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

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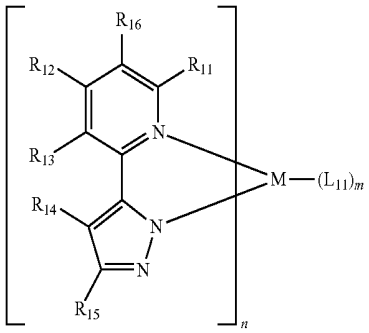
(57) **ABSTRACT**

An organometallic compound represented by Formula 1:

Formula 1



wherein, in Formula 1, L_{11}, M, m, n, and R_{11} to R_{16} are the same as described in the specification.

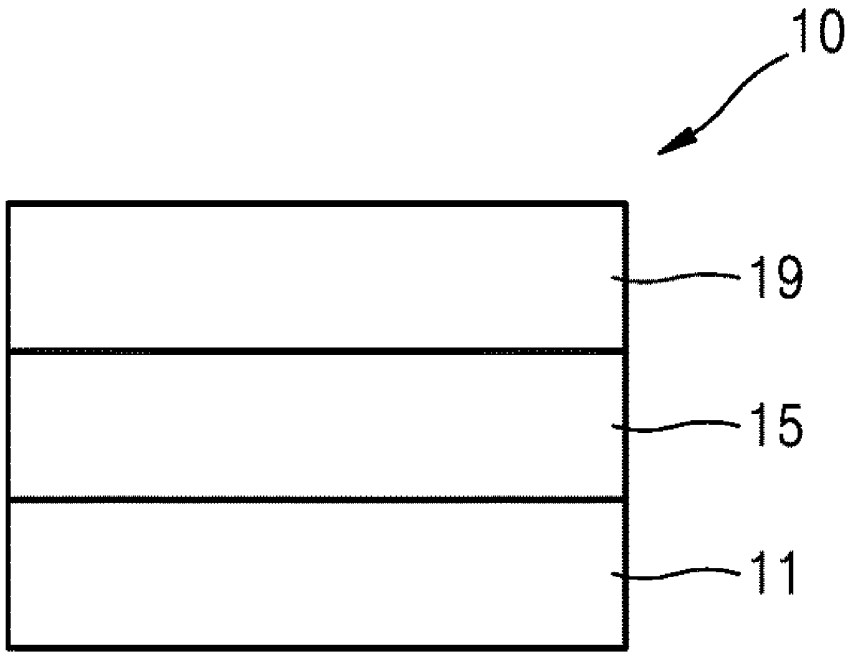


FIG. 1

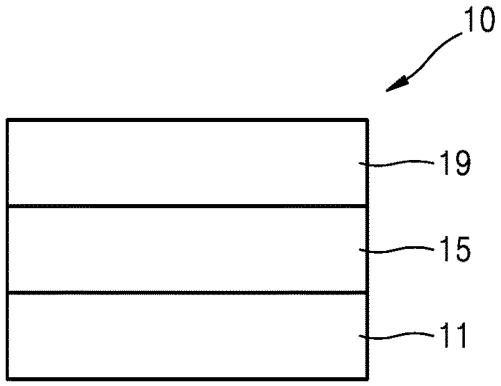

10
19
15
11

FIG. 2

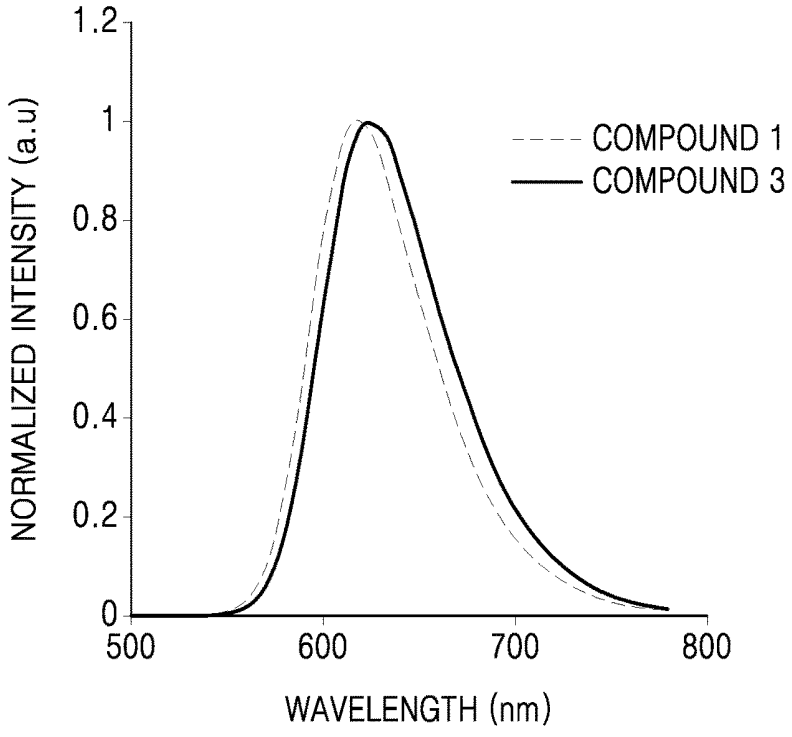
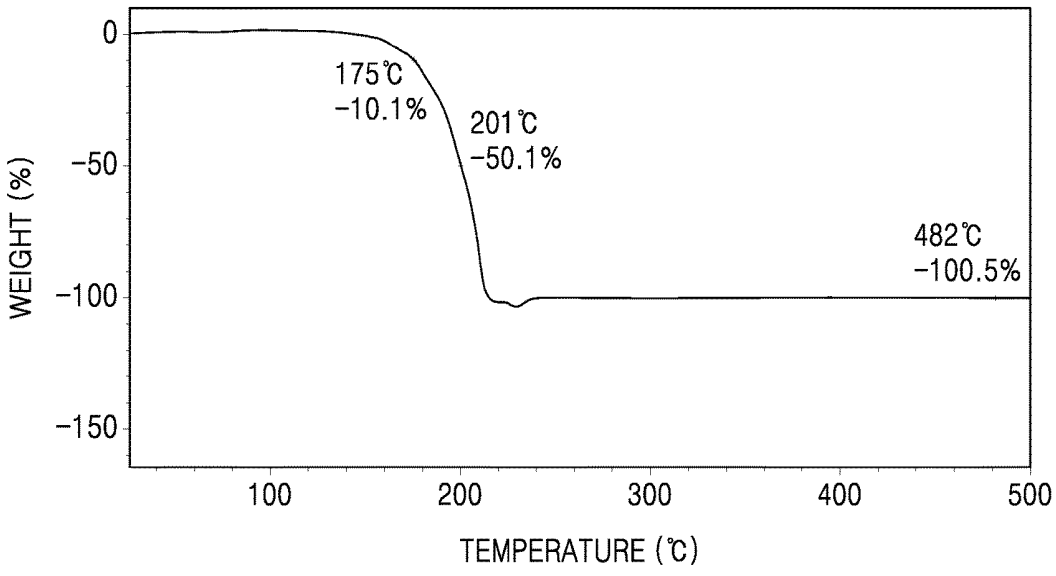

1.2
1
0.8
0.6
0.4
0.2
0
NORMALIZED INTENSITY (a.u)
500
600
700
800
WAVELENGTH (nm)
COMPOUND 1
COMPOUND 3

FIG. 3


0
-50
-100
-150
WEIGHT (%)
175℃
-10.1%
201℃
-50.1%
482℃
-100.5%
100
200
300
400
500
TEMPERATURE (℃)

ORGANOMETALLIC COMPOUND AND ORGANIC LIGHT-EMITTING DEVICE INCLUDING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to Korean Patent Application No. 10-2015-0119823, filed on Aug. 25, 2015 and Korean Patent Application No. 10-2016-0105589, filed on Aug. 19, 2016, and all the benefits accruing therefrom under 35 U.S.C. §119, in the Korean Intellectual Property Office, the contents of which are incorporated herein in their entirety by reference.

BACKGROUND

[0002] 1. Field

[0003] The present disclosure relates to an organometallic compound and an organic light-emitting device including the same.

[0004] 2. Description of the Related Art

[0005] 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 excellent luminance, driving voltage, and response speed characteristics, and produce full-color images.

[0006] In an example, an organic light-emitting device includes an anode, a cathode, and an organic layer disposed between the anode and the cathode, wherein the organic layer includes an emission layer. A hole transport region may be disposed between the anode and the emission layer, and an electron transport region may be disposed between the emission layer and the cathode. Holes provided from the anode may move toward the emission layer through the hole transport region, and electrons provided from the cathode may move toward the emission layer through the electron transport region. The holes and the electrons recombine in the emission layer to produce excitons. These excitons transit from an excited state to a ground state to thereby generate light.

[0007] Various types of organic light emitting devices are known. However, there still remains a need in OLEDs having low driving voltage, high efficiency, high brightness, and long lifespan.

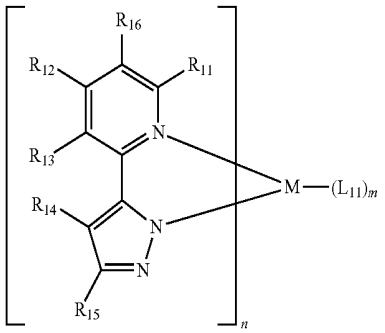
SUMMARY

[0008] Provided are an organometallic compound and an organic light-emitting device including the same.

[0009] 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.

[0010] According to an aspect of an embodiment, an organometallic compound is represented by Formula 1:

Formula 1



[0011] wherein, in Formula 1,

[0012] M is selected from osmium (Os) and ruthenium (Ru),

[0013] R_{11} to R_{13} and R_{16} are each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_7-C_{60} arylalkyl 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 C_2-C_{60} heteroarylalkyl 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 selected from R_{11} to R_{13} and R_{16} is selected from 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, R_{14} and R_{15} are each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, and a substituted or unsubstituted C_6-C_{60} aryl group,

[0014] n is selected from 1, 2, and 3,

[0015] L_{11} is selected from a monodentate ligand and a bidentate ligand, and

[0016] m is selected from 0, 1, 2, 3, and 4.

[0017] According to an aspect of another embodiment, an organic light-emitting device includes:

[0018] a first electrode;

[0019] a second electrode; and

[0020] an organic layer disposed between the first electrode and the second electrode,

[0021] wherein the organic layer includes an emission layer and at least one organometallic compound represented by Formula 1.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] 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:

[0023] FIG. **1** is a schematic view of an organic light-emitting device according to an embodiment;

[0024] FIG. **2** is a graph of normalized intensity (arbitrary units, a.u.) versus wavelength (nanometers, nm) illustrating photoluminescence (PL) spectra of Compounds 1 and 3; and

[0025] FIG. **3** is a graph of weight (percent, %) versus temperature (° C.) illustrating thermal gravimetric analysis (TGA) result of Compound 3.

DETAILED DESCRIPTION

[0026] Reference will now be made in 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 disclosure. 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," when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list.

[0027] The present disclosure will now be described more fully with reference to exemplary embodiments. The disclosure may, however, be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the concept of the disclosure to those skilled in the art. Advantages, features, and how to achieve them of the present disclosure will become apparent by reference to the embodiment that will be described later in detail, together with the accompanying drawings. This inventive concept may, however, be embodied in many different forms and should not be limited to the embodiments.

[0028] Hereinafter, embodiments are described in detail by referring to the attached drawings, in which like reference numerals denote like elements, and a redundant explanation thereof will not be provided herein.

[0029] As used herein, the singular forms "a," "an", and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise.

[0030] The term "or" means "and/or." It will be further understood that the terms "comprises" and/or "comprising" or "includes" and/or "including" as used herein specify the presence of stated features, regions, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, regions, integers, steps, operations, elements, and/or components.

[0031] 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 on the other layer, region, or component. That is, for example, intervening layers, regions, or components may be present.

[0032] It will be understood that, although the terms first, second, third etc. may be used herein to describe various elements, components, regions, layers, and/or sections, these elements, components, regions, layers, and/or sections should not be limited by these terms. These terms are only used to distinguish one element, component, region, layer, or section from another element, component, region, layer, or section. Thus, a first element, component, region, layer, or section discussed below could be termed a second element, component, region, layer, or section without departing from the teachings of the present embodiments.

[0033] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this general inventive concept belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and the present disclosure, and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0034] Exemplary embodiments are described herein with reference to cross section illustrations that are schematic illustrations of idealized embodiments. As such, variations from the shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Thus, embodiments described herein should not be construed as limited to the particular shapes of regions as illustrated herein but are to include deviations in shapes that result, for example, from manufacturing. For example, a region illustrated or described as flat may, typically, have rough and/or nonlinear features. Moreover, sharp angles that are illustrated may be rounded. Thus, the regions illustrated in the figures are schematic in nature and their shapes are not intended to illustrate the precise shape of a region and are not intended to limit the scope of the present claims.

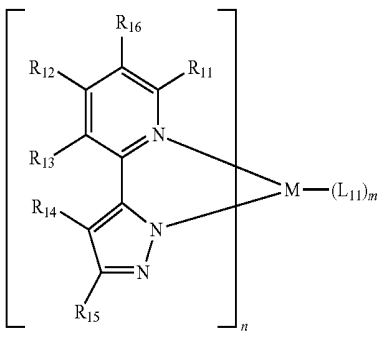
[0035] Sizes of components in the drawings may be exaggerated for convenience of explanation. In other words, since sizes and thicknesses of components in the drawings are arbitrarily illustrated for convenience of explanation, the following embodiments are not limited thereto.

[0036] "About" or "approximately" as used herein is inclusive of the stated value and means within an acceptable range of deviation for the particular value as determined by one of ordinary skill in the art, considering the measurement in question and the error associated with measurement of the particular quantity (i.e., the limitations of the measurement system). For example, "about" can mean within one or more standard deviations, or within ±30%, 20%, 10%, 5% of the stated value.

[0037] The term "organic layer" as used herein refers to a single layer and/or multiple layers disposed between a first electrode and a second electrode of an organic light-emitting device. A material included in the "organic layer" is not limited to an organic material.

[0038] An organometallic compound may be represented by Formula 1:

Formula 1



[0039] wherein, in Formula 1, M may be selected from a Group 1 transition metal, a Group 2 transition metal, and a Group 3 transition metal.

[0040] R_{11} to R_{13} and R_{16} in Formula 1 may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_7-C_{60} arylalkyl 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 C_2-C_{60} heteroarylalkyl 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 selected from R_{11} to R_{13} and R_{16} may be selected from 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.

[0041] In an embodiment, R_{11}, R_{12}, R_{13}, or R_{16} in Formula 1 may be selected from 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, but embodiments are not limited thereto.

[0042] For example, in Formula 1, R_{11} may be selected from 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, R_{12}, R_{13}, and R_{16} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_r C_{60} alkyl group, and a substituted or unsubstituted C_3-C_{10} cycloalkyl group;

[0043] R_{12} may be selected from 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, and R_{11}, R_{13}, and R_{16} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, and a substituted or unsubstituted C_3-C_{10} cycloalkyl group;

[0044] R_{13} may be selected from 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, and R_{11}, R_{12}, and R_{16} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, and a substituted or unsubstituted C_3-C_{10} cycloalkyl group; or

[0045] R_{16} may be selected from 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, and R_{11} to R_{13} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, and a substituted or unsubstituted C_3-C_{10} cycloalkyl group, but embodiments are not limited thereto.

[0046] In another embodiment, two substituents of among R_{11}, R_{12}, R_{13}, and R_{16} may each independently be selected from 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, but embodiments are not limited thereto.

[0047] For example, in Formula 1, R_{11} and R_{16} may each independently be selected from 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, and R_{12} and R_{13} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, and a substituted or unsubstituted C_3-C_{10} cycloalkyl group;

[0048] R_{11} and R_{12} may each independently be selected from 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, and R_{13} and R_{16} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, and a substituted or unsubstituted C_3-C_{10} cycloalkyl group;

[0049] R_{11} and R_{13} may each independently be selected from 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, and R_{12} and R_{16} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_r C_{60} alkyl group, and a substituted or unsubstituted C_3-C_{10} cycloalkyl group;

[0050] R_{12} and R_{16} may each independently be selected from 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, and R_{11} and R_{13} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_r C_{60} alkyl group, and a substituted or unsubstituted C_3-C_{10} cycloalkyl group;

[0051] R_{13} and R_{16} may each independently be selected from 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, and R_{11} and R_{12} may each independently be selected

from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted $C_r C_{60}$ alkyl group, and a substituted or unsubstituted C_3-C_{10} cycloalkyl group; or

[0052] R_{12} and R_{13} may each independently be selected from 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, and R_{11} and R_{16} may each independently be hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, and a substituted or unsubstituted C_3-C_{10} cycloalkyl group, but embodiments are not limited thereto.

[0053] In still another embodiment, three substituents of among R_{11}, R_{12}, R_{13}, and R_{16} may each independently be selected from 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, but embodiments are not limited thereto.

[0054] For example, in Formula 1, R_{11}, R_{12}, and R_{16} may each independently be selected from 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, and R_{13} may be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted $C_r C_{60}$ alkyl group, and a substituted or unsubstituted C_3-C_{10} cycloalkyl group;

[0055] R_{11}, R_{13}, and R_{16} may each independently be selected from 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, and R_{12} may be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, and a substituted or unsubstituted C_3-C_{10} cycloalkyl group;

[0056] R_{11} to R_{13} may each independently be selected from 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, and R_{16} may be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, and a substituted or unsubstituted C_3-C_{10} cycloalkyl group; or

[0057] R_{12}, R_{13}, and R_{16} may each independently be selected from 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, and R_{11} may be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, and a substituted or unsubstituted C_3-C_{10} cycloalkyl group, but embodiments are not limited thereto.

[0058] In still another embodiment, R_{11}, R_{12}, R_{13}, and R_{16} may each independently be selected from 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, but embodiments are not limited thereto.

[0059] In some embodiments, in Formula 1, R_{11} to R_{13} and R_{16} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a neo-pentyl group, a cyclopentyl group, a cyclohexyl group, and a cycloheptyl group;

[0060] a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, and a neo-pentyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group;

[0061] a cyclopentyl group, a cyclohexyl group, and a cycloheptyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, and a neo-pentyl group;

[0062] a phenyl group, a naphthyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a thiazolyl group, an oxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a naphthyridinyl group, a benzofuranyl group, a benzothiophenyl group, a triazinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

[0063] a phenyl group, a naphthyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a thiazolyl group, an oxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a naphthyridinyl group, a benzofuranyl group, a benzothiophenyl group, a triazinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, $—CD_3$, $—CD_2H$, $—CDH_2$, $—CF_3$, $—CF_2H$, $—CFH_2$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a triazinyl group, and $—Si(Q_1)(Q_2)(Q_3)$,

[0064] provided that at least one selected from R_{11} to R_{13} and R_{16} may be selected from a phenyl group, a naphthyl

group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a thiazolyl group, an oxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a naphthyridinyl group, a benzofuranyl group, a benzothiophenyl group, a triazinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

[0065] a phenyl group, a naphthyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a thiazolyl group, an oxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a naphthyridinyl group, a benzofuranyl group, a benzothiophenyl group, a triazinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a triazinyl group, and —$Si(Q_1)(Q_2)(Q_3)$, wherein Q_1 to Q_3 may each independently be selected from a C_1-C_{20} alkyl group and a C_6-C_{60} aryl group.

[0066] In some embodiments, in Formula 1, R_{11} to R_{13} and R_{16} may each independently be selected from hydrogen, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a cyclopentyl group, and a cyclohexyl group;

[0067] a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, and a tert-butyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group;

[0068] a cyclopentyl group and a cyclohexyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a cyano group, a methyl group, and an ethyl group;

[0069] a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

[0070] a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a methoxy group, an ethoxy group, an n-propoxy group, an iso-propoxy group, an n-butoxy group, a tert-butoxy group, a phenyl group, and —$Si(CH_3)_3$, provided that at least one selected from R_{11} to R_{13} and R_{16} may be selected from a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a methoxy group, an ethoxy group, an n-propoxy group, an iso-propoxy group, an n-butoxy group, a tert-butoxy group, a phenyl group, and —$Si(CH_3)_3$, but embodiments are not limited thereto.

[0071] In some embodiments, in Formula 1, R_{11} to R_{13} may each independently be selected from hydrogen, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a cyclopentyl group, and a cyclohexyl group;

[0072] a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, and a tert-butyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group;

[0073] a cyclopentyl group and a cyclohexyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a cyano group, a methyl group, and an ethyl group;

[0074] a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

[0075] a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a methoxy group, an ethoxy group, an n-propoxy group, an iso-propoxy group, an n-butoxy group, a tert-butoxy group, a phenyl group, and —$Si(CH_3)_3$, and

[0076] R_{16} may be selected from a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

[0077] a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a methoxy group, an ethoxy group, an n-propoxy group, an iso-propoxy group, an n-butoxy group, a tert-butoxy group, a phenyl group, and —$Si(CH_3)_3$, but embodiments are not limited thereto.

[0078] In some embodiments, in Formula 1, R_{11}, R_{13}, and R_{16} may each independently be selected from hydrogen, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a cyclopentyl group, and a cyclohexyl group;

[0079] a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a

sec-butyl group, and a tert-butyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group;

[0080] a cyclopentyl group and a cyclohexyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a cyano group, a methyl group, and an ethyl group;

[0081] a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

[0082] a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, $—CD_3$, $—CD_2H$, $—CDH_2$, $—CF_3$, $—CF_2H$, $—CFH_2$, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a methoxy group, an ethoxy group, an n-propoxy group, an iso-propoxy group, an n-butoxy group, a tert-butoxy group, a phenyl group, and $—Si(CH_3)_3$, and

[0083] R_{12} may be selected from a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

[0084] a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, $—CD_3$, $—CD_2H$, $—CDH_2$, $—CF_3$, $—CF_2H$, $—CFH_2$, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a methoxy group, an ethoxy group, an n-propoxy group, an iso-propoxy group, an n-butoxy group, a tert-butoxy group, a phenyl group, and $—Si(CH_3)_3$, but embodiments are not limited thereto.

[0085] R_{14} and R_{15} in Formula 1 may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, and a substituted or unsubstituted C_6-C_{60} aryl group.

[0086] In some embodiments, R_{14} and R_{15} in Formula 1 may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a neo-pentyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a phenyl group, a naphthyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, and a chrysenyl group;

[0087] a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, and a neo-pentyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, and —I; and a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a phenyl group, a naphthyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, and a chrysenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, and a neo-pentyl group, but embodiments are not limited thereto.

[0088] In some embodiments, R_{14} and R_{15} in Formula 1 may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a cyclopentyl group, a cyclohexyl group, a phenyl group, and a naphthyl group; and

[0089] a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, and a tert-butyl group, each substituted with at least one selected from deuterium and —F, but embodiments are not limited thereto.

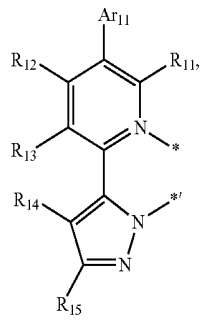
[0090] In some embodiments, R_{14} and R_{15} in Formula 1 may each independently be selected from hydrogen, deuterium, —F, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, $—CD_3$, $—CD_2H$, $—CDH_2$, $—CF_3$, $—CF_2H$, $—CFH_2$, and a phenyl group, but embodiments are not limited thereto.

[0091] In some embodiments, in Formula 1, R_{14} may be hydrogen, and R_{15} may be selected from —F, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, $—CD_3$, $—CD_2H$, $—CDH_2$, $—CF_3$, $—CF_2H$, $—CFH_2$, and a phenyl group, but embodiments are not limited thereto.

[0092] In some embodiments, in Formula 1, R_{15} may be hydrogen, and R_{14} may be selected from —F, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, $—CD_3$, $—CD_2H$, $—CDH_2$, $—CF_3$, $—CF_2H$, $—CFH_2$, and a phenyl group, but embodiments are not limited thereto.

[0093] In some embodiments, R_{14} and R_{15} in Formula 1 may each independently be selected from —F, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, $—CD_3$, $—CD_2H$, $—CDH_2$, $—CF_3$, $—CF_2H$, $—CFH_2$, and a phenyl group, but embodiments are not limited thereto.

[0094] In Formula 1, n indicates the number of ligands represented by



and * and *' each indicate a binding site to M in Formula 1. In Formula 1, n may be selected from 1, 2, and 3, and when n is 2 or greater, the ligands may be identical to or different from each other.

[0095] In some embodiments, n in Formula 1 may be 2, but embodiments are not limited thereto.

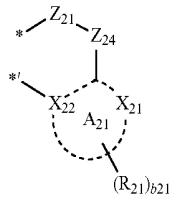
[0096] In Formula 1, L_{11} may be selected from a monodentate ligand and a bidentate ligand.

[0097] Examples of the monodentate ligand may include an iodide ion, a bromide ion, a chloride ion, sulfide, a thiocyanate ion, a nitrate ion, an azide ion, a hydroxide ion, a cyanide ion, an isocyanide ion, water, acetonitrile, pyridine, carbene, ammonia, carbon monoxide, PPh_3, PPh_2CH_3, $PPh(CH_3)_2$, and $P(CH_3)_3$, but embodiments are not limited thereto.

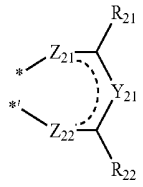
[0098] Examples of the bidentate ligand may include an oxalate ion, acetylacetonate, a picolinic acid, 2-(2-hydroxyphenyl)-pyridine, 2-phenylpyridine, 1,2-bis(diphenylphosphino)ethane (dppe), 1,1-bis(biphenylphosphino)methane (dppm), glycinate, ethylenediamine, 2,2'-bipyridine, and 1,10-phenanthroline, but embodiments are not limited thereto.

[0099] In some embodiments, L_{11} in Formula 1 may be a ligand represented by one of Formulae 2-1 to 2-12, but embodiments are not limited thereto:

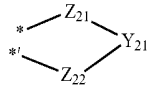
2-1



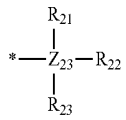
2-2



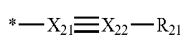
2-3



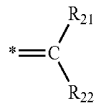
2-4



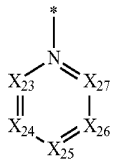
2-5



2-6



2-7



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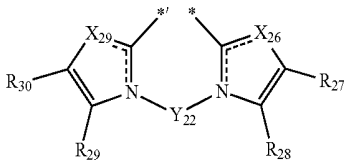
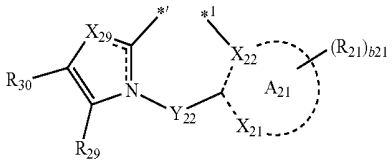
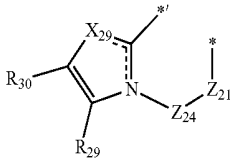
2-9



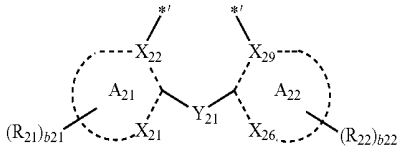
2-10



2-11



2-12



[0100] wherein, in Formulae 2-1 to 2-12,

[0101] A_{21} and A_{22} may each independently be selected from a C_5-C_{20} carbocyclic group and a C_1-C_{20} heterocyclic group,

[0102] X_{21}, X_{22}, X_{25}, and X_{29} may each independently be selected from C and N,

[0103] X_{23} may be N or $C(Q_{23})$, X_{24} may be N or $C(Q_{24})$, X_{25} may be N or $C(Q_{25})$, X_{26} may be N or $C(Q_{26})$, X_{27} may be N or $C(Q_{27})$,

[0104] X_{28} may be O, S, or $N(Q_{28})$, X_{29} may be O, S, or $N(Q_{29})$,

[0105] Y_{21} and Y_{22} may each independently be selected from a single bond, a double bond, a substituted or unsubstituted C_1-C_5 alkylene group, a substituted or unsubstituted C_2-C_5 alkenylene group, and a substituted or unsubstituted C_6-C_{10} arylene group,

[0106] Z_{21} and Z_{22} may each independently be selected from N, O, $N(R_{25})$, $P(R_{25})(R_{26})$, and $As(R_{25})(R_{26})$,

[0107] Z_{23} may be selected from phosphorus (P) and arsenic (As),

[0108] Z_{24} may be selected from CO and CH_2,

[0109] R_{21} to R_{30} and Q_{23} to Q_{29} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_2-C_{60} alkenyl group, a substituted or unsubstituted C_2-C_{60} alkynyl group, a substituted or unsubstituted C_1-C_{60} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or

unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, R_{21} and R_{22} may optionally be bound to form a ring, R_{27} and R_{28} may optionally be bound to form a ring, R_{28} and R_{29} may optionally be bound to form a ring, R_{29} and R_{30} may optionally be bound to form a ring,

[0110] b21 and b22 may each independently be selected from 1, 2, and 3, and

[0111] * and *' each independently indicate a binding site to an adjacent atom.

[0112] In some embodiments, A_{21} and A_{22} in Formula 2-1 may each independently be a benzene group, a naphthalene group, an imidazole group, a benzimidazole group, a pyridine group, a pyrimidine group, a triazine group, a quinoline group, and an isoquinoline group, but embodiments are not limited thereto.

[0113] In some embodiments, X_{22} and X_{29} in Formula 2-1 may be N, but embodiments are not limited thereto.

[0114] In some embodiments, in Formula 2-7, X_{23} may be $C(Q_{23})$, X_{24} may be $C(Q_{24})$, X_{25} may be $C(Q_{25})$, X_{26} may be $C(Q_{26})$, and X_{27} may be $C(Q_{27})$, but embodiments are not limited thereto.

[0115] In some embodiments, in Formula 2-8, X_{28} may be $N(Q_{28})$ and X_{29} may be $N(Q_{29})$, but embodiments are not limited thereto.

[0116] In some embodiments, Y_{21} and Y_{22} in Formulae 2-2, 2-3, and 2-8 may each independently be selected from a substituted or unsubstituted methylene group and a substituted or unsubstituted phenylene group, but embodiments are not limited thereto.

[0117] In some embodiments, Z_{21} and Z_{22} in Formulae 2-1 and 2-2 may be 0, but embodiments are not limited thereto.

[0118] In some embodiments, Z_{23} in Formula 2-4 may be P, but embodiments are not limited thereto.

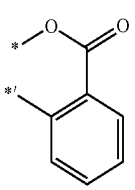
[0119] In some embodiments, R_{21} to R_{30} and Q_{23} to Q_{29} in Formulae 2-1 to 2-8 may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1-C_{20} alkyl group, and a C_1-C_{20} alkoxy group;

[0120] 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 amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a phenyl group, a naphthyl group, a pyridinyl group, and a pyrimidinyl group;

[0121] a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, and an imidazopyridinyl group; and a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, and an imidazopyridinyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, $—CD_3$, $—CD_2H$, $—CDH_2$, $—CF_3$, $—CF_2H$, $—CFH_2$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a naphthyl group, a fluorenyl group, a phenanthrenyl group, an anthracenyl group, a fluoranthenyl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a pyrazolyl group, a thiazolyl group, an isothiazolyl group, an oxazolyl group, an isoxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a cinnolinyl group, a carbazolyl group, a phenanthrolinyl group, a benzimidazolyl group, a benzofuranyl group, a benzothiophenyl group, an isobenzothiazolyl group, a benzoxazolyl group, an isobenzoxazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a triazinyl group, a dibenzofuranyl group, a dibenzothiophenyl group, a benzocarbazolyl group, a dibenzocarbazolyl group, and an imidazopyridinyl group, but embodiments are not limited thereto.

[0122] In some embodiments, L_{11} in Formula 1 may be a ligand represented by one of Formulae 3-1 to 3-25, but embodiments are not limited thereto:

3-1



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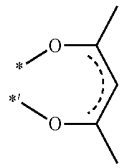

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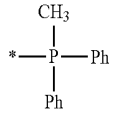

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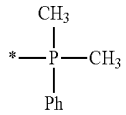

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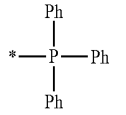

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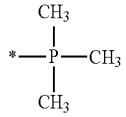

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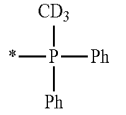

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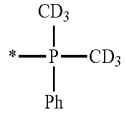

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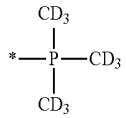

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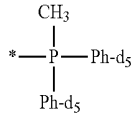

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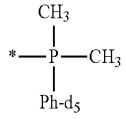

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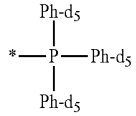

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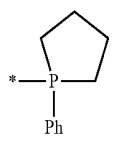

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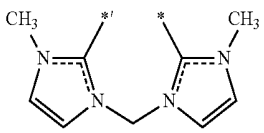

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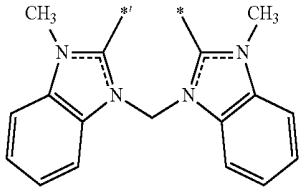

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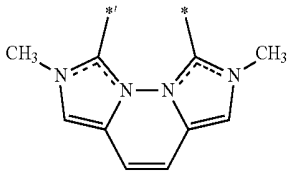

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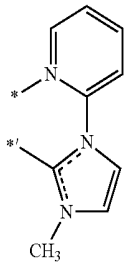

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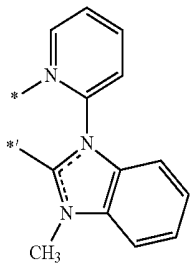

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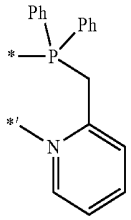

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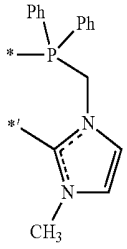

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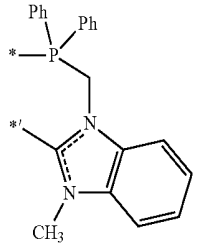

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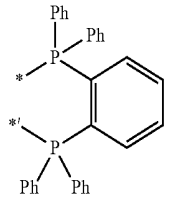

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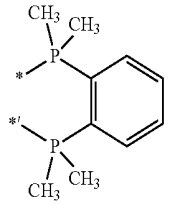

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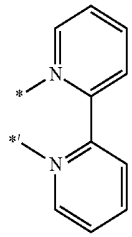
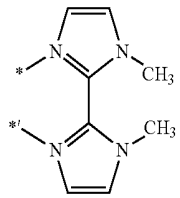


3-25



[0123] wherein, in Formulae 3-1 to 3-25,

[0124] "Ph" represents a phenyl group,

[0125] "Ph-d_5" represents a phenyl group of which all hydrogen atoms are substituted with deuterium atoms, and

[0126] * and *' each indicate a binding site to an adjacent atom.

[0127] m in Formula 1 indicates the number of groups L_{11}, and m may be selected from 0, 1, 2, 3, and 4. When m is 2 or greater, groups L_{11} may be identical to or different from each other.

[0128] In some embodiments, m in Formula 1 may be selected from 1 and 2, but embodiments are not limited thereto.

[0129] In some embodiments, the organometallic compound represented by Formula 1 may be a heteroleptic organometallic compound or a homoleptic organometallic compound, but embodiments are not limited thereto.

[0130] In some embodiments, in Formula 1, n may be 2 and m may be 2, but embodiments are not limited thereto.

[0131] In some embodiments, in Formula 1, n may be 2 and m may be 1, but embodiments are not limited thereto.

[0132] In some embodiments, in Formula 1, M may be selected from iridium (Ir), platinum (Pt), osmium (Os), ruthenium (Ru), rhodium (Rh), palladium (Pd), copper (Cu), silver (Ag), gold (Au), titanium (Ti), zirconium (Zr), hafnium (Hf), europium (Eu), terbium (Tb), and thulium (Tm). For example, M may be selected from Os or Ru.

[0133] In Formula 1, R_{11} to R_{13} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkyl 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,

[0134] R_{16} may be selected from 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,

[0135] R_{14} and R_{15} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, and a substituted or unsubstituted C_6-C_{60} aryl group,

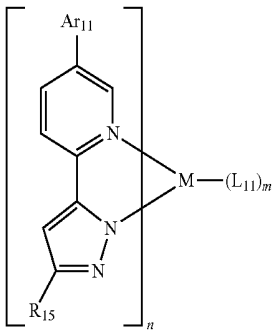
[0136] n may be selected from 1, 2, and 3,

[0137] L_{11} may be selected from a monodentate ligand and a bidentate ligand, and

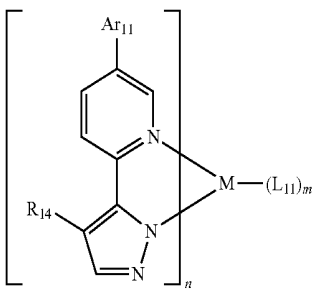
[0138] m may be selected from 0, 1, 2, 3, and 4, but embodiments are not limited thereto.

[0139] In some embodiments, the organometallic compound represented by Formula 1 may be represented by one of Formulae 1-1 to 1-9, but embodiments are not limited thereto:

1-1



1-2



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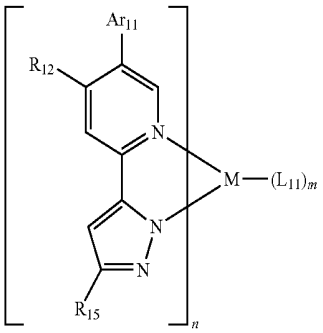
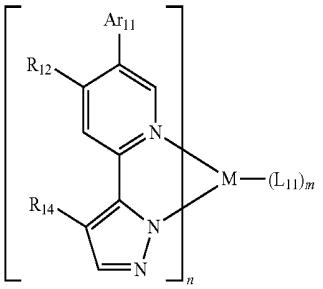


1-4



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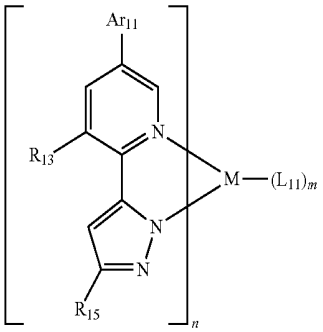

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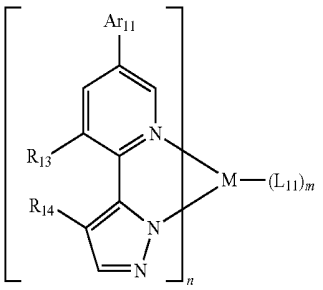

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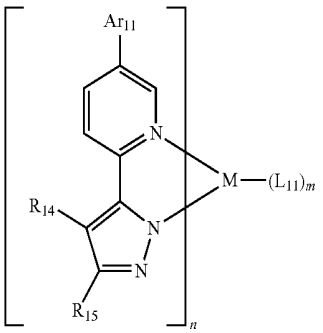

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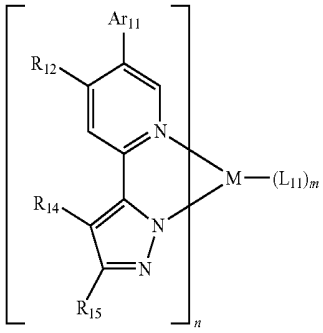

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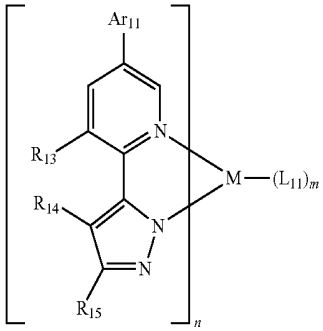


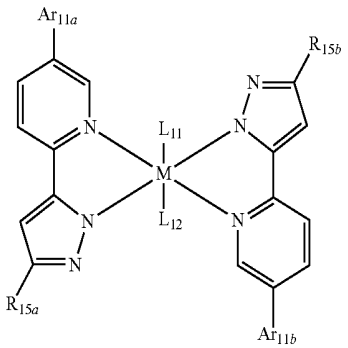
[0140] wherein, in Formulae 1-1 to 1-9,

[0141] M, R_{12} to R_{15}, n, L_{11}, and m may be the same as those described above in connection with Formula 1, and

[0142] Ar_{11} may be selected from 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 each of R_{12} to R_{15} may not be hydrogen.

[0143] The organometallic compound represented by Formula 1 may be represented by one of Formulae 1-11 to 1-19 and 1-21 to 1-29, but embodiments are not limited thereto:

1-11



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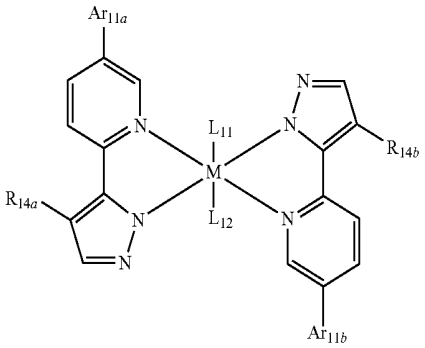

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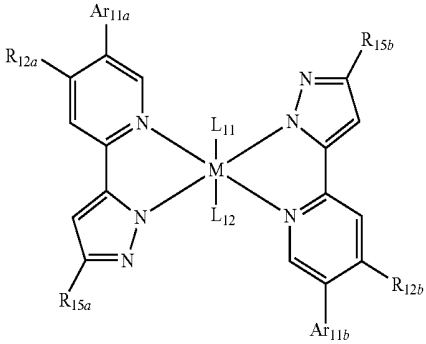

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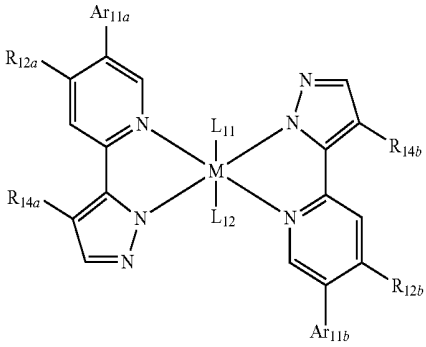

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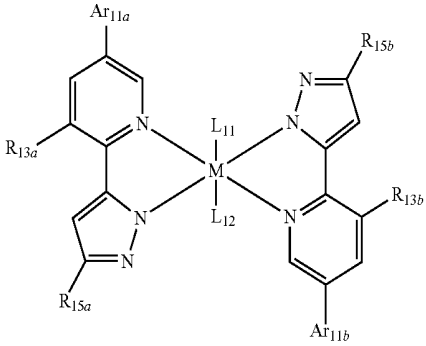

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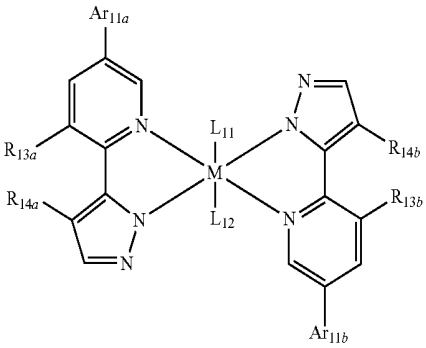

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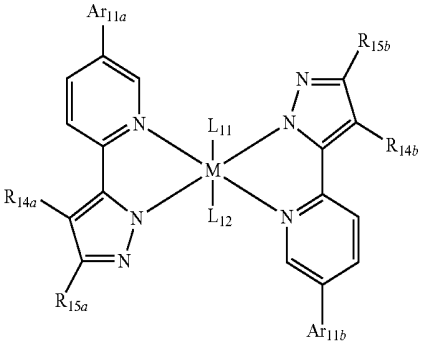

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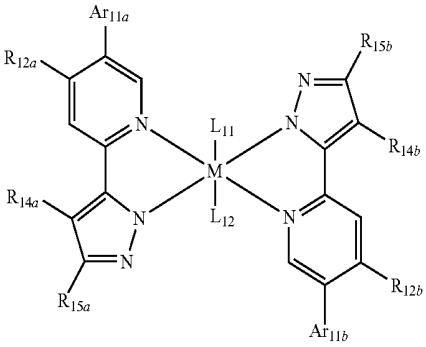

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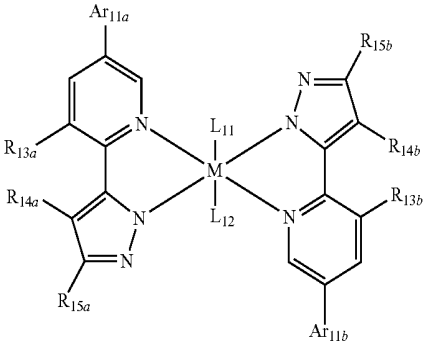

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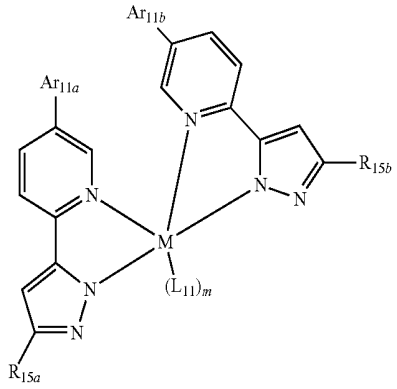

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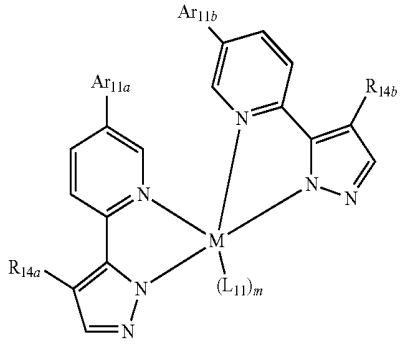

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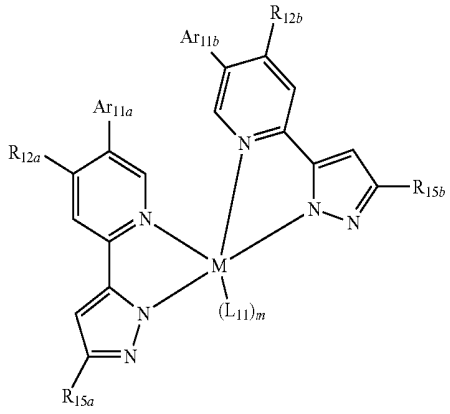

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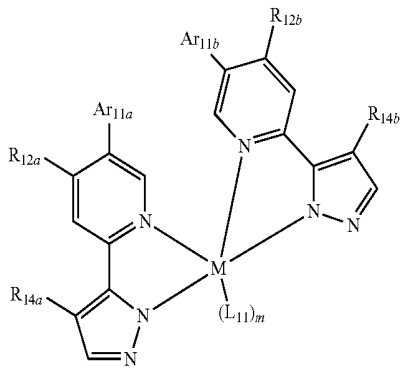

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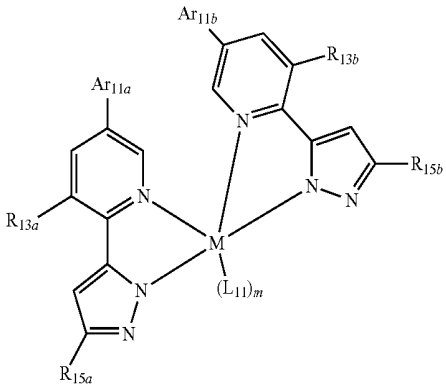

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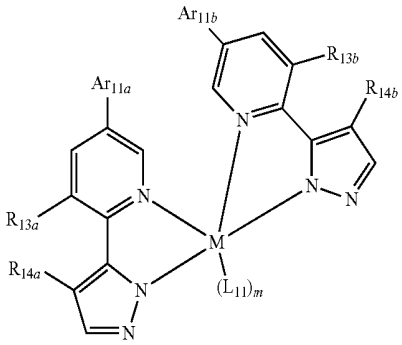

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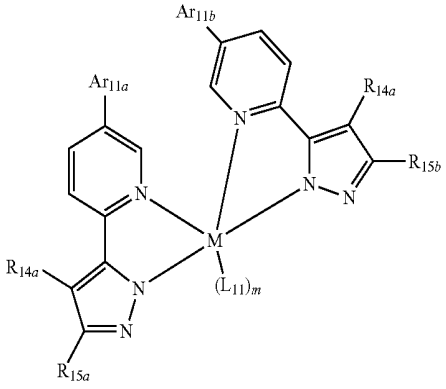

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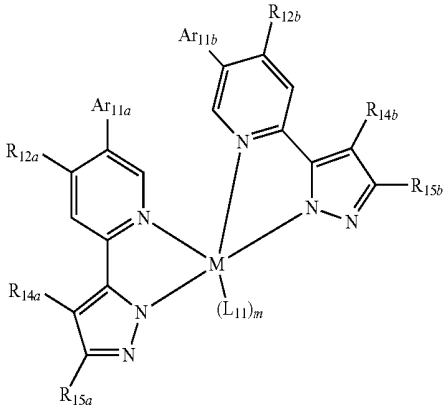

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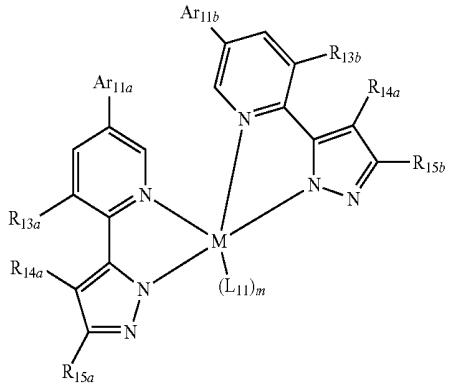


[0144] wherein, in Formulae 1-11 to 1-19 and 1-21 to 1-29,

[0145] L_{11} and m may be the same as those described above in connection with Formula 1,

[0146] Ar_{11a} and Ar_{11b} may each independently be selected from 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,

[0147] R_{12a} and R_{12b} may each independently be the same as those described in Formula 1 in connection with R_{12},

[0148] R_{13a} and R_{13b} may each independently be the same as those described in Formula 1 in connection with R_{13},

[0149] R_{14a} and R_{14b} may each independently be the same as those described in Formula 1 in connection with R_{14},

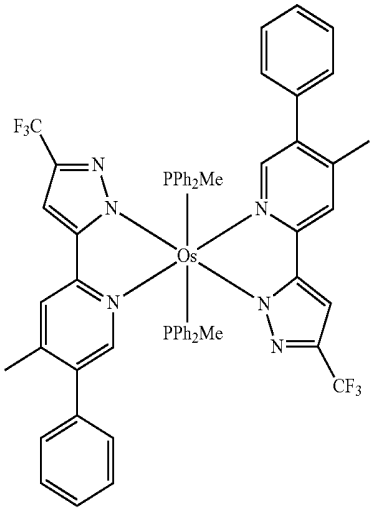
[0150] R_{15a} and R_{15b} may each independently be the same as those described in Formula 1 in connection with R_{15}, and

[0151] L_{12} may be the same as L_{11} described in Formula 1,

[0152] provided that each of R_{12} to R_{15} may not be hydrogen.

[0153] The organometallic compound represented by Formula 1 may be selected from Compounds 1 to 176, but embodiments are not limited thereto:

1



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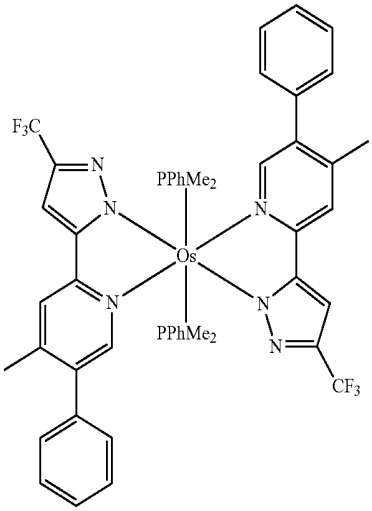

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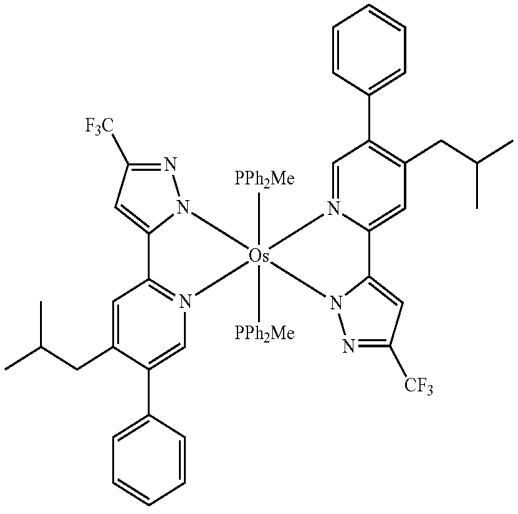

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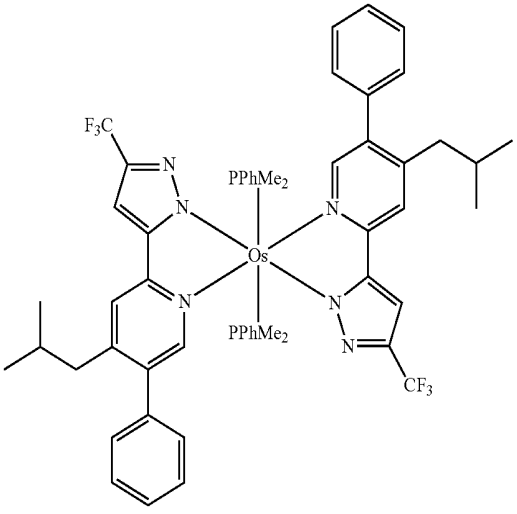

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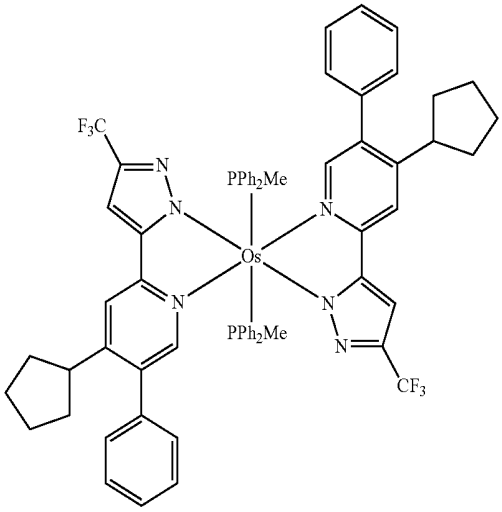

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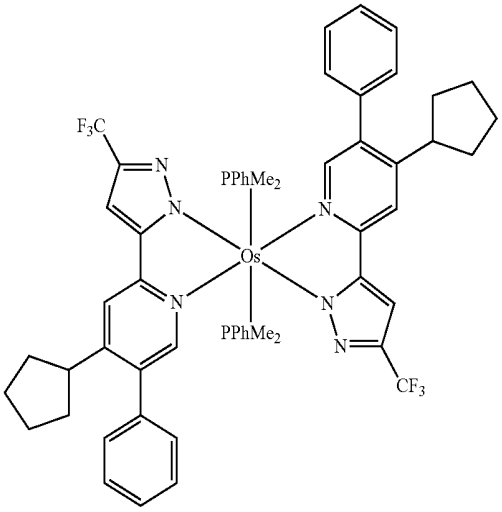

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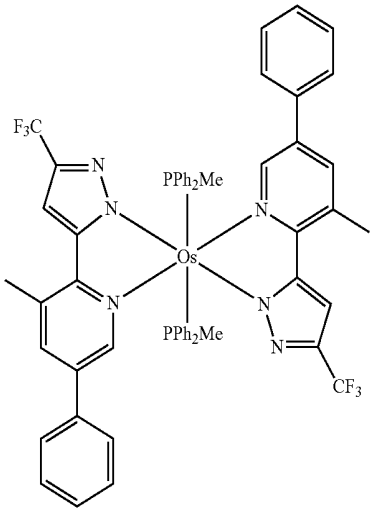

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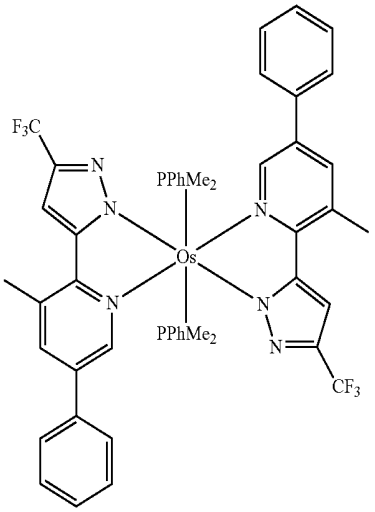

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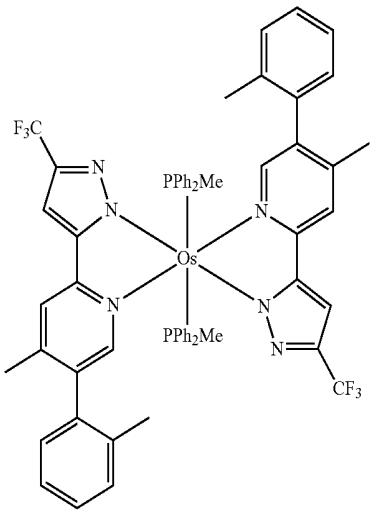

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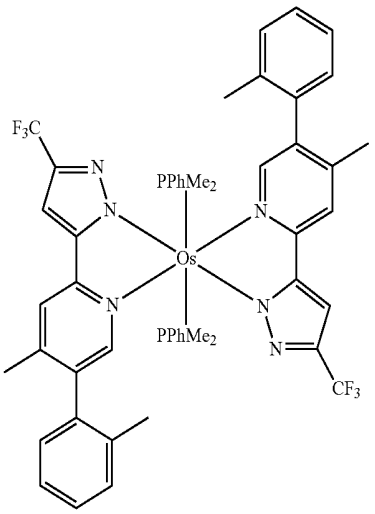

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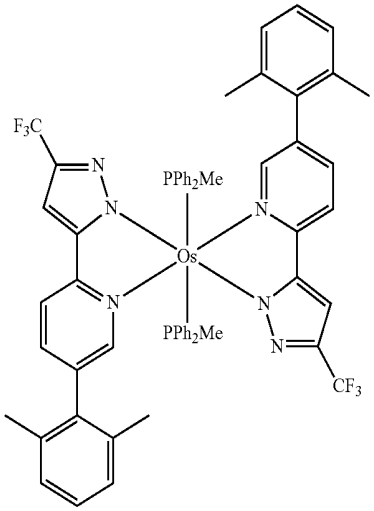

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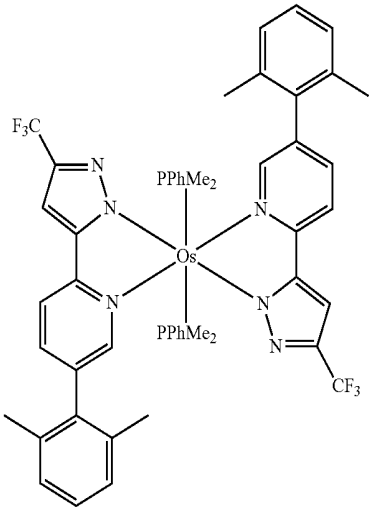

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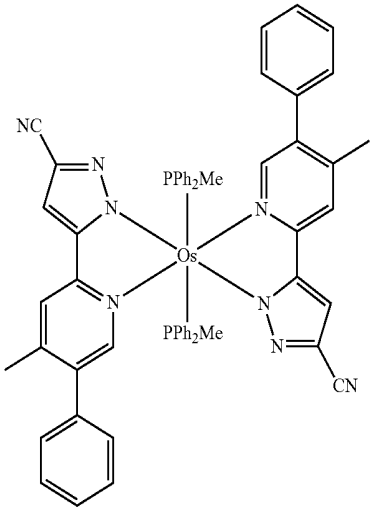

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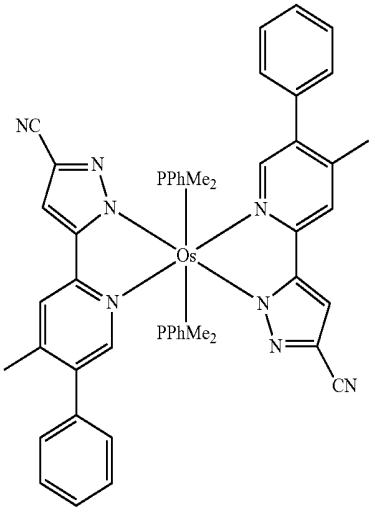

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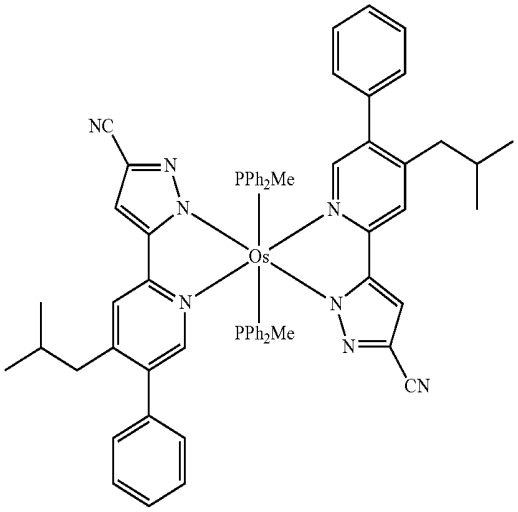

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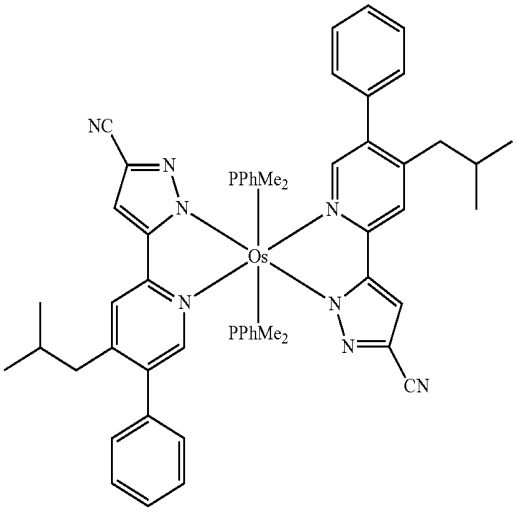

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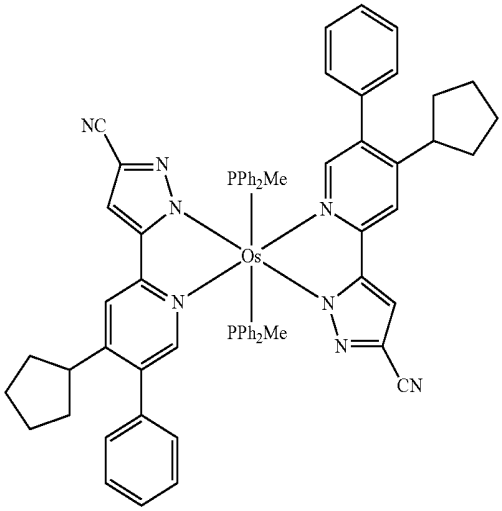

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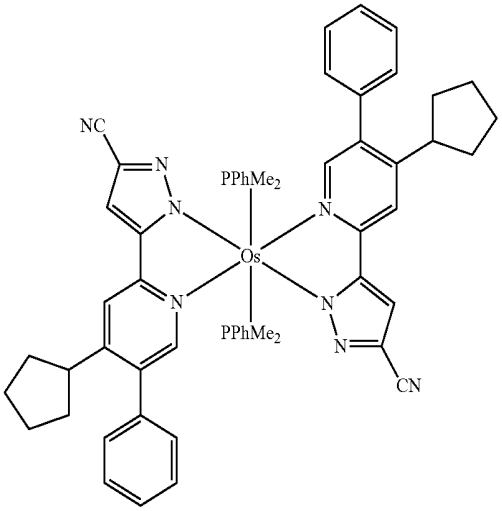

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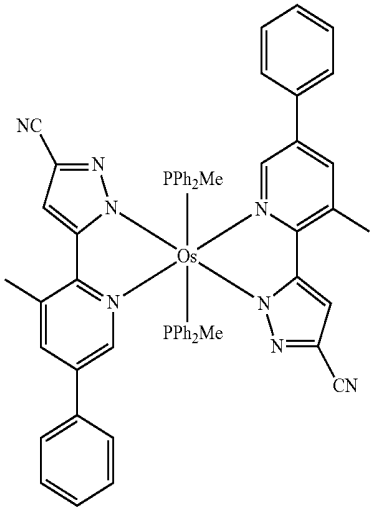

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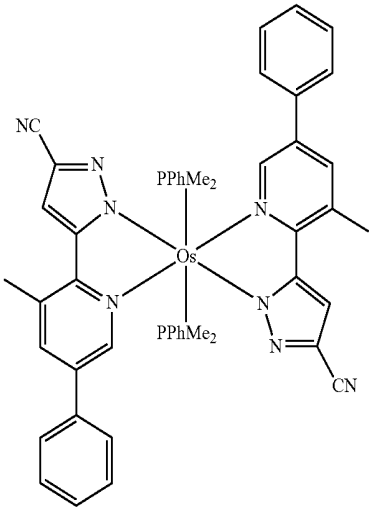

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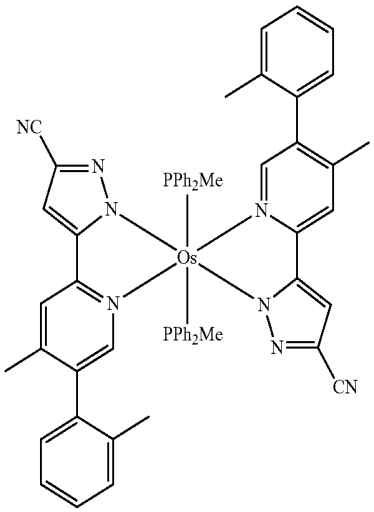

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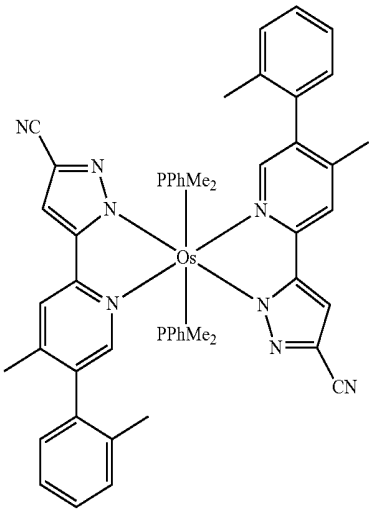

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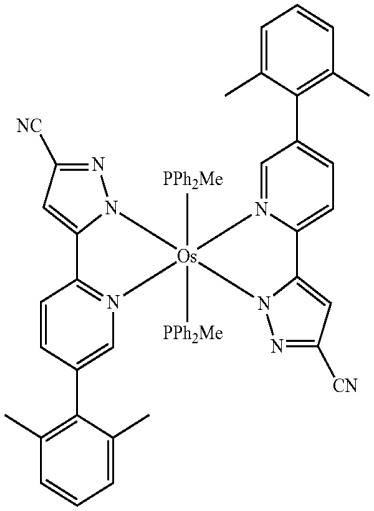

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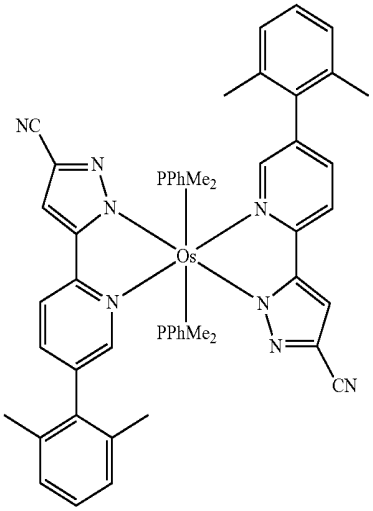

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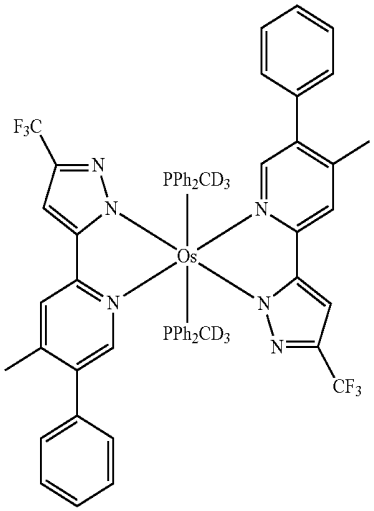

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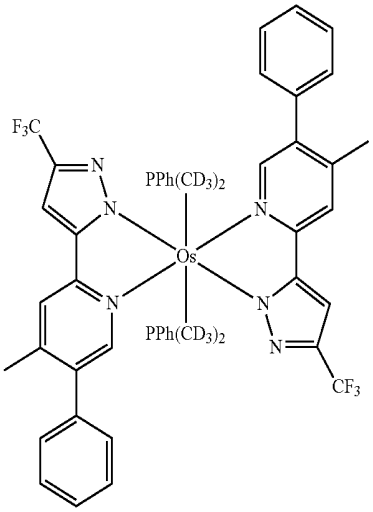

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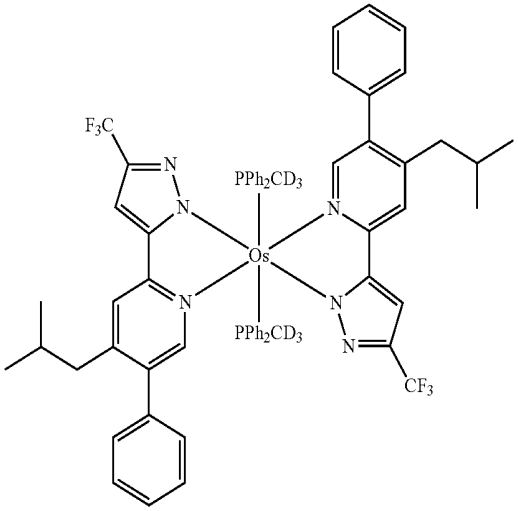

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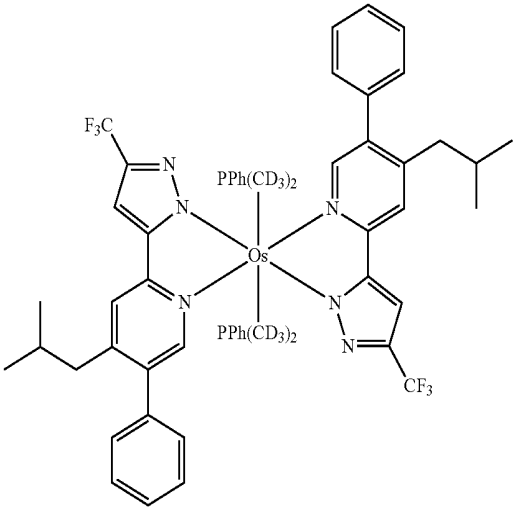

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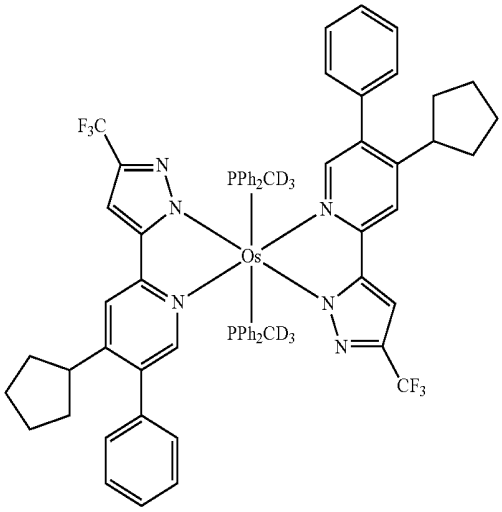

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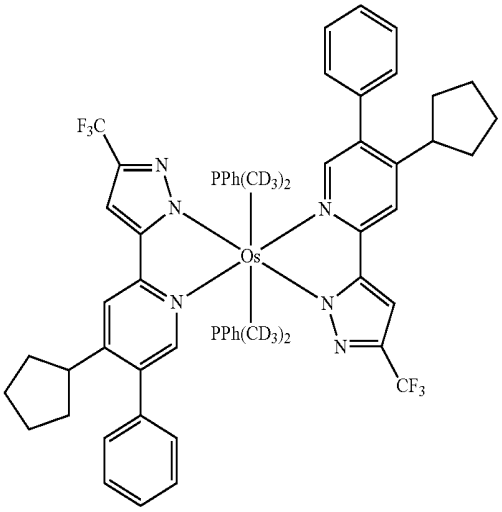

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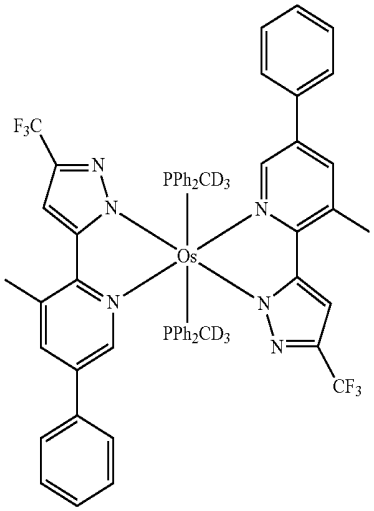

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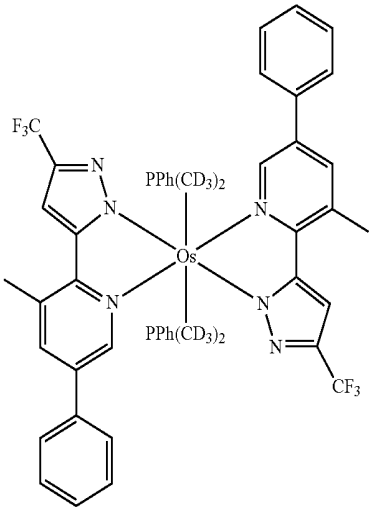

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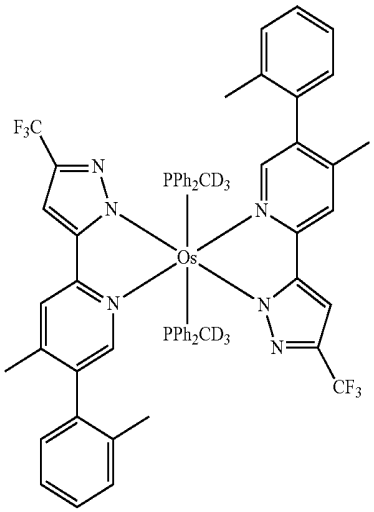

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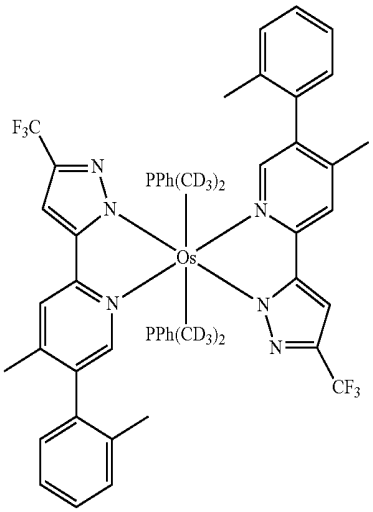

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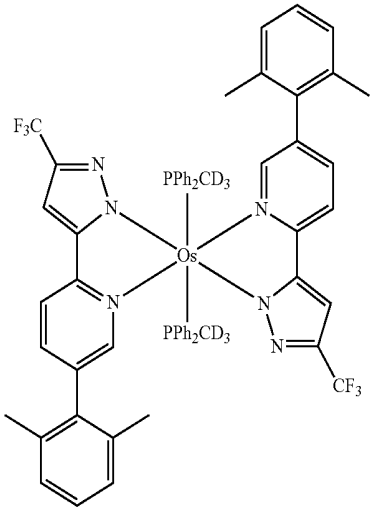

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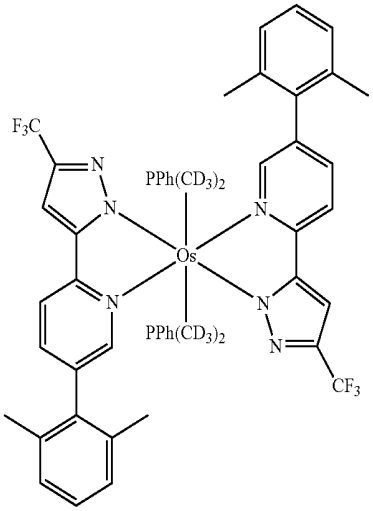

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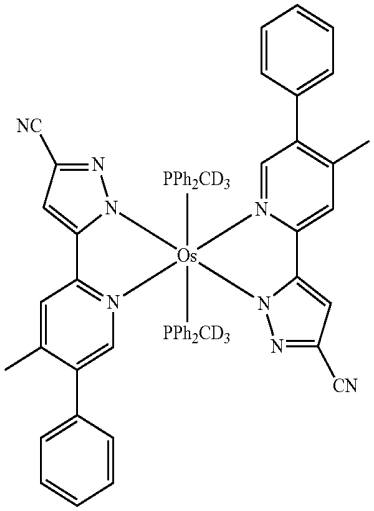

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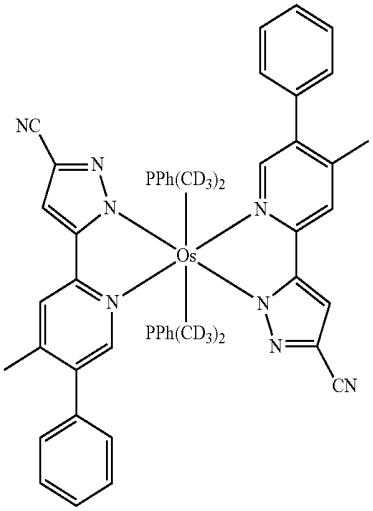

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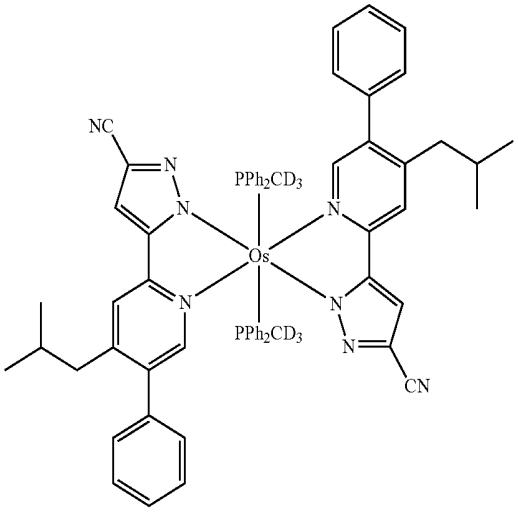

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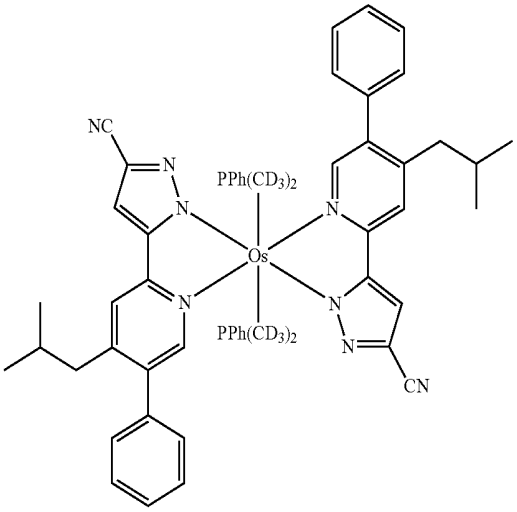

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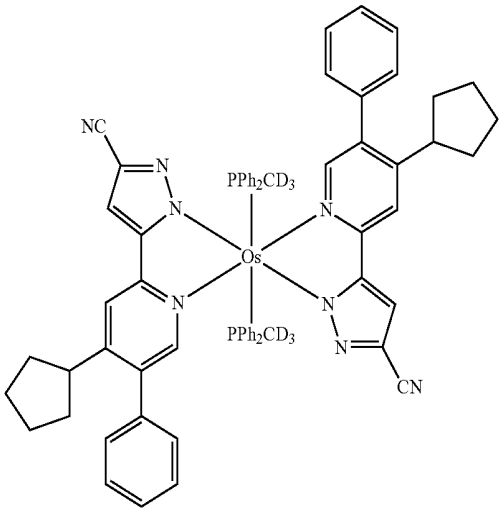

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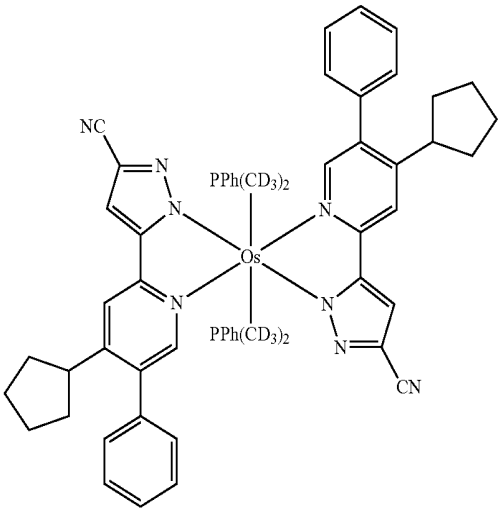

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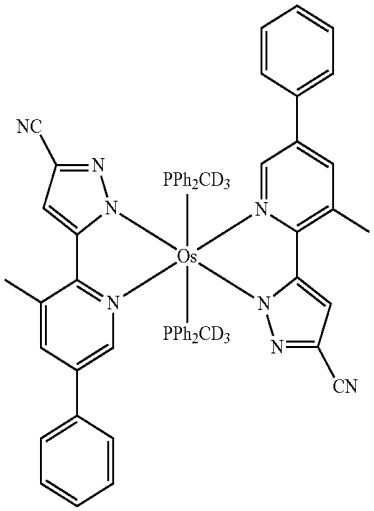

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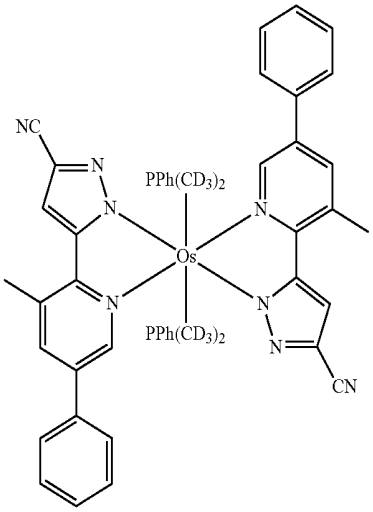

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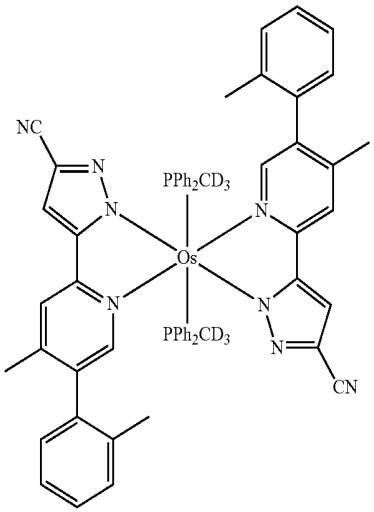

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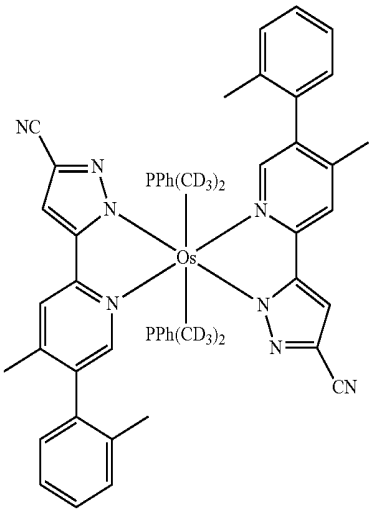

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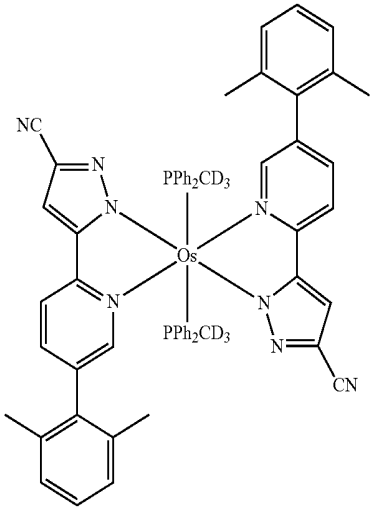

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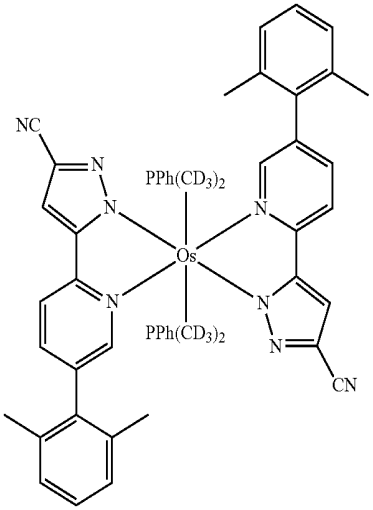

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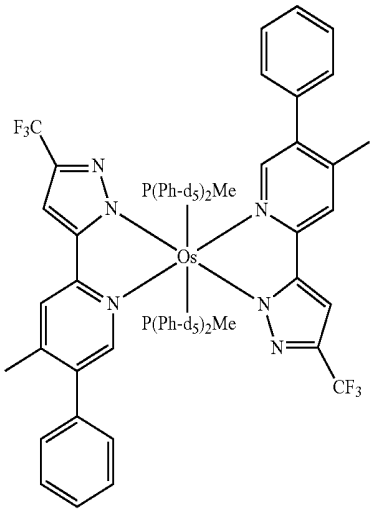

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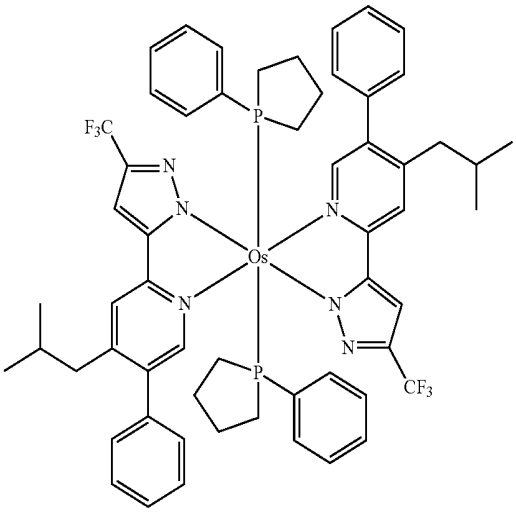

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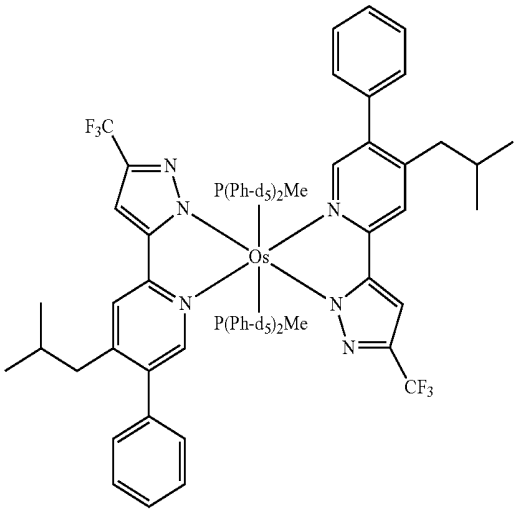

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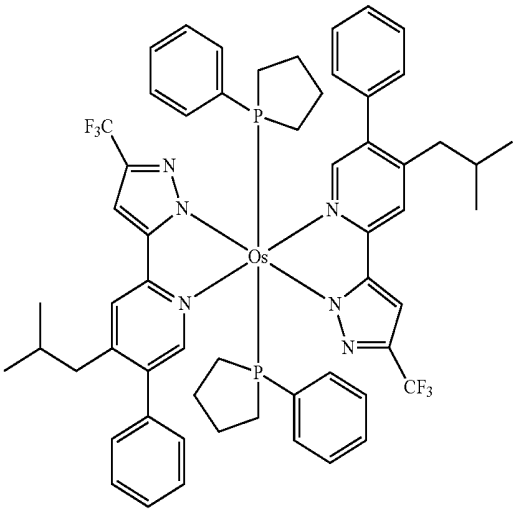

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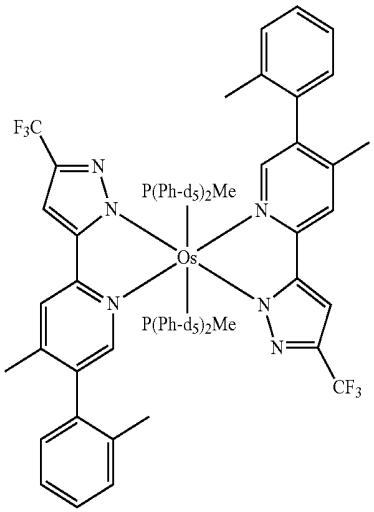

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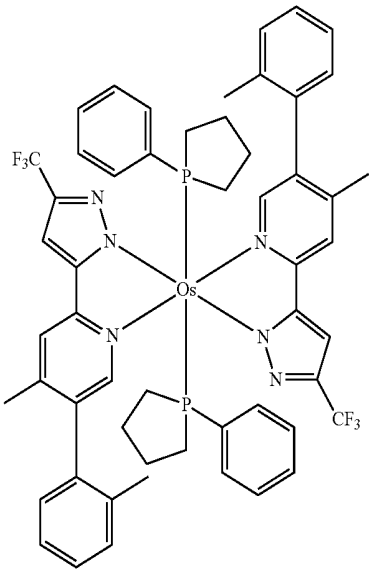

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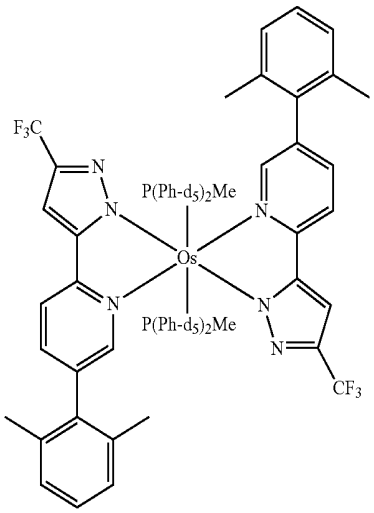

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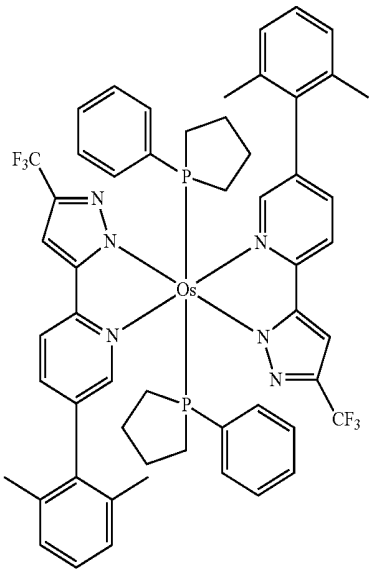

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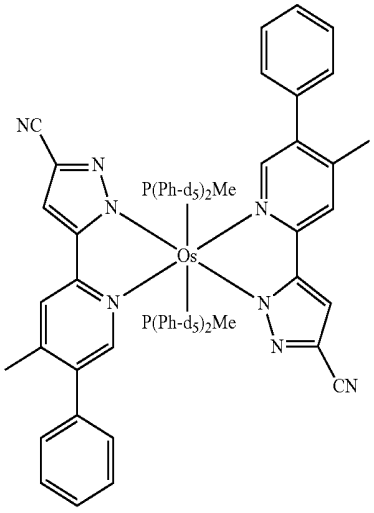

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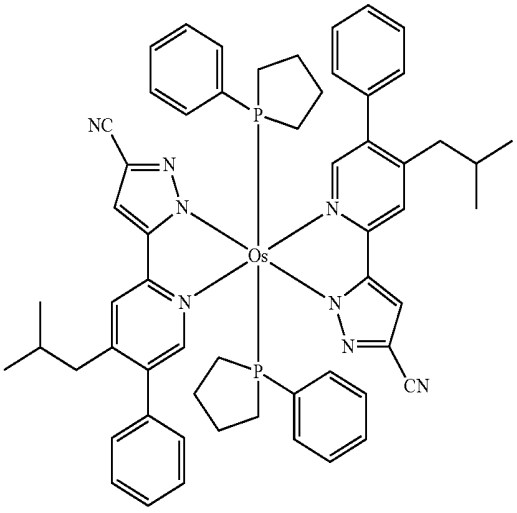

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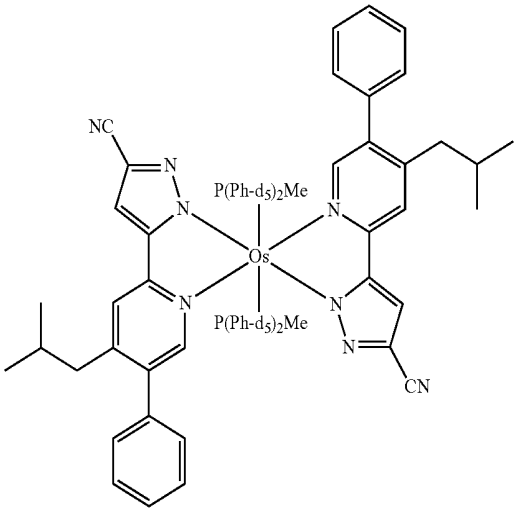

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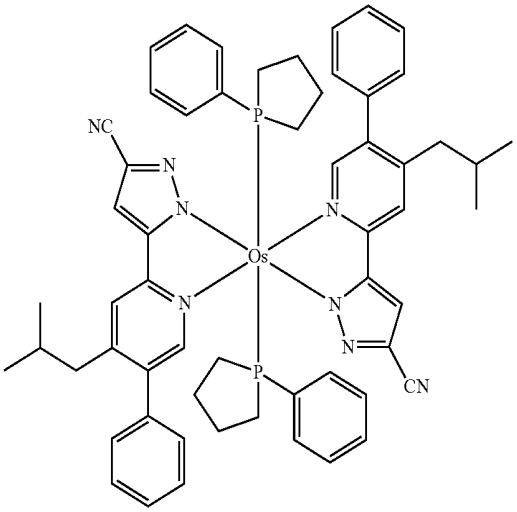

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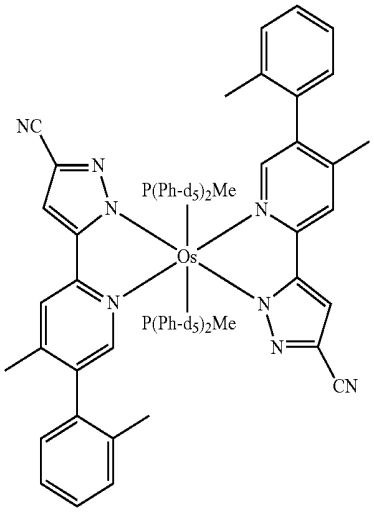

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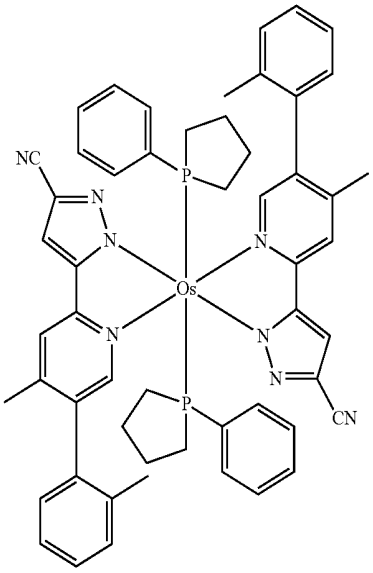

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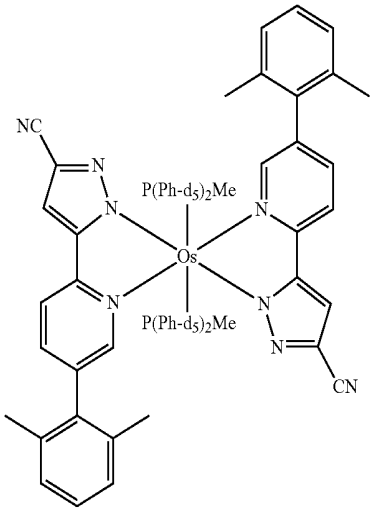

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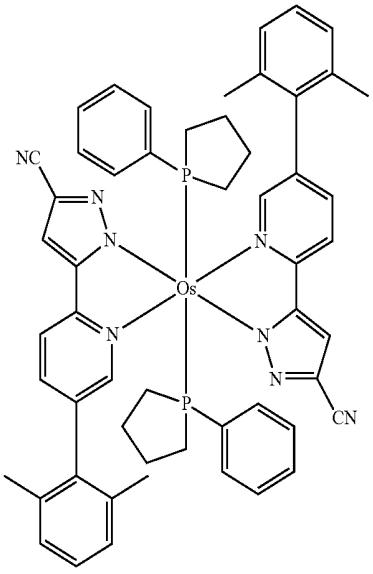

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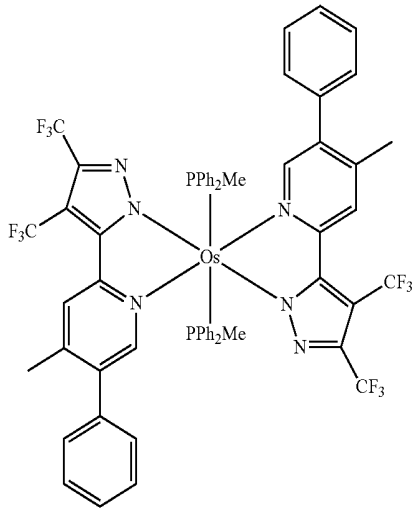

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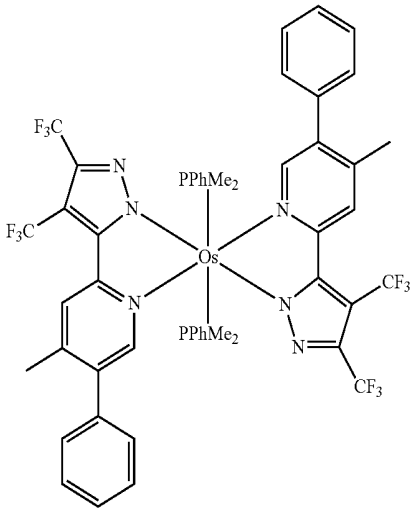

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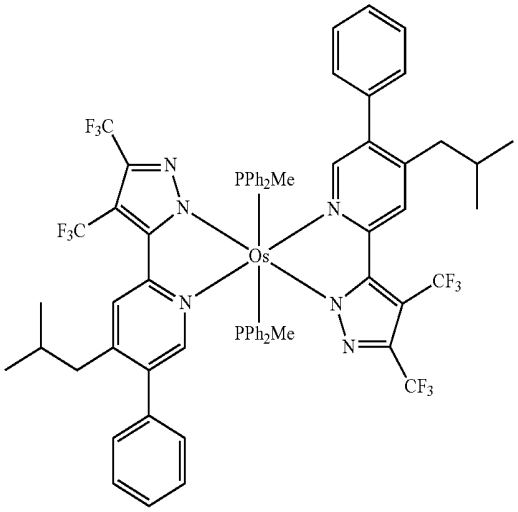

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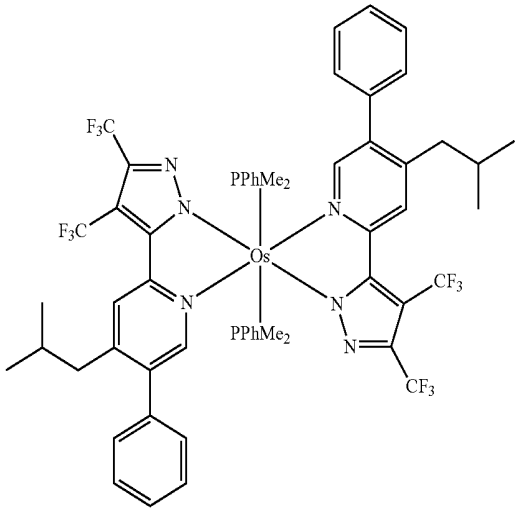

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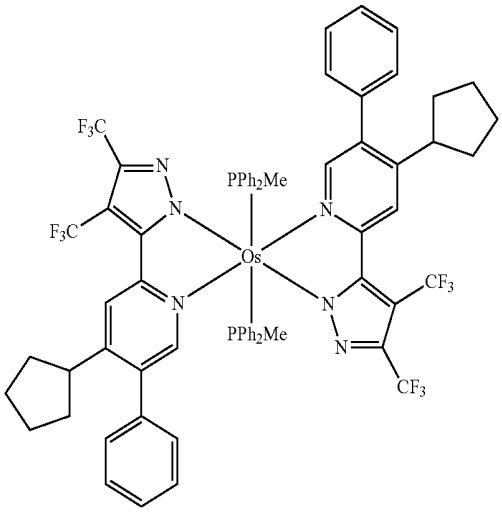

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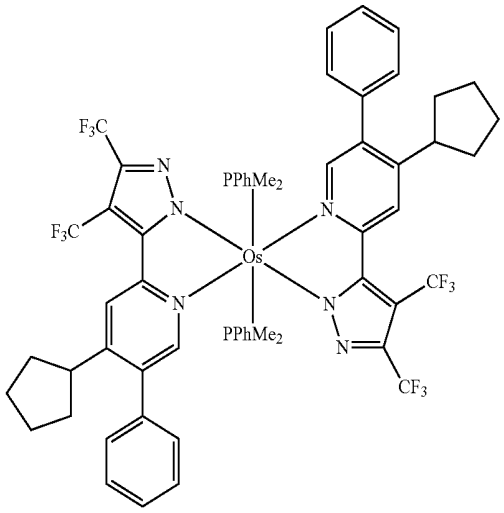

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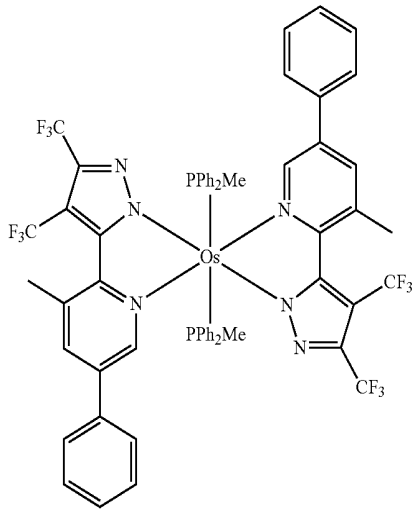

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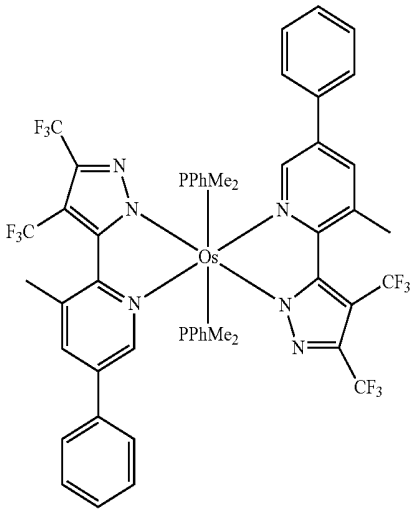

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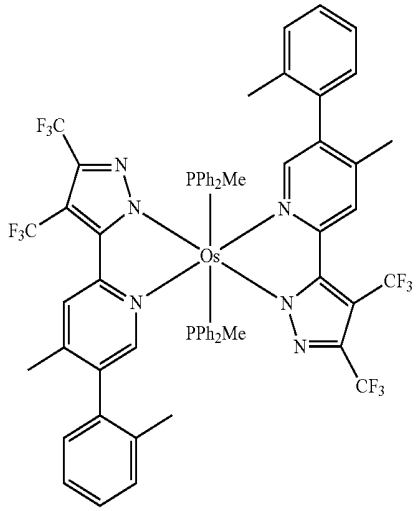

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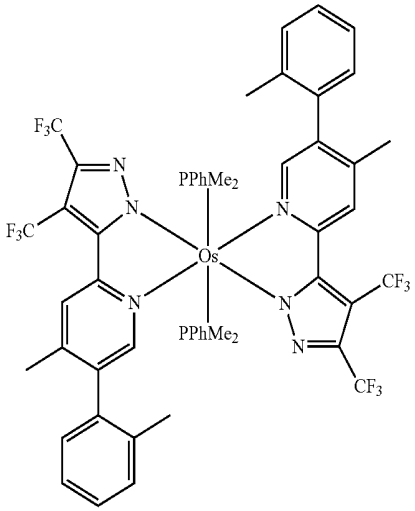

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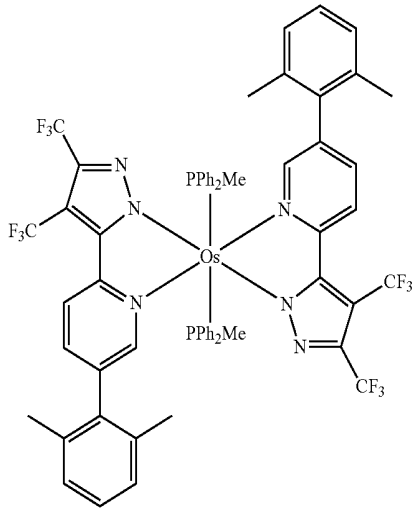

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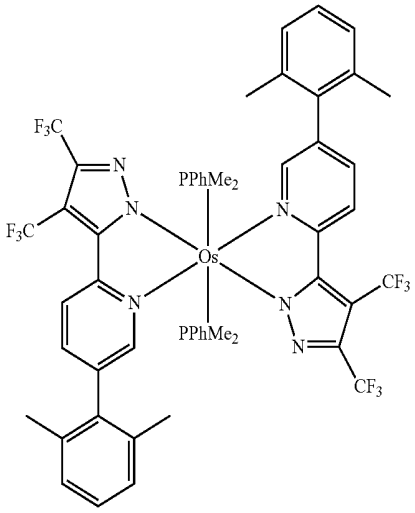

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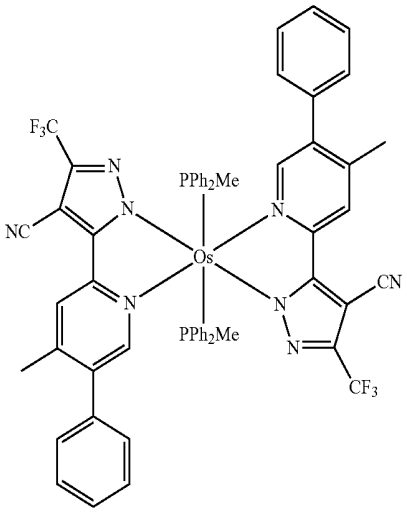

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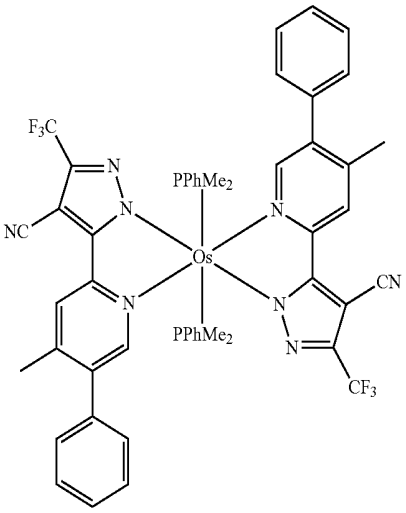

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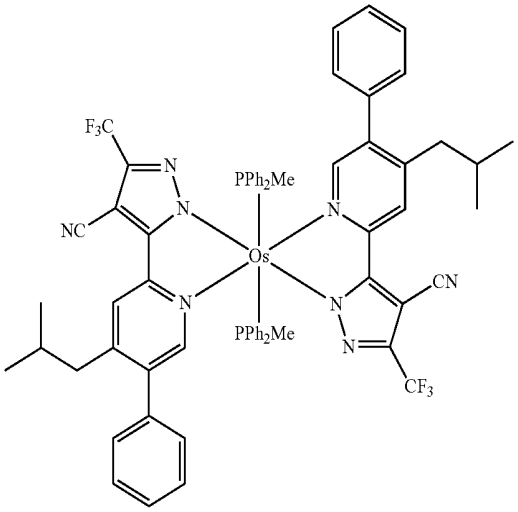

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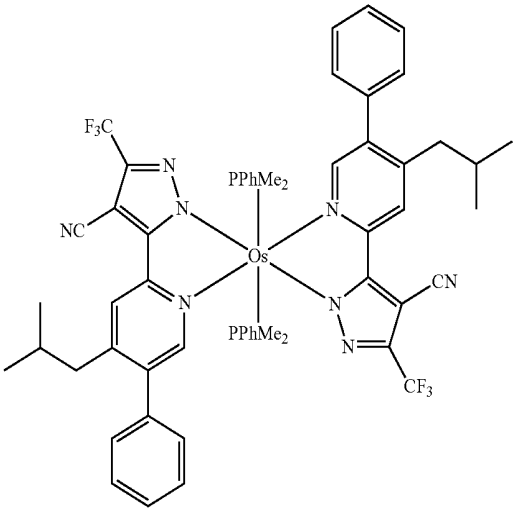

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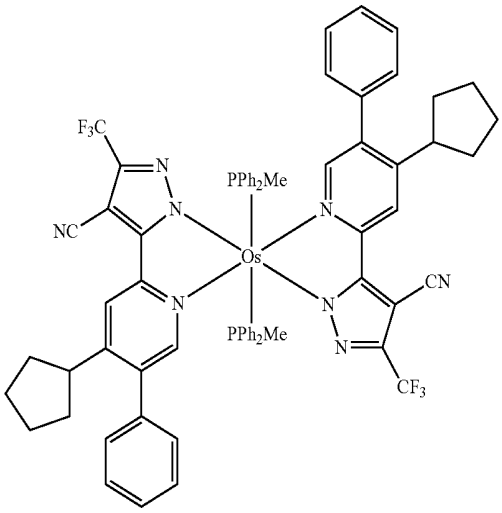

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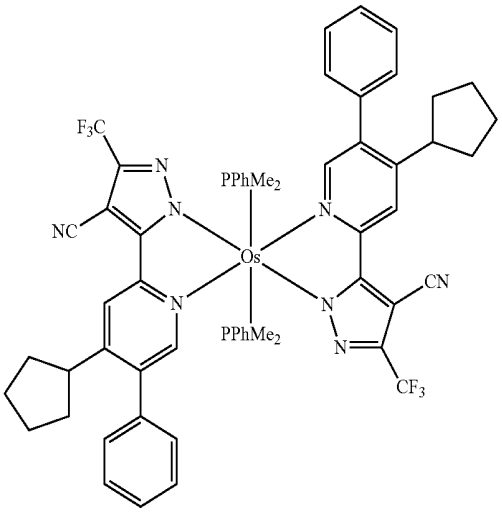

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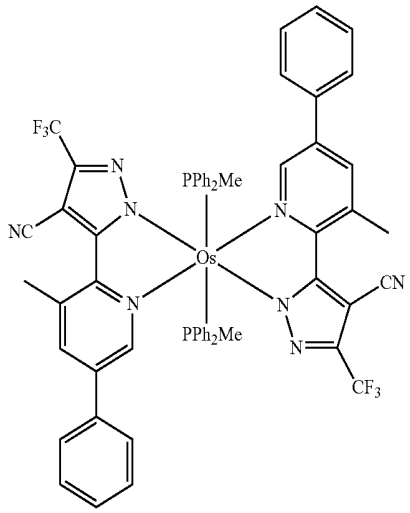

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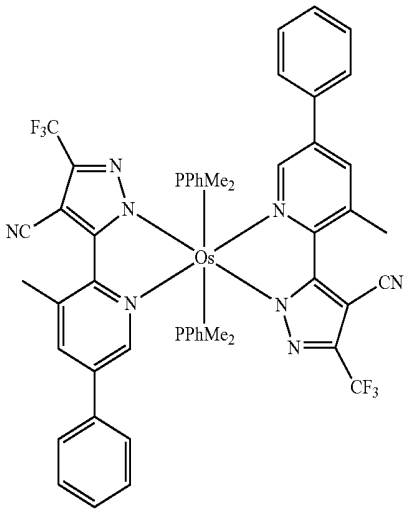

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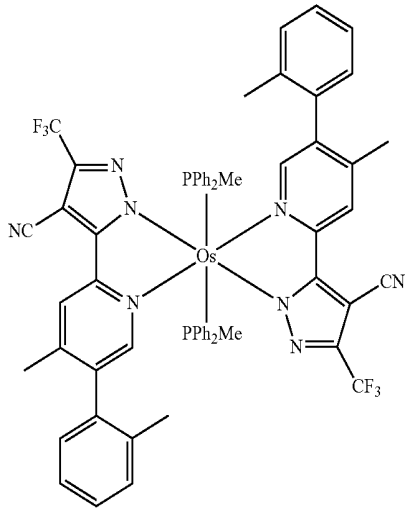

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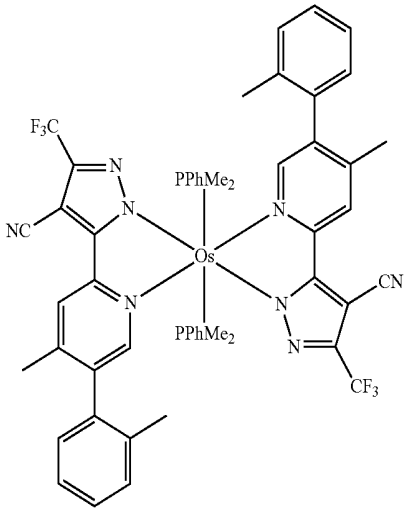

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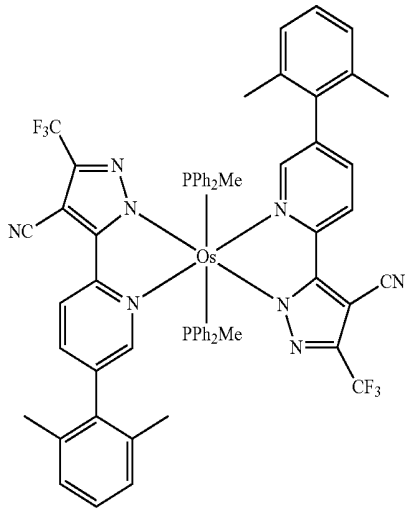

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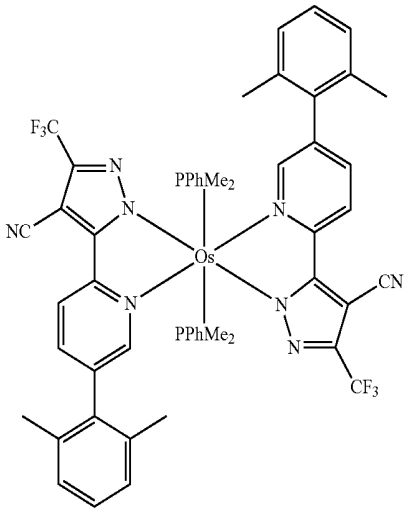

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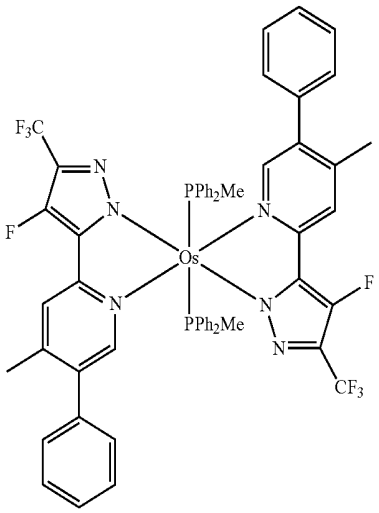

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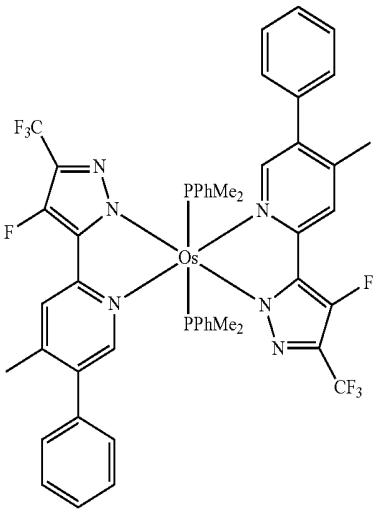

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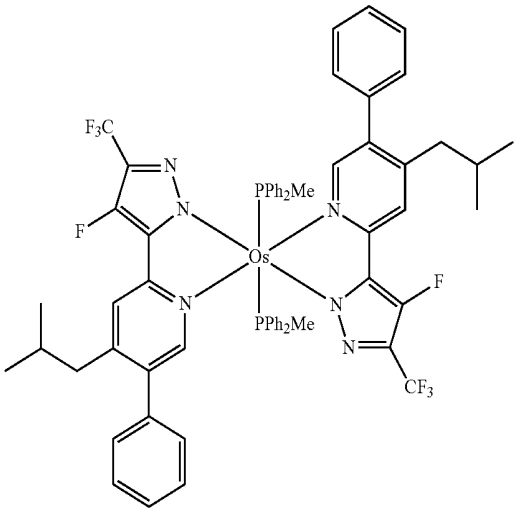

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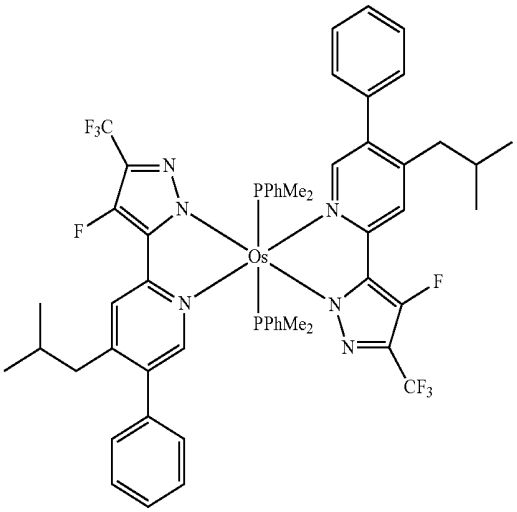

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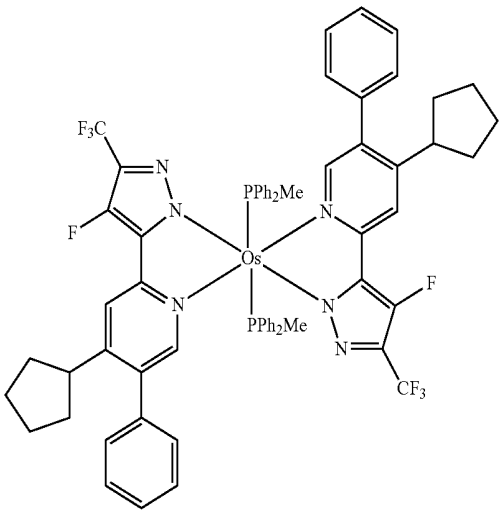

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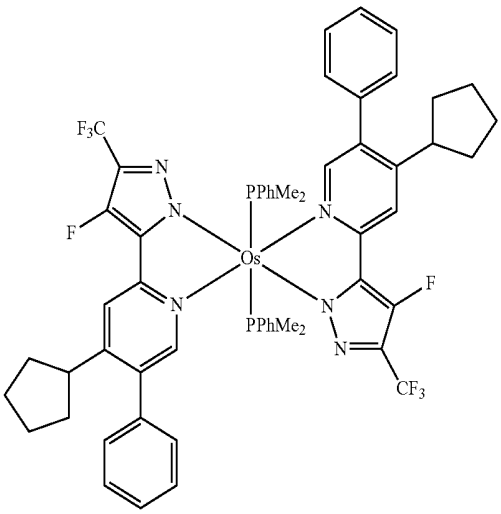

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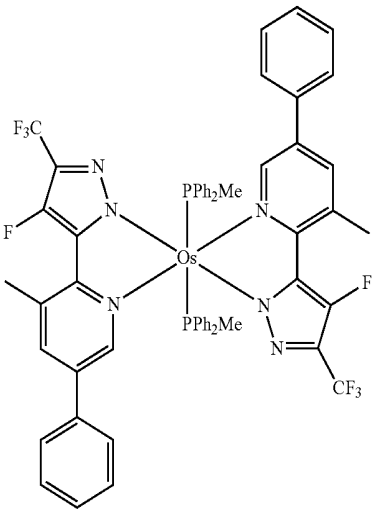

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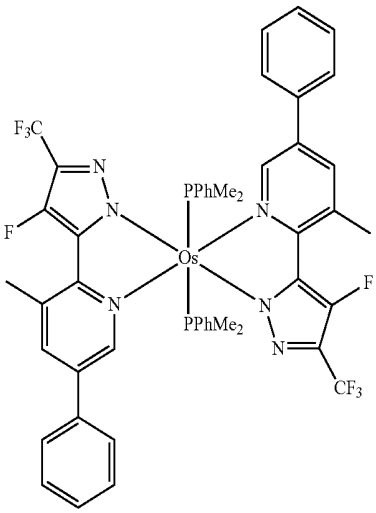

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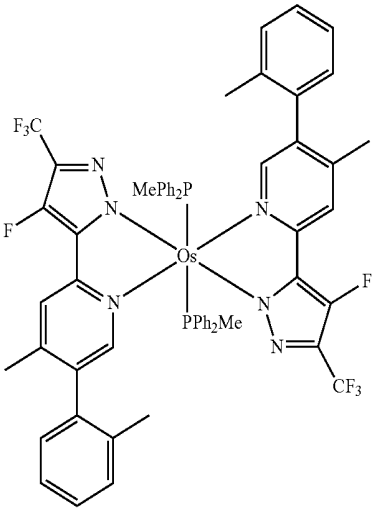

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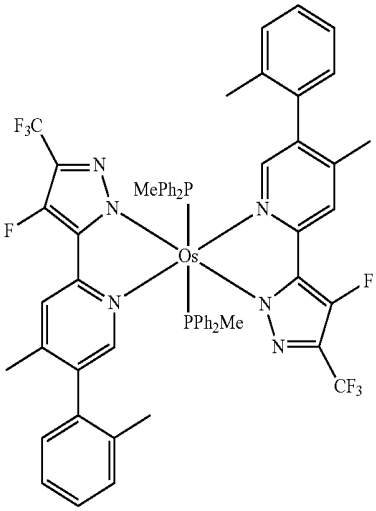

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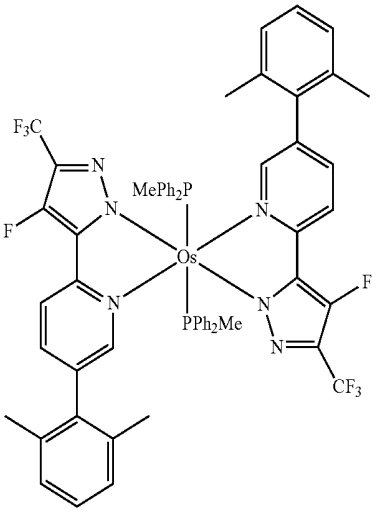

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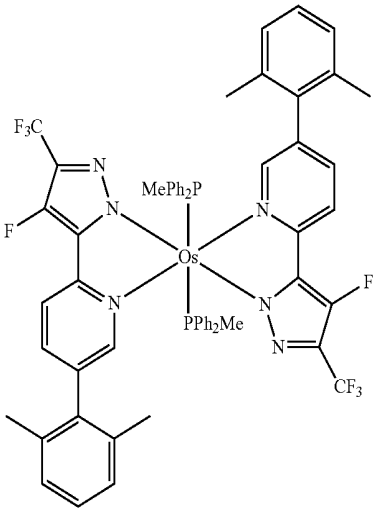

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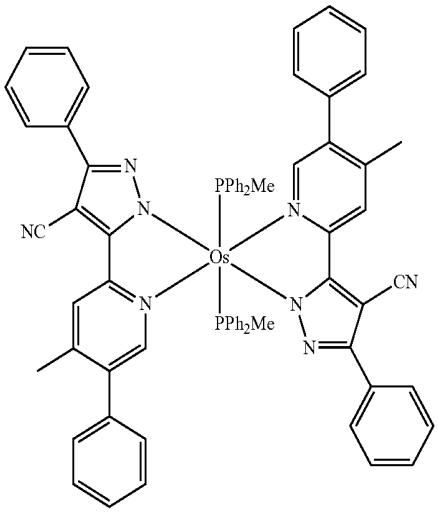

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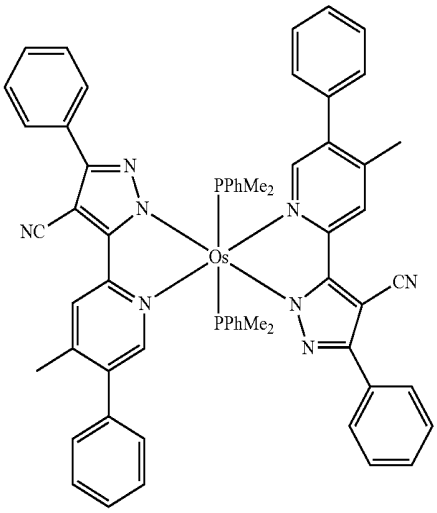

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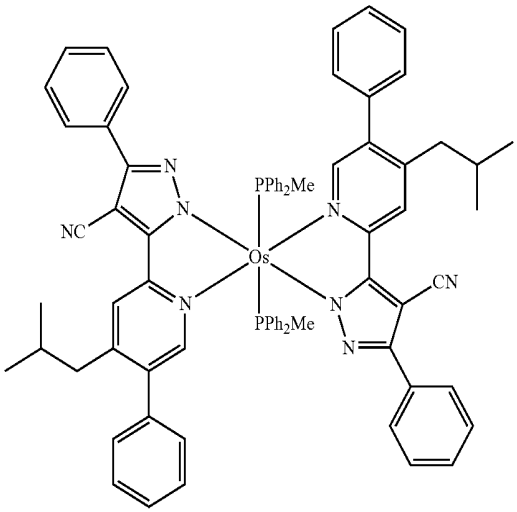

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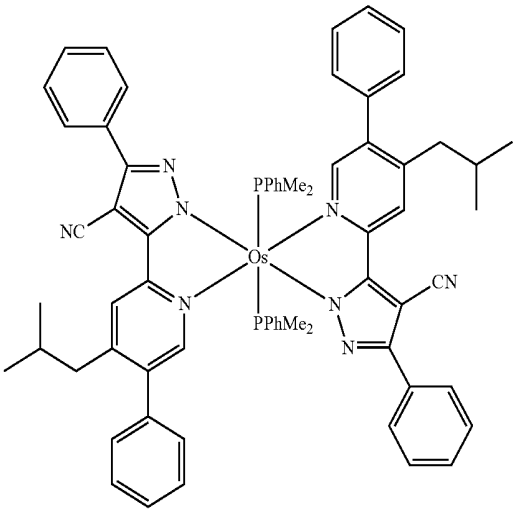

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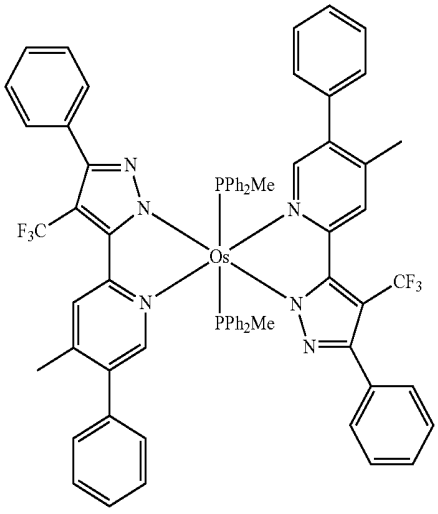

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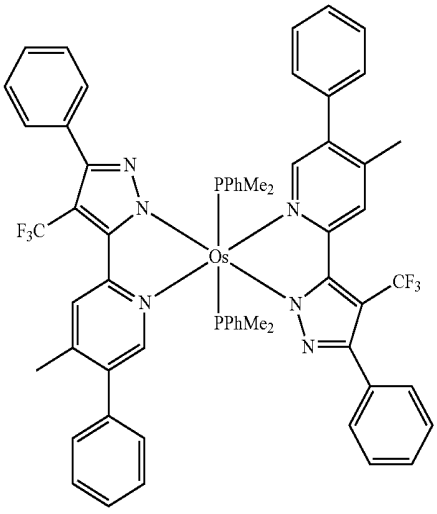

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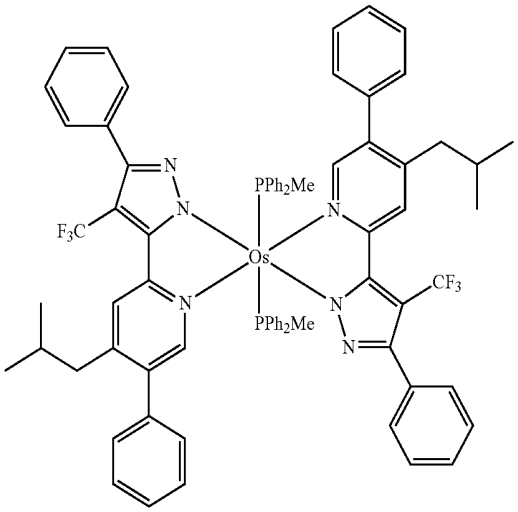

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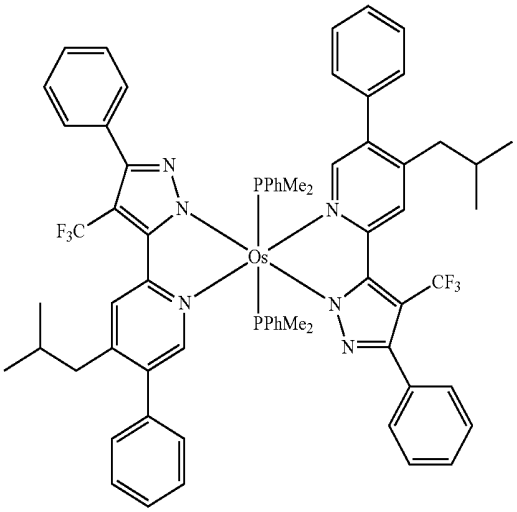

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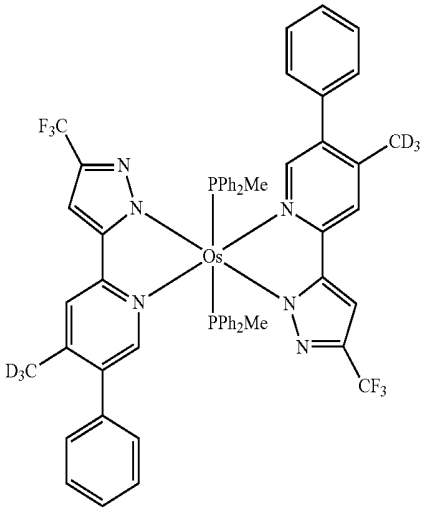

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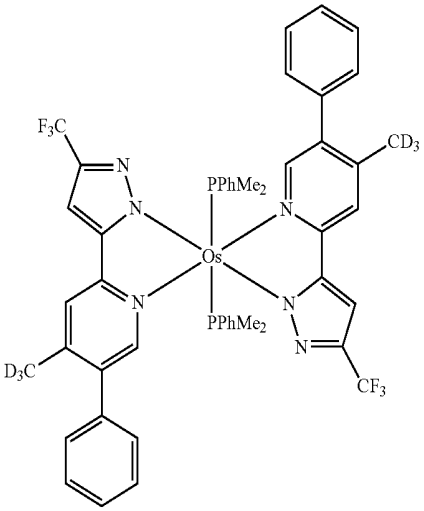

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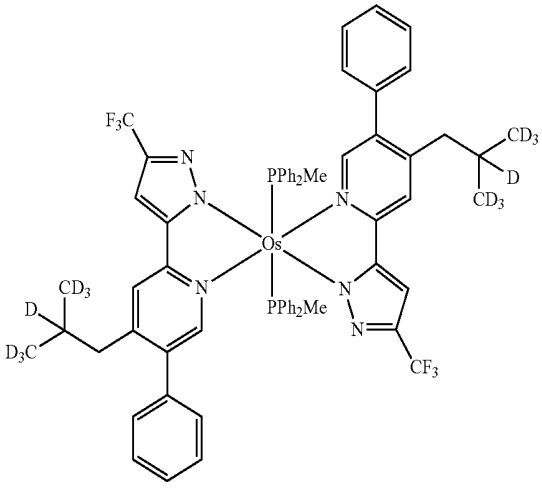

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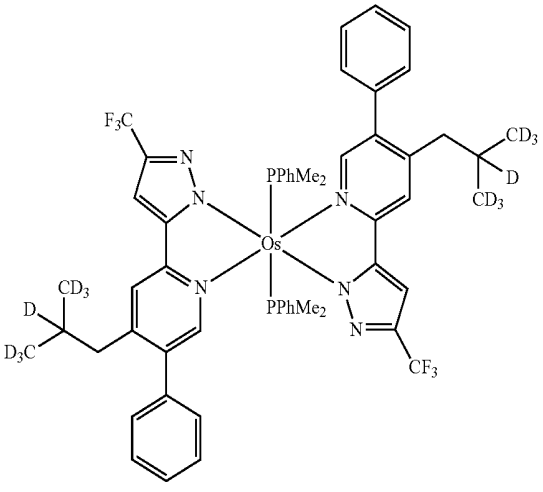

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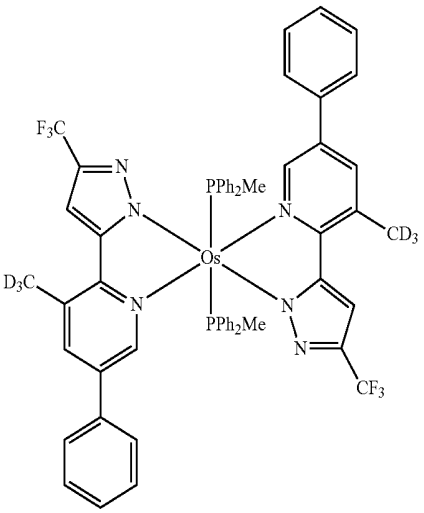

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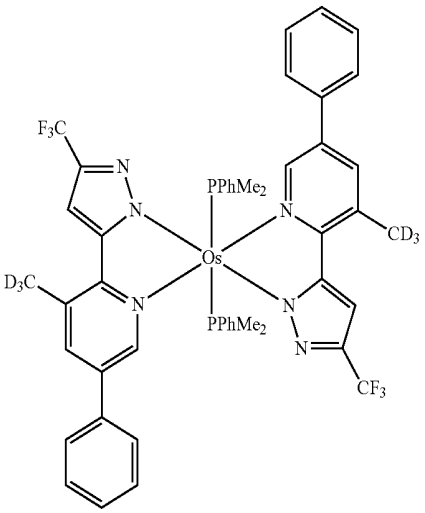

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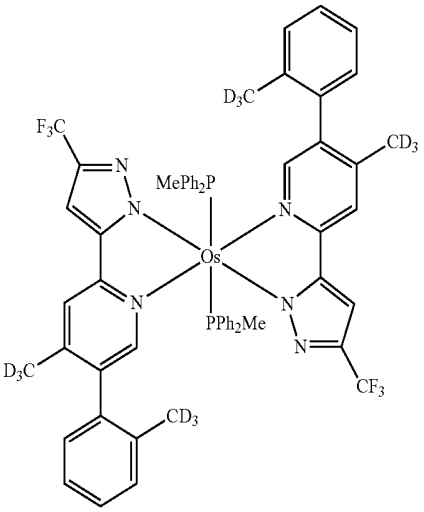

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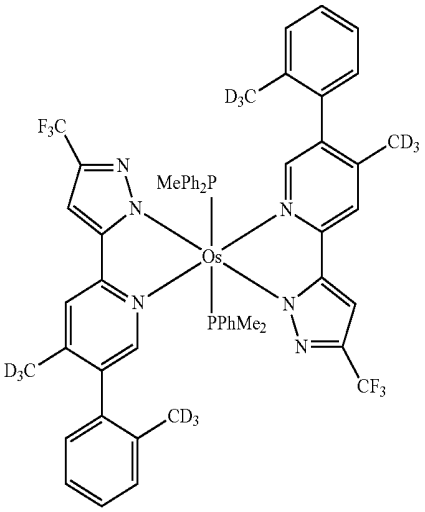

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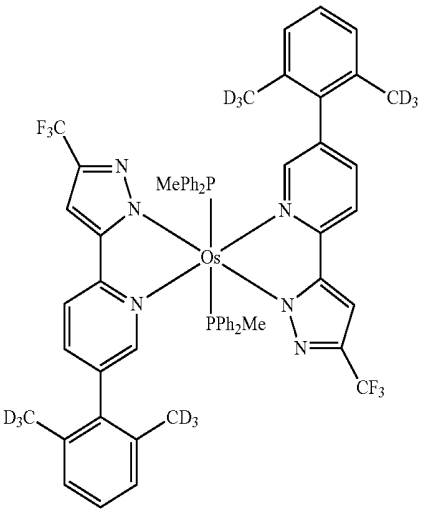

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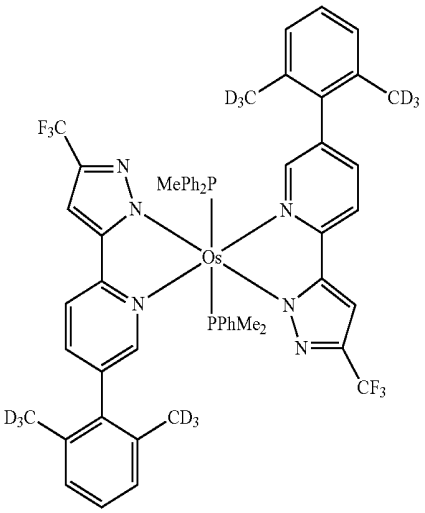

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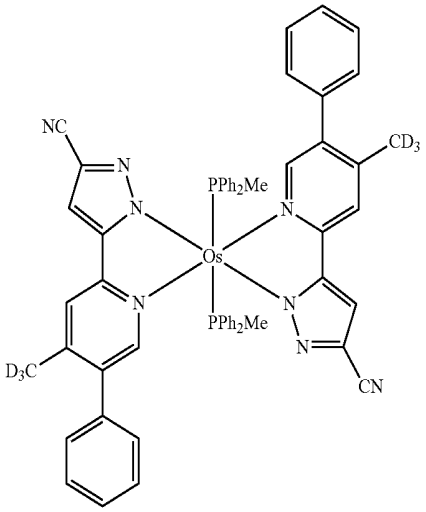

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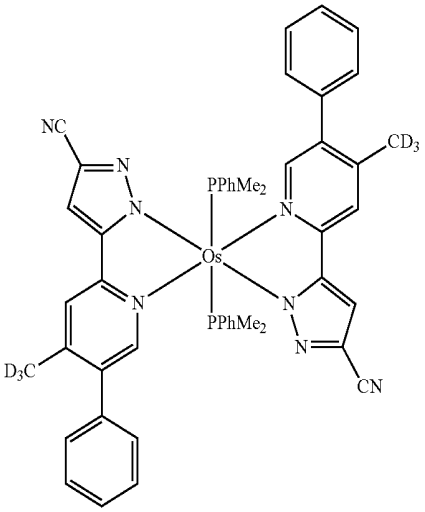

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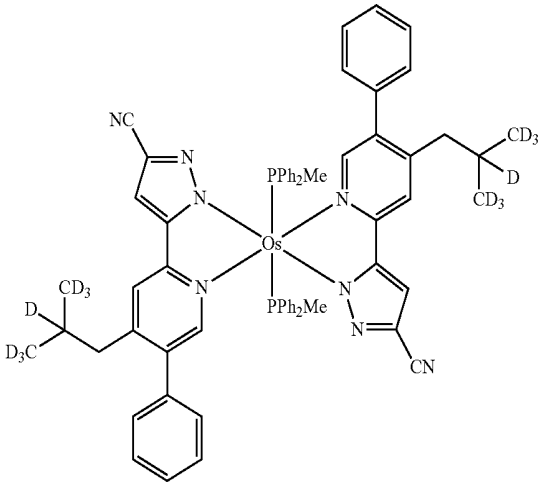

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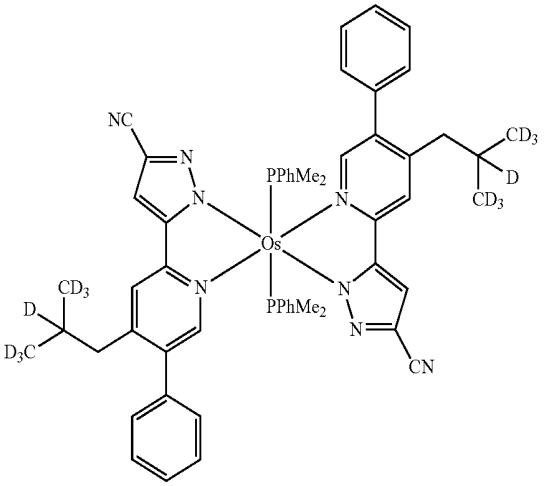

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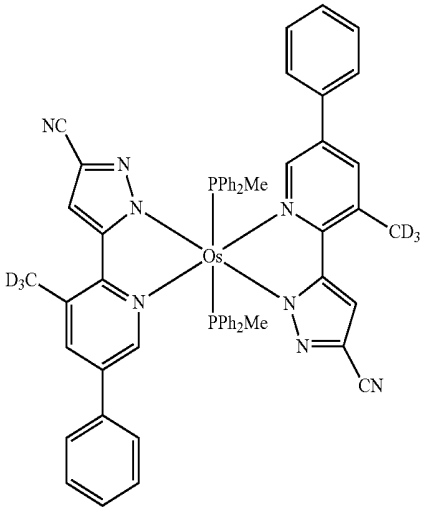

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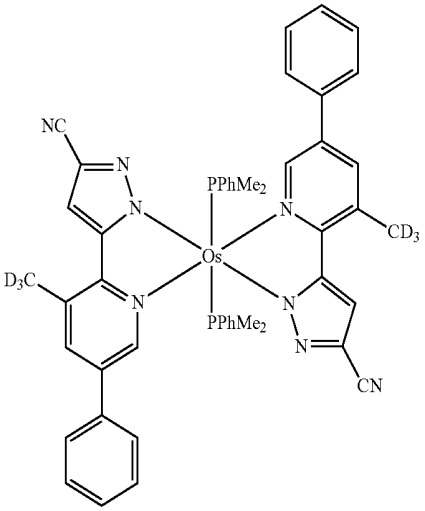

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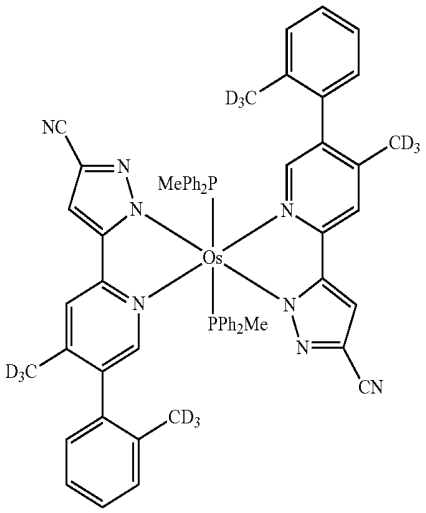

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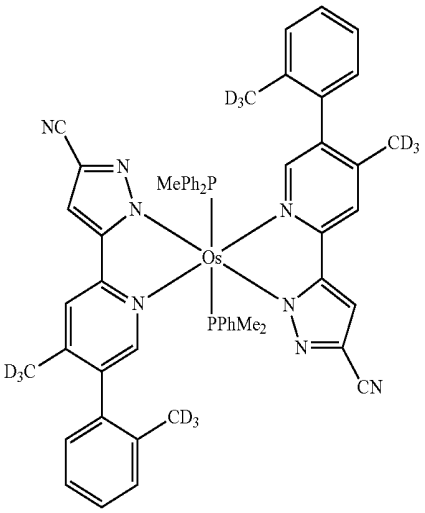

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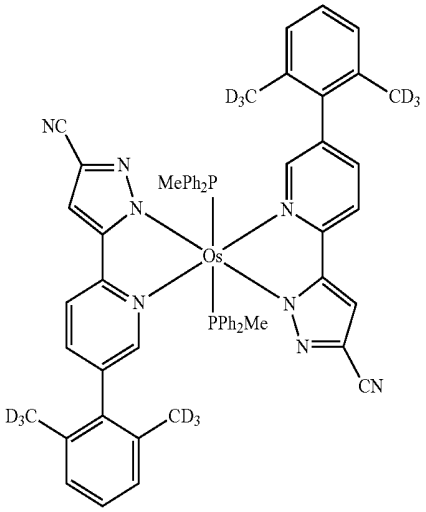

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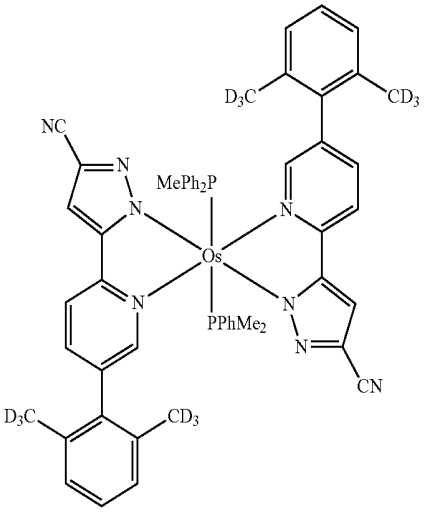

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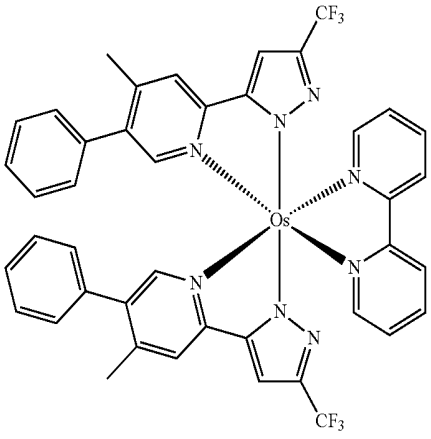

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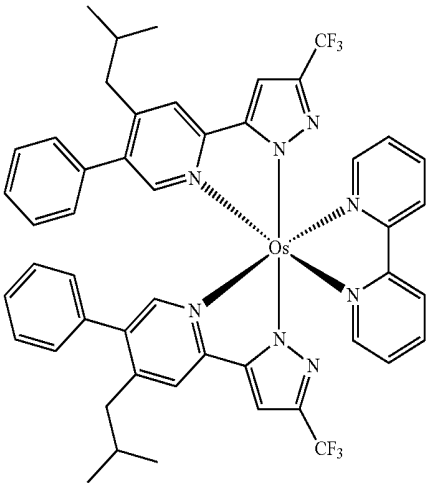

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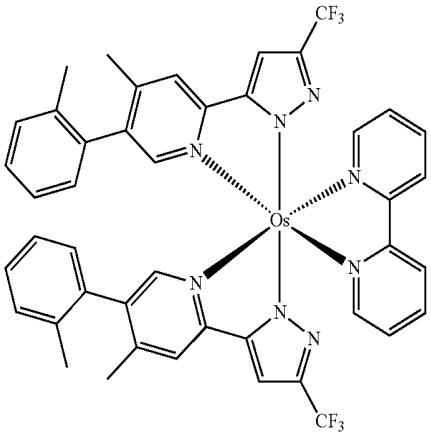

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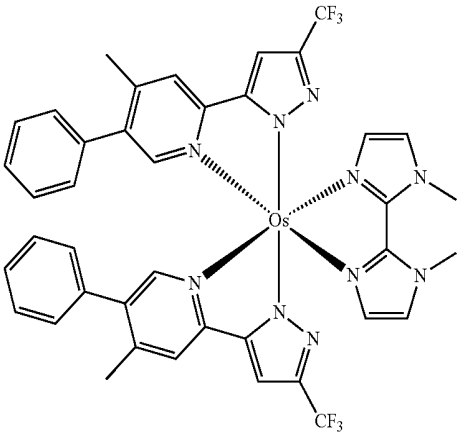

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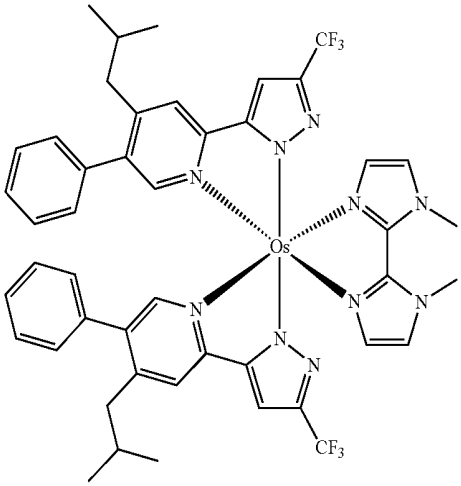

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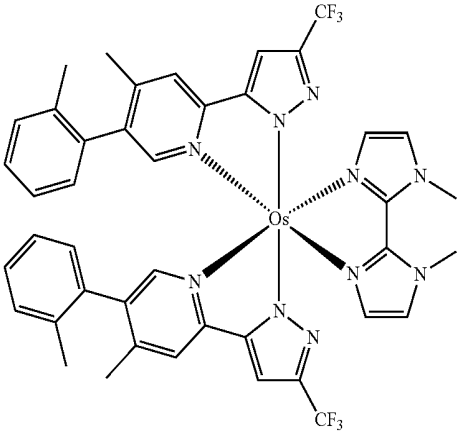

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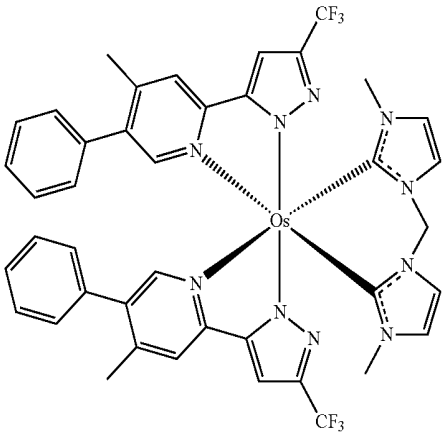

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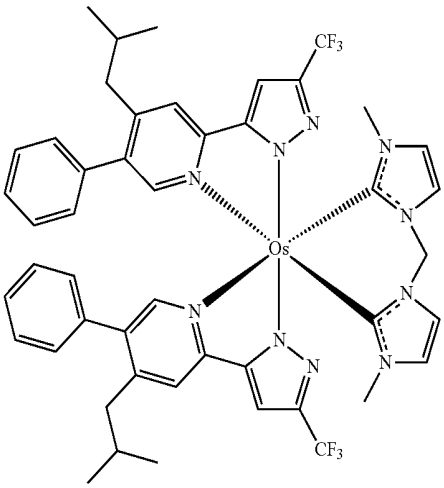

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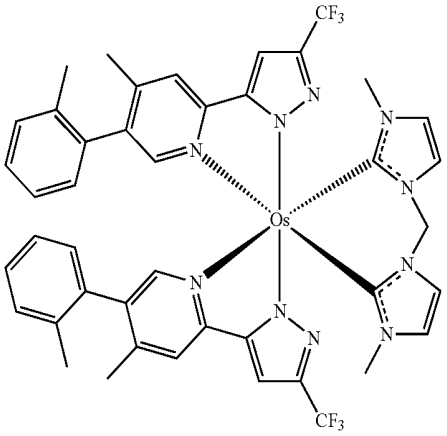

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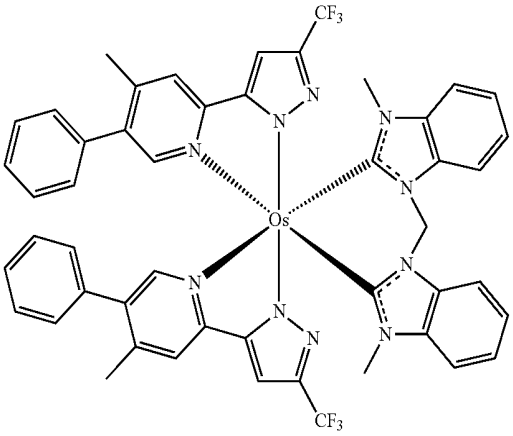

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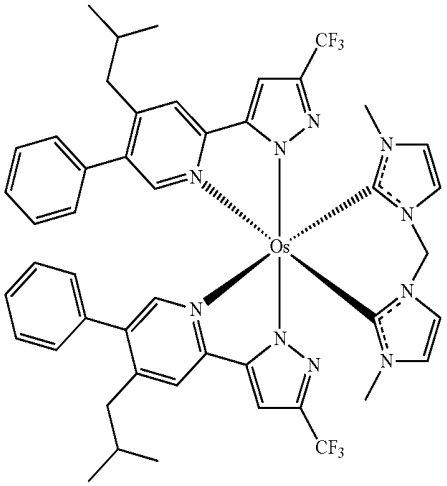

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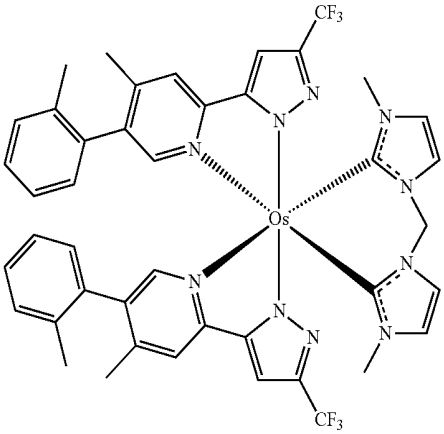

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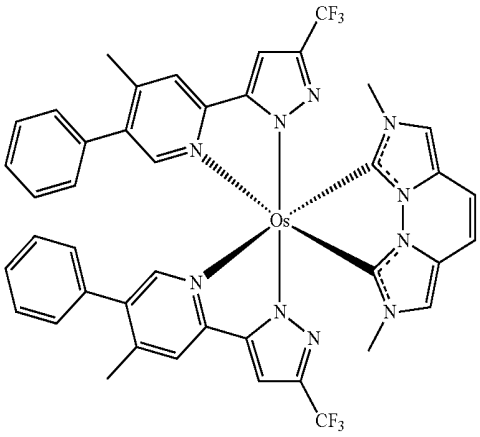

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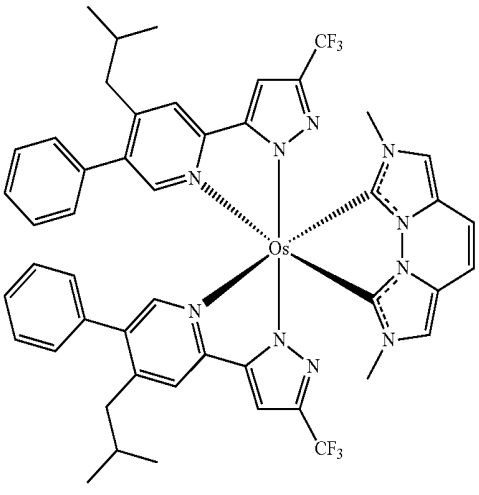

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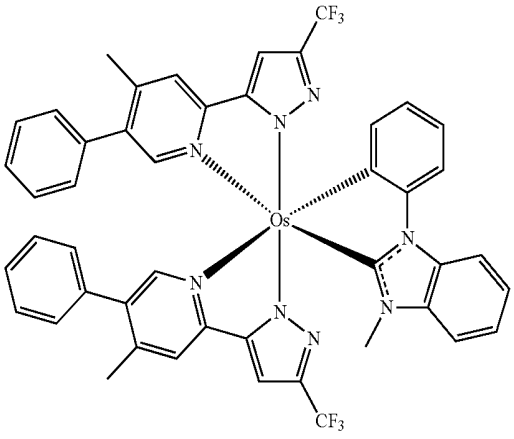

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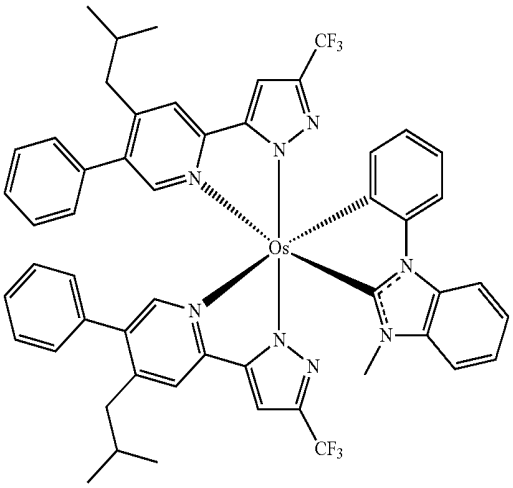

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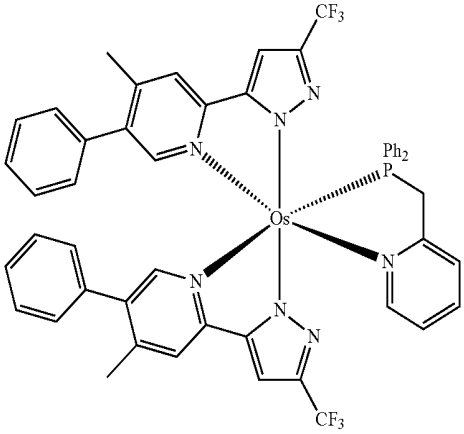

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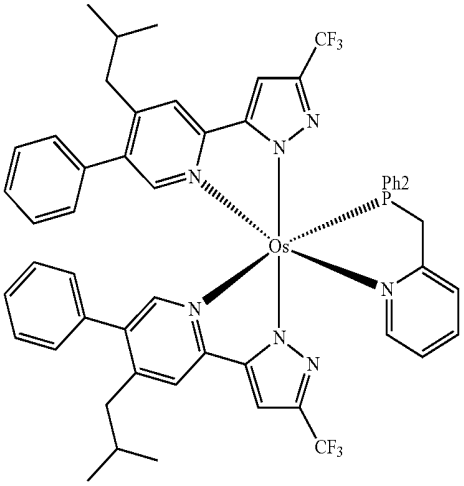

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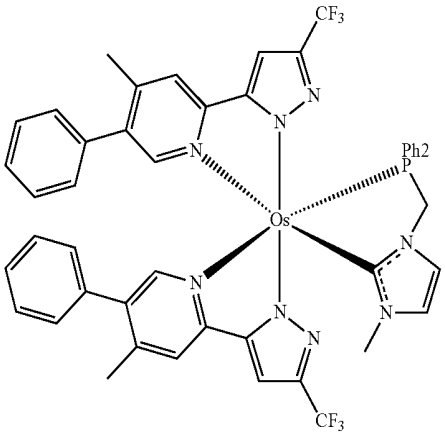

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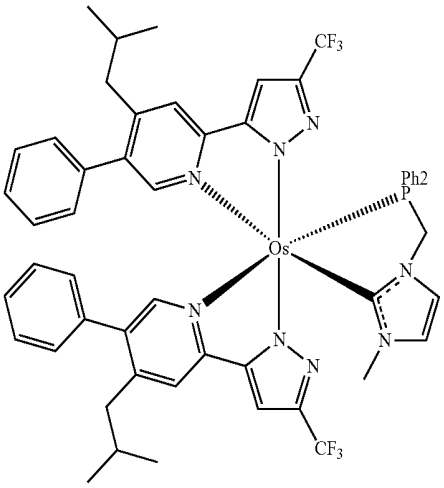

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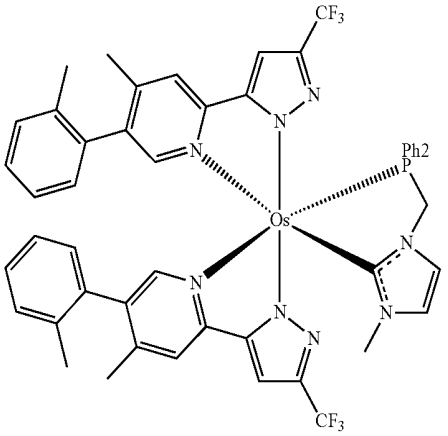

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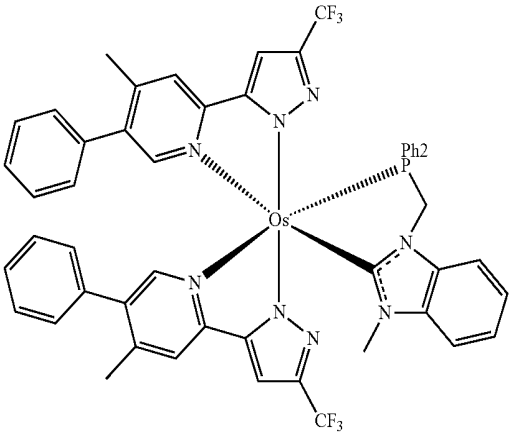

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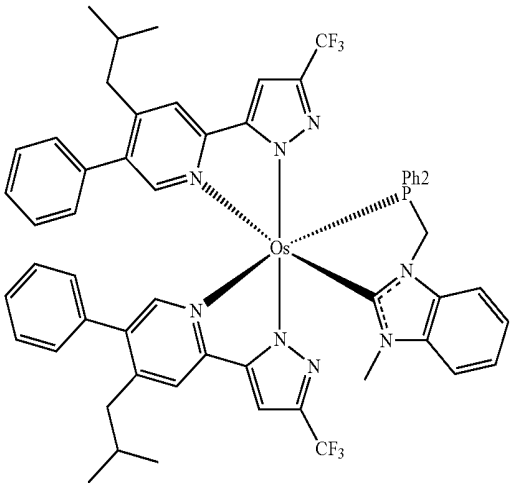

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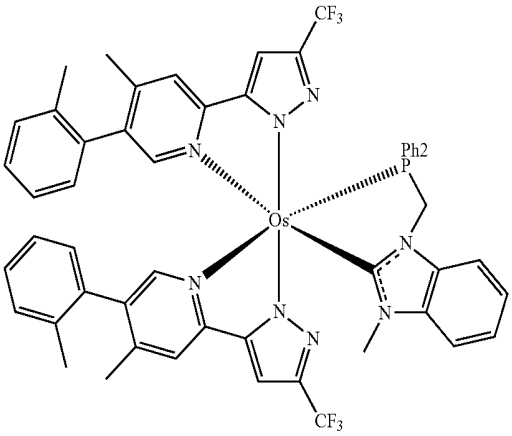

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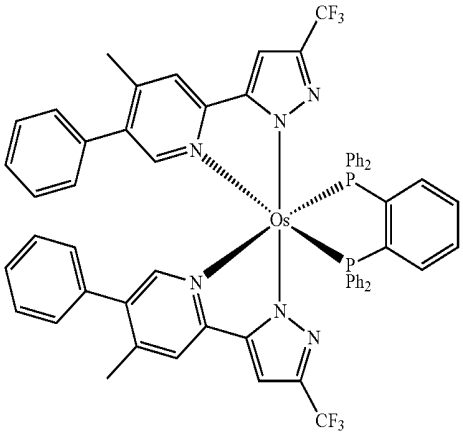

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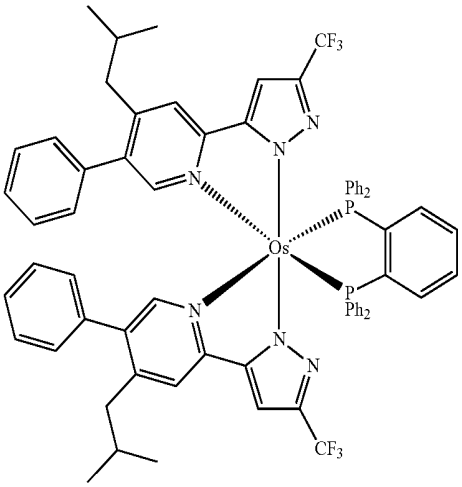

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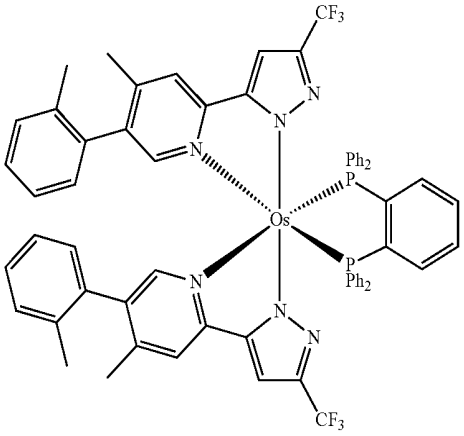

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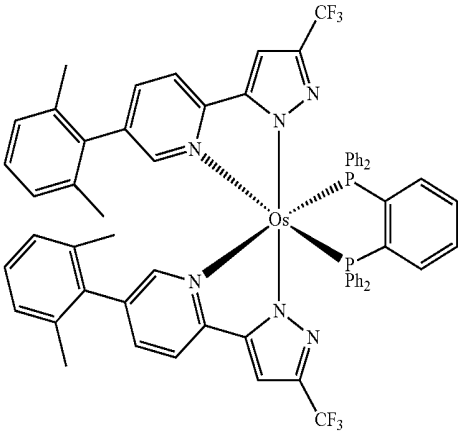

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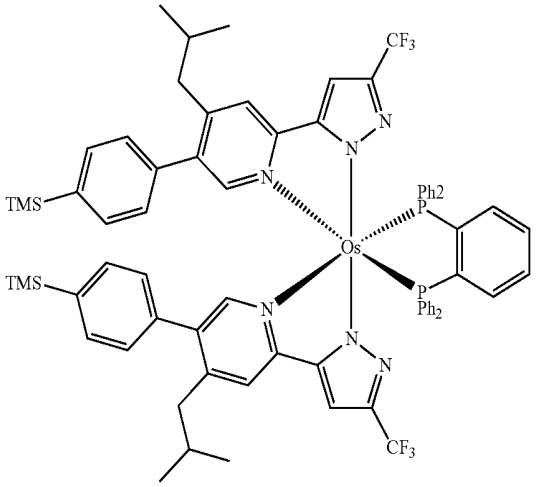

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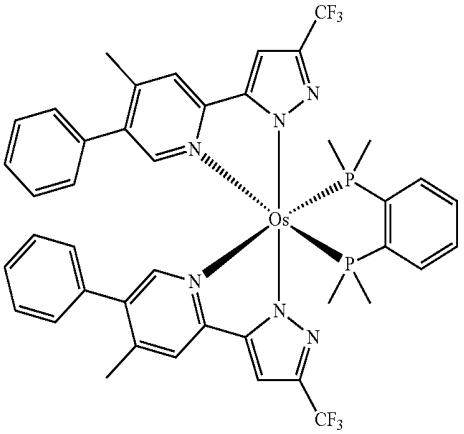

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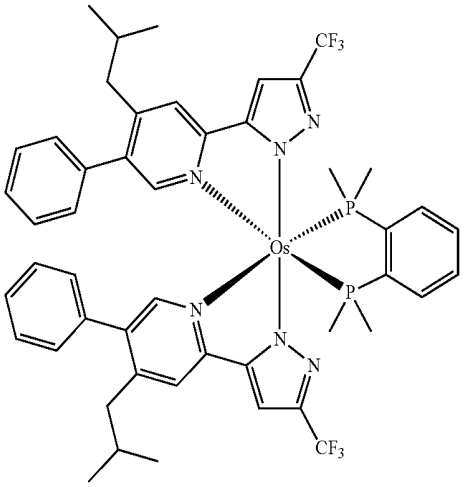

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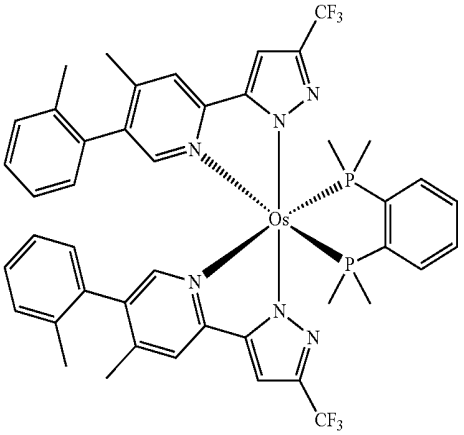

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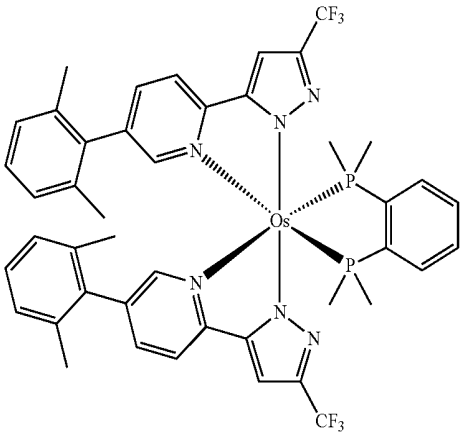

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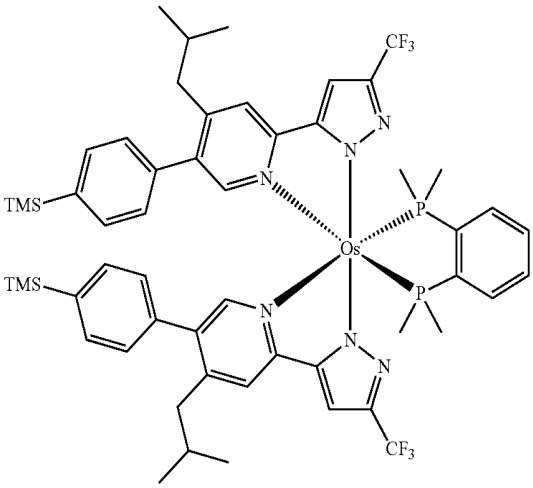

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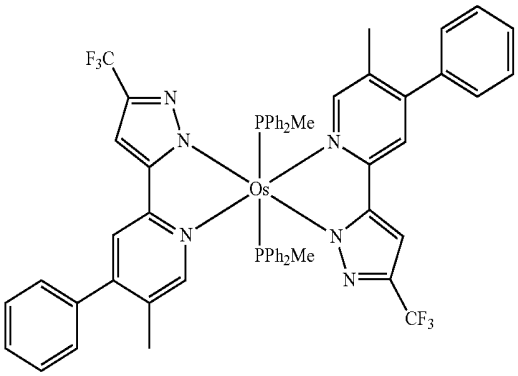

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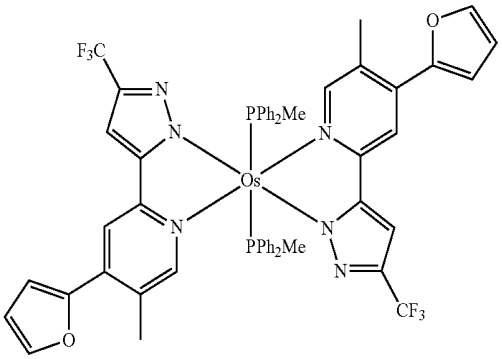

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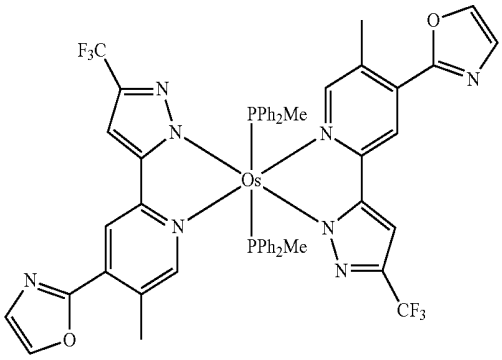

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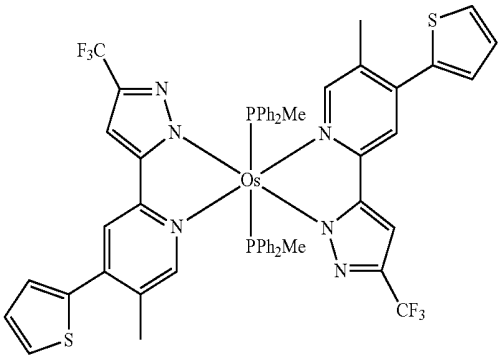

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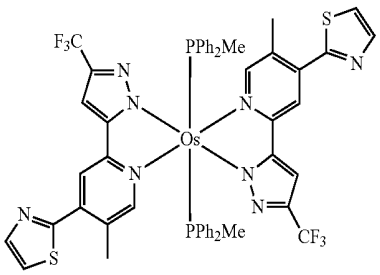

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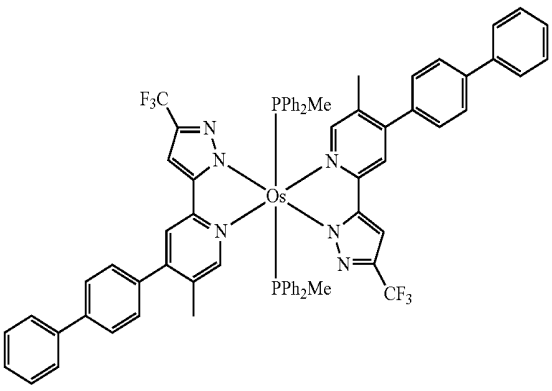

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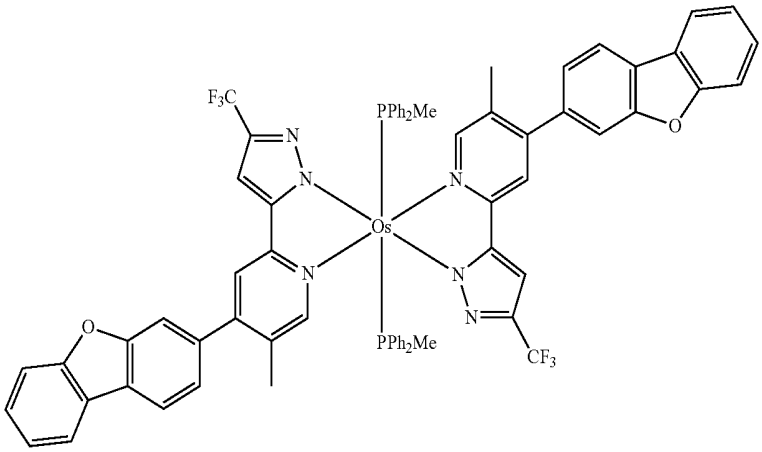

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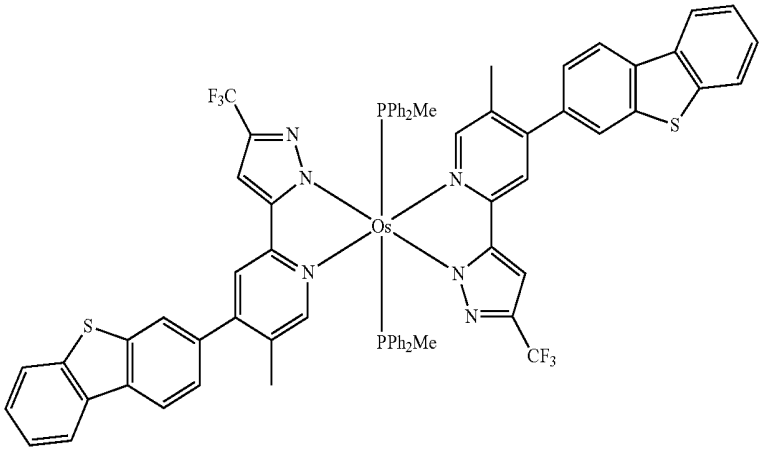

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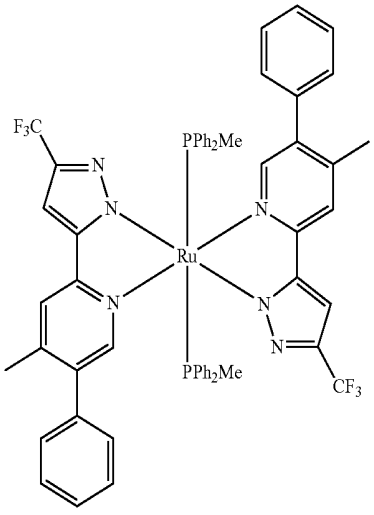

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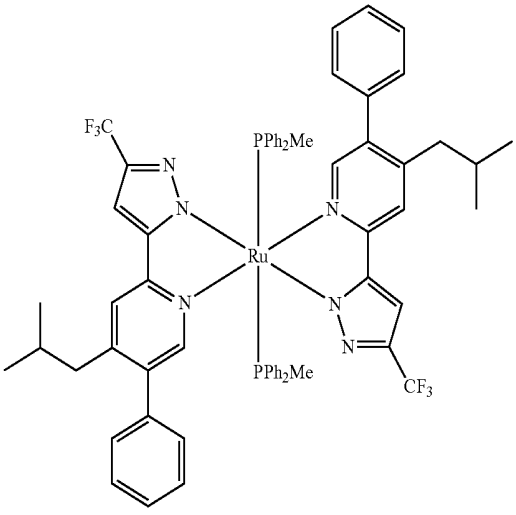

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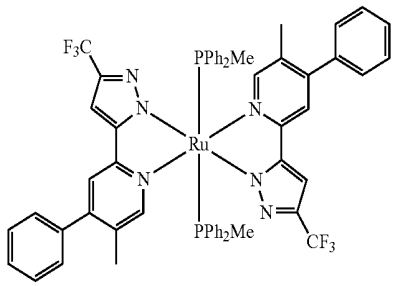

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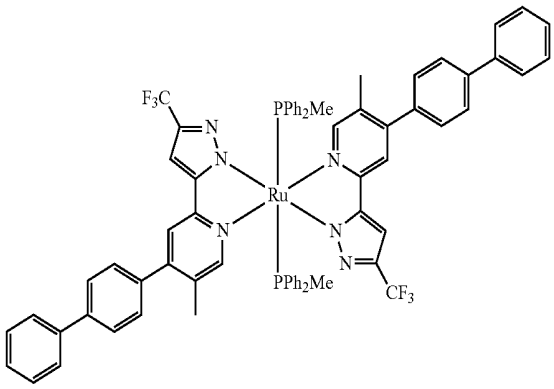

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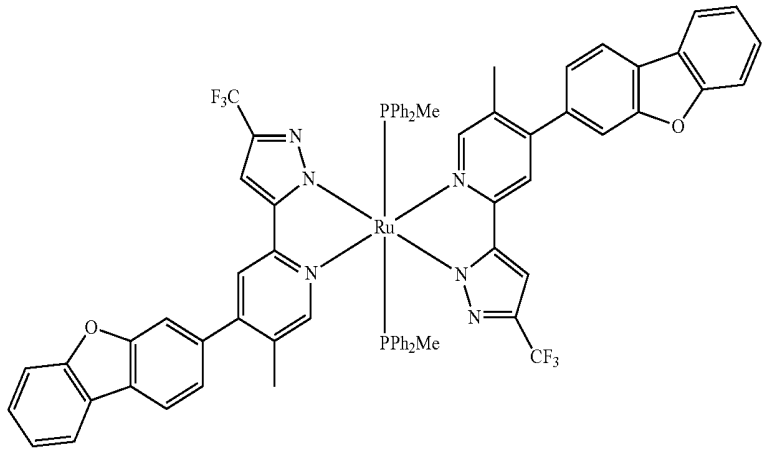

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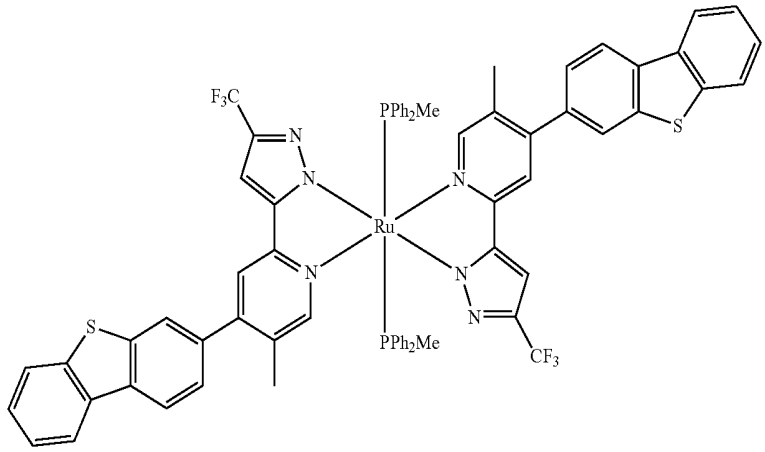


[0154] Since the organometallic compound represented by Formula 1 includes a pyridine ring substituted with an aryl group or the like, the pyridine ring may have improved electrical, chemical, and/or physical stability. In addition, since the organometallic compound represented by Formula 1 includes an aryl group or the like, hole mobility is improved. Thus, an organic light-emitting device including the organometallic compound represented by Formula 1 may have improved lifespan and efficiency.

[0155] Since the organometallic compound represented by Formula 1 includes a pyridine ring substituted with an aryl group or the like, the organometallic compound represented by Formula 1 may have low planarity. Accordingly, the aggregation of the organometallic compound represented by Formula 1 may decrease, thus improving the efficiency of an organic light-emitting device including the organometallic compound.

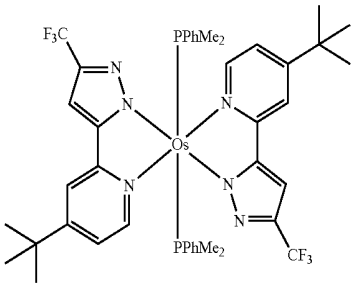
[0156] Since the organometallic compound represented by Formula 1 includes Os or Ru, the organometallic compound may have an octahedral structure. Compounds having such an octahedral structure may have a short decay time, as compared with compounds having a square planer structure (e.g., an organometallic compound including platinum (Pt)). In addition, the organometallic compound represented by

Formula 1 may be less likely to cause exciton quenching and decrease triplet-triplet annihilation, and thus, an organic light-emitting device including the organometallic compound may have improved efficiency and low roll-off.

[0157] For example, the highest occupied molecular orbital (HOMO), lowest unoccupied molecular orbital (LUMO), and T_1 energy levels of Compounds 1, 3, 9, and 7 and Compound B were simulated by using the Gaussian. The simulation evaluation results are shown in Table 1:

TABLE 1

Compound No.	HOMO (eV)	LUMO (eV)	T_1 (eV)
1	−4.548	−1.367	2.309
3	−4.569	−1.348	2.330
9	−4.571	−1.316	2.355
7	−4.580	−1.509	2.210
B	−4.522	−1.317	2.304



B

[0158] Synthesis methods of the organometallic compound represented by Formula 1 may be recognizable by one of ordinary skill in the art by referring to Synthesis Examples provided below.

[0159] The organometallic compound represented by Formula 1 is suitable for use in an organic layer of an organic light-emitting device, for example, for use as a dopant in an emission layer of the organic layer. Thus, another aspect provides an organic light-emitting device that includes:

[0160] a first electrode;

[0161] a second electrode; and

[0162] an organic layer that is disposed between the first electrode and the second electrode,

[0163] wherein the organic layer includes an organic layer including an emission layer and at least one organometallic compound represented by Formula 1.

[0164] The organometallic compound of Formula 1 may be used between a pair of electrodes of an organic light-emitting device. For example, the organometallic compound represented by Formula 1 may be included in the emission layer. In this regard, the organometallic compound may act as a dopant, and the emission layer may further include a host (that is, the amount of the organometallic compound represented by Formula 1 may be less than the amount of the host).

[0165] The expression that "(an organic layer) includes at least one of organometallic compounds" as used herein refers to an embodiment in which "(an organic layer) includes identical organometallic compounds represented by Formula 1 and to an embodiment in which (an organic layer) includes two or more different organometallic compounds represented by Formula 1".

[0166] In some embodiments, the organic layer may include, as the organometallic compound, only Compound 1. In this regard, Compound 1 may be included in an emission layer of the organic light-emitting device. In one or more embodiments, the organic layer may include, as the organometallic compound, Compound 1 and Compound 2. In this regard, Compound 1 and Compound 2 may be included in an identical layer (for example, Compound 1 and Compound 2 both may be in an emission layer).

[0167] The first electrode may be an anode, which is a hole injection electrode, and the second electrode may be a cathode, which is an electron injection electrode; or the first electrode may be a cathode, which is an electron injection electrode, and the second electrode may be an anode, which is a hole injection electrode.

[0168] For example, the first electrode may be an anode, and the second electrode may be a cathode, and the organic layer may include: i) a hole transport region that is disposed between the first electrode and the emission layer, wherein the hole transport region may include at least one selected from a hole injection layer, a hole transport layer, and an electron blocking layer, and ii) an electron transport region that is disposed between the emission layer and the second electrode, wherein the electron transport region may include at least one selected from a hole blocking layer, an electron transport layer, and an electron injection layer.

[0169] FIG. **1** is a schematic diagram of an organic light-emitting device **10** according to an embodiment. Hereinafter, the structure of an organic light-emitting device according to an embodiment and a method of manufacturing an organic light-emitting device, according to an embodiment, will be described in connection with FIG. **1**. The organic light-emitting device **10** includes a first electrode **11**, an organic layer **15**, and a second electrode **19**, which are sequentially stacked in this stated order.

[0170] A substrate may be additionally disposed under the first electrode **11** or above the second electrode **19**. Any substrate that is used in general organic light-emitting devices may be used as the substrate, and the substrate may be a glass substrate or a transparent plastic substrate, each having excellent mechanical strength, thermal stability, transparency, surface smoothness, ease of handling, and water-resistance.

[0171] In one or more embodiments, the first electrode **11** may be formed by depositing or sputtering a material for forming the first electrode **11** on the substrate. The first electrode **11** may be an anode. The material for forming the first electrode **11** may be selected from materials with a high work function to facilitate hole injection. The first electrode **11** may be a reflective electrode, a semi-transmissive electrode, or a transmissive electrode. The material for forming the first electrode **11** may be indium tin oxide (ITO), indium zinc oxide (IZO), tin oxide (SnO_2), or zinc oxide (ZnO). In one or more embodiments, the material for forming the first electrode **11** may be a metal, such as magnesium (Mg),

aluminum (Al), aluminum-lithium (Al—Li), calcium (Ca), magnesium-indium (Mg—In), or magnesium-silver (Mg—Ag).

[0172] The first electrode **11** may have a single-layered structure or a multi-layered structure including two or more layers. For example, the first electrode **11** may have a three-layered structure of ITO/Ag/ITO, but embodiments of the structure of the first electrode **110** are not limited thereto.

[0173] The organic layer **15** may be disposed on the first electrode **11**.

[0174] The organic layer **15** may include a hole transport region, an emission layer, and an electron transport region.

[0175] The hole transport region may be disposed between the first electrode **11** and the emission layer.

[0176] The hole transport region may include at least one selected from a hole injection layer, a hole transport layer, an electron blocking layer, and a buffer layer.

[0177] The hole transport region may include either a hole injection layer or a hole transport layer. In various embodiments, the hole transport region may have a hole injection layer/hole transport layer structure or a hole injection layer/hole transport layer/electron blocking layer structure, which are sequentially stacked in this stated order on the first electrode **11**.

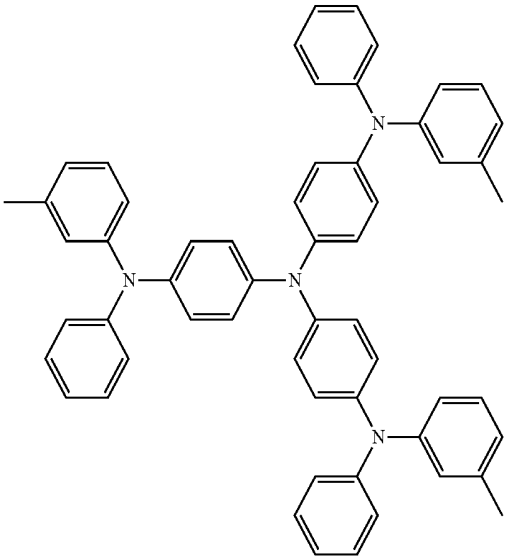
[0178] When the hole transport region includes a hole injection layer, the hole injection layer may be formed on the first electrode **11** by using one or more suitable methods, for example, vacuum deposition, spin coating, casting, and/or Langmuir-Blodgett (LB) deposition.

[0179] When a hole injection layer is formed by vacuum deposition, the deposition conditions may vary depending on a material that is used to form the hole injection layer and the structure and thermal properties of the hole injection layer. In some embodiments, the deposition conditions may include a deposition temperature of about 100° C. to about 500° C., a vacuum pressure of about 10^{-8} torr to about 10^{-3} torr, and a deposition rate of about 0.01 Angstroms per second (A/sec) to about 100 Å/sec. However, the deposition conditions are not limited thereto.

[0180] When the hole injection layer is formed using spin coating, coating conditions may vary depending on the material that is used to form the hole injection layer and the structure and thermal properties of the hole injection layer. For example, a coating speed may be from about 2,000 revolutions per minute (rpm) to about 5,000 rpm, and a temperature at which a heat treatment is performed to remove a solvent after coating may be from about 80° C. to about 200° C. However, the coating conditions are not limited thereto.

[0181] Conditions for forming a hole transport layer and an electron blocking layer may be understood to be substantially the same as conditions for forming the hole injection layer.

[0182] The hole transport region may include at least one selected from m-MTDATA, TDATA, 2-TNATA, NPB, β-NPB, TPD, Spiro-TPD, Spiro-NPB, methylated-NPB, TAPC, HMTPD, 4,4',4"-tris(N-carbazolyl)triphenylamine (TCTA), polyaniline/dodecylbenzene sulfonic acid (PANI/DBSA), poly(3,4-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:



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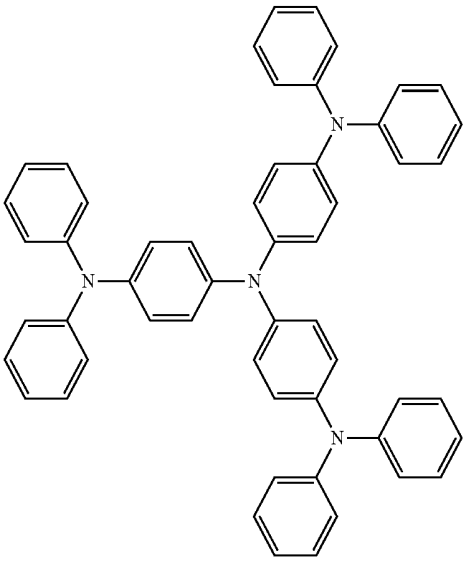

TDATA

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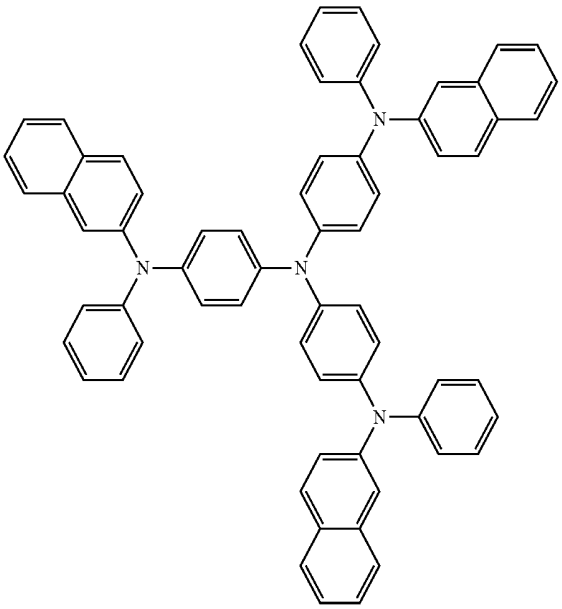
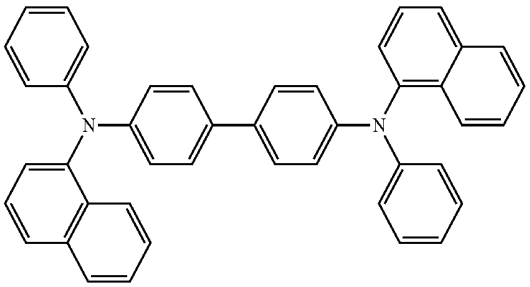
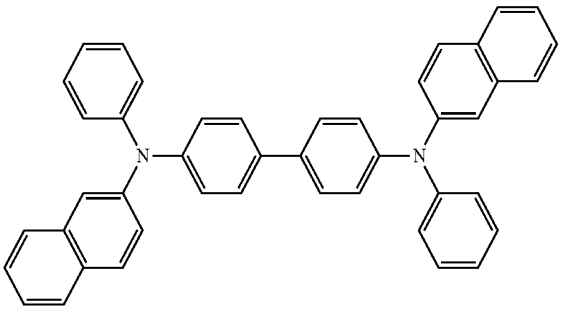


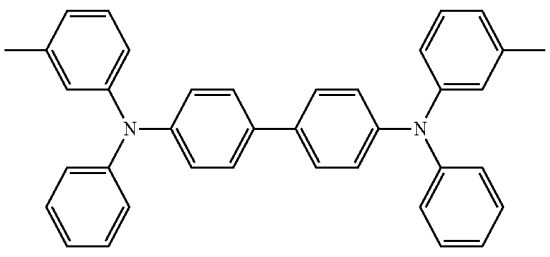
2-TNATA



NPB



β-NPB



TPD

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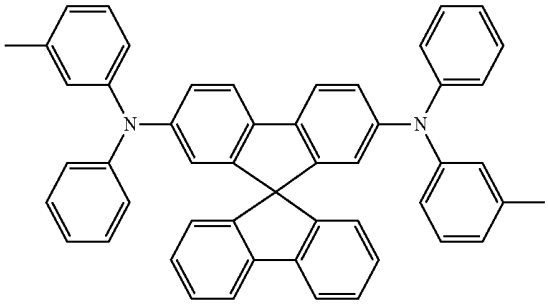
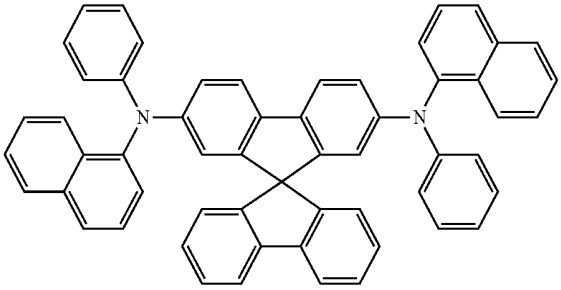


Spiro-TPD



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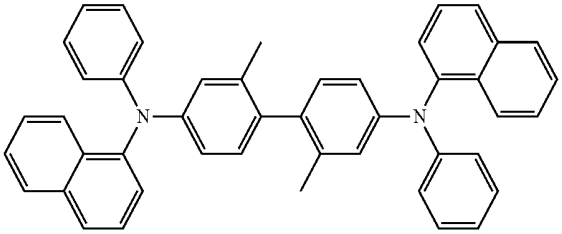
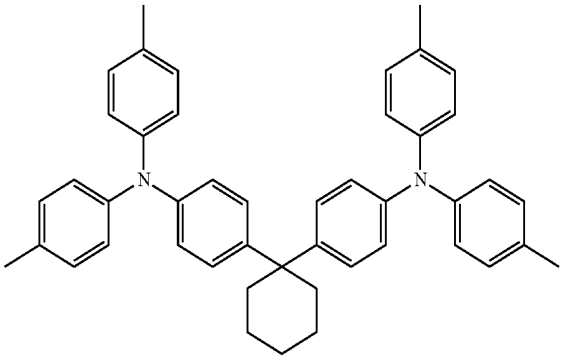
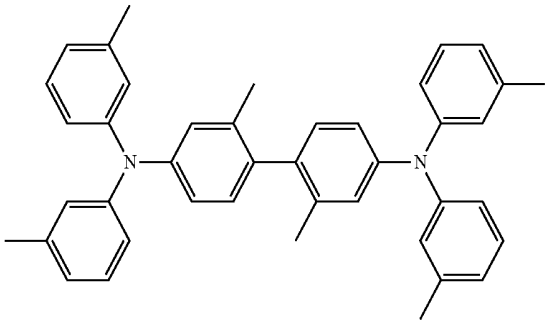


methylated NPB



TAPC



HMTPD

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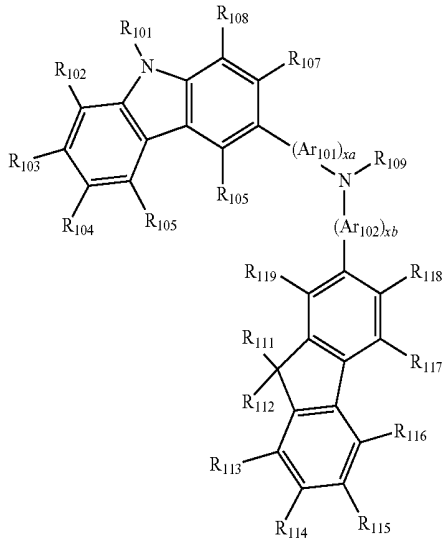
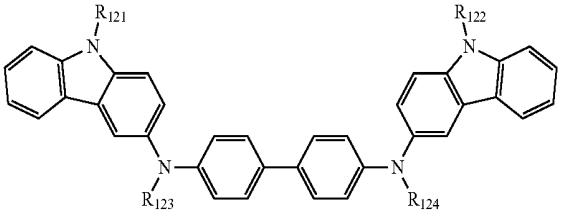
Formula 201



Formula 202



[0183] wherein, Ar_{101} and Ar_{102} in Formula 201 may each independently be selected from

[0184] a phenylene group, a pentalenylene group, an indenylene group, a naphthylene group, an azulenylene group, a heptalenylene group, an acenaphthylene group, a fluorenylene group, a phenalenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylenylene group, a naphthacenylene group, a picenylene group, a perylenylene group, and a pentacenylene group; and

[0185] a phenylene group, a pentalenylene group, an indenylene group, a naphthylene group, an azulenylene group, a heptalenylene group, an acenaphthylene group, a fluorenylene group, a phenalenylene group, a phenanthrenylene group, an anthracenylene group, a fluoranthenylene group, a triphenylenylene group, a pyrenylene group, a chrysenylenylene group, a naphthacenylene group, a picenylene group, a perylenylene group, and a pentacenylene 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 carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, 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_3-C_{10} cycloalkenyl group, a C_1-C_{10} heterocycloalkyl 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.

[0186] xa and xb in Formula 201 may each independently be an integer selected from 0 to 5. Alternatively, xa and xb may each independently be an integer selected from 0, 1, and 2. In some embodiments, xa may be 1 and xb may be 0, but embodiments are not limited thereto.

[0187] R_{101} to R_{108}, R_{111} to R_{119}, and R_{121} to R_{124} in Formulae 201 and 202 may each independently be selected from

[0188] hydrogen, 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 carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1-C_{10} alkyl group (e.g., a methyl group, an ethyl group, a propyl group, a butyl group, pentyl group, or a hexyl group), and a C_1-C_{10} alkoxy group (e.g., a methoxy group, an ethoxy group, a propoxy group, a butoxy group, or a pentoxy group);

[0189] a C_1-C_{10} alkyl group and a C_1-C_{10} 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 amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, and a phosphoric acid group or a salt thereof;

[0190] a phenyl group, a naphthyl group, an anthracenyl group, a fluorenyl group, and a pyrenyl group; and

[0191] a phenyl group, a naphthyl group, an anthracenyl group, a fluorenyl group, and a pyrenyl 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 carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1-C_{10} alkyl group, and a C_1-C_{10} alkoxy group, but embodiments are not limited thereto.

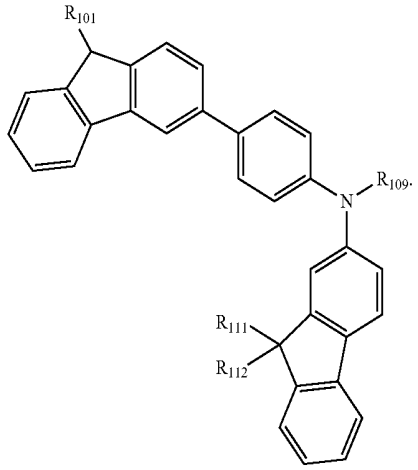
[0192] R_{109} in Formula 201 may be selected from

[0193] a phenyl group, a naphthyl group, an anthracenyl group, and a pyridinyl group; and

[0194] a phenyl group, a naphthyl group, an anthracenyl 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 amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a naphthyl group, an anthracenyl group and a pyridinyl group.

[0195] In some embodiments, the compound represented by Formula 201 may be represented by Formula 201A, but embodiments are not limited thereto:

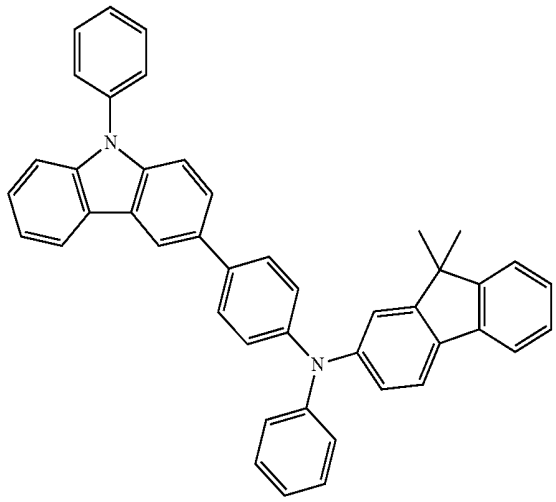
Formula 201A



[0196] R_{101}, R_{111}, R_{112}, and R_{109} in Formula 201A may be the same as those described above.

[0197] In some embodiments, the compound represented by Formula 201 and the compound represented by Formula 202 may include Compounds HT1 to HT20, but embodiments are not limited thereto:

HT1



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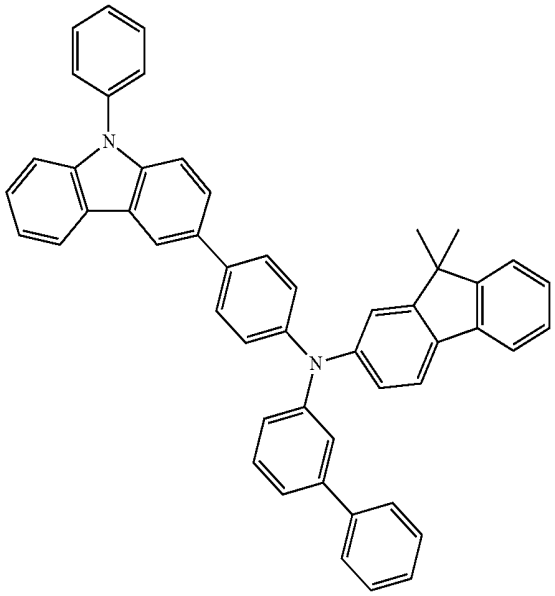
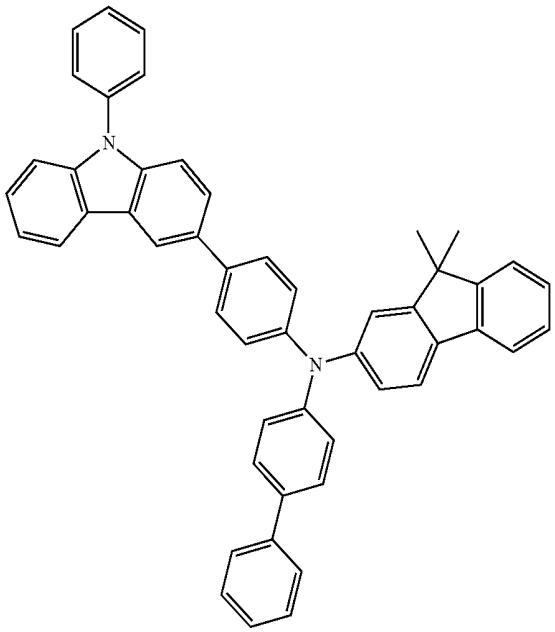
HT2



HT3



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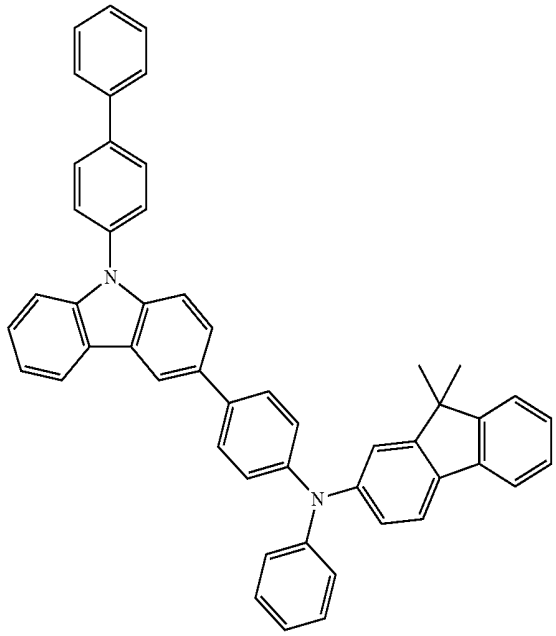
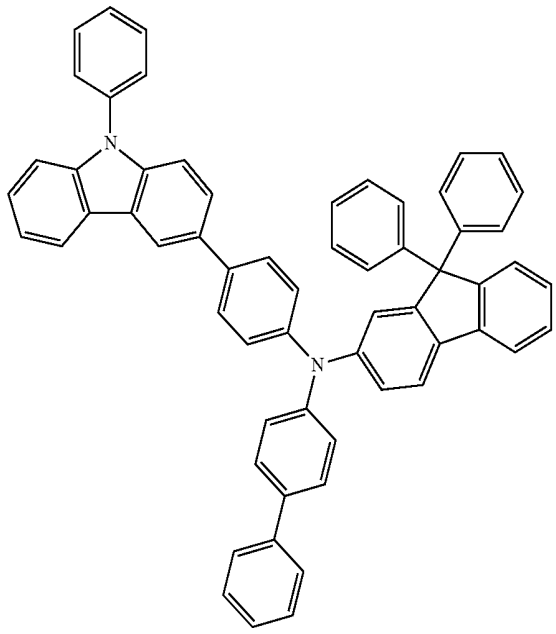
HT4



HT5



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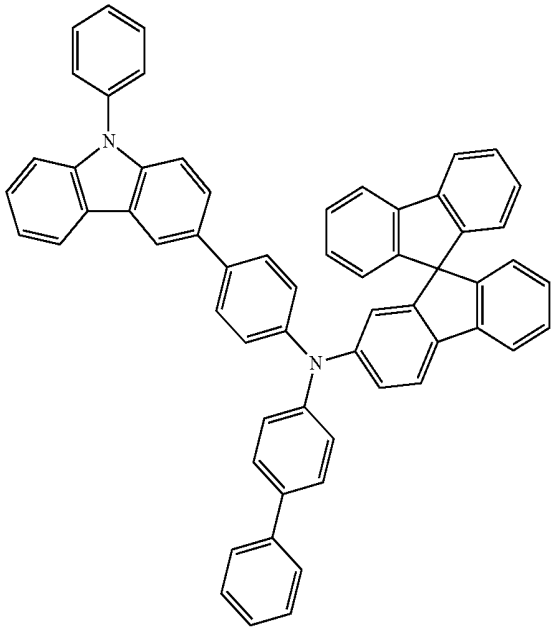
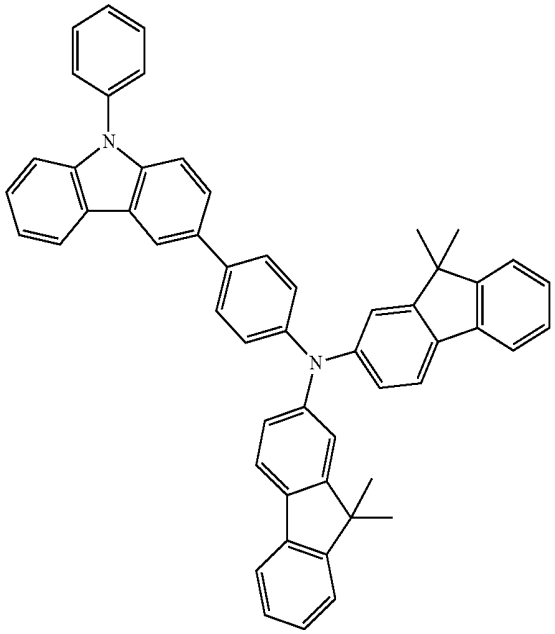
HT6



HT7



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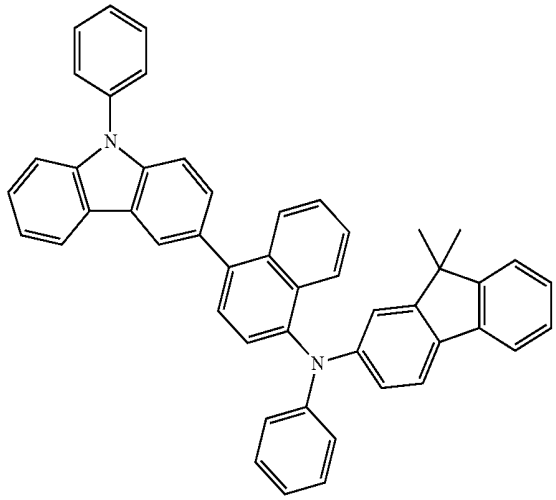

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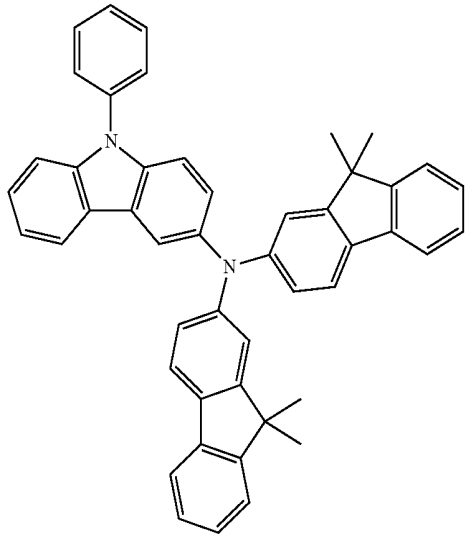

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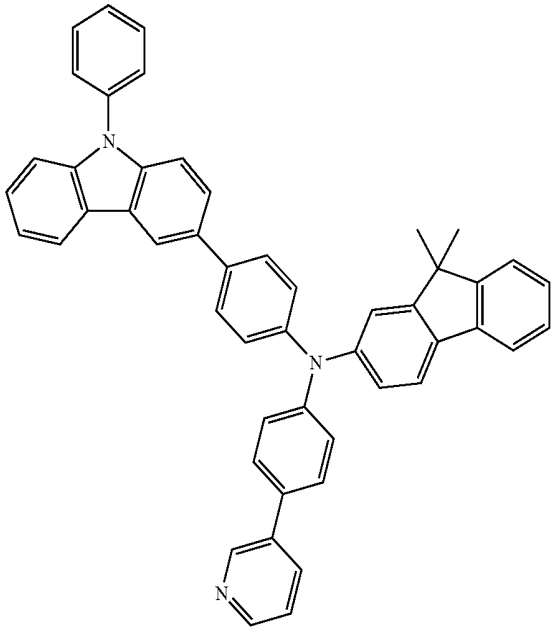

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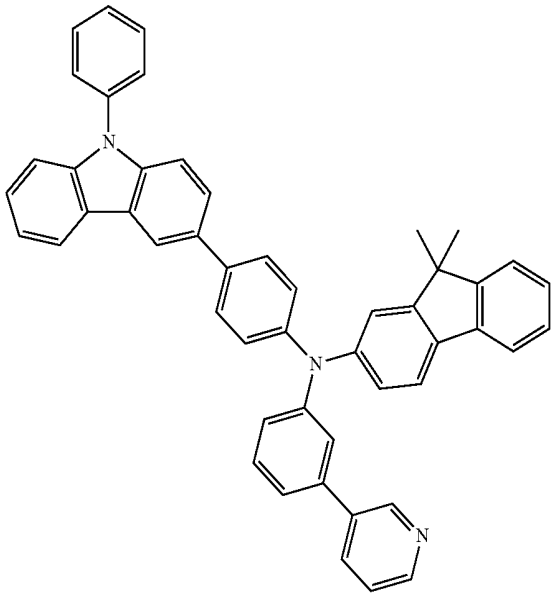

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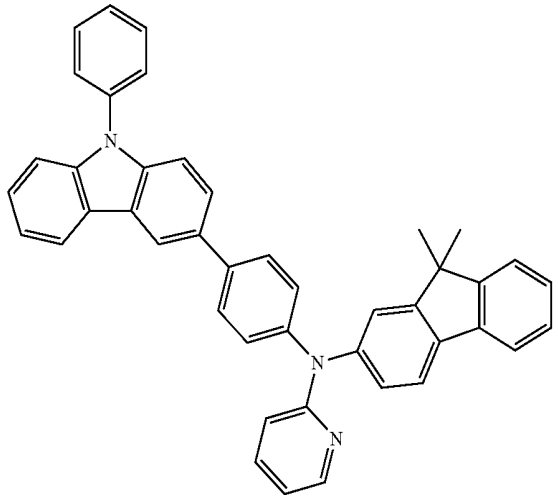

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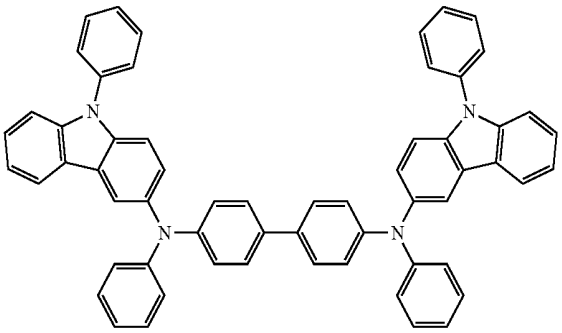

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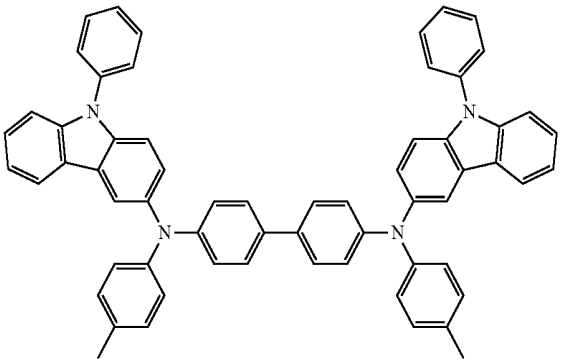

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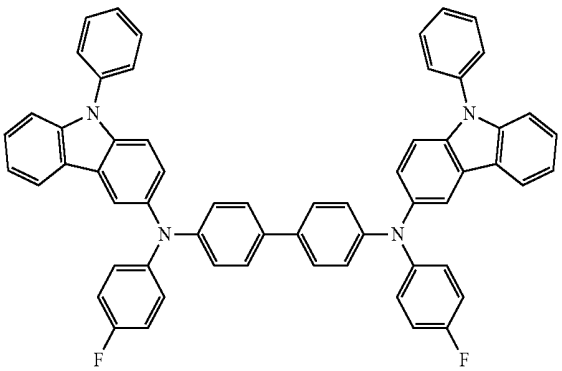

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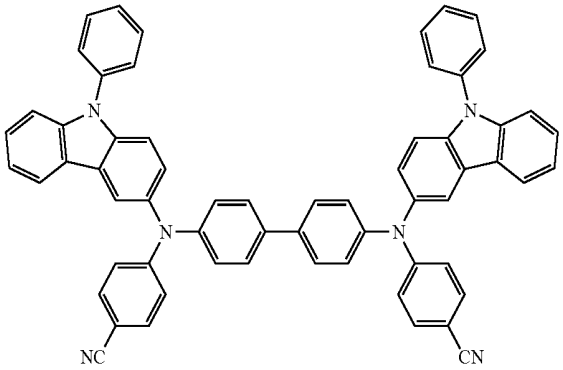

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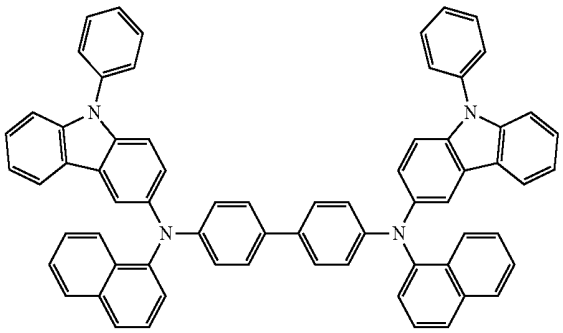

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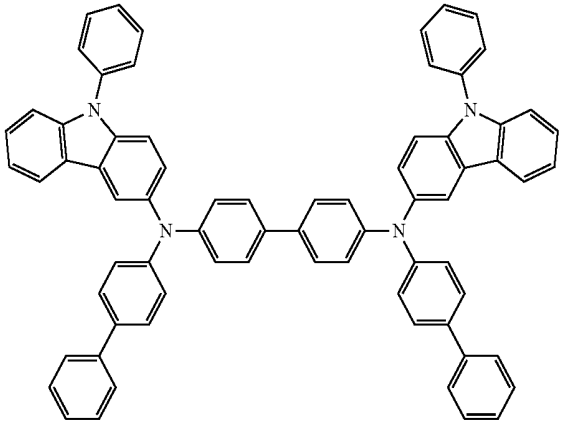

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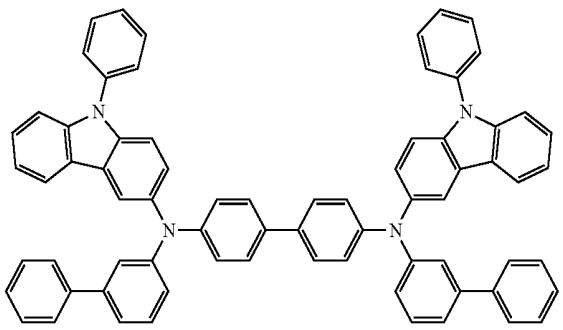

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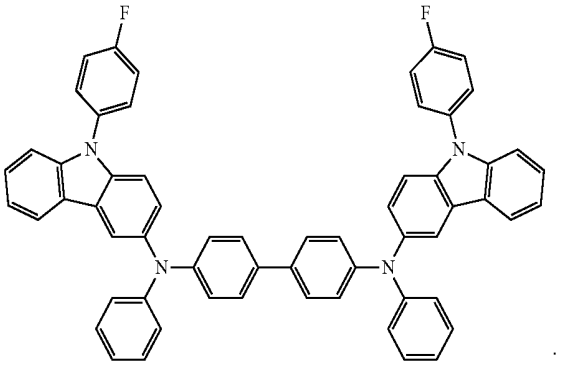
HT20

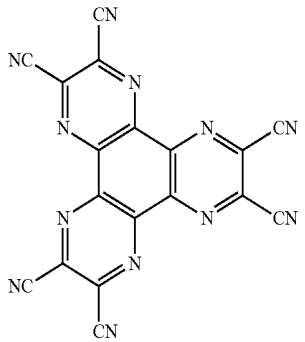


[0198] The thickness of the hole transport region may be in a range of about 100 Å to about 10,000 Å, for example, about 100 Å to about 1,000 Å. When the hole transport region includes both a hole injection layer and a hole transport layer, the thickness of the hole injection layer may be in a range of about 100 Å to about 10,000 Å, for example, 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, for example about 100 Å to about 1,500 Å. While not wishing to be bound by theory, it is understood that when the thicknesses of the hole transport region, the hole injection layer, and the hole transport layer are within any of these ranges, satisfactory hole transporting characteristics may be obtained without a substantial increase in driving voltage.

[0199] The hole transport region may further include, in addition to these materials, a charge-generation material for the improvement of conductive properties. The charge-generation material may be homogeneously or non-homogeneously dispersed in the hole transport region.

[0200] The charge-generation material may be, for example, a p-dopant. The p-dopant may be one selected from a quinone derivative, a metal oxide, and a cyano group-containing compound, but embodiments are not limited thereto. Non-limiting examples of the p-dopant are a quinone derivative, such as tetracyanoquinonedimethane (TCNQ) or 2,3,5,6-tetrafluoro-tetracyano-1,4-benzoquinonedimethane (F4-TCNQ); a metal oxide, such as a tungsten oxide or a molybdenum oxide; and a cyano group-containing compound, such as Compound HT-D1 below, but are not limited thereto:

Compound HT-D1



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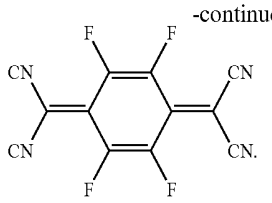


F4-TCNQ

[0201] The hole transport region may include a buffer layer.

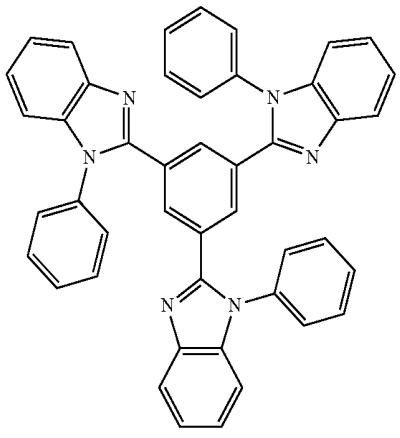
[0202] Also, the buffer layer may compensate for an optical resonance distance depending on a wavelength of light emitted from the emission layer, and thus, the efficiency of a formed organic light-emitting device may improve.

[0203] Then, an emission layer may be formed on the hole transport region by vacuum deposition, spin coating, casting, LB deposition, or the like. When the emission layer is formed by vacuum deposition or spin coating, the deposition or coating conditions may be similar to those applied to form the hole injection layer although the deposition or coating conditions may vary depending on the material that is used to form the emission layer.

[0204] Meanwhile, when the hole transport region includes an electron blocking layer, a material for the electron blocking layer may be selected from materials for the hole transport region described above and materials for a host described below. However, the material for the electron blocking layer is not limited thereto. For example, when the hole transport region includes an electron blocking layer, a material for the electron blocking layer may be mCP described below.

[0205] The emission layer may include a host and a dopant, and the dopant may include the organometallic compound represented by Formula 1.

[0206] The host may include at least one selected from TPBi, TBADN, ADN (also referred to as "DNA"), CBP, CDBP, TCP, mCP, Compound H50, and Compound H51:



TPBi

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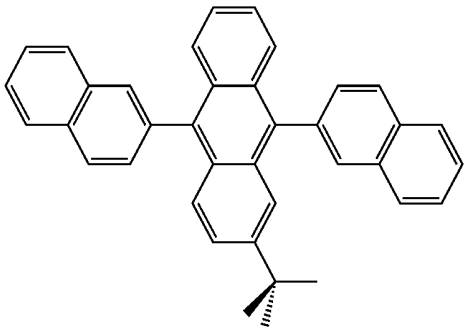
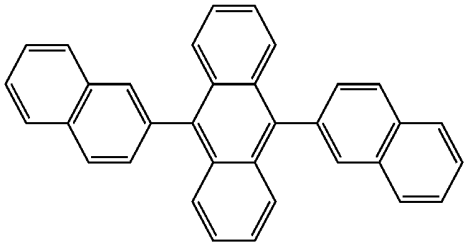
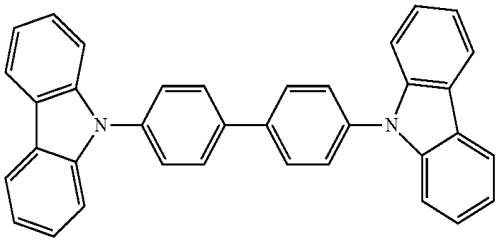


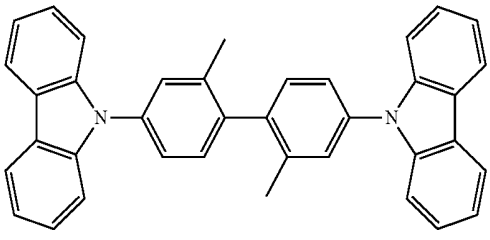
TBADN



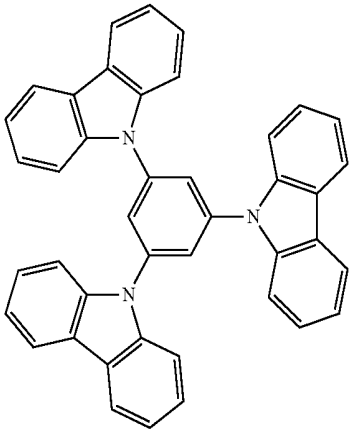
ADN



CBP



CDBP



TCP

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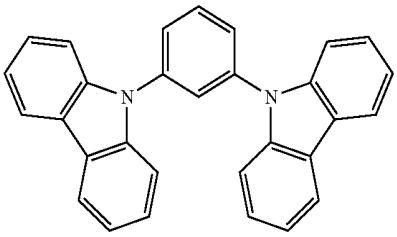
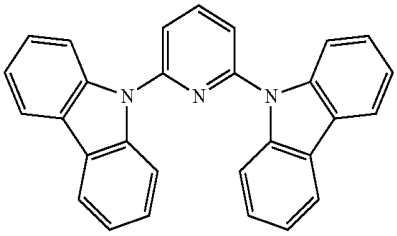
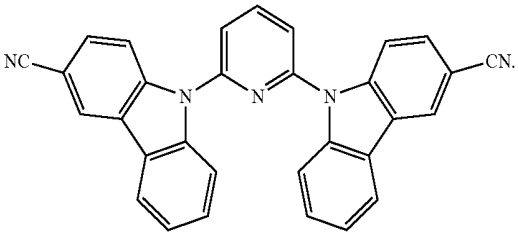


mCP

Compound H50

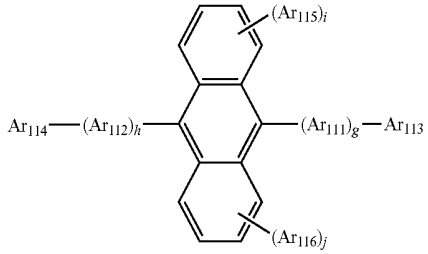


Compound H51



[0207] In some embodiments, the host may further include a compound represented by Formula 301:

Formula 301



[0208] wherein, Ar_{111} and Ar_{112} in Formula 301 may each independently be selected from

[0209] a phenylene group, a naphthylene group, a phenanthrenylene group, and a pyrenylene group; and

[0210] a phenylene group, a naphthylene group, a phenanthrenylene group, and a pyrenylene group, each substituted with at least one selected from a phenyl group, a naphthyl group, and an anthracenyl group.

[0211] Ar_{113} to Ar_{116} in Formula 301 may each independently be selected from

[0212] a C_1-C_{10} alkyl group, a phenyl group, a naphthyl group, a phenanthrenyl group, and a pyrenyl group; and

[0213] a phenyl group, a naphthyl group, a phenanthrenyl group, and a pyrenyl group, each substituted with at least one selected from a phenyl group, a naphthyl group, and an anthracenyl group.

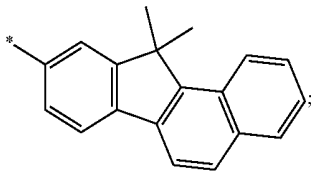
[0214] g, h, i, and j in Formula 301 may each independently be an integer selected from 0 to 4, for example, 0, 1, or 2.

[0215] Ar_{113} to Ar_{116} in Formula 301 may each independently be selected from

[0216] a C_1-C_{10} alkyl group substituted with at least one selected from a phenyl group, a naphthyl group, and an anthracenyl group;

[0217] a phenyl group, a naphthyl group, an anthracenyl group, a pyrenyl group, a phenanthrenyl group, and a fluorenyl group;

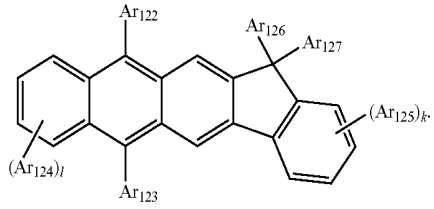
[0218] a phenyl group, a naphthyl group, an anthracenyl group, a pyrenyl group, a phenanthrenyl group, and a fluorenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, 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 phenyl group, a naphthyl group, an anthracenyl group, a pyrenyl group, a phenanthrenyl group, and a fluorenyl group; and



[0219] but embodiments are not limited thereto.

[0220] In some embodiments, the host may include a compound represented by Formula 302:

Formula 302



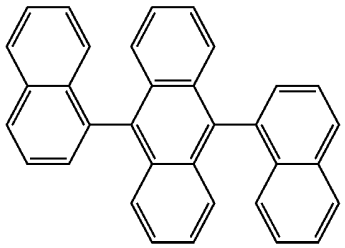
[0221] Ar_{122} to Ar_{125} in Formula 302 may be the same as described herein in connection with Ar_{113} in Formula 301.

[0222] Ar_{126} and Ar_{127} in Formula 302 may each independently be a C_1-C_{10} alkyl group, e.g., a methyl group, an ethyl group, or a propyl group.

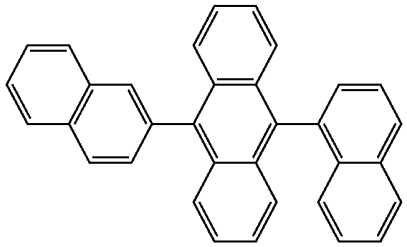
[0223] k and l in Formula 302 may each independently be an integer selected from 0 to 4. In some embodiments, k and l may each be 0, 1, or 2.

[0224] In some embodiments, the compound represented by Formula 301 and the compound represented by Formula 302 may include Compounds HT1 to HT42, but embodiments are not limited thereto:

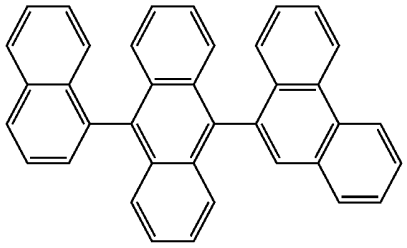
H1



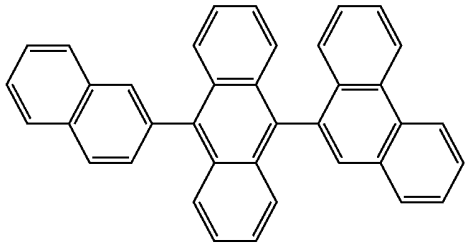
H2



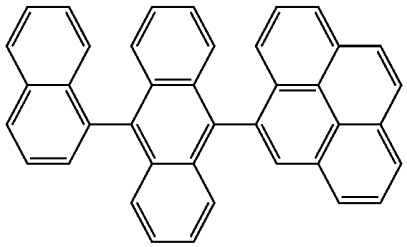
H3



H4



H5



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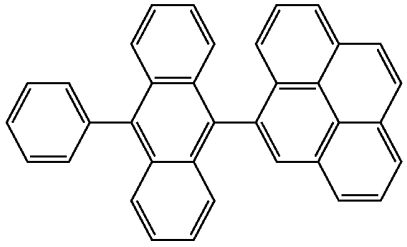

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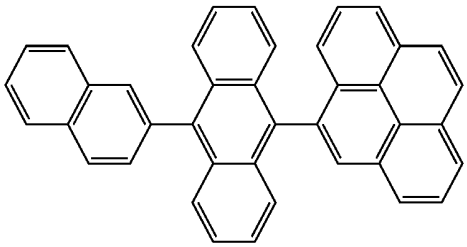
H7



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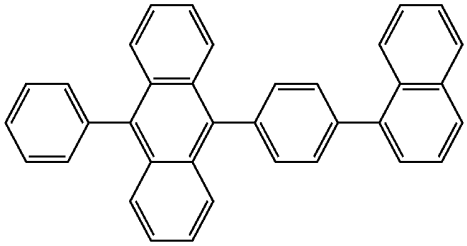

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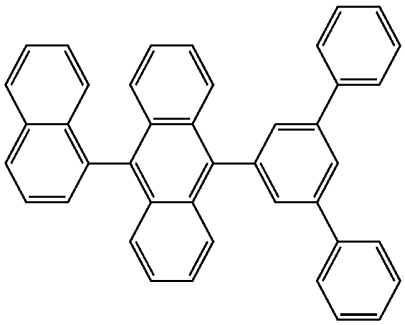

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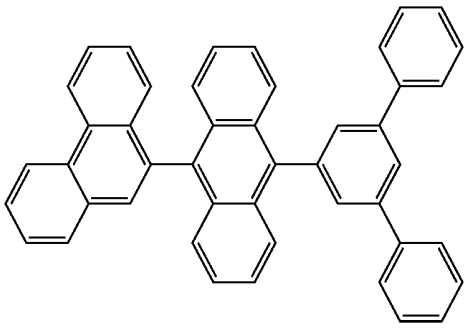

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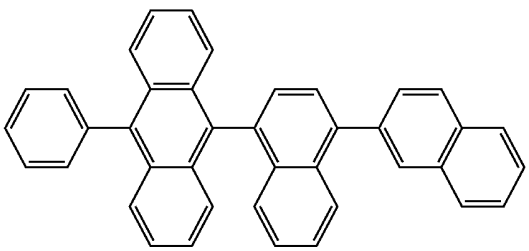

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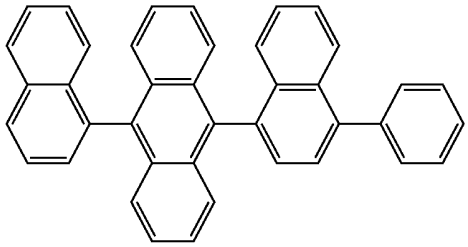

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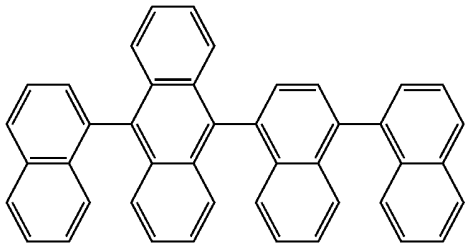
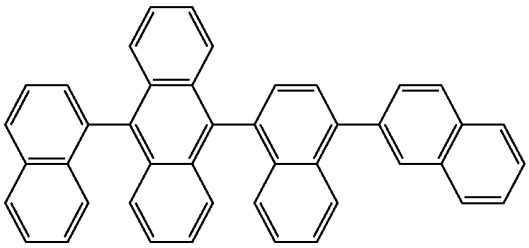
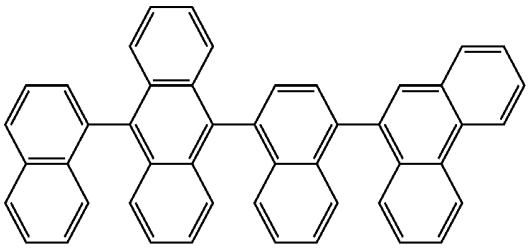


H14



H15



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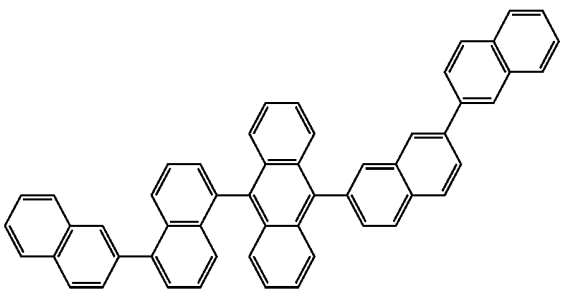

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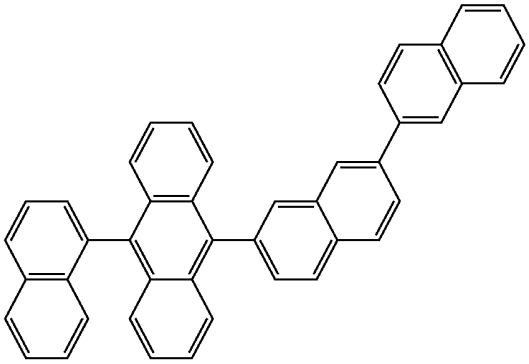
H17



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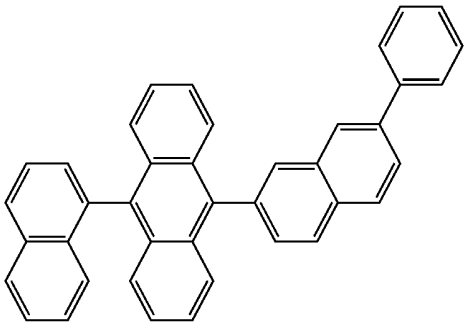

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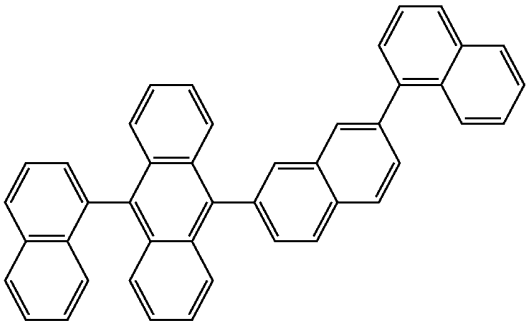

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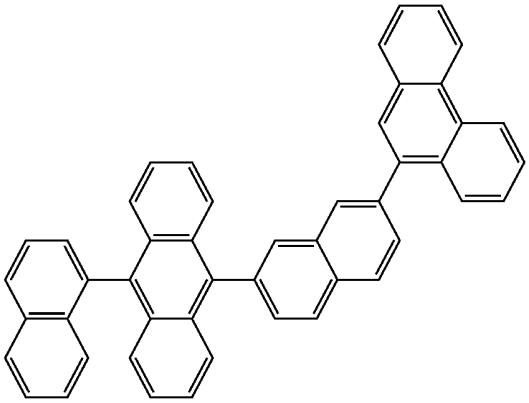

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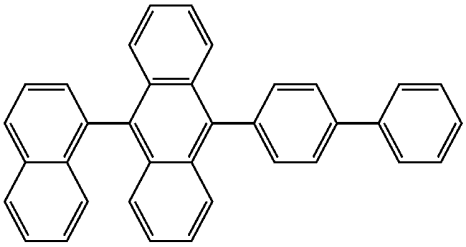
H21



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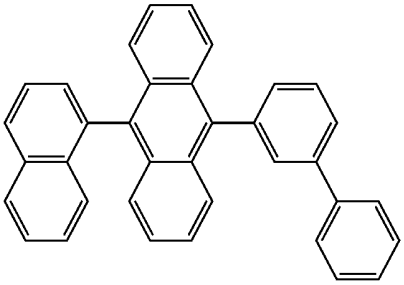

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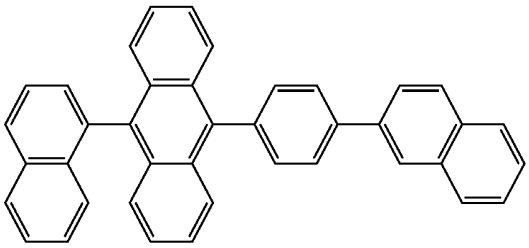

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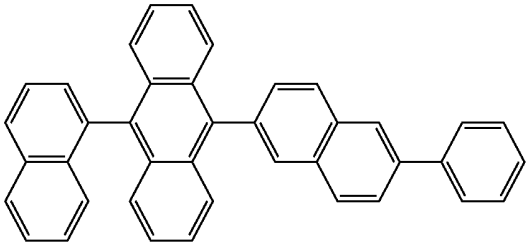

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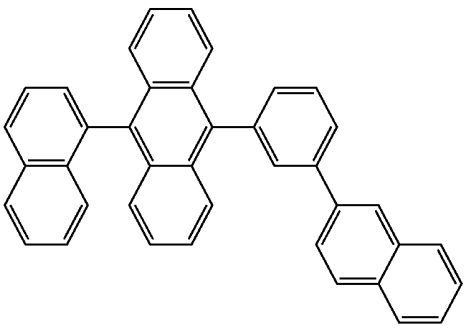

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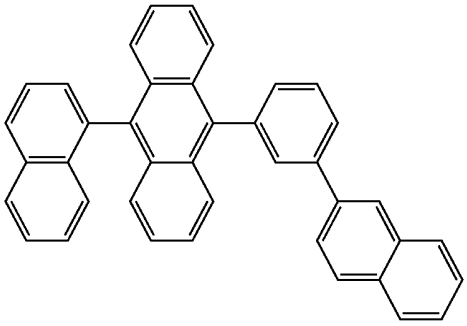

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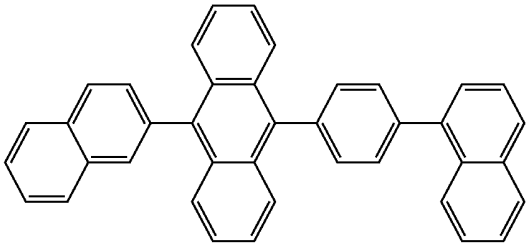

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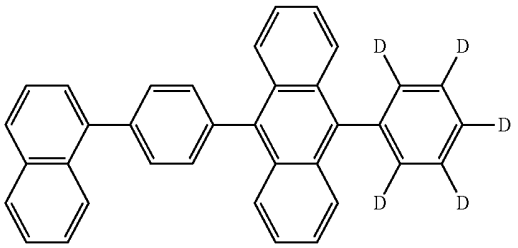

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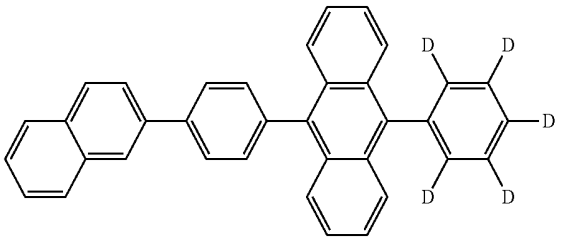

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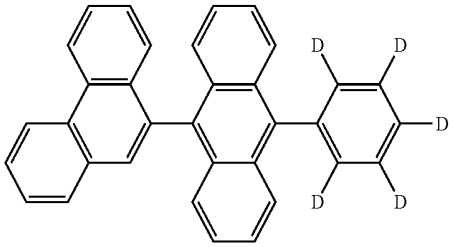

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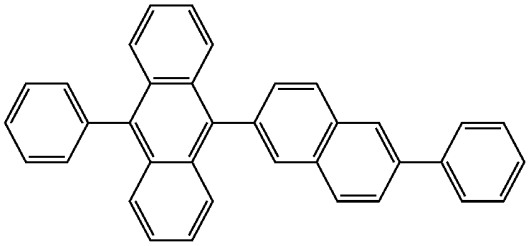

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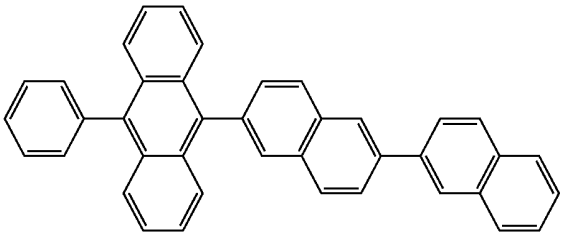

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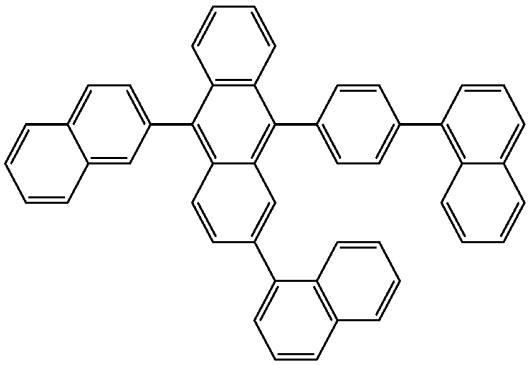

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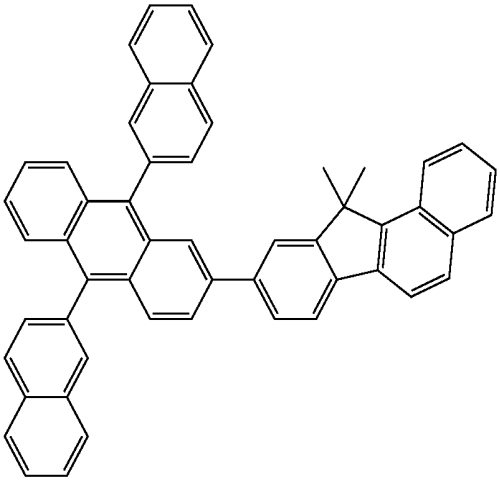

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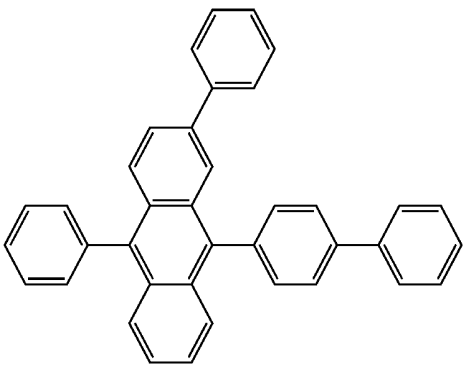

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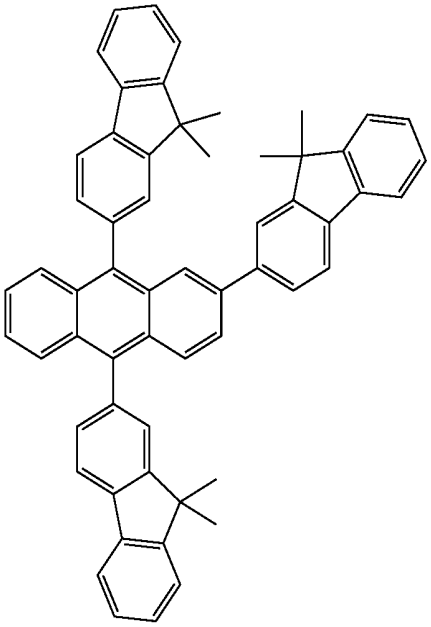

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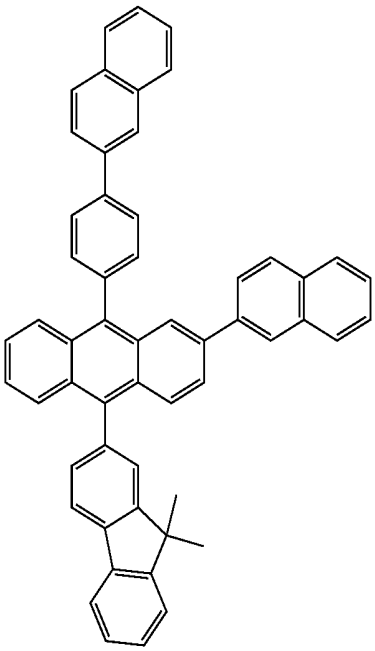

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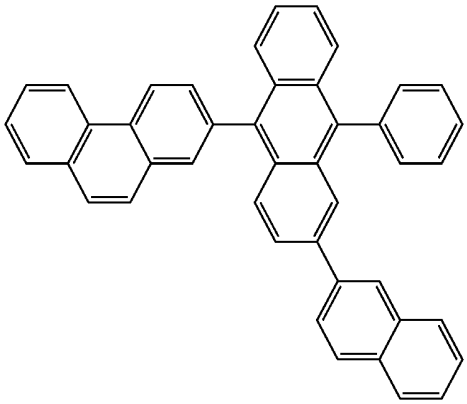

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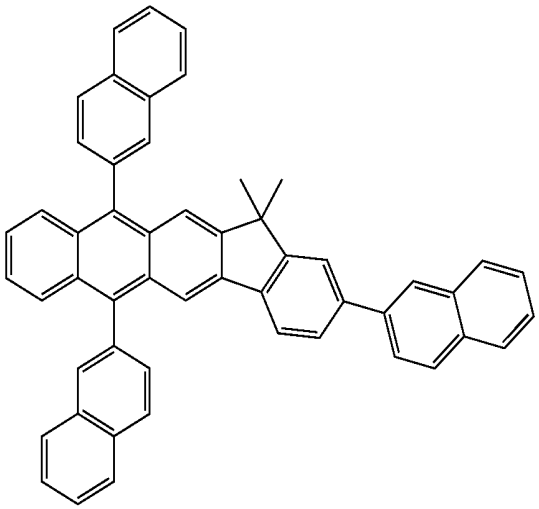

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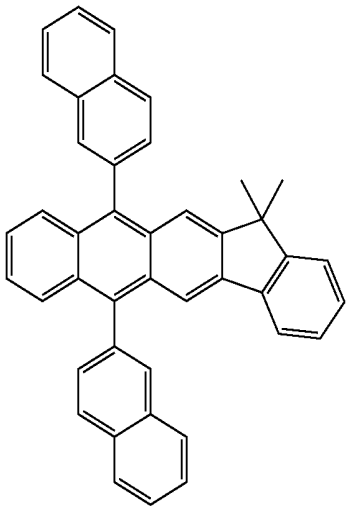

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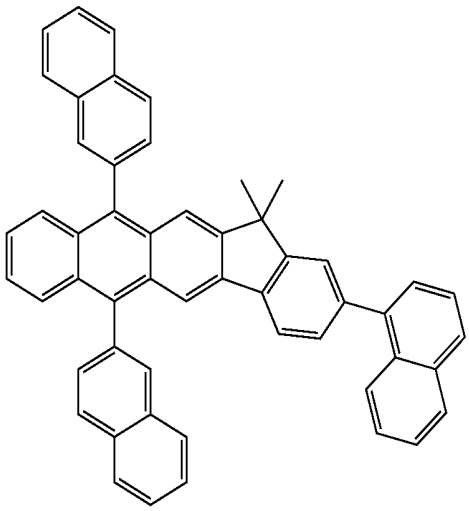

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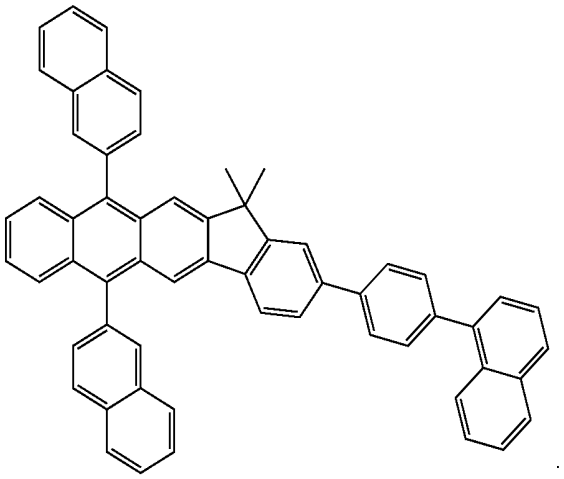
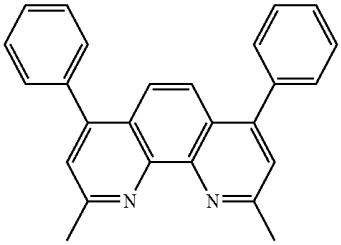
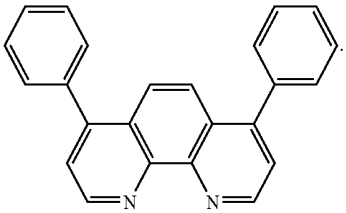




BCP



Bphen

[0225] When the organic light-emitting device is a full color organic light-emitting device, the emission layer may be patterned into a red emission layer, a green emission layer, and a blue emission layer. In one or more embodiments, due to a stack structure including a red emission layer, a green emission layer, and/or a blue emission layer, the emission layer may emit white light.

[0226] When the emission layer includes a host and a dopant, the amount of the dopant may be in a range of about 0.01 parts by weight to about 15 parts by weight based on 100 parts by weight of the host, but embodiments are not limited thereto.

[0227] 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. While not wishing to be bound by theory, it is understood that when the thickness of the emission layer is within any of these ranges, excellent light-emission characteristics may be obtained without a substantial increase in driving voltage.

[0228] Then, an electron transport region may be disposed on the emission layer.

[0229] The electron transport region may include at least one selected from a hole blocking layer, an electron transport layer, and an electron injection layer.

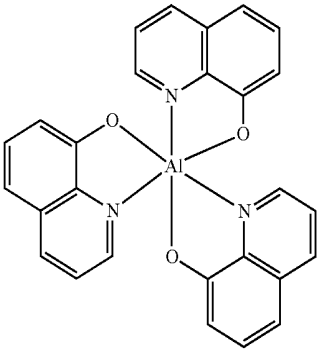
[0230] For example, the electron transport region may have a hole blocking layer/electron transport layer/electron injection layer structure or an electron transport layer/electron injection layer structure, but the structure of the electron transport region is not limited thereto. The electron transport layer may have a single-layered structure or a multi-layered structure including two or more different materials.

[0231] Conditions for forming the hole blocking layer, the electron transport layer, and the electron injection layer, which constitute the electron transport region, may be understood to be substantially the same as conditions for forming the hole injection layer.

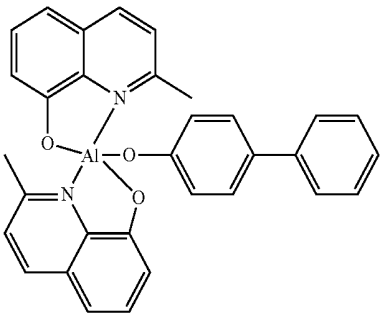
[0232] When the electron transport region includes a hole blocking layer, the hole blocking layer may include, for example, at least one selected from BCP, Bphen, and BAlq but embodiments are not limited thereto:

[0233] The thickness of the hole blocking layer may be in a range of about 20 Å to about 1,000 Å, for example, about 30 Å to about 300 Å. While not wishing to be bound by theory, it is understood that when the thickness of the hole blocking layer is within any of these ranges, the hole blocking layer may have excellent hole blocking characteristics without a substantial increase in driving voltage.

[0234] The electron transport layer may further include at least one selected from BCP, Bphen, Alq_3, BAlq, TAZ, and NTAZ:



Alq_3



BAlq

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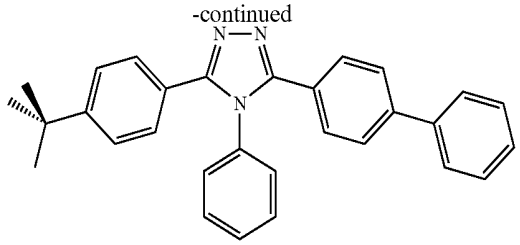
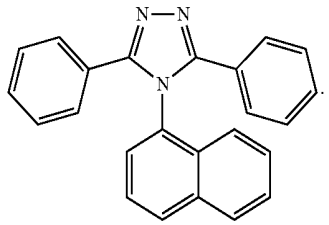


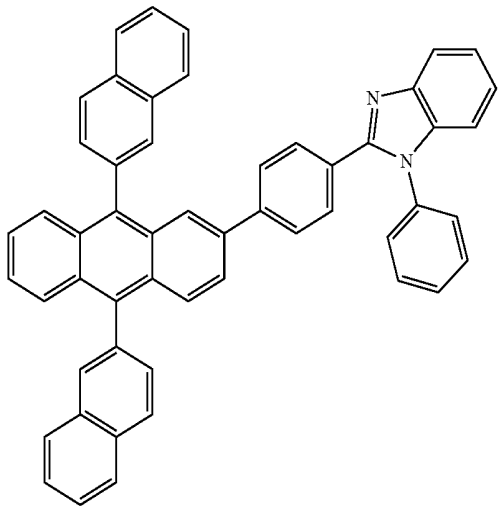
TAZ



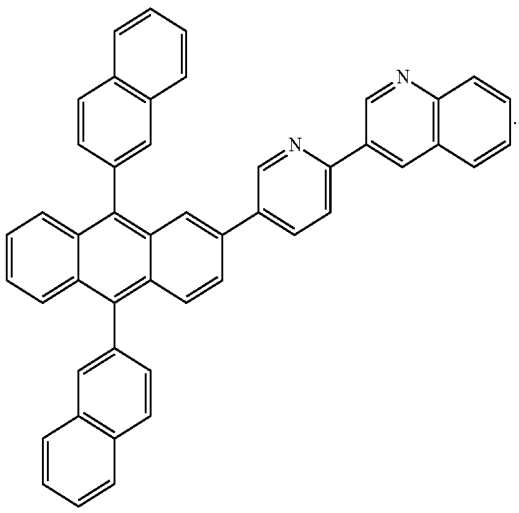
NTAZ

[0235] In one or more embodiments, the electron transport layer may include at least one selected from ET1 and ET2, but is not limited thereto:

ET1



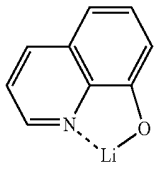
ET2



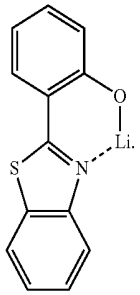
[0236] The thickness of the electron transport layer may be in a range of about 100 Å to about 1,000 Å, and in some embodiments, about 150 Å to about 500 Å. While not wishing to be bound by theory, it is understood that when the thickness of the electron transport layer is within any of these ranges, the electron transport layer may have satisfactory electron transport characteristics without a substantial increase in driving voltage.

[0237] Also, the electron transport layer may further include, in addition to the materials described above, a metal-containing material.

[0238] The metal-containing material may include a Li complex. The Li complex may include, for example, Compound ET-D1 (lithium quinolate, LiQ) or ET-D2:



ET-D1



ET-D2

[0239] The electron transport region may include an electron injection layer that promotes flow of electrons from the second electrode **19** thereinto.

[0240] The electron injection layer may include at least one selected from LiF, NaCl, CsF, Li_2O, BaO, and LiQ.

[0241] 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. While not wishing to be bound by theory, it is understood that when the thickness of the electron injection layer is within any of these ranges, the electron injection layer may have satisfactory electron injection characteristics without a substantial increase in driving voltage.

[0242] The second electrode **19** may be disposed on the organic layer **15**. The second electrode **19** may be a cathode. The material for forming the second electrode **19** may be a metal, an alloy, an electrically conductive compound, and a combination thereof, which have a relatively low work function. For example, lithium (Li), magnesium (Mg), aluminum (Al), aluminum-lithium (Al—Li), calcium (Ca), magnesium-indium (Mg—In), or magnesium-silver (Mg—Ag) may be used as the material for forming the second electrode **19**. To manufacture a top emission-type light-emitting device, a transmissive electrode formed using ITO or IZO may be used as the second electrode **19**.

[0243] Hereinbefore, the organic light-emitting device has been described with reference to FIG. **1**, but is not limited thereto.

[0244] The term "C_1-C_{60} alkyl group" as used herein refers to a linear or branched aliphatic saturated hydrocarbon monovalent group having 1 to 60 carbon atoms.

[0245] Examples thereof may include a methyl group, an ethyl group, a propyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, a pentyl group, an iso-amyl group, and a hexyl group. The term "C_1-C_{60} alkylene group" as used herein refers to a divalent group having the same structure as the C_1-C_{60} alkyl group.

[0246] The term "C_1-C_{60} alkoxy group" as used herein refers to a monovalent group represented by —OA_{101} (wherein A_{101} is a C_1-C_{60} alkyl group), and examples thereof may include a methoxy group, an ethoxy group, and an iso-propyloxy (iso-propoxy) group.

[0247] The term "C_2-C_{30} alkenyl group" as used herein refers to a hydrocarbon group having at least one carbon-carbon double bond in the middle or at the terminus of the C_2-C_{30} alkyl group. Examples thereof may include an ethenyl group, a propenyl group, and a butenyl group. The term "C_2-C_{60} alkenylene group" as used herein refers to a divalent group having the same structure as the C_2-C_{60} alkenyl group.

[0248] The term "C_2-C_{30} alkynyl group" as used herein refers to a hydrocarbon group having at least one carbon-carbon triple bond in the middle or at the terminus of the C_2-C_{30} alkyl group. Examples thereof may include an ethynyl group and a propynyl group. The term "C_2-C_{60} alkynylene group" as used herein refers to a divalent group having the same structure as the C_2-C_{60} alkynyl group.

[0249] The term "C_3-C_{10} cycloalkyl group" as used herein refers to a monovalent saturated hydrocarbon monocyclic group having 3 to 10 carbon atoms. Examples thereof may include a cyclopropyl group, a cyclobutyl group, a cyclopentyl group, a cyclohexyl group, and a cycloheptyl group. The term "C_3-C_{10} cycloalkylene group" as used herein refers to a divalent group having the same structure as the C_3-C_{10} cycloalkyl group.

[0250] The term "C_1-C_{10} heterocycloalkyl group" as used herein refers to a monovalent monocyclic group having at least one heteroatom selected from N, O, P, and S as a ring-forming atom, in addition to 1 to 10 carbon atoms. Examples thereof may include a tetrahydrofuranyl group and a tetrahydrothiophenyl group. The term "C_1-C_{10} heterocycloalkylene group" as used herein refers to a divalent group having the same structure as the C_1-C_{10} heterocycloalkyl group.

[0251] The term "C_3-C_{10} cycloalkenyl group" as used herein refers to a monovalent monocyclic group that has 3 to 10 carbon atoms, at least one carbon-carbon double bond in its ring, and which is not aromatic. Examples thereof may include a cyclopentenyl group, a cyclohexenyl group, and a cycloheptenyl group. The term "C_3-C_{10} cycloalkenylene group" as used herein refers to a divalent group having the same structure as the C_3-C_{10} cycloalkenyl group.

[0252] The term "C_1-C_{10} heterocycloalkenyl group" as used herein refers to a monovalent monocyclic group that has at least one heteroatom selected from N, O, P, and S as a ring-forming atom, 1 to 10 carbon atoms, and at least one carbon-carbon double bond in its ring. Examples of the C_1-C_{10} heterocycloalkenyl group include a 2,3-dihydrofuranyl group and a 2,3-dihydrothiophenyl group. The term "C_1-C_{10} heterocycloalkenylene group" as used herein refers to a divalent group having the same structure as the C_1-C_{10} heterocycloalkenyl group.

[0253] The term "$C_{6\text{-}60}$ aryl group" as used herein refers 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 refers to a divalent group having a carbocyclic aromatic system having 6 to 60 carbon atoms. Examples of the C_6-C_{60} aryl group may 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 include two or more rings, the rings may be fused.

[0254] The term "C_1-C_{60} heteroaryl group" as used herein refers to a monovalent group having a heterocyclic aromatic system that has at least one heteroatom selected from N, O, P, and S as a ring-forming atom, in addition to 1 to 60 carbon atoms. The term "C_1-C_{60} heteroarylene group" as used herein refers to a divalent group having a heterocyclic aromatic system that has at least one heteroatom selected from N, O, P, and S as a ring-forming atom, in addition to 1 to 60 carbon atoms. Examples of the C_1-C_{60} heteroaryl group may include a pyridinyl group, a pyrimidinyl group, a pyrazinyl group, a pyridazinyl group, a triazinyl group, a quinolinyl group, and an isoquinolinyl group. When the C_1-C_{60} heteroaryl group and the C_1-C_{60} heteroarylene group each include two or more rings, the rings may be fused.

[0255] The term "$C_{6\text{-}60}$ aryloxy group" as used herein indicates —OA_{102} (wherein A_{102} is a C_6-C_{60} aryl group). The term "C_6-C_{60} arylthio group" as used herein indicates —SA_{103} (wherein A_{103} is a C_6-C_{60} aryl group). The term "C_7-C_{60} arylalkyl group" as used herein indicates -$A_{104}A_{105}$ (wherein A_{105} is a C_6-C_{59} aryl group and A_{104} is a C_1-C_{54} alkylene group).

[0256] The term "C_1-C_{60} heteroaryloxy group" as used herein indicates —OA_{106} (wherein A_{106} is a C_1-C_{60} heteroaryl group), the term "C_1-C_{60} heteroarylthio group" as used herein indicates —SA_{107} (wherein A_{107} is a C_1-C_{60} heteroaryl group), and the term "C_2-C_{60} heteroarylalkyl group" as used herein indicates -$A_{108}A_{109}$ (wherein A_{109} is a C_1-C_{59} heteroaryl group and A_{108} is a C_1-C_{59} alkylene group).

[0257] The term "monovalent non-aromatic condensed polycyclic group" as used herein refers to a monovalent group (e.g., having 8 to 60 carbon atoms) that has two or more rings condensed, only carbon atoms as ring-forming atoms, and which is non-aromatic in the entire molecular structure. Examples of the monovalent non-aromatic condensed polycyclic group may include a fluorenyl group. The term "divalent non-aromatic condensed polycyclic group" as used herein refers to a divalent group having the same structure as the monovalent non-aromatic condensed polycyclic group.

[0258] The term "monovalent non-aromatic condensed heteropolycyclic group" as used herein refers to a monovalent group (for example, having 2 to 60 carbon atoms) that has two or more rings condensed, has heteroatoms selected from N, O, P, and S, other than carbon atoms, as ring-forming atoms, and which is non-aromatic in the entire molecular structure. Examples of the monovalent non-aromatic condensed heteropolycyclic group may include a carbazolyl group. The term "divalent non-aromatic condensed heteropolycyclic group" as used herein refers to a divalent group having the same structure as the monovalent non-aromatic condensed heteropolycyclic group.

[0259] In the presented specification, at least one substituent of the 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_7-C_{60} arylalkyl group, substituted C_1-C_{60} heteroaryl group, substituted C_1-C_{60} heteroaryloxy group, substituted C_1-C_{60} heteroarylthio group, substituted C_2-C_{60} heteroarylalkyl group, substituted monovalent non-aromatic condensed polycyclic group, and substituted monovalent non-aromatic condensed heteropolycyclic group may be selected from:

[0260] deuterium, —F, —Cl, —Br, —I, $—CD_3$, $—CD_2H$, $—CDH_2$, $—CF_3$, $—CF_2H$, $—CFH_2$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a 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;

[0261] 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, $—CD_3$, $—CD_2H$, $—CDH_2$, $—CF_3$, $—CF_2H$, $—CFH_2$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a 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_7-C_{60} arylalkyl group, a C_1-C_{60} heteroaryl group, a C_1-C_{60} heteroaryloxy group, a C_1-C_{60} heteroarylthio group, a C_2-C_{60} heteroarylalkyl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group;

[0262] 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_7-C_{60} arylalkyl group, a C_1-C_{60} heteroaryl group, a C_1-C_{60} heteroaryloxy group, a C_1-C_{60} heteroarylthio group, a C_2-C_{60} heteroarylalkyl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group;

[0263] 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_7-C_{60} arylalkyl group, a C_1-C_{60} heteroaryl group, a C_1-C_{60} heteroaryloxy group, a C_1-C_{60} heteroarylthio group, a C_2-C_{60} heteroarylalkyl 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, $—CD_3$, $—CD_2H$, $—CDH_2$, $—CF_3$, $—CF_2H$, $—CFH_2$, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a 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_7-C_{60} arylalkyl group, a C_1-C_{60} heteroaryl group, a C_1-C_{60} heteroaryloxy group, a C_1-C_{60} heteroarylthio group, a C_2-C_{60} heteroarylalkyl group, a monovalent non-aromatic condensed polycyclic group, and a monovalent non-aromatic condensed heteropolycyclic group; and

$$—C(=O)(Q_{11}),—Si(Q_{11})(Q_{12})(Q_{13}), \text{ and } —N(Q_{11})(Q_{12}),$$

[0264] wherein Q_{11} to Q_{13} may each independently be selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_2-C_{60} alkenyl group, a substituted or unsubstituted C_2-C_{60} alkynyl group, a substituted or unsubstituted C_1-C_{60} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_7-C_{60} arylalkyl 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 C_2-C_{60} heteroarylalkyl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group.

[0265] When a group containing a specified number of carbon atoms is substituted with any of the groups listed in the preceding paragraphs, the number of carbon atoms in the

resulting "substituted" group is defined as the sum of the carbon atoms contained in the original (unsubstituted) group and the carbon atoms (if any) contained in the substituent. For example, when the term "substituted C_1-C_{60} alkyl" refers to a C_1-C_{60} alkyl group substituted with C_6-C_{60} aryl group, the total number of carbon atoms in the resulting aryl substituted alkyl group is C_7-C_{120}.

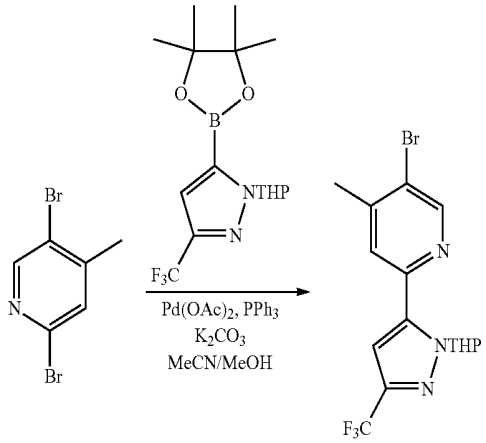
[0266] Hereinafter, a compound and an organic light-emitting device according to an embodiment will be described in detail with reference to Synthesis Examples and Examples, however, the present disclosure is not limited thereto. The wording "B was used instead of A" used in describing Synthesis Examples means that an amount of B used was identical to an amount of A used in terms of molar equivalents.

EXAMPLES

Synthesis Example 1

Synthesis of Compound 1

[0267] 1) Synthesis of Compound A3



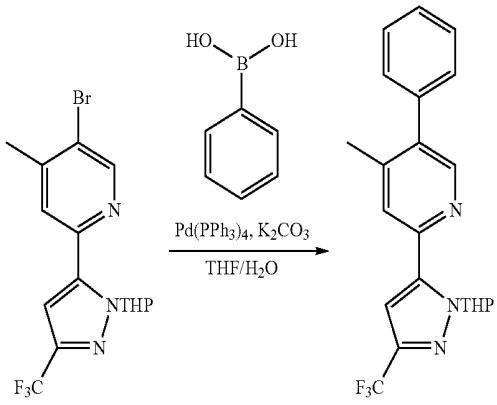
Compound A3

[0268] 6.56 grams (g) (26.14 millimoles (mmol)) of 2,5-dibromo-4-methylpyridine, 10.9 g (31.37 mmol) of pyrazole pinacol boronate (wherein "THP" is 2-tetrahydropyranyl), 0.29 g (1.31 mmol) of $Pd(OAc)_2$, 0.69 g (2.61 mmol) of triphenylphosphine, and 7.23 g (52.28 mmol) of K_2CO_3 were mixed with 90 milliliters (mL) of acetonitrile and 45 mL of methanol. Then, the mixture was stirred at a temperature of 50° C. for about 18 hours, cooled to room temperature, and filtered. An organic layer was extracted therefrom by using dichloromethane, and anhydrous magnesium sulfate ($MgSO_4$) was added thereto to dry the organic layer. The resultant was filtered and a solvent in the obtained filtrate was removed under reduced pressure. The residual was purified by column chromatography using ethyl acetate and hexane at a ratio of 1:25 (volume to volume, v/v) to obtain 2.43 g (24%) of Compound A3. The identity of the obtained compound was confirmed by using LCMS and ^{1}H NMR.

[0269] 1H-NMR ($CDCl_3$) δ 8.61 (s, 1H), 7.36 (s, 1H), 6.79 (s, 1H), 6.30 (dd, 1H), 4.02 (d, 1H), 3.60 (t, 1H), 2.51 (s, 3H), 2.09 (m, 2H), 1.71 (m, 2H), 1.54 (m, 2H).

[0270] MS: m/z 391.04 [$(M+1)^+$].

[0271] 2) Synthesis of Compound A2



Compound A3 Compound A2

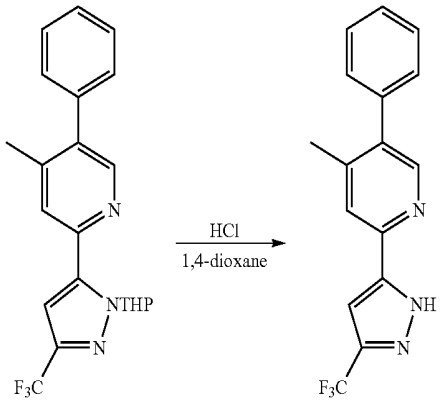
[0272] 2.43 g (6.23 mmol) of Compound A3 (wherein "THP" is 2-tetrahydropyranyl), 0.91 g (7.47 mmol) of phenylboronic acid, 0.50 g (0.44 mmol) of $Pd(PPh_3)_4$, and 1.29 g (9.34 mmol) of K_2CO_3 were mixed with 20 mL of tetrahydrofuran (THF) and 10 mL of distilled water. Then, the mixture was stirred at a temperature of 75° C. for about 12 hours, and cooled to room temperature. An organic layer was extracted therefrom by using ethyl acetate, and anhydrous $MgSO_4$ was added thereto to dry the organic layer.

[0273] The resultant was filtered and a solvent in the obtained filtrate was removed under reduced pressure. The residual was purified by column chromatography using ethyl acetate and hexane at a ratio of 1:10 (v/v) to obtain 2.08 g (86%) of Compound A2. The identity of the obtained compound was confirmed by using LCMS and ^{1}H NMR.

[0274] 1H-NMR ($CDCl_3$) δ 8.50 (s, 1H), 7.61 (s, 1H), 7.53 (m, 3H), 7.39 (m, 2H), 7.03 (s, 1H), 6.30 (dd, 1H), 4.02 (d, 1H), 3.60 (t, 1H), 2.42 (s, 3H), 2.09 (m, 2H), 1.71 (m, 2H), 1.54 (m, 2H).

[0275] MS: m/z 388.16 [$(M+1)^+$].

[0276] 3) Synthesis of Compound A1



Compound A2 Compound A1

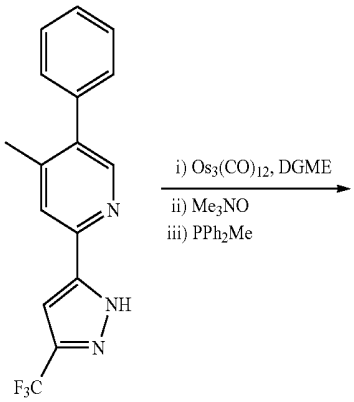
[0277] 0.99 g (2.58 mmol) of Compound A2 (wherein "THP" is 2-tetrahydropyranyl) was dissolved in 15 mL of 1,4-dioxane. The solution was slowly added to 6.44 mL (12.88 mmol) of hydrochloric acid dissolved in diethyl ether

at a concentration of 2.0 normal (N) and stirred at a temperature of 65° C. for 2 hours. Once the reaction was completed, the mixture was cooled to room temperature, and the obtained precipitate was filtered under reduced pressure, and washed with diethyl ether. The obtained solid was neutralized by using a sodium hydrogen carbonate aqueous solution. Subsequently, an organic layer was extracted therefrom by using ethyl acetate, and anhydrous $MgSO_4$ was added thereto to dry the organic layer. The resultant was filtered and a solvent in the obtained filtrate was removed under reduced pressure. The residual was purified by column chromatography using ethyl acetate and hexane at a ratio of 1:5 (v/v) to obtain 0.55 g (71%) of Compound A1. The identity of the obtained compound was confirmed by using LCMS and ^1H NMR.

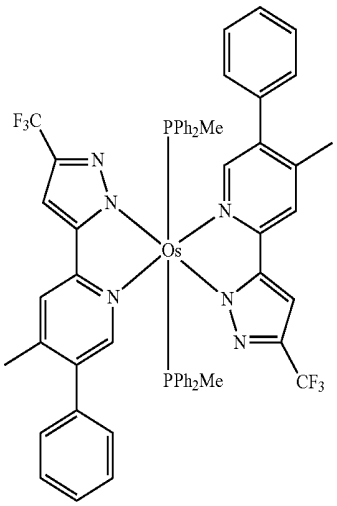
[0278] 1H-NMR ($CDCl_3$) δ 12.1 (br. s, 1H), 8.49 (s, 1H), 7.59 (s, 1H), 7.51 (m, 3H), 7.37 (m, 3H), 7.00 (s, 1H), 2.41 (s, 3H).

[0279] MS: m/z 304.10 [$(M+1)^+$].

[0280] 4) Synthesis of Compound 1



Compound A1



Compound 1

[0281] 0.55 g (1.82 mmol) of Compound A1 and 0.27 g (0.29 mmol) of triosmium dodecacarbonyl were dissolved in 15 mL of diethylene glycol monoethyl ether (DGME), and the solution was refluxed at a temperature of 180° C. for 18 hours. The solution was cooled to a temperature of 110° C., and 0.16 g (2.11 mmol) of trimethyl amine N-oxide dissolved in 5 mL of diethylene glycol monoethyl ether was slowly added thereto.

[0282] Subsequently, the reaction solution was stirred at a temperature of 110° C. for 10 minutes to carry out a reaction, 0.79 mL (4.25 mmol) of diphenylmethyl phosphine was added thereto, the temperature was raised to 180° C., and then the resulting mixture was stirred for 18 hours. Once the reaction was completed, the resultant was cooled to room temperature, and the obtained solid was filtered under reduced pressure, and washed with methanol. The identity of the obtained compound was confirmed by using LCMS and ^1H NMR.

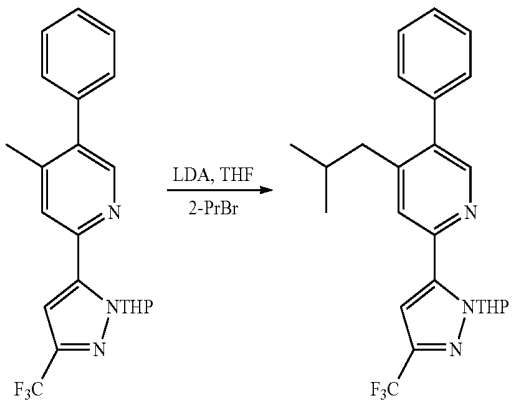
[0283] 1H-NMR ($CDCl_3$) (9.85 (br. s, 2H), 7.52 (t, 4H), 7.43 (t, 2H), 7.31 (d, 4H), 6.98 (m, 12H), 6.80 (t, 4H), 6.69 (s, 2H), 6.58 (d, 4H), 6.36 (br. s, 2H), 2.14 (s, 6H), 0.993 (s, 6H).

[0284] MS: m/z 1197.29 [$(M+1)^+$].

Synthesis Example 2

Synthesis of Compound 3

[0285] 1) Synthesis of Compound B2



Compound A2 Compound B2

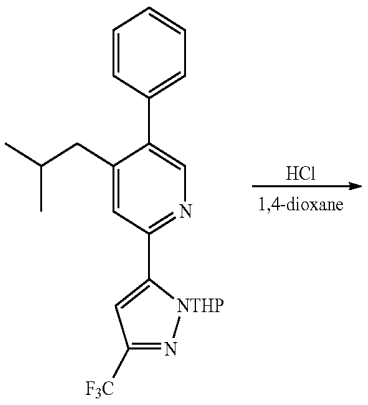
[0286] 2.08 g (5.37 mmol) of Compound A2 was mixed with 30 mL of THF, and the mixture was cooled up to a temperature of −78° C. 13.42 mmol of lithium diisopropylamide (LDA) was slowly added thereto. The mixture was stirred at a temperature of −78° C. for 1 hour to carry out a reaction. The temperature was then raised to room temperature, and the reaction was additionally carried out for 1.5 hours. The temperature was subsequently reduced to −78° C., and 1.26 mL (13.42 mmol) of 2-bromopropane was slowly added to the reaction mixture. Then, the temperature was raised to room temperature, and the reaction was carried out for 12 hours. An organic layer was extracted therefrom by using dichloromethane, and $MgSO_4$ was added thereto to dry the organic layer. The resultant was filtered, and a solvent in the obtained filtrate was removed under reduced pressure. The residual was purified by column chromatography using ethyl acetate and hexane at a ratio of 1:8 (v/v) to obtain 0.92 g (40%) of Compound B2. The identity of the obtained compound was confirmed by using LCMS and ^1H NMR.

[0287] 1H-NMR ($CDCl_3$) δ 8.50 (s, 1H), 7.61 (s, 1H), 7.53 (m, 3H), 7.39 (m, 2H), 7.03 (s, 1H), 6.30 (dd, 1H), 4.02 (d,

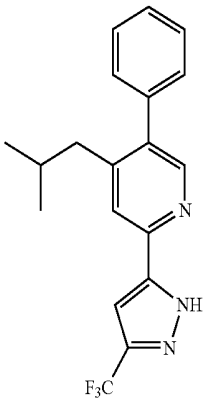
1H), 3.60 (t, 1H), 2.41 (d, 2H), 2.09 (m, 2H), 1.99 (m, 1H), 1.71 (m, 2H), 1.54 (m, 2H), 1.07 (d, 6H).

[0288] MS: m/z 430.20 [(M+1)$^+$].

[0289] 2) Synthesis of Compound B1



Compound B2



Compound B1

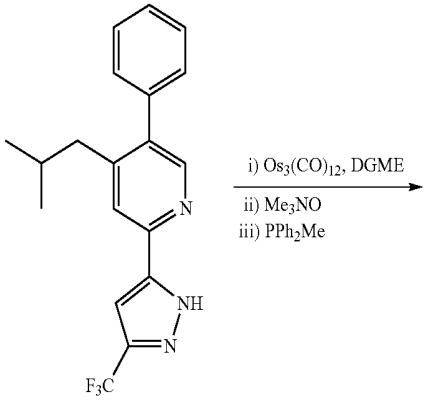
[0290] 0.92 g (2.37 mmol) of Compound B2 was dissolved in 15 mL of 1,4-dioxane. The solution was slowly added to 5.94 mL (11.87 mmol) of hydrochloric acid dissolved in diethyl ether at a concentration of 2.0 N and stirred at a temperature of 65° C. for 2 hours. Once the reaction was completed, the mixture was cooled to room temperature, and the obtained precipitate was filtered under reduced pressure, and washed with diethyl ether. The obtained solid was neutralized by using a sodium hydrogen carbonate aqueous solution. Subsequently, an organic layer was extracted therefrom by using ethyl acetate, and anhydrous $MgSO_4$ was added thereto to dry the organic layer. The resultant was filtered and a solvent in the obtained filtrate was removed under reduced pressure. The residual was purified by column chromatography using ethyl acetate and hexane at a ratio of 1:5 (v/v) to obtain 0.83 g (71%) of Compound B1.

[0291] The identity of the obtained compound was confirmed by using LCMS and ^{1}H NMR.

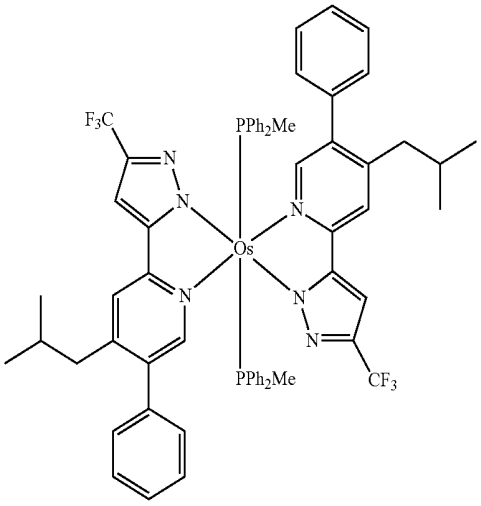
[0292] 1H-NMR ($CDCl_3$) δ 12.1 (br. s, 1H), 8.43 (s, 1H), 7.53 (s, 1H), 7.46 (m, 3H), 7.31 (m, 2H), 6.99 (s, 1H), 2.57 (d, 2H), 1.78 (m, 1H), 0.79 (d, 6H).

[0293] MS: m/z 346.15 [(M+1)$^+$].

[0294] 3) Synthesis of Compound 3



Compound B1



Compound 3

[0295] 0.82 g (2.38 mmol) of Compound B1 and 0.35 g (0.39 mmol) of triosmium dodecacarbonyl were dissolved in 20 mL of diethylene glycol monoethyl ether, and the solution was refluxed at a temperature of 180° C. for 18 hours. The solution was cooled to a temperature of 110° C., and 0.21 g (2.81 mmol) of trimethyl amine N-oxide dissolved in 5 mL of diethylene glycol monoethyl ether was slowly added thereto. Subsequently, the reaction solution was stirred at a temperature of 110° C. for 10 minutes to carry out a reaction, 1.05 mL (5.67 mmol) of diphenylmethyl phosphine was added thereto, the temperature was raised to 180° C., and the resulting mixture was stirred for 18 hours. Once the reaction was completed, the resultant was cooled to room temperature, and the obtained solid was filtered under reduced pressure, and washed with methanol. The identity of the obtained compound was confirmed by using LCMS and ^{1}H NMR.

[0296] 1H-NMR ($CDCl_3$) δ 7.50 (m, 7H), 7.18 (m, 1H), 7.03 (m, 7H), 6.97 (m, 7H), 6.83 (t, 5H), 6.63 (m, 7H), 6.39 (m, 2H), 2.36 (d, 4H), 1.90 (m, 2H), 0.65 (d, 12H), 0.60 (d, 3H), 0.55 (d, 3H).

[0297] MS: m/z 1281.39 [(M+1)$^+$].

Evaluation Example 1

Photoluminescence (PL) Spectrum Evaluation

[0298] Compounds 1 and 3 were dissolved at a concentration of 0.1 millimolar (mM) in toluene, and an ISC PC1 spectrofluorometer, in which a Xenon lamp was mounted, was used to measure PL spectra of Compounds 1 and 3 at room temperature. The results thereof are shown in Table 2 and FIG. **2**.

TABLE 2

Compound No.	λ_{max} (nm)
Compound 1	622
Compound 3	623

[0299] Referring to Table 2, it was found that Compounds 1 and 3 emitted red light.

Evaluation Example 2

Thermal Characteristics Evaluation

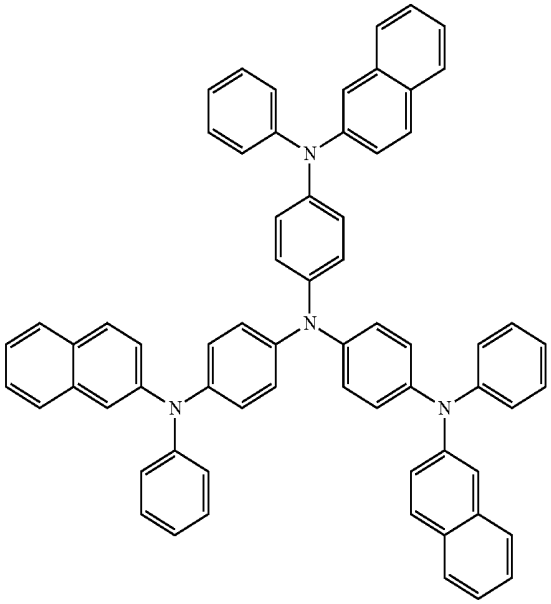
[0300] Thermal analysis (N_2 atmosphere, temperature range: room temperature to 800° C. (10 degrees Centigrade per minute, ° C./min)-TGA, and Pan Type: Pt Pan in disposable Al Pan (TGA)) was performed on Compound 3 by using thermogravimetric analysis (TGA). The results thereof are shown in FIG. **3**. Referring to FIG. **3**, Compound 3 was found to have excellent thermal stability.

Example 1

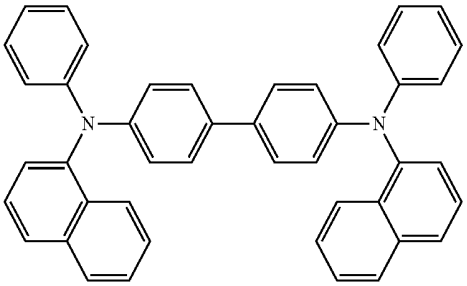
[0301] A glass substrate, on which an anode having an ITO/Ag/ITO (70 Å/1,000 Å/70 Å) structure was deposited, was cut to a size of 50 millimeters (mm)×50 mm×0.5 mm, sonicated in iso-propyl alcohol and water for 5 minutes, respectively, and cleaned by exposure to ultraviolet rays for 30 minutes, and then—to ozone. The glass substrate was mounted on a vacuum-deposition device.

[0302] 2-TNATA was deposited on the anode to form a hole injection layer having a thickness of 600 Å. 4,4'-bis [N-(1-naphthyl)-N-phenylamino]biphenyl (hereinafter, referred as "NPB") was deposited on the hole injection layer to form a hole transport layer having a thickness of 1,350 Å.

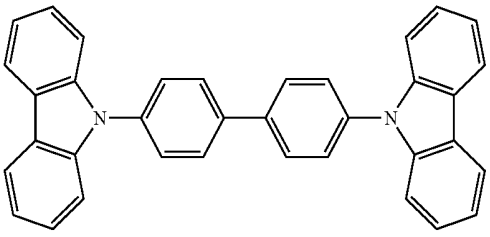
[0303] CBP (as a host) and Compound 1 (as a dopant) were co-deposited on the hole transport layer at a weight ratio of 94:6 to form an emission layer having a thickness of 400 Å. BCP was deposited on the emission layer to form a hole blocking layer having a thickness of 50 Å. Subsequently, Alq_3 was deposited on the hole blocking layer to form an electron transport layer having a thickness of 350 Å. LiF was deposited on the electron transport layer to form an electron injection layer having a thickness of 10 Å. Mg:Ag was deposited on the electron injection layer at a weight ratio of 90:10 to form a cathode having a thickness of 120 Å, thereby completing the manufacture of an organic light-emitting device (red light-emitting organic light-emitting device).



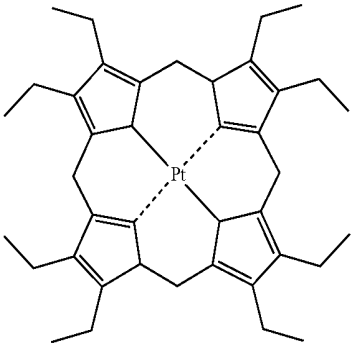
2-TNATA



NPB

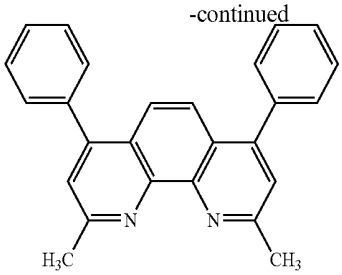


CBP



PtOEP

-continued



BCP

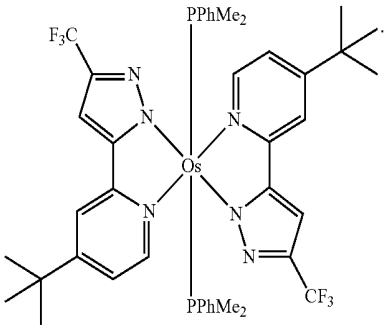
Example 2

[0304] An organic light-emitting device (emitting red light) was manufactured in the same manner as in Example 1, except that Compound 3 was used in place of Compound 1 to form the emission layer.

Comparative Example 1

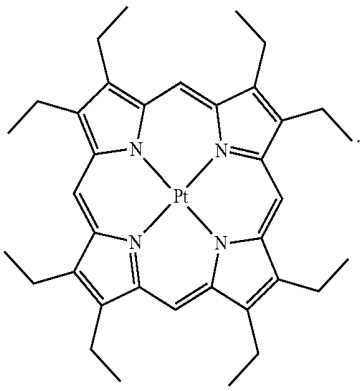
[0305] An organic light-emitting device was manufactured in the same manner as in Example 1, except that Compound B was used in place of Compound 1 to form the emission layer:

B



Comparative Example 2

[0306] An organic light-emitting device was manufactured in the same manner as in Example 1, except that PtOEP was used in place of Compound 1 to form the emission layer:



PtOEP

Evaluation Example 3

Evaluation of Characteristics of Organic Light-Emitting Device

[0307] The driving voltage, current density, luminance, efficiency, external quantum efficiency, PL decay time, roll-off, color-coordinate, and lifespan (T_{97}) of the organic light-emitting devices manufactured in Examples 1 to 3 and Comparative Examples 1 and 2 were evaluated. The results thereof are shown in Table 3. A Keithley 2400 current voltmeter and a luminance meter (Minolta Cs-1000A) were used in the evaluation. The lifespan (T_{97}) refers to time required for the initial luminance of the organic light-emitting device to reduce by 97%.

TABLE 3

	Dopant	Driving voltage (V)	Current density (mA/cm^2)	Efficiency (cd/A)	External quantum efficiency (%)	Decay time (μs)	Roll-off (%)	λ_{max} (nm)	CIEx	LT_{97} (hr)
Example 1	Compound 1	4.7	7.9	19.1	18.7	0.89	11	622	0.66	125
Example 2	Compound 3	4.5	6.5	23.1	23.3	0.79	9	623	0.67	200
Comparative Example 1	B	4.9	8.0	18.9	15.1	0.87	15	616	0.64	65
Comparative Example 2	PtOEP	7.3	10.1	4.5	4.0	24	43	645	0.69	40

[0308] Referring to Table 3, the organic light-emitting devices manufactured in Examples 1 and 2 were found to have excellent efficiency, as compared with the organic light-emitting devices manufactured in Comparative Examples 1 and 2.

[0309] In addition, since the organometallic compound represented by Formula 1 includes a pyridine ring substi-

tuted with an aryl group, such as a phenyl group, at a certain position, an organic light-emitting device including the organometallic compound may have improved lifespan and efficiency as seen by Examples 1 and 2 and Comparative Examples 1 and 2.

[0310] In addition, by introducing a bulky substituent at an α-position of an aryl group of a pyridine ring, triplet-triplet annihilation may decrease, thus improving the efficiency of an organic light-emitting device as seen by Examples 1 and 2.

[0311] Since the compounds included in the organic light-emitting devices of Examples 1 and 2 may have relatively short decay time, the organic light-emitting devices of Examples 1 and 2 may each have low roll-off and high efficiency.

[0312] As described above, an organometallic compound, according to one or more embodiments, has excellent electric characteristics and thermal stability. Accordingly, an organic light-emitting device using the organometallic compound has excellent efficiency, excellent external quantum efficiency, low driving voltage, high luminance, long lifespan characteristics, and low roll-off characteristics.

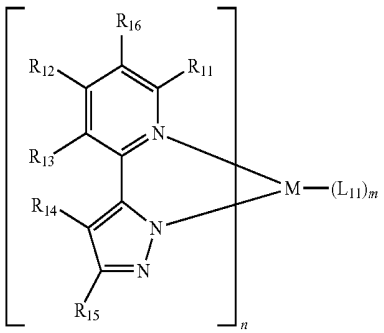
[0313] It should be understood that embodiments described herein should be considered in a descriptive sense only and not for purposes of limitation. Descriptions of features or aspects within each embodiment should typically be considered as available for other similar features or aspects in other embodiments.

[0314] 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.

What is claimed is:

1. An organometallic compound represented by Formula 1:

Formula 1



wherein, in Formula 1,

M is selected from osmium (Os) and ruthenium (Ru),

R_{11} to R_{13} and R_{16} are each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_7-C_{60} arylalkyl 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 C_2-C_{60} heteroarylalkyl 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 selected from R_{11} to R_{13} and R_{16} is selected from 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,

R_{14} and R_{15} are each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, and a substituted or unsubstituted C_6-C_{60} aryl group,

n is selected from 1, 2, and 3,

L_{11} is selected from a monodentate ligand and a bidentate ligand, and

m is selected from 0, 1, 2, 3, and 4.

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

R_{11}, R_{12}, R_{13}, or R_{16} is selected from 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;

two substituents of among R_{11}, R_{12}, R_{13}, and R_{16} are each independently selected from 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;

three substituents of among R_{11}, R_{12}, R_{13}, and R_{16} are each independently selected from 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; or

R_{11}, R_{12}, R_{13}, and R_{16} are each independently selected from 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.

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

R_{11} to R_{13} and R_{16} are each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a neo-pentyl group, a cyclopentyl group, a cyclohexyl group, and a cycloheptyl group;

a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl

group, and a neo-pentyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group;

a cyclopentyl group, a cyclohexyl group, and a cycloheptyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, and a neo-pentyl group;

a phenyl group, a naphthyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a thiazolyl group, an oxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a naphthyridinyl group, a benzofuranyl group, a benzothiophenyl group, a triazinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

a phenyl group, a naphthyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a thiazolyl group, an oxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a naphthyridinyl group, a benzofuranyl group, a benzothiophenyl group, a triazinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a triazinyl group, and —$Si(Q_1)(Q_2)(Q_3)$,

provided that at least one selected from R_{11} to R_{13} and R_{16} is selected from a phenyl group, a naphthyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a thiazolyl group, an oxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a naphthyridinyl group, a benzofuranyl group, a benzothiophenyl group, a triazinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

a phenyl group, a naphthyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, a chrysenyl group, a pyrrolyl group, a thiophenyl group, a furanyl group, an imidazolyl group, a thiazolyl group, an oxazolyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a quinolinyl group, an isoquinolinyl group, a benzoquinolinyl group, a quinoxalinyl group, a quinazolinyl group, a naphthyridinyl group, a benzofuranyl group, a benzothiophenyl group, a triazinyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine group, a hydrazone group, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1-C_{20} alkyl group, a C_1-C_{20} alkoxy group, a phenyl group, a naphthyl group, a pyridinyl group, a pyrazinyl group, a pyrimidinyl group, a triazinyl group, and —$Si(Q_1)(Q_2)(Q_3)$,

wherein Q_1 to Q_3 are each independently selected from a C_1-C_{20} alkyl group and a C_6-C_{60} aryl group.

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

R_{11} to R_{13} and R_{16} are each independently selected from hydrogen, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a cyclopentyl group, and a cyclohexyl group;

a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, and a tert-butyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group;

a cyclopentyl group and a cyclohexyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a cyano group, a methyl group, and an ethyl group;

a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a methoxy group, an ethoxy group, an n-propoxy group, an iso-propoxy group, an n-butoxy group, a tert-butoxy group, a phenyl group, and —$Si(CH_3)_3$,

provided that at least one selected from R_{11} to R_{13} and R_{16} is selected from a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a methoxy group, an ethoxy group, an n-propoxy group, an iso-propoxy group, an n-butoxy group, a tert-butoxy group, a phenyl group, and —$Si(CH_3)_3$.

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

R_{11} to R_{13} are each independently selected from hydrogen, a methyl group, an ethyl group, an n-propyl group,

an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a cyclopentyl group, and a cyclohexyl group;

a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, and a tert-butyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group;

a cyclopentyl group and a cyclohexyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a cyano group, a methyl group, and an ethyl group;

a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, $—CD_3$, $—CD_2H$, $—CDH_2$, $—CF_3$, $—CF_2H$, $—CFH_2$, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a methoxy group, an ethoxy group, an n-propoxy group, an iso-propoxy group, an n-butoxy group, a tert-butoxy group, a phenyl group, and $—Si(CH_3)_3$, and

R_{16} is selected from a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, $—CD_3$, $—CD_2H$, $—CDH_2$, $—CF_3$, $—CF_2H$, $—CFH_2$, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a methoxy group, an ethoxy group, an n-propoxy group, an iso-propoxy group, an n-butoxy group, a tert-butoxy group, a phenyl group, and $—Si(CH_3)_3$.

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

R_{11}, R_{13}, and R_{16} are each independently selected from hydrogen, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a cyclopentyl group, and a cyclohexyl group;

a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, and a tert-butyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, and a cyano group;

a cyclopentyl group and a cyclohexyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a cyano group, a methyl group, and an ethyl group;

a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, $—CD_3$, $—CD_2H$, $—CDH_2$, $—CF_3$, $—CF_2H$, $—CFH_2$, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a methoxy group, an ethoxy group, an n-propoxy group, an iso-propoxy group, an n-butoxy group, a tert-butoxy group, a phenyl group, and $—Si(CH_3)_3$, and

R_{12} is selected from a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group; and

a phenyl group, a thiophenyl group, a furanyl group, a thiazolyl group, an oxazolyl group, a dibenzofuranyl group, and a dibenzothiophenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, $—CD_3$, $—CD_2H$, $—CDH_2$, $—CF_3$, $—CF_2H$, $—CFH_2$, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a methoxy group, an ethoxy group, an n-propoxy group, an iso-propoxy group, an n-butoxy group, a tert-butoxy group, a phenyl group, and $—Si(CH_3)_3$.

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

R_{14} and R_{15} are each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, a neo-pentyl group, a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a phenyl group, a naphthyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, and a chrysenyl group;

a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, and a neo-pentyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, and —I; and

a cyclopentyl group, a cyclohexyl group, a cycloheptyl group, a phenyl group, a naphthyl group, a phenanthrenyl group, an anthracenyl group, a pyrenyl group, and a chrysenyl group, each substituted with at least one selected from deuterium, —F, —Cl, —Br, —I, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, an n-pentyl group, an iso-pentyl group, a sec-pentyl group, a tert-pentyl group, and a neo-pentyl group.

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

R_{14} and R_{15} are each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, a cyclopentyl group, a cyclohexyl group, a phenyl group, and a naphthyl group; and

a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group,

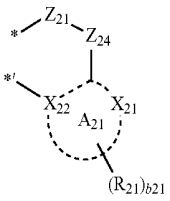
a sec-butyl group, and a tert-butyl group, each substituted with at least one selected from deuterium and —F.

9. The organometallic compound of claim **1**, wherein R_{14} and R_{15} are each independently selected from hydrogen, deuterium, —F, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a sec-butyl group, a tert-butyl group, —CD_3, —CD_2H, —CDH_2, —CF_3, —CF_2H, —CFH_2, and a phenyl group.

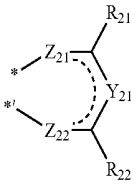
10. The organometallic compound of claim **1**, wherein n is 2.

11. The organometallic compound of claim **1**, wherein L_{11} is a ligand represented by one of Formulae 2-1 to 2-12:

2-1



2-2



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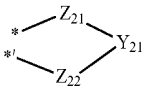

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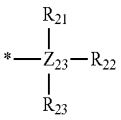

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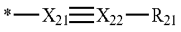
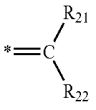


2-6



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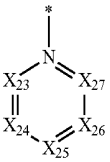
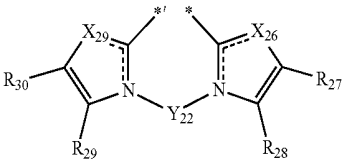
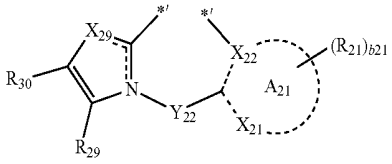


2-9

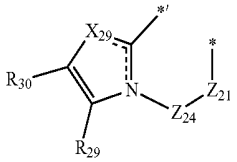


-continued

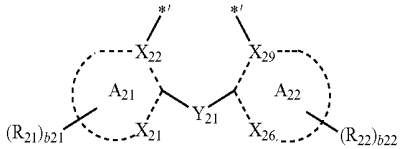
2-10



2-11



2-12



wherein, in Formulae 2-1 to 2-12,

A_{21} and A_{22} are each independently selected from a C_5-C_{20} carbocyclic group and a C_1-C_{20} heterocyclic group,

X_{21}, X_{22}, X_{28}, and X_{29} are each independently selected from C and N,

X_{23} is N or $C(Q_{23})$, X_{24} is N or $C(Q_{24})$, X_{25} is N or $C(Q_{25})$, X_{26} is N or $C(Q_{26})$, X_{27} is N or $C(Q_{27})$,

X_{28} is O, S, or $N(Q_{28})$, X_{29} is O, S, or $N(Q_{29})$, Y_{21} and Y_{22} are each independently selected from a single bond, a double bond, a substituted or unsubstituted C_1-C_5 alkylene group, a substituted or unsubstituted C_2-C_5 alkenylene group, and a substituted or unsubstituted C_6-C_{10} arylene group, Z_{21} and Z_{22} are each independently selected from N, O, $N(R_{25})$, $P(R_{25})(R_{26})$, and $As(R_{25})(R_{26})$,

Z_{23} is selected from phosphorus (P) and arsenic (As),

Z_{24} is selected from CO and CH_2,

R_{21} to R_{30} and Q_{23} to Q_{29} are each independently selected from hydrogen, 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 carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_2-C_{60} alkenyl group, a substituted or unsubstituted C_2-C_{60} alkynyl group, a substituted or unsubstituted C_1-C_{60} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_1-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted monovalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted monovalent non-aromatic condensed heteropolycyclic group, R_{21} and R_{22} are optionally bound to form a ring, R_{27} and R_{28} are optionally bound to form

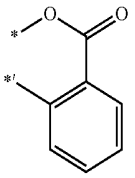
a ring, R_{28} and R_{29} are optionally bound to form a ring, R_{29} and R_{30} are optionally bound to form a ring,

b21 and b22 are each independently selected from 1, 2, and 3, and

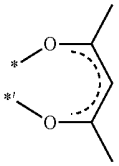
* and *' each independently indicate a binding site to an adjacent atom.

12. The organometallic compound of claim **1**, wherein L_{11} is a ligand represented by one of Formulae 3-1 to 3-25:

3-1



3-2



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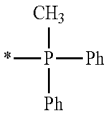

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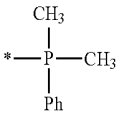

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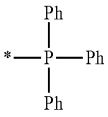
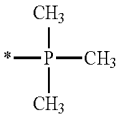


3-6



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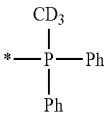

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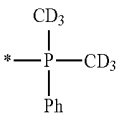

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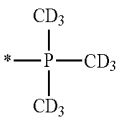

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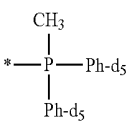

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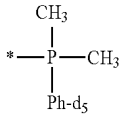
3-11



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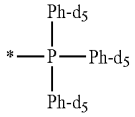

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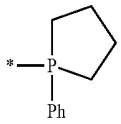

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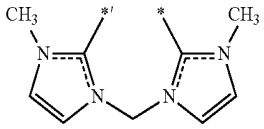

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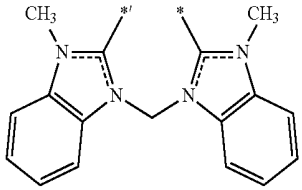

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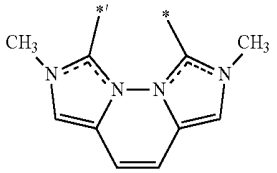

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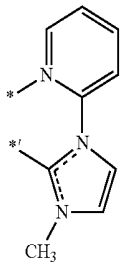

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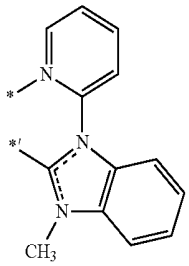

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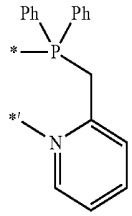
3-19



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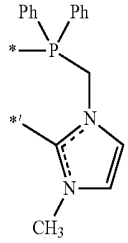

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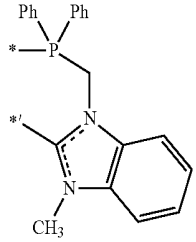

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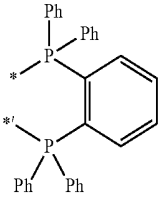

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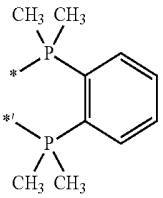

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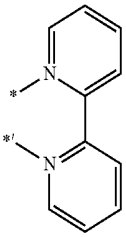
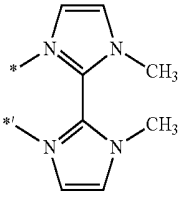


3-25



wherein, in Formulae 3-1 to 3-25,

"Ph" represents a phenyl group,

"Ph-d_5" represents a phenyl group of which all hydrogen atoms are substituted with deuterium atoms, and

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

13. The organometallic compound of claim **1**, wherein m is selected from 1 and 2.

14. The organometallic compound of claim **1**, wherein n is 2 and m is 2, or n is 2 and m is 1.

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

M is selected from Os and Ru,

R_{11} to R_{13} are each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkyl 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 divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

R_{16} is selected from a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

R_{14} and R_{15} are each independently selected from hydrogen, deuterium, —F, —Cl, —Br, —I, a cyano group, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, and a substituted or unsubstituted C_6-C_{60} aryl group,

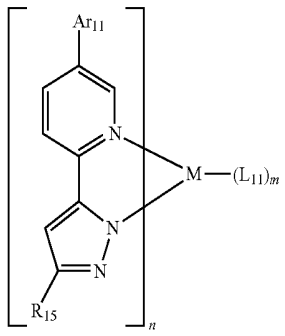
n is selected from 1, 2, and 3,

L_{11} is selected from a monodentate ligand and a bidentate ligand, and

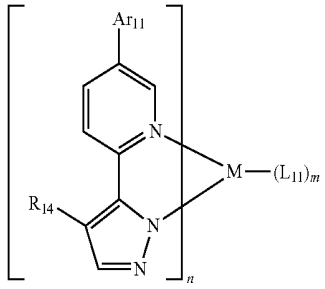
m is selected from 0, 1, 2, 3, and 4.

16. The organometallic compound of claim **1**, wherein the organometallic compound represented by Formula 1 is represented by one of Formulae 1-1 to 1-9:

1-1



1-2



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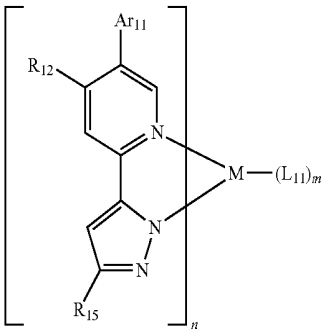
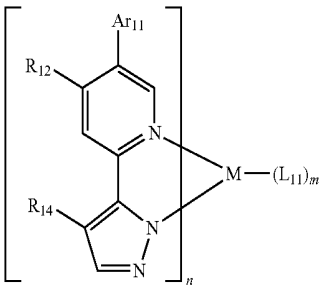
1-3



1-4



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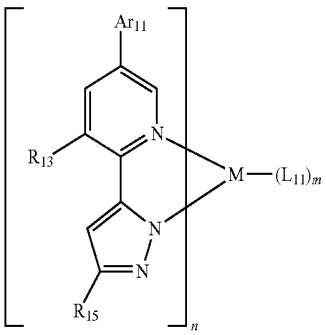

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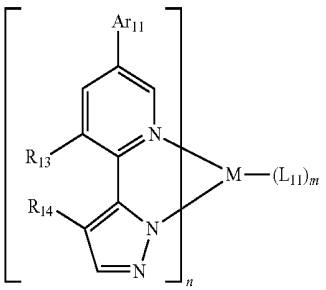
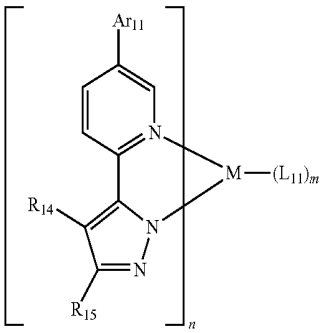


1-7



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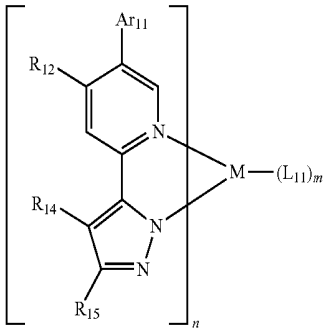
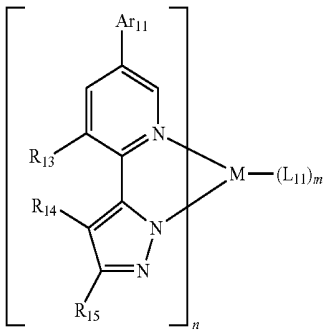


1-9



wherein, in Formulae 1-1 to 1-9,

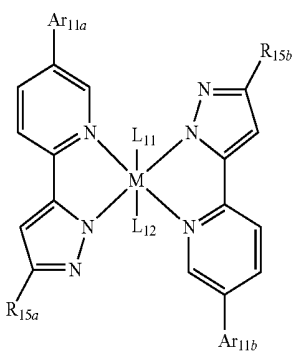
M, R_{12} to R_{15}, n, L_{11}, and m are the same as those defined above in connection with Formula 1, and

Ar_{11} is selected from a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

provided that each of R_{12} to R_{15} is not hydrogen.

17. The organometallic compound of claim **1**, wherein the organometallic compound represented by Formula 1 is represented by one of Formulae 1-11 to 1-19 and 1-21 to 1-29:

1-11



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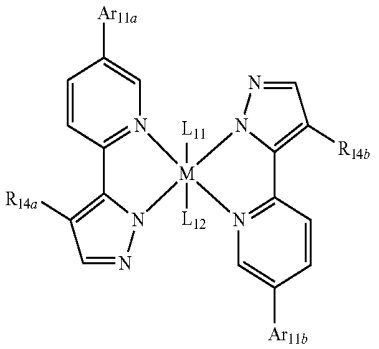
1-12



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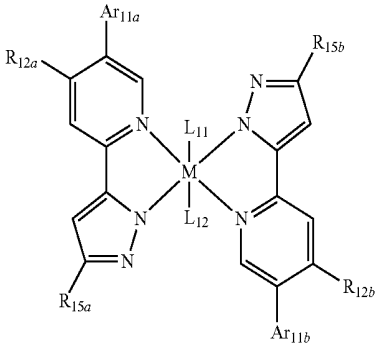
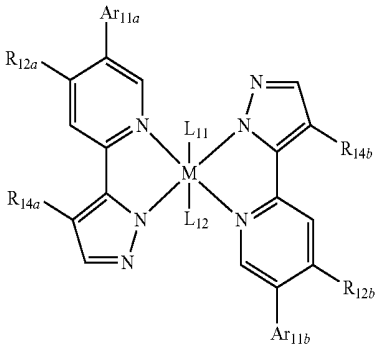
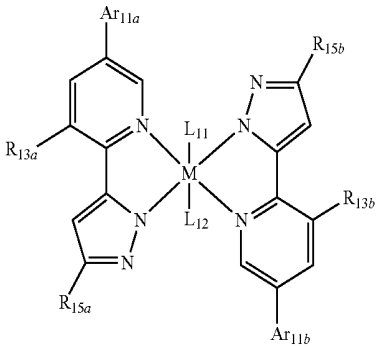


1-14



1-15



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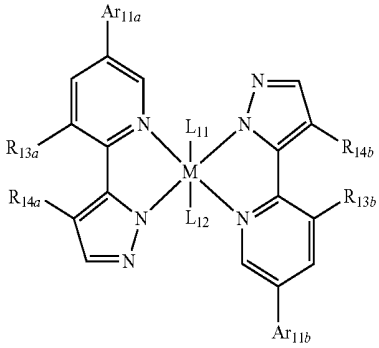
1-16



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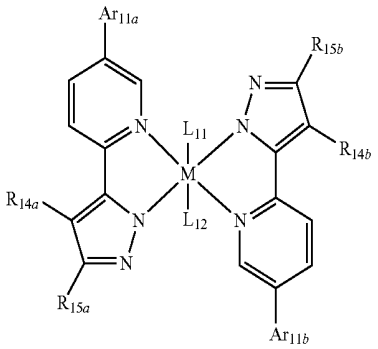

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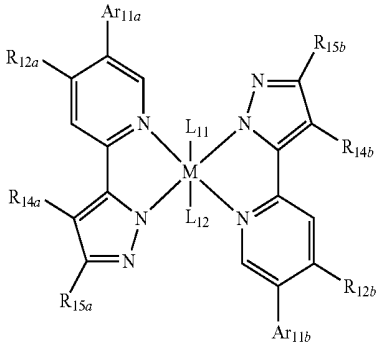

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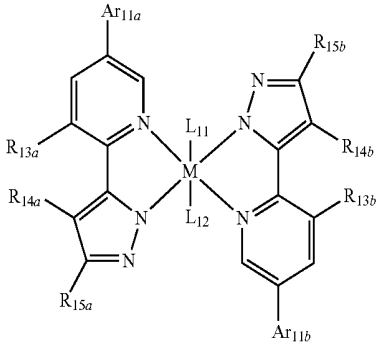

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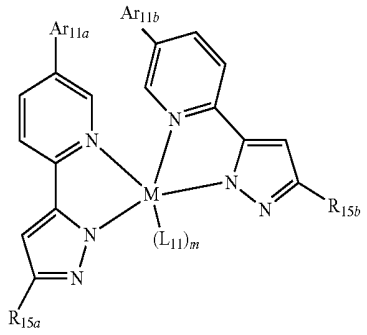

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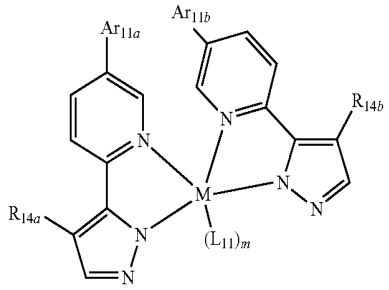

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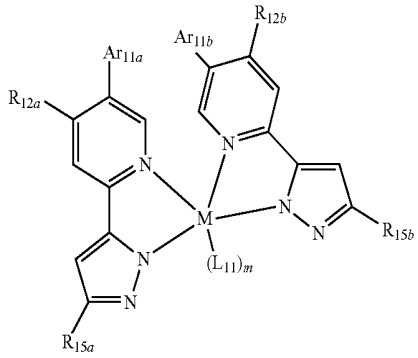

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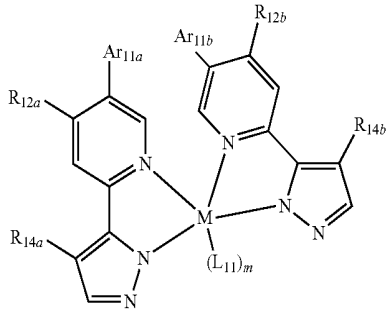

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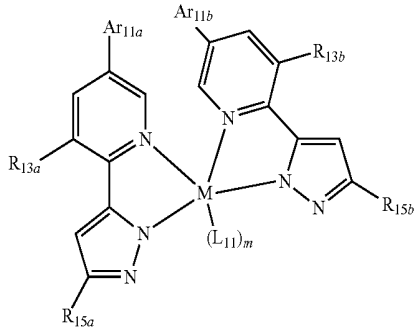

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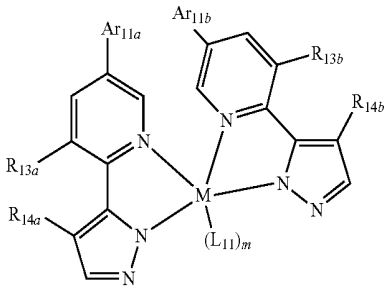

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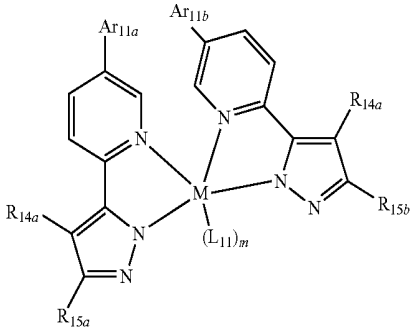

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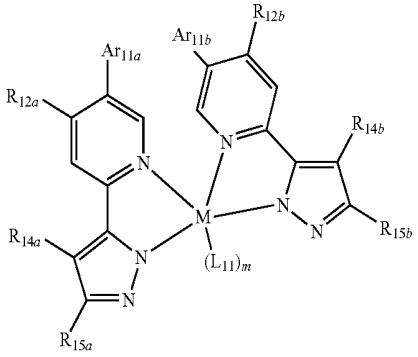

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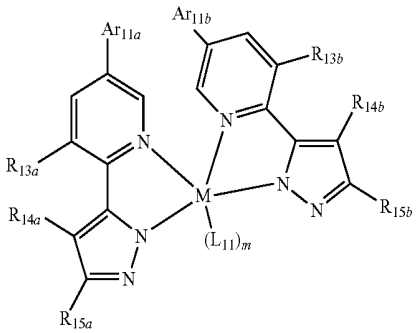


wherein, in Formulae 1-11 to 1-19 and 1-21 to 1-29,

L_{11} and m are the same as those defined above in connection with Formula 1,

Ar_{11a} and Ar_{11b} are each independently selected from a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_1-C_{60} heteroaryl group, a substituted or unsubstituted divalent non-aromatic condensed polycyclic group, and a substituted or unsubstituted divalent non-aromatic condensed heteropolycyclic group,

R_{12a} and R_{12b} are each independently the same as those defined in Formula 1 in connection with R_{12},

R_{13a} and R_{13b} are each independently the same as those defined in Formula 1 in connection with R_{13},

R_{14a} and R_{14b} are each independently the same as those defined in Formula 1 in connection with R_{14},

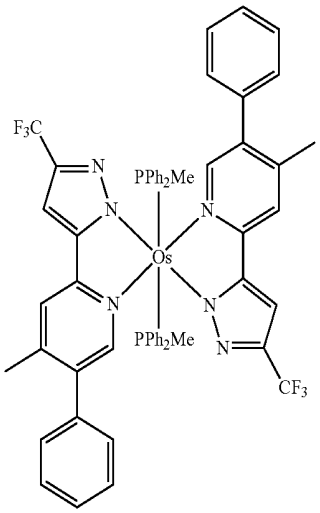
R_{15a} and R_{15b} are each independently the same as those defined in Formula 1 in connection with R_{15}, and

L_{12} is the same as L_{11} defined in Formula 1,

provided that each of R_{12} to R_{15} is not hydrogen.

18. The organometallic compound of claim **1**, wherein the organometallic compound represented by Formula 1 is selected from Compounds 1 to 176:

1



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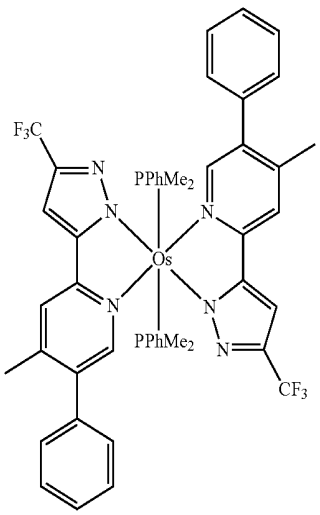

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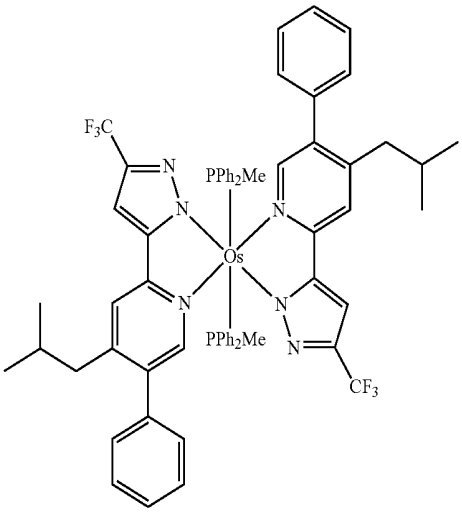

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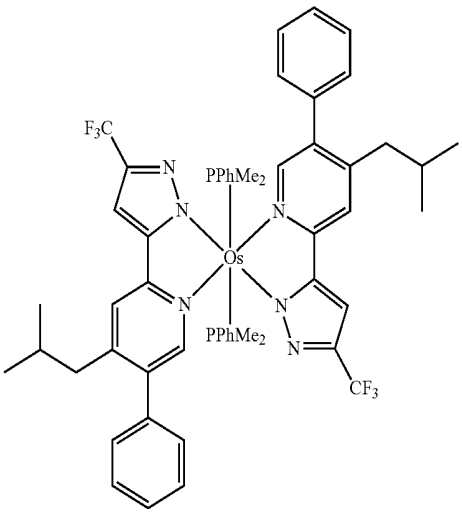

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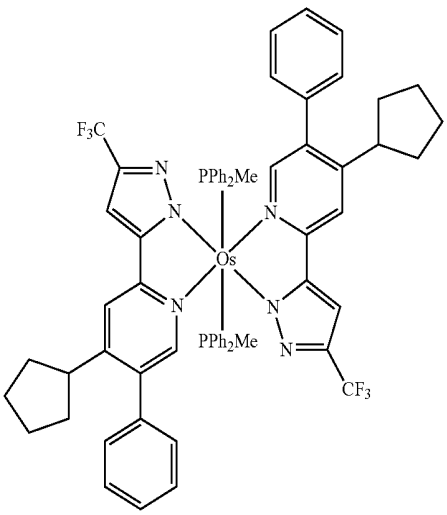

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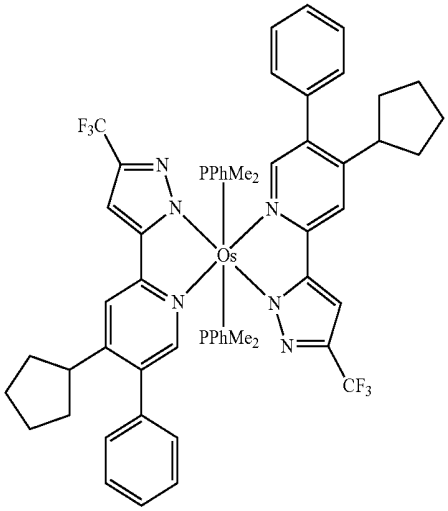

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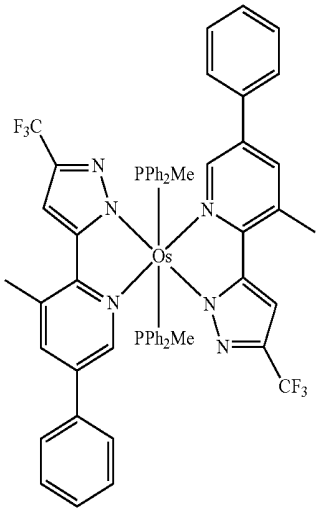

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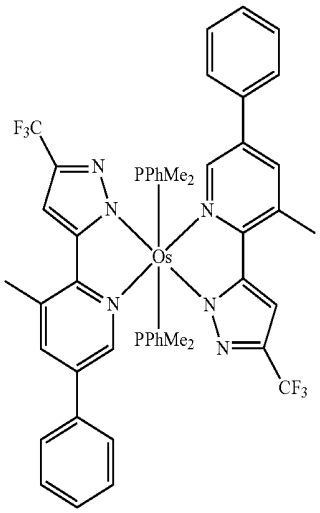

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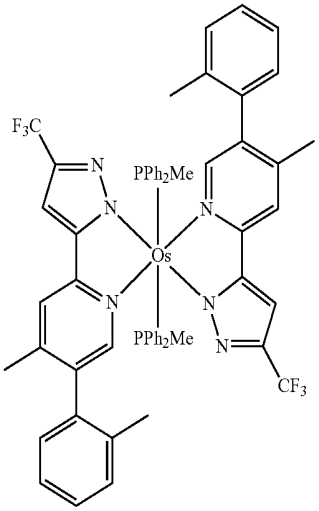

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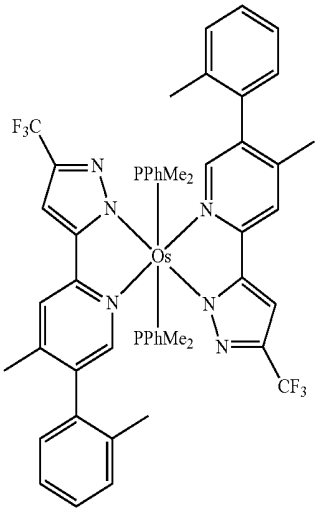

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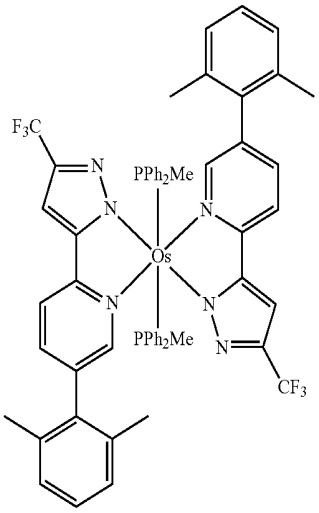

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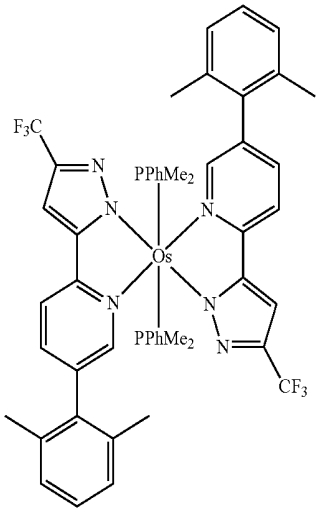

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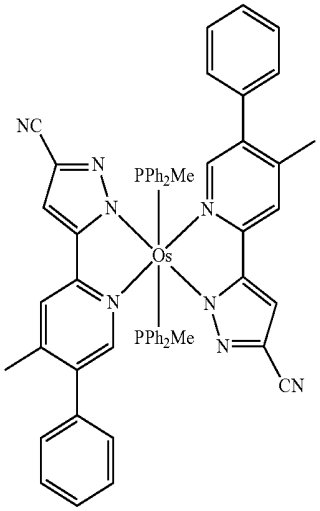

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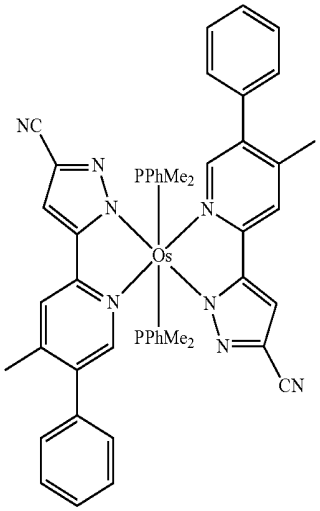

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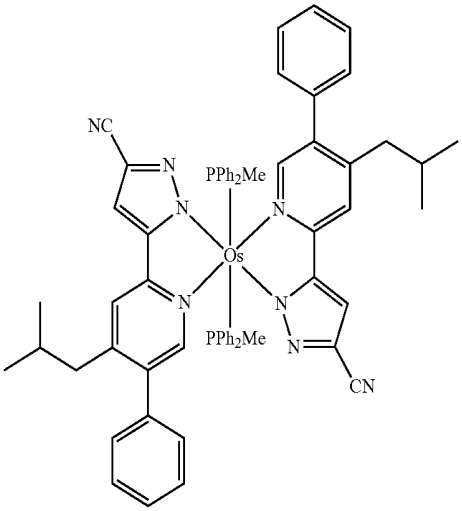

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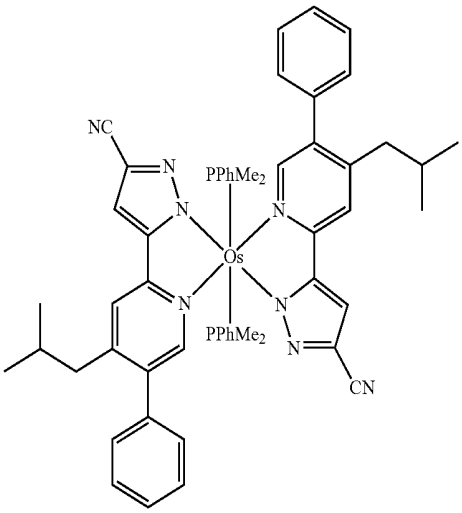

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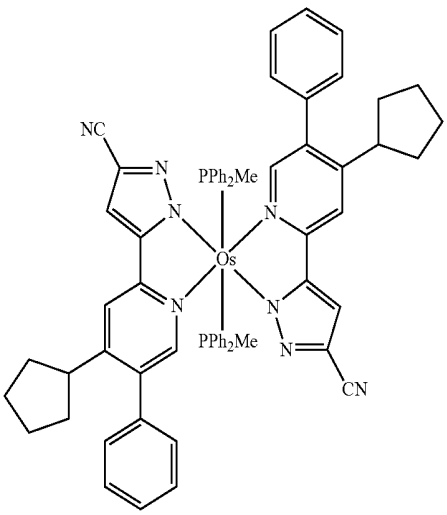

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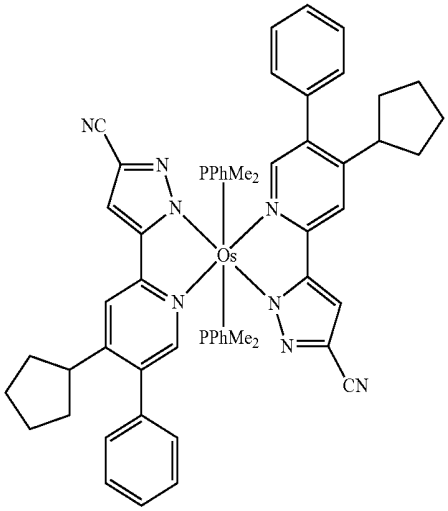

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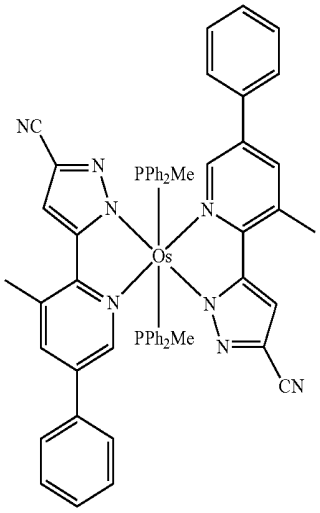

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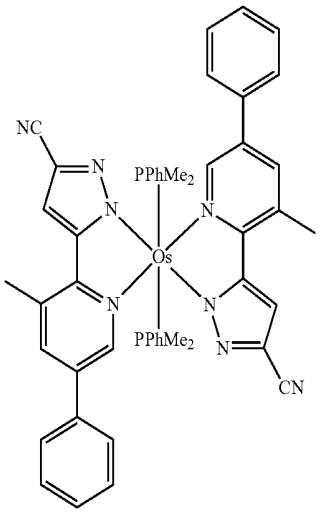

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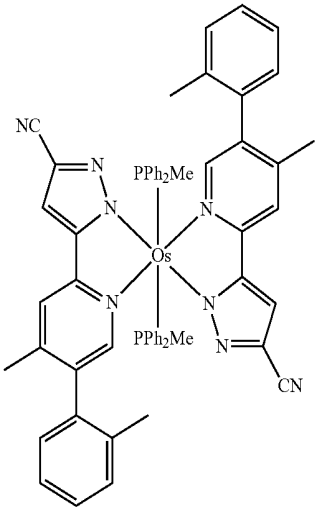

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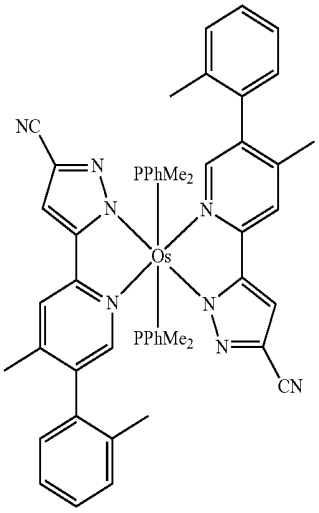

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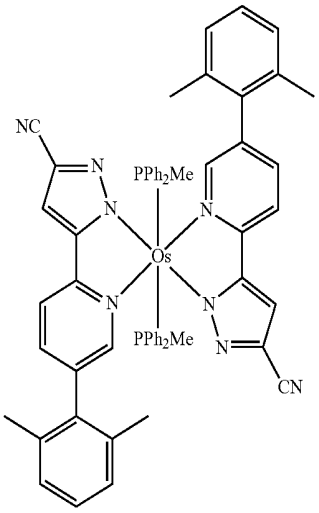

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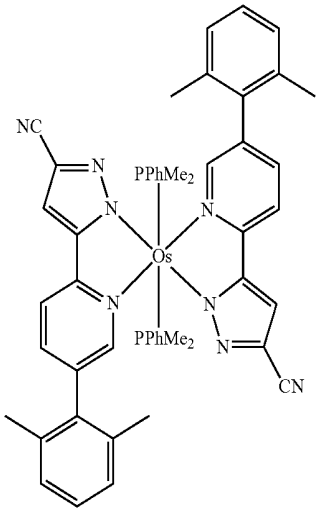

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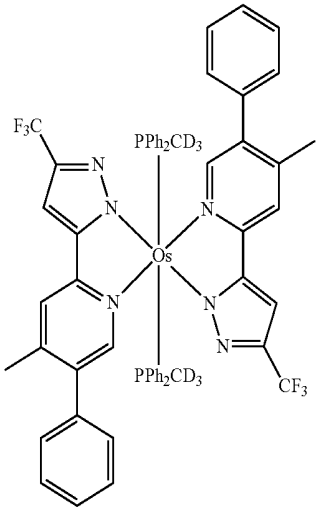

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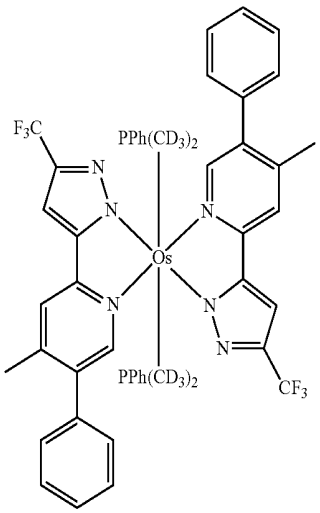

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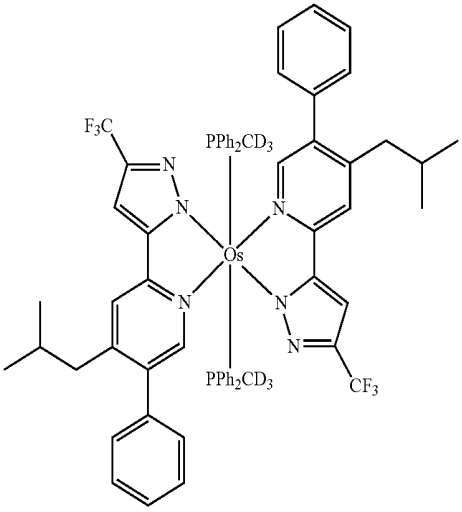

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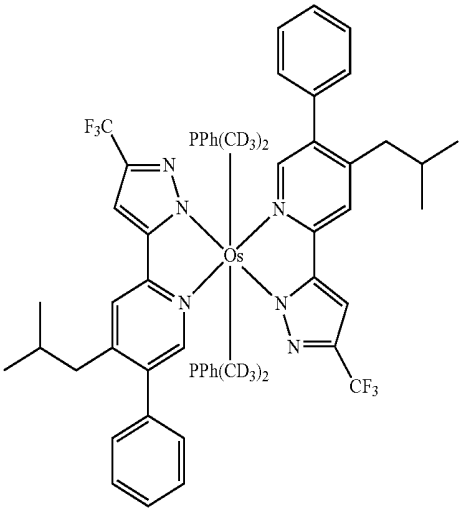

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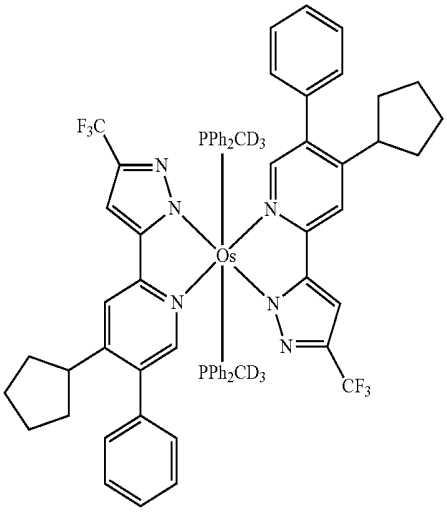

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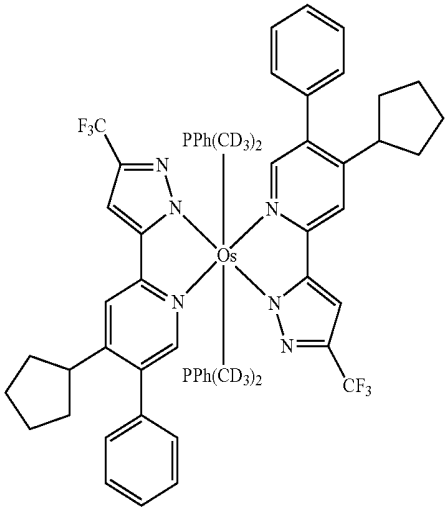

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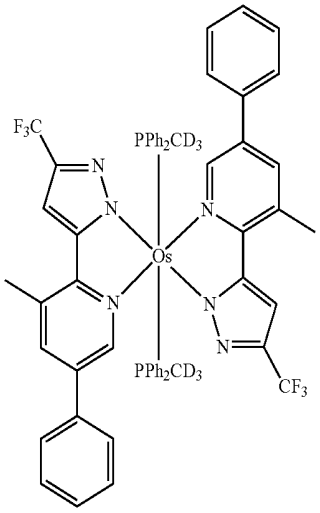

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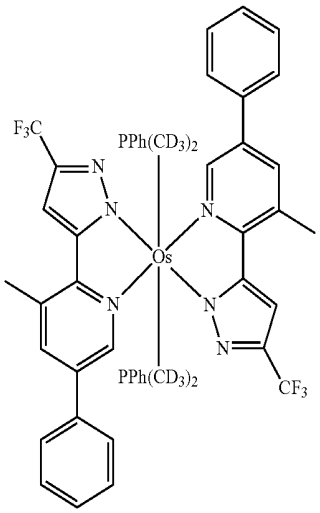

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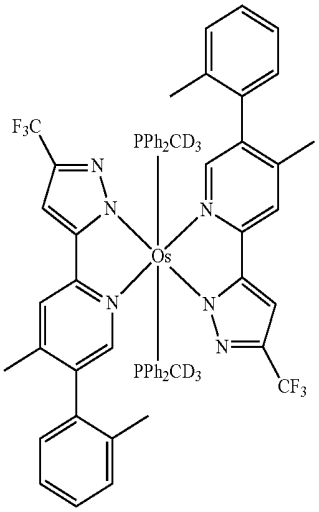

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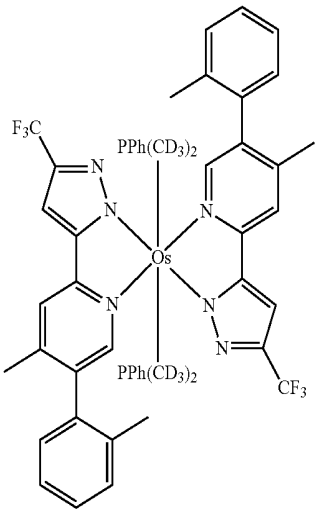

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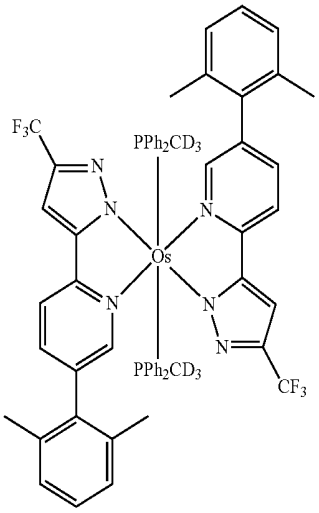

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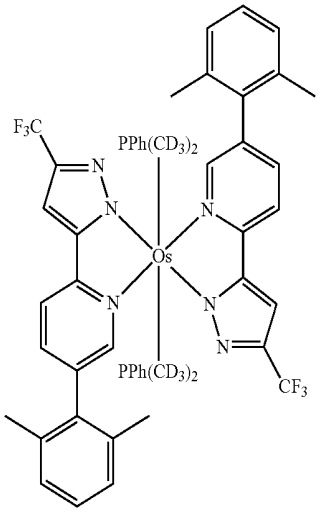

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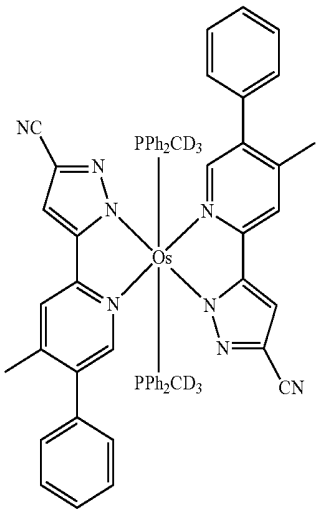

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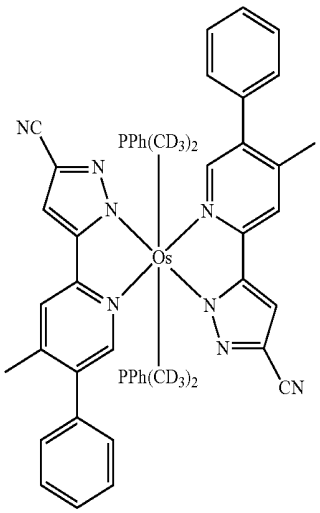

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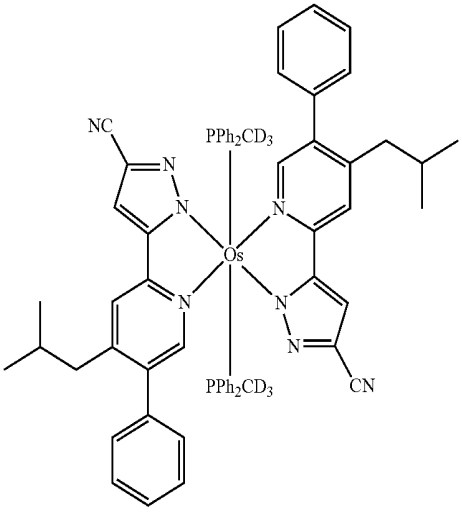

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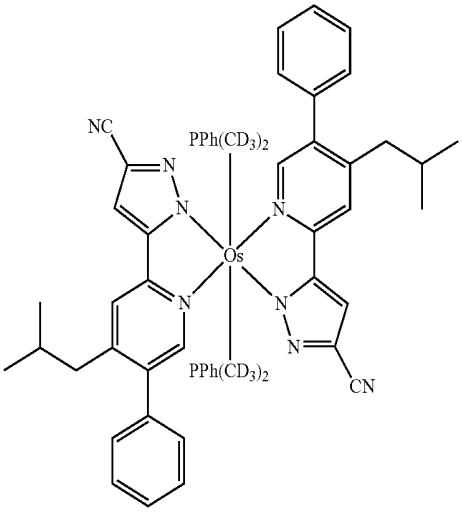

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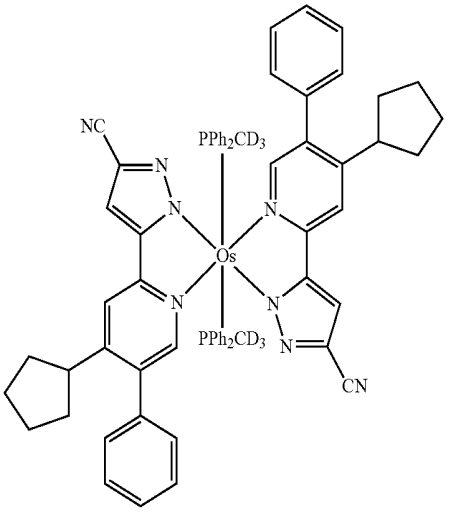

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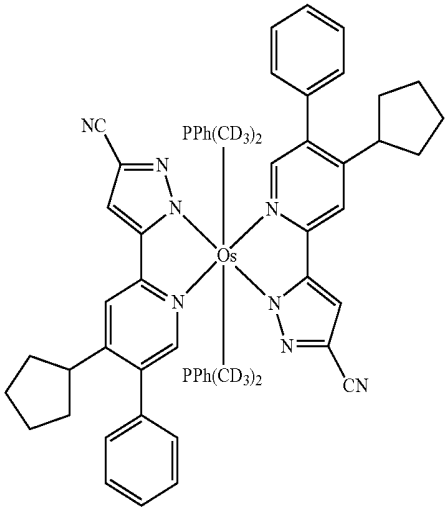

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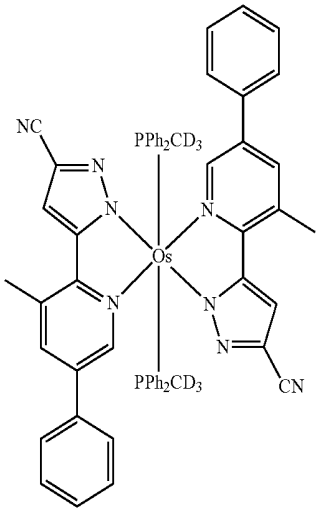

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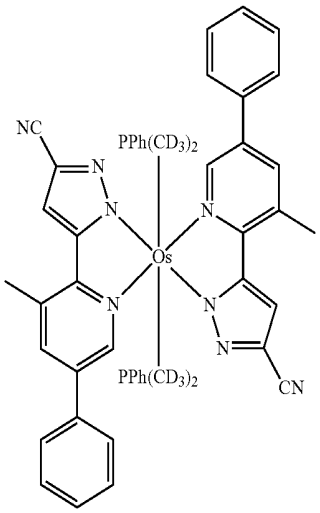

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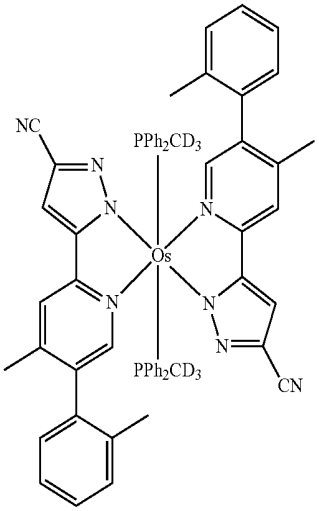

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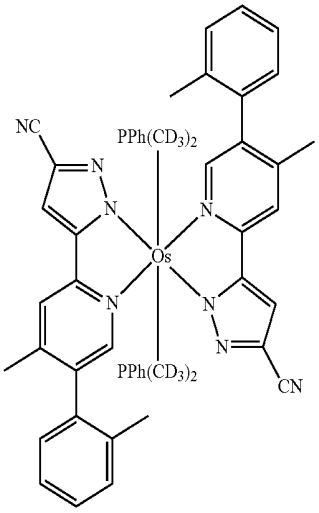

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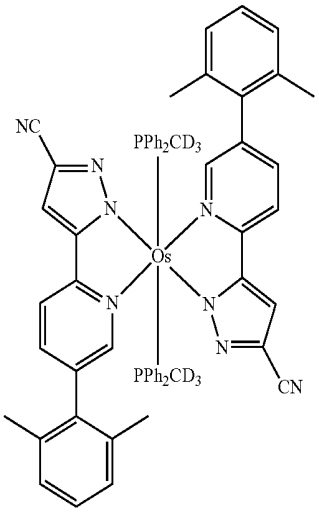

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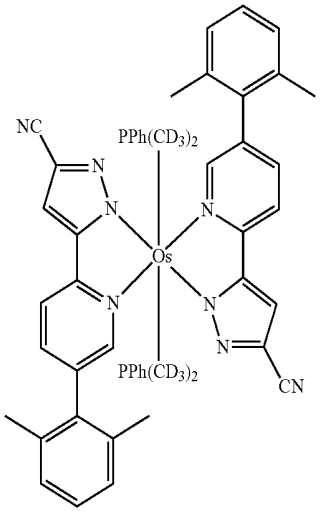

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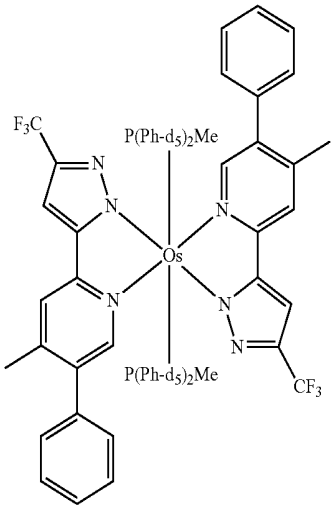

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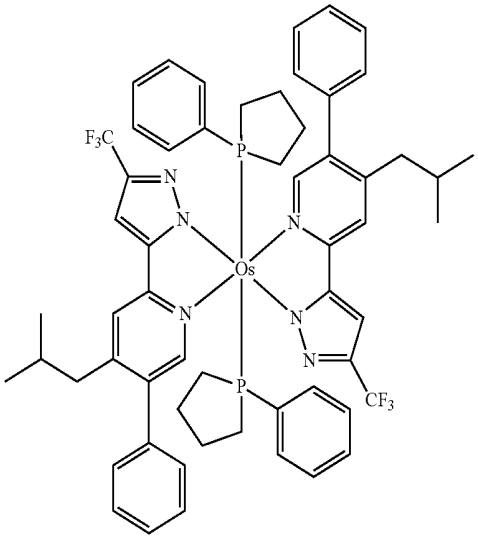

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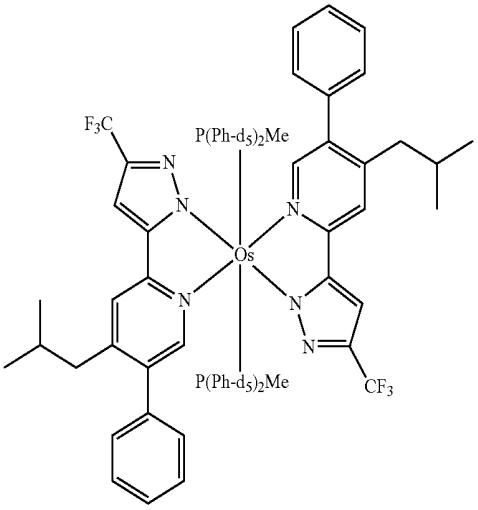

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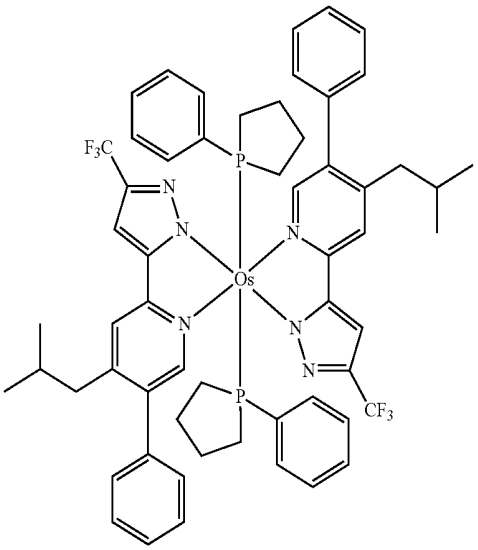

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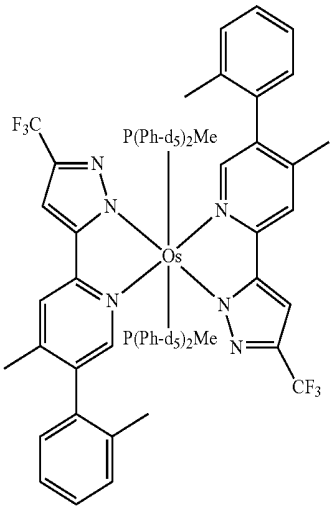

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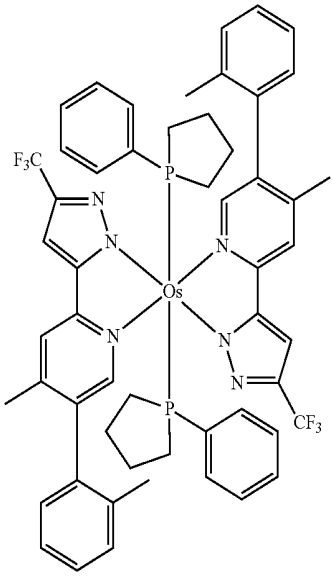

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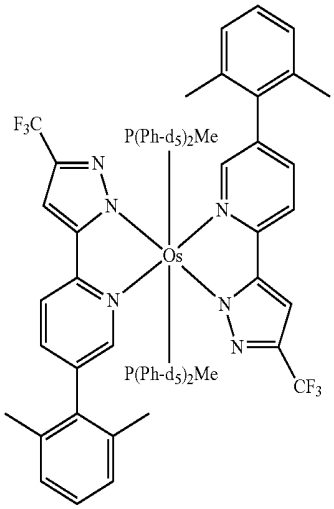

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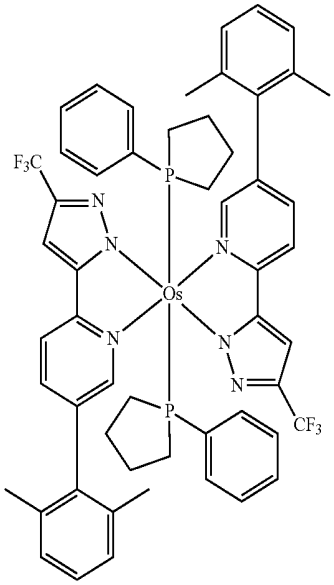

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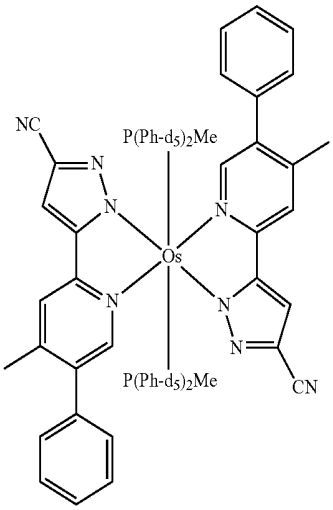

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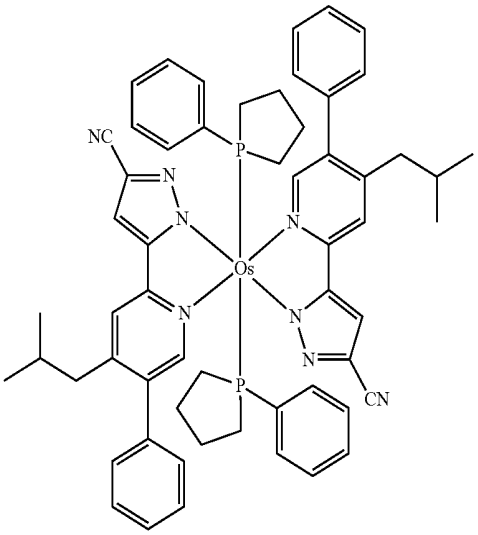

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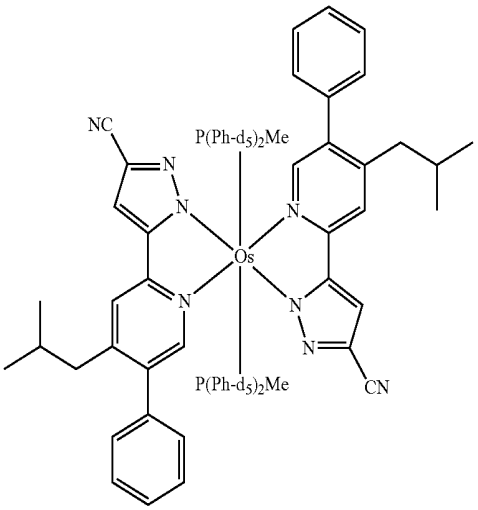

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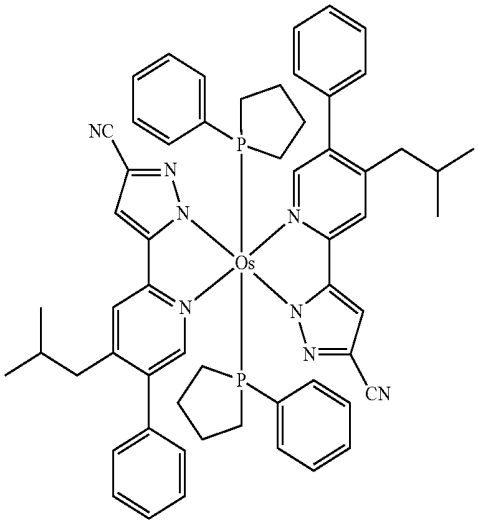

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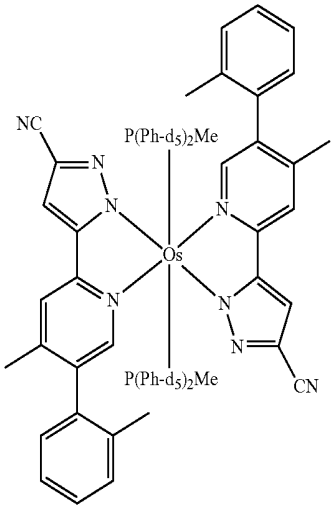

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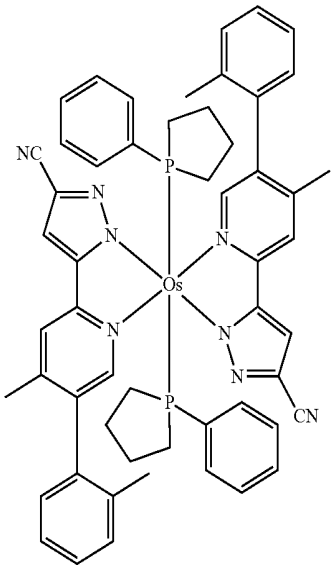

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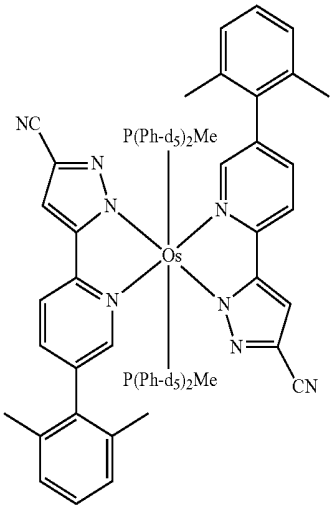

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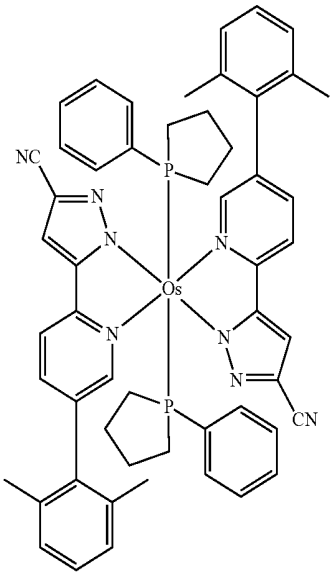

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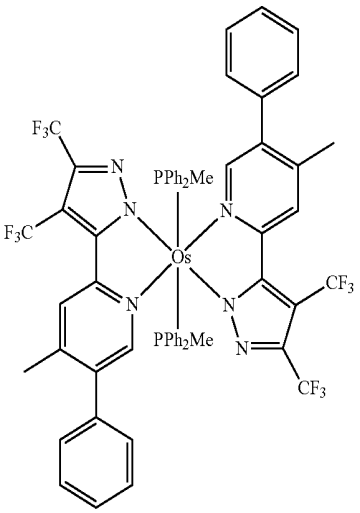

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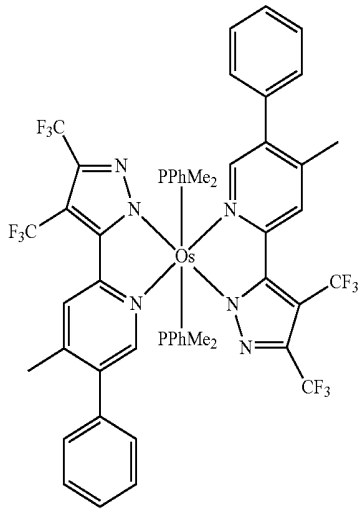

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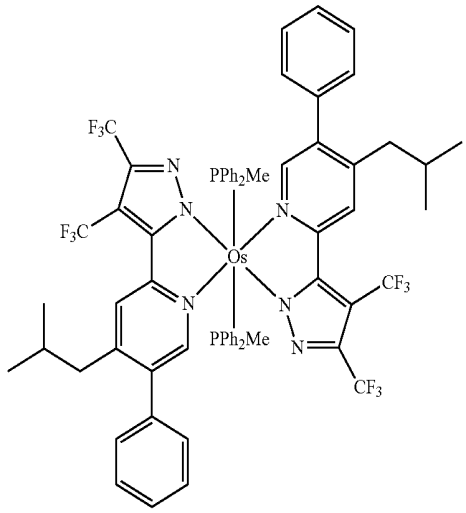

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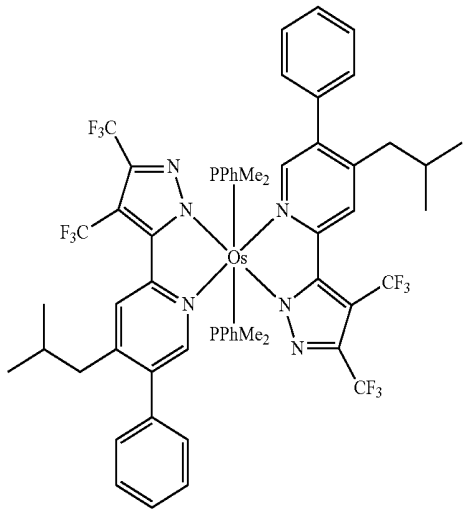

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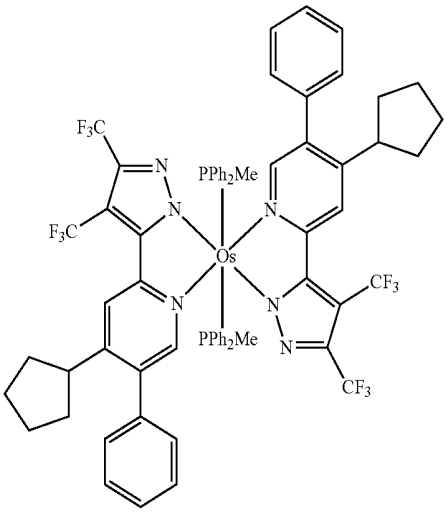

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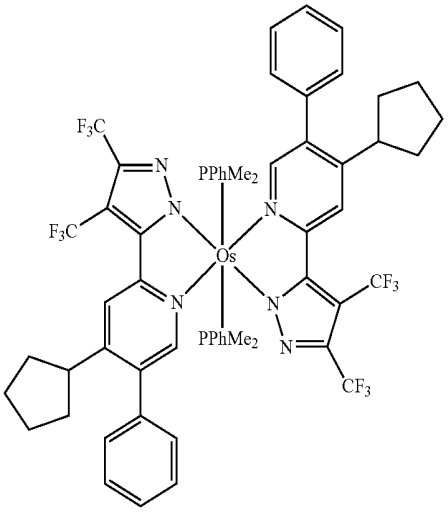

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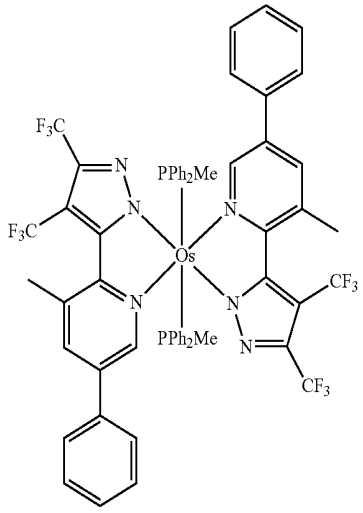

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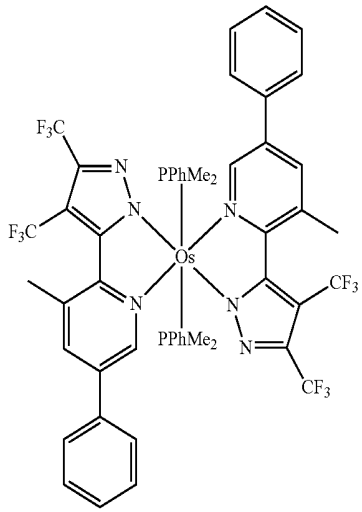

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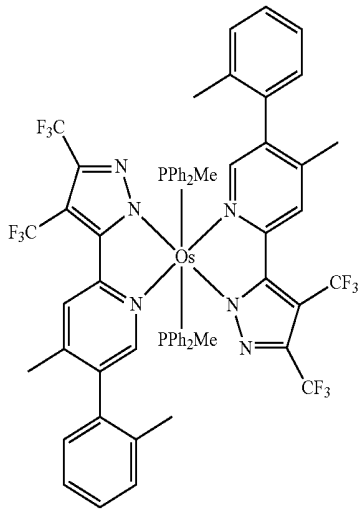

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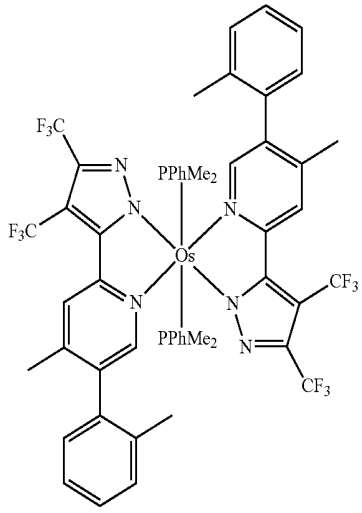

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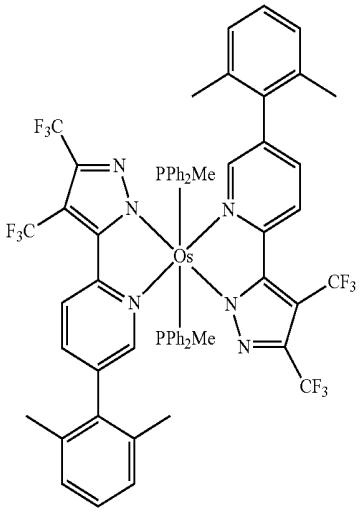

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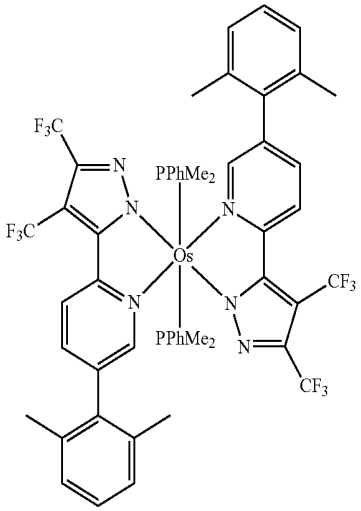

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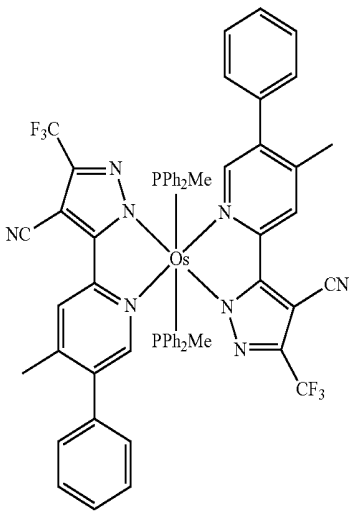

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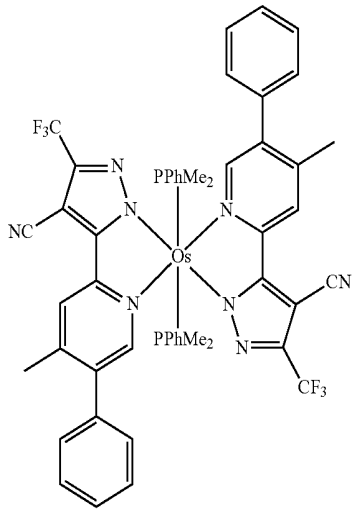

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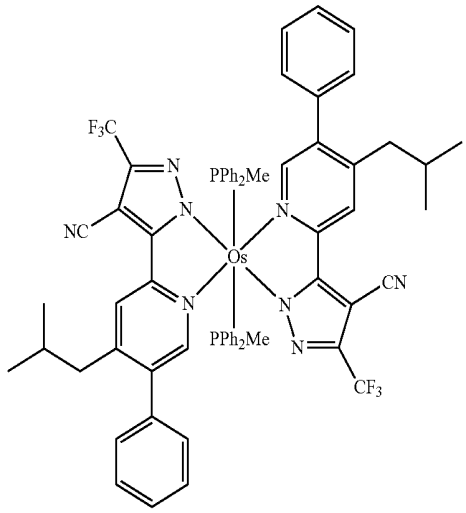

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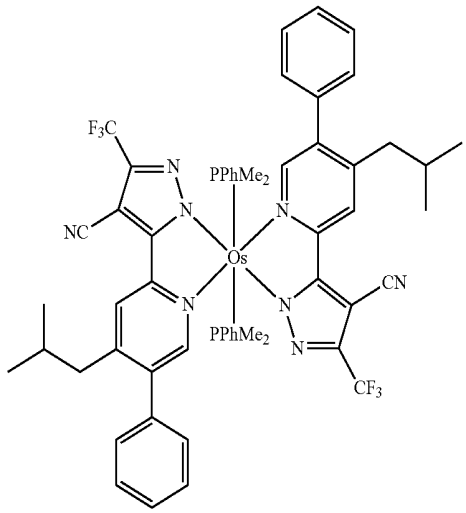

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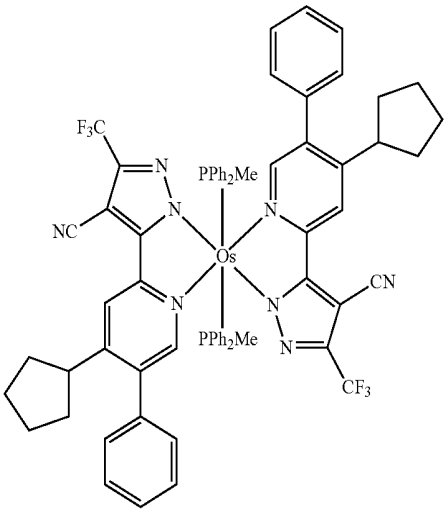

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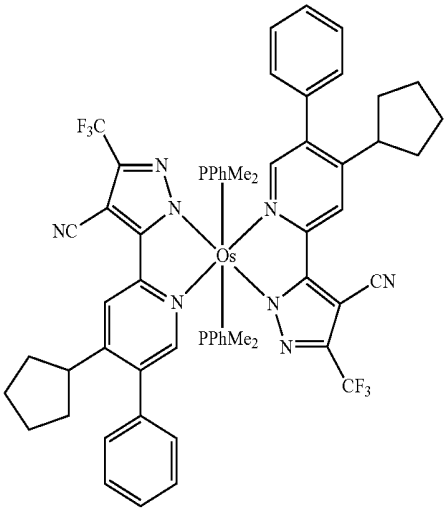

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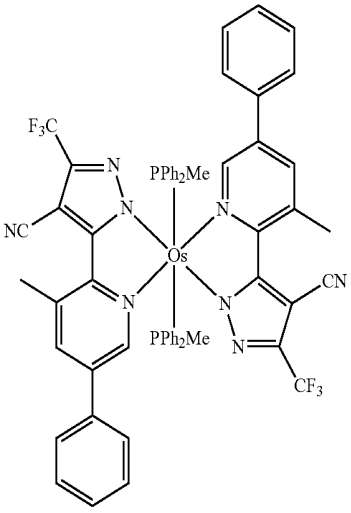

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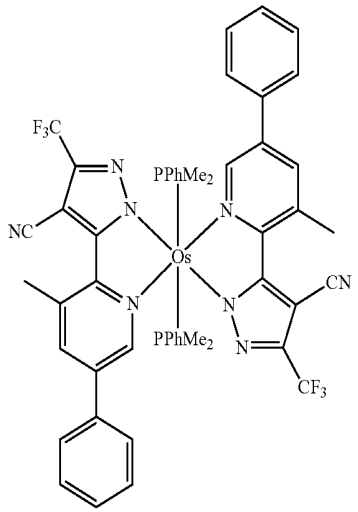

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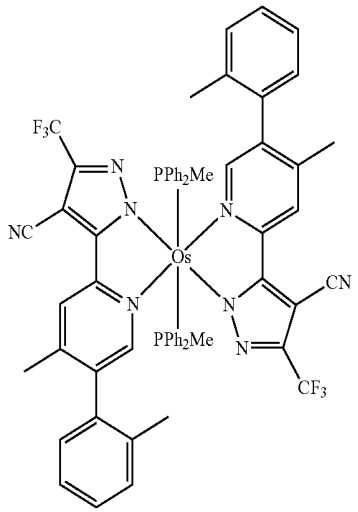

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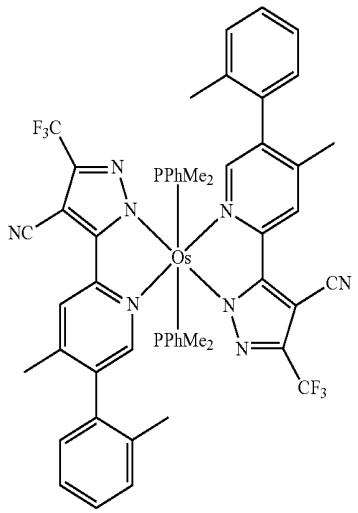

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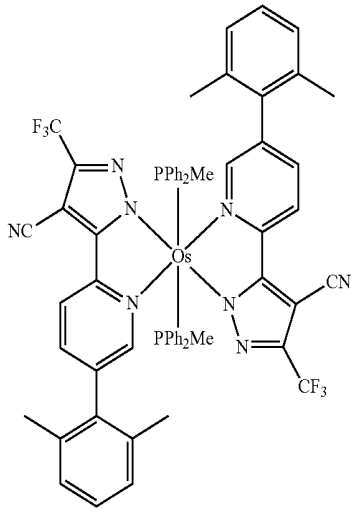

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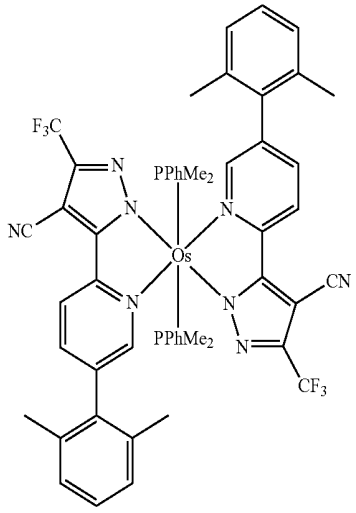

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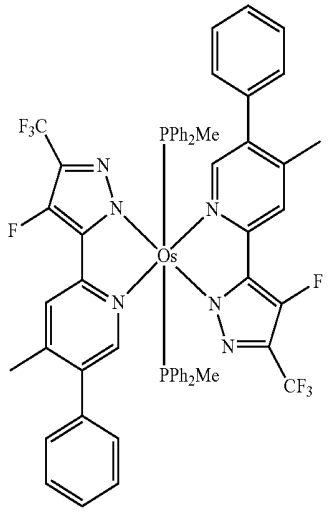

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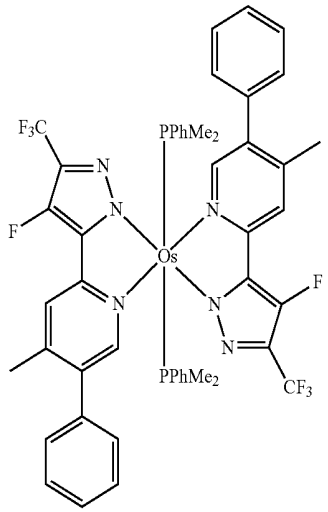

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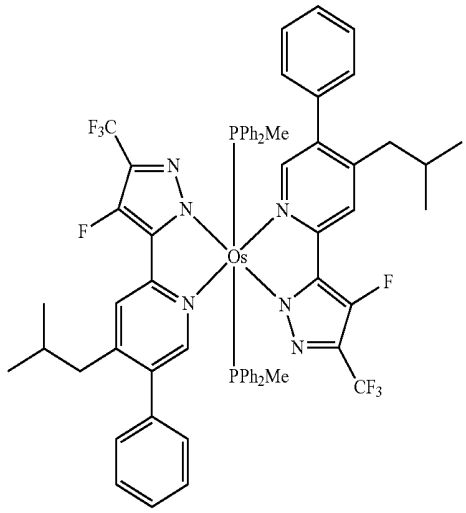

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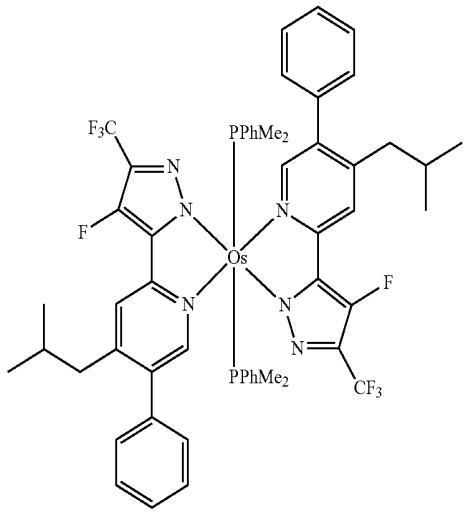

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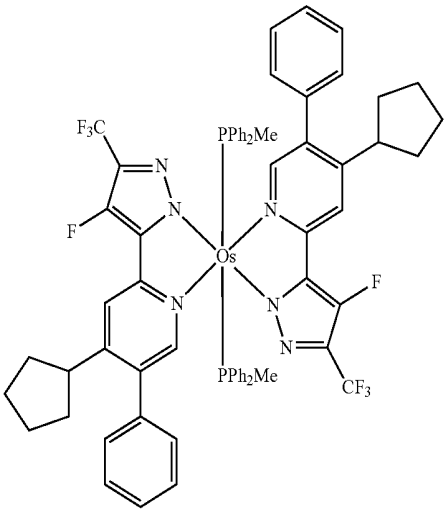

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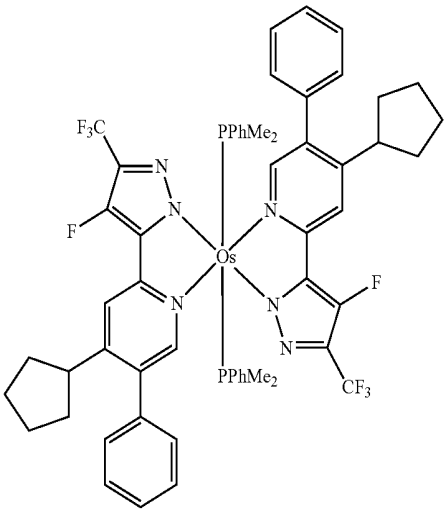

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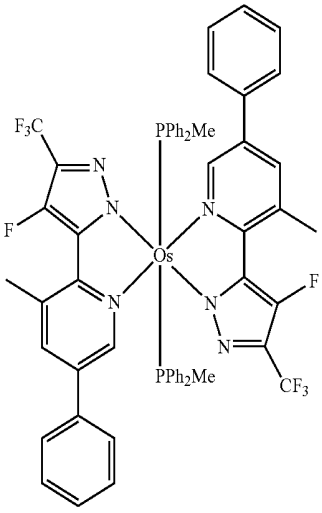

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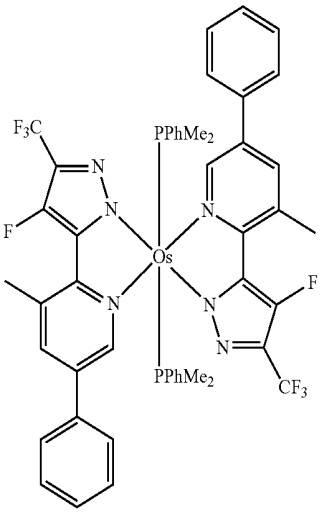

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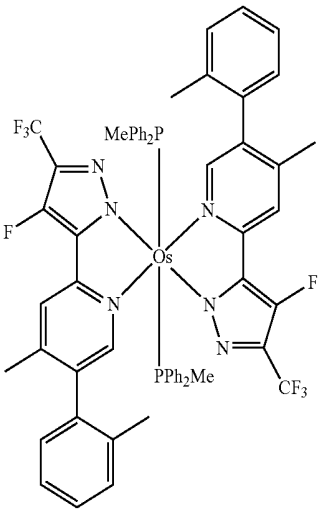

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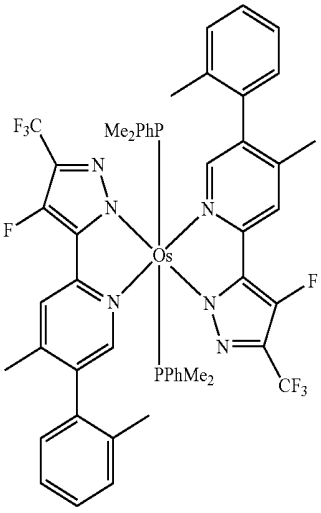

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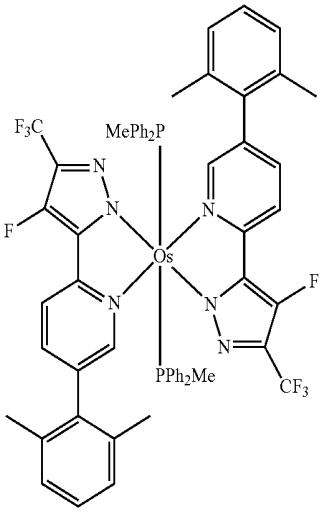

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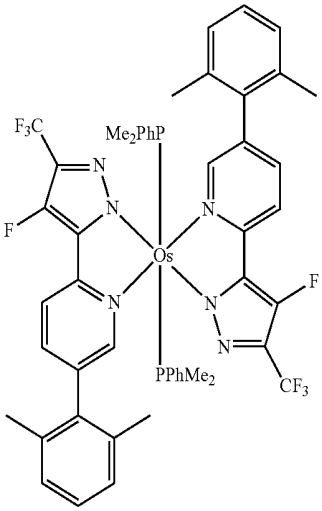

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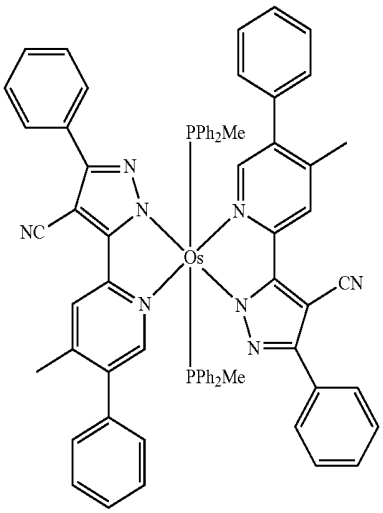

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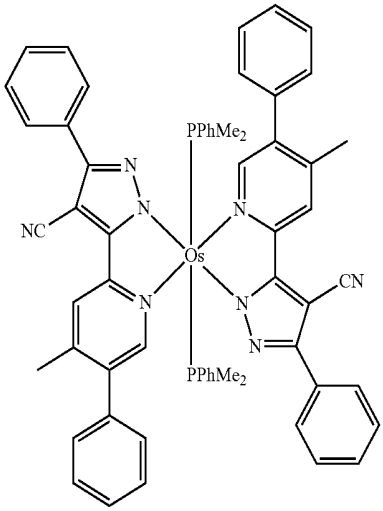

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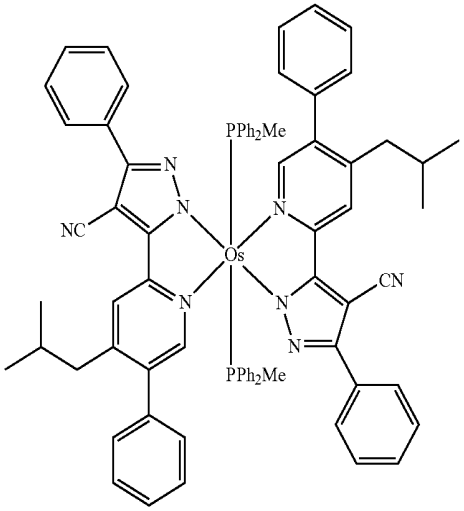

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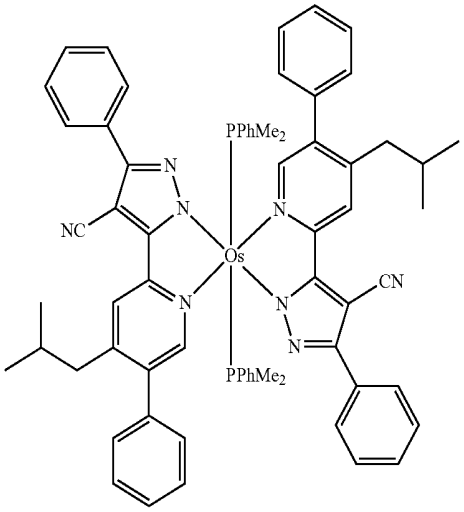

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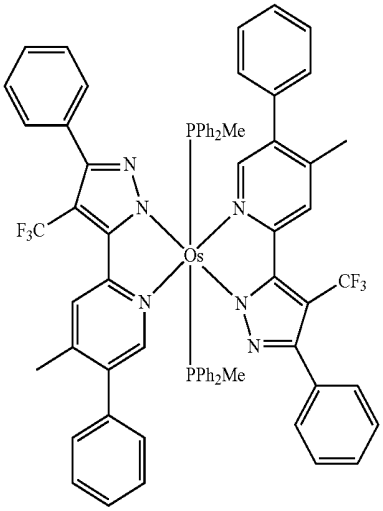

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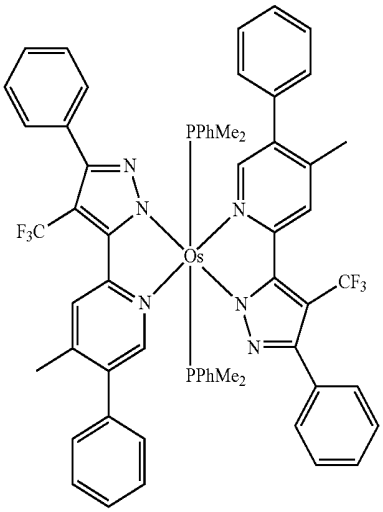

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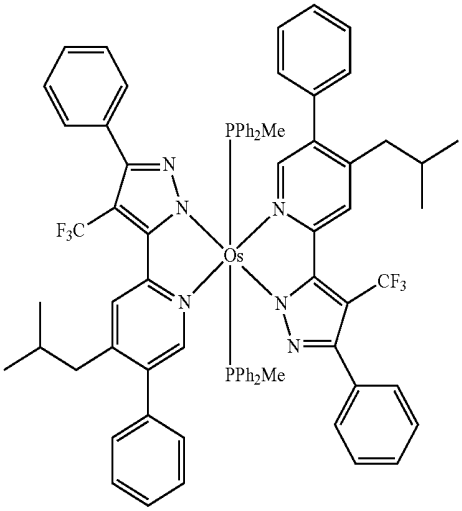

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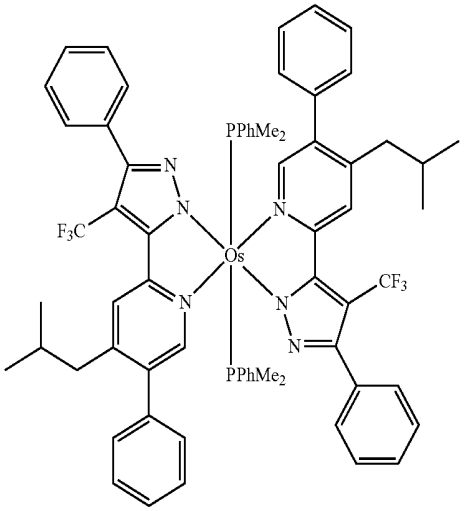

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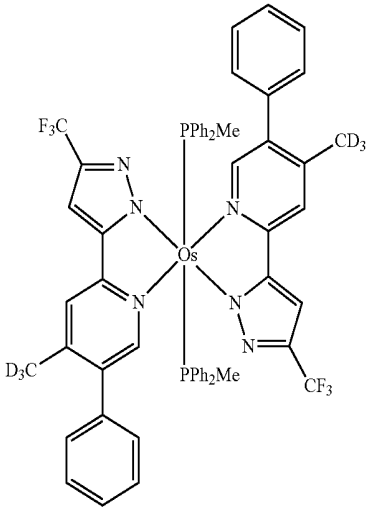

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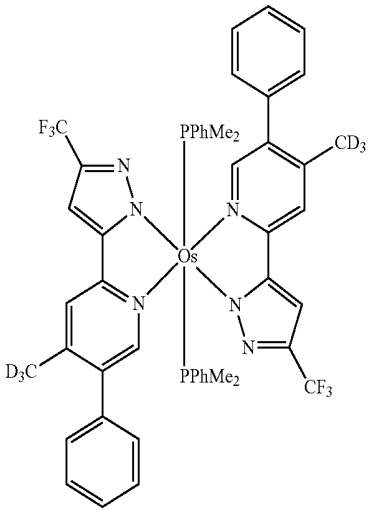

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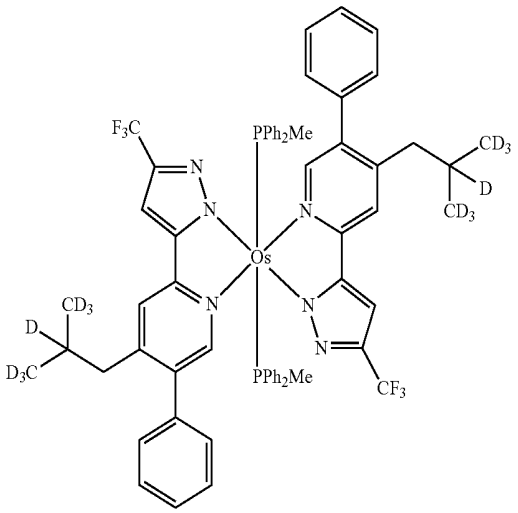

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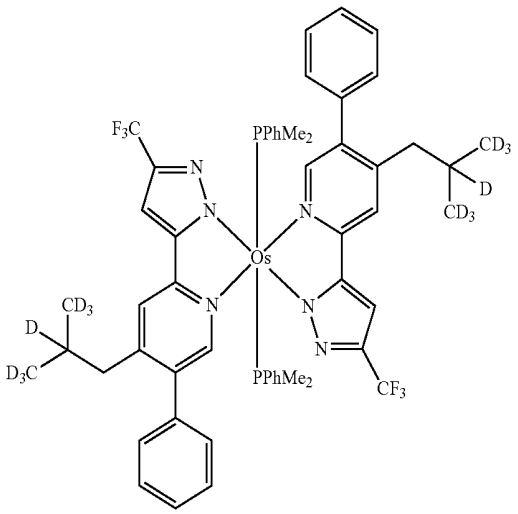

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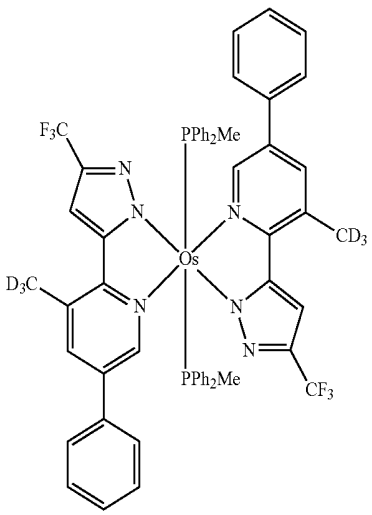

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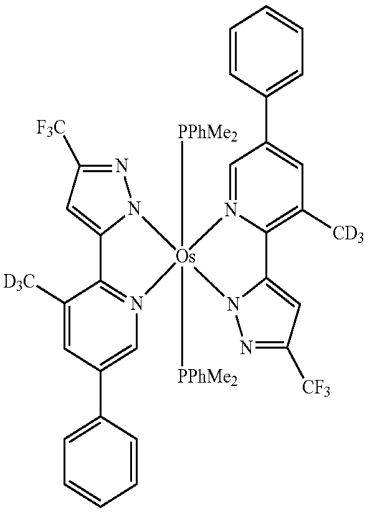

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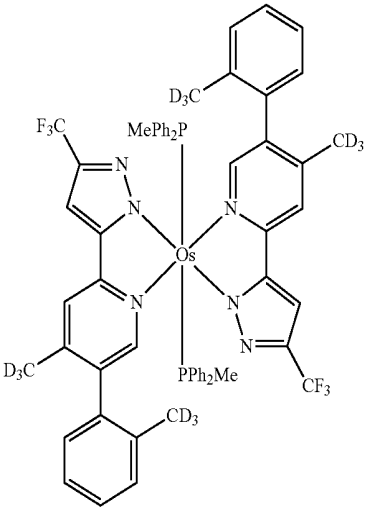

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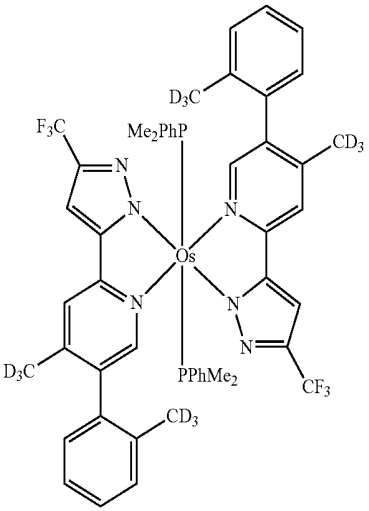

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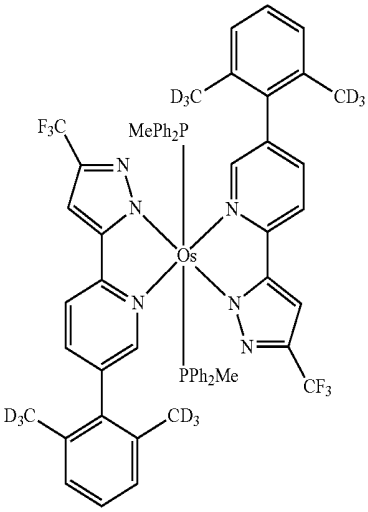

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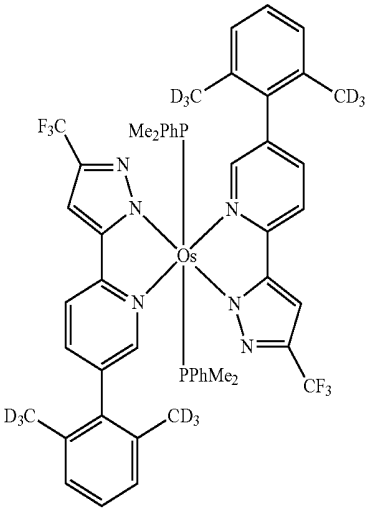

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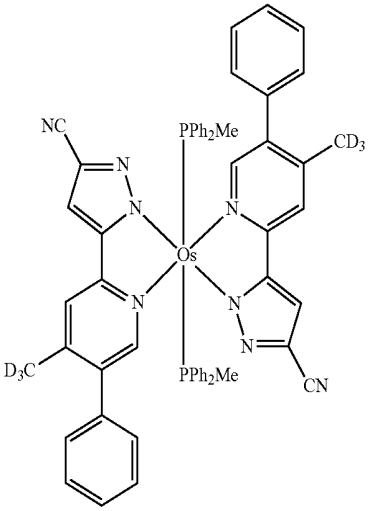

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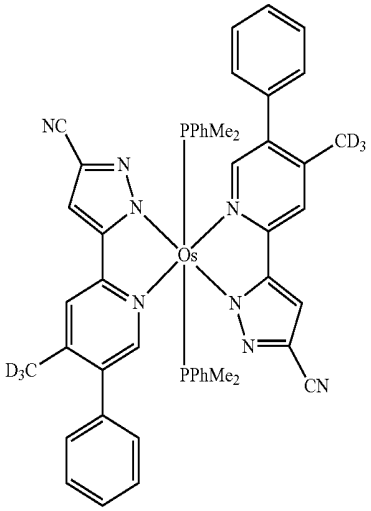

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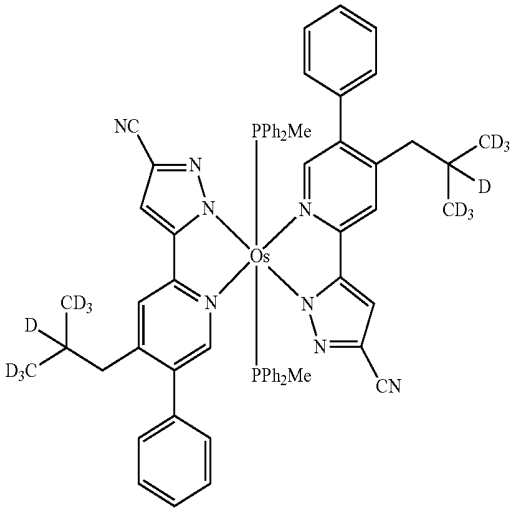

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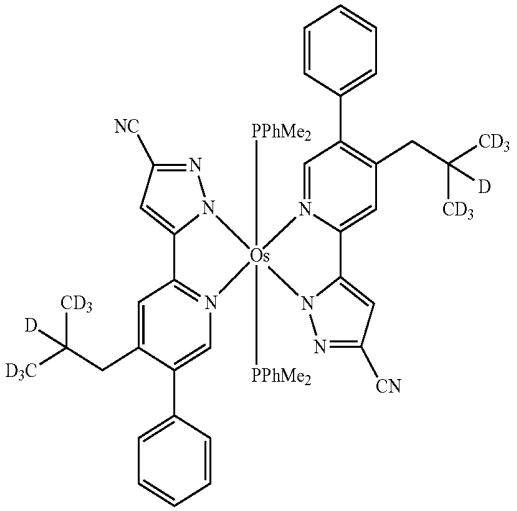

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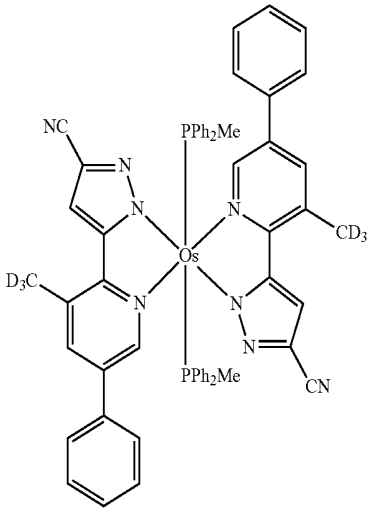

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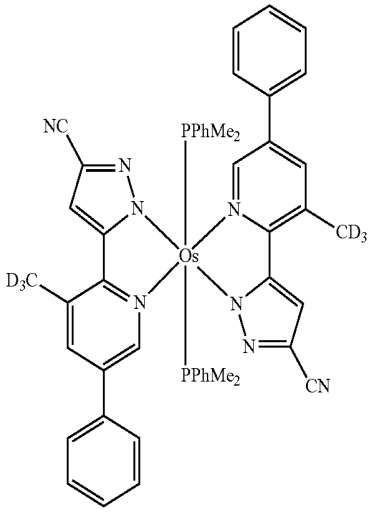

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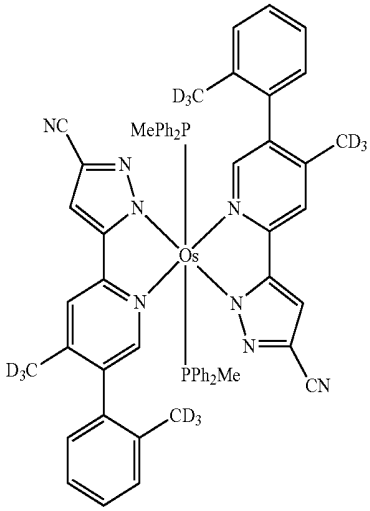

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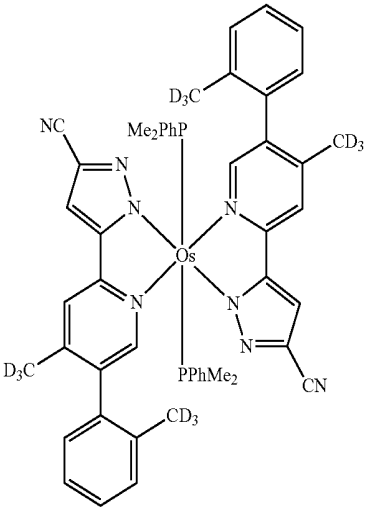

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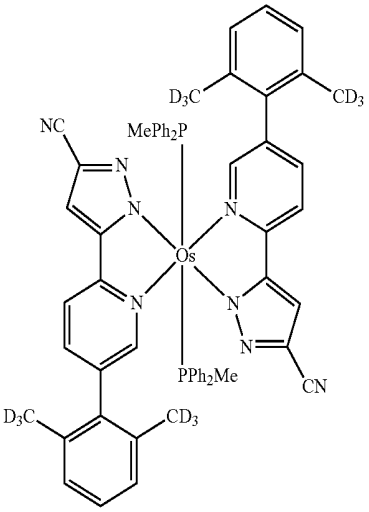

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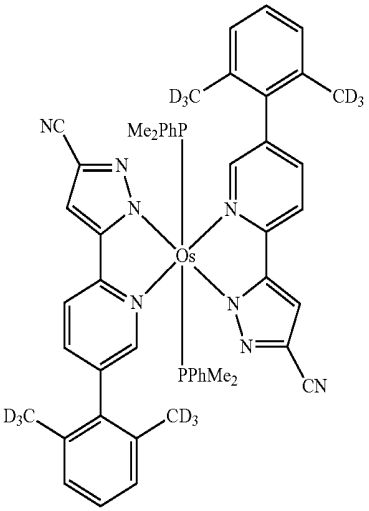

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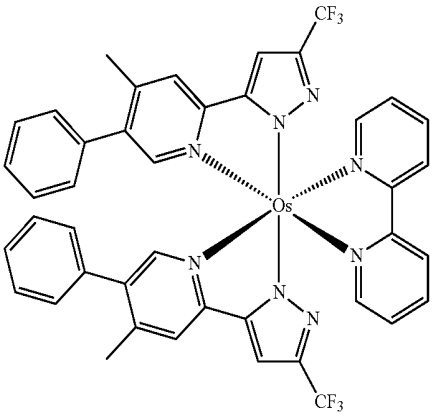

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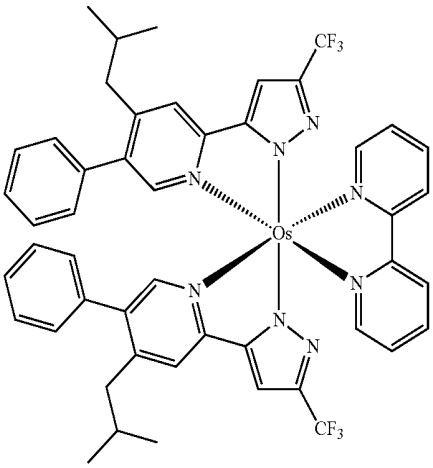

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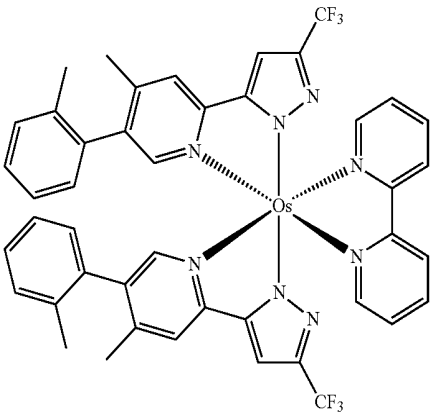

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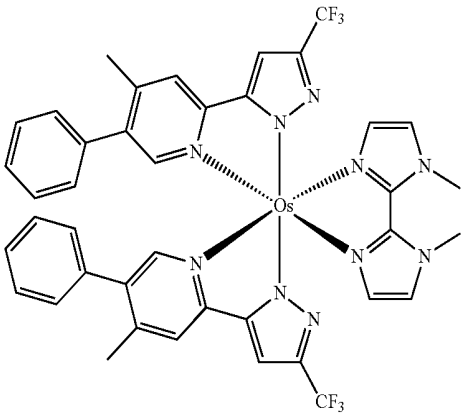

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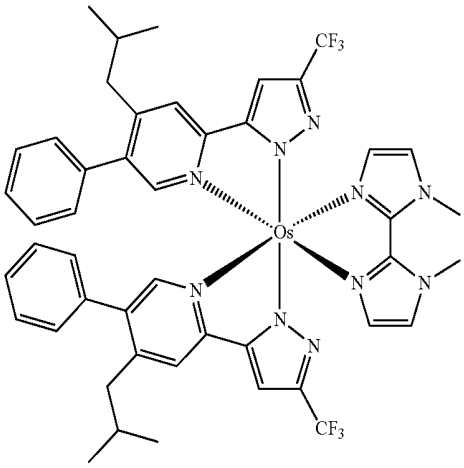

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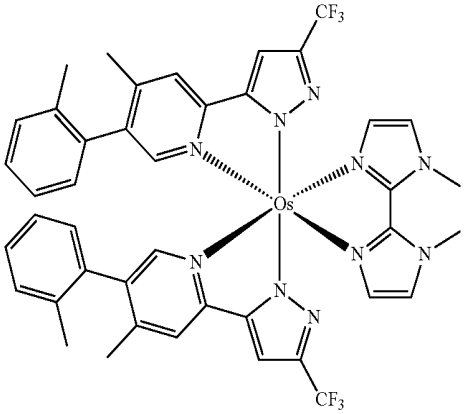

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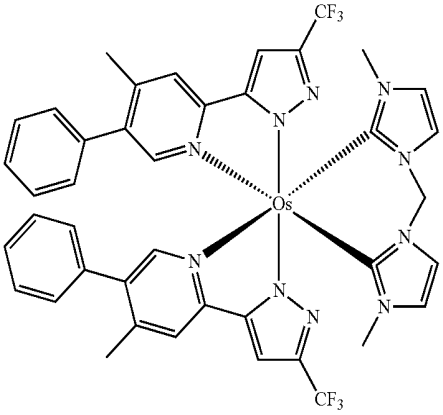

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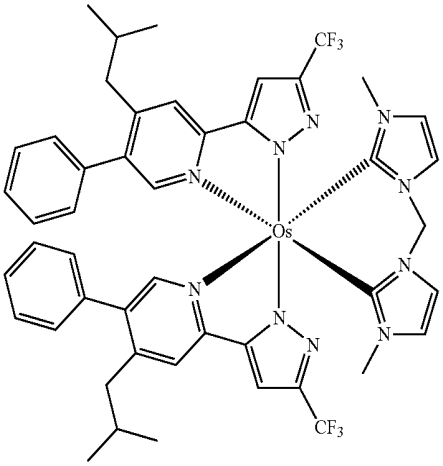

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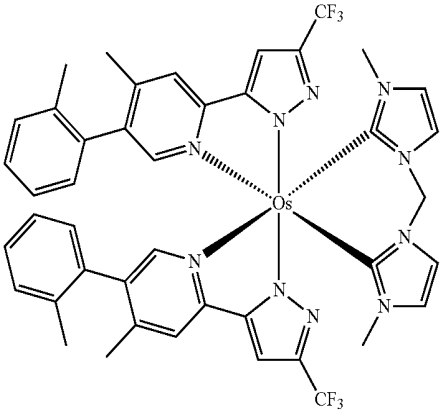

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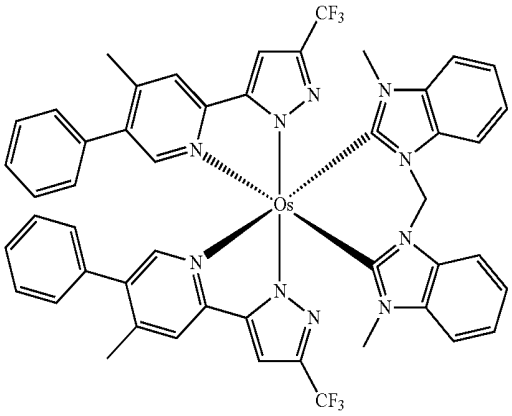

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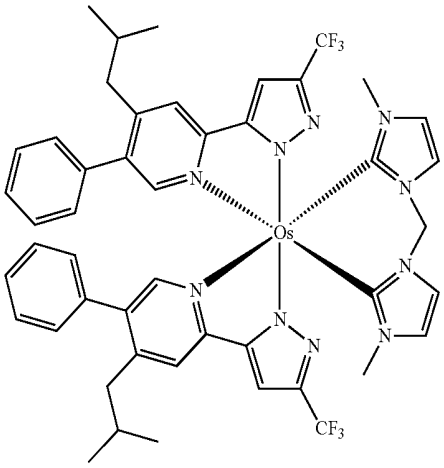

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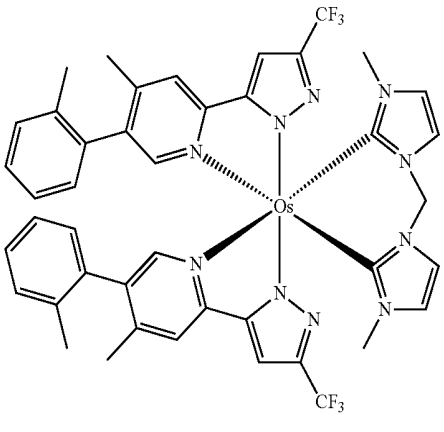

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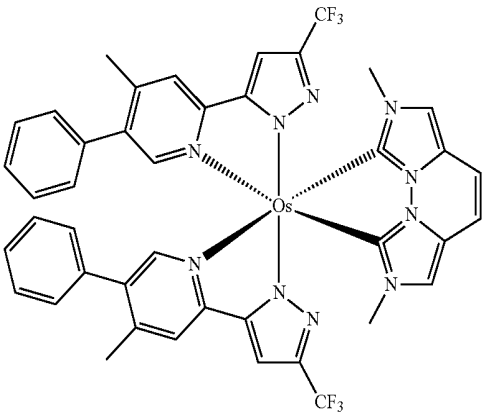

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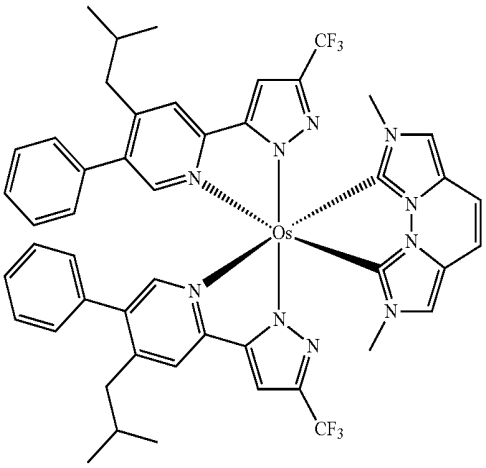

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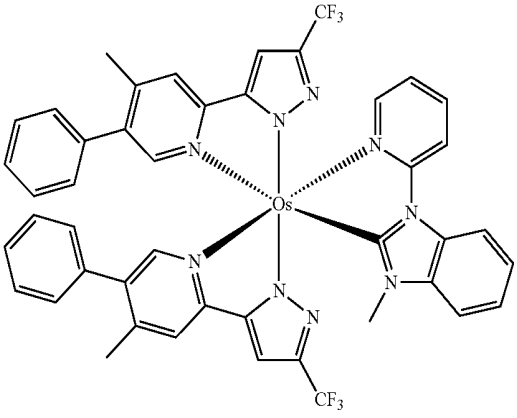

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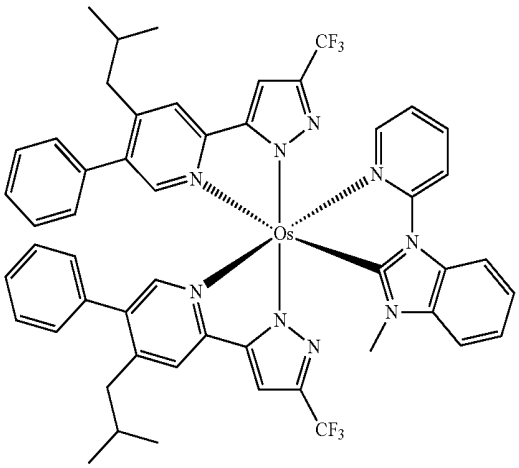

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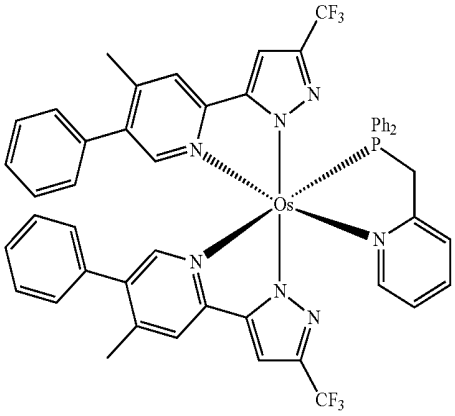

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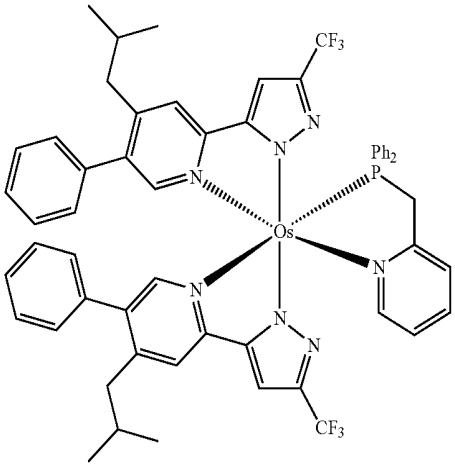

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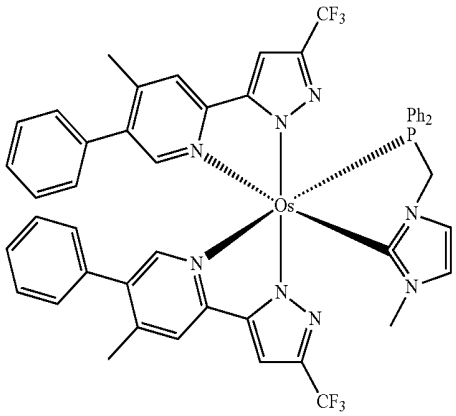

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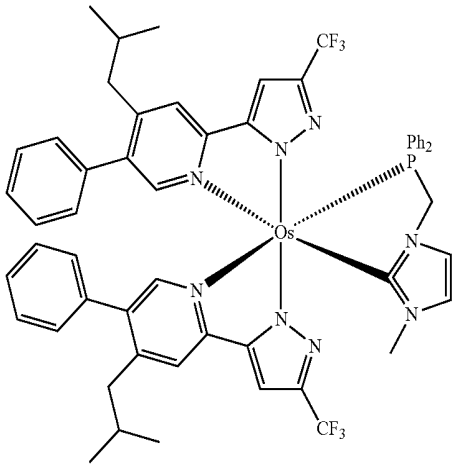

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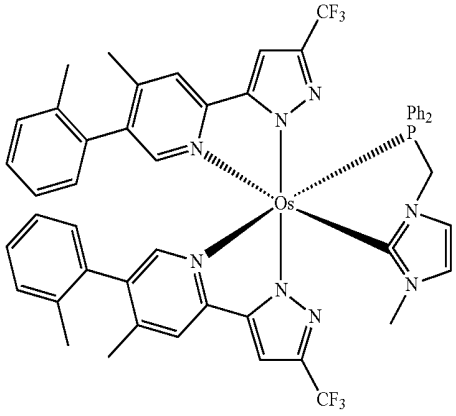

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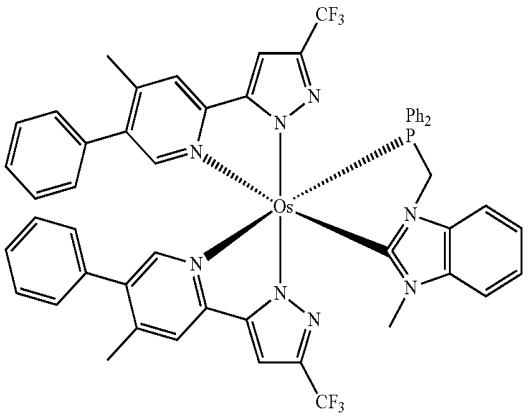

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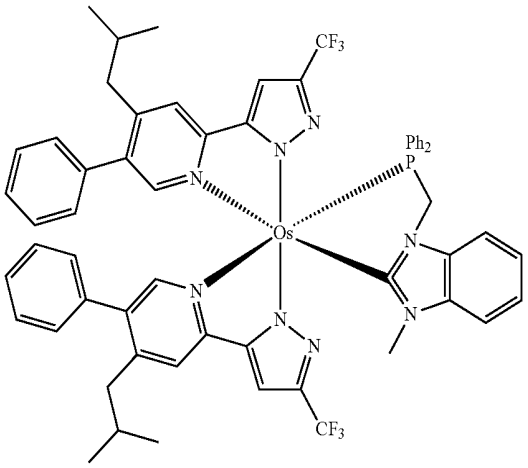

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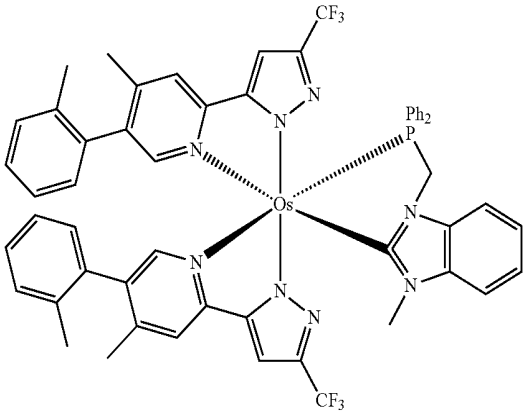

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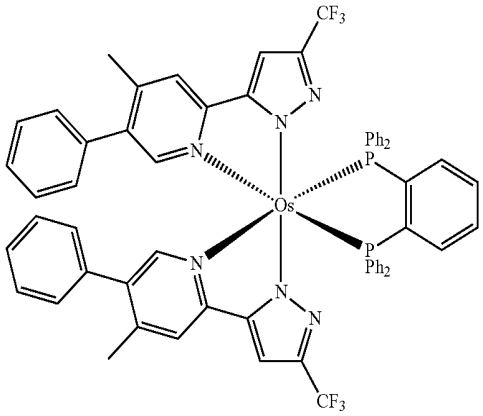

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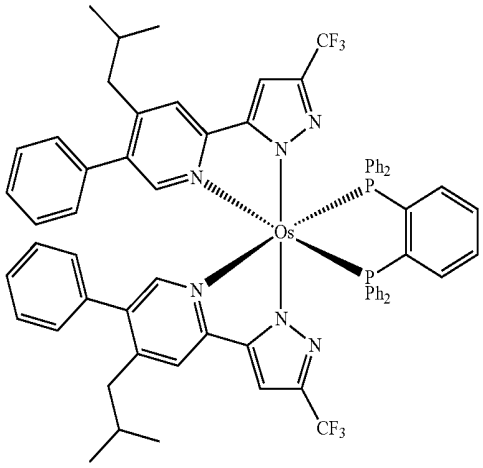

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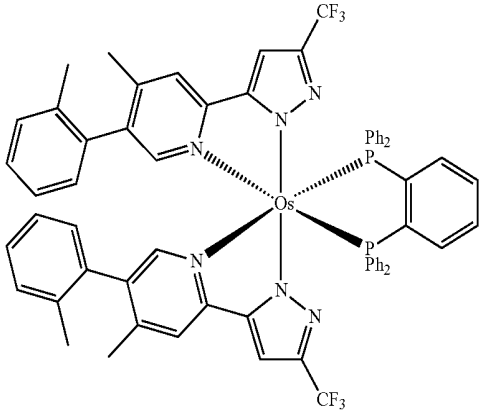

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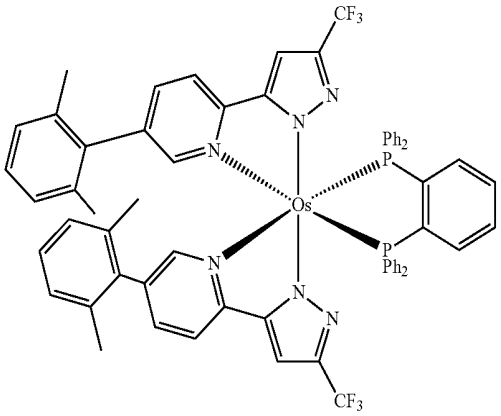

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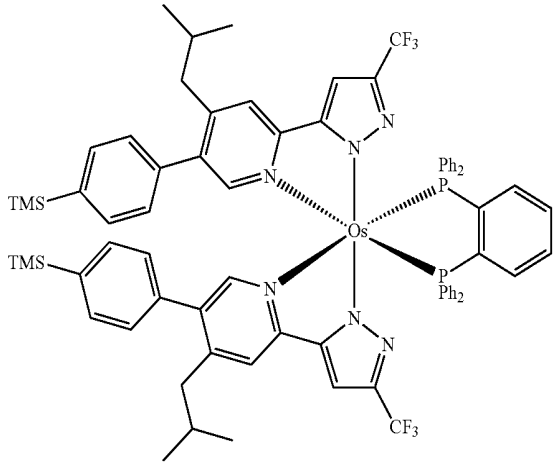

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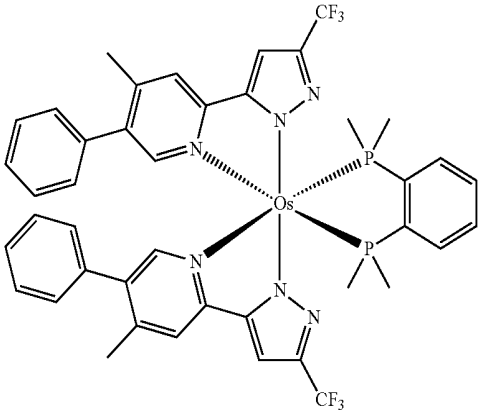

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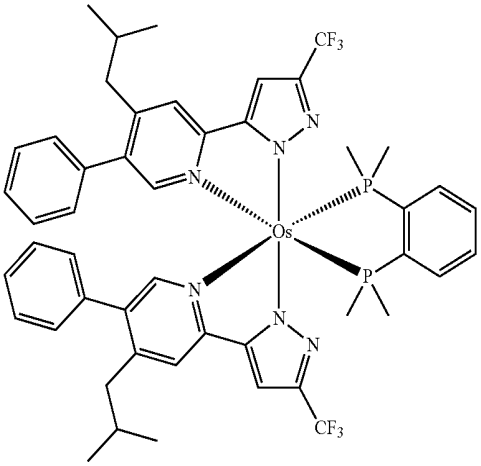

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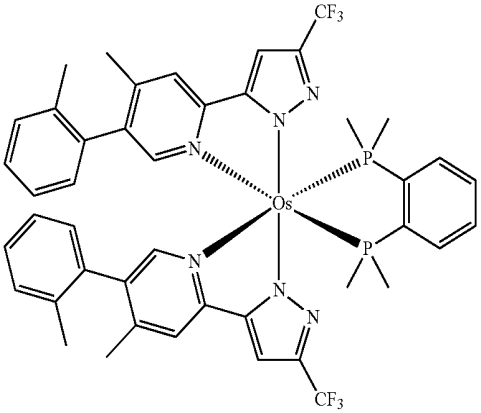

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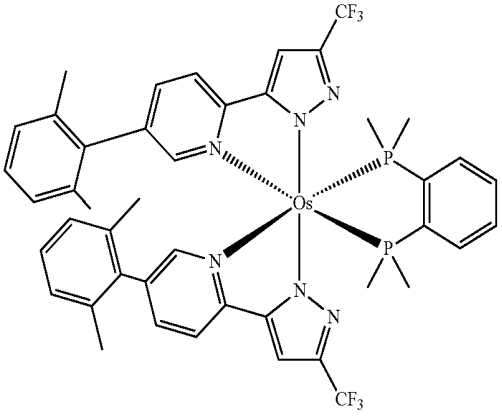

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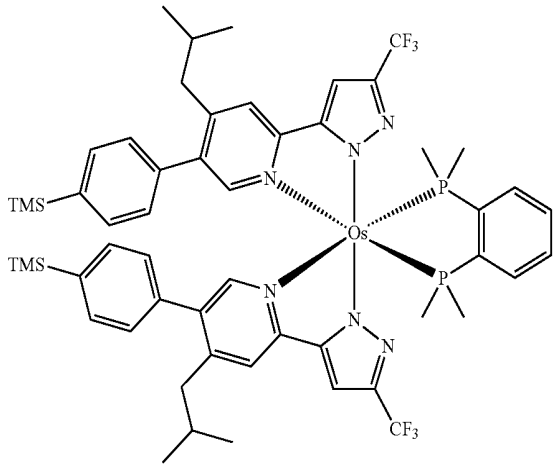

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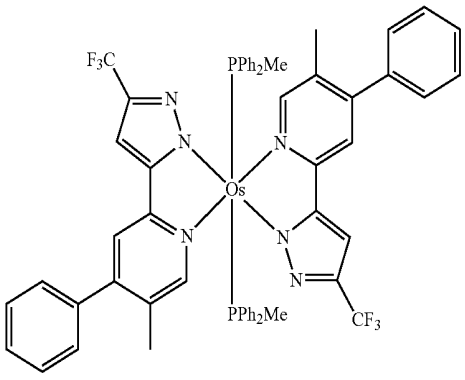

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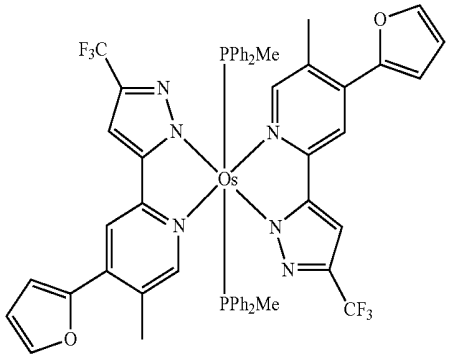

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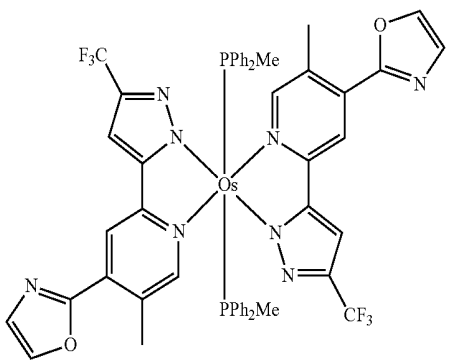

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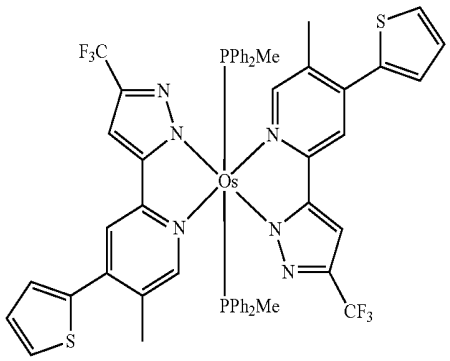

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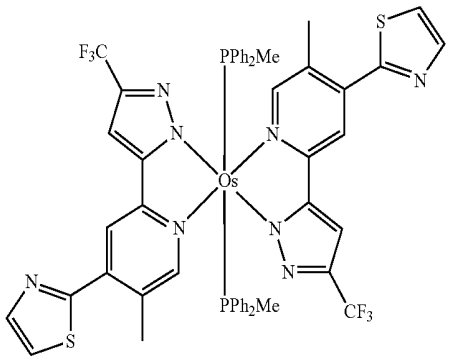

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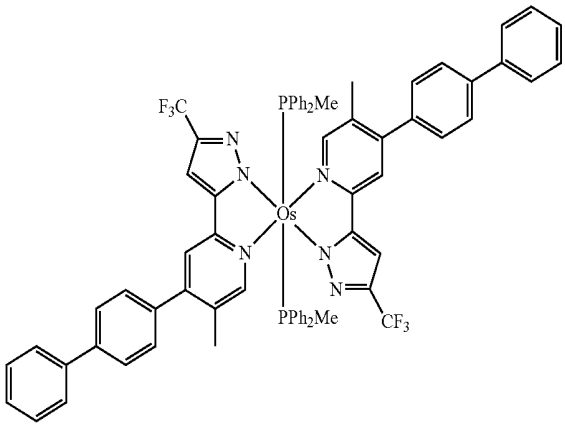

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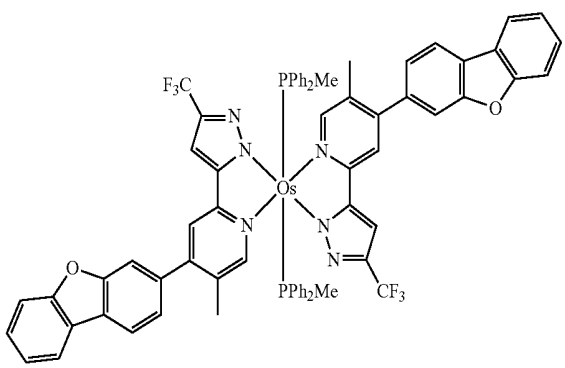

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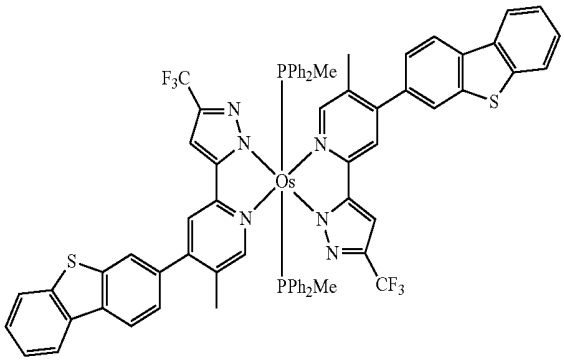

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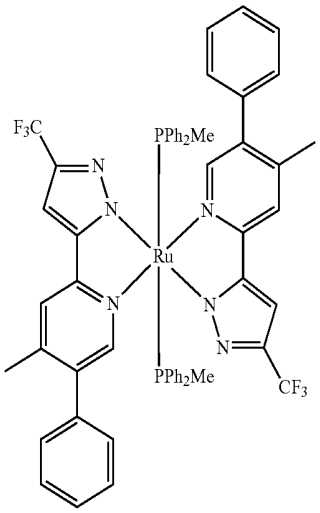

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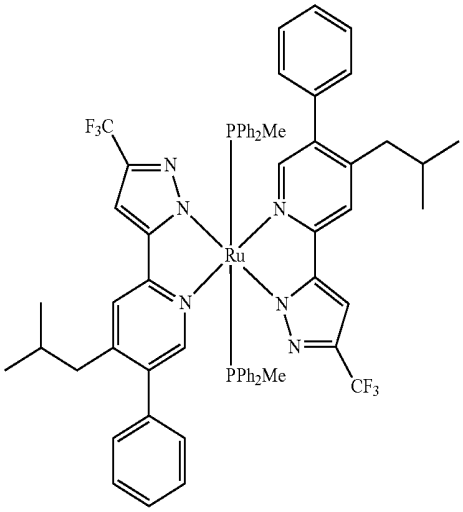

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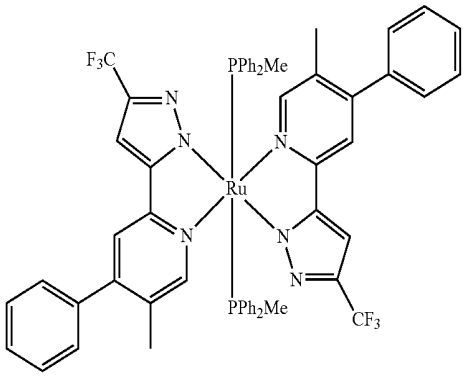
173



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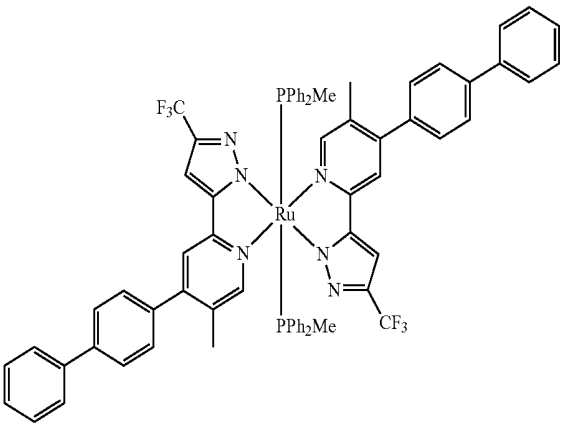

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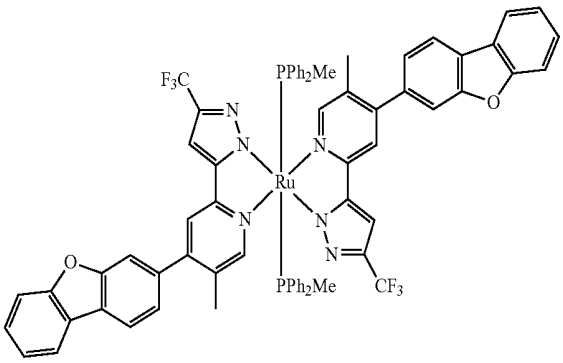

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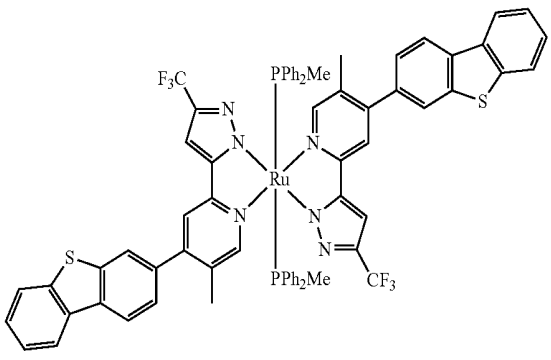

19. An organic light-emitting device comprising:
a first electrode;
a second electrode; and
an organic layer disposed between the first electrode and the second electrode,
wherein the organic layer comprises an emission layer and at least one organometallic compound of claim **1**.

20. The organic light-emitting device of claim **19**, wherein the emission layer comprises the at least one organometallic compound.

* * * * *

专利名称(译)	有机金属化合物和包括其的有机发光器件		
公开(公告)号	US20170062739A1	公开(公告)日	2017-03-02
申请号	US15/245431	申请日	2016-08-24
[标]申请(专利权)人(译)	三星电子株式会社		
申请(专利权)人(译)	SAMSUNG ELECTRONICS CO.，LTD.		
当前申请(专利权)人(译)	SAMSUNG ELECTRONICS CO.，LTD.		
[标]发明人	CHOI WHAIL KWAK SEUNGYEON KWAK YOONHYUN KIM SANGDONG LEE SANGYOON CHOI BYOUNGKI CHOI HYEONHO HWANG KYUYOUNG		
发明人	CHOI, WHAIL KWAK, SEUNGYEON KWAK, YOONHYUN KIM, SANGDONG LEE, SANGYOON CHOI, BYOUNGKI CHOI, HYEONHO HWANG, KYUYOUNG		
IPC分类号	H01L51/00 C09K11/06 C07F15/00		
CPC分类号	H01L51/0088 C07F15/0026 C09K11/06 H01L51/5012 C09K2211/1044 C09K2211/185 C09K2211/1007 C07F15/0093 H01L51/5016		
优先权	1020150119823 2015-08-25 KR 1020160105589 2016-08-19 KR		
外部链接	Espacenet USPTO		

摘要(译)

由式1表示的有机金属化合物： <ul class =“uspto-list”> <li class =“uspto-list-item”> <ul class =“uspto-list”> <li class =“uspto-list-item”>其中，在公式1中，L <sub> 11 </ sub>，M，m，n和R <sub> 11 </ sub>至R <sub> 16 </ sub>与说明书中描述的相同。</ li> </ UL> </ LI> </ UL>

