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(54) METHOD OF MAKING ORGANIC ELECTROLUMINESCENT MATERIALS

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(57) ABSTRACT

A method of making ligands for producing novel heteroleptic iridium complexes is provided. The method includes reacting the condensation product of an aryl 1,2-diamine and an aryl aldehyde with manganese dioxide in a solvent. The novel iridium complexes produced using the ligands are useful compounds in OLED devices.

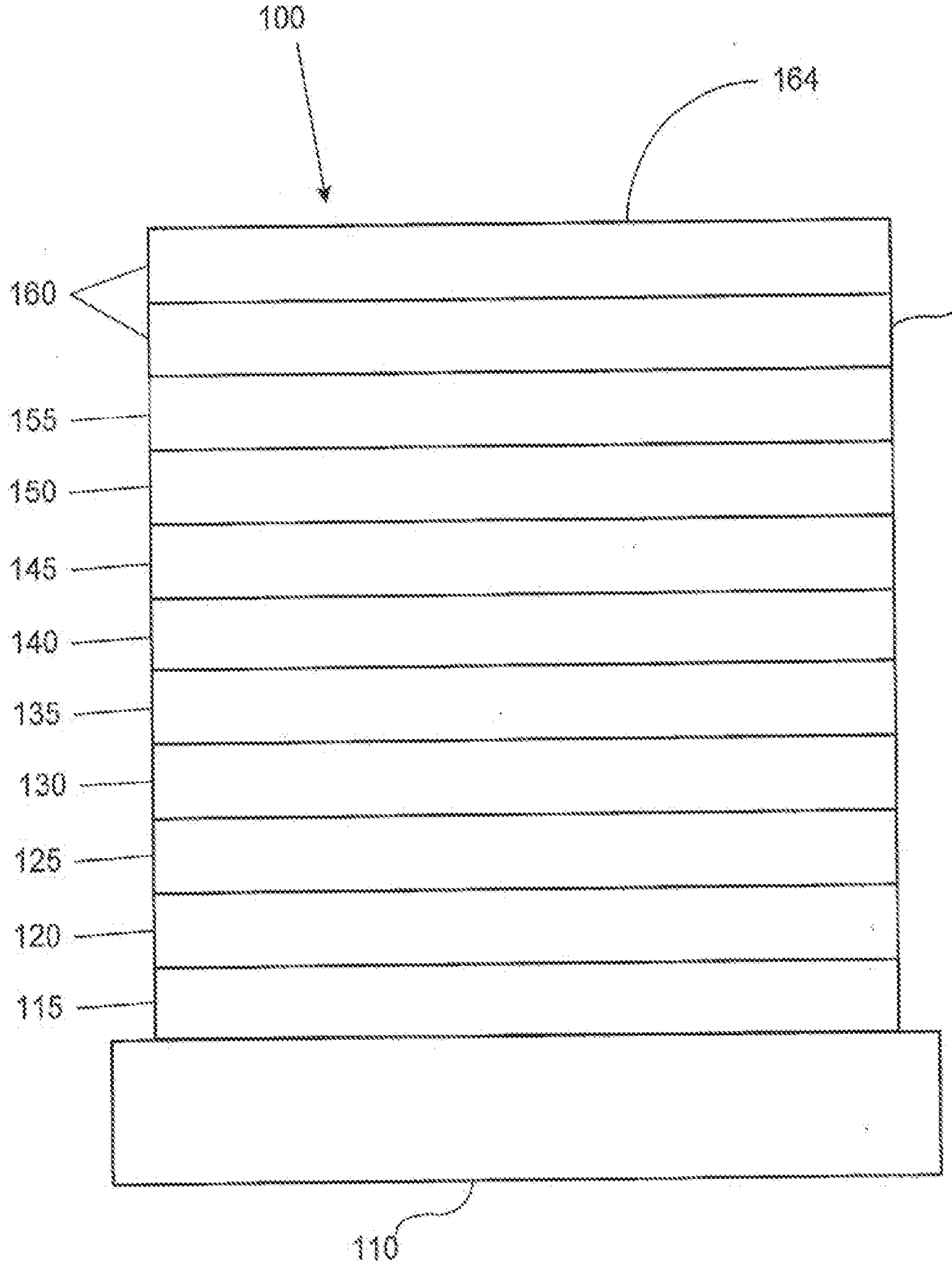


FIGURE 1

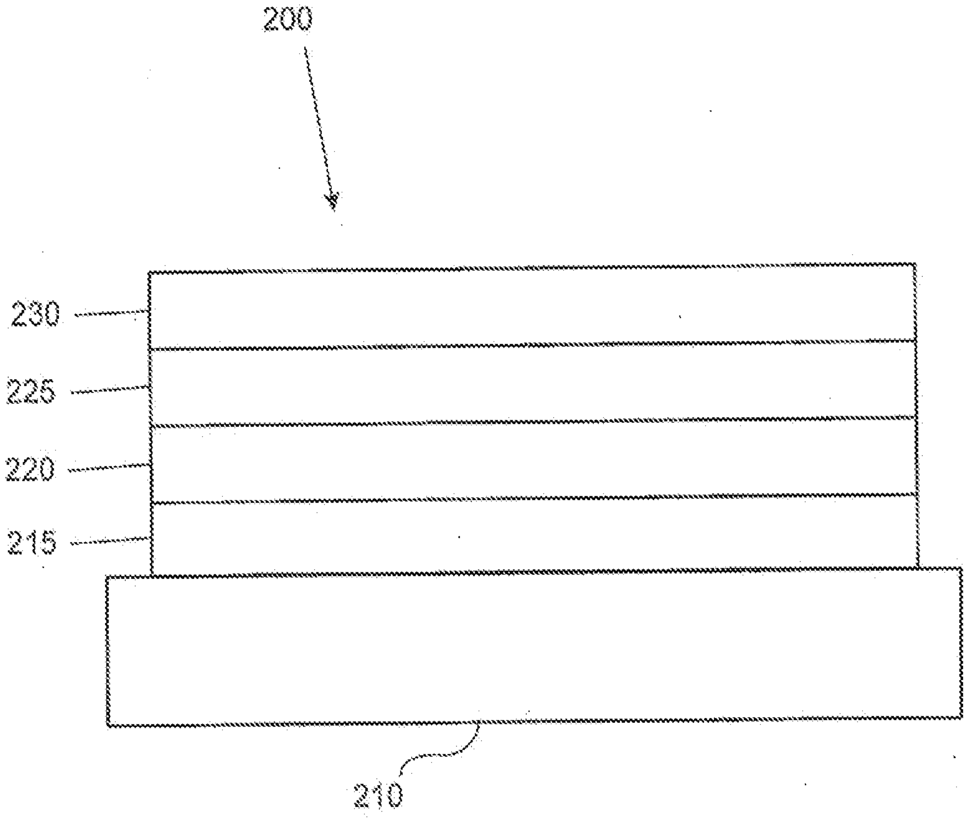
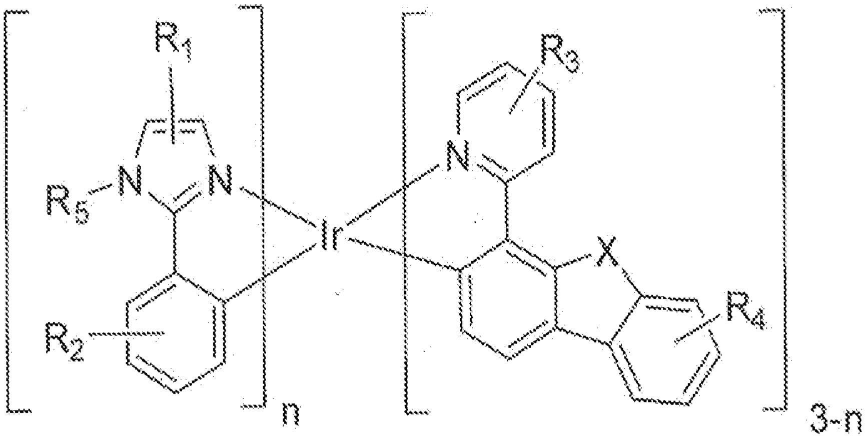


FIGURE 2



Formula I

FIGURE 3

METHOD OF MAKING ORGANIC ELECTROLUMINESCENT MATERIALS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a divisional of U.S. patent application Ser. No. 13/111,555, filed May 19, 2011, the entire content of which is incorporated herein by reference.

PARTIES TO A JOINT RESEARCH AGREEMENT

[0002] The claimed invention was made by, on behalf of, and/or in connection with one or more of the following parties to a joint university corporation research agreement: Regents of the University of Michigan, Princeton University, The University of Southern California, and the Universal Display Corporation. The agreement was in effect on and before the date the claimed invention was made, and the claimed invention was made as a result of activities undertaken within the scope of the agreement.

FIELD OF THE INVENTION

[0003] The present invention relates to compounds useful for incorporation into OLEDs, specifically heteroleptic iridium complexes, and methods of making phenylbenzimidazole ligands.

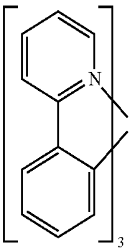
BACKGROUND

[0004] Opto-electronic devices that make use of organic materials are becoming increasingly desirable for a number of reasons. Many of the materials used to make such devices are relatively inexpensive, so organic opto-electronic devices have the potential for cost advantages over inorganic devices. In addition, the inherent properties of organic materials, such as their flexibility, may make them well suited for particular applications such as fabrication on a flexible substrate. Examples of organic opto-electronic devices include organic light emitting devices (OLEDs), organic phototransistors, organic photovoltaic cells, and organic photodetectors. For OLEDs, the organic materials may have performance advantages over conventional materials. For example, the wavelength at which an organic emissive layer emits light may generally be readily tuned with appropriate dopants.

[0005] OLEDs make use of thin organic films that emit light when voltage is applied across the device. OLEDs are becoming an increasingly interesting technology for use in applications such as flat panel displays, illumination, and backlighting. Several OLED materials and configurations are described in U.S. Pat. Nos. 5,844,363, 6,303,238, and 5,707,745, which are incorporated herein by reference in their entirety.

[0006] One application for phosphorescent emissive molecules is a full color display. Industry standards for such a display call for pixels adapted to emit particular colors, referred to as "saturated" colors. In particular, these standards call for saturated red, green, and blue pixels. Color may be measured using CIE coordinates, which are well known to the art.

[0007] One example of a green emissive molecule is tris(2-phenylpyridine)iridium, denoted Ir(ppy)$_3$, which has the following structure:



[0008] In this, and later figures herein, we depict the dative bond from nitrogen to metal (here, Ir) as a straight line.

[0009] As used herein, the term "organic" includes polymeric materials as well as small molecule organic materials that may be used to fabricate organic opto-electronic devices. "Small molecule" refers to any organic material that is not a polymer, and "small molecules" may actually be quite large. Small molecules may include repeat units in some circumstances. For example, using a long chain alkyl group as a substituent does not remove a molecule from the "small molecule" class. Small molecules may also be incorporated into polymers, for example as a pendent group on a polymer backbone or as a part of the backbone. Small molecules may also serve as the core moiety of a dendrimer, which consists of a series of chemical shells built on the core moiety. The core moiety of a dendrimer may be a fluorescent or phosphorescent small molecule emitter. A dendrimer may be a "small molecule," and it is believed that all dendrimers currently used in the field of OLEDs are small molecules.

[0010] As used herein, "top" means furthest away from the substrate, while "bottom" means closest to the substrate. Where a first layer is described as "disposed over" a second layer, the first layer is disposed further away from substrate. There may be other layers between the first and second layer, unless it is specified that the first layer is "in contact with" the second layer. For example, a cathode may be described as "disposed over" an anode, even though there are various organic layers in between.

[0011] As used herein, "solution processible" means capable of being dissolved, dispersed, or transported in and/or deposited from a liquid medium, either in solution or suspension form.

[0012] A ligand may be referred to as "photoactive" when it is believed that the ligand directly contributes to the photoactive properties of an emissive material. A ligand may be referred to as "ancillary" when it is believed that the ligand does not contribute to the photoactive properties of an emissive material, although an ancillary ligand may alter the properties of a photoactive ligand.

[0013] As used herein, and as would be generally understood by one skilled in the art, a first "Highest Occupied Molecular Orbital" (HOMO) or "Lowest Unoccupied Molecular Orbital" (LUMO) energy level is "greater than" or "higher than" a second HOMO or LUMO energy level if the first energy level is closer to the vacuum energy level. Since ionization potentials (IP) are measured as a negative energy relative to a vacuum level, a higher HOMO energy level corresponds to an IP having a smaller absolute value (an IP that is less negative). Similarly, a higher LUMO energy level corresponds to an electron affinity (EA) having a smaller absolute value (an EA that is less negative). On a conventional energy level diagram, with the vacuum level at the top, the LUMO energy level of a material is higher than the HOMO energy level of the same material. A "higher" HOMO or LUMO energy level appears closer to the top of such a diagram than a "lower" HOMO or LUMO energy level.

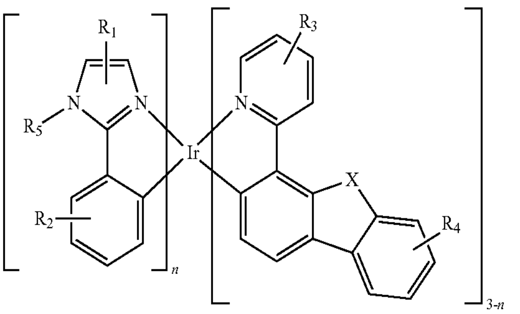
[0014] As used herein, and as would be generally understood by one skilled in the art, a first work function is "greater than" or "higher than" a second work function if the first work function has a higher absolute value. Because work functions are generally measured as negative numbers relative to vacuum level, this means that a "higher" work function is more negative. On a conventional energy level diagram, with the vacuum level at the top, a "higher" work function is illustrated as further away from the vacuum level in the downward direction. Thus, the definitions of HOMO and LUMO energy levels follow a different convention than work functions.

[0015] More details on OLEDs, and the definitions described above, can be found in U.S. Pat. No. 7,279,704, which is incorporated herein by reference in its entirety.

SUMMARY OF THE INVENTION

[0016] A compound comprising a heteroleptic iridium complex having the formula:

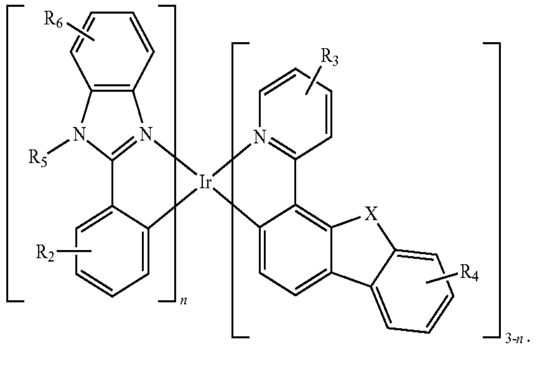
Formula I



is provided. R_1, R_2, R_3 and R_4 can represent mono-, di-, tri- or tetra-substitution, and R_1, R_2, R_3, R_4 and R_5 are each independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. R_1, R_2, R_3 and R_4 are optionally fused. X is selected from the group consisting of CRR', SiRR', C═O, N—R, B—R, O, S, SO, SO_2, and Se. R and R' are independently selected from the group consisting of linear alkyl, branched alkyl, and aryl. n is 1 or 2.

[0017] In one aspect, the compound has the formula:

Formula II

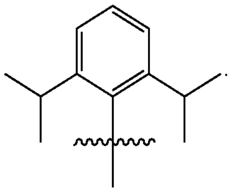


R_6 represents mono-, di-, tri- or tetra-substitution, and R_6 is selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. R_6 is optionally fused and may be further substituted.

[0018] In one aspect, n is 2. In another aspect, n is 1.

[0019] In one aspect, X is selected from the group consisting of O and S. In another aspect, X is O. In another aspect, X is S.

[0020] In one aspect, R_5 is aryl or substituted aryl. In another aspect, R_5 is alkyl. In one aspect, R_5 is a 2,6-disubstituted aryl. In one aspect, R_5 is



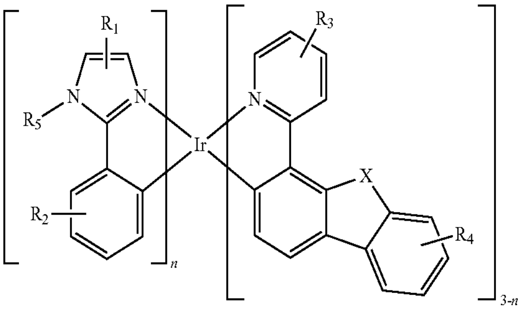
[0021] In one aspect, R_2, R_3, and R_4 are independently selected from the group consisting of hydrogen and alkyl, and at least one of R_2, R_3, and R_4 is alkyl.

[0022] In one aspect, R_3 is aryl or heteroaryl. In another aspect, R_3 is phenyl or substituted phenyl. In one aspect, R_6, R_2, and R_4 are hydrogen.

[0023] Specific non-limiting compounds are provided. In one aspect, the compound is selected from the group consisting of Compound 1-Compound 80. In another aspect, the compound is selected from the group consisting of Compound 81-Compound 156.

[0024] A first device is also provided. The first device comprises an organic light-emitting device, further comprising an anode, a cathode, and an organic layer, disposed between the anode and the cathode, comprising a compound having the formula:

Formula I



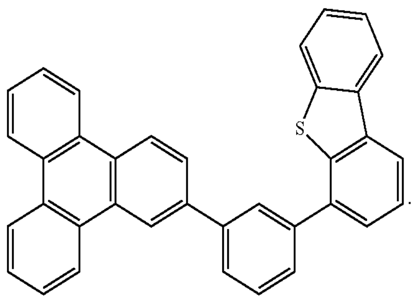
R_1, R_2, R_3 and R_4 can represent mono-, di-, tri- or tetra-substitution, and R_1, R_2, R_3, R_4 and R_5 are each independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. R_1, R_2, R_3 and R_4 are optionally fused and may be further substituted. X is selected from the group consisting of CRR', SiRR', C═O, N—R, B—R, O, S, SO, SO2, and Se. R and R' are independently selected from the group consisting of linear alkyl, branched alkyl, and aryl. n is 1 or 2.

[0025] In one aspect, the organic layer is an emissive layer and the compound of Formula I is an emissive dopant. In one aspect, the organic layer further comprises a host.

[0026] In one aspect, the host comprises a triphenylene containing benzo-fused thiophene or benzo-fused furan, where any substituent in the host is an unfused substituent independently selected from the group consisting of C_nH_{2n+1}, OC_nH_{2n+1}, OAr_1, $N(C_nH_{2n+1})_2$, $N(Ar_1)(Ar_2)$, $CH{=}CH{-}C_nH_{2n+1}$, $C{\equiv}CHC_nH_{2n+1}$, Ar_1, $Ar_1{-}Ar_2$, $C_nH_{2n}{-}Ar_1$, or no substitution. Ar_1 and Ar_2 are independently selected from the group consisting of benzene, biphenyl, naphthalene, triphenylene, carbazole, and heteroaromatic analogs thereof, and n is from 1 to 10.

[0027] In one aspect, the host has the formula

Compound F



[0028] In one aspect, the host is a metal complex.

[0029] In one aspect the first device is a consumer product. In another aspect, the first device is an organic light-emitting device.

[0030] In one aspect, the first device further comprises a second emissive dopant having a peak wavelength of between 400 to 500 nanometers. In another aspect, the second emissive dopant is a fluorescent emitter. In another aspect, the second emissive dopant is a phosphorescent emitter.

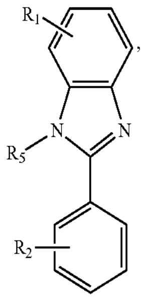
[0031] In one aspect, the first device comprises a lighting panel.

[0032] In another aspect, the first device further comprises a first organic light-emitting device comprising a compound of Formula I and a second light-emitting device separate from the first organic light-emitting device comprising an emissive dopant having a peak wavelength of between 400 to 500 nanometers.

[0033] In another aspect, the first device comprises an organic light-emitting device having a first emissive layer and a second emissive layer, where the first emissive layer comprises a compound of Formula I, and the second emissive layer comprises an emissive dopant having a peak wavelength of between 400 to 500 nanometers.

[0034] A method of making a compound of formula:

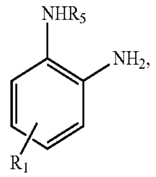
Formula III



is provided. The method comprises reacting the condensation product of an aryl 1,2-diamine and an aryl aldehyde with manganese dioxide in a solvent. R_1, R_2 and R_5 may represent mono-, di-, tri- or tetra-substitution. Additionally, R_1, R_2 and R_5 are each independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. R_1, R_2 and R_5 are optionally fused and may be further substituted.

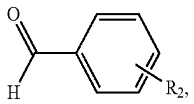
[0035] In one aspect, the condensation product comprises reacting an aryl 1,2-diamine of formula:

Formula IV



with an aryl aldehyde of formula

Formula V



in the presence of phase transfer catalyst and solvent.

[0036] In one aspect, the phase transfer catalyst comprises 1-hexadecylpyridinium bromide.

[0037] In one aspect, R_5 is aryl or substituted aryl. In another aspect, R_5 is a 2,6-disubstituted aryl. In another aspect, R_5 is alkyl.

BRIEF DESCRIPTION OF THE DRAWINGS

[0038] FIG. **1** shows an organic light emitting device.

[0039] FIG. **2** shows an inverted organic light emitting device that does not have a separate electron transport layer.

[0040] FIG. **3** shows a compound of Formula I.

DETAILED DESCRIPTION

[0041] Generally, an OLED comprises at least one organic layer disposed between and electrically connected to an anode and a cathode. When a current is applied, the anode injects holes and the cathode injects electrons into the organic layer(s). The injected holes and electrons each migrate toward the oppositely charged electrode. When an electron and hole localize on the same molecule, an "exciton," which is a localized electron-hole pair having an excited energy state, is formed. Light is emitted when the exciton relaxes via a photoemissive mechanism. In some cases, the exciton may be localized on an excimer or an exciplex. Non-radiative mechanisms, such as thermal relaxation, may also occur, but are generally considered undesirable.

[0042] The initial OLEDs used emissive molecules that emitted light from their singlet states ("fluorescence") as disclosed, for example, in U.S. Pat. No. 4,769,292, which is incorporated by reference in its entirety. Fluorescent emission generally occurs in a time frame of less than 10 nanoseconds.

[0043] More recently, OLEDs having emissive materials that emit light from triplet states ("phosphorescence") have been demonstrated. Baldo et al., "Highly Efficient Phosphorescent Emission from Organic Electroluminescent Devices," Nature, vol. 395, 151-154, 1998; ("Baldo-I") and Baldo et al., "Very high-efficiency green organic light-emitting devices based on electrophosphorescence," Appl. Phys. Lett., vol. 75, No. 3, 4-6 (1999) ("Baldo-II"), which are incorporated by reference in their entireties. Phosphorescence is described in more detail in U.S. Pat. No. 7,279,704 at cols. 5-6, which are incorporated by reference.

[0044] FIG. **1** shows an organic light emitting device **100**. The figures are not necessarily drawn to scale. Device **100** may include a substrate **110**, an anode **115**, a hole injection layer **120**, a hole transport layer **125**, an electron blocking layer **130**, an emissive layer **135**, a hole blocking layer **140**, an electron transport layer **145**, an electron injection layer **150**, a protective layer **155**, and a cathode **160**. Cathode **160** is a compound cathode having a first conductive layer **162** and a second conductive layer **164**. Device **100** may be fabricated by depositing the layers described, in order. The properties and functions of these various layers, as well as example materials, are described in more detail in U.S. Pat. No. 7,279,704 at cols. 6-10, which are incorporated by reference.

[0045] More examples for each of these layers are available. For example, a flexible and transparent substrate-anode combination is disclosed in U.S. Pat. No. 5,844,363, which is incorporated by reference in its entirety. An example of a p-doped hole transport layer is m-MTDATA doped with F.sub.4-TCNQ at a molar ratio of 50:1, as disclosed in U.S. Patent Application Publication No. 2003/0230980, which is incorporated by reference in its entirety. Examples of emissive and host materials are disclosed in U.S. Pat. No. 6,303,238 to Thompson et al., which is incorporated by reference in its entirety. An example of an n-doped electron transport layer is BPhen doped with Li at a molar ratio of 1:1, as disclosed in U.S. Patent Application Publication No. 2003/0230980, which is incorporated by reference in its entirety. U.S. Pat. Nos. 5,703,436 and 5,707,745, which are incorporated by reference in their entireties, disclose examples of cathodes including compound cathodes having a thin layer of metal such as Mg:Ag with an overlying transparent, electrically-conductive, sputter-deposited ITO layer. The theory and use of blocking layers is described in more detail in U.S. Pat. No. 6,097,147 and U.S. Patent Application Publication No. 2003/0230980, which are incorporated by reference in their entireties. Examples of injection layers are provided in U.S. Patent Application Publication No. 2004/0174116, which is incorporated by reference in its entirety. A description of protective layers may be found in U.S. Patent Application Publication No. 2004/0174116, which is incorporated by reference in its entirety.

[0046] FIG. **2** shows an inverted OLED **200**. The device includes a substrate **210**, a cathode **215**, an emissive layer **220**, a hole transport layer **225**, and an anode **230**. Device **200** may be fabricated by depositing the layers described, in order. Because the most common OLED configuration has a cathode disposed over the anode, and device **200** has cathode **215** disposed under anode **230**, device **200** may be referred to as an "inverted" OLED. Materials similar to those described with respect to device **100** may be used in the corresponding layers of device **200**. FIG. **2** provides one example of how some layers may be omitted from the structure of device **100**.

[0047] The simple layered structure illustrated in FIGS. **1** and **2** is provided by way of non-limiting example, and it is understood that embodiments of the invention may be used in connection with a wide variety of other structures. The specific materials and structures described are exemplary in nature, and other materials and structures may be used. Functional OLEDs may be achieved by combining the various layers described in different ways, or layers may be omitted entirely, based on design, performance, and cost factors. Other layers not specifically described may also be included. Materials other than those specifically described may be used. Although many of the examples provided herein describe various layers as comprising a single material, it is understood that combinations of materials, such as a mixture of host and dopant, or more generally a mixture, may be used. Also, the layers may have various sublayers. The names given to the various layers herein are not intended to be strictly limiting. For example, in device **200**, hole transport layer **225** transports holes and injects holes into emissive layer **220**, and may be described as a hole transport layer or a hole injection layer. In one embodiment, an OLED may be described as having an "organic layer" disposed between a cathode and an anode. This organic layer may comprise a single layer, or may further comprise multiple layers of different organic materials as described, for example, with respect to FIGS. **1** *and* **2**.

[0048] Structures and materials not specifically described may also be used, such as OLEDs comprised of polymeric materials (PLEDs) such as disclosed in U.S. Pat. No. 5,247,190 to Friend et al., which is incorporated by reference in its entirety. By way of further example, OLEDs having a single organic layer may be used. OLEDs may be stacked, for example as described in U.S. Pat. No. 5,707,745 to Forrest et al, which is incorporated by reference in its entirety. The OLED structure may deviate from the simple layered structure illustrated in FIGS. **1** and **2**. For example, the substrate may include an angled reflective surface to improve outcoupling, such as a mesa structure as described in U.S. Pat. No. 6,091,195 to Forrest et al., and/or a pit structure as described in U.S. Pat. No. 5,834,893 to Bulovic et al., which are incorporated by reference in their entireties.

[0049] Unless otherwise specified, any of the layers of the various embodiments may be deposited by any suitable method. For the organic layers, preferred methods include thermal evaporation, ink-jet, such as described in U.S. Pat. Nos. 6,013,982 and 6,087,196, which are incorporated by reference in their entireties, organic vapor phase deposition (OVPD), such as described in U.S. Pat. No. 6,337,102 to Forrest et al., which is incorporated by reference in its entirety, and deposition by organic vapor jet printing (OVJP), such as described in U.S. patent application Ser. No. 10/233, 470, which is incorporated by reference in its entirety. Other suitable deposition methods include spin coating and other solution based processes. Solution based processes are preferably carried out in nitrogen or an inert atmosphere. For the other layers, preferred methods include thermal evaporation. Preferred patterning methods include deposition through a mask, cold welding such as described in U.S. Pat. Nos. 6,294,398 and 6,468,819, which are incorporated by reference in their entireties, and patterning associated with some of the deposition methods such as ink jet and OVJD. Other methods may also be used. The materials to be deposited may be modified to make them compatible with a particular deposition method. For example, substituents such as alkyl and aryl groups, branched or unbranched, and preferably containing at least 3 carbons, may be used in small molecules to enhance their ability to undergo solution processing. Substituents having 20 carbons or more may be used, and 3-20 carbons is a preferred range. Materials with asymmetric structures may have better solution processibility than those having symmetric structures, because asymmetric materials may have a lower tendency to recrystallize. Dendrimer substituents may be used to enhance the ability of small molecules to undergo solution processing.

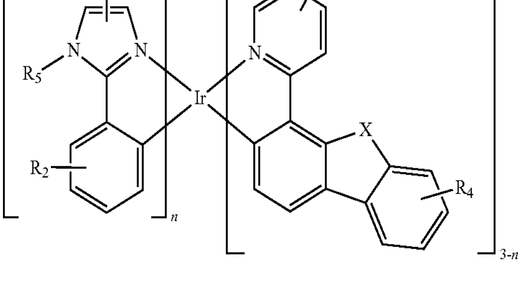
[0050] Devices fabricated in accordance with embodiments of the invention may be incorporated into a wide variety of consumer products, including flat panel displays, computer monitors, televisions, billboards, lights for interior or exterior illumination and/or signaling, heads up displays, fully transparent displays, flexible displays, laser printers, telephones, cell phones, personal digital assistants (PDAs), laptop computers, digital cameras, camcorders, viewfinders, micro-displays, vehicles, a large area wall, theater or stadium screen, or a sign. Various control mechanisms may be used to control devices fabricated in accordance with the present invention, including passive matrix and active matrix. Many of the devices are intended for use in a temperature range comfortable to humans, such as 18 degrees C. to 30 degrees C., and more preferably at room temperature (20-25 degrees C.).

[0051] The materials and structures described herein may have applications in devices other than OLEDs. For example, other optoelectronic devices such as organic solar cells and organic photodetectors may employ the materials and structures. More generally, organic devices, such as organic transistors, may employ the materials and structures.

[0052] The terms halo, halogen, alkyl, cycloalkyl, alkenyl, alkynyl, arylkyl, heterocyclic group, aryl, aromatic group, and heteroaryl are known to the art, and are defined in U.S. Pat. No. 7,279,704 at cols. 31-32, which are incorporated herein by reference.

[0053] A novel compound comprising a heteroleptic iridium complex having the formula:

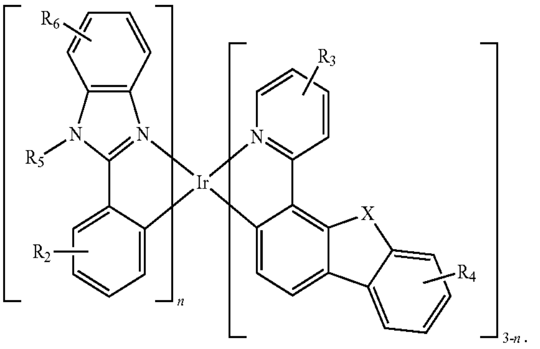
Formula I



is provided. R_1, R_2, R_3 and R_4 can represent mono-, di-, tri- or tetra-substitution, and R_1, R_2, R_3, R_4 and R_5 are each independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. R_1, R_2, R_3 and R_4 are optionally fused. When any of R_1 to R_4 are fused, an additional ring or rings is/are formed with the ring to which R_1 to R_4 were attached. Both the additional ring or rings, and the ring to which R_1 to R_4 were attached to may be further substituted with any of the aforementioned groups in this paragraph, including combinations of groups. X is selected from the group consisting of CRR', SiRR', C═O, N—R, B—R, O, S, SO, SO_2, and Se. R and R' are independently selected from the group consisting of linear alkyl, branched alkyl, and aryl. n is 1 or 2.

[0054] In one embodiment, the compound has the formula:

Formula II



R_6 represents mono-, di-, tri- or tetra-substitution, and R_6 is selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. R_6 is optionally fused and may be further substituted.

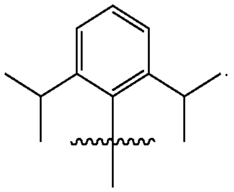
[0055] In one embodiment, n is 2. In another embodiment, n is 1.

[0056] In one embodiment, X is selected from the group consisting of O and S. In a preferred embodiment, X is O. In another preferred embodiment, X is S.

[0057] The phenylimidazole and phenylbenzimidazole ligands in compounds of Formula I form highly stable iridium (III) complexes. Heteroleptic compounds give highly tunable phosphorescent emission and are thus important to achieve a wide range of colors. The emission of transition-metal complexes can be tuned by choosing ligands with different triplet states and HOMO/LUMO levels. Phenylimidazole and phenylbenzimidazole ligands in compounds of Formula I have shallow HOMOs and deep LUMOs, and the resulting transition can be tuned by using complementary ligands in a heteroleptic complex. For example, phenylpyridine complexes have deeper HOMO levels and shallower LUMO levels and unexpected interactions between the two ligands in heteroleptic systems can occur. The pyridyldibenzofuran- or pyridyldibenzothiophene-containing ligands presented here are phenylpyridine derivatives and the properties of the combination are unexpected. While a variety of dibenzo derivatives are suitable, the use of dibenzofuran- and dibenzthiophene-containing ligands is preferred due to their narrow line shape, high device efficiency, and long lifetime. However, complexes containing three dibenzofuran or dibenzthiophene ligands have high sublimation temperatures. By making heteroleptic complexes, the sublimation temperatures can be lowered enabling efficient purification and subsequent incorporation into OLEDs.

[0058] Additionally, heteroleptic iridium(III) complexes of Formula I containing a pyridyldibenzofuran- or pyridyldibenzothiophene-containing ligand experience less vibronic coupling and consequently have narrower spectra, which is important for monochromatic light emission. Without being bound by theory, it is believed that this is due to interactions between the phenylimidazole or phenylbenzimidazole ligand and the pyridyldibenzofuran- or pyridyldibenzothiophene-containing ligand in the metal complex. The combination of these two ligands in a compound of Formula I gives unexpected results with respect to the properties of compounds of Formula I.

[0059] In one embodiment, R_5 is aryl or substituted aryl. In another embodiment, R_5 is alkyl. Proper selection of R_5 can decrease the sublimation temperature of the complex without having a significant impact on the overall stability. In one embodiment, R_5 is a 2,6-disubstituted aryl. In a preferred embodiment, R_5 is



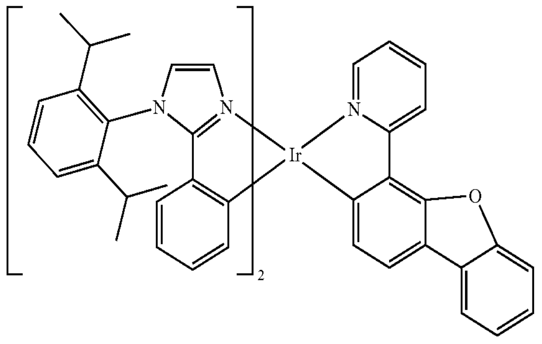
Without being bound by theory, it is believed that the use of 2,6-diisopropylphenyl moieties can be advantageous due to increased steric bulk around the iridium center, which can prevent solid state packing and result in high efficiency.

[0060] In one embodiment, R_2, R_3, and R_4 are independently selected from the group consisting of hydrogen and alkyl, and at least one of R_2, R_3, and R_4 is alkyl.

[0061] In one embodiment, R_3 is aryl or heteroaryl. In another embodiment, R_3 is phenyl or substituted phenyl. In one embodiment, R_6, R_2, and R_4 are hydrogen.

[0062] Specific non-limiting compounds are provided. In one embodiment, the compound is selected from the group consisting of:

Compound 1



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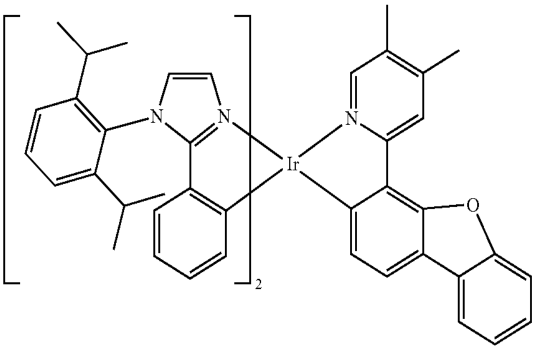

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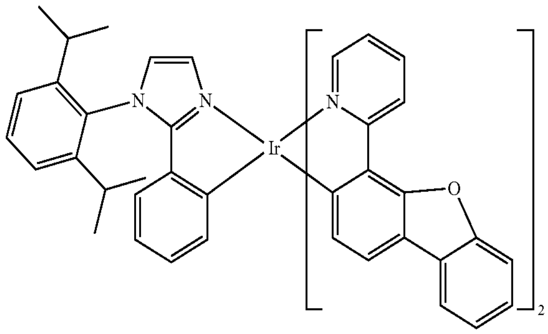

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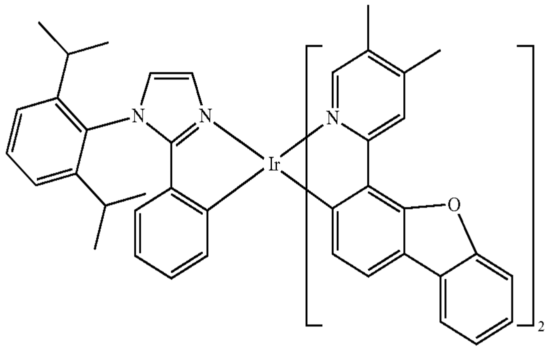

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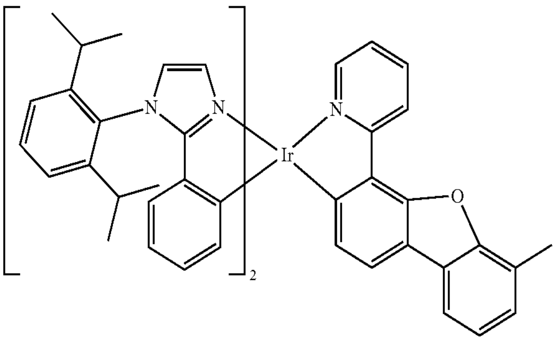

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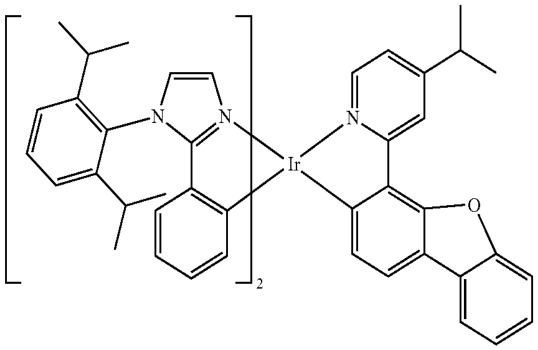

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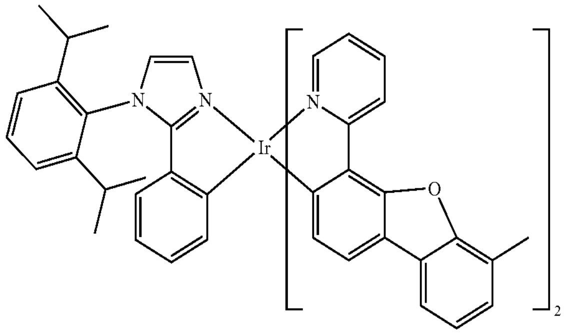

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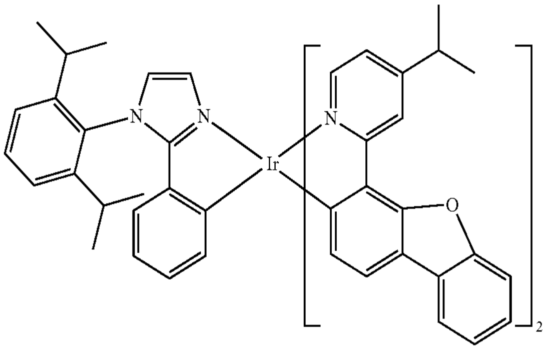

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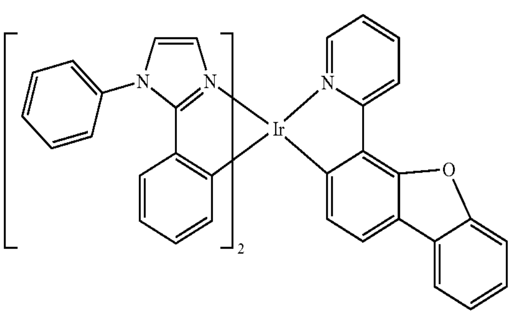

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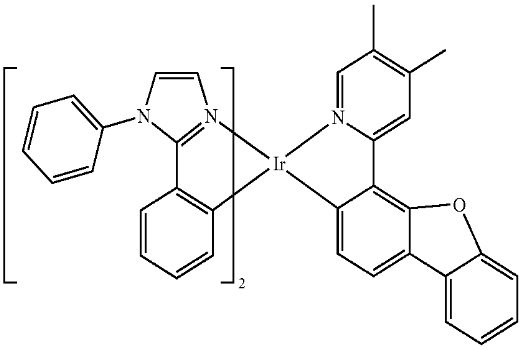

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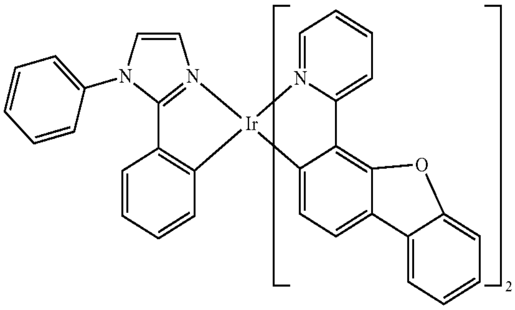

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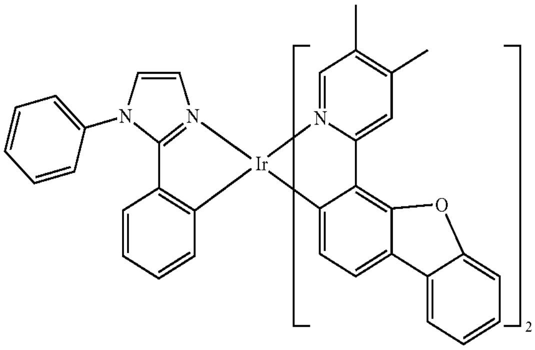

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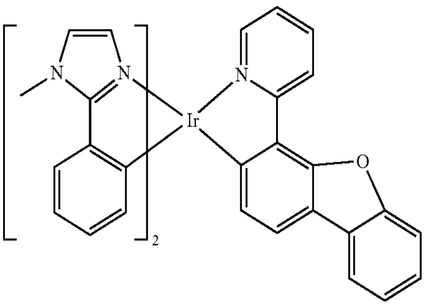

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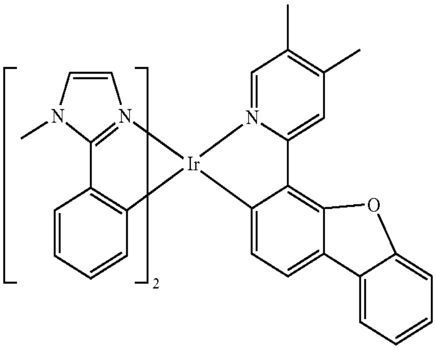

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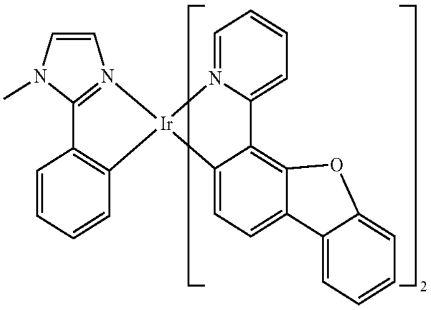

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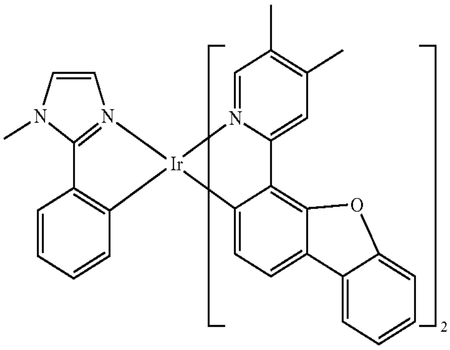

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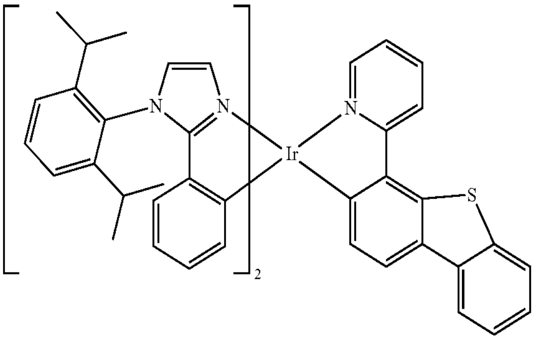

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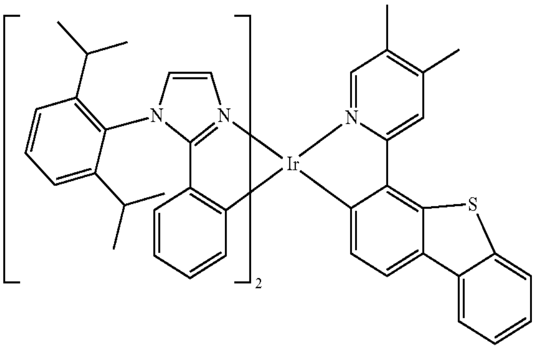

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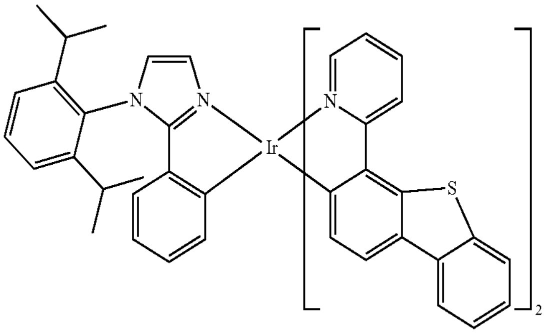

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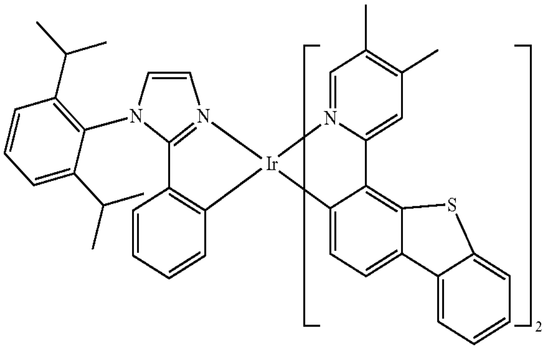

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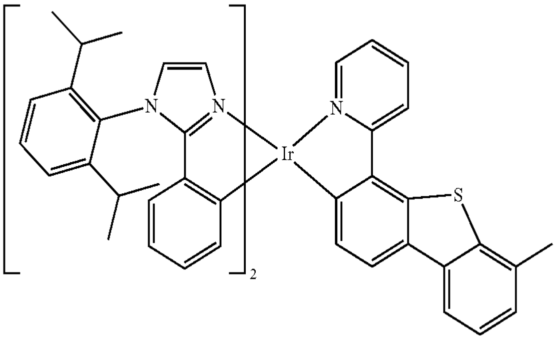

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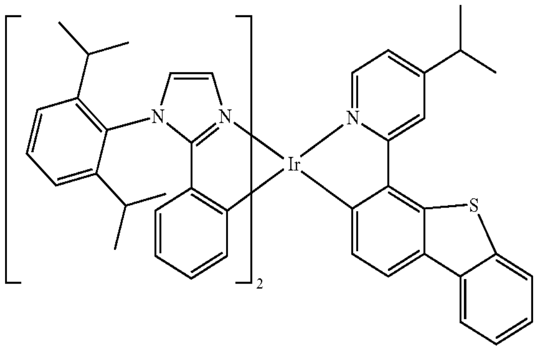

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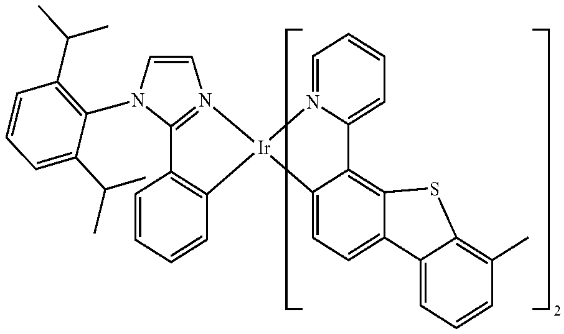

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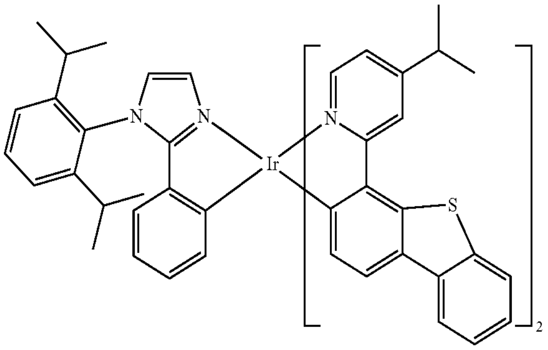

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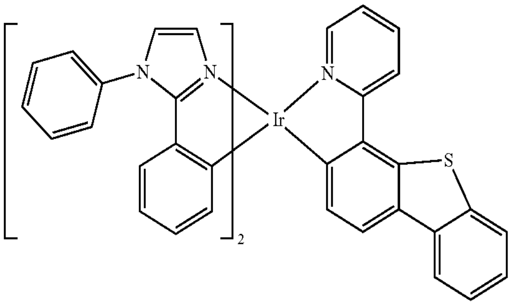

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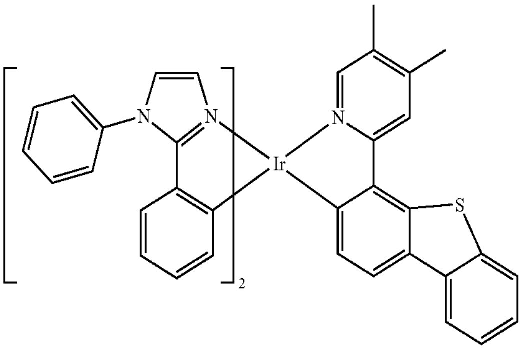

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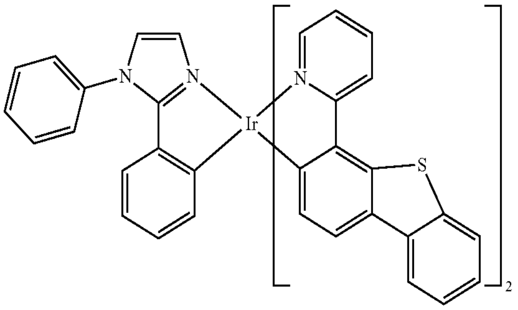

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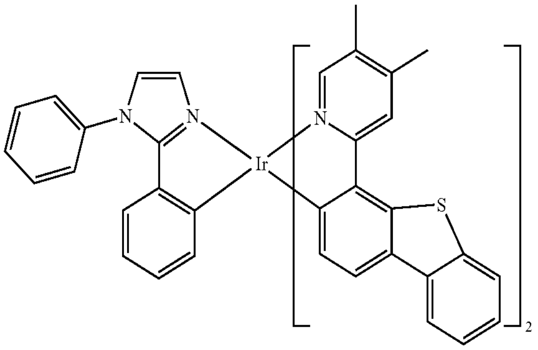

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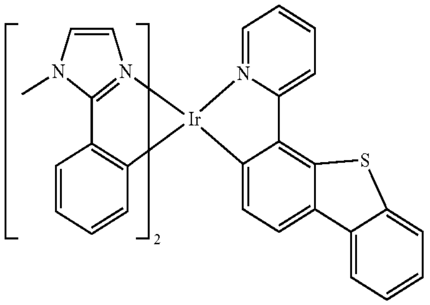

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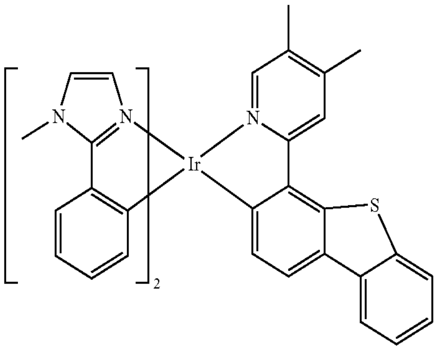

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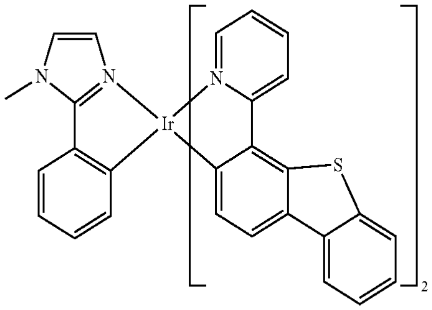

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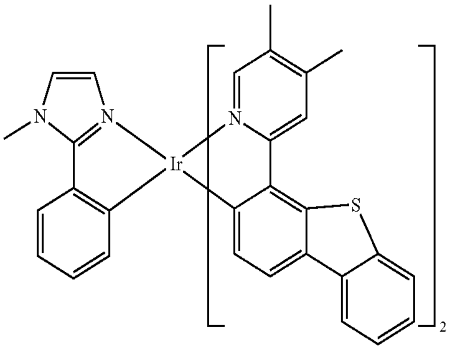

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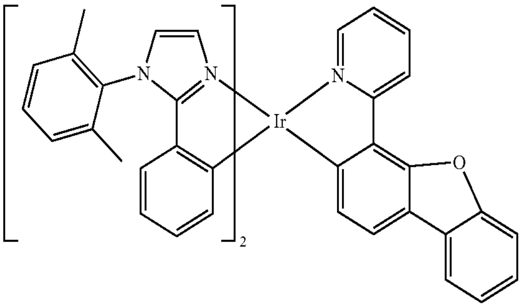

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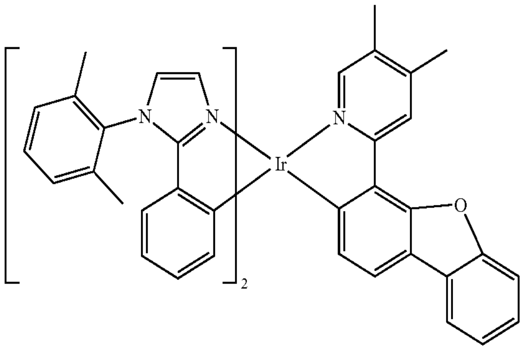

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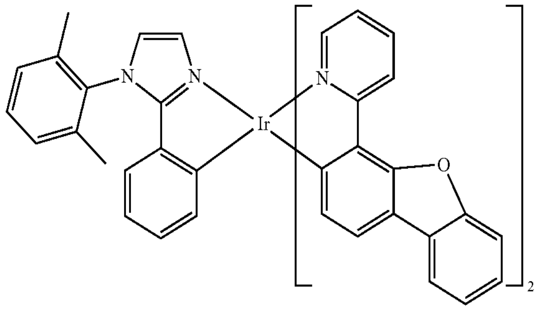

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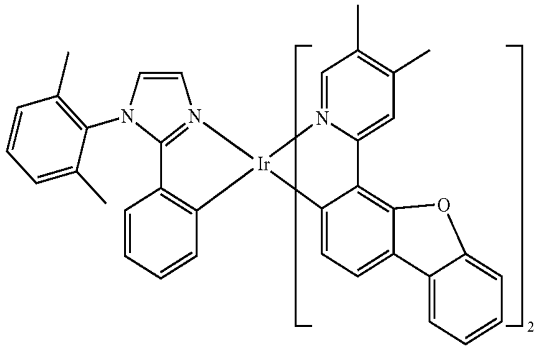

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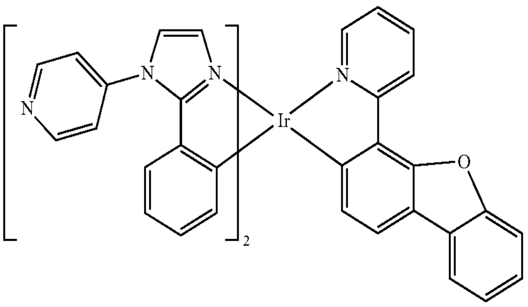

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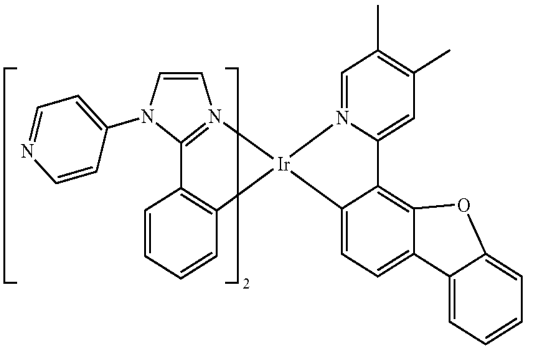

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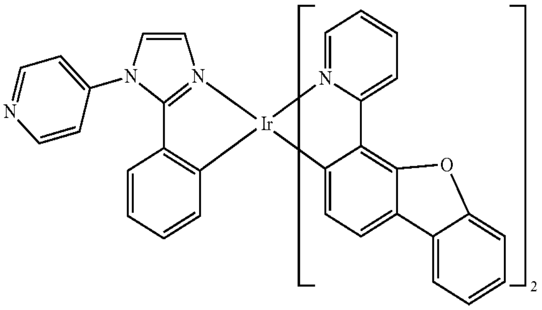

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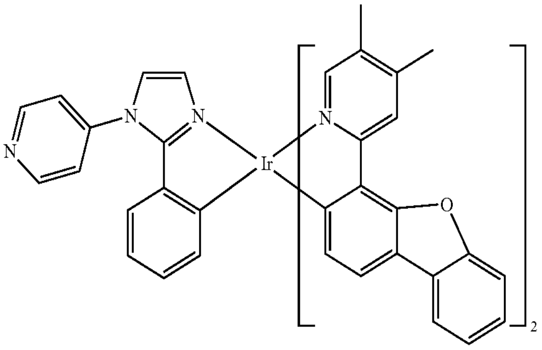

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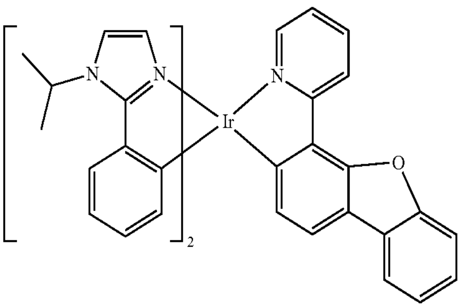

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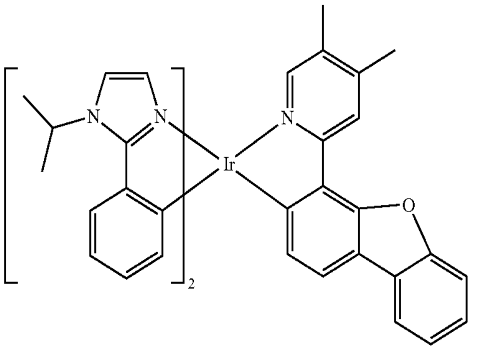

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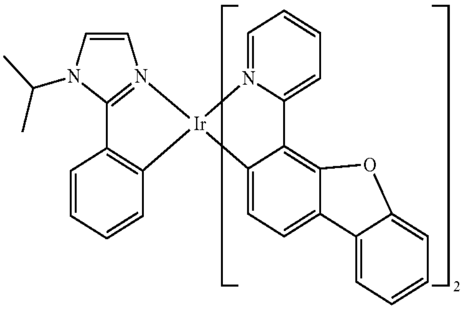

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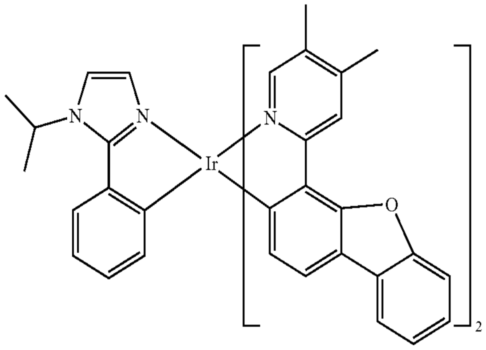

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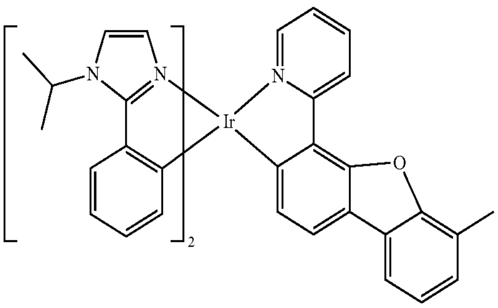

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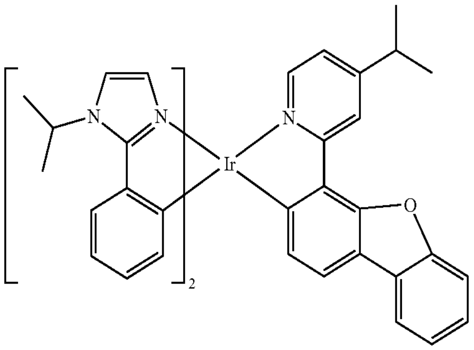

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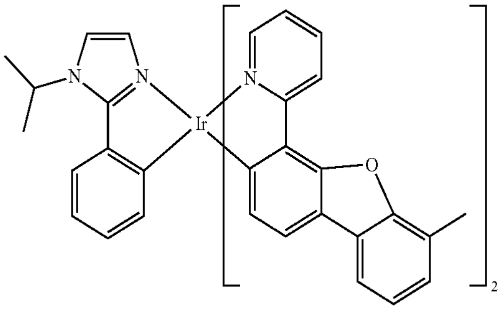

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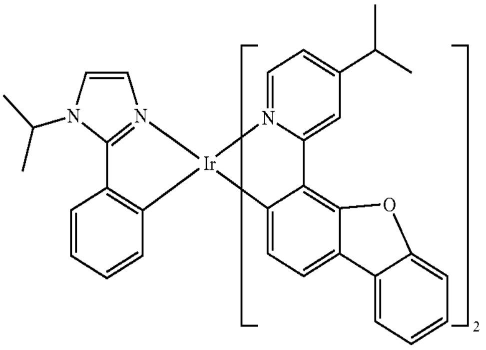

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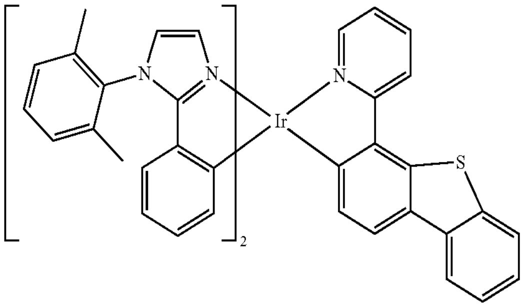

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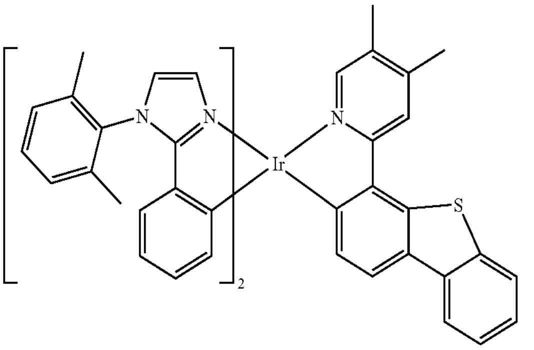

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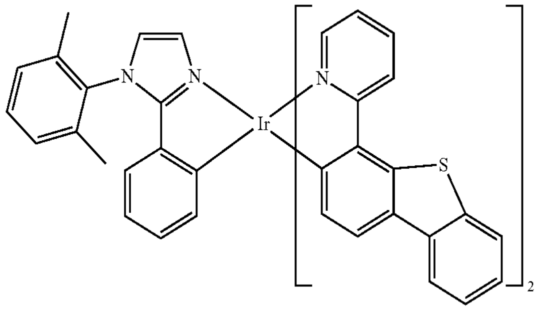

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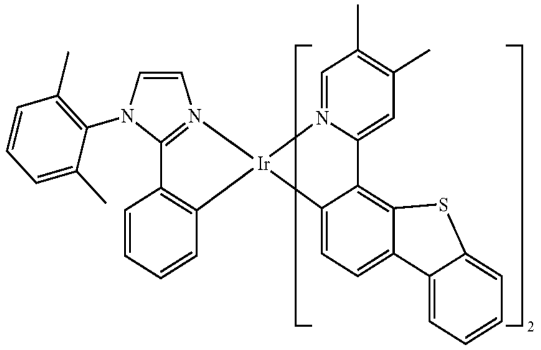

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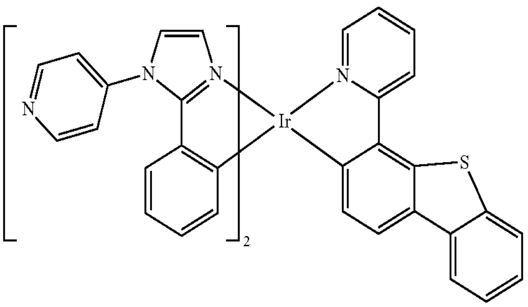

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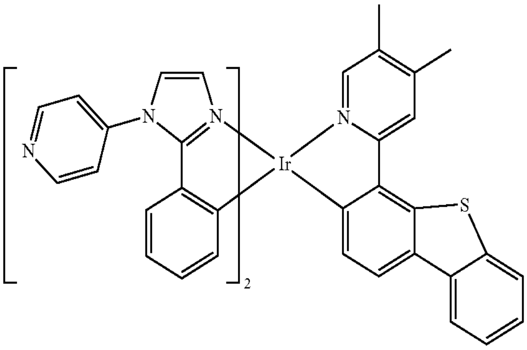

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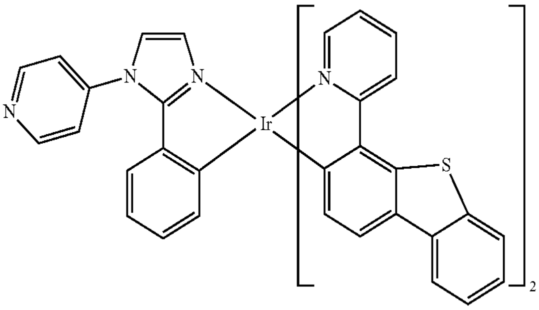

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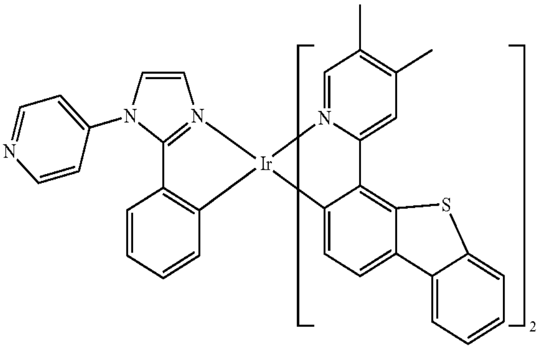

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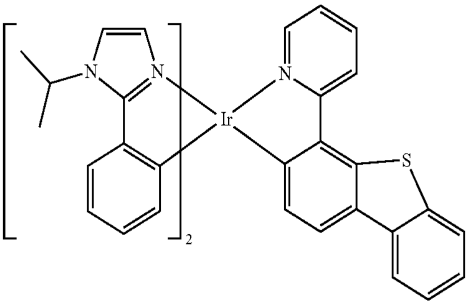

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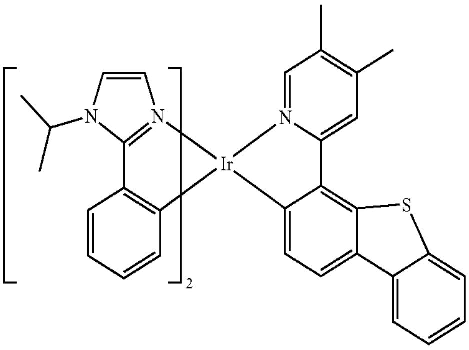

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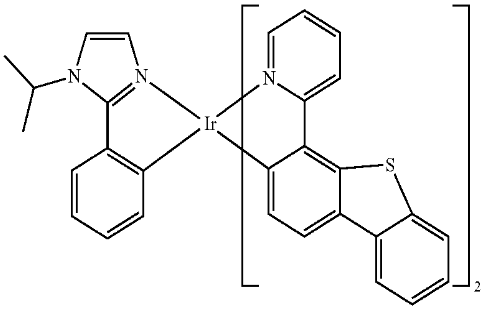

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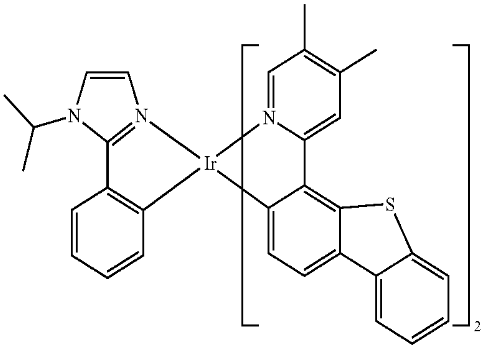

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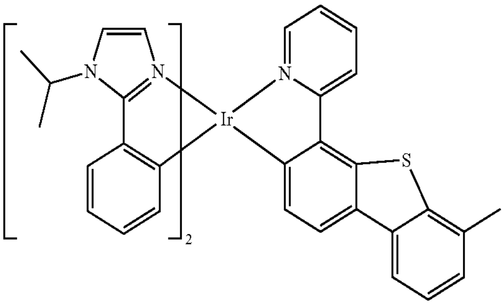

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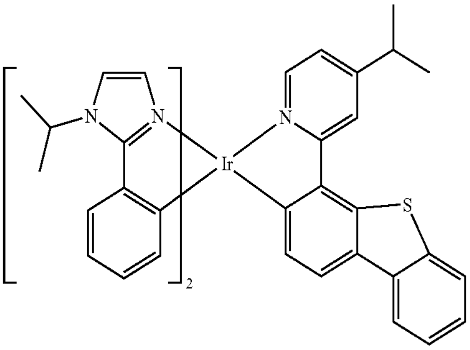

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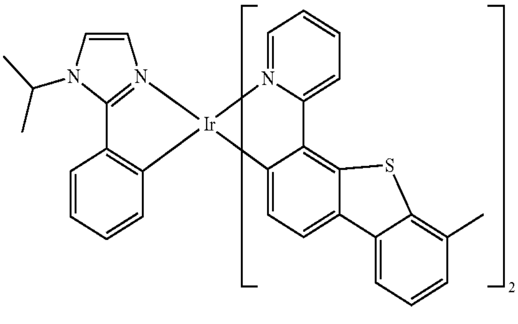
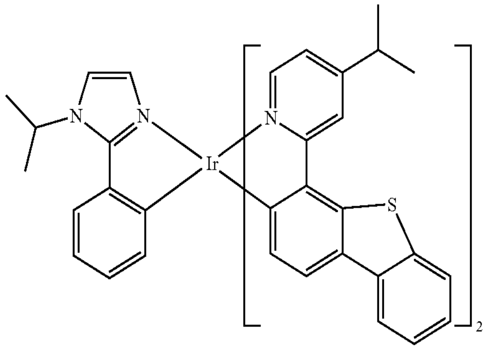
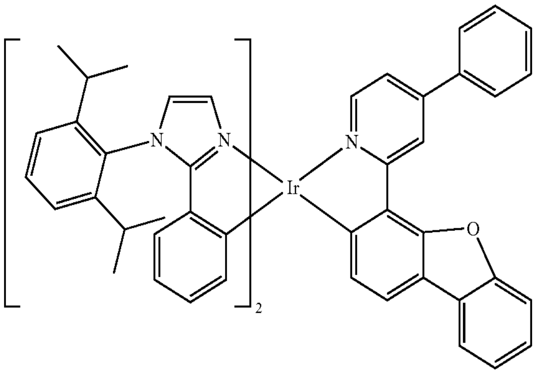


Compound 64



Compound 65



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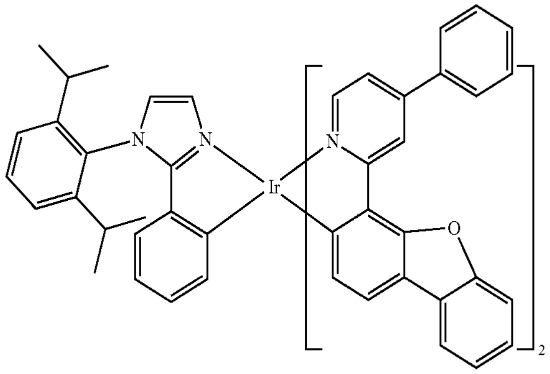
Compound 66



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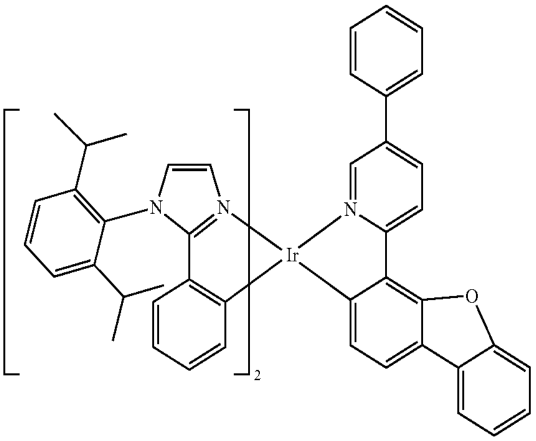

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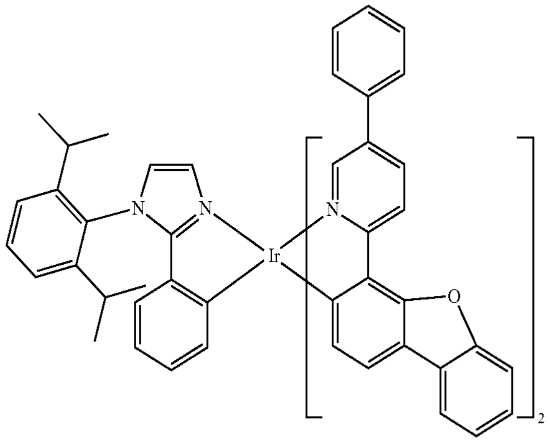

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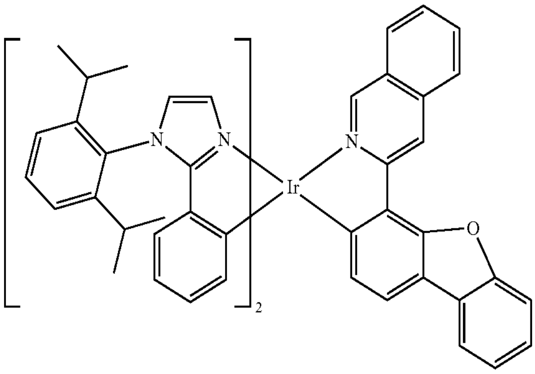
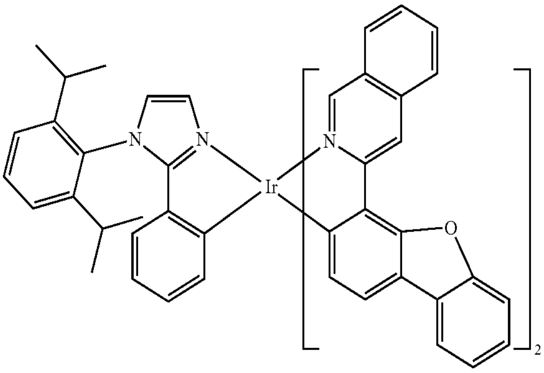
Compound 69



Compound 70



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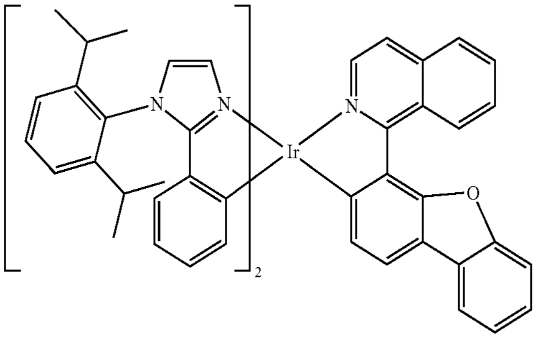

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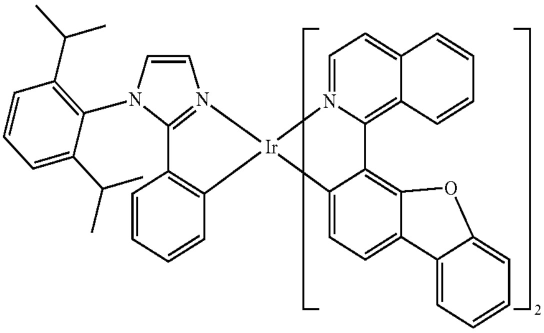

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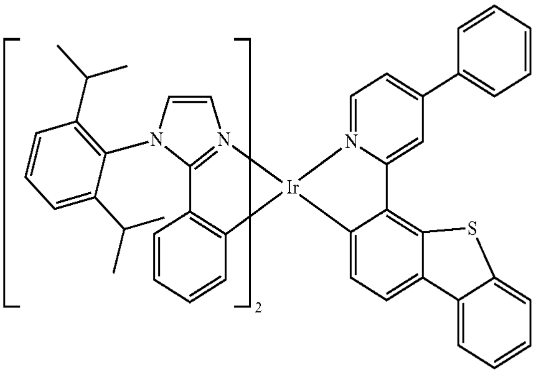
Compound 73



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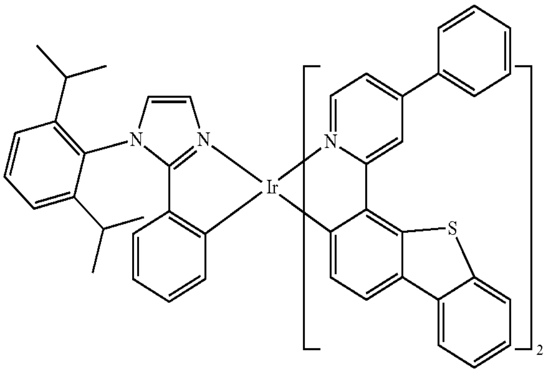
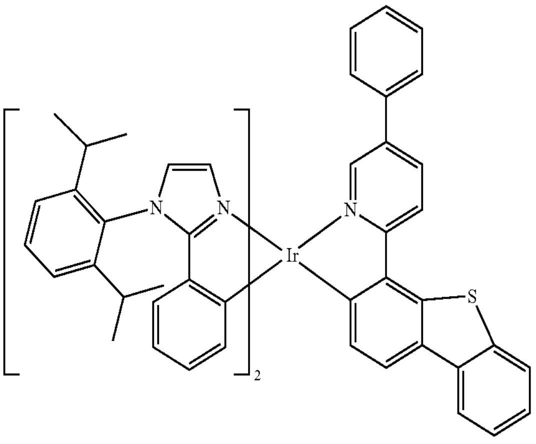


Compound 75



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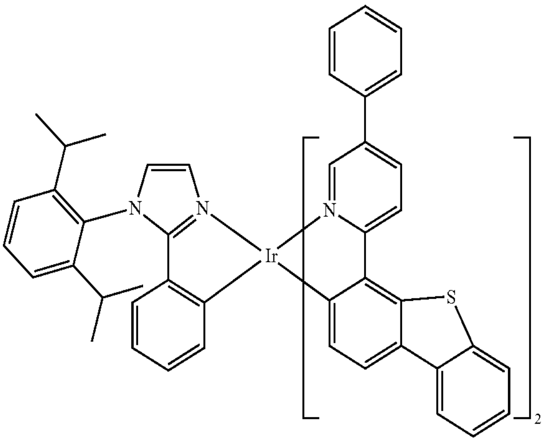
Compound 76



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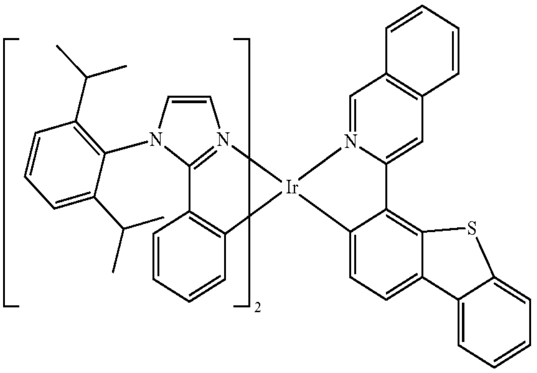

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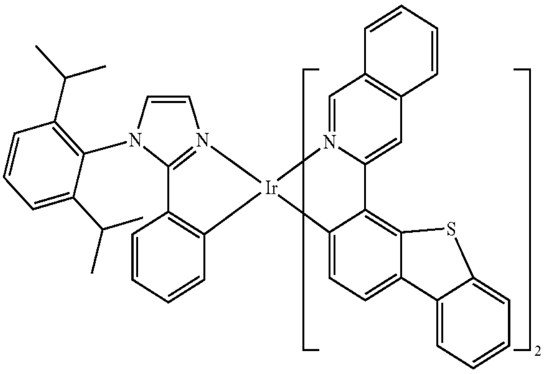
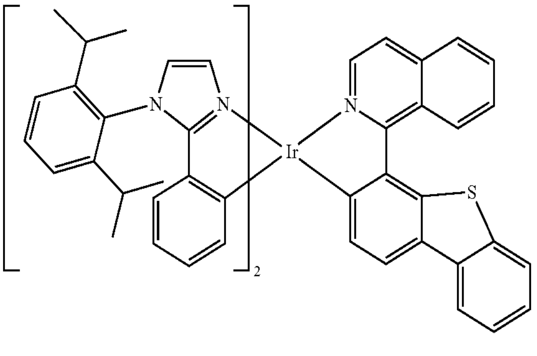


Compound 79



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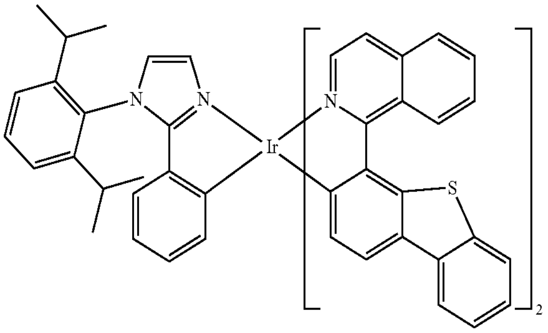
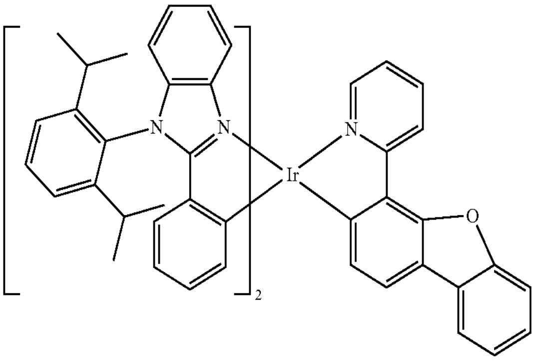
Compound 80

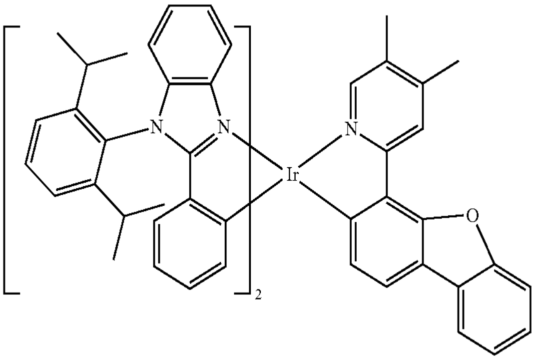


[0063] In another embodiment, the compound is selected from the group consisting of:

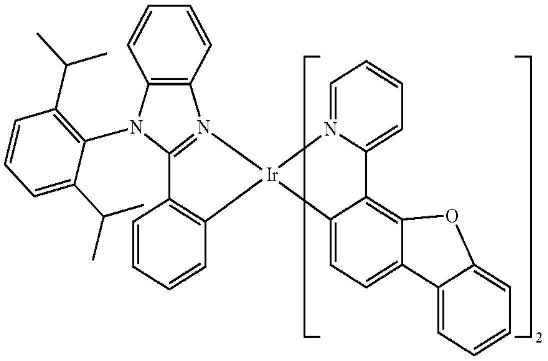
Compound 81



Compound 82



Compound 83



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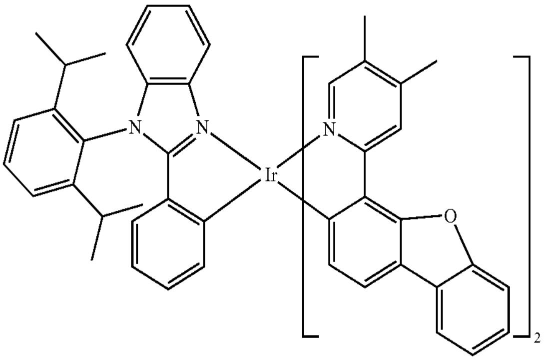
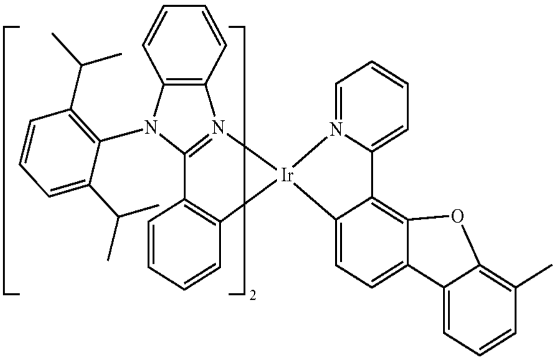
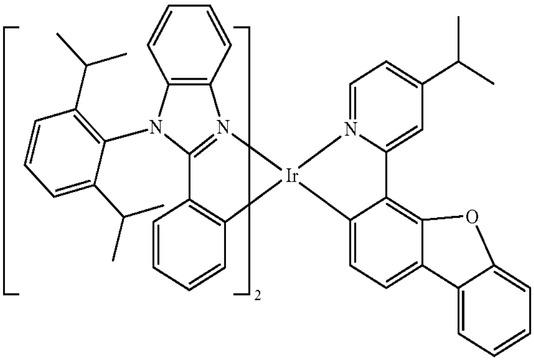
Compound 84



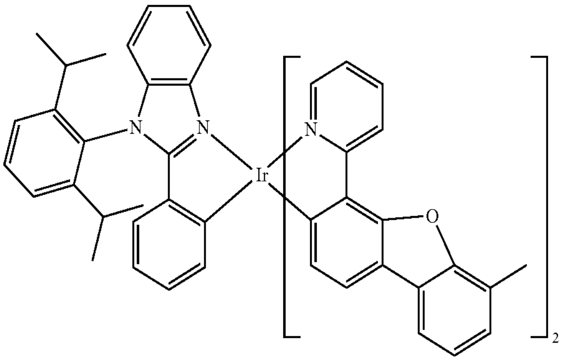
Compound 85



Compound 86



Compound 87



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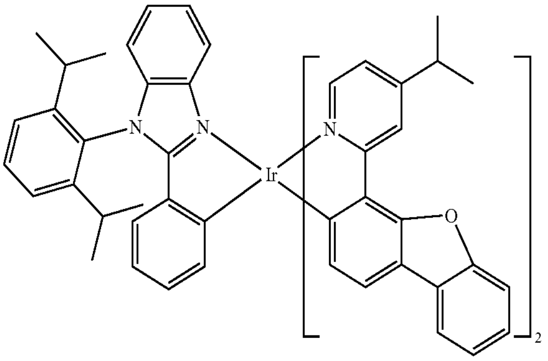
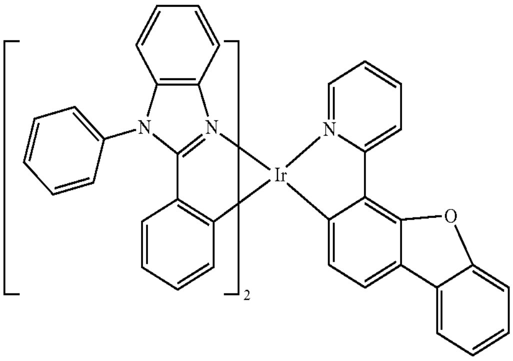
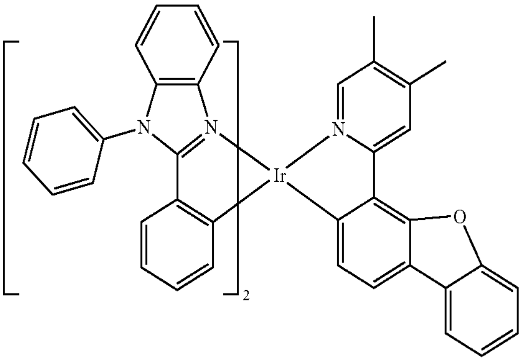
Compound 88



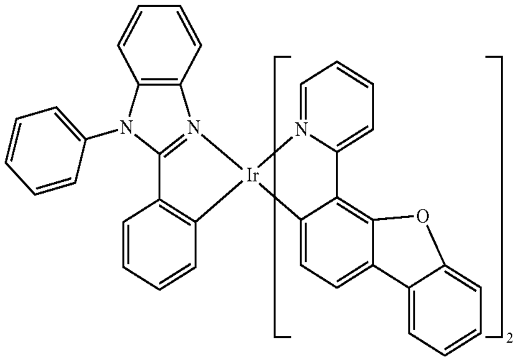
Compound 89



Compound 90



Compound 91



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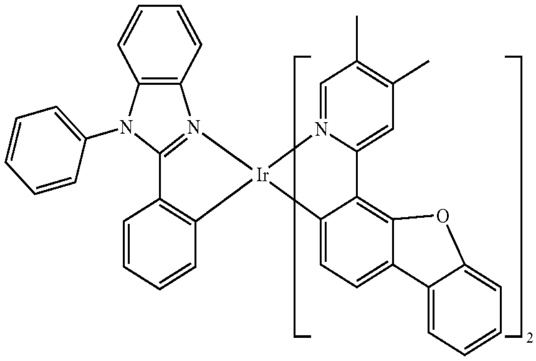
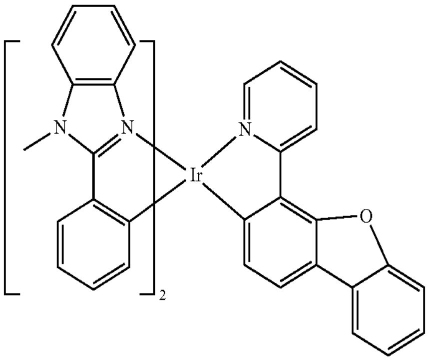
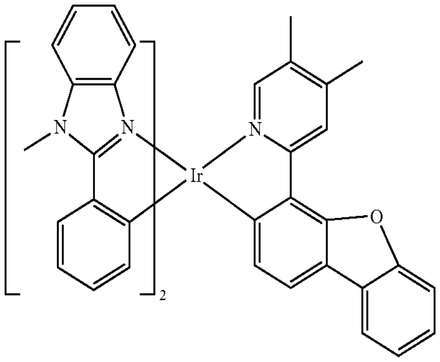
Compound 92



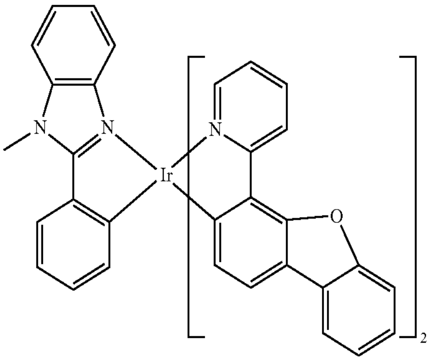
Compound 93



Compound 94



Compound 95



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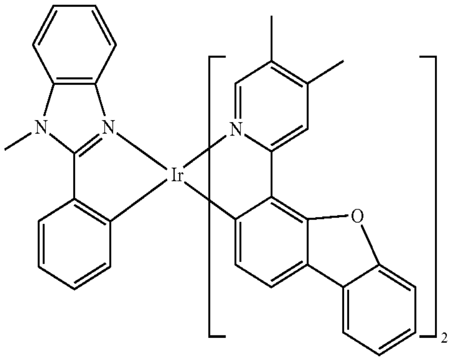
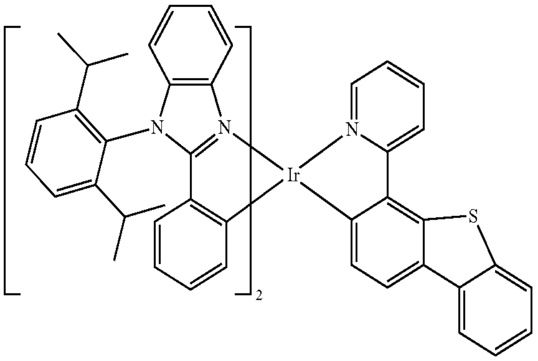
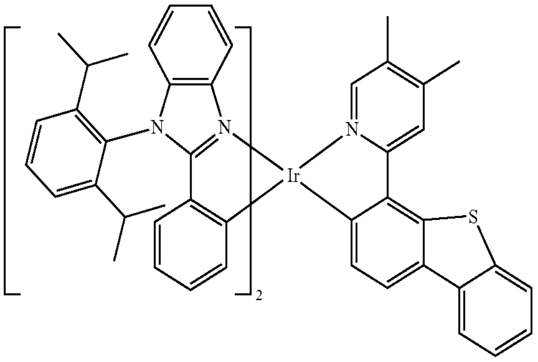
Compound 96



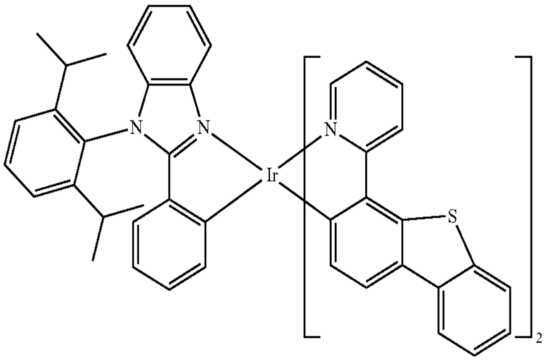
Compound 97



Compound 98



Compound 99



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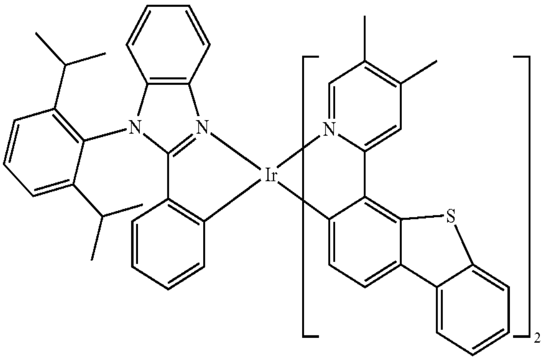
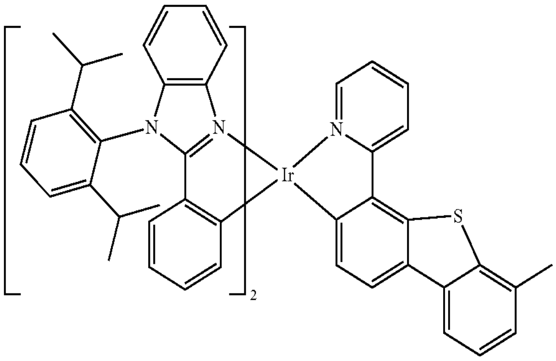
Compound 100



Compound 101



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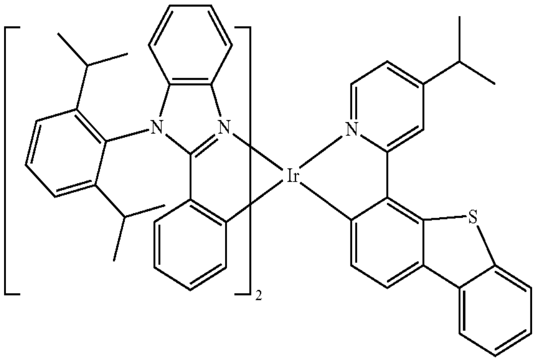

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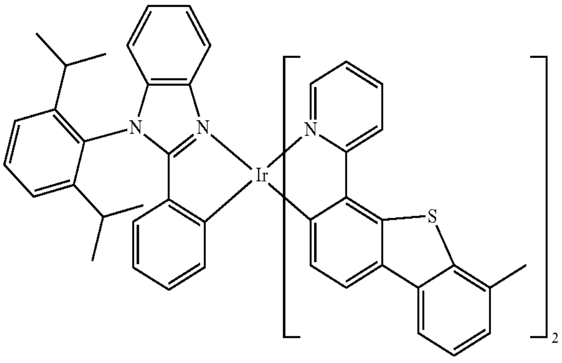

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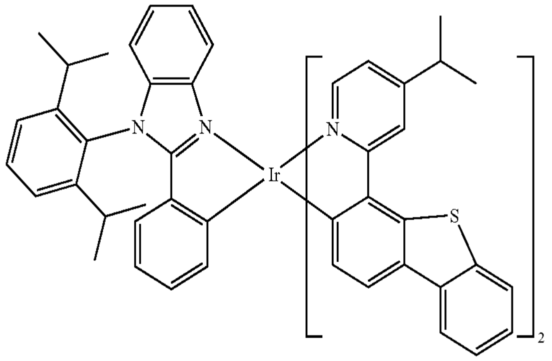

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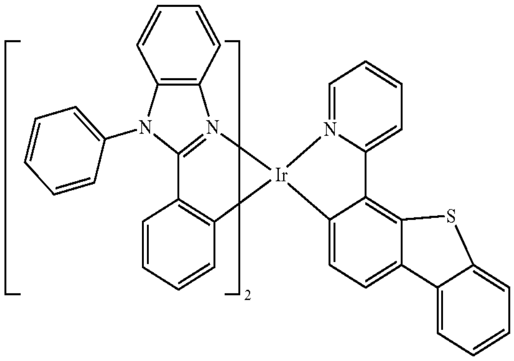

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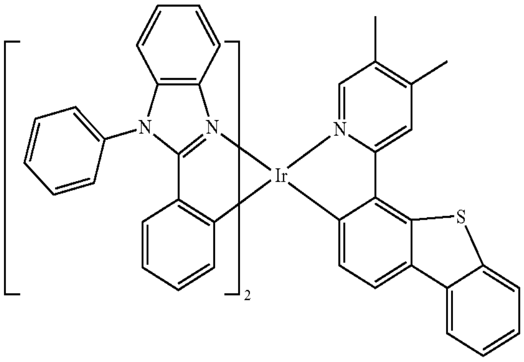

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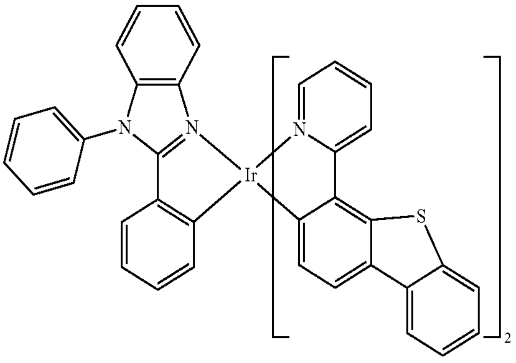

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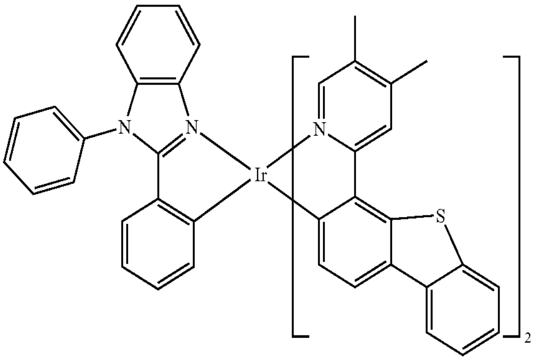
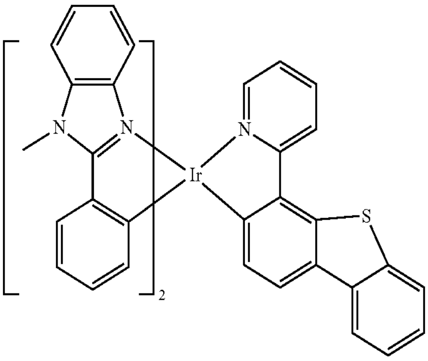
Compound 108



Compound 109



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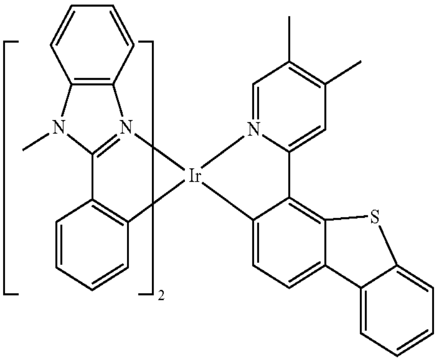

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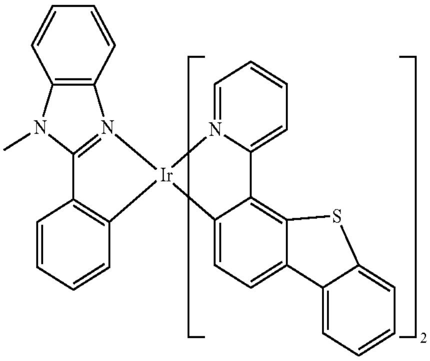

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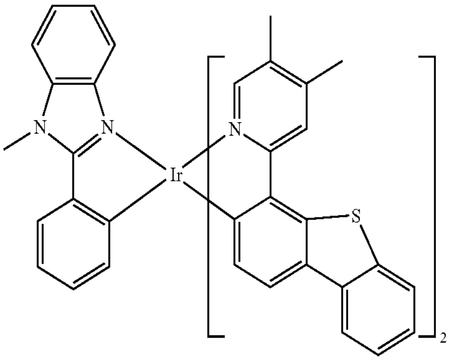

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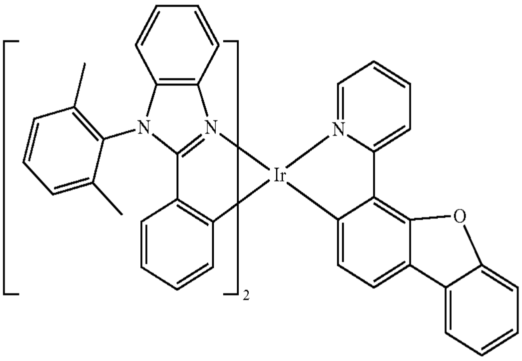

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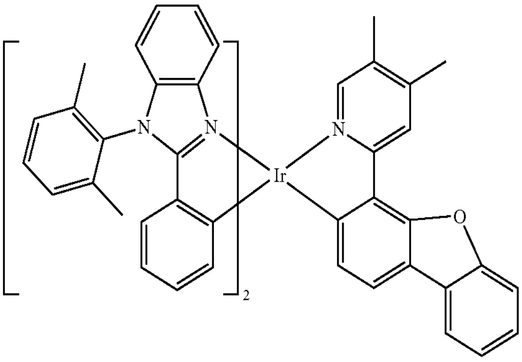

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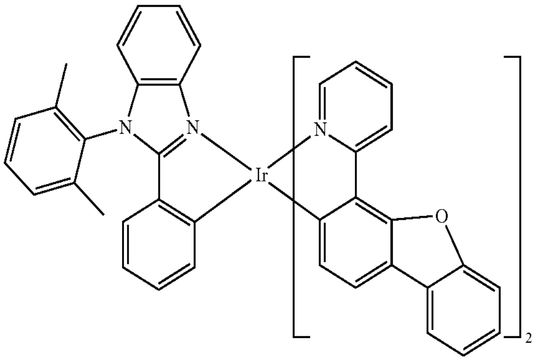

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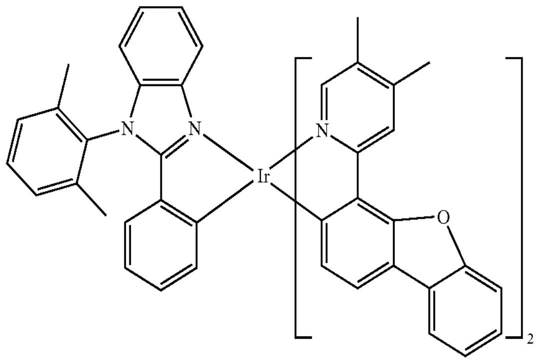
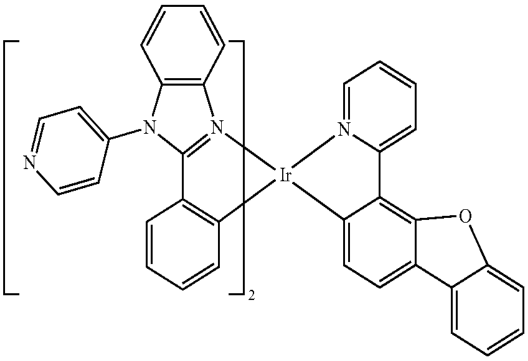
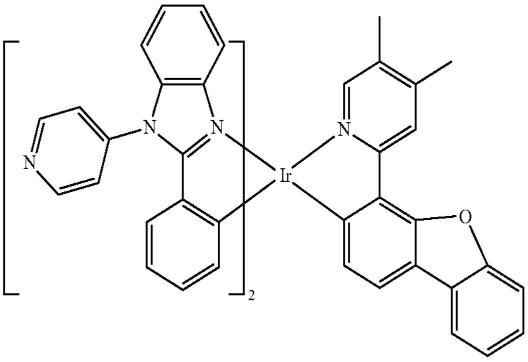


Compound 1117



Compound 118



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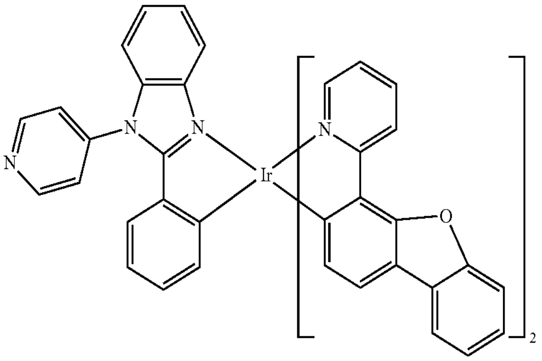

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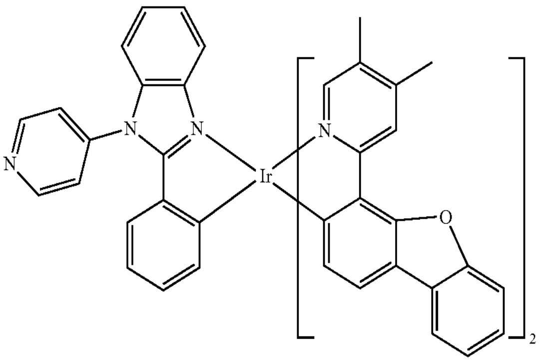
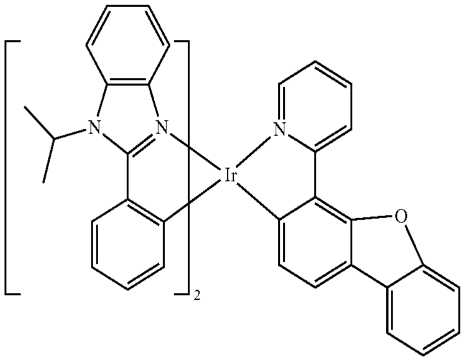
Compound 120



Compound 121



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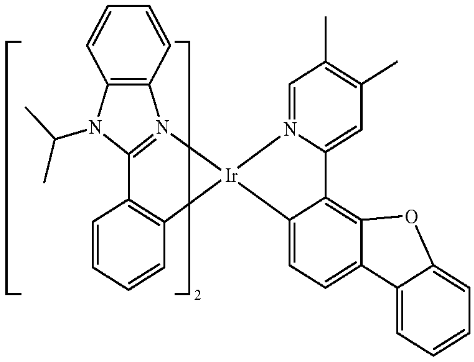

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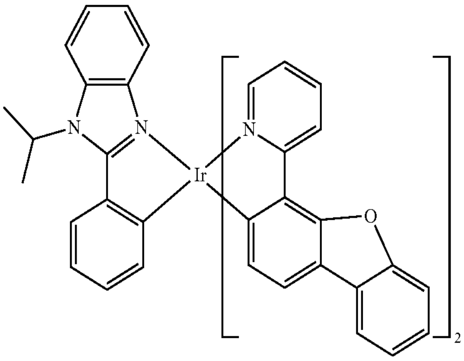

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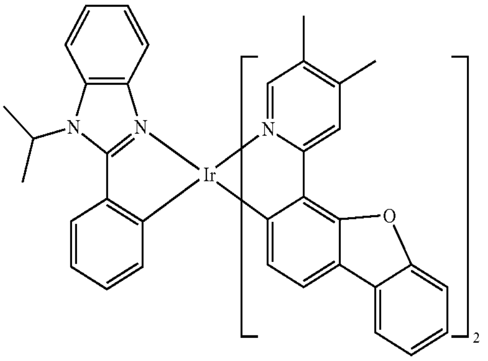
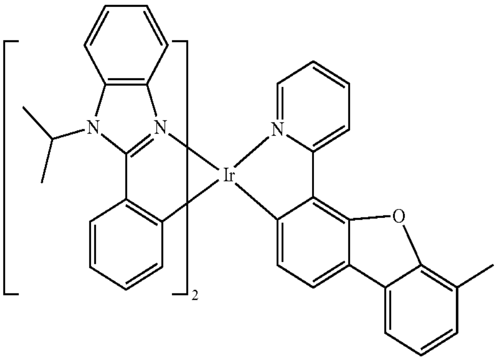
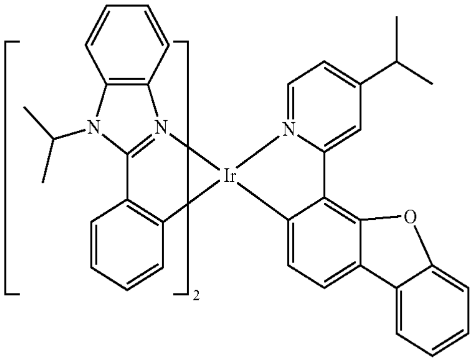
Compound 124



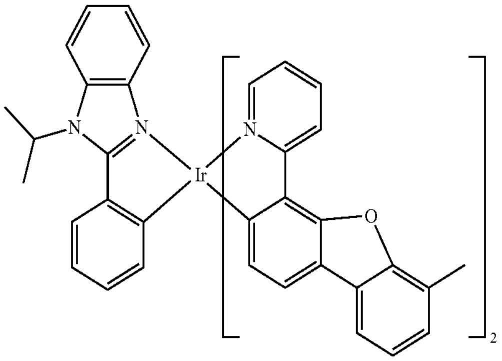
Compound 125



Compound 126



Compound 127



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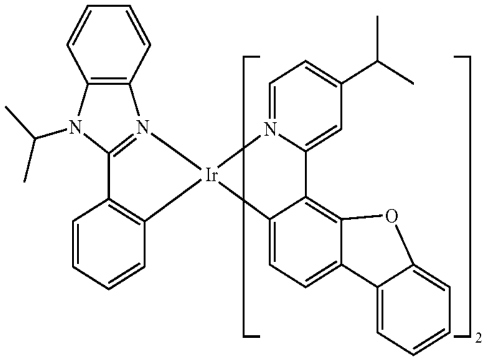
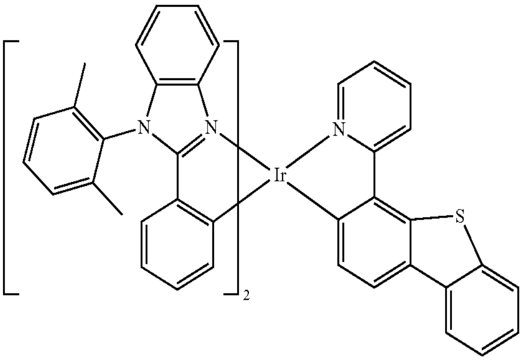
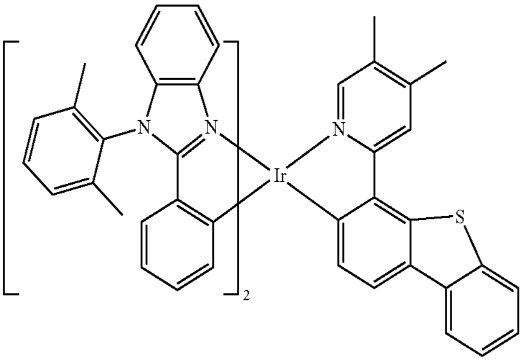
Compound 128



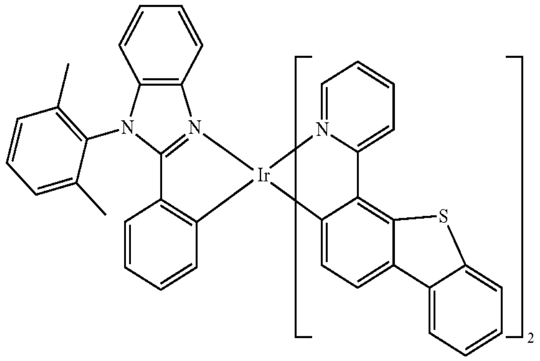
Compound 129



Compound 130



Compound 131



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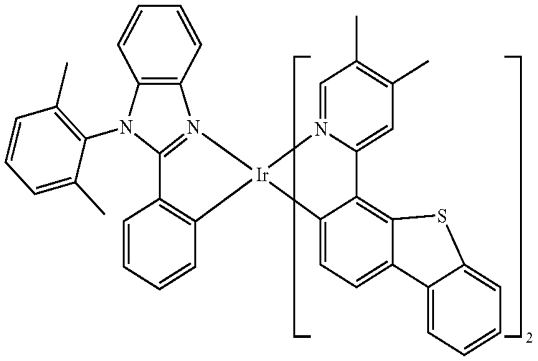
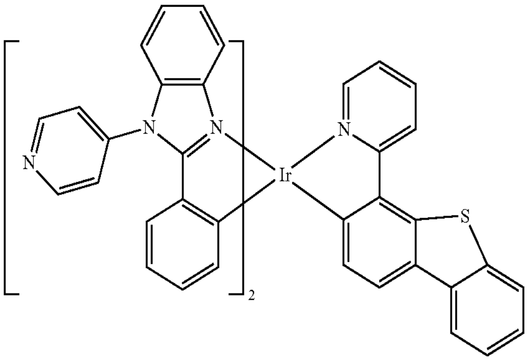
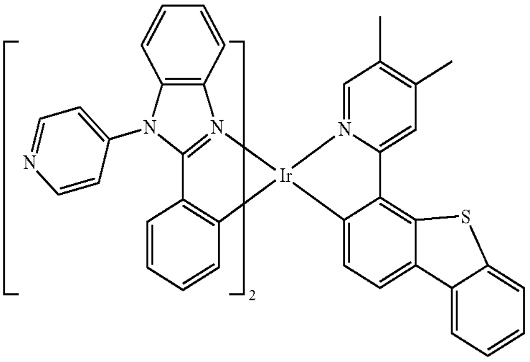
Compound 132



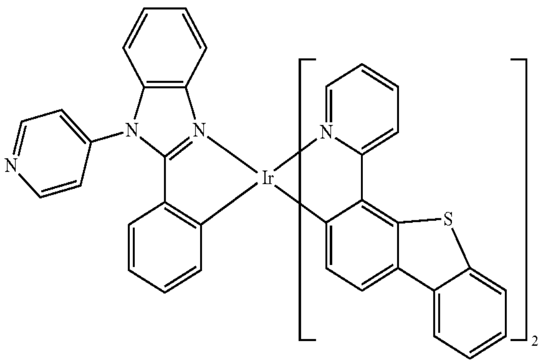
Compound 133



Compound 134



Compound 135



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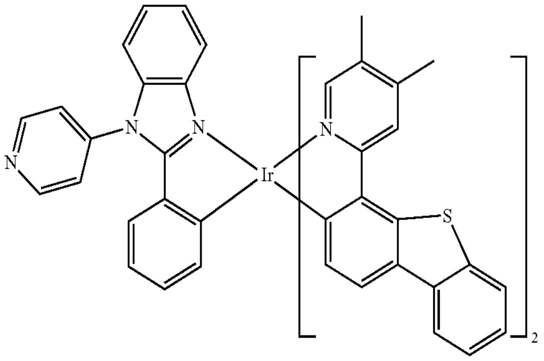
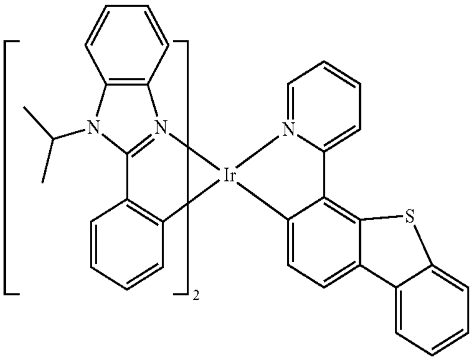
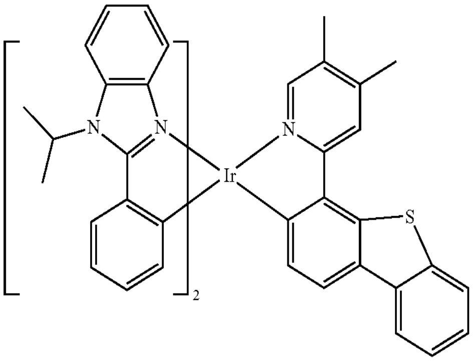
Compound 136



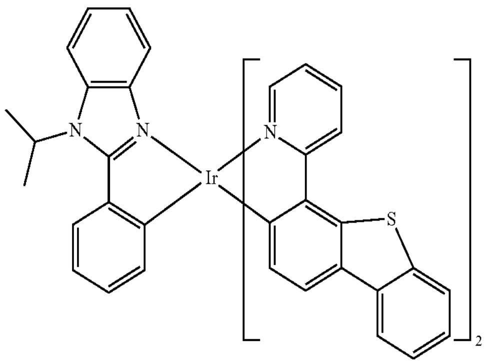
Compound 137



Compound 138



Compound 139



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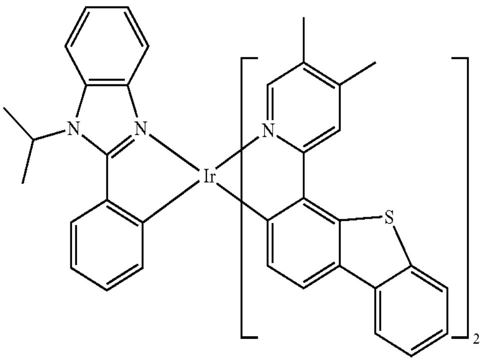
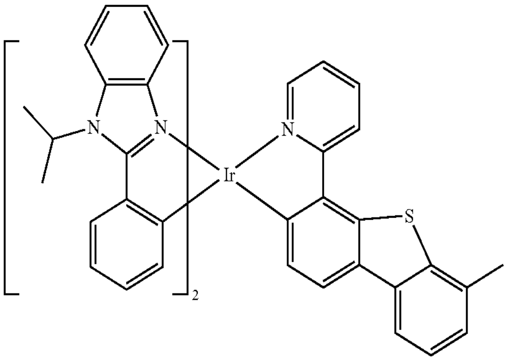
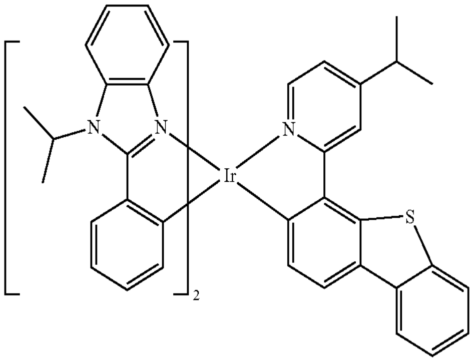
Compound 140



Compound 141



Compound 142



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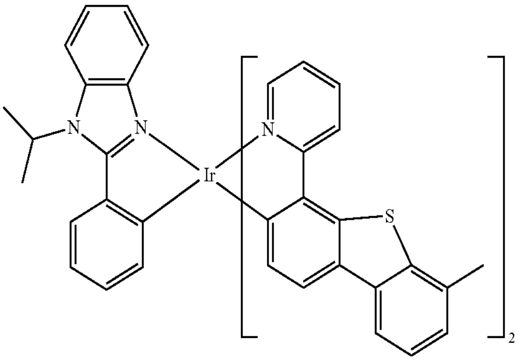

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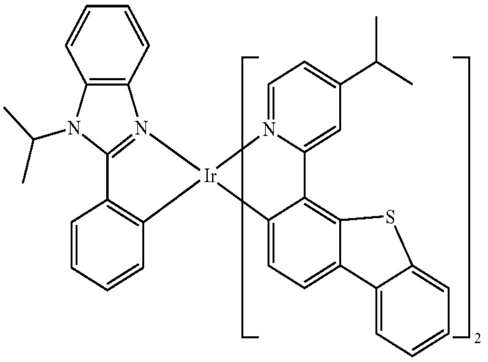
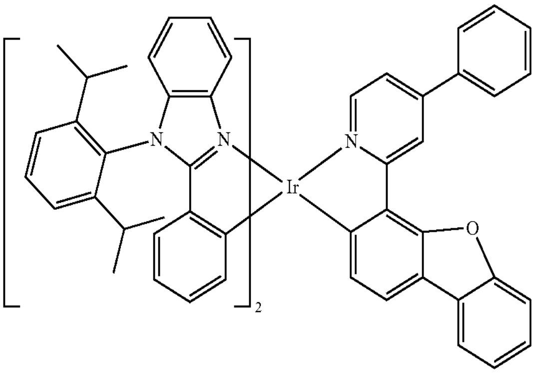
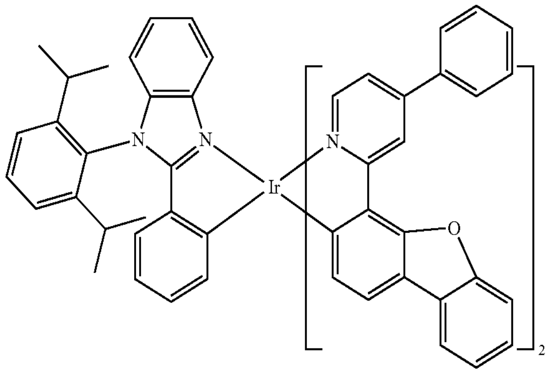
Compound 144



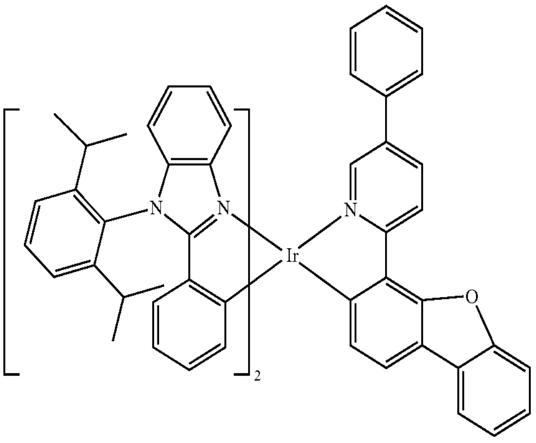
Compound 145



Compound 146



Compound 147



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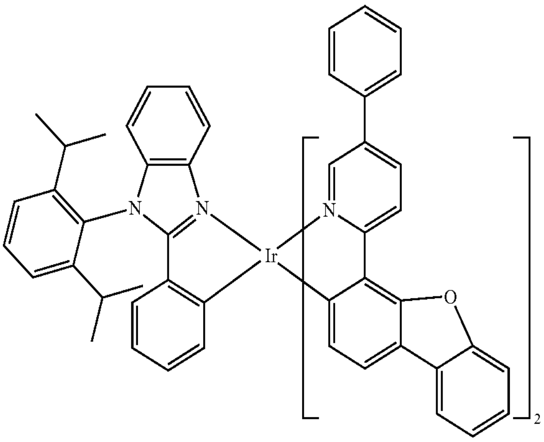
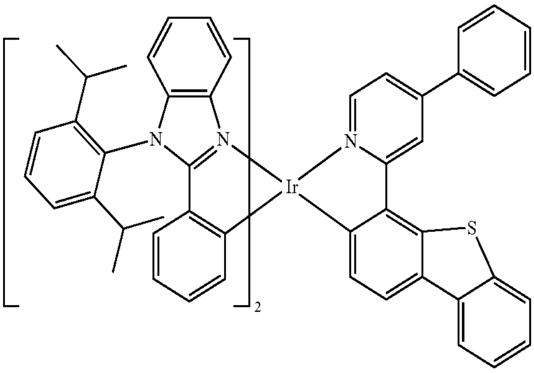
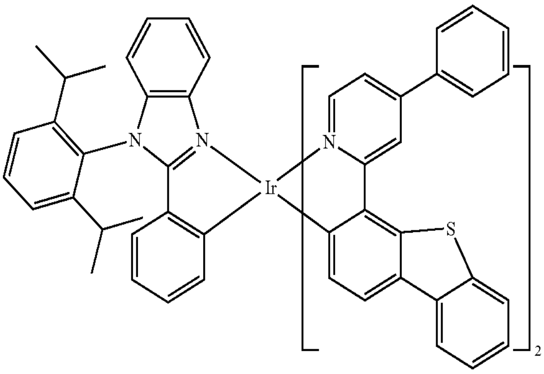
Compound 148



Compound 149



Compound 150



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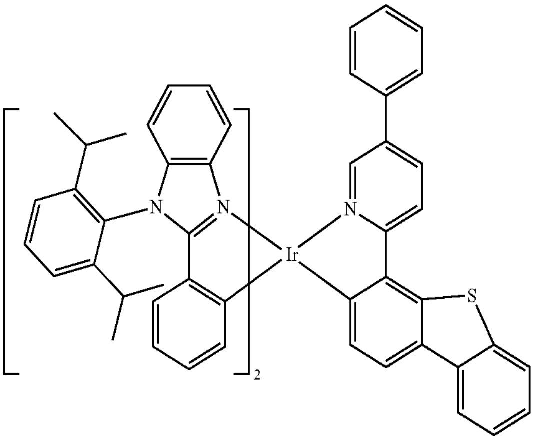
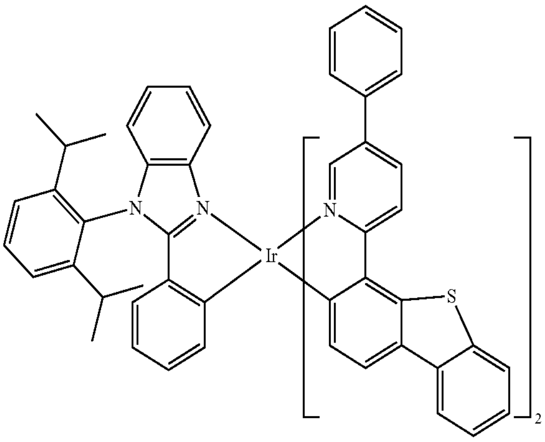
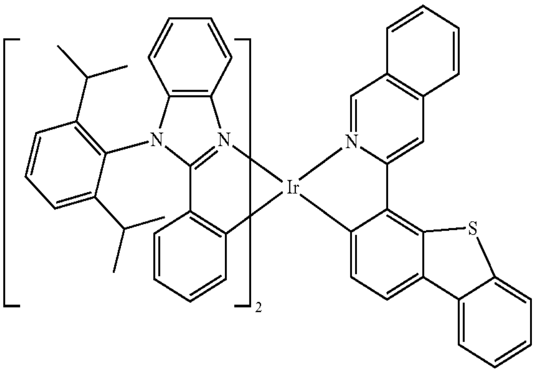
Compound 151



Compound 152

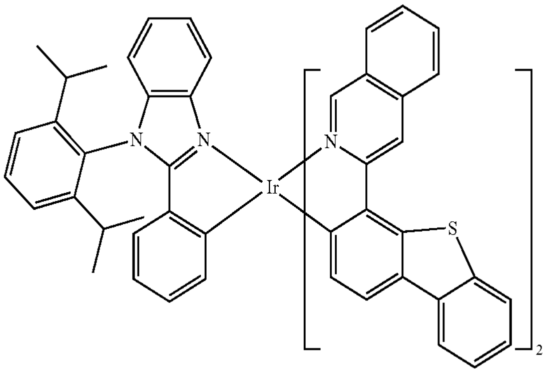


Compound 153

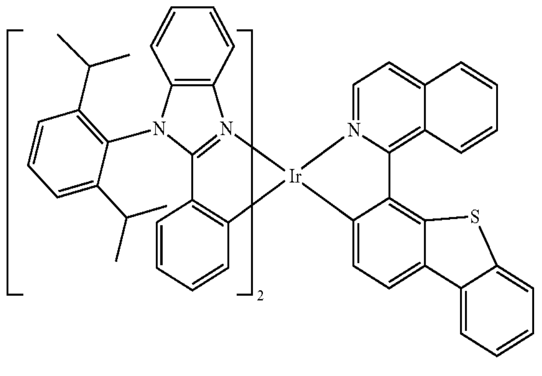


-continued

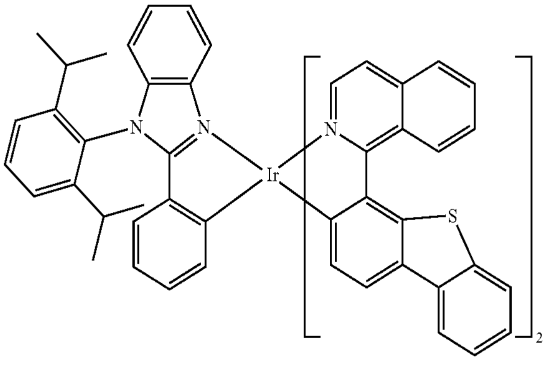
Compound 154



Compound 155

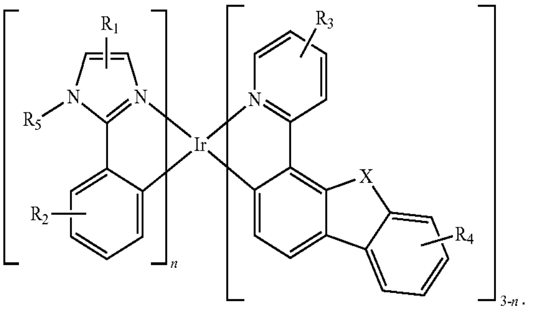


Compound 156



[0064] A first device is also provided. The first device comprises an organic light emitting device, further comprising an anode, a cathode, and an organic layer, disposed between the anode and the cathode, comprising a compound having the formula:

Formula I



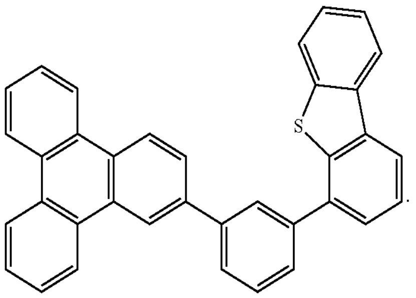
R_1, R_2, R_3 and R_4 can represent mono-, di-, tri- or tetra-substitution, and R_1, R_2, R_3, R_4 and R_5 are each independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. R_1, R_2, R_3 and R_4 are optionally fused and may be further substituted. X is selected from the group consisting of CRR', SiRR', C=O, N—R, B—R, O, S, SO, SO2, and Se. R and R' are independently selected from the group consisting of linear alkyl, branched alkyl, and aryl. n is 1 or 2. Compounds of Formula I are useful as phosphorescent dopants in OLEDs.

[0065] In one embodiment, the organic layer is an emissive layer and the compound of Formula I is an emissive dopant. In one embodiment, the organic layer further comprises a host.

[0066] In one embodiment, the host comprises a triphenylene containing benzo-fused thiophene or benzo-fused furan, where any substituent in the host is an unfused substituent independently selected from the group consisting of C_nH_{2n+1}, OC_nH_{2n+1}, OAr_1, $N(C_nH_{2n+1})_2$, $N(Ar_1)(Ar_2)$, $CH{=}CH{-}C_nH_{2n+1}$, $C{\equiv}CC_nH_{2n+1}$, Ar_1, $Ar_1{-}Ar_2$, $C_nH_{2n}{-}Ar_1$, or no substitution. Ar_1 and Ar_2 are independently selected from the group consisting of benzene, biphenyl, naphthalene, triphenylene, carbazole, and heteroaromatic analogs thereof, and n is from 1 to 10.

[0067] In one embodiment, the host has the formula

Compound F



[0068] In one embodiment, the host is a metal complex.

[0069] In one embodiment the first device is a consumer product. In another embodiment, the first device is an organic light-emitting device.

[0070] In one embodiment, the first device further comprises a second emissive dopant having a peak wavelength of between 400 to 500 nanometers. In another embodiment, the second emissive dopant is a fluorescent emitter. In another embodiment, the second emissive dopant is a phosphorescent emitter.

[0071] In some embodiments, OLEDs that incorporate compounds of Formula I can be used in white illumination devices.

[0072] The quality of white illumination sources can be fully described by a simple set of parameters. The color of the light source is given by its CIE chromaticity coordinates x and y (1931 2-degree standard observer CIE chromaticity). The CIE coordinates are typically represented on a two dimensional plot. Monochromatic colors fall on the perimeter of the horseshoe shaped curve starting with blue in the lower left, running through the colors of the spectrum in a clockwise direction to red in the lower right. The CIE coordinates of a light source of given energy and spectral shape will fall within the area of the curve. Summing light at all wavelengths uniformly gives the white or neutral point, found at the center of the diagram (CIE x,y-coordinates, 0.33, 0.33). Mixing light from two or more sources gives light whose color is represented by the intensity weighted average of the CIE coordinates of the independent sources. Thus, mixing light from two or more sources can be used to generate white light.

[0073] When considering the use of these white light sources for illumination, the CIE color rendering index (CRI) may be considered in addition to the CIE coordinates of the source. The CRI gives an indication of how well the light source will render colors of objects it illuminates. A perfect match of a given source to the standard illuminant gives a CRI of 100. Though a CRI value of at least 70 may be acceptable for certain applications, a preferred white light source may have a CRI of about 80 or higher.

[0074] In some embodiments, the first device comprises compounds of Formula I, a red emitter and a blue emitter.

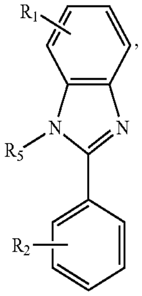
[0075] In one embodiment, the first device comprises a lighting panel.

[0076] In another embodiment, the first device further comprises a first organic light-emitting device comprising a compound of Formula I and a second light-emitting device separate from the first organic light-emitting device comprising an emissive dopant having a peak wavelength of between 400 to 500 nanometers.

[0077] In another embodiment, the first device comprises an organic light-emitting device having a first emissive layer and a second emissive layer, where the first emissive layer comprises a compound of Formula I, and the second emissive layer comprises an emissive dopant having a peak wavelength of between 400 to 500 nanometers. The first emissive layer and the second emissive layer may have one or more other layers in between them.

[0078] A method of making a compound of formula:

Formula III



is provided. The method comprises reacting the condensation product of an aryl 1,2-diamine and an aryl aldehyde with manganese dioxide in a solvent. R_1, R_2 and R_5 may represent mono-, di-, tri- or tetra-substitution. Additionally, R_1, R_2 and R_5 are each independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. R_1, R_2 and R_5 are optionally fused and may be further substituted.

[0079] Condensation of an aryl 1,2-diamine and an aryl aldehyde to produce a compound of Formula III is believed to involve an air oxidation step, as disclosed in, for example, *Monatsh. Chem.* 2009, 140, 375-380, which discloses a one-pot procedure. Typically, after a condensation of an aryl 1,2-diamine and an aryl aldehyde, the reaction product contains a mixture of corresponding benzimidazoles and aminals. However, the one-pot procedure of the prior art was not effective in synthesizing compounds of Formula III with bulky R_5 substituents, e.g 2,6-disubstituted aryl. Other procedures, which use $FeCl_3$ to assist in the oxidation to produce compounds of Formula III, gave low yields (typically 30% or less).

[0080] It was surprisingly discovered that the use of manganese(IV) dioxide (MnO_2) produced compounds of Formula III in good yields, ranging from 48-75%. This result is particularly unexpected given the observed results with DDQ, a commonly used reagent for aromatization/oxidation reactions. For example, with R_5=2,6-disubstituted aryl, the use of DDQ provided only an 18% yield of the desired product. Another commonly used oxidant, H_2O_2, gave no reaction at all with R_5=2,6-disubstituted aryl. Table 1 contains a summary of the results obtained using the method disclosed herein, and a comparison with other methods.

TABLE 1

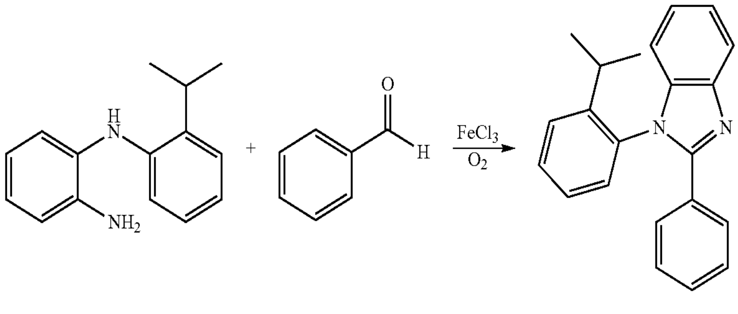
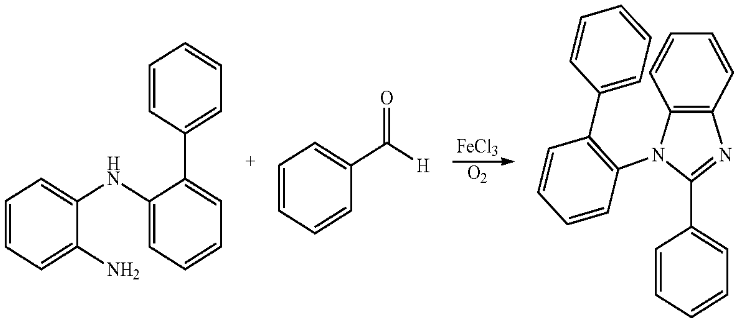
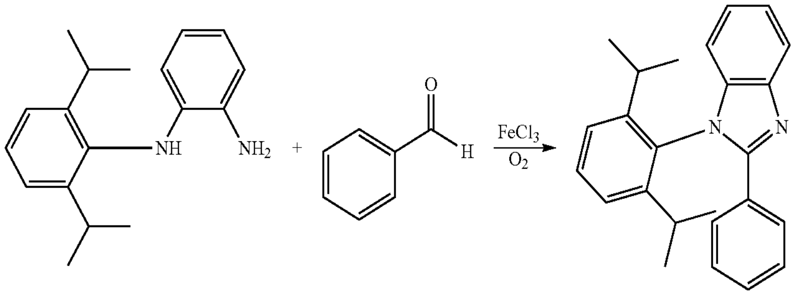
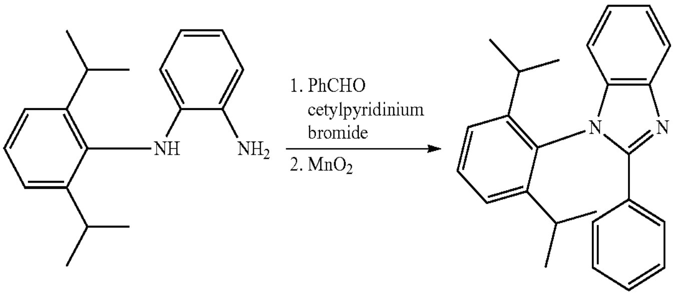
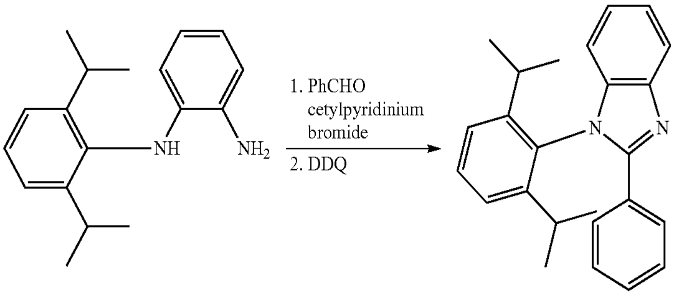
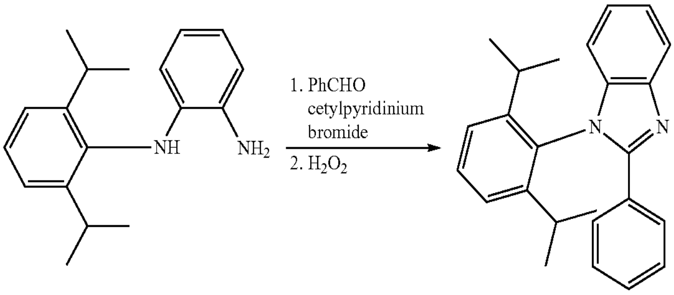
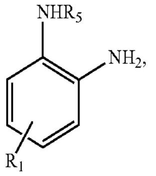
Reaction	Yield	Reference
	29%	US2010/141127

TABLE 1-continued

Reaction	Yield	Reference
	37%	US2010/141127
	30%	US2010/141127
	48-75%	This work
	18%	This work
	No Rxn	This work

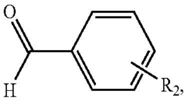
[0081] In one embodiment, the condensation product comprises reacting an aryl 1,2-diamine of formula:

Formula IV



with an aryl aldehyde of formula

Formula V



in the presence of phase transfer catalyst and solvent. A variety of phase transfer catalysts known to those in the art can be used, such as, and without limitation, ammonium salts, heterocyclic ammonium salts, and phosphonium salts. In one embodiment, the phase transfer catalyst comprises 1-hexadecylpyridinium bromide. A variety of organic and inorganic solvents can be used, and mixtures of organic solvents with water are preferred.

[0082] In one embodiment, R_5 is aryl or substituted aryl. In one embodiment, R_5 is a 2,6-disubstituted aryl. In another embodiment, R_5 is alkyl.

Device Examples

[0083] Compounds of Formula I were incorporated into OLEDs and compared with Compounds A-D as references. All example devices were fabricated by high vacuum ($<10^{-7}$ Torr) thermal evaporation (VTE). The anode electrode is 1200 Å of indium tin oxide (ITO). The cathode consisted of 10 Å of LiF followed by 1,000 Å of Al. All devices are encapsulated with a glass lid sealed with an epoxy resin in a nitrogen glove box (<1 ppm of H_2O and O_2) immediately after fabrication, and a moisture getter was incorporated inside the package.

[0084] The organic stack of the device examples consisted of sequentially, from the ITO surface, 100 Å of Compound E as the hole injection layer (HIL), 300 Å of 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl (alpha-NPD) as the hole transporting layer (HTL), 300 Å of 10-15 wt % of compound of Formula I doped in with Compound F as host as the emissive layer (EML), 50 Å of Compound F as blocking layer (BL), 400 Å of Alq (tris-8-hydroxyquinoline aluminum) as the electron transport layer (ETL). Comparative Examples with Compound A, Compound B, Compound C, and Compound D were fabricated similarly to the Device Examples except that Compound A, Compound B, Compound C, and Compound D were used as the emitter in the EML.

[0085] The device results and data are summarized in Table 2 and Table 3 from those devices. As used herein, NPD, Alq, Compound A, B, C, D, E, F, Compound 81 and Compound 82 have the following structures:

TABLE 2

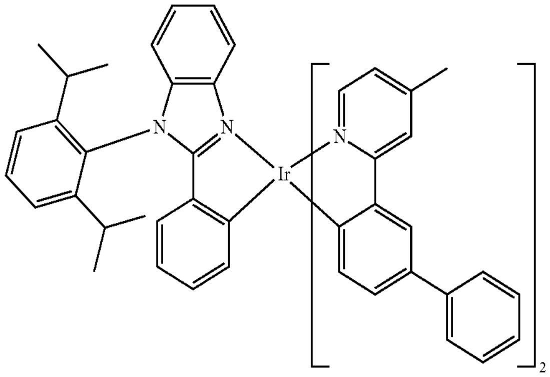
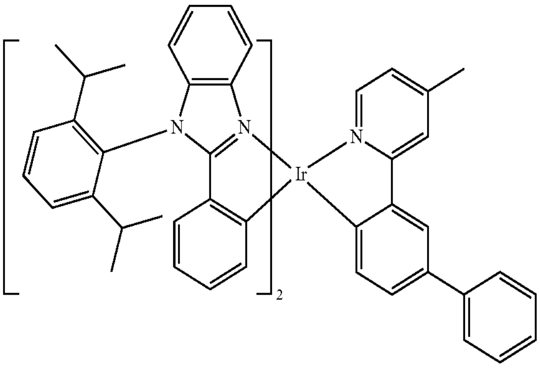
VTE Phosphorescent OLEDs
Compound A 

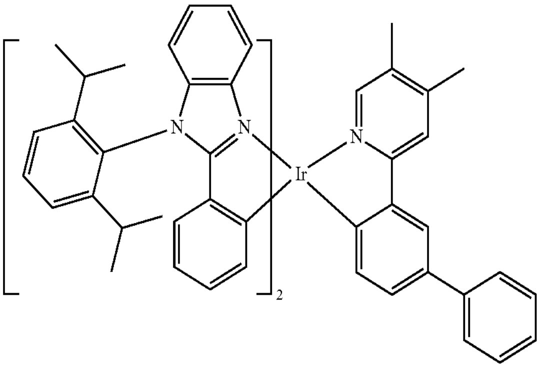
TABLE 2-continued

VTE Phosphorescent OLEDs

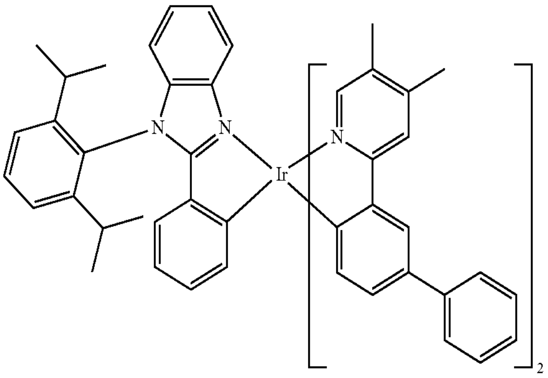
Compound B



Compound C



Compound D



Compound 81

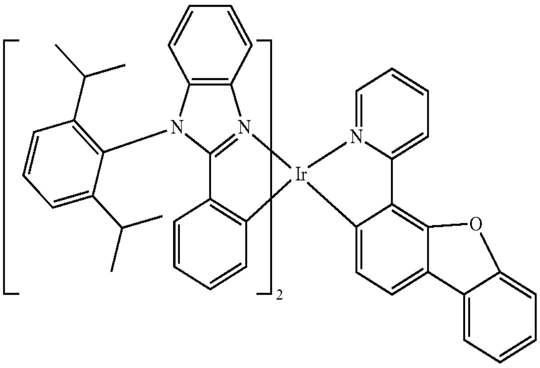
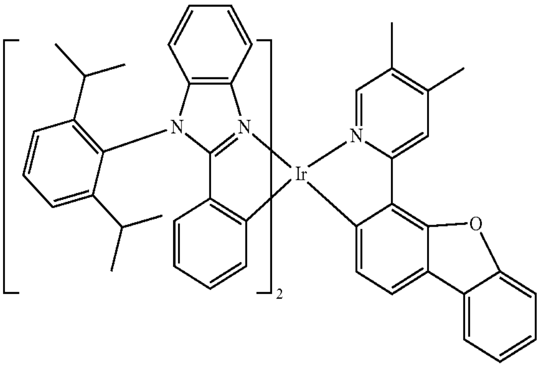


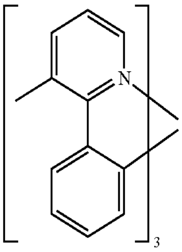
TABLE 2-continued

VTE Phosphorescent OLEDs

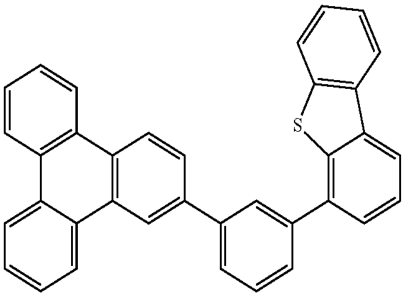
Compound 82

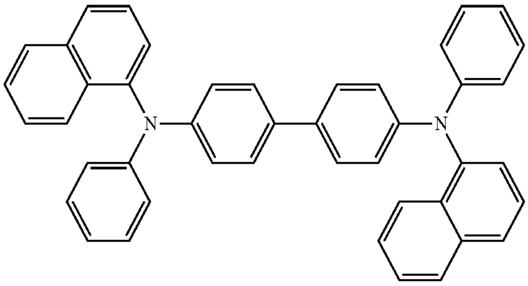


Compound E



Compound F

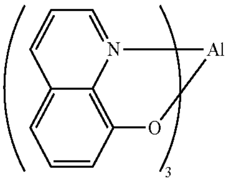




NPD

TABLE 2-continued

VTE Phosphorescent OLEDs



Alq

Example	HIL	HTL	EML (300Å, doping %)		BL	ETL 1
Comparative Example 1	Compound E 100Å	NPD 300Å	Compound F	Compound A, 10%	Compound F 50Å	Alq 400Å
Comparative Example 2	Compound E 100Å	NPD 300Å	Compound F	Compound B, 15%	Compound F 50Å	Alq 400Å
Comparative Example 3	Compound E 100Å	NPD 300Å	Compound F	Compound C, 12%	Compound F 50Å	Alq 400Å
Comparative Example 4	Compound E 100Å	NPD 300Å	Compound F	Compound D, 10%	Compound F 50Å	Alq 400Å
Example 1	Compound E 100Å	NPD 300Å	Compound F	Compound 81, 15%	Compound F 50Å	Alq 400Å
Example 2	Compound E 100Å	NPD 300Å	Compound F	Compound 82, 12%	Compound F 50Å	Alq 400Å

TABLE 3

VTE Device Data

	x	y	λ_{max}	FWHM (nm)	Voltage (V)	LE (Cd/A)	EQE (%)	PE (lm/W)	LT80% (h)
Comparative Example 1	0.328	0.619	520	70	6.2	55.1	15.4	27.9	189
Comparative Example 2	0.327	0.618	516	68	4.5	51.2	14.5	36.1	98
Comparative Example 3	0.337	0.605	512	72	5.4	44.1	12.9	25.8	100
Comparative Example 4	0.332	0.609	514	74	5.5	60.5	17.4	34.5	147
Example 1	0.376	0.603	534	60	6.2	47	12.4	23.7	165
Example 2	0.329	0.625	520	60	5.9	54.4	15.0	29.0	122

[0086] The device data show that Example 1 and Example 2, which are compounds of Formula I, both show narrow line shapes, high efficiency, and long lifetimes. Compound 82 and Compound C are similar except that Compound 82 contains a pyridylbenzofuran ligand, whereas Compound C does not. Compound 82 has a more saturated green color (0.329, 0.625) than Compound C (0.337, 0.605), a narrower emission (60 nm FWHM vs. 72 nm for Compound C), higher luminous efficacy (54.4 cd/A), external quantum efficiency (15.0%) and power efficacy (29 lm/W) than Compound C (44.1 cd/A, 12.9%, and 25.8 lm/W, respectively). Additionally, Compound 82 has a longer lifetime to LT_{80}% (122 h) than Compound C (100 h).

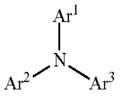
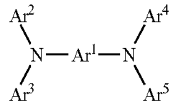
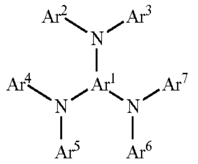
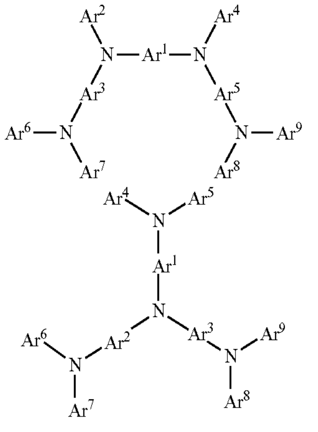
Combination with Other Materials

[0087] The materials described herein as useful for a particular layer in an organic light emitting device may be used in combination with a wide variety of other materials present in the device. For example, emissive dopants disclosed herein may be used in conjunction with a wide variety of hosts, transport layers, blocking layers, injection layers, electrodes and other layers that may be present. The materials described or referred to below are non-limiting examples of materials that may be useful in combination with the compounds disclosed herein, and one of skill in the art can readily consult the literature to identify other materials that may be useful in combination.

HIL/HTL:

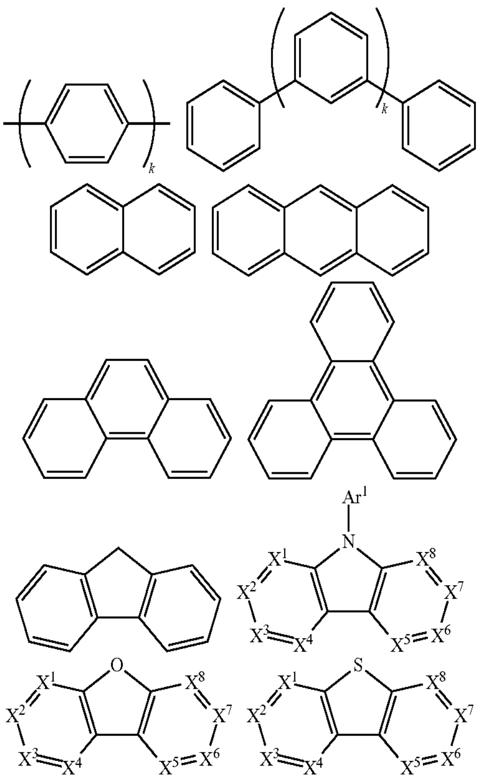
[0088] A hole injecting/transporting material to be used in the present invention is not particularly limited, and any compound may be used as long as the compound is typically used as a hole injecting/transporting material. Examples of the material include, but not limit to: a phthalocyanine or porphryin derivative; an aromatic amine derivative; an indolocarbazole derivative; a polymer containing fluorohydrocarbon; a polymer with conductivity dopants; a conducting polymer, such as PEDOT/PSS; a self-assembly monomer derived from compounds such as phosphonic acid and sliane derivatives; a metal oxide derivative, such as MoO_x; a p-type semiconducting organic compound, such as 1,4,5,8,9,12-Hexaazatriphenylenehexacarbonitrile; a metal complex, and a cross-linkable compounds.

[0089] Examples of aromatic amine derivatives used in HIL or HTL include, but not limit to the following general structures:

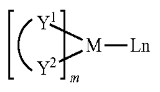
[0090] Each of Ar^1 to Ar^9 is selected from the group consisting aromatic hydrocarbon cyclic compounds such as benzene, biphenyl, triphenyl, triphenylene, naphthalene, anthracene, phenalene, phenanthrene, fluorene, pyrene, chrysene, perylene, azulene; group consisting aromatic heterocyclic compounds such as dibenzothiophene, dibenzofuran, dibenzoselenophene, furan, thiophene, benzofuran, benzothiophene, benzoselenophene, carbazole, indolocarbazole, pyridylindole, pyrrolodipyridine, pyrazole, imidazole, triazole, oxazole, thiazole, oxadiazole, oxatriazole, dioxazole, thiadiazole, pyridine, pyridazine, pyrimidine, pyrazine, triazine, oxazine, oxathiazine, oxadiazine, indole, benzimidazole, indazole, indoxazine, benzoxazole, benzisoxazole, benzothiazole, quinoline, isoquinoline, cinnoline, quinazoline, quinoxaline, naphthyridine, phthalazine, pteridine, xanthene, acridine, phenazine, phenothiazine, phenoxazine, benzofuropyridine, furodipyridine, benzothienopyridine, thienodipyridine, benzoselenophenopyridine, and selenophenodipyridine; and group consisting 2 to 10 cyclic structural units which are groups of the same type or different types selected from the aromatic hydrocarbon cyclic group and the aromatic heterocyclic group and are bonded to each other directly or via at least one of oxygen atom, nitrogen atom, sulfur atom, silicon atom, phosphorus atom, boron atom, chain structural unit and the aliphatic cyclic group. Wherein each Ar is further substituted by a substituent selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

[0091] In one aspect, Ar^1 to Ar^9 is independently selected from the group consisting of:



[0092] k is an integer from 1 to 20; X^1 to X^8 is C (including CH) or N; Ar^1 has the same group defined above.

[0093] Examples of metal complexes used in HIL or HTL include, but not limit to the following general formula:



[0094] M is a metal, having an atomic weight greater than 40; (Y^1—Y^2) is a bidentate ligand, Y^1 and Y^2 are independently selected from C, N, O, P, and S; L is an ancillary ligand; m is an integer value from 1 to the maximum number of ligands that may be attached to the metal; and m+n is the maximum number of ligands that may be attached to the metal.

[0095] In one aspect, (Y^1—Y^2) is a 2-phenylpyridine derivative.

[0096] In another aspect, (Y^1—Y^2) is a carbene ligand.

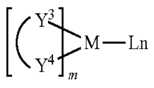
[0097] In another aspect, M is selected from Ir, Pt, Os, and Zn.

[0098] In a further aspect, the metal complex has a smallest oxidation potential in solution vs. Fc^+/Fc couple less than about 0.6 V.

Host:

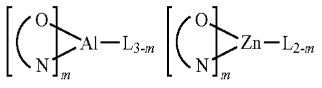
[0099] The light emitting layer of the organic EL device of the present invention preferably contains at least a metal complex as light emitting material, and may contain a host material using the metal complex as a dopant material. Examples of the host material are not particularly limited, and any metal complexes or organic compounds may be used as long as the triplet energy of the host is larger than that of the dopant.

[0100] Examples of metal complexes used as host are preferred to have the following general formula:



[0101] M is a metal; (Y^3—Y^4) is a bidentate ligand, Y^3 and Y^4 are independently selected from C, N, O, P, and S; L is an ancillary ligand; m is an integer value from 1 to the maximum number of ligands that may be attached to the metal; and m+n is the maximum number of ligands that may be attached to the metal.

[0102] In one aspect, the metal complexes are:



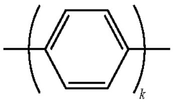
[0103] (O—N) is a bidentate ligand, having metal coordinated to atoms O and N.

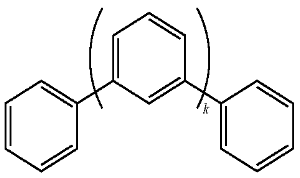
[0104] In another aspect, M is selected from Ir and Pt.

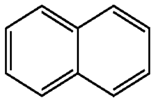
[0105] In a further aspect, (Y^3—Y^4) is a carbene ligand.

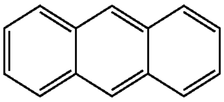
[0106] Examples of organic compounds used as host are selected from the group consisting aromatic hydrocarbon cyclic compounds such as benzene, biphenyl, triphenyl, triphenylene, naphthalene, anthracene, phenalene, phenanthrene, fluorene, pyrene, chrysene, perylene, azulene; group consisting aromatic heterocyclic compounds such as dibenzothiophene, dibenzofuran, dibenzoselenophene, furan, thiophene, benzofuran, benzothiophene, benzoselenophene, carbazole, indolocarbazole, pyridylindole, pyrrolodipyridine, pyrazole, imidazole, triazole, oxazole, thiazole, oxadiazole, oxatriazole, dioxazole, thiadiazole, pyridine, pyridazine, pyrimidine, pyrazine, triazine, oxazine, oxathiazine, oxadiazine, indole, benzimidazole, indazole, indoxazine, benzoxazole, benzisoxazole, benzothiazole, quinoline, isoquinoline, cinnoline, quinazoline, quinoxaline, naphthyridine, phthalazine, pteridine, xanthene, acridine, phenazine, phenothiazine, phenoxazine, benzofuropyridine, furodipyridine, benzothienopyridine, thienodipyridine, benzoselenophenopyridine, and selenophenodipyridine; and group consisting 2 to 10 cyclic structural units which are groups of the same type or different types selected from the aromatic hydrocarbon cyclic group and the aromatic heterocyclic group and are bonded to each other directly or via at least one of oxygen atom, nitrogen atome, sulfur atom, silicon atom, phosphorus atom, boron atom, chain structural unit and the aliphatic cyclic group. Wherein each group is further substituted by a substituent selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

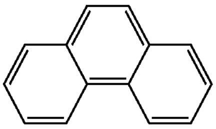
[0107] In one aspect, host compound contains at least one of the following groups in the molecule:

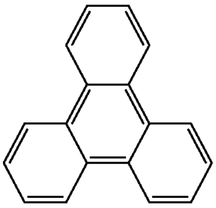


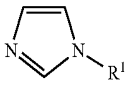


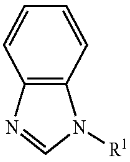


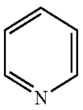


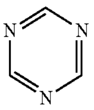


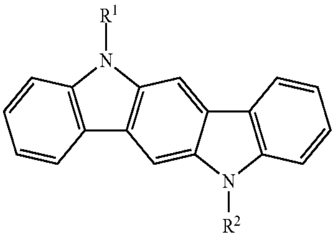


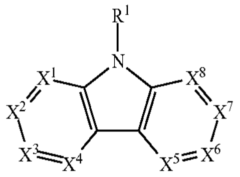


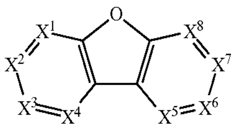


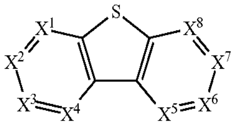


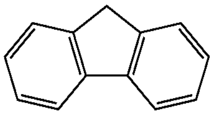


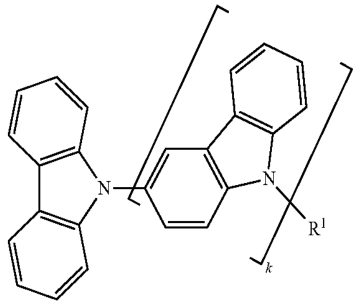


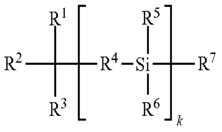


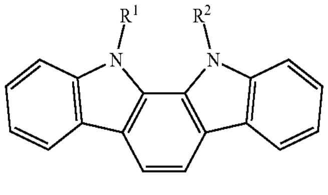












[0108] R^1 to R^7 is independently selected from the group consisting of hydrogen, alkyl, alkoxy, amino, alkenyl, alkynyl, arylalkyl, heteroalkyl, aryl and heteroaryl, when it is aryl or heteroaryl, it has the similar definition as Ar's mentioned above.

[0109] k is an integer from 0 to 20.

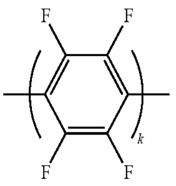
[0110] X^1 to X^8 is selected from C (including CH) or N.

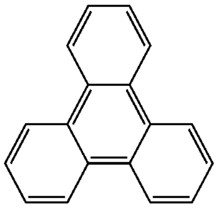
HBL:

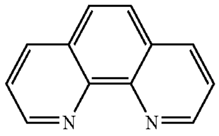
[0111] A hole blocking layer (HBL) may be used to reduce the number of holes and/or excitons that leave the emissive layer. The presence of such a blocking layer in a device may result in substantially higher efficiencies as compared to a similar device lacking a blocking layer. Also, a blocking layer may be used to confine emission to a desired region of an OLED.

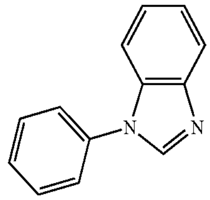
[0112] In one aspect, compound used in HBL contains the same molecule used as host described above.

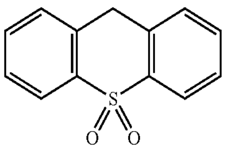
[0113] In another aspect, compound used in HBL contains at least one of the following groups in the molecule:

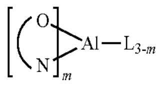










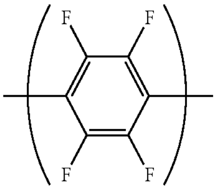


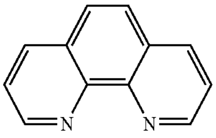
[0114] k is an integer from 0 to 20; L is an ancillary ligand, m is an integer from 1 to 3.

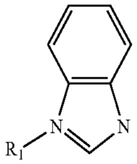
ETL:

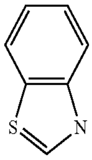
[0115] Electron transport layer (ETL) may include a material capable of transporting electrons. Electron transport layer may be intrinsic (undoped), or doped. Doping may be used to enhance conductivity. Examples of the ETL material are not particularly limited, and any metal complexes or organic compounds may be used as long as they are typically used to transport electrons.

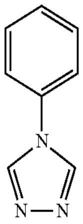
[0116] In one aspect, compound used in ETL contains at least one of the following groups in the molecule:

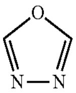


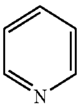


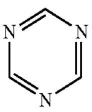


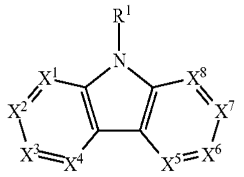


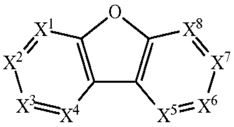


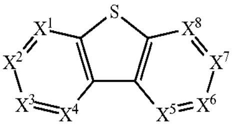


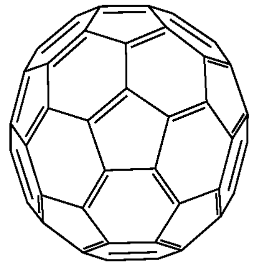


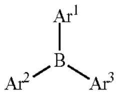












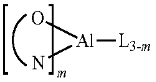
[0117] R^1 is selected from the group consisting of hydrogen, alkyl, alkoxy, amino, alkenyl, alkynyl, arylalkyl, heteroalkyl, aryl and heteroaryl, when it is aryl or heteroaryl, it has the similar definition as Ar's mentioned above.

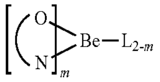
[0118] Ar^1 to Ar^3 has the similar definition as Ar's mentioned above.

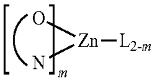
[0119] k is an integer from 0 to 20.

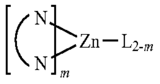
[0120] X^1 to X^8 is selected from C (including CH) or N.

[0121] In another aspect, the metal complexes used in ETL contains, but not limit to the following general formula:









[0122] (O—N) or (N—N) is a bidentate ligand, having metal coordinated to atoms O, N or N, N; L is an ancillary ligand; m is an integer value from 1 to the maximum number of ligands that may be attached to the metal.

[0123] In any above-mentioned compounds used in each layer of the OLED device, the hydrogen atoms can be partially or fully deuterated.

[0124] In addition to and/or in combination with the materials disclosed herein, many hole injection materials, hole transporting materials, host materials, dopant materials, exiton/hole blocking layer materials, electron transporting and electron injecting materials may be used in an OLED. Non-limiting examples of the materials that may be used in an OLED in combination with materials disclosed herein are listed in Table 4 below. Table 4 lists non-limiting classes of materials, non-limiting examples of compounds for each class, and references that disclose the materials.

TABLE 4

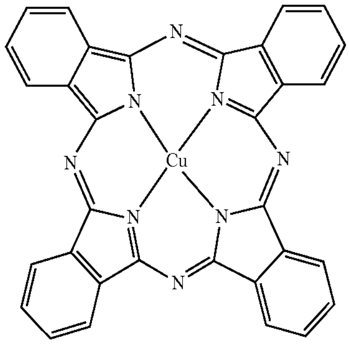
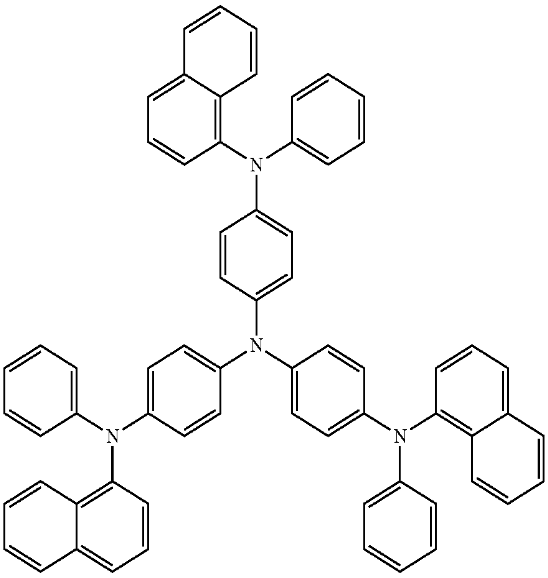
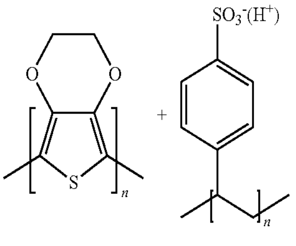
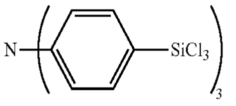
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
	Hole injection materials	
Phthalocyanine and porphryin compounds		Appl. Phys. Lett. 69, 2160 (1996)
Starburst triarylamines		J. Lumin. 72-74, 985 (1997)
CF_X Fluorohydrocarbon polymer	$-[CH_xF_y]_n-$	Appl. Phys. Lett. 78, 673(2001)
Conducting polymers (e.g., PEDOT:PSS, polyaniline, polythiophene)		Synth. Met. 87, 171 (1997) WO2007002683
Phosphonic acid and sliane SAMs		US20030162053

TABLE 4-continued

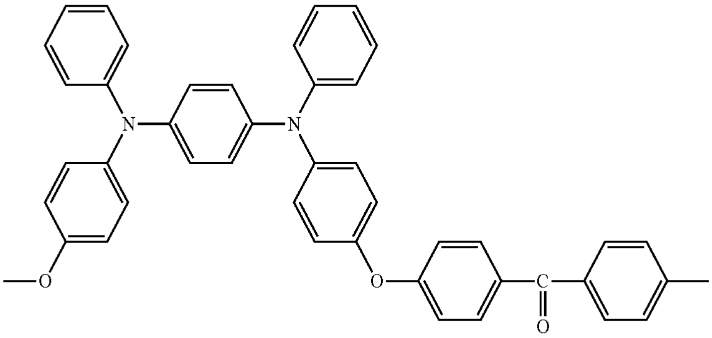
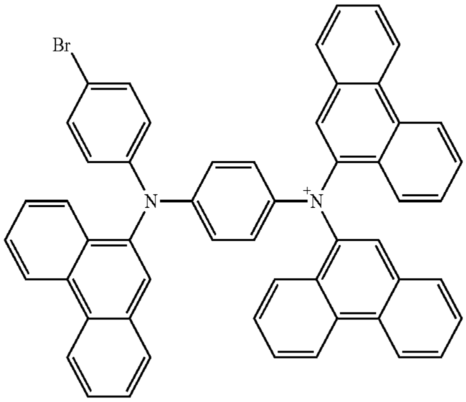
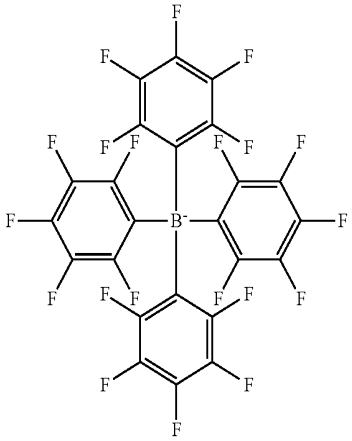
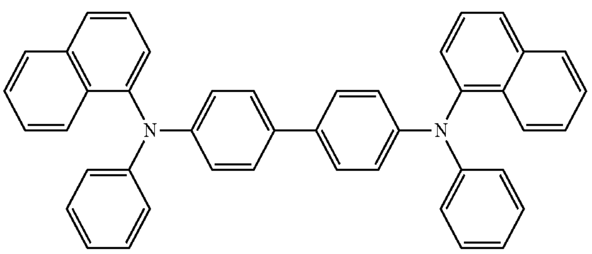
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Triarylamine or polythiophene polymers with conductivity dopants	 and  	EP1725079A1
Arylamines complexed with metal oxides such as molybdenum and tungsten oxides	 + MoO_x	SID Symposium Digest, 37, 923 (2006) WO2009018009

TABLE 4-continued

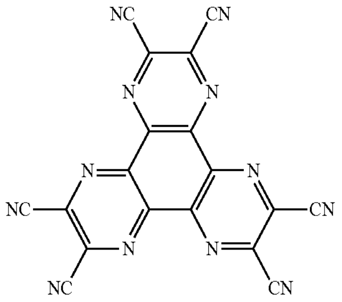
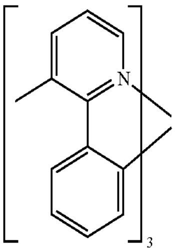
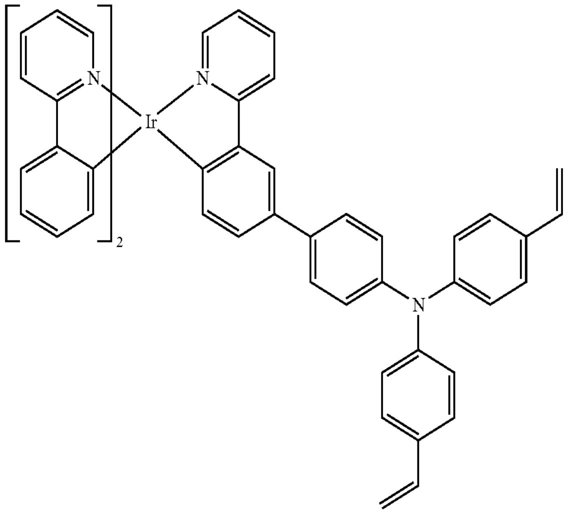
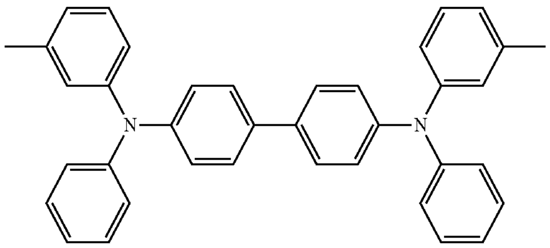
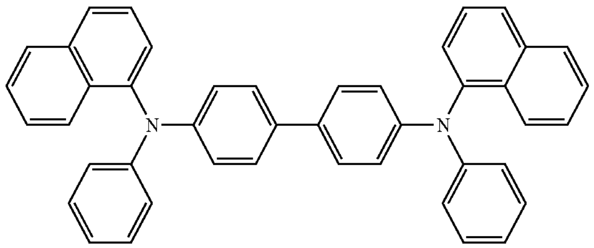
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
p-type semiconducting organic complexes		US20020158242
Metal organometallic complexes		US20060240279
Cross-linkable compounds		US20080220265
	Hole transporting materials	
Triarylamines (e.g., TPD, α-NPD)		Appl. Phys. Lett. 51, 913 (1987)
		U.S. Pat. No. 5061569

TABLE 4-continued

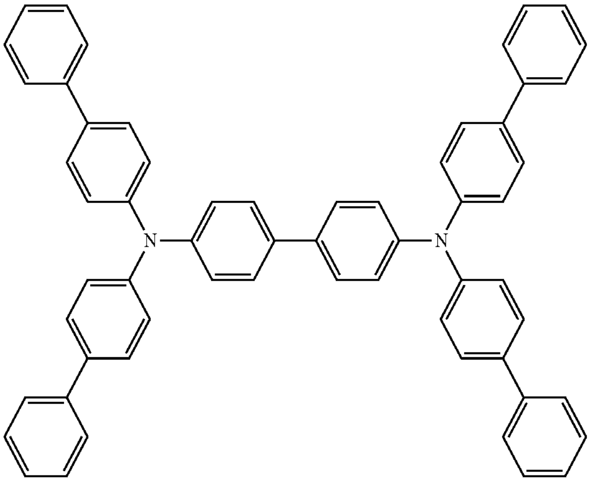
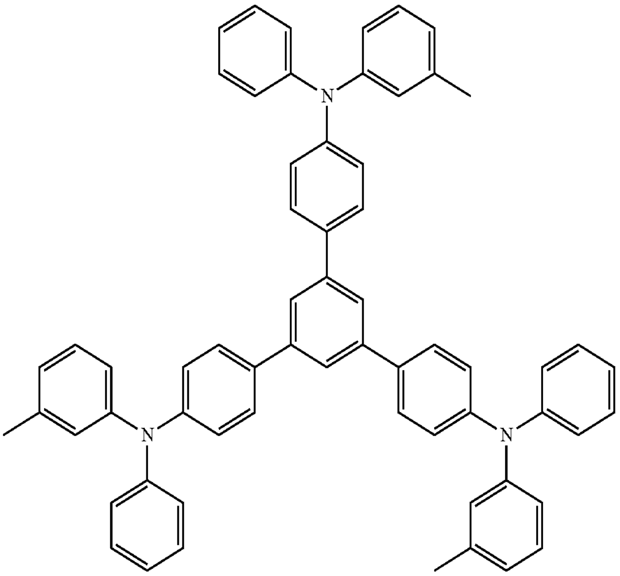
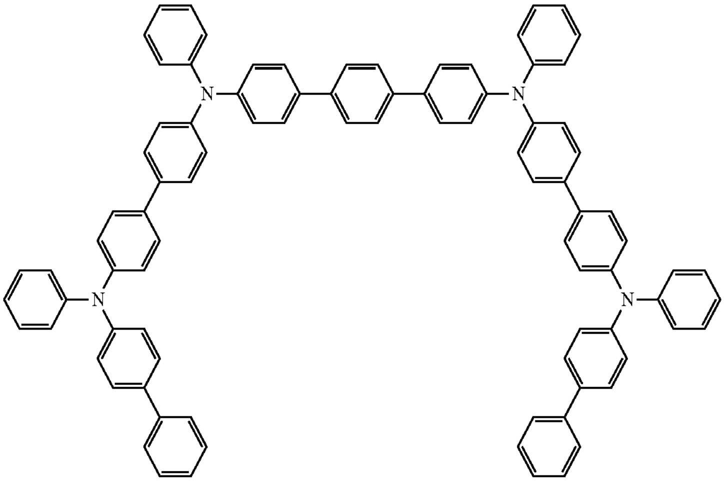
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		EP650955
		J. Mater. Chem. 3, 319 (1993)
		Appl. Phys. Lett. 90, 183503 (2007)

TABLE 4-continued

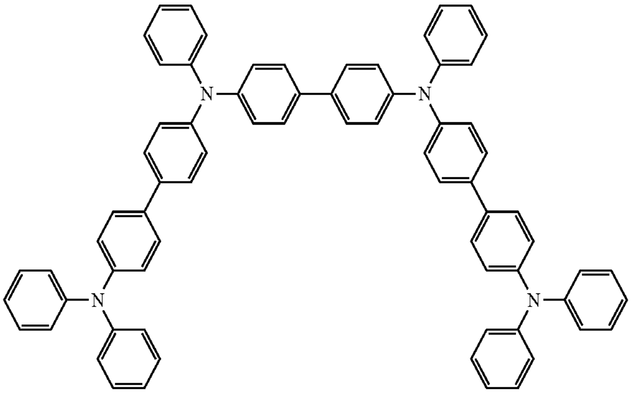
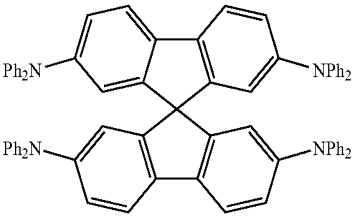
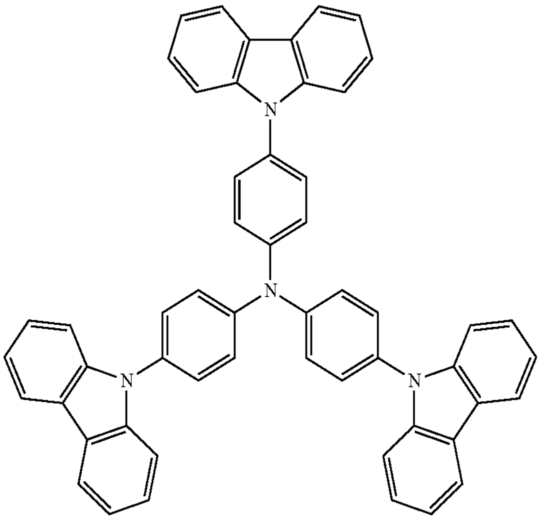
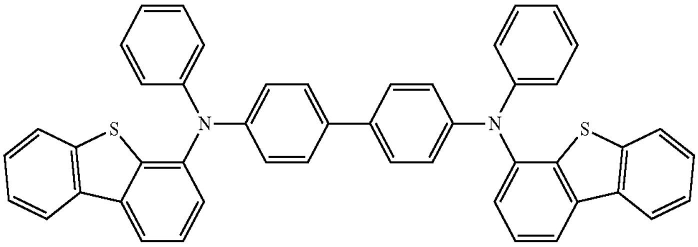
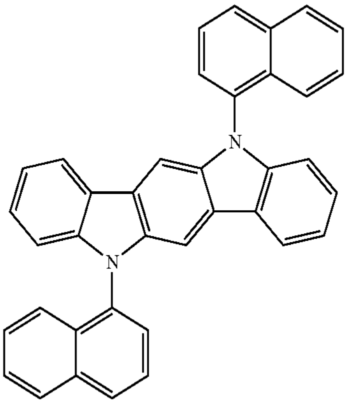
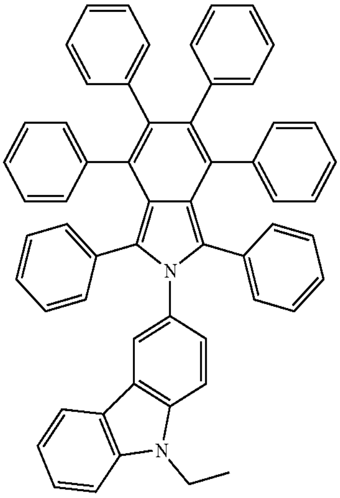
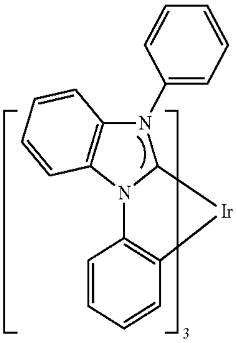
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		Appl. Phys. Lett. 90, 183503 (2007)
Triarylamine on spirofluorene core		Synth. Met. 91, 209 (1997)
Arylamine carbazole compounds		Adv. Mater. 6, 677 (1994), US20080124572
Triarylamine with (di)benzothiophene/(di)benzofuran		US20070278938, US20080106190

TABLE 4-continued

MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Indolocarbazoles		Synth. Met. 111, 421 (2000)
Isoindole compounds		Chem. Mater. 15, 3148 (2003)
Metal carbene complexes		US20080018221

Phosphorescent OLED host materials
Red hosts

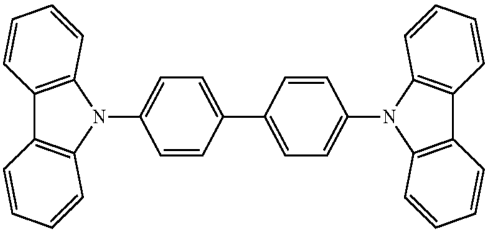
Arylcarbazoles		Appl. Phys. Lett. 78, 1622 (2001)

TABLE 4-continued

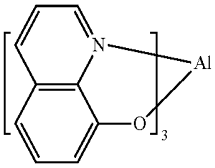
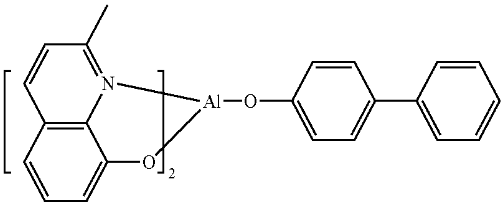
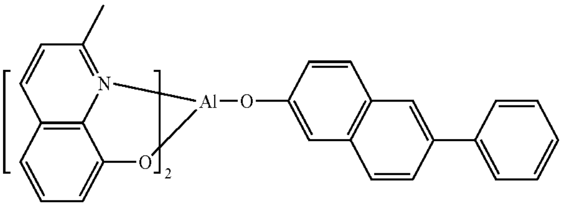
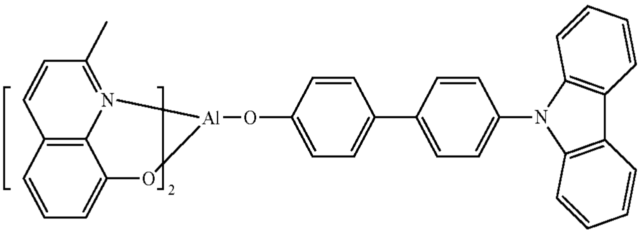
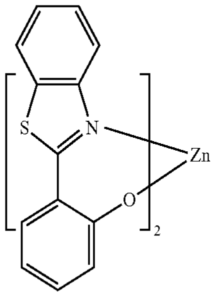
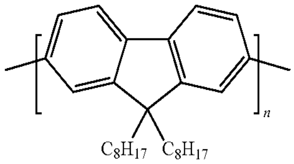
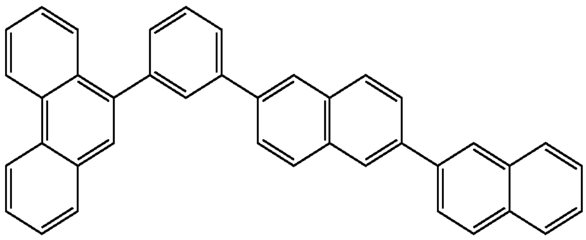
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Metal 8-hydroxyquinolates (e.g., Alq, BAlq)		Nature 395, 151 (1998)
		US20060202194
		WO2005014551
		WO2006072002
Metal phenoxybenzothiazole compounds		Appl. Phys. Lett. 90, 123509 (2007)
Conjugated oligomers and polymers (e.g., polyfluorene)		Org. Electron. 1, 15 (2000)
Aromatic fused rings		WO2009066779, WO2009066778, WO2009063833, US20090045731, US20090045730, WO2009008311, US20090008605, US20090009065

TABLE 4-continued

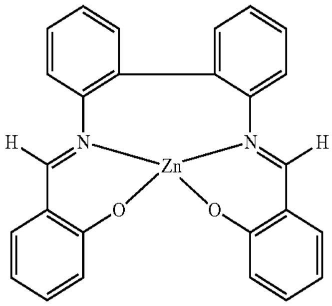
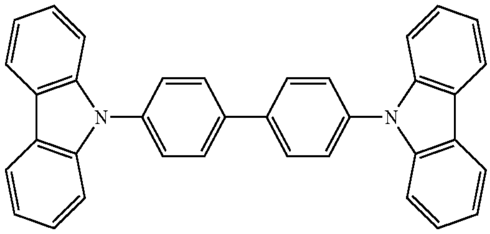
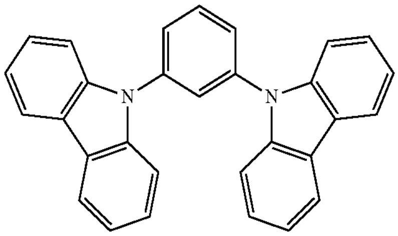
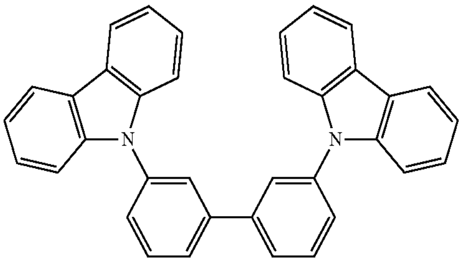
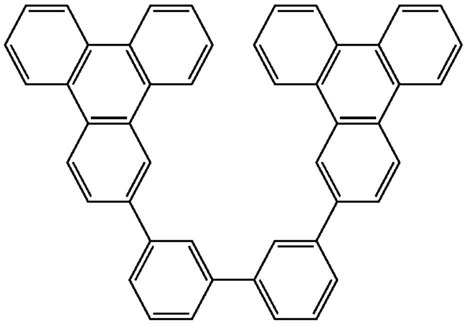
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Zinc complexes		WO2009062578
	Green hosts	
Arylcarbazoles		Appl. Phys. Lett. 78, 1622 (2001)
		US20030175553
		WO2001039234
Aryltriphenylene compounds		US20060280965

TABLE 4-continued

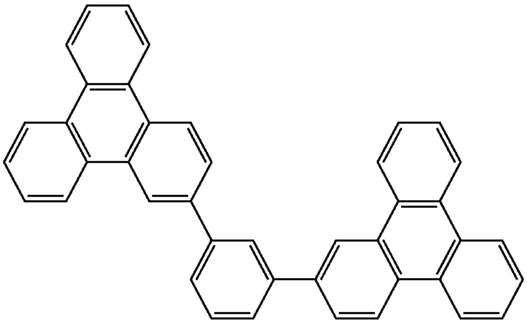
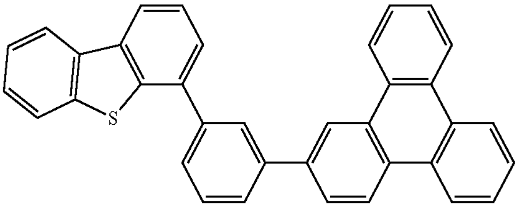
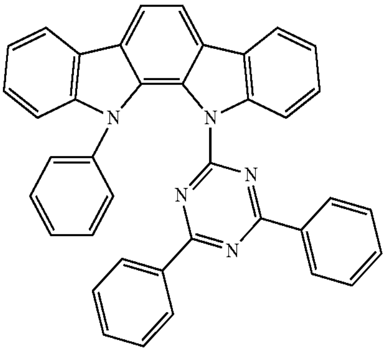
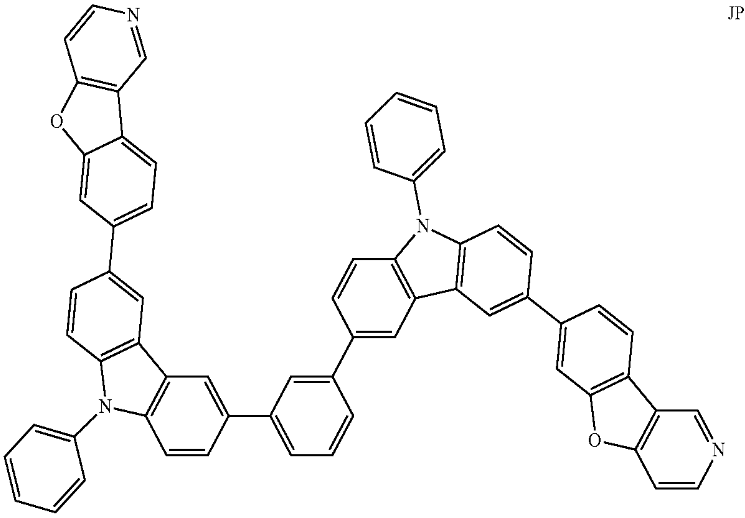
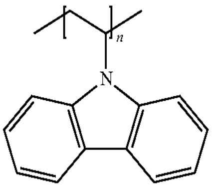
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20060280965
		WO2009021126
Donor acceptor type molecules		WO2008056746
Aza-carbazole/DBT/DBF		JP2008074939
Polymers (e.g., PVK)		Appl. Phys. Lett. 77, 2280 (2000)

TABLE 4-continued

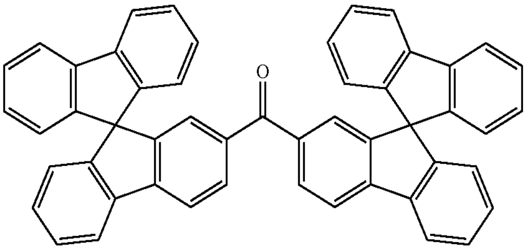
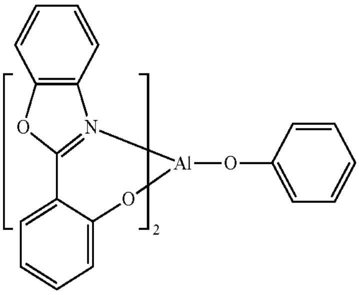
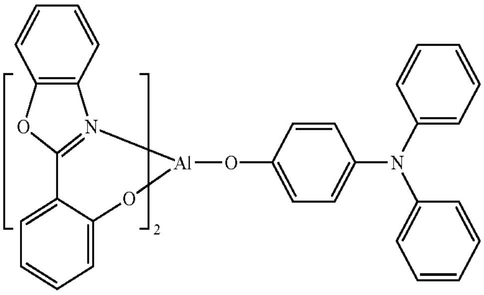
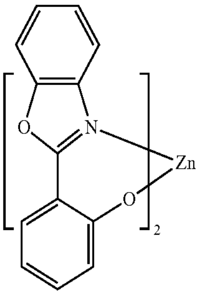
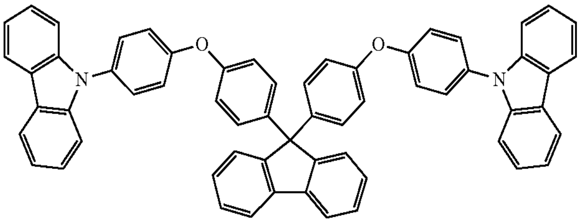
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Spirofluorene compounds		WO2004093207
Metal phenoxybenzooxazole compounds		WO2005089025
		WO2006132173
		JP200511610
Spirofluorene-carbazole compounds		JP2007254297

TABLE 4-continued

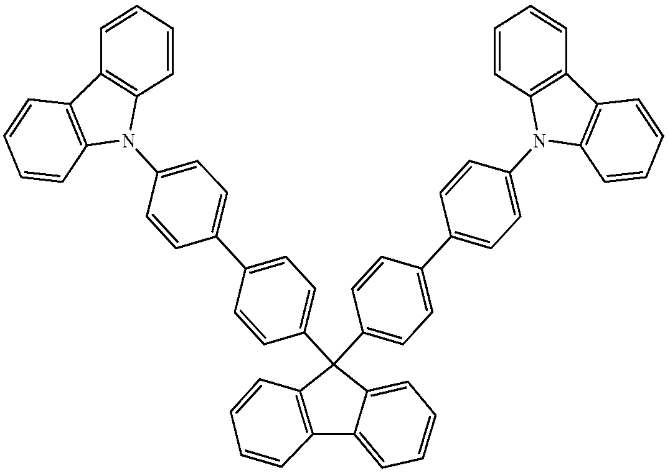
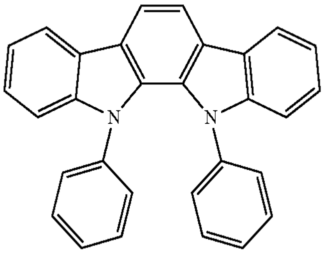
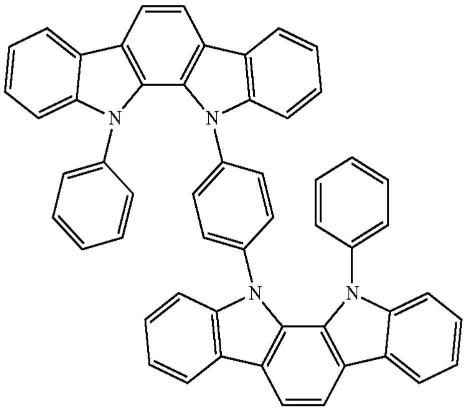
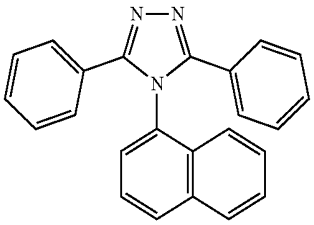
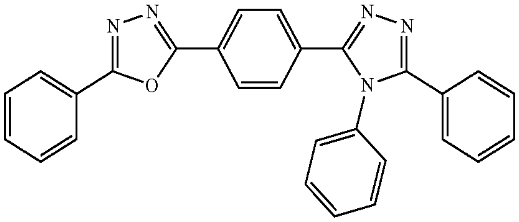
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		JP2007254297
Indolocabazoles		WO2007063796
		WO2007063754
5-member ring electron deficient heterocycles (e.g., triazole, oxadiazole)		J. Appl. Phys. 90, 5048 (2001)
		WO2004107822

TABLE 4-continued

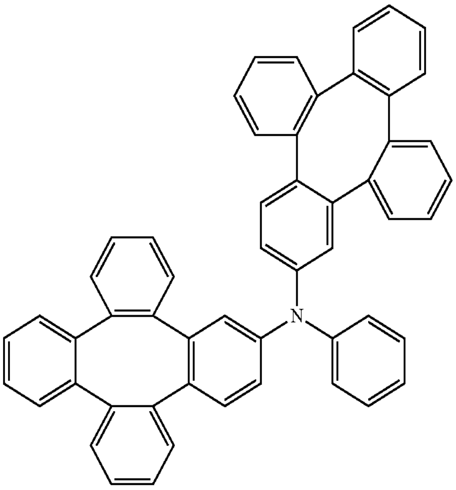
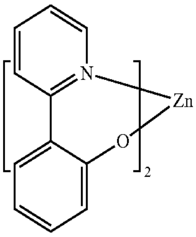
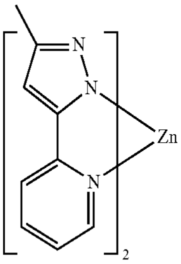
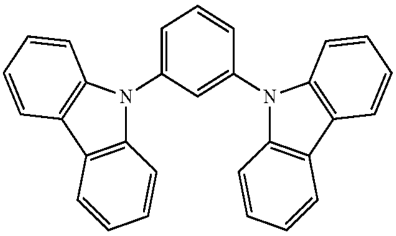
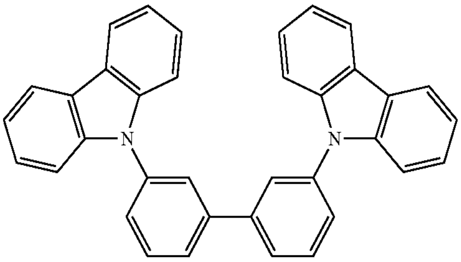
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Tetraphenylene complexes		US20050112407
Metal phenoxypyridine compounds		WO2005030900
Metal coordination complexes (e.g., Zn, Al with $\mathrm{N}^\wedge\mathrm{N}$ ligands)		US20040137268, US20040137267
	Blue hosts	
Arylcarbazoles		Appl. Phys. Lett, 82, 2422 (2003)
		US20070190359

TABLE 4-continued

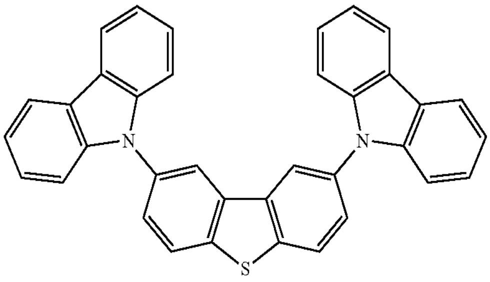
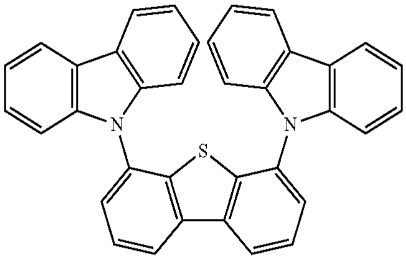
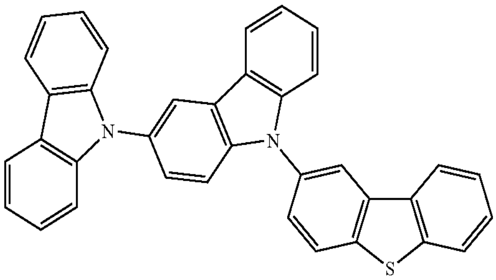
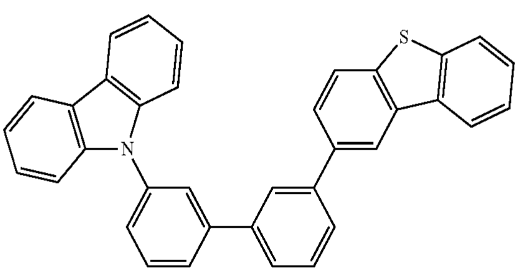
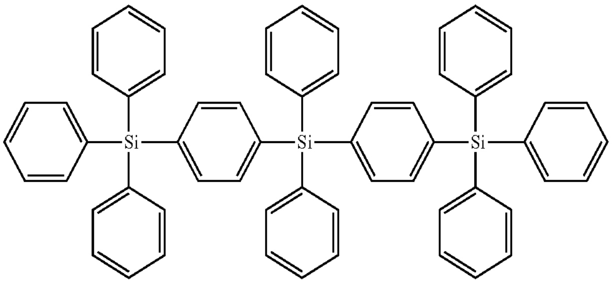
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Dibenzothiophene/Dibenzofuran-carbazole compounds		WO2006114966, US20090167162
		US20090167162
		WO2009086028
		US20090030202, US20090017330
Silicon aryl compounds		US20050238919

TABLE 4-continued

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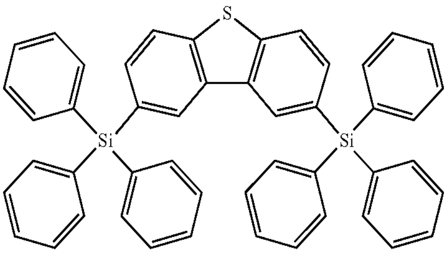
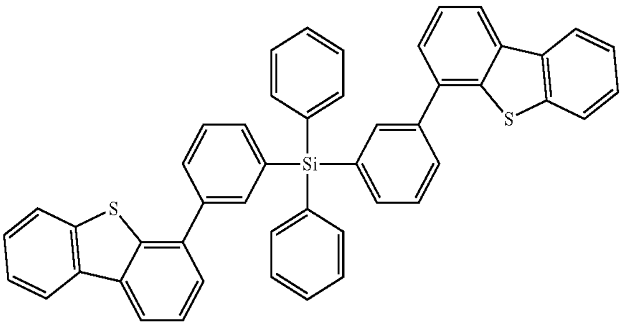
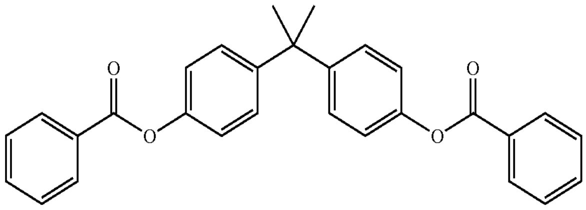
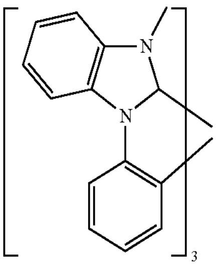
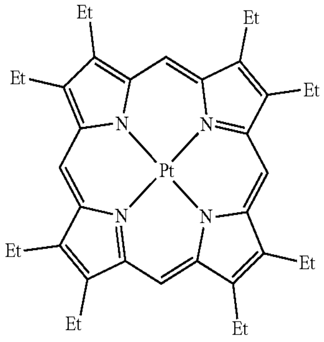
		WO2009003898
Silicon/Germanium aryl compounds		EP2034538A
Aryl benzoyl ester		WO2006100298
High triplet metal organometallic complex		U.S. Pat. No. 7154114
	Phosphorescent dopants Red dopants	
Heavy metal porphyrins (e.g., PtOEP)		Nature 395, 151 (1998)

TABLE 4-continued

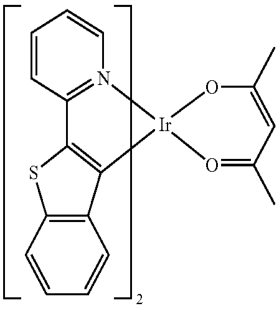
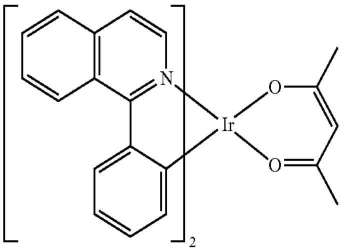
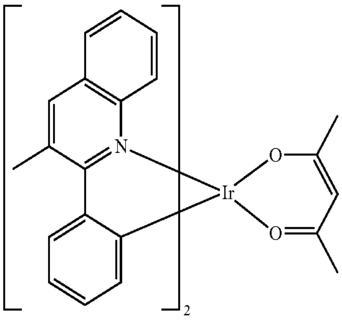
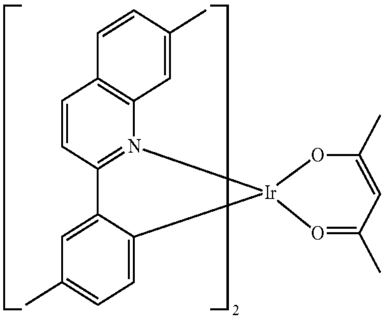
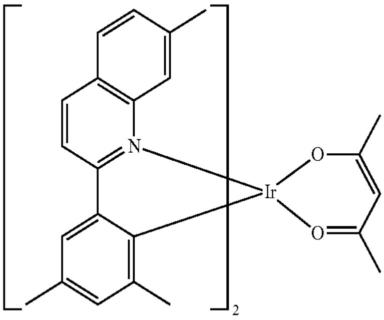
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Iridium(III) organometallic complexes		Appl. Phys. Lett. 78, 1622 (2001)
		US20030072964
		US20030072964
		US20060202194
		US20060202194

TABLE 4-continued

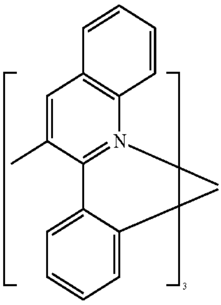
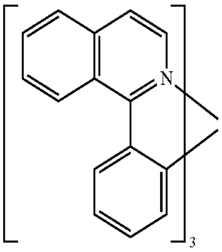
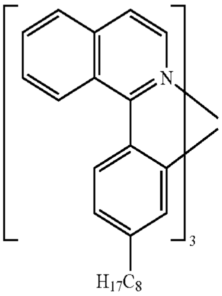
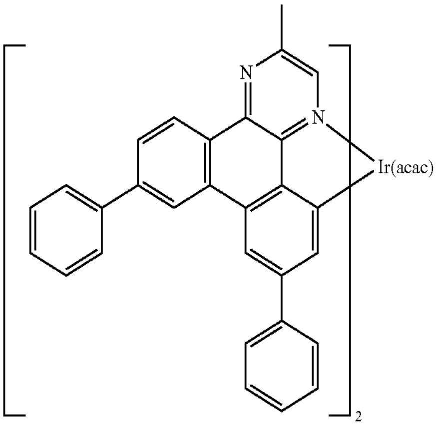
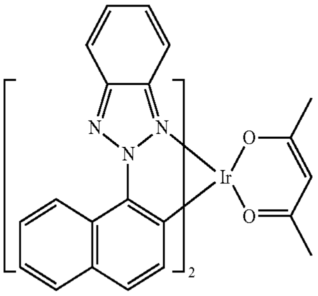
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20070087321
		US20070087321
		Adv. Mater. 19, 739 (2007)
		WO2009100991
		WO2008101842

TABLE 4-continued

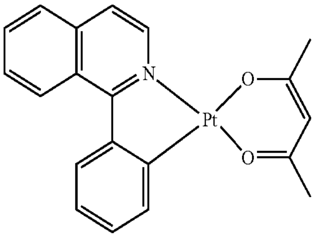
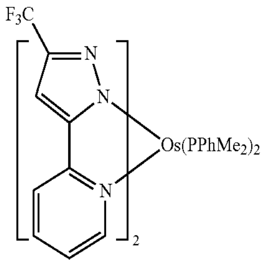
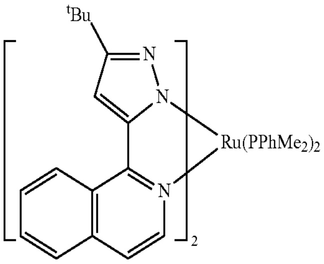
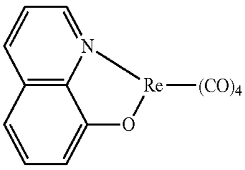
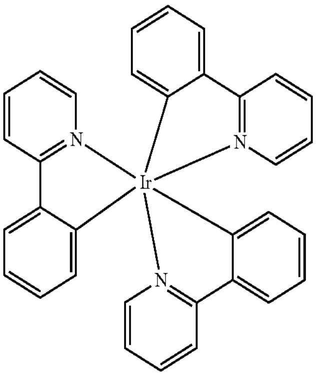
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Platinum(II) organometallic complexes		WO2003040257
Osminum(III) complexes		Chem. Mater. 17, 3532 (2005)
Ruthenium(II) complexes		Adv. Mater. 17, 1059 (2005)
Rhenium (I), (II), and (III) complexes		US20050244673
	Green dopants	
Iridium(III) organometallic complexes	 and its derivatives	Inorg. Chem, 40, 1704 (2001)

TABLE 4-continued

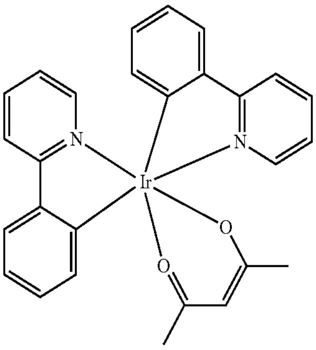
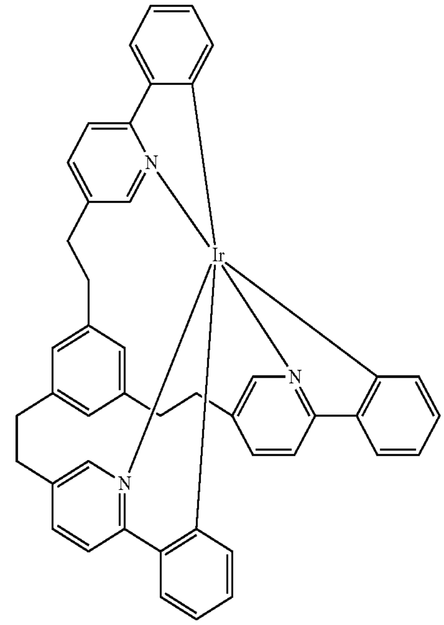
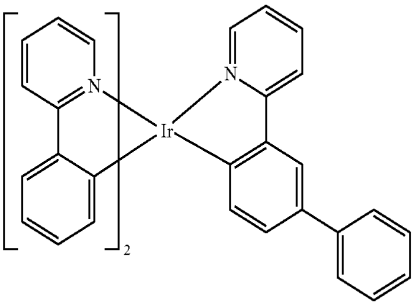
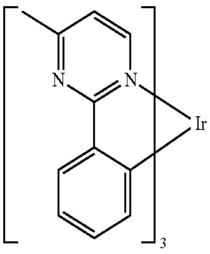
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20020034656
		U.S. Pat. No. 7332232
		US20090108737
		US20090039776

TABLE 4-continued

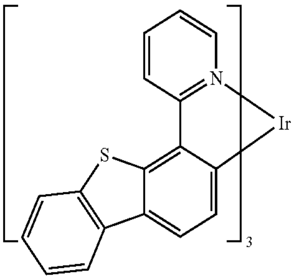
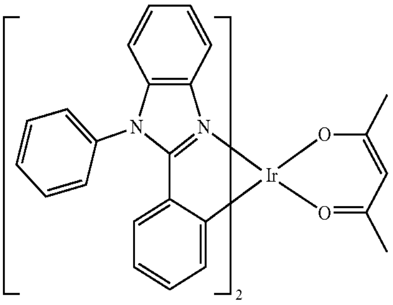
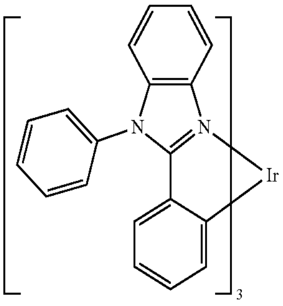
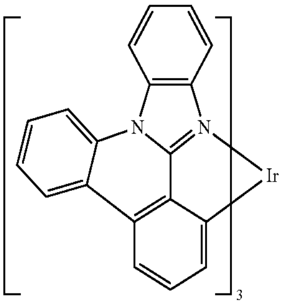
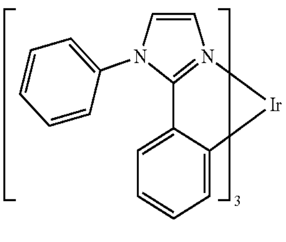
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		U.S. Pat. No. 6921915
		U.S. Pat. No. 6687266
		Chem. Mater. 16, 2480 (2004)
		US20070190359
		US 20060008670 JP2007123392

TABLE 4-continued

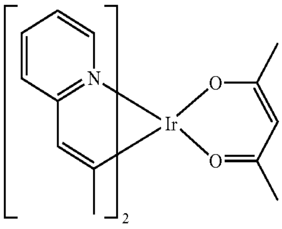
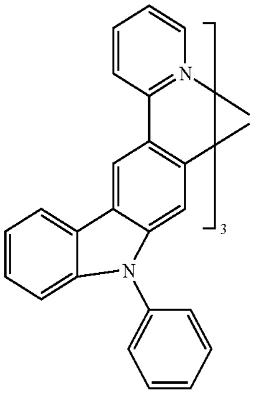
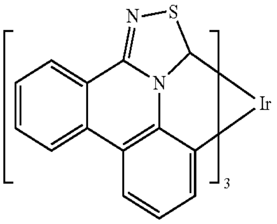
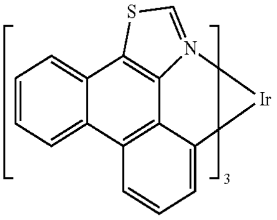
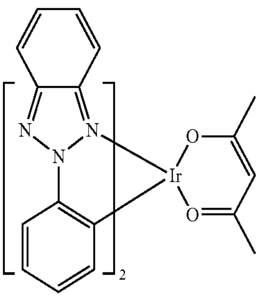
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		Adv. Mater. 16, 2003 (2004)
		Angew. Chem. Int. Ed. 2006, 45, 7800
		WO2009050290
		US20090165846
		US20080015355

TABLE 4-continued

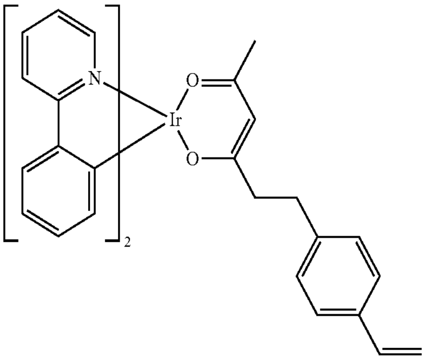
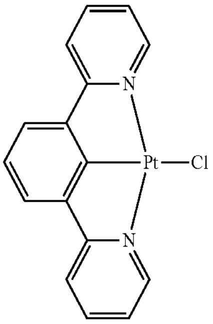
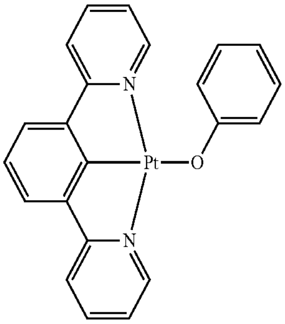
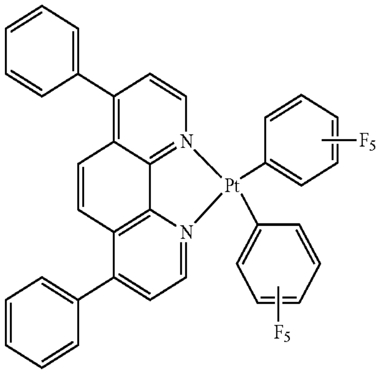
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Monomer for polymeric metal organometallic compounds		U.S. Pat. No. 7250226, U.S. Pat. No. 7396598
Pt(II) organometallic complexes, including polydentated ligands		Appl. Phys. Lett. 86, 153505 (2005)
		Appl. Phys. Lett. 86, 153505 (2005)
		Chem. Lett. 34, 592 (2005)

TABLE 4-continued

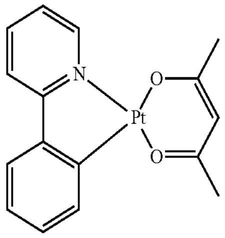
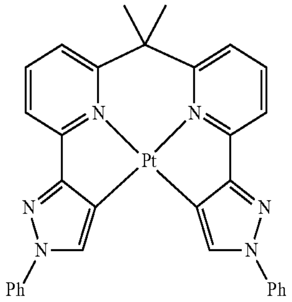
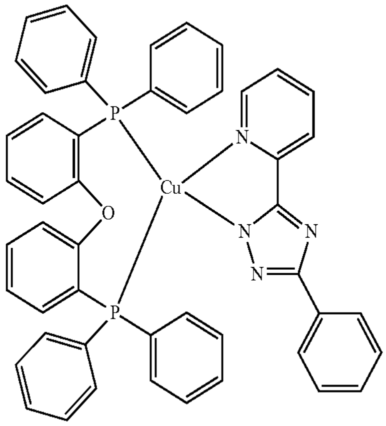
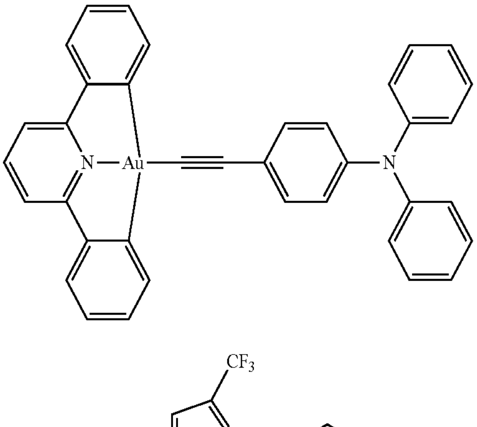
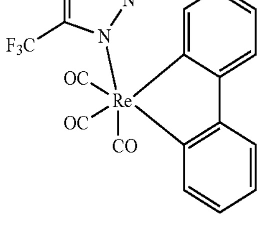
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		WO2002015645
		US20060263635
Cu complexes		WO2009000673
Gold complexes		Chem. Commun. 2906 (2005)
Rhenium(III) complexes		Inorg. Chem. 42, 1248 (2003)

TABLE 4-continued

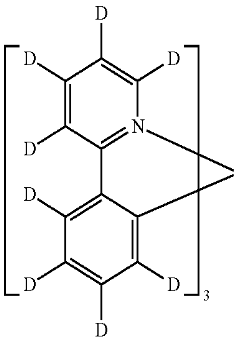
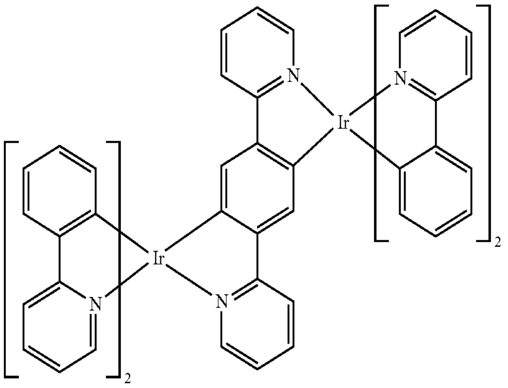
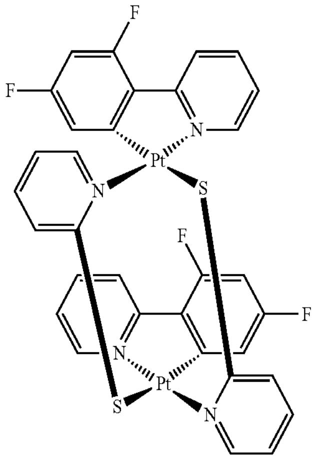
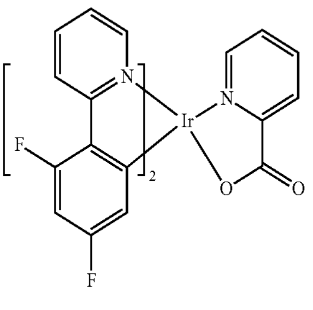
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Deuterated organometallic complexes		US20030138657
Organometallic complexes with two or more metal centers		US20030152802
		U.S. Pat. No. 7090928
	Blue dopants	
Iridium(III) organometallic complexes		WO2002002714

TABLE 4-continued

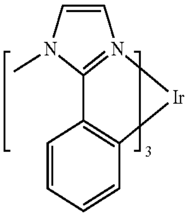
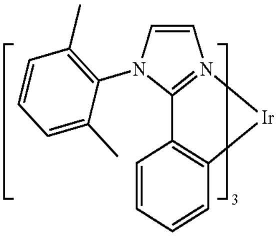
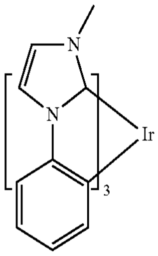
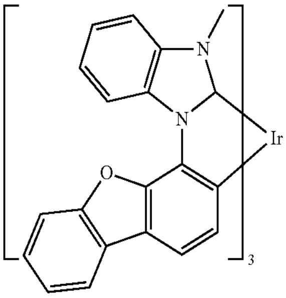
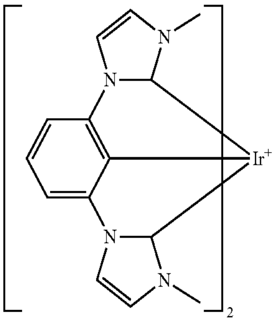
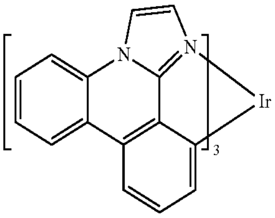
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		WO2006009024
		US20060251923
		U.S. Pat. No. 7393599, WO2006056418, US20050260441, WO2005019373
		U.S. Pat. No. 7534505
		U.S. Pat. No. 7445855
		US20070190359, US20080297033

TABLE 4-continued

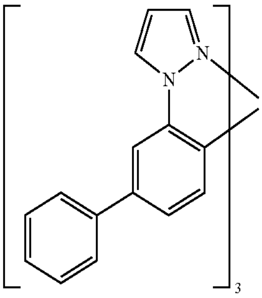
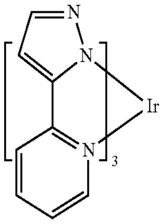
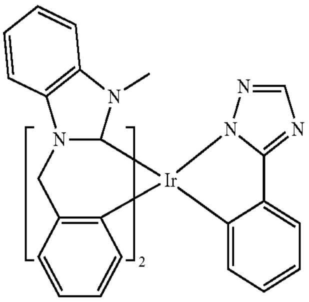
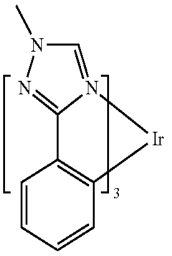
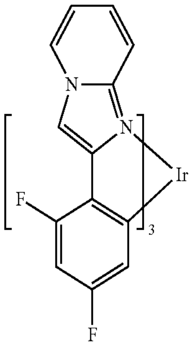
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		U.S. Pat. No. 7338722
		US20020134984
		Angew. Chem. Int. Ed. 47, 1 (2008)
		Chem. Mater. 18, 5119 (2006)
		Inorg. Chem. 46, 4308 (2007)

TABLE 4-continued

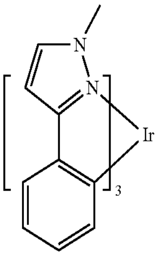
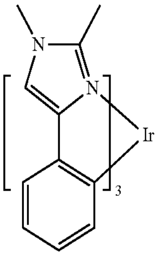
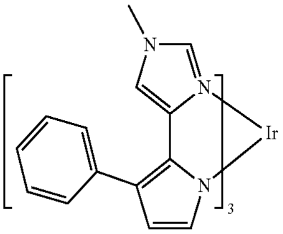
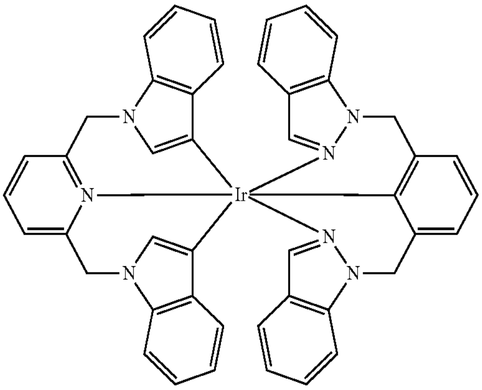
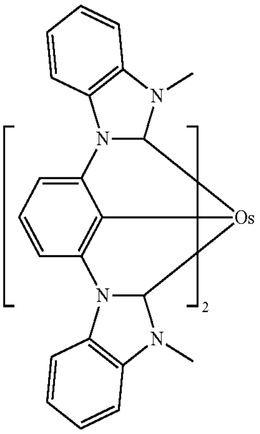
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		WO2005123873
		WO2005123873
		WO2007004380
		WO2006082742
Osmium(II) complexes		U.S. Pat. No. 7279704

TABLE 4-continued

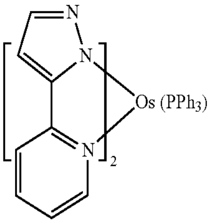
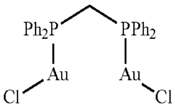
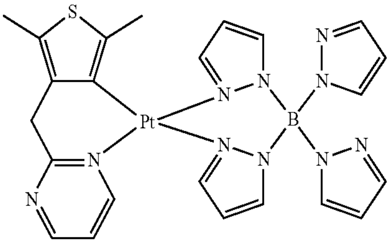
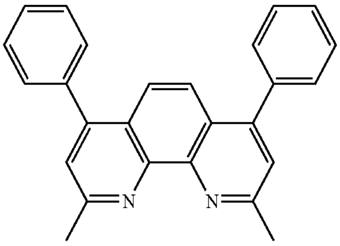
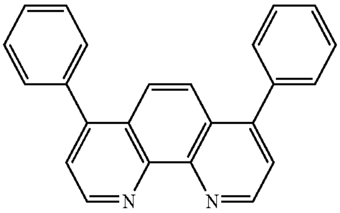
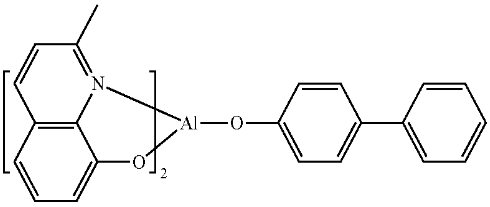
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		Organometallics 23, 3745 (2004)
Gold complexes		Appl. Phys. Lett. 74, 1361 (1999)
Platinum(II) complexes		WO2006098120, WO2006103874
	Exciton/hole blocking layer materials	
Bathocuprine compounds (e.g., BCP, BPhen)		Appl. Phys. Lett. 75, 4 (1999)
		Appl. Phys. Lett. 79, 449 (2001)
Metal 8-hydroxyquinolates (e.g., BAlq)		Appl. Phys. Lett. 81, 162 (2002)

TABLE 4-continued

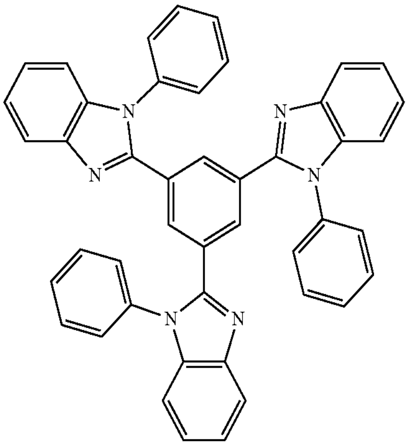
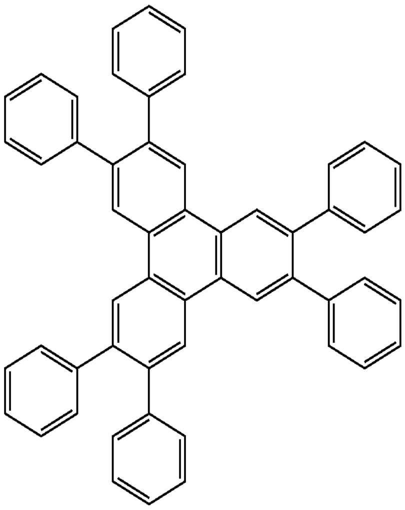
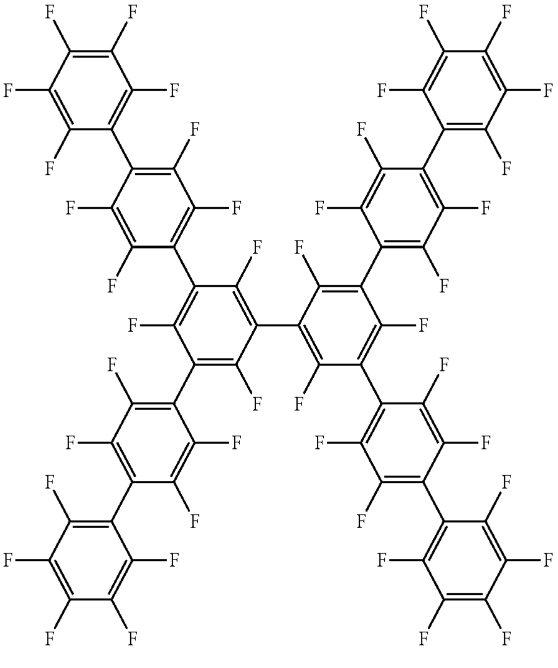
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
5-member ring electron deficient heterocycles such as triazole, oxadiazole, imidazole, benzoimidazole		Appl. Phys. Lett. 81, 162 (2002)
Triphenylene compounds		US20050025993
Fluorinated aromatic compounds		Appl. Phys. Lett. 79, 156 (2001)

TABLE 4-continued

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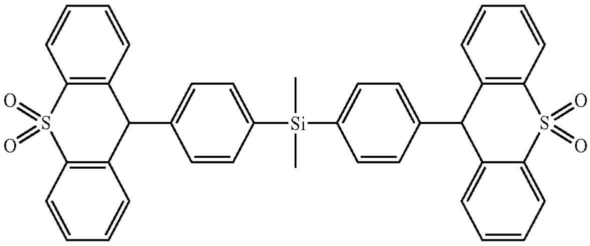
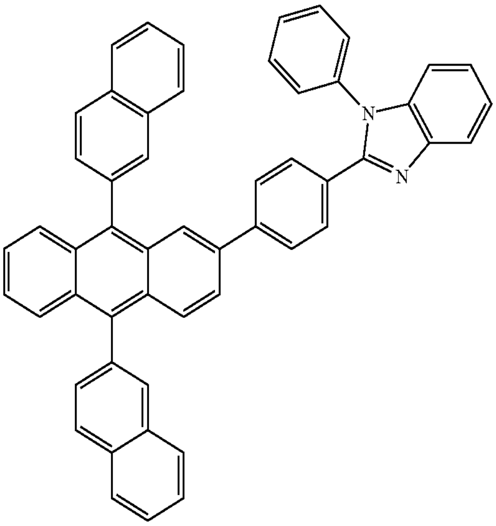
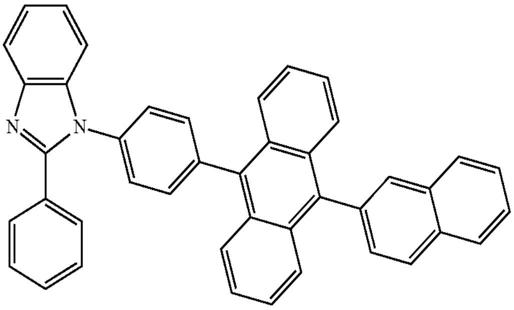
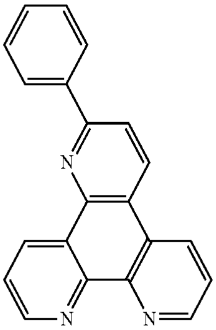
Phenothiazine-S-oxide		WO2008132085
	Electron transporting materials	
Anthracene-benzoimidazole compounds		WO2003060956
		US20090179554
Aza triphenylene derivatives		US20090115316

TABLE 4-continued

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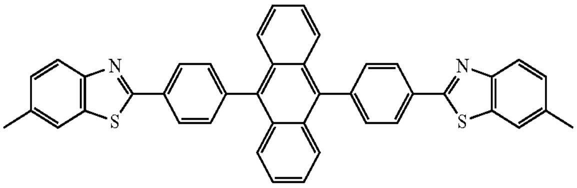
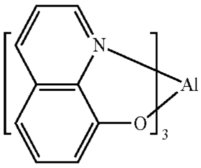
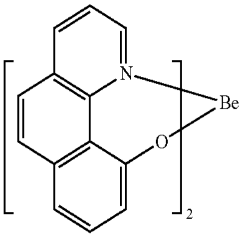
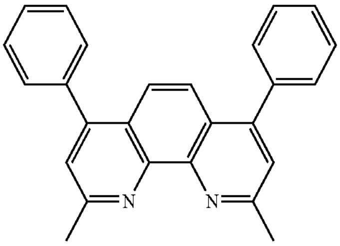
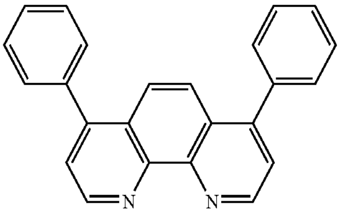
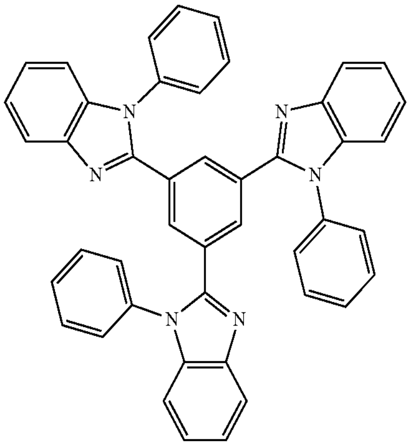
Anthracene-benzothiazole compounds		Appl. Phys. Lett. 89, 063504 (2006)
Metal 8-hydroxyquinolates (e.g., Alq_3, Zrq_4)		Appl. Phys. Lett. 51, 913 (1987) U.S. Pat. No. 7230107
Metal hydroxybenoquinolates		Chem. Lett. 5, 905 (1993)
Bathocuprine compounds such as BCP, BPhen, etc		Appl. Phys. Lett. 91, 263503 (2007)
		Appl. Phys. Lett. 79, 449 (2001)
5-member ring electron deficient heterocycles (e.g., triazole, oxadiazole, imidazole, benzoimidazole)		Appl. Phys. Lett. 74, 865 (1999)

TABLE 4-continued

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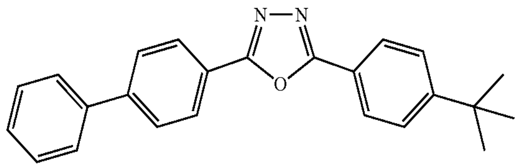
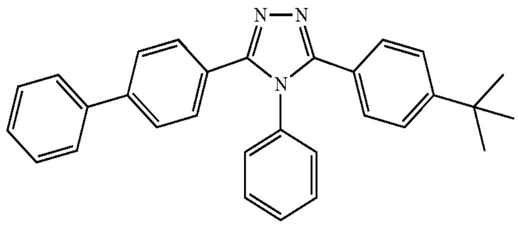
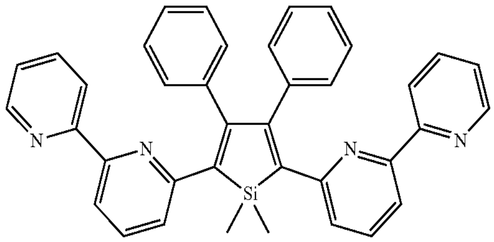
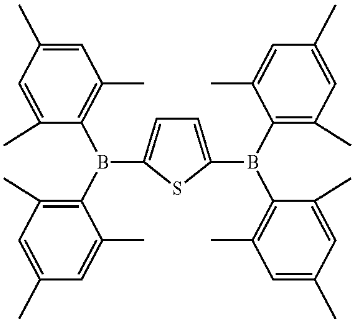
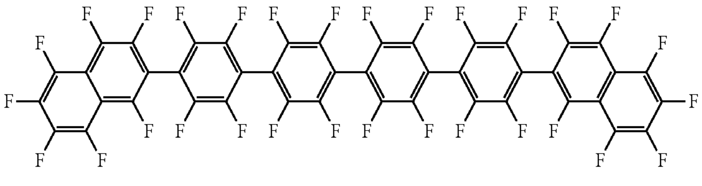
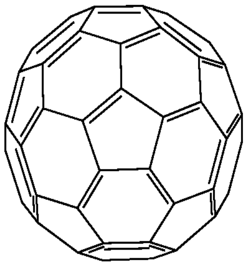
		Appl. Phys. Lett. 55, 1489 (1989)
		Jpn. J. Apply. Phys. 32, L917 (1993)
Silole compounds		Org. Electron. 4, 113 (2003)
Arylborane compounds		J. Am. Chem. Soc. 120, 9714 (1998)
Fluorinated aromatic compounds		J. Am. Chem. Soc. 122, 1832 (2000)
Fullerene (e.g., C60)		US20090101870

TABLE 4-continued

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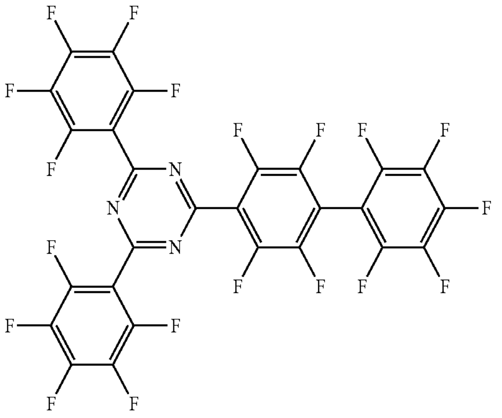
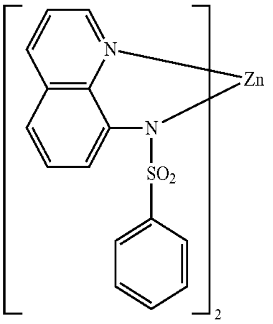
Triazine complexes		US20040036077
Zn (N^N) complexes		U.S. Pat. No. 6528187

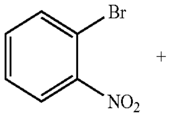
EXPERIMENTAL

[0125] Chemical abbreviations used throughout this document are as follows: Cy is cyclohexyl, dba is dibenzylideneacetone, EtOAc is ethyl acetate, PPh_3 is triphenylphosphine, DDQ is dichloro-5,6-dicyanobenzoquinone, DCM is dichloromethane.

Example 1

Synthesis of Condensation Product of Benzaldehyde and N-(2,6-diisopropylphenyl)benzene-1,2-diamine

[0126]



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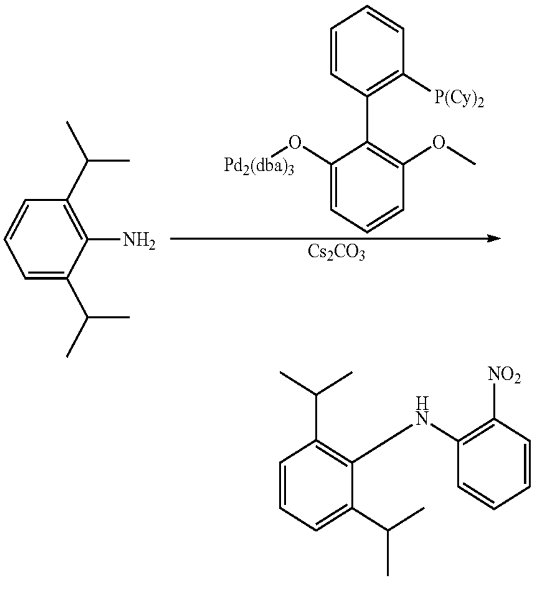
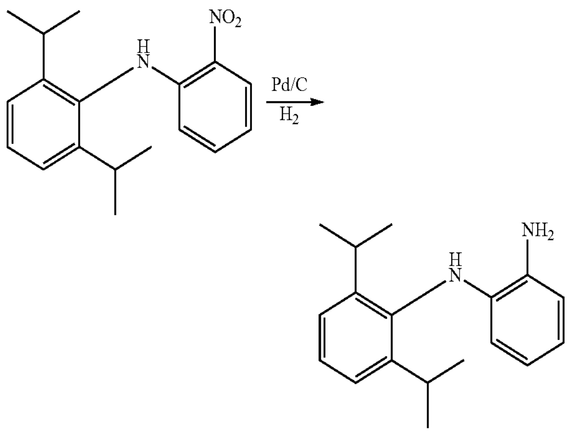
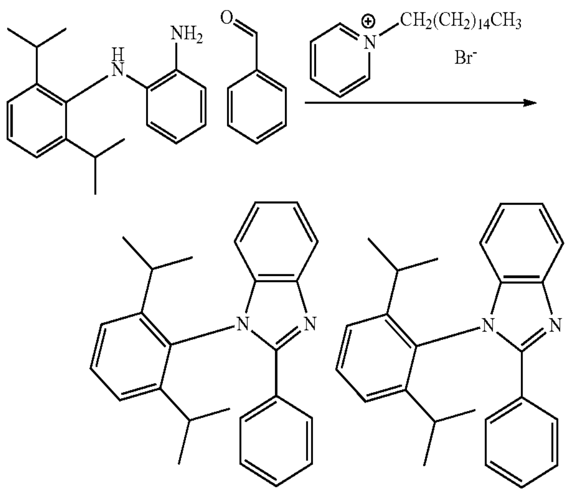


[0127] 1-Bromo-2-nitrobenzene (15 g, 75 mmol), 2,6-diisopropylaniline (14.0 mL, 75 mmol) and cesium carbonate (41.5 g, 127 mmol) were mixed in 500 mL of toluene and the solution was bubbled with nitrogen for 20 min. $Pd_2(dba)_3$ (1.36 g, 1.49 mmol) and dicyclohexyl(2',6'-dimethoxy-[1,1'-biphenyl]-2-yl)phosphine (2.44 g, 5.94 mmol) were added and reaction mixture was heated to reflux for 18 h. After cooling, the organic layer separated and the aqueous layer was extracted with 3×50 mL dichloromethane and dried over sodium sulfate. After removing the solvent under reduced pressure, the crude product was chromatographed on silica gel with 10:90 (v/v) ethyl acetate:hexane and 20 g (72%) of the product was obtained. The product was confirmed by GC/MS, NMR and HPLC (99.96% pure)



[0128] 2,6-Diisopropyl-N-(2-nitrophenyl) aniline (12 g, 40.2 mmol) was dissolved in 200 mL ethanol and palladium on carbon (0.642 g) was added. The reaction mixture was placed on the Parr hydrogenator for 1 h. The reaction mixture was filtered through a Celite® plug, washed with dichloromethane and evaporated. The crude product was chromatographed on silica gel with 10:90 (v/v) ethyl acetate:hexane and 10 g (93%) of the product was obtained. The product was confirmed by GC/MS and NMR.

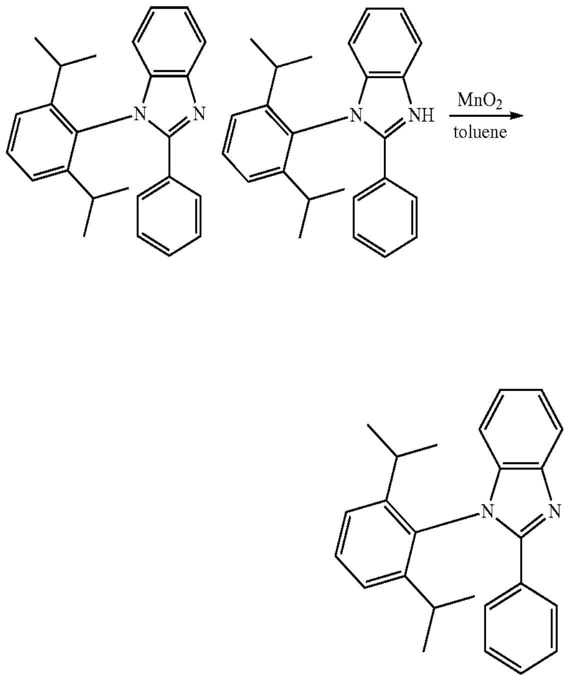


[0129] N-(2,6-diisopropylphenyl)benzene-1,2-diamine (16.5 g, 61.5 mmol), benzaldehyde (9.8 mL, 92 mmol) and 1-hexadecylpyridinium bromide (1.2 g, 3.1 mmol) were dissolved in 50 mL THF and 500 mL water and stirred at room temperature overnight. By GC/MS the reaction mixture typically showed a mixture of the phenylbenzimidazole product and the phenyl-2,3-dihydro-1H-benzo[d]imidazole product (ca. 50:50). Brine (200 mL) was added and the reaction mixture extracted with EtOAc (3×300 mL), dried over sodium sulfate and evaporated. The total crude yield was 20 g (~91%) and was carried onto the next step.

Example 2

Reaction of Condensation Product of Benzaldehyde and N-(2,6-diisopropylphenyl)benzene-1,2-diamine with Manganese (IV) Oxide

[0130]

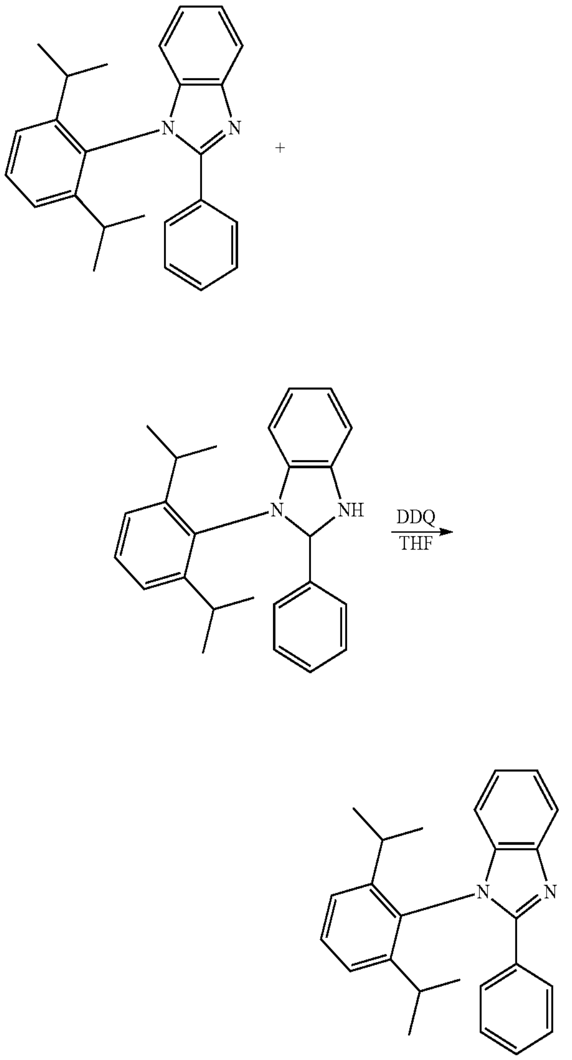


[0131] The mixture of the phenylbenzimidazole product and the phenyl-2,3-dihydro-1H-benzo[d]imidazole product (18 g, 50.5 mmol) obtained as in Example 1 was combined and manganese(IV) oxide (22 g, 252 mmol) in 300 mL of toluene. With vigorous stirring, the reaction was heated to reflux for 10 h, cooled, filtered through a plug of silica gel eluted with dichloromethane and evaporated. The crude product was chromatographed on silica gel with 0-3% ethyl acetate in dichloromethane and then recrystallized from hexane to give 14.7 g (82%) of the product. The product was confirmed by HPLC (>98%) and NMR. Yields ranged from 48-75%.

Example 3

Reaction of Condensation Product of Benzaldehyde and N-(2,6-diisopropylphenyl)benzene-1,2-diamine with DDQ

[0132]

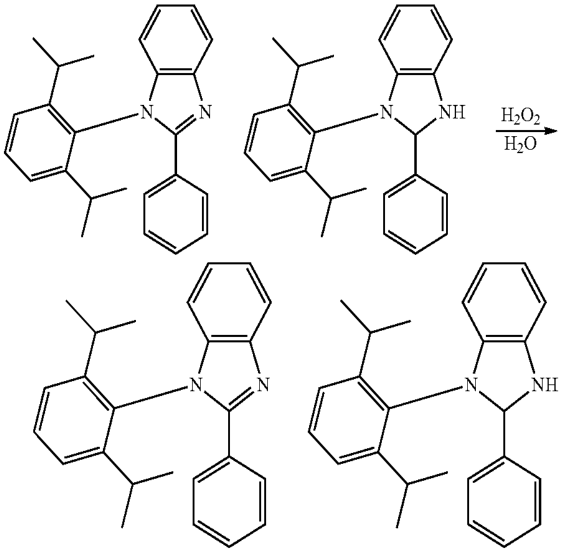


[0133] To the mixture of the phenylbenzimidazole product and the phenyl-2,3-dihydro-1H-benzo[d]imidazole product (10.19 g, 44.9 mmol) obtained as in Example 1 was added 2,3-dichloro-5,6-dicyanobenzoquinone (DDQ) (10.19 g, 44.9 mmol) in 300 mL THF at 0° C. An exothermic reaction resulted, with the temperature increasing to 45° C. The reaction mixture was allowed to stir at room temperature for 3 h. GC/MS confirmed the complete oxidation to the benzimidazole. Brine (200 mL) was added and the reaction mixture extracted 3 x 200 mL with ethyl acetate. The combined organic layers were dried over sodium sulfate, filtered and the solvent removed under reduced pressure. The crude product was chromatographed on silica gel with 0-3% ethyl acetate in DCM to give 3.2 g (20%) of the product. The product was confirmed by HPLC and GC/MS.

Example 4

Reaction of Condensation Product of Benzaldehyde and N-(2,6-diisopropylphenyl)benzene-1,2-diamine with H_2O_2

[0134]



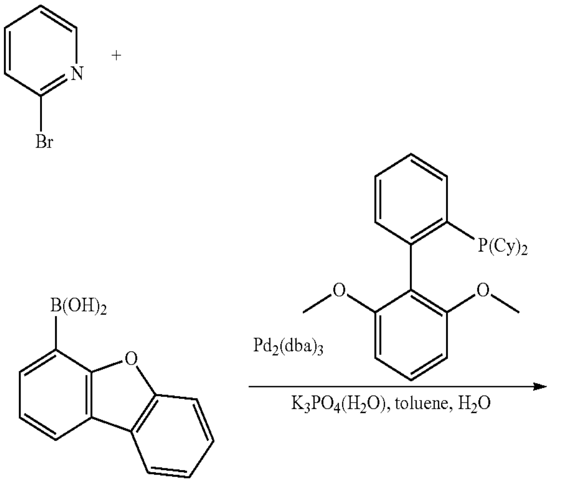
[0135] The mixture of the phenylbenzimidazole product and the phenyl-2,3-dihydro-1H-benzo[d]imidazole product (1 g, 4.5 mmol) obtained as in Example 1 was combined and 30% H_2O_2 in water and allowed to stir overnight. The reaction was checked by GC/MS and showed the same product ratio as the starting material.

Synthesis of Compounds 81 and 82

Example 5

Synthesis of 4-(2-pyridyl)dibenzo[b,d]furan

[0136]



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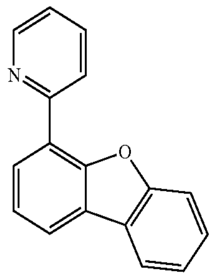


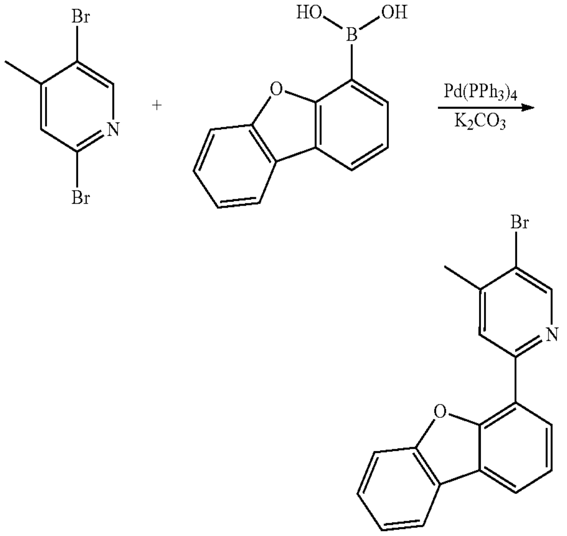
[0137] To a 1 L round-bottom flask was added 2-bromopyridine (13.80 mL, 142 mmol), dibenzo[b,d]furan-4-ylboronic acid (25 g, 118 mmol), dicyclohexyl(2',6'-dimethoxy-[1,1'-biphenyl]-2-yl)phosphine (1.936 g, 4.72 mmol) and potassium phosphate tribasic monohydrate (81 g, 354 mmol) with toluene (350 mL) and water (35 mL). The reaction mixture was degassed with N_2 for 20 minutes. $Pd_2(dba)_3$ (2.16 g, 2.35 mmol) was added and the reaction mixture was refluxed for 18 h. Completion of the reaction was confirmed by HPLC, GC and TLC. After cooling, the aqueous layer was removed and toluene was evaporated under reduced pressure. The residue was dissolved in dichloromethane and passed through one inch silica gel plug on a frit, eluting with dichloromethane. The crude product was chromatographed on silica gel with 20-25% ethyl acetate in hexane to give 18 g (62%) of the product. The product was confirmed by HPLC (99.6% purity) and GC/MS.

Example 6

Synthesis of 5-bromo-2-(dibenzo[b,d]furan-4-yl)-4-methylpyridine

Step 1

[0138]

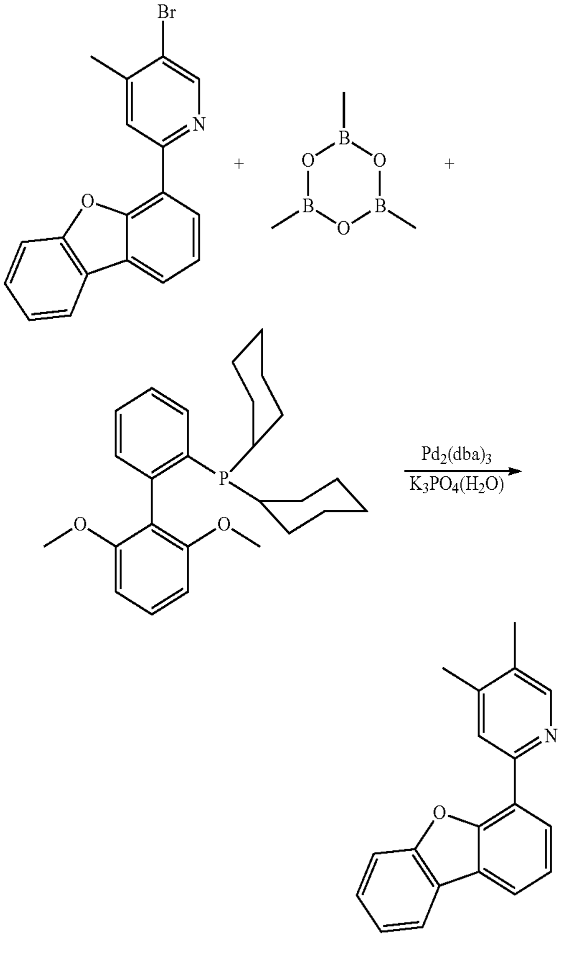


[0139] 2,5-Dibromo-4-methylpyridine (30 g, 118 mmol), dibenzo[b,d]furan-4-ylboronic acid (25 g, 118 mmol), $Pd(PPh_3)_4$ (1.4 g, 1.18 mmol), and K_2CO_3 (49 g, 354 mmol) were added to a flask with dimethoxyethane (450 mL) and water (100 mL) and degassed with nitrogen. The reaction mixture was heated to reflux for 15 h before cooling to room temperature. EtOAc and water were added, the organic layer separated and the aqueous layer was extracted with 3×50 mL dichloromethane and dried over sodium sulfate. After removing the solvent under reduced pressure, the crude product was chromatographed on silica gel with dichloromethane and 29.7 g of crude product was obtained. The product was crystallized from hexane to give 28.8 g (72%) of pure product. The product was confirmed by NMR and HPLC (99.3% pure)

Step 2

Synthesis of 2-(dibenzo[b,d]furan-4-yl)-4,5-dimethylpyridine

[0140]



[0141] -Bromo-2-(dibenzo[b,d]furan-4-yl)-4-methylpyridine (28.7 g, 85 mmol), dicyclohexyl(2',6'-dimethoxy-[1,1'-biphenyl]-2-yl)phosphine (1.394 g, 3.39 mmol) and potassium phosphate monohydrate (58.6 g, 255 mmol) were added to toluene (500 mL) and water (50 mL) and degassed for 20 min. Trimethylboroxine (14.83 mL, 106 mmol) and $Pd_2(dba)_3$ (0.777 g, 0.849 mmol) were added and the reaction mixture heated to reflux overnight. After cooling, the organic layer was separated and the aqueous layer extracted 3 x 50 mL with EtOAc, dried over sodium sulfate and evaporated. The crude product was chromatographed on silica gel with 8/2 dichloromethane/EtOAc in hexane to give 19.2 g of an off-white solid which was recrystallized from hexane to give 16.8 g (83%) of the product as white needles. The product was confirmed by NMR and HPLC (99.97% pure).

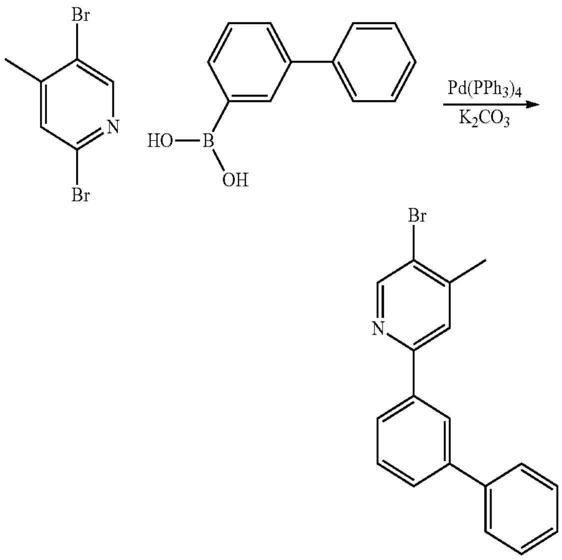
Synthesis of Compounds A-D

Example 7

Synthesis of 2-([1,1'-biphenyl]-3-yl)-4,5-dimethylpyridine

Step 1

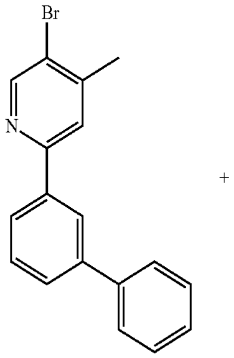
[0142]



[0143] 2,5-Dibromo-4-methylpyridine (10 g, 39.9 mmol), [1,1'-biphenyl]-3-ylboronic acid (7.89 g, 39.9 mmol) and tetrakis(triphenylphosphine)palladium(0) (2.303 g, 1.99 mmol), toluene (250 mL) and water (25 mL) were placed in a flask under nitrogen. The reaction mixture was degassed with nitrogen for 20 minutes and heated to reflux for 18 h. After cooling, the organic layer was separated and the aqueous layer extracted 3 x 50 mL with dichloromethane, dried over sodium sulfate and evaporated. The crude product was chromatographed on silica gel with 10% ethyl acetate in hexane to give 11.5 g (85%) of the product. The product was confirmed by NMR and GC/MS.

Step 2

[0144]



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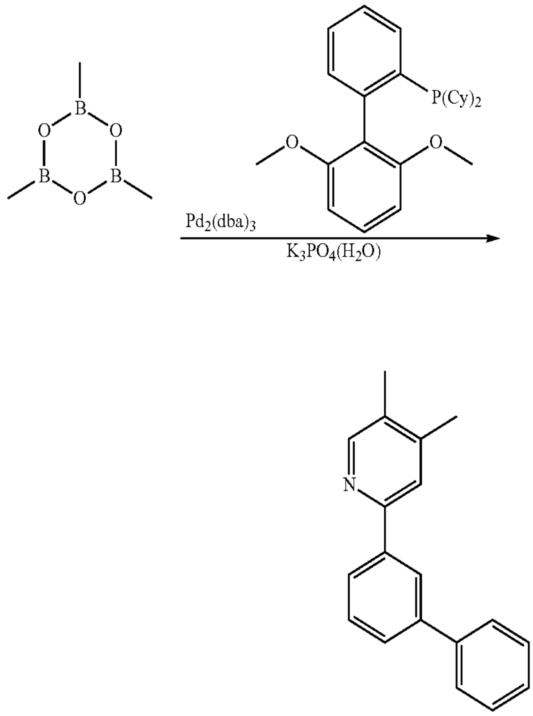
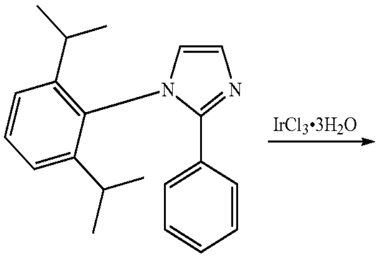


[0145] 2-([1,1'-Biphenyl]-3-yl)-5-bromo-4-methylpyridine 11.5 g (35.5 mmol), 2,4,6-trimethyl-1,3,5,2,4,6-trioxatriborinane (5.57 g, 44.3 mmol), dicyclohexyl(2',6'-dimethoxy-[1,1'-biphenyl]-3-yl)phosphine (1.2 g, 2.84 mmol), Pd_2dba_3 (0.650 g, 0.709 mmol) and potassium phosphate tribasic monohydrate, 250 mL toluene and 25 mL of water were placed in flask under nitrogen. The reaction mixture was degassed with nitrogen for 20 minutes and heated to reflux for 24 h. After cooling, the organic layer was separated and the aqueous layer extracted 3×50 mL with dichloromethane, dried over sodium sulfate and evaporated. The crude product was chromatographed on silica gel with 5% dichloromethane in hexane to give 8.0 g (87%) of the product. The product was confirmed by NMR and GC/MS.

Example 8

[0146]



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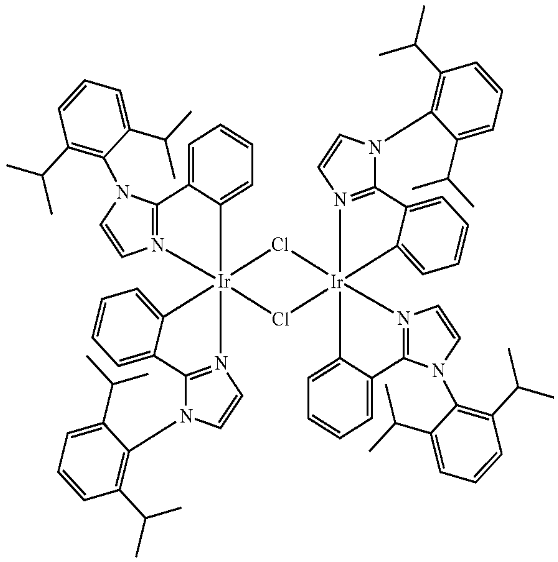
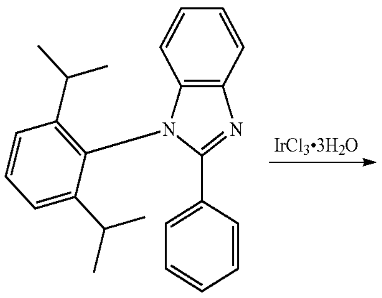


[0147] To a round-bottom flask was added 1-(2,6-diisopropylphenyl)-2-phenyl-1H-imidazole (8.00 g, 26.3 mmol) and iridium(III) chloride hydrate (3.09 g, 8.76 mmol) with 2-ethoxyethanol (90 mL) and water (30 mL) under N_2 atmosphere. The resulting reaction mixture was refluxed at 130° C. for 18 h. The green precipitate was filtered, washed with ethanol (3-4 times) and hexane (3-4 times) to yield 7.3 g (98.9%) of a green solid after drying. The product was used without further purification.

Example 9

[0148]



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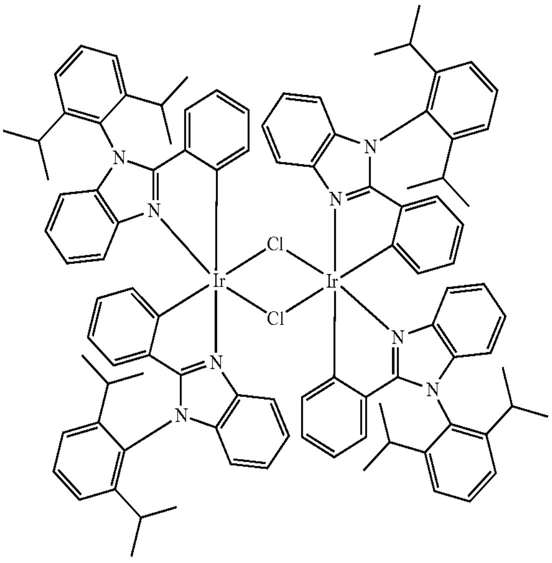
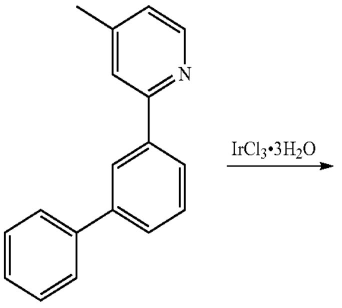


[0149] To a round-bottom flask was added 1-(2,6-diisopropylcyclohexa-2,4-dien-1-yl)-2-phenyl-1H-benzo[d]imidazole (6.0 g, 16.83 mmol) and iridium(III) chloride hydrate (1.98 g, 5.61 mmol) with 2-ethoxyethanol (100 mL) and water (33 mL) under N_2 atmosphere. The resulting reaction mixture was refluxed at 130° C. for 18 h. The yellow precipitate was filtered, washed with methanol (3-4 times) and hexane (3-4 times) to yield 5.2 g (98.8%) of a yellow solid after drying. The product was used without further purification.

Example 10

[0150]



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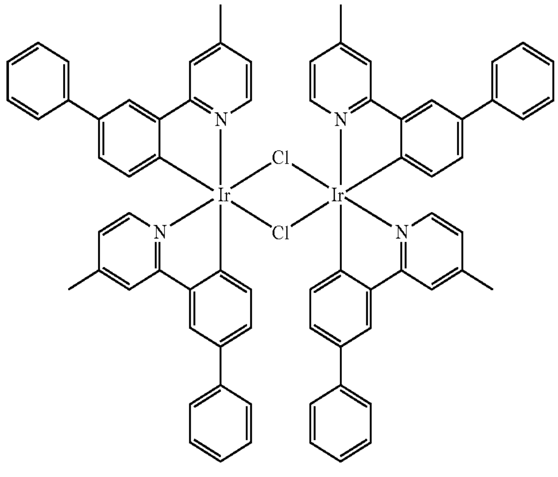
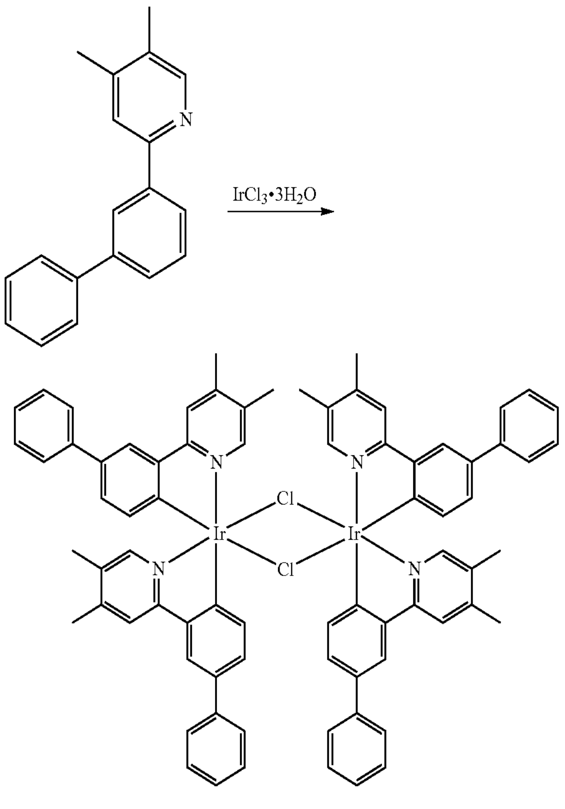


[0151] To a round-bottom flask was 2-([1, 1'-biphenyl]-3-yl)-4-methylpyridine (10 g, 40.8 mmol) and iridium(III) chloride hydrate (4.11 g, 11.66 mmol) with 2-ethoxyethanol (100 mL) and water (33 mL) under N_2 atmosphere. The resulting reaction mixture was refluxed at 130° C. for 18 h. The yellow precipitate was filtered, washed with methanol (3-4 times) and hexane (3-4 times) to yield 10.5 g (63%) of a yellow solid after drying. The product was used without further purification.

Example 11

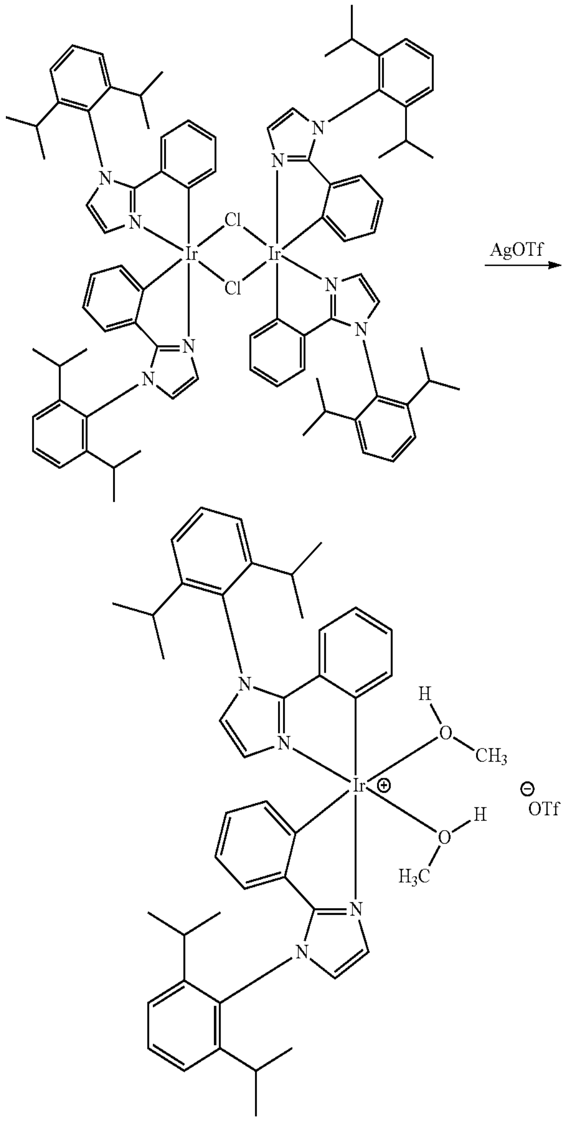
[0152]



[0153] To a round-bottom flask was added 2-([1,1'-biphenyl]-3-yl)-4,5-dimethylpyridine (6.5 g, 25.06 mmol) and iridium(III) chloride hydrate (2.95 g, 8.35 mmol) with 2-ethoxyethanol (100 mL) and water (33 mL) under N_2 atmosphere. The resulting reaction mixture was refluxed at 130° C. for 18 h. The yellow precipitate was filtered, washed with methanol (3-4 times) and hexane (3-4 times) to yield 6.2 g (100%) of a yellow solid after drying. The product was used without further purification.

Example 12

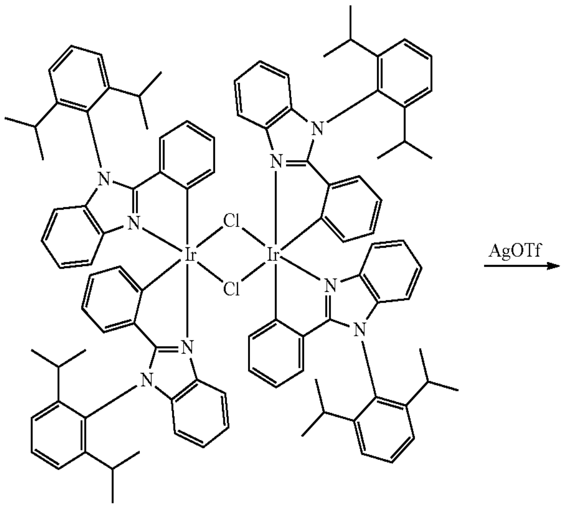
[0154]



[0155] In a round-bottom flask, the iridium dimer complex obtained as in Example 8 (7.2 g, 4.3 mmol) was dissolved in 600 mL dichloromethane. In a separate flask, silver(I) triflate (2.4 g, 9.5 mmol) was dissolved in 300 mL of MeOH. This was added slowly to the dimer solution with continuous stirring at room temperature. The reaction mixture was stirred overnight in the dark, then filtered through a tightly packed Celite® bed to remove silver chloride precipitate. The solvent was removed under reduced pressure to give 9.6 g (100%) of a yellow-green solid and used without further purification.

Example 13

[0156]



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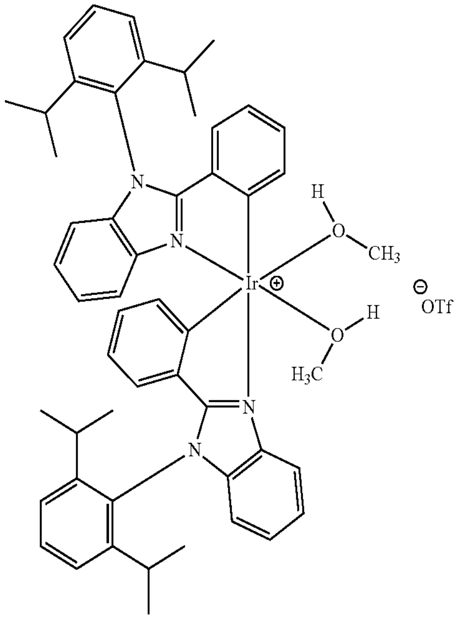
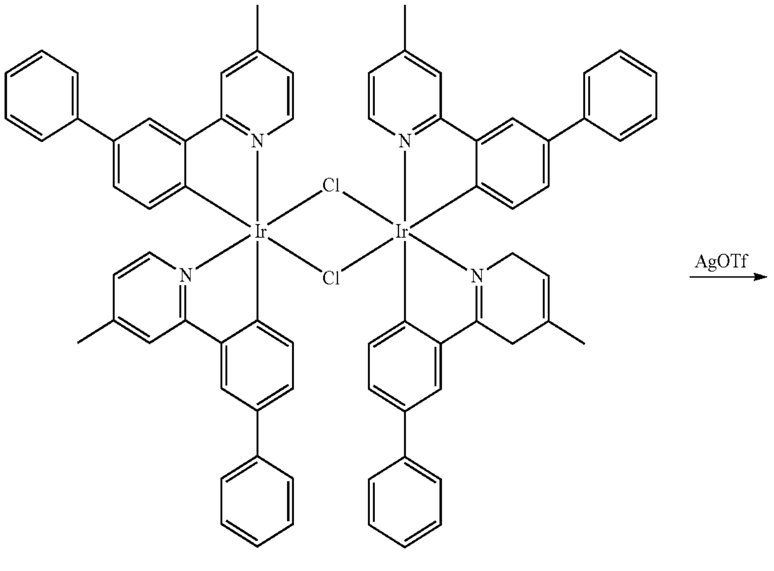


[0157] In a round-bottom flask, the iridium dimer complex (5.2 g, 2.78 mmol) was dissolved in 200 mL dichloromethane. In a separate flask, silver(I) triflate (1.5 g, 5.84 mmol) was dissolved in 250 mL of MeOH. This was added slowly to the dimer solution with continuous stirring at room temperature. The reaction mixture was stirred overnight in the dark, then filtered through a tightly packed Celite® bed to remove silver chloride precipitate. The solvent was removed under reduced pressure to give 6.0 g (100%) of a brownish green solid and used without further purification.

Example 14

[0158]



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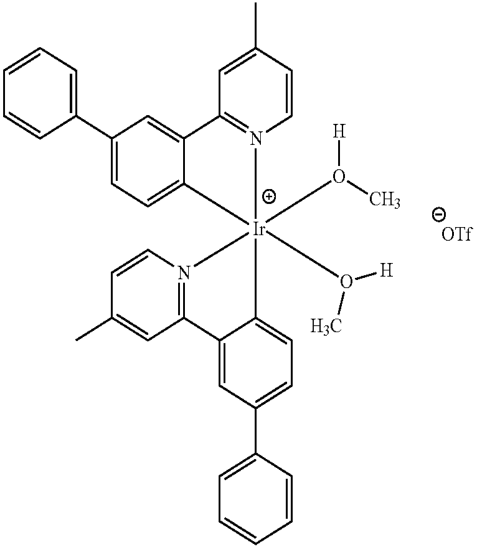
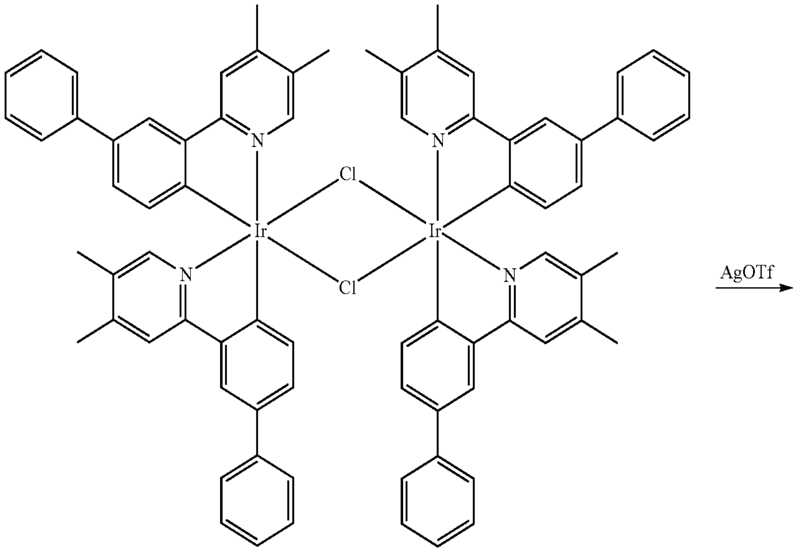


[0159] In a round-bottom flask, the iridium dimer complex (10.5 g, 7.3 mmol) was dissolved in 600 mL dichloromethane. In a separate flask, silver(I) triflate (4.0 g, 15.4 mmol) was dissolved in 300 mL of MeOH. This was added slowly to the dimer solution with continuous stirring at room temperature. The reaction mixture was stirred overnight in the dark, then filtered through a tightly packed Celite® bed to remove silver chloride precipitate. The solvent was removed under reduced pressure to give 11.5 g (100%) of a brownish green solid and used without further purification.

Example 15

[0160]



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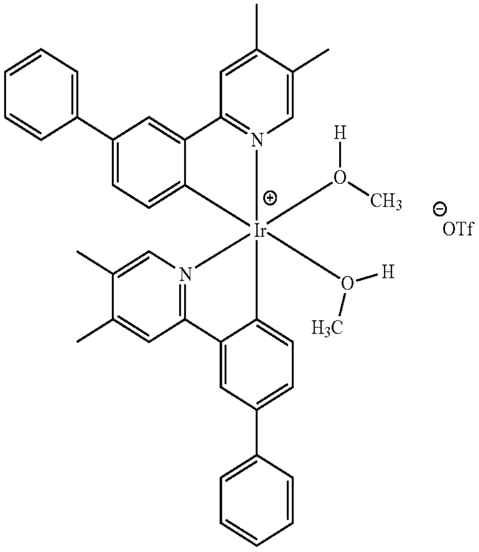
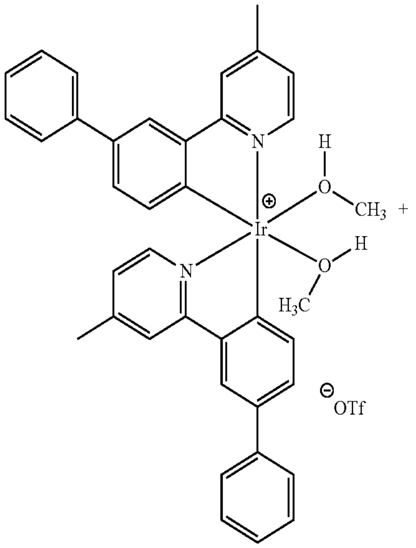


[0161] In a round-bottom flask, the iridium dimer complex (6.2 g, 4.2 mmol) was dissolved in 600 mL dichloromethane. In a separate flask, silver(I) triflate (2.3 g, 8.8 mmol) was dissolved in 300 mL of MeOH. This was added slowly to the dimer solution with continuous stirring at room temperature. The reaction mixture was stirred overnight in the dark, then filtered through a tightly packed Celite® bed to remove silver chloride precipitate. The solvent was removed under reduced pressure to give 8.0 g (100%) of a brownish green solid and used without further purification.

Example 16

Synthesis of Compound A

[0162]



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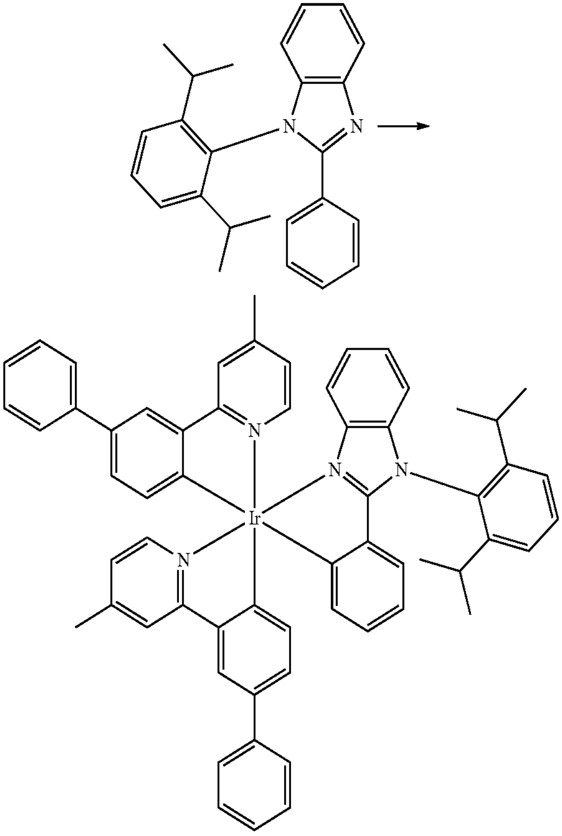


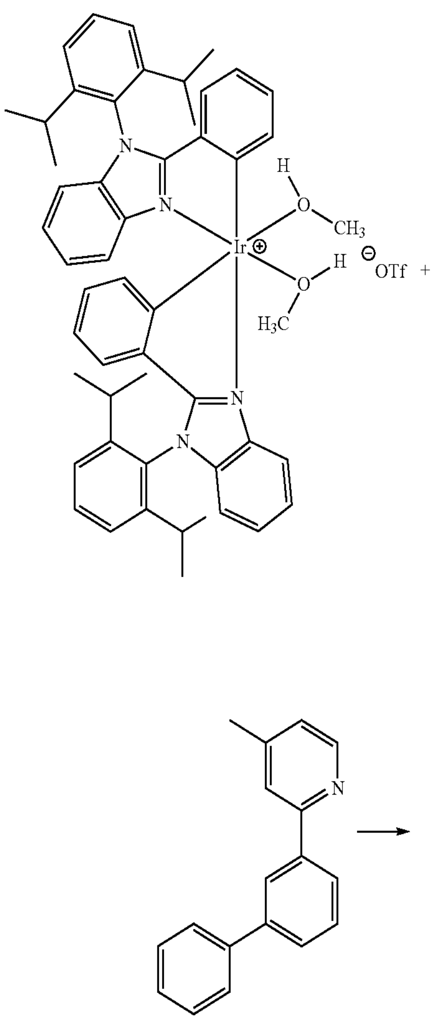
[0163] To a flask was added the iridium triflate complex obtained as in Example 14 (2.5 g, 2.2 mmol) and 2-(dibenzo[b,d]furan-4-yl)-4,5-dimethylpyridine (1.6 g, 5.8 mmol), 25 mL EtOH and 25 mL MeOH. The reaction mixture was refluxed for 36 h, forming a yellow precipitate. The reaction mixture was cooled to room temperature, diluted with ethanol, Celite® was added and the mixture stirred for 10 min. The mixture was filtered on a small silica gel plug on a frit and washed with ethanol (3-4 times) and with hexane (3-4 times).

The filtrate was discarded. The Celite®/silica plug was then washed with dichloromethane to dissolve the product. Half the volume of dichloromethane was removed under reduced pressure and hexane was added to precipitate the product, which was filtered and washed with hexane. The crude product was chromatographed on silica gel with 1/1 (v/v) dichloromethane/hexane and then sublimed to yield 1.0 g (30%) of product as a yellow solid. The product, Compound A, was confirmed by HPLC (99.7% pure) and LC/MS.

Example 17

Synthesis of Compound B

[0164]



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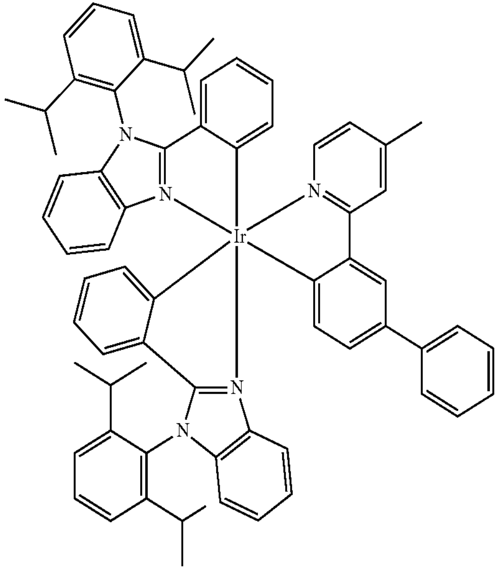
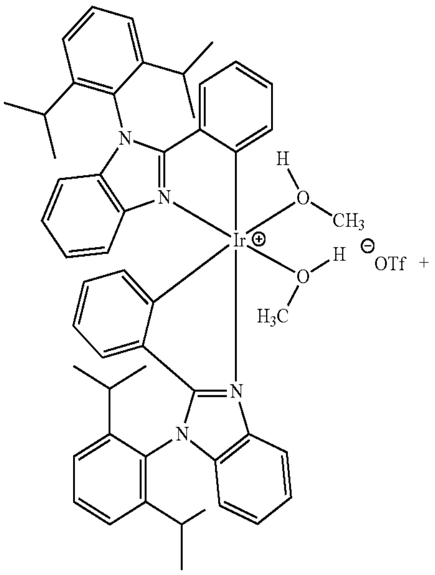


[0165] To a flask was added the iridium triflate complex obtained as in Example 13 (3.3 g, 3.0 mmol) and 2-([1,1'-biphenyl]-3-yl)-4-methylpyridine (1.9 g 7.7 mmol), 25 mL EtOH and 25 mL MeOH. The reaction mixture was refluxed for 36 h, with a yellow precipitate forming. The reaction mixture was cooled to room temperature, diluted with ethanol, Celite® was added and the mixture stirred for 10 min. The mixture was filtered on a small silica gel plug on a frit and washed with ethanol (3-4 times) and with hexane (3-4 times). The filtrate was discarded. The Celite®/silica plug was then washed with dichloromethane to dissolve the product. Half the volume of dichloromethane was removed under reduced pressure and hexane was added to precipitate the product, which was filtered and washed with hexane. The crude product was chromatographed on silica gel with 1/1 (v/v) dichloromethane/hexane and then sublimed to yield 1.0 g (30%) of product as a yellow solid. The product, Compound B, was confirmed by HPLC (99.6% pure) and LC/MS.

Example 18

Synthesis of Compound C

[0166]



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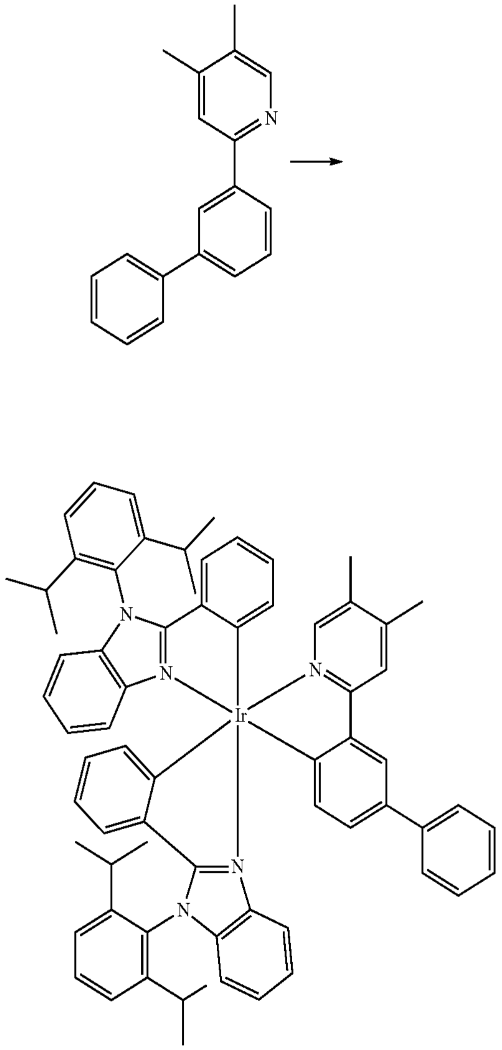
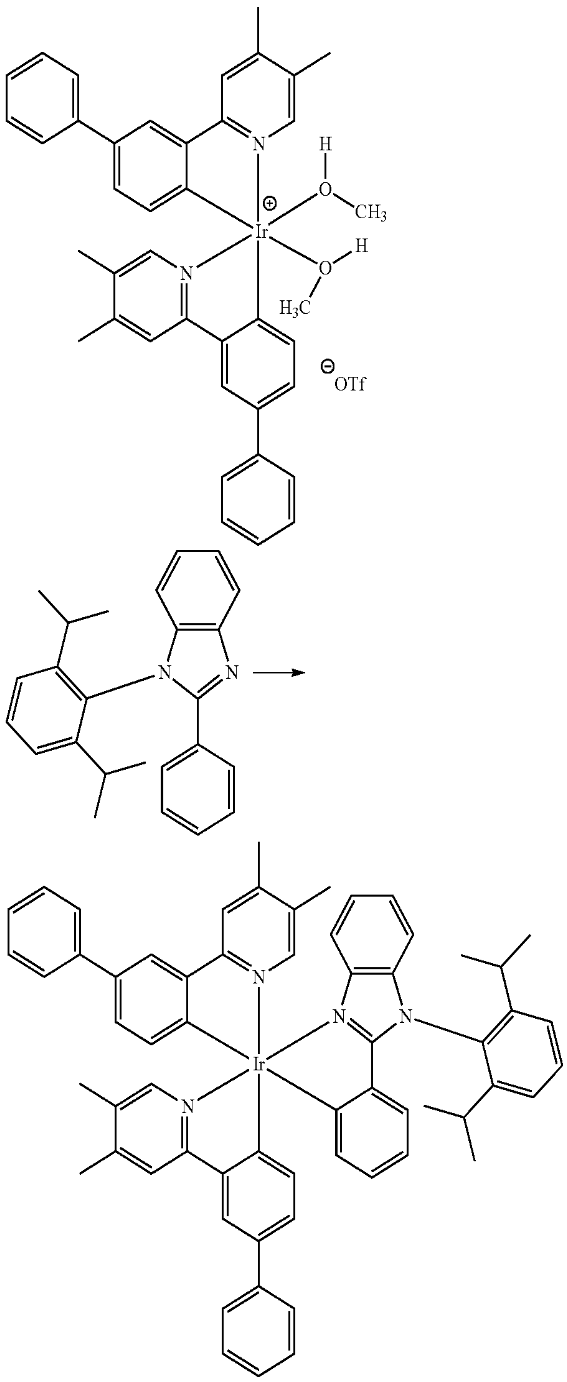


[0167] To a flask was added the iridium triflate complex obtained as in Example 13 (3.0 g, 2.7 mmol) and 2-([1,1'-biphenyl]-3-yl)-4,5-dimethylpyridine (1.8 g, 7.0 mmol), 25 mL EtOH and 25 mL MeOH. The reaction mixture was refluxed for 36 h, with a yellow precipitate forming. The reaction mixture was cooled to room temperature, diluted with ethanol, Celite® was added and the mixture stirred for 10 min. The mixture was filtered on a small silica gel plug on a frit and washed with ethanol (3-4 times) and with hexane (3-4 times). The filtrate was discarded. The Celite®/silica plug was then washed with dichloromethane to dissolve the product. Half the volume of dichloromethane was removed under reduced pressure and hexane was added to precipitate the product, which was filtered and washed with hexane. The crude product was chromatographed on silica gel with 1/1 (v/v) dichloromethane/hexane and then sublimed to yield 1.0 g (32%) of product as a yellow solid. The product, Compound C, was confirmed by HPLC (99.6% pure) and LC/MS.

Example 19

Synthesis of Compound D

[0168]



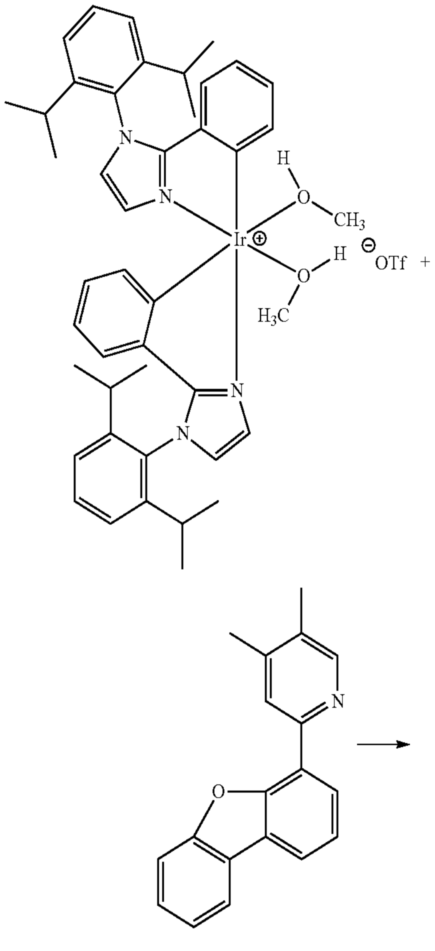
[0169] To a flask was added the iridium triflate complex obtained as in Example 15 (1.8 g, 2.0 mmol) and 1-(2,6-diisopropylcyclohexa-2,4-dien-1-yl)-2-phenyl-1H-benzo[d]imidazole (1.8 g, 5.05 mmol), 25 mL EtOH and 25 mL MeOH. The reaction mixture was refluxed for 20 h, with a yellow precipitate forming. The reaction mixture was cooled to room temperature, diluted with ethanol, Celite® was added and the mixture stirred for 10 min. The mixture was filtered on a small silica gel plug on a frit and washed with ethanol (3-4 times) and with hexane (3-4 times). The filtrate was discarded. The Celite®/silica plug was then washed with dichloromethane to dissolve the product. Half the volume of dichloromethane was removed under reduced pressure and isopropanol was added to precipitate the product, which was filtered and washed with methanol and hexane. The crude product was chromatographed on silica gel with 1/1 (v/v) dichloromethane/hexane to yield 1.4 g of product as fac- and mer-isomers. The isomeric mixture was photoisomerized with 365 nm light in a Rayonet for 10 days to yield only the fac-isomer. This isomer was once again chromatographed on silica gel with 1/1 (v/v) dichloromethane/hexane and then sublimed to yield 0.6 g (30%) of product as a yellow solid. The product, Compound D, was confirmed by HPLC (99.2% pure) and LC/MS.

Synthesis of Compound 2

Example 20

Synthesis of Compound 2

[0170]



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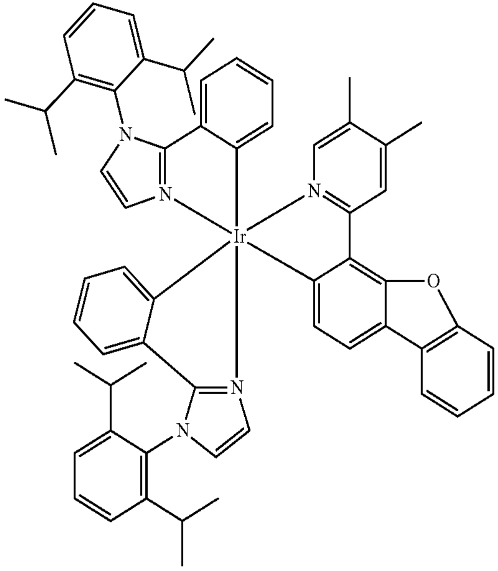


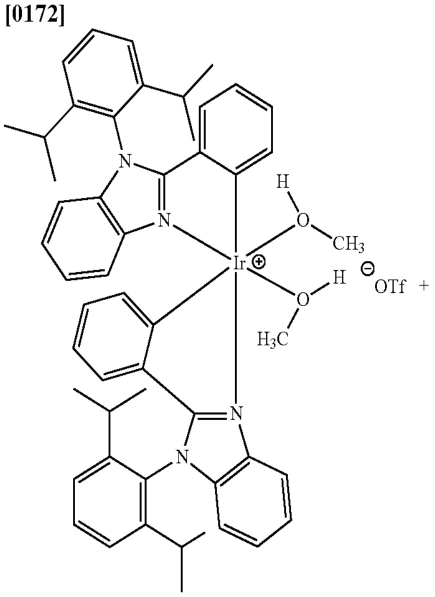
[0171] To a flask was added the iridium triflate complex obtained as in Example 12 (3.0 g, 3.0 mmol) and 2-(dibenzo[b,d]furan-4-yl)-4,5-dimethylpyridine (2.8 g, 10.4 mmol), 25 mL EtOH and 25 mL MeOH. The reaction mixture was refluxed for 36 h, with a yellow precipitate forming. The reaction mixture was cooled to room temperature, diluted with ethanol, celite was added and the mixture stirred for 10 min. The mixture was filtered on a small silica gel plug on a frit and washed with ethanol (3-4 times) and with hexane (3-4 times). The filtrate was discarded. The Celite®/silica plug was then washed with dichloromethane to dissolve the product. Half the volume of dichloromethane was removed under reduced pressure and hexane was added to precipitate the product, which was filtered and washed with hexane. The crude product was chromatographed on silica gel with 2/3 (v/v) dichloromethane/hexane and then sublimed to yield 0.55 g (17%) of product as a yellow solid. The product, Compound 2, was confirmed by HPLC (99.7% pure) and LC/MS.

Synthesis of Compound 81 and Compound 82

Example 21

Synthesis of Compound 81

[0172]



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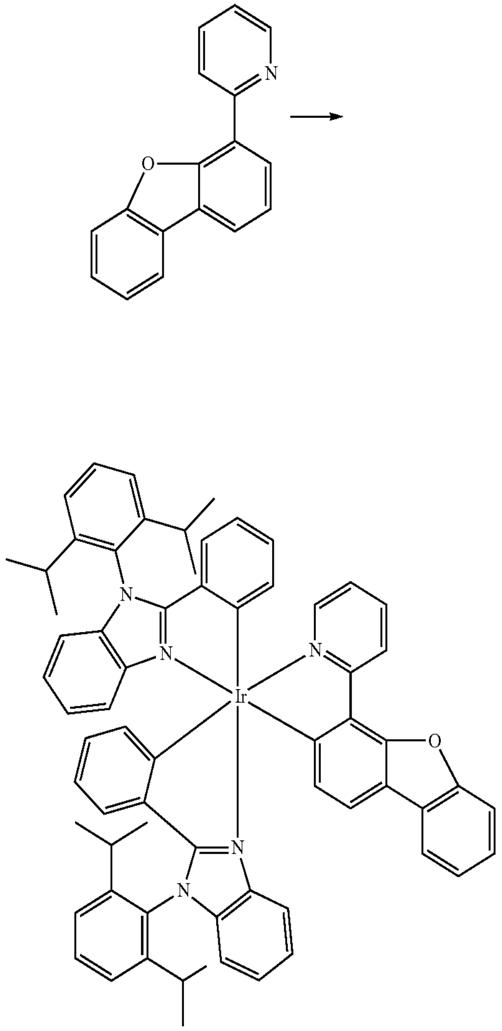
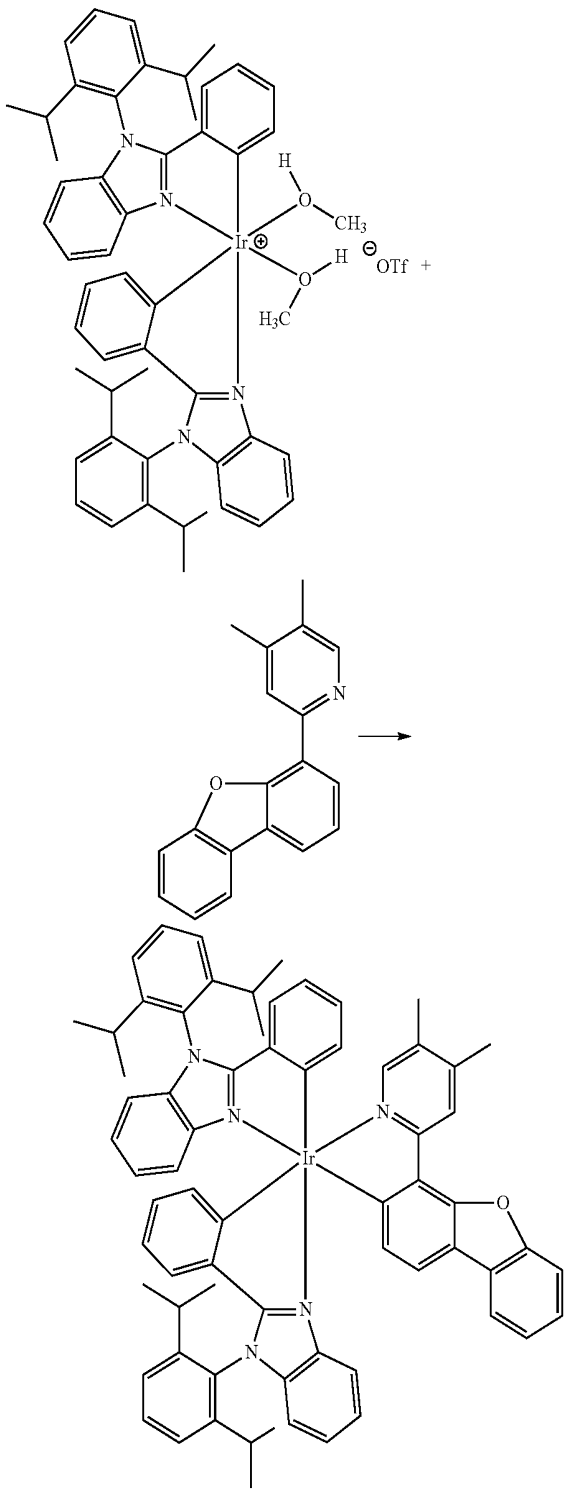


[0173] To a flask was added the iridium triflate complex obtained as in Example 13 (2.5 g, 2.2 mmol) and 2-(dibenzo[b,d]furan-4-yl)pyridine (2.5 g, 10.2 mmol), 25 mL EtOH and 25 mL MeOH. The reaction mixture was refluxed for 20 h, with a yellow precipitate forming. The reaction mixture was cooled to room temperature, diluted with ethanol, Celite® was added and the mixture stirred for 10 min. The mixture was filtered on a small silica gel plug on a frit and washed with ethanol (3-4 times) and with hexane (3-4 times). The filtrate was discarded. The Celite®/silica plug was then washed with dichloromethane to dissolve the product. Half the volume of dichloromethane was removed under reduced pressure and isopropanol was added to precipitate the product, which was filtered and washed with methanol and hexane. The crude product was chromatographed on silica gel with 7/3 (v/v) dichloromethane/hexane and then sublimed to yield 1.1 g (43%) of product as a yellow solid. The product, Compound 81, was confirmed by HPLC (99.1% pure) and LC/MS.

Example 22

Synthesis of Compound 82

[0174]

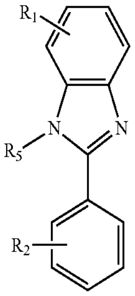


[0175] To a flask was added the iridium triflate complex obtained as in Example 13 (2.5 g, 2.2 mmol) and 2-(dibenzo[b,d]furan-4-yl)-4,5-dimethylpyridine (1.6 g, 5.8 mmol), 25 mL EtOH and 25 mL MeOH. The reaction mixture was refluxed for 36 h, with a yellow precipitate forming. The reaction mixture was cooled to room temperature, diluted with ethanol, Celite® was added and the mixture stirred for 10 min. The mixture was filtered on a small silica gel plug on a frit and washed with ethanol (3-4 times) and with hexane (3-4 times). The filtrate was discarded. The Celite®/silica plug was then washed with dichloromethane to dissolve the product. Half the volume of dichloromethane was removed under reduced pressure and hexane was added to precipitate the product, which was filtered and washed with hexane. The crude product was chromatographed on silica gel with 7/3 (v/v) dichloromethane/hexane and then sublimed to yield 0.9 g (34%) of product as a yellow solid. The product, Compound 82, was confirmed by HPLC (99.6% pure) and LC/MS.

[0176] It is understood that the various embodiments described herein are by way of example only, and are not intended to limit the scope of the invention. For example, many of the materials and structures described herein may be substituted with other materials and structures without deviating from the spirit of the invention. The present invention as claimed may therefore include variations from the particular examples and preferred embodiments described herein, as will be apparent to one of skill in the art. It is understood that various theories as to why the invention works are not intended to be limiting.

1. A method of making a compound of formula:

Formula III



comprising reacting the condensation product of an aryl 1,2-diamine and an aryl aldehyde with manganese dioxide in a solvent;

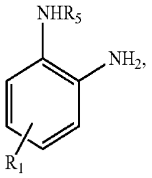
wherein R_1, R_2 and R_5 may represent mono-, di-, tri- or tetra-substitution;

wherein R_1, R_2 and R_5 are each independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof; and

wherein R_1, R_2 and R_5 are optionally fused and may be further substituted.

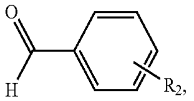
2. The method of claim **1**, wherein the condensation product comprises reacting an aryl 1,2-diamine of formula:

Formula IV



with an aryl aldehyde of formula:

Formula V



in the presence of phase transfer catalyst and solvent.

3. The method of claim **2**, wherein the phase transfer catalyst comprises 1-hexadecylpyridinium bromide.

4. The method of claim **1**, wherein R_5 is aryl or substituted aryl.

5. The method of claim **1**, wherein R_5 is a 2,6-disubstituted aryl.

6. The method of claim **1**, wherein R_5 is alkyl.

* * * * *

专利名称(译)	制备有机电致发光材料的方法		
公开(公告)号	US20140303370A1	公开(公告)日	2014-10-09
申请号	US14/310606	申请日	2014-06-20
[标]申请(专利权)人(译)	环球展览公司		
申请(专利权)人(译)	通用显示器公司		
当前申请(专利权)人(译)	通用显示器公司		
[标]发明人	KOTTAS GREGG XIA CHUANJUN ELSHENAWY ZEINAB ANSARI NASRIN		
发明人	KOTTAS, GREGG XIA, CHUANJUN ELSHENAWY, ZEINAB ANSARI, NASRIN		
IPC分类号	H01L51/00		
CPC分类号	H01L51/0085 H01L51/5016 C09K11/06 H05B33/14 C09K2211/1007 C07F15/0033 C09K2211/1044 C09K2211/1088 C09K2211/1092 C09K2211/185 C09K2211/1029 C07D235/18		
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摘要(译)

提供了制备用于制备新型杂配铱络合物的配体的方法。该方法包括使芳基1,2-二胺和芳基醛的缩合产物与二氧化锰在溶剂中反应。使用配体产生的新型铱络合物是OLED器件中的有用化合物。