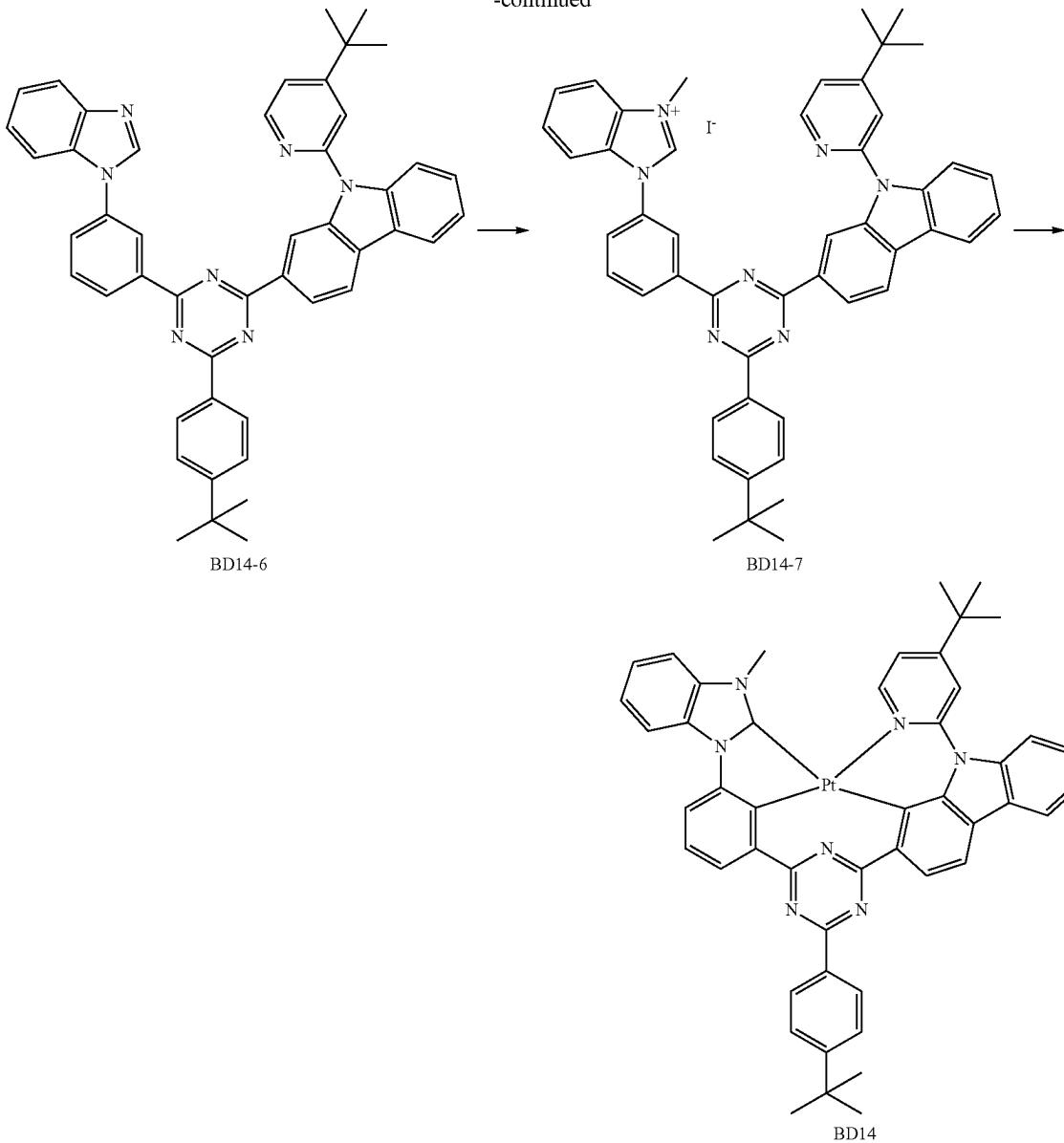
sulfate and concentrated, and column chromatography was utilized to synthesize Compound BD10 (yield: 21%).

Synthesis Example 3: Synthesis of Compound
BD14



259**260**

-continued



1) Synthesis of Intermediate Compound BD14-1

2-bromo-4-(tert-butyl)pyridine (1.0 eq), 2-bromo-9H-carbazole (1.2 eq), CuI (0.01 eq), K_2N_3 (2.0 eq), and L-proline (0.02 eq) were dissolved in dimethyl sulfoxide (0.1M) and stirred at a temperature of 130° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD14-1 (yield: 65%).

2) Synthesis of Intermediate Compound BD14-2

Intermediate compound BD14-1 was dissolved in THF (0.1M), n-butyllithium (2.5M in Hexane, 1.2 eq) was slowly added dropwise thereto at a temperature of -78 OC and

stirred for 1 hour. Trimethyl borate (1.2 eq) was added to the reaction mixture and stirred at room temperature for 24 hours. 2M HCl was added to the resultant, was stirred for 30 minutes, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried utilizing magnesium sulfate, concentrated, and recrystallized utilizing hexane to synthesize Intermediate compound BD14-2 (yield: 80%).

3) Synthesis of Intermediate Compound BD14-3

2,4,6-trichloro-1,3,5-triazine (1.0 eq), 4-tert-butylphenylboronic acid (1.2 eq), $Ph(PPh_3)_4$ (0.02 eq), and K_2CO_3 (2.0 eq) were dissolved in toluene and stirred at a temperature of 120° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to

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obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD14-3 (yield: 92%).

4) Synthesis of Intermediate Compound BD14-4

Intermediate compound BD14-2 (1.2 eq), Intermediate compound BD14-3 (1.0 eq), Ph(PPh₃)₄ (0.02 eq), and K₂CO₃ (2.0 eq) were dissolved in toluene and stirred at a temperature of 120° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD14-4 (yield: 65%).

3) Synthesis of Intermediate Compound BD14-5

Intermediate compound BD14-4 (1.0 eq), 3-fluorophenylboronic acid (1.2 eq), Ph(PPh₃)₄ (0.02 eq), and K₂CO₃ (2.0 eq) were dissolved in Toluene and stirred at a temperature of 120° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD14-5 (yield: 55%).

6) Synthesis of Intermediate Compound BD14-6

Intermediate compound BD14-5 (1.0 eq), 1H-benzo[d]imidazole (2.5 eq), and K₃PO₄ (2.0 eq) were dissolved in

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dimethyl sulfoxide (0.1M) and stirred at a temperature of 160° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD14-6 (yield: 88%).

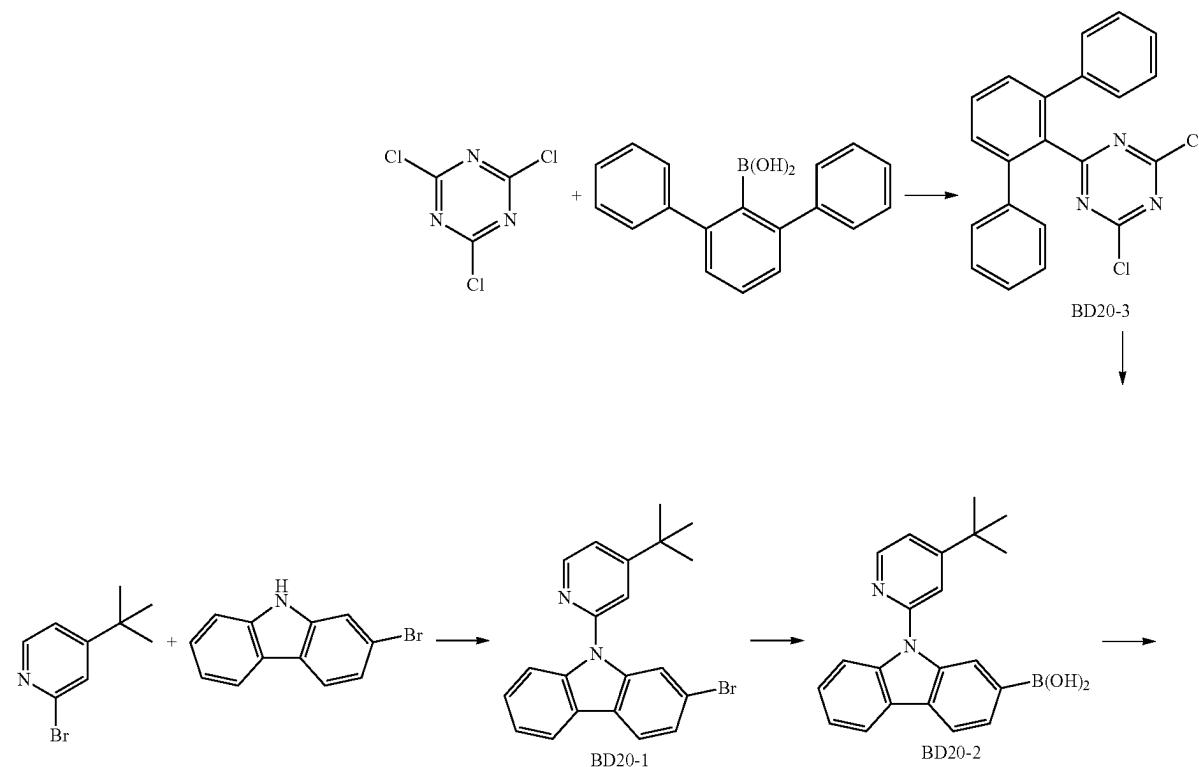
7) Synthesis of Intermediate Compound BD14-7

Intermediate compound BD14-6 (1.0 eq) and iodomethane (3.0 eq) were dissolved in THF (1.0 M) and stirred at a temperature of 70° C. for 12 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD14-7 (yield: 70%).

8) Synthesis of Compound BD14

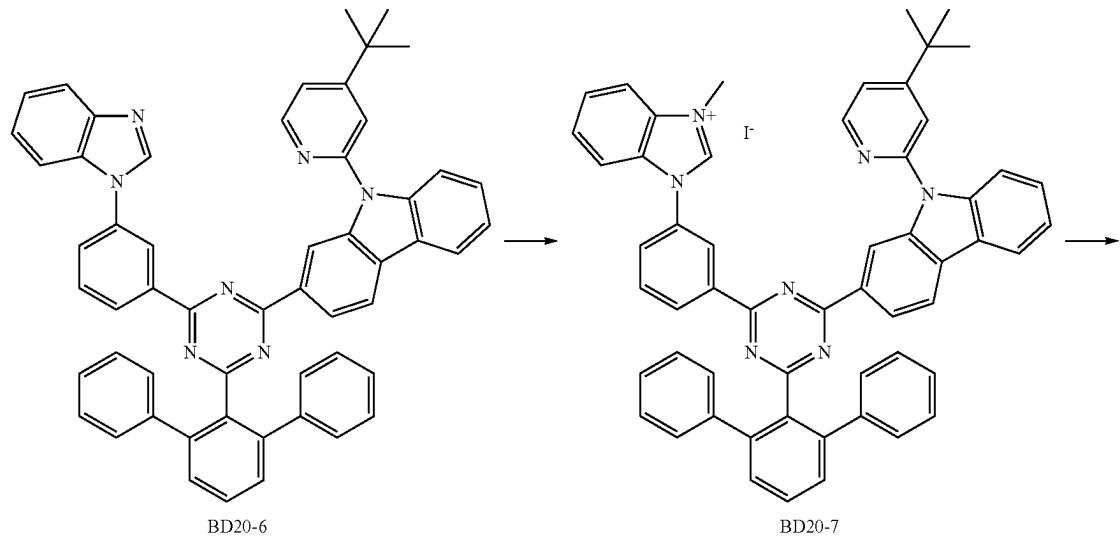
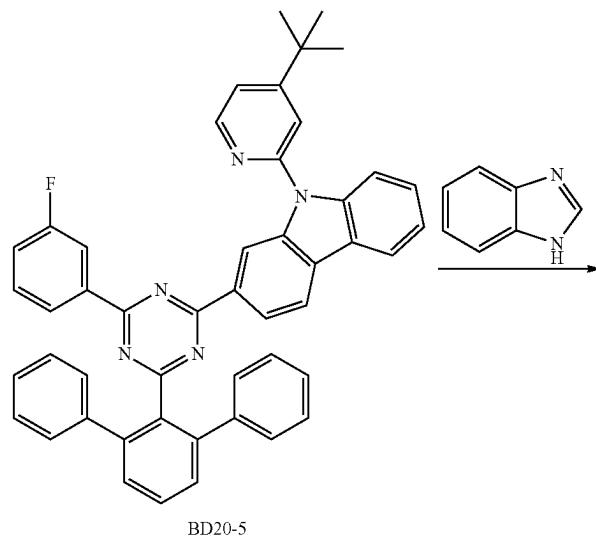
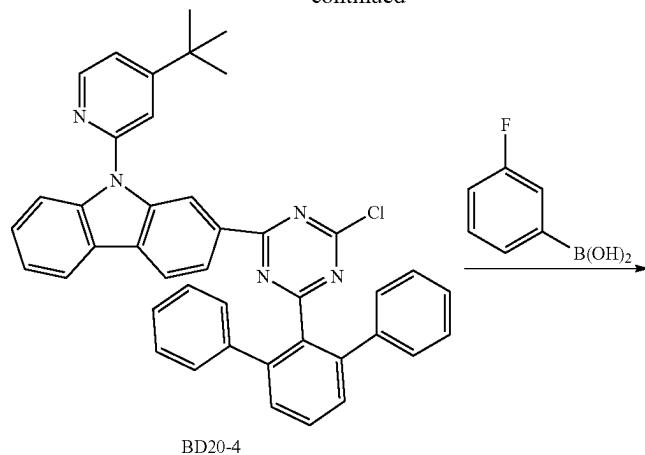
Intermediate compound BD14-7 (1.0 eq), dichloro(1,2-dicyclooctadiene)platinum (Pt(COD)Cl₂) (1.1 eq), and sodium acetate (2.0 eq) were dissolved in dioxane (0.1 M) and stirred at a temperature of 120° C. for 72 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Compound BD14 (yield: 30%).

Synthesis Example 4: Synthesis of Compound BD20

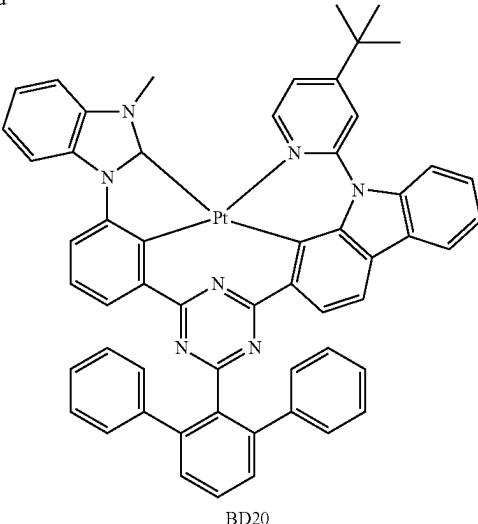


263**264**

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1) Synthesis of Intermediate Compound BD20-1

2-bromo-4-(tert-butyl)pyridine (1.0 eq), 2-bromo-9H-carbazole (1.2 eq), CuI (0.01 eq), K₂CO₃ (2.0 eq), and L-proline (0.02 eq) were dissolved in dimethyl sulfoxide (0.1M) and stirred at a temperature of 130° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD20-1 (yield: 70%).

2) Synthesis of Intermediate Compound BD20-2

Intermediate compound BD20-1 was dissolved in THF (0.1M), n-butyllithium (2.5M in Hexane, 1.2 eq) was slowly added dropwise thereto at a temperature of -78° C. and stirred for 1 hour. Trimethyl borate (1.2 eq) was added to the reaction mixture and stirred at room temperature for 24 hours. 2M HCl was added to the resultant and stirred for 30 minutes, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried utilizing magnesium sulfate, concentrated, and recrystallized utilizing hexane to synthesize Intermediate compound BD20-2 (yield: 85%).

3) Synthesis of Intermediate Compound BD20-3

2,4,6-trichloro-1,3,5-triazine (1.0 eq), [1,1':3',1"-terphenyl]-2'-ylboronic acid (1.2 eq), Ph(PPh₃)₄ (0.02 eq), and K₂CO₃ (2.0 eq) were dissolved in toluene and stirred at a temperature of 120° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD20-3 (yield: 88%).

4) Synthesis of Intermediate Compound BD20-4

Intermediate compound BD20-2 (1.2 eq), Intermediate compound BD20-3 (1.0 eq), Ph(PPh₃)₄ (0.02 eq), and

K₂CO₃ (2.0 eq) were dissolved in toluene and stirred at a temperature of 120° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD20-3 (yield: 71%).

5) Synthesis of Intermediate Compound BD20-5

Intermediate compound BD14-4 (1.0 eq), 3-fluorophenylboronic acid (1.2 eq), Ph(PPh₃)₄ (0.02 eq), and K₂CO₃ (2.0 eq) were dissolved in toluene and stirred at a temperature of 120° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD20-4 (yield: 62%).

6) Synthesis of Intermediate Compound BD20-6

Intermediate compound BD20-5 (1.0 eq), 1H-benzo[d]imidazole (2.5 eq), and K₃PO₄ (2.0 eq) were dissolved in dimethyl sulfoxide (0.1M) and stirred at a temperature of 160° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD20-6 (yield: 80%).

6) Synthesis of Intermediate Compound BD20-7

Intermediate compound BD20-6 (1.0 eq) and iodomethane (3.0 eq) were dissolved in THF (1.0 M) and stirred at a temperature of 70° C. for 12 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was

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dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD20-7 (yield: 71%).

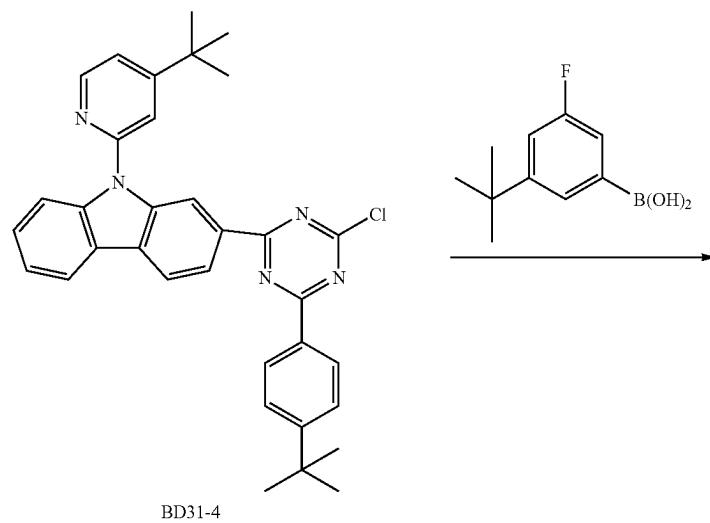
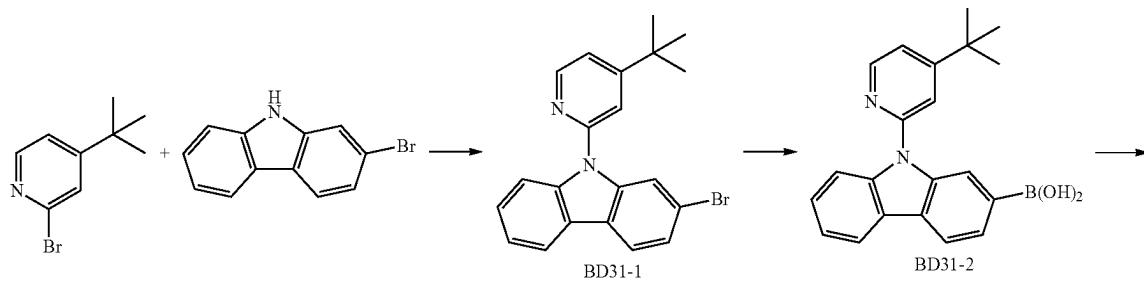
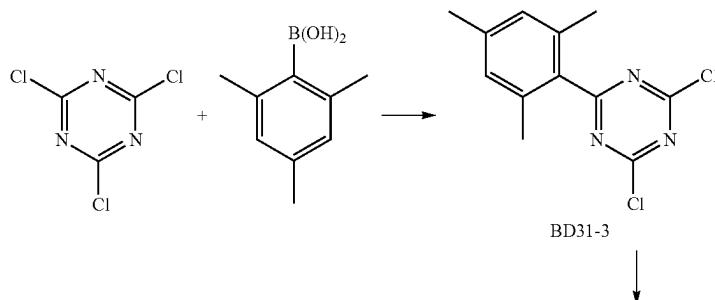
8) Synthesis of Compound BD20

Intermediate compound BD14-7 (1.0 eq), dichloro(1,2-dicyclooctadiene)platinum ($\text{Pt}(\text{COD})\text{Cl}_2$) (1.1 eq), and sodium acetate (2.0 eq) were dissolved in dioxane (0.1 M) and stirred at a temperature of 120° C. for 72 hours. The

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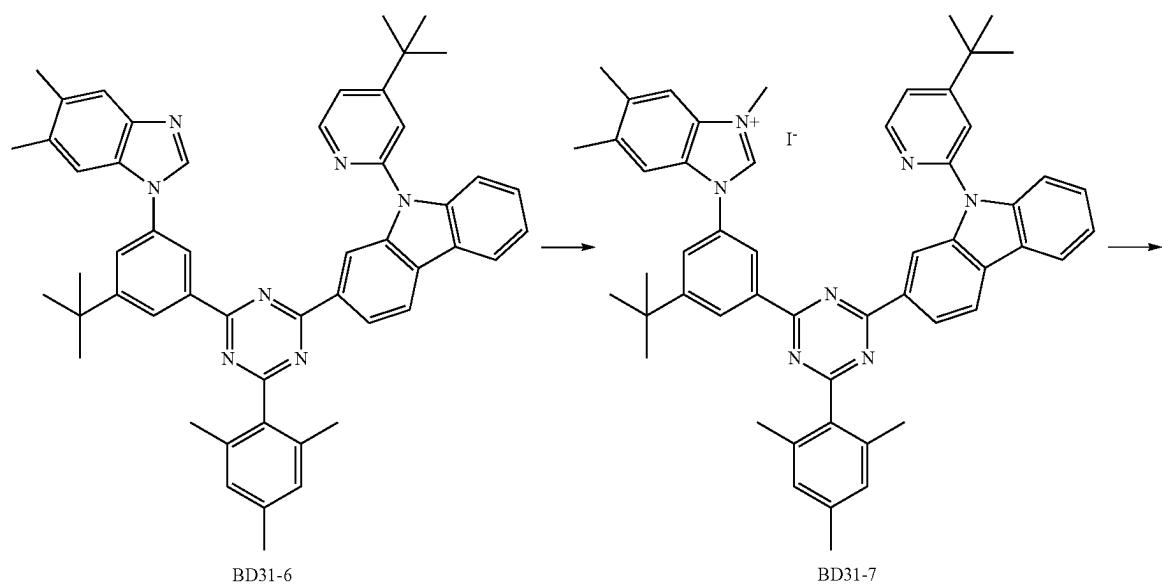
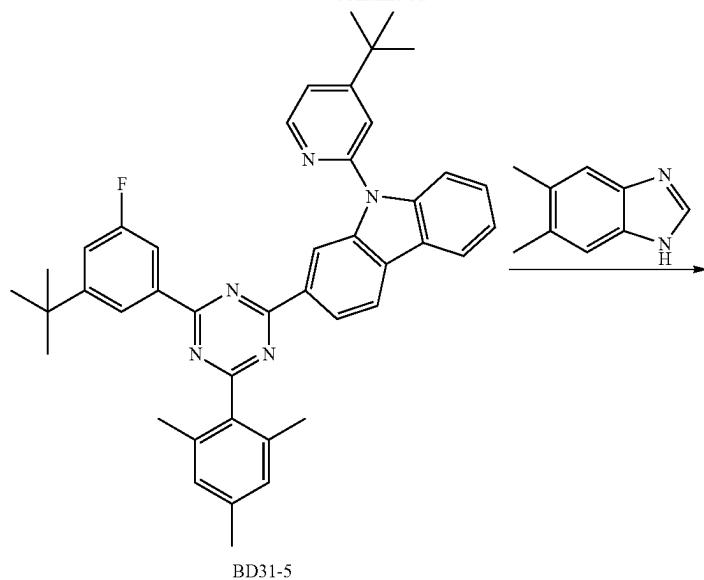
reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Compound BD20 (yield: 33%).

Synthesis Example 5: Synthesis of Compound BD31

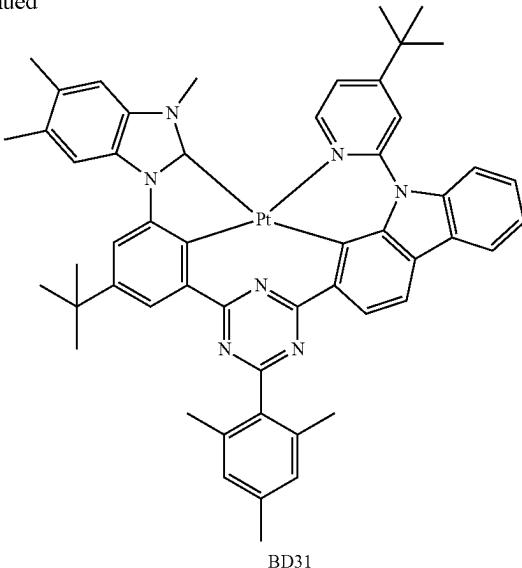


269**270**

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1) Synthesis of Intermediate Compound BD31-1

2-bromo-4-(tert-butyl)pyridine (1.0 eq), 2-bromo-9H-carbazole (1.2 eq), CuI (0.01 eq), K₂CO₃ (2.0 eq), and L-proline (0.02 eq) were dissolved in dimethyl sulfoxide (0.1M) and stirred at a temperature of 130° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate BD31-1 (yield: 72%).

2) Synthesis of Intermediate Compound BD31-2

Intermediate compound BD31-1 was dissolved in THF (0.1M), n-butyllithium (2.5M in Hexane, 1.2 eq) was slowly added dropwise thereto at a temperature of -78° C., and stirred for 1 hour. Trimethyl borate (1.2 eq) was added to the reaction mixture and stirred at room temperature for 24 hours. 2M HCl was added to the resultant and stirred for 30 minutes, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried utilizing magnesium sulfate, concentrated, and recrystallized utilizing hexane to synthesize Intermediate compound BD31-2 (yield: 80%).

3) Synthesis of Intermediate Compound BD31-3

2,4,6-trichloro-1,3,5-triazine (1.0 eq), mesitylboronic acid (1.2 eq), Ph(PPh₃)₄ (0.02 eq), and K₂CO₃ (2.0 eq) were dissolved in toluene and stirred at a temperature of 120° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate BD31-3 (yield: 80%).

4) Synthesis of Intermediate Compound BD31-4

Intermediate compound BD31-2 (1.2 eq), Intermediate compound BD31-3 (1.0 eq), Ph(PPh₃)₄ (0.02 eq), and

K₂CO₃ (2.0 eq) were dissolved in toluene and stirred at a temperature of 120° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate BD31-4 (yield: 72%).

5) Synthesis of Intermediate Compound BD31-5

Intermediate compound BD31-4 (1.0 eq), 3-fluorophenylboronic acid (1.2 eq), Ph(PPh₃)₄ (0.02 eq), and K₂CO₃ (2.0 eq) were dissolved in toluene and stirred at a temperature of 120° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD31-5 (yield: 68%).

6) Synthesis of Intermediate Compound BD31-6

Intermediate compound BD31-5 (1.0 eq), 1H-benzo[d]imidazole (2.5 eq), and K₃PO₄ (2.0 eq) were dissolved in dimethyl sulfoxide (0.1M) and stirred at a temperature of 160° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate BD31-6 (yield: 82%).

7) Synthesis of Intermediate Compound BD31-7

Intermediate compound BD31-6 (1.0 eq) and iodomethane (3.0 eq) were dissolved in THF (1.0 M) and stirred at a temperature of 70° C. for 12 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water

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to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate BD31-7 (yield: 76%).

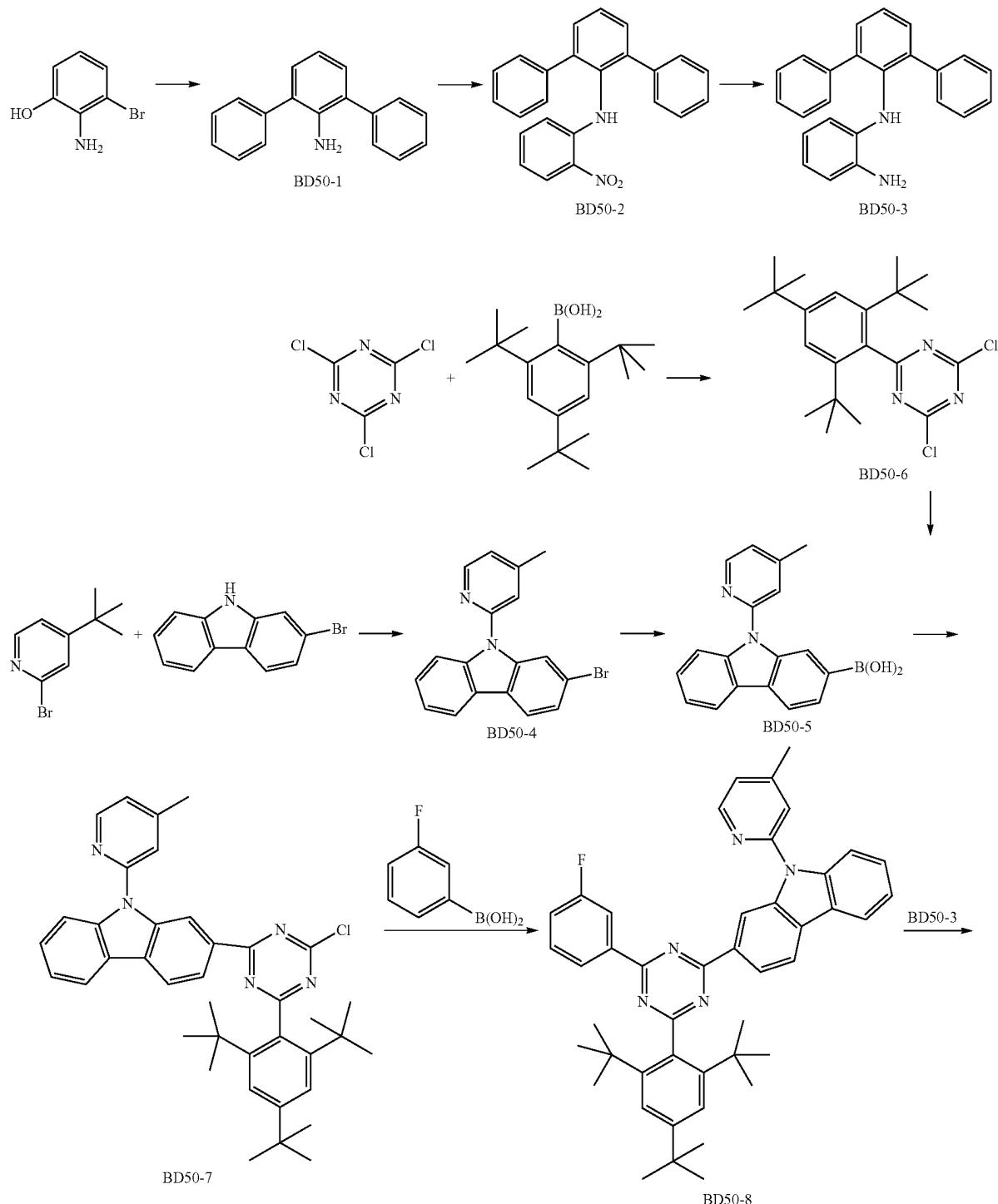
8) Synthesis of Compound BD31

Intermediate compound BD31-7 (1.0 eq), dichloro(1,2-dicyclooctadiene)platinum ($\text{Pt}(\text{COD})\text{Cl}_2$) (1.1 eq), and sodium acetate (2.0 eq) were dissolved in dioxane (0.1 M)

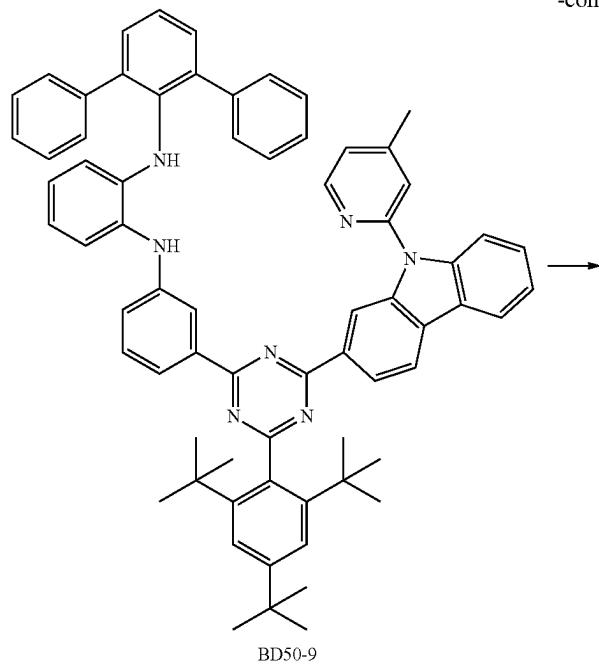
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and stirred at a temperature of 120° C. for 72 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Compound BD31 (yield: 21%).

Synthesis Example 6: Synthesis of Compound 50

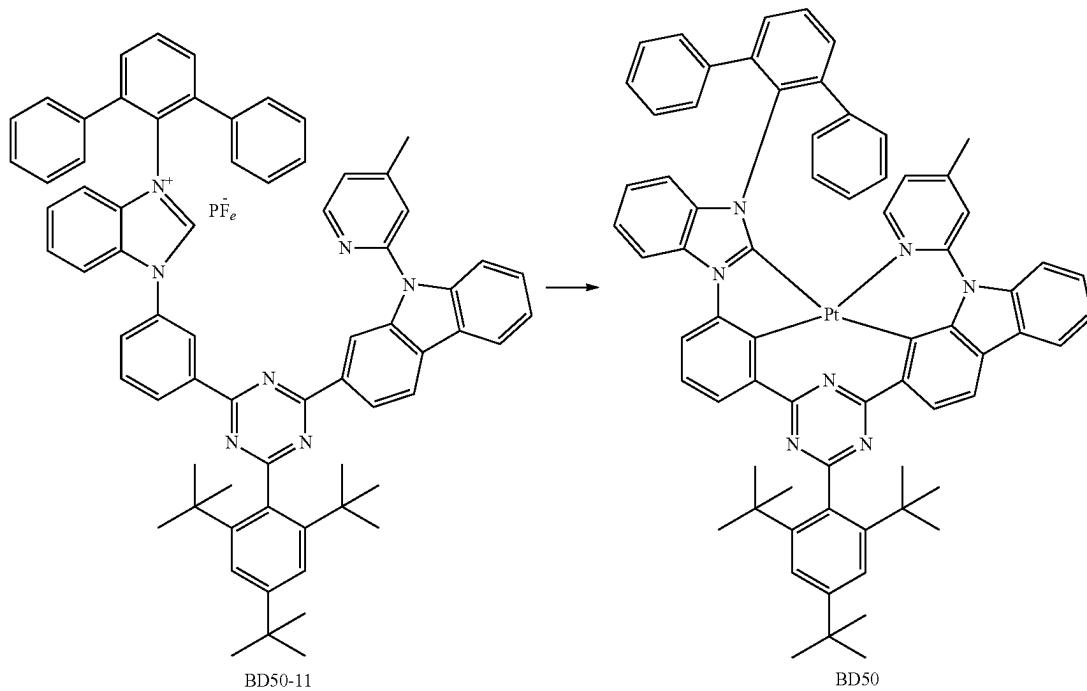
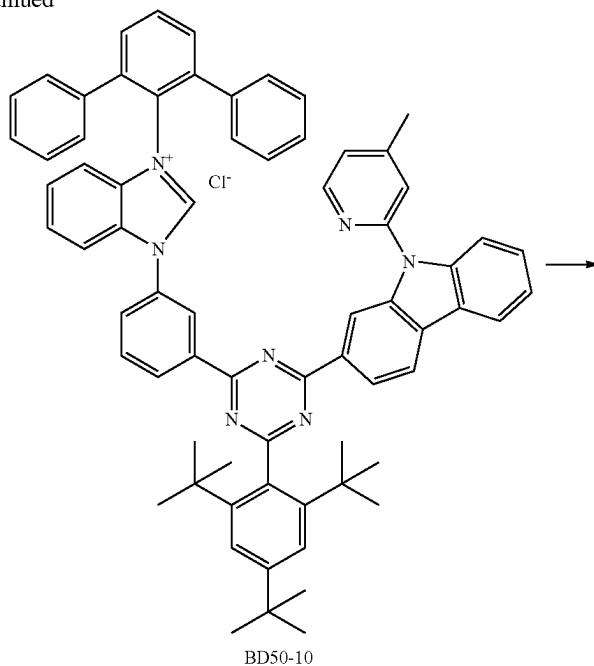


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1) Synthesis of Intermediate Compound BD50-1

2,6-dibromoaniline (1.0 eq), phenyl boronic acid (3.0 eq), $\text{Ph}(\text{PPh}_3)_4$ (0.02 eq), and K_2CO_3 (2.0 eq) were dissolved in toluene and stirred at a temperature of 120°C . for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was

utilized to synthesize Intermediate compound BD50-1 (yield: 91%).

2) Synthesis of Intermediate Compound BD50-2

Intermediate compound BD50-1 (1.0 eq), 1-iodo-2-nitrobenzene (1.2 eq), $\text{Pd}_2(\text{dba})_3$ (0.05 eq), Sphos (0.05 eq), and sodium tert-butoxide (2.0 eq) were dissolved in toluene (0.05 M) and stirred at a temperature of 120°C . for 24 hours. The reaction mixture was cooled at room temperature, and

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then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD50-2 (yield: 80%).

3) Synthesis of Intermediate Compound BD50-3

Intermediate compound BD50-2, Sn (2.5 eq), and HCl (2.0 eq) were dissolved in EtOH and stirred at a temperature of 80° C. for 12 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD50-3 (yield: 88%).

4) Synthesis of Intermediate Compound BD50-4

2-bromo-4-(tert-butyl)pyridine (1.0 eq), 2-bromo-9H-carbazole (1.2 eq), CuI (0.01 eq), K₂CO₃ (2.0 eq), and L-proline (0.02 eq) were dissolved in dimethyl sulfoxide (0.1M) and stirred at a temperature of 130° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD50-4 (yield: 68

5) Synthesis of Intermediate Compound BD50-5

Intermediate compound BD50-4 was dissolved in THF (0.1M), n-butyllithium (2.5M in hexane, 1.2 eq) was slowly added dropwise thereto at a temperature of -78° C. and stirred for 1 hour. Trimethyl borate (1.2 eq) was added to the reaction mixture and stirred at room temperature for 24 hours. 2M HCl was added to the resultant and stirred for 30 minutes, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried utilizing magnesium sulfate, concentrated, and recrystallized utilizing hexane to synthesize Intermediate compound BD50-2 (yield: 85%).

6) Synthesis of Intermediate Compound BD50-6

2,4,6-trichloro-1,3,5-triazine (1.0 eq), (2,4,6-tri-tert-butylphenyl)boronic acid (1.2 eq), Ph(PPh₃)₄ (0.02 eq), and K₂CO₃ (2.0 eq) were dissolved in toluene and stirred at a temperature of 120° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer

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was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD50-6 (yield: 22%).

7) Synthesis of Intermediate Compound BD50-7

Intermediate compound BD50-6 (1.2 eq), Intermediate compound BD50-5 (1.0 eq), Ph(PPh₃)₄ (0.02 eq), and K₂CO₃ (2.0 eq) were dissolved in toluene and stirred at a temperature of 120° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD50-7 (yield: 72%).

8) Synthesis of Intermediate Compound BD50-8

Intermediate compound BD50-7 (1.0 eq), 3-fluorophenylboronic acid (1.2 eq), Ph(PPh₃)₄ (0.02 eq), and K₂CO₃ (2.0 eq) were dissolved in toluene and stirred at a temperature of 120° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD50-8 (yield: 70%).

9) Synthesis of Intermediate Compound BD50-9

Intermediate compound BD50-8 (1.0 eq), Intermediate compound BD60-3 (1.2 eq), and K₃PO₄ (2.0 eq) were dissolved in dimethyl sulfoxide (0.1M) and stirred at a temperature of 160° C. for 24 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Intermediate compound BD50-9 (yield: 70%).

55 10) Synthesis of Intermediate Compound BD50-10

Intermediate compound BD50-9 (1.0 eq), triethylorthoformate (50 eq), and HCl (25 eq) were dissolved and stirred at a temperature of 80° C. for 12 hours. The reaction mixture was cooled at room temperature, triethylorthoformate was removed, and then the reaction mixture was subjected to an extraction process three times utilizing ethyl acetate and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated,

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and column chromatography was utilized to synthesize Intermediate compound BD50-10 (yield: 88%).

11) Synthesis of Intermediate Compound BD50-11

Intermediate compound BD50-10 was dissolved in methanol (0.1M), distilled water was slowly added thereto and stirred, and then NH₄PF₆ (1.2 eq) was added thereto and stirred at room temperature for 12 hours. The resultant solid was filtered, washed three times with diethyl ether, and dried to synthesize Intermediate compound BD50-11 (yield: 96%).

12) Synthesis of Compound BD50

Intermediate compound BD50-11 (1.0 eq), dichloro(1,2-dicyclooctadiene)platinum (Pt(COD)Cl₂) (1.1 eq), and sodium acetate (2.0 eq) were dissolved in dioxane (0.1 M) and stirred at a temperature of 120° C. for 72 hours. The reaction mixture was cooled at room temperature, and then subjected to an extraction process three times utilizing dichloromethane and water to obtain an organic layer. The obtained organic layer was dried by utilizing magnesium sulfate and concentrated, and column chromatography was utilized to synthesize Compound BD50 (yield: 22%).

¹H NMR and MS/FAB of the compounds synthesized according to Synthesis Examples 1 to 6 are shown in Table 1. Synthesis methods for other compounds than the compounds shown in Table 1 may be easily recognized by those skilled in the technical field by referring to the synthesis paths and source material materials described above.

TABLE 1

Compound	H NMR(δ)	MS/FAB	
		Calc	found
BD1	8.55 (d, 2H), 8.36 (d, 2H), 8.31 (d, 1H), 7.94-7.91 (m, 3H), 7.50-7.40 (m, 8H), 7.16 (t, 1H), 7.00 (d, 1H), 6.90 (t, 1H), 6.63 (t, 1H), 6.53 (d, 1H), 3.02 (s, 3H), 1.32 (s, 9H)	855.89	855.25
BD10	8.52 (d, 2H), 8.37 (d, 2H), 8.30 (d, 1H), 7.99 (s, 2H), 7.94 (m, 3H), 7.50-7.35 (m, 14H), 7.14-7.08 (m, 7H), 6.95 (d, 2H), 1.35 (s, 9H), 1.30 (s, 9H)	1126.26	1125.39
BD14	8.54 (d, 2H), 8.35 (d, 2H), 8.32 (d, 1H), 7.98-7.90 (m, 3H), 7.52-7.41 (m, 7H), 7.20 (t, 1H), 7.01 (d, 1H), 6.94 (t, 1H), 6.64 (t, 1H), 6.51 (d, 1H), 3.02 (s, 3H), 1.32 (s, 9H), 1.28 (s, 9H)	912.00	911.31
BD20	8.54 (d, 2H), 8.35 (d, 2H), 8.32 (d, 1H), 7.98-7.90 (m, 3H), 7.52-7.41 (m, 6H), 7.20 (t, 1H), 7.14-7.08 (m, 10H), 7.01 (d, 1H), 6.94 (t, 1H), 6.64 (t, 1H), 6.51 (d, 1H), 3.02 (s, 3H), 1.32 (s, 9H)	1008.09	1007.31
BD31	8.55 (d, 2H), 8.36 (d, 2H), 8.31 (d, 1H), 7.94-7.91 (m, 3H), 7.50-7.40 (m, 4H), 6.90 (t, 1H), 6.63 (t, 1H), 6.53 (d, 1H), 3.02 (s, 3H), 2.94 (s, 9H), 2.04 (s, 6H), 1.37 (s, 9H), 1.32 (s, 9H)	982.13	981.39
BD50	8.52 (d, 2H), 8.37 (d, 2H), 8.30 (d, 1H), 7.99 (s, 2H), 7.94 (m, 3H), 7.50-7.35 (m, 12H), 7.14-7.08 (m, 7H), 6.95 (d, 2H), 1.35 (s, 3H), 1.30 (s, 27H)	1196.40	1195.47

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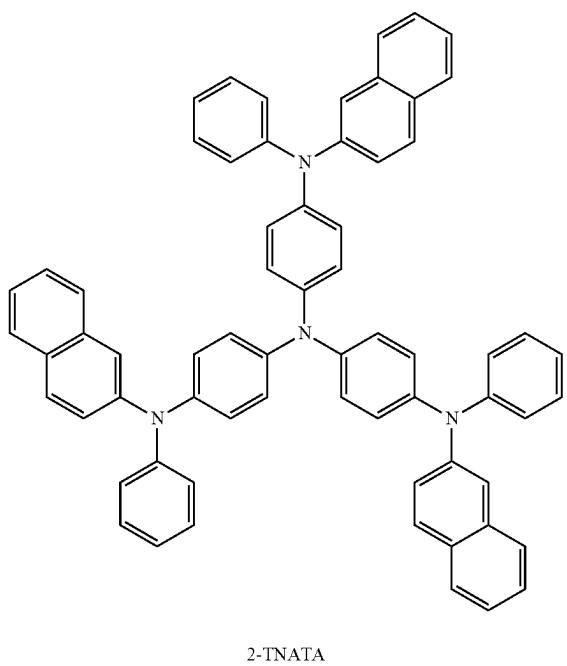
Example 1

As an anode, a 15 Ω/cm² (1,200 Å) ITO glass substrate (a product of Corning Inc.) was cut to a size of 50 mm×50 mm×0.7 mm, sonicated with isopropyl alcohol and pure water each for 5 minutes, and then cleaned by exposure to ultraviolet rays and ozone for 30 minutes. The resultant glass substrate was loaded onto a vacuum deposition apparatus.

2-TNATA was vacuum-deposited on the anode to form a hole injection layer having a thickness of 600 Å, and 4,4'-bis[N-(1-naphthyl)-N-phenylamino] biphenyl (hereinafter referred to as NPB) was vacuum-deposited on the hole injection layer to form a hole transport layer having a thickness of 300 Å.

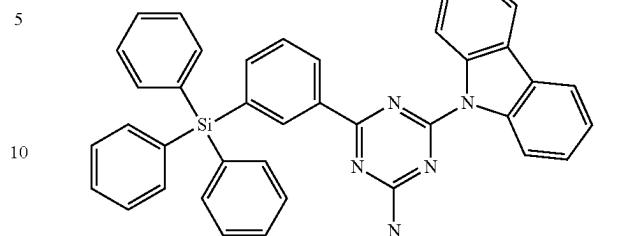
Compound BD1 (first compound), compound DFD2 (fourth compound), compound ETH66 (second compound), and compound HTH29 (third compound) were vacuum-deposited on the hole transport layer at a weight ratio of 1:0.5:3:6 to form an emission layer having a thickness of 400 Å.

Compound ETH2 was vacuum-deposited on the emission layer to form a hole blocking layer having a thickness of 50 Å, Alq₃ was vacuum-deposited on the hole blocking layer to form an electron transport layer having a thickness of 300 Å, LiF was vacuum-deposited on the electron transport layer to form an electron injection layer having a thickness of 10 Å, and then, Al was vacuum-deposited thereon to form a cathode having a thickness of 3,000 Å, thereby completing the manufacture of an organic light-emitting device.

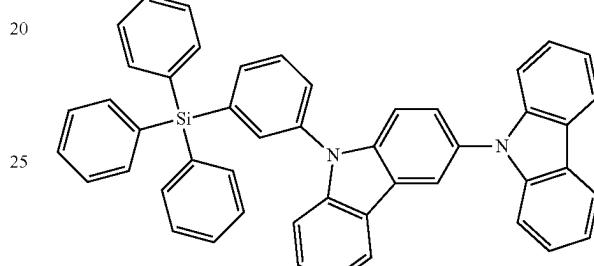
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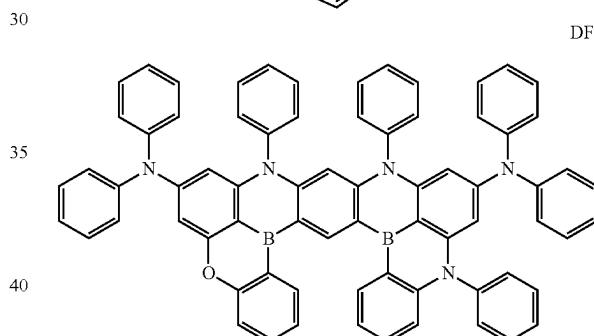
ETH66



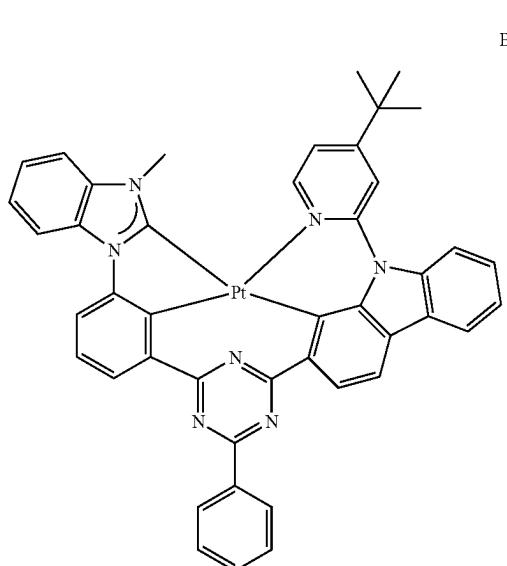
HTH29



DFD2



ETH2



Examples 2 to 6

Organic light-emitting devices were manufactured in substantially the same manner as in Example 1, except that, in forming an emission layer, compounds shown in Table 2 were utilized as a first compound, a fourth compound, a second compound, and a third compound.

Evaluation Example 1

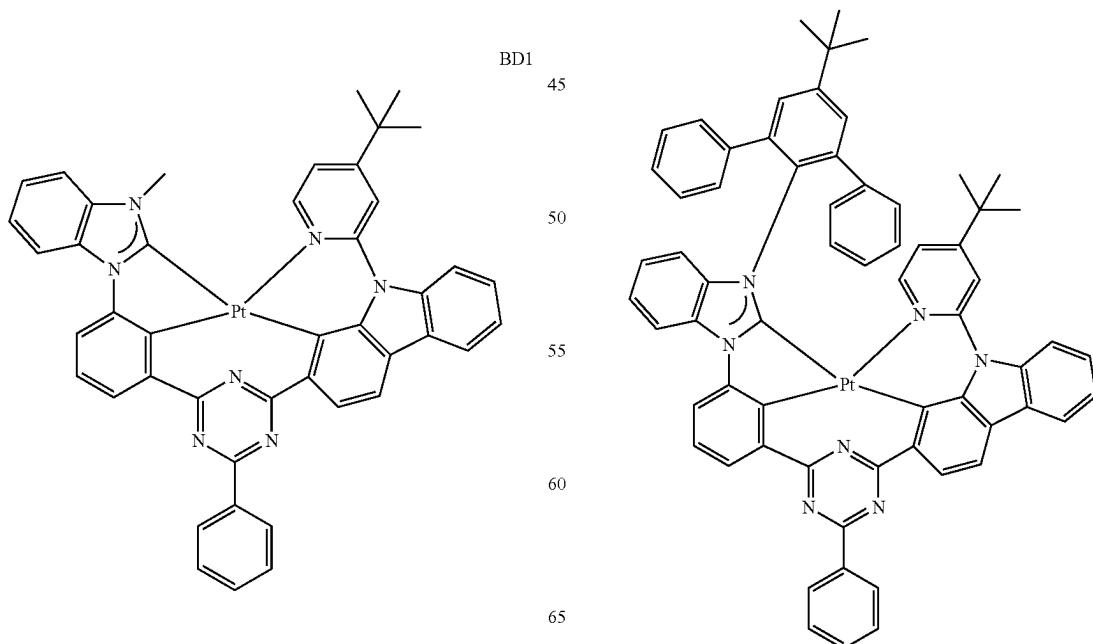
The driving voltage (V) at a brightness of 1,000 cd/m², color purity (CIE_{x,y}), emission efficiency (cd/A), color conversion efficiency (cd/A/y), maximum emission wavelength (nm), and lifespan (T₉₅) of the light-emitting devices manufactured according to Examples 1 to 6 were measured by utilizing a Keithley MU 236 and a luminance meter PR650, and results thereof are each shown in Tables 2 and 3. In Table 3, the lifespan (T₉₅) is a measure of the time (hours) elapsed when the brightness reaches 95% of the initial brightness.

TABLE 2

No.	Dopant		Host		Driving		
	First compound	Fourth compound	Second compound	Third compound	Luminance (cd/m ²)	Voltage (V)	Color purity (CIE _{x,y})
Example 1	BD1	DFD2	ETH66	HTH29	1000	3.9	(0.137, 0.159)
Example 2	BD10	DFD2	ETH66	HTH29	1000	4.1	(0.136, 0.158)
Example 3	BD14	DFD2	ETH66	HTH29	1000	3.8	(0.136, 0.156)
Example 4	BD20	DFD2	ETH66	HTH29	1000	4.0	(0.135, 0.155)
Example 5	BD31	DFD2	ETH66	HTH29	1000	4.2	(0.135, 0.149)
Example 6	BD50	DFD2	ETH66	HTH29	1000	3.7	(0.138, 0.168)

TABLE 3

No.	Dopant		Host		Maximum emission		
	First compound	Fourth compound	Second compound	Third compound	Emission efficiency (cd/A)	wavelength (nm)	Lifespan (LT ₉₅) (hr)
Example 1	BD1	DFD2	ETH66	HTH29	20	461	55
Example 2	BD10	DFD2	ETH66	HTH29	21	461	51
Example 3	BD14	DFD2	ETH66	HTH29	22	461	52
Example 4	BD20	DFD2	ETH66	HTH29	19	461	47
Example 5	BD31	DFD2	ETH66	HTH29	21	461	49
Example 6	BD50	DFD2	ETH66	HTH29	24	461	41

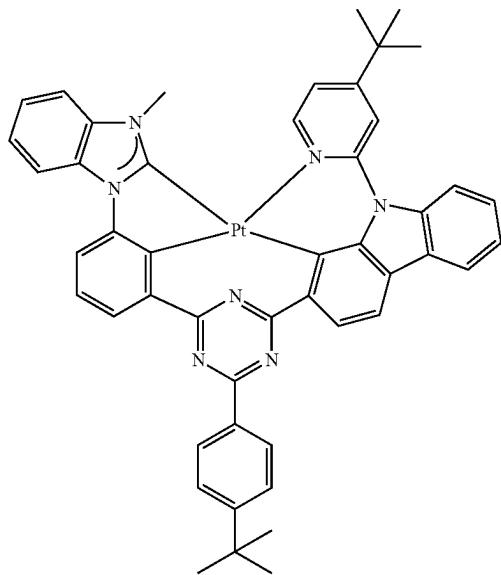


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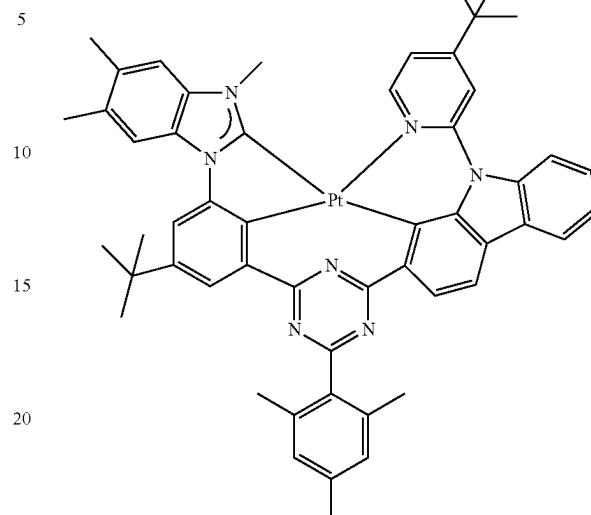
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BD14

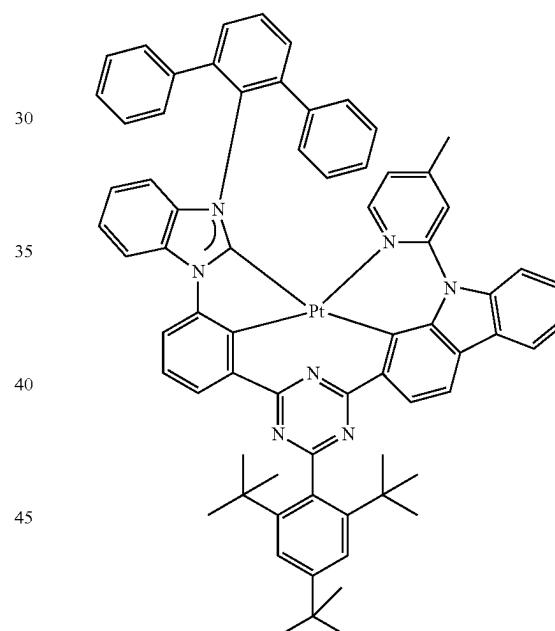
**286**

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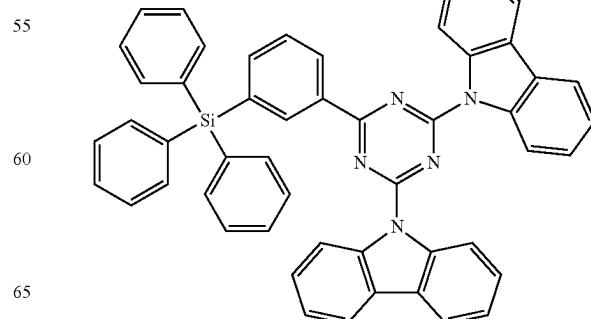
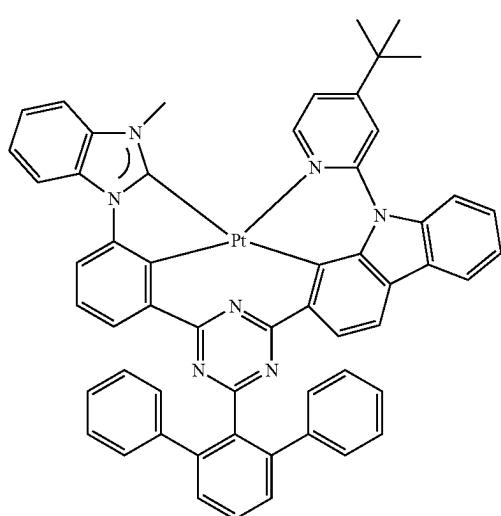
BD31



BD50

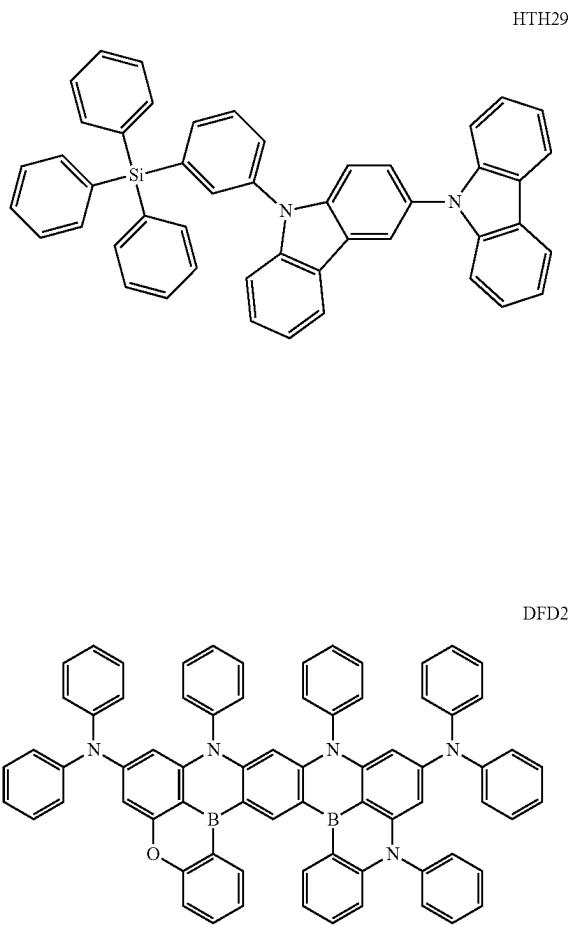


ETH66



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Tables 2 and 3 show that the organic light-emitting devices of Examples 1 to 6 emit deep blue light and have excellent or suitable driving voltage, color purity, emission efficiency, color conversion efficiency, and/or lifespan characteristics.

Example 7

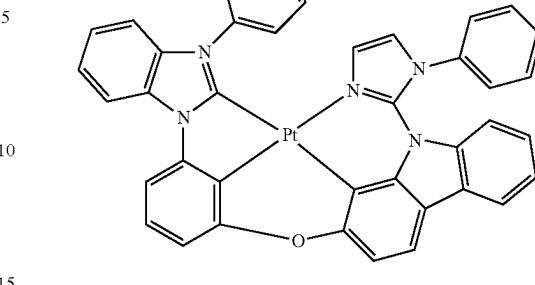
Organic light-emitting devices were manufactured in substantially the same manner as in Example 1, except that, in forming an emission layer, instead of vacuum-depositing Compound BD1 (first compound), Compound DFD2 (fourth compound), Compound ETH66 (second compound), and Compound HTH29 (third compound) on the hole transport layer at a weight ratio of 1:0.5:3:6 to form an emission layer having a thickness of 400 Å, Compound BD1 (first compound) and Compound HTH29 (third compound) were vacuum-deposited at a weight ratio of 10:90 to form an emission layer having a thickness of 300 Å.

Comparative Example 1

Organic light-emitting devices were manufactured in substantially the same manner as in Example 7, except that, in forming an emission layer, Compound A was utilized instead of Compound BD1.

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A



Evaluation Example 2

The driving voltage (V) at a brightness of 1000 cd/m², color purity (CIE_{x,y}), emission efficiency (cd/A), color conversion efficiency (cd/A/y), maximum emission wavelength (nm), and lifespan (T₉₅ at room temperature) of the organic light-emitting devices manufactured according to Example 7 and Comparative Example 1 were each measured utilizing the same method as in Evaluation Example 1, and the results thereof are each shown in Tables 4 and 5.

TABLE 4

No.	Dopant	Host	Brightness (cd/m ²)	Driving voltage (V)	Color purity (CIE _{x,y})
Example 7	BD10	HTH29	1000	4.0	(0.132, 0.178)
Comparative Example 1	Compound A	HTH29	1000	4.7	(0.20, 0.212)

TABLE 5

No.	Dopant	Host	Emission efficiency (cd/A)	Maximum emission wavelength (nm)	Lifespan (T ₉₅) (hr)
Example 7	BD10	HTH29	24	464	50
Comparative Example 1	Compound A	HTH29	15	468	25

Tables 4 and 5 show that the organic light-emitting devices of Example 7 emit deep blue light and have excellent or suitable driving voltage, color purity, emission efficiency, color conversion efficiency, and lifespan characteristics compared to the organic light-emitting device of Comparative Example 1.

The organometallic compound can be utilized to manufacture a light-emitting device having high emission efficiency and/or long lifespan, and the light-emitting device may have excellent or suitable driving voltage and current density, as well as high emission efficiency and long lifespan, and thus may be utilized in manufacturing high-quality electronic apparatuses.

It should be understood that the 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 being available for other similar features or aspects in other embodiments. While one or more embodiments have been described with reference to the drawings,

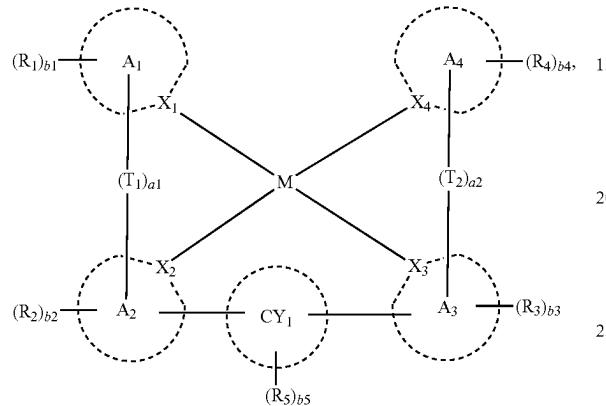
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it will be understood by those of ordinary skill in the art that various suitable changes in form and details may be made therein without departing from the spirit and scope as defined by claims and equivalents thereof.

What is claimed is:

1. An organometallic compound represented by Formula 1:

Formula 1



wherein, in Formula 1,

M is platinum (Pt), palladium (Pd), gold (Au), nickel (Ni), silver (Ag), or copper (Cu),

X₁ to X₄ are each independently C or N,

A₁ to A₄ are each independently a C₃-C₆₀ carbocyclic group or a C₁-C₆₀ heterocyclic group,

CY₁ is a triazine group,

T₁ and T₂ are each independently a single bond, a double bond, *—N[(L₁)_{c1}(Z₁₁)—*], *—B(Z₁₁)—*, *—P(Z₁₁)—*, *—C(Z₁₁)(Z₁₂)—*, *—Si(Z₁₁)(Z₁₂)—*, *—Ge(Z₁₁)(Z₁₂)—*, *—S—*, *—Se—*, *—O—*, *—C(=O)—*, *—S(=O)—*, *—S(=O)₂—*, *—C(Z₁₁)—*, *—C(Z₁₁)—*, *—C(Z₁₁)=C(Z₁₂)—*, *—C(=S)—*, or *—C≡C—*, where * and *' each indicate a binding site to a neighboring atom,

L₁ is a single bond, a C₅-C₃₀ carbocyclic group unsubstituted or substituted with at least one R_{10a}, or a C₁-C₃₀ heterocyclic group unsubstituted or substituted with at least one R_{10a},

c1 is an integer from 0 to 5,

a1 and a2 are each independently an integer from 0 to 3,

R₁ to R₄, Z₁₁, and Z₁₂ are each independently hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C₁-C₆₀ alkyl group unsubstituted or substituted with at least one R_{10a}, a C₂-C₆₀ alkenyl group unsubstituted or substituted with at least one R_{10a}, a C₂-C₆₀ alkynyl group unsubstituted or substituted with at least one R_{10a}, a C₁-C₆₀ alkoxy group unsubstituted or substituted with at least one R_{10a}, a C₃-C₆₀ carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C₁-C₆₀ heterocyclic group unsubstituted or substituted with at least one R_{10a}, a C₆-C₆₀ aryloxy group unsubstituted or substituted with at least one R_{10a}, a C₆-C₆₀ arylthio group unsubstituted or substituted with at least one R_{10a}, —Si(Q₁)(Q₂)(Q₃), —N(Q₁)(Q₂), —B(Q₁)(Q₂), —C(=O)(Q₁), —S(=O)₂(Q₁), or —P(=O)(Q₁)(Q₂),

5

10

15

20

25

30

35

40

45

50

55

60

65

290

R₅ is a substituted or unsubstituted phenyl group, b1 to b4 are each independently an integer from 0 to 10, b5 is 1,

two or more of R₁ to R₄, Z₁₁ and Z₁₂ are optionally linked to form a C₅-C₃₀ carbocyclic group unsubstituted or substituted with at least one R_{10a} or a C₂-C₃₀ heterocyclic group unsubstituted or substituted with at least one R_{10a},

R_{10a} is:

deuterium (-D), —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, or a nitro group;

a C₁-C₆₀ alkyl group, a C₂-C₆₀ alkenyl group, a C₂-C₆₀ alkynyl group, or a C₁-C₆₀ alkoxy group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C₃-C₆₀ carbocyclic group, a C₁-C₆₀ heterocyclic group, a C₆-C₆₀ aryloxy group, a C₆-C₆₀ arylthio group, —Si(Q₁₁)(Q₁₂)(Q₁₃), —N(Q₁₁)(Q₁₂), —B(Q₁₁)(Q₁₂), —C(=O)(Q₁₁), —S(=O)₂(Q₁₁), —P(=O)(Q₁₁)(Q₁₂), or any combination thereof;

a C₃-C₆₀ carbocyclic group, a C₁-C₆₀ heterocyclic group, a C₆-C₆₀ aryloxy group, or a C₆-C₆₀ arylthio group, each unsubstituted or substituted with deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C₁-C₆₀ alkyl group, a C₂-C₆₀ alkenyl group, a C₂-C₆₀ alkynyl group, a C₁-C₆₀ alkoxy group, a C₃-C₆₀ carbocyclic group, a C₁-C₆₀ heterocyclic group, a C₆-C₆₀ aryloxy group, a C₆-C₆₀ arylthio group, —Si(Q₂₁)(Q₂₂)(Q₂₃), —N(Q₂₁)(Q₂₂), —B(Q₂₁)(Q₂₂), —C(=O)(Q₂₁), —S(=O)₂(Q₂₁), —P(=O)(Q₂₁)(Q₂₂), or any combination thereof; or —Si(Q₃₁)(Q₃₂)(Q₃₃), —N(Q₃₁)(Q₃₂), —B(Q₃₁)(Q₃₂), —C(=O)(Q₃₁), —S(=O)₂(Q₃₁), or —P(=O)(Q₃₁)(Q₃₂),

wherein Q₁ to Q₃, Q₁₁ to Q₁₃, Q₂₁ to Q₂₃, and Q₃₁ to Q₃₃ are each independently: hydrogen; deuterium; —F; —Cl; —Br; —I; a hydroxyl group; a cyano group; a nitro group; a C₁-C₆₀ alkyl group; a C₂-C₆₀ alkenyl group; a C₂-C₆₀ alkynyl group; a C₁-C₆₀ alkoxy group; or a C₃-C₆₀ carbocyclic group or a C₁-C₆₀ heterocyclic group, each unsubstituted or substituted with deuterium, —F, a cyano group, a C₁-C₆₀ alkyl group, a C₁-C₆₀ alkoxy group, a phenyl group, a biphenyl group, or any combination thereof.

2. The organometallic compound of claim 1, wherein a bond between X₁ and M and a bond between X₄ and M are each a coordinate bond, and

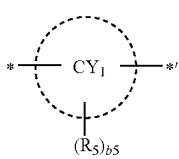
a bond between X₂ and M and a bond between X₃ and M are each a covalent bond.

3. The organometallic compound of claim 1, wherein A₁ is i) an X₁-containing 5-membered ring, ii) the X₁-containing 5-membered ring, to which at least one 6-membered ring is condensed, or iii) an X₁-containing 6-membered ring, and A₄ is an X₄-containing 6-membered ring.

4. The organometallic compound of claim 3, wherein the X₁-containing 5-membered ring is a pyrrole group, a pyrazole group, an imidazole group, a triazole group, an oxazole group, an isoxazole group, a thiazole group, an isothiazole group, an oxadiazole group, or a thiadiazole group, and the X₁-containing 6-membered ring, the 6-membered ring condensed to the X₁-containing 5-membered ring, and/or the X₄-containing 6-membered ring are each independently a benzene group, a pyridine group, or a pyrimidine group.

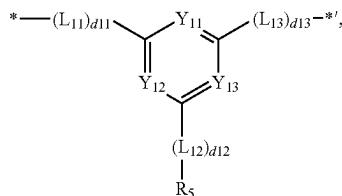
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5. The organometallic compound of claim 1, wherein the group represented by



in Formula 1 is represented by Formula 1a:

Formula 1a



wherein, in Formula 1a,

R₅ is the same as described above,

Y₁₁ is N, Y₁₂ is N, Y₁₃ is N,

L₁₁ to L₁₃ are each independently a single bond, a C₃-C₆₀ carbocyclic group unsubstituted or substituted with at least one R_{10a}, or a C₁-C₆₀ heterocyclic group unsubstituted or substituted with at least one R_{10a},

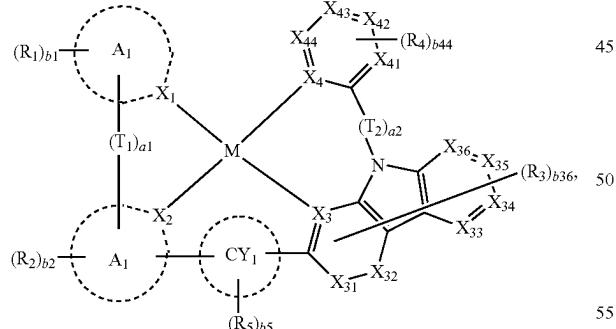
d11 to d13 are each independently an integer from 1 to 5,

* indicates a binding site to A₂ in Formula 1, and

*' indicates a binding site to A₃ in Formula 1.

6. The organometallic compound of claim 1, wherein Formula 1 is represented by Formula 1-1:

Formula 1-1



wherein, in Formula 1-1,

M, X₁ to X₄, A₁, A₂, CY₁, T₁, T₂, a₁, a₂, R₁, b₁, b₂, and b₅ are each independently the same as described above,

X₃₁ to X₃₆ are each independently the same as described in connection with X₃ above,

X₄₁ to X₄₄ are each independently the same as described in connection with X₄ above,

b₃₆ is an integer from 0 to 6, and

b₄₄ is an integer from 0 to 4.

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7. A light-emitting device comprising:

a first electrode;

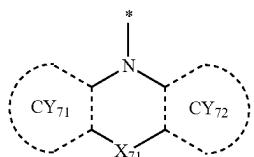
a second electrode facing the first electrode;

an interlayer located between the first electrode and the second electrode and comprising an emission layer, wherein the interlayer comprises:

i) a first compound, which is the organometallic compound of claim 1; and

ii) a second compound comprising at least one TT electron-deficient nitrogen-containing C₁-C₆₀ cyclic group, a third compound comprising a group represented by Formula 3, a fourth compound capable of emitting delayed fluorescence, or any combination thereof, and the first compound and second compound, and the third compound and fourth compound are different from each other;

Formula 3

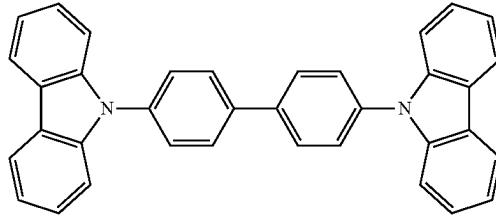


wherein, in Formula 3, ring CY₇₁ and ring CY₇₂ are each independently a TT electron-rich C₃-C₆₀ cyclic group or a pyridine group,

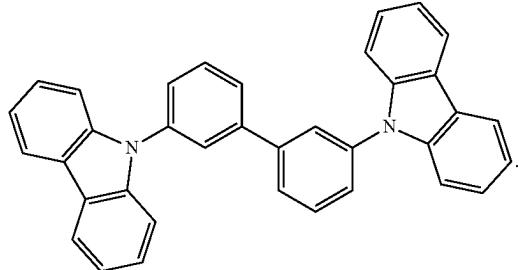
in Formula 3, X₇₁ is a linking group comprising a single bond, O, S, N, B, C, Si, or any combination thereof,

in Formula 3, * indicates a binding site to a neighboring atom in the third compound, and

in the third compound, the compounds below are excluded:



CBP



mCBP

8. The light-emitting device of claim 7, wherein the second compound comprises a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, or any combination thereof.

9. The light-emitting device of claim 7, wherein the interlayer comprises the second compound.

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10. The light-emitting device of claim 9, wherein the interlayer further comprises the third compound, the fourth compound, or a combination thereof.

11. The light-emitting device of claim 7, wherein the fourth compound comprises at least one cyclic group comprising both B (boron) and N (nitrogen) as ring-forming atoms.

12. The light-emitting device of claim 7, wherein the fourth compound comprises a condensed cyclic group in which at least one third ring and at least one fourth ring are condensed with each other,

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

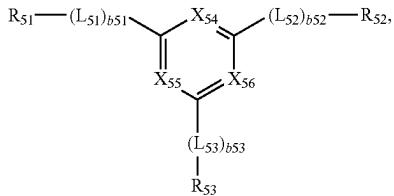
the fourth ring is a 1,2-azaborinine group, a 1,3-azaborinine group, a 1,4-azaborinine group, a 1,2-dihydro-1,2-azaborinine group, a 1,4-oxaborinine group, a 1,4-oxaborinine group, a 1,4-thiaborinine group, or a 1,4-dihydroborinine group.

13. The light-emitting device of claim 7, wherein i) the first compound; and ii) the second compound, the third compound, the fourth compound, or any combination thereof are comprised in the emission layer, and

the first compound is to emit phosphorescence or fluorescence.

14. The light-emitting device of claim 7, wherein the second compound comprises a compound represented by Formula 2:

Formula 2



wherein, in Formula 2,

L_{51} to L_{53} are each independently a single bond, a $C_3\text{-}C_{60}$ carbocyclic group unsubstituted or substituted with at least one R_{10a} , or a $C_1\text{-}C_{60}$ heterocyclic group unsubstituted or substituted with at least one R_{10a} ,

$b51$ to $b53$ are each independently an integer from 1 to 5, X_{54} is N or $C(R_{54})$, X_{55} is N or $C(R_{55})$, X_{56} is N or $C(R_{56})$, and at least one of X_{54} to X_{56} is N,

R_{51} to R_{56} are each independently hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a $C_1\text{-}C_{60}$ alkyl group unsubstituted or substituted with at least one R_{10a} , a $C_2\text{-}C_{60}$ alkenyl group unsubstituted or substituted with at least one R_{10a} , a $C_2\text{-}C_{60}$ alkynyl group unsubstituted or substituted with at least one R_{10a} , a $C_1\text{-}C_{60}$ alkoxy group unsubstituted or substituted with at least one R_{10a} , a $C_3\text{-}C_{60}$ carbocyclic group unsubstituted or substituted with at least one R_{10a} , a $C_1\text{-}C_{60}$ heterocyclic group unsubstituted or substituted with at least one R_{10a} , a $C_6\text{-}C_{60}$ aryloxy group unsubstituted or substituted with

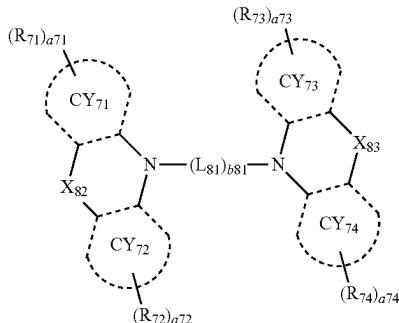
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at least one R_{10a} , a $C_6\text{-}C_{60}$ arylthio group unsubstituted or substituted with at least one R_{10a} , —C(Q_1)(Q_2)(Q_3), —Si(Q_1)(Q_2)(Q_3), —N(Q_1)(Q_2), —B(Q_1)(Q_2), —C(=O)(Q_1), —S(=O)₂(Q_1), or —P(=O)(Q_1)(Q_2), and

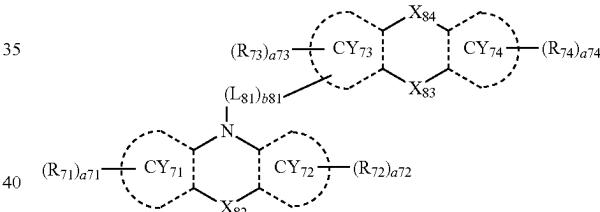
R_{10a} and Q_1 to Q_3 are each independently the same as described above.

15. The light-emitting device of claim 7, wherein the third compound comprises a compound represented by Formula 3-1, a compound represented by Formula 3-2, a compound represented by Formula 3-3, a compound represented by Formula 3-4, a compound represented by Formula 3-5, or any combination thereof:

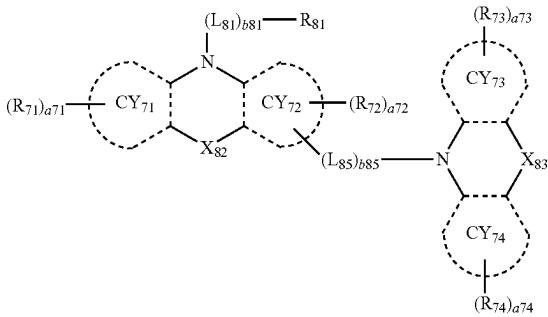
Formula 3-1



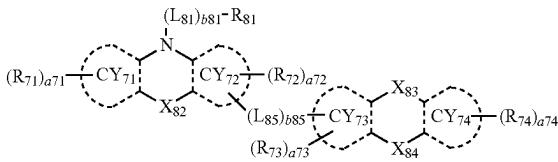
Formula 3-2



Formula 3-3



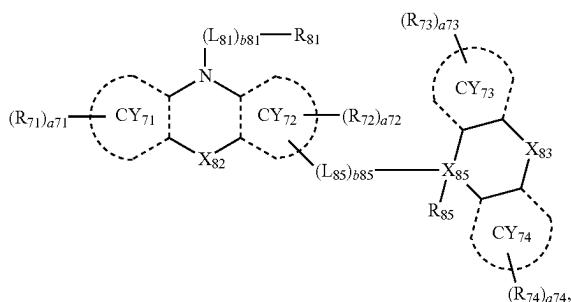
Formula 3-4



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-continued

Formula 3-5



wherein, in Formulae 3-1 to 3-5,

ring CY₇₁ and ring CY₇₄ are each independently a TT electron-rich C₃-C₆₀ cyclic group or a pyridine group,
X₈₂ is a single bond, O, S, N-[(L₈₂)_{b82}-R₈₂], C(R_{82a})
(R_{82b}), or Si(R_{82a}) (R_{82b}),
X₈₃ is a single bond, O, S, N-[(L₈₃)_{b83}-R₈₃], C(R_{83a})
(R_{83b}), or Si(R_{83a}) (R_{83b}),
X₈₄ is O, S, N-[(L₈₄)_{b84}-R₈₄], C(R_{84a}) (R_{84b}), or Si(R_{84a})
(R_{84b})X₈₅ is C or Si,L₈₁ to L₈₅ are each independently a single bond, *—C(Q₄)(Q₅)-*, *—Si(Q₄)(Q₅)-*, a C₃-C₆₀ cyclic group unsubstituted or substituted with at least one R_{10a}, or a pyridine group unsubstituted or substituted with at least one R_{10a}, and Q₄ and Q₅ are each independently the same as described in connection with Q₁,

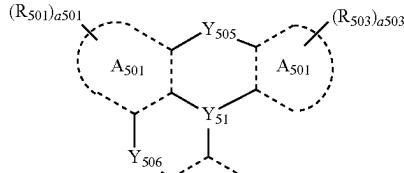
b81 to b85 are each independently an integer from 1 to 5,

R₇₁ to R₇₄, R₈₁ to R₈₅, R_{82a}, R_{82b}, R_{83a}, R_{83b}, R_{84a}, and R_{84b} are each independently hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C₁-C₆₀ alkyl group unsubstituted or substituted with at least one R_{10a}, a C₂-C₆₀ alkenyl group unsubstituted or substituted with at least one R_{10a}, a C₂-C₆₀ alkynyl group unsubstituted or substituted with at least one R_{10a}, a C₁-C₆₀ heterocyclic group unsubstituted or substituted with at least one R_{10a}, a C₃-C₆₀ carbocyclic group unsubstituted or substituted with at least one R_{10a}, a C₁-C₆₀ heterocyclic group unsubstituted or substituted with at least one R_{10a}, a C₆-C₆₀ aryloxy group unsubstituted or substituted with at least one R_{10a}, a C₆-C₆₀ arylthio group unsubstituted or substituted with at least one R_{10a}, —C(Q₁)(Q₂)(Q₃), —Si(Q₁)(Q₂)(Q₃), —N(Q₁)(Q₂), —B(Q₁)(Q₂), —C(=O)(Q₁), —S(=O)₂(Q₁), or —P(=O)(Q₁)(Q₂),

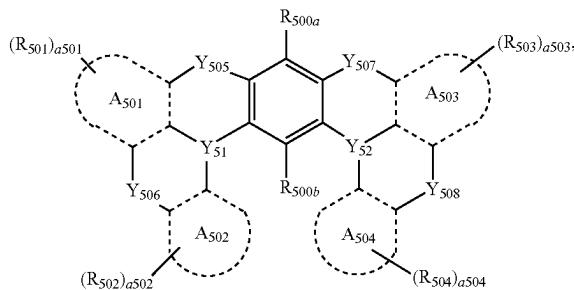
a71 to a74 are each independently an integer from 0 to 20, and

R_{10a} and Q₁ to Q₃ are each independently the same as described above.**16.** The light-emitting device of claim 7, wherein the fourth compound comprises a compound represented by Compound 502, a compound represented by Compound 503, or any combination thereof:**296**

Formula 502



Formula 503



wherein, in Formulae 502 and 503,

ring A₅₀₁ to ring A₅₀₄ are each independently a C₃-C₆₀ carbocyclic group or a C₁-C₆₀ heterocyclic group, Y₅₀₅ is O, S, N(R₅₀₅), B(R₅₀₅), C(R_{505a}) (R_{505b}), or Si(R_{505a}) (R_{505b}), Y₅₀₆ is O, S, N(R₅₀₆), B(R₅₀₆), C(R_{506a}) (R_{506b}), or Si(R_{506a}) (R_{506b}), Y₅₀₇ is O, S, N(R₅₀₇), B(R₅₀₇), C(R_{507a}) (R_{507b}), or Si(R_{507a}) (R_{507b}), Y₅₀₈ is O, S, N(R₅₀₈), B(R₅₀₈), C(R_{508a}) (R_{508b}), or Si(R_{508a}) (R_{508b}), Y₅₁ and Y₅₂ are each independently B, P(=O), or S(=O), R_{500a}, R_{500b}, R₅₀₁ to R₅₀₈, R_{505a}, R_{505b}, R_{506a}, R_{506b}, R_{507a}, R_{507b}, R_{508a}, and R_{508b} are each independently hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, a C₁-C₆₀ alkyl group unsubstituted or substituted with at least one R_{10a}, a C₂-C₆₀ alkenyl group unsubstituted or substituted with at least one R_{10a}, a C₂-C₆₀ alkynyl group unsubstituted or substituted with at least one R_{10a}, a C₁-C₆₀ alkoxyl group unsubstituted or substituted with at least one R_{10a}, a C₁-C₆₀ aryloxy group unsubstituted or substituted with at least one R_{10a}, a C₆-C₆₀ arylthio group unsubstituted or substituted with at least one R_{10a}, —C(Q₁)(Q₂)(Q₃), —Si(Q₁)(Q₂)(Q₃), —N(Q₁)(Q₂), —B(Q₁)(Q₂), —C(=O)(Q₁), —S(=O)₂(Q₁), or —P(=O)(Q₁)(Q₂),a501 to a504 are each independently an integer from 0 to 20, and R_{10a} and Q₁ to Q₃ are each independently the same as described above.**17.** An electronic apparatus comprising the light-emitting device of claim 7.**18.** The electronic apparatus of claim 17, further comprising a thin-film transistor, wherein:
the thin-film transistor comprises a source electrode and a drain electrode, and
the first electrode of the light-emitting device is electrically connected to at least one of the source electrode or the drain electrode of the thin-film transistor.

19. The electronic apparatus of claim 17, further comprising a color filter, a color conversion layer, a touch screen layer, a polarizing layer, or any combination thereof.

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