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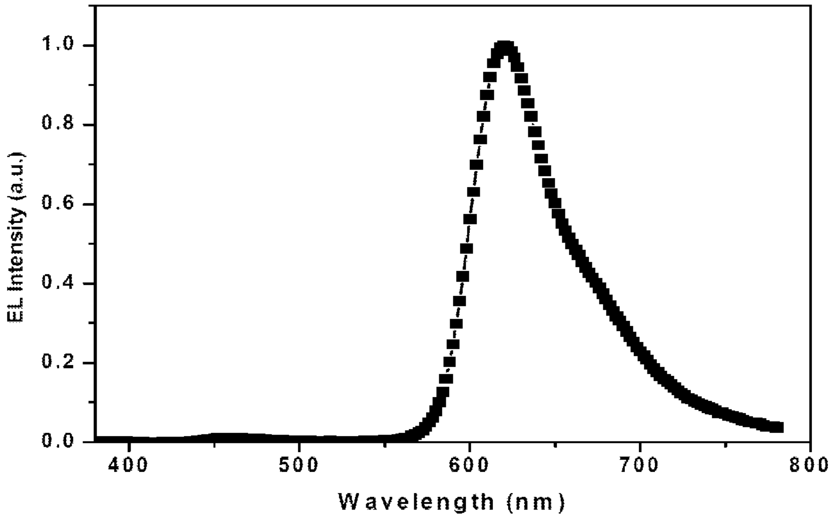
(54) **Title**: INORGANIC HOSTS IN OLEDS

FIGURE 3



(57) **Abstract**: A novel electronic device is reported containing a host comprising an inorganic material with a band gap of less than 4 eV. The use of an inorganic material is advantageous due to its desirable physical properties, including increased stability and charge mobility

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INORGANIC HOSTS IN OLEDS

[0001] This applications claims priority to U.S. Patent Application Serial No. 61/507,657, filed July 14, 2011, which is herein incorporated by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present invention relates to inorganic materials that can be used as hosts in organic electronic devices.

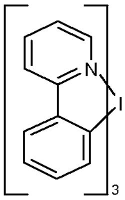
BACKGROUND

[0003] 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.

[0004] 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.

[0005] 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.

[0006] One example of a green emissive molecule is tris(2-phenylpyridine) iridium, denoted $Ir(ppy)_3$, which has the following structure:



[0007] In this, and later figures herein, we depict the dative bond from nitrogen to metal (here, Ir) as a straight line.

[0008] 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.

[0009] 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.

[0010] 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.

[0011] 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.

[0012] 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.

[0013] 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.

[0014] More details on OLEDs, and the definitions described above, can be found in US Pat. No. 7,279,704, which is incorporated herein by reference in its entirety.

SUMMARY OF THE INVENTION

[0015] A first device is provided. The first device comprises a first organic light emitting device, further comprising: an anode; a cathode; and an emissive layer, disposed between the anode and the cathode. In one aspect, the emissive layer comprises a first host comprising a substance containing at least 70 wt % inorganic material, and a first phosphorescent emissive dopant; wherein the energy band gap of the first host is less than 4 eV.

[0016] In one aspect, the substance comprises the inorganic material capped with capping groups.

[0017] In one aspect, the capping groups comprise carboxylate, amine, thiols, tetrafluoroborate, sulfide, thiocyanate, or metal chacogenide complxes.

[0018] In one aspect, the first host comprises particles of the substance having a size ranging from 1 to 20 nm.

[0019] In one aspect, the first device further comprises a plurality of organic layers that are optionally disposed between the emissive layer and the cathode, wherein the organic layers do not contain the first host.

[0020] In one aspect, the inorganic material comprises one or more of the following: a sulfide, a nitride, a carbide, or an oxide.

[0021] In one aspect, the inorganic material comprises an oxide.

[0022] In one aspect, the inorganic material comprises a sulfide.

[0023] In one aspect, the inorganic material comprises a carbide.

[0024] In one aspect, the inorganic material comprises a nitride.

[0025] In one aspect, the oxide comprises a metal oxide.

[0026] In one aspect, the metal oxide comprises a transition metal oxide.

[0027] In one aspect, the sulfide comprises a metal sulfide.

[0028] In one aspect, the carbide comprises a metal carbide.

[0029] In one aspect, the ntiride comprises a metal nitride.

[0030] In one aspect, the inorganic material comprises a binary compound.

[0031] In one aspect, the inorganic material comprises a ternary compound.

[0032] In one aspect, the first host comprises a non-emitting inorganic nanocrystal.

[0033] In one aspect, the first host has energy band gap value between 1 to 4 eV.

[0034] In one aspect, the first host has an energy band gap value between 2 to 3 eV.

[0035] In one aspect, the first host has an energy band gap value larger than the triplet energy of the first phosphorescent emissive dopant.

[0036] In one aspect, the concentration of the first host in the emissive layer is at least 50 wt%.

[0037] In one aspect, the concentration of the first host in the emissive layer is at least 70 wt%.

[0038] In one aspect, the concentration of the first host in the emissive layer is at least 80 wt%.

[0039] In one aspect, the first host consists essentially of a substance containing at least 70 wt % inorganic material.

[0040] In one aspect, the first host consists essentially of a substance containing at least 80 wt % inorganic material.

[0041] In one aspect, the first host consists essentially of a substance containing at least 90 wt % inorganic material.

[0042] In one aspect, the first host consists essentially of a substance containing at least 95 wt % inorganic material.

[0043] In one aspect, the first device is a consumer product.

[0044] In one aspect, the first device an organic light-emitting device.

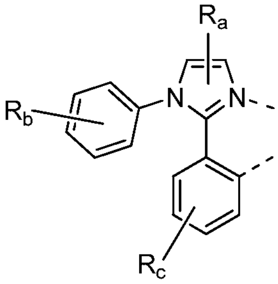
[0045] In one aspect, the first device comprises a lighting panel.

[0046] In one aspect, the first phosphorescent emissive dopant is a metal complex with metal having an atomic number greater than 40.

[0047] In one aspect, the first phosphorescent emissive dopant is an iridium complex.

[0048] In one aspect, the first phosphorescent emissive dopant is a platinum complex.

[0049] In one aspect, the first phosphorescent emissive dopant comprises a transition metal complex having at least one ligand or part of the ligand if the ligand is more than bidentate selected from the group consisting of: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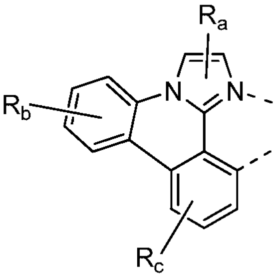
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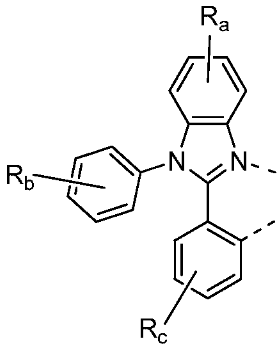
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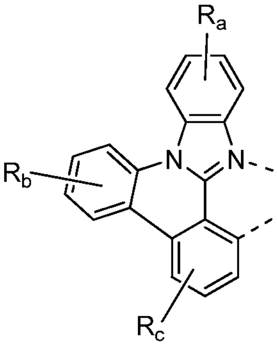
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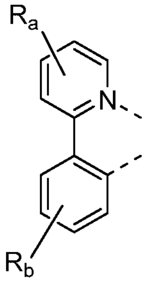
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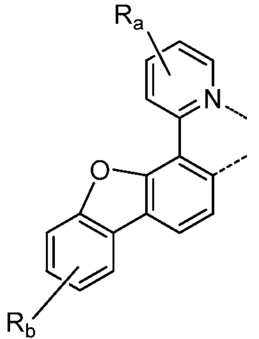
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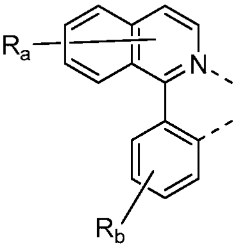
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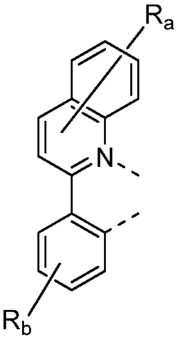
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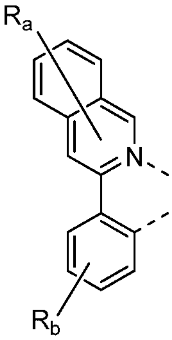
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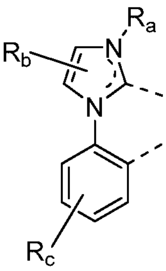
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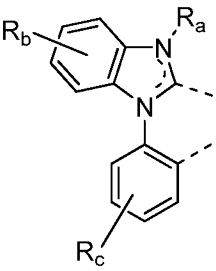
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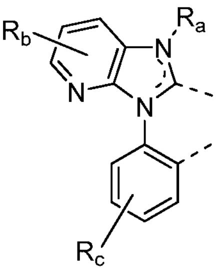
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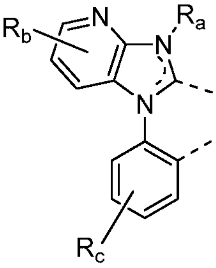
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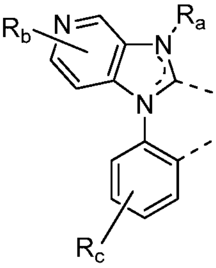
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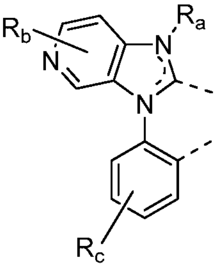
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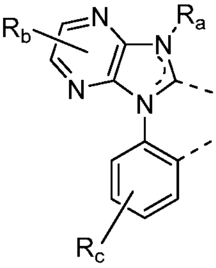
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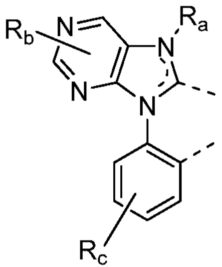

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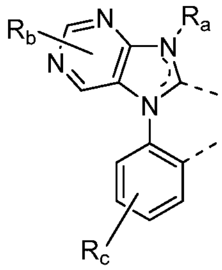

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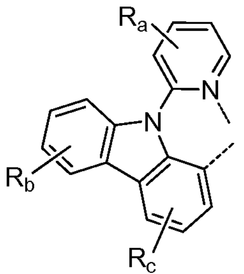

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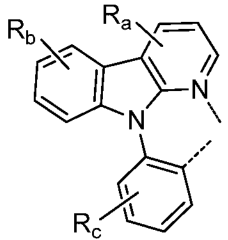

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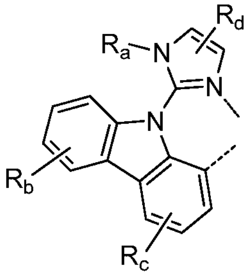

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wherein R_a, R_b, R_c, and R_d may represent mono, di, tri, or tetra substitution, or no substitution. R_a, R_b, R_c, and R_d are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, 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 two adjacent substituents of R_a, R_b, R_c, and R_d are optionally joined to form a fused ring or form a multidentate ligand.

[0050] In one aspect, the emissive layer is deposited using a solution process.

[0051] In one aspect, the first host reacts with the first phosphorescent emissive dopant to form a covalent bond.

[0052] In one aspect, the emissive layer further comprises a second host.

[0053] In one aspect, the second host is an organic compound.

[0054] In one aspect, the organic compound contains at least one of the groups selected from the group consisting of triphenylene, dibenzothiophene, aza-dibenzothiophene, dibenzofuran, aza-dibenzofuran, carbazole, and aza-carbazole.

[0055] In one aspect, the second host is an inorganic material.

[0056] In one aspect, the emissive layer further comprises a second emissive dopant.

[0057] In one aspect, a method of making a first device comprising: depositing an anode layer on a substrate, depositing at least one emissive layer after the anode layer, and depositing a cathode layer after the at least one emissive layer; wherein the at least one emissive layer contains a first host comprising a substance containing at least 70 wt % inorganic material and a first phosphorescent emissive dopant, the energy band gap of the first host compound is less than 4 eV.

[0058] In one aspect, the first host reacts with the first phosphorescent emissive dopant to form a covalent bond.

BRIEF DESCRIPTION OF THE DRAWINGS

[0059] FIG. 1 shows an organic light emitting device.

[0060] FIG. 2 shows an inverted organic light emitting device that does not have a separate electron transport layer.

[0061] FIG. 3 shows an emission spectrum for an exemplary device using inorganic material as a host.

DETAILED DESCRIPTION

[0062] 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.

[0063] 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.

[0064] 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 US Pat. No. 7,279,704 at cols. 5-6, which are incorporated by reference.

[0065] 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, a cathode 160, and a barrier layer 170. 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 US 7,279,704 at cols. 6-10, which are incorporated by reference.

[0066] 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.

[0067] 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.

[0068] 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.

[0069] 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 out-coupling, 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.

[0070] 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.

[0071] Devices fabricated in accordance with embodiments of the present invention may further optionally comprise a barrier layer. One purpose of the barrier layer is to protect the electrodes and organic layers from damaging exposure to harmful species in the environment including moisture, vapor and/or gases, etc. The barrier layer may be deposited over, under or next to a substrate, an electrode, or over any other parts of a device including an edge. The barrier layer may comprise a single layer, or multiple layers. The barrier layer may be formed by various known chemical vapor deposition techniques and may include compositions having a single phase as well as compositions having multiple phases. Any suitable material or combination of materials may be used for the barrier layer. The barrier layer may incorporate an inorganic or an organic compound or both. The preferred barrier layer comprises a mixture of a polymeric material and a non-polymeric material as described in U.S. Pat. No. 7,968,146, PCT Pat. Application Nos. PCT/US2007/023098 and PCT/US2009/042829, which are herein incorporated by reference in their entireties. To be considered a “mixture”, the aforesaid polymeric and non-polymeric materials comprising the barrier layer should be deposited under the same reaction conditions and/or at the same time. The weight ratio of polymeric to non-polymeric material may be in the range of 95:5 to 5:95. The polymeric material and the non-polymeric material may be created from the same precursor material. In one example, the mixture of a polymeric material and a non-polymeric material consists essentially of polymeric silicon and inorganic silicon.

[0072] 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, medical 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.).

[0073] 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.

[0074] 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 US 7,279,704 at cols. 31-32, which are incorporated herein by reference.

[0075] A first device is provided. The first device comprises a first organic light emitting device, further comprising: an anode, a cathode, and an emissive layer, disposed between the anode and the cathode. In one embodiment, the emissive layer comprises a first host comprising a substance containing at least 70 wt % inorganic material, and a first phosphorescent emissive dopant; wherein the energy band gap of the first host is less than 4 eV.

[0076] The term "inorganic material," as used herein refers to those conventional inorganic compounds. Inorganic material can be different kinds of metals such as main group metal, transition metal, lanthanoid, or alloys. Inorganic material can contain groups 13 to 17 elements, such as oxides, sulfides, carbides; the most common ones are binary or ternary compounds; those with more than three elements can also be used; they can have metal elements, such as metal oxides, metal sulfides, metal carbides; or they don't have metal elements, such as silicon carbides, silicon oxides. Many of these inorganic material, such as binary compounds: ZnO, In_2O_3, Ni_2O, MnO, MoS_2, TiO_2, CdS, CdSe, GaAs, InP, ZnSe, ZnTe, GeS_2, InAs, CdTe, ZnS; and ternary compounds: $CdSe_xS_{1-x}$, $ZnSe_xTe_{1-x}$, $Al_xZn_{1-x}O$, $Sn_xIn_{1-x}O_3$, AlGaAs, $CuInS_2$, $CuInSe_2$, $NaYF_4$, $BaTiO_3$; can exist as a form of inorganic nanocrystals.

[0077] Inorganic nanocrystals can consist of 1-20 nm diameter inorganic material particles capped with capping groups. Capping group can be a layer of organic or inorganic ligands, these surface-passivating ligands are used to stabilize the nanocrystals in solvents and in the matrix. These nanocrystal structures can show quantum confinement effects that can be harnessed in creating complex heterostructures with electronic and optical properties that are tunable with the size and type of the nanocrystals. The inorganic nanocrystal can have a CdSe core and a ZnS shell. Inorganic material as used herein does not encompass metal coordination complex, such as metal actylacetonate.

[0078] The typical host materials used in phosphorescent emissive layer in modern OLEDs are either pure organic compounds or metal coordination compounds. In some cases, an organic host is doped with inert inorganic compounds. These inert compounds have energy band gaps larger than 4 eV. In some fluorescent devices, others have doped each layer (e.g. HTL, EML, and ETL) with an inorganic compound at the same time. Inorganic compounds have also been used as a hole or electron acceptors and doped in injecting layers or their interfaces. The present invention uses inorganic compounds as a host component in the emissive layer for a phosphorescent device. Compared to organic or metal coordination compounds, inorganic compounds can have higher chemical stability, higher triplet energy, better physical properties, such as transparency, low toxicity, high charge mobilities and inexpensiveness, and enable construction of devices having low operating voltages. Inorganic compounds intended for use as major host component should generally be semiconductors, i.e., the energy band gap value (W. H. Strehlow, E. L. Cook, J. Phys. Chem. Ref. Data, Vol 2, No. 1, 1973, pp163-199.) is less than 4 eV.

[0079] In one embodiment, the substance comprises the inorganic material capped with capping groups. These capping groups interact with the surface atoms of a nanocrystal surface atoms, stabilizing the nanocrystals in polar and nonpolar solvents without aggregation or precipitation for the subsequent solution processing.

[0080] In one embodiment, the capping groups comprise carboxylate, amine, thiols, tetrafluoroborate, sulfide, thiocyanate, or metal chacogenide complxes.

[0081] In one embodiment, the first host comprises particles of the substance having a size ranging from 1 to 20 nm.

[0082] In one embodiment, the first device further comprises a plurality of organic layers that are optionally disposed between the emissive layer and the cathode, wherein the organic layers do not contain the first host.

[0083] In one embodiment, the inorganic material comprises one or more of the following: a sulfide, a nitride, a carbide, or an oxide.

[0084] In one embodiment, the inorganic material comprises an oxide.

[0085] In one embodiment, the inorganic material comprises a sulfide.

[0086] In one embodiment, the inorganic material comprises a carbide.

[0087] In one embodiment, the inorganic material comprises a nitride.

[0088] In one embodiment, the oxide comprises a metal oxide.

[0089] In one embodiment, the metal oxide comprises a transition metal oxide.

[0090] In one embodiment, the sulfide comprises a metal sulfide.

[0091] In one embodiment, the carbide comprises a metal carbide.

[0092] In one embodiment, the ntiride comprises a metal nitride.

[0093] In one embodiment, the inorganic material comprises a binary compound.

[0094] In one embodiment, the inorganic material comprises a ternary compound.

[0095] In one embodiment, the first host comprises a non-emitting inorganic nanocrystal.

[0096] In one embodiment, the first host has energy band gap value between 1 to 4 eV.

[0097] In one embodiment, the first host has an energy band gap value between 2 to 3 eV.

[0098] In one embodiment, the first host has an energy band gap value larger than the triplet energy of the first phosphorescent emissive dopant.

[0099] In one embodiment, the concentration of the first host in the emissive layer is at least 50 wt%.

[0100] In one embodiment, the concentration of the first host in the emissive layer is at least 70 wt%.

[0101] In one embodiment, the concentration of the first host in the emissive layer is at least 80 wt%.

[0102] In one embodiment, the first host consists essentially of a substance containing at least 70 wt % inorganic material.

[0103] In one embodiment, the first host consists essentially of a substance containing at least 80 wt % inorganic material.

[0104] In one embodiment, the first host consists essentially of a substance containing at least 90 wt % inorganic material.

[0105] In one embodiment, the first host consists essentially of a substance containing at least 95 wt % inorganic material.

[0106] In one embodiment, the first device is a consumer product.

[0107] In one embodiment, the first device an organic light-emitting device.

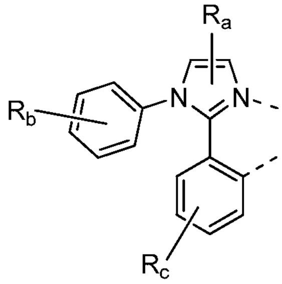
[0108] In one embodiment, the first device comprises a lighting panel.

[0109] In one embodiment, the first phosphorescent emissive dopant is a metal complex with metal having an atomic number greater than 40.

[0110] In one embodiment, the first phosphorescent emissive dopant is an iridium complex.

[0111] In one embodiment, the first phosphorescent emissive dopant is a platinum complex.

[0112] In one embodiment, the first phosphorescent emissive dopant comprises a transition metal complex having at least one ligand or part of the ligand if the ligand is more than bidentate selected from the group consisting of: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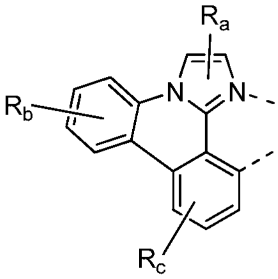
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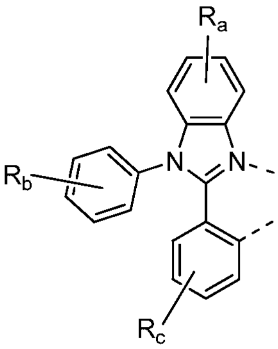
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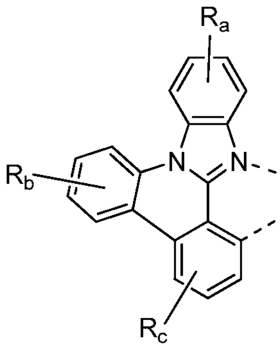
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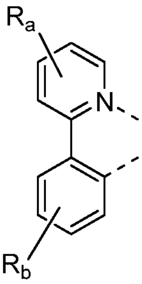
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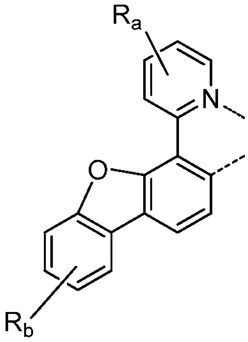
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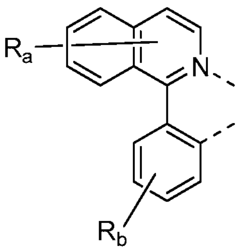
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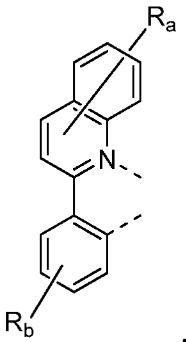
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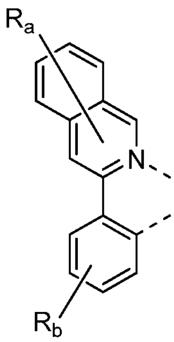
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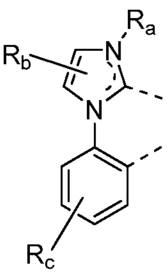
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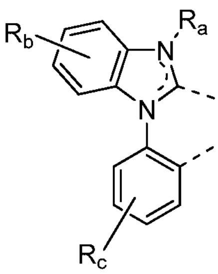
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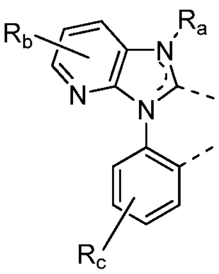
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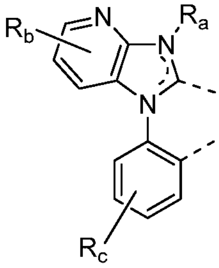
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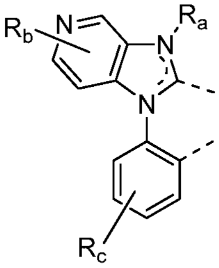
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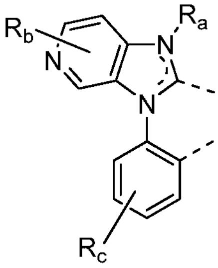
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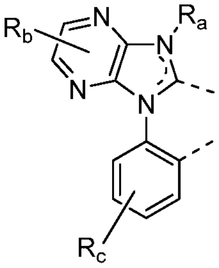
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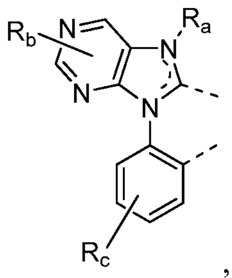

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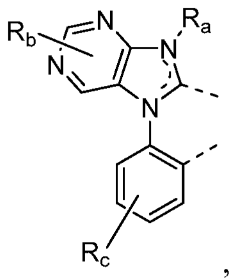

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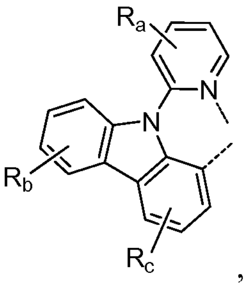

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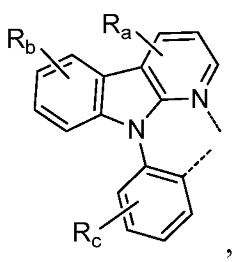

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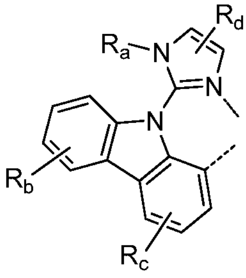

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wherein R_a, R_b, R_c, and R_d may represent mono, di, tri, or tetra substitution, or no substitution. R_a, R_b, R_c, and R_d are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, 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 two adjacent substituents of R_a, R_b, R_c, and R_d are optionally joined to form a fused ring or form a multidentate ligand.

[0113] In one embodiment, the emissive layer is deposited using a solution process.

[0114] In one embodiment, the first host reacts with the first phosphorescent emissive dopant to form a covalent bond.

[0115] In one embodiment, the emissive layer further comprises a second host.

[0116] In one embodiment, the second host is an organic compound.

[0117] In one embodiment, the organic compound contains at least one of the groups selected from the group consisting of triphenylene, dibenzothiophene, aza-dibenzothiophene, dibenzofuran, aza-dibenzofuran, carbazole, and aza-carbazole.

[0118] In one embodiment, the second host is an inorganic material.

[0119] In one embodiment, the emissive layer further comprises a second emissive dopant.

[0120] In one embodiment, a method of making a first device comprising: depositing an anode layer on a substrate, depositing at least one emissive layer after the anode layer, and depositing a cathode layer after the at least one emissive layer; wherein the at least one emissive layer contains a first host comprising a substance containing at least 70 wt % inorganic material and a first phosphorescent emissive dopant, the energy band gap of the first host compound is less than 4 eV.

[0121] In one embodiment, the first host reacts with the first phosphorescent emissive dopant to form a covalent bond.

[0122] Specific representative embodiments of the invention will now be described, including how such embodiments may be made. It is understood that the specific methods, materials, conditions, process parameters, apparatus and the like do not necessarily limit the scope of the invention.

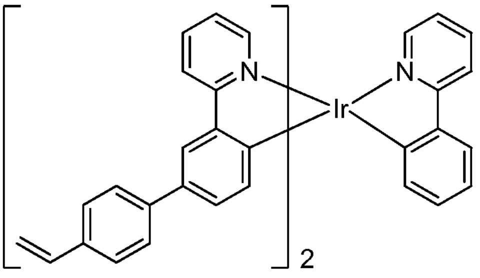
[0123] An exemplary organic light-emitting device was fabricated using spin-coating and vacuum thermal evaporation of the compounds shown below. The device was fabricated on a glass substrate precoated with indium tin oxide (ITO) as the anode. The cathode was a layer of LiF followed by a layer of aluminum. The device was encapsulated with a glass lid sealed with an epoxy resin under nitrogen (<1 ppm H_2O and O_2) immediately after fabrication, and a moisture getter is incorporated inside the package.

[0124] In one embodiment of the first device, the hole injecting material HIL-1 along with Conducting dopant-1 were dissolved in cyclohexanone solvent. The amount of Conducting dopant-1 in the solution was 10 wt% relative to HIL-1. The total combined concentration of HIL-1 and Conducting dopant-1 was 0.5 wt% in cyclohexanone. To form the hole injection layer (HIL), the solution was spin-coated at 4000 rpm for 60 seconds onto the patterned indium tin oxide (ITO) electrode. The resulting film was baked for 30 minutes at 250° C, which rendered the film insoluble. On top of the HIL, a hole transporting layer (HTL) and then an emissive layer (EML) were also formed by spin-coating.

[0125] The HTL was made by spin-coating a 0.5 wt% solution of the hole transporting material of the mixture of HTL-1 and HTL-2 in toluene at 4000 rpm for 60 seconds. The amount of HTL-2 was 30 wt% relative to HTL-1, or 70:30 ratio of HTL-1:HTL-2.The HTL film was baked at 210° C for 30 minutes. After baking, the HTL became an insoluble film.

[0126] The EML was formed using a toluene solution containing Host-1 and RD-1 at a doping concentration of 0.75 wt%. Host-1 was oleic-acid-capped $CdSe_xS_{1-x}/ZnS$ core/shell nanocrystals (4-5 nm in diameter with the band gap of 2.76 eV) dispersed in toluene (25 mg/mL) (purchased from Cytodiagnostics) and used without any further treatment. The solution was spin-coated on top of the insoluble HTL at 1000 rpm for 60 seconds, and then baked at 85° C for 60 minutes to remove solvent residues. A 15 nm of hole blocking layer containing HB-1, a 40 nm of electron transport layer containing LG201 (purchased from LG Chemical Corp.), an electron injection layer containing LiF, and an aluminum electrode (cathode) were sequentially vacuum deposited in a conventional fashion.

[0127] The structures of the materials used for making the devices are as follows:



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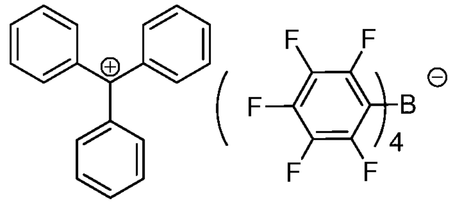
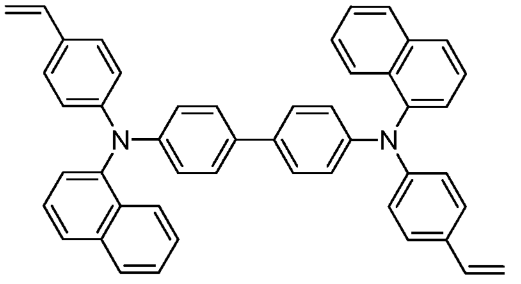
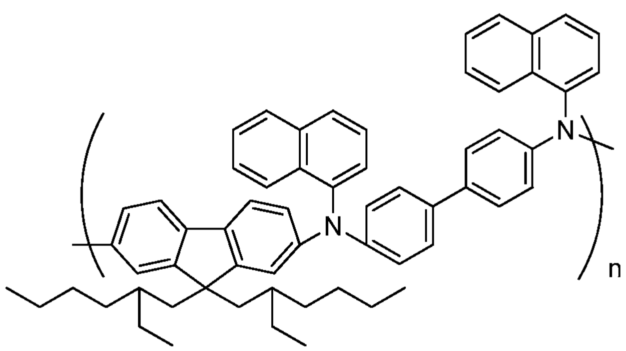


Conducting Dopant-1 ,



HTL-1 ,



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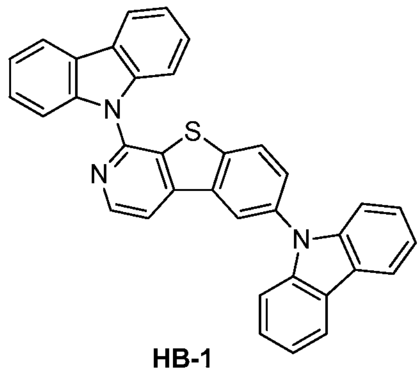
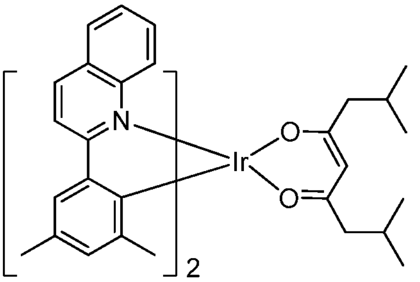


HB-1,



RD-1

[0128] The performance of the device was tested by operation under a constant DC current. Fig. 3 shows a plot of normalized emission spectrum for the device. It can be seen that the device is able to give pure emission from RD-1 at 620 nm with 1931 CIE coordinate of (0.656, 0.330). Under a driving voltage of 17.5 V, the device achieved a current density of 10 mA/cm^2 and a current efficiency of 1.74 cd/A. Nanocrystal materials have been thought to have low conductivity and thus not suitable for use as a host material in an OLED device. Surprisingly, it has been discovered that careful selection of nanocrystal materials, can render them useful as hosts in phosphorescent OLED devices.

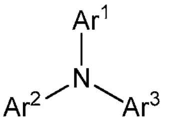
COMBINATION WITH OTHER MATERIALS

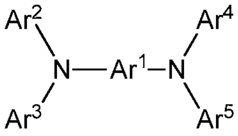
[0129] The materials described herein as useful for a particular layer in an organic light emitting device may be used in combination with a wide variety of other materials present in the device. For example, emissive dopants disclosed herein may be used in conjunction with a wide variety of hosts, transport 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.

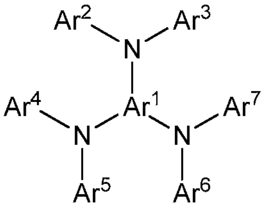
HIL/HTL:

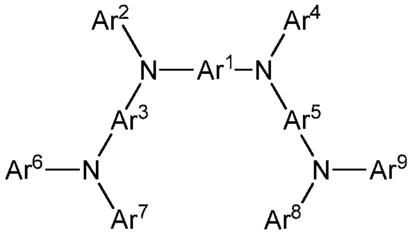
[0130] A hole injecting/transporting material to be used in the present invention is not particularly limited, and any compound may be used as long as the compound is typically used as a hole injecting/transporting material. Examples of the material include, but not limit to: a phthalocyanine or porphryin 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.

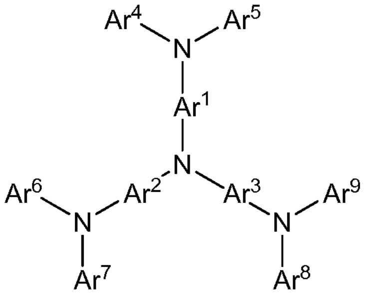
[0131] Examples of aromatic amine derivatives used in HIL or HTL include, but not limit to the following general structures:





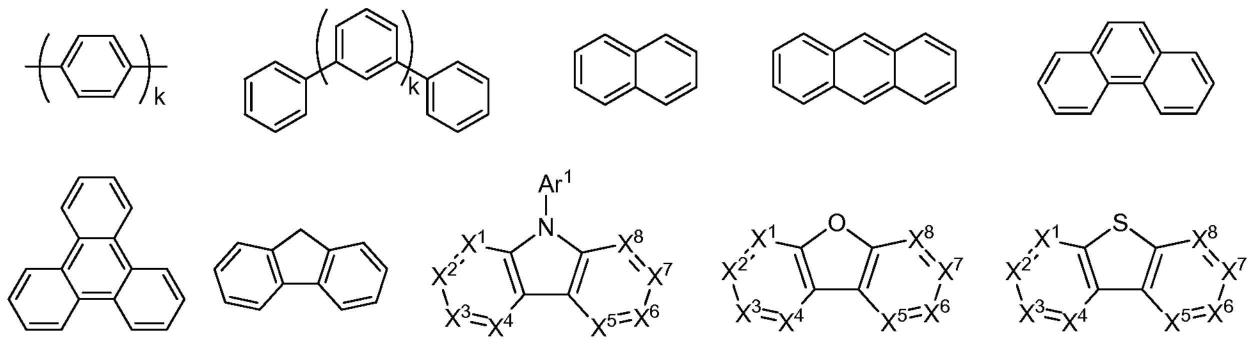






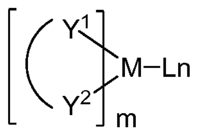
[0132] Each of Ar^1 to Ar^9 is selected from the group consisting aromatic hydrocarbon cyclic compounds such as benzene, biphenyl, triphenyl, triphenylene, naphthalene, anthracene, phenalene, phenanthrene, fluorene, pyrene, chrysene, perylene, azulene; group consisting aromatic heterocyclic compounds 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.

[0133] In one aspect, Ar^1 to Ar^9 is independently selected from the group consisting of:



[0134] 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.

[0135] Examples of metal complexes used in HIL or HTL include, but not limit to the following general formula:



[0136] M is a metal, having an atomic weight greater than 40; $(Y^1\text{-}Y^2)$ 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.

[0137] In one aspect, $(Y^1\text{-}Y^2)$ is a 2-phenylpyridine derivative.

[0138] In another aspect, $(Y^1\text{-}Y^2)$ is a carbene ligand.

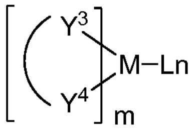
[0139] In another aspect, M is selected from Ir, Pt, Os, and Zn.

[0140] 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:

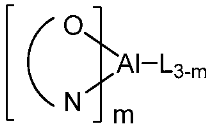
[0141] The light emitting layer of the organic EL device of the present invention preferably contains at least a metal complex as light emitting material, and may contain a host material using the metal complex as a dopant material. Examples of the host material are not particularly limited, and any metal complexes or organic compounds may be used as long as the triplet energy of the host is larger than that of the dopant. While the Table below categorizes host materials as preferred for devices that emit various colors, any host material may be used with any dopant so long as the triplet criteria is satisfied.

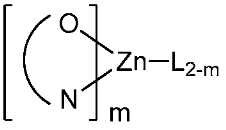
[0142] Examples of metal complexes used as host are preferred to have the following general formula:



[0143] M is a metal; $(Y^3\text{-}Y^4)$ 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.

[0144] In one aspect, the metal complexes are:





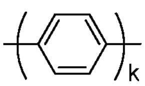
[0145] (O-N) is a bidentate ligand, having metal coordinated to atoms O and N.

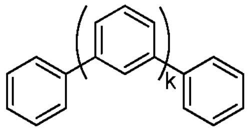
[0146] In another aspect, M is selected from Ir and Pt.

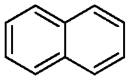
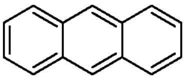
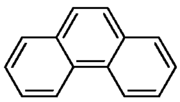
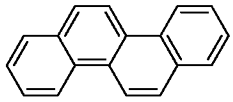
[0147] In a further aspect, (Y^3-Y^4) is a carbene ligand.

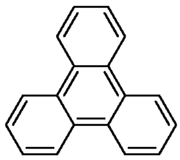
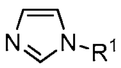
[0148] Examples of organic compounds used as host are selected from the group consisting aromatic hydrocarbon cyclic compounds such as benzene, biphenyl, triphenyl, triphenylene, naphthalene, anthracene, phenalene, phenanthrene, fluorene, pyrene, chrysene, perylene, azulene; group consisting aromatic 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.

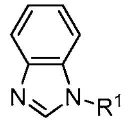
[0149] In one aspect, host compound contains at least one of the following groups in the molecule:

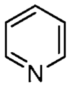


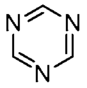


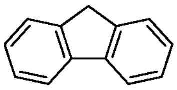
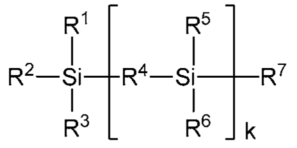





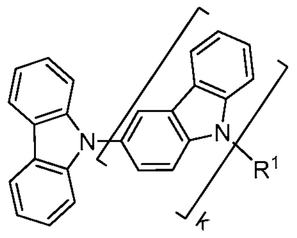



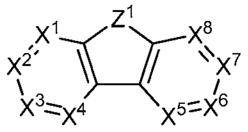


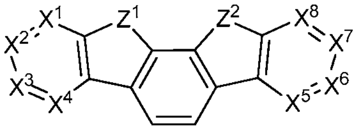


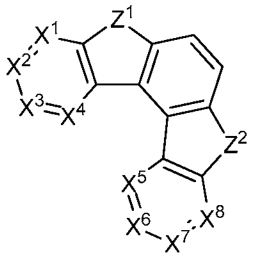


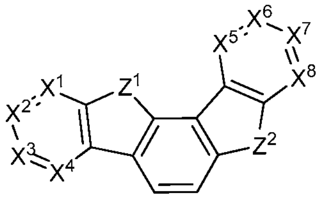



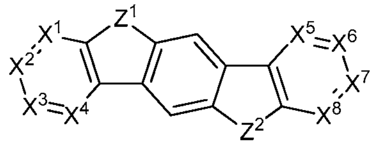


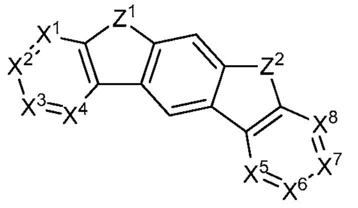












[0150] R^1 to R^7 is independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, when it is aryl or heteroaryl, it has the similar definition as Ar's mentioned above.

[0151] k is an integer from 0 to 20.

[0152] X^1 to X^8 is selected from C (including CH) or N.

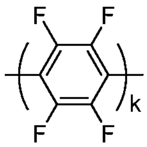
Z^1 and Z^2 is selected from NR^1, O, or S.

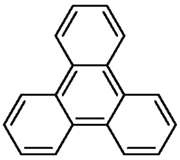
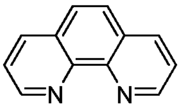
HBL:

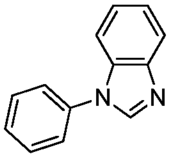
[0153] A hole blocking layer (HBL) may be used to reduce the number of holes and/or excitons that leave the emissive layer. The presence of such a blocking layer in a device may result in substantially higher efficiencies as compared to a similar device lacking a blocking layer. Also, a blocking layer may be used to confine emission to a desired region of an OLED.

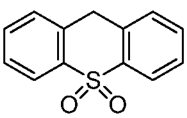
[0154] In one aspect, compound used in HBL contains the same molecule or the same functional groups used as host described above.

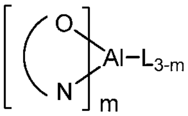
[0155] In another aspect, compound used in HBL contains at least one of the following groups in the molecule:







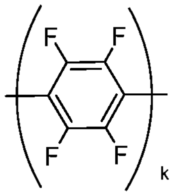


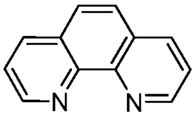
[0156] k is an integer from 0 to 20; L is an ancillary ligand, m is an integer from 1 to 3.

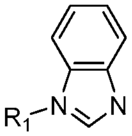
ETL:

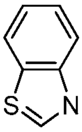
[0157] Electron transport layer (ETL) may include a material capable of transporting electrons. Electron transport layer may be intrinsic (undoped), or doped. Doping may be used to enhance conductivity. Examples of the ETL material are not particularly limited, and any metal complexes or organic compounds may be used as long as they are typically used to transport electrons.

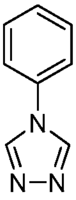
[0158] In one aspect, compound used in ETL contains at least one of the following groups in the molecule:

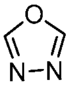


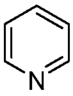


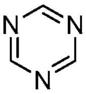


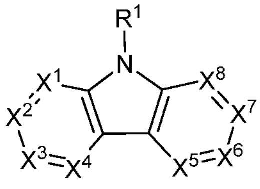


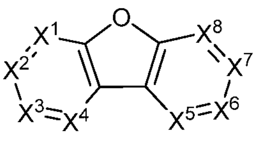


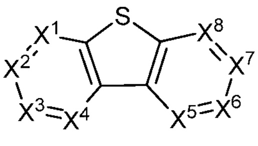


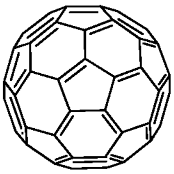
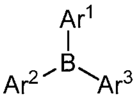










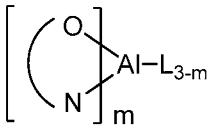
[0159] R^1 is selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, when it is aryl or heteroaryl, it has the similar definition as Ar's mentioned above.

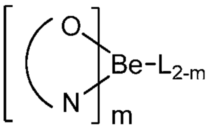
[0160] Ar^1 to Ar^3 has the similar definition as Ar's mentioned above.

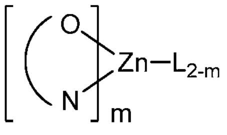
[0161] k is an integer from 0 to 20.

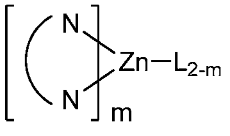
[0162] X^1 to X^8 is selected from C (including CH) or N.

[0163] In another aspect, the metal complexes used in ETL contains, but not limit to the following general formula:







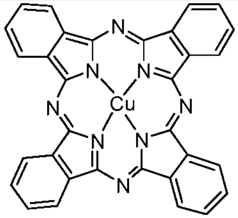
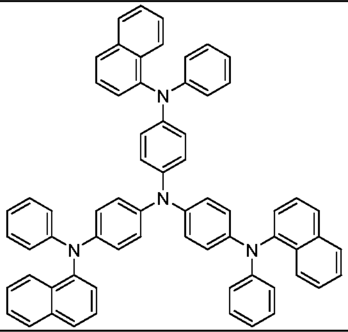
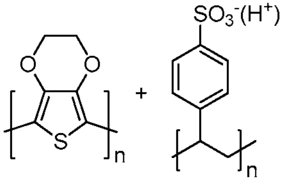
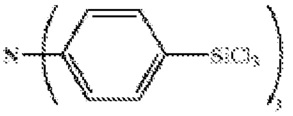
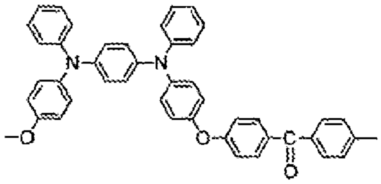


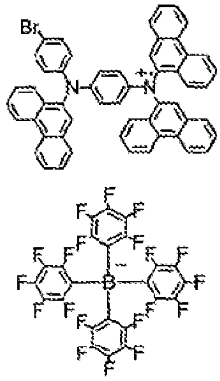
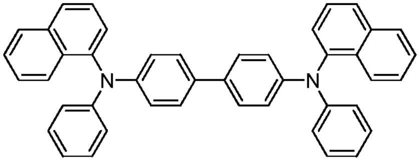
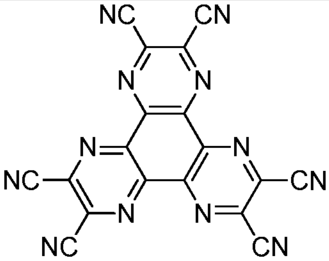
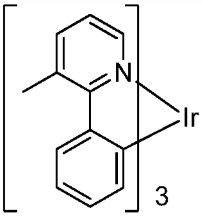
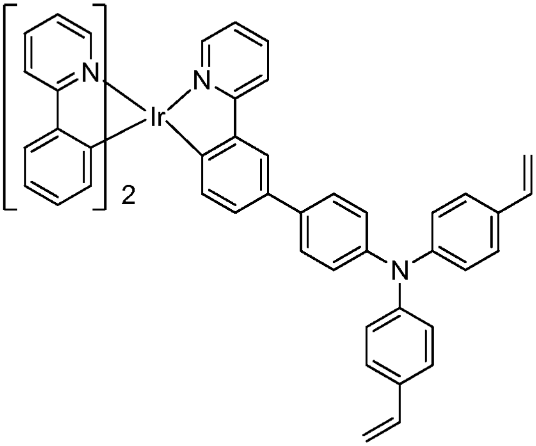
[0164] (O-N) or (N-N) is a bidentate ligand, having metal coordinated to atoms O, N or N, N; L is an ancillary ligand; m is an integer value from 1 to the maximum number of ligands that may be attached to the metal.

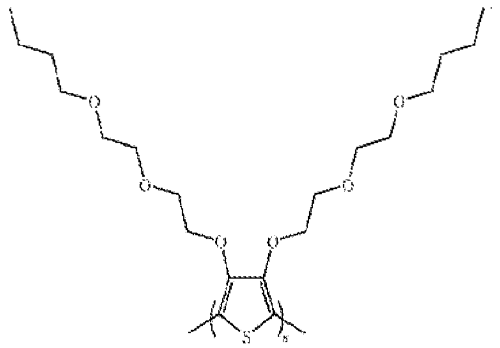
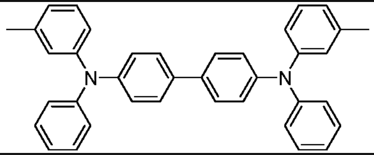
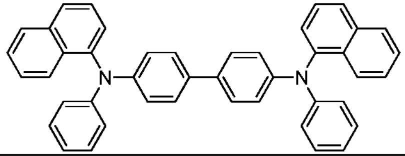
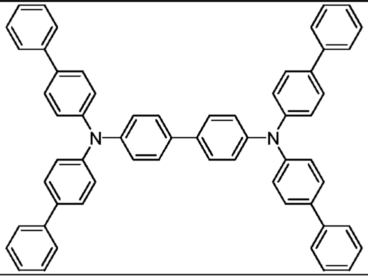
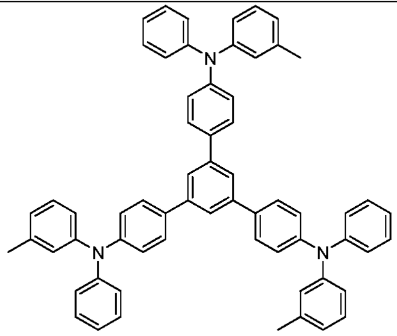
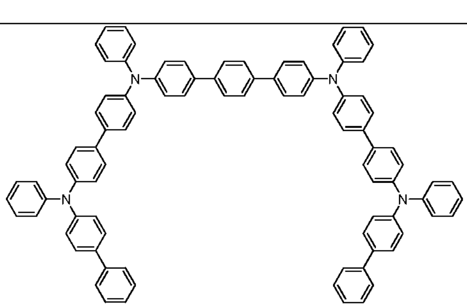
[0165] In any above-mentioned compounds used in each layer of the OLED device, the hydrogen atoms can be partially or fully deuterated. Thus, any specifically listed substituent, such as, without limitation, methyl, phenyl, pyridyl, etc. encompasses undeuterated, partially deuterated, and fully deuterated versions thereof. Similarly, classes of substituents such as, without limitation, alkyl, aryl, cycloalkyl, heteroaryl, etc. also encompass undeuterated, partially deuterated, and fully deuterated versions thereof.

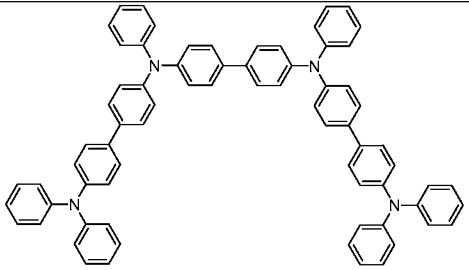
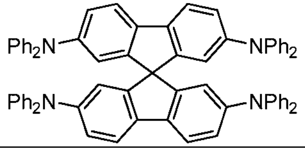
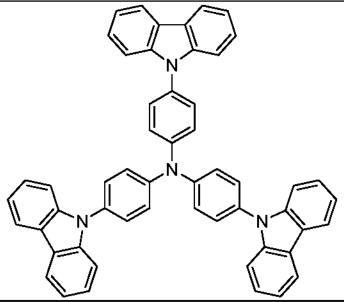
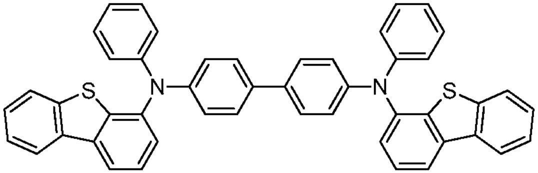
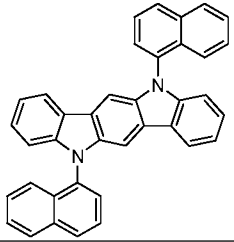
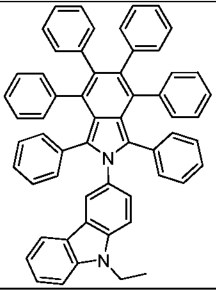
[0166] In addition to and / or in combination with the materials disclosed herein, many hole injection materials, hole transporting materials, host materials, dopant materials, exiton/hole blocking layer materials, electron transporting and electron injecting materials may be used in an OLED. Non-limiting examples of the materials that may be used in an OLED in combination with materials disclosed herein are listed in Table 1 below. Table 1 lists non-limiting classes of materials, non-limiting examples of compounds for each class, and references that disclose the materials.

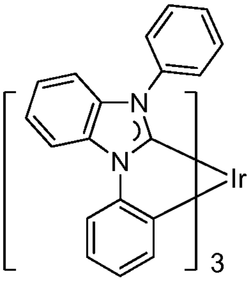
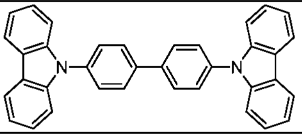
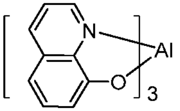
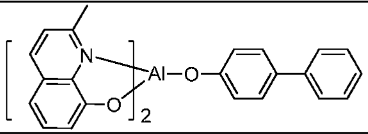
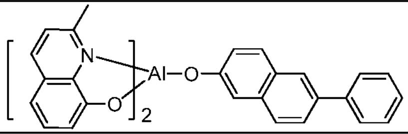
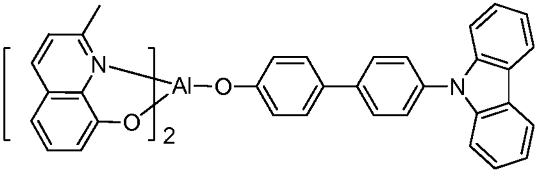
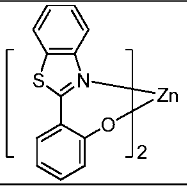
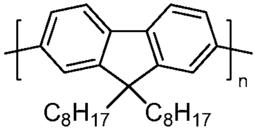
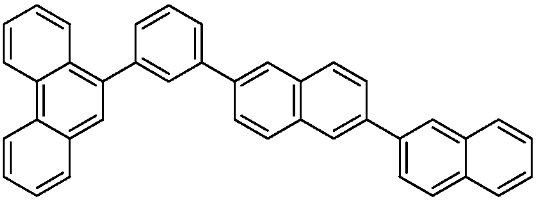
TABLE 1

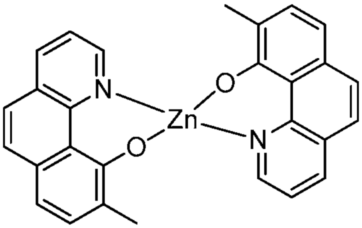
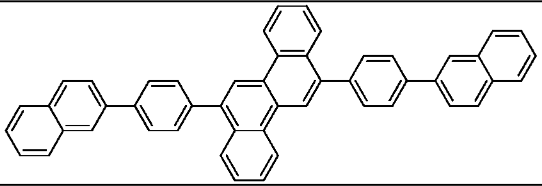
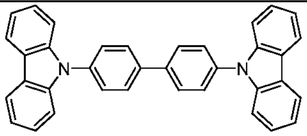
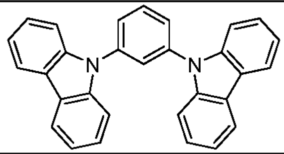
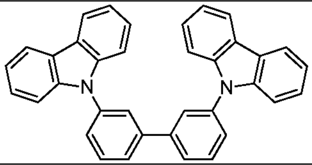
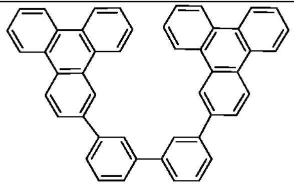
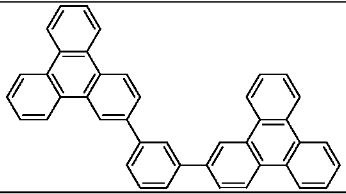
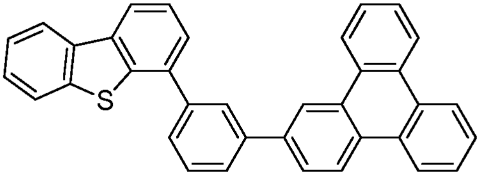
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Hole injection materials		
Phthalocyanine and porphryin compounds		Appl. Phys. Lett. 69, 2160 (1996)
Starburst triarylamines		J. Lumin. 72-74, 985 (1997)
CF_x Fluorohydrocarbon polymer	$\left[CH_xF_y \right]_n$	Appl. Phys. Lett. 78, 673 (2001)
Conducting polymers (e.g., PEDOT:PSS, polyaniline, polypthiophene)		Synth. Met. 87, 171 (1997) WO2007002683
Phosphonic acid and sliane SAMs		US20030162053
Triarylamine or polythiophene polymers with conductivity dopants	 and	EP1725079A1

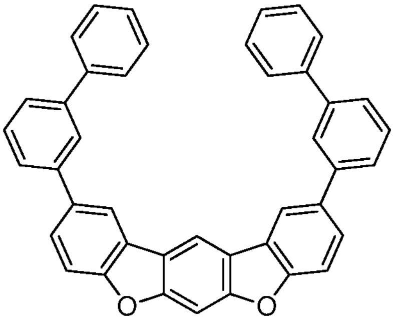
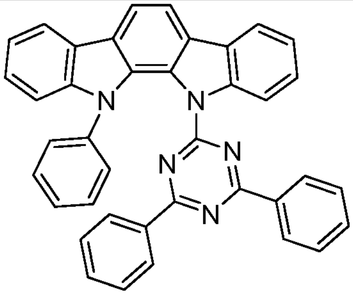
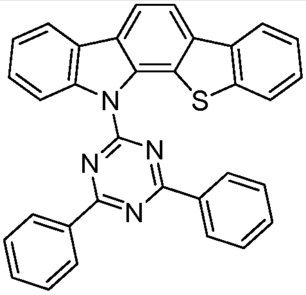
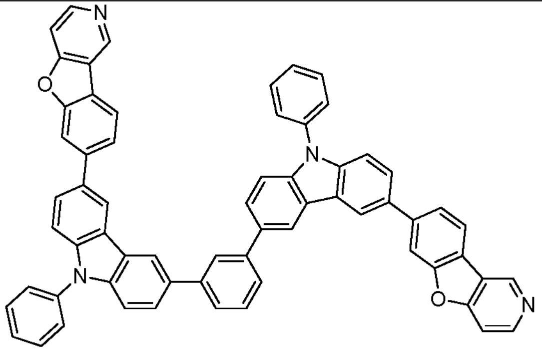
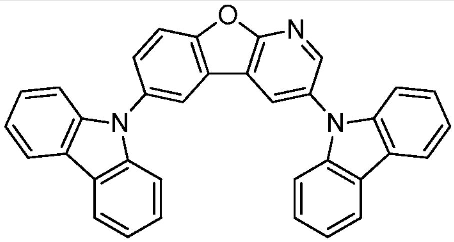
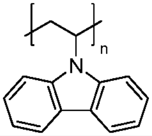
		
Organic compounds with conductive inorganic compounds, such as molybdenum and tungsten oxides	 + MoO_x	US20050123751 SID Symposium Digest, 37, 923 (2006) WO2009018009
n-type semiconducting organic complexes		US20020158242
Metal organometallic complexes		US20060240279
Cross-linkable compounds		US20080220265

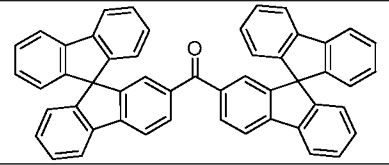
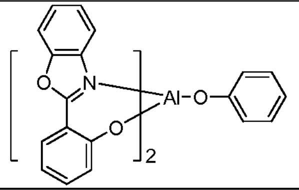
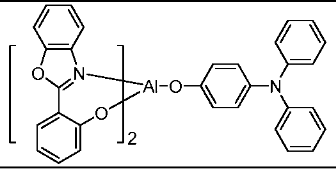
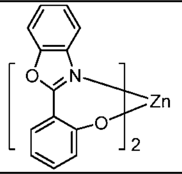
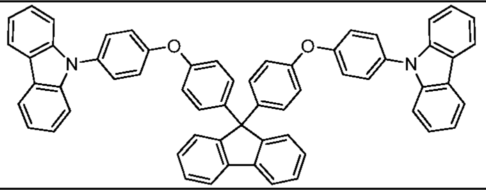
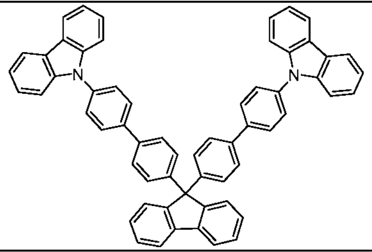
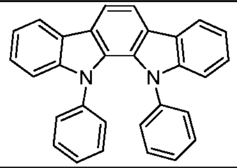
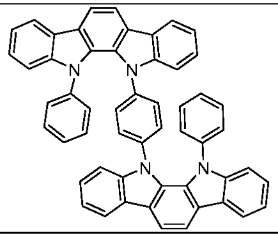
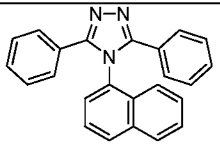
Polythiophene based polymers and copolymers		WO 2011075644 EP2350216
Hole transporting materials		
Triarylamines (e.g., TPD, α-NPD)		Appl. Phys. Lett. 51, 913 (1987)
		US5061569
		EP650955
		J. Mater. Chem. 3, 319 (1993)
		Appl. Phys. Lett. 90, 183503 (2007)

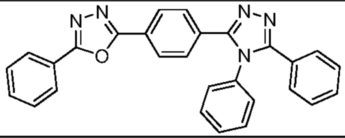
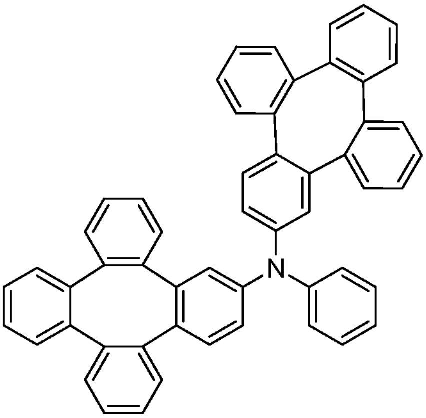
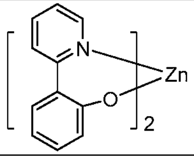
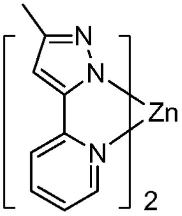
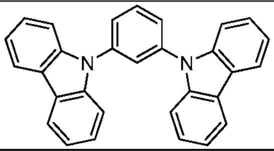
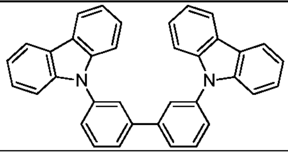
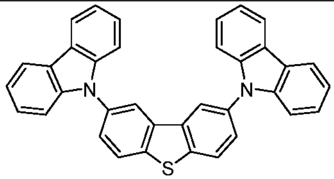
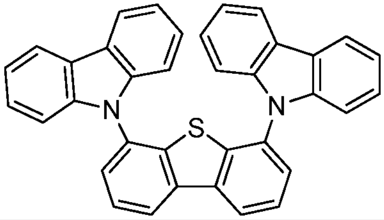
		Appl. Phys. Lett. 90, 183503 (2007)
Triaylamine on spirofluorene core		Synth. Met. 91, 209 (1997)
Arylamine carbazole compounds		Adv. Mater. 6, 677 (1994), US20080124572
Triarylamine with (di)benzothiophene/(di)benzofuran		US20070278938, US20080106190 US20110163302
Indolocarbazoles		Synth. Met. 111, 421 (2000)
Isoindole compounds		Chem. Mater. 15, 3148 (2003)

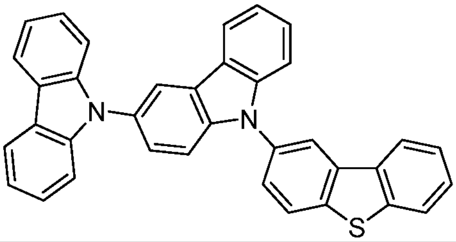
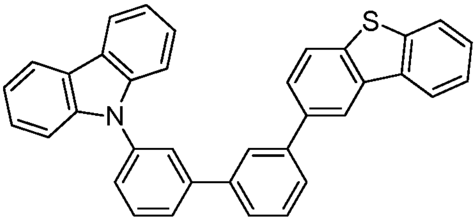
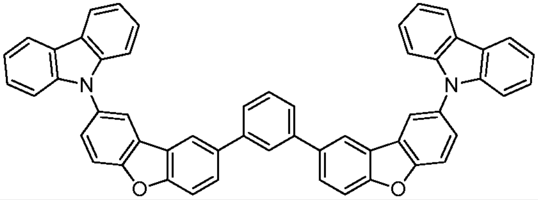
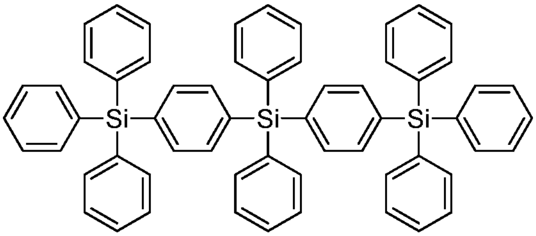
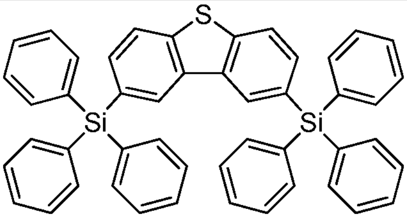
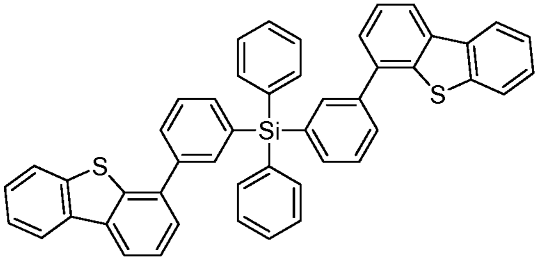
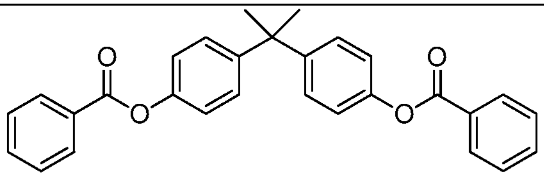
Metal carbene complexes		US20080018221
Phosphorescent OLED host materials		
Red hosts		
Arylcarbazoles		Appl. Phys. Lett. 78, 1622 (2001)
Metal 8-hydroxyquinolates (e.g., Alq_3, BAlq)		Nature 395, 151 (1998)
		US20060202194
		WO2005014551
		WO2006072002
Metal phenoxybenzothiazole compounds		Appl. Phys. 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

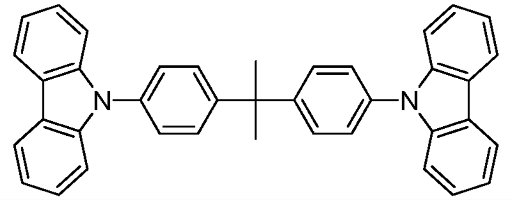
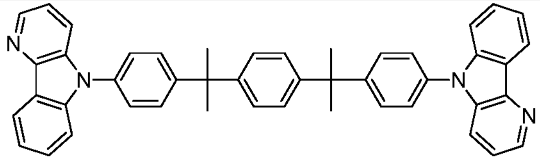
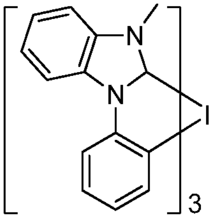
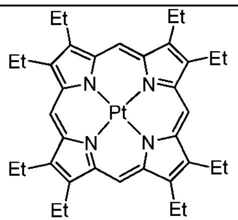
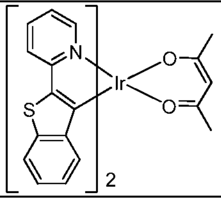
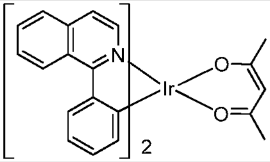
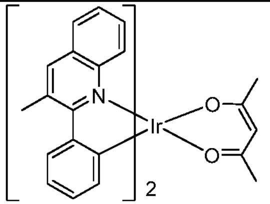
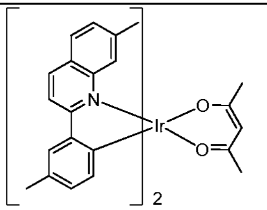
Zinc complexes		WO2010056066
Chrysene based compounds		WO2011086863
Green hosts		
Arylcarbazoles		Appl. Phys. Lett. 78, 1622 (2001)
		US20030175553
		WO2001039234
Aryltriphenylene compounds		US20060280965
		US20060280965
		WO2009021126

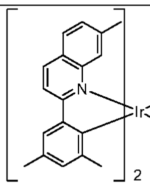
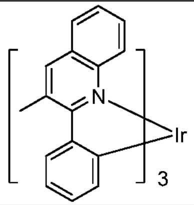
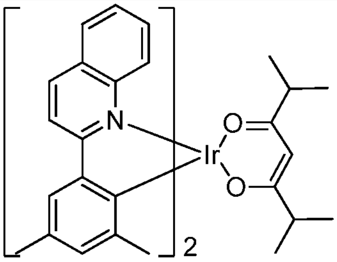
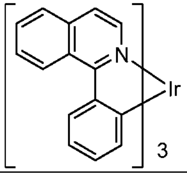
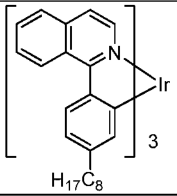
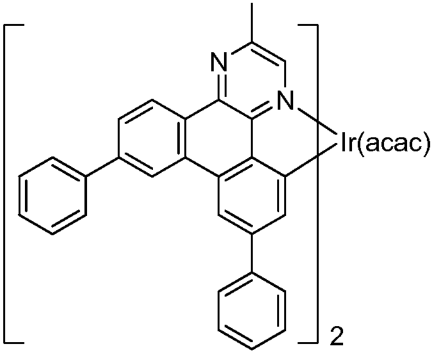
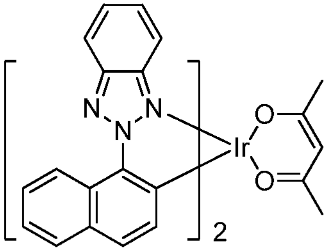
Poly-fused heteroaryl compounds		US20090309488 US20090302743 US20100012931
Donor acceptor type molecules		WO2008056746
		WO2010107244
Aza-carbazole/DBT/DBF		JP2008074939
		US20100187984
Polymers (e.g., PVK)		Appl. Phys. Lett. 77, 2280 (2000)

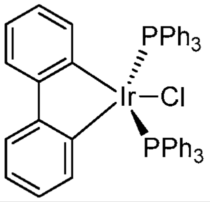
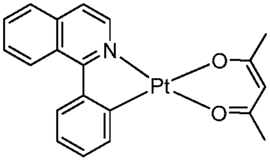
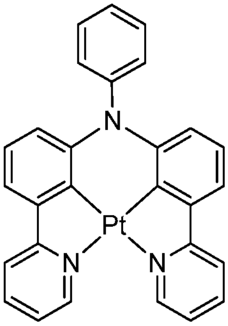
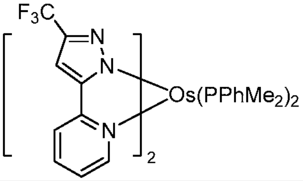
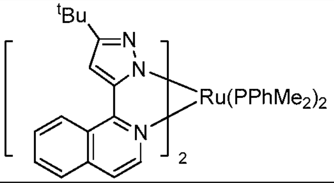
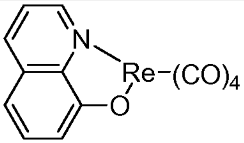
Spirofluorene compounds		WO2004093207
Metal phenoxybenzooxazole compounds		WO2005089025
		WO2006132173
		JP200511610
Spirofluorene-carbazole compounds		JP2007254297
		JP2007254297
Indolocabazoles		WO2007063796
		WO2007063754
5-member ring electron deficient heterocycles (e.g., triazole, oxadiazole)		J. Appl. Phys. 90, 5048 (2001)

		WO2004107822
Tetraphenylene complexes		US20050112407
Metal phenoxypyridine compounds		WO2005030900
Metal coordination complexes (e.g., Zn, Al with N^N ligands)		US20040137268, US20040137267
Blue hosts		
Arylcarbazoles		Appl. Phys. Lett, 82, 2422 (2003)
		US20070190359
Dibenzothiophene/Dibenzofuran-carbazole compounds		WO2006114966, US20090167162
		US20090167162

		WO2009086028
		US20090030202, US20090017330
		US20100084966
Silicon aryl compounds		US20050238919
		WO2009003898
Silicon/Germanium aryl compounds		EP2034538A
Aryl benzoyl ester		WO2006100298

Carbazole linked by non-conjugated groups		US20040115476
Aza-carbazoles		US20060121308
High triplet metal organometallic complex		US7154114
Phosphorescent dopants		
Red dopants		
Heavy metal porphyrins (e.g., PtOEP)		Nature 395, 151 (1998)
Iridium(III) organometallic complexes		Appl. Phys. Lett. 78, 1622 (2001)
		US2006835469
		US2006835469
		US20060202194

		US20060202194
		US20070087321
		US20080261076 US20100090591
		US20070087321
		Adv. Mater. 19, 739 (2007)
		WO2009100991
		WO2008101842

		US7232618
Platinum(II) organometallic complexes		WO2003040257
		US20070103060
Osminum(III) complexes		Chem. Mater. 17, 3532 (2005)
Ruthenium(II) complexes		Adv. Mater. 17, 1059 (2005)
Rhenium (I), (II), and (III) complexes		US20050244673
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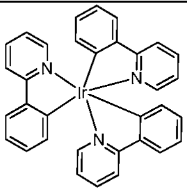
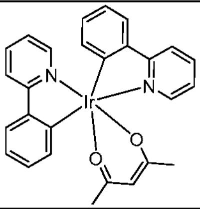
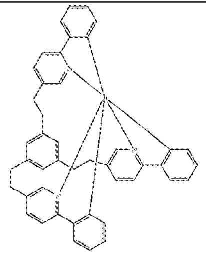
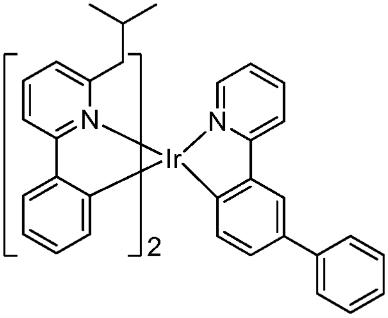
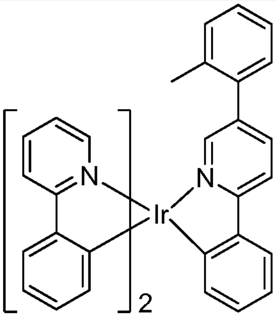
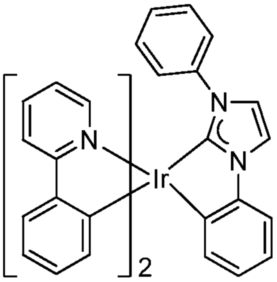
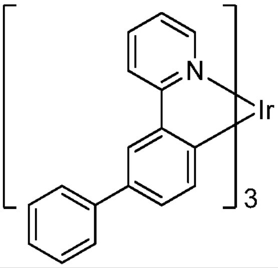
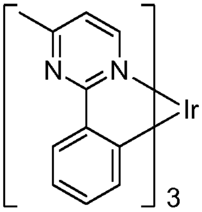
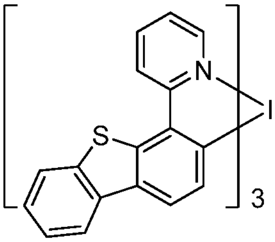
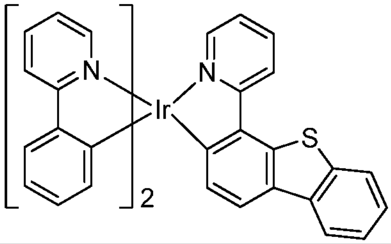
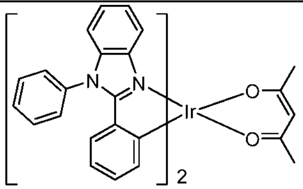
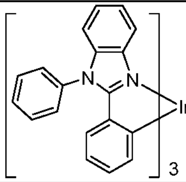
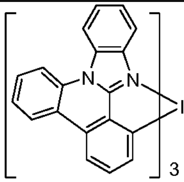
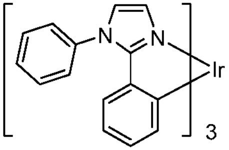
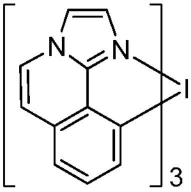
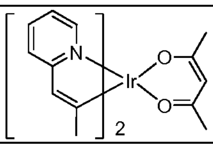
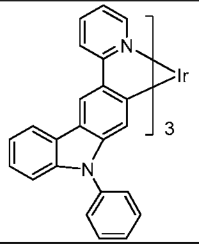
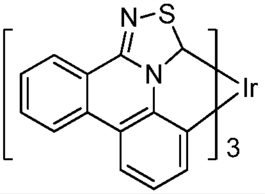
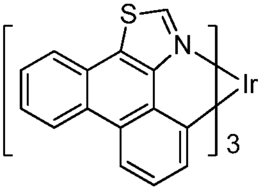
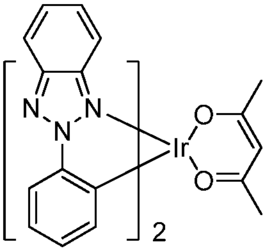
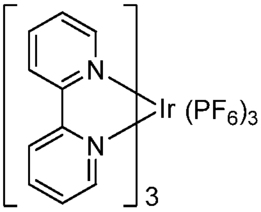
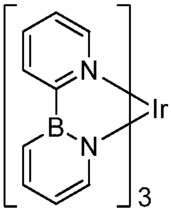
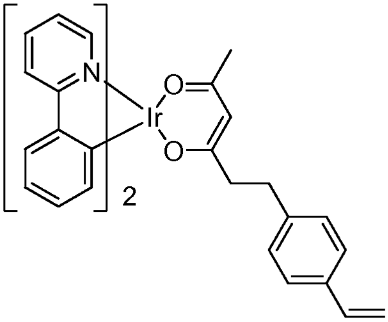
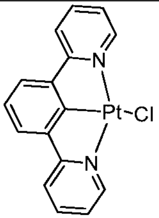
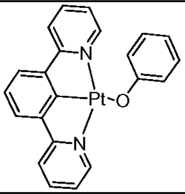
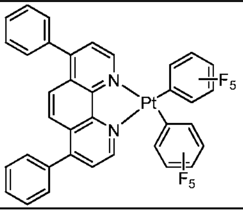
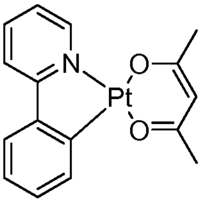
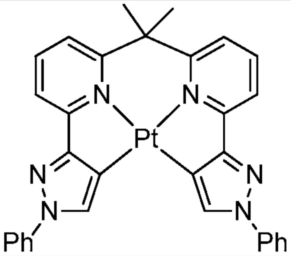
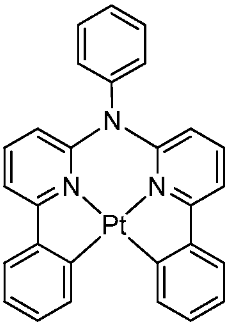
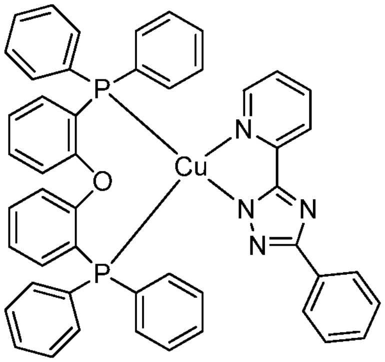
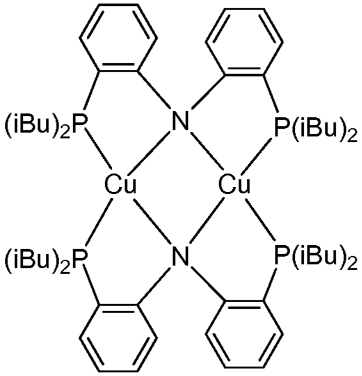
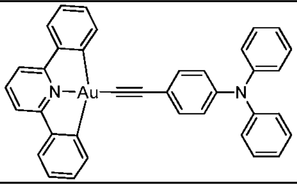
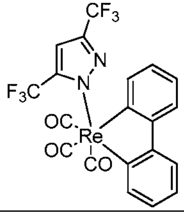
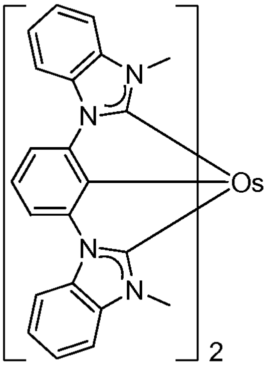
Iridium(III) organometallic complexes	 and its derivatives	Inorg. Chem. 40, 1704 (2001)
		US20020034656

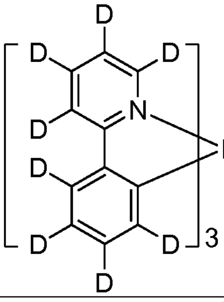
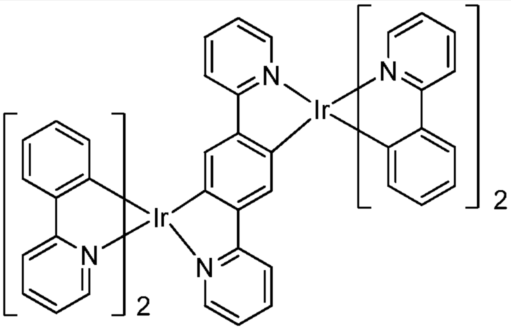
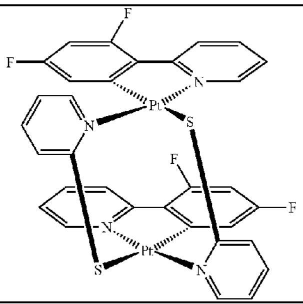
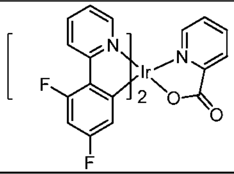
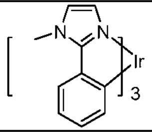
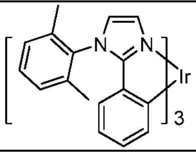
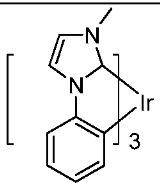
		US7332232
		US20090108737
		WO2010028151
		EP1841834B
		US20060127696
		US20090039776

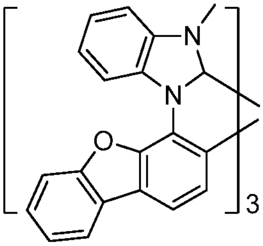
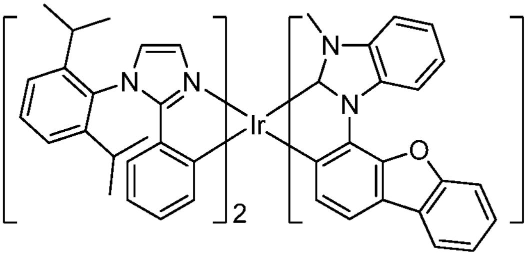
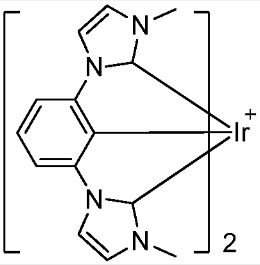
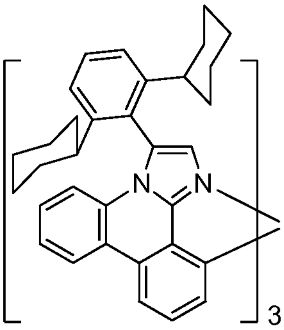
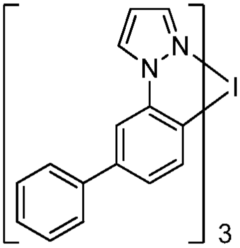
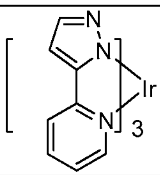
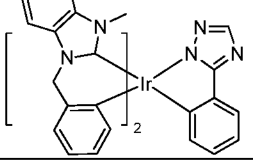
		US6921915
		US20100244004
		US6687266
		Chem. Mater. 16, 2480 (2004)
		US20070190359
		US 20060008670 JP2007123392
		WO2010086089, WO2011044988
		Adv. Mater. 16, 2003 (2004)

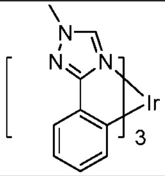
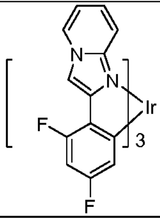
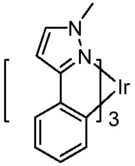
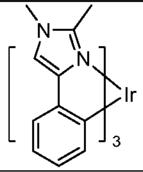
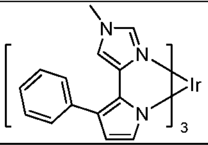
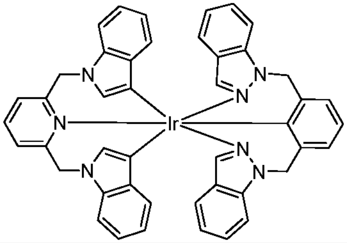
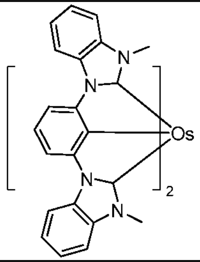
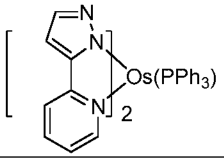
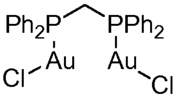
		Angew. Chem. Int. Ed. 2006, 45, 7800
		WO2009050290
		US20090165846
		US20080015355
		US20010015432
		US20100295032
Monomer for polymeric metal organometallic compounds		US7250226, US7396598

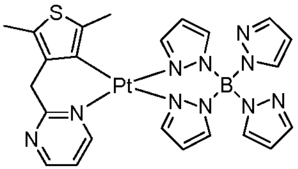
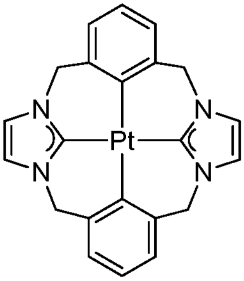
Pt(II) organometallic complexes, including polydentated ligands		Appl. Phys. Lett. 86, 153505 (2005)
		Appl. Phys. Lett. 86, 153505 (2005)
		Chem. Lett. 34, 592 (2005)
		WO2002015645
		US20060263635
		US20060182992 US20070103060

Cu complexes		WO2009000673
		US20070111026
Gold complexes		Chem. Commun. 2906 (2005)
Rhenium(III) complexes		Inorg. Chem. 42, 1248 (2003)
Osmium(II) complexes		US7279704

Deuterated organometallic complexes		US20030138657
Organometallic complexes with two or more metal centers		US20030152802
		US7090928
Blue dopants		
Iridium(III) organometallic complexes		WO2002002714
		WO2006009024
		US20060251923 US20110057559 US20110204333
		US7393599, WO2006056418, US20050260441, WO2005019373

		US7534505
		WO2011051404
		US7445855
		US20070190359, US20080297033 US20100148663
		US7338722
		US20020134984
		Angew. Chem. Int. Ed. 47, 1 (2008)

		Chem. Mater. 18, 5119 (2006)
		Inorg. Chem. 46, 4308 (2007)
		WO2005123873
		WO2005123873
		WO2007004380
		WO2006082742
Osmium(II) complexes		US7279704
		Organometallics 23, 3745 (2004)
Gold complexes		Appl. Phys. Lett.74,1361 (1999)

Platinum(II) complexes		WO2006098120, WO2006103874
Pt tetradentate complexes with at least one metal-carbene bond		US7655323
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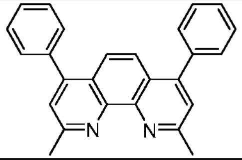
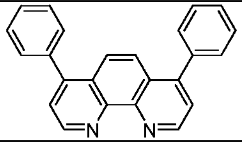
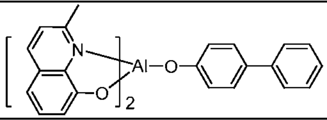
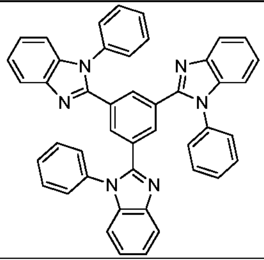
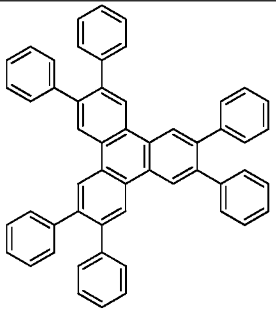
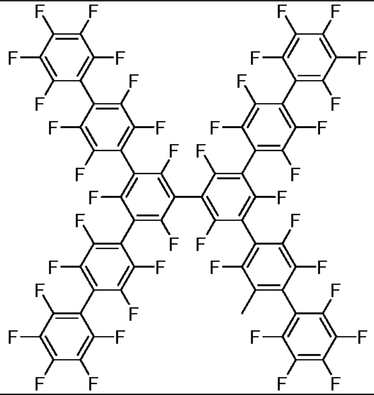
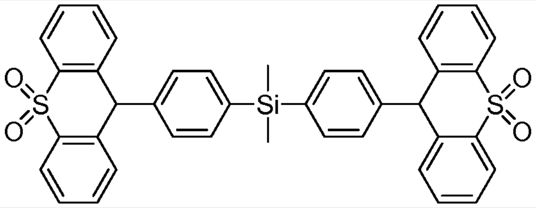
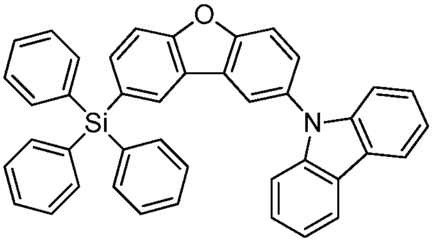
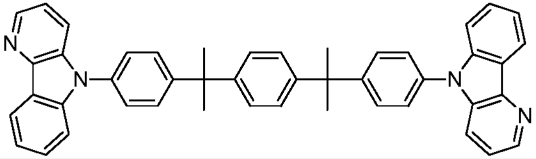
Bathocuprine compounds (e.g., BCP, BPhen)		Appl. Phys. Lett. 75, 4 (1999)
		Appl. Phys. Lett. 79, 449 (2001)
Metal 8-hydroxyquinolates (e.g., BAlq)		Appl. Phys. Lett. 81, 162 (2002)
5-member ring electron deficient heterocycles such as triazole, oxadiazole, imidazole, benzoimidazole		Appl. Phys. Lett. 81, 162 (2002)
Triphenylene compounds		US20050025993

Fluorinated aromatic compounds		Appl. Phys. Lett. 79, 156 (2001)
Phenothiazine-S-oxide		WO2008132085
Silylated five-membered nitrogen, oxygen, sulfur or phosphorus dibenzoheterocycles		WO2010079051
Aza-carbazoles		US20060121308
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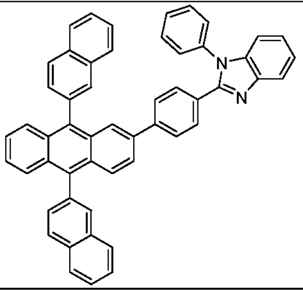
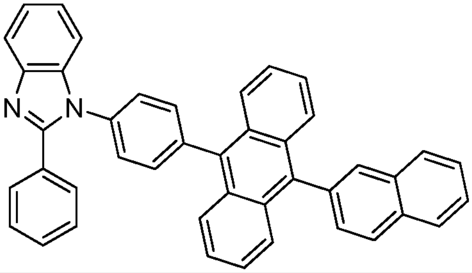
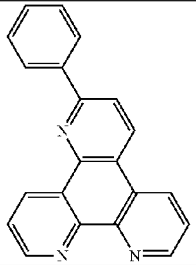
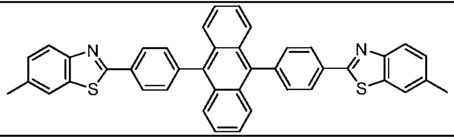
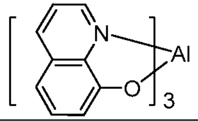
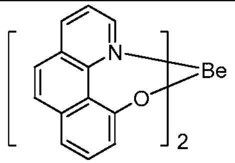
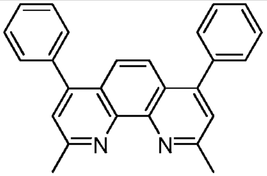
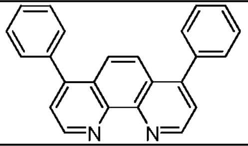
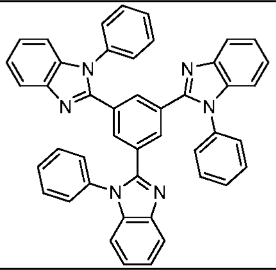
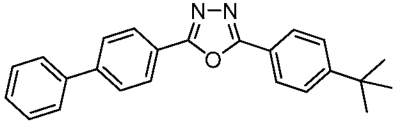
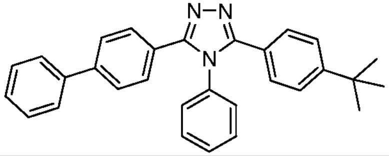
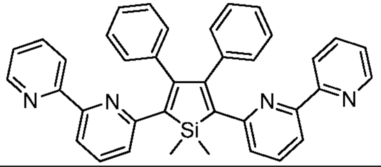
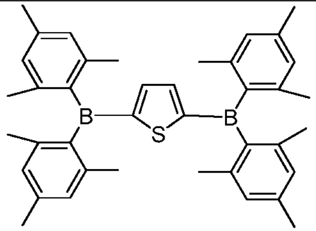
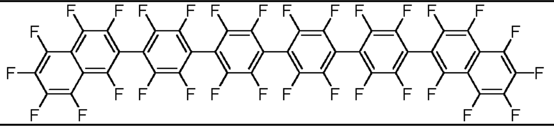
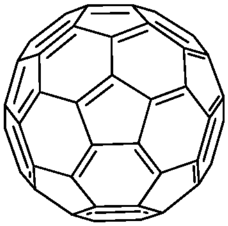
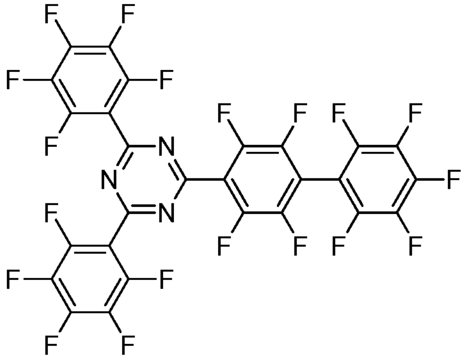
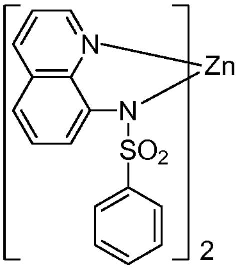
Anthracene-benzoimidazole compounds		WO2003060956
		US20090179554

Aza triphenylene derivatives		US20090115316
Anthracene-benzothiazole compounds		Appl. Phys. Lett. 89, 063504 (2006)
Metal 8-hydroxyquinolates (e.g., Alq$_3$, Zrq$_4$)		Appl. Phys. Lett. 51, 913 (1987) US7230107
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)
		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
Triazine complexes		US20040036077
Zn (N^N) complexes		US6528187

[0167] 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.

CLAIMS

1. A first device comprising a first organic light emitting device, further comprising:
an anode;
a cathode; and
an emissive layer, disposed between the anode and the cathode,
a first host comprising a substance containing at least 70 wt % inorganic material; and a first phosphorescent emissive dopant; wherein the energy band gap of the first host is less than 4 eV.

2. The first device of claim 1, wherein the substance comprises the inorganic material capped with capping groups.

3. The first device of claim 2, wherein the capping groups comprise carboxylate, amine, thiols, tetrafluoroborate, sulfide, thiocyanate, or metal chacogenide complxes.

4. The first device of claim 2, wherein the first host comprises particles of the substance having a size ranging from 1 to 20 nm.

5. The first device of claim 1, further comprising a plurality of organic layers that are optionally disposed between the emissive layer and the cathode, wherein the organic layers do not contain the first host.

6. The first device of claim 1, wherein the inorganic material comprises one or more of the following: a sulfide, a nitride, a carbide, or an oxide.

7. The first device of claim 1, wherein the inorganic material comprises an oxide.

8. The first device of claim 1, wherein the inorganic material comprises a sulfide.

9. The first device of claim 1, wherein the inorganic material comprises a carbide.

10. The first device of claim 1, wherein the inorganic material comprises a nitride.

11. The first device of claim 7, wherein the oxide comprises a metal oxide.

12. The first device of claim 11, wherein the metal oxide comprises a transition metal oxide.

13. The first device of claim 8, wherein the sulfide comprises a metal sulfide.

14. The first device of claim 9, wherein the carbide comprises a metal carbide.

15. The first device of claim 9, wherein the ntiride comprises a metal nitride.

16. The first device of claim 1, wherein the inorganic material comprises a binary compound.

17. The first device of claim 1, wherein the inorganic material comprises a ternary compound.

18. The first device of claim 1, wherein the first host comprises a non-emitting inorganic nanocrystal.

19. The first device of claim 1, wherein the first host has energy band gap value between 1 to 4 eV.

20. The first device of claim 19, wherein the first host has an energy band gap value between 2 to 3 eV.

21. The first device of claim 1, wherein the first host has an energy band gap value larger than the triplet energy of the first phosphorescent emissive dopant.

22. The first device of claim 1, wherein the concentration of the first host in the emissive layer is at least 50 wt%.

23. The first device of claim 22, wherein the concentration of the first host in the emissive layer is at least 70 wt%.

24. The first device of claim 23, wherein the concentration of the first host in the emissive layer is at least 80 wt%.

25. The first device of claim 1, wherein the first host consists essentially of a substance containing at least 70 wt % inorganic material.

26. The first device of claim 1, wherein the first host consists essentially of a substance containing at least 80 wt % inorganic material.

27. The first device of claim 1, wherein the first host consists essentially of a substance containing at least 90 wt % inorganic material.

28. The first device of claim 1, wherein the first host consists essentially of a substance containing at least 95 wt % inorganic material.

29. The first device of claim 1, wherein the first device is a consumer product.

30. The first device of claim 1, wherein the first device an organic light-emitting device.

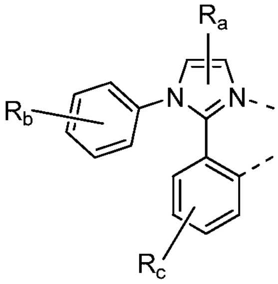
31. The first device of claim 1, wherein the first device comprises a lighting panel.

32. The first device of claim 1, wherein the first phosphorescent emissive dopant is a metal complex with metal having an atomic number greater than 40.

33. The first device of claim 32, wherein the first phosphorescent emissive dopant is an iridium complex.

34. The first device of claim 32, wherein the first phosphorescent emissive dopant is a platinum complex.

35. The first device of claim 1, wherein the first phosphorescent emissive dopant comprises a transition metal complex having at least one ligand or part of the ligand if the ligand is more than bidentate selected from the group consisting of:



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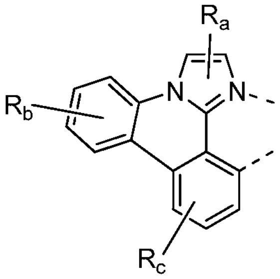

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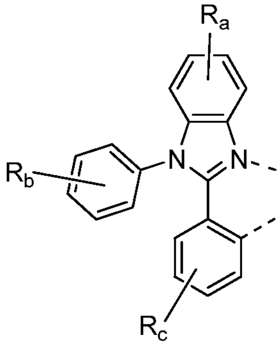

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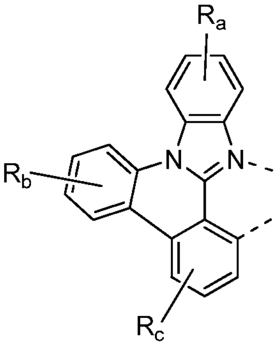

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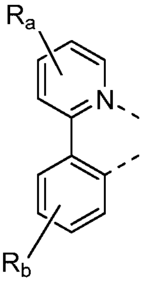

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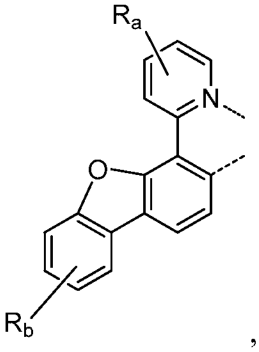

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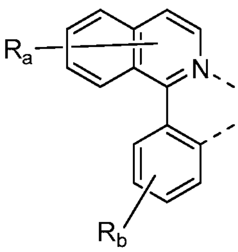

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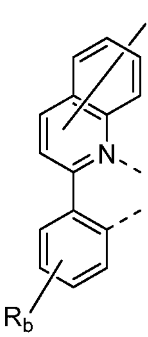

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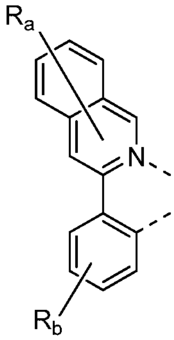

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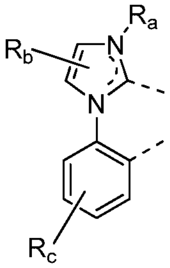

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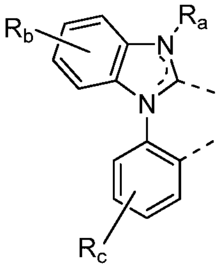

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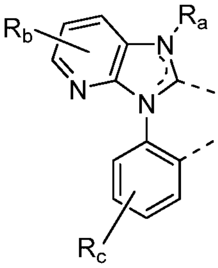

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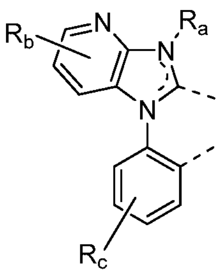

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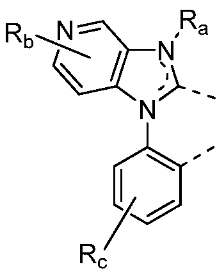

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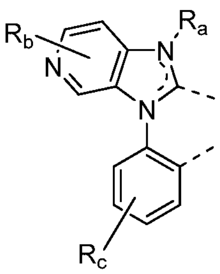

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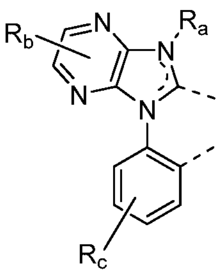

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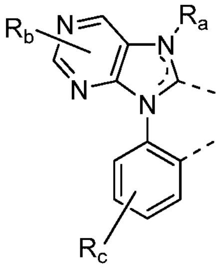

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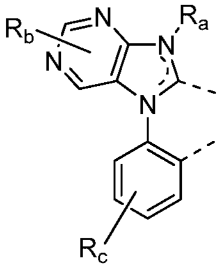

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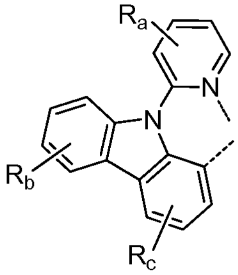

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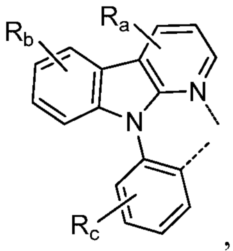

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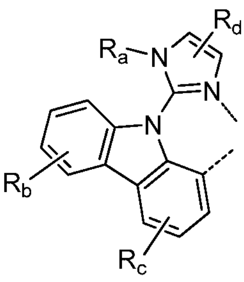
and 

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wherein R_a, R_b, R_c, and R_d may represent mono, di, tri, or tetra substitution, or no substitution;

wherein R_a, R_b, R_c, and R_d are 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 two adjacent substituents of R_a, R_b, R_c, and R_d are optionally joined to form a fused ring or form a multidentate ligand.

36. The first device of claim 1, wherein the emissive layer is deposited using a solution process.

37. The first device of claim 1, wherein the first host reacts with the first phosphorescent emissive dopant to form a covalent bond.

38. The first device of claim 1, wherein the emissive layer further comprises a second host.

39. The first of claim 38, wherein the second host is an organic compound.

40. The first of claim 39, wherein the organic compound contains at least one of the groups selected from the group consisting of triphenylene, dibenzothiophene, aza-dibenzothiophene, dibenzofuran, aza-dibenzofuran, carbazole, and aza-carbazole.

41. The first device of claim 38, wherein the second host is an inorganic material.

42. The first device of claim 1, wherein the emissive layer further comprises a second emissive dopant.

43. A method of making a first device comprising:
depositing an anode layer on a substrate;
depositing at least one emissive layer after the anode layer; and
depositing a cathode layer after the at least one emissive layer; wherein the at least one emissive layer contains a first host comprising a substance containing at least 70 wt % inorganic material and a first phosphorescent emissive dopant;
wherein the energy band gap of the first host compound is less than 4 eV.

44. The method of claim 43, wherein the first host reacts with the first phosphorescent emissive dopant to form a covalent bond.

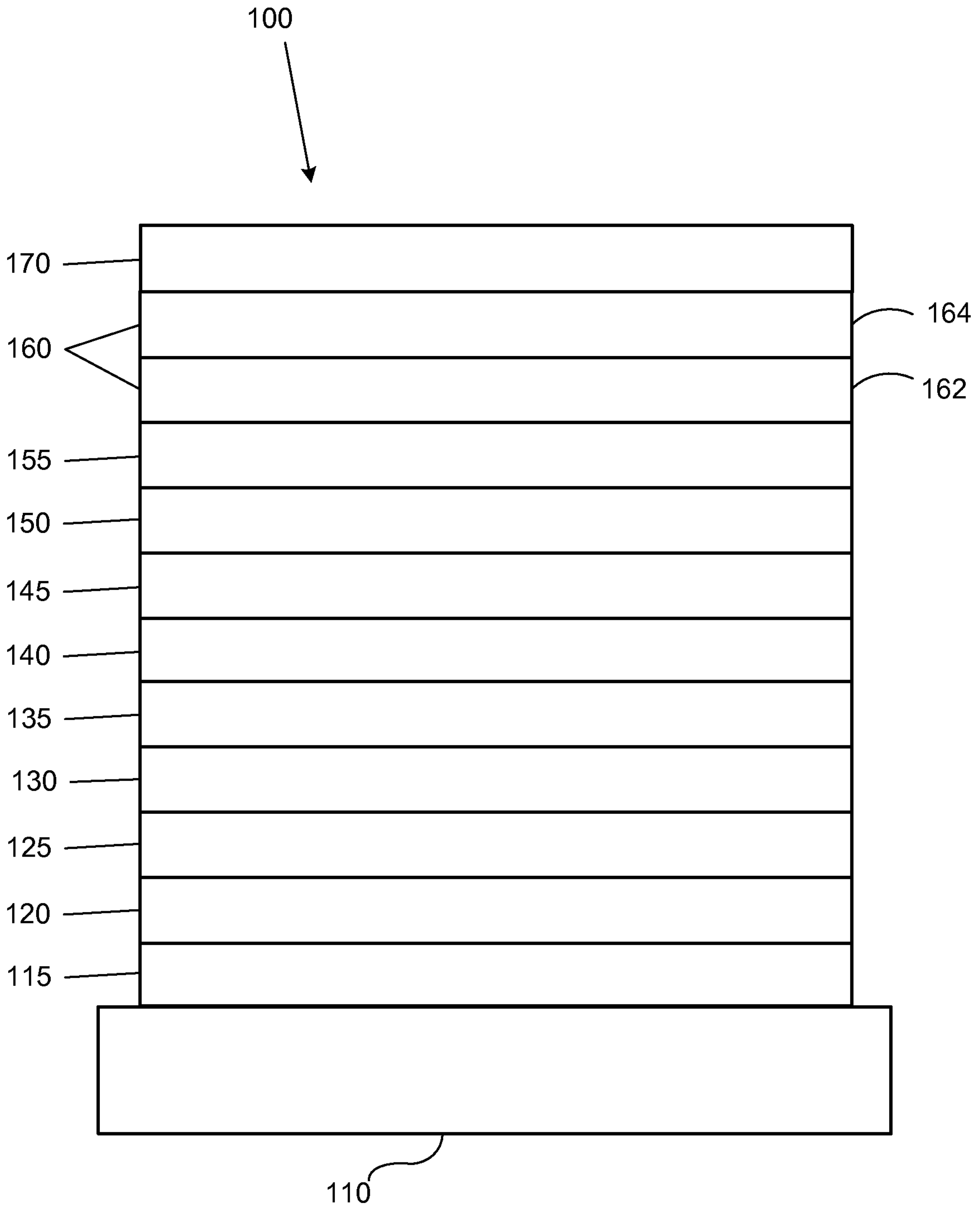

FIGURE 1

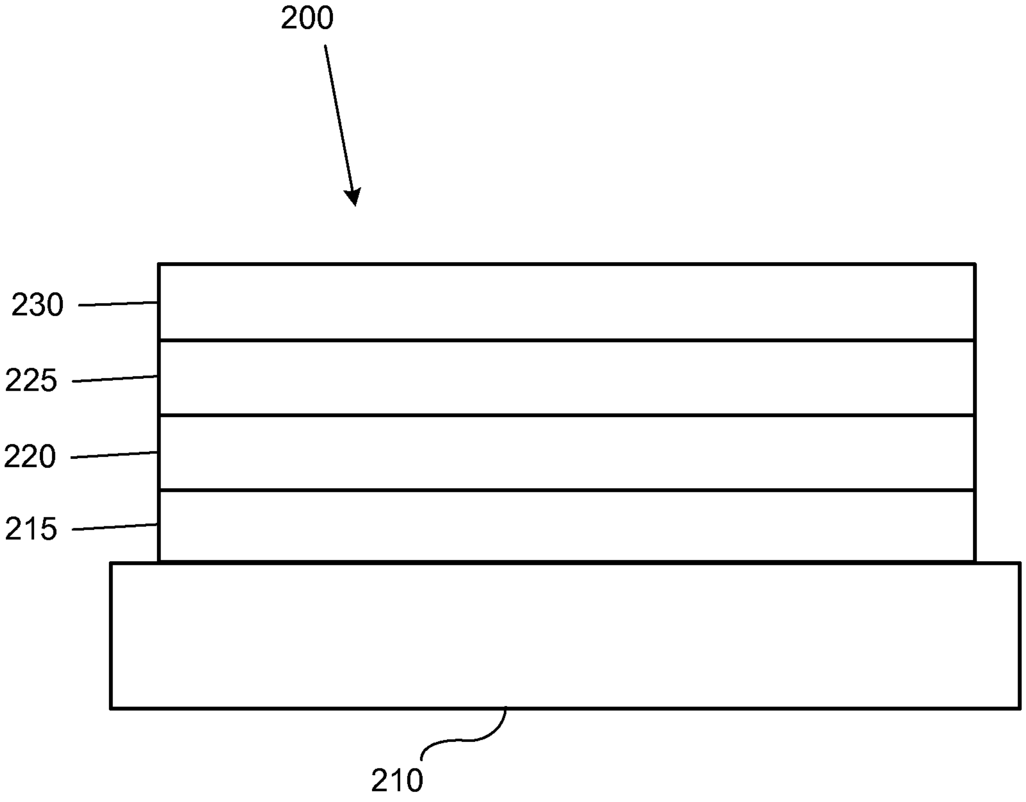

FIGURE 2

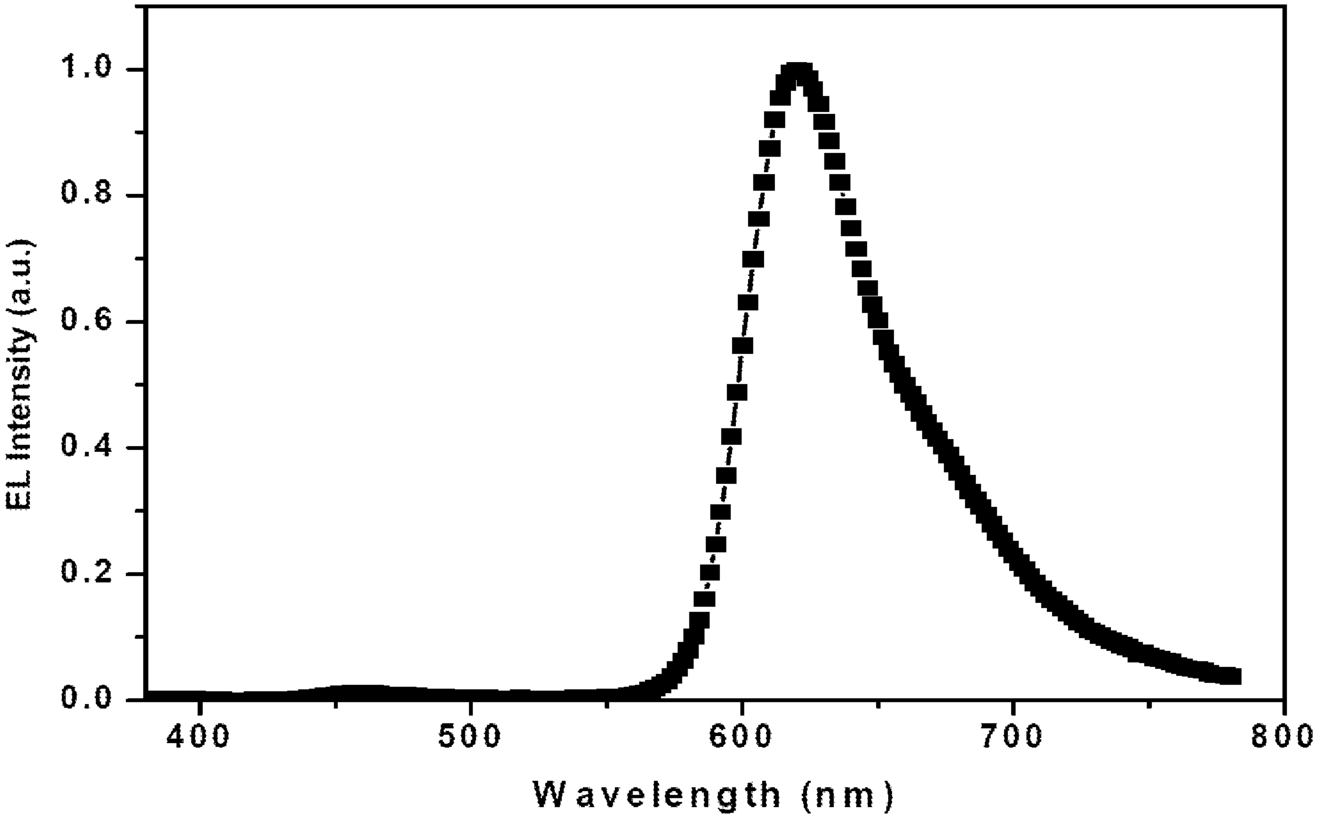
EL Intensity (a.u.)
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
800
Wavelength (nm)

FIGURE 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/045962

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L51/50
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	LASKAR I R ET AL: "OBSERVING ENHANCED PHOSPHORESCENCE AND ELECTROLUMINESCENCE FROM TRIPLET EMITTER BY QUANTUM DOT DOPING", JAPANESE JOURNAL OF APPLIED PHYSICS, THE JAPAN SOCIETY OF APPLIED PHYSICS, JAPAN SOCIETY OF APPLIED PHYSICS, TOKYO; JP, vol. 44, no. 20-23, 1 January 2005 (2005-01-01), pages L727-L730, XP001236973, ISSN: 0021-4922, DOI: 10.1143/JJAP.44.L727 page L728, column 1, lines 22-32; figures 4,5; table I ----- -/--	1,5-19, 21-33, 35,36, 38-43

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search

17 October 2012

Date of mailing of the international search report

26/10/2012

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Fax: (+31-70) 340-3016

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Fratiloiu, Silvia

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	TORRISS B ET AL: "White light-emitting organic device with electroluminescent quantum dots and organic molecules", ORGANIC ELECTRONICS, ELSEVIER, AMSTERDAM, NL, vol. 10, no. 8, 1 December 2009 (2009-12-01), pages 1454-1458, XP026746925, ISSN: 1566-1199, DOI: 10.1016/J.ORGEL.2009.08.007 [retrieved on 2009-08-18] page 1454, column 2, line 12 - page 1455, column 1, line 23; figure 1 -----	1,4-6,8, 13,18, 20, 25-28, 30,32, 33,43
X	US 2005/035346 A1 (BAZAN GUILLERMO C [US] ET AL) 17 February 2005 (2005-02-17) paragraph [0054]; example 2 -----	1-4,6,8, 13,18, 25-28,43
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X	WO 2009/006550 A1 (NITTO DENKO CORP [JP]; CHAE HYUN SIK [US]; OHMORI YUTAKA [JP]; FROEHLI) 8 January 2009 (2009-01-08) claim 1 -----	37,44
A	WO 2009/052122 A1 (HCF PARTNERS L P [US]; GOUGH NEIL [US]; WILLIAMS CHRISTOPHER [US]) 23 April 2009 (2009-04-23) paragraph [0067] ----- -/--	1-44

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/045962

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	WO 2011/147522 A1 (MERCK PATENT GMBH [DE]; PAN JUNYOU [DE]; SCHULTE NIELS [DE]; EBERLE TH) 1 December 2011 (2011-12-01) pages 68-73; examples 1-3; table 1 -----	1,43

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Information on patent family members

International application No
PCT/US2012/045962

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		JP 2011501440 A	06-01-2011
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