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(54) **NOVEL ORGANOMETALLIC COMPOUNDS FOR USE IN ELECTROLUMINESCENT DEVICES**

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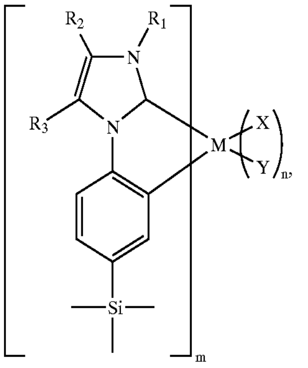
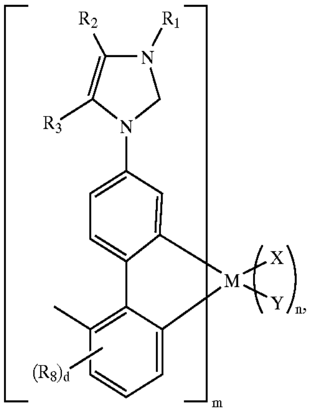
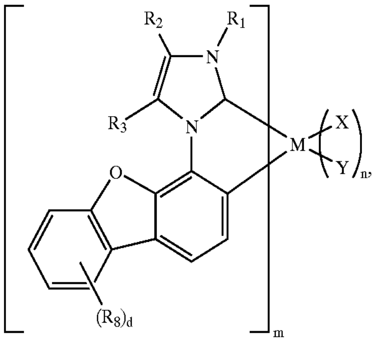
(57) **ABSTRACT**

An organic light emitting device having an anode, a cathode and an organic layer between the anode and the cathode is provided. The organic layer comprises a carbene-metal complex having the structure:







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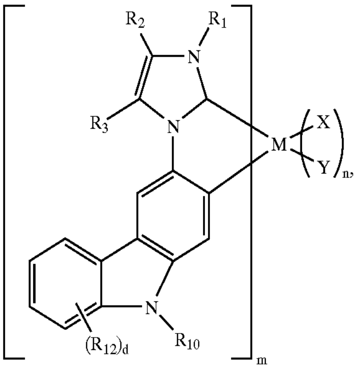

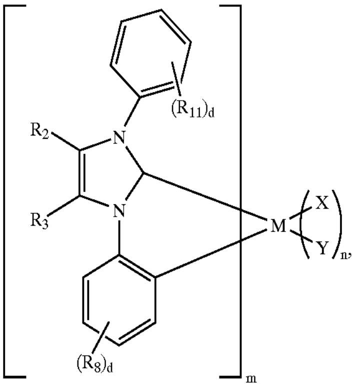

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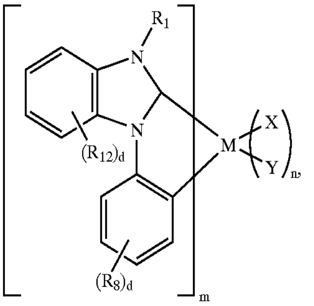
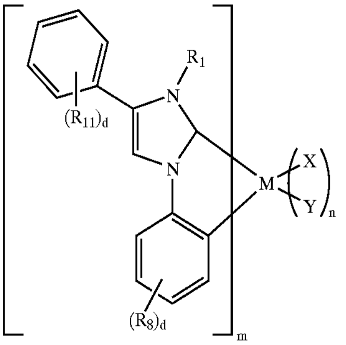


or



where R may be halo, hydrogen, alkyl, alkenyl, alkynyl, aralkyl, aryl, heteroaryl, substituted aryl, substituted heteroaryl, or a heterocyclic group; and additionally or alternatively, two or more R groups on the same ring form independently a 5 or 6-member cyclic group, which may be cycloalkyl, cycloheteroalkyl, aryl or heteroaryl; and which may be substituted by one or more substituents J; and J may be R', CN, CF_3, C(O)OR', C(O)R', $C(O)NR'_2$, NR'_2, NO_2, OR', SR', SO_2, SOR', or SO_3R', and additionally or alternatively, two J groups on adjacent ring atoms form a fused 5- or 6-membered aromatic group; each R' may be halo, H, alkyl, alkenyl, alkynyl, heteroalkyl, aralkyl, aryl and heteroaryl.

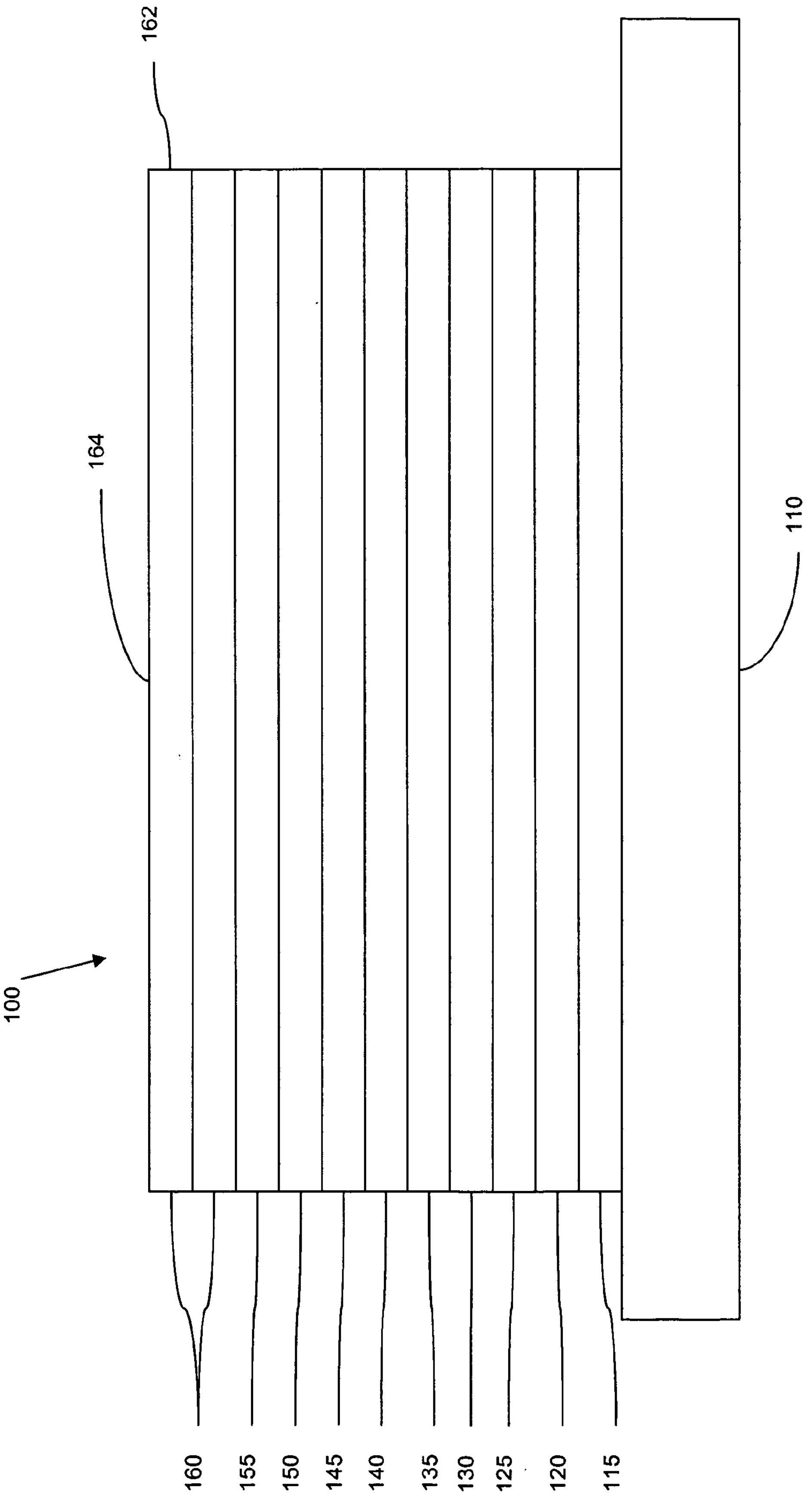


Figure 1

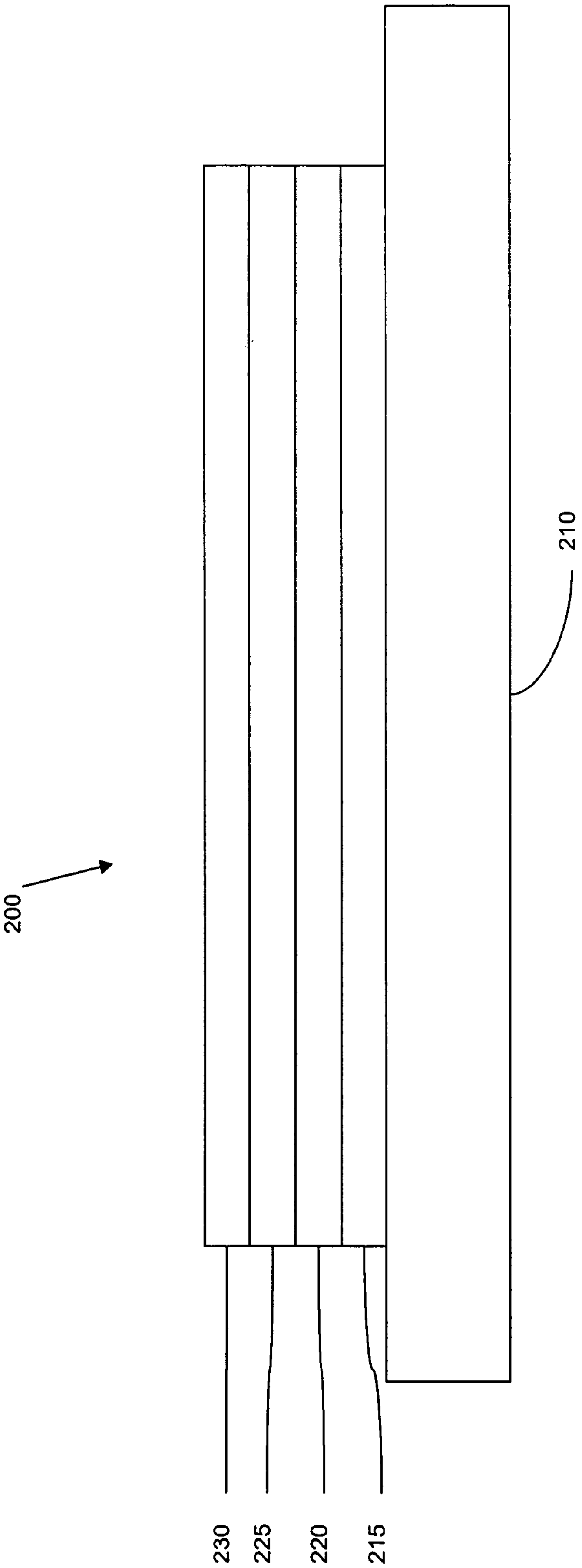


Figure 2

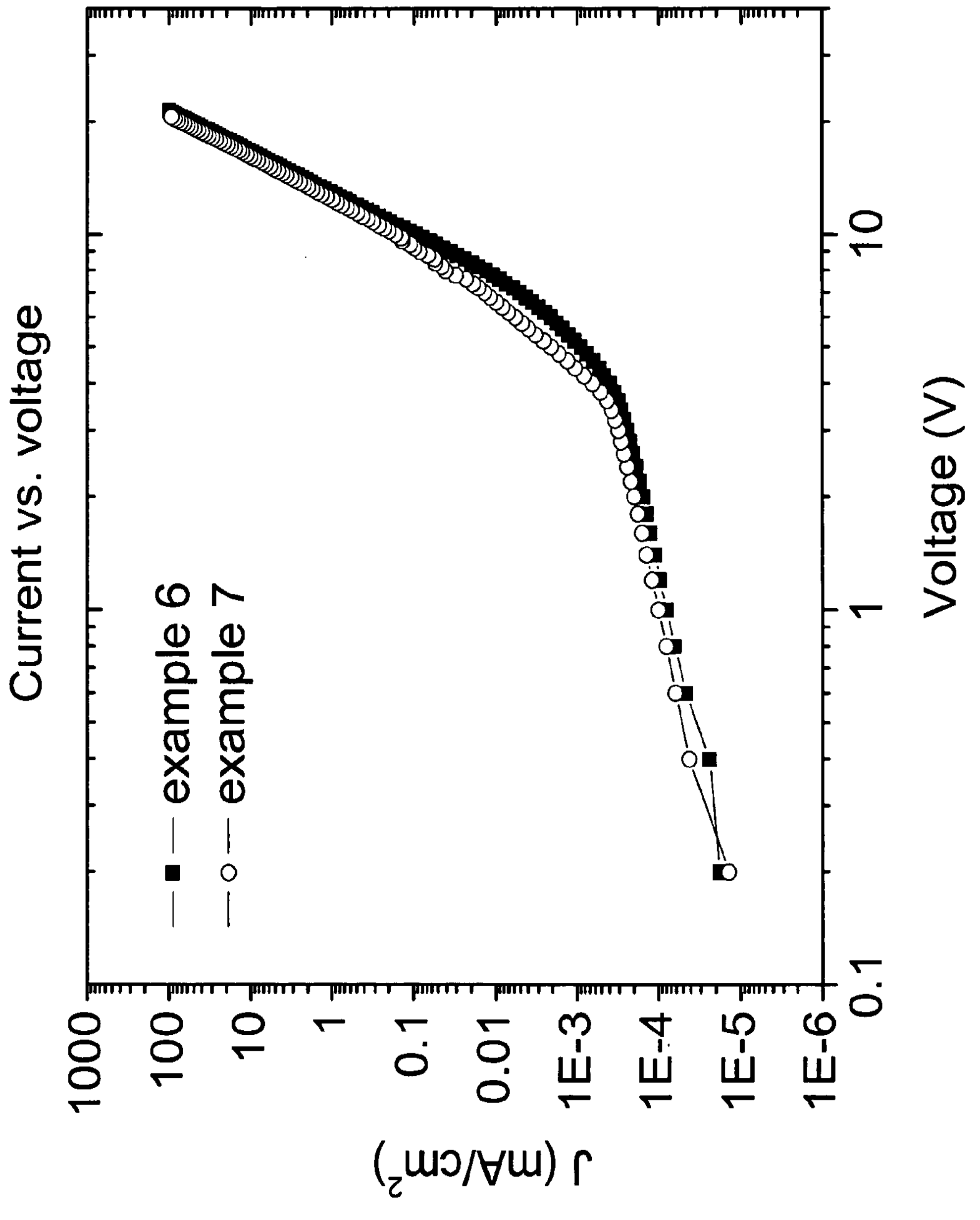

Current vs. voltage
■ example 6
○ example 7
J (mA/cm^2)
1000
100
10
1
0.1
0.01
1E-3
1E-4
1E-5
1E-6
0.1
1
10
Voltage (V)

Figure 3

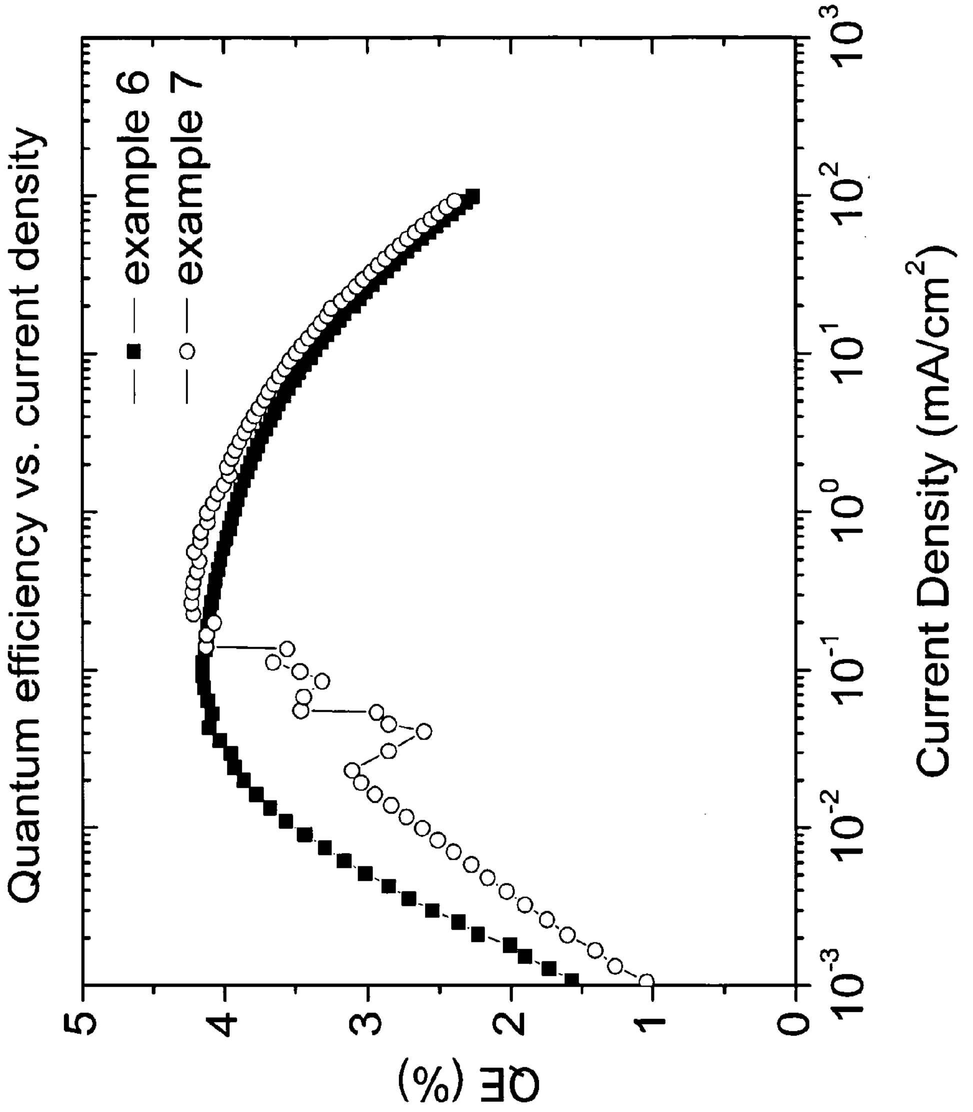

Quantum efficiency vs. current density
—■— example 6
—○— example 7
QE (%)
0
1
2
3
4
5
Current Density (mA/cm^2)
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}

Figure 4

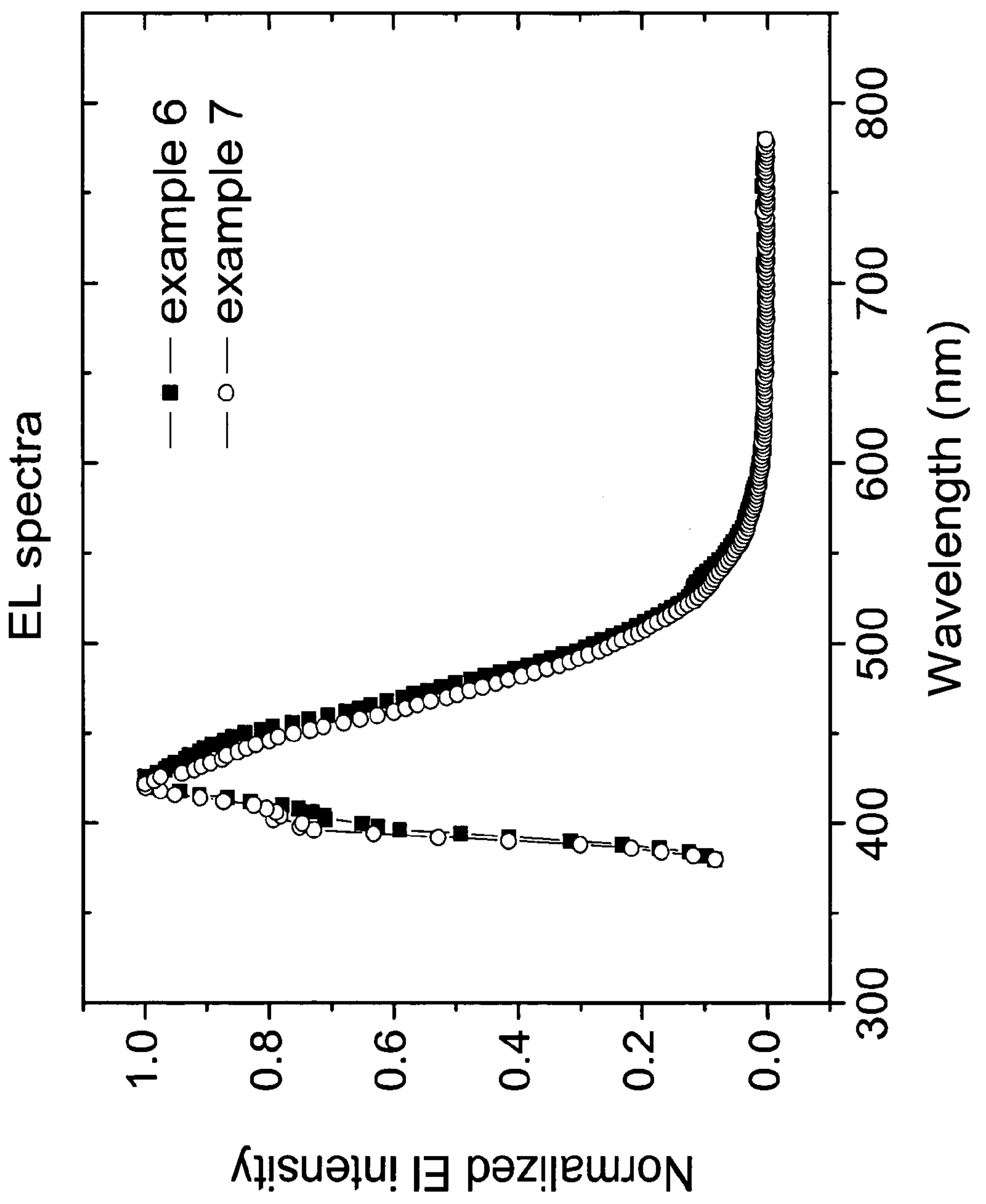

EL spectra
—■— example 6
—○— example 7
Normalized El intensity
1.0
0.8
0.6
0.4
0.2
0.0
300
400
500
600
700
800
Wavelength (nm)

Figure 5

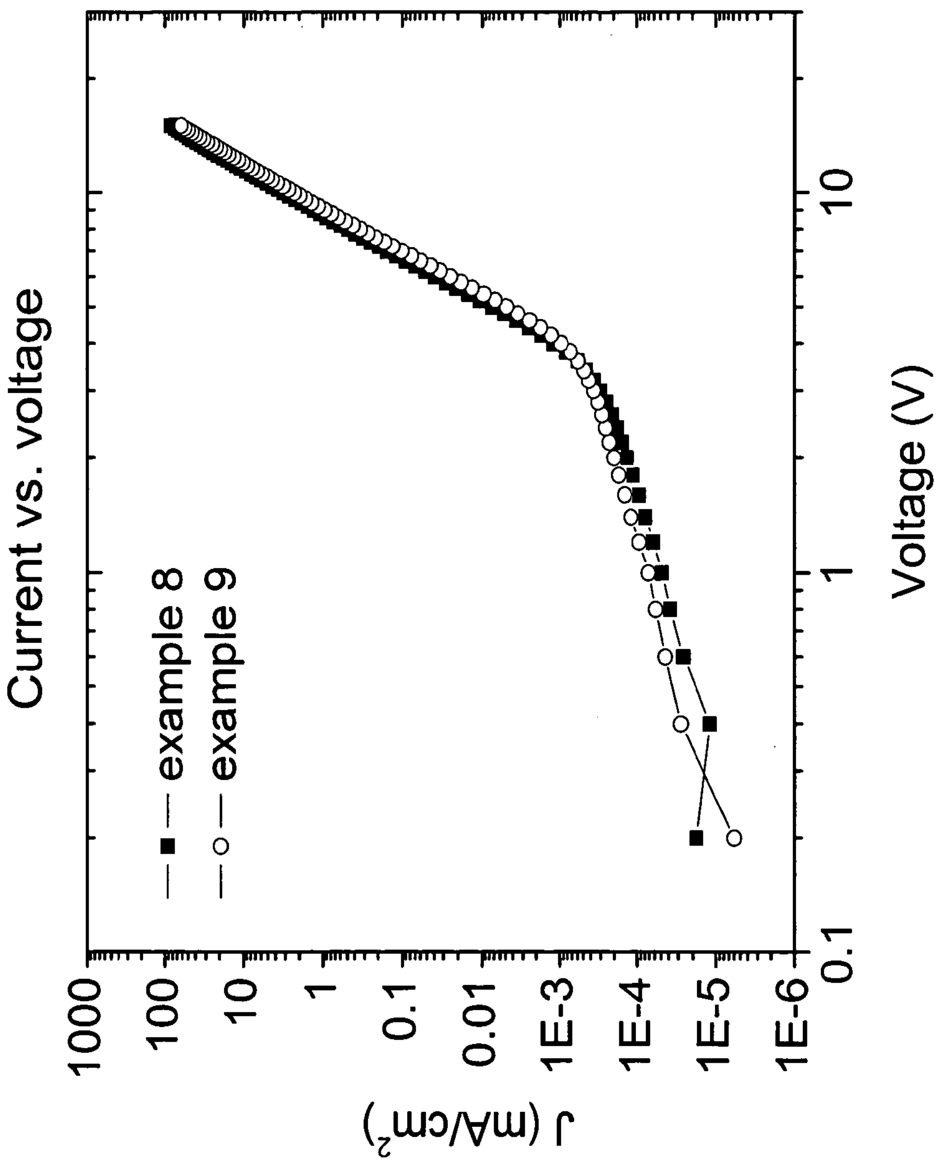

Current vs. voltage
example 8
example 9
1000
100
10
1
0.1
0.01
1E-3
1E-4
1E-5
1E-6
J (mA/cm^2)
0.1
1
10
Voltage (V)

Figure 6

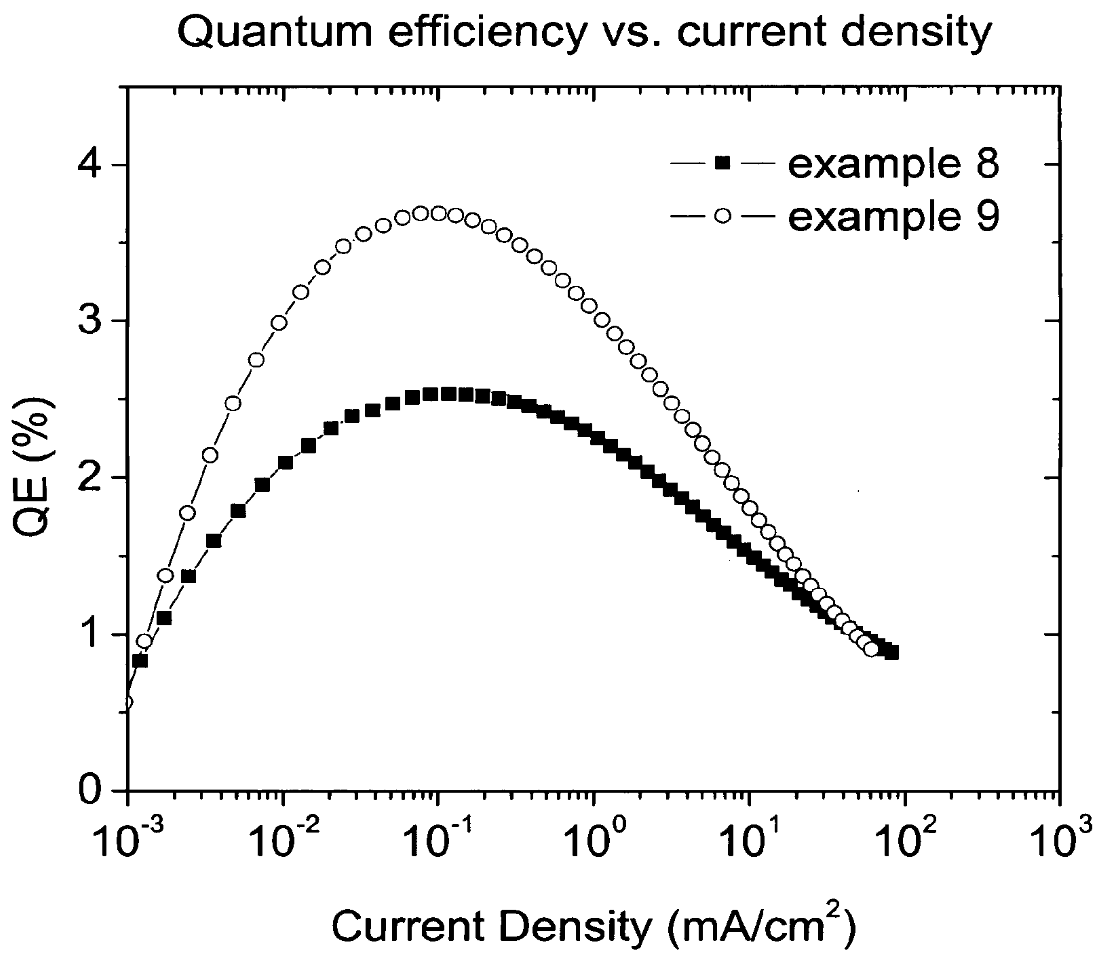

Quantum efficiency vs. current density

Figure 7

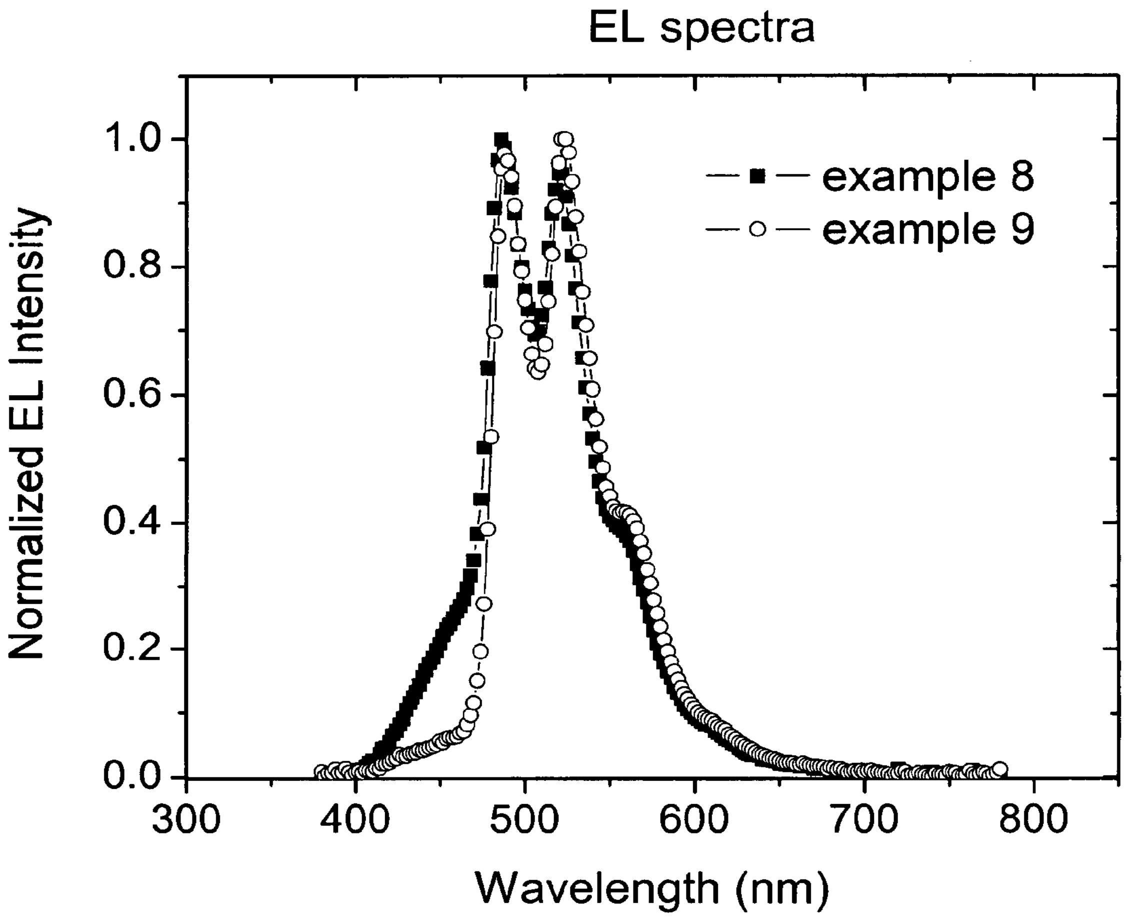

EL spectra
Normalized EL Intensity
1.0
0.8
0.6
0.4
0.2
0.0
300
400
500
600
700
800
Wavelength (nm)
■ example 8
○ example 9

Figure 8

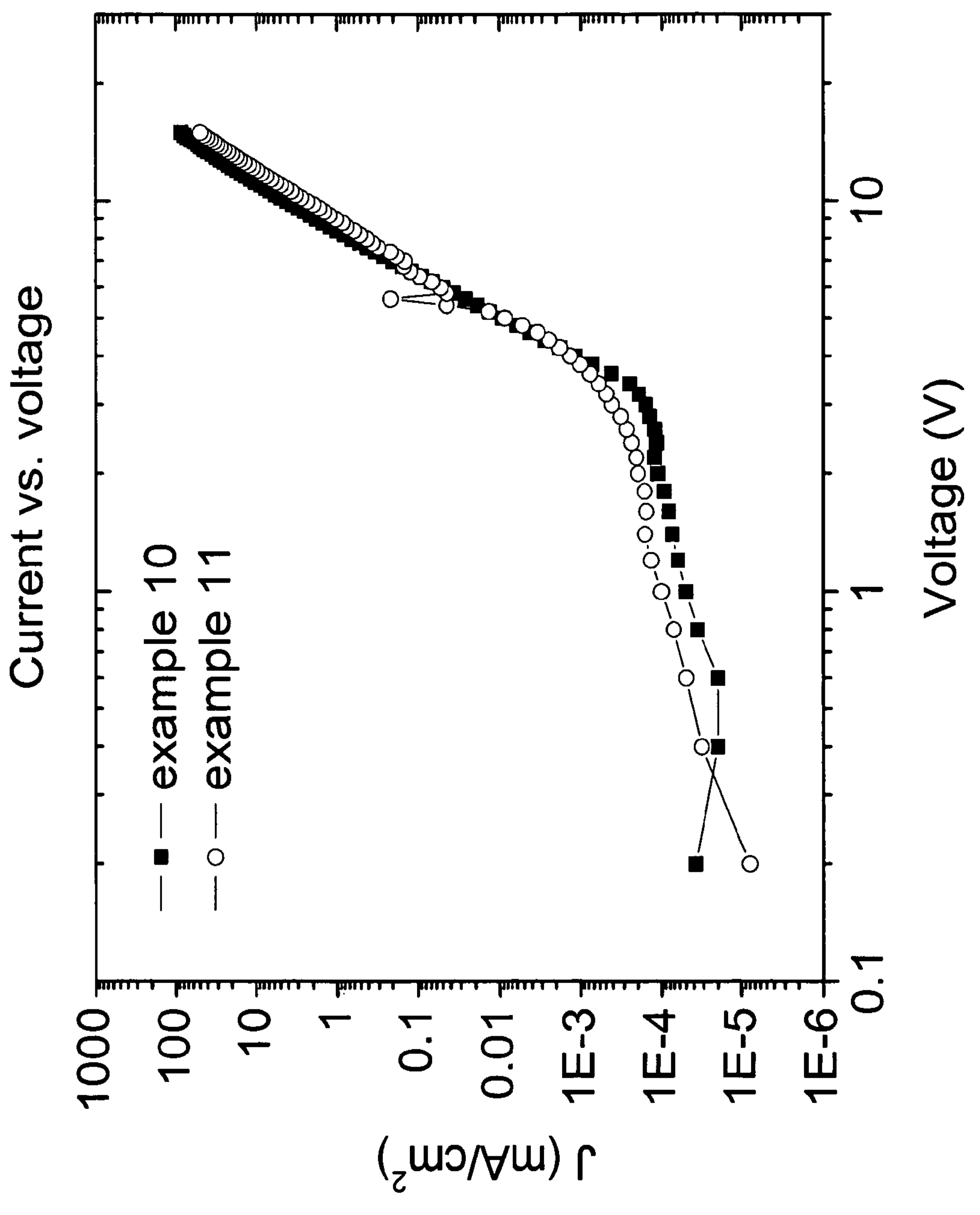

Current vs. voltage
example 10
example 11
J (mA/cm^2)
1000
100
10
1
0.1
0.01
1E-3
1E-4
1E-5
1E-6
0.1
1
10
Voltage (V)

Figure 9

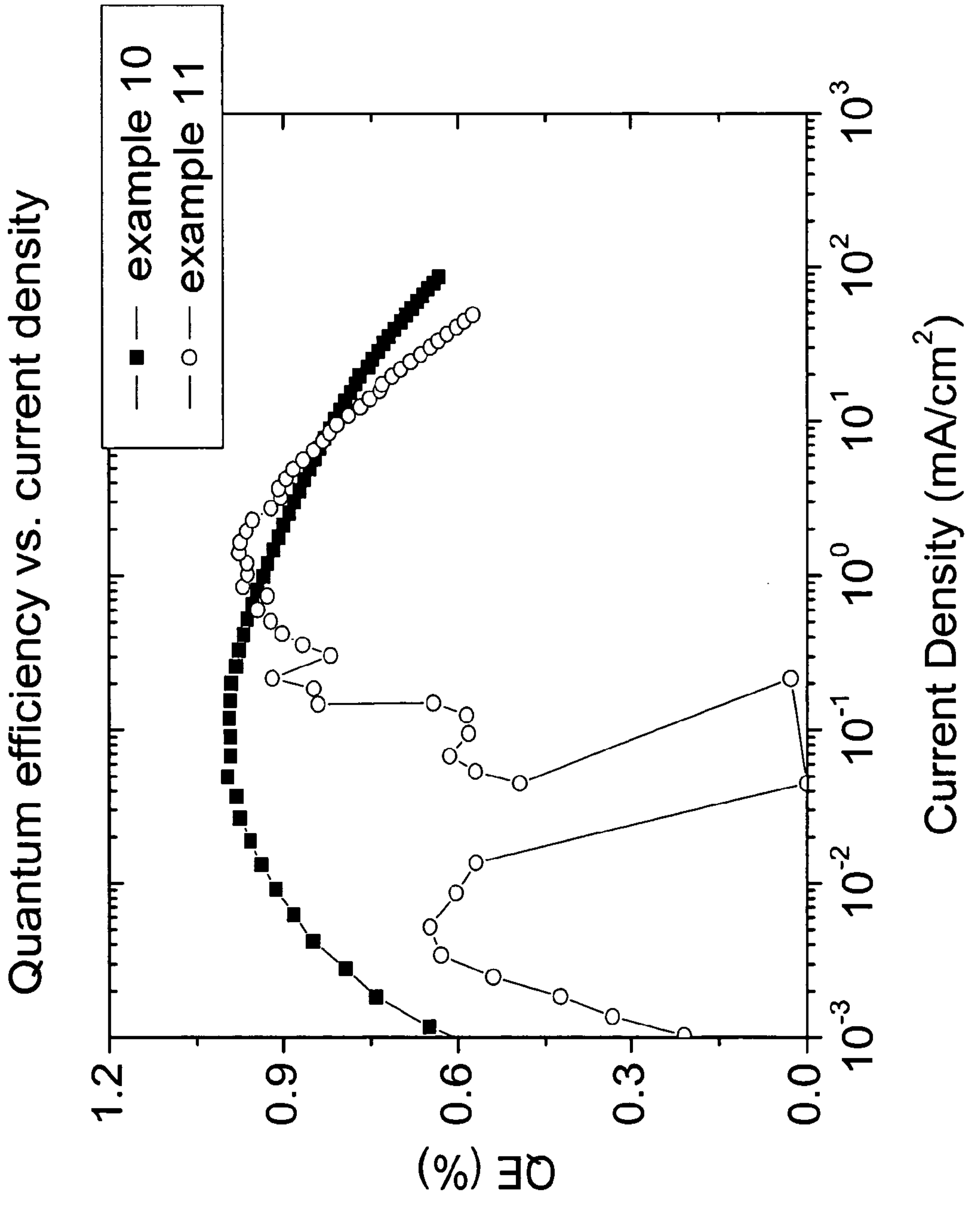

Quantum efficiency vs. current density
example 10
example 11
QE (%)
1.2
0.9
0.6
0.3
0.0
Current Density (mA/cm^2)
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}

Figure 10

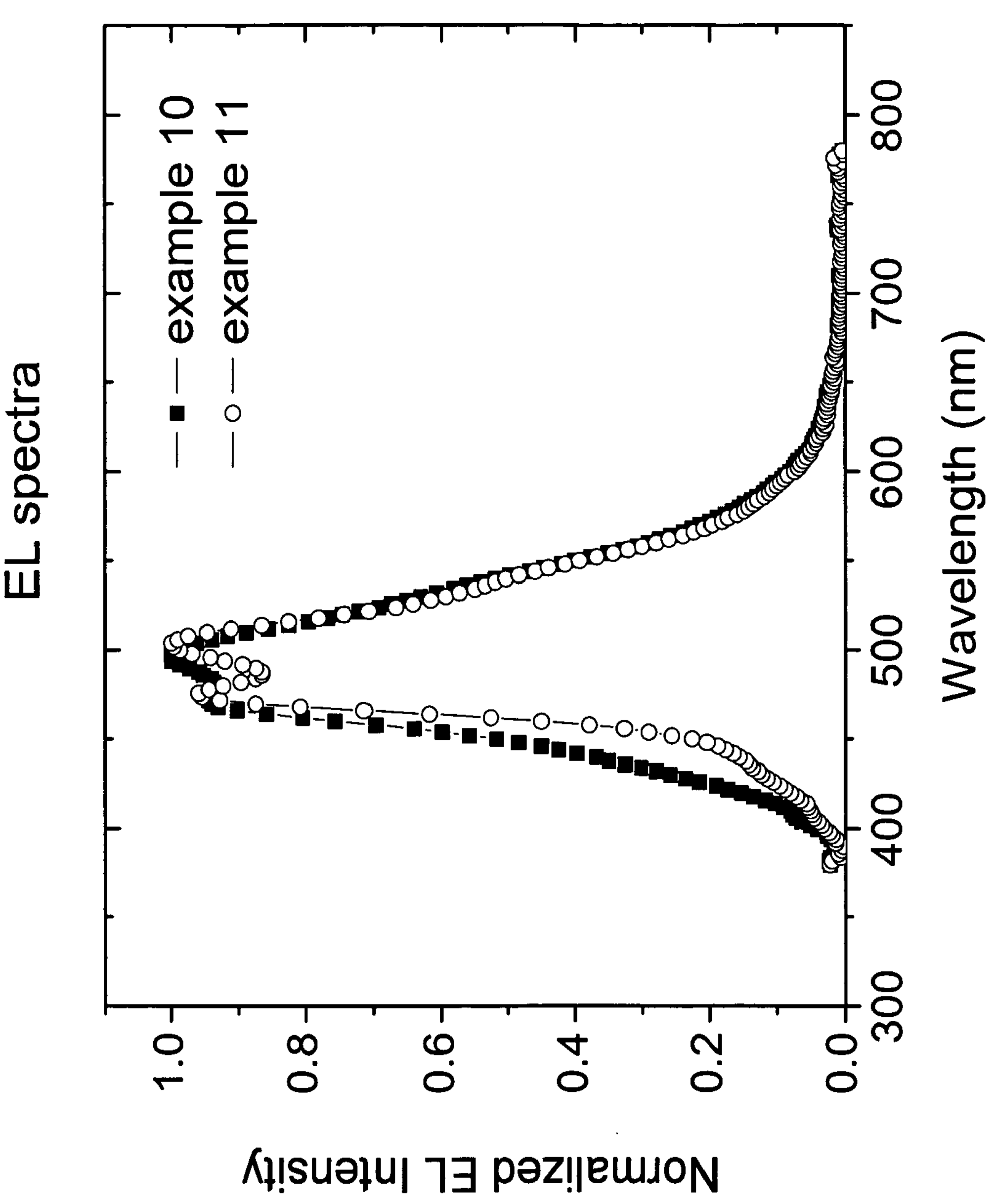

EL spectra
—■— example 10
—○— example 11
Normalized EL Intensity
0.0
0.2
0.4
0.6
0.8
1.0
300
400
500
600
700
800
Wavelength (nm)

Figure 11

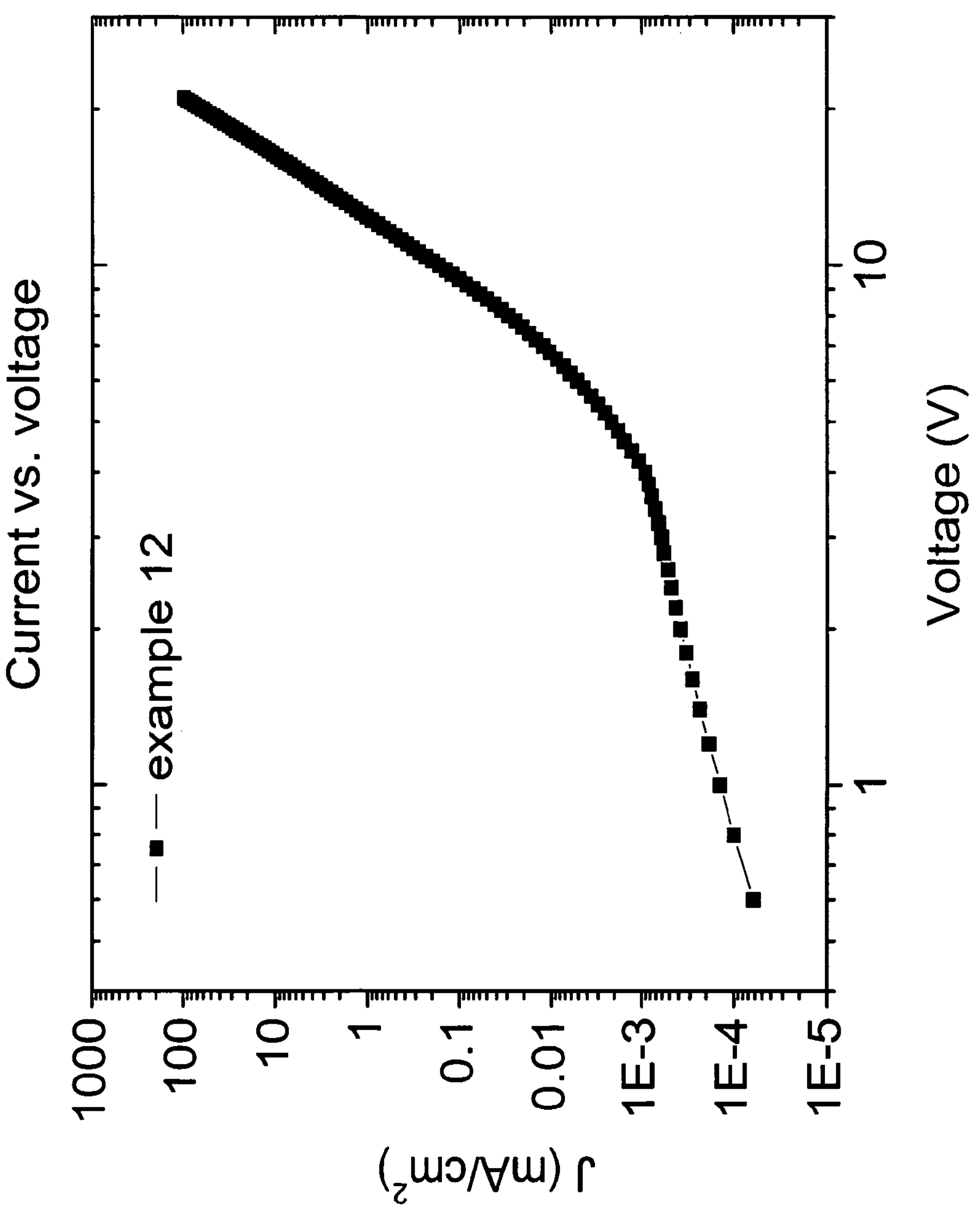

Current vs. voltage
example 12
1000
100
10
1
0.1
0.01
1E-3
1E-4
1E-5
J (mA/cm^2)
1
10
Voltage (V)

Figure 12

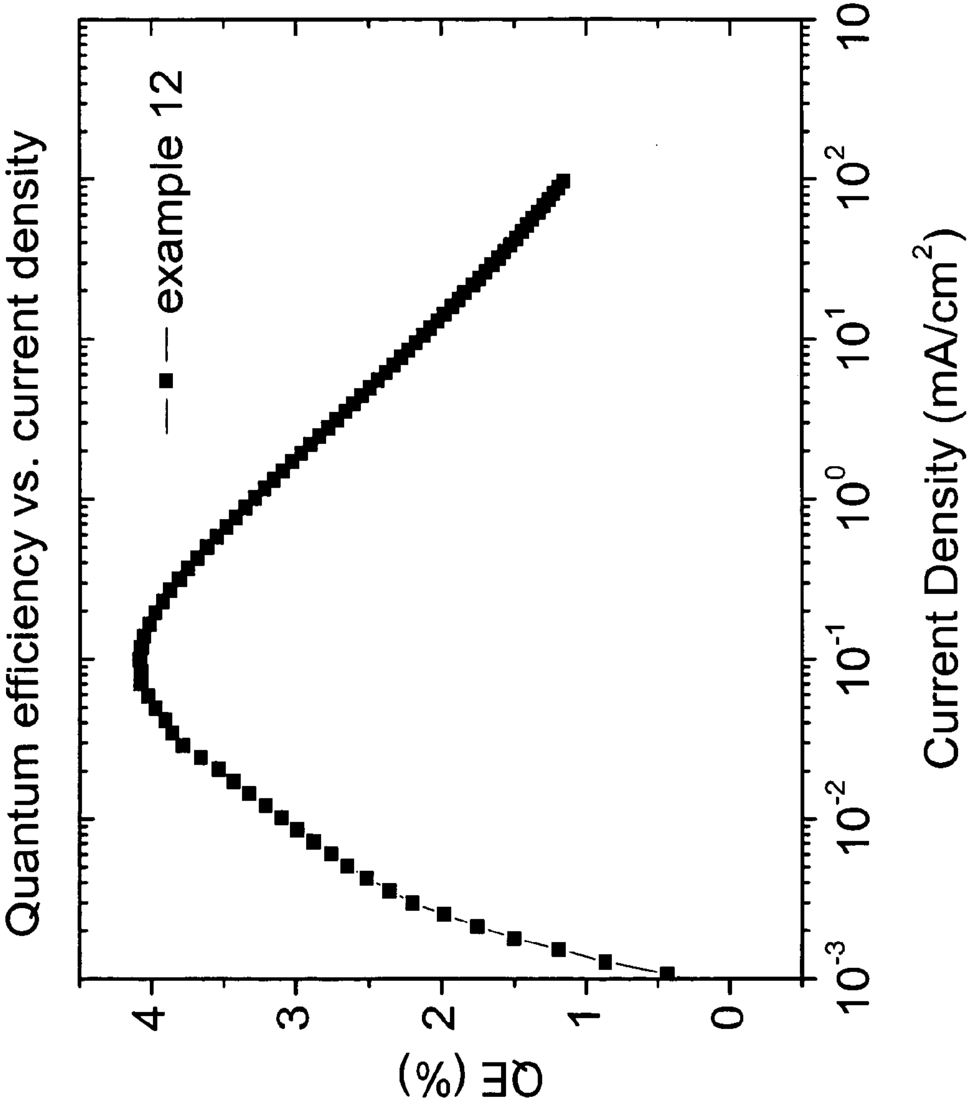

Quantum efficiency vs. current density
—■— example 12
QE (%)
0
1
2
3
4
Current Density (mA/cm^2)
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}

Figure 13

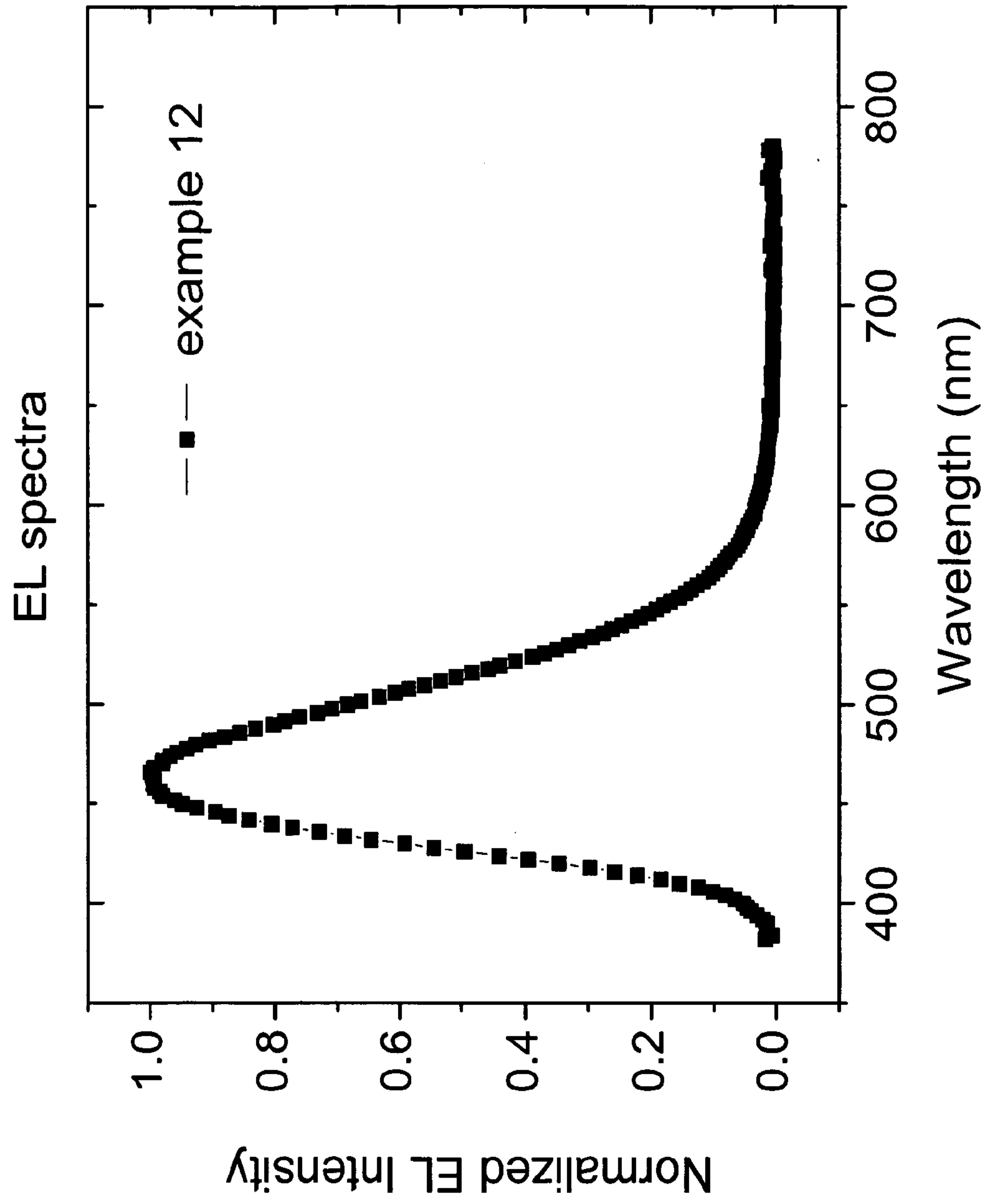

EL spectra
■ example 12
Normalized EL Intensity
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
800
Wavelength (nm)

Figure 14

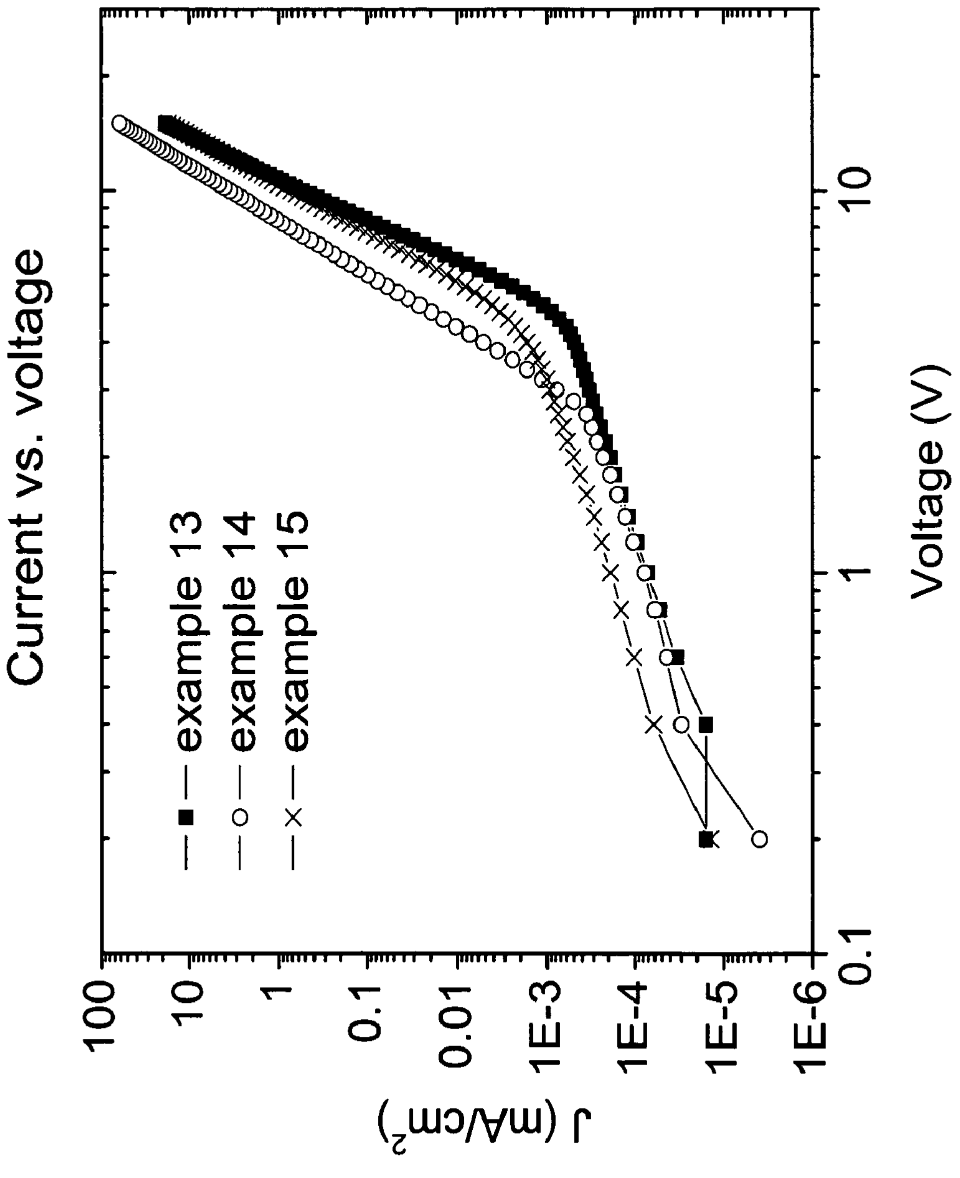

Current vs. voltage
■ example 13
○ example 14
× example 15
J (mA/cm²)
100
10
1
0.1
0.01
1E-3
1E-4
1E-5
1E-6
0.1
1
10
Voltage (V)

Figure 15

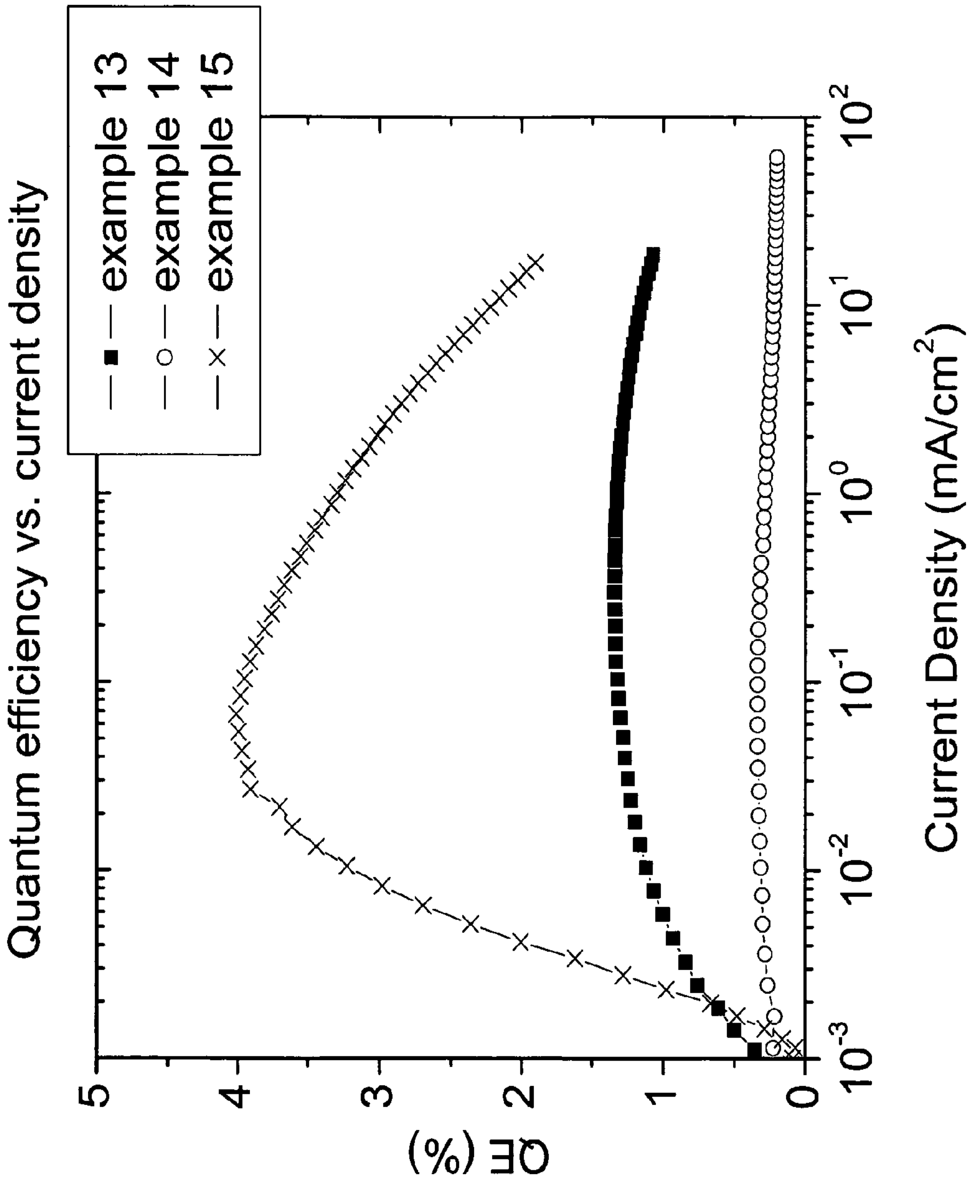

Quantum efficiency vs. current density
—■— example 13
—○— example 14
—×— example 15
QE (%)
0
1
2
3
4
5
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
Current Density (mA/cm^2)

Figure 16

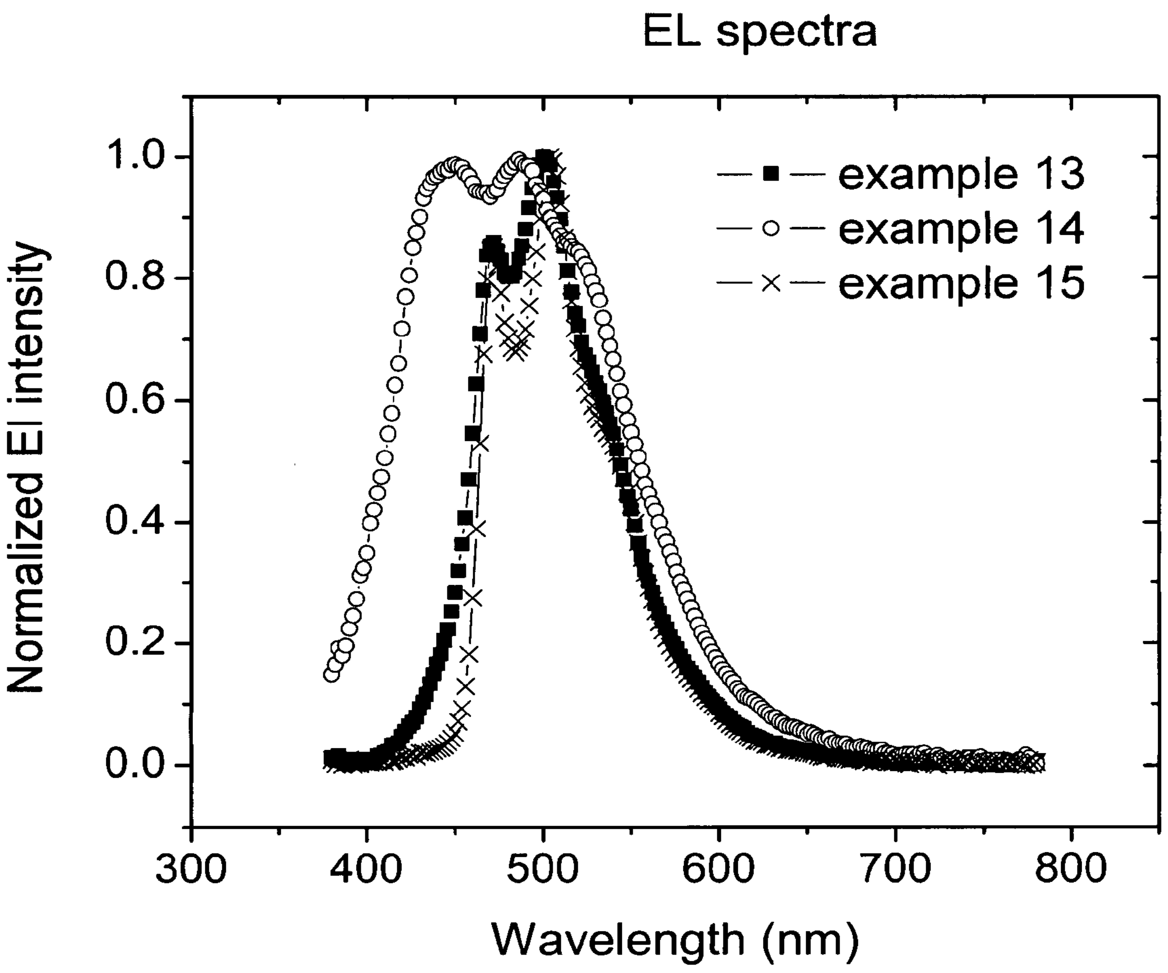

EL spectra
Normalized El intensity
1.0
0.8
0.6
0.4
0.2
0.0
300
400
500
600
700
800
Wavelength (nm)
example 13
example 14
example 15

Figure 17

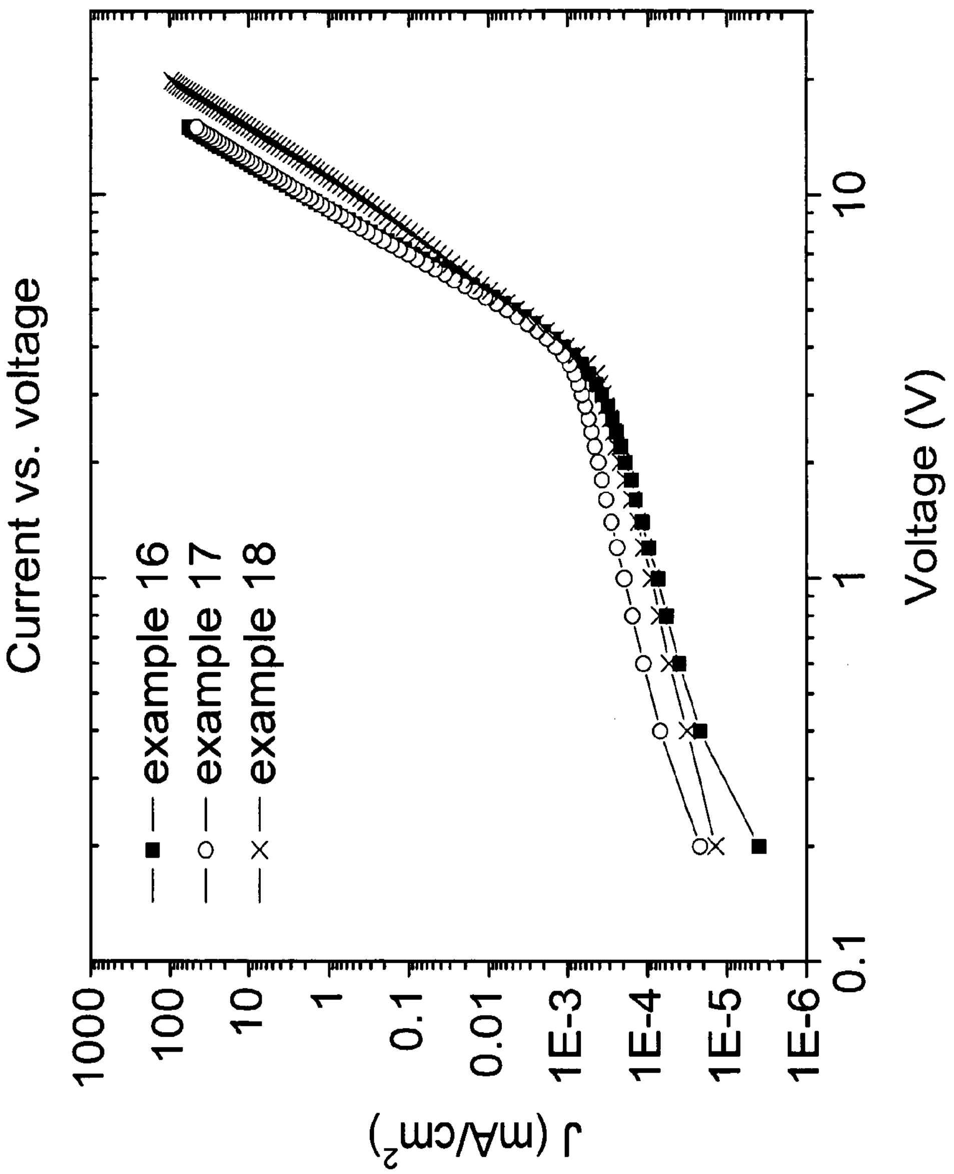

Current vs. voltage
—■— example 16
—○— example 17
—×— example 18
J (mA/cm^2)
1000
100
10
1
0.1
0.01
1E-3
1E-4
1E-5
1E-6
0.1
1
10
Voltage (V)

Figure 18

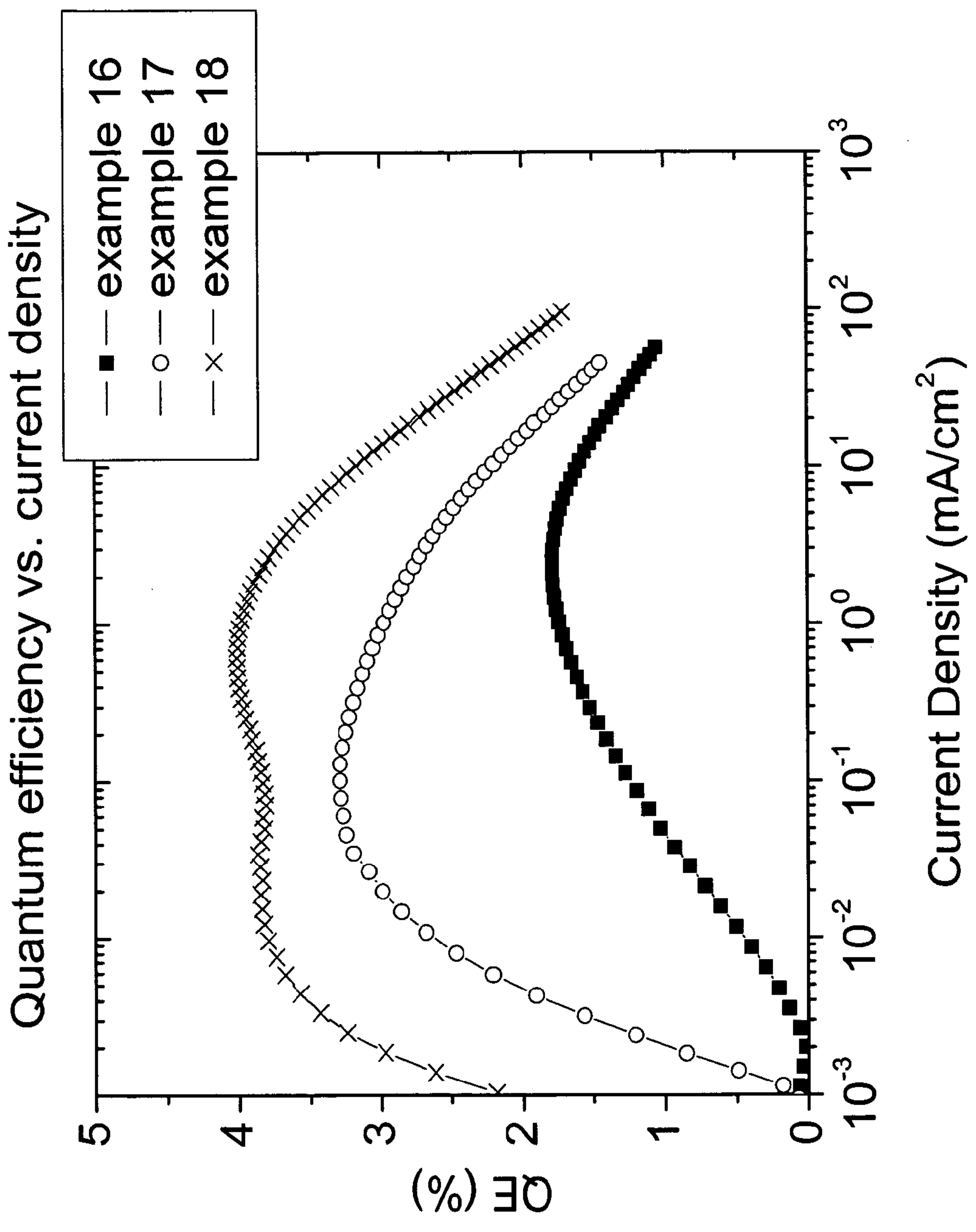

Quantum efficiency vs. current density
—■— example 16
—○— example 17
—×— example 18
QE (%)
0
1
2
3
4
5
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Current Density (mA/cm^2)

Figure 19

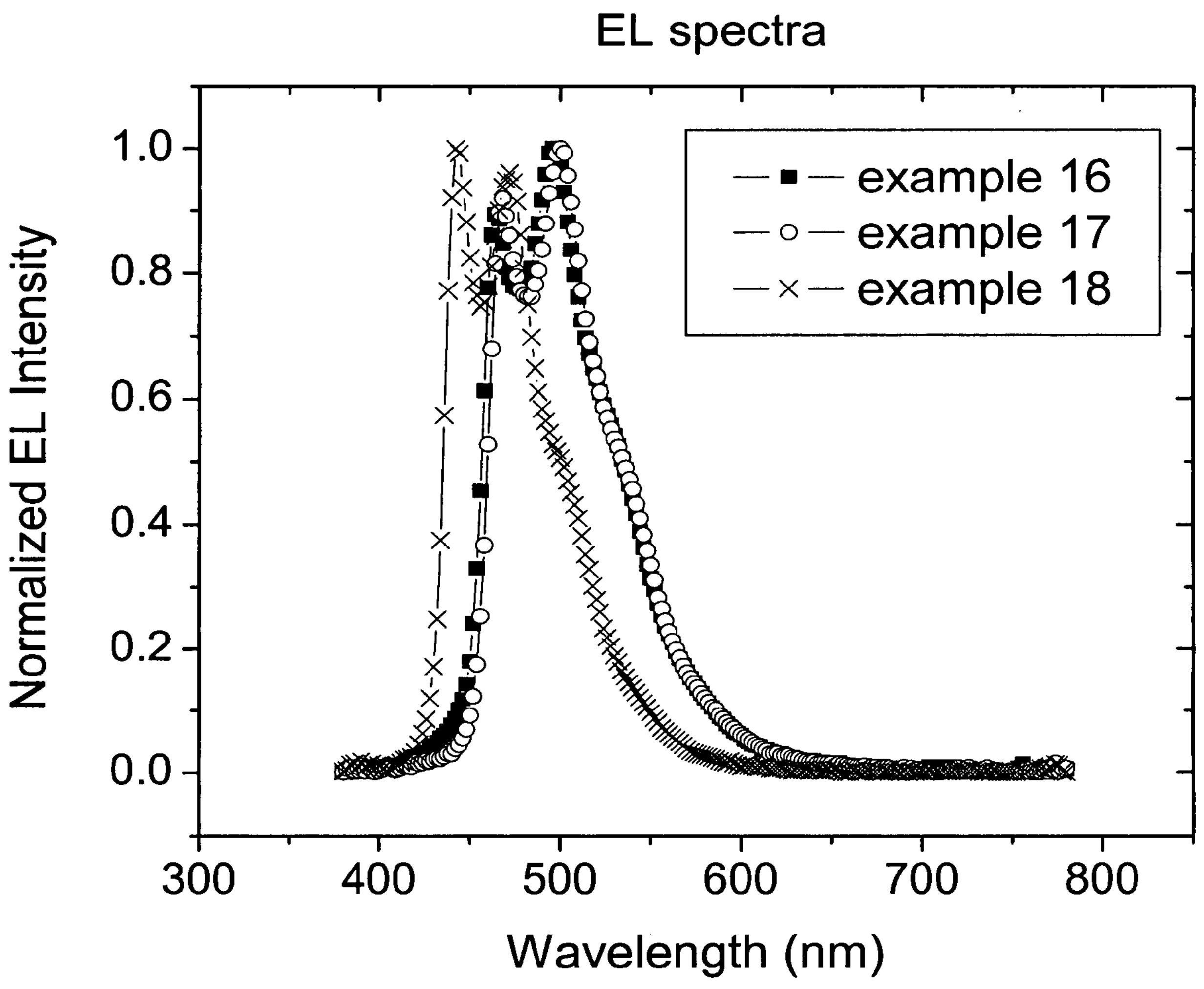

EL spectra
Normalized EL Intensity
1.0
0.8
0.6
0.4
0.2
0.0
300
400
500
600
700
800
Wavelength (nm)
—■— example 16
—○— example 17
—×— example 18

Figure 20

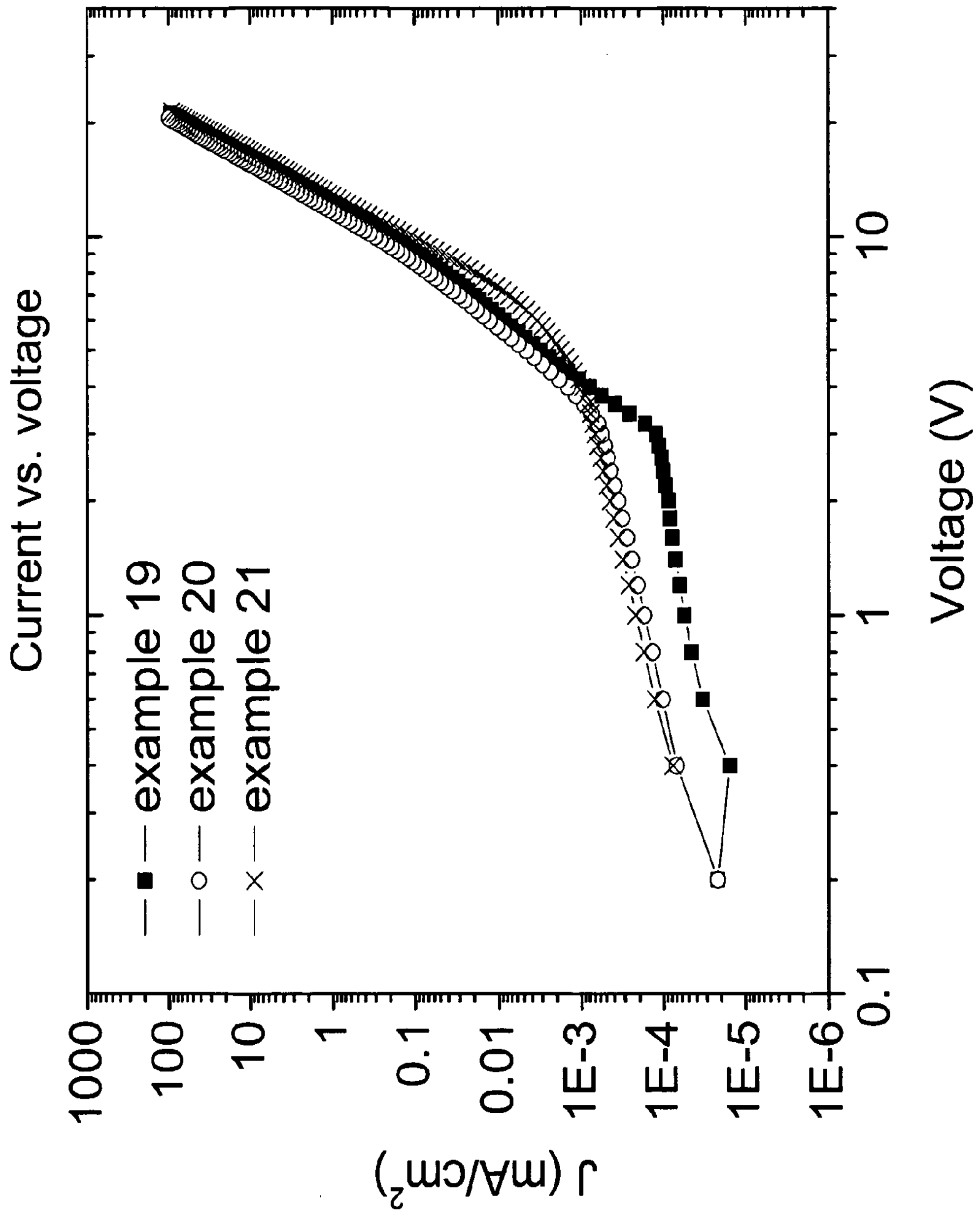

Current vs. voltage
—■— example 19
—○— example 20
—×— example 21
1000
100
10
1
0.1
0.01
1E-3
1E-4
1E-5
1E-6
J (mA/cm^2)
0.1
1
10
Voltage (V)

Figure 21

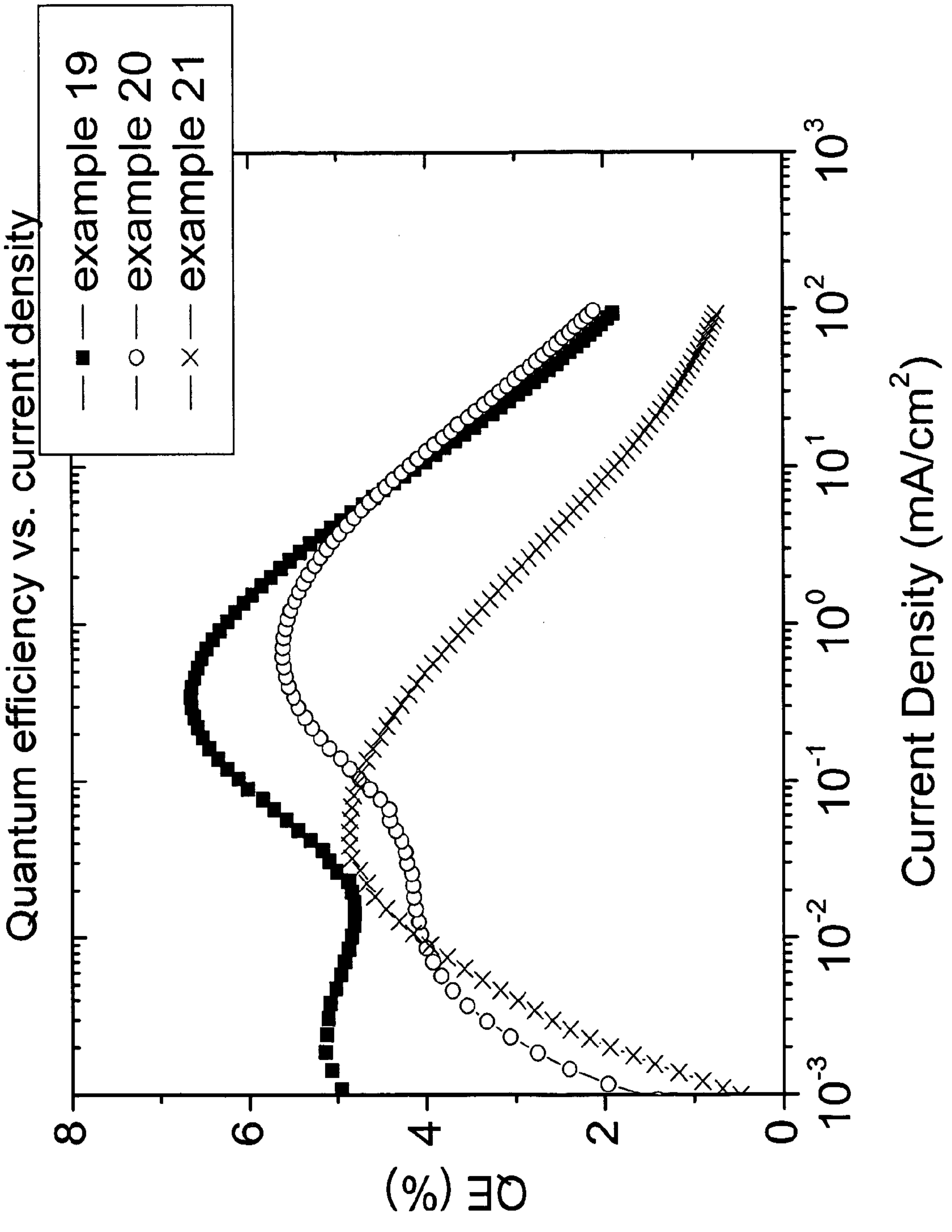

Quantum efficiency vs. current density
—■— example 19
—○— example 20
—×— example 21
QE (%)
0
2
4
6
8
Current Density (mA/cm^2)
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3

Figure 22

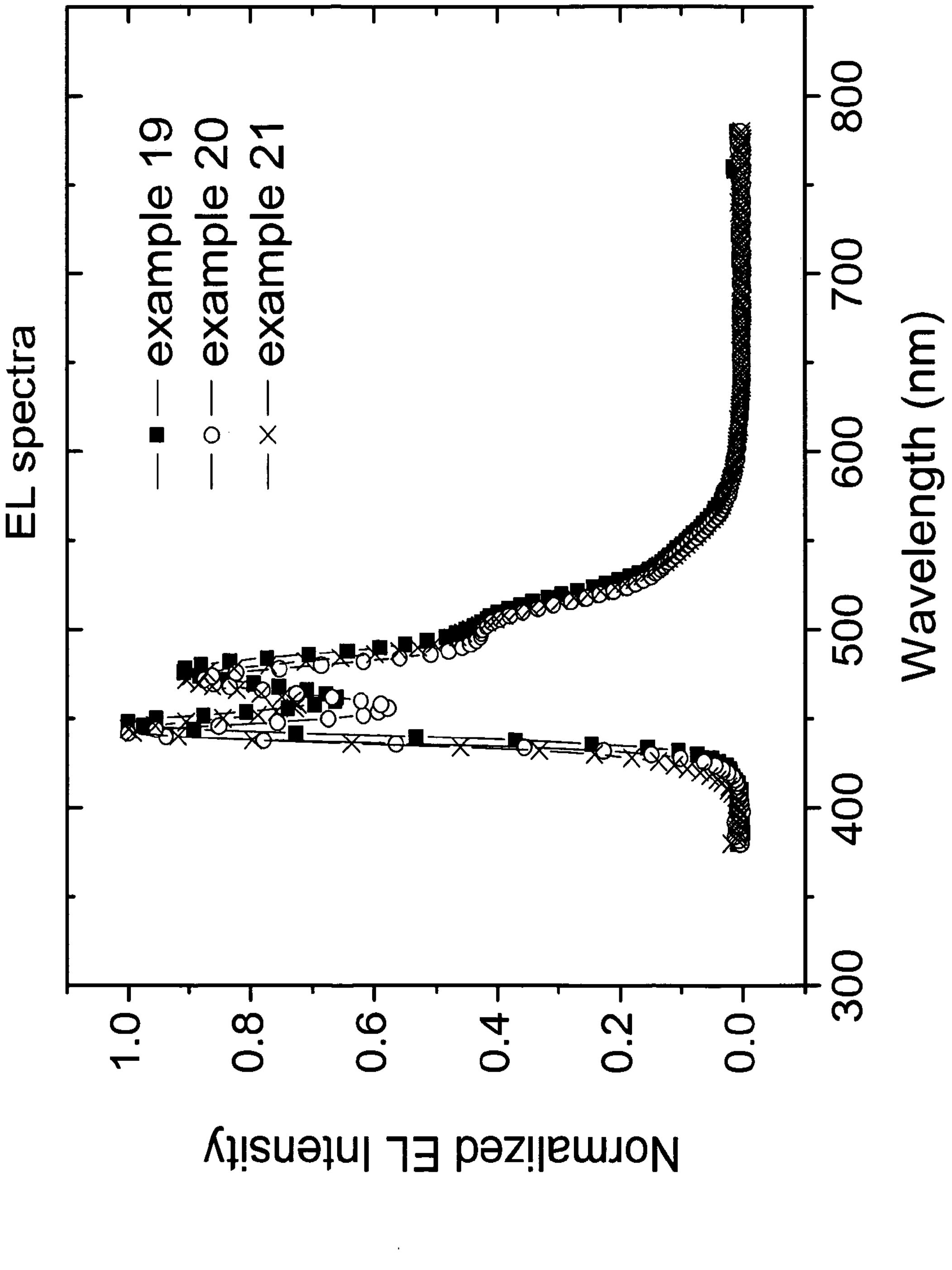

EL spectra
—■— example 19
—○— example 20
—×— example 21
Normalized EL Intensity
1.0
0.8
0.6
0.4
0.2
0.0
Wavelength (nm)
300
400
500
600
700
800

Figure 23

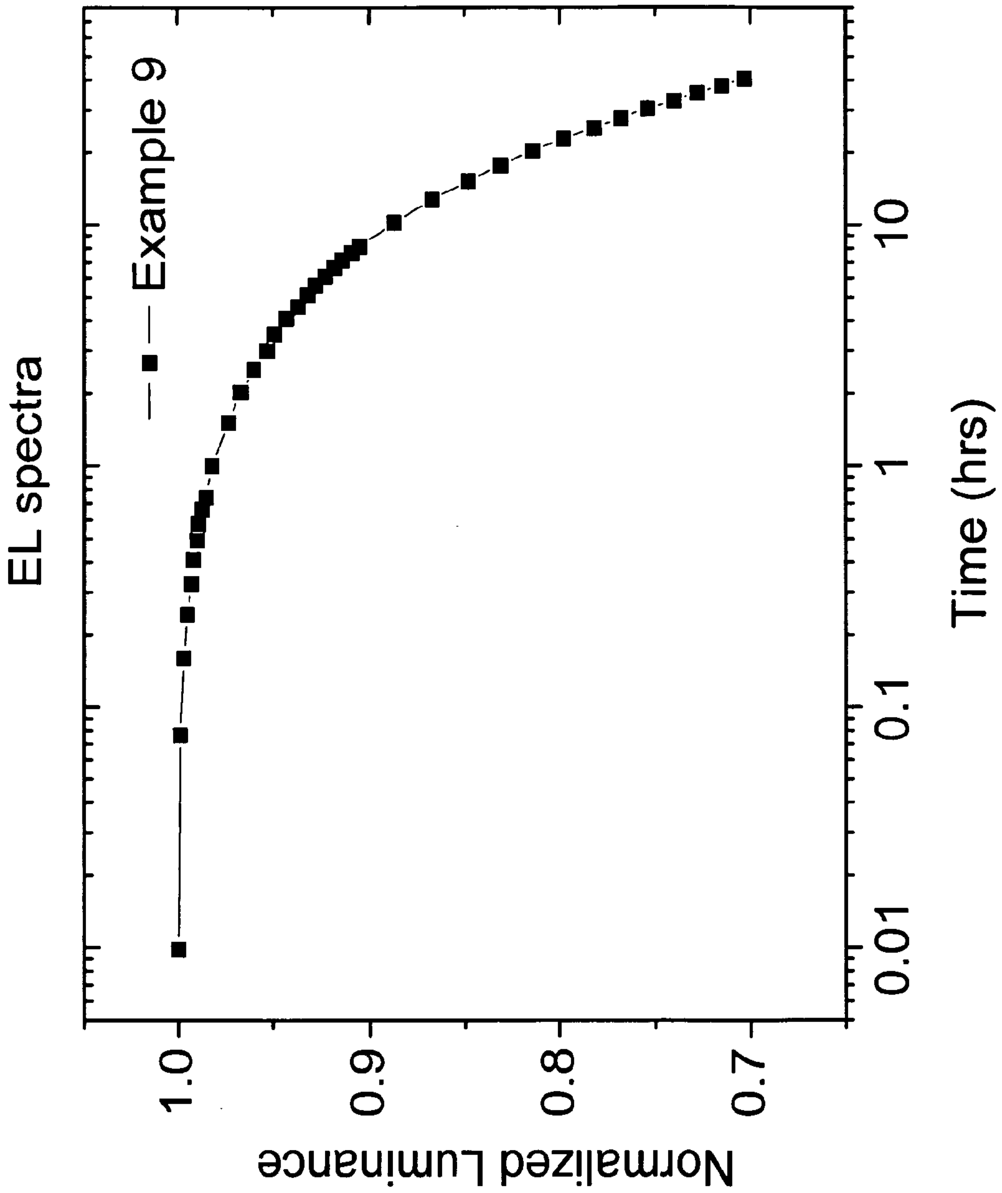

EL spectra
Example 9
Normalized Luminance
1.0
0.9
0.8
0.7
0.01
0.1
1
10
Time (hrs)

Figure 24

NOVEL ORGANOMETALLIC COMPOUNDS FOR USE IN ELECTROLUMINESCENT DEVICES

[0001] This application is a continuation-in-part of U.S. application Ser. No. 10/880,384, filed Jun. 28, 2004, entitled Luminescent Compounds with Carbene Ligands, which is a continuation-in-part of U.S. application Ser. No. 10/849,301, filed May 18, 2004, and both of which are incorporated by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present invention relates to organic light emitting devices (OLEDs), and more specifically to phosphorescent organic materials used in such devices. More specifically, the present invention relates to carbene-metal complexes incorporated into OLEDs.

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] 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. In general, a small molecule has a well-defined chemical formula with a single molecular weight, whereas a polymer has a chemical formula and a molecular weight that may vary from molecule to molecule. As used herein, "organic" includes metal complexes of hydrocarbyl and heteroatom-substituted hydrocarbyl ligands.

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

[0006] OLED devices are generally (but not always) intended to emit light through at least one of the electrodes, and one or more transparent electrodes may be useful in organic opto-electronic devices. For example, a transparent electrode material, such as indium tin oxide (ITO), may be used as the bottom electrode. A transparent top electrode, such as disclosed in U.S. Pat. Nos. 5,703,436 and 5,707,745, which are incorporated by reference in their entireties, may also be used. For a device intended to emit light only through the bottom electrode, the top electrode does not need to be transparent, and may be comprised of a thick and reflective metal layer having a high electrical conductivity. Similarly, for a device intended to emit light only through the top electrode, the bottom electrode may be opaque and/or reflective. Where an electrode does not need to be transparent, using a thicker layer may provide better conductivity, and using a reflective electrode may increase the amount of light emitted through the other electrode, by reflecting light back towards the transparent electrode. Fully transparent devices may also be fabricated, where both electrodes are transparent. Side emitting OLEDs may also be fabricated, and one or both electrodes may be opaque or reflective in such devices.

[0007] As used herein, "top" means furthest away from the substrate, while "bottom" means closest to the substrate. For example, for a device having two electrodes, the bottom electrode is the electrode closest to the substrate, and is generally the first electrode fabricated. The bottom electrode has two surfaces, a bottom surface closest to the substrate, and a top surface further away from 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 physical 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.

[0008] 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.

[0009] 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.

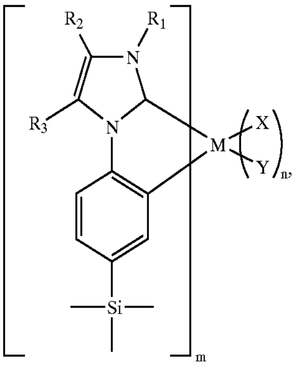
[0010] The carbene ligand has been well known in organometallic chemistry, and is used to generate a wide range of thermally stable catalytic materials. The carbene ligands have been employed both as active groups, directly engaged in the catalytic reactions, and serving a role of stabilizing the metal in a particular oxidation state or coordination geometry. However, applications of carbene ligands are not well known in photochemistry.

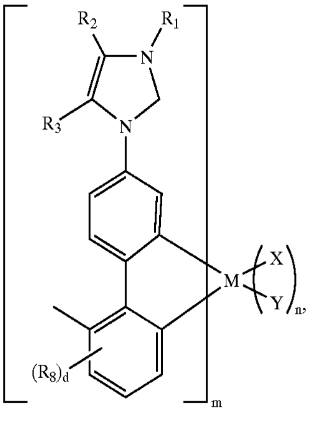
[0011] One issue with many existing organic electroluminescent compounds is that they are not sufficiently stable for use in commercial devices. An object of the invention is to provide a class of organic emissive compounds having improved stability.

[0012] In addition, existing compounds do not include compounds that are stable emitters for high energy spectra, such as a blue spectra. An object of the invention is to provide a class of organic emissive compounds that can emit light with various spectra, including high energy spectra such as blue, in a stable manner.

SUMMARY OF THE INVENTION

[0013] An organic light emitting device is provided. The device has an anode, a cathode and an organic layer disposed between the anode and the cathode. The organic layer comprises a compound further comprising one or more carbene ligands coordinated to a metal center having the following structures:





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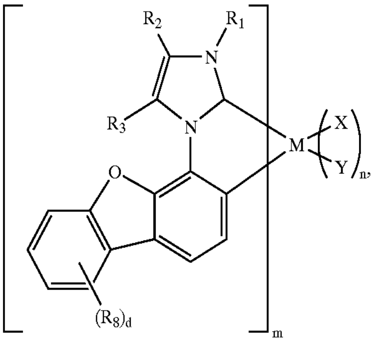
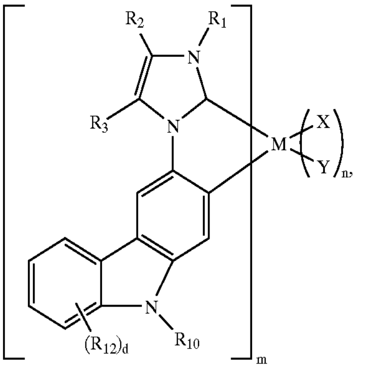
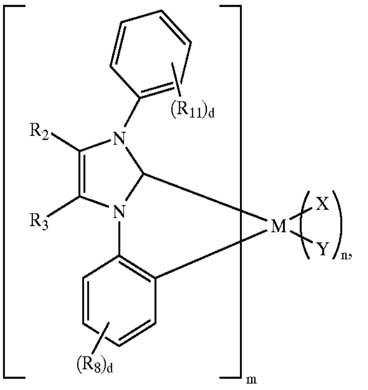
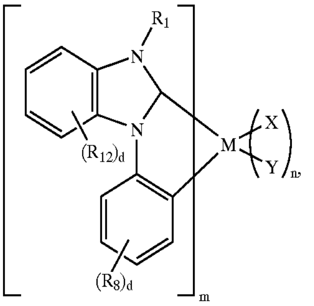
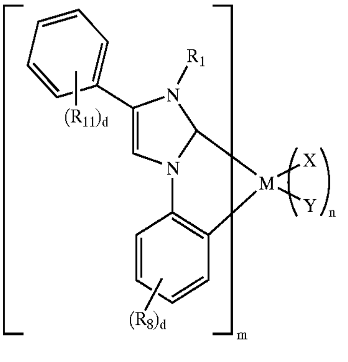








or



[0014] in which M is a metal; R_1 is independently selected from hydrogen, alkyl, alkenyl, alkynyl, aralkyl, aryl, heteroaryl, substituted aryl, substituted heteroaryl, or a heterocyclic group; R_2, R_3, R_8, R_{10}, R_{11}, and R_{12} are independently selected from hydrogen, alkyl, alkenyl, alkynyl, aralkyl, CN, CF_3, CO_2R', C(O)R', C(O)NR'2, NR'2, NO_2, OR', SR', SO_2, SOR', SO_3R', halo, aryl, heteroaryl, substituted aryl, substituted heteroaryl, or a heterocyclic group; and additionally or alternatively, one or more of R_1 and R_2, and R_2 and R_3, and two R_8 groups, two R_{10} groups, and two R_{12} groups on the same ring together form independently a 5 or 6-member cyclic group, wherein said cyclic group is cycloalkyl, cycloheteroalkyl, aryl or heteroaryl; and wherein said cyclic group is optionally substituted by one or more substituents J; each substituent J is independently selected from the group consisting of R', CN, CF_3, C(O)OR', C(O)R', $C(O)NR'_2$, NR'2, NO_2, OR', SR', SO_2, SOR', or SO_3R', and additionally, or alternatively, two J groups on adjacent ring atoms form a fused 5- or 6-membered aromatic group; each R' is independently selected from halo, H, alkyl, alkenyl, alkynyl, heteroalkyl, aralkyl, aryl and heteroaryl; (X—Y) is selected from a photoactive ligand or an ancillary ligand; d is 0, 1, 2, 3, or 4; m is a value from 1 to the maximum number of ligands that may be attached to metal M; m+n is the maximum number of ligands that may be attached to metal M.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] **FIG. 1** shows an organic light emitting device having separate electron transport, hole transport, and emissive layers, as well as other layers.

[0016] **FIG. 2** shows an inverted organic light emitting device that does not have a separate electron transport layer.

[0017] **FIG. 3** shows plots of current vs. voltage for device CuPc(100)/NPD(300)/UGH5: Dopant A (6%, 300)/BAlQ(400) and device CuPc(100)/NPD(300)/UGH5: Dopant B (6%, 300)/BAlQ(400).

[0018] **FIG. 4** shows plots of quantum efficiency vs. current density for device CuPc(100)/NPD(300)/UGH5: Dopant A (6%, 300)/BAlQ(400) and device CuPc(100)/NPD(300)/UGH5: Dopant B (6%, 300)/BAlQ(400).

[0019] **FIG. 5** shows plots of the electroluminescent spectra of device CuPc(100)/NPD(300)/UGH5: Dopant A (6%, 300)/BAlQ(400) and device CuPc(100)/NPD(300)/UGH5: Dopant B (6%, 300)/BAlQ(400).

[0020] **FIG. 6** shows plots of current vs. voltage for device CuPc(100)/NPD(300)/mCBP: Dopant C (6%, 300)/BAlQ(400) and device CuPc(100)/NPD(300)/mCBP-:Dopant D (6%, 300)/BAlQ(400).

[0021] **FIG. 7** shows plots of quantum efficiency vs. current density for device CuPc(100)/NPD(300)/mCBP: Dopant C (6%, 300)/BAlQ(400) and device CuPc(100)/NPD(300)/mCBP: Dopant D (6%, 300)/BAlQ(400).

[0022] **FIG. 8** shows plots of the electroluminescent spectra of device CuPc(100)/NPD(300)/mCBP: Dopant C (6%, 300)/BAlQ(400) and device CuPc(100)/NPD(300)/mCBP: Dopant D (6%, 300)/BAlQ(400).

[0023] **FIG. 9** shows plots of current vs. voltage for device CuPc(100)/NPD(300)/mCBP: Dopant E (300, 6%)/BAlQ(400) and device CuPc(100)/NPD(300)/mCBP: Dopant F (300, 6%)/BAlQ(400).

[0024] **FIG. 10** shows plots of quantum efficiency vs. current density for device CuPc(100)/NPD(300)/mCBP: Dopant E (300, 6%)/BAlQ(400) and device CuPc(100)/NPD(300)/mCBP: Dopant F (300, 6%)/BAlQ(400).

[0025] **FIG. 11** shows plots of the electroluminescent spectra of device CuPc(100)/NPD(300)/mCBP: Dopant E (300, 6%)/BAlQ(400) and device CuPc(100)/NPD(300)/mCBP: Dopant F (300, 6%)/BAlQ(400).

[0026] **FIG. 12** shows plots of current vs. voltage for device CuPc(1 00)/NPD(300)/UGH5: Dopant G (6%, 300)/BAlQ(400).

[0027] **FIG. 13** shows plots of quantum efficiency vs. current density for CuPc(100)/NPD(300)/UGH5: Dopant G (6%, 300)/BAlQ(400).

[0028] **FIG. 14** shows plots of the electroluminescent spectra of CuPc(100)/NPD(300)/UGH5: Dopant G (6%, 300)/BAlQ(400).

[0029] **FIG. 15** shows plots of current vs. voltage for device CuPc(100)/NPD(300)/mCP: Dopant H (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/CBP-:dopant132(6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/mCBP:dopant130(6%, 300)/BAlQ(400).

[0030] **FIG. 16** shows plots of quantum efficiency vs. current density for device CuPc(100)/NPD(300)/mCP: Dopant H (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/CBP: Dopant I (6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/mCBP: Dopant J (6%, 300)/BAlQ(400).

[0031] **FIG. 17** shows plots of the electroluminescent spectra of device CuPc(100)/NPD(300)/mCP: Dopant H (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/CBP: Dopant I (6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/mCBP: Dopant J (6%, 300)/BAlQ(400).

[0032] **FIG. 18** shows plots of current vs. voltage for device CuPc(100)/NPD(300)/mCBP: Dopant K (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/mCBP: Dopant L (6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/UGH5: Dopant M (6%, 300)/BAlQ(400).

[0033] **FIG. 19** shows plots of quantum efficiency vs. current density for device CuPc(100)/NPD(300)/mCBP: Dopant K (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/mCBP: Dopant L (6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/UGH5: Dopant M (6%, 300)/BAlQ(400).

[0034] **FIG. 20** shows plots of the electroluminescent spectra of device CuPc(100)/NPD(300)/mCBP: Dopant K (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/mCBP: Dopant L (6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/UGH5: Dopant M (6%, 300)/BAlQ(400).

[0035] **FIG. 21** shows plots of current vs. voltage for device CuPc(100)/NPD(300)/UGH5: Dopant N (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/UGH5: Dopant O (6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/UGH5: Dopant P (6%, 300)/BAlQ(400).

[**0036**] **FIG. 22** shows plots of quantum efficiency vs. current density for device CuPc(100)/NPD(300)/UGH5: Dopant N (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/UGH5: Dopant O (6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/UGH5: Dopant P (6%, 300)/BAlQ(400).

[**0037**] **FIG. 23** shows plots of the electroluminescent spectra of device CuPc(100)/NPD(300)/UGH5: Dopant N (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/UGH5: Dopant O (6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/UGH5: Dopant P (6%, 300)/BAlQ(400).

[**0038**] **FIG. 24** shows plots of the plot of operation lifetime of device CuPc(100)/NPD(300)/UGH5: Dopant D (6%, 300)/BAlQ(400).

DETAILED DESCRIPTION

[**0039**] 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.

[**0040**] 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.

[**0041**] 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 may be referred to as a "forbidden" transition because the transition requires a change in spin states, and quantum mechanics indicates that such a transition is not favored. As a result, phosphorescence generally occurs in a time frame exceeding at least 10 nanoseconds, and typically greater than 100 nanoseconds. If the natural radiative lifetime of phosphorescence is too long, triplets may decay by a non-radiative mechanism, such that no light is emitted. Organic phosphorescence is also often observed in molecules containing heteroatoms with unshared pairs of electrons at very low temperatures. 2,2'-bipyridine is such a molecule. Non-radiative decay mechanisms are typically temperature dependent, such that an organic material that exhibits phosphorescence at liquid nitrogen temperatures typically does not exhibit phosphorescence at room temperature. But, as demonstrated by Baldo, this problem may be addressed by selecting phosphorescent compounds that do phosphoresce at room temperature. Representative emissive layers include doped or un-doped phosphorescent organo-metallic materials such as disclosed in U.S. Pat. Nos. 6,303,238 and 6,310,360; U.S. Patent Application Publication Nos. 2002-0034656; 2002-0182441; 2003-0072964; and WO-02/074015.

[**0042**] Generally, the excitons in an OLED are believed to be created in a ratio of about 3:1, i.e., approximately 75% triplets and 25% singlets. See, Adachi et al., "Nearly 100% Internal Phosphorescent Efficiency In An Organic Light Emitting Device," J. Appl. Phys., 90, 5048 (2001), which is incorporated by reference in its entirety. In many cases, singlet excitons may readily transfer their energy to triplet excited states via "intersystem crossing," whereas triplet excitons may not readily transfer their energy to singlet excited states. As a result, 100% internal quantum efficiency is theoretically possible with phosphorescent OLEDs. In a fluorescent device, the energy of triplet excitons is generally lost to radiationless decay processes that heat-up the device, resulting in much lower internal quantum efficiencies. OLEDs utilizing phosphorescent materials that emit from triplet excited states are disclosed, for example, in U.S. Pat. No. 6,303,238, which is incorporated by reference in its entirety.

[**0043**] Phosphorescence may be preceded by a transition from a triplet excited state to an intermediate non-triplet state from which the emissive decay occurs. For example, organic molecules coordinated to lanthanide elements often phosphoresce from excited states localized on the lanthanide metal. However, such materials do not phosphoresce directly from a triplet excited state but instead emit from an atomic excited state centered on the lanthanide metal ion. The europium diketonate complexes illustrate one group of these types of species.

[**0044**] Phosphorescence from triplets can be enhanced over fluorescence by confining, preferably through bonding, the organic molecule in close proximity to an atom of high atomic number. This phenomenon, called the heavy atom effect, is created by a mechanism known as spin-orbit coupling. Such a phosphorescent transition may be observed from an excited metal-to-ligand charge transfer (MLCT) state of an organometallic molecule such as tris(2-phenylpyridine)iridium(III).

[**0045**] As used herein, the term "triplet energy" refers to an energy corresponding to the highest energy feature discernable in the phosphorescence spectrum of a given material. The highest energy feature is not necessarily the peak having the greatest intensity in the phosphorescence spectrum, and could, for example, be a local maximum of a clear shoulder on the high energy side of such a peak.

[**0046**] The term "organometallic" as used herein is as generally understood by one of ordinary skill in the art and as given, for example, in "Inorganic Chemistry" (2nd Edition) by Gary L. Miessler and Donald A. Tarr, Prentice Hall (1998). Thus, the term organometallic refers to compounds which have an organic group bonded to a metal through a carbon-metal bond. This class does not include per se coordination compounds, which are substances having only donor bonds from heteroatoms, such as metal complexes of amines, halides, pseudohalides (CN, etc.), and the like. In practice, organometallic compounds generally comprise, in addition to one or more carbon-metal bonds to an organic species, one or more donor bonds from a heteroatom. The carbon-metal bond to an organic species refers to a direct bond between a metal and a carbon atom of an organic group, such as phenyl, alkyl, alkenyl, etc., but does not refer to a metal bond to an "inorganic carbon," such as the carbon of CN or CO.

[0047] **FIG. 1** shows an organic light emitting device **100**. The figures are not necessarily drawn to scale. Device **100** may include a substrate **110**, an anode **115**, a hole injection layer **120**, a hole transport layer **125**, an electron blocking layer **130**, an emissive layer **135**, a hole blocking layer **140**, an electron transport layer **145**, an electron injection layer **150**, a protective layer **155**, and a cathode **160**. Cathode **160** is a compound cathode having a first conductive layer **162** and a second conductive layer **164**. Device **100** may be fabricated by depositing the layers described, in order.

[0048] Substrate **110** may be any suitable substrate that provides desired structural properties. Substrate **110** may be flexible or rigid. Substrate **110** may be transparent, translucent or opaque. Plastic and glass are examples of preferred rigid substrate materials. Plastic and metal foils are examples of preferred flexible substrate materials. Substrate **110** may be a semiconductor material in order to facilitate the fabrication of circuitry. For example, substrate **110** may be a silicon wafer upon which circuits are fabricated, capable of controlling OLEDs subsequently deposited on the substrate. Other substrates may be used. The material and thickness of substrate **110** may be chosen to obtain desired structural and optical properties.

[0049] Anode **115** may be any suitable anode that is sufficiently conductive to transport holes to the organic layers. The material of anode **115** preferably has a work function higher than about 4 eV (a "high work function material"). Preferred anode materials include conductive metal oxides, such as indium tin oxide (ITO) and indium zinc oxide (IZO), aluminum zinc oxide (AlZnO), and metals. Anode **115** (and substrate **110**) may be sufficiently transparent to create a bottom-emitting device. A preferred transparent substrate and anode combination is commercially available ITO (anode) deposited on glass or plastic (substrate). A flexible and transparent substrate-anode combination is disclosed in U.S. Pat. Nos. 5,844,363 and 6,602,540 B2, which are incorporated by reference in their entireties. Anode **115** may be opaque and/or reflective. A reflective anode **115** may be preferred for some top-emitting devices, to increase the amount of light emitted from the top of the device. The material and thickness of anode **115** may be chosen to obtain desired conductive and optical properties. Where anode **115** is transparent, there may be a range of thickness for a particular material that is thick enough to provide the desired conductivity, yet thin enough to provide the desired degree of transparency. Other anode materials and structures may be used.

[0050] Hole transport layer **125** may include a material capable of transporting holes. Hole transport layer **130** may be intrinsic (undoped), or doped. Doping may be used to enhance conductivity. α-NPD and TPD are examples of intrinsic hole transport layers. An example of a p-doped hole transport layer is m-MTDATA doped with F_4-TCNQ at a molar ratio of 50:1, as disclosed in U.S. patent application Publication No. 2002-0071963 A1 to Forrest et al., which is incorporated by reference in its entirety. Other hole transport layers may be used.

[0051] Emissive layer **135** may include an organic material capable of emitting light when a current is passed between anode **115** and cathode **160**. Preferably, emissive layer **135** contains a phosphorescent emissive material, although fluorescent emissive materials may also be used. Phosphorescent materials are preferred because of the higher luminescent efficiencies associated with such materials. Emissive layer **135** may also comprise a host material capable of transporting electrons and/or holes, doped with an emissive material that may trap electrons, holes, and/or excitons, such that excitons relax from the emissive material via a photoemissive mechanism. Emissive layer **135** may comprise a single material that combines transport and emissive properties. Whether the emissive material is a dopant or a major constituent, emissive layer **135** may comprise other materials, such as dopants that tune the emission of the emissive material. Emissive layer **135** may include a plurality of emissive materials capable of, in combination, emitting a desired spectrum of light. Examples of phosphorescent emissive materials include $Ir(ppy)_3$. Examples of fluorescent emissive materials include DCM and DMQA. Examples of host materials include Alq_3, CBP and mCP. 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. Emissive material may be included in emissive layer **135** in a number of ways. For example, an emissive small molecule may be incorporated into a polymer. This may be accomplished by several ways: by doping the small molecule into the polymer either as a separate and distinct molecular species; or by incorporating the small molecule into the backbone of the polymer, so as to form a co-polymer; or by bonding the small molecule as a pendant group on the polymer. Other emissive layer materials and structures may be used. For example, a small molecule emissive material may be present as the core of a dendrimer.

[0052] Many useful emissive materials include one or more ligands bound to a metal center. A ligand may be referred to as "photoactive" if it contributes directly to the luminescent properties of an organometallic emissive material. A "photoactive" ligand may provide, in conjunction with a metal, the energy levels from which and to which an electron moves when a photon is emitted. Other ligands may be referred to as "ancillary." Ancillary ligands may modify the photoactive properties of the molecule, for example by shifting the energy levels of a photoactive ligand, but ancillary ligands do not directly provide the energy levels directly involved in light emission. A ligand that is photoactive in one molecule may be ancillary in another. These definitions of photoactive and ancillary are intended as non-limiting theories.

[0053] Electron transport layer **145** may include a material capable of transporting electrons. Electron transport layer **145** may be intrinsic (undoped), or doped. Doping may be used to enhance conductivity. Alq_3 is an example of an intrinsic electron transport layer. 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. 2002-0071963 A1 to Forrest et al., which is incorporated by reference in its entirety. Other electron transport layers may be used.

[0054] The charge carrying component of the electron transport layer may be selected such that electrons can be efficiently injected from the cathode into the LUMO (Lowest Unoccupied Molecular Orbital) energy level of the electron transport layer. The "charge carrying component" is the material responsible for the LUMO energy level that actually transports electrons. This component may be the base material, or it may be a dopant. The LUMO energy level of an organic material may be generally characterized by the electron affinity of that material and the relative electron injection efficiency of a cathode may be generally characterized in terms of the work function of the cathode material. This means that the preferred properties of an electron transport layer and the adjacent cathode may be specified in terms of the electron affinity of the charge carrying component of the ETL and the work function of the cathode material. In particular, so as to achieve high electron injection efficiency, the work function of the cathode material is preferably not greater than the electron affinity of the charge carrying component of the electron transport layer by more than about 0.75 eV, more preferably, by not more than about 0.5 eV. Similar considerations apply to any layer into which electrons are being injected.

[0055] Cathode **160** may be any suitable material or combination of materials known to the art, such that cathode **160** is capable of conducting electrons and injecting them into the organic layers of device **100**. Cathode **160** may be transparent or opaque, and may be reflective. Metals and metal oxides are examples of suitable cathode materials. Cathode **160** may be a single layer, or may have a compound structure. **FIG. 1** shows a compound cathode **160** having a thin metal layer **162** and a thicker conductive metal oxide layer **164**. In a compound cathode, preferred materials for the thicker layer **164** include ITO, IZO, and other materials known to the art. U.S. Pat. Nos. 5,703,436, 5,707,745, 6,548,956 B2, and 6,576,134 B2, 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 part of cathode **160** that is in contact with the underlying organic layer, whether it is a single layer cathode **160**, the thin metal layer **162** of a compound cathode, or some other part, is preferably made of a material having a work function lower than about 4 eV (a "low work function material"). Other cathode materials and structures may be used.

[0056] Blocking layers may be used to reduce the number of charge carriers (electrons or holes) and/or excitons that leave the emissive layer. An electron blocking layer **130** may be disposed between emissive layer **135** and the hole transport layer **125**, to block electrons from leaving emissive layer **135** in the direction of hole transport layer **125**. Similarly, a hole blocking layer **140** may be disposed between emissive layer **135** and electron transport layer **145**, to block holes from leaving emissive layer **135** in the direction of electron transport layer **145**. Blocking layers may also be used to block excitons from diffusing out of the emissive 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. 2002-0071963 A1 to Forrest et al., which are incorporated by reference in their entireties.

[0057] As used herein, and as would be understood by one of skill in the art, the term "blocking layer" means that the layer provides a barrier that significantly inhibits transport of charge carriers and/or excitons through the device, without suggesting that the layer necessarily completely blocks the charge carriers and/or excitons. 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.

[0058] Generally, injection layers are comprised of a material that may improve the injection of charge carriers from one layer, such as an electrode or an organic layer, into an adjacent organic layer. Injection layers may also perform a charge transport function. In device **100**, hole injection layer **120** may be any layer that improves the injection of holes from anode **115** into hole transport layer **125**. CuPc is an example of a material that may be used as a hole injection layer from an ITO anode **115**, and other anodes. In device **100**, electron injection layer **150** may be any layer that improves the injection of electrons into electron transport layer **145**. LiF/Al is an example of a material that may be used as an electron injection layer into an electron transport layer from an adjacent layer. Other materials or combinations of materials may be used for injection layers. Depending upon the configuration of a particular device, injection layers may be disposed at locations different than those shown in device **100**. More examples of injection layers are provided in U.S. patent application Ser. No. 09/931,948 to Lu et al., which is incorporated by reference in its entirety. A hole injection layer may comprise a solution deposited material, such as a spin-coated polymer, e.g., PEDOT:PSS, or it may be a vapor deposited small molecule material, e.g., CuPc or MTDATA.

[0059] A hole injection layer (HIL) may planarize or wet the anode surface so as to provide efficient hole injection from the anode into the hole injecting material. A hole injection layer may also have a charge carrying component having HOMO (Highest Occupied Molecular Orbital) energy levels that favorably match up, as defined by their herein-described relative ionization potential (EP) energies, with the adjacent anode layer on one side of the HIL and the hole transporting layer on the opposite side of the HIL. The "charge carrying component" is the material responsible for the HOMO energy level that actually transports holes. This component may be the base material of the HIL, or it may be a dopant. Using a doped HIL allows the dopant to be selected for its electrical properties, and the host to be selected for morphological properties such as wetting, flexibility, toughness, etc. Preferred properties for the HIL material are such that holes can be efficiently injected from the anode into the HIL material. In particular, the charge carrying component of the HIL preferably has an IP not more than about 0.7 eV greater that the IP of the anode material. More preferably, the charge carrying component has an IP not more than about 0.5 eV greater than the anode material. Similar considerations apply to any layer into which holes are being injected. HIL materials are further distinguished from conventional hole transporting materials that are typically used in the hole transporting layer of an

OLED in that such HIL materials may have a hole conductivity that is substantially less than the hole conductivity of conventional hole transporting materials. The thickness of the HIL of the present invention may be thick enough to help planarize or wet the surface of the anode layer. For example, an HIL thickness of as little as 10 nm may be acceptable for a very smooth anode surface. However, since anode surfaces tend to be very rough, a thickness for the HIL of up to 50 nm may be desired in some cases.

[0060] A protective layer may be used to protect underlying layers during subsequent fabrication processes. For example, the processes used to fabricate metal or metal oxide top electrodes may damage organic layers, and a protective layer may be used to reduce or eliminate such damage. In device **100**, protective layer **155** may reduce damage to underlying organic layers during the fabrication of cathode **160**. Preferably, a protective layer has a high carrier mobility for the type of carrier that it transports (electrons in device **100**), such that it does not significantly increase the operating voltage of device **100**. CuPc, BCP, and various metal phthalocyanines are examples of materials that may be used in protective layers. Other materials or combinations of materials may be used. The thickness of protective layer **155** is preferably thick enough that there is little or no damage to underlying layers due to fabrication processes that occur after organic protective layer **160** is deposited, yet not so thick as to significantly increase the operating voltage of device **100**. Protective layer **155** may be doped to increase its conductivity. For example, a CuPc or BCP protective layer **160** may be doped with Li. A more detailed description of protective layers may be found in U.S. patent application Ser. No. 09/931,948 to Lu et al., which is incorporated by reference in its entirety.

[0061] **FIG. 2** shows an inverted OLED **200**. The device includes a substrate **210**, an 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**.

[0062] 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**.

[0063] 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, 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.

[0064] 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.

[0065] The molecules disclosed herein may be substituted in a number of different ways without departing from the scope of the invention. For example, substituents may be added to a compound having three bidentate ligands, such that after the substituents are added, one or more of the bidentate ligands are linked together to form, for example, a tetradentate or hexadentate ligand. Other such linkages may be formed. It is believed that this type of linking may increase stability relative to a similar compound without linking, due to what is generally understood in the art as a "chelating effect."

[0066] Devices fabricated in accordance with embodiments of the invention may be incorporated into a wide variety of consumer products, including flat panel displays, computer monitors, televisions, billboards, lights for interior or exterior illumination and/or signaling, heads up displays, fully transparent displays, flexible displays, laser printers, telephones, cell phones, personal digital assistants (PDAs), laptop computers, digital cameras, camcorders, viewfinders, micro-displays, vehicles, a large area wall, theater or stadium screen, or a sign. Various control mechanisms may be used to control devices fabricated in accordance with the present invention, including passive matrix and active matrix. Many of the devices are intended for use in a temperature range comfortable to humans, such as 18 degrees C. to 30 degrees C., and more preferably at room temperature (20-25 degrees C.).

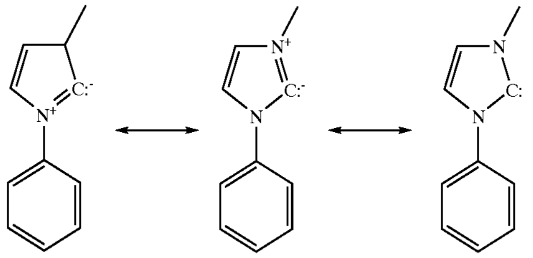
[0067] The materials and structures described herein may have applications in devices other than OLEDs. For example, other optoelectronic devices such as organic solar cells and organic photodetectors may employ the materials and structures. More generally, organic devices, such as organic transistors, may employ the materials and structures.

[0068] A compound comprising a carbene ligand bound to a metal center is provided. Carbene compounds include small molecules, dendrimers, and polymers that include a carbene-metal bond. In one embodiment, the compound is a phosphorescent emissive material, preferably a dopant. The compound may also be doped into a wide band gap host material such as disclosed in U.S. patent application Ser. No. 10/680,066, which is incorporated by reference in its entirety, or it may be doped into an inert wide band gap host such as disclosed in WO-074015, which is incorporated by reference in its entirety.

[0069] In another embodiment, the metal-carbene compound is a host material in an emissive layer. For example, the metal-carbene compound may be used as a high energy host materials for doped blue devices. The dopant in this case could be a triplet emitter or a singlet emitter (using phosphor sensitized fluorescence). In some embodiments, the dopant is a blue or UV emissive material. In this case, the host material preferably has a wide energy gap. As used herein, the energy gap refers to the difference in the energy between the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) for a particular compound. The triplet energy for a given material is related to, but less than, the energy gap. Materials for use as a wide gap host are selected to have a wide energy gap so that the host material does not quench the dopant emission by endothermic or exothermic energy transfer. The wide gap host is preferably selected so as to have a triplet energy at least about 300 mV higher than that of the dopant.

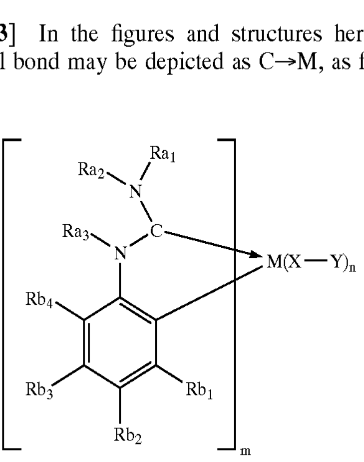
[0070] Additionally, the high band gap of metal-carbene compounds may make these materials effective in carrier blocking and transporting layers. Specifically, these materials may be used in the electron blocking layer, hole blocking layer, exciton blocking layer, hole transport layer, or electron transport layer of an OLED. In other embodiments a metal-carbene compound may be used as a hole injection layer, electron injection layer, or protective layer. It is believed that metal-carbene compounds described herein have improved thermal stability when incorporated into an organic light emitting device due to the carbene-metal bond, as compared to existing compounds without a carbene-metal bond.

[0071] As used herein, the term "carbene" refers to compounds having a divalent carbon atom with only six electrons in its valence shell when not coordinated to a metal. A useful exercise to determine whether a ligand includes a carbene-metal bond is to mentally deconstruct the complex as a metal fragment and a ligand, and to then determine whether a carbon atom in the ligand that was previously bound to the metal is a neutral divalent carbon atom in the deconstructed state. The resonance forms of a preferred embodiment may be shown as:



[0072] This definition of carbene is not limited to metal-carbene complexes synthesized from carbenes, but is rather intended to address the orbital structure and electron distribution associated with the carbon atom that is bound to the metal. The definition recognizes that the "carbene" may not technically be divalent when bound to the metal, but it would be divalent if it were detached from the metal. Although many such compounds are synthesized by first synthesizing a carbene and then binding it to a metal, the definition is intended to encompass compounds synthesized by other methods that have a similar orbital structure and electron configuration. Lowry & Richardson, *Mechanism and Theory in Organic Chemistry* 256 (Harper & Row, 1976) defines "carbene" in a way that is consistent with the way the term is used herein. Some references may define "carbene" as a carbon ligand that forms a double bond to a metal. While this definition is not being used in the present application, there may be some overlap between the two definitions. A variety of representations are used to depict the bonding in such carbenes, including those in which a curved line is used to indicate partial multiple bonding between the carbene carbon and the adjacent heteroatom(s).

[0073] In the figures and structures herein, a carbene-metal bond may be depicted as C→M, as for example:



[0074] Such structures that use an arrow to represent the presence of a metal-carbene bond are used interchangeably herein with structures that do not include the arrow, without any intention of suggesting there is a difference in the structure shown.

[0075] Carbene ligands are especially desirable in OLED applications due to the high thermal stability exhibited by metal-carbene complexes. It is believed that the carbene, which behaves much as an electron donative group, generally bonds strongly to the metals, thus forming a more thermally stable complex than, for example, previous cyclometallated complexes used as phosphorescent emitters. It is also believed that carbene analogs of ligands employed in existing phosphorescent emissive materials (for example the phenylpyridine or Irppy, etc.) may exhibit greater stability and emit at substantially higher energy than their existing analogs.

[0076] As used herein, a "non-carbene analog" of a metal carbene compound refers to existing ligands having a substantially similar chemical structure to the metal-carbene compound, but unlike the carbene compounds of the present invention, which features a carbene-metal bond, the analog has some other bond, such as a carbon-metal or a nitrogen-metal bond, in place of the carbene-metal bond. For example, $Ir(ppz)_3$ has a nitrogen in each ligand bound to the Ir. Ir(1-phenylimidazolin-2-ylidene) is analogous to $Ir(Ppz)_3$ where the nitrogen bound to the Ir has been replaced with a carbene bound to the Ir, and where the atoms surrounding the carbene have been changed to make the carbon a carbene. Thus, embodiments of the present invention include metal-carbene complexes (e.g. Ir(1-phenylimidazolin-2-ylidene) with similar structures to existing emissive compounds (e.g. $Ir(ppz)_3$).

[0077] Examples of existing emissive compounds include $Ir(ppy)_3$ and $Ir(ppz)_3$, discussed above. Other examples are disclosed in the references below, which are incorporated herein by reference in their entirety. In preferred embodiments, the carbene ligands are imidazoles, pyrazoles, benzimidazoles, and pyrroles.

[0078] It is believed that the carbene-metal bond in $Ir(1\text{-}Ph\text{-}3\text{-}Me\text{-}imid)_3$ is stronger than the N-metal bond in $Ir(ppz)_3$. Moreover, due to the nature of a carbene-metal bond, it is believed that replacing a carbon-metal bond or nitrogen-metal bond in existing emissive organometallic molecules with a carbene-metal bond (making other changes as needed to make the carbon atom a carbene) may result in an emissive molecule that is more stable than the non-carbene analog, and that has stronger spin-orbit coupling. It is further believed that the emissive spectra of the molecule including a carbene may be different from the emissive spectra of the analog without a carbene.

[0079] Metal-carbene complexes may be tuned to emit a wide variety of spectra from the near-ultraviolet across the entire visible spectra by the selection of substituents and/or chemical groups on the ligand(s). More significantly, it may now be possible to obtain saturated blue color emissions with peak wavelengths at about 450 nm. Because it is believed to be materially easier to reduce than to increase the triplet energy by tuning an emissive compound, the ability to make stable blue emitters at such high energies would also allow for the possibility of obtaining any color by reducing the energy so as to red-shift the emission.

[0080] The appropriate selection of substituents and/or chemical groups attached to carbene ligands may also minimize quantum efficiency losses associated with increasing temperatures. The observable difference in lifetime measurements between emission at room temperature and at low temperatures (e.g. 77 K) is believed to be attributed to non-radiative quenching mechanisms that compete with phosphorescent emission. Such quenching mechanisms are further believed to be thermally activated, and consequently, at cooler temperatures of about 77 K, where energy loss due to quenching is not an issue, quantum efficiency is about 100%. It is believed that appropriate substituents on the carbene ligand, or doping in a more rigid matrix, such as disclosed in Turro, "Modem Molecular Photochemistry", University Science Books (1991), 109-10, may increase quantum efficiency at room temperature and correspondingly show longer lifetimes.

[0081] Due to the nature of the carbene-metal bond, the emission of a carbene analog may be substantially different from that of its non-carbene analog, and the emission of the carbene analog may be stable and at a higher energy than previously obtainable with stable non-carbene compounds.

[0082] In some embodiments, the triplet energy of the carbene complex has a corresponding wavelength in the deep blue or ultraviolet (UV) part of the spectra. In some embodiments, the phosphorescent emissive compound has triplet energy corresponding to a wavelength of less than 450 nm. In preferred embodiments, the triplet energy corresponds to a wavelength of less than 440 nm, and in even more preferred embodiments, it corresponds to a wavelength less than 400 nm, which is believed to be in the UV region of the spectrum, since 400 nm is believed to represent the cut-off between the UV and the visible regions of the spectrum. Such high triplet energy may make these compounds useful in optically pumping down converting layers. For such applications, an overlap is preferred between the emission spectra of the ultraviolet carbene compound and the absorption spectra of the down converting layer. It is believed that when about 50% of the integral of the curve for the normalized electroluminescent spectra of the device is at a wavelength less than about 450 nm, there is sufficient energy to optically pump a down converting layer. More preferably, greater than 90% of the emission may be produced below 440 nm, as disclosed herein. Preferably, 50% of the integral of the curve for the normalized electroluminescent spectra is less than about 440 nm, and more preferably, it is less than about 400 nm. The wavelength cutoffs mentioned above are not intended to be absolute limitations as they depend on the energy of the material to be pumped. It is also believed that these emissions may occur at room temperature.

[0083] The strong metal-carbon bond is also believed to lead to greater spin-orbit coupling in metal carbene complexes. Moreover, the triplet energy of coordinated carbenes are shown to be significantly higher than pyridine analogs.

[0084] The stability of metal-carbene complexes may also allow increased versatility in the types of ligands and metals that may be used as phosphorescent emitters in OLEDs. The strong metal-carbene bond may allow a variety of metals to form useful phosphorescent complexes with carbene ligands to give novel emissive compounds. For example, one embodiment includes gold or copper bonded to a carbene ligand. Such metals have been calculated to form metal-carbon bonds having quite high bond dissociation energies, such as illustrated in Nemcsok et al., "*The Significance of π-Interactions in Group* 11 Complexes with N-Heterocyclic Carbenes," American Chemical Society, Publ. on Web, Jun. 19, 2004. Such high bond dissociation energies may be expected to improve the chemical stability of metal-carbene complexes as compared with the analogous metal-phenylpyridine ("metal-ppy") based complexes that are typically used in an OLED. Thus, in addition to their use as the emissive materials in an OLED, metal-carbene complexes may be also used advantageously, because of their improved chemical stability, for other functions in an OLED, for example, as a host material in the emissive layer, as an electron or hole transporting material in an electron or hole transporting layer, and/or as an electron or hole blocking material in an electron or hole blocking layer.

[0085] Additionally, although cyclometallated complexes are preferred embodiments, the present invention is not limited to such embodiments. The increased strength of a metal-carbene bond, as compared to other types of bonds with metal, may make monodentate ligands feasible for use as emissive materials. Until recently, bidentate ligands were strongly preferred due to stability concerns. Thus, embodiments include monodentate carbene ligands as well as bidentate. Embodiments also include tridentate carbene ligands, which may be quite stable, and many examples are found in the art, such as those disclosed in Koizumi et al., *Organometallics* 2003, 22, 970-975. Other embodiments may also feature a tetradentate ligand, such as porphyrin analogs in which one or more nitrogens are replaced by a carbene, which is disclosed in Bourissou et al. *Chem Rev.* 2000, 100, 39-91. Still other embodiments may include metallaquinone carbenes, which are compounds in which one of the oxygen atoms of a quinone has been replaced by a metal, such as those disclosed in Ashekenazi et al., *J. Am. Chem. Soc.* 2000, 122, 8797-8798. In addition, The metal-carbene compound may be present as part of a multi-dentate group such as disclosed in U.S. patent application Ser. No. 10/771,423 to Ma et al., which is incorporated by reference in its entirety.

[0086] It is believed that many of the (C,C) or (C,N) ligands of many existing electroluminescent compounds may be modified to create an analogous (C,C) ligand including a carbene. Specific non limiting examples of such modification include:

[0087] (1) the substituents on the carbene-bonded branch of the (C,C)-ligand and the substituents on the mono-anionic-carbon-bonded branch of the (C,C)-ligand may be independently selected from the group consisting of

[0088] (a) the substituents on the N-bonded branch of the existing (C,N)-ligands, such as disclosed in the references listed below, which is typically but not necessarily a pyridine group; and

[0089] (b) the substituents on the mono-anionic-carbon-bonded branch of the existing (C,N)-ligands, such as disclosed in the references listed below, which is typically but not necessarily a phenyl group;

[0090] (c) and/or a combination thereof; and

[0091] (2) the compounds including the metal-carbene bonds may further include ancillary ligands selected from the group consisting of the ancillary ligands such as disclosed in the following references:

[0092] U.S. patent application Publ. No. 2002-0034656, FIGS. 11-50, U.S. patent application Publ. No. 2003-0072964 (Thompson et al.), paragraphs 7-132; and FIGS. 1-8; U.S. patent application Publ. No. 2002-0182441 (Lamansky et al.), paragraphs 13-165, including FIGS. 1-9(g); U.S. Pat. No. 6,420,057 B1 (Ueda et al.), col. 1, line 57, through col. 88, line 17, including each compound I-1 through XXIV-12; U.S. Pat. No. 6,383,666 B1 (Kim et al.), col. 2, line 9, through col. 21, lin3 67; U.S. patent application Publ. No. 2001-0015432 A1 (Igarashi et al.), paragraphs 2-57, including compounds (1-1) through (1-30); U.S. patent application Publ. No. 2001-0019782 A1 (Igarashi et al.), paragraphs 13-126, including compounds (1-1) through (1-70), and (2-1) through (2-20); U.S. patent application Publ. No. 2002-0024293 (Igarashi et al.), paragraphs 7-95, including general formulas K-I through K-VI, and example compounds (K-1) through (K-25); U.S. patent application Publ. No. 2002-0048689 A1 (Igarashi et al.), paragraphs 5-134, including compounds 1-81, and example compounds (1-1) through (1-81); U.S. patent application Publ. No. 2002-0063516 (Tsuboyama et al.), paragraphs 31-161, including each compound 1-16; U.S. patent application Publ. No. 2003-0068536 (Tsuboyama et al.), paragraphs 31-168, including each compound in Tables 1-17, corresponds to EP-1-239-526-A2; U.S. patent application Publ. No. 2003-0091862 (Tokito et al.), paragraphs 10-190, including each compound in Tables 1-17, corresponds to EP-1-239-526-A2; U.S. patent application Publ. No. 2003-0096138 (Lecloux et al.), paragraphs 8-124, including FIGS. 1-5; U.S. patent application Publ. No. 2002-0190250 (Grushin et al.), paragraphs 9-191; U.S. patent application Publ. No. 2002-0121638 (Grushin et al.), paragraphs 8-125; U.S. patent application Publ. No. 2003-0068526 (Kamatani et al.), paragraphs 33-572, including each compound in Tables 1-23; U.S. patent application Publ. No. 2003-0141809 (Furugori et al.), paragraphs 29-207; U.S. patent application Publ. No. 2003-0162299 A1 (Hsieh et al.), paragraphs 8-42; WO 03/084972, (Stossel et al.), Examples 1-33; WO 02/02714 A2 ((Petrov et al.), pages 2-30, including each compound in Tables 1-5; EP 1-191-613 A1(Takiguchi et al.), paragraphs 26-87, including each compound in Tables 1-8, (corresponding to U.S. patent application Publ. No. 2002-0064681); and EP 1-191-614 A2 (Tsuboyama et al.), paragraphs 25-86, including each compound in Tables 1-7; which are incorporated herein by reference in their entirety.

[0093] Carbene ligands may be synthesized using methods known in the art, such as those disclosed in Cattoën, et al., *J. Am. Chem. Soc.,* 2004, 126; 1342-1343; Chiu-Yuen Wong, et al, *Organometallics* 2004, 23, 2263-2272; Klapars, et al, *J. Am. Chem. Soc.,* 2001, 123; 7727-7729; Bourissou et al. *Chem Rev.* 2000, 100,39-91; Siu-Wai Lai, et al, *Organometallics* 1999, 18, 3327-3336; Wen-Mei Xue et al., *Organometallics* 1998, 17, 1622-1630; Wang & Lin, *Organometallics* 1998, 17, 972-975; Cardin, et al., *Chem Rev.* 1972, 5, 545-574; and other references discussed herein.

[0094] The term "halo" or "halogen" as used herein includes fluorine, chlorine, bromine and iodine.

[0095] The term "alkyl" as used herein contemplates both straight and branched chain alkyl radicals. Preferred alkyl groups are those containing from one to fifteen carbon atoms and includes methyl, ethyl, propyl, isopropyl, butyl, isobutyl, tert-butyl, and the like. Additionally, the alkyl group may be optionally substituted with one or more substituents selected from halo, CN, CO_2R, C(O)R, NR_2, cyclic-amino, NO_2, and OR.

[0096] The term "cycloalkyl" as used herein contemplates cyclic alkyl radicals. Preferred cycloalkyl groups are those containing 3 to 7 carbon atoms and includes cyclopropyl, cyclopentyl, cyclohexyl, and the like. Additionally, the cycloalkyl group may be optionally substituted with one or more substituents selected from halo, CN, CO_2R, C(O)R, NR_2, cyclic-amino, NO_2, and OR.

[0097] The term "alkenyl" as used herein contemplates both straight and branched chain alkene radicals. Preferred alkenyl groups are those containing two to fifteen carbon atoms. Additionally, the alkenyl group may be optionally substituted with one or more substituents selected from halo, CN, CO_2R, C(O)R, NR_2, cyclic-amino, NO_2, and OR.

[0098] The term "alkynyl" as used herein contemplates both straight and branched chain alkyne radicals. Preferred alkyl groups are those containing two to fifteen carbon atoms. Additionally, the alkynyl group may be optionally substituted with one or more substituents selected from halo, CN, CO_2R, C(O)R, NR_2, cyclic-amino, NO_2, and OR.

[0099] The terms "aralkyl" as used herein contemplates an alkyl group that has as a substituent an aromatic group. Additionally, the aralkyl group may be optionally substituted on the aryl with one or more substituents selected from halo, CN, CO_2R, C(O)R, NR_2, cyclic-amino, NO_2, and OR.

[0100] The term "heterocyclic group" as used herein contemplates non-aromatic cyclic radicals. Preferred heterocyclic groups are those containing 3 or 7 ring atoms which includes at least one hetero atom, and includes cyclic amines such as morpholino, piperdino, pyrrolidino, and the like, and cyclic ethers, such as tetrahydrofuran, tetrahydropyran, and the like.

[0101] The term "aryl" or "aromatic group" as used herein contemplates single-ring groups and polycyclic ring systems. The polycyclic rings may have two or more rings in which two carbons are common by two adjoining rings (the rings are "fused") wherein at least one of the rings is aromatic, e.g., the other rings can be cycloalkyls, cycloalkenyls, aryl, heterocycles and/or heteroaryls.

[0102] The term "heteroaryl" as used herein contemplates single-ring hetero-aromatic groups that may include from one to four heteroatoms, for example, pyrrole, furan, thiophene, imidazole, oxazole, thiazole, triazole, tetrazole, pyrazole, pyridine, pyrazine and pyrimidine, and the like. The term heteroaryl also includes polycyclic hetero-aromatic systems having two or more rings in which two atoms are common to two adjoining rings (the rings are "fused") wherein at least one of the rings is a heteroaryl, e.g., the other rings can be cycloalkyls, cycloalkenyls, aryl, heterocycles and/or heteroaryls.

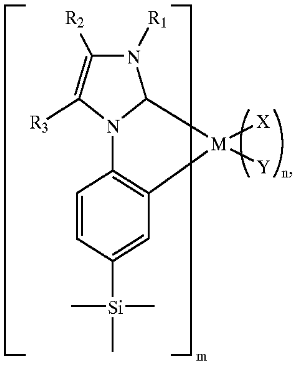
[0103] All value ranges, for example those given for n and m, are inclusive over the entire range. Thus, for example, a range between 0-4 would include the values 0, 1, 2, 3 and 4.

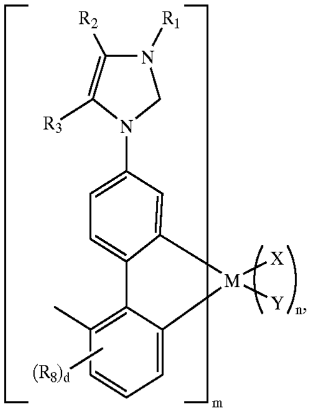
[0104] Embodiments include photoactive carbene ligands. m represents the number of photoactive ligands. For example, for Ir, m may be 1, 2 or 3. n, the number of "ancillary" ligands of a particular type, may be any integer from zero to one less than the maximum number of ligands that may be attached to the metal. (X—Y) represents an ancillary ligand. The definitions of photoactive and ancillary are intended as non-limiting theories. For example, for Ir, n may be 0, 1 or 2 for bidentate ligands. Ancillary ligands for use in the emissive material may be selected from those known in the art. Non-limiting examples of ancillary ligands may be found in PCT Application Publication WO 02/15645 A1 to Lamansky et al. at pages 89-90, which is incorporated herein by reference.

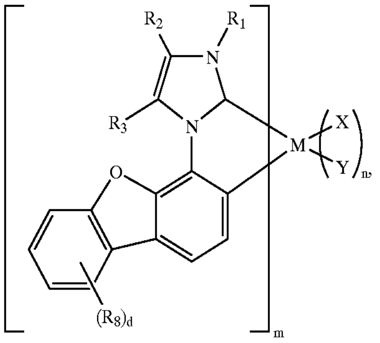
[0105] The metal forming the metal-carbene bond may be selected from a wide range of metals. Preferred metals include main group metals, 1st row transition metals, 2nd row transition metals, 3rd row transition metals, and lanthanides. Although one skilled in the art typically expects room temperature phosphorescence only from metal atoms that exert a strong heavy atom effect, phosphorescent emission has been observed in Kunkley, et al. *J. Organometallic Chem.* 2003, 684, 113-116 for a compound with a Nickel (Ni) metal, which is typically not expected to exert a strong heavy atom effect. Thus, embodiments also include first row transition metal, such as Ni, and other metals that do not normally exert a strong heavy atom effect but exhibits phosphorescent emission when coordinated to one or more carbene ligands. More preferred metals include 3rd row transition metals. The following are also preferred metals: Ir, Pt, Pd, Rh, Re, Ru, Os, Tl, Pb, Bi, In, Sn, Sb, Te, Au, and Ag. Most preferably, the metal is Iridium.

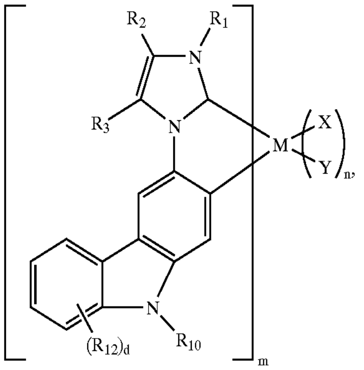
[0106] The most preferred embodiments are N-heterocyclic carbenes, which Bourissou has also reported as having "remarkable stability" as free compounds in Bourissou et al. *Chem Rev.* 2000, 100, 39-91.

[0107] Preferred embodiments include metal-carbene compounds having the general structure selected from:









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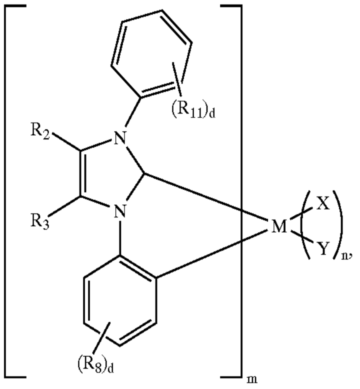

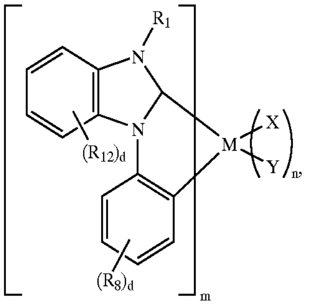

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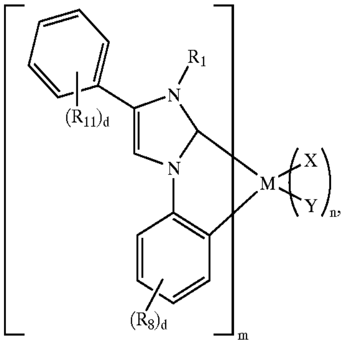
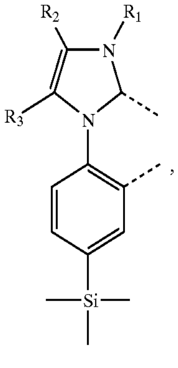
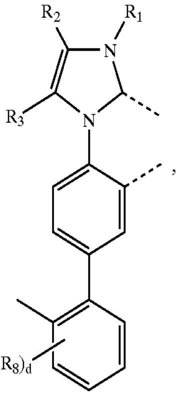


[0108] with corresponding ligands having the structures selected from





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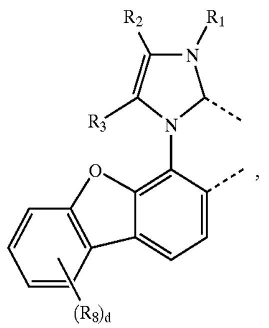
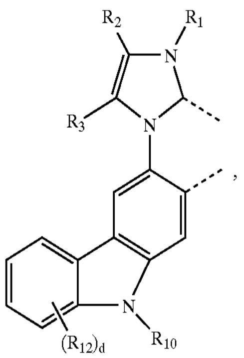
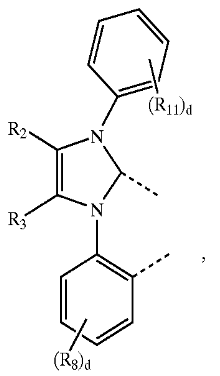
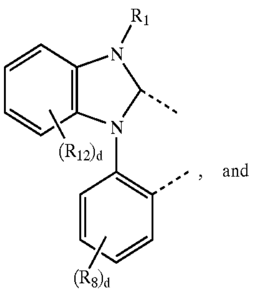
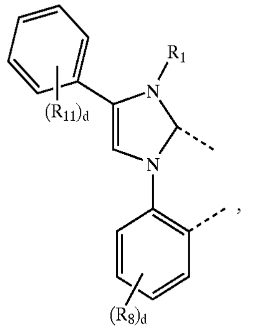










[0109] in which R_1 may be hydrogen, alkyl, alkenyl, alkynyl, aralkyl, aryl, heteroaryl, substituted aryl, substituted heteroaryl, or a heterocyclic group; R_2, R_3, R_8, R_{10}, R_{11}, and R_{12} may independently be hydrogen, alkyl, alkenyl, alkynyl, aralkyl, CN, CF_3, CO_2R', C(O)R', C(O)NR'2, NR'2, NO_2, OR', SR', SO_2, SOR', SO_3R', halo, aryl, heteroaryl, substituted aryl, substituted heteroaryl, or a heterocyclic group; and additionally or alternatively, one or more of R_1 and R_2, and R_2 and R_3, and two R_8 groups, two R_{10} groups, and two R_{12} groups on the same ring together may form independently a 5 or 6-member cyclic group, wherein said cyclic group is cycloalkyl, cycloheteroalkyl, aryl or heteroaryl; and wherein said cyclic group may be optionally substituted by one or more substituents J;

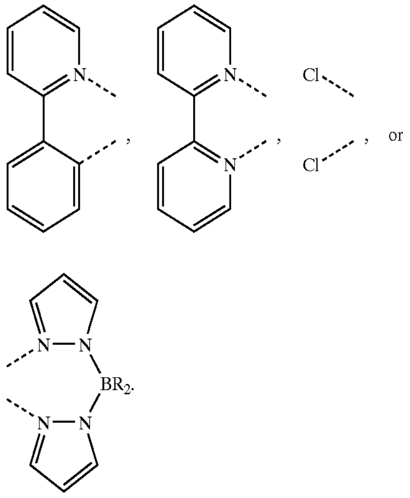
[0110] each substituent J may be R', CN, CF_3, C(O)OR', C(O)R', C(O)NR'$_2$, NR'$_2$, NO_2, OR', SR', SO_2, SOR', or SO_3R', and additionally, or alternatively, two J groups on adjacent ring atoms may form a fused 5- or 6-membered aromatic group; each R' may be independently halo, H, alkyl, alkenyl, alkynyl, heteroalkyl, aralkyl, aryl and heteroaryl;

[0111] (X—Y) may be a photoactive ligand or an ancillary ligand,

[0112] d is 0, 1, 2, 3, or 4;

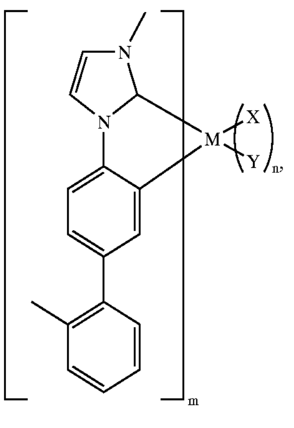
[0113] m is a value from 1 to the maximum number of ligands that may be attached to metal M; m+n is the maximum number of ligands that may be attached to metal M.

[0114] In a most preferred embodiment, the metal is Ir. Preferably, m is 3 and n is 0. In one embodiment, R6 is methyl. In another embodiment m is 2 and n is one. The ancillary ligand X—Y may have one of the following structures:



[0115] Other preferred ancillary ligands are acetylacetonate, picolinate, and pyrazolyls (as found in the reference Li, J. et al. *Polyhedron* 2004, 23, 419-428), and their derivatives.

[0116] More preferred embodiments have the following structures:



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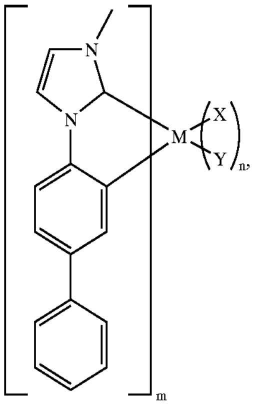

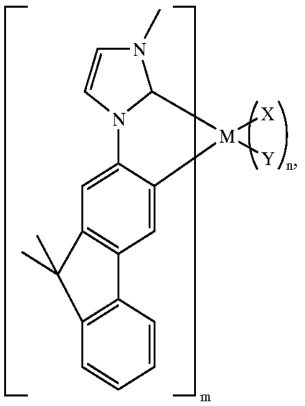

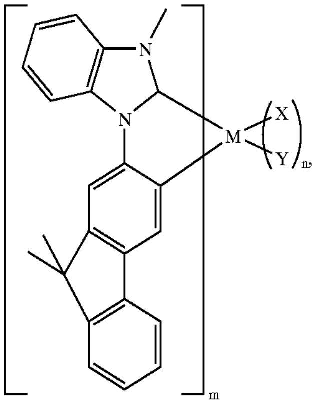

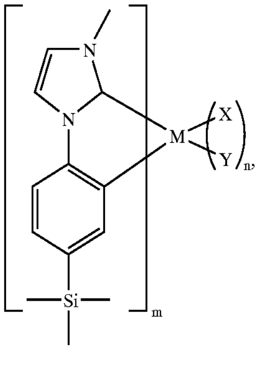

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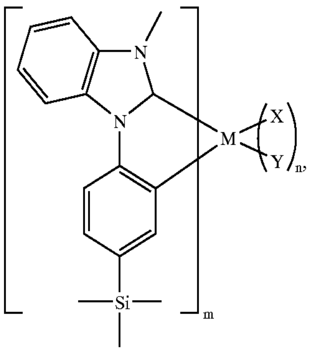

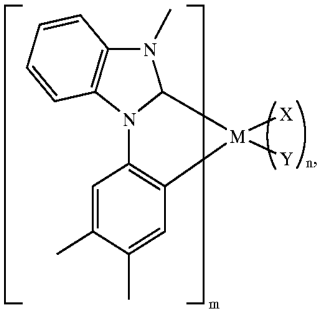

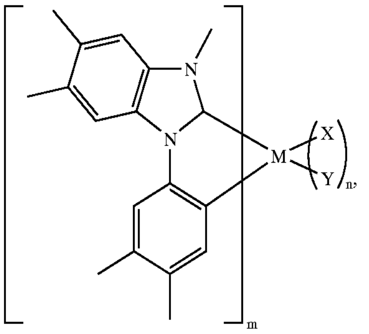

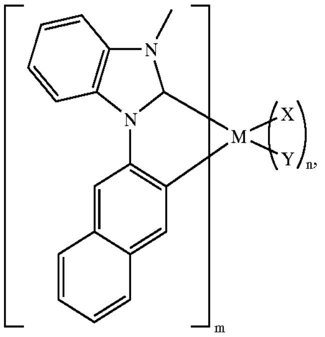

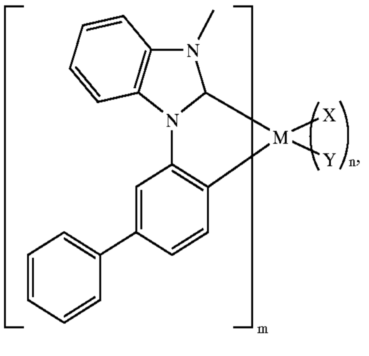

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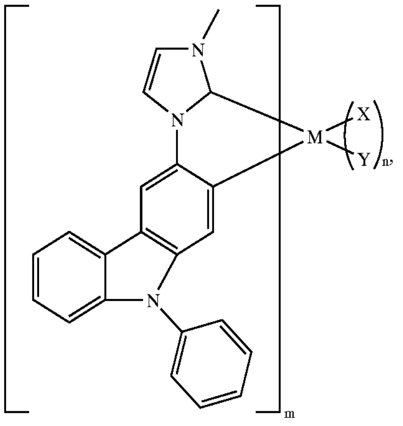

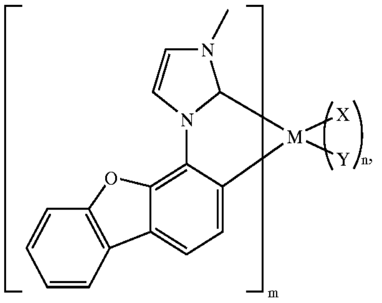

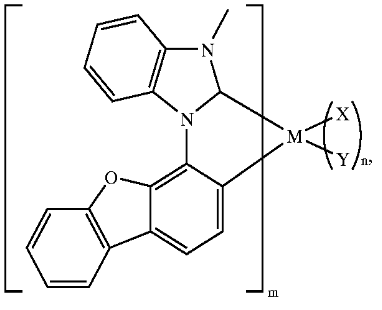

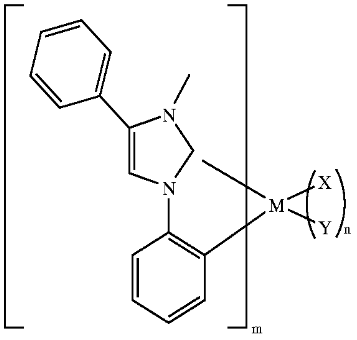

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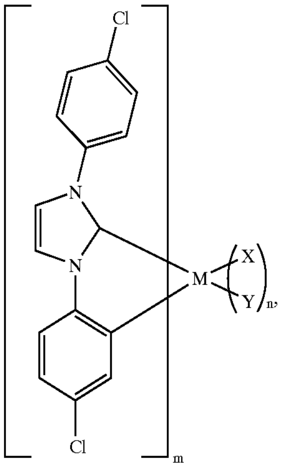
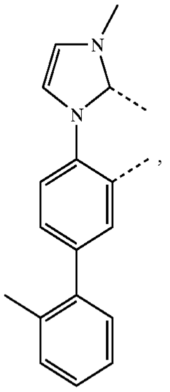
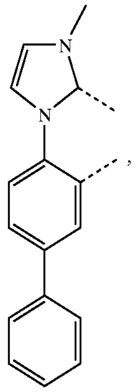
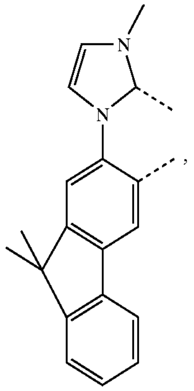
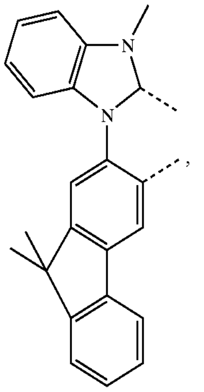


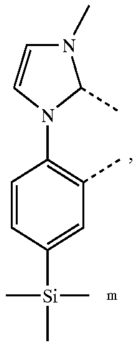
[0117] and more preferred ligands have the following corresponding structures

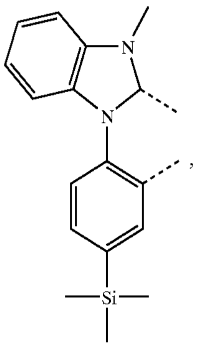


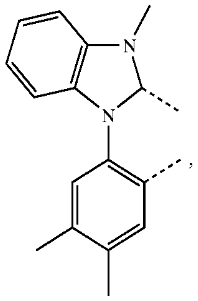












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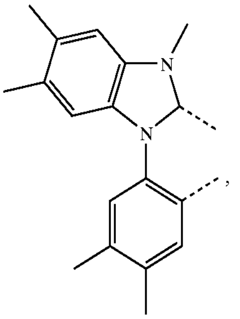

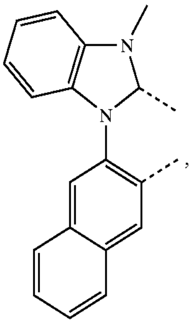

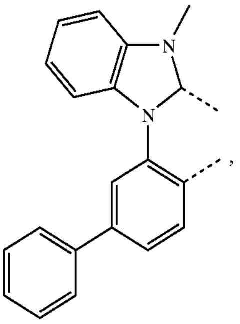

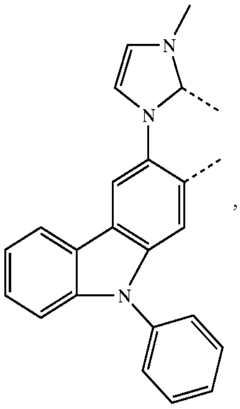

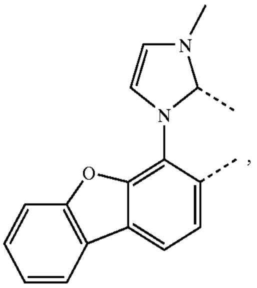

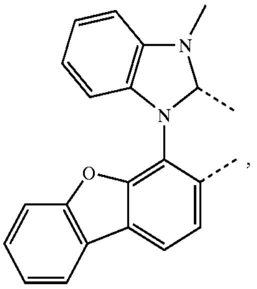

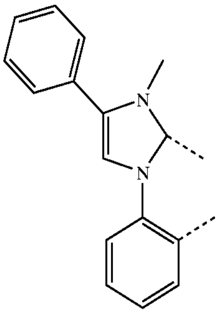

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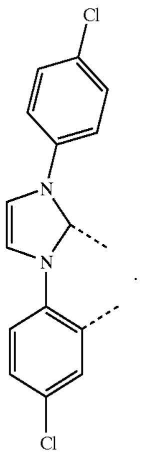


[0118] Devices incorporating the above compounds have been shown to exhibit phosphorescent emissions that span the spectrum of blue light. For example, Dopant A and B, in Examples 6 and 7 respectively, are UV emitters in solution photoluminescence (PL) and the electroluminescence (EL) emission has a highest energy peak or shoulder at about 400 nm as shown in **FIG. 5**. Dopants M, N, O, and P, in Examples 18, 19, 20 and 21 respectively, have slightly lower triplet energy and emit in a device with high efficiency using the wide band gap (high triplet energy) host, UGH5. These examples have similar triplet energy and the EL emission shows vibronic fine structure characteristic of the dopant. The emission from these examples is a desirable blue color with a CIE coordinate of about (0.14, 0.15).

[0119] Other devices, for example, the devices of Examples 13, 14 and 15 (Dopants H, I, and J) exhibit emissions at lower energy with a highest triplet energy emission at about 470 nm and vibronic fine structure characteristic of the dopant (**FIG. 17**). Examples 8 and 9 (Dopants C and D) exhibit still lower energy with highest energy emission at about 485 nm (**FIG. 8**).

[0120] 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. It is understood that various theories as to why the invention works are not intended to be limiting. For example, theories relating to charge transfer are not intended to be limiting.

[0121] Material Definitions:

As used herein, abbreviations refer to materials as follows:

CBP:	4,4'-N,N-dicarbazole-biphenyl
m-MTDATA	4,4',4"-tris(3-methylphenylphenlyamino)triphenylamine
Alq$_3$:	8-tris-hydroxyquinoline aluminum
Bphen:	4,7-diphenyl-1,10-phenanthroline
n-BPhen:	n-doped BPhen (doped with lithium)
F$_4$-TCNQ:	tetrafluoro-tetracyano-quinodimethane
p-MTDATA:	p-doped m-MTDATA (doped with F$_4$-TCNQ)
Ir(ppy)$_3$:	tris(2-phenylpyridine)-iridium
Ir(ppz)$_3$:	tris(1-phenylpyrazoloto,N,C(2')iridium(III)
BCP:	2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline
TAZ:	3-phenyl-4-(1'-naphthyl)-5-phenyl-1,2,4-triazole
CuPc:	copper phthalocyanine.
ITO:	indium tin oxide
NPD:	N,N'-diphenyl-N-N'-di(1-naphthyl)-benzidine
TPD:	N,N'-diphenyl-N-N'-di(3-toly)-benzidine
BAlq, BAlQ:	aluminum(III)bis(2-methyl-8-hydroxyquinolinato)4-phenylphenolate
mCP:	1,3-N,N-dicarbazole-benzene
DCM:	4-(dicyanoethylene)-6-(4-dimethylaminostyryl-2-methyl)-4H-pyran
DMQA:	N,N'-dimethylquinacridone
PEDOT:PSS:	an aqueous dispersion of poly(3,4-ethylenedioxythiophene) with polystyrenesulfonate (PSS)
UGH5	1,3-bis(triphenylsilyl)benzene
mCBP	3,3'-N,N-dicarbazole-biphenyl
1-Ph-3-Me-imid	1-phenyl-3-methyl-imidazolin-2-ylidene-C,C$^{2'}$
mer-Ir(1-Ph-3-Me-imid)$_3$	mer-iridium(III)tris(1-phenyl-3-methyl-imidazolin-2-ylidene-C,C$^{2'}$)

EXPERIMENTAL

[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.

EXAMPLE 1

Synthesis of fac-iridium(III) tris(n-[p-trimethylsilylphenyl]-2-methyl-benzimidazole)

Step 1: Synthesis of N-(p-trimethylsilylphenyl)benzimidazole

[0123] To a 1L 3-neck flask equipped with a mechanical stir arm was added 14.5 g (65.1 mmol) of 1-bromo-4-trimethylsilylbenzene, 9.2 g (78.1 mmol) of benzimidazole, 9.1 g (143 mmol) of copper power, 31.4 g (228 mmol) of potassium carbonate, and 1.7 g (6.5 mmol) of 18-crown-6. These chemicals were stirred vigorously in 400 mL tetrahydronaphthalene at 180° C. under N_2 atmosphere. After 20 hours of heating, the mixture was filtered warm. The solids on the funnel were repeatedly washed with dichloromethane to remove all organic products as filtrate. The mother liquor was then evaporated in vacuo and pooled with a small batch of crude material from a previous reaction. This residue was purified by distilling on a Kugelrohr apparatus twice. At 160° C., the removal of organic impurities was evidenced. At 200° C. the product distilled. Purification gave 14.2 g N-(p-trimethylsilylphenyl)benzimidazole as a white solid.

Step 2: Methylation of N-(p-trimethylsilylphenyl)benzimidazole

[0124] 14.1 g (52.9 mmol) of N-(p-trimethylsilylphenyl-)benzimidazole was solubilized with 200 mL of toluene in a 500 mL flask equipped with a stir bar. To the stirred solution was carefully added 22.5 g (159 mmol) iodomethane and then was allowed to reflux for 2 hours. Next, the condenser was removed and the flask enriched with 100 mL toluene. A stream of N_2 was then passed over the flask to remove excess iodomethane. After the volume of the solution was reduced by half, it was cooled and the white solids collected on a filter and rinsed with toluene followed by hexanes. 20.8 g N-(p-trimethylsilylphenyl)benzimidazole was achieved after drying in vacuo (96.3% yield).

Step 3: Synthesis of fac-iridium(III) tris(n-[p-trimethylsilylphenyl]-2-methyl-benzimidazole)

[0125] 20 mL 2-methoxyethanol was purged with N_2 and refluxed in a 100 mL round bottom flask equipped with a stir bar. After deoxygenation of the solvent, the flask was cooled and 1.0 g (2.45 mmol) N-(p-trimethylsilylphenyl)benzimidazole was added along with 0.29 g (0.29 mmol) $IrCl_3.3H_2O$ and 0.76 g (3.27 mmol) silver(I) oxide. The mixture was refluxed for 2 hours under a stream of N_2. The reaction mixture was cooled and the solvent evaporated in vacuo. This residue was dissolved in a minimal amount of dichloromethane and purified on a silica gel column using dichloromethane as eluent. The product fractions were evaporated of solvent and recrystallized from methylene chloride/methanol to give 0.14 g fac-iridium(III) tris(n-[p-trimethylsilylphenyl]-2-methyl-benzimidazole) as pale-grey solids (MS confirmed)

EXAMPLES 2, 3

Synthesis of fac(mer)-iridium(III) tris(n-[3-biphenyl]-2-methyl-benzimidazole) [Dopant E, F]

Step 1: Synthesis of N-(3-biphenyl)benzimidazole

[0126] To a 3 L 3-neck flask equipped with a mechanical stir arm was added 100 g (429 mmol) of 3-bromobiphenyl, 60.7 g (514 mmol) of benzimidazole, 60 g (943 mmol) of copper powder, 207 g (1500 mmol) of potassium carbonate and 11.3 g (42.9 mmol) of 18-crown-6. These chemicals were stirred vigorously in ~1.5 L tetrahydronaphthalene at 180° C. under N_2 atmosphere. After 48 hours of heating, the mixture was filtered warm. The solids on the funnel were repeatedly washed with dichloromethane to remove all organic products as filtrate. The mother liquor was then evaporated in vacuo to give a dark residue that was solubilized with a minimal amount of dichloromethane and purified on a silica gel column using a gradient of 50% EtOAc/hexanes→100% EtOAc. The purest fractions were evaporated of solvent, and the resultant solids sonciated in hexanes, filtered, washed with hexanes and dried to give 74 g N-(3-biphenyl)benzimidazole as off-white solids (64% yield).

Step 2: Methylation of N-(3-biphenyl)-benzimidazole

[0127] 74 g (274 mmol) of N-(3-biphenyl)benzimidazole was solubilized with 400 mL of toluene in a 1 L flask equipped with a stir bar. To the stirred solution was carefully added 117 g (821 mmol) iodomethane and then was allowed to reflux for 2 hours. Next, the condenser was removed and the flask enriched with 200 mL toluene. A stream of N_2 was then passed over the flask to remove excess iodomethane. After the volume of the solution was reduced by half, it was cooled and the white solids collected on a filter and rinsed with toluene followed by hexanes. 108 g N-(3-biphenyl)-2-methylbenzimidazole was achieved after drying in vacuo (95.6% yield).

Step 3: Synthesis of fac(mer)-iridium(III) tris(n-[3-biphenyl]-2-methyl-benzimidazole)

[0128] 200 mL 2-methoxyethanol was purged with N_2 and refluxed in a 500 mL round bottom flask equipped with a stir bar. After deoxygenation of the solvent, the flask was cooled and 10.0 g (24.3 mmol) N-(3-biphenyl)-2-methylbenzimidazole was added along with 2.18 g (6.06 mmol) $IrCl_3.3H_2O$ and 4.2 g (18.2 mmol) silver(I) oxide. The mixture was refluxed for 30 minutes whereupon an additional 4.2 g (18.2 mmol) silver(I) oxide was added. After heating for an additional 1.5 hours at reflux, HPLC indicated favorable formation of both the mer and fac isomers (~1:2 ratio). The reaction mixture was cooled, enriched with 100 mL dichloromethane and filtered. Whereas the filtrate was put to the side (mer-rich), the resulting solids were removed the filter, stirred vigorously in 500 mL $MeCl_2$ and filtered again. This process was performed a second time and the 1 L of dichloromethane filtrates were evaporated of solvent to give beige solids that were 1× recrystallized from dichloromethane/methanol giving 0.95 g fac-iridium(III) tris(n-[3-biphenyl]-2-methyl-benzimidazole) as off-white solids. This material was sublimed in vacuo and afforded 0.23 g to be tested in an OLED device (99.5% HPLC assay, ^{1}HNMR confirmed). The mer-rich filtrate was evaporated of solvent and the residue solubilized in dichloromethane and purified on a column of silica using dichloromethane as eluent. The mer-rich fractions were evaporated of solvent and recrystallized from acetonitrile to give ~1.0 g 4:1 mer/fac iridium(III) tris(n-[3-biphenyl]-2-methyl-benzimidazole) as an off-white solid that could not be sublimed (^{1}H NMR confirmed).

EXAMPLES 4, 5

Synthesis of fac(mer)-iridium(III) tris(1-(N-[2-methylbenzimidazole])-4-(o-tolyl)benzene) [Dopant G]

Step 1: Synthesis of 1-(N-benzimidazole)-4-(o-tolyl)benzene

[0129] To a 2 L 3-neck flask equipped with a mechanical stir arm was added 46.6 g (189 mmol) of 1-bromo-4-(o-tolyl)benzene, 26.7 (226 mmol) of benzimidazole, 26.3 g (415 mmol) of copper powder, 91.1 g (660 mmol) of potassium carbonate and 5.0 g (18.9 mmol) of 18-crown-6. These chemicals were stirred vigorously in ~1.0 L tetrahydronaphthalene at 180° C. under N_2 atmosphere. After 48 hours of heating, the mixture was filtered warm. The solids on the funnel were repeatedly washed with dichloromethane to remove all organic products as filtrate. The mother liquor was then evaporated in vacuo to give a dark residue that was solubilized with a minimal amount of dichloromethane and purified on a silica gel column using a gradient of 50% EtOAc/hexanes→100% dicoloromethane. The purest fractions were evaporated of solvent and the resultant residue distilled via a Kugelrohr apparatus (190° C.) to give 26.1 g 1-(N-benzimidazole)-4-(o-tolyl)benzene as a clear liquid (48.5% yield).

Step2: Methylation of 1-(N-benzimidazole)-4-(o-tolyl)benzene

[0130] 26.1 g (91.8 mmol) of 1-(N-benzimidazole)-4-(o-tolyl)benzene was solubilized with 400 mL of toluene in a 1 L flask equipped with a stir bar. To the stirred solution was carefully added 26.1 g (184 mmol) iodomethane and then was allowed to reflux for 2 hours. Next, the condenser was removed and a stream of N_2 was passed over the flask to remove excess iodomethane. After the volume of the solution was reduced by half, it was cooled and the white solids collected on a filter and rinsed with toluene followed by hexanes. 35.0 g 1-(N-[2-methylbenzimidazole])-4-(o-tolyl-)benzene was achieved after drying in vacuo (90.0% yield).

Step 3: Synthesis of fac(mer)-iridium(III) tris(1-(N-[2-methylbenzimidazole])-4-(o-tolyl)benzene

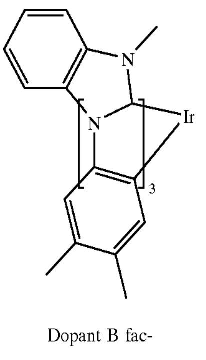
[0131] 250 mL 2-methoxyethanol was purged with N_2 and refluxed in a 500 mL round bottom flask equipped with a stir bar. After deoxygenation of the solvent, the flask was cooled and 10.0 g (23.5 mmol) 1-(N-[2-methylbenzimidazole])-4-(o-tolyl)benzene was added along with 2.1 g (5.86 mmol) $IrCl_3.3H_2O$ and 4.1 g (17.6 mmol) silver(I) oxide. The mixture was refluxed for 30 minutes whereupon an additional 4.1 g (17.6 mmol) silver(I) oxide was added. After heating for an additional 1.5 hours at reflux, HPLC indicated favorable formation of both the mer and fac isomers (~1:2 ratio). The reaction mixture was cooled and filtered. Whereas the filtrate was put to the side (mer-rich), the resulting solids were removed the filter, stirred vigorously in 300 mL $MeCl_2$ and filtered again. This process was performed a second time and the 600 mL of dichloromethane filtrates were evaporated of solvent to give beige solids that were purified on a silica gel column using a gradient of 20% dichloromethane→100% dichloromethane to give ~2.5 g iridium(III) tris(1-(N-[2-methylbenzimidazole])-4-(o-tolyl-)benzene as off-white solids. This material was sublimed in vacuo and afforded 1.5 g to be tested in an OLED device (97.8% HPLC assay, ^{1}HNMR confirmed, λ_{max} emission: 466 nm, ox: 0.52 (r), 77K excited state lifetime: 67 μsec). The mer-rich filtrate was evaporated of solvent and the residue solubilized in dichloromethane and purified on a column of silica using a gradient of EtoAc/hexanes as eluent. The mer fractions were evaporated of solvent to give ~1.0 g mer iridium(III) tris(1-(N-[2-methylbenzimidazole])-4-(o-tolyl)benzene as an off-white solid (98.0% mer) that converted to fac (3:1 mer:fac) upon sublimation (^{1}H NMR confirmed, λ_{max} emission: 468 nm, ox: 0.43 (i), 77K excited state lifetime: 48 μsec).

[0132] Device Fabrication and Measurement

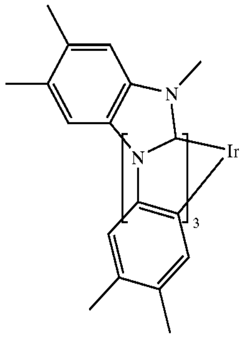
[0133] All devices were fabricated by high vacuum (<10-7 Torr) thermal evaporation. The anode electrode was ~1200 Å of indium tin oxide (ITO). The cathode consisted of 10 Å of LiF followed by 1,000 Å of Al. All devices were encapsulated with a glass lid sealed with an epoxy resin in a nitrogen glove box (<1 ppm of H20 and O2) immediately after fabrication, and a moisture getter was incorporated inside the package.

[0134] The following table indicates the dopants used for the devices of Examples 6-21.

Dopant A fac-

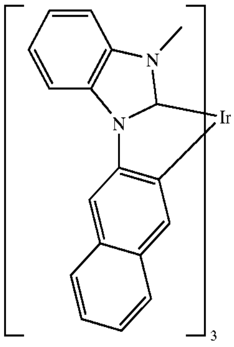


Dopant B fac-

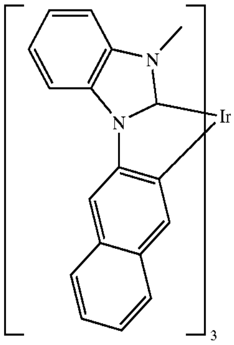


Dopant C fac-

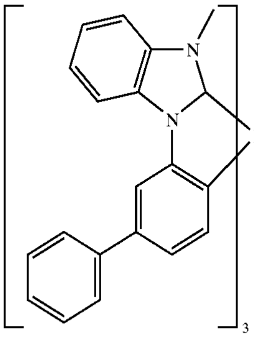
-continued



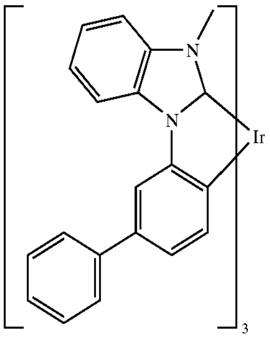
Dopant D mer-



Dopant E fac-

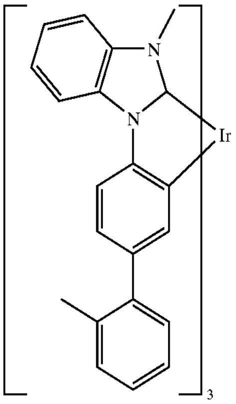


Dopant F mer-

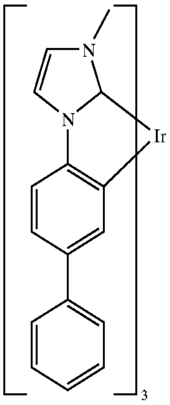


Dopant G fac-

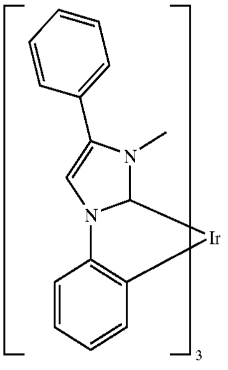
-continued



Dopant H fac-

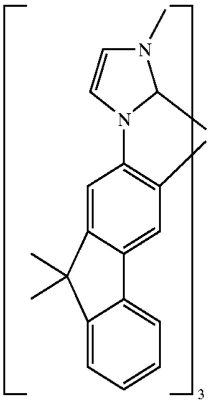


Dopant I fac-

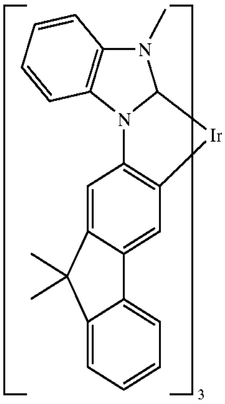


Dopant J mer-

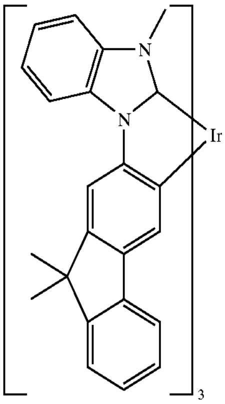
-continued



Dopant K fac-

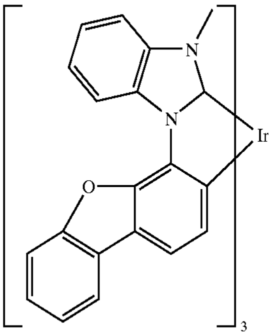


Dopant L mer-

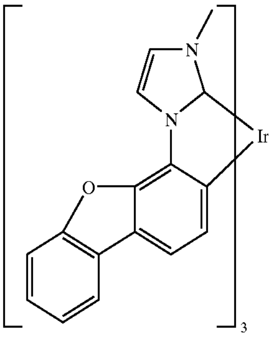


Dopant M fac-

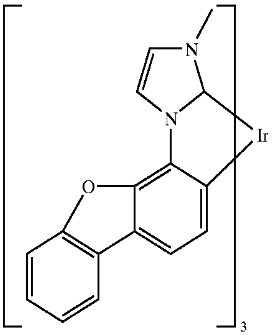
-continued



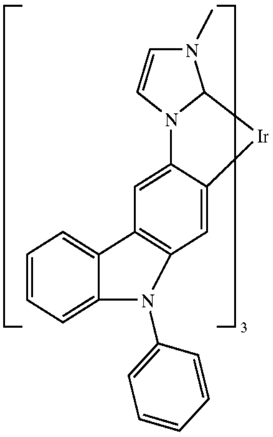
Dopant N mer-



Dopant O fac-



Dopant P mer-



EXAMPLE 6

[**0135**] The organic stack consisted of sequentially, from the ITO surface, 100 Å thick of copper phthalocyanine (CuPc) as the hole injection layer (HIL), 300 Å of 4,4'-bis [N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD), as the hole transporting layer (HTL), 300 Å of UGH5 doped with 6 wt % Dopant A as the emissive layer (EML), 400 Å of aluminum(III)bis(2-methyl-8-hydroxyquinolinato)4-phenylphenolate (BAlq) as the electron transporting layer (ETL).

EXAMPLE 7

[**0136**] The organic stack consisted of sequentially, from the ITO surface, 100 Å thick of copper phthalocyanine (CuPc) as the hole injection layer (HIL), 300 Å of 4,4'-bis [N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD), as the hole transporting layer (HTL), 300 Å of UGH5 doped with 6 wt % Dopant B as the emissive layer (EML), 400 Å of aluminum(III)bis(2-methyl-8-hydroxyquinolinato)4-phenylphenolate (BAlq) as the electron transporting layer (ETL).

[**0137**] **FIG. 3** shows plots of current vs. voltage for device CuPc(100)/NPD(300)/UGH5: Dopant A (6%, 300)/BAlQ(400) and device CuPc(100)/NPD(300)/UGH5: Dopant B (6%, 300)/BAlQ(400).

[**0138**] **FIG. 4** shows plots of quantum efficiency vs. current density for device CuPc(100)/NPD(300)/UGH5: Dopant A (6%, 300)/BAlQ(400) and device CuPc(100)/NPD(300)/UGH5: Dopant B (6%, 300)/BAlQ(400).

[**0139**] **FIG. 5** shows plots of the electroluminescent spectra of device CuPc(100)/NPD(300)/UGH5: Dopant A (6%, 300)/BAlQ(400) and device CuPc(100)/NPD(300)/UGH5: Dopant B (6%, 300)/BAlQ(400).

EXAMPLE 8

[**0140**] The organic stack consisted of sequentially, from the ITO surface, 100 Å thick of copper phthalocyanine (CuPc) as the hole injection layer (HIL), 300 Å of 4,4'-bis [N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD), as the hole transporting layer (HTL), 300 Å of mCBP doped with 6 wt % Dopant C as the emissive layer (EML), 400 Å of aluminum(III)bis(2-methyl-8-hydroxyquinolinato)4-phenylphenolate (BAlq) as the electron transporting layer (ETL).

EXAMPLE 9

[**0141**] The organic stack consisted of sequentially, from the ITO surface, 100 Å thick of copper phthalocyanine (CuPc) as the hole injection layer (HIL), 300 Å of 4,4'-bis [N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD), as the hole transporting layer (HTL), 300 Å of mCBP doped with 6 wt % Dopant D as the emissive layer (EML), 400 Å of aluminum(III)bis(2-methyl-8-hydroxyquinolinato)4-phenylphenolate (BAlq) as the electron transporting layer (ETL).

[**0142**] **FIG. 6** shows plots of current vs. voltage for device CuPc(100)/NPD(300)/mCBP: Dopant C (6%, 300)/BAlQ(400) and device CuPc(100)/NPD(300)/mCBP-:Dopant D (6%, 300)/BAlQ(400).

[**0143**] **FIG. 7** shows plots of quantum efficiency vs. current density for device CuPc(100)/NPD(300)/mCBP: Dopant C (6%, 300)/BAlQ(400) and device CuPc(100)/NPD(300)/mCBP: Dopant D (6%, 300)/BAlQ(400).

[**0144**] **FIG. 8** shows plots of the electroluminescent spectra of device CuPc(100)/NPD(300)/mCBP: Dopant C (6%, 300)/BAlQ(400) and device CuPc(100)/NPD(300)/mCBP: Dopant D (6%, 300)/BAlQ(400).

[**0145**] **FIG. 24** shows plots of the plot of operation lifetime of device CuPc(100)/NPD(300)/UGH5: Dopant D (6%, 300)/BAlQ(400).

EXAMPLE 10

[**0146**] The organic stack consisted of sequentially, from the ITO surface, 100 Å thick of copper phthalocyanine (CuPc) as the hole injection layer (HIL), 300 Å of 4,4'-bis [N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD), as the hole transporting layer (HTL), 300 Å of mCBP doped with 6 wt % Dopant E as the emissive layer (EML), 400 Å of aluminum(III)bis(2-methyl-8-hydroxyquinolinato)4-phenylphenolate (BAlq) as the electron transporting layer (ETL).

EXAMPLE 11

[**0147**] The organic stack consisted of sequentially, from the ITO surface, 100 Å thick of copper phthalocyanine (CuPc) as the hole injection layer (HIL), 300 Å of 4,4'-bis [N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD), as the hole transporting layer (HTL), 300 Å of mCBP doped with 6 wt % Dopant F as the emissive layer (EML), 400 Å of aluminum(III)bis(2-methyl-8-hydroxyquinolinato)4-phenylphenolate (BAlq) as the electron transporting layer (ETL).

[**0148**] **FIG. 9** shows plots of current vs. voltage for device CuPc(100)/NPD(300)/mCBP: Dopant E (300, 6%)/BAlQ(400) and device CuPc(100)/NPD(300)/mCBP: Dopant F (300, 6%)/BAlQ(400).

[**0149**] **FIG. 10** shows plots of quantum efficiency vs. current density for device CuPc(100)/NPD(300)/mCBP: Dopant E (300, 6%)/BAlQ(400) and device CuPc(100)/NPD(300)/mCBP: Dopant F (300, 6%)/BAlQ(400).

[**0150**] **FIG. 11** shows plots of the electroluminescent spectra of device CuPc(100)/NPD(300)/mCBP: Dopant E (300, 6%)/BAlQ(400) and device CuPc(100)/NPD(300)/mCBP: Dopant F (300, 6%)/BAlQ(400).

EXAMPLE 12

[**0151**] The organic stack consisted of sequentially, from the ITO surface, 100 Å thick of copper phthalocyanine (CuPc) as the hole injection layer (HIL), 300 Å of 4,4'-bis [N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD), as the hole transporting layer (HTL), 300 Å of UGH5 doped with 6 wt % Dopant G as the emissive layer (EML), 400 Å of aluminum(III)bis(2-methyl-8-hydroxyquinolinato)4-phenylphenolate (BAlq) as the electron transporting layer (ETL).

[**0152**] **FIG. 12** shows plots of current vs. voltage for device CuPc(100)/NPD(300)/UGH5: Dopant G (6%, 300)/BAlQ(400).

[0153] **FIG. 13** shows plots of quantum efficiency vs. current density for CuPc(100)/NPD(300)/UGH5: Dopant G (6%, 300)/BAlQ(400).

[0154] **FIG. 14** shows plots of the electroluminescent spectra of CuPc(100)/NPD(300)/UGH5: Dopant G (6%, 300)/BAlQ(400).

EXAMPLE 13

[0155] The organic stack consisted of sequentially, from the ITO surface, 100 Å thick of copper phthalocyanine (CuPc) as the hole injection layer (HIL), 300 Å of 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD), as the hole transporting layer (HTL), 300 Å of mCP doped with 6 wt % Dopant H as the emissive layer (EML), 400 Å of aluminum(III)bis(2-methyl-8-hydroxyquinolinato)4-phenylphenolate (BAlq) as the electron transporting layer (ETL).

EXAMPLE 14

[0156] The organic stack consisted of sequentially, from the ITO surface, 100 Å thick of copper phthalocyanine (CuPc) as the hole injection layer (HIL), 300 Å of 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD), as the hole transporting layer (HTL), 300 Å of CBP doped with 6 wt % Dopant I as the emissive layer (EML), 400 Å of aluminum(III)bis(2-methyl-8-hydroxyquinolinato)4-phenylphenolate (BAlq) as the electron transporting layer (ETL).

EXAMPLE 15

[0157] The organic stack consisted of sequentially, from the ITO surface, 100 Å thick of copper phthalocyanine (CuPc) as the hole injection layer (HIL), 300 Å of 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD), as the hole transporting layer (HTL), 300 Å of mCBP doped with 6 wt % Dopant J as the emissive layer (EML), 400 Å of aluminum(III)bis(2-methyl-8-hydroxyquinolinato)4-phenylphenolate (BAlq) as the electron transporting layer (ETL).

[0158] **FIG. 15** shows plots of current vs. voltage for device CuPc(100)/NPD(300)/mCP: Dopant H (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/CBP-:dopant132(6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/mCBP:dopant130(6%, 300)/BAlQ(400).

[0159] **FIG. 16** shows plots of quantum efficiency vs. current density for device CuPc(100)/NPD(300)/mCP: Dopant H (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/CBP: Dopant I (6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/mCBP: Dopant J (6%, 300)/BAlQ(400).

[0160] **FIG. 17** shows plots of the electroluminescent spectra of device CuPc(100)/NPD(300)/mCP: Dopant H (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/CBP: Dopant I (6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/mCBP: Dopant J (6%, 300)/BAlQ(400).

EXAMPLE 16

[0161] The organic stack consisted of sequentially, from the ITO surface, 100 Å thick of copper phthalocyanine (CuPc) as the hole injection layer (HIL), 300 Å of 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD), as the hole transporting layer (HTL), 300 Å of mCBP doped with 6 wt % Dopant K as the emissive layer (EML), 400 Å of aluminum(III)bis(2-methyl-8-hydroxyquinolinato)4-phenylphenolate (BAlq) as the electron transporting layer (ETL).

EXAMPLE 17

[0162] The organic stack consisted of sequentially, from the ITO surface, 100 Å thick of copper phthalocyanine (CuPc) as the hole injection layer (HIL), 300 Å of 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD), as the hole transporting layer (HTL), 300 Å of mCBP doped with 6 wt % Dopant L as the emissive layer (EML), 400 Å of aluminum(III)bis(2-methyl-8-hydroxyquinolinato)4-phenylphenolate (BAlq) as the electron transporting layer (ETL).

EXAMPLE 18

[0163] The organic stack consisted of sequentially, from the ITO surface, 100 Å thick of copper phthalocyanine (CuPc) as the hole injection layer (HIL), 300 Å of 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD), as the hole transporting layer (HTL), 300 Å of UGH5 doped with 6 wt % Dopant M as the emissive layer (EML), 400 Å of aluminum(III)bis(2-methyl-8-hydroxyquinolinato)4-phenylphenolate (BAlq) as the electron transporting layer (ETL).

[0164] **FIG. 18** shows plots of current vs. voltage for device CuPc(100)/NPD(300)/mCBP: Dopant K (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/mCBP: Dopant L (6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/UGH5: Dopant M (6%, 300)/BAlQ(400).

[0165] **FIG. 19** shows plots of quantum efficiency vs. current density for device CuPc(100)/NPD(300)/mCBP: Dopant K (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/mCBP: Dopant L (6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/UGH5: Dopant M (6%, 300)/BAlQ(400).

[0166] **FIG. 20** shows plots of the electroluminescent spectra of device CuPc(100)/NPD(300)/mCBP: Dopant K (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/mCBP: Dopant L (6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/UGH5: Dopant M (6%, 300)/BAlQ(400).

EXAMPLE 19

[0167] The organic stack consisted of sequentially, from the ITO surface, 100 Å thick of copper phthalocyanine (CuPc) as the hole injection layer (HIL), 300 Å of 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD), as the hole transporting layer (HTL), 300 Å of UGH5 doped with 6 wt % Dopant N as the emissive layer (EML), 400 Å of aluminum(III)bis(2-methyl-8-hydroxyquinolinato)4-phenylphenolate (BAlq) as the electron transporting layer (ETL).

EXAMPLE 20

[0168] The organic stack consisted of sequentially, from the ITO surface, 100 Å thick of copper phthalocyanine (CuPc) as the hole injection layer (HIL), 300 Å of 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD), as the hole transporting layer (HTL), 300 Å of UGH5 doped with 6 wt % Dopant O as the emissive layer (EML), 400 Å of aluminum(III)bis(2-methyl-8-hydroxyquinolinato)4-phenylphenolate (BAlq) as the electron transporting layer (ETL).

EXAMPLE 21

[0169] The organic stack consisted of sequentially, from the ITO surface, 100 Å thick of copper phthalocyanine (CuPc) as the hole injection layer (HIL), 300 Å of 4,4'-bis [N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD), as the hole transporting layer (HTL), 300 Å of UGH5 doped with 6 wt % Dopant P as the emissive layer (EML), 400 Å of aluminum(III)bis(2-methyl-8-hydroxyquinolinato)4-phenylphenolate (BAlq) as the electron transporting layer (ETL).

[0170] **FIG. 21** shows plots of current vs. voltage for device CuPc(100)/NPD(300)/UGH5: Dopant N (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/UGH5: Dopant O (6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/UGH5: Dopant P (6%, 300)/BAlQ(400).

[0171] **FIG. 22** shows plots of quantum efficiency vs. current density for device CuPc(100)/NPD(300)/UGH5: Dopant N (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/UGH5: Dopant O (6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/UGH5: Dopant P (6%, 300)/BAlQ(400).

[0172] **FIG. 23** shows plots of the electroluminescent spectra of device CuPc(100)/NPD(300)/UGH5: Dopant N (6%, 300)/BAlQ(400), device CuPc(100)/NPD(300)/UGH5: Dopant O (6%, 300)/BAlQ(400), and device CuPc(100)/NPD(300)/UGH5: Dopant P (6%, 300)/BAlQ(400).

[0173] Synthesis of Carbene Dopants

EXAMPLE 22, 23

Synthesis of fac-iridium(III) tris (1-(2-naphthyl-3-methyl-benzimidazoline-2-ylidene-C,C^2) and mer-iridium(III) tris (1-(2-naphthyl-3-methyl-benzimidazoline-2-ylidene-C,C^2) [Dopant C, D]

[0174] A 3 L round-bottomed flask was charged with 113.83 g of silver(I) oxide, 38 g of 1-(2-naphthyl)-3-methyl-benzimidazolate iodide, 9.1 g of iridium trichloride hydrate, and 2000 mL of 2-ethoxyethanol. The reaction was stirred and heated at 120oC for 2 h under nitrogen while protected from light with aluminum foil. The reaction mixture was cooled to ambient temperature and concentrated under reduced pressure(20 mmHg). Filtration through Celite using dichloromethane as the eluent was performed to remove the silver(I) salts. A light brown solution was obtained and further purified by flash column chromatography on silica gel using dichloromethane as the eluent and 6 g (25.2%) of iridium complex was obtained. The mer isomer was selectively crystallized from a mixture of dichloromethane and methanol. The mother liquid was evaporated to dryness and the residue was recrystallized from dichloromethane to obtain the fac isomer.

EXAMPLE 24

Synthesis of fac-iridium(III) tris (1-(4,5-dimethylphenyl)-3-methyl-benzimidazoline-2-ylidene-C,C^2) [Dopant A]

[0175] A 3 L round-bottomed flask was charged with 66.74 g of silver(I) oxide, 21 g of 1-(4,5-dimethylphenyl)-3-methyl-benzimidazolate iodide, 5.33 g of iridium trichloride hydrate, molecular sieve (200 g) and 1108 mL of 2-ethoxyethanol. The reaction was stirred and heated at 120° C. for 3.5 h under nitrogen while protected from light with aluminum foil. The reaction mixture was cooled to ambient temperature and concentrated under reduced pressure(20 mmHg). Filtration through Celite using dichloromethane as the eluent was performed to remove the silver(I) salts. A light brown solution was obtained and further purified by flash column chromatography on silica gel using dichlormethane as the eluent and 9 g (60%) of iridium complex was obtained. The fac isomer was selectively crystallized from a mixture of dichloromethane and methanol.

EXAMPLE 25

Synthesis of fac-iridium(III) tris (1-(4,5-dimethylphenyl)-3-methyl-5,6-dimethyl-benzimidazoline-2-ylidene-C,C^2) [Dopant B]

[0176] A 3 L round-bottomed flask was charged with 118.14 g of silver(I) oxide, 40 g of 1-(4,5-dimethylphenyl)-3-methyl-benzimidazolate iodide, 9.44 g of iridium trichloride hydrate, molecular sieve (100 g) and 2000 mL of 2-ethoxyethanol. The reaction was stirred and heated at 120° C. for 3 h under nitrogen while protected from light with aluminum foil. The reaction mixture was cooled to ambient temperature and concentrated under reduced pressure(20 mmHg). Filtration through Celite using dichloromethane as the eluent was performed to remove the silver(I) salts. A light brown solution was obtained and further purified by flash column chromatography on silica gel using dichloromethane as the eluent and 9 g (35%) of iridium complex was obtained. The fac isomer was selectively crystallized from a mixture of dichloromethane and methanol.

EXAMPLE 26

Synthesis of fac-iridium(III) tris (1-(4-chlorolphenyl)-3-(4-chlorophenyl)-imidazoline-2-ylidene-C,C^2)

[0177] A 100 ml round-bottomed flask was charged with 177.9 mg of silver(I) oxide, 250 mg of 1,3-bis(4-chlorophenyl)imidazolium Chloride, 71.09 mg of iridium trichloride hydrate, and 20 mL of 2-ethoxyethanol. The reaction was stirred and heated at 120° C. for 1 h under nitrogen while protected from light with aluminum foil. The reaction mixture was cooled to ambient temperature and concentrated under reduced pressure(20 mmHg). Filtration through Celite using dichloromethane as the eluent was performed to remove the silver(I) salts. A light brown solution was obtained and further purified by flash column chromatography on silica gel using dichloromethane as the eluent and 50 mg (25%) of iridium complex was obtained. The fac isomer was selectively crystallized from a mixture of dichloromethane and methanol.

[0178] While the present invention is described with respect to particular examples and preferred embodiments, it is understood that the present invention is not limited to these examples and embodiments. The present invention as claimed therefore includes variations from the particular examples and preferred embodiments described herein, as will be apparent to one of skill in the art.

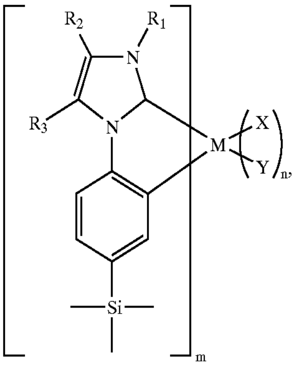
What is claimed is:

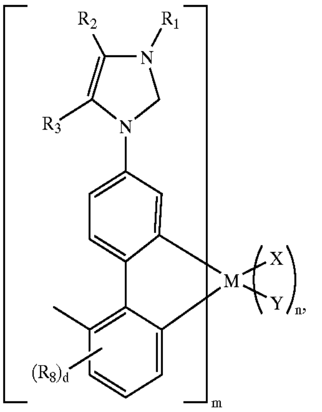
1. An organic light emitting device, comprising:

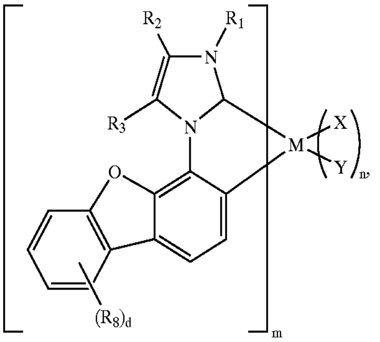
(a) an anode;

(b) a cathode;

(c) an organic layer disposed between the anode and the cathode, wherein the organic layer comprises a compound further comprising one or more carbene ligands coordinated to a metal center, wherein the compound has the structure:







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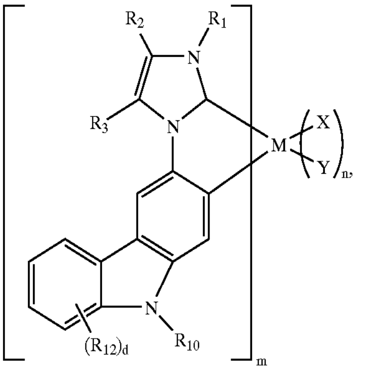

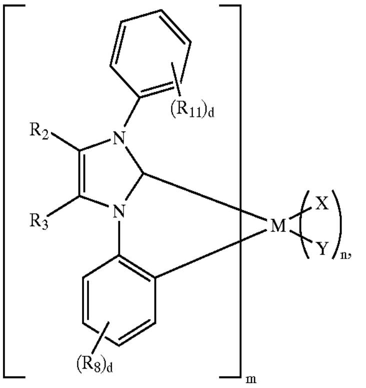

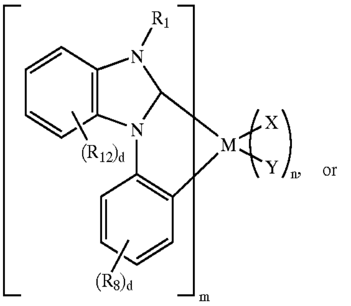

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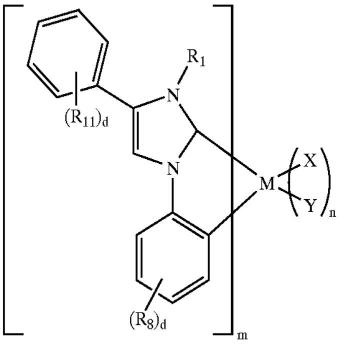


wherein M is a metal;

R_1 is independently selected from hydrogen, alkyl, alkenyl, alkynyl, aralkyl, aryl, heteroaryl, substituted aryl, substituted heteroaryl, or a heterocyclic group; R_2, R_3, R_8, R_{10}, R_{11}, and R_{12} are independently selected from hydrogen, alkyl, alkenyl, alkynyl, aralkyl, CN, CF_3, CO_2R', C(O)R', C(O)NR'2, NR'2, NO_2, OR', SR', SO_2, SOR', SO_3R', halo, aryl, heteroaryl, substituted aryl, substituted heteroaryl, or a heterocyclic group; and additionally or alternatively, one or more of R_1 and R_2, and R_2 and R_3, and two R_8 groups, two R_{10} groups, and two R_{12} groups on the same ring together form independently a 5 or 6-member cyclic group, wherein said cyclic group is cycloalkyl, cycloheteroalkyl, aryl or heteroaryl; and wherein said cyclic group is optionally substituted by one or more substituents J;

each substituent J is independently selected from the group consisting of R', CN, CF_3, C(O)OR', C(O)R', C(O)NR'$_2$, NR'$_2$, NO_2, OR', SR', SO_2, SOR', or SO_3R', and additionally, or alternatively, two J groups on adjacent ring atoms form a fused 5- or 6-membered aromatic group; each R' is independently selected from halo, H, alkyl, alkenyl, alkynyl, heteroalkyl, aralkyl, aryl and heteroaryl;

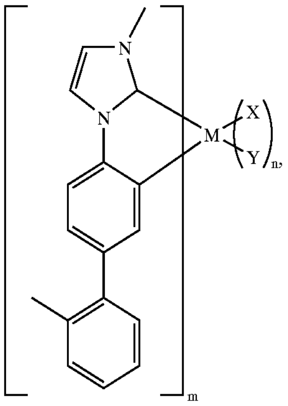
(X—Y) is selected from a photoactive ligand or an ancillary ligand;

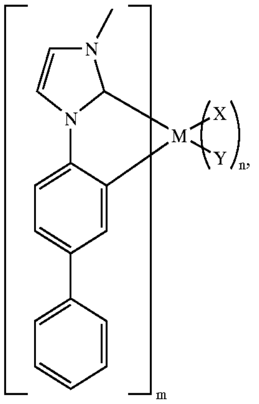
d is 0, 1, 2, 3, or 4;

m is a value from 1 to the maximum number of ligands that may be attached to metal M;

m+n is the maximum number of ligands that may be attached to metal M.

2. The device of claim 1, wherein the compound is selected from the group consisting of:





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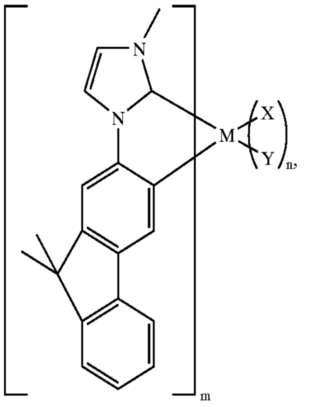

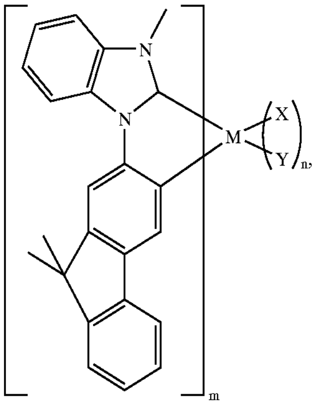

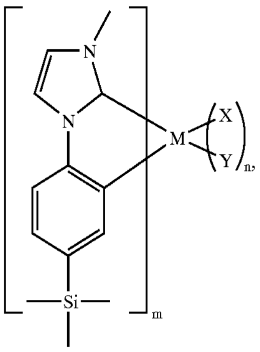

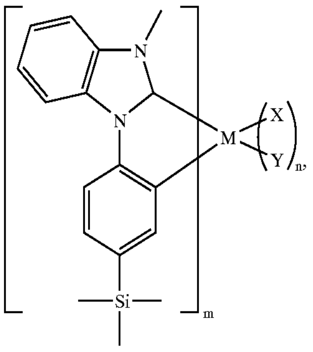

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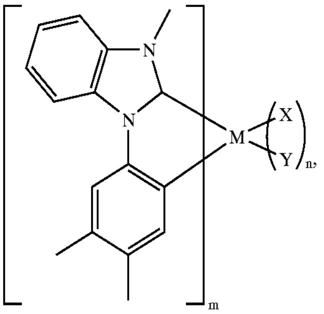

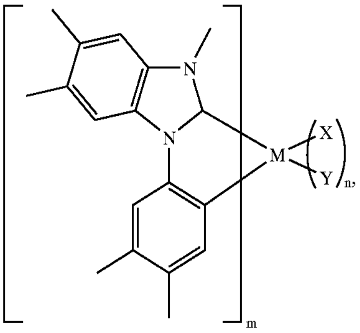

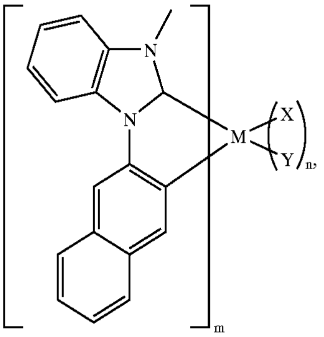

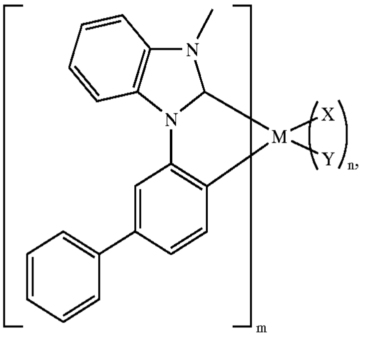

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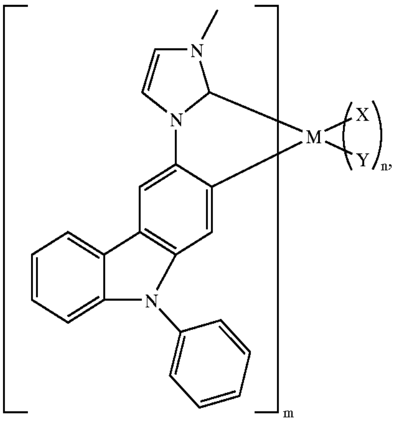

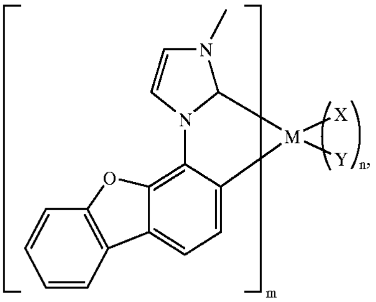

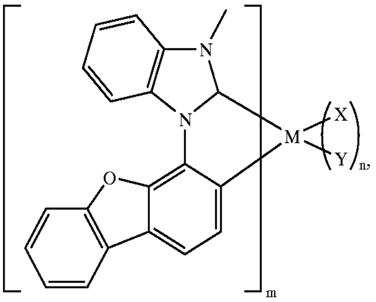

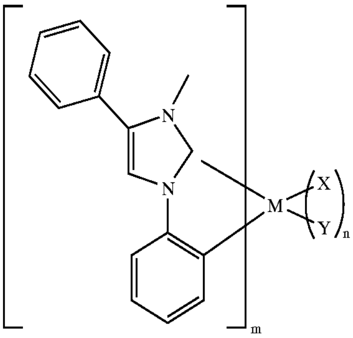

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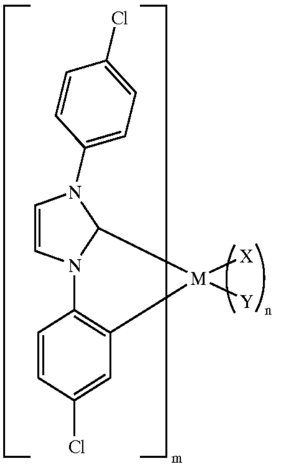


3. The device of claim 2, wherein M is selected from the group consisting of Ir, Pt, Pd, Rh, Re, Ru, Os, Tl, Pb, Bi, In, Sn, Sb, Te, Au, and Ag.

4. The device of claim 3, wherein M is Ir.

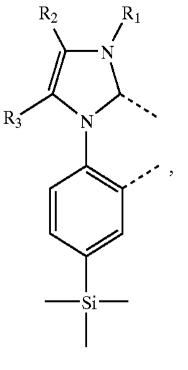
5. The device of claim 4, wherein m is 3 and n is 0.

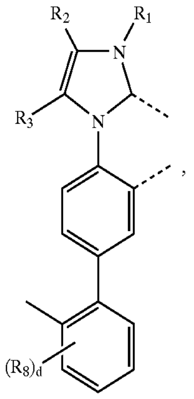
6. An organic light emitting device, comprising:

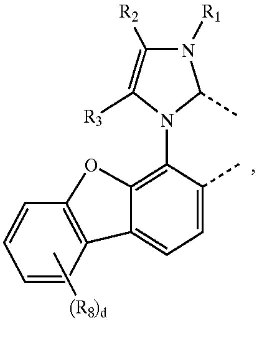
(a) an anode;

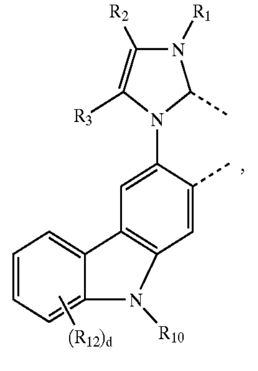
(b) a cathode;

(c) an organic layer disposed between the anode and the cathode, wherein the organic layer comprises a compound further comprises a carbene ligand having the structure:









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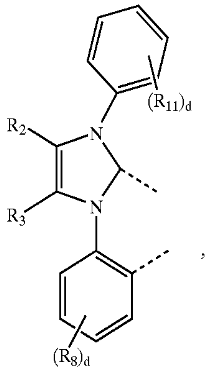

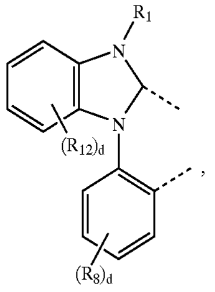

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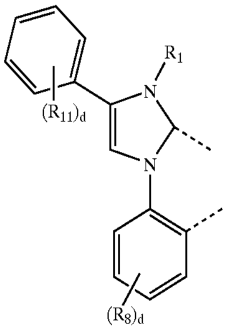


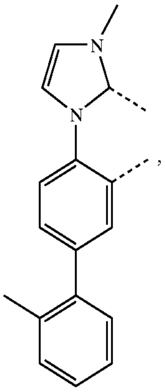
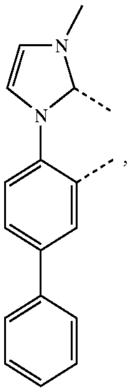
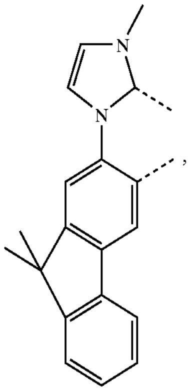
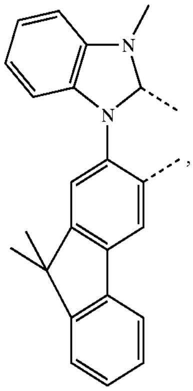
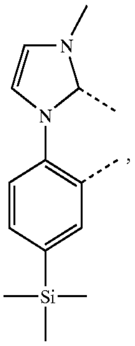
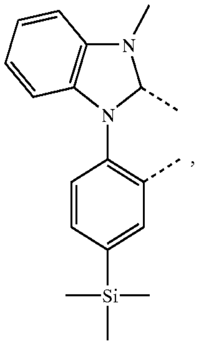
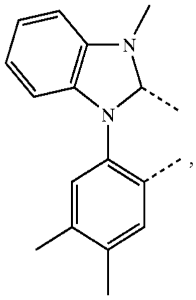
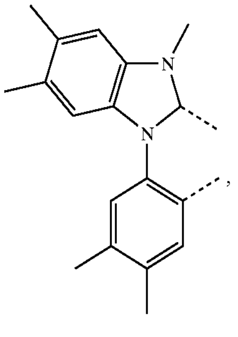
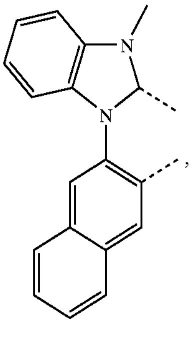
wherein R_1 is independently selected from hydrogen, alkyl, alkenyl, alkynyl, aralkyl, aryl, heteroaryl, substituted aryl, substituted heteroaryl, or a heterocyclic group; R_2, R_3, R_8, R_{10}, R_{11}, and R_{12} are independently selected from hydrogen, alkyl, alkenyl, alkynyl, aralkyl, CN, CF_3, CO_2R', C(O)R', C(O)NR'2, NR'2, NO_2, OR', SR', SO_2, SOR', SO_3R', halo, aryl, heteroaryl, substituted aryl, substituted heteroaryl, or a heterocyclic group; and additionally or alternatively, one or more of R_1 and R_2, and R_2 and R_3, and two R_8 groups, two R_{10} groups, and two R_{12} groups on the same ring together form independently a 5 or 6-member cyclic group, wherein said cyclic group is cycloalkyl, cycloheteroalkyl, aryl or heteroaryl; and wherein said cyclic group is optionally substituted by one or more substituents J;

each substituent J is independently selected from the group consisting of R', CN, CF_3, C(O)OR', C(O)R', C(O)NR'_2, NR'_2, NO_2, OR', SR', SO_2, SOR', or SO_3R', and additionally, or alternatively, two J groups on adjacent ring atoms form a fused 5- or 6-membered aromatic group; each R' is independently selected from halo, H, alkyl, alkenyl, alkynyl, heteroalkyl, aralkyl, aryl and heteroaryl;

(X—Y) is selected from a photoactive ligand or an ancillary ligand,

d is 0, 1, 2, 3, or 4.

7. The device of claim 6, wherein the ligand is selected from the group consisting of:

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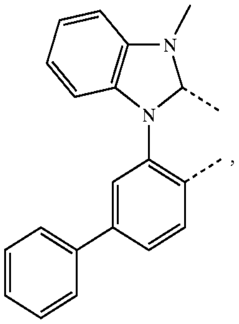
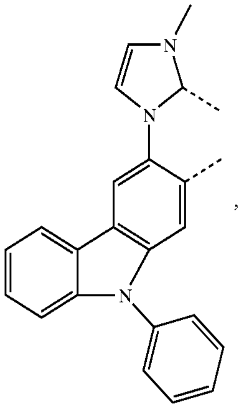
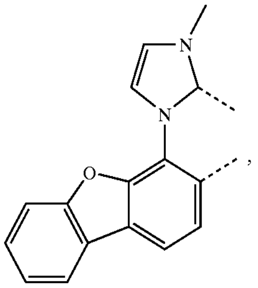
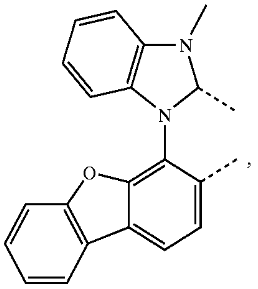
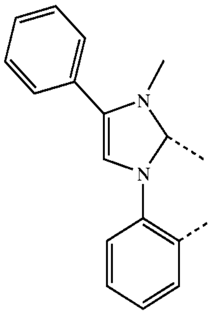

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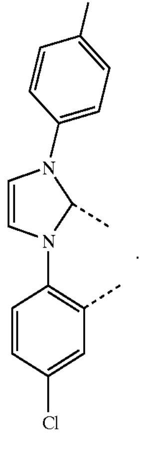
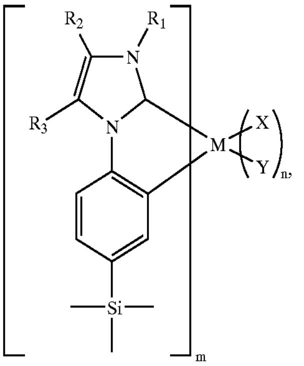
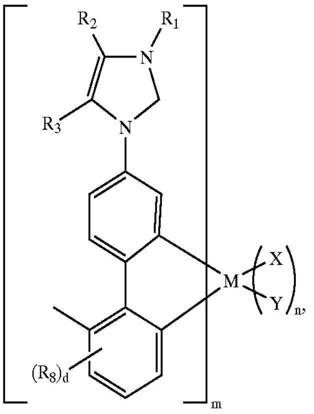
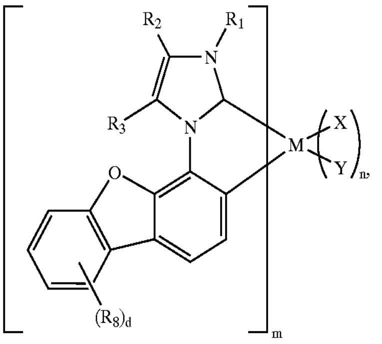
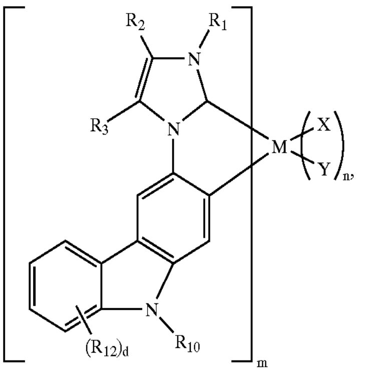


8. A compound selected from the group consisting of:









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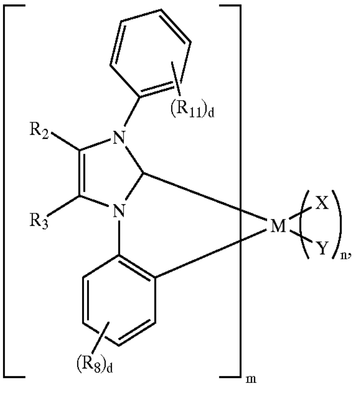

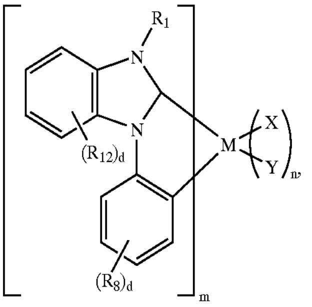

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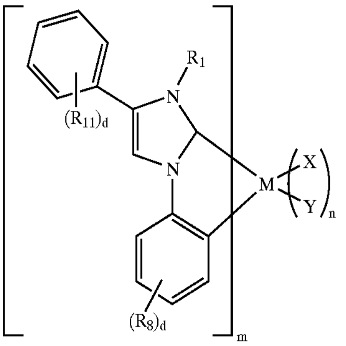


wherein

R_1 is independently selected from hydrogen, alkyl, alkenyl, alkynyl, aralkyl, aryl, heteroaryl, substituted aryl, substituted heteroaryl, or a heterocyclic group; R_2, R_3, R_8, R_{10}, R_{11}, and R_{12} are independently selected from hydrogen, alkyl, alkenyl, alkynyl, aralkyl, CN, CF_3, CO_2R', C(O)R', C(O)NR'2, NR'2, NO_2, OR', SR', SO_2, SOR', SO_3R', halo, aryl, heteroaryl, substituted aryl, substituted heteroaryl, or a heterocyclic group; and additionally or alternatively, one or more of R_1 and R_2, and R_2 and R_3, and two R_8 groups, two R_{10} groups, and two R_{12} groups on the same ring together form independently a 5 or 6-member cyclic group, wherein said cyclic group is cycloalkyl, cycloheteroalkyl, aryl or heteroaryl; and wherein said cyclic group is optionally substituted by one or more substituents J;

each substituent J is independently selected from the group consisting of R', CN, CF_3, C(O)OR', C(O)R', C(O)NR'$_2$, NR'$_2$, NO_2, OR', SR', SO_2, SOR', or SO_3R', and additionally, or alternatively, two J groups on adjacent ring atoms form a fused 5- or 6-membered aromatic group; each R' is independently selected from halo, H, alkyl, alkenyl, alkynyl, heteroalkyl, aralkyl, aryl and heteroaryl;

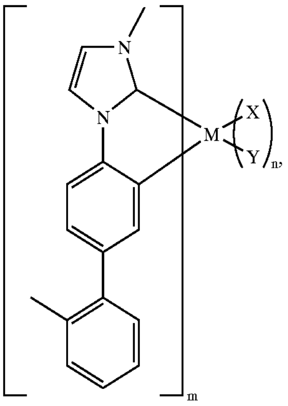
(X—Y) is selected from a photoactive ligand or an ancillary ligand,

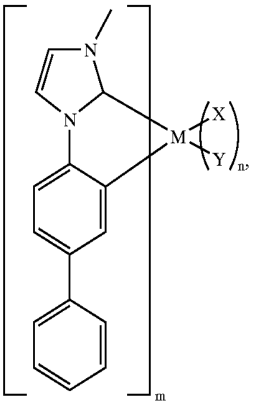
d is 0, 1, 2, 3, or 4;

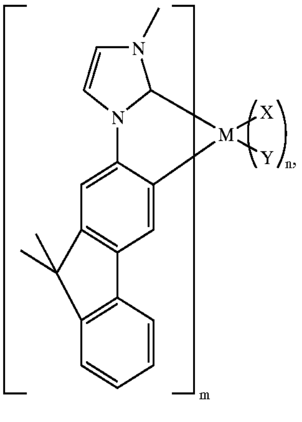
m is a value from 1 to the maximum number of ligands that may be attached to metal M;

m+n is the maximum number of ligands that may be attached to metal M.

9. The compound of claim 8, selected from the group consisting of:







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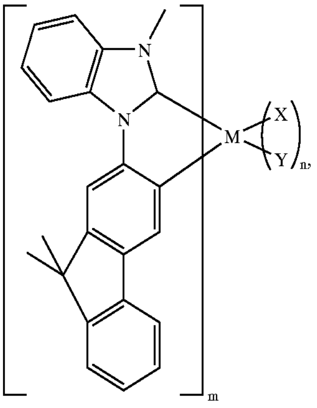

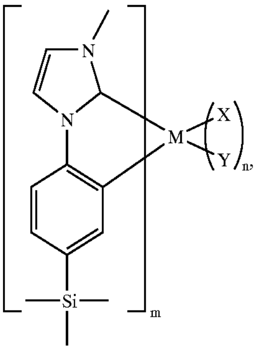

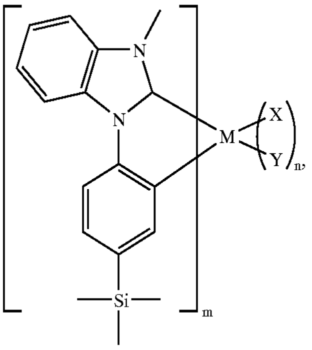

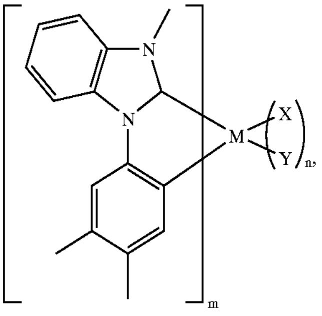

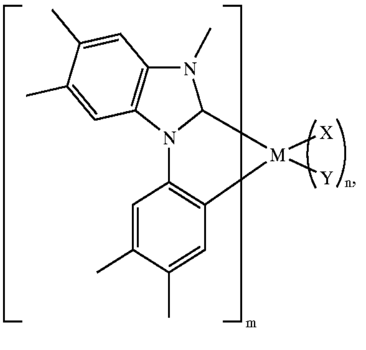

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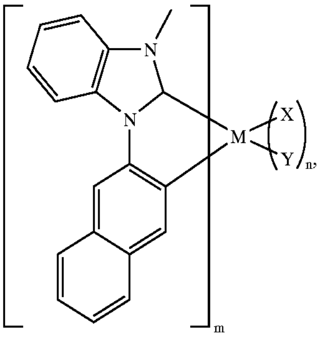

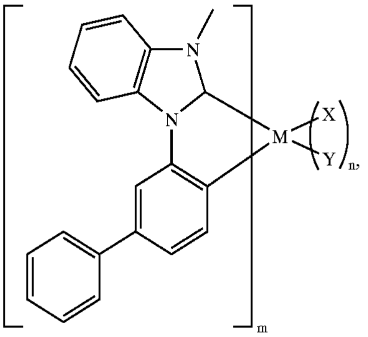

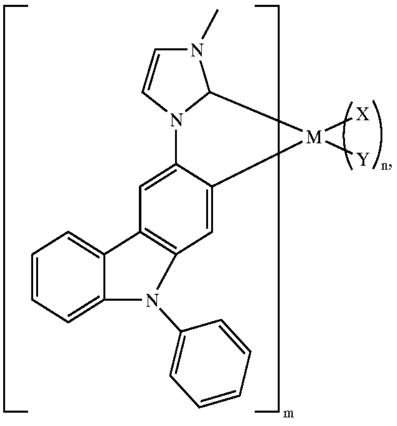

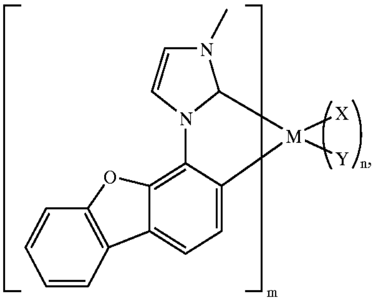

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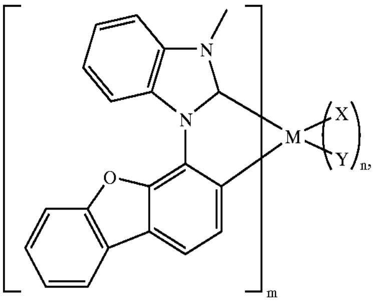

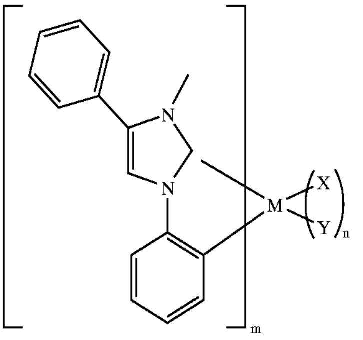

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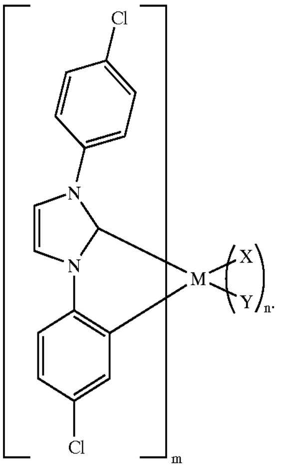

10. The compound of claim 9, wherein M is selected from the group consisting of Ir, Pt, Pd, Rh, Re, Ru, Os, Tl, Pb, Bi, In, Sn, Sb, Te, Au, and Ag.

11. The compound of claim 10, wherein M is Ir.

12. The compound of claim 11, wherein m is 3 and n is 0.

* * * * *

专利名称(译)	用于电致发光器件的新型有机金属化合物		
公开(公告)号	US20050260448A1	公开(公告)日	2005-11-24
申请号	US11/032885	申请日	2005-01-10
[标]申请(专利权)人(译)	蔡瑞YI BROOKS JASON 阿莱恩BERT THOMPSON标志着e DJUROVICH PETER 塔马约ARNOLD SAJOTO TISSA WALTERS ROBERT		
申请(专利权)人(译)	林春 蔡瑞-YI BROOKS JASON 阿莱恩BERT THOMPSON标志着e DJUROVICH PETER 塔马约ARNOLD SAJOTO TISSA WALTERS ROBERT		
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IPC分类号	C09K11/06 H01L51/00 H01L51/50 H05B33/14		

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其他公开文献	US7534505
外部链接	Espacenet USPTO

摘要(译)

提供一种有机发光器件，其具有阳极，阴极和在阳极和阴极之间的有机层。有机层包含具有以下结构的卡宾 - 金属配合物： 其中R可以是卤素，氢，烷基，链烯基，炔基，芳烷基，芳基，杂芳基，取代的芳基，取代的杂芳基或杂环基;另外或可选地，同一环上的两个或多个R基团独立地形成5或6元环状基团，其可以是环烷基，环杂烷基，芳基或杂芳基;并且可以被一个或多个取代基J取代;和J可以是R'，CN，CF3，C（O）OR'，C（O）R'，C（O）NR'2，NR'2，NO2，OR'，SR'，SO2，SOR'，或另外或作为另外一种选择，相邻环原子上的两个J基团形成稠合的5-或6-元芳族基团;或SO3 R'。每个R'可以是卤素，H，烷基，烯基，炔基，杂烷基，芳烷基，芳基和杂芳基。