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(54) **ORGANOMETALLIC COMPOUND AND ORGANIC LIGHT-EMITTING DEVICE INCLUDING THE SAME**

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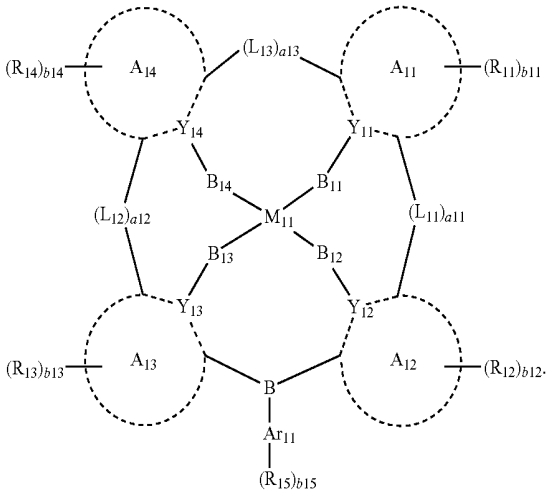
(57) **ABSTRACT**

An organic light-emitting device includes: a first electrode; a second electrode facing the first electrode; and an organic layer between the first electrode and the second electrode, wherein the organic layer includes an emission layer. The emission layer may including an organometallic compound represented by Formula 1 as a dopant:

Formula 1



10

190

150

110

FIG. 1

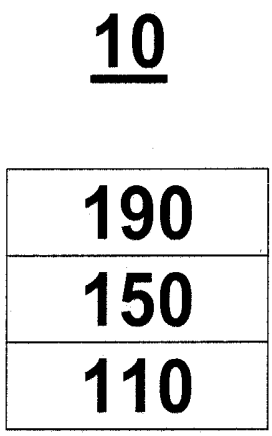


FIG. 2

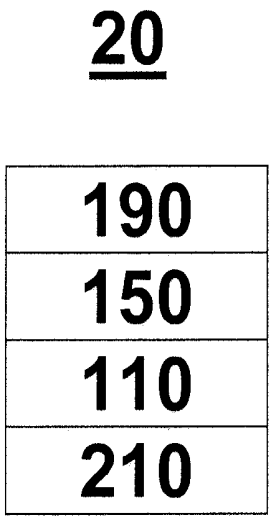


FIG. 3

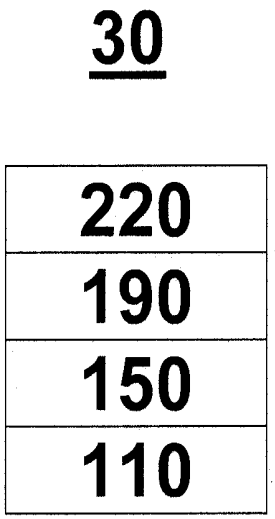
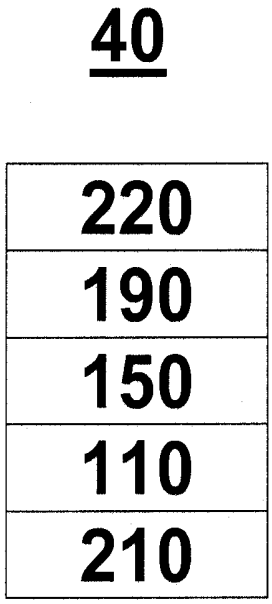


FIG. 4



ORGANOMETALLIC COMPOUND AND ORGANIC LIGHT-EMITTING DEVICE INCLUDING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to and the benefit of Korean Patent Application No. 10-2017-0095712, filed on Jul. 27, 2017, in the Korean Intellectual Property Office, the entire content of is incorporated herein by reference.

BACKGROUND

1. Field

[0002] One or more aspects of one or more embodiments of the present disclosure relate to an organometallic compound and an organic light-emitting device including the same.

2. Description of the Related Art

[0003] Organic light-emitting devices (OLEDs) are self-emission devices that have wide viewing angles, high contrast ratios, and short response times. In addition, OLEDs exhibit high luminance, driving voltage, and response speed characteristics, and produce full-color images.

[0004] An organic light-emitting device may include a first electrode disposed (e.g., positioned) on a substrate, and may include a hole transport region, an emission layer, an electron transport region, and a second electrode sequentially disposed on the first electrode. Holes provided from the first electrode may move toward the emission layer through the hole transport region. Electrons provided from the second electrode may move toward the emission layer through the electron transport region. Carriers, such as holes and electrons, may then recombine in the emission layer to produce excitons. These excitons transit from an excited state to a ground state to thereby generate light.

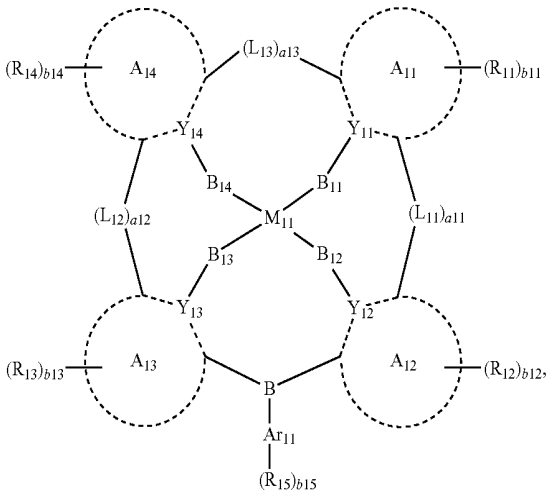
SUMMARY

[0005] One or more aspects of one or more embodiments of the present disclosure are directed towards an organometallic compound and an organic light-emitting device including the same.

[0006] Additional aspects will be set forth in part in the description which follows and, in part, will be apparent from the description, or may be learned by practice of the presented embodiments.

[0007] According to one or more embodiments, an organometallic compound is represented by Formula 1:

Formula 1



[0008] wherein, in Formula 1,

[0009] M_{11} is selected from platinum (Pt), palladium (Pd), copper (Cu), silver (Ag), gold (Au), rhodium (Rh), iridium (Ir), ruthenium (Ru), and osmium (Os),

[0010] A_{11} to A_{14} are each independently selected from a C_5-C_{60} carbocyclic group and a C_1-C_{60} heterocyclic group,

[0011] Ar_{11} is a C_1-C_{60} heterocyclic group,

[0012] Y_{11} to Y_{14} are each independently selected from a carbon atom (C) and a nitrogen atom (N),

[0013] B_{11} to B_{14} are each independently selected from a single bond, O, and S,

[0014] L_{11} to L_{13} are each independently selected from a single bond, *—O—*', *—S—*', *—C(R_{16})(R_{17})—*', *—C(R_{16})=*', *=C(R_{16})—*', *—C(R_{16})=C(R_{17})—*', *—C(=O)—*', *—C(=S)—*', *—C≡C—*', *—B(R_{16})—*', *—N(R_{16})—*', *—P(R_{16})—*', *—Si(R_{16})(R_{17})—*', *—P(R_{16})(R_{17})—*', and *—Ge(R_{16})(R_{17})—*',

[0015] a11 to a13 are each independently an integer selected from 0 to 3,

[0016] when a11 is 0, A_{11} and A_{12} are not bound, when a12 is 0, A_{13} and A_{14} are not bound, when a13 is 0, A_{11} and A_{14} are not bound,

[0017] when a11 is two or greater, at least two L_{11} groups are identical to or different from each other, when a12 is two or greater, at least two L_{12} groups are identical to or different from each other, when a13 is two or greater, at least two L_{13} groups are identical to or different from each other,

[0018] at least two selected from al 1l to a13 are each independently an integer from 1 to 3,

[0019] R_{11} to R_{17} are each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_2-C_{60} alkenyl group, a substituted or unsubstituted C_2-C_{60} alkynyl group, a substituted or unsubstituted C_1-C_{60} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10}

heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted C_1-C_{60} heteroaryloxy group, a substituted or unsubstituted C_1-C_{60} heteroarylthio group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, —$Si(Q_1)(Q_2)(Q_3)$, —$B(Q_1)(Q_2)$, —$N(Q_1)(Q_2)$, —$P(Q_1)(Q_2)$, —$C(=O)(Q_1)$, —$S(=O)(Q_1)$, —$S(=O)_2(Q_1)$, —$P(=O)(Q_1)(Q_2)$, and —$P(=S)(Q_1)(Q_2)$,

[0020] R_{16} and R_{11}, R_{16} and R_{12}, R_{16} and R_{13}, and/or R_{16} and R_{14} are optionally bound to form a substituted or unsubstituted C_5-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group,

[0021] b1 to b15 are each independently an integer from 1 to 8,

[0022] when b11 is two or greater, at least two R_{11} groups are identical to or different from each other, when b12 is two or greater, at least two R_{12} groups are identical to or different from each other, when b13 is two or greater, at least two R_{13} groups are identical to or different from each other, when b14 is two or greater, at least two R_{14} groups are identical to or different from each other, when b15 is two or greater, at least two R_{15} groups are identical to or different from each other,

[0023] at least one of the b15 number of R_{15} groups is not hydrogen, and

[0024] at least one substituent of the substituted C_5-C_{60} carbocyclic group, substituted C_1-C_{60} heterocyclic group, substituted C_1-C_{60} alkyl group, substituted C_2-C_{60} alkenyl group, substituted C_2-C_{60} alkynyl group, substituted C_1-C_{60} alkoxy group, substituted C_3-C_{10} cycloalkyl group, substituted C_1-C_{10} heterocycloalkyl group, substituted C_3-C_{10} cycloalkenyl group, substituted C_1-C_{10} heterocycloalkenyl group, substituted C_6-C_{60} aryl group, substituted C_6-C_{60} aryloxy group, substituted C_6-C_{60} arylthio group, substituted C_1-C_{60} heteroaryl group, substituted C_1-C_{60} heteroaryloxy group, substituted C_1-C_{60} heteroarylthio group, substituted monovalent non-aromatic condensed polycyclic group, and substituted monovalent non-aromatic condensed heteropolycyclic group may be selected from:

[0025] deuterium (-D), —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group;

[0026] a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —$Si(Q_{11})(Q_{12})(Q_{13})$, —$N(Q_{11})(Q_{12})$, —$B(Q_{11})(Q_{12})$, —$C(=O)(Q_{11})$, —$S(=O)_2(Q_{11})$, and —$P(=O)(Q_{11})(Q_{12})$;

[0027] a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group;

[0028] a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —$Si(Q_{21})(Q_{22})(Q_{23})$, —$N(Q_{21})(Q_{22})$, —$B(Q_{21})(Q_{22})$, —$C(=O)(Q_{21})$, —$S(=O)_2(Q_{21})$, and —$P(=O)(Q_{21})(Q_{22})$; and

[0029] —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$,

[0030] wherein Q_1 to Q_3, Q_{11} to Q_{13}, Q_{21} to Q_{23}, and Q_{31} to Q_{33} are each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl group, and

[0031] * indicates a binding site to an adjacent atom.

[0032] According to one or more embodiments, an organic light-emitting device includes: a first electrode; a second electrode facing the first electrode; and an organic layer between the first electrode and the second electrode, the organic layer including an emission layer and at least one of the organometallic compound represented by Formula 1.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] These and/or other aspects will become apparent and more readily appreciated from the following description of the embodiments, taken in conjunction with the accompanying drawings in which:

[0034] FIG. **1** illustrates a schematic cross-sectional view of an organic light-emitting device according to an embodiment;

[0035] FIG. **2** illustrates a schematic cross-sectional view of an organic light-emitting device according to an embodiment;

[0036] FIG. **3** illustrates a schematic cross-sectional view of an organic light-emitting device according to an embodiment; and

[0037] FIG. **4** illustrates a schematic cross-sectional view of an organic light-emitting device according to an embodiment.

DETAILED DESCRIPTION

[0038] Reference will now be made in more detail to embodiments, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to like elements throughout. In this regard, the present embodiments may have different forms and should not be construed as being limited to the descriptions set forth herein. Accordingly, the embodiments are merely described below, by referring to the figures, to explain aspects of the present description. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items. Expressions such as "at least one of", "one of," and "selected from," when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list. Further, the use of "may" when describing embodiments of the present invention may refer to "one or more embodiments of the present invention."

[0039] As the inventive concept allows for various changes and numerous embodiments, particular embodiments will be illustrated in the drawings and described in more detail in the written description. Effects, features, and a method of achieving the inventive concept should become apparent to those of ordinary skill in the art by referring to example embodiments of the inventive concept with reference to the attached drawings. The inventive concept may, however, be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein.

[0040] Hereinafter, the inventive concept will be described in more detail by explaining example embodiments of the inventive concept with reference to the attached drawings. Like reference numerals in the drawings and specification denote like elements, and the duplicative descriptions will not be provided.

[0041] In the embodiments described in the present specification, an expression used in the singular encompasses the expression of the plural, unless it has a clearly different meaning in the context.

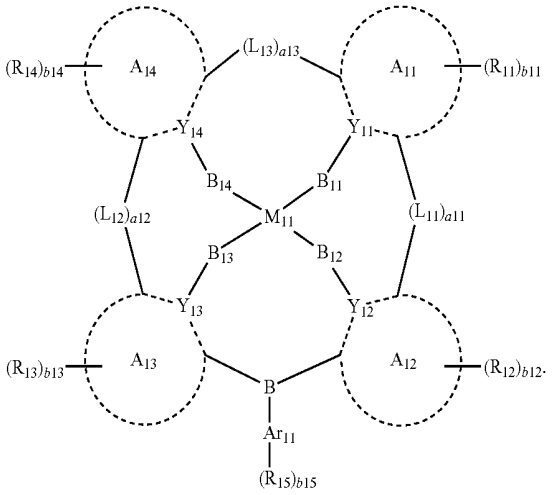
[0042] In the present specification, it is to be understood that the terms such as "including," "having," and "comprising" are intended to indicate the existence of the features or components disclosed in the specification, and are not intended to preclude the possibility that one or more other features or components may exist or may be added.

[0043] It will be understood that when a layer, region, or component is referred to as being "on" or "onto" another layer, region, or component, it may be directly or indirectly formed over the other layer, region, or component. That is, for example, intervening layers, regions, or components may be present.

[0044] Sizes of components in the drawings may be exaggerated for convenience of explanation. As such, since sizes and thicknesses of components in the drawings are arbitrarily illustrated for convenience of explanation, the following embodiments are not limited thereto.

[0045] An organometallic compound according to embodiments of the present disclosure may be represented by Formula 1:

Formula 1



[0046] In Formula 1, M_{11} may be selected from platinum (Pt), palladium (Pd), copper (Cu), silver (Ag), gold (Au), rhodium (Rh), iridium (Ir), ruthenium (Ru), and osmium (Os).

[0047] In one embodiment, M_{11} may be selected from Pt, Pd, Cu, Ag, and Au, but embodiments are not limited thereto.

[0048] In Formula 1, A_{11} to A_{14} may each independently be selected from a C_5-C_{60} carbocyclic group and a C_1-C_{60} heterocyclic group.

[0049] In some embodiments, A_{11} to A_{14} may each independently be selected from a benzene group, a naphthalene group, an anthracene group, a phenanthrene group, a triphenylene group, a pyrene group, a chrysene group, a cyclopentadiene group, a 1,2,3,4-tetrahydronaphthalene group, a furan group, a thiophene group, a silole group, an indene group, a fluorene group, an indole group, a carbazole group, an azacarbazole group, a benzofuran group, a dibenzofuran group, a benzothiophene group, a dibenzothiophene group, a benzosilole group, a dibenzosilole group, an indenopyridine group, an indolopyridine group, a benzofuropyridine group, a benzothienopyridine group, a benzosilolopyridine group, an indenopyrimidine group, an indolopyrimidine group, a benzofuropyrimidine group, a benzothienopyrimidine group, a benzosilolopyrimidine group, a dihydropyridine group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a quinoxaline group, a quinazoline group, a phenanthroline group, a pyrrole group, a pyrazole group, an imidazole group, a 2,3-dihydroimidazole group, a triazole group, a 2,3-dihydrotriazole group, an oxazole group, an iso-oxazole group, a thiazole group, an isothiazole group, an oxadiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a 2,3-dihydrobenzimidazole group, an imidazopyridine group, a 2,3-dihydroimidazopyridine group, an imidazopyrimidine group, a 2,3-dihydroimidazopyrimidine group, an imidazopyrazine group, a 2,3-dihydroimidazopyrazine group, a benzoxazole group, a benzothiazole group, a benzoxadiazole group, a benzothiadiazole group, a 5,6,7,8-tetrahydroisoquinoline group, and a 5,6,7,8-tetrahydroquinoline group, but embodiments are not limited thereto.

[0050] In some embodiments, A_{11} to A_{14} may each independently be selected from a benzene group, a carbazole group, an azacarbazole group, a pyridine group, an imidazole group, a triazole group, a benzimidazole group, an imidazopyridine group, and an imidazopyrazine group, but embodiments are not limited thereto.

[0051] In Formula 1, Ar_{11} may be a C_1-C_{60} heterocyclic group, but embodiments are not limited thereto.

[0052] In some embodiments, Ar_{11} may be a nitrogen-containing C_1-C_{60} heterocyclic group including at least one *—N=*' moiety, but embodiments are not limited thereto.

[0053] In some embodiments, Ar_{11} may be selected from a pyrrole group, an imidazole group, a pyrazole group, a pyridine group, a pyrazine group, a pyrimidine group, a pyridazine group, an isoindole group, an indole group, an indazole group, a purine group, a quinoline group, a benzoquinoline group, a phthalazine group, a naphthyridine group, a quinoxaline group, a quinazoline group, a cinnoline group, a carbazole group, an azacarbazole group, a phenanthridine group, an acridine group, a phenanthroline group, a phenazine group, a benzoxazole group, a benzimidazole group, a furan group, a benzofuran group, a thiophene group, a benzothiophene group, a thiazole group, an isothiazole group, a benzothiazole group, an iso-oxazole group, an oxazole group, a triazole group, a tetrazole group, an oxadiazole group, a triazine group, a benzoxazole group, a dibenzofuran group, a dibenzothiophene group, and a benzocarbazole group, but embodiments are not limited thereto.

[0054] In Formula 1, Y_{11} to Y_{14} may each independently be selected from a carbon atom (C) and a nitrogen atom (N).

[0055] In some embodiments, Y_{11}, Y_{12}, and Y_{13} may each be C, and Y_{14} may be N;

[0056] Y_{11}, Y_{12}, and Y_{14} may each be C, and Y_{13} may be N;

[0057] Y_{11}, Y_{13}, and Y_{14} may each be C, and Y_{12} may be N;

[0058] Y_{12}, Y_{13}, and Y_{14} may each be C, and Y_{11} may be N;

[0059] Y_{11} and Y_{14} may each be C, and Y_{12} and Y_{13} may each be N;

[0060] Y_{11} and Y_{14} may each be N, and Y_{12} and Y_{13} may each be C;

[0061] Y_{11} and Y_{12} may each be C, and Y_{13} and Y_{14} may each be N;

[0062] Y_{11} and Y_{12} may each be N, and Y_{13} and Y_{14} may each be C;

[0063] Y_{11} and Y_{13} may each be C, and Y_{12} and Y_{14} may each be N; or

[0064] Y_{11} and Y_{13} may each be N, and Y_{12} and Y_{14} may each be C, but embodiments are not limited thereto.

[0065] In Formula 1, B_{11} to B_{14} may each independently be selected from a single bond, O, and S.

[0066] In some embodiments, B_{11} to B_{14} may each be a single bond;

[0067] B_{11} may be selected from O and S, and B_{12} to B_{14} may each be a single bond;

[0068] B_{12} may be selected from O and S, and B_{11}, B_{13}, and B_{14} may each be a single bond;

[0069] B_{13} may be selected from O and S, and B_{11}, B_{12}, and B_{14} may each be a single bond; or

[0070] B_{14} may be selected from O and S, and B_{11}, B_{12}, and B_{13} may each be a single bond, but embodiments are not limited thereto.

[0071] In some embodiments, B_{11} to B_{14} may each be a single bond, M_{11} may be bound (e.g., coupled) to Y_{11} via a coordinate bond, M_{11} may be bound to Y_{14} via a coordinate bond, M_{11} may be bound to Y_{12} via a covalent bond, and M_{11} may be bound to Y_{13} via a covalent bond, but embodiments are not limited thereto.

[0072] In some embodiments,

[0073] a) Y_{11}, Y_{12}, and Y_{13} may each be C, and Y_{14} may be N;

[0074] Y_{12}, Y_{13}, and Y_{14} may each be C, and Y_{11} may be N; or

[0075] Y_{11} and Y_{14} may each be N, and Y_{12} and Y_{13} may each be C,

[0076] b) B_{11} to B_{14} may each be a single bond, and

[0077] c) M_{11} may be bound to Y_{11} via a coordinate bond, M_{11} may be bound to Y_{14} via a coordinate bond, M_{11} may be bound to Y_{12} via a covalent bond, and M_{11} may be bound to Y_{13} via a covalent bond, but embodiments are not limited thereto.

[0078] In Formula 1, L_{11} to L_{13} may each independently be selected from a single bond, *—O—*', *—S—*', *—C(R_{16})(R_{17})—*', *—C(R_{16})=*', *=C(R_{16})—*', *—C(R_{16})=C(R_{17})—*', *—C(=O)—*', *—C(=S)—*', *—C≡C—*', *—B(R_{16})—*', *—N(R_{16})—*', *—P(R_{16})—*', *—Si(R_{16})(R_{17})—*', *—P(R_{16})(R_{17})—*', and *—Ge(R_{16})(R_{17})—*'.

[0079] In some embodiments, L_{11} to L_{13} may each independently be selected from a single bond, *—O—*', *—S—*', *—C(R_{16})(R_{17})—*', *—C(R_{16})=*', *=C(R_{16})—*', *—B(R_{16})—*', *—N(R_{16})—*', *—Si(R_{16})(R_{17})—*', and *—P(R_{16})(R_{17})—*', but embodiments are not limited thereto.

[0080] a11 to a13 may each independently be an integer from 0 to 3, provided that at least two selected from a11 to a13 may each independently be an integer from 1 to 3.

[0081] a11 indicates the number of L_{11} groups; when a11 is two or greater, at least two L_{11} groups may be identical to or different from each other. Descriptions of a12 and a13 may each independently be understood by referring to the description provided herein in connection with a11.

[0082] When a11 is 0, A_{11} and A_{12} may not be bound, when a12 is 0, A_{13} and A_{14} may not be bound, when a13 is 0, and A_{11} and A_{14} may not be bound.

[0083] In some embodiments, a11 may be 0, and a12 and a13 may each independently be an integer from 1 to 3;

[0084] a12 may be 0, and a11 and a13 may each independently be an integer from 1 to 3; or

[0085] a13 may be 0, and a11 and a12 may each independently be an integer from 1 to 3, but embodiments are not limited thereto.

[0086] In some embodiments, a11 may be 0, and a12 and a13 may each be 1;

[0087] a12 may be 0, and a11 and a13 may each be 1; or

[0088] a13 may be 0, and a11 and a12 may each be 1, but embodiments are not limited thereto.

[0089] In Formula 1, R_{11} to R_{17} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino

group, a hydrazino group, a hydrazono group, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_2-C_{60} alkenyl group, a substituted or unsubstituted C_2-C_{60} alkynyl group, a substituted or unsubstituted C_1-C_{60} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted C_1-C_{60} heteroaryloxy group, a substituted or unsubstituted C_1-C_{60} heteroarylthio group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, —$Si(Q_1)(Q_2)(Q_3)$, —$B(Q_1)(Q_2)$, —$N(Q_1)(Q_2)$, —$P(Q_1)(Q_2)$, —$C(=O)(Q_1)$, —$S(=O)(Q_1)$, —$S(=O)_2(Q_1)$, —$P(=O)(Q_1)(Q_2)$, and —$P(=S)(Q_1)(Q_2)$,

[0090] R_{16} and R_{11}, R_{16} and R_{12}, R_{16} and R_{13}, and/or R_{16} and R_{14} may optionally be bound to form a substituted or unsubstituted C_5-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group, and

[0091] R_{16} and R_{17} may optionally be bound to form a substituted or unsubstituted C_5-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group,

[0092] wherein Q_1 to Q_3 may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl group.

[0093] In some embodiments, R_{11} to R_{17} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a spiro-fluorene-benzofluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a triazinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, but embodiments are not limited thereto.

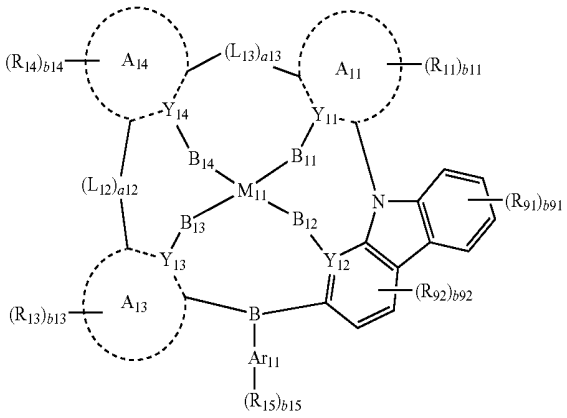
[0094] In Formula 1, b11 to b15 may each independently be an integer from 1 to 8.

[0095] b11 indicates the number of R_{11} groups. When b11 is 2 or greater, at least two R_{11} groups may be identical to or different from each other. Descriptions of b12 to b15 may each independently be understood by referring to the description provided herein in connection with b 1.

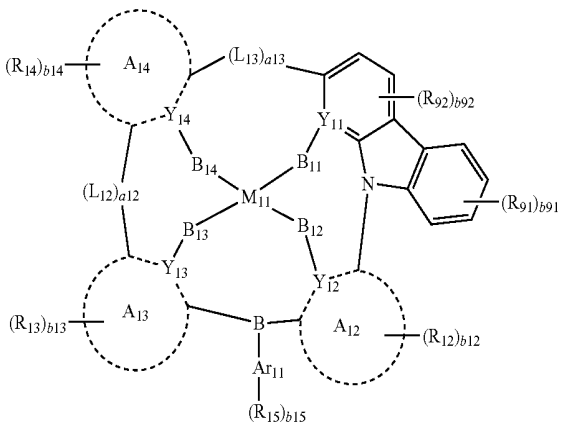
[0096] In Formula 1, b15 number of R_{15} groups may not all be hydrogen at the same time (e.g., at least one of b15 number of R_{15} groups is not hydrogen).

[0097] In some embodiments, the organometallic compound represented by Formula 1 may be represented by one of Formulae 1-1 to 1-5, but embodiments are not limited thereto:

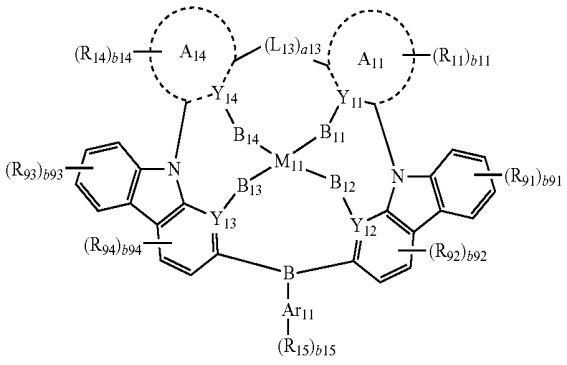
Formula 1-1



Formula 1-2



Formula 1-3



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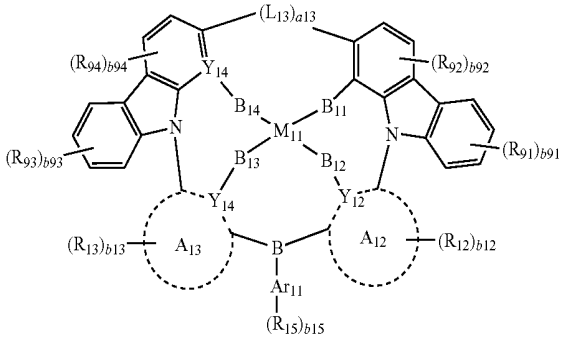
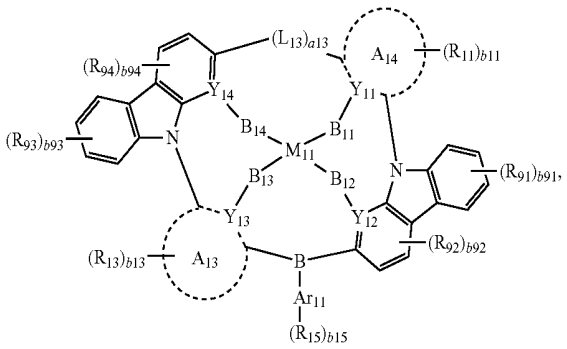
Formula 1-4



Formula 1-5



[0098] wherein, in Formulae 1-1 to 1-5,

[0099] descriptions of R_{91} to R_{94} may each independently be the same as the description for R_{11} provided herein with reference to Formula 1,

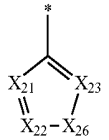
[0100] b91 and b93 may each independently be an integer from 1 to 4,

[0101] b92 and b94 may each independently be selected from 1 and 2, and

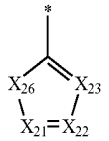
[0102] M_{11}, A_{11} to A_{14}, Ar_{11}, Y_{11} to Y_{14}, B_{11} to B_{14}, L_{11} to L_{13}, a11 to a13, R_{11} to R_{17}, and b11 to b15 may be the same as their respective definitions provided herein with reference to Formula 1.

[0103] In Formula 1, a substituent represented by *—Ar_{11}—$(R_{15})_{b15}$ may be represented by one of Formulae 2-1 to 2-3, hut embodiments are not limited thereto:

Formula 2-1



Formula 2-2



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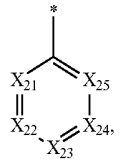
Formula 2-3



[0104] wherein, in Formulae 2-1 to 2-3,

[0105] X_{21} may be selected from $C(R_{21})$ and N, X_{22} may be selected from $C(R_{22})$ and N, X_{23} may be selected from $C(R_{23})$ and N, X_{24} may be selected from $C(R_{24})$ and N, X_{25} may be selected from $C(R_{25})$ and N,

[0106] X_{26} may be selected from O, S, $N(R_{26})$, $C(R_{26})(R_{27})$, and $Si(R_{26})(R_{27})$,

[0107] descriptions for R_{21} to R_{27} may each independently be the same as the description for R_{11} provided herein with reference to Formula 1,

[0108] in Formulae 2-1 and 2-2, at least one selected from X_{21} to X_{23} may be N, or X_{26} may be selected from O, S, and $N(R_{26})$,

[0109] in Formula 2-3, at least one selected from X_{21} to X_{25} may be N,

[0110] in Formulae 2-1 and 2-2, at least one selected from R_{21} to R_{23}, R_{26}, and R_{27} may not be hydrogen (e.g., may be a substituent group other than hydrogen),

[0111] in Formula 2-3, at least one selected from R_{21} to R_{25} may not be hydrogen, and

[0112] * indicates a binding site to an adjacent atom.

[0113] In some embodiments, in Formulae 2-1 to 2-3, R_{21} to R_{27} may each independently be selected from hydrogen, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, and a triazinyl group; and

[0114] a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, and a triazinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a triazinyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, and —$N(Q_{31})(Q_{32})$, wherein Q_{31} to Q_{33} are as defined herein, but embodiments are not limited thereto.

[0115] In some embodiments, in Formulae 2-1 to 2-3, R_{21} to R_{27} may each independently be selected from hydrogen, a methyl group, an ethyl group, a propyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a ter-butyl group, an n-pentyl group, an isopentyl group, a sec-pentyl group, a ter-pentyl group, an n-hexyl group, an iso-hexyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, and a triazinyl group, but embodiments are not limited thereto.

[0116] In some embodiments, at least one selected from R_{21} and R_{23} in Formula 2-1, at least one selected from R_{23} and R_{26} in Formula 2-2, and at least one selected from R_{21} and R_{25} in Formula 2-3 may each independently be selected from a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, and a triazinyl group; and

[0117] a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, and a triazinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a triazinyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, and —$N(Q_{31})(Q_{32})$, wherein Q_{31} to Q_{33} are as defined herein, but embodiments are not limited thereto.

[0118] In some embodiments,

[0119] a) in Formula 2-1, X_{21} may be $C(R_{21})$, and X_{23} may be $C(R_{23})$ or N;

[0120] in Formula 2-1, X_{21} may be N, and X_{23} may be $C(R_{23})$;

[0121] in Formula 2-2, X_{26} may be O or S, and X_{23} may be $C(R_{23})$;

[0122] in Formula 2-2, X_{26} may be $N(R_{26})$, and X_{23} may be $C(R_{23})$ or N;

[0123] in Formula 2-3, X_{21} may be $C(R_{21})$, and X_{25} may be $C(R_{25})$ or N; or

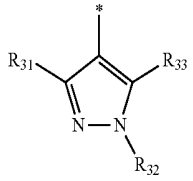
[0124] in Formula 2-3, X_{21} may be N, and X_{25} may be $C(R_{25})$, and

[0125] b) at least one selected from R_{21} and R_{23} in Formula 2-1, at least one selected from R_{23} and R_{26} in Formula 2-2, and at least one selected from R_{21} and R_{25} in Formula 2-3 may each independently be selected from a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, and a triazinyl group; and

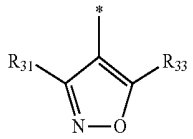
[0126] a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, and a triazinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a triazinyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, and —$N(Q_{31})(Q_{32})$, wherein Q_{31} to Q_{33} are as defined herein, but embodiments are not limited thereto.

[0127] In some embodiments, in Formula 1, a substituent represented by *—Ar_{11}—$(R_{15})_{b15}$ may be selected from groups represented by Formulae 3-1 to 3-3, but embodiments are not limited thereto:

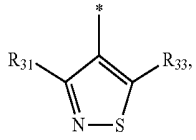
Formula 3-1



Formula 3-2



Formula 3-3



[0128] wherein, in Formulae 3-1 to 3-3,

[0129] descriptions of R_{31} to R_{33} may each independently be the same as the description for R_{11} provided herein with reference to Formula 1,

[0130] R_{31} to R_{33} may not be hydrogen at the same time (e.g., at least one selected from R_{31} to R_{33} is not hydrogen), and

[0131] * indicates a binding site to an adjacent atom.

[0132] In some embodiments, in Formulae 3-1 to 3-3, R_{31} to R_{33} may each independently be selected from a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, and a triazinyl group; and

[0133] a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, and a triazinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a triazinyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, and —$N(Q_{31})(Q_{32})$, wherein Q_{31} to Q_{33} are as defined herein, but embodiments are not limited thereto.

[0134] In some embodiments, in Formulae 3-1 to 3-3, R_{31} to R_{33} may each independently be selected from a methyl group, an ethyl group, a propyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a ter-butyl group, an n-pentyl group, an isopentyl group, a sec-pentyl group, a ter-pentyl group, an n-hexyl group, an iso-hexyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, and a triazinyl group, but embodiments are not limited thereto.

[0135] In some embodiments, in Formula 1, a substituent represented by *—Ar_{11}—$(R_{15})_{b15}$ may be selected from groups represented by Formulae 3-1 to 3-3, and

[0136] a11 may be 0, and a12 and a13 may each be 1; a12 may be 0, and a11 and a13 may each be 1; or a13 may be 0, and a11 and a12 may each be 1, but embodiments are not limited thereto.

[0137] In some embodiments, in Formula 1, a substituent represented by *—Ar_{11}—$(R_{15})_{b15}$ may be selected from groups represented by Formulae 3-1 to 3-3,

[0138] a11 may be 0, and a12 and a13 may each be 1; a12 may be 0, and a11 and a13 may each be 1; or a13 may be 0, and a11 and a12 may each be 1, and

[0139] R_{31} to R_{33} may each independently be selected from a methyl group, an ethyl group, a propyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a ter-butyl group, an n-pentyl group, an isopentyl group, a sec-pentyl group, a ter-pentyl group, an n-hexyl group, an iso-hexyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, and a triazinyl group, but embodiments are not limited thereto.

[0140] In some embodiments, the organometallic compound represented by Formula 1 may be selected from Compounds 1 to 45, but embodiments are not limited thereto:

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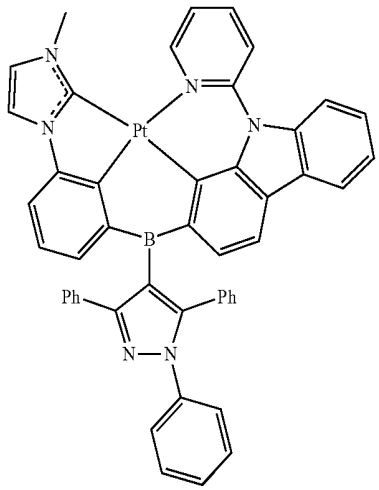

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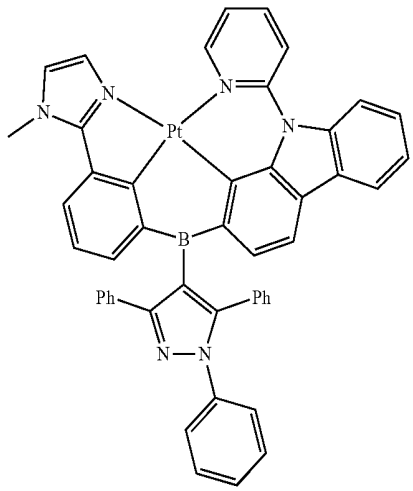

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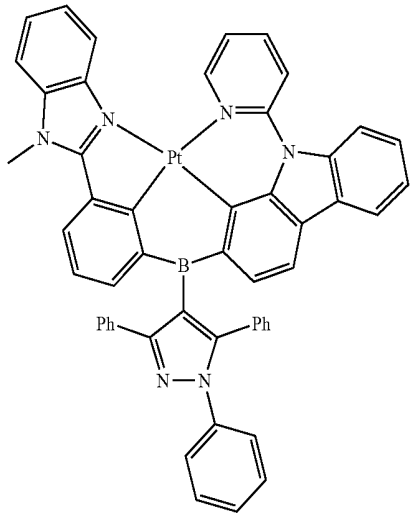

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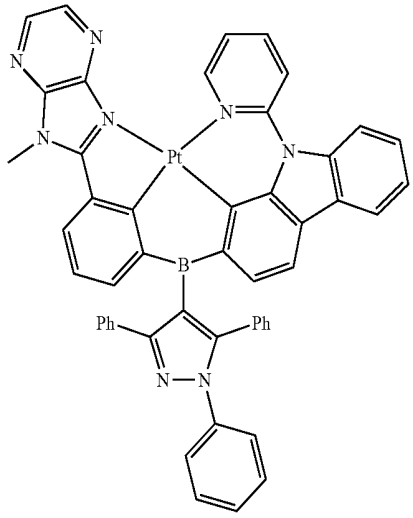

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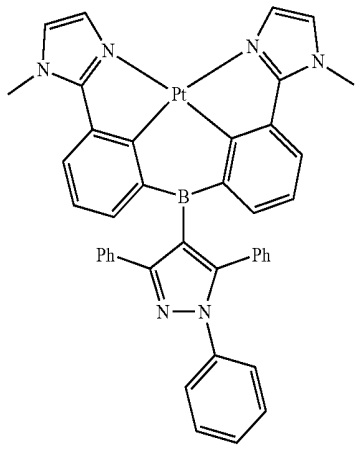

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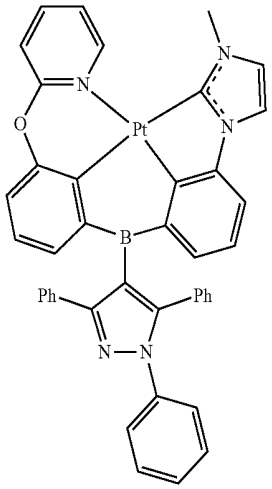

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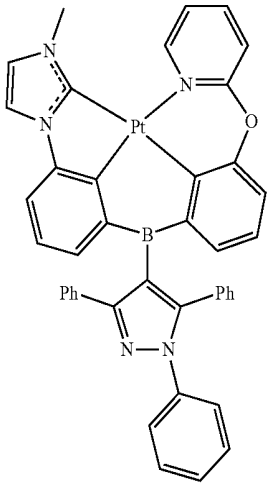

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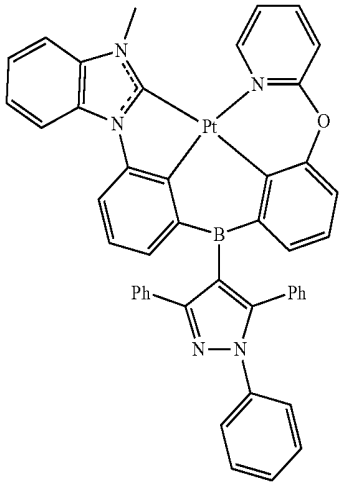

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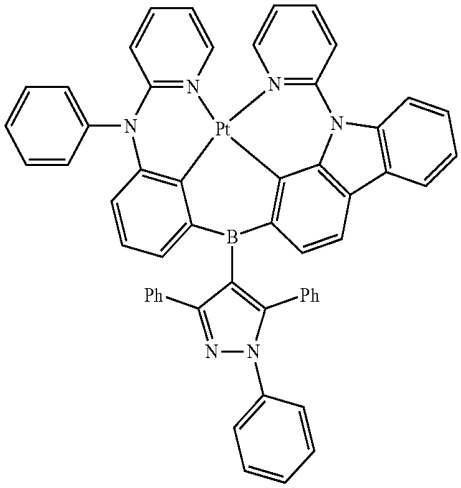

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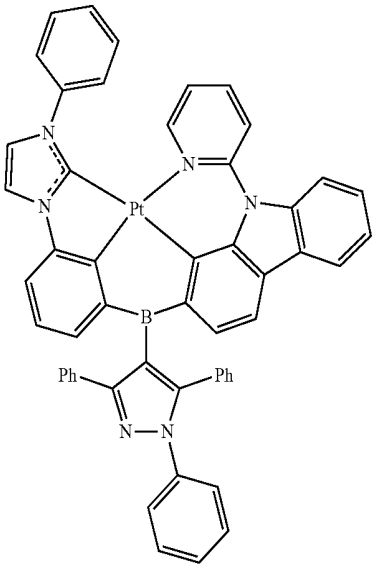

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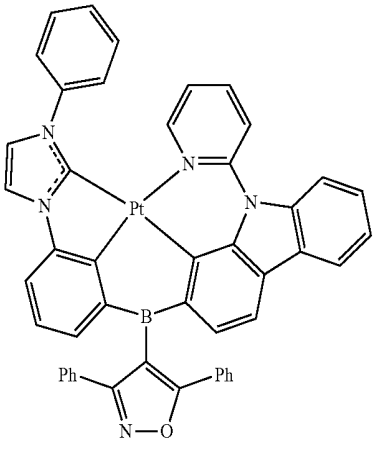

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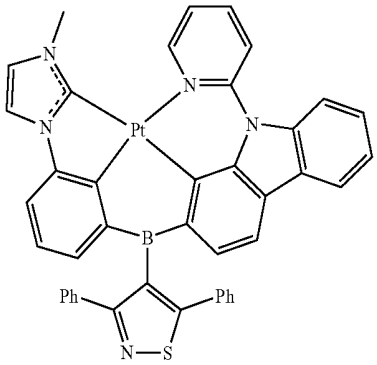

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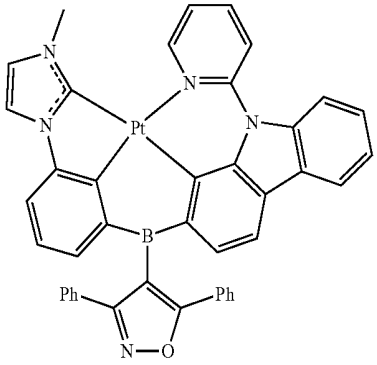

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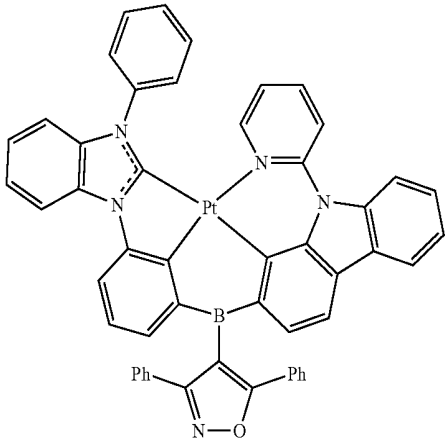

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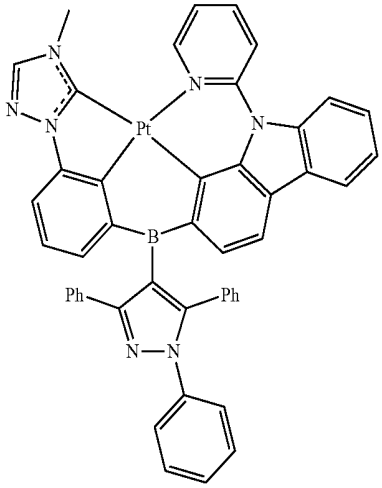

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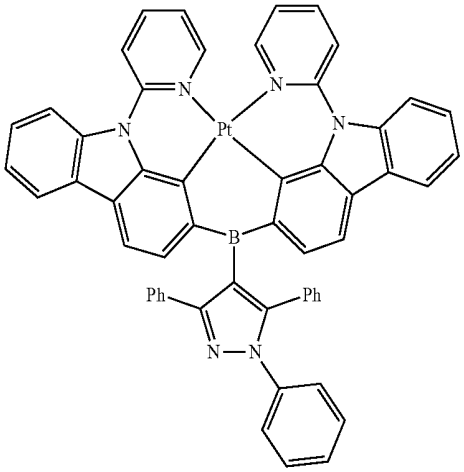

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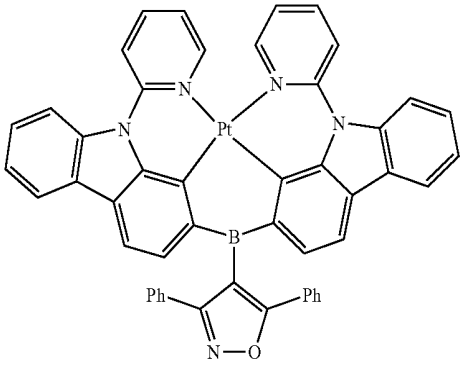

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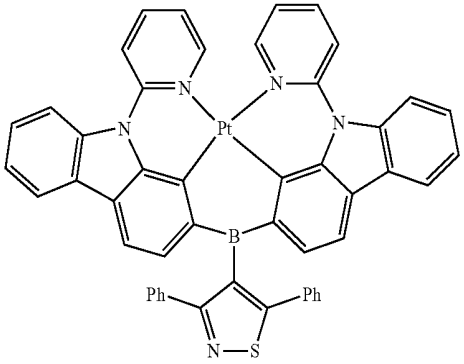

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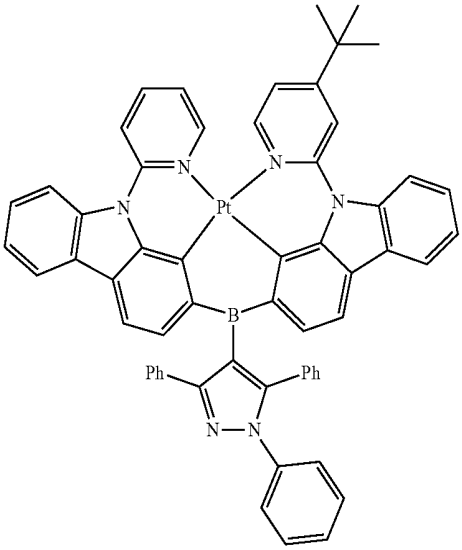

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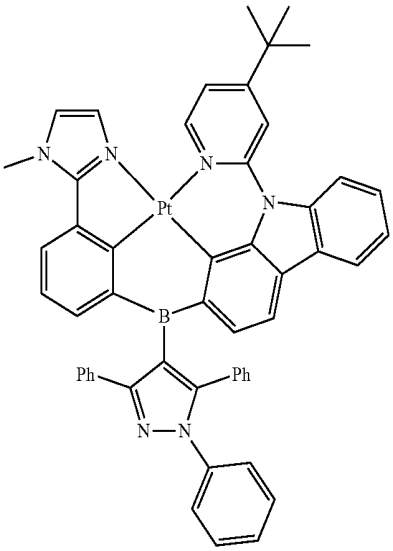

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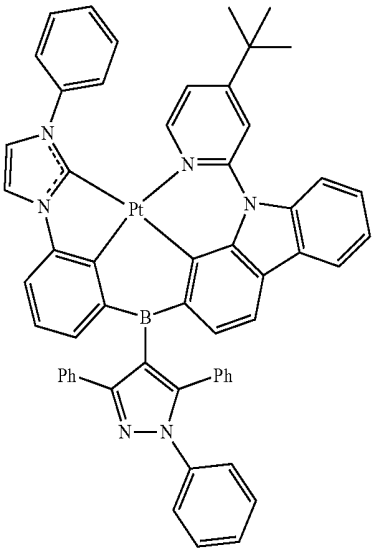

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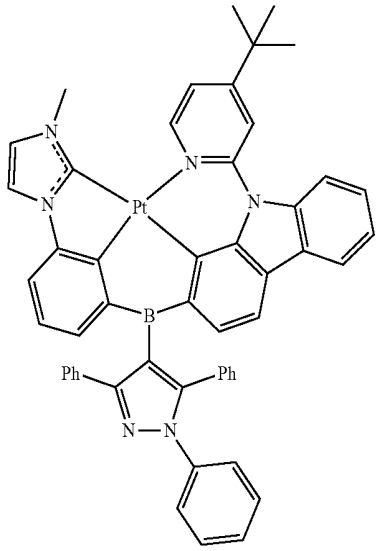

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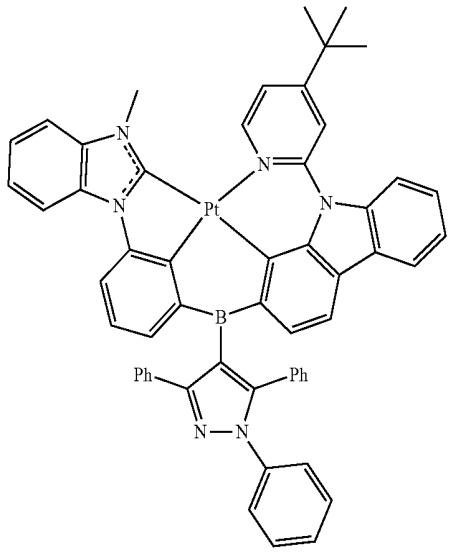

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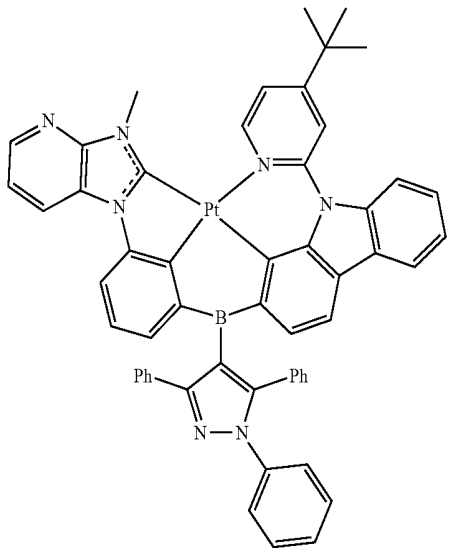

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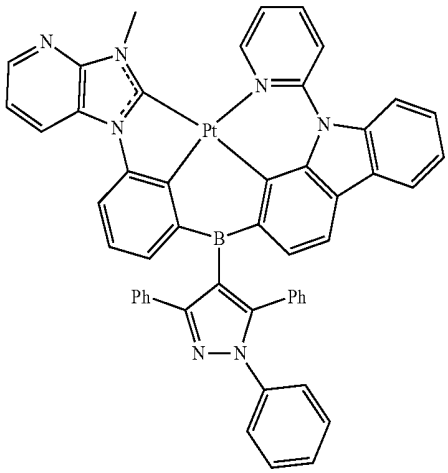

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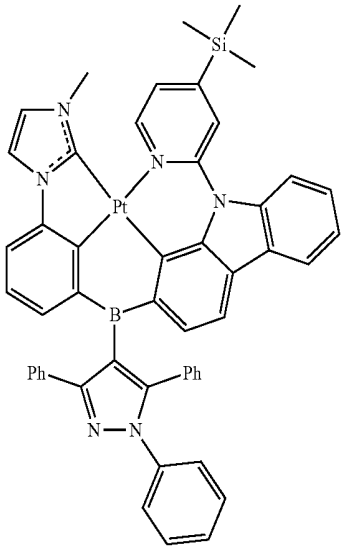

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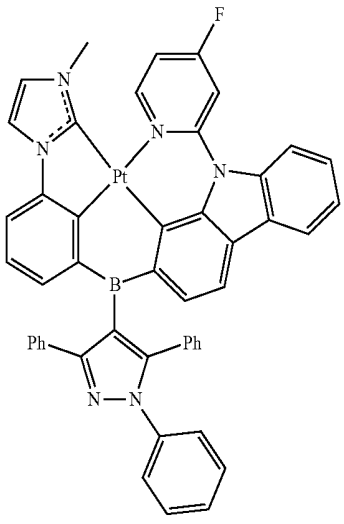

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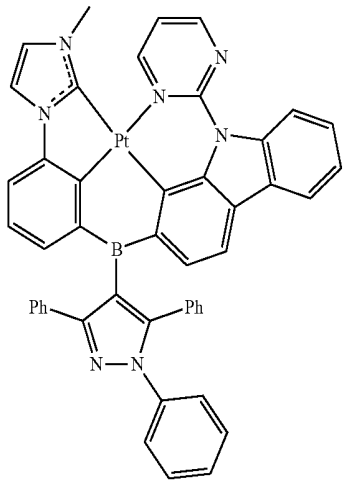

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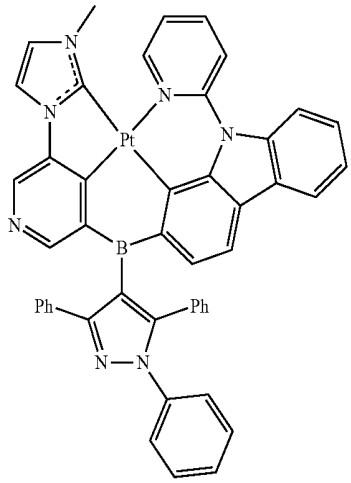

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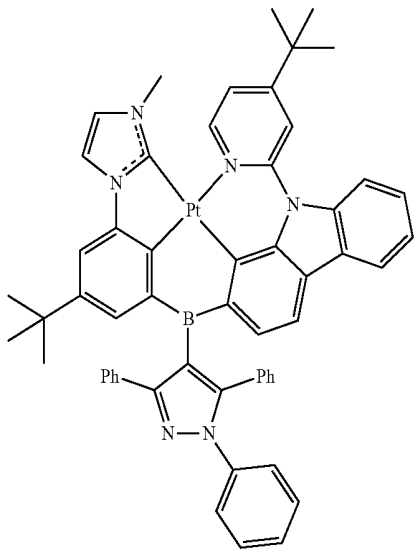

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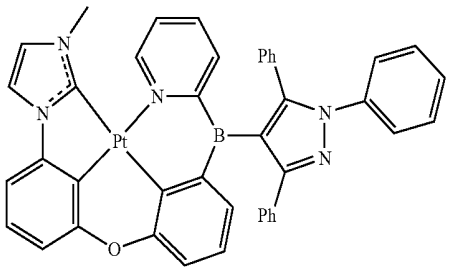

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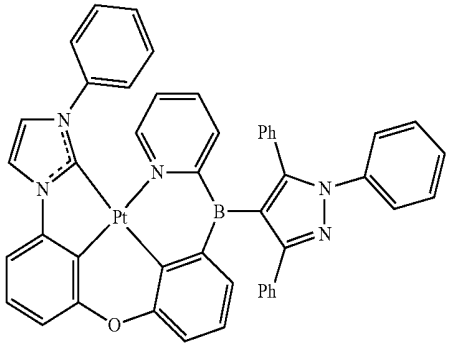

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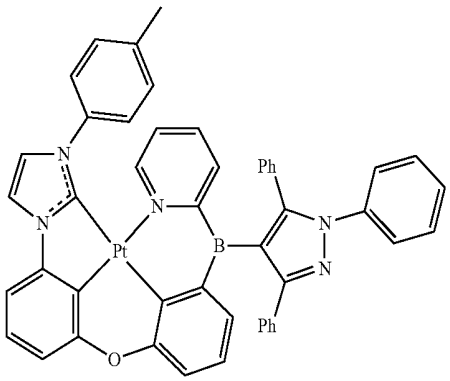

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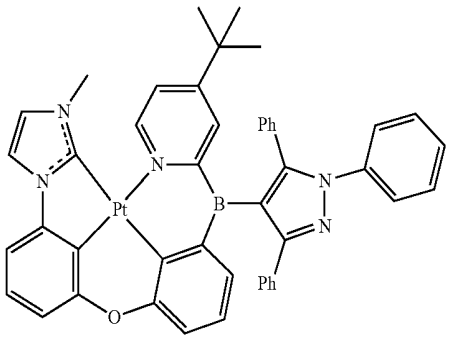

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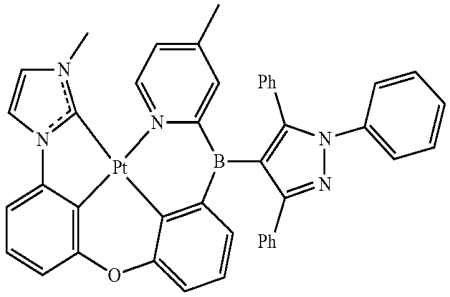

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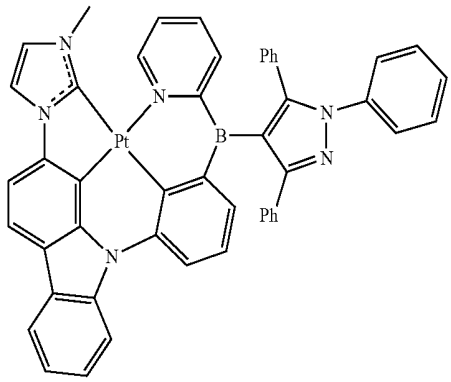

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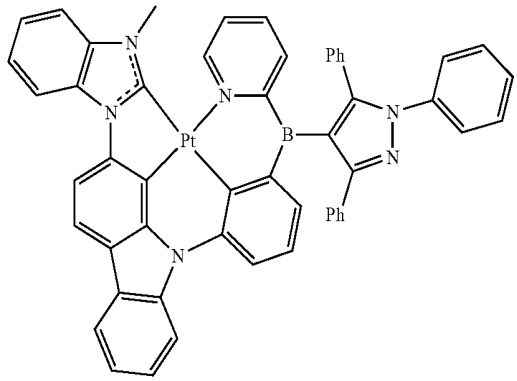

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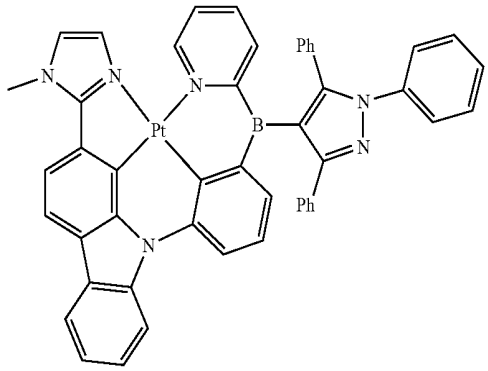

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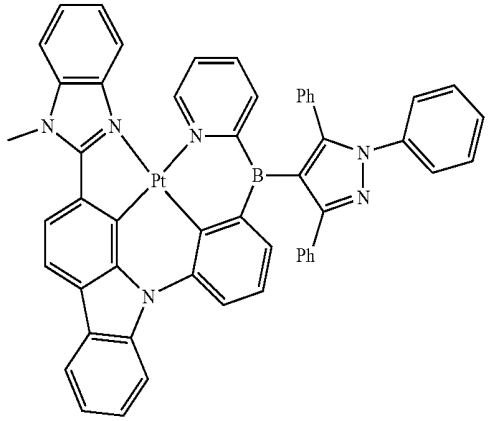

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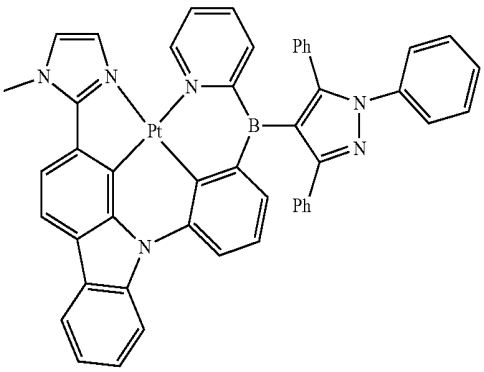

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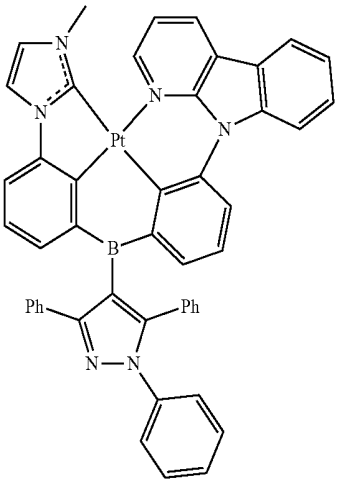

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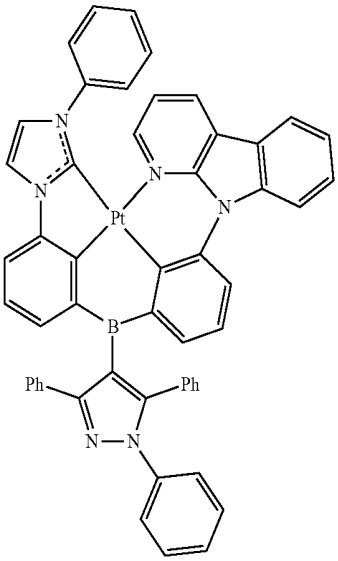

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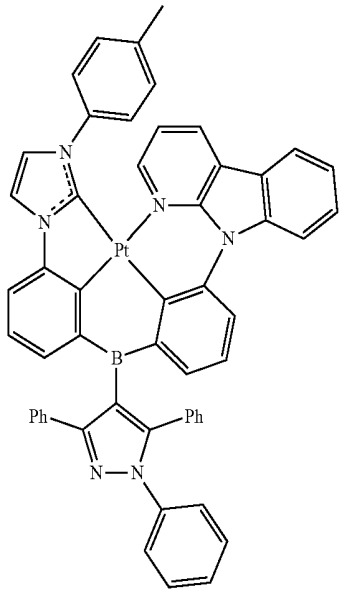

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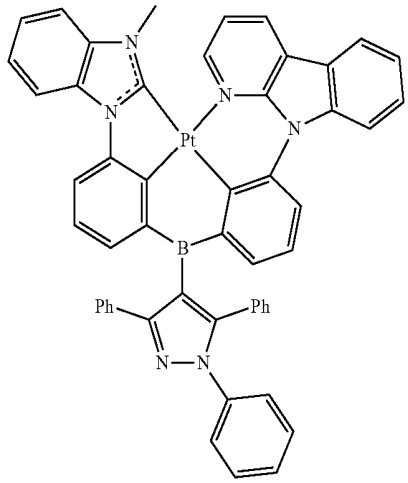

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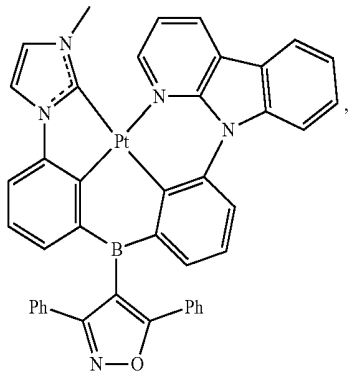


[0141] wherein "Ph" in Compounds 1 to 45 represents a phenyl group.

[0142] The organometallic compound represented by Formula 1 may include at least one substituent which is not a hydrogen atom, as a substituent of an Ar_1 group bound to the boron atom. Accordingly, in the organometallic compound represented by Formula 1, a first plane including A_{11} to A_{14} is misaligned with respect to a second plane including Ar_{11} and $(R_{15})_{b15}$. Thus, intermolecular interaction may decrease, and the formation of an intermolecular excimer may be prevented or reduced. Therefore, shifting of a spectrum toward long wavelengths, which may be caused by formation of an excimer, may be prevented or reduced by the organometallic compound represented by Formula 1, and consequently, light of a deep blue color may be emitted. In addition, in the organometallic compound represented by Formula 1, the substituent of the Ar_{11} group bound to the boron atom may sterically shield the central metal ion. By shielding the central metal ion, the organometallic compound may be chemically and/or physically stable. Thus, an organic light-emitting device including the organometallic compound may have improved lifespan characteristics. Therefore, an organic light-emitting device including the organometallic compound may have high efficiency, long lifespan, and high color purity.

[0143] The organometallic compound represented by Formula 1 may be synthesized by using any suitable organic synthetic method. A method of synthesizing the organometallic compound may be understood by one of ordinary skill in the art by referring to Examples described herein.

[0144] The organometallic compound represented by Formula 1 may be used in a pair of electrodes in an organic light-emitting device.

[0145] For example, the organic light-emitting device may include a first electrode; a second electrode; and an organic layer that may be between the first electrode and the second electrode, and that may include an emission layer and the organometallic compound represented by Formula 1.

[0146] In some embodiments, the emission layer may include the organometallic compound, but embodiments are not limited thereto.

[0147] In some embodiments, the organometallic compound included in the emission layer may be a dopant, and the emission layer may further include a host, but embodiments are not limited thereto.

[0148] As used herein, the expression "(the organic layer) includes at least one organometallic compound" may refer to the organic layer including one or more identical organometallic compounds of Formula 1, or at least two different organometallic compounds of Formula 1.

[0149] For example, Compound 1 may only be included in the organic layer as an organometallic compound. In this case, Compound 1 may be included in the emission layer of the organic light-emitting device. In some embodiments, Compounds 1 and 2 may be included in the organic layer as organometallic compounds. In this regard, Compounds 1 and 2 may both be present in the same layer (e.g., Compounds 1 and 2 may be both present in an emission layer), or in different layers (e.g., Compound 1 may be present in an emission layer, and Compound 2 may be present in a hole transport layer).

[0150] The organic layer may include i) a hole transport region between the first electrode (anode) and the emission layer that includes at least one selected from a hole injection layer, a hole transport layer, an emission auxiliary layer, and an electron blocking layer, and ii) an electron transport region between the emission layer and the second electrode (cathode) that includes at least one selected from a hole blocking layer, an electron transport layer, and an electron injection layer. The emission layer may include at least one organometallic compound represented by Formula 1.

[0151] The term "organic layer" as used herein may refer to a single layer and/or a plurality of layers between the first electrode and the second electrode in an organic light-emitting device. A material included in the "organic layer" is not limited to an organic material.

[0152] FIG. **1** illustrates a schematic cross-sectional view of an organic light-emitting device **10** according to an embodiment. The organic light-emitting device **10** may include the first electrode **110**, the organic layer **150**, and the second electrode **190**.

[0153] Hereinafter, a structure of the organic light-emitting device **10** according to an embodiment and a method of manufacturing the organic light-emitting device according to an embodiment will be described in connection with FIG. **1**.

[0154] Referring to FIG. **1**, a substrate may be additionally disposed (e.g., positioned) under a first electrode **110** or over a second electrode **190**. The substrate may be a glass substrate or a plastic substrate, each having excellent mechanical strength, thermal stability, transparency, surface smoothness, ease of handling, and/or water resistance.

[0155] The first electrode **110** may be formed by depositing or sputtering a material for forming the first electrode **110** over the substrate. When the first electrode **110** is an anode, the material for forming the first electrode **110** may be selected from materials with a high work function that facilitate hole injection.

[0156] 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 be selected from indium tin oxide (ITO), indium zinc oxide (IZO), tin oxide (SnO_2), zinc oxide (ZnO), and any combinations thereof, but embodiments are not limited thereto. When the first electrode **110** is a semi-transmissive electrode or a reflective electrode, as a material for forming the first electrode **110**, at least one selected from magnesium (Mg), aluminum (Al), aluminum-lithium (Al—Li), calcium (Ca), magnesium-indium (Mg—In), magnesium-silver (Mg—Ag), and any combination thereof may be used, but embodiments are not limited thereto.

[0157] The first electrode **110** may have a single-layered structure, or a multi-layered structure including two or more layers. In some embodiments, the first electrode **110** may have a triple-layered structure of ITO/Ag/ITO, but embodiments are not limited thereto.

[0158] The organic layer **150** may be positioned on the first electrode **110**. The organic layer **150** may include an emission layer.

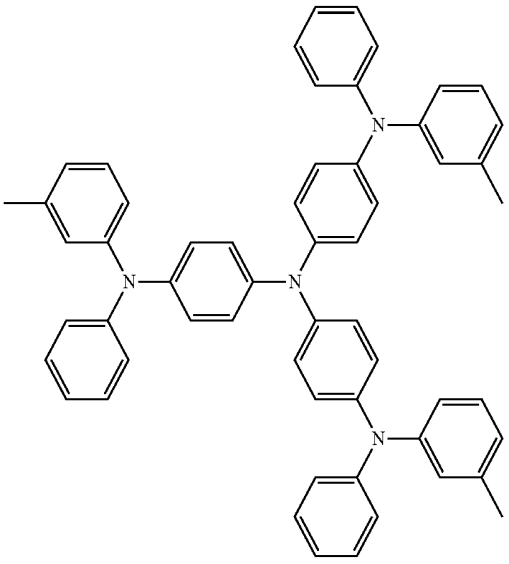
[0159] The organic layer **150** may further include a hole transport region between the first electrode **110** and the emission layer and an electron transport region between the emission layer and the second electrode **190**.

[0160] The hole transport region may have i) a single-layered structure including a single layer including a single material, ii) a single-layered structure including a single layer including a plurality of different materials, or iii) a multi-layered structure having a plurality of layers including a plurality of different materials.

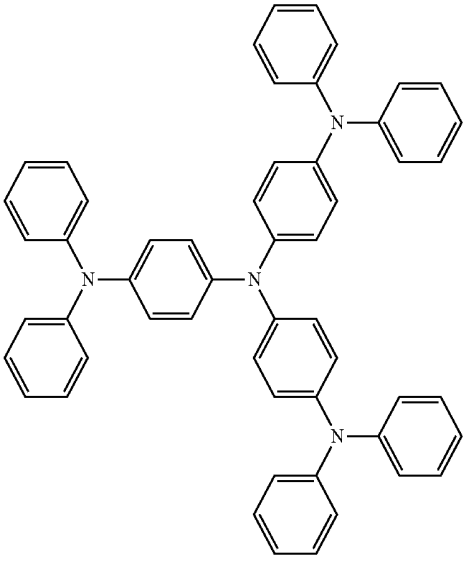
[0161] The hole transport region may include at least one selected from a hole injection layer, a hole transport layer, an emission auxiliary layer, and an electron blocking layer.

[0162] For example, the hole transport region may have a single-layered structure including a single layer including a plurality of different materials or a multi-layered structure, for example, a hole injection layer/hole transport layer structure, a hole injection layer/hole transport layer/emission auxiliary layer structure, a hole injection layer/emission auxiliary layer structure, a hole transport layer/emission auxiliary layer structure, or a hole injection layer/hole transport layer/electron blocking layer structure, wherein the layers of each structure are sequentially stacked on the first electrode **110** in the stated order, but embodiments are not limited thereto.

[0163] The hole transport region may include at least one selected from m-MTDATA, TDATA, 2-TNATA, NPB (NPD), β-NPB, TPD, a spiro-TPD, a spiro-NPB, methylated NPB, TAPC, HMTPD, 4,4',4"-tris(N-carbazolyl)triphenylamine (TCTA), polyaniline/dodecylbenzenesulfonic acid (PANI/DBSA), poly(3,4-ethylenedioxythiophene)/poly(4-styrenesulfonate) (PEDOT/PSS), polyaniline/camphor sulfonic acid (PANI/CSA), (polyaniline)/poly(4-styrenesulfonate) (PANI/PSS), a compound represented by Formula 201, and a compound represented by Formula 202:



m-MTDATA



TDATA

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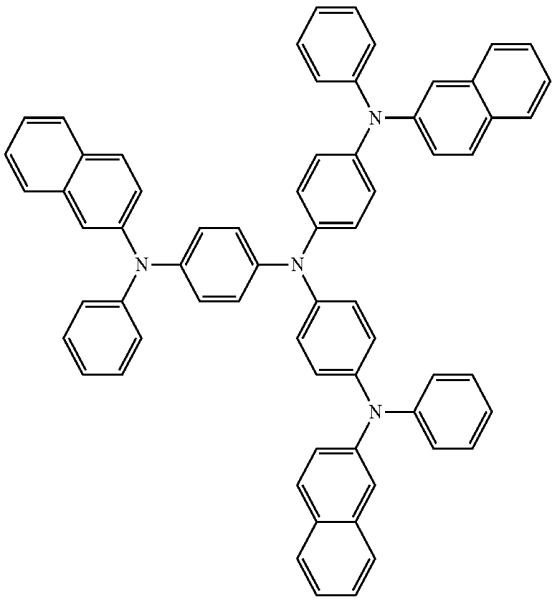
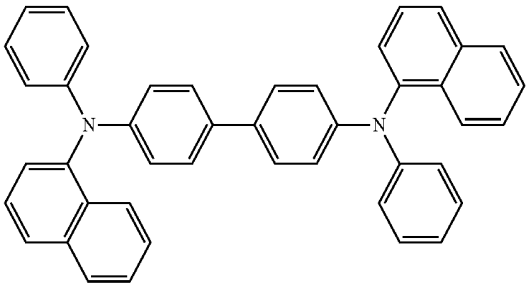
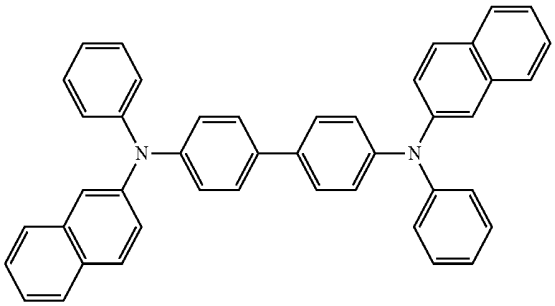


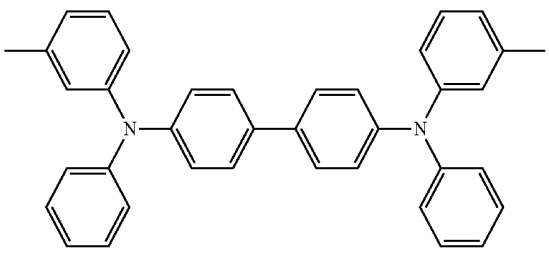
2-TNATA



NPB



β-NPB



TPD

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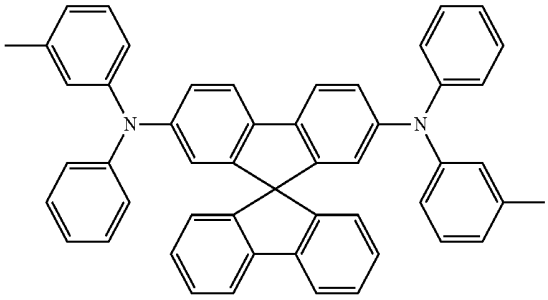
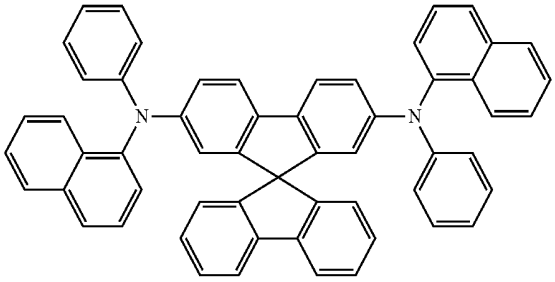
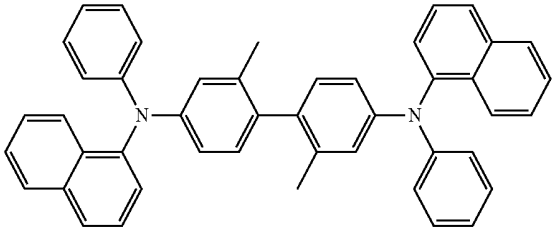


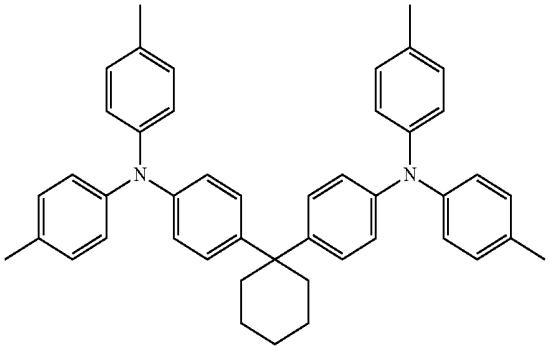
Spiro-TPD



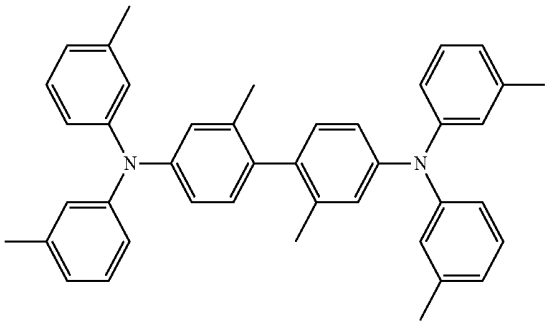
Spiro-NPB



methylated NPB



TAPC



HMTPD

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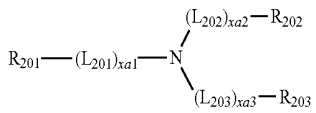
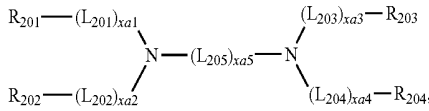
Formula 201



Formula 202



[0164] wherein, in Formulae 201 and 202,

[0165] L_{201} to L_{204} may each independently be selected from a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, a substituted or unsubstituted C_1-C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0166] L_{205} may be selected from *—O—*', *—S—*', *—N(Q_{201})-*', a substituted or unsubstituted C_1-C_{20} alkylene group, a substituted or unsubstituted C_2-C_{20} alkenylene group, a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, a substituted or unsubstituted C_1-C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0167] xa1 to xa4 may each independently be an integer from 0 to 3,

[0168] xa5 may be an integer from 1 to 10, and

[0169] R_{201} to R_{204} and Q_{201} may each independently be selected from a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group.

[0170] In some embodiments, in Formula 202, R_{201} and R_{202} may optionally be bound via a single bond, a dimethyl-methylene group, or a diphenyl-methylene group, and R_{203} and R_{204} may optionally be bound via a single bond, a dimethyl-methylene group, or a diphenyl-methylene group.

[0171] In one embodiment, in Formulae 201 and 202, L_{201} to L_{205} may each independently be selected from:

[0172] a phenylene group, a pentalenylene group, an indenylene group, a naphthylene group, an azulenylene group, a heptalenylene group, an indacenylene group, an acenaphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenalenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a naphthacenylene group, a picenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a rubicenylene group, a coronenylene group, an ovalenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, and a pyridinylene group; and

[0173] a phenylene group, a pentalenylene group, an indenylene group, a naphthylene group, an azulenylene group, a heptalenylene group, an indacenylene group, an acenaphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenalenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a naphthacenylene group, a picenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a rubicenylene group, a coronenylene group, an ovalenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, and a pyridinylene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a phenyl group substituted with a C_1-C_{10} alkyl group, a phenyl group substituted with —F, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a naphthacenyl group, a picenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophe-

nyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, and —$N(Q_{31})(Q_{32})$,

[0174] wherein Q_{31} to Q_{33} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0175] In one or more embodiments, xa1 to xa4 may each independently be 0, 1, or 2.

[0176] In one or more embodiments, xa5 may be 1, 2, 3, or 4.

[0177] In one or more embodiments, R_{201} to R_{204} and Q_{201} may each independently be selected from a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a naphthacenyl group, a picenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, and a pyridinyl group; and

[0178] a phenyl group, a biphenyl group, a terphenyl group, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a naphthacenyl group, a picenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, and a pyridinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a phenyl group substituted with a C_1-C_{10} alkyl group, a phenyl group substituted with —F, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a naphthacenyl group, a picenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, and —$N(Q_{31})(Q_{32})$,

[0179] wherein Q_{31} to Q_{33} may be the same as those described herein.

[0180] In one or more embodiments, in Formula 201, at least one of R_{201} to R_{203} may each independently be selected from:

[0181] a fluorenyl group, a spiro-bifluorenyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

[0182] a fluorenyl group, a spiro-bifluorenyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a phenyl group substituted with a C_1-C_{10} alkyl group, a phenyl group substituted with —F, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, but embodiments are not limited thereto.

[0183] In one or more embodiments, in Formula 202, i) R_{201} may be bound to R_{202} via a single bond, and/or ii) R_{203} may be bound to R_{204} via a single bond.

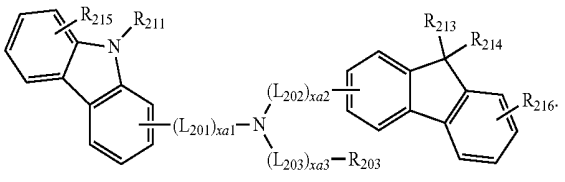
[0184] In one or more embodiments, in Formula 202, at least one of R_{201} to R_{204} may be selected from:

[0185] a carbazolyl group; and

[0186] a carbazolyl group substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a phenyl group substituted with a C_1-C_{10} alkyl group, a phenyl group substituted with —F, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, but embodiments are not limited thereto.

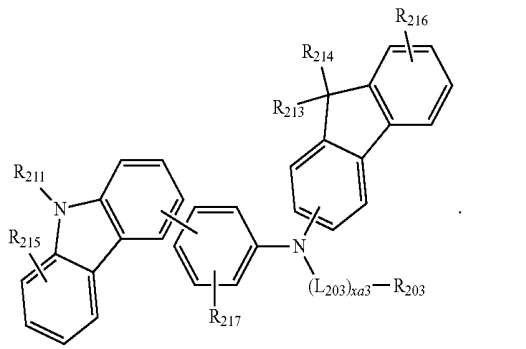
[0187] The compound represented by Formula 201 may be represented by Formula 201A:

Formula 201A



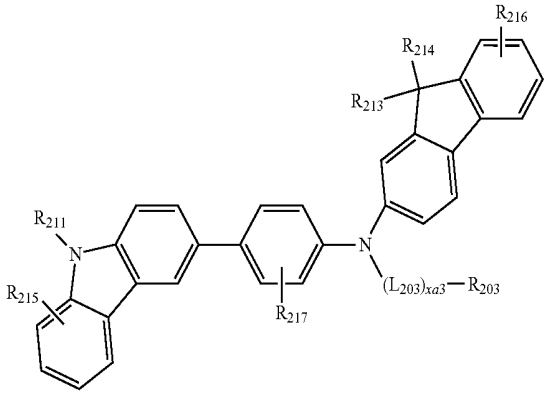
[0188] In some embodiments, the compound represented by Formula 201 may be represented by Formula 201A(1), but embodiments are not limited thereto:

Formula 201A(1)

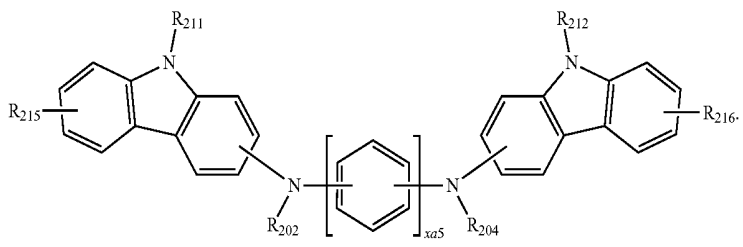


[0189] In some embodiments, the compound represented by Formula 201 may be represented by Formula 201A-1, but embodiments are not limited thereto:

Formula 201A-1



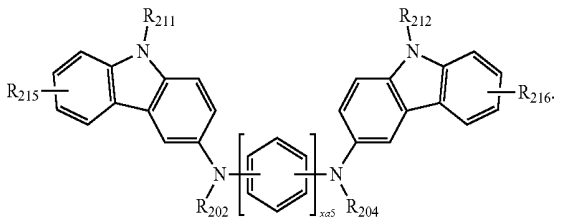
[0190] In some embodiments, the compound represented by Formula 202 may be represented by Formula 202A:



Formula 202A

[0191] In some embodiments, the compound represented by Formula 202 may be represented by Formula 202A-1:

Formula 202A-1



[0192] In Formulae 201A, 201A(1), 201A-1, 202A, and 202A-1,

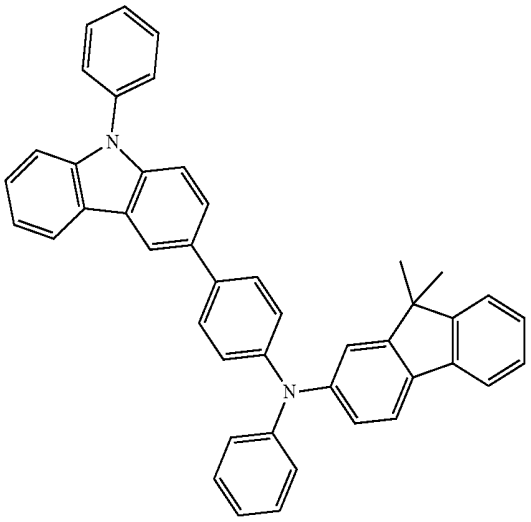
[0193] descriptions of L_{201} to L_{203}, xa1 to xa3, xa5, and R_{202} to R_{204} may be respectively the same as those provided herein,

[0194] descriptions of R_{211} and R_{212} may each independently be substantially the same as that provided herein in connection with R_{203}, and

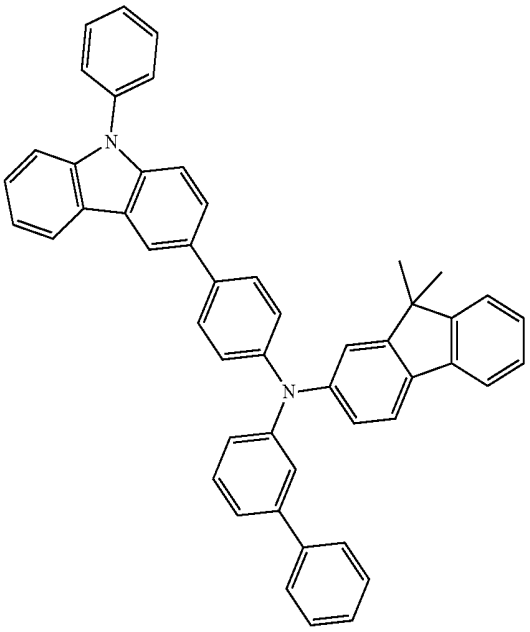
[0195] R_{213} to R_{217} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a biphenyl group, a terphenyl group, a phenyl group substituted with a C_1-C_{10} alkyl group, a phenyl group substituted with —F, a pentalenyl group, an indenyl group, a naphthyl group, an azulenyl group, a heptalenyl group, an indacenyl group, an acenaphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenalenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a naphthacenyl group, a picenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a rubicenyl group, a coronenyl group, an ovalenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, and a pyridinyl group.

[0196] The hole transport region may include at least one compound selected from Compounds HT1 to HT39, but embodiments are not limited thereto:

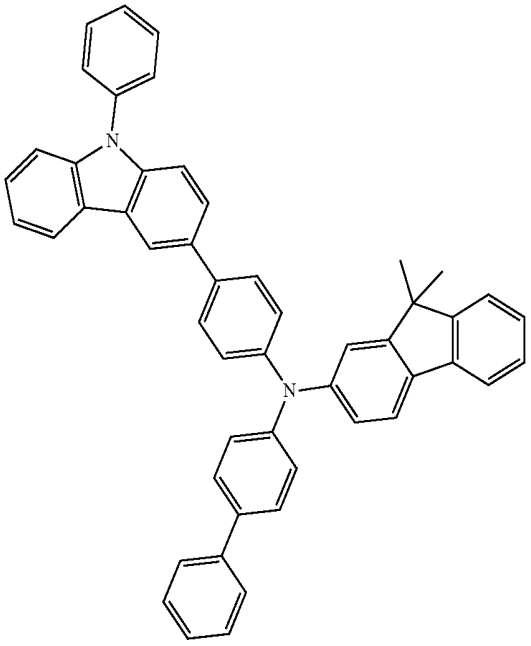
HT1



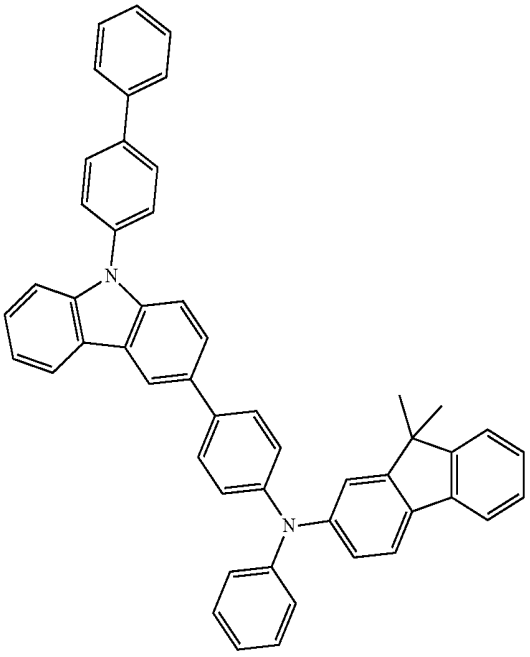
HT2



HT3



HT4



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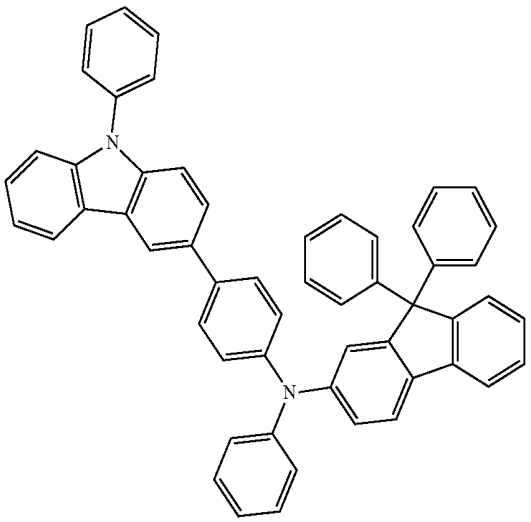
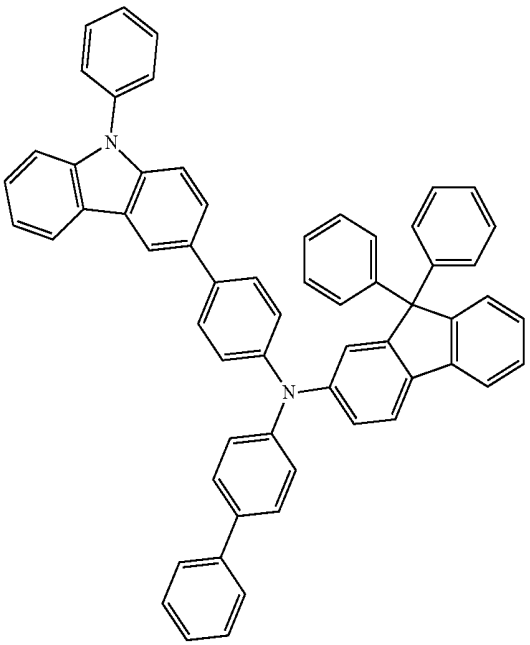
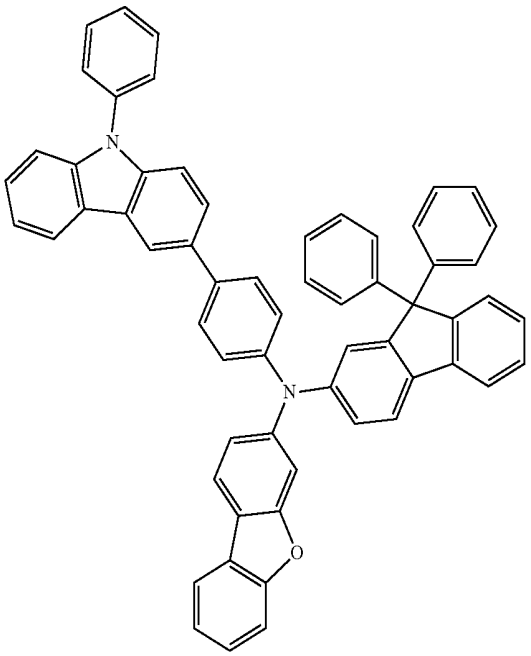
HT5



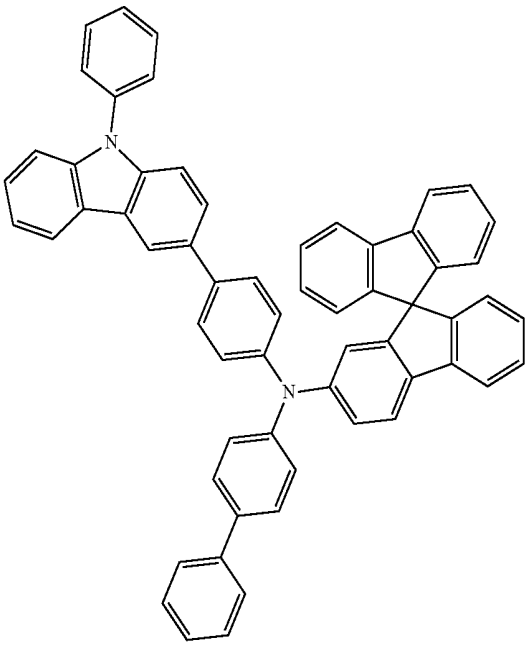
HT6



HT7



HT8



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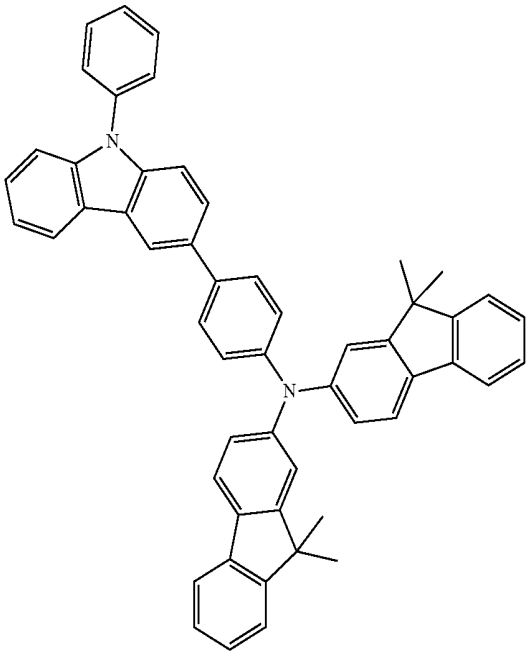

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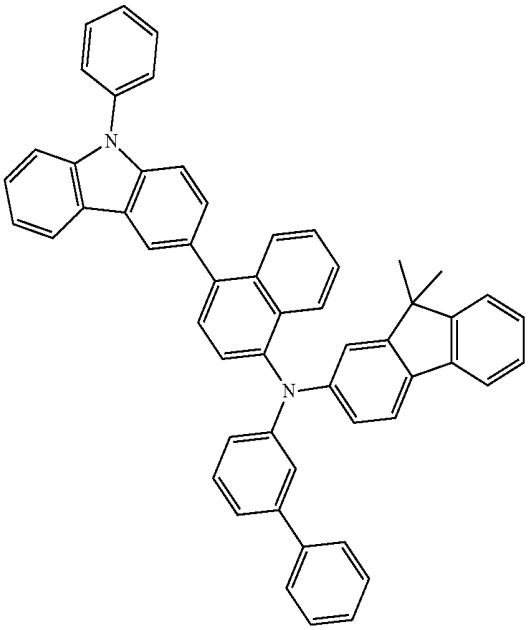

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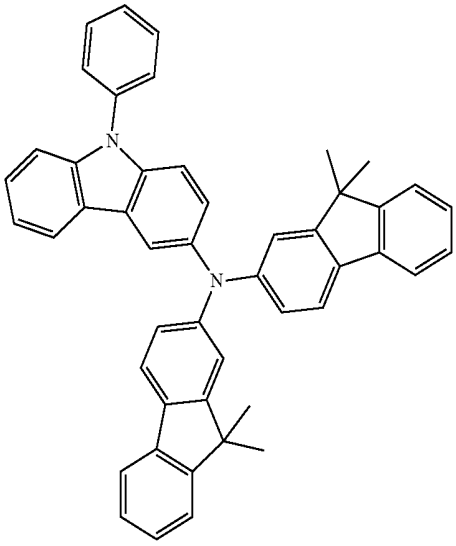

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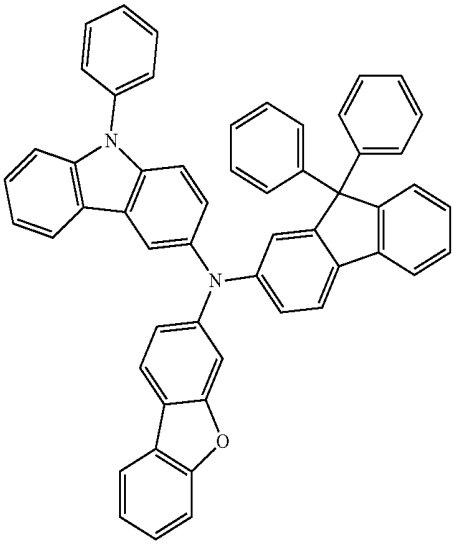

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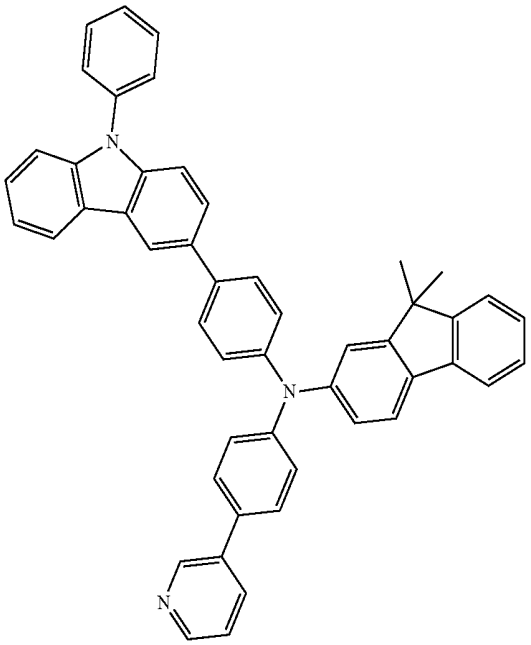

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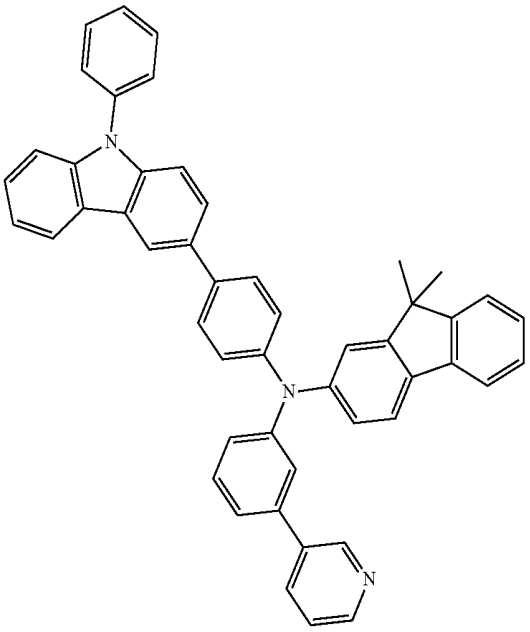

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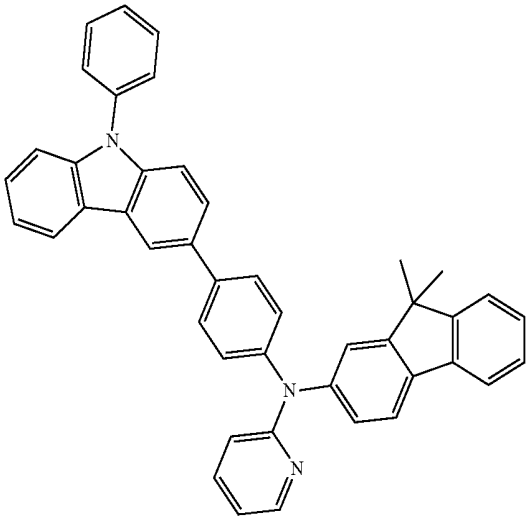

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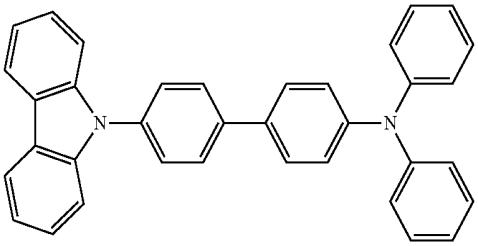

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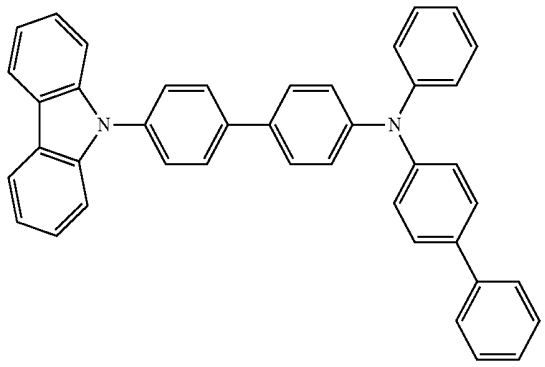

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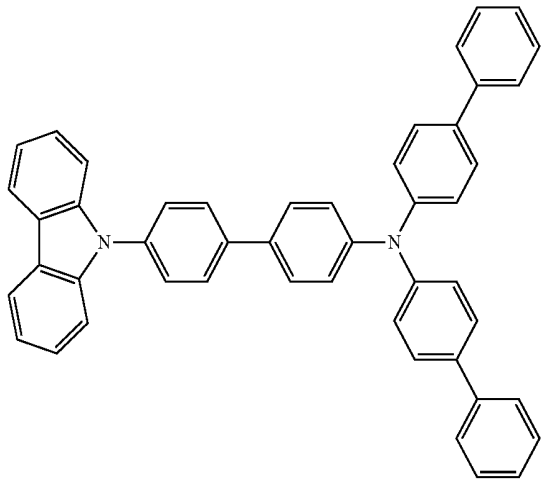

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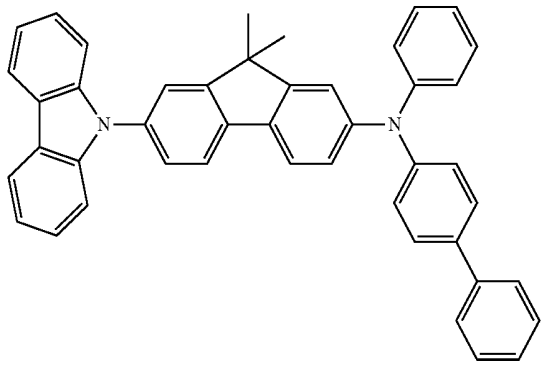

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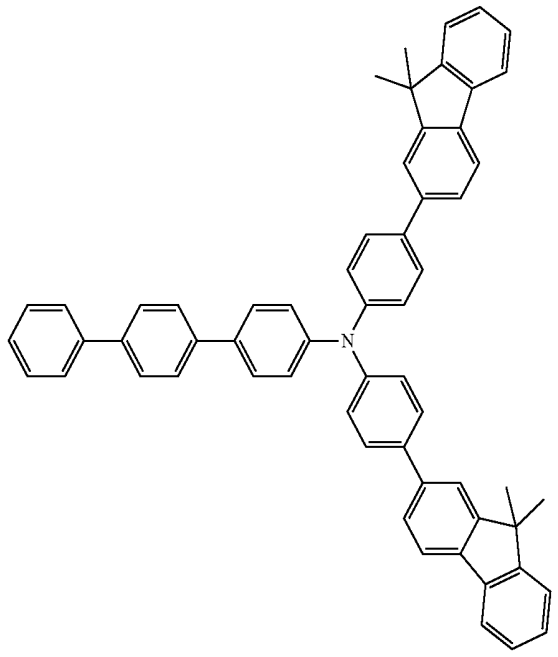

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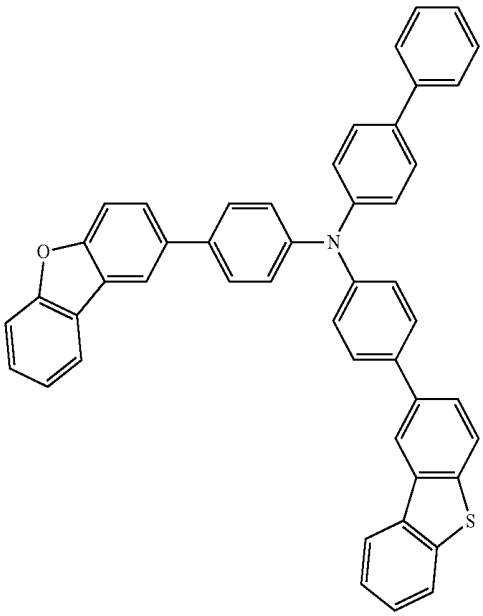

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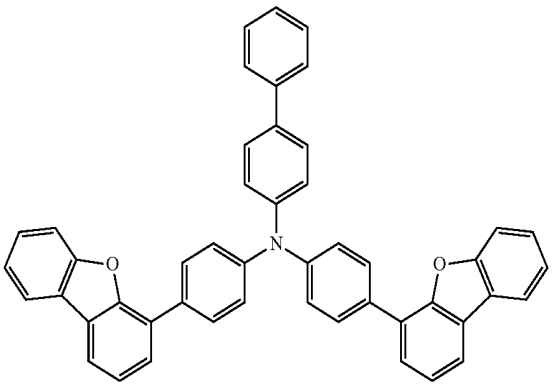

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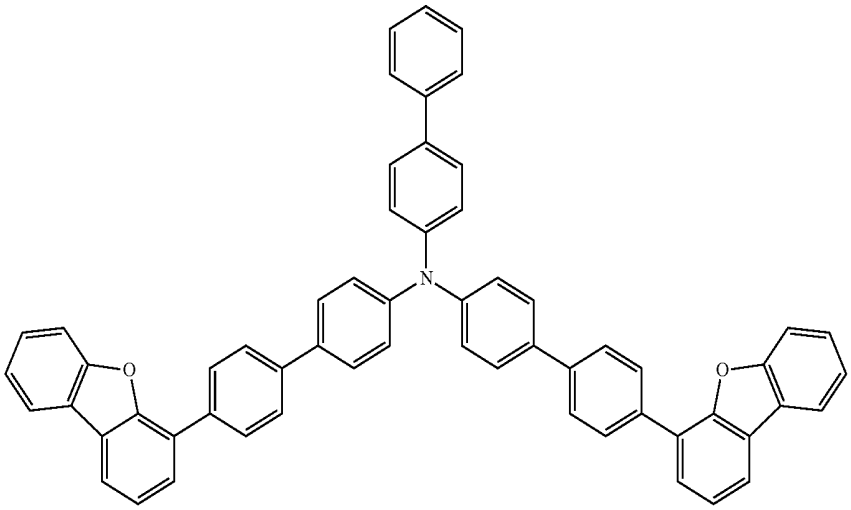

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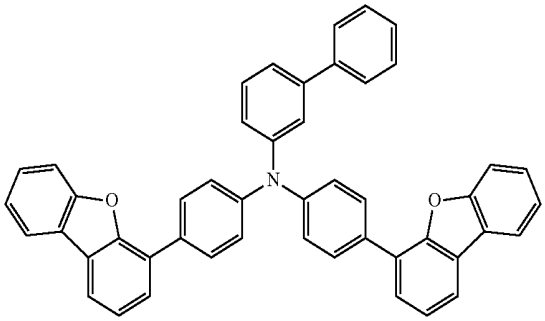

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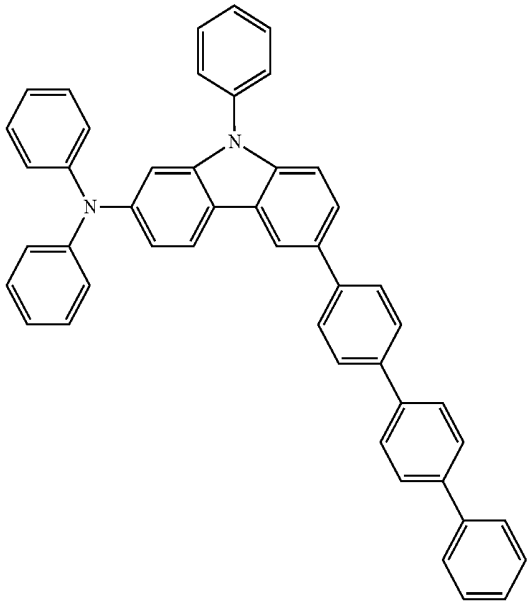

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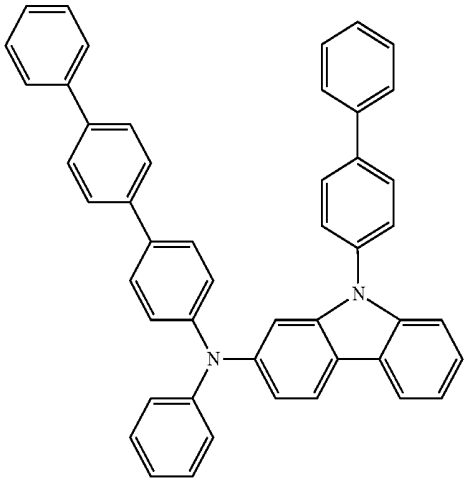

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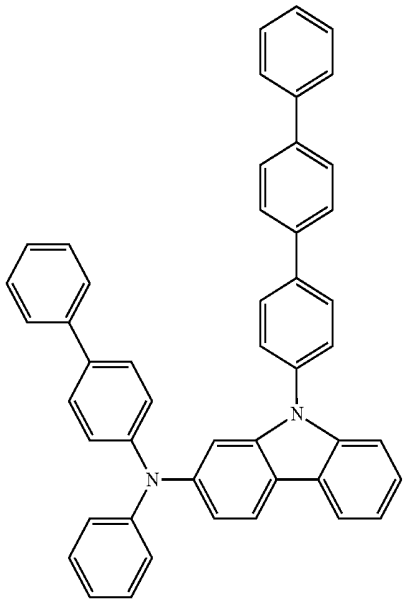

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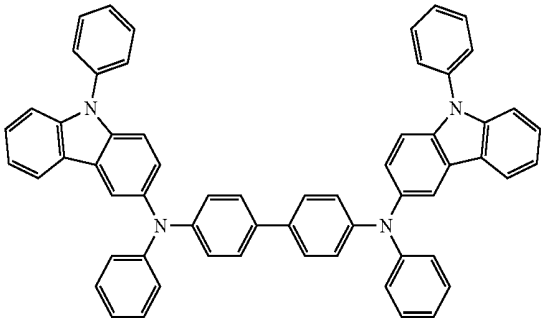

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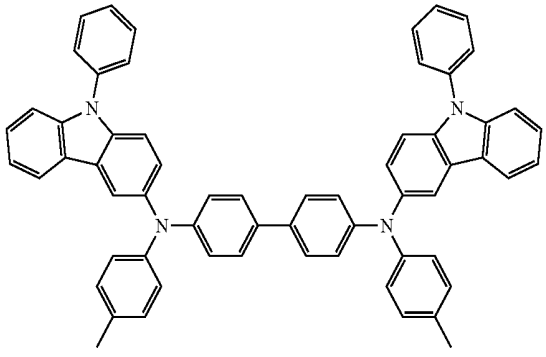

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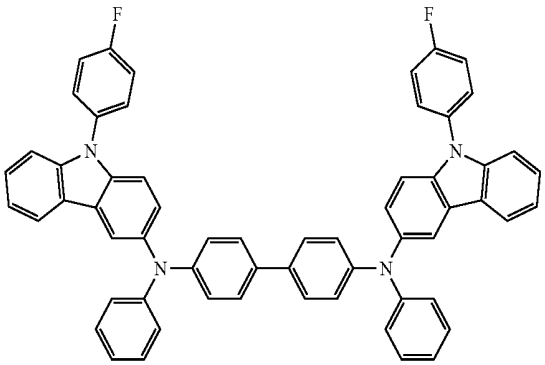

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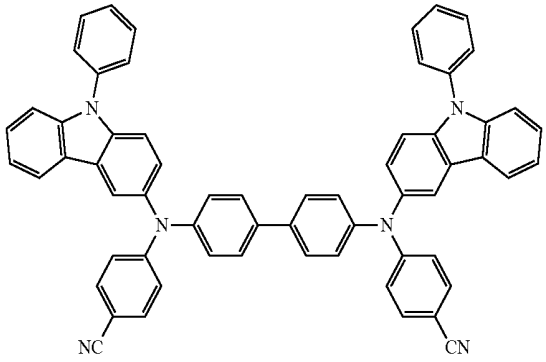

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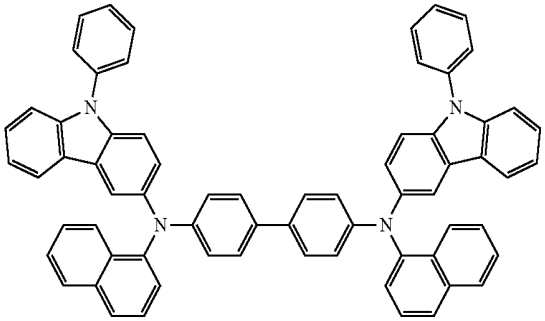

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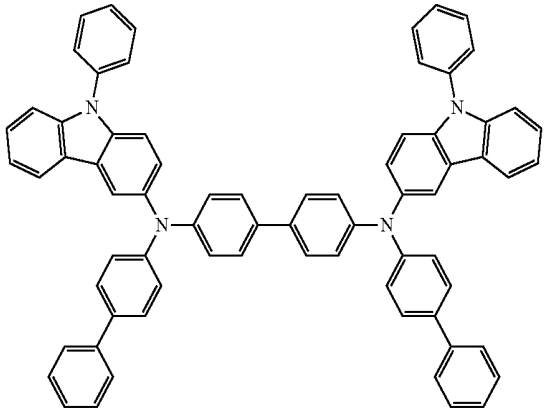

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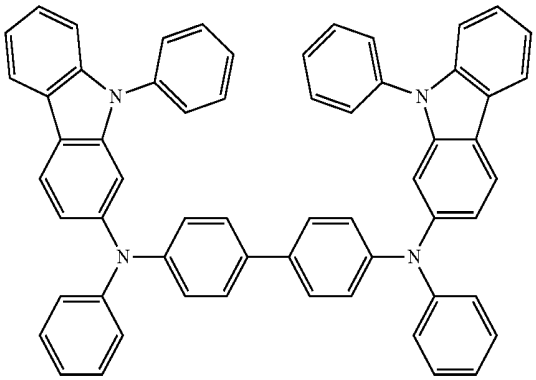

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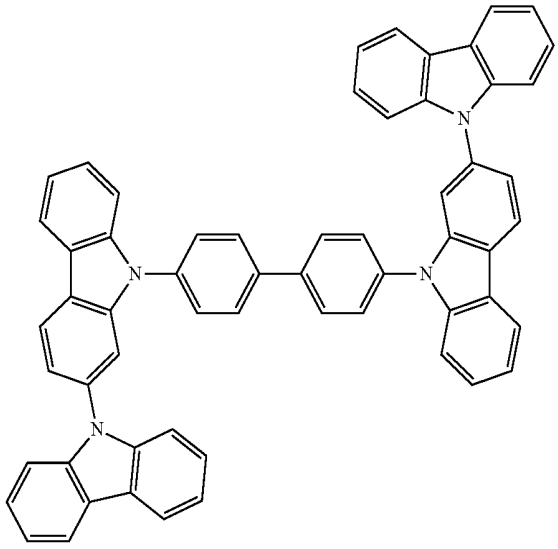

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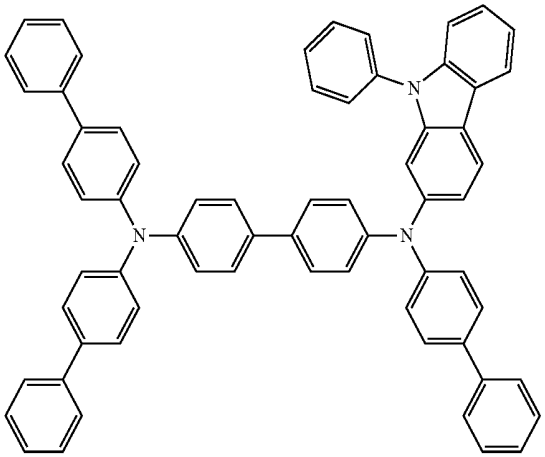

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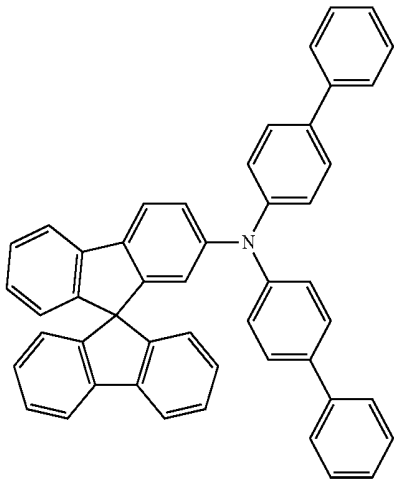

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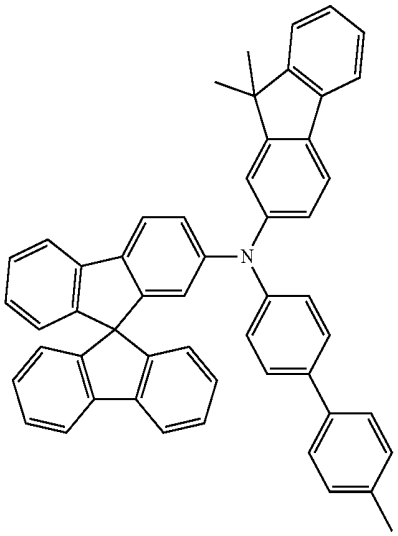

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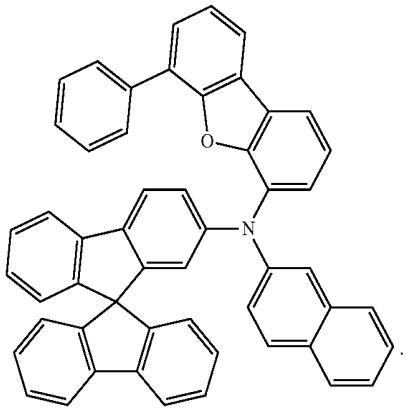


[0197] The thickness of the hole transport region may be in a range of about 100 (Angstroms) Å to about 10,000 Å, and in some embodiments, about 100 Å to about 1,000 Å. When the hole transport region includes at least one selected from a hole injection layer and a hole transport layer, the thickness of the hole injection layer may be in a range of about 100 Å to about 9,000 Å, and in some embodiments, about 100 Å to about 1,000 Å, and the thickness of the hole transport layer may be in a range of about 50 Å to about 2,000 Å, and in some embodiments, about 100 Å to about 1,500 Å. When the thicknesses of the hole transport region, the hole injection layer, and the hole transport layer are within any of these ranges, excellent (or suitable) hole transport characteristics may be obtained without a substantial increase in driving voltage.

[0198] The emission auxiliary layer may increase light emission efficiency by compensating for an optical resonance distance according to the wavelength of light emitted by an emission layer. The electron blocking layer may reduce or eliminate the flow of electrons from an electron transport region. The emission auxiliary layer and the electron blocking layer may each independently include any of the materials described herein.

[0199] The hole transport region may include a charge generating material as well as the aforementioned materials, to improve conductive properties of the hole transport region. The charge generating material may be substantially homogeneously or non-homogeneously dispersed in the hole transport region.

[0200] The charge generating material may include, for example, a p-dopant.

[0201] In some embodiments, a lowest unoccupied molecular orbital (LUMO) of the p-dopant may be about −3.5 electron Volts (eV) or less.

[0202] The p-dopant may include at least one selected from a quinone derivative, a metal oxide, and a cyano group-containing compound, but embodiments are not limited thereto.

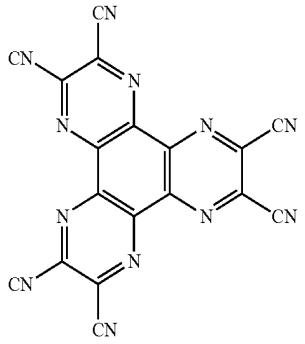
[0203] In some embodiments, the p-dopant may include at least one selected from:

[0204] a quinone derivative, such as tetracyanoquinodimethane (TCNQ) and/or 2,3,5,6-tetrafluoro-7,7,8,8-tetracyanoquinodimethane (F4-TCNQ);

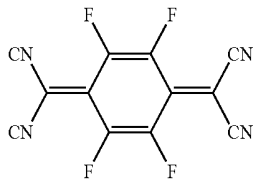
[0205] a metal oxide, such as tungsten oxide and/or molybdenum oxide;

[0206] 1,4,5,8,9,11-hexaazatriphenylene-hexacarbonitrile (HAT-CN); and

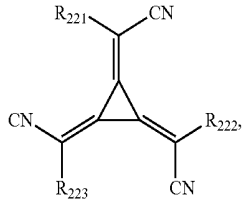
[0207] a compound represented by Formula 221, but embodiments are not limited thereto:



HAT-CN



F4-TCNQ



Formula 221

[0208] wherein, in Formula 221,

[0209] R_{221} to R_{223} may each independently be selected from a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, provided that at least one of R_{221} to R_{223} may include at least one substituent selected from a cyano group, —F, —Cl, —Br, —I, a C_1-C_{20} alkyl group substituted with —F, a C_1-C_{20} alkyl group substituted with —Cl, a C_1-C_{20} alkyl group substituted with —Br, and a C_1-C_{20} alkyl group substituted with —I.

[0210] When the organic light-emitting device **10** is a full color organic light-emitting device, the emission layer may be patterned into a red emission layer, a green emission layer, or a blue emission layer, according to a sub-pixel. In some embodiments, the emission layer may have a stacked structure. The stacked structure may include two or more layers selected from a red emission layer, a green emission layer, and a blue emission layer. The two or more layers may be in direct contact with each other. Alternatively, the two or more layers may be separated from each other. In one or more embodiments, the emission layer may include two or more materials. The two or more materials may include a red light-emitting material, a green light-emitting material, and/or a blue light-emitting material. The two or more materials may be mixed with each other in a single layer. The two or more materials mixed with each other in the single layer may emit white light.

[0211] The emission layer may include a host and a dopant. The dopant may include the organometallic compound represented by Formula 1. In some embodiments, the dopant may include at least one of a phosphorescent dopant and a fluorescent dopant, in addition to the organometallic compound represented by Formula 1

[0212] The amount of the dopant in the emission layer may be, for example, in a range of about 0.01 parts to about 15 parts by weight based on 100 parts by weight of the host, but embodiments are not limited thereto.

[0213] The thickness of the emission layer may be in a range of about 100 Å to about 1,000 Å, and in some embodiments, about 200 Å to about 600 Å. When the thickness of the emission layer is within any of these ranges, improved (or suitable) luminous characteristics may be obtained without a substantial increase in driving voltage.

[0214] The host may include a compound represented by Formula 301:

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

[0215] wherein, in Formula 301,

[0216] Ar_{301} may be a substituted or unsubstituted C_5-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group,

[0217] xb11 may be 1, 2, or 3,

[0218] L_{301} may be selected from a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, a substituted or unsubstituted C_1-C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0219] xb1 may be an integer from 0 to 5,

[0220] R_{301} may be selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_2-C_{60} alkenyl group, a substituted or unsubstituted C_2-C_{60} alkynyl group, a substituted or unsubstituted C_1-C_{60} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, —$Si(Q_{301})(Q_{302})(Q_{303})$, —$N(Q_{301})(Q_{302})$, —$B(Q_{301})(Q_{302})$, —$C(=O)(Q_{301})$, —$S(=O)_2(Q_{301})$, and —$P(=O)(Q_{301})(Q_{302})$, and

[0221] xb21 may be an integer from 1 to 5,

[0222] wherein Q_{301} to Q_{303} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group, but embodiments are not limited thereto.

[0223] In some embodiments, in Formula 301, Ar_{301} may be selected from:

[0224] a naphthalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, a dibenzofuran group, and a dibenzothiophene group; and

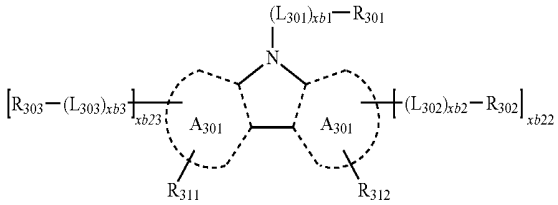
[0225] a naphthalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, a dibenzofuran group, and a dibenzothiophene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, $—Si(Q_{31})(Q_{32})(Q_{33})$, $—N(Q_{31})(Q_{32})$, $—B(Q_{31})(Q_{32})$, $—C(=O)(Q_{31})$, $—S(=O)_2(Q_{31})$, and $—P(=O)(Q_{31})(Q_{32})$,

[0226] wherein Q_{31} to Q_{33} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group, but embodiments are not limited thereto.

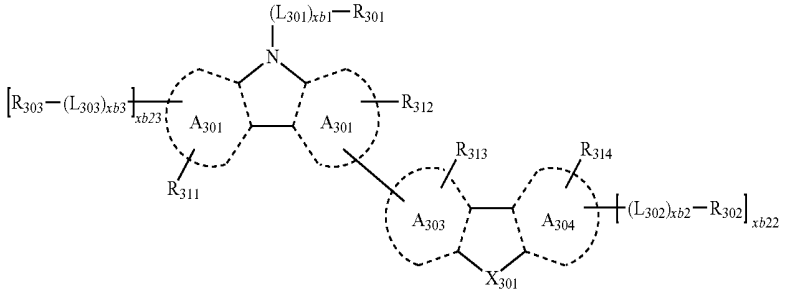
[0227] When xb11 in Formula 301 is two or greater, at least two Ar_{301} groups may be bound via a single bond.

[0228] In one or more embodiments, the compound represented by Formula 301 may be represented by Formula 301-1 or Formula 301-2:

Formula 301-1



Formula 301-2



[0229] wherein, in Formulae 301-1 to 301-2,

[0230] A_{301} to A_{304} may each independently be selected from a benzene group, a naphthalene group, a phenanthrene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a pyridine group, a pyrimidine group, an indene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, an indole group, a carbazole group, a benzocarbazole group, a dibenzocarbazole group, a furan group, a benzofuran group, a dibenzofuran group, a naphthofuran group, a benzonaphthofuran group, a dinaphthofuran group, a thiophene group, a benzothiophene group, a dibenzothiophene group, a naphthothiophene group, a benzonapthothiophene group, and a dinaphthothiophene group,

[0231] X_{301} may be O, S, or N-$[(L_{304})_{xb4}$-$R_{304}]$,

[0232] R_{311} to R_{314} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group $—Si(Q_{31})(Q_{32})(Q_{33})$, $—N(Q_{31})(Q_{32})$, $—B(Q_{31})(Q_{32})$, $—C(=O)(Q_{31})$, $—S(=O)_2(Q_{31})$, and $—P(=O)(Q_{31})(Q_{32})$,

[0233] xb22 and xb23 may each independently be 0, 1, or 2,

[0234] L_{301}, xb1, R_{301}, and Q_{31} to Q_{33} may each independently be the same as respectively described herein,

[0235] L_{302} to L_{304} may each independently be substantially the same as the description for L_{301} provided herein,

[0236] xb2 to xb4 may each independently be substantially the same as the description of xb1 provided herein, and

[0237] R_{302} to R_{304} may each independently be substantially the same as the description of R_{301} provided herein.

[0238] In some embodiments, in Formulae 301, 301-1, and 301-2, L_{301} to L_{304} may each independently be selected from:

[0239] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a diben-

zofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, a pyridinylene group, an imidazolylene group, a pyrazolylene group, a thiazolylene group, an isothiazolylene group, an oxazolylene group, an isoxazolylene group, a thiadiazolylene group, an oxadiazolylene group, a pyrazinylene group, a pyrimidinylene group, a pyridazinylene group, a triazinylene group, a quinolinylene group, an isoquinolinylene group, a benzoquinolinylene group, a phthalazinylene group, a naphthyridinylene group, a quinoxalinylene group, a quinazolinylene group, a cinnolinylene group, a phenanthridinylene group, an acridinylene group, a phenanthrolinylene group, a phenazinylene group, a benzimidazolylene group, an isobenzothiazolylene group, a benzoxazolylene group, an isobenzoxazolylene group, a triazolylene group, a tetrazolylene group, an imidazopyridinylene group, an imidazopyrimidinylene group, and an azacarbazolylene group; and

[0240] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, a pyridinylene group, an imidazolylene group, a pyrazolylene group, a thiazolylene group, an isothiazolylene group, an oxazolylene group, an isoxazolylene group, a thiadiazolylene group, an oxadiazolylene group, a pyrazinylene group, a pyrimidinylene group, a pyridazinylene group, a triazinylene group, a quinolinylene group, an isoquinolinylene group, a benzoquinolinylene group, a phthalazinylene group, a naphthyridinylene group, a quinoxalinylene group, a quinazolinylene group, a cinnolinylene group, a phenanthridinylene group, an acridinylene group, a phenanthrolinylene group, a phenazinylene group, a benzimidazolylene group, an isobenzothiazolylene group, a benzoxazolylene group, an isobenzoxazolylene group, a triazolylene group, a tetrazolylene group, an imidazopyridinylene group, an imidazopyrimidinylene group, and an azacarbazolylene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, an azacarbazolyl group, $—Si(Q_{31})(Q_{32})(Q_{33})$, $—N(Q_{31})(Q_{32})$, $—B(Q_{31})(Q_{32})$, $—C(=O)(Q_{31})$, $—S(=O)_2(Q_{31})$, and $—P(=O)(Q_{31})(Q_{32})$,

[0241] wherein Q_{31} to Q_{33} may each independently be the same as described herein.

[0242] In some embodiments, in Formulae 301, 301-1, and 301-2, R_{301} to R_{304} may each independently be selected from:

[0243] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group; and

[0244] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl

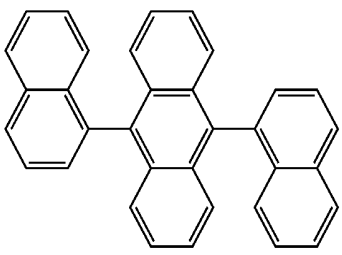
group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a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

[0245] wherein Q_{31} to Q_{33} may each independently be the same as described herein.

[0246] In some embodiments, the host may include an alkaline earth metal complex. For example, the host may include a beryllium (Be) complex, for example, Compound H55 (shown below), a magnesium (Mg) complex, and/or a zinc (Zn) complex.

[0247] The host may include at least one selected from 9,10-Di(2-naphthyl)anthracene (ADN), 2-methyl-9,10-bis(naphthalen-2-yl)anthracene (MADN), 9,10-di-(2-naphthyl)-2-t-butyl-anthracene (TBADN), 4,4'-bis(N-carbazolyl)-1,1'-biphenyl (CBP), 1,3-di-9-carbazolylbenzene (mCP), 1,3,5-tri(carbazol-9-yl)benzene (TCP), and Compounds H1 to H55, but embodiments are not limited thereto:

H1



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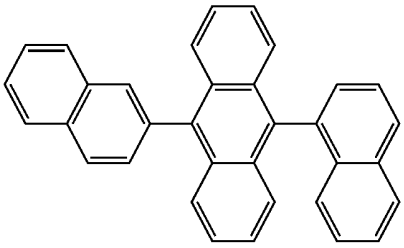
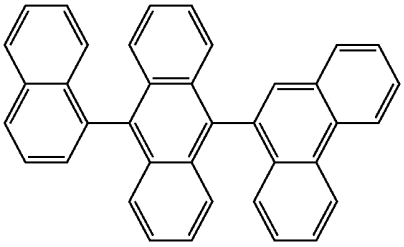
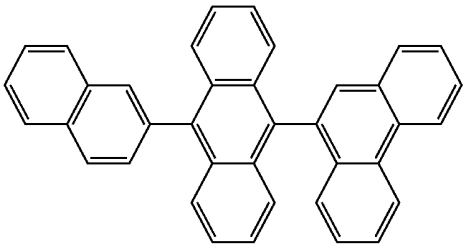
H2



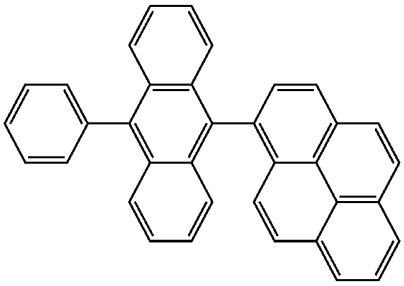
H3



H4



H5



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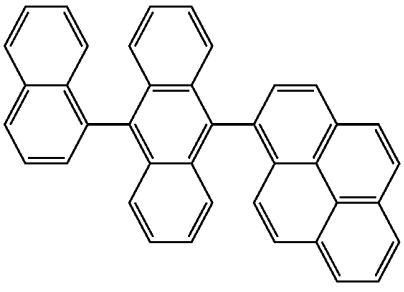

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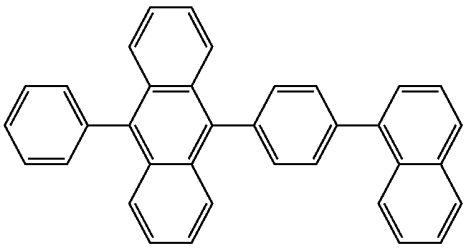

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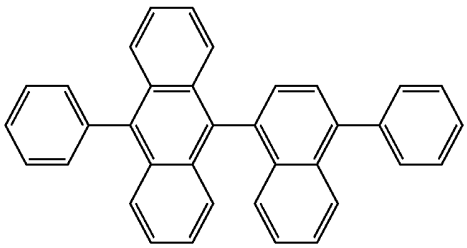
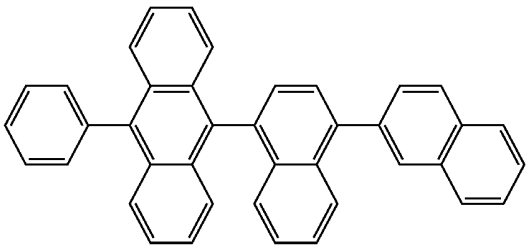
H8



H9



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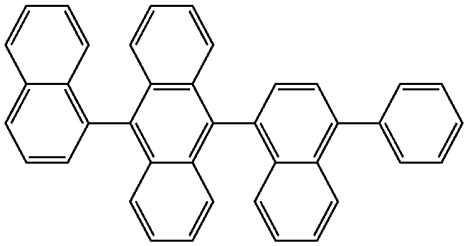
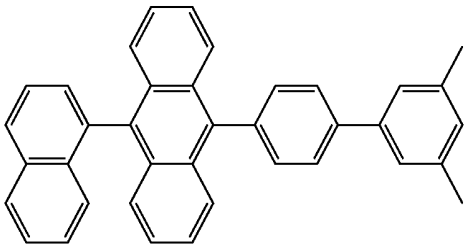


H11



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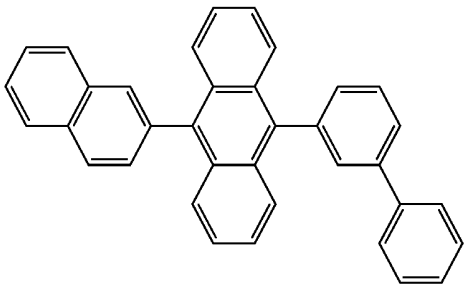
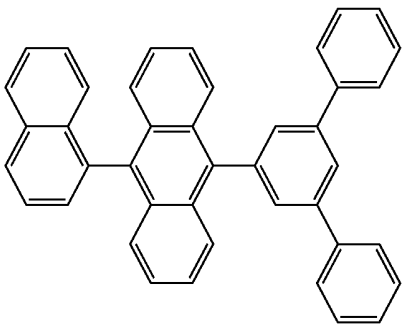


H13



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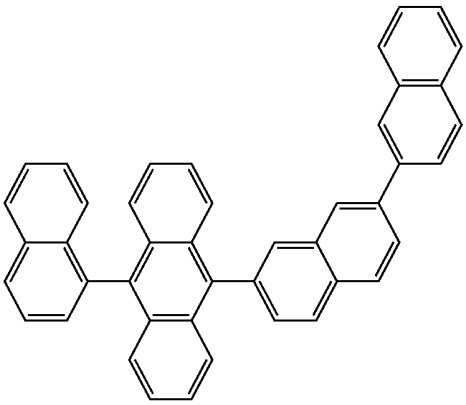
H14



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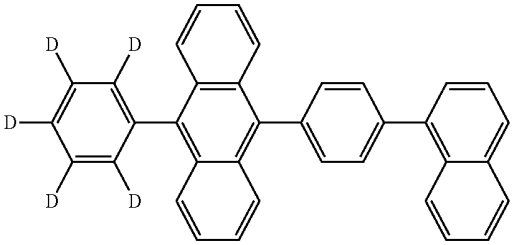

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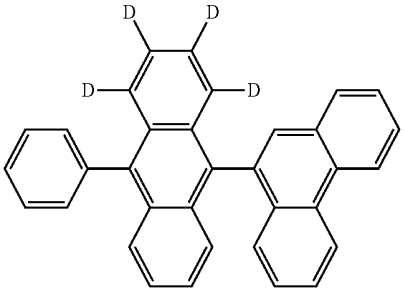

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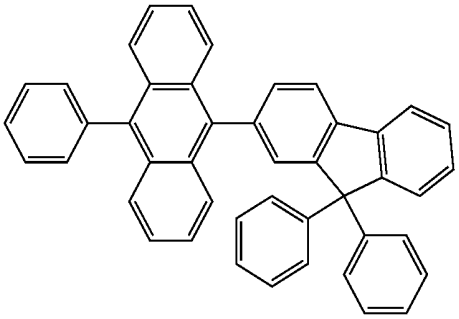

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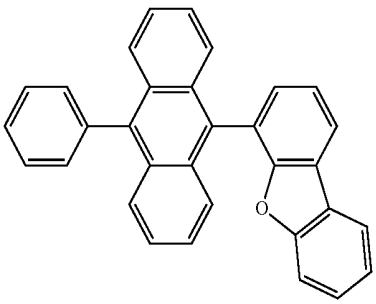

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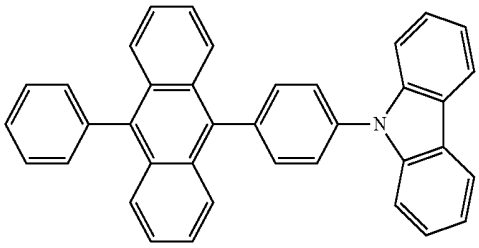
H19



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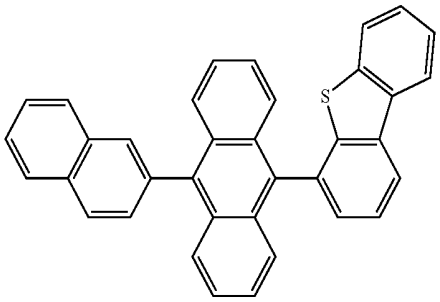

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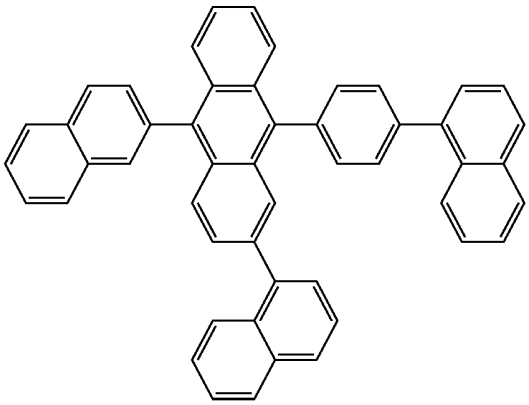

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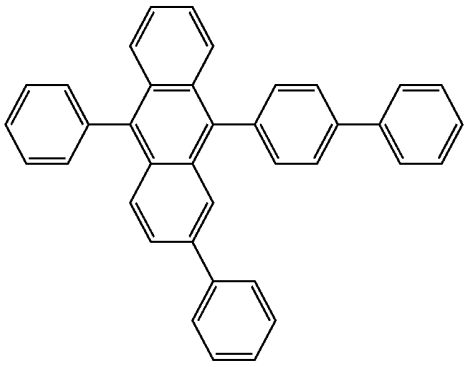

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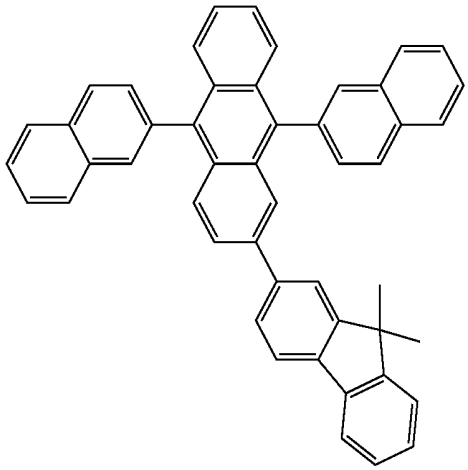

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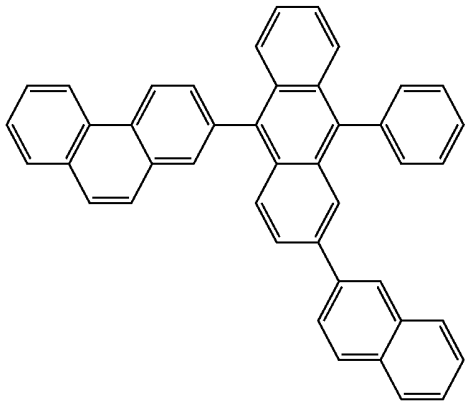

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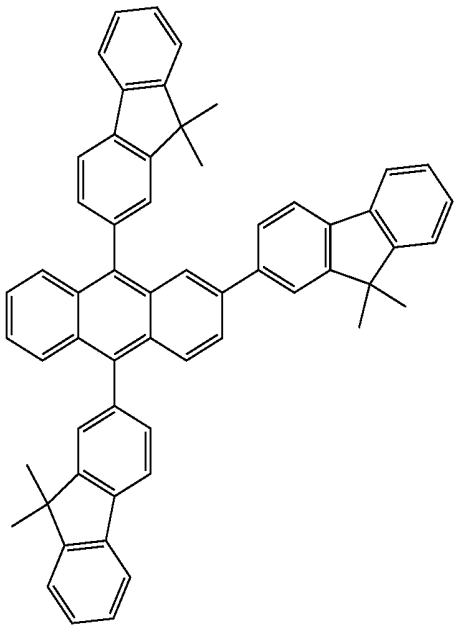

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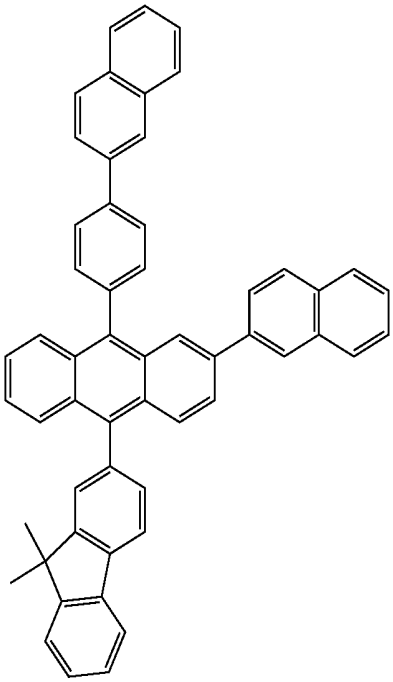
H26



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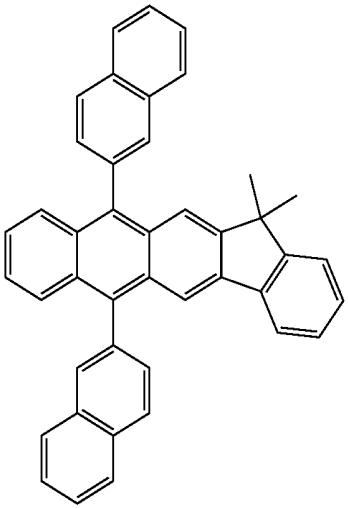

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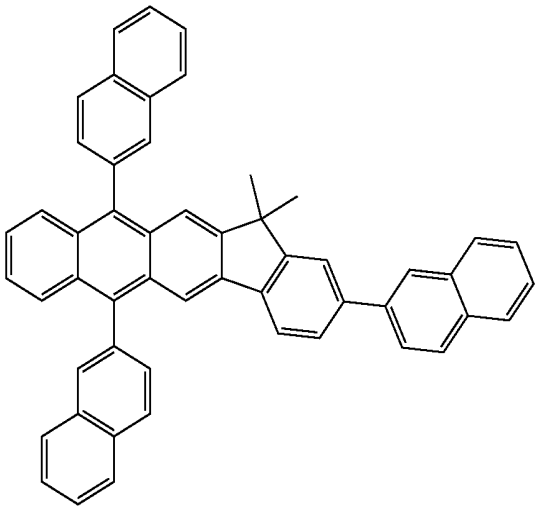
H28



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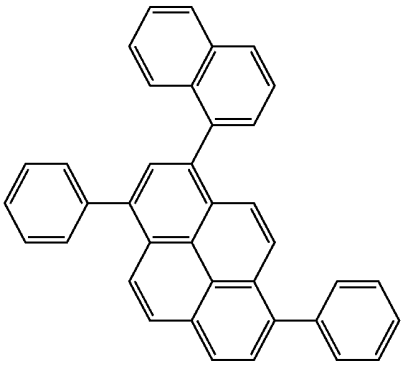

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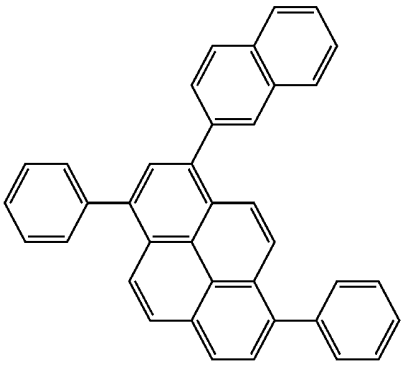
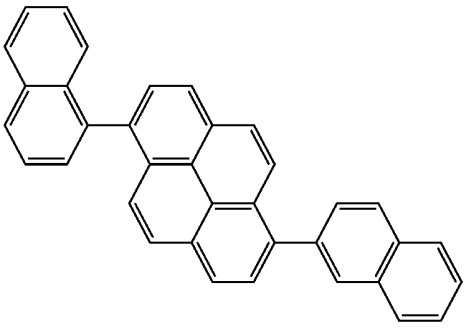


H31



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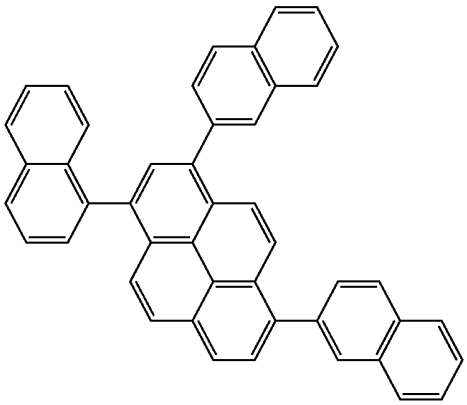

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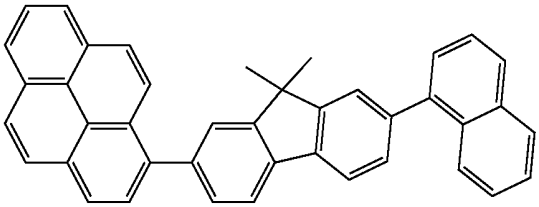

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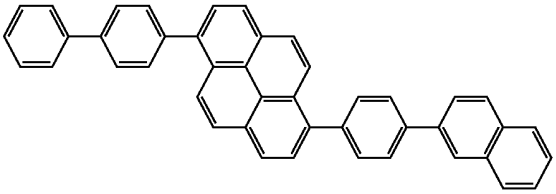

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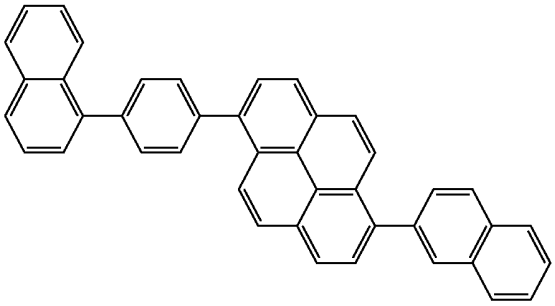

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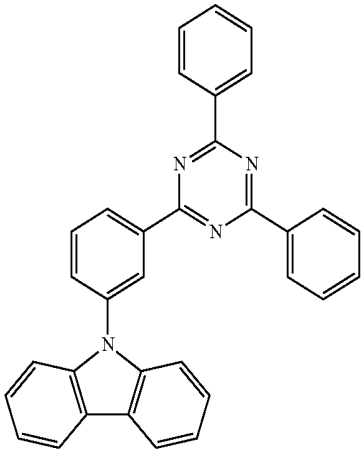

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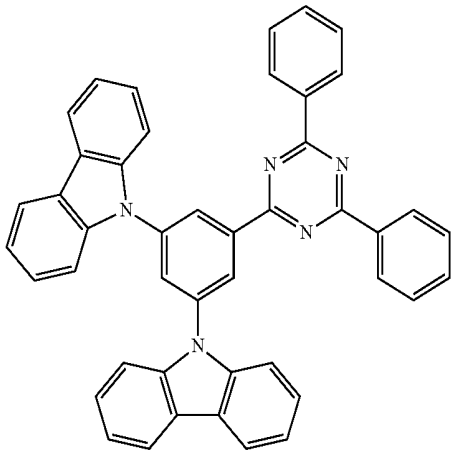

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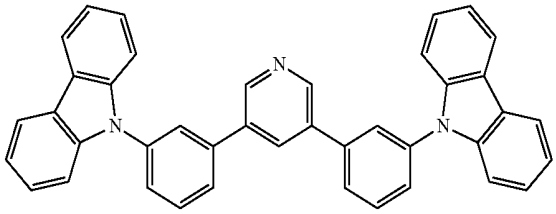

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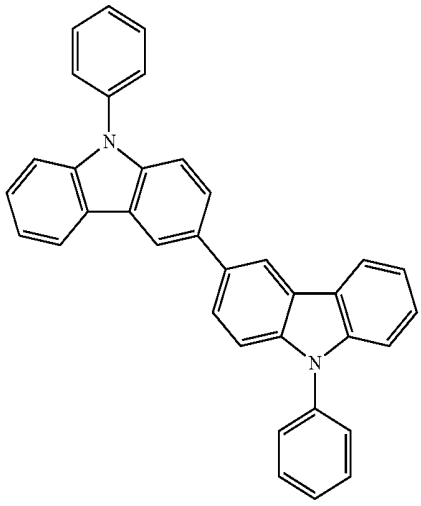

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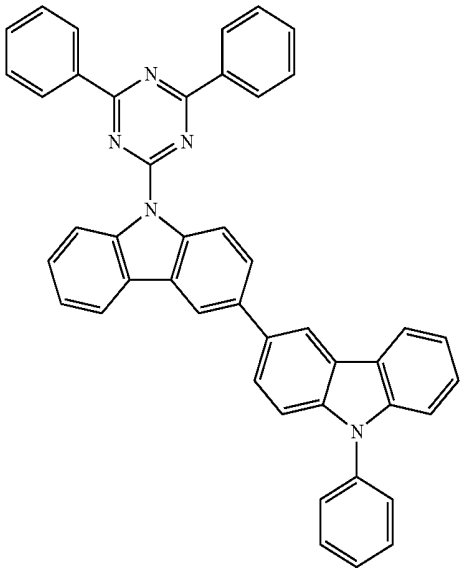

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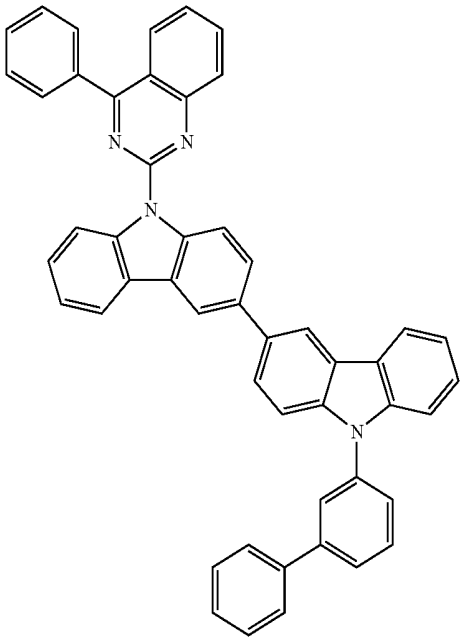

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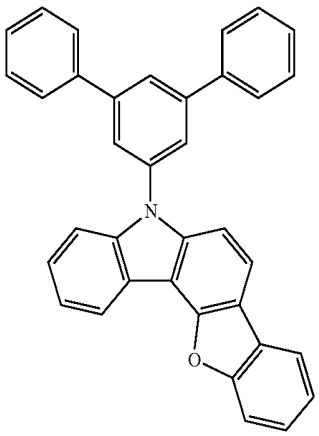

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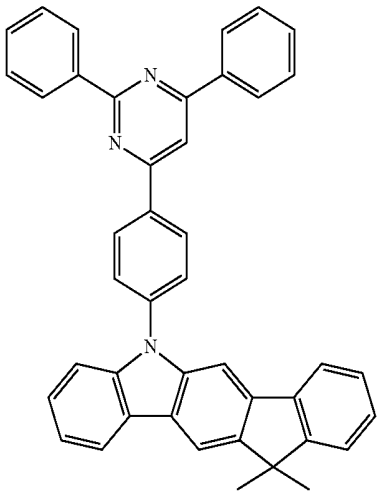

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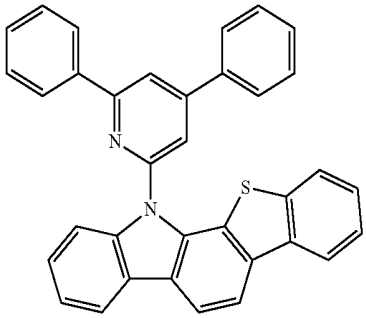

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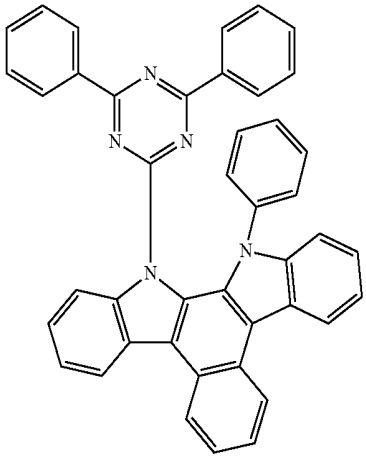

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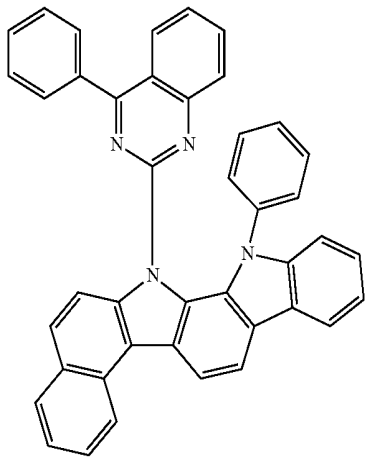

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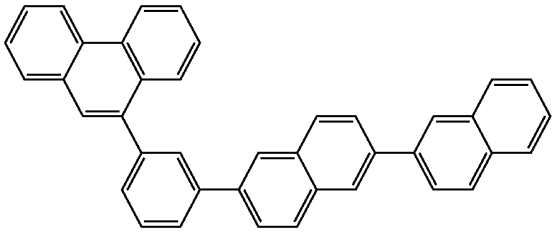

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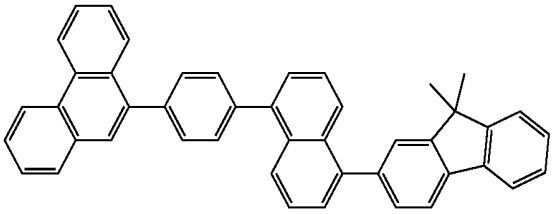

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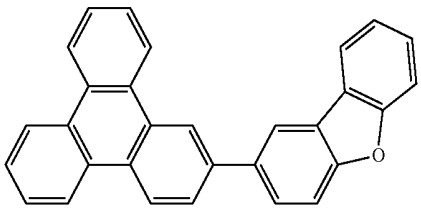

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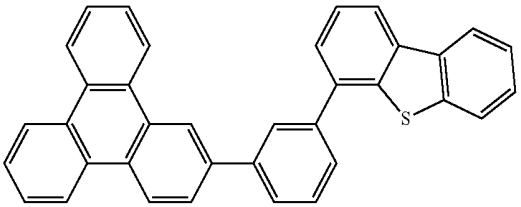

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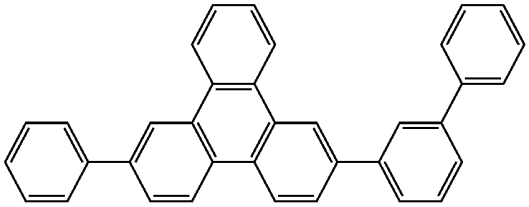

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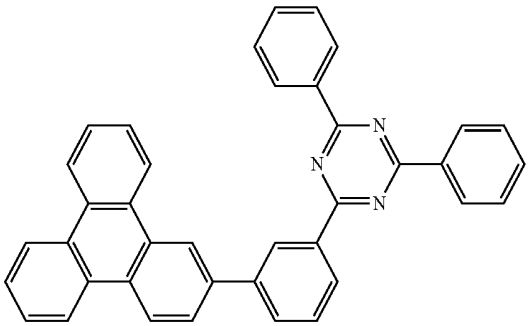

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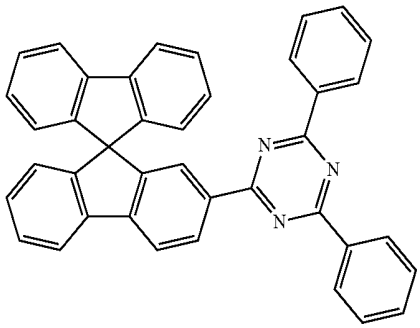

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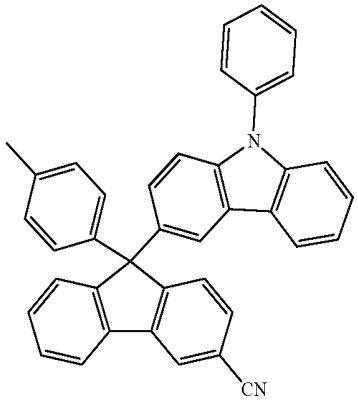

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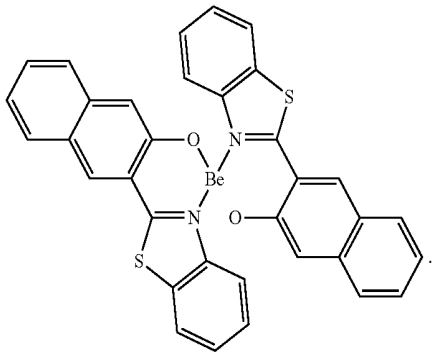


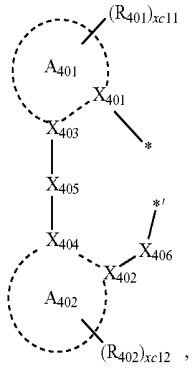
[0248] The phosphorescent dopant may include the organometallic compound represented by Formula 1.

[0249] In some embodiments, the phosphorescent dopant may include, in addition to the organometallic compound represented by Formula 1, an organometallic complex represented by Formula 401:

Formula 401

$$M(L_{401})_{xc1}(L_{402})_{xc2}$$

Formula 402



[0250] wherein, in Formulae 401 and 402,

[0251] M may be selected from iridium (Ir), platinum (Pt), palladium (Pd), osmium (Os), titanium (Ti), zirconium (Zr), hafnium (Hf), europium (Eu), terbium (Tb), rhodium (Rh), and thulium (Tm),

[0252] L_{401} may be selected from ligands represented by Formula 402, xc1 may be an integer selected from 1, 2, and 3; wherein when xc1 is two or greater, at least two L_{401} groups may be identical to or different from each other,

[0253] L_{402} may be an organic ligand, xc2 may be an integer from 0 to 4; wherein when xc2 is two or greater, at least two L_{402} groups may be identical to or different from each other,

[0254] X_{401} to X_{404} may each independently be nitrogen (N) or carbon (C),

[0255] X_{401} and X_{403} may be linked via a single bond or a double bond, X_{402} and X_{404} may be linked via a single bond or a double bond,

[0256] A_{401} and A_{402} may each independently be a C_5-C_{60} carbocyclic group or a C_1-C_{60} heterocyclic group,

[0257] X_{405} may be a single bond, *—O—*', *—S—*', *—C(═O)—*', *—N(Q_{411})-*', *—C(Q_{411})(Q_{412})-*', *—C(Q_{411})═C(Q_{412})-*, *—C(Q_{411})═*', or *═C(Q_{411})=*', wherein Q_{411} and Q_{412} may each independently be hydrogen, deuterium, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, or a naphthyl group,

[0258] X_{406} may be a single bond, 0, or S,

[0259] R_{401} and R_{402} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a substituted or unsubstituted C_1-C_{20} alkyl group, a substituted or unsubstituted C_1-C_{20} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, —Si(Q_{401})(Q_{402})(Q_{403}), —N(Q_{401})(Q_{402}), —B(Q_{401})(Q_{402}), —C(═O)(Q_{401}), —S(═O)$_2$(Q_{401}), and —P(═O)(Q_{401})(Q_{402}), wherein Q_{401} to Q_{403} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a C_6-C_{20} aryl group, and a C_1-C_{20} heteroaryl group,

[0260] xc11 and xc12 may each independently be an integer from 0 to 10, and

[0261] * and *' in Formula 402 each indicate a binding site to M in Formula 401.

[0262] In one embodiment, in Formula 402, A_{401} and A_{402} may each independently be selected from a benzene group, a naphthalene group, a fluorene group, a spiro-bifluorene group, an indene group, a pyrrole group, a thiophene group, a furan group, an imidazole group, a pyrazole group, a thiazole group, an isothiazole group, an oxazole group, an isoxazole group, a pyridine group, a pyrazine group, a pyrimidine group, a pyridazine group, a quinoline group, an isoquinoline group, a benzoquinoline group, a quinoxaline group, a quinazoline group, a carbazole group, a benzimidazole group, a benzofuran group, a benzothiophene group, an isobenzothiophene group, a benzoxazole group, an isobenzoxazole group, a triazole group, a tetrazole group, an oxadiazole group, a triazine group, a dibenzofuran group, and a dibenzothiophene group.

[0263] In one or more embodiments, in Formula 402, i) X_{401} may be nitrogen, and X_{402} may be carbon, or ii) X_{401} and X_{402} may each be nitrogen.

[0264] In one or more embodiments, in Formula 402, R_{401} and R_{402} may each independently be selected from:

[0265] hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, and a C_1-C_{20} alkoxy group;

[0266] a C_1-C_{20} alkyl group and a C_1-C_{20} alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a phenyl group, a naphthyl group, a cyclopentyl group, a cyclohexyl group, an adamantyl group, a norbornanyl group, and a norbornenyl group;

[0267] a cyclopentyl group, a cyclohexyl group, an adamantyl group, a norbornanyl group, a norbornenyl group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group;

[0268] a cyclopentyl group, a cyclohexyl group, an adamantyl group, a norbornanyl group, a norbornenyl group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, an adamantyl group, a norbornanyl group, a norbornenyl group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a

quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

[0269] —Si(Q_{401})(Q_{402})(Q_{403}), —N(Q_{401})(Q_{402}), —B(Q_{401})(Q_{402}), —C(=O)(Q_{401}), —S(=O)$_2$(Q_{401}), and —P(=O)(Q_{401})(Q_{402}),

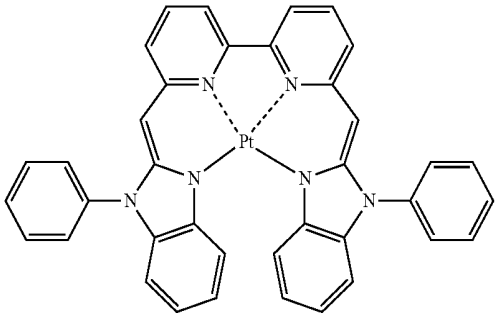
[0270] wherein Q_{401} to Q_{403} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a biphenyl group, and a naphthyl group, but embodiments are not limited thereto.

[0271] In one or more embodiments, when xc1 in Formula 401 is two or greater, in at least two L_{401} groups, two A_{401} groups may optionally be bound to each other via a linking group X_{407}; or two A_{402} groups may optionally be bound to each other via a linking group X_{408} (see e.g., Compounds PD1 to PD4 and PD7 shown below). X_{407} and X_{408} may each independently be selected from a single bond, *—O—*', *—S—*', *—C(=O)—*', *—N(Q_{413})-*', *—C(Q_{413})(Q_{414})-*', and *—C(Q_{413})=C(Q_{414})-*', wherein Q_{413} and Q_{414} may each independently be hydrogen, deuterium, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, or a naphthyl group, but embodiments are not limited thereto.

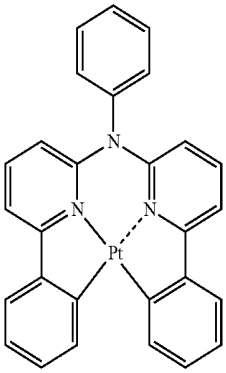
[0272] L_{402} in Formula 401 may be any suitable monovalent, divalent, or trivalent organic ligand. For example, L_{402} may be selected from halogen, diketone (e.g., acetylacetonate), a carboxylic acid (e.g., picolinate), —C(=O), isonitrile, —CN, and phosphorus (e.g., phosphine and/or phosphite), but embodiments are not limited thereto.

[0273] In some embodiments, the phosphorescent dopant may include, for example, at least one selected from Compounds PD1 to PD25, but embodiments are not limited thereto:

PD1



PD2



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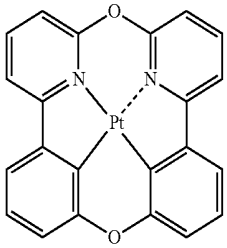
PD3



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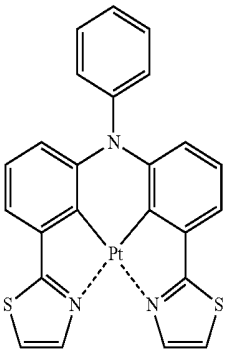
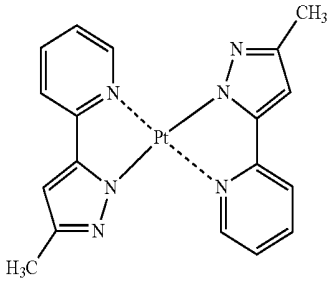
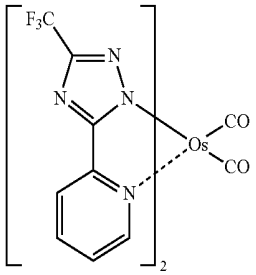


PD5



PD6



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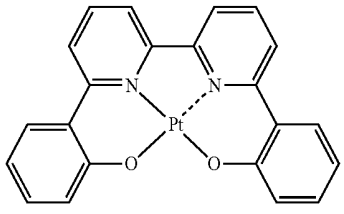

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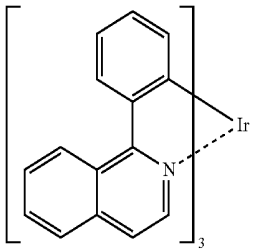

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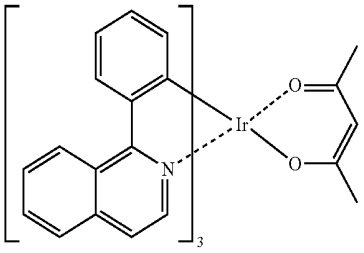
PD9



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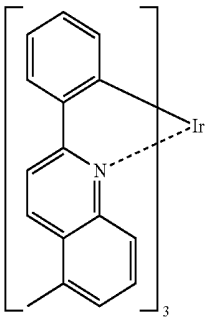

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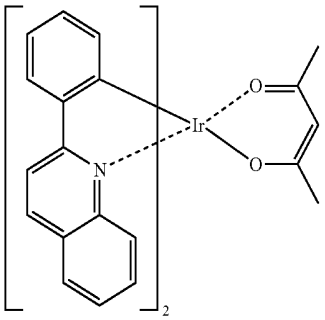

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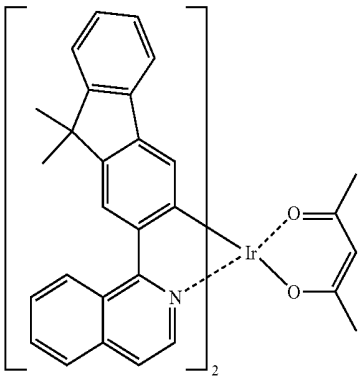
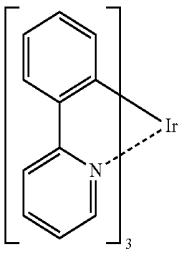


PD13



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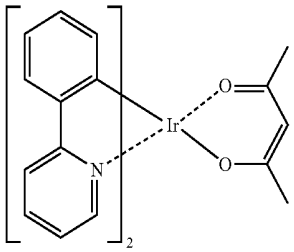
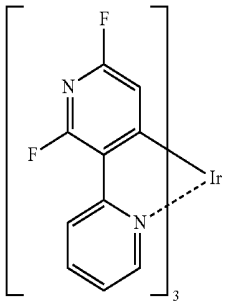
PD14



PD15



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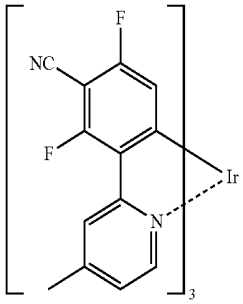
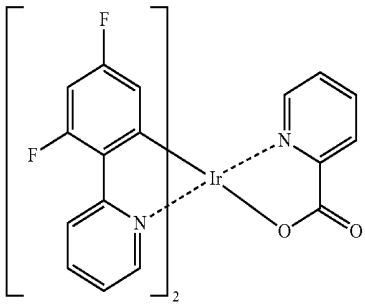


PD17



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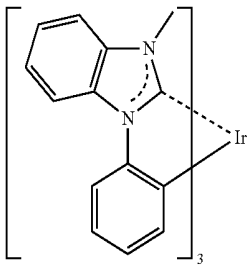

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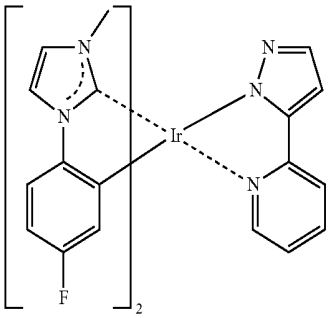
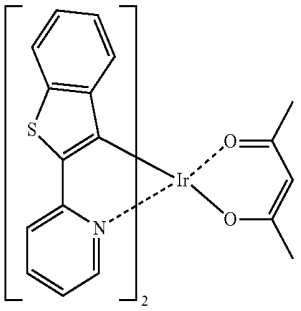
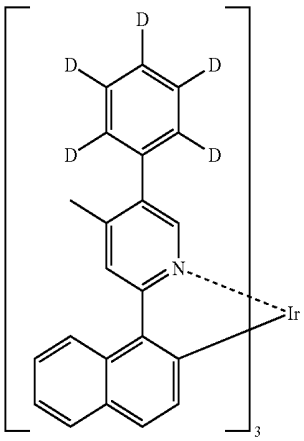


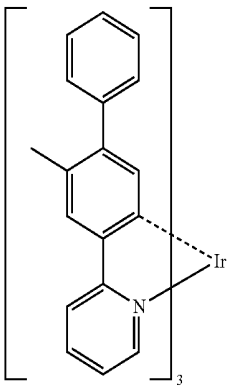
PD20



PD21



PD22



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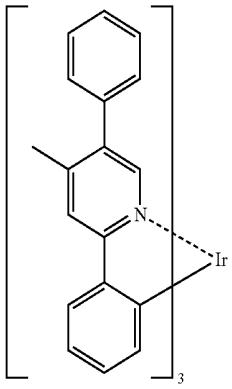
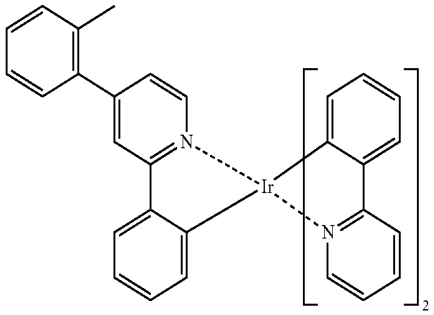
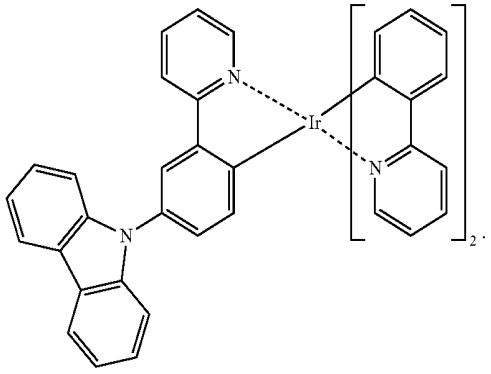


PD24



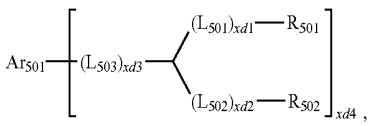
PD25



[0274] The fluorescent dopant may include an arylamine compound or a styrylamine compound.

[0275] In some embodiments, the fluorescent dopant may include a compound represented by Formula 501:

Formula 501



[0276] wherein, in Formula 501,

[0277] Ar_{501} may be a substituted or unsubstituted C_5-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group,

[0278] L_{501} to L_{503} may each independently be selected from a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10}

cycloalkenylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, a substituted or unsubstituted C_1-C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0279] xd1 to xd3 may each independently be an integer from 0 to 3,

[0280] R_{501} and R_{502} may each independently be selected from a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, and

[0281] xd4 may be an integer from 1 to 6.

[0282] In some embodiments, Ar_{501} in Formula 501 may be selected from:

[0283] a naphthalene group, a heptalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, and an indenophenanthrene group; and

[0284] a naphthalene group, a heptalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, and an indenophenanthrene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0285] In one or more embodiments, in Formula 501, L_{501} to L_{503} may each independently be selected from:

[0286] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, and a pyridinylene group; and

[0287] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, and a pyridinylene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, and a pyridinyl group.

[0288] In one or more embodiments, in Formula 501, R_{501} and R_{502} may each independently be selected from:

[0289] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, and a pyridinyl group; and

[0290] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, and a pyridinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br,

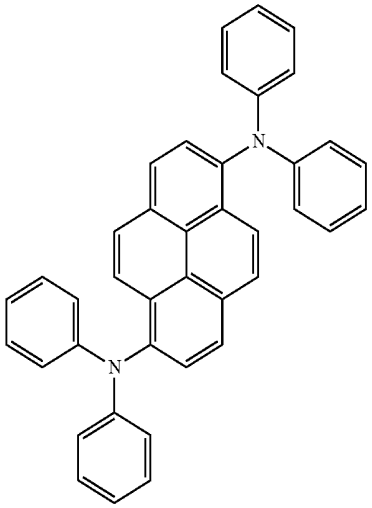
—I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, and —$Si(Q_{31})(Q_{32})(Q_{33})$,

[0291] wherein Q_{31} to Q_{33} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

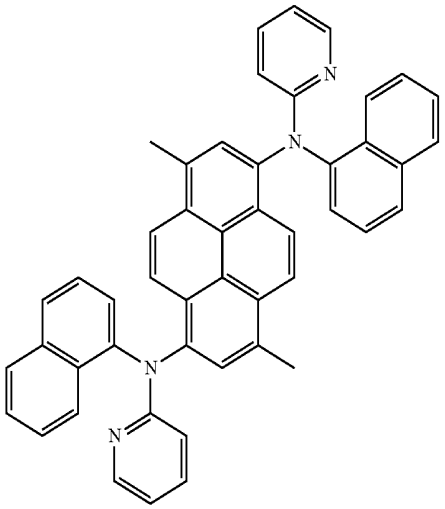
[0292] In one or more embodiments, xd4 in Formula 501 may be 2, but embodiments are not limited thereto.

[0293] In some embodiments, the fluorescent dopant may be selected from Compounds FD1 to FD22:

FD1



FD2



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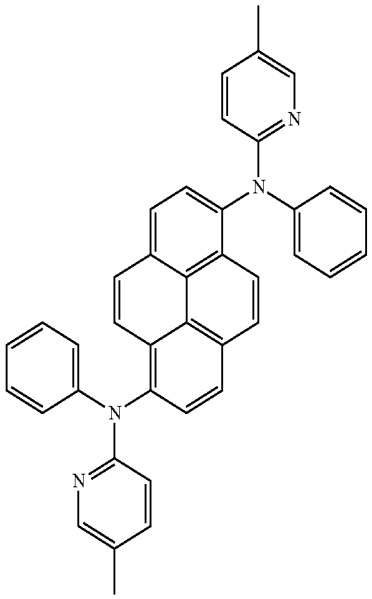
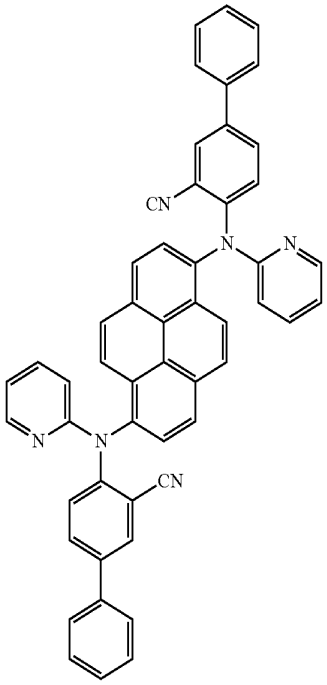
FD3



FD4



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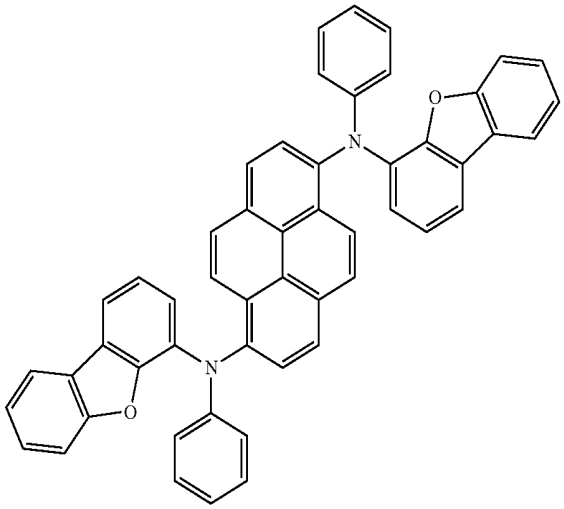
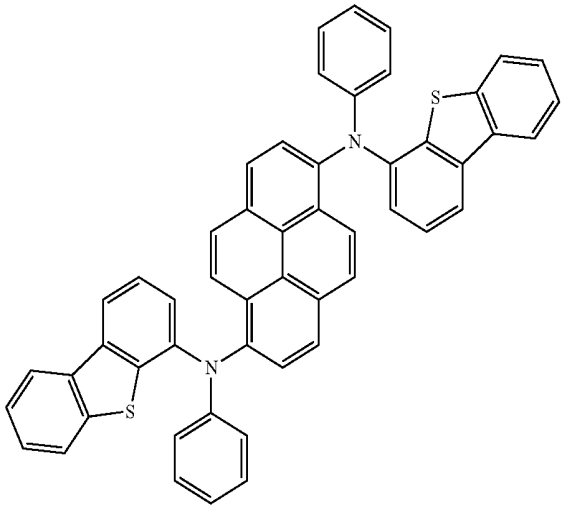
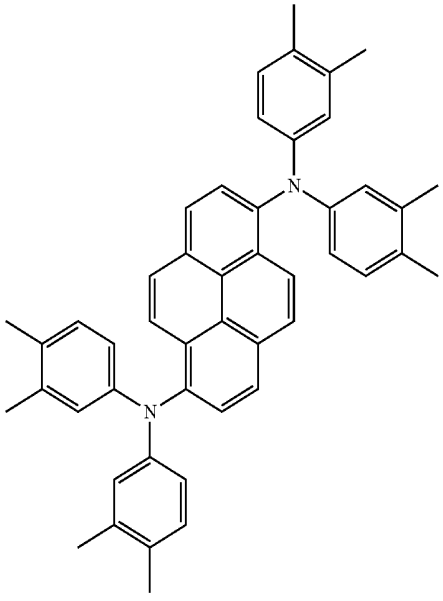
FD5



FD6



FD7



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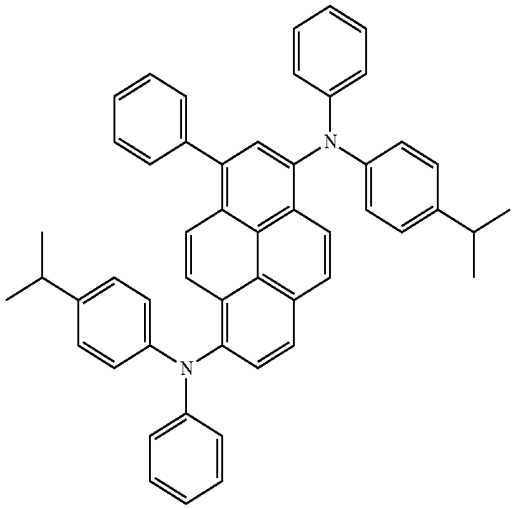
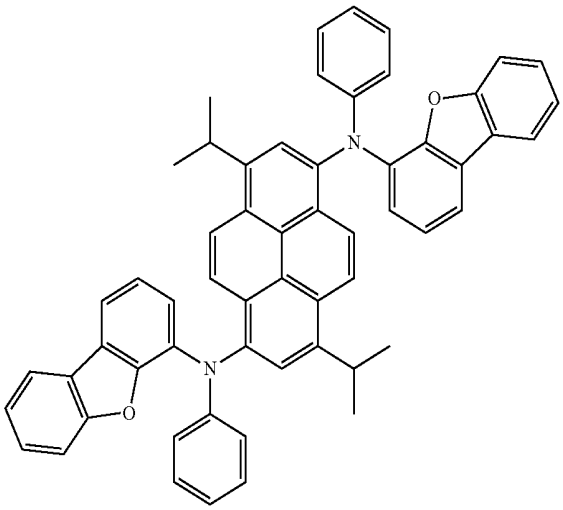
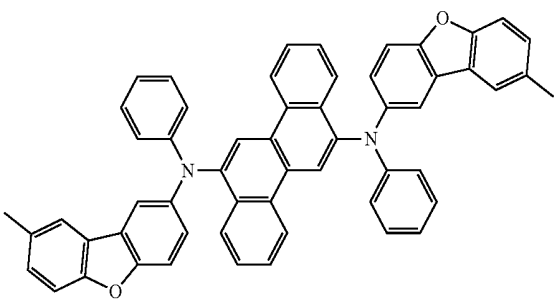
FD8



FD9



FD10



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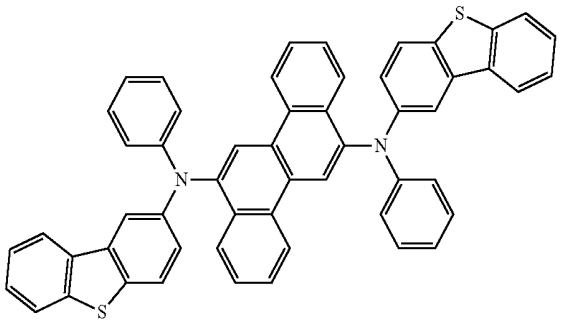
FD11



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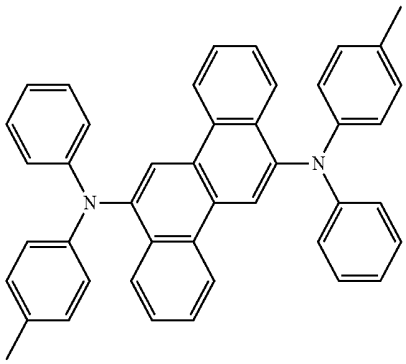
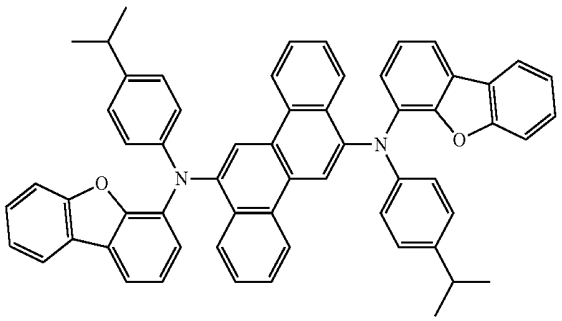
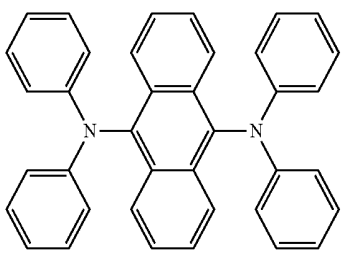


FD13



FD14



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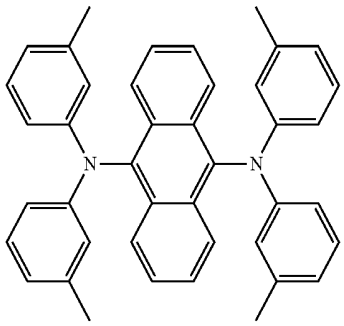
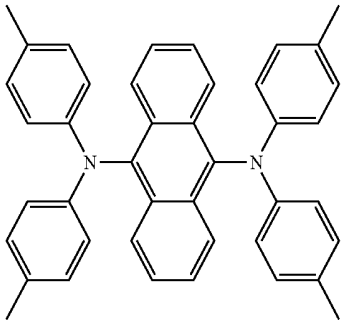
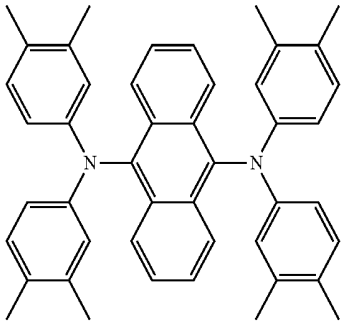
FD15



FD16



FD17



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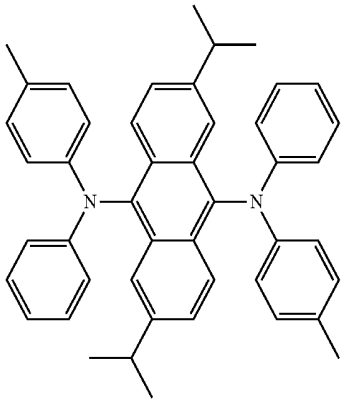

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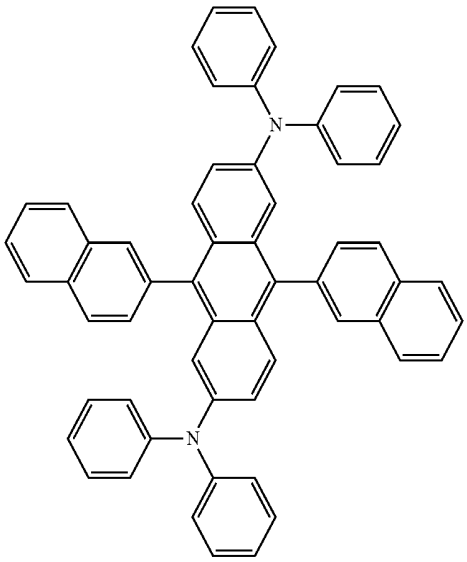
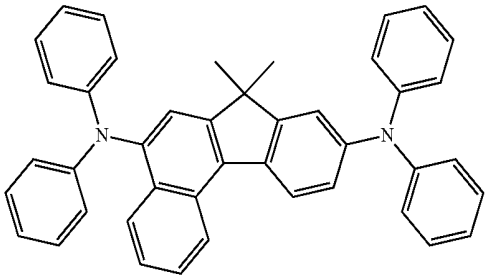
FD19



FD20



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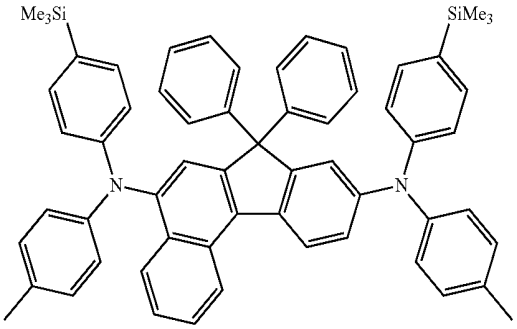
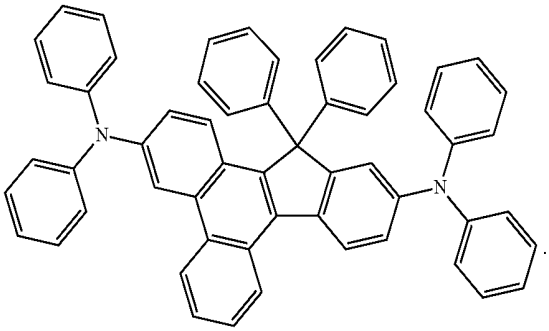
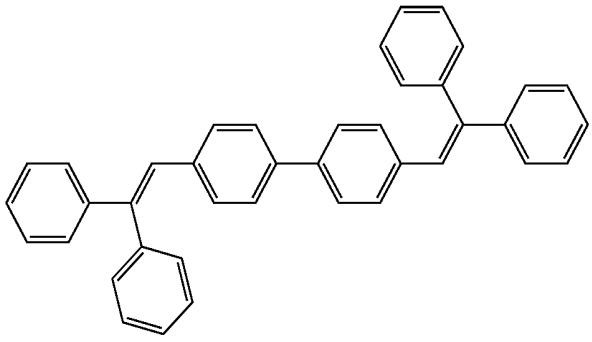
FD21



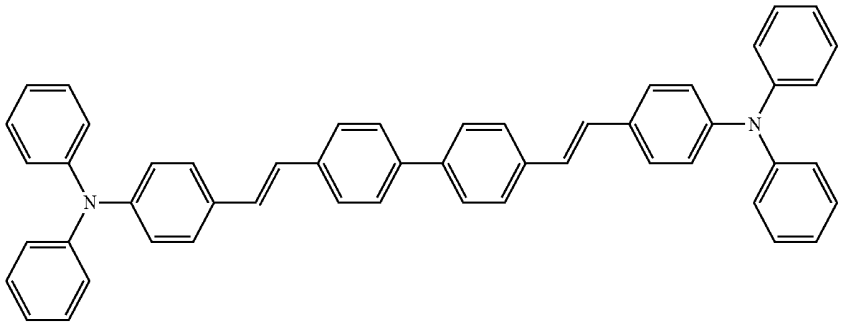
FD22



[0294] In some embodiments, the fluorescent dopant may be selected from the following compounds, but embodiments are not limited thereto:



DPVBi



DPAVBi

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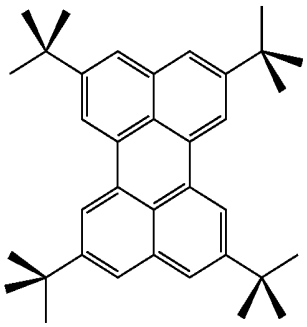
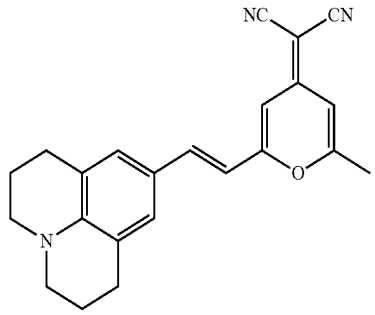
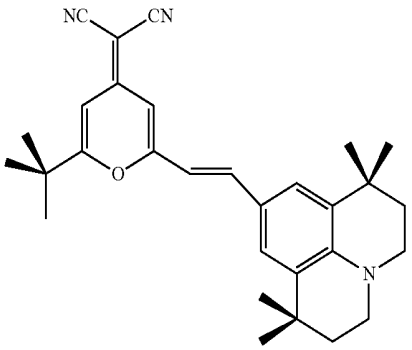


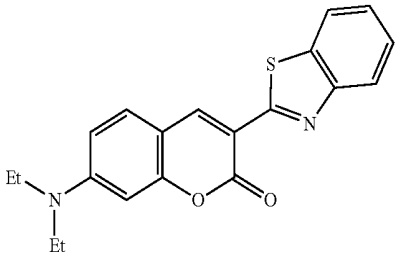
TBPe



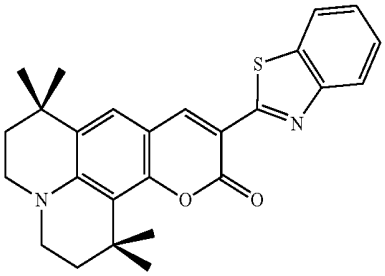
DCM



DCJTB



Coumarin 6



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[0295] The electron transport region may have i) a single-layered structure including a single layer including a single material, ii) a single-layered structure including a single layer including a plurality of different materials, or iii) a multi-layered structure each having a plurality of layers, each having a plurality of different materials.

[0296] The electron transport region may include at least one selected from a buffer layer, a hole blocking layer, an electron control layer, an electron transport layer, and an electron injection layer, but embodiments are not limited thereto.

[0297] In some embodiments, the electron transport region may have an electron transport layer/electron injection layer structure, a hole blocking layer/electron transport layer/electron injection layer structure, an electron control layer/electron transport layer/electron injection layer structure, or a buffer layer/electron transport layer/electron injection layer structure, wherein the layers of each structure are sequentially stacked on the emission layer in the stated order, but embodiments are not limited thereto.

[0298] The electron transport region, for example, a buffer layer, a hole blocking layer, an electron control layer, and/or an electron transport layer in the electron transport region, may include a metal-free compound. The metal-free compound may include at least one π electron-depleted nitrogen-containing ring.

[0299] The term "π electron-depleted nitrogen-containing ring" as used herein may refer to a C_1-C_{60} heterocyclic group having at least one *—N=*' moiety as a ring-forming moiety.

[0300] For example, the "π electron-depleted nitrogen-containing ring" may be i) a 5-membered to 7-membered heteromonocyclic group having at least one *—N=*' moiety, ii) a heteropolycyclic group in which two or more 5-membered to 7-membered heteromonocyclic groups each having at least one *—N=*' moiety are condensed, or iii) a heteropolycyclic group in which at least one 5-membered to 7-membered heteromonocyclic group having at least one *—N=*' moiety is condensed with at least one C_5-C_{60} carbocyclic group.

[0301] Examples of the π electron-depleted nitrogen-containing ring may include an imidazole, a pyrazole, a thiazole, an isothiazole, an oxazole, an isoxazole, a pyridine, a pyrazine, a pyrimidine, a pyridazine, an indazole, a purine, a quinoline, an isoquinoline, a benzoquinoline, a phthalazine, a naphthyridine, a quinoxaline, a quinazoline, a cinnoline, a phenanthridine, an acridine, a phenanthroline, a

phenazine, a benzimidazole, an iso-benzothiazole, a benzoxazole, an isobenzoxazole, a triazole, a tetrazole, an oxadiazole, a triazine, a thiadiazole, an imidazopyridine, an imidazopyrimidine, and an azacarbazole, but embodiments of the present disclosure are not limited thereto.

[0302] In some embodiments, the electron transport region may include a compound represented by Formula 601:

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

[0303] wherein, in Formula 601,

[0304] Ar_{601} may be a substituted or unsubstituted C_5-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group,

[0305] xe11 may be 1, 2, or 3,

[0306] L_{601} may be selected from a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, a substituted or unsubstituted C_1-C_{60} heteroarylene group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

[0307] xe1 may be an integer from 0 to 5,

[0308] R_{601} may be selected from a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, —$Si(Q_{601})(Q_{602})(Q_{603})$, —$C(=O)(Q_{601})$, —$S(=O)_2(Q_{601})$, and —$P(=O)(Q_{601})(Q_{602})$,

[0309] wherein Q_{601} to Q_{603} may each independently be a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, or a naphthyl group, and

[0310] xe21 may be an integer from 1 to 5.

[0311] In one embodiment, at least one of xe11 number of Ar_{601} groups and xe21 number of R_{601} groups may include the π electron-depleted nitrogen-containing ring.

[0312] In some embodiments, Ar_{601} in Formula 601 may be selected from:

[0313] a benzene group, a naphthalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, a dibenzofuran group, a dibenzothiophene group, a carbazole group, an imidazole group, a pyrazole group, a thiazole group, an isothiazole group, an oxazole group, an isoxazole group, a pyridine group, a pyrazine group, a pyrimidine group, a pyridazine group, an indazole group, a purine group, a quinoline group, an isoquinoline group, a benzoquinoline group, a phthalazine group, a naphthyridine group, a quinoxaline group, a quinazoline group, a cinnoline group, a phenanthridine group, an acridine group, a phenanthroline group, a phenazine group, a benzimidazole group, an isobenzothiazole group, a benzoxazole group, an isobenzoxazole group, a triazole group, a tetrazole group, an oxadiazole group, a triazine group, a thiadiazole group, an imidazopyridine group, an imidazopyrimidine group, and an azacarbazole group; and

[0314] a benzene group, a naphthalene group, a fluorene group, a spiro-bifluorene group, a benzofluorene group, a dibenzofluorene group, a phenalene group, a phenanthrene group, an anthracene group, a fluoranthene group, a triphenylene group, a pyrene group, a chrysene group, a naphthacene group, a picene group, a perylene group, a pentaphene group, an indenoanthracene group, a dibenzofuran group, a dibenzothiophene group, a carbazole group, an imidazole group, a pyrazole group, a thiazole group, an isothiazole group, an oxazole group, an isoxazole group, a pyridine group, a pyrazine group, a pyrimidine group, a pyridazine group, an indazole group, a purine group, a quinoline group, an isoquinoline group, a benzoquinoline group, a phthalazine group, a naphthyridine group, a quinoxaline group, a quinazoline group, a cinnoline group, a phenanthridine group, an acridine group, a phenanthroline group, a phenazine group, a benzimidazole group, an isobenzothiazole group, a benzoxazole group, an isobenzoxazole group, a triazole group, a tetrazole group, an oxadiazole group, a triazine group, a thiadiazole group, an imidazopyridine group, an imidazopyrimidine group, and an azacarbazole group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$,

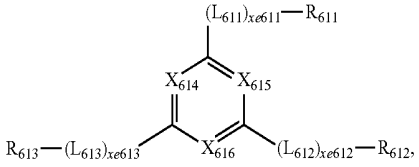
[0315] wherein Q_{31} to Q_{33} may each independently be selected from a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0316] When xe11 in Formula 601 is two or greater, at least two Ar_{601} groups may be bound via a single bond.

[0317] In one or more embodiments, in Formula 601, Ar_{601} may be an anthracene group.

[0318] In some embodiments, the compound represented by Formula 601 may be represented by Formula 601-1:

Formula 601-1



[0319] wherein, in Formula 601-1,

[0320] X_{614} may be N or $C(R_{614})$, X_{615} may be N or $C(R_{615})$, X_{616} may be N or $C(R_{616})$, and at least one selected from X_{614} to X_{616} may be N,

[0321] descriptions of L_{611} to L_{613} may each independently be substantially the same as that provided herein with reference to L_{601},

[0322] descriptions of xe611 to xe613 may each independently be substantially the same as that provided herein with reference to xe1,

[0323] descriptions of R_{611} to R_{613} may each independently be substantially the same as that provided herein with reference to R_{601}, and

[0324] R_{614} to R_{616} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, and a naphthyl group.

[0325] In one embodiment, L_{601} and L_{611} to L_{613} in Formulae 601 and 601-1 may each independently be selected from:

[0326] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, a pyridinylene group, an imidazolylene group, a pyrazolylene group, a thiazolylene group, an isothiazolylene group, an oxazolylene group, an isoxazolylene group, a thiadiazolylene group, an oxadiazolylene group, a pyrazinylene group, a pyrimidinylene group, a pyridazinylene group, a triazinylene group, a quinolinylene group, an isoquinolinylene group, a benzoquinolinylene group, a phthalazinylene group, a naphthyridinylene group, a quinoxalinylene group, a quinazolinylene group, a cinnolinylene group, a phenanthridinylene group, an acridinylene group, a phenanthrolinylene group, a phenazinylene group, a benzimidazolylene group, an isobenzothiazolylene group, a benzoxazolylene group, an isobenzoxazolylene group, a triazolylene group, a tetrazolylene group, an imidazopyridinylene group, an imidazopyrimidinylene group, and an azacarbazolylene group; and

[0327] a phenylene group, a naphthylene group, a fluorenylene group, a spiro-bifluorenylene group, a benzofluorenylene group, a dibenzofluorenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylene group, a perylenylene group, a pentaphenylene group, a hexacenylene group, a pentacenylene group, a thiophenylene group, a furanylene group, a carbazolylene group, an indolylene group, an isoindolylene group, a benzofuranylene group, a benzothiophenylene group, a dibenzofuranylene group, a dibenzothiophenylene group, a benzocarbazolylene group, a dibenzocarbazolylene group, a dibenzosilolylene group, a pyridinylene group, an imidazolylene group, a pyrazolylene group, a thiazolylene group, an isothiazolylene group, an oxazolylene group, an isoxazolylene group, a thiadiazolylene group, an oxadiazolylene group, a pyrazinylene group, a pyrimidinylene group, a pyridazinylene group, a triazinylene group, a quinolinylene group, an isoquinolinylene group, a benzoquinolinylene group, a phthalazinylene group, a naphthyridinylene group, a quinoxalinylene group, a quinazolinylene group, a cinnolinylene group, a phenanthridinylene group, an acridinylene group, a phenanthrolinylene group, a phenazinylene group, a benzimidazolylene group, an isobenzothiazolylene group, a benzoxazolylene group, an isobenzoxazolylene group, a triazolylene group, a tetrazolylene group, an imidazopyridinylene group, an imidazopyrimidinylene group, and an azacarbazolylene group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group, but embodiments are not limited thereto.

[0328] In one or more embodiments, xe1 and xe611 to xe613 in Formulae 601 and 601-1 may each independently be 0, 1, or 2.

[0329] In one or more embodiments, in Formulae 601 and 601-1, R_{601} and R_{611} to R_{613} may each independently be selected from:

[0330] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl

group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group; and

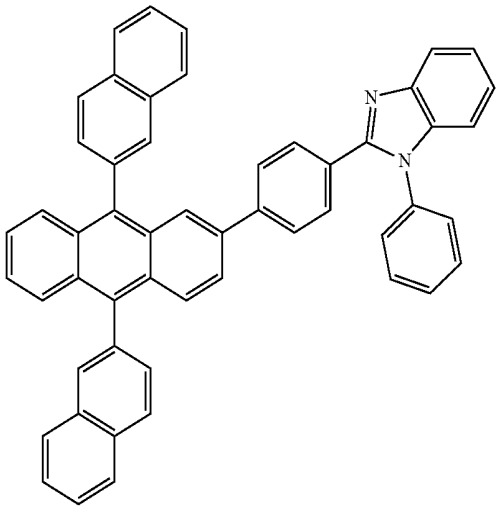
[0331] a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a biphenyl group, a terphenyl group, a naphthyl group, a fluorenyl group, a spiro-bifluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a perylenyl group, a pentaphenyl group, a hexacenyl group, a pentacenyl group, a thiophenyl group, a furanyl group, a carbazolyl group, an indolyl group, an isoindolyl group, a benzofuranyl group, a benzothiophenyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, a dibenzosilolyl group, a pyridinyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a thiadiazolyl group, an oxadiazolyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a phthalazinyl group, a naphthyridinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a phenanthridinyl group, an acridinyl group, a phenanthrolinyl group, a phenazinyl group, a benzimidazolyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an imidazopyridinyl group, an imidazopyrimidinyl group, and an azacarbazolyl group; and

[0332] —$S(=O)_2(Q_{601})$ and —$P(=O)(Q_{601})(Q_{602})$,

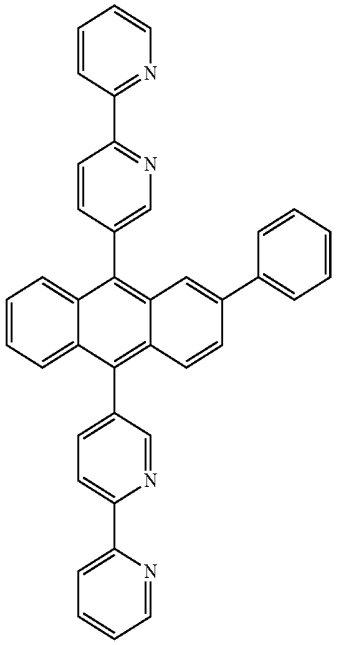
[0333] wherein Q_{601} and Q_{602} may each independently be substantially the same as described herein.

[0334] The electron transport region may include at least one compound selected from Compounds ET1 to ET36, but embodiments are not limited thereto:

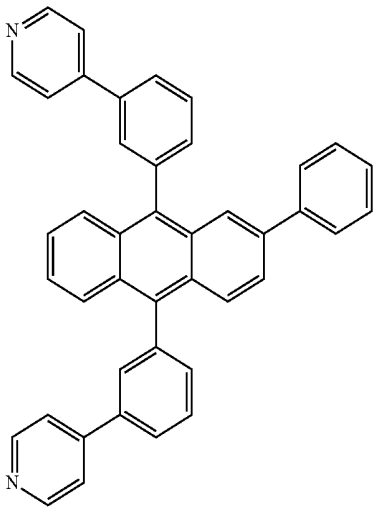
ET1



ET2



ET3



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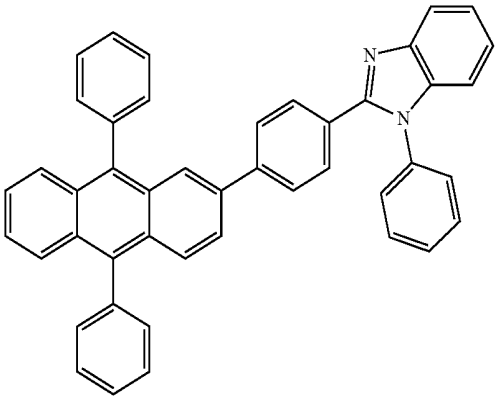
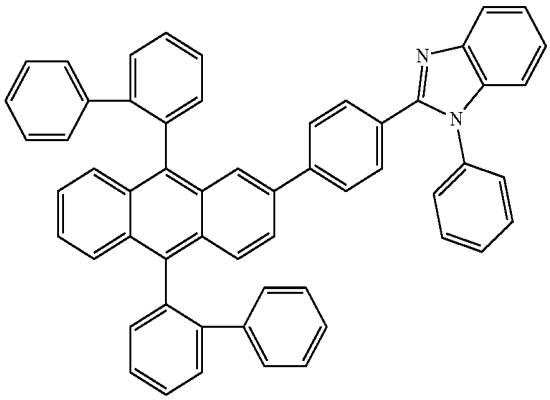
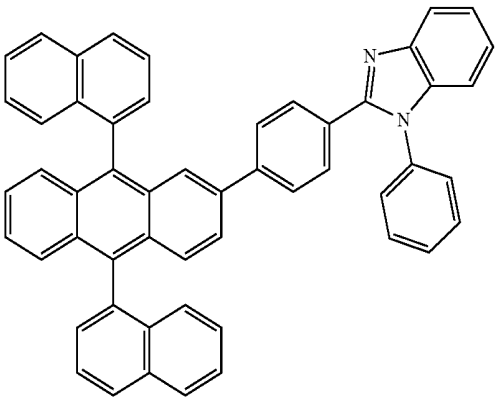
ET4



ET5



ET6



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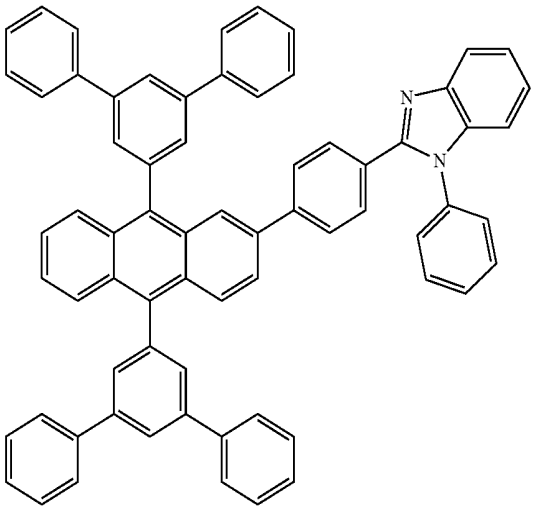
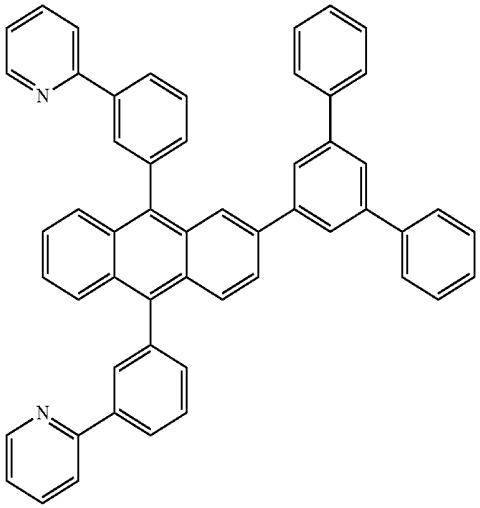
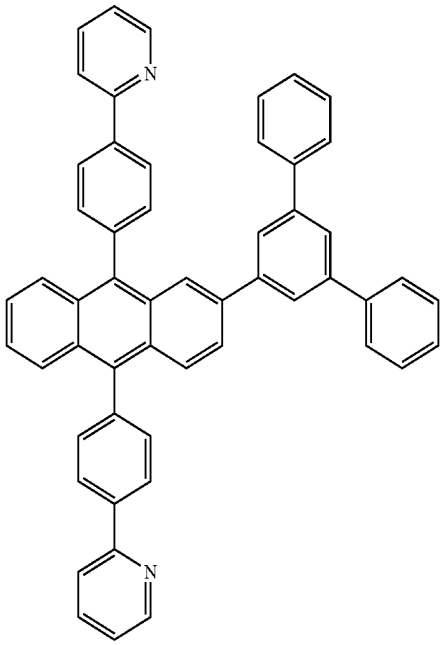
ET7



ET8



ET9



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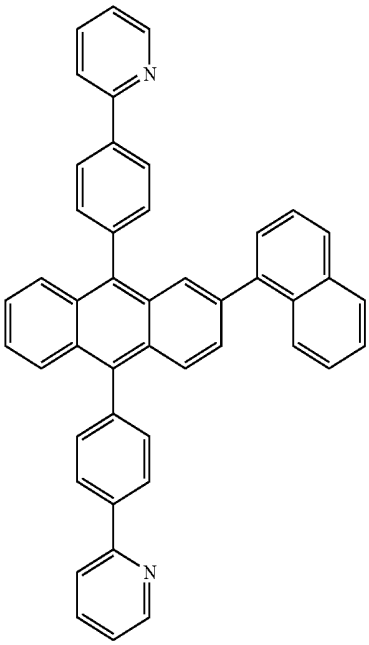
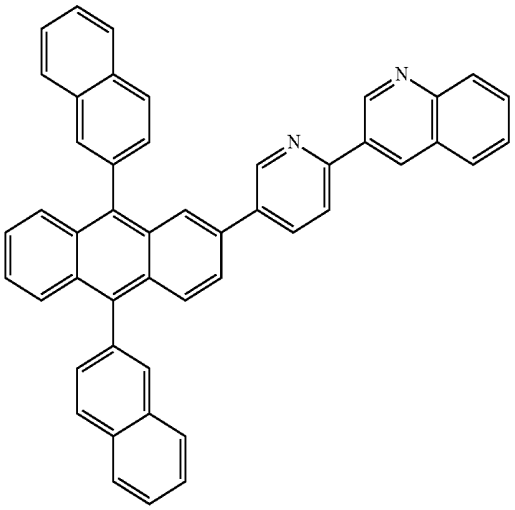
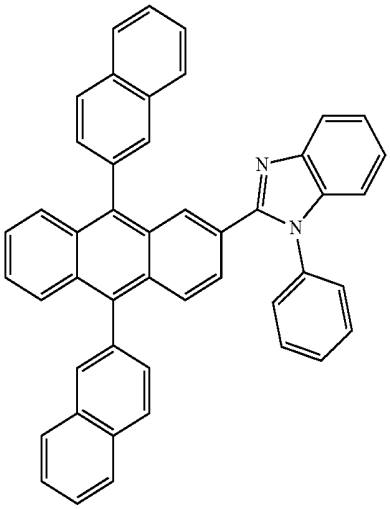
ET10



ET11



ET12



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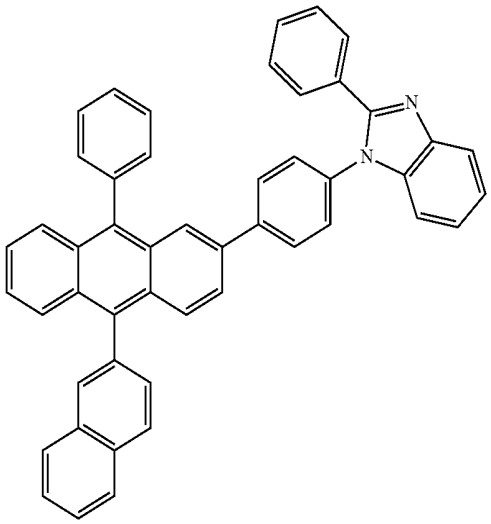
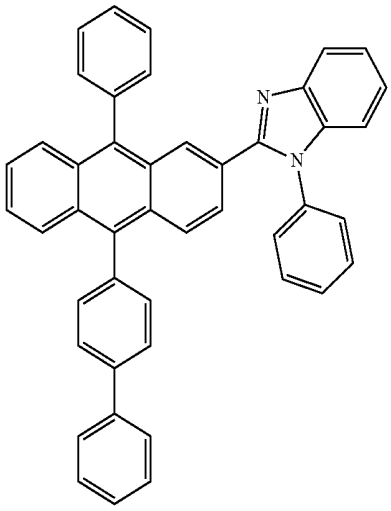
ET13



ET14



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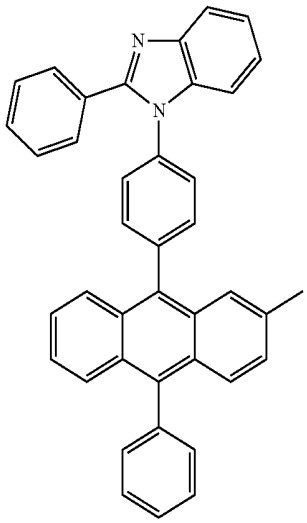

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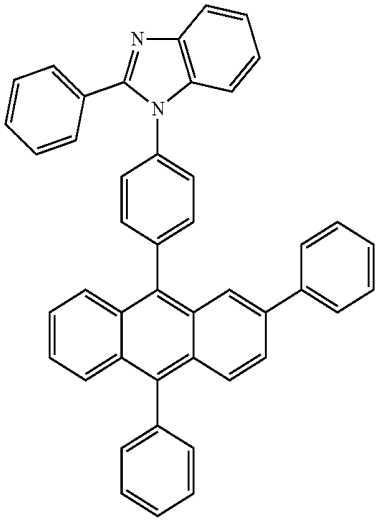

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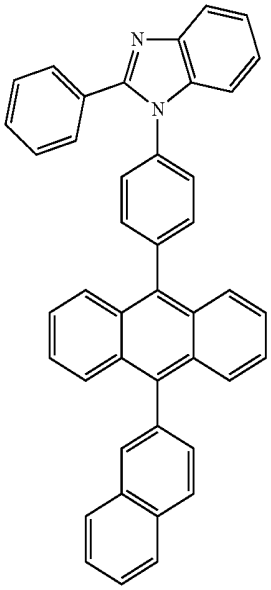

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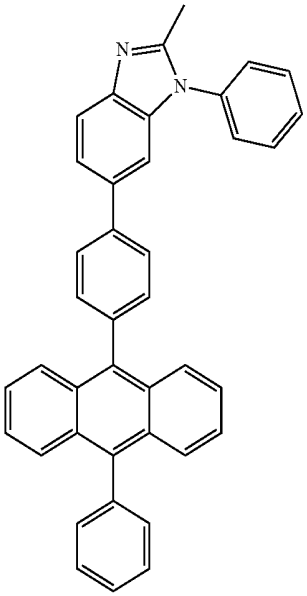

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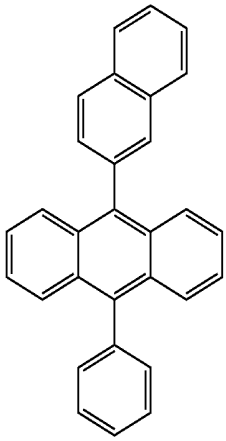

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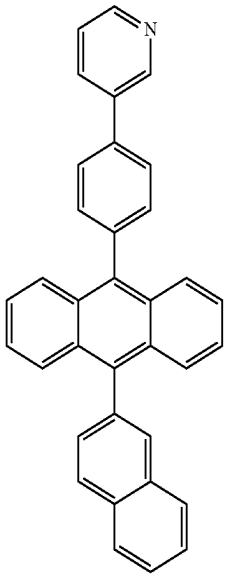

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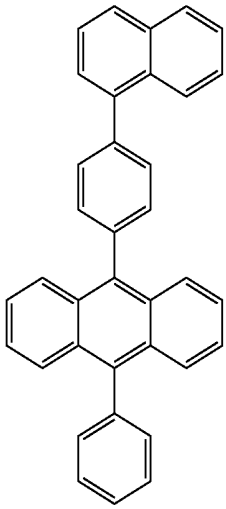

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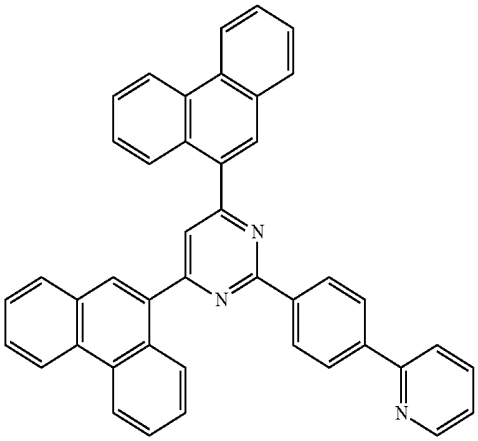
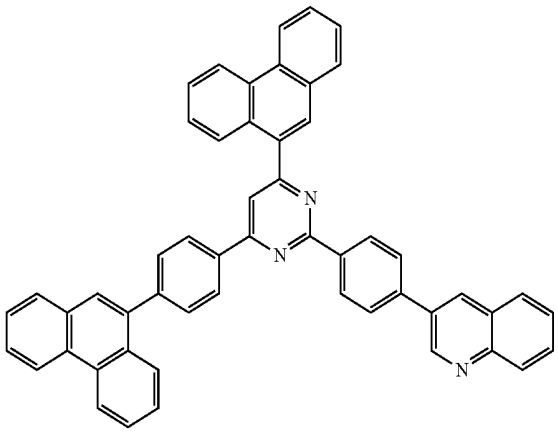
ET22



ET23



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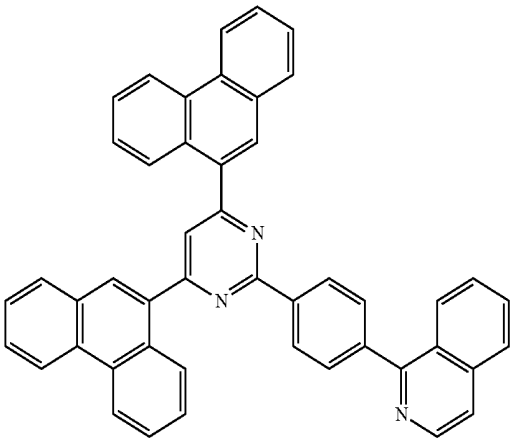

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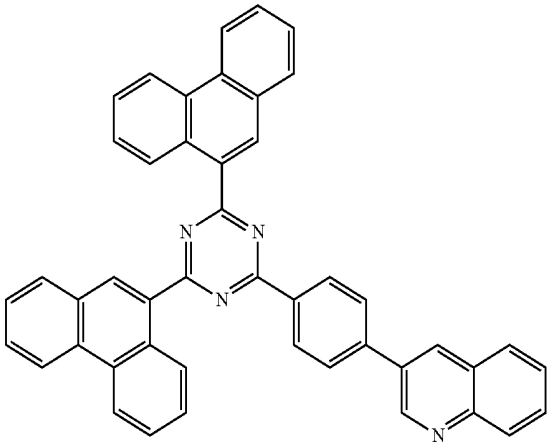
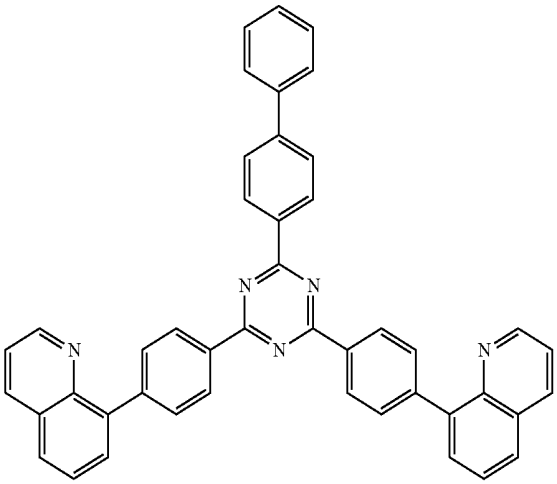
ET25



ET26



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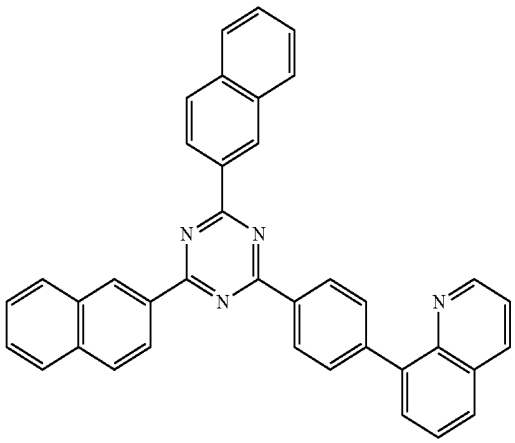

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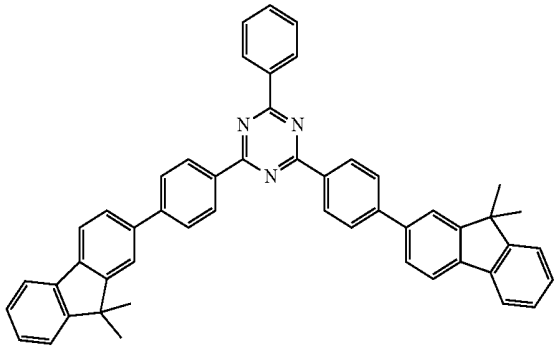
ET28



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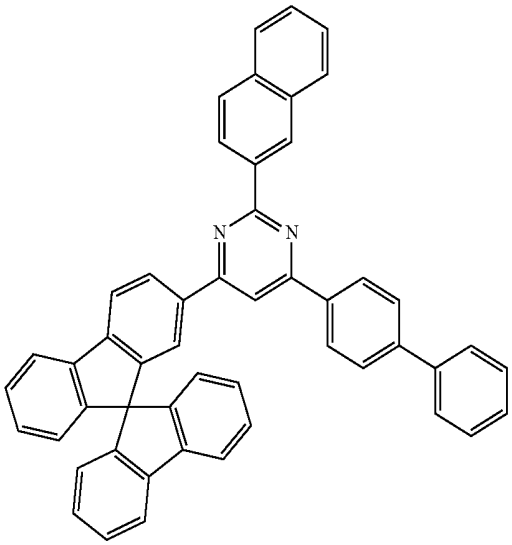
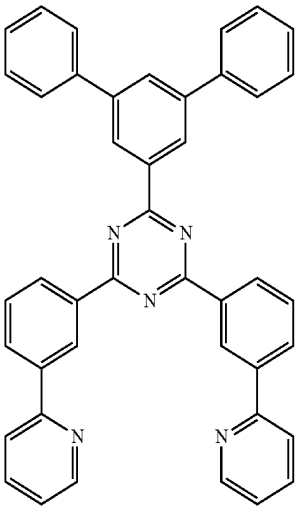


ET30



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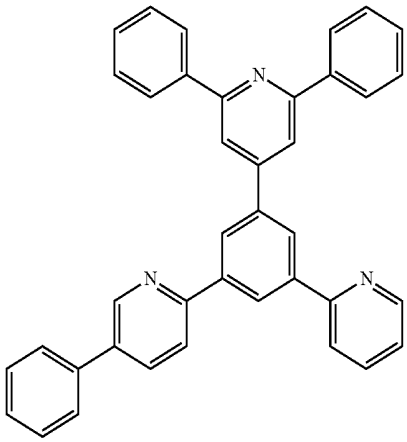
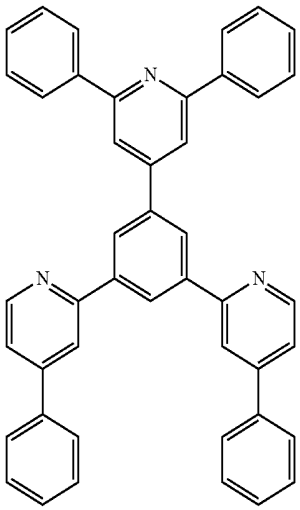
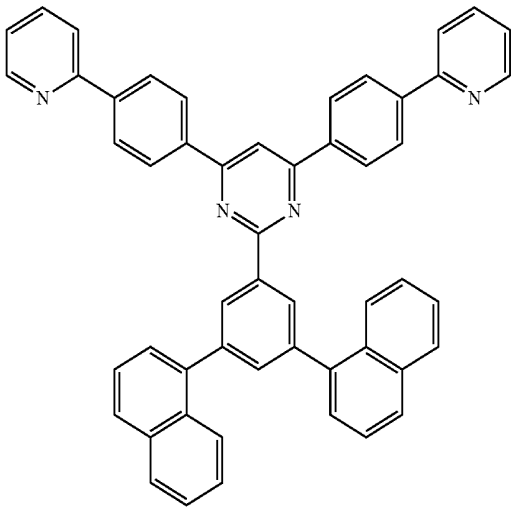
ET31



ET32



ET33



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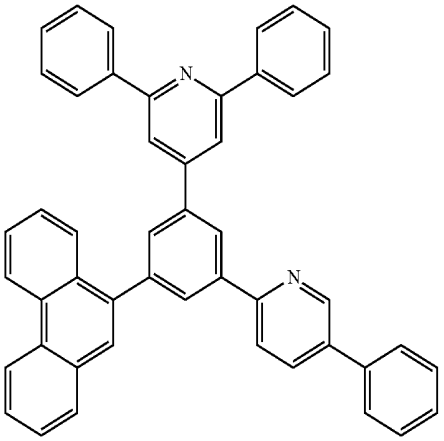
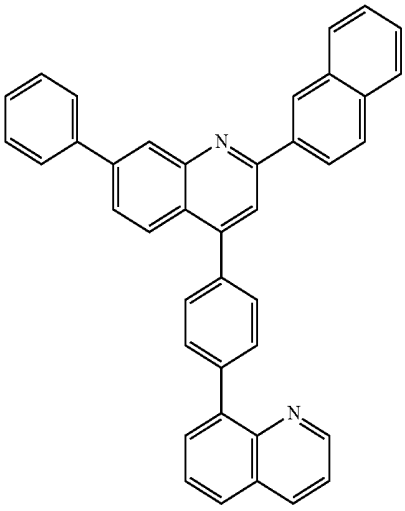
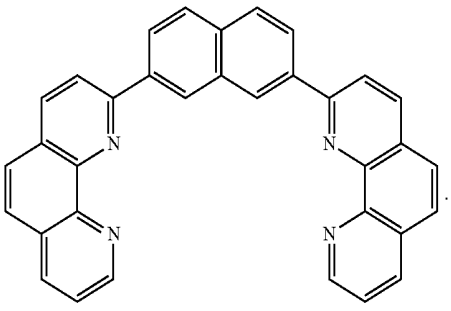
ET34



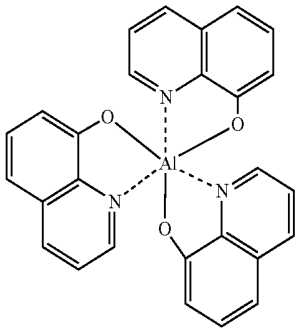
ET35



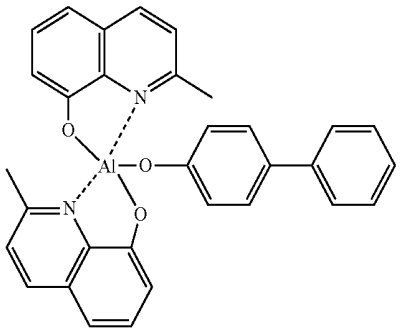
ET36



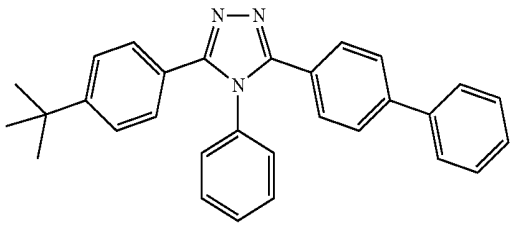
[0335] In one or more embodiments, the electron transport region may include at least one selected from 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP), 4,7-dphenyl-1,10-phenanthroline (Bphen), Alq_3, BAlq, 3-(biphenyl-4-yl)-5-(4-tert-butylphenyl)-4-phenyl-4H-1,2,4-triazole (TAZ), and NTAZ:



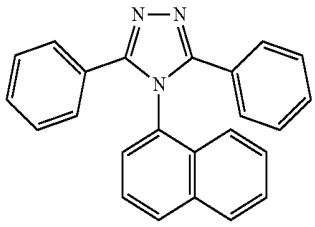
Alq_3



BAlq



TAZ



NTAZ

[0336] The thicknesses of the buffer layer, the hole blocking layer, and the electron control layer may each independently be in a range of about 20 Å to about 1,000 Å, and in some embodiments, about 30 Å to about 300 Å. When the thicknesses of the buffer layer, the hole blocking layer and/or the electron control layer are within any of these ranges, excellent (or suitable) hole blocking characteristics and/or excellent (or suitable) electron controlling characteristics may be obtained without a substantial increase in driving voltage.

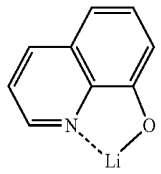
[0337] The thickness of the electron transport layer may be in a range of about 100 Å to about 1,000 Å, and in some embodiments, about 150 Å to about 500 Å. When the thickness of the electron transport layer is within any of these ranges, excellent (or suitable) electron transport characteristics may be obtained without a substantial increase in driving voltage.

[0338] The electron transport region (e.g., the electron transport layer in the electron transport region) may further include, in addition to the materials described above, a material including metal.

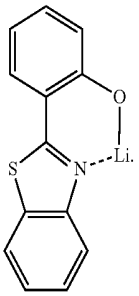
[0339] The material including metal may include at least one selected from an alkali metal complex and an alkaline earth metal complex. The alkali metal complex may include a metal ion selected from a lithium (Li) ion, a sodium (Na) ion, a potassium (K) ion, a rubidium (Rb) ion, and a cesium (Cs) ion. The alkaline earth metal complex may include a metal ion selected from a beryllium (Be) ion, a magnesium (Mg) ion, a calcium (Ca) ion, an strontium (Sr) ion, and a barium (Ba) ion. Ligands coordinated with the metal ion of the alkali metal complex and the alkaline earth metal complex may each independently be selected from a hydroxyquinoline, a hydroxyisoquinoline, a hydroxybenzoquinoline, a hydroxyacridine, a hydroxyphenanthridine, a hydroxyphenyloxazole, a hydroxyphenylthiazole, a hydroxydiphenyl oxadiazole, a hydroxydiphenyl thiadiazole, a hydroxyphenyl pyridine, a hydroxyphenyl benzimidazole, a hydroxyphenyl benzothiazole, a bipyridine, a phenanthroline, and a cyclopentadiene, but embodiments are not limited thereto.

[0340] For example, the material including metal may include a Li complex. The Li complex may include, for example, Compound ET-D1 (lithium quinolate, LiQ) and/or Compound ET-D2:

ET-D1



ET-D2



[0341] The electron transport region may include an electron injection layer that facilitates injection of electrons from the second electrode **190**. The electron injection layer may be in direct contact with the second electrode **190**.

[0342] The electron injection layer may have i) a single-layered structure including a single layer including a single material, ii) a single-layered structure including a single layer including a plurality of different materials, or iii) a multi-layered structure having a plurality of layers, each including a plurality of different materials.

[0343] The electron injection layer may include an alkali metal, an alkaline earth metal, a rare earth metal, an alkali metal compound, an alkaline earth metal compound, a rare earth metal compound, an alkali metal complex, an alkaline earth metal complex, a rare earth metal complex, or a combination thereof.

[0344] The alkali metal may be selected from Li, Na, K, Rb, and Cs. In one embodiment, the alkali metal may be Li, Na, or Cs. In one or more embodiments, the alkali metal may be Li or Cs, but embodiments are not limited thereto.

[0345] The alkaline earth metal may be selected from Mg, Ca, Sr, and Ba.

[0346] The rare earth metal may be selected from Sc, Y, Ce, Tb, Yb, and Gd.

[0347] The alkali metal compound, the alkaline earth metal compound, and the rare earth metal compound may each independently be selected from oxides and halides (e.g., fluorides, chlorides, bromides, and/or iodines) of the alkali metal, the alkaline earth metal, and the rare earth metal, respectively.

[0348] The alkali metal compound may be selected from alkali metal oxides (such as Li_2O, Cs_2O, and/or K_2O), and alkali metal halides (such as LiF, NaF, CsF, KF, LiI, NaI, CsI, KI, and/or RbI). In one embodiment, the alkali metal compound may be selected from LiF, Li_2O, NaF, LiI, NaI, CsI, and KI, but embodiments are not limited thereto.

[0349] The alkaline earth metal compound may be selected from alkaline earth metal compounds such as BaO, SrO, CaO, $Ba_xSr_{1-x}O$ (where $0<x<1$), and $Ba_xCa_{1-x}O$ (where $0<x<1$). In one embodiment, the alkaline earth metal compound may be selected from BaO, SrO, and CaO, but embodiments are not limited thereto.

[0350] The rare earth metal compound may be selected from YbF_3, ScF_3, ScO_3, Y_2O_3, Ce_2O_3, GdF_3, and TbF_3. In one embodiment, the rare earth metal compound may be selected from YbF_3, ScF_3, TbF_3, YbI_3, ScI_3, and TbI_3, but embodiments are not limited thereto.

[0351] The alkali metal complex, the alkaline earth metal complex, and the rare earth metal complex may each independently include ions of the above-described alkali metal, alkaline earth metal, and rare earth metal, respectively. Ligands coordinated with the metal ion of the alkali metal complex, the alkaline earth metal complex, and the rare earth metal complex may each independently be selected from a hydroxyquinoline, a hydroxyisoquinoline, a hydroxybenzoquinoline, a hydroxyacridine, a hydroxyphenanthridine, a hydroxyphenyl oxazole, a hydroxyphenyl thiazole, a hydroxydiphenyl oxadiazole, a hydroxydiphenyl thiadiazole, a hydroxyphenyl pyridine, a hydroxyphenyl benzimidazole, a hydroxyphenyl benzothiazole, a bipyridine, a phenanthroline, and a cyclopentadiene, but embodiments are not limited thereto.

[0352] The electron injection layer may include (e.g., consist of) an alkali metal, an alkaline earth metal, a rare earth metal, an alkali metal compound, an alkaline earth metal compound, a rare earth metal compound, an alkali metal complex, an alkaline earth metal complex, a rare earth metal complex, or a combination thereof, as described above. In some embodiments, the electron injection layer may further include an organic material. When the electron injection layer further includes an organic material, the alkali metal, the alkaline earth metal, the rare earth metal, the alkali metal compound, the alkaline earth metal compound, the rare earth metal compound, the alkali metal complex, the alkaline earth metal complex, the rare earth metal complex, or a combination thereof may be homogeneously or non-homogeneously dispersed in a matrix including the organic material.

[0353] The thickness of the electron injection layer may be in a range of about 1 Å to about 100 Å, and in some

embodiments, about 3 Å to about 90 Å. When the thickness of the electron injection layer is within any of these ranges, excellent (or suitable) electron injection characteristics may be obtained without a substantial increase in driving voltage.

[0354] The second electrode **190** may be disposed (e.g., positioned) on the organic layer **150**. The second electrode **190** may be a cathode, that is an electron injection electrode. In this regard, a material for forming the second electrode **190** may be a material having a low work function, for example, a metal, an alloy, an electrically conductive compound, or a combination thereof.

[0355] The second electrode **190** may include at least one selected from lithium (Li), silver (Ag), magnesium (Mg), aluminum (Al), aluminum-lithium (Al—Li), calcium (Ca), magnesium-indium (Mg—In), magnesium-silver (Mg—Ag), ITO, and IZO, but embodiments are not limited thereto. The second electrode **190** may be a transmissive electrode, a semi-transmissive electrode, or a reflective electrode.

[0356] The second electrode **190** may have a single-layered structure, or a multi-layered structure including two or more layers.

[0357] Referring to FIG. **2**, an organic light-emitting device **20** has a structure including a first capping layer **210**, the first electrode **110**, the organic layer **150**, and the second electrode **190**, wherein the layers are sequentially stacked in this stated order. Referring to FIG. **3**, an organic light-emitting device **30** has a structure including the first electrode **110**, the organic layer **150**, the second electrode **190**, and a second capping layer **220**, wherein the layers are sequentially stacked in this stated order. Referring to FIG. **4**, an organic light-emitting device **40** has a structure including the first capping layer **210**, the first electrode **110**, the organic layer **150**, the second electrode **190**, and the second capping layer **220**, wherein the layers are stacked in this stated order.

[0358] The first electrode **110**, the organic layer **150**, and the second electrode **190** illustrated in FIGS. **2** to **4** may be substantially the same as those illustrated in FIG. **1**.

[0359] In the organic light-emitting devices **20** and **40**, light emitted from the emission layer in the organic layer **150** may pass through the first electrode **110** (which may be a semi-transmissive electrode or a transmissive electrode) and through the first capping layer **210** to the outside. In the organic light-emitting devices **30** and **40**, light emitted from the emission layer in the organic layer **150** may pass through the second electrode **190** (which may be a semi-transmissive electrode or a transmissive electrode) and through the second capping layer **220** to the outside.

[0360] The first capping layer **210** and the second capping layer **220** may improve the external luminous efficiency based on the principle of constructive interference.

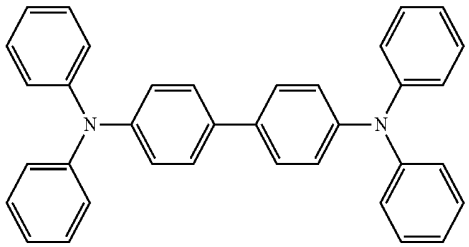
[0361] The first capping layer **210** and the second capping layer **220** may each independently be an organic capping layer including an organic material, an inorganic capping layer including an inorganic material, or a composite capping layer including an organic material and an inorganic material.

[0362] At least one selected from the first capping layer **210** and the second capping layer **220** may each independently include at least one material selected from carbocyclic compounds, heterocyclic compounds, amine-based compounds, porphine derivatives, phthalocyanine derivatives, naphthalocyanine derivatives, alkali metal complexes, and alkaline earth metal complexes. The carbocyclic compound, the heterocyclic compound, and the amine-based compound may each independently be optionally substituted with a substituent containing at least one element selected from O, N, S, Se, Si, F, Cl, Br, and I. In one embodiment, at least one of the first capping layer **210** and the second capping layer **220** may each independently include an amine-based compound.

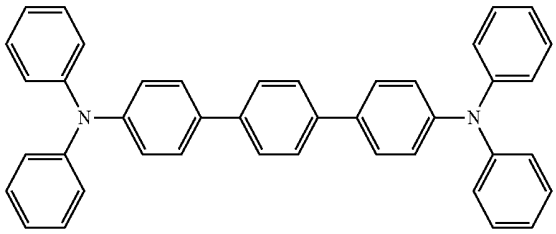
[0363] In one or more embodiments, at least one of the first capping layer **210** and the second capping layer **220** may each independently include a compound represented by Formula 201 or 202.

[0364] In one or more embodiments, at least one of the first capping layer **210** and the second capping layer **220** may each independently include a compound selected from Compounds HT28 to HT33 (shown above) and Compounds CP1 to CP5 (shown below), but embodiments are not limited thereto:

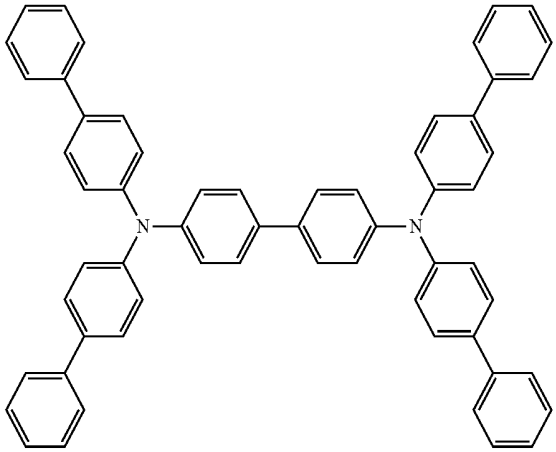
CP1



CP2



CP3



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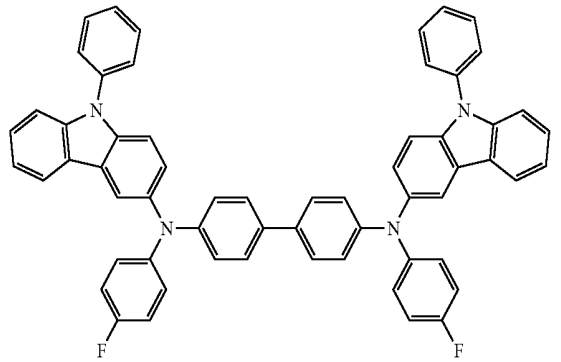
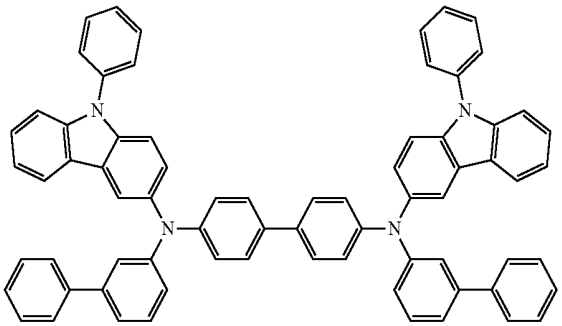
CP4



CP5



[0365] Hereinbefore, the organic light-emitting device has been described with reference to FIGS. **1** to **4**, but embodiments are not limited thereto.

[0366] Layers constituting the hole transport region, an emission layer, and layers constituting the electron transport region may each independently be formed in a certain region by using one or more suitable methods such as vacuum deposition, spin coating, casting, Langmuir-blodgett (LB) deposition, ink-jet printing, laser printing, and/or laser-induced thermal imaging.

[0367] When any of the layers constituting the hole transport region, the emission layer, and layers constituting the electron transport region are formed by vacuum deposition, the vacuum deposition may be performed at a deposition temperature in a range of about 100° C. to about 500° C. at a vacuum degree in a range of about 10-08 torr to about 10^{-3} torr, and at a deposition rate in a range of about 0.01 Angstroms per second (Å/sec) to about 100 Å/sec, depending on the material to be included in each layer and the structure of each layer to be formed.

[0368] When any of the layers constituting the hole transport region, the emission layer, and layers constituting the electron transport region are formed by spin coating, the spin coating may be performed at a coating rate of about 2,000 revolutions per minute (rpm) to about 5,000 rpm and at a heat treatment temperature of about 80° C. to about 200° C., depending on the material to be included in each layer and the structure of each layer to be formed.

[0369] The term "C_1-C_{60} alkyl group" as used herein may refer to a linear or branched aliphatic hydrocarbon monovalent group having 1 to 60 carbon atoms. Non-limiting examples thereof include a methyl group, an ethyl group, a propyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a pentyl group, an iso-amyl group, and a hexyl group. The term "C_1-C_{60} alkylene group" as used herein may refer to a divalent group having substantially the same structure as the C_1-C_{60} alkyl group.

[0370] The term "C_2-C_{60} alkenyl group" as used herein may refer to a hydrocarbon group having at least one carbon-carbon double bond at one or more positions along the hydrocarbon chain (e.g., in the middle or at either terminus) of the C_2-C_{60} alkyl group. Non-limiting examples thereof include an ethenyl group, a propenyl group, and a butenyl group. The term "C_1-C_{60} alkenylene group" as used herein may refer to a divalent group having substantially the same structure as the C_2-C_{60} alkenyl group.

[0371] The term "C_2-C_{60} alkynyl group" as used herein may refer to a hydrocarbon group having at least one carbon-carbon triple bond at one or more positions along the hydrocarbon chain (e.g., in the middle or at either terminus) of the C_2-C_{60} alkyl group. Non-limiting examples thereof include an ethynyl group and a propynyl group. The term "C_2-C_{60} alkynylene group" as used herein may refer to a divalent group having substantially the same structure as the C_2-C_{60} alkynyl group.

[0372] The term "C_1-C_{60} alkoxy group" as used herein may refer to a monovalent group represented by —OA_{101} (wherein A_{101} is a C_1-C_{60} alkyl group). Non-limiting examples thereof include a methoxy group, an ethoxy group, and an isopropoxy group.

[0373] The term "C_3-C_{10} cycloalkyl group" as used herein may refer to a monovalent monocyclic saturated hydrocarbon group including 3 to 10 carbon atoms. Non-limiting examples thereof include a cyclopropyl group, a cyclobutyl group, a cyclopentyl group, a cyclohexyl group, and a cycloheptyl group. The term "C_3-C_{10} cycloalkylene group" as used herein may refer to a divalent group having substantially the same structure as the C_3-C_{10} cycloalkyl group.

[0374] The term "C_1-C_{10} heterocycloalkyl group" as used herein may refer to a monovalent monocyclic group including at least one heteroatom selected from N, O, Si, P, and S as a ring-forming atom and 1 to 10 carbon atoms. Non-limiting examples thereof include a 1,2,3,4-oxatriazolidinyl group, a tetrahydrofuranyl group, and a tetrahydrothiophenyl group. The term "C_1-C_{10} heterocycloalkylene group" as used herein may refer to a divalent group having substantially the same structure as the C_1-C_{10} heterocycloalkyl group.

[0375] The term "C_3-C_{10} cycloalkenyl group" as used herein may refer to a monovalent monocyclic group that has 3 to 10 carbon atoms and at least one double bond in its ring, and is not aromatic. Non-limiting examples thereof include a cyclopentenyl group, a cyclohexenyl group, and a cycloheptenyl group. The term "C_3-C_{10} cycloalkenylene group" as used herein may refer to a divalent group having substantially the same structure as the C_3-C_{10} cycloalkenyl group.

[0376] The term "C_1-C_{10} heterocycloalkenyl group" as used herein may refer to a monovalent monocyclic group including at least one heteroatom selected from N, O, Si, P, and S as a ring-forming atom, 1 to 10 carbon atoms, and at least one double bond in its ring. Non-limiting examples of the C_1-C_{10} heterocycloalkenyl group include a 4,5-dihydro-1,2,3,4-oxatriazolyl group, a 2,3-dihydrofuranyl group, and a 2,3-dihydrothiophenyl group. The term "C_1-C_{10} heterocycloalkenylene group" as used herein may refer to a divalent group having substantially the same structure as the C_1-C_{10} heterocycloalkenyl group.

[0377] The term "C_6-C_{60} aryl group" as used herein may refer to a monovalent group having a carbocyclic aromatic system having 6 to 60 carbon atoms. The term "C_6-C_{60} arylene group" as used herein may refer to a divalent group having a carbocyclic aromatic system having 6 to 60 carbon atoms. Non-limiting examples of the C_6-C_{60} aryl group include a phenyl group, a naphthyl group, an anthracenyl group, a phenanthrenyl group, a pyrenyl group, and a chrysenyl group. When the C_6-C_{60} aryl group and the C_6-C_{60} arylene group each independently include two or more rings, the respective rings may be fused.

[0378] The term "C_1-C_{60} heteroaryl group" as used herein may refer to a monovalent group having a heterocyclic aromatic system having at least one heteroatom selected from N, O, Si, P, and S as a ring-forming atom and 1 to 60 carbon atoms. The term "C_1-C_{60} heteroarylene group" as used herein may refer to a divalent group having a heterocyclic aromatic system having at least one heteroatom selected from N, O, Si, P, and S as a ring-forming atom and 1 to 60 carbon atoms. Non-limiting examples of the C_1-C_{60} heteroaryl group include a pyridinyl group, a pyrimidinyl group, a pyrazinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, and an isoquinolinyl group. When the C_1-C_{60} heteroaryl group and the C_1-C_{60} heteroarylene group each independently include two or more rings, the respective rings may be fused.

[0379] The term "C_6-C_{60} aryloxy group" as used herein may refer to a group represented by $—OA_{102}$ (where A_{102} is a C_6-C_{60} aryl group). The term "C_6-C_{60} arylthio group" as used herein may refer to a group represented by $—SA_{103}$ (where A_{103} is a C_6-C_{60} aryl group).

[0380] The term "C_1-C_{60} heteroaryloxy group" as used herein may refer to a group represented by $—OA_{104}$ (wherein A_{104} is a C_1-C_{60} heteroaryl group). The term "C_1-C_{60} heteroarylthio group" as used herein may refer to a group represented by $—SA_{105}$ (wherein A_{105} is a C_1-C_{60} heteroaryl group).

[0381] The term "monovalent non-aromatic condensed polycyclic group" as used herein may refer to a monovalent group that has two or more rings condensed and only carbon atoms (e.g., 8 to 60 carbon atoms) as ring forming atoms, wherein the entire molecular structure is non-aromatic. A non-limiting example of the monovalent non-aromatic condensed polycyclic group is a fluorenyl group. The term "divalent non-aromatic condensed polycyclic group" as used herein may refer to a divalent group having substantially the same structure as the monovalent non-aromatic condensed polycyclic group.

[0382] The term "monovalent non-aromatic condensed heteropolycyclic group" as used herein may refer to a monovalent group that has two or more condensed rings and at least one heteroatom selected from N, O, Si, P, and S, in addition to carbon atoms (e.g., 1 to 60 carbon atoms), as a ring-forming atom, wherein the entire molecular structure is non-aromatic. A non-limiting example of the monovalent non-aromatic condensed heteropolycyclic group is a carbazolyl group. The term "divalent non-aromatic condensed heteropolycyclic group" as used herein may refer to a divalent group having substantially the same structure as the monovalent non-aromatic condensed heteropolycyclic group.

[0383] The term "C_5-C_{60} carbocyclic group" as used herein may refer to a monocyclic or polycyclic group having only carbon atoms (e.g., 5 to 60 carbon atoms) as ring-forming atoms. The C_5-C_{60} carbocyclic group may be an aromatic carbocyclic group or a non-aromatic carbocyclic group. The term "C_5-C_{60} carbocyclic group" as used herein may refer to a ring (e.g., a benzene group), a monovalent group (e.g., a phenyl group), or a divalent group (e.g., a phenylene group). In one or more embodiments, depending on the number of substituents connected to the C_5-C_{60} carbocyclic group, the C_5-C_{60} carbocyclic group may be a trivalent group or a quadrivalent group.

[0384] The term "C_1-C_{60} heterocyclic group" as used herein may refer to a group having substantially the same structure as a C_1-C_{60} carbocyclic group, except that at least one heteroatom selected from N, O, Si, P, and S is used as a ring-forming atom, in addition to carbon atoms (e.g., 1 to 60 carbon atoms).

[0385] In the present specification, at least one substituent of the substituted C_5-C_{60} carbocyclic group, substituted C_1-C_{60} heterocyclic group, substituted C_3-C_{10} cycloalkylene group, substituted C_1-C_{10} heterocycloalkylene group, substituted C_3-C_{10} cycloalkenylene group, substituted C_1-C_{10} heterocycloalkenylene group, substituted C_6—C_{60} arylene group, substituted C_1-C_{60} heteroarylene group, a substituted divalent non-aromatic condensed polycyclic group, a substituted divalent non-aromatic condensed heteropolycyclic group, substituted C_1-C_{60} alkyl group, substituted C_2-C_{60} alkenyl group, substituted C_2-C_{60} alkynyl group, substituted C_1-C_{60} alkoxy group, substituted C_3-C_{10} cycloalkyl group, substituted C_1-C_{10} heterocycloalkyl group, substituted C_3-C_{10} cycloalkenyl group, substituted C_1-C_{10} heterocycloalkenyl group, substituted C_6-C_{60} aryl group, substituted C_6-C_{60} aryloxy group, substituted C_6-C_{60} arylthio group, substituted C_1-C_{60} heteroaryl group, substituted C_1-C_{60} heteroaryloxy group, substituted C_1-C_{60} heteroarylthio group, substituted monovalent non-aromatic condensed polycyclic group, and substituted monovalent non-aromatic condensed heteropolycyclic group may be selected from:

[0386] deuterium (-D), —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group;

[0387] a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, and a C_1-C_{60} alkoxy group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a C_1-C_{60} heteroaryloxy group, a C_1-C_{60} heteroarylthio group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, $—Si(Q_{11})(Q_{12})(Q_{13})$, $—N(Q_{11})(Q_{12})$, $—B(Q_{11})(Q_{12})$, $—C(=O)(Q_{11})$, $—S(=O)_2(Q_{11})$, and $—P(=O)(Q_{11})(Q_{12})$;

[0388] a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a C_1-C_{60} heteroaryloxy group, a C_1-C_{60} heteroarylthio group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group;

[0389] a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a C_1-C_{60} heteroaryloxy group, a C_1-C_{60} heteroarylthio group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a C_1-C_{60} heteroaryloxy group, a C_1-C_{60} heteroarylthio group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, —$Si(Q_{21})(Q_{22})(Q_{23})$, —$N(Q_{21})(Q_{22})$, —$B(Q_{21})(Q_{22})$, —$C(=O)(Q_{21})$, —$S(=O)_2(Q_{21})$, and —$P(=O)(Q_{21})(Q_{22})$; and

[0390] —$Si(Q_{31})(Q_{32})(Q_{33})$, —$N(Q_{31})(Q_{32})$, —$B(Q_{31})(Q_{32})$, —$C(=O)(Q_{31})$, —$S(=O)_2(Q_{31})$, and —$P(=O)(Q_{31})(Q_{32})$,

[0391] wherein Q_{11} to Q_{13}, Q_{21} to Q_{23}, and Q_{31} to Q_{33} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_1-C_{60} heteroaryl group, a C_1-C_{60} heteroaryloxy group, a C_1-C_{60} heteroarylthio group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, a biphenyl group, and a terphenyl group.

[0392] The term "Ph" as used herein may refer to a phenyl group. The term "Me" as used herein may refer to a methyl group. The term "Et" as used herein may refer to an ethyl group. The term "ter-Bu" or "But" as used herein may refer to a tert-butyl group. The term "OMe" as used herein may refer to a methoxy group.

[0393] The term "biphenyl group" as used herein may refer to a phenyl group substituted with a phenyl group. For example, the "biphenyl group" may be described as a substituted phenyl group having a C_6-C_{60} aryl group as a substituent.

[0394] The term "terphenyl group" as used herein may refer to a phenyl group substituted with a biphenyl group. For example, the "terphenyl group" may be described as a substituted phenyl group having a C_6-C_{60} aryl group substituted with a C_6-C_{60} aryl group as a substituent.

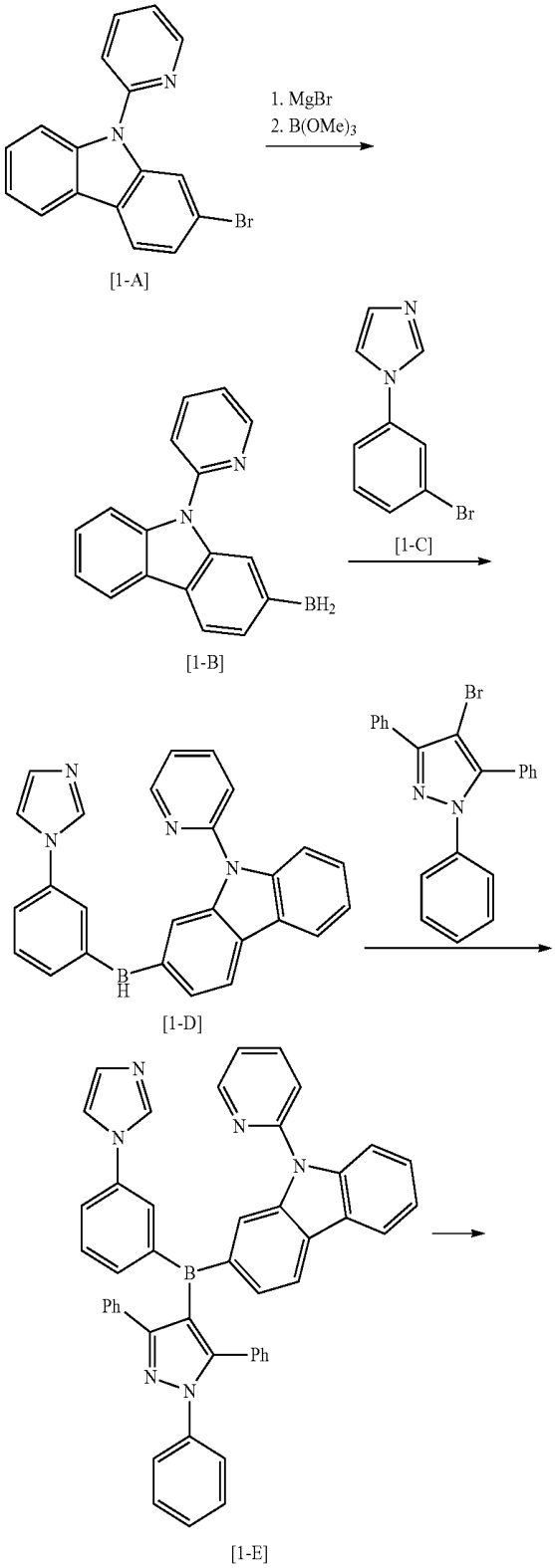
[0395] The symbols * and *' as used herein, unless defined otherwise, refer to a binding site to an adjacent atom in a corresponding formula.

[0396] Hereinafter a compound and an organic light-emitting device according to one or more embodiments will be described in more detail with reference to Synthesis Examples and Examples. The expression "B was used instead of A" used in describing Synthesis Examples means that an identical molar equivalent of B was used in place of A.

Examples

Synthesis Example 1: Synthesis of Compound 1

[0397]



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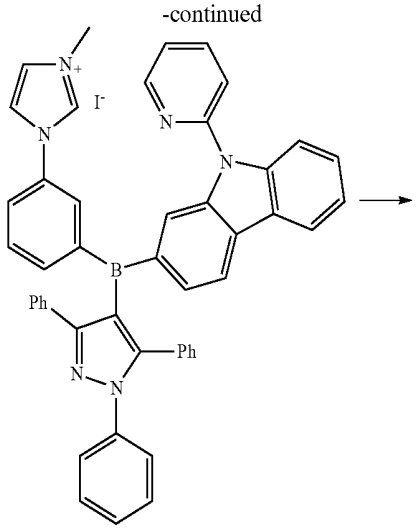
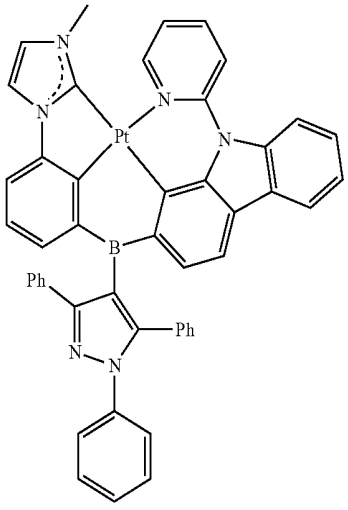


[1-F]



[1]

1) Synthesis of Intermediate Compound 1-A

[0398] 9-bromocarbazole (1.0 eq), 2-bromopyridine (1.2 eq), CuI (0.01 eq), K_2CO_3 (2.0 eq), and L-proline (0.02 eq) were dissolved in 0.50 molar (M) dimethyl sulfoxide (DMSO), and the mixture was stirred at a temperature of 130° C. for 24 hours. The obtained reaction mixture was cooled to room temperature, and then an extraction process was performed thereon three times using dichloromethane and water to thereby obtain an organic layer. The obtained organic layer was dried using magnesium sulfate, and then concentrated. By using column chromatography, Compound 1-A was synthesized (yield: 70%).

2) Synthesis of Intermediate Compound 1-B

[0399] To a reaction vessel containing the dried Mg turning (3.0 eq), 0.1 M tetrahydrofuran (THF) was added. Subsequently, trimethylborate (1.1 eq) and Compound 1-A (1.0 eq) were slowly added thereto. The temperature was maintained in a range of 20° C. to 40° C. to allow reaction to occur for 15 minutes. Then, 1,2-dibromoethane (0.1 eq) was slowly added thereto. The temperature was then raised and the mixture stirred under reflux for 4 hours. The obtained reaction mixture was cooled to room temperature, and then an extraction process was performed thereon three times using diethylether and water to thereby obtain an organic layer. The organic layer was concentrated under reduced pressure. This organic layer was dissolved in diethyl ether and n-pentane, and a lithium aluminum hydride solution (1 M diethyl ether) (3.0 eq) was slowly added thereto. The mixture was stirred for 2 hours at a temperature of 0° C., and then the mixture was stirred again for 16 hours at ambient temperature. A precipitate was separated using a filter paper. The filtrate was recrystallized using n-hexane, while being dissolved in Et_2O, to thereby synthesize Compound 1-B.Et_2O (yield: 32%).

3) Synthesis of Intermediate Compound 1-C

[0400] 3-bromoiodobenzene (1.0 eq), imidazole (1.8 eq), CuI (0.02 eq), and Cs_2CO_3 (2.0 eq) were suspended in 0.25 M acetonitrile (ACN), which was then stirred at a temperature of 90° C. for 12 hours. The obtained reaction mixture was cooled to room temperature, and then an extraction process was performed thereon three times using dichloromethane and water to thereby obtain an organic layer. The obtained organic layer was dried using magnesium sulfate, and then concentrated. By using column chromatography, Compound 1-C was obtained (yield: 90%).

4) Synthesis of Intermediate Compound 1-D

[0401] Compound 1-B (1.0 eq), Compound 1-C(1.2 eq), CuI (0.01 eq), K_2CO_3 (2.0 eq), and L-proline (0.02 eq) were dissolved in 0.50 M DMSO, and the mixture was stirred at a temperature of 160° C. for 48 hours. The obtained reaction mixture was cooled to room temperature, and then an extraction process was performed thereon three times using dichloromethane and water to thereby obtain an organic layer. The obtained organic layer was dried using magnesium sulfate, and then concentrated. By using column chromatography, Compound 1-D was obtained (yield: 57%).

5) Synthesis of Intermediate Compound 1-E

[0402] Compound 1-D (1.0 eq), 4-bromo-1,3,5-triphenyl-1H-pyrazole (1.2 eq), CuI (0.01 eq), K_2CO_3 (2.0 eq), and L-proline (0.02 eq) were dissolved in 0.1 M DMSO, and the mixture was stirred at a temperature of 130° C. for 72 hours. The obtained reaction mixture was cooled to room temperature, and then an extraction process was performed thereon three times using dichloromethane and water to thereby obtain an organic layer. The obtained organic layer was dried using magnesium sulfate, and then concentrated. By using column chromatography, Compound 1-E was obtained (yield: 72%).

6) Synthesis of Intermediate Compound 1-F

[0403] Compound 1-E (1.0 eq) was dissolved in acetone, and iodomethane (1.2 eq) was added thereto, which was then stirred at a room temperature for 3 days. The obtained reaction mixture was concentrated under reduced pressure, and then by using a column chromatography, Compound 1-F was obtained (yield: 91%).

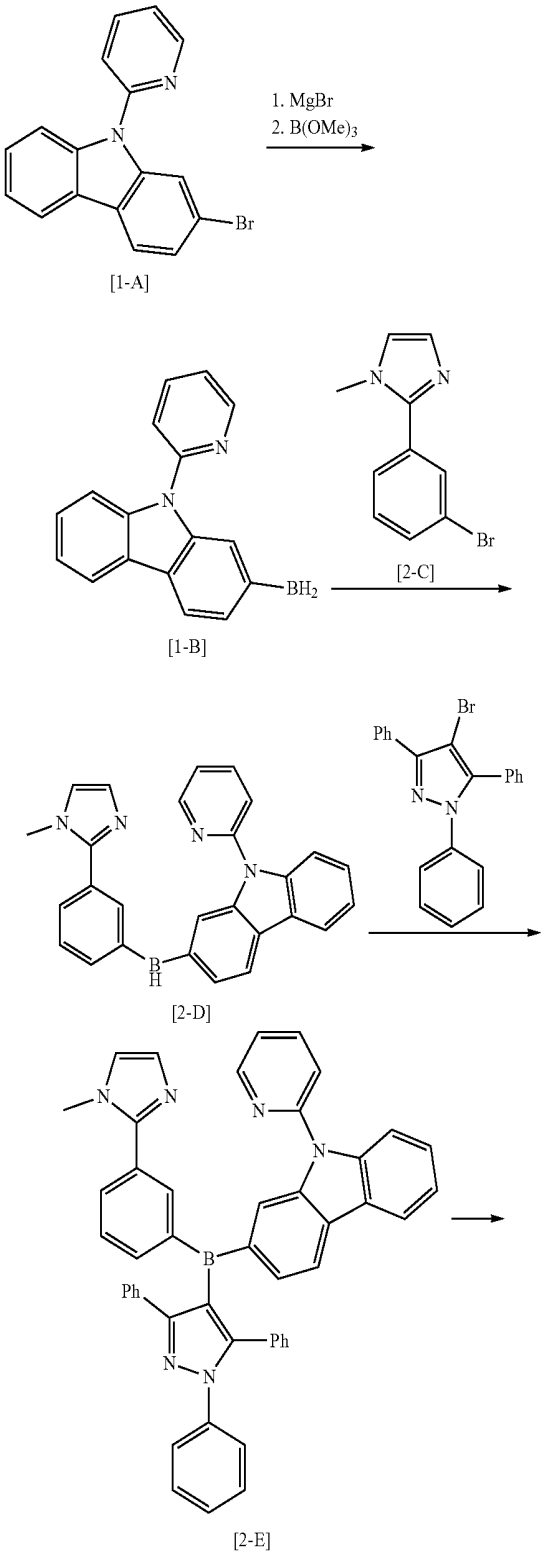
7) Synthesis of Compound 1

[0404] Compound 1-F (1.0 eq), potassium tetrachloroplatinate (K_2PtCl_4, 1.1 eq), and tetrabutylammonium bromide (0.1 eq) were dissolved in 0.1 M acetic acid, and the mixture was stirred at a temperature of 120° C. for 72 hours. The obtained reaction mixture was cooled to room temperature, and then an extraction process was performed thereon three times using dichloromethane and water to thereby obtain an organic layer. The obtained organic layer was dried using

magnesium sulfate, and then concentrated. By using column chromatography, Compound 1 was obtained (yield: 28%).

Synthesis Example 2: Synthesis of Compound 2

[0405]



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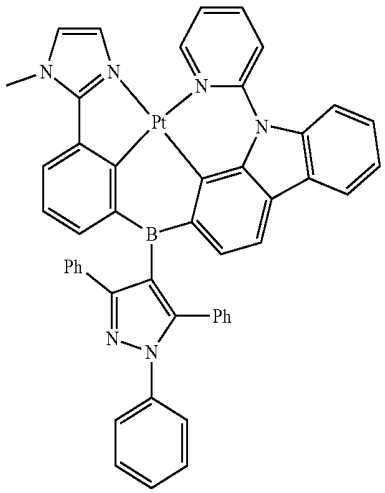


1) Synthesis of Intermediate Compound 2-D

[0406] Compound 1-B (1.0 eq) (synthesized as in Synthesis Example 1), Compound 2-C(1.2 eq), CuI (0.01 eq), K_2CO_3 (2.0 eq), and L-proline (0.02 eq) were dissolved in 0.50 M DMSO, and the mixture was stirred at a temperature of 160° C. for 48 hours. The obtained reaction mixture was cooled to room temperature, and then an extraction process was performed thereon three times using dichloromethane and water to thereby obtain an organic layer. The obtained organic layer was dried using magnesium sulfate, and then concentrated. By using column chromatography, Compound 2-D was obtained (yield: 45%).

2) Synthesis of Intermediate Compound 2-E

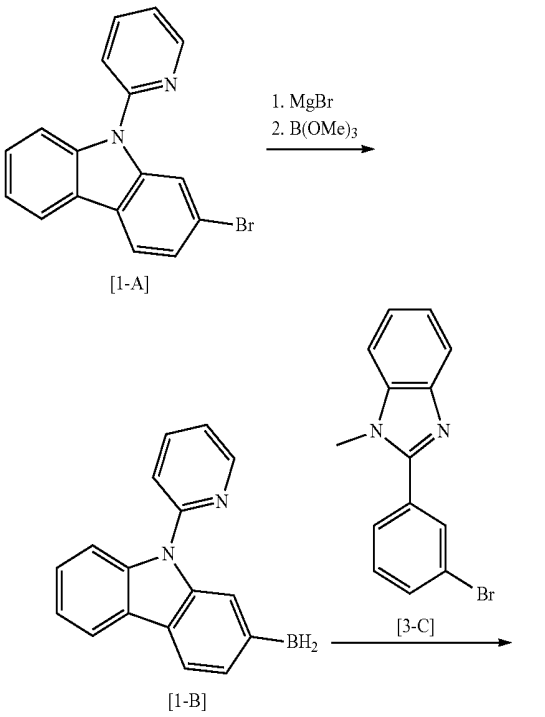
[0407] Compound 2-D (1.0 eq), 4-bromo-1,3,5-triphenyl-1H-pyrazole (1.2 eq), CuI (0.01 eq), K_2CO_3 (2.0 eq), and L-proline (0.02 eq) were dissolved in 0.1 M DMSO, and the mixture was stirred at a temperature of 130° C. for 72 hours. The obtained reaction mixture was cooled to room temperature, and then an extraction process was performed thereon three times using dichloromethane and water to thereby obtain an organic layer. The obtained organic layer was dried using magnesium sulfate, and then concentrated. By using column chromatography, Compound 2-E was obtained (yield: 49%).

3) Synthesis of Compound 2

[0408] Compound 2-E (1.0 eq), potassium tetrachloroplatinate (K_2PtCl_4, 1.1 eq), and tetrabutylammonium bromide (0.1 eq) were dissolved in 0.1 M acetic acid, and the mixture was stirred at a temperature of 120° C. for 72 hours. The obtained reaction mixture was cooled to room temperature, and then an extraction process was performed thereon three times using dichloromethane and water to thereby obtain an organic layer. The obtained organic layer was dried using magnesium sulfate, and then concentrated. By using column chromatography, Compound 1 was obtained (yield: 20%).

Synthesis Example 3: Synthesis of Compound 3

[0409]



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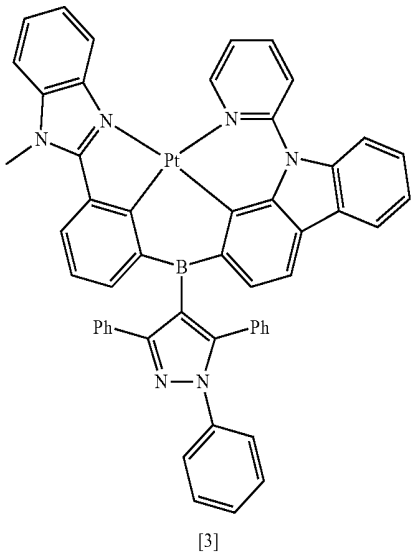


1) Synthesis of Intermediate Compound 3-E

[0410] Compound 3-E was obtained in substantially the same manner as Compound 2-E in Synthesis Example 2, except that Compound 3-C was used to obtain Compound 3-D instead of using Compound 2-C to obtain Compound 2-D.

2) Synthesis of Compound 3

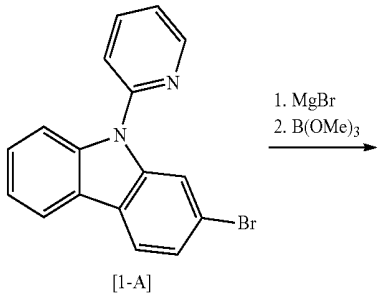
[0411] Compound 3-E (1.0 eq), potassium tetrachloroplatinate (K_2PtCl_4, 1.1 eq), and tetrabutylammonium bromide (0.1 eq) were dissolved in 0.1 M acetic acid, and the mixture was stirred at a temperature of 120° C. for 72 hours. The obtained reaction mixture was cooled to room temperature, and then an extraction process was performed thereon three times using dichloromethane and water to thereby obtain an organic layer. The obtained organic layer was dried using magnesium sulfate, and then concentrated. By using column chromatography, Compound 3 was obtained (yield: 33%).

Synthesis Example 4: Synthesis of Compound 8

[0412] Compound 8 was obtained in substantially the same manner as Compound 1 in Synthesis Example 1, except that 2-(3-bromophenoxy)pyridine was used instead of Compound 1-A, and 1-(3-bromophenyl)-1H-benzo[d] imidazole was used instead of Compound 1-C.

Synthesis Example 5: Synthesis of Compound 10

[0413]



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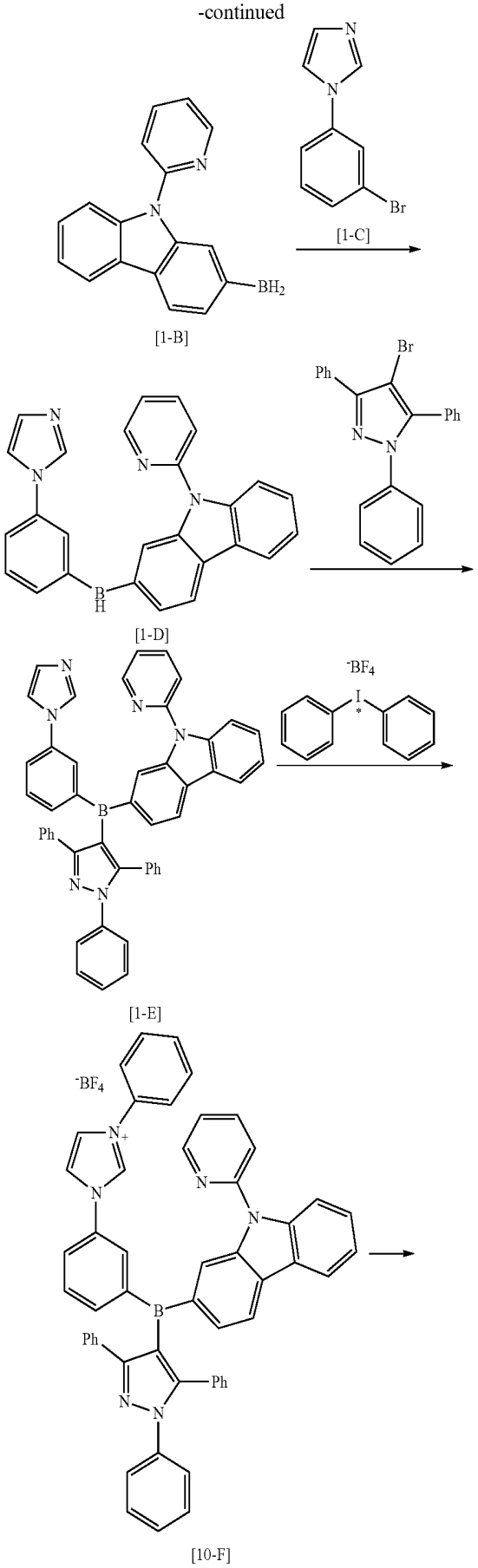

[1-B]

[1-C]

[1-D]

[1-E]

[10-F]

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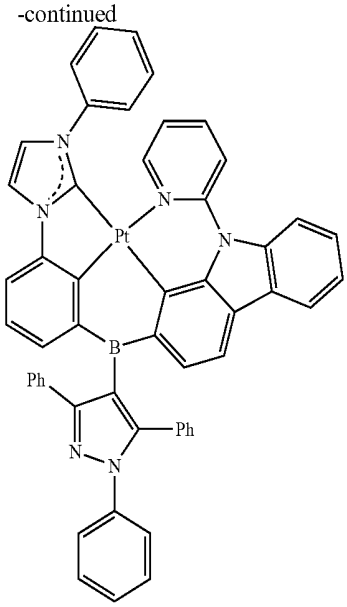


[10]

1) Synthesis of Intermediate Compound 10-F

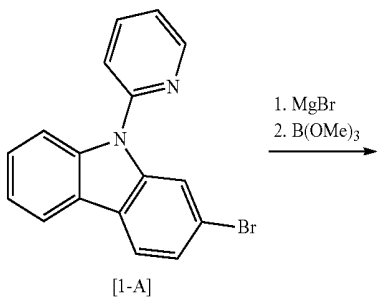
[0414] Compound 1-E (1.0 eq) (synthesized as in Synthesis Example 1), diphenyliodonium tetrafluoroboronate (1.5 eq), and $CuOAc_2$ (5 mol %) were suspended in dimethylformamide (0.025 M), which was then stirred at a temperature of 100° C. for 4 hours. The obtained reaction mixture was cooled to room temperature, which was then concentrated under reduced pressure. By purifying with column chromatography, Compound 10-F was obtained (yield: 77%).

2) Synthesis of Compound 10

[0415] Compound 10-F (1.0 eq), potassium tetrachloroplatinate (K_2PtCl_4, 1.1 eq), and tetrabutylammonium bromide (0.1 eq) were dissolved in 0.1 M acetic acid, and the mixture was stirred at a temperature of 120° C. for 72 hours. The obtained reaction mixture was cooled to room temperature, and then an extraction process was performed thereon three times using dichloromethane and water to thereby obtain an organic layer. The obtained organic layer was dried using magnesium sulfate, and then concentrated. By using column chromatography, Compound 10 was obtained (yield: 26%).

Synthesis Example 6: Synthesis of Compound 11

[0416]



[1-A]

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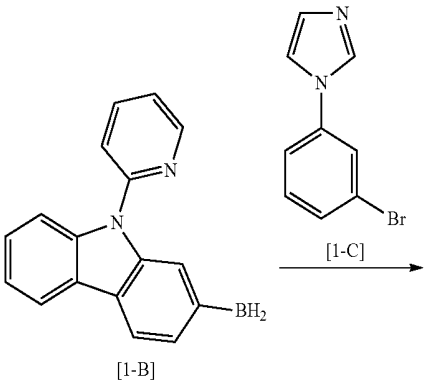
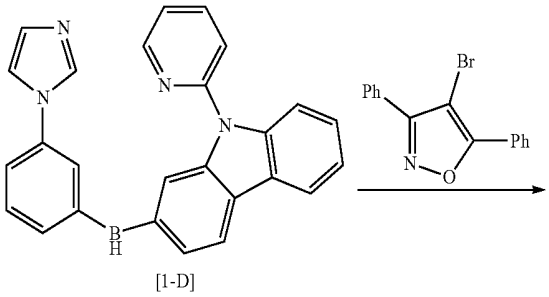
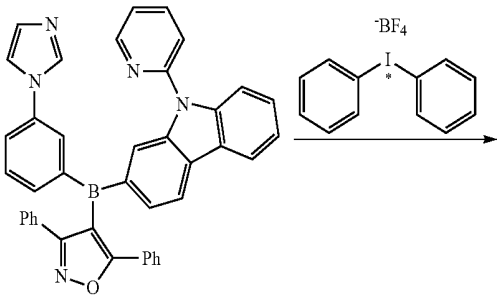


[1-B]

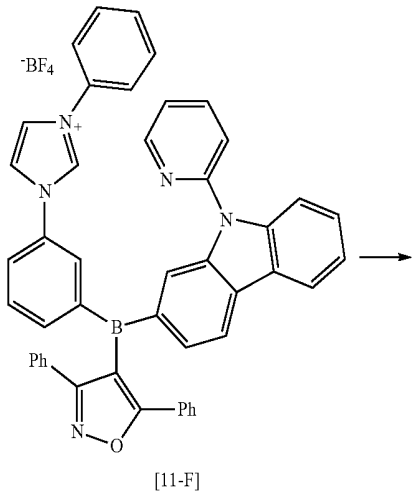
[1-C]



[1-D]



[11-E]



[11-F]

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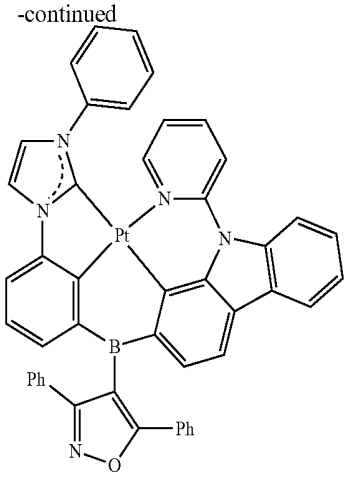


[11]

1) Synthesis of Intermediate Compound 11-E

[0417] Compound 1-D (1.0 eq) (synthesized as in Synthesis Example 1), 4-bromo-3,5-diphenylisoxazole (1.2 eq), CuI (0.01 eq), K_2CO_3 (2.0 eq), and L-proline (0.02 eq) were dissolved in 0.1 M DMSO, and the mixture was stirred at a temperature of 130° C. for 72 hours. The obtained reaction mixture was cooled to room temperature, and then an extraction process was performed thereon three times using dichloromethane and water to thereby obtain an organic layer. The obtained organic layer was dried using magnesium sulfate, and then concentrated. By using column chromatography, Compound 11-E was obtained (yield: 56%).

2) Synthesis of Intermediate Compound 11-F

[0418] Compound 11-E (1.0 eq), diphenyliodonium tetrafluoroboronate (1.5 eq), and $CuOAc_2$ (5 mol %) were suspended in dimethylformamide (0.025 M), which was then stirred at a temperature of 100° C. for 4 hours. The obtained reaction mixture was cooled to room temperature, which was then concentrated under reduced pressure. By purifying with column chromatography, Compound 11-F was obtained (yield: 85%).

3) Synthesis of Compound 11

[0419] Compound 11-F (1.0 eq), potassium tetrachloroplatinate (K_2PtCl_4, 1.1 eq), and tetrabutylammonium bromide (0.1 eq) were dissolved in 0.1 M acetic acid, and the mixture was stirred at a temperature of 120° C. for 72 hours. The obtained reaction mixture was cooled to room temperature, and then an extraction process was performed thereon three times using dichloromethane and water to thereby obtain an organic layer. The obtained organic layer was dried using magnesium sulfate, and then concentrated. By using column chromatography, Compound 11 was obtained (yield: 15%).

Synthesis Example 7: Synthesis of Compound 21

[0420] Compound 21 was obtained in substantially the same manner as Compound 10 in Synthesis Example 5, except that 2-bromo-9-(4-(tert-butyl)pyridin-2-yl)-9H-carbazole was used instead of Compound 1-A.

Synthesis Example 8: Synthesis of Compound 22

[0421] Compound 22 was obtained in substantially the same manner as Compound 1 in Synthesis Example 1, except that 2-bromo-9-(4-(tert-butyl)pyridin-2-yl)-9H-carbazole was used instead of Compound 1-A.

Synthesis Example 9: Synthesis of Compound 26

[0422] Compound 26 was obtained in substantially the same manner as Compound 1 in Synthesis Example 1, except that 2-bromo-9-(4-(trimethylsilyl)pyridin-2-yl)-9H-carbazole was used instead of Compound 1-A.

Synthesis Example 10: Synthesis of Compound 29

[0423] Compound 29 was obtained in substantially the same manner as Compound 1 in Synthesis Example 1, except that 3-bromo-5-(1H-imidazol-1-yl)pyridine was used instead of Compound 1-C.

[0424] Compounds synthesized in Synthesis Examples 1 to 10 were identified by ^{1}H nuclear magnetic resonance (NMR) and mass spectroscopy (MS) data. The results thereof are shown in Table 1.

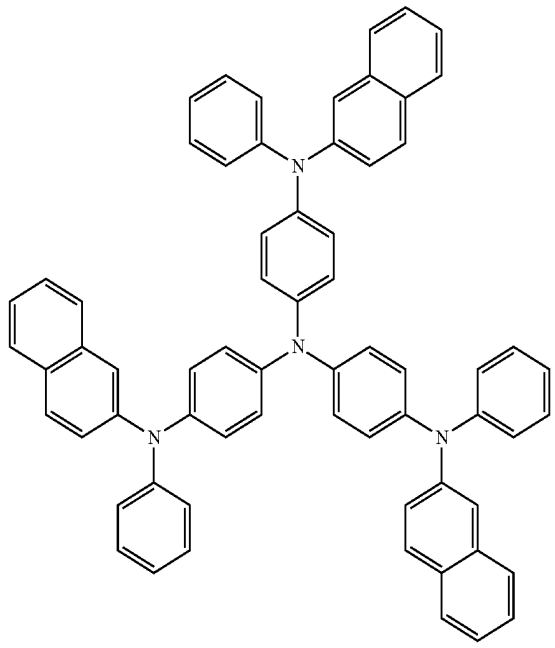
[0425] Methods of synthesizing compounds other than compounds shown in Table 1 may be easily understood to those skilled in the art by referring to the synthesis pathways and raw materials described above.

TABLE 1

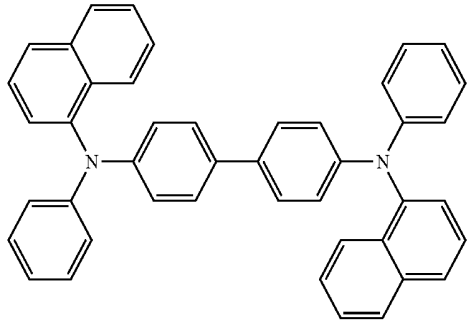
		HR-EIMS	
Compound	^{1}H NMR ($CDCl_3$, 500 MHz)	found	calc.
1	δ8.56 (d, 1H), 8.20 (m, 2H), 8.14 (d, 2H), 8.05 (m, 2H), 7.87 (d, 1H), 7.60~7.62 (m, 5H), 7.50~7.52 (m, 2H), 7.49 (d, 1H), 7.46 (t, 1H), 7.25~7.43 (m, 9H), 7.14~7.18 (m, 4H), 3.88 (s, 3H)	899.2489	899.2507
2	δ8.42 (d, 1H), 8.19 (m, 1H), 8.10 (m, 1H), 7.89~7.91 (m, 4H), 7.83 (d, 1H), 7.67~7.73 (m, 3H), 7.62~7.64 (m, 2H), 7.35~7.41 (m, 9H), 7.29~7.32 (m, 5H), 7.08~7.09 (m, 2H), 6.29 (d, 1H), 3.95 (s, 3H)	899.2486	916.2507
3	δ8.47 (m, 1H), 8.08~8.10 (m, 2H), 7.90~7.91 (m, 3H), 7.67~7.74 (m, 3H), 7.59~7.62 (m, 2H), 7.35~7.44 (m, 11H), 7.32~7.33 (m, 3H), 7.29~7.30 (m, 2H), 7.07~7.10 (m, 3H), 6.95 (m, 1H), 3.88 (s, 3H)	888.3361	888.3356
8	δ8.18 (m, 1H), 7.89~7.91 (m, 2H), 7.40~7.43 (m, 6H), 7.30~7.38 (m, 7H), 7.24~7.26 (m, 2H), 7.02~7.06 (m, 3H), 6.96 (m, 1H), 6.90 (m, 1H), 6.78 (m, 1H), 6.48, (m, 1H), 6.39 (m, 2H), 6.31~6.33 (m, 2H), 6.24~6.25 (m, 1H), 5.94~5.96 (m, 1H), 2.74 (s, 3H)	876.2348	876.2327
10	δ8.40 (m, 1H), 8.04~8.07 (m, 2H), 7.87~7.91 (m, 3H), 7.70 (m, 1H), 7.62 (d, 1H), 7.40~7.41 (m, 6H), 7. 35~7.37 (m, 3H), 7.29~7.35 (m, 7H), 7.23 (d, 1H), 7.15~7.17 (m, 3H), 7.10~7.12 (m, 2H), 7.01~7.03 (m, 2H), 6.87~6.89m, 2H), 6.69 (d, 2H), 6.33~6.35 (m, 3H)	961.2664	961.2610
11	δ8.27 (m, 1H), 8.03~8.07 (m, 4H), 7.87 (d, 1H), 7.67~7.69 (m, 3H), 7.60~7.62 (m, 1H), 7.43 (d, 1H), 7.37 (d, 1H), 7.29~7.32 (m, 5H), 7.20~7.23 (m, 2H), 7.11~7.15 (m, 5H), 7.05~7.07 (m, 1H), 6.69~7.03 (m, 3H), 6.33~6.35 (m, 3H)	886.2191	886.2155
21	δ8.56~8.57 (m, 1H), 8.08 (d, 1H), 7.81~7.83 (m, 1H), 7.69~7.72 (m, 3H), 7.66 (d, 1H), 7.53~7.56 (m, 3H),. 7.37~7.46 (m, 3H), 7.32~7.38 (m, 9H), 7.20~7.24 (m, 6H), 7.16 (d, 2H), 7.06~7.08 (m, 2H), 7.01 (m, 2H), 1.35 (s, 9H)	1017.3290	1017.3269
22	δ8.44 (d, 1H), 8.07 (d 2H), 7.98~7.99 (m, 2H), 7.89~7.91 (m, 2H), 7.86 (d, 1H), 7.65~7.70 (m, 2H), 7.38~7.41 (m, 8H), 7.35 (d, 1H), 7.29~7.32 (m, 5H), 7.24 (d, 1H), 7.04~7.06 (m, 1H), 6.98~7.02 (m, 2H), 6.38~6.40 (m, 1H), 6.06 (d, 1H), 5.16 (d, 1H), 3.18 (s, 3H), 1.36 (s, 9H)	955.3133	955.3095
26	δ8.44 (m, 1H), 8.06~8.07 (m, 2H), 7.91~8.01 (m, 3H), 7.62~7.63 (m, 2H), 7.35~7.42 (m, 11H), 7.28~7.32 (m, 6H), 7.10~7.12 (m, 2H), 7.01 (m, 1H), 6.34~6.36 (m, 1H), 6.06 (d, 1H), 5.16 (d, 1H), 3.18 (s, 9H)	971.2903	971.2880
29	δ8.45~8.47 (m, 1H), 8.04~8.07 (m, 3H), 7.87~7.91 (m, 3H), 7.60~7.62 (m, 1H), 7.35~7.43 (m, 9H), 7.29~7.32 (m, 6H), 7.10~7.11 (m, 1H), 7.07 (d, 2H), 6.45 (m, 1H), 6.11~6.13 (m, 2H), 5.18 (m, 1H), 3.09 (s, 3H)	900.2460	900.2438

Example 1

[0426] As for a substrate and an anode, a Corning 15 Ohms per square centimeter (15 Ω/cm^2, 1,200 Å) glass substrate on which ITO was formed was cut to a size of 50 millimeters (mm)×50 mm×0.7 mm, sonicated by using isopropyl alcohol and deionized water for 5 minutes, respectively, and cleaned by exposure to ultraviolet rays with ozone. Then, the obtained glass substrate was mounted on a vacuum deposition device. 2-TNATA was vacuum-deposited on the ITO anode formed on the glass substrate to form a hole injection layer having a thickness of about 600 Å. NPB was then deposited on the hole injection layer to form a hole transport layer having a thickness of about 300 Å. BCPDS, POPCPA, and Compound 1 were co-deposited at a ratio of 45:45:10 on the hole transport layer to form an emission layer having a thickness of 300 Å. TSPO1 was deposited on the emission layer to form a hole blocking layer having a thickness of 50 Å, Alq_3 was deposited on the hole blocking layer to form an electron transport layer having a thickness of 300 Å, LiF was deposited on the electron transport layer to form an electron injection layer having a thickness of 10 Å, and Al was vacuum-deposited on the electron injection layer having a thickness of 3,000 Å, thereby completing the manufacture of an organic light-emitting device.



2-TNATA



NPB

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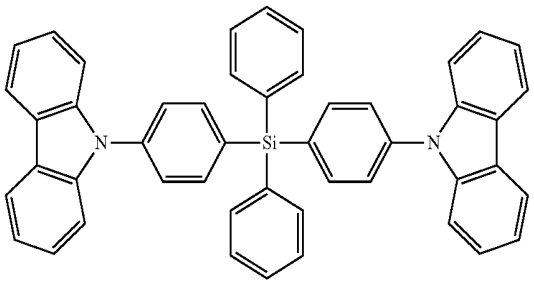
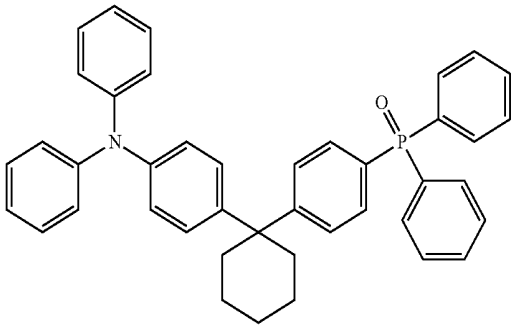
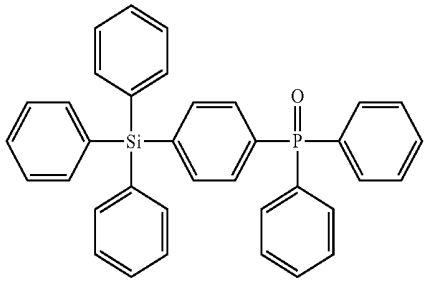


BCPDS



POPCPA



TSPO1

Examples 2 to 10 and Comparative Examples A to C

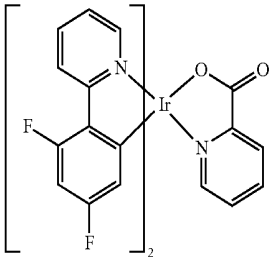
[0427] Organic light-emitting devices were manufactured in substantially the same manner as in Example 1, except that the compounds shown in Table 2 were respectively used instead of Compound 1 as a dopant in the formation of an emission layer.

[0428] The driving voltage, current density, luminous efficiency of the organic light-emitting device manufactured in Examples 1 to 10 and Comparative Examples A to C at a luminance of 15 candelas per square meter (cd/m^2) were measured by using a Keithley 236 source-measure unit (SMU) and a PR650 luminance meter. The results thereof are shown in Table 2.

TABLE 2

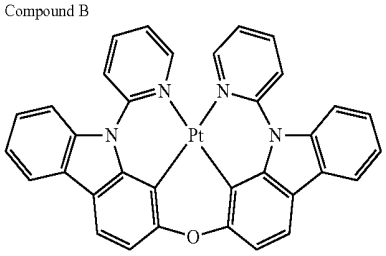
	Compound No.	Driving voltage (V)	Current density (mA/cm^2)	Luminance (cd/m^2)	Luminous efficiency (cd/A)	Emission color	Maximum emission wavelength (nm)
Example 1	1	3.4	0.09	15	19.6	Blue	450
Example 2	2	3.4	0.08	15	17.2	Blue	455
Example 3	3	3.3	0.08	15	15.1	Blue	452
Example 4	8	3.3	0.08	15	16.2	Blue	456
Example 5	10	3.3	0.09	15	16.7	Blue	450
Example 6	11	3.3	0.08	15	15.3	Blue	451
Example 7	21	3.4	0.08	15	19.2	Blue	449
Example 8	22	3.4	0.06	15	18.4	Blue	452
Example 9	26	3.3	0.10	15	16.9	Blue	449
Example 10	29	3.4	0.10	15	16.2	Blue	453
Comparative Example A	A	4.3	0.23	15	5.9	Blue	471
Comparative Example B	B	4.2	0.17	15	6.5	Sky blue	478
Comparative Example C	C	4.1	0.15	15	5.9	Sky blue	481

Compound A



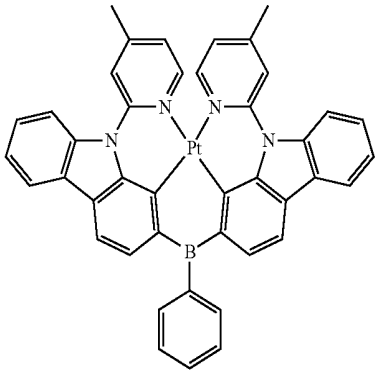
Firpic

Compound B



PtNON

Compound C



[0429] As can be seen from the results shown in Table 2, the organic light-emitting devices of Examples 1 to 10 had excellent driving voltage, efficiency, lifespan, and emission color, as compared with those of the organic light-emitting devices of Comparative Examples A to C.

[0430] As used herein, the terms "use," "using," and "used" may be considered synonymous with the terms "utilize," "utilizing," and "utilized," respectively.

[0431] In addition, the terms "substantially," "about," and similar terms are used as terms of approximation and not as terms of degree, and are intended to account for the inherent deviations in measured or calculated values that would be recognized by those of ordinary skill in the art.

[0432] Also, any numerical range recited herein is intended to include all sub-ranges of the same numerical

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

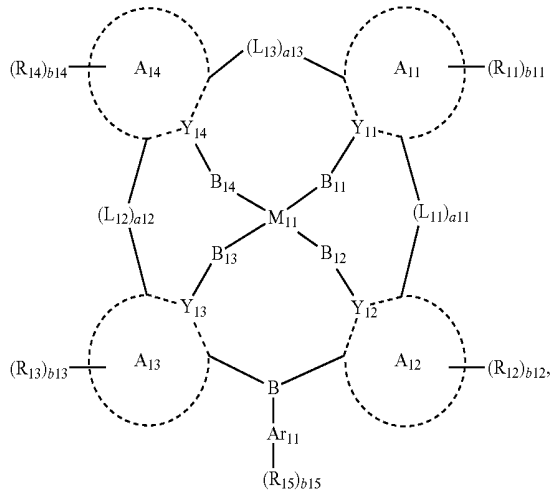
[0433] It should be understood that embodiments described herein should be considered in a descriptive sense only and not for purposes of limitation. Descriptions of features or aspects within each embodiment should typically be considered as available for other similar features or aspects in other embodiments.

[0434] While one or more embodiments have been described with reference to the figures, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the present disclosure as defined by the following claims and equivalents thereof.

What is claimed is:

1. An organometallic compound represented by Formula 1:

Formula 1



wherein, in Formula 1,

M_{11} is selected from platinum (Pt), palladium (Pd), copper (Cu), silver (Ag), gold (Au), rhodium (Rh), iridium (Ir), ruthenium (Ru), and osmium (Os),

A_{11} to A_{14} are each independently selected from a C_5-C_{60} carbocyclic group and a C_1-C_{60} heterocyclic group,

Ar_{11} is a C_1-C_{60} heterocyclic group,

Y_{11} to Y_{14} are each independently selected from a carbon atom (C) and a nitrogen atom (N),

B_{11} to B_{14} are each independently selected from a single bond, O, and S,

L_{11} to L_{13} are each independently selected from a single bond, *—O—*', *—S—*', *—C(R_{16})(R_{17})—*', *—C(R_{16})=*', *=C(R_{16})—*', *—C(R_{16})=C(R_{17})—*', *—C(=O)—*', *—C(=S)—*', *—C≡C—*', *—B(R_{16})—*', *—N(R_{16})—*', *—P(R_{16})—*', *—Si(R_{16})(R_{17})—*', *—P(R_{16})(R_{17})—*', and *—Ge(R_{16})(R_{17})—*',

a11 to a13 are each independently an integer from 0 to 3,

at least two selected from al 1 to a13 are each independently an integer from 1 to 3,

when a11 is 0, A_{11} and A_{12} are not bound, when a12 is 0, A_{13} and A_{14} are not bound, when a13 is 0, A_1 and A_{14} are not bound,

when a11 is two or greater, at least two L_{11} groups are identical to or different from each other, when a12 is two or greater, at least two L_{12} groups are identical to or different from each other, when a13 is two or greater, at least two L_{13} groups are identical to or different from each other,

R_{11} to R_{17} are each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_2-C_{60} alkenyl group, a substituted or unsubstituted C_2-C_{60} alkynyl group, a substituted or unsubstituted C_1-C_{60} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted C_1-C_{60} heteroaryloxy group, a substituted or unsubstituted C_1-C_{60} heteroarylthio group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, —Si(Q_1)(Q_2)(Q_3), —B(Q_1)(Q_2), —N(Q_1)(Q_2), —P(Q_1)(Q_2), —C(=O)(Q_1), —S(=O)(Q_1), —S(=O)$_2$(Q_1), —P(=O)(Q_1)(Q_2), and —P(=S)(Q_1)(Q_2),

R_{16} and R_{11}, R_{16} and R_{12}, R_{16} and R_{13}, and/or R_{16} and R_{14} are optionally bound to form a substituted or unsubstituted C_5-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group,

R_{16} and R_{17} are optionally bound to form a substituted or unsubstituted C_5-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group,

b11 to b15 are each independently an integer from 1 to 8,

when b11 is two or greater, at least two R_{11} groups are identical to or different from each other, when b12 is two or greater, at least two R_{12} groups are identical to or different from each other, when b13 is two or greater, at least two R_{13} groups are identical to or different from each other, when b14 is two or greater, at least two R_{14} groups are identical to or different from each other, when b15 is two or greater, at least two R_{15} groups are identical to or different from each other,

at least one of b15 number of R_{15} groups is not hydrogen, and

at least one substituent of the substituted C_5-C_{60} carbocyclic group, substituted C_1-C_{60} heterocyclic group, substituted C_1-C_{60} alkyl group, substituted C_2-C_{60} alk-

enyl group, substituted C_2-C_{60} alkynyl group, substituted C_1-C_{60} alkoxy group, substituted C_3-C_{10} cycloalkyl group, substituted C_1-C_{10} heterocycloalkyl group, substituted C_3-C_{10} cycloalkenyl group, substituted C_1-C_{10} heterocycloalkenyl group, substituted C_6-C_{60} aryl group, substituted C_6-C_{60} aryloxy group, substituted C_6-C_{60} arylthio group, substituted C_1-C_{60} heteroaryl group, substituted C_1-C_{60} heteroaryloxy group, substituted C_1-C_{60} heteroarylthio group, substituted monovalent non-aromatic condensed polycyclic group, and substituted monovalent non-aromatic condensed heteropolycyclic group is selected from:

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

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

a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group;

a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amidino group, a hydrazino group, a hydrazono group, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_3-C_{10} cycloalkyl group, a C_1-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, a C_1-C_{60} heteroaryl group, a monovalent non-aromatic condensed polycyclic group, a monovalent non-aromatic condensed heteropolycyclic group, $—Si(Q_{21})(Q_{22})(Q_{23})$, $—N(Q_{21})(Q_{22})$, $—B(Q_{21})(Q_{22})$, $—C(=O)(Q_{21})$, $—S(=O)_2(Q_{21})$, and $—P(=O)(Q_{21})(Q_{22})$; and

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

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

* indicates a binding site to an adjacent atom.

2. The organometallic compound of claim **1**, wherein M_{11} is selected from Pt, Pd, Cu, Ag, and Au.

3. The organometallic compound of claim **1**, wherein A_{11} to A_{14} are each independently selected from a benzene group, a naphthalene group, an anthracene group, a phenanthrene group, a triphenylene group, a pyrene group, a chrysene group, a cyclopentadiene group, a 1,2,3,4-tetrahydronaphthalene group, a furan group, a thiophene group, a silole group, an indene group, a fluorene group, an indole group, a carbazole group, an azacarbazole group, a benzofuran group, a dibenzofuran group, a benzothiophene group, a dibenzothiophene group, a benzosilole group, a dibenzosilole group, an indenopyridine group, an indolopyridine group, a benzofuropyridine group, a benzothienopyridine group, a benzosilolopyridine group, an indenopyrimidine group, an indolopyrimidine group, a benzofuropyrimidine group, a benzothienopyrimidine group, a benzosilolopyrimidine group, a dihydropyridine group, a pyridine group, a pyrimidine group, a pyrazine group, a pyridazine group, a triazine group, a quinoline group, an isoquinoline group, a quinoxaline group, a quinazoline group, a phenanthroline group, a pyrrole group, a pyrazole group, an imidazole group, a 2,3-dihydroimidazole group, a triazole group, a 2,3-dihydrotriazole group, an oxazole group, an iso-oxazole group, a thiazole group, an isothiazole group, an oxadiazole group, a thiadiazole group, a benzopyrazole group, a benzimidazole group, a 2,3-dihydrobenzimidazole group, an imidazopyridine group, a 2,3-dihydroimidazopyridine group, an imidazopyrimidine group, a 2,3-dihydroimidazopyrimidine group, an imidazopyrazine group, a 2,3-dihydroimidazopyrazine group, a benzoxazole group, a benzothiazole group, a benzoxadiazole group, a benzothiadiazole group, a 5,6,7,8-tetrahydroisoquinoline group, and a 5,6,7,8-tetrahydroquinoline group.

4. The organometallic compound of claim **1**, wherein

Y_{11}, Y_{12}, and Y_{13} are each C, and Y_{14} is N;

Y_{11}, Y_{12}, and Y_{14} are each C, and Y_{13} is N;

Y_{11}, Y_{13}, and Y_{14} are each C, and Y_{12} is N;

Y_{12}, Y_{13}, and Y_{14} are each C, and Y_{11} is N;

Y_{11} and Y_{14} are each C, and Y_{12} and Y_{13} are each N;

Y_{11} and Y_{14} are each N, and Y_{12} and Y_{13} are each C;

Y_{11} and Y_{12} are each C, and Y_{13} and Y_{14} are each N;

Y_{11} and Y_{12} are each N, and Y_{13} and Y_{14} are each C;

Y_{11} and Y_{13} are each C, and Y_{12} and Y_{14} are each N; or

Y_{11} and Y_{13} are each N, and Y_{12} and Y_{14} are each C.

5. The organometallic compound of claim **1**, wherein

B_{11} to B_{14} are each a single bond;

B_{11} is selected from O and S, and B_{12} to B_{14} are each a single bond;

B_{12} is selected from O and S, and B_{11}, B_{13}, and B_{14} are each a single bond;

B_{13} is selected from O and S, and B_{11}, B_{12}, and B_{14} are each a single bond; or

B_{14} is selected from O and S, and B_{11}, B_{12}, and B_{13} are each a single bond.

6. The organometallic compound of claim **1**, wherein B_{11} to B_{14} are each a single bond, M_{11} is bound to Y_{11} via a coordinate bond, M_{11} is bound to Y_{14} via a coordinate bond, M_{11} is bound to Y_{12} via a covalent bond, and M_{11} is bound to Y_{13} via a covalent bond.

7. The organometallic compound of claim **1**, wherein

a11 is 0, and a12 and a13 are each independently an integer from 1 to 3;

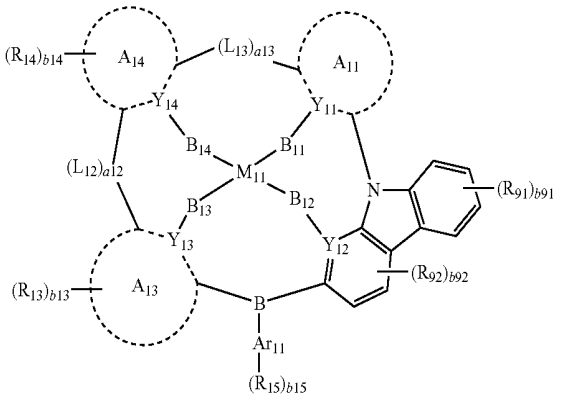
a12 is 0, and a11 and a13 are each independently an integer from 1 to 3; or

a13 is 0, and a11 and a12 are each independently an integer from 1 to 3.

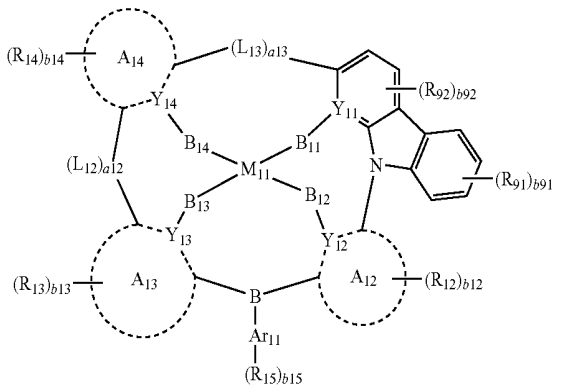
8. The organometallic compound of claim **1**, wherein R_{16} and R_{11}, R_{16} and R_{12}, R_{16} and R_{13}, and/or R_{16} and R_{14} are bound to form a substituted or unsubstituted C_5-C_{60} carbocyclic group or a substituted or unsubstituted C_1-C_{60} heterocyclic group.

9. The organometallic compound of claim **1**, being represented by any one selected from Formulae 1-1 to 1-5:

Formula 1-1



Formula 1-2



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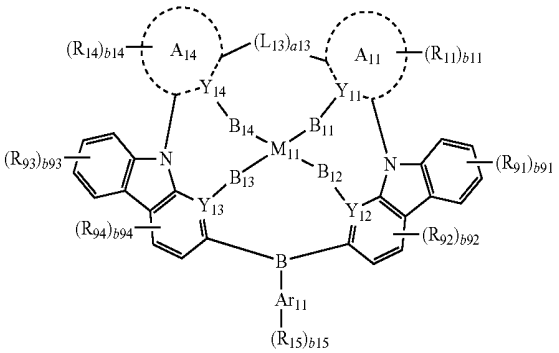
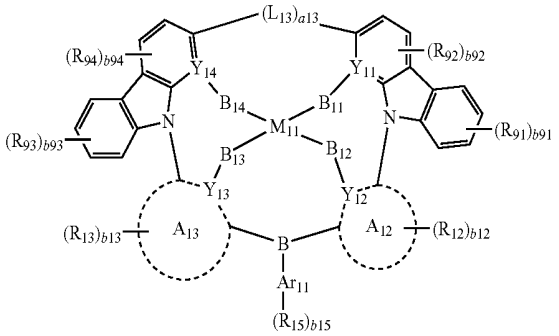
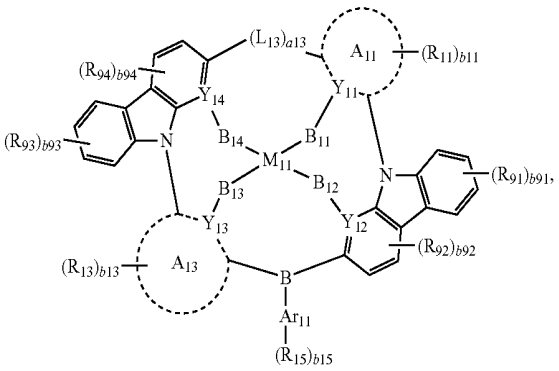
Formula 1-3



Formula 1-4



Formula 1-5



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

R_{91} to R_{94} are each independently defined as R_{11} in Formula 1,

b91 and b93 are each independently an integer from 1 to 4,

b92 and b94 are each independently selected from 1 and 2, and

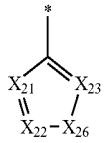
M_{11}, A_{11} to A_{14}, Ar_{11}, Y_{11} to Y_{14}, B_{11} to B_{14}, L_{11} to L_{13}, a11 to a13, R_{11} to R_{17}, and b11 to b_{15} are respectively defined as in Formula 1.

10. The organometallic compound of claim **1**, wherein Ar_{11} is selected from a pyrrole group, an imidazole group, a pyrazole group, a pyridine group, a pyrazine group, a pyrimidine group, a pyridazine group, an isoindole group, an indole group, an indazole group, a purine group, a quinoline group, a benzoquinoline group, a phthalazine group, a naphthyridine group, a quinoxaline group, a quinazoline group, a cinnoline group, a carbazole group, an azacarbazole group, a phenanthridine group, an acridine group, a phenanthroline group, a phenazine group, a benzoxazole group, a

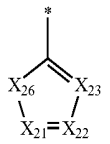
benzimidazole group, a furan group, a benzofuran group, a thiophene group, a benzothiophene group, a thiazole group, an isothiazole group, a benzothiazole group, an iso-oxazole group, an oxazole group, a triazole group, a tetrazole group, an oxadiazole group, a triazine group, a benzoxazole group, a dibenzofuran group, a dibenzothiophene group, and a benzocarbazole group.

11. The organometallic compound of claim **1**, wherein a substituent represented by *—Ar_{11}—$(R_{15})_{b15}$ is represented by any one of Formulae 2-1 to 2-3:

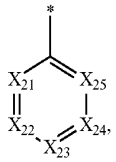
Formula 2-1



Formula 2-2



Formula 2-3



wherein, in Formulae 2-1 to 2-3,

X_{21} is selected from $C(R_{21})$ and N, X_{22} is selected from $C(R_{22})$ and N, X_{23} is selected from $C(R_{23})$ and N, X_{24} is selected from $C(R_{24})$ and N, X_{25} is selected from $C(R_{25})$ and N,

X_{26} is selected from O, S, $N(R_{26})$, $C(R_{26})(R_{27})$, and $Si(R_{26})(R_{27})$,

R_{21} to R_{27} are each independently defined the same as R_{11} in Formula 1,

in Formulae 2-1 and 2-2, at least one selected from X_{21} to X_{23} is N, or X_{26} is selected from O, S, and $N(R_{26})$,

in Formula 2-3, at least one selected from X_{21} to X_{25} is N,

in Formulae 2-1 and 2-2, at least one selected from R_{21} to R_{23}, R_{26}, and R_{27} is not hydrogen,

in Formula 2-3, at least one selected from R_{21} to R_{25} is not hydrogen, and

* indicates a binding site to an adjacent atom.

12. The organometallic compound of claim **11**, wherein R_{21} to R_{27} are each independently selected from:

hydrogen, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, and a triazinyl group; and

a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, and a triazinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a triazinyl group, $—Si(Q_{31})(Q_{32})(Q_{33})$, and $—N(Q_{31})(Q_{32})$.

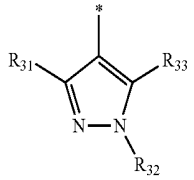
13. The organometallic compound of claim **11**, wherein at least one selected from R_{21} and R_{23} in Formula 2-1, at least one selected from R_{23} and R_{26} in Formula 2-2, and at least one selected from R_{21} and R_{25} in Formula 2-3 are each independently selected from:

a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, and a triazinyl group; and

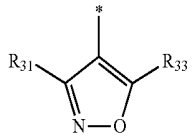
a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, and a triazinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a triazinyl group, $—Si(Q_{31})(Q_{32})(Q_{33})$, and $—N(Q_{31})(Q_{32})$.

14. The organometallic compound of claim **1**, wherein a substituent represented by *—Ar_{11}—$(R_{15})_{b15}$ is selected from Formulae 3-1 to 3-3:

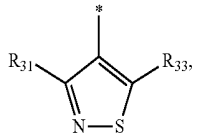
Formula 3-1



Formula 3-2



Formula 3-3



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

R_{31} to R_{33} are each independently defined the same as R_{11} in Formula 1,

at least one of R_{31} to R_{33} is not hydrogen, and

* indicates a binding site to an adjacent atom.

15. The organometallic compound of claim **14**, wherein R_{31} to R_{33} are each independently selected from:

a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a cyclopentenyl group, a cyclohexenyl group, a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, and a triazinyl group; and

a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, and a triazinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a naphthyl group, a fluorenyl group, a spiro-fluorenyl group, a benzofluorenyl group, a dibenzofluorenyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, a quinolinyl group, an isoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a carbazolyl group, a triazinyl group, —$Si(Q_{31})(Q_{32})(Q_{33})$, and —$N(Q_{31})(Q_{32})$.

16. The organometallic compound of claim **14**, wherein

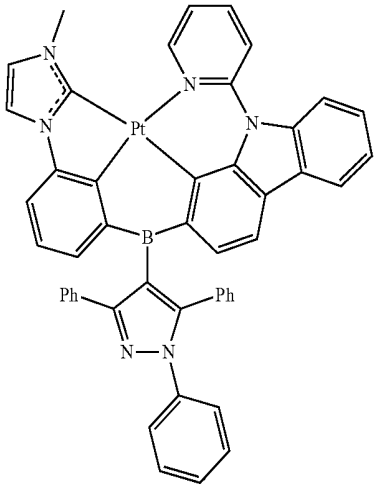
a11 is 0, and a12 and a13 are each 1;

a12 is 0, and a11 and a13 are each 1; or

a13 is 0, and a11 and a12 are each 1.

17. The organometallic compound of claim **1**, being selected from Compounds 1 to 45:

1



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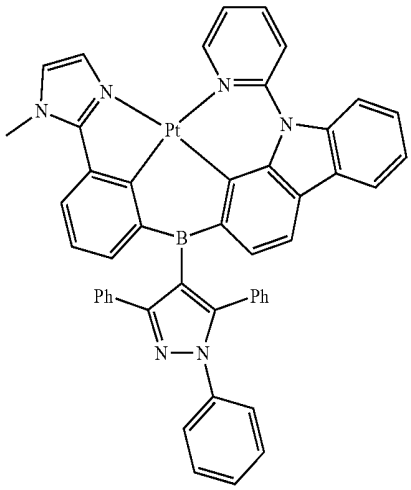

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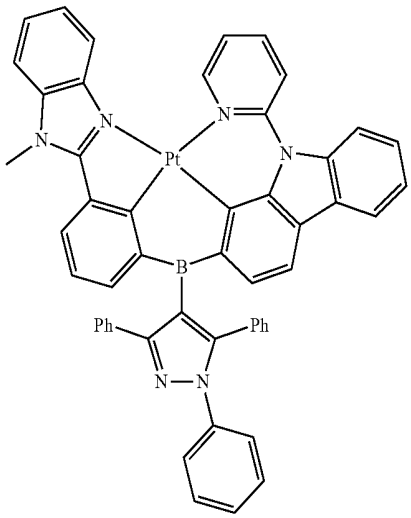

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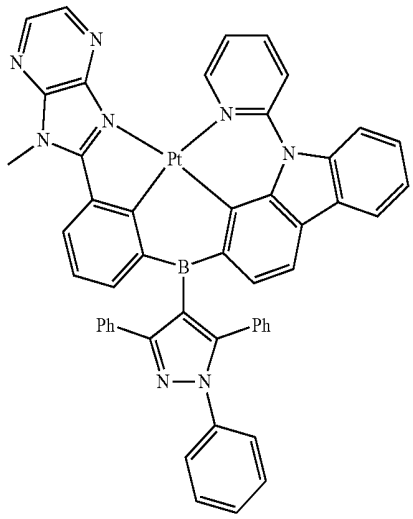
4



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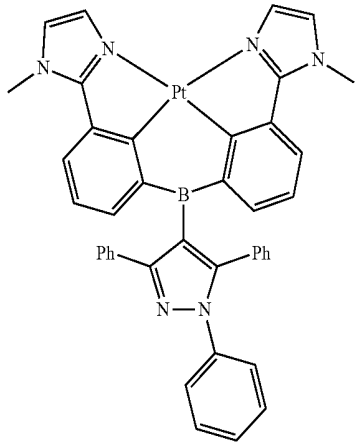

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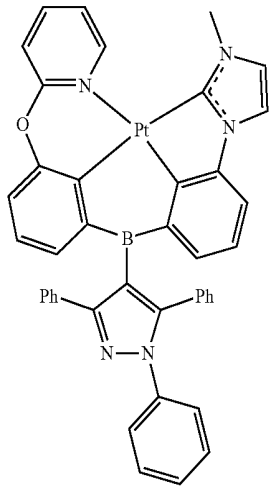

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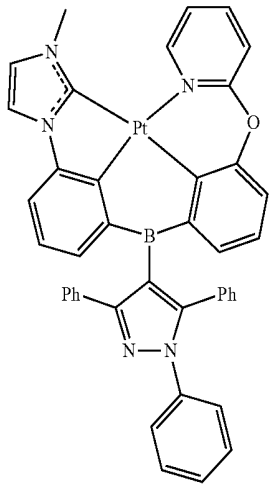

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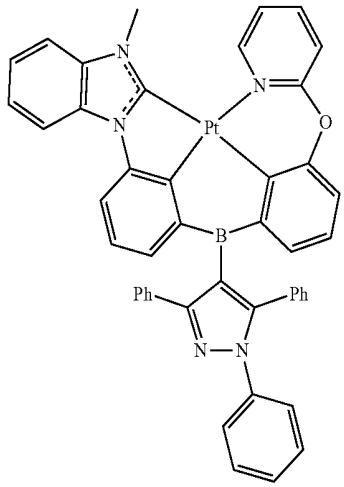

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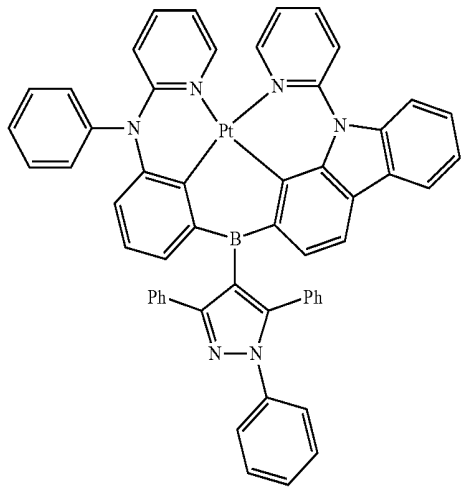

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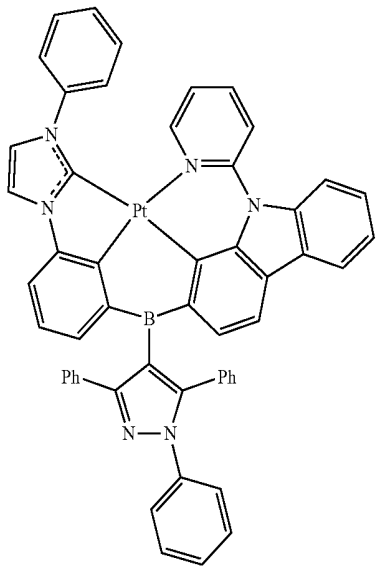

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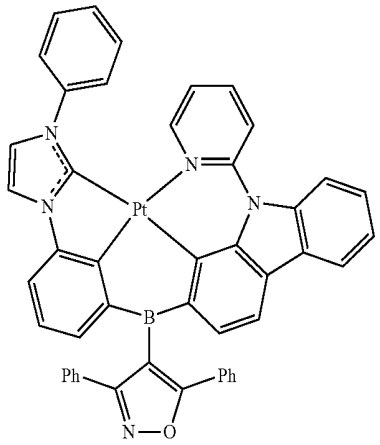

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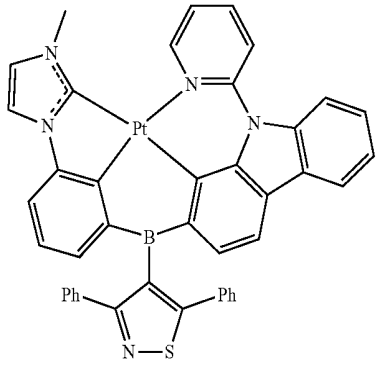

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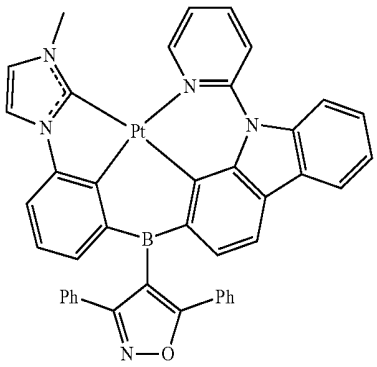

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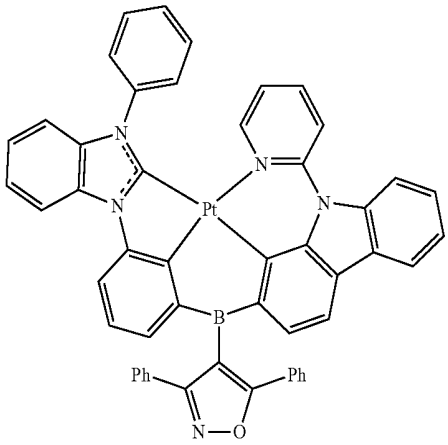

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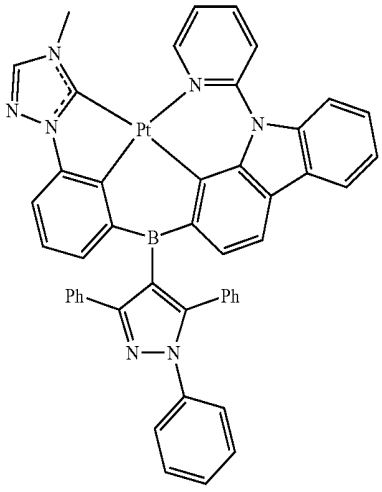

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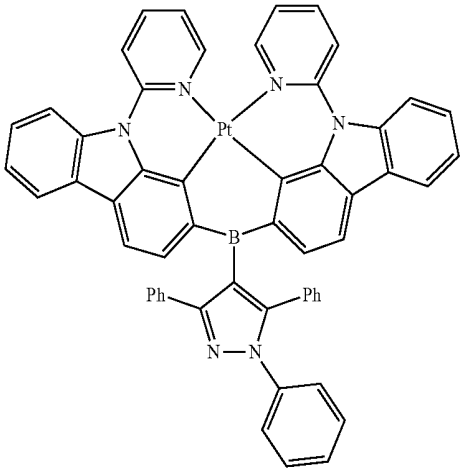

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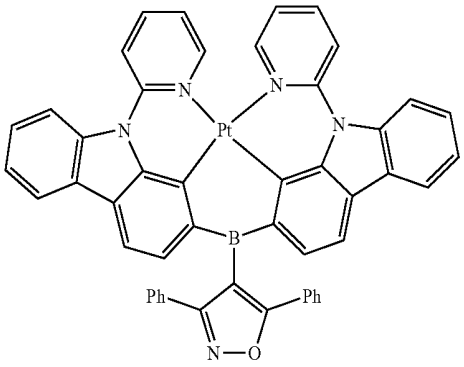

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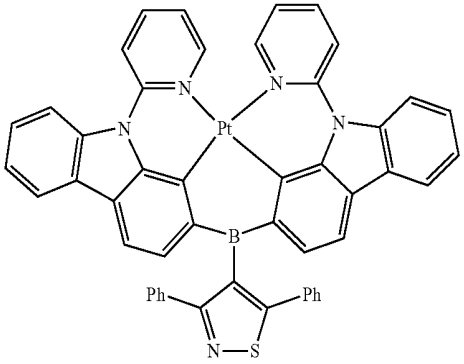

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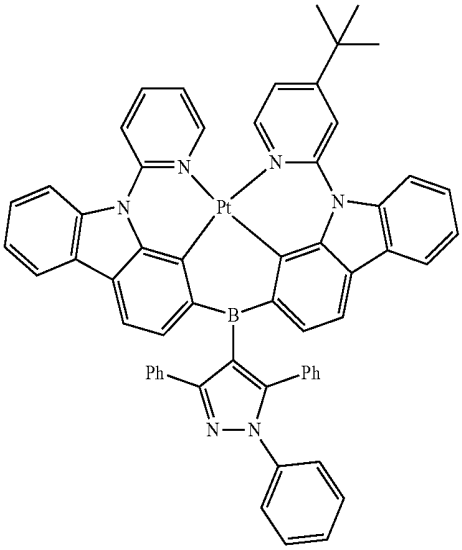

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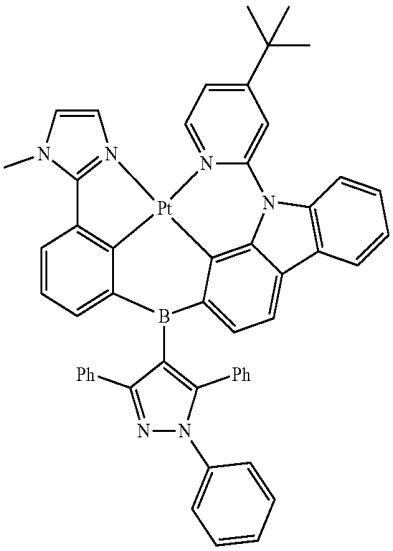

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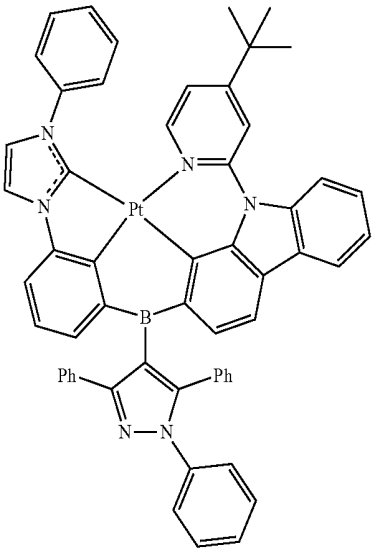

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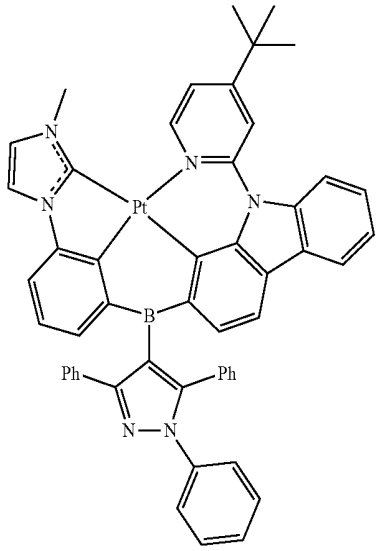

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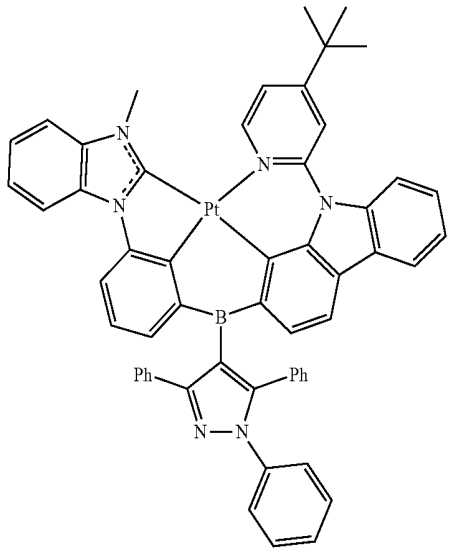

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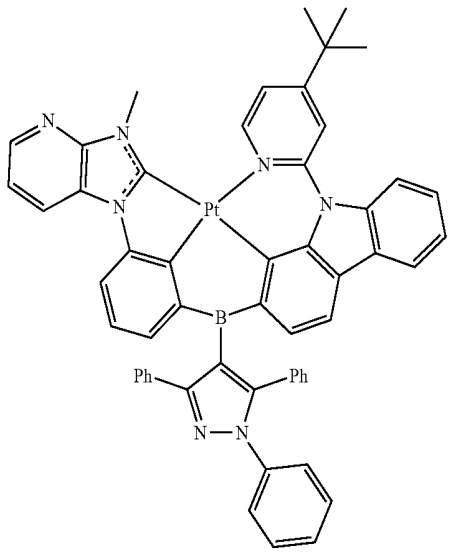

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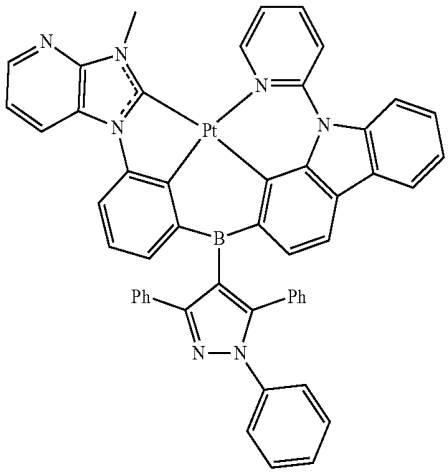

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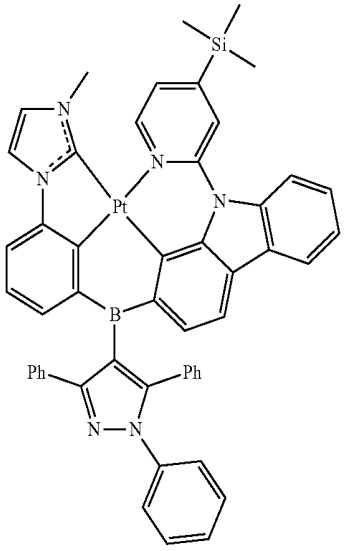

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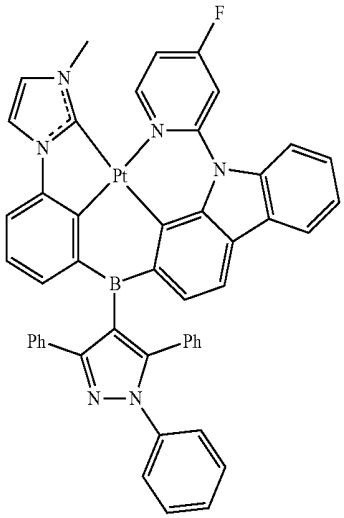

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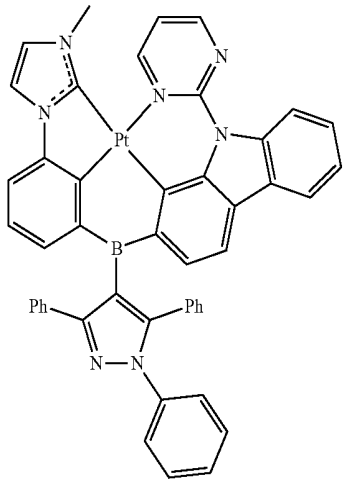

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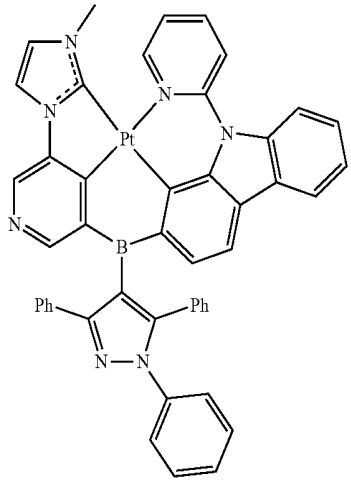

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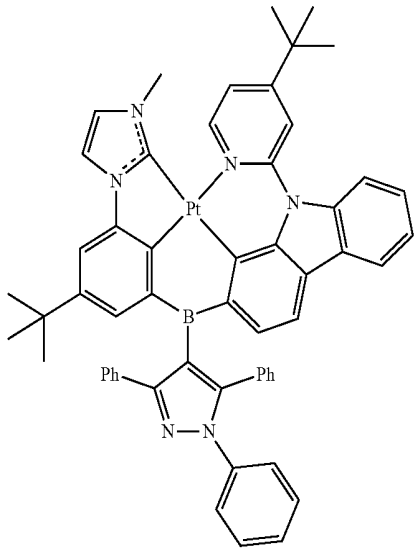

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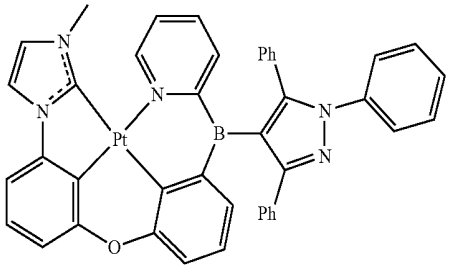

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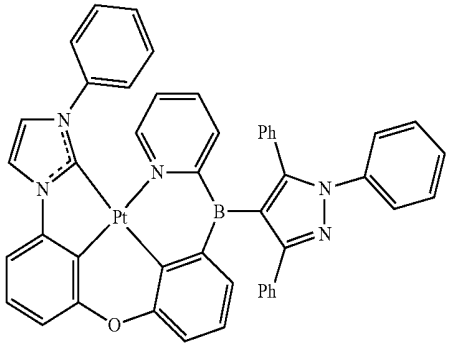

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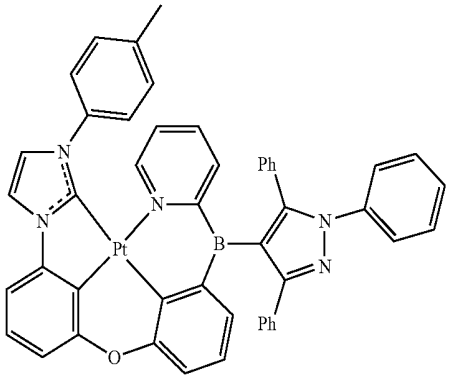

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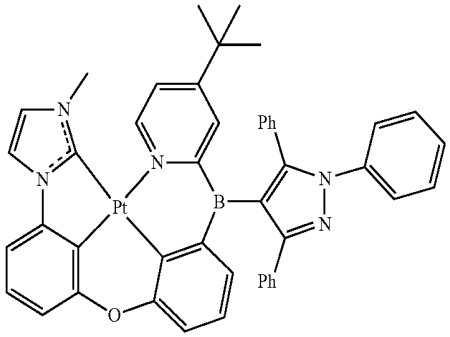

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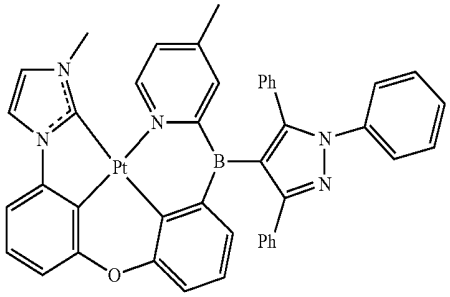

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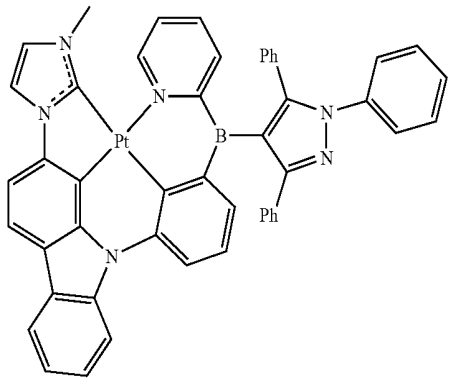

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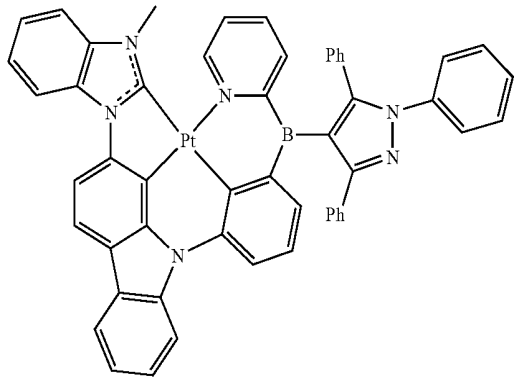

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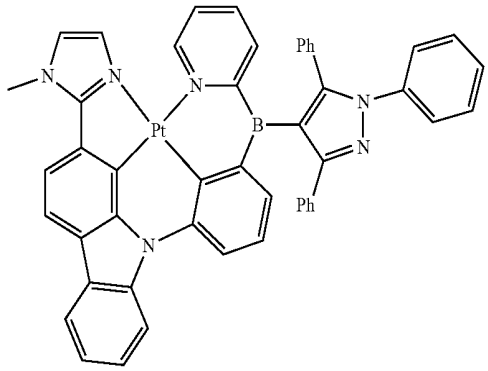

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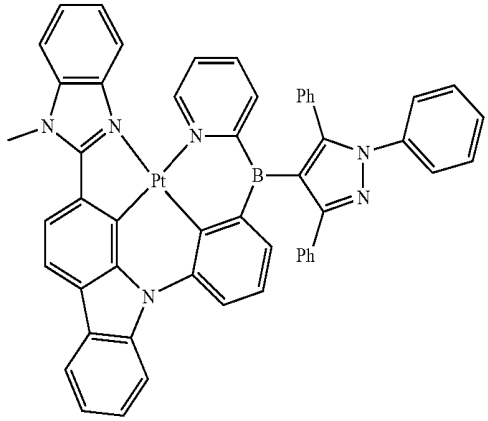

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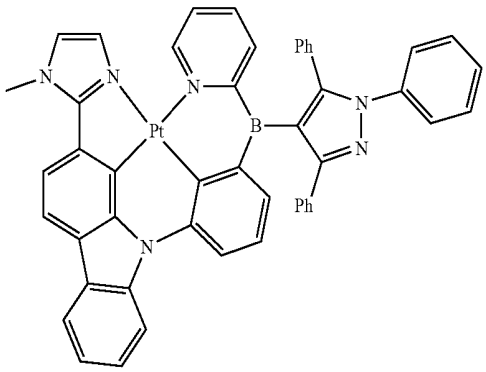

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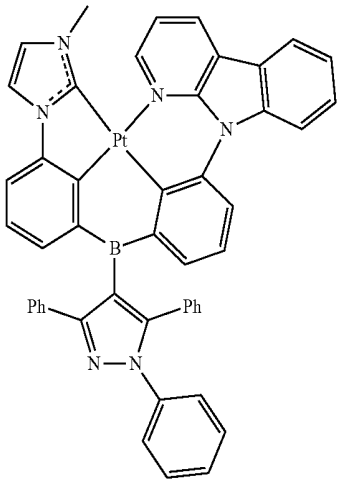

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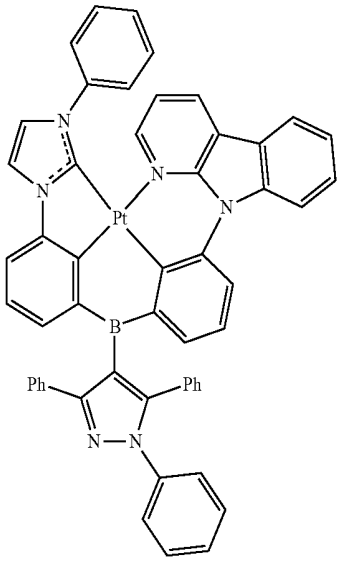

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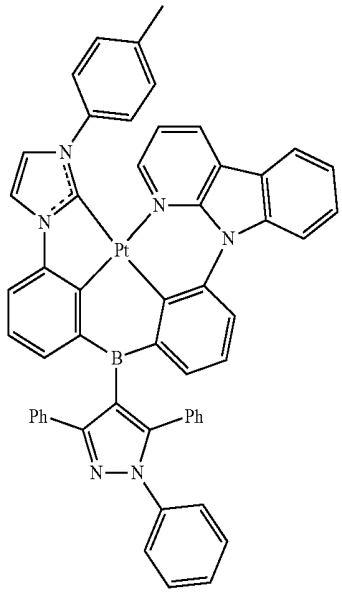

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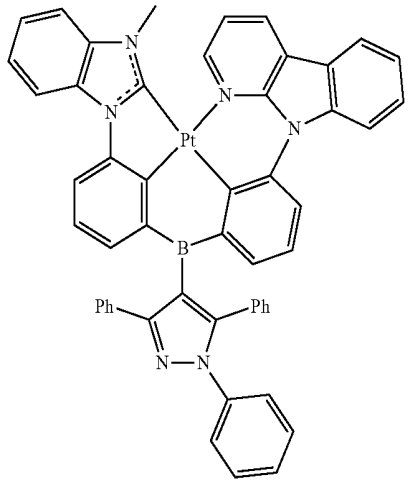

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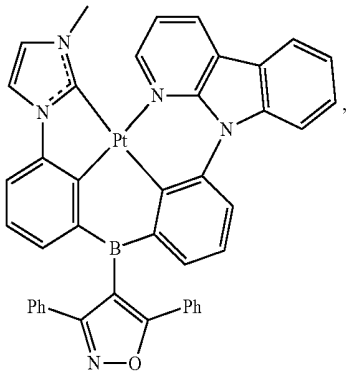

wherein "Ph" in Compounds 1 to 45 represents a phenyl group.

18. An organic light-emitting device comprising:

a first electrode;

a second electrode facing the first electrode; and

an organic layer between the first electrode and the second electrode, wherein the organic layer comprises an emission layer and at least one of the organometallic compound of claim **1**.

19. The organic light-emitting device of claim **18**, wherein the emission layer comprises the organometallic compound.

20. The organic light-emitting device of claim **19**, wherein the organometallic compound comprised in the emission layer is a dopant, and the emission layer further comprises a host.

* * * * *

专利名称(译)	有机化合物和有机发光装置，包括相同的装置		
公开(公告)号	US20190036042A1	公开(公告)日	2019-01-31
申请号	US15/868853	申请日	2018-01-11
[标]申请(专利权)人(译)	三星显示有限公司		
申请(专利权)人(译)	三星DISPLAY CO.，LTD.		
当前申请(专利权)人(译)	三星DISPLAY CO.，LTD.		
[标]发明人	KIM SUNGBUM KO SOOBYUNG JEON MINA AHN HEECHOON JUN MIEUN KIM YOUNGKOOK HWANG SEOKHWAN		
发明人	KIM, SUNGBUM KO, SOOBYUNG JEON, MINA AHN, HEECHOON JUN, MIEUN KIM, YOUNGKOOK HWANG, SEOKHWAN		
IPC分类号	H01L51/00 C07F15/00 C09K11/06		
CPC分类号	H01L51/0087 C07F15/0086 C09K11/06 H01L51/5206 H01L51/5221 H01L51/5016 C09K2211/185 C09K2211/1029 C09K2211/1044 C09K2211/1033 H01L51/0072 H01L51/0094 H01L2251/5384		
优先权	1020170095712 2017-07-27 KR		
外部链接	Espacenet USPTO		

摘要(译)

一种有机发光装置，包括：第一电极;面向第一电极的第二电极;以及第一电极和第二电极之间的有机层，其中有机层包括发光层。发光层可包括由式1表示的有机金属化合物作为掺杂剂：