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(54) **HOST MATERIALS FOR OLED**

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H01L 51/54 (2006.01)

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USPC **428/690**; 428/917; 313/504; 313/505; 313/506; 257/40; 257/E51.05; 257/E51.026; 257/E51.032; 548/304.1; 548/418; 548/440; 546/18; 546/24; 546/79; 546/81; 546/101

(58) **Field of Classification Search**
USPC 428/690, 917; 313/504, 505, 506; 257/40, E51.05, E51.026, E51.032; 546/18, 79, 81, 101, 24; 548/440, 548/304.1, 418
See application file for complete search history.

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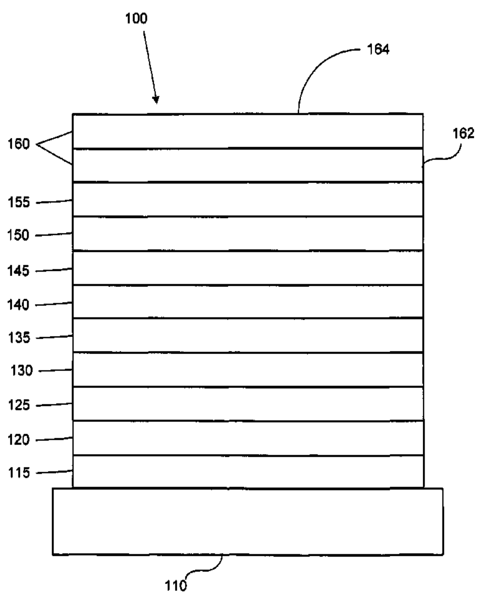
(57) **ABSTRACT**

Novel aryl silicon and aryl germanium host materials are described. These compounds improve OLED device performance when used as hosts in the emissive layer of the OLED.

19 Claims, 4 Drawing Sheets



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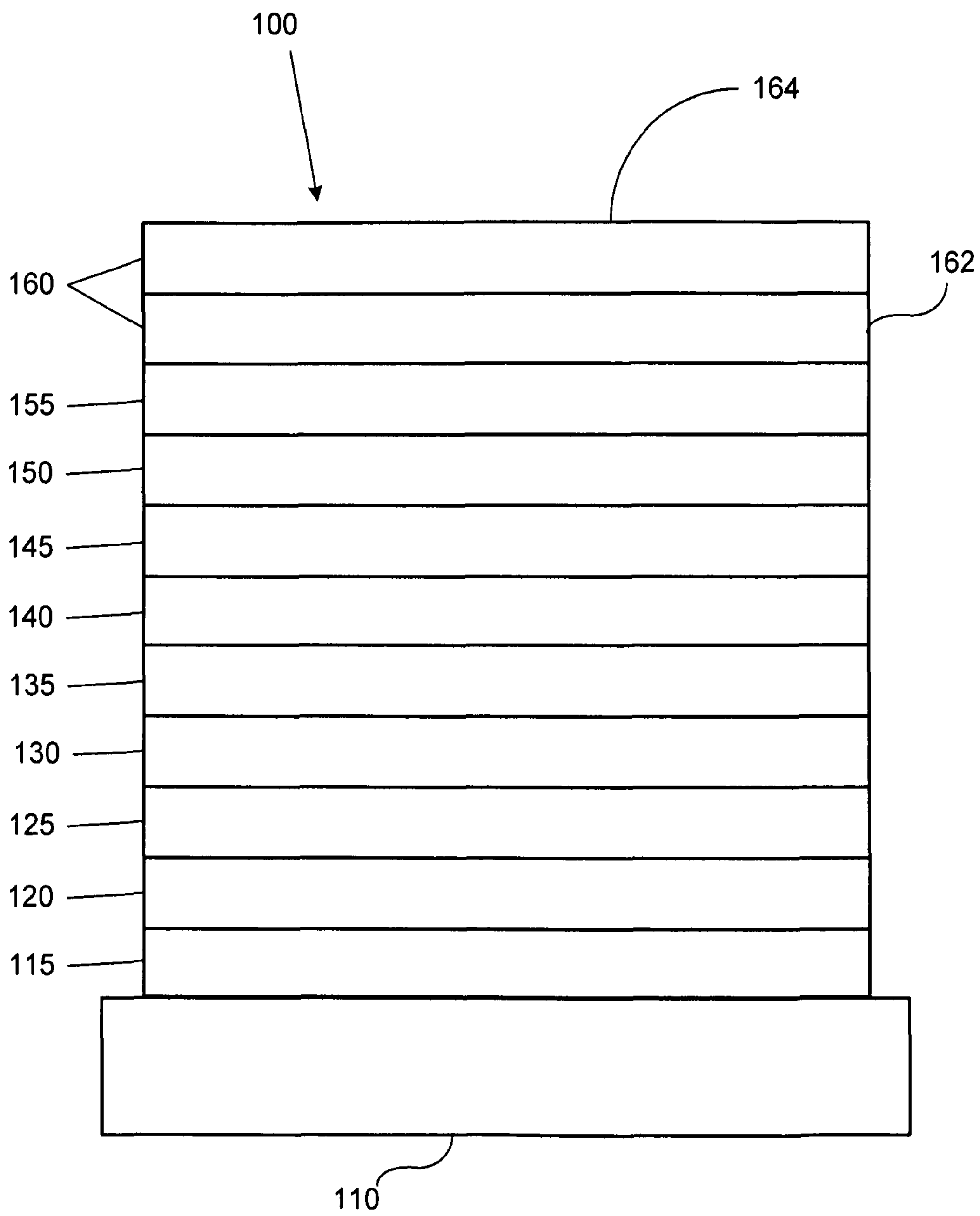


FIGURE 1

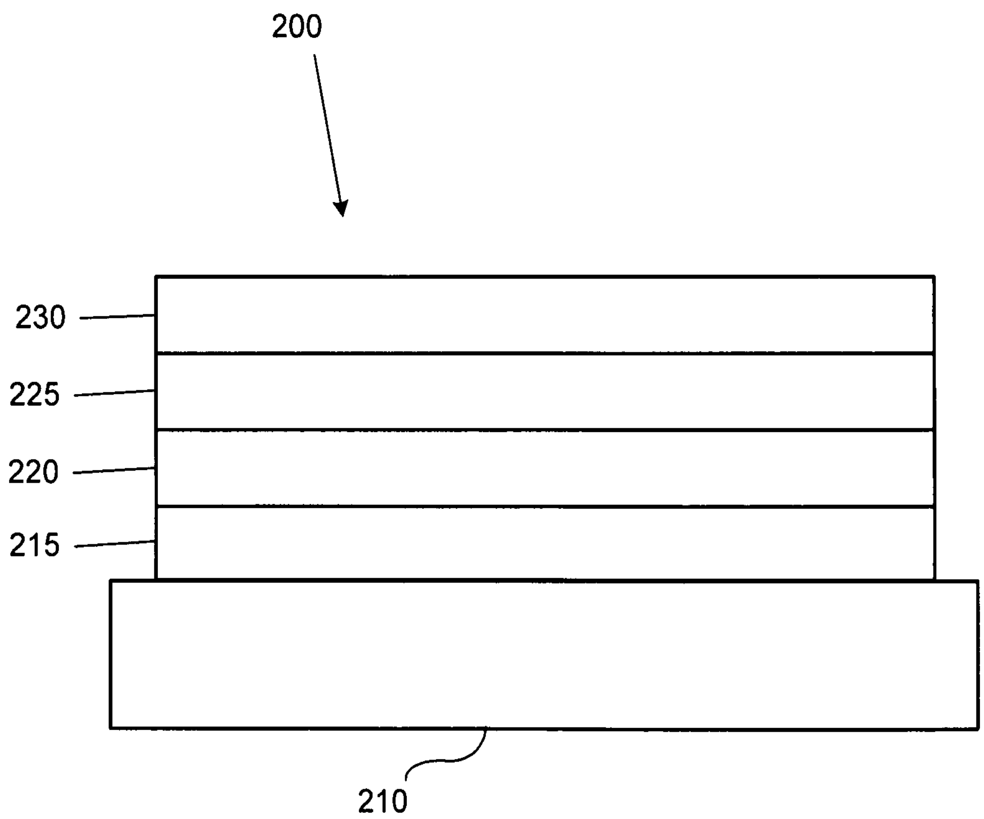
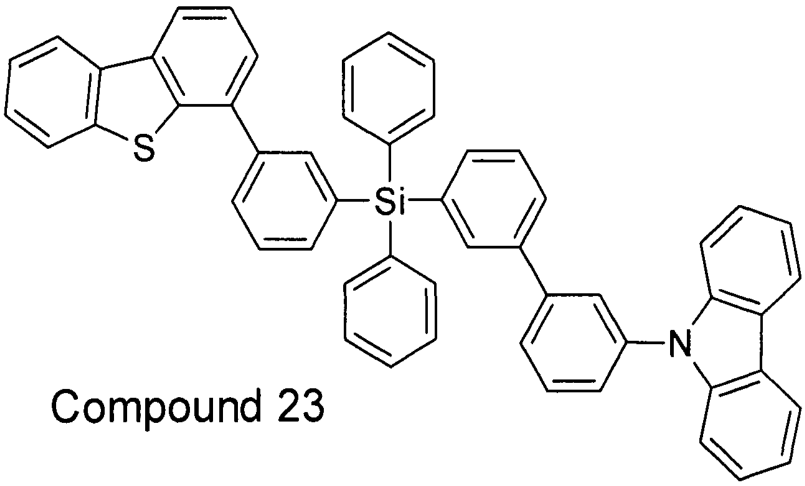


FIGURE 2



Compound 23

FIGURE 3

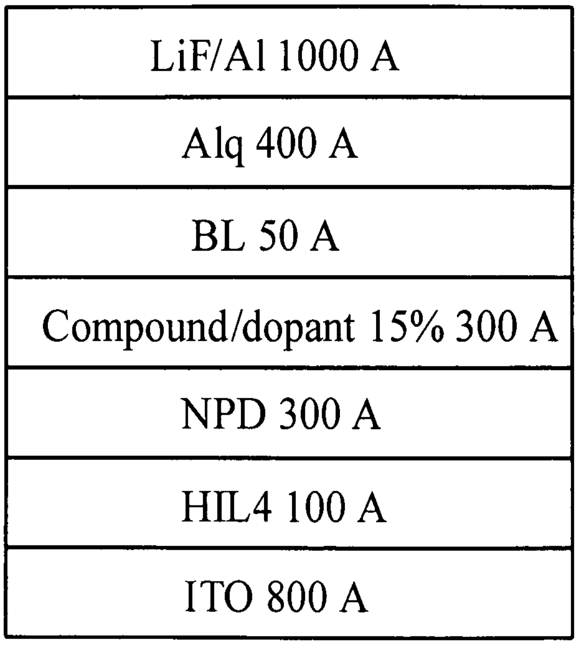

LiF/Al 1000 A
Alq 400 A
BL 50 A
Compound/dopant 15% 300 A
NPD 300 A
HIL4 100 A
ITO 800 A

FIGURE 4

HOST MATERIALS FOR OLED

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

FIELD OF THE INVENTION

The present invention relates to compounds suitable for use as host materials in OLEDs, specifically compounds comprising arylgermane and arylsilane groups.

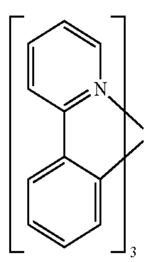
BACKGROUND

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.

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.

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

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



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

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.

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

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.

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

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.

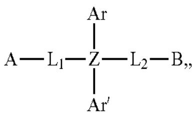
As used herein, and as would be generally understood by one skilled in the art, a first work function is "greater than" or "higher than" a second work function if the first work function has a higher absolute value. Because work functions are generally measured as negative numbers relative to vacuum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

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

SUMMARY OF THE INVENTION

A compound of Formula I is provided.

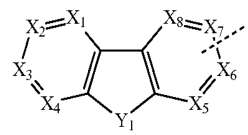
Formula I

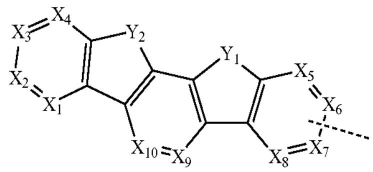


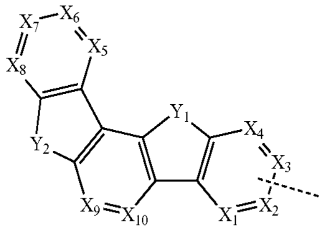
In one aspect, Ar and Ar' are independently selected from the group consisting of phenyl, biphenyl, napthyl, dibenzothiolyl, and dibenzofuranyl, which are optionally further substituted. Z is selected from Si and Ge. L_1 comprises aryl or heteroaryl groups, and any heteroatoms in the heteroaryl groups are nitrogen. L_2 is a single bond or comprises aryl or heteroaryl groups, and any heteroatoms in the heteroaryl groups are nitrogen. L_1 and L_2 can be optionally further substituted.

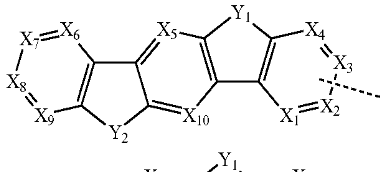
Group A contains a group selected from the group consisting of dibenzofuran, dibenzothiophene, azadibenzofuran, azadibenzothiophene, dibenzoselenophene and azadibenzoselenophene, which are optionally further substituted, and wherein the substitution is optionally fused to at least one benzo ring. Group B contains a group selected from the group consisting of carbazole and azacarbazole, which are optionally further substituted, and wherein the substitution is optionally fused to the carbazole or azacarbazole group.

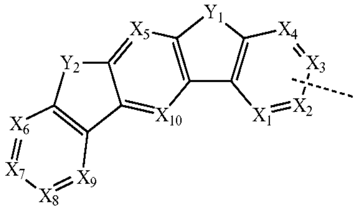
In one aspect, A is selected from the group consisting of:











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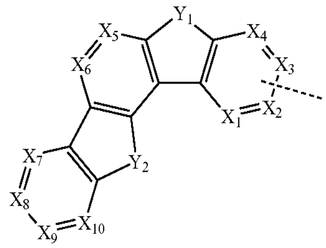
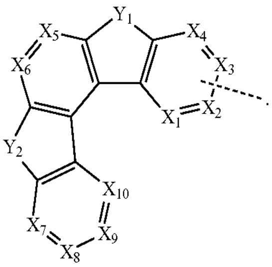
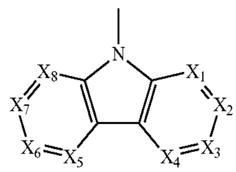
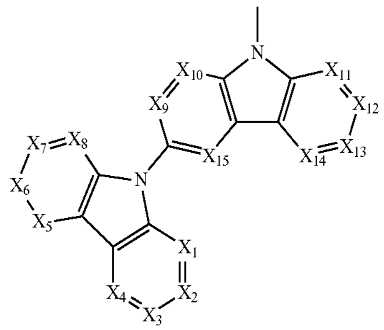
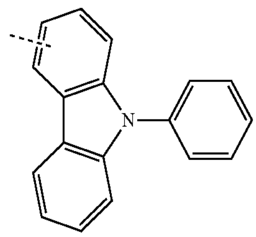


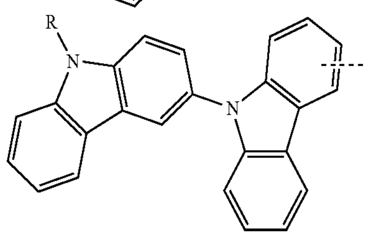


In another aspect, B is selected from the group consisting of:









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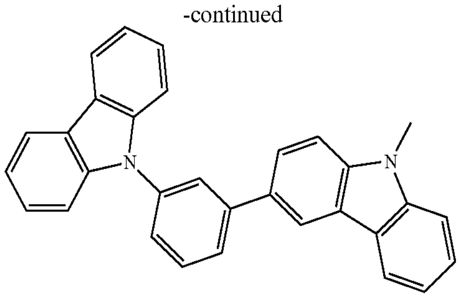

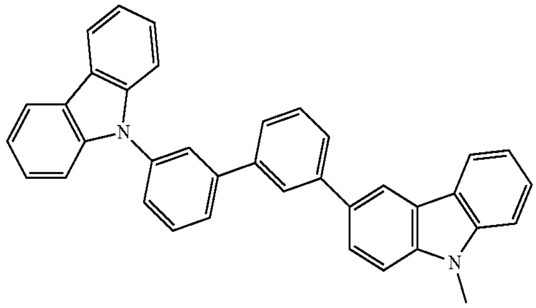

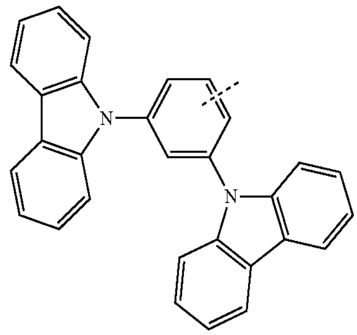

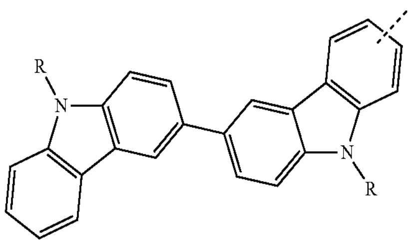

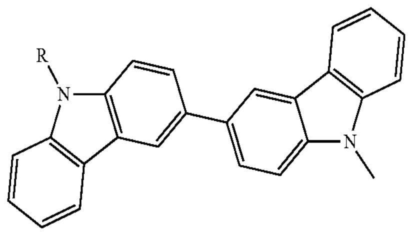

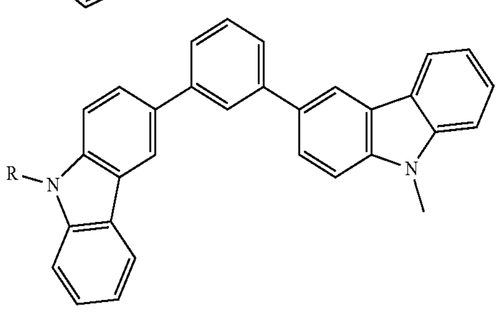

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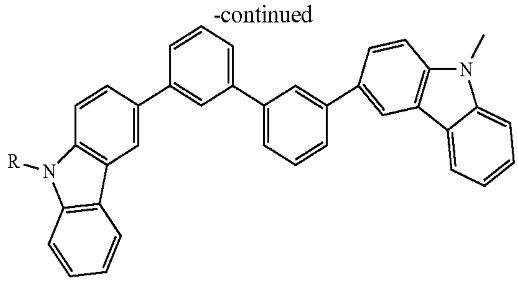

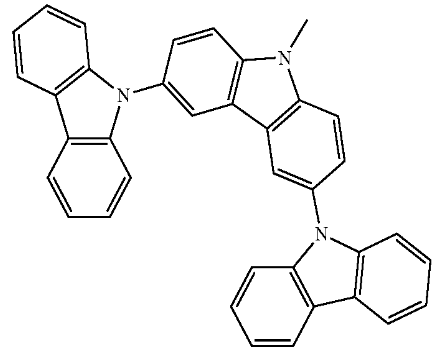

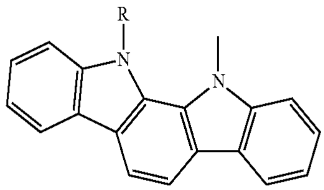

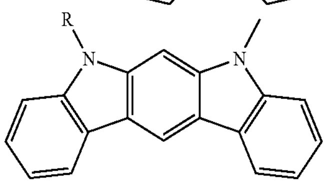

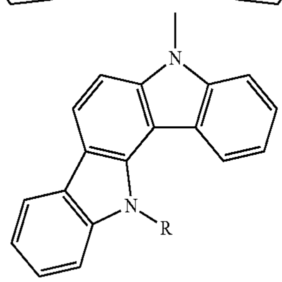

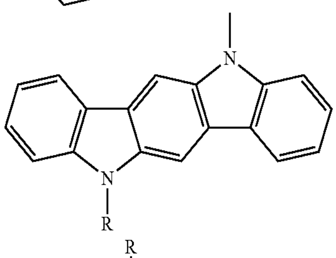

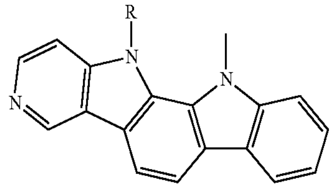

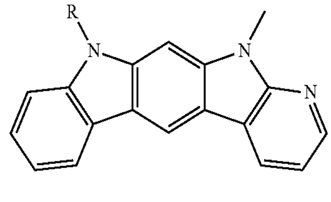

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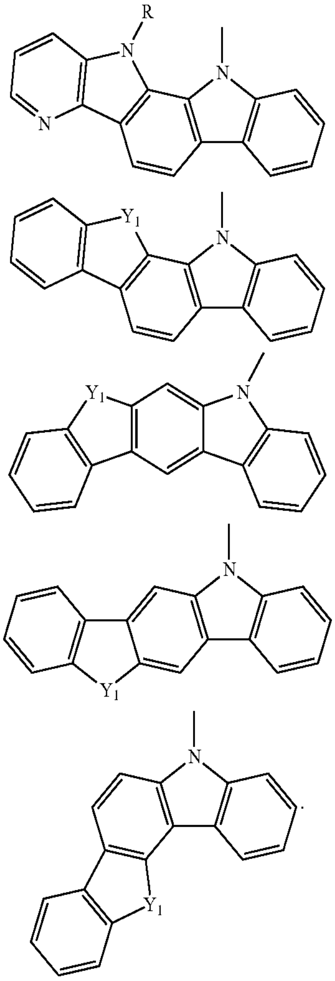
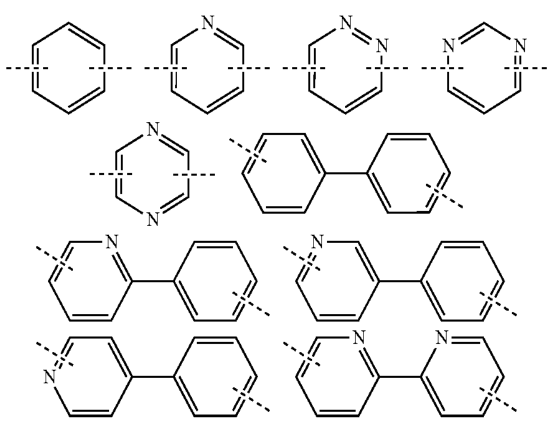


Y_1 and Y_2 are independently selected from the group consisting of O, S, and Se. X_1 to X_{10} are independently selected from the group consisting of CR and N, and wherein each benzo ring contains at most one N. R is selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

In one aspect, L_1 and L_2 are independently selected from the group consisting of:



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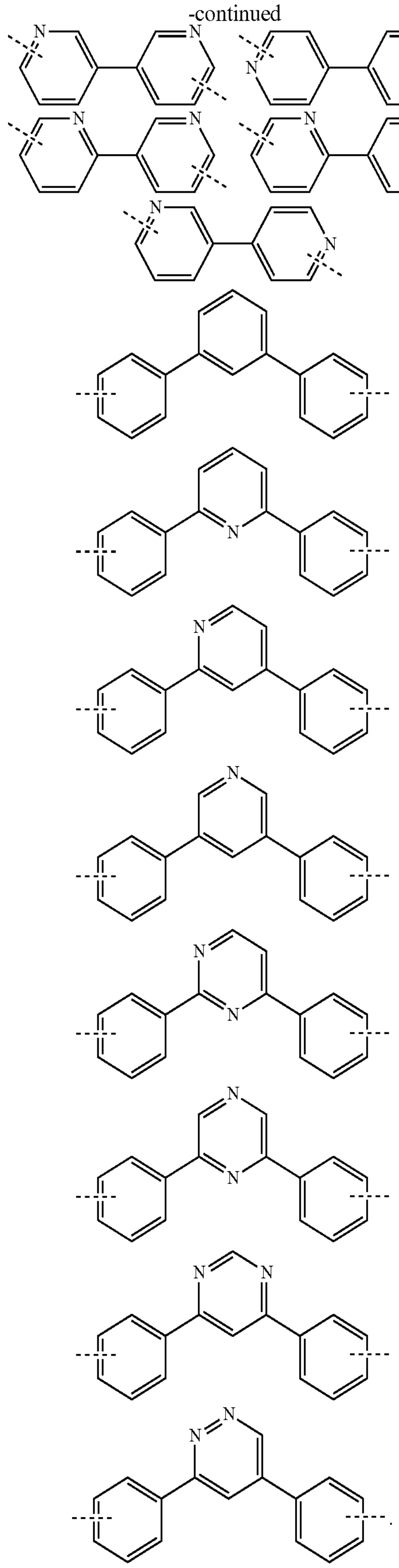


In one aspect, L_2 is a single bond. In another aspect, L_1 and L_2 contain at least one phenyl bonded directly to Z.

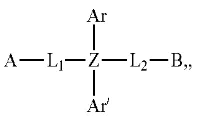
In one aspect, Ar and Ar' are phenyl. In another aspect, Ar, Ar', A and B are independently substituted with at least one group selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

In one aspect, "aryl" comprises phenyl, biphenyl, triphenyl, terphenyl, naphthalene, phenalene, phenanthrene, fluorene or chrysene, and in another aspect, "heteroaryl" comprises dibenzothiophene, dibenzofuran, benzofuran, benzothiophene, pyrazole, imidazole, triazole, oxazole, thiazole, oxadiazole, oxatriazole, dioxazole, thiadiazole, pyridine, pyridazine, pyrimidine, pyrazine, triazine, indole, azaindole, benzimidazole, indazole, benzoxazole, benzisoxazole, benzothiazole, quinoline, isoquinoline, cinnoline, quinazoline, quinoxaline, naphthyridine, phthalazine, pteridine, xanthene, phenothiazine, phenoxazine, benzofuropyridine, furodipyridine, benzothienopyridine and thienodipyridine.

Non-limiting compounds are provided. In one aspect, the compound of Formula I is selected from Compound 1-Compound 22. In Compound 1-Compound 22, Y_1 and Y_2 are independently selected from the group consisting of O, S and Se, and Z is selected from the group consisting of Si and Ge. In another aspect, the compound of Formula I is selected from Compound 23-Compound 38.

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

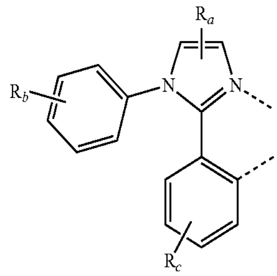
Formula I

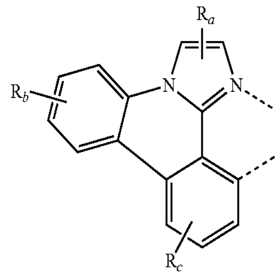


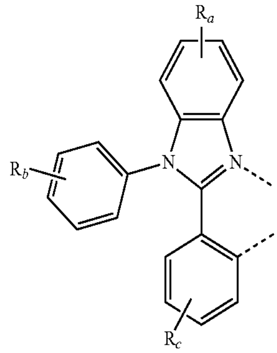
Ar and Ar' are independently selected from the group consisting of phenyl, biphenyl, napthyl, dibenzothiolyl, and dibenzofuranyl, which are optionally further substituted. Z is selected from Si and Ge. L_1 comprises aryl or heteroaryl groups, and any heteroatoms in the heteroaryl groups are nitrogen. L_2 is a single bond or comprises aryl or heteroaryl groups, and any heteroatoms in the heteroaryl groups are nitrogen. L_1 and L_2 can be optionally further substituted.

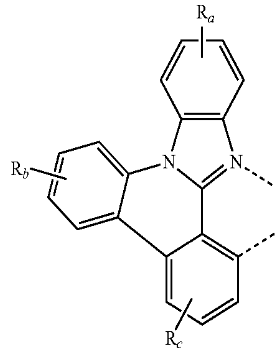
Group A contains a group selected from the group consisting of dibenzofuran, dibenzothiophene, azadibenzofuran, azadibenzothiophene, dibenzoselenophene and azadibenzoselenophene, which are optionally further substituted, and wherein the substitution is optionally fused to at least one benzo ring. Group B contains a group selected from the group consisting of carbazole and azacarbazole, which are optionally further substituted, and wherein the substitution is optionally fused to the carbazole or azacarbazole group.

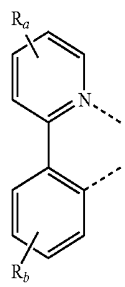
In one aspect, the organic layer is an emissive layer and the compound of formula I is a host. In another aspect, the organic layer further comprises an emissive dopant. In one aspect, the organic layer is deposited using a solution process. In one aspect, the emissive dopant is a transition metal complex having at least one ligand selected from the group consisting of:

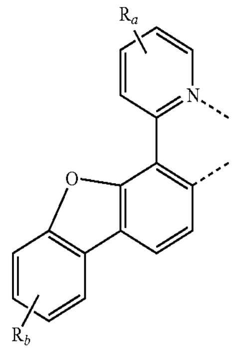


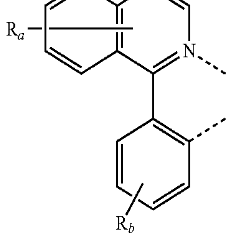


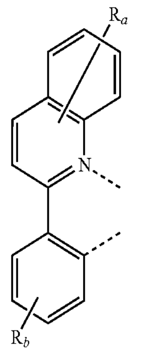


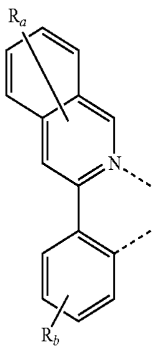


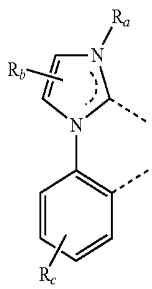


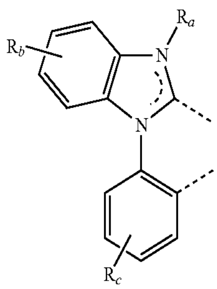












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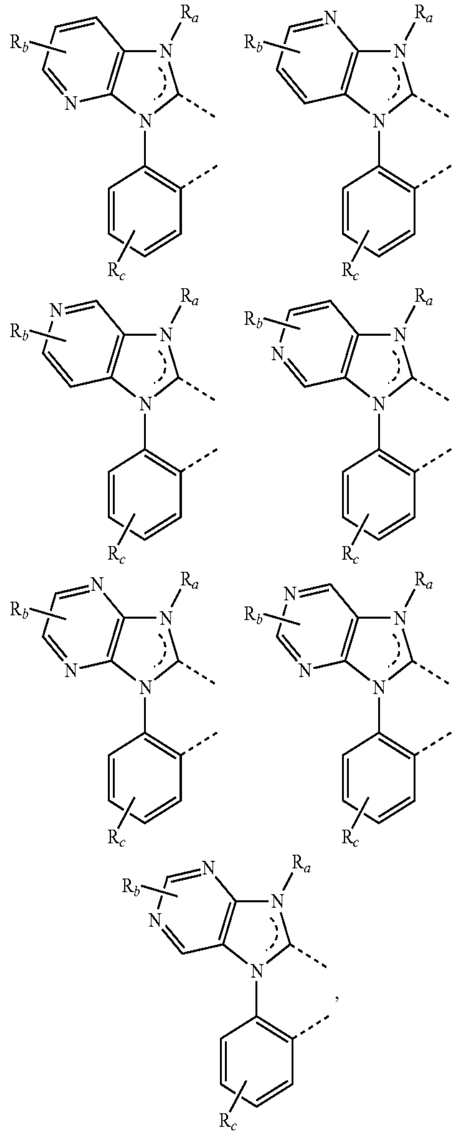


wherein R_a, R_b, and R_c may represent mono, di, tri or tetra substitutions. R_a, R_b, and R_c are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, and wherein two adjacent substituents of R_a, R_b, and R_c are optionally joined to form a fused ring.

In one aspect, the device further comprises a second organic layer that is a non-emissive layer and the compound having Formula I is a material in the second organic layer. In another aspect, the second organic layer is a blocking layer and the compound having Formula I is a blocking material in the second organic layer.

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

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows an organic light emitting device.

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

FIG. **3** shows a compound of Formula I.

FIG. **4** shows the layout of an OLED device.

DETAILED DESCRIPTION

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.

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.

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

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

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

6,097,147 and U.S. Patent Application Publication No. 2003/0230980, which are incorporated by reference in their entireties. Examples of injection layers are provided in U.S. Patent Application Publication No. 2004/0174116, which is incorporated by reference in its entirety. A description of protective layers may be found in U.S. Patent Application Publication No. 2004/0174116, which is incorporated by reference in its entirety.

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

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**.

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

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.

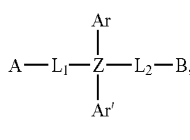
Devices fabricated in accordance with embodiments of the invention may be incorporated into a wide variety of consumer products, including flat panel displays, computer monitors, televisions, billboards, lights for interior or exterior illumination and/or signaling, heads up displays, fully transparent 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.).

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.

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

A compound of Formula I is provided.

Formula I

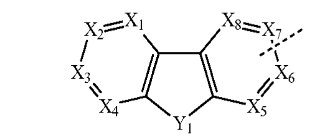


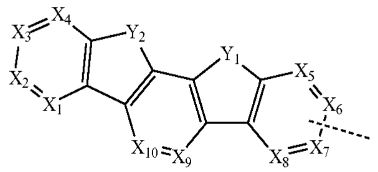
In one embodiment, Ar and Ar' are independently selected from the group consisting of phenyl, biphenyl, napthyl, dibenzothiolyl, and dibenzofuranyl, which are optionally further substituted. Z is selected from Si and Ge. L_1 comprises aryl or heteroaryl groups, and any heteroatoms in the heteroaryl groups are nitrogen. L_2 is a single bond or comprises aryl or heteroaryl groups, and any heteroatoms in the heteroaryl groups are nitrogen. L_1 and L_2 can be optionally further substituted. In one embodiment, the substituents on L_1, L_2, Ar, and Ar' can be hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

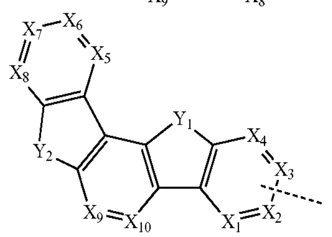
An "aryl" group is an aromatic all carbon group, which can contain one or more fused rings within it. Merely by way of example, and without any limitation, exemplary aryl groups can be phenyl, naphthalene, phenanthrene, corannulene, etc. A "heteroaryl" group is an "aryl" group containing at least one heteroatom. Merely by way of example, and without any limitation, exemplary heteroaryl groups can be pyridine, quinoline, phenanthroline, azacorannulene, etc. Both "aryl" and "heteroaryl" groups in L_1 and L_2 can have multiple attachment points connecting them to other fragments. L_1 and L_2 can contain any desired number of aryl or heteroaryl groups.

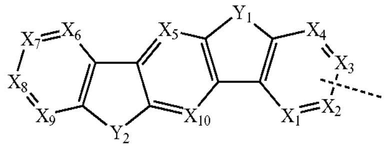
Group A contains a group selected from the group consisting of dibenzofuran, dibenzothiophene, azadibenzofuran, azadibenzothiophene, dibenzoselenophene and azadibenzoselenophene, which are optionally further substituted, and wherein the substitution is optionally fused to at least one benzo ring. Group B contains a group selected from the group consisting of carbazole and azacarbazole, which are optionally further substituted, and wherein the substitution is optionally fused to the carbazole or azacarbazole group.

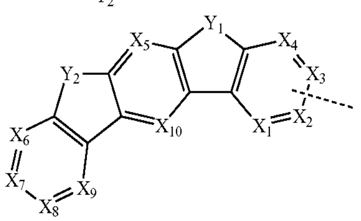
In one embodiment, A is selected from the group consisting of:











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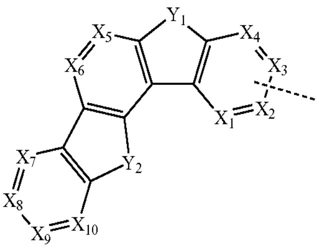
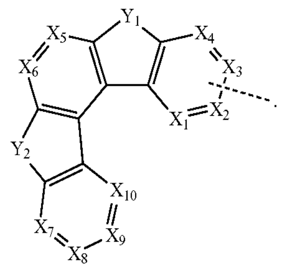
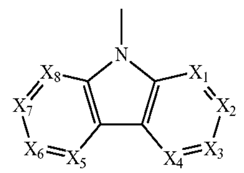
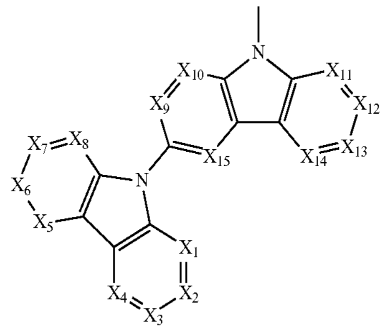
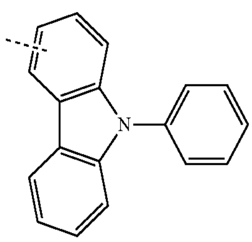


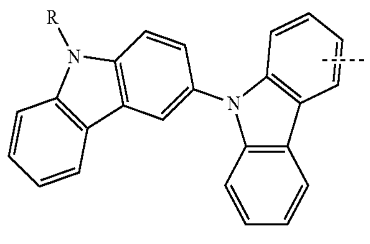


In another embodiment, B is selected from the group consisting of:









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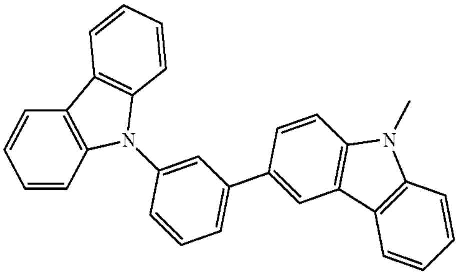

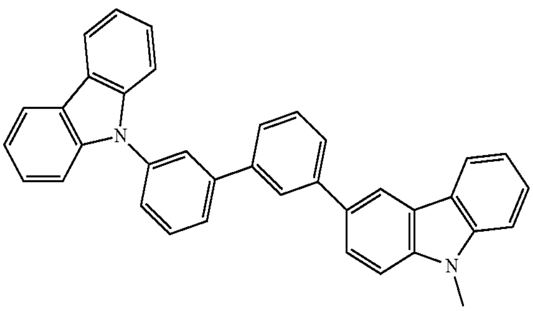

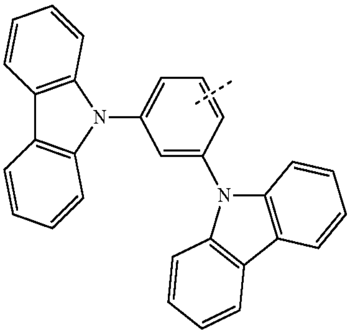

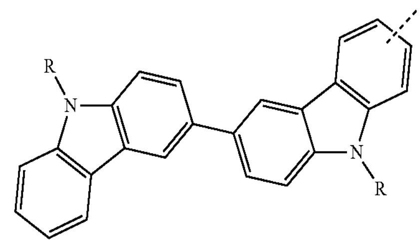

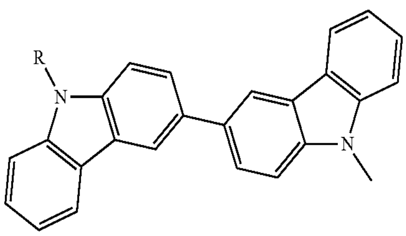

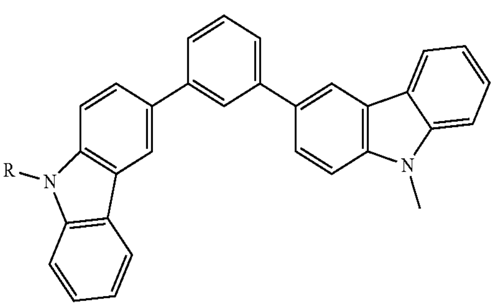

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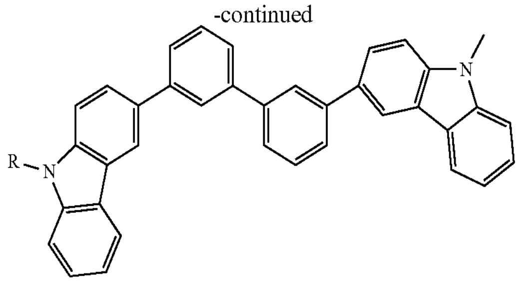

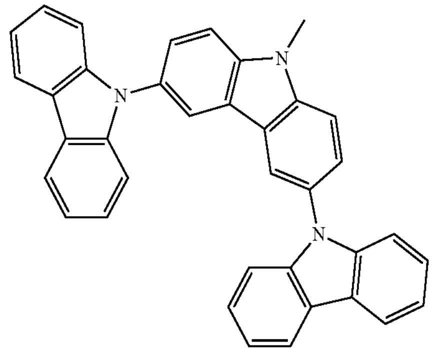

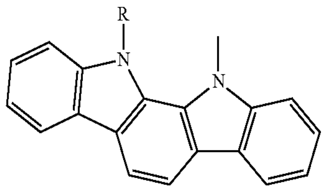

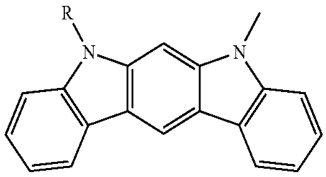

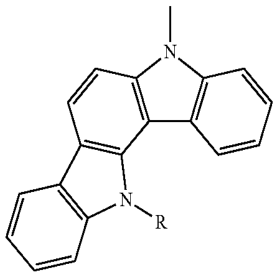

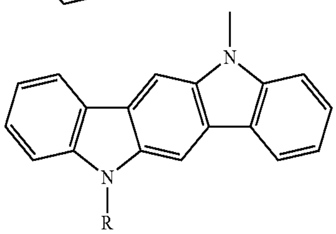

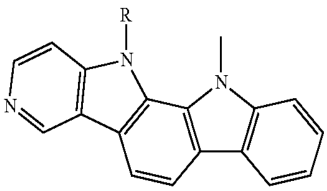

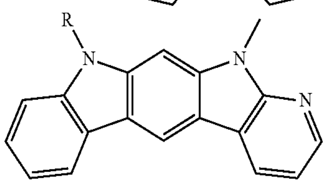

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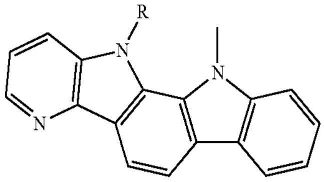
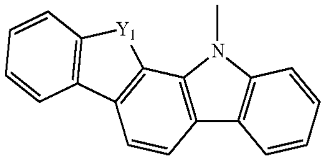
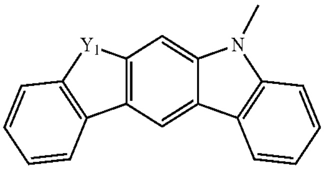
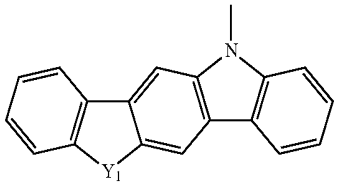
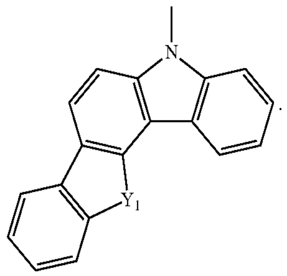




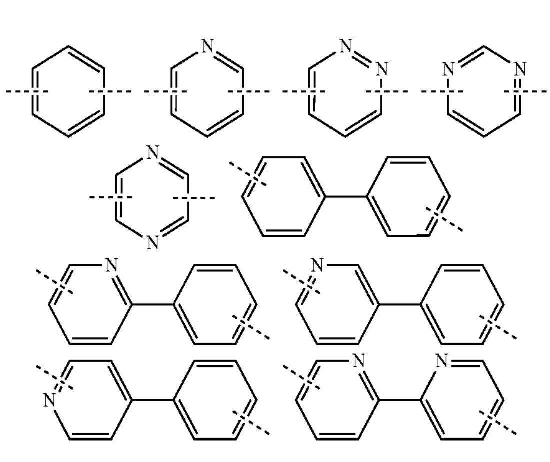






Y_1 and Y_2 are independently selected from the group consisting of O, S, and Se. X_1 to X_{10} are independently selected from the group consisting of CR and N, and wherein each benzo ring contains at most one N. R is selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

In one embodiment, L_1 and L_2 are independently selected from the group consisting of:



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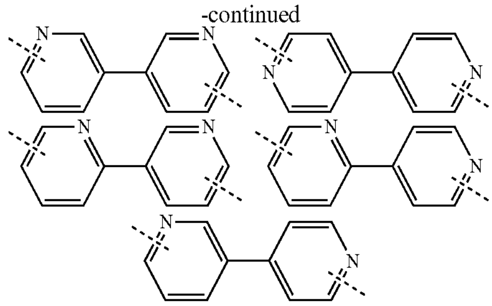
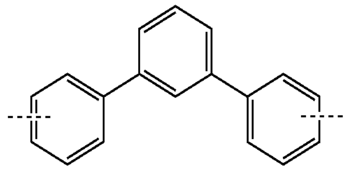
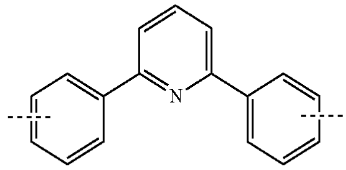
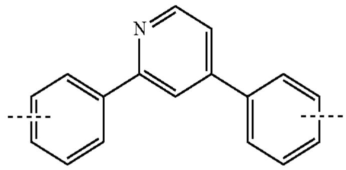
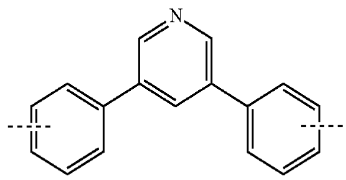
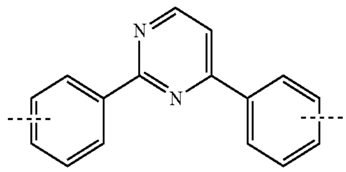


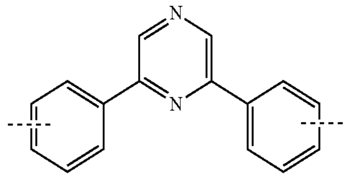


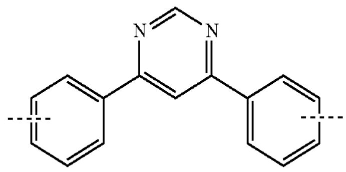


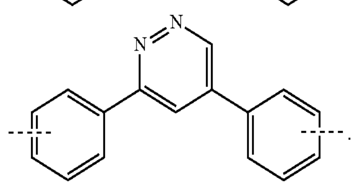












In one embodiment, L_2 is a single bond. In another embodiment, L_1 and L_2 contain at least one phenyl bonded directly to Z. The dashed lines in the chemical structures disclosed herein represent a bond through any position on that group capable of forming a single bond with another atom.

In one embodiment, Ar and Ar' are phenyl. In another embodiment, Ar, Ar', A and B are independently substituted with at least one group selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

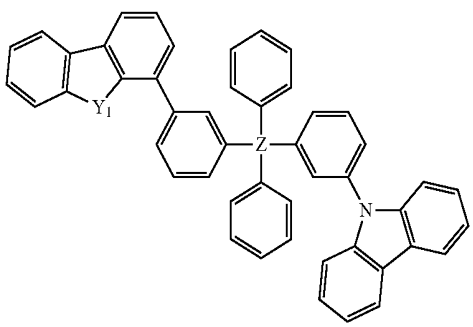
In one embodiment, "aryl" comprises phenyl, biphenyl, triphenyl, terphenyl, naphthalene, phenalene, phenanthrene, fluorene or chrysene, and in another embodiment, "heteroaryl" comprises dibenzothiophene, dibenzofuran, benzofuran, benzothiophene, pyrazole, imidazole, triazole, oxazole, thiazole, oxadiazole, oxatriazole, dioxazole, thiadiazole, pyridine, pyridazine, pyrimidine, pyrazine, triazine, indole, azaindole, benzimidazole, indazole, benzoxazole, benzisoxazole, benzothiazole, quinoline, isoquinoline, cinnoline, quinazoline, quinoxaline, naphthyridine, phthalazine, pteridine, xanthene, phenothiazine, phenoxazine, benzofuropyridine, furodipyridine, benzothienopyridine and thienodipyridine.

The novel compounds of Formula I disclosed herein contain of two different moieties, groups A and B, connected with an arylsilane or arylgermane spacer, resulting in an asymmetric structure. By "asymmetric" it is meant that groups A and B, as described above, have different structures. The compounds of Formula I have a number of advantageous properties when used in OLED devices. Firstly, inclusion of two distinct moieties allows fine-tuning the energy levels of the resultant compound, which may facilitate charge injection from adjacent layers and modulate charge trapping by the emitter dopants. Secondly, the two different moieties can be independently selected to have as electron and/or hole transport properties, yielding compounds with bipolar charge transport characteristics. These characteristics may not only suppresses operation voltage but also balance electron and hole fluxes to achieve an extended charge recombination zone. Thirdly, the arylsilane and arylgermane spacers break the conjugation between groups A and B, retaining high triplet energy for the entire molecule, and thus effectively reducing quenching.

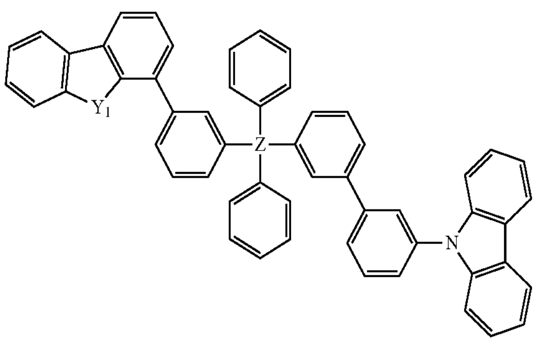
The compounds of Formula I have additional advantages over known symmetric analogs because compounds of Formula I are less prone to crystallization. As a result, compounds of Formula I possess improved film uniformity, which, without being bound by theory, is believed to be a result of reduction in phase separation between the emitters and host materials. The novel compounds of Formula I can be used to improve OLED device performance parameters, such as emission spectrum line shape, efficiency and lifetime. Furthermore, compounds of Formula I also tend to be soluble in organic solvents such as toluene, xylene, and 3-phenoxytoluene, and are amenable to solution processing which is highly desirable for low-cost lighting applications.

In one embodiment, the compound of Formula I is selected from the group consisting of:

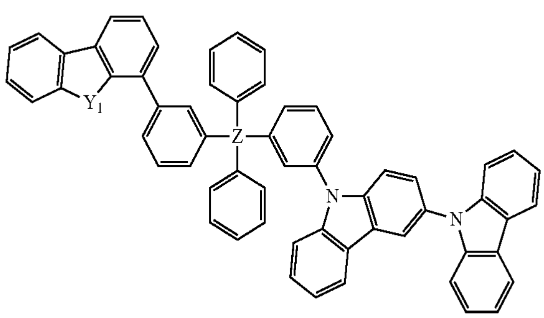
Compound 1



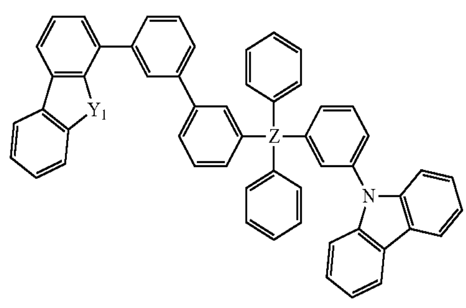
Compound 2



Compound 3



Compound 4



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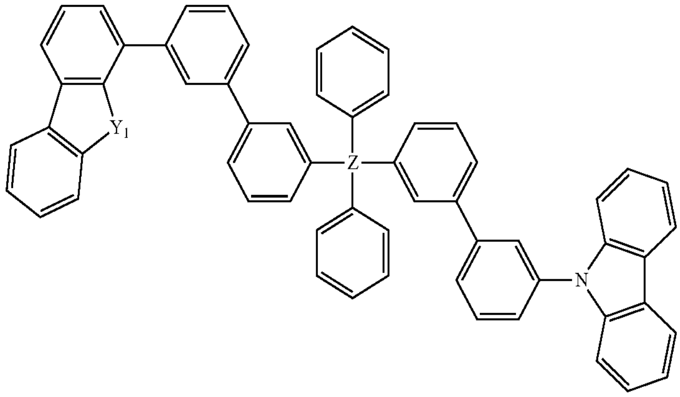
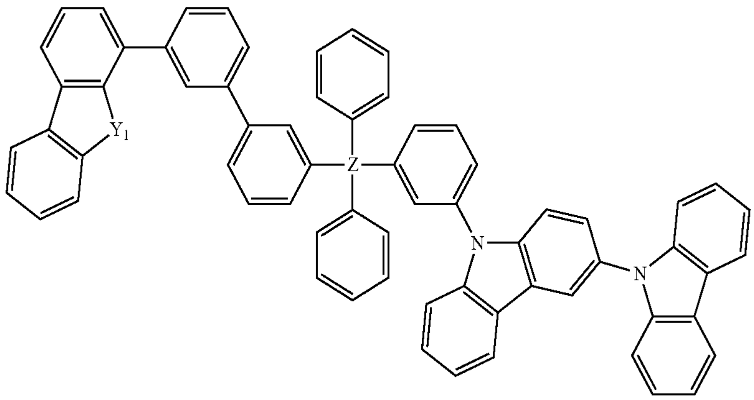
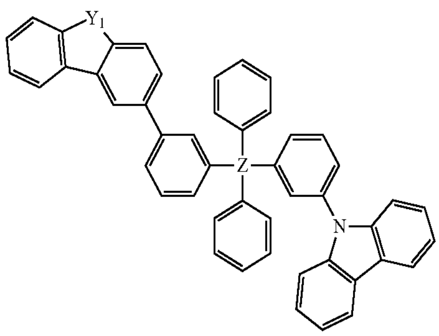
Compound 5



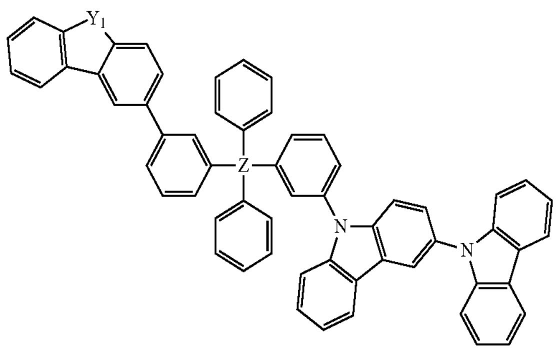
Compound 6



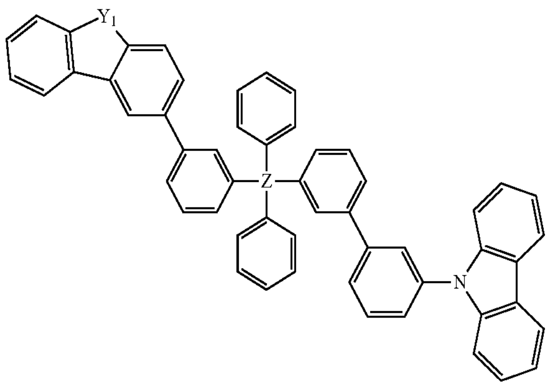
Compound 7



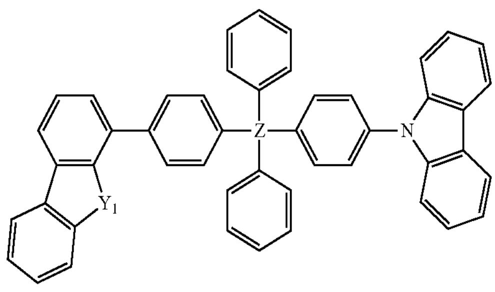
Compound 8



Compound 9



Compound 10



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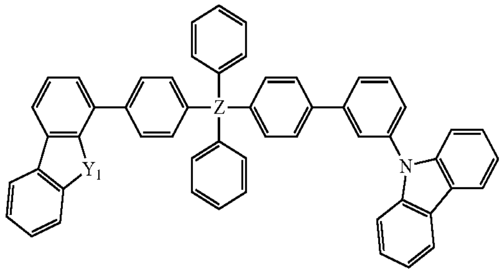
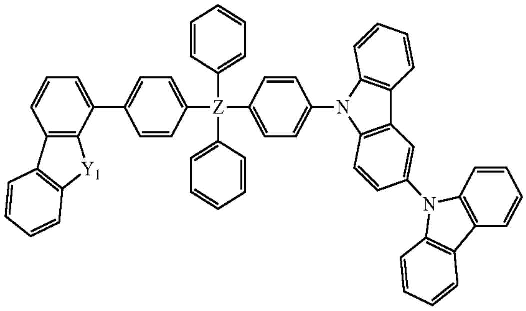
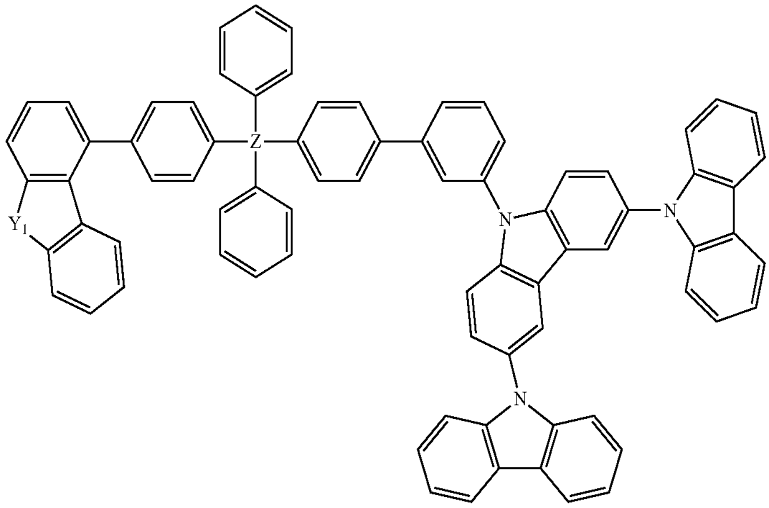
Compound 11



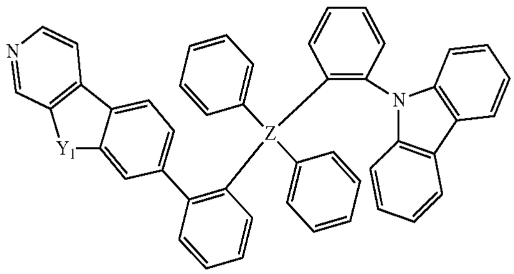
Compound 12



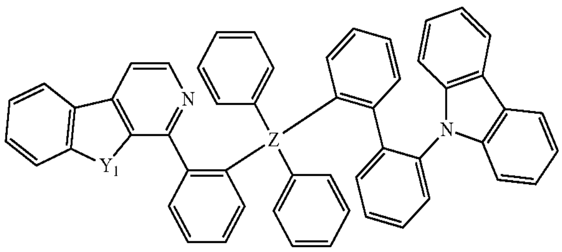
Compound 13



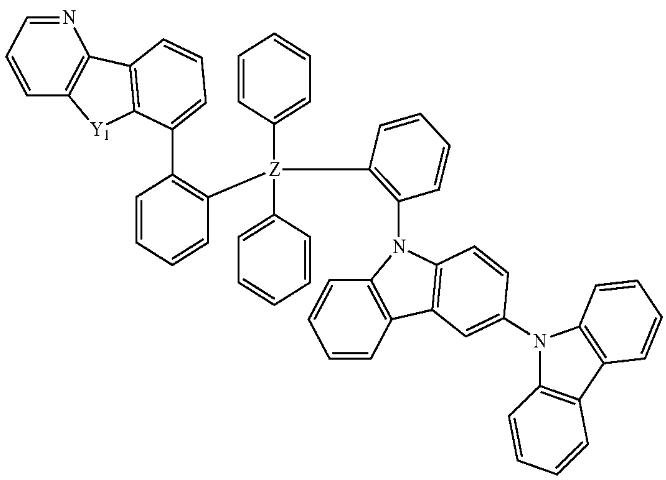
Compound 14



Compound 15



Compound 16



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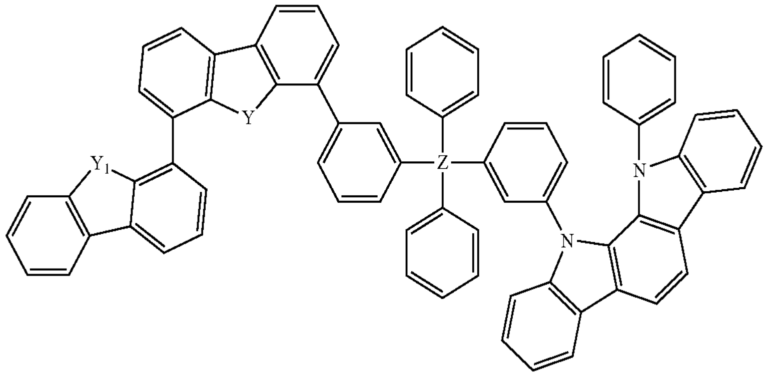
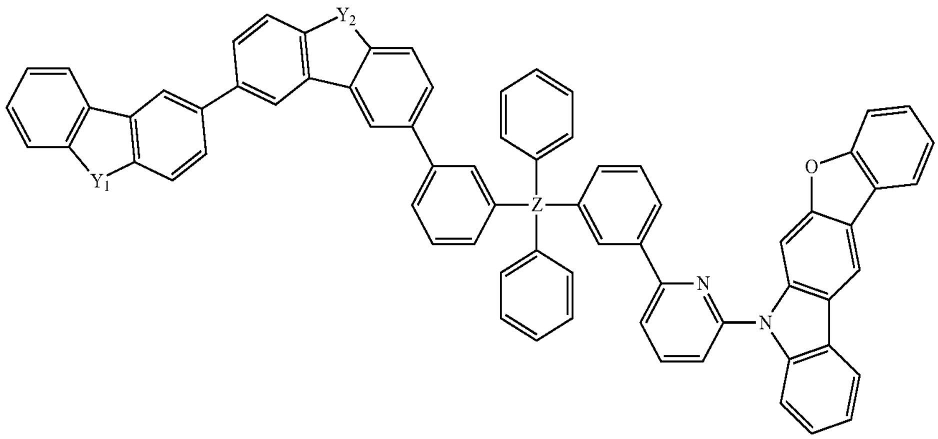
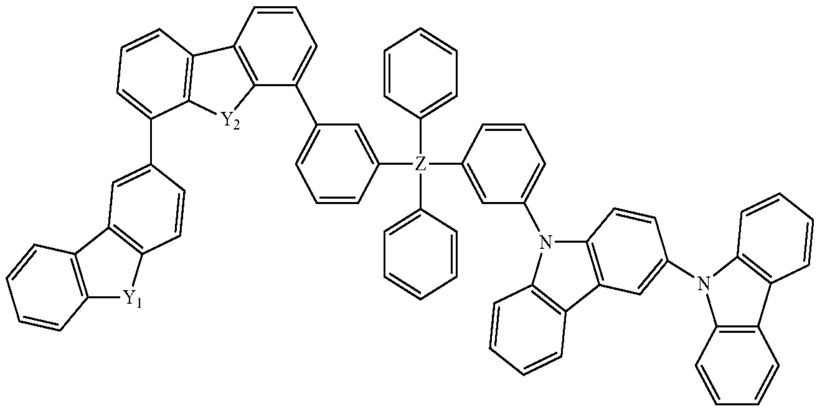
Compound 17



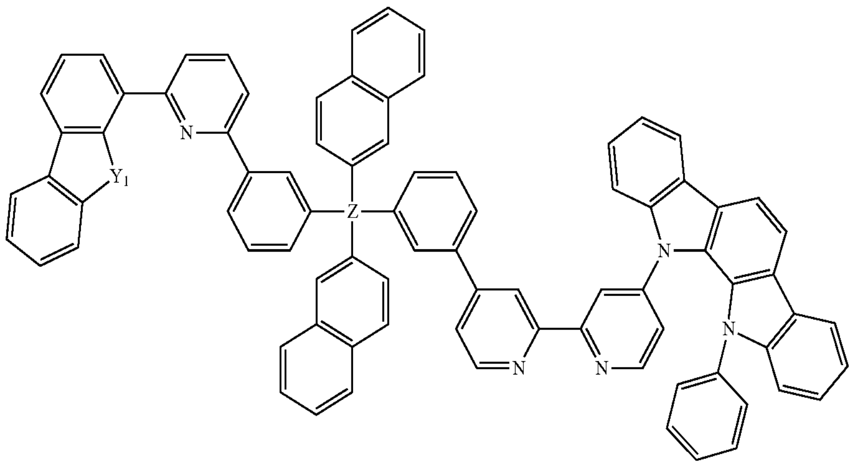
Compound 18



Compound 19



Compound 20



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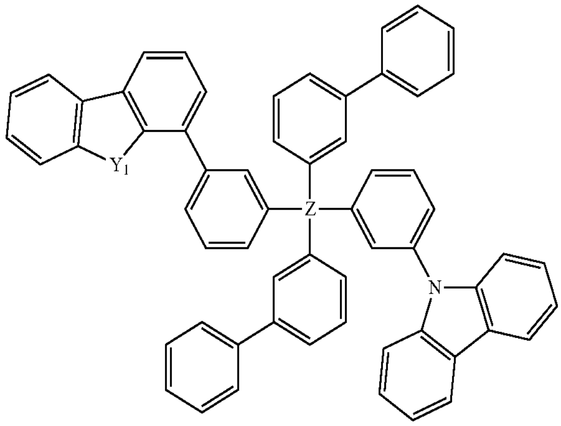
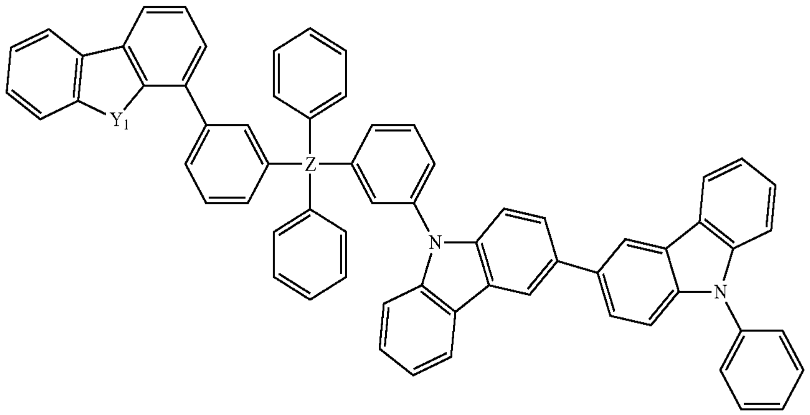
Compound 21



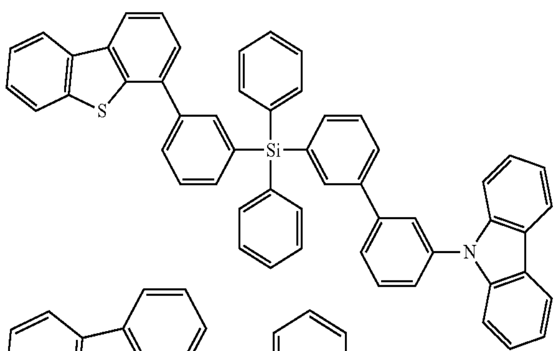
Compound 22



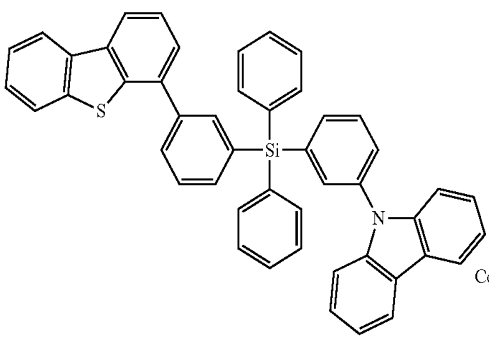
Y_1 and Y_2 are independently selected from the group consisting of O, S and Se. Z is selected from the group consisting of Si and Ge.

In another embodiment, the compound of Formula I is selected from the group consisting of:

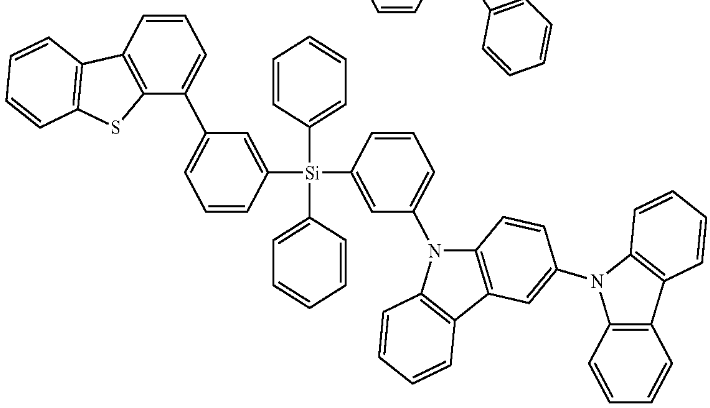
Compound 23



Compound 24



Compound 25



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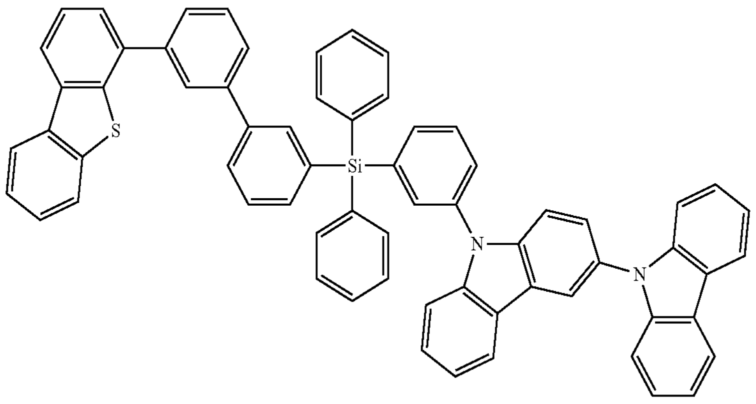
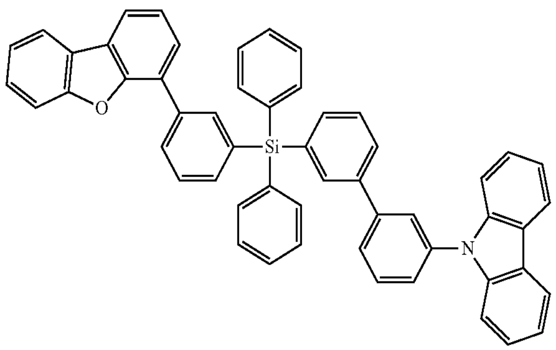
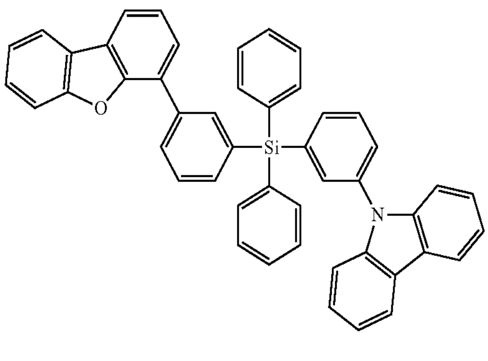
Compound 26



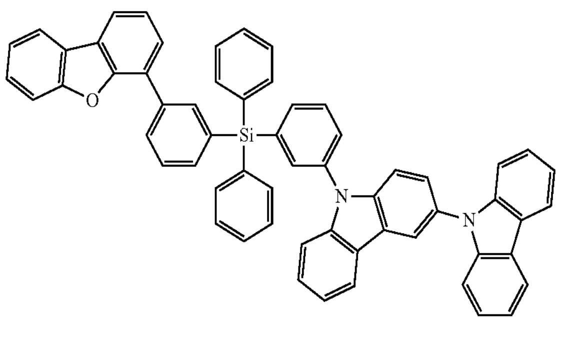
Compound 27



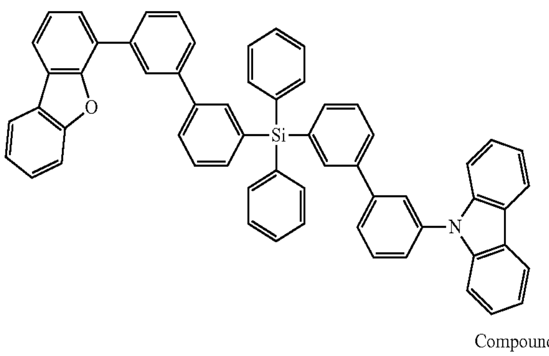
Compound 28



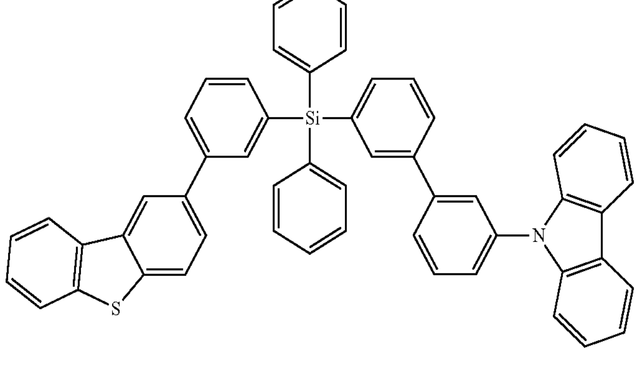
Compound 29



Compound 30



Compound 31



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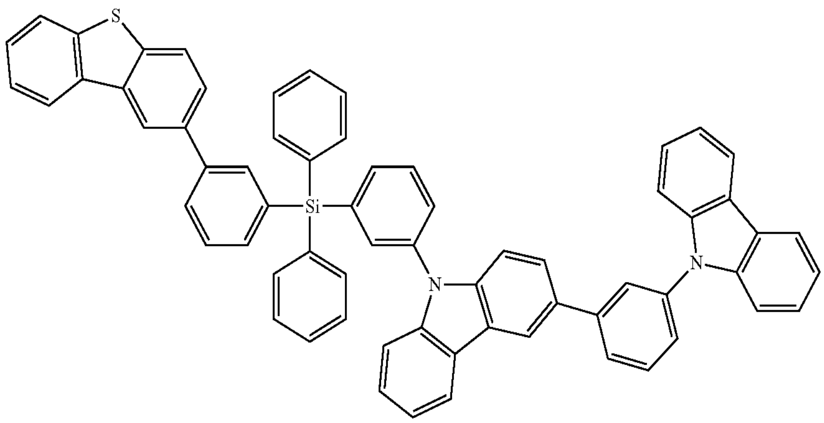
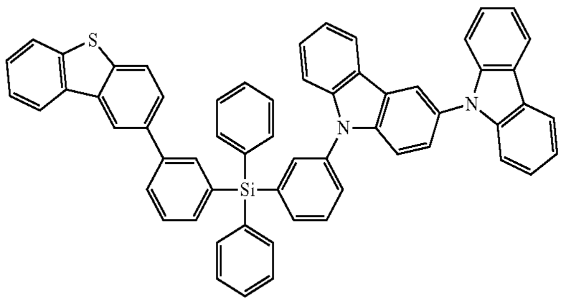
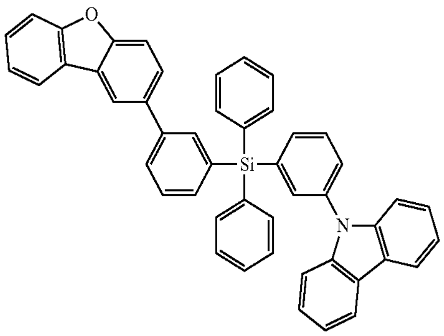
Compound 32



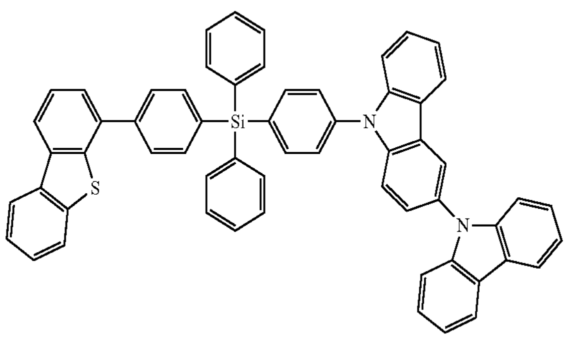
Compound 33



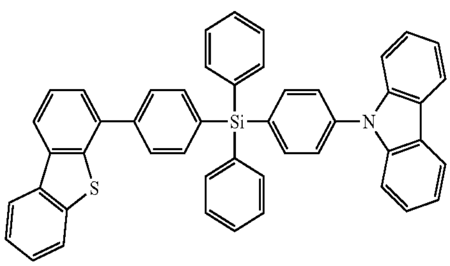
Compound 34



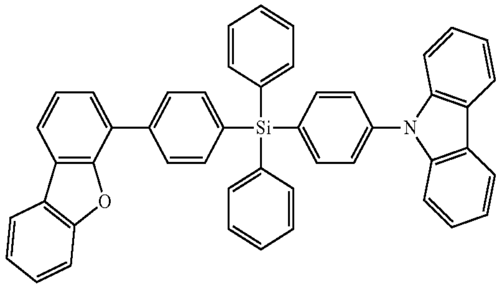
Compound 35



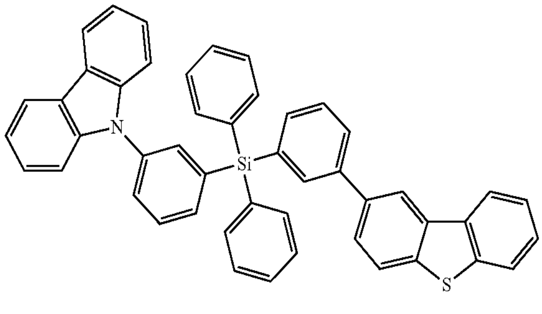
Compound 36



Compound 37

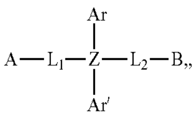


Compound 38



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

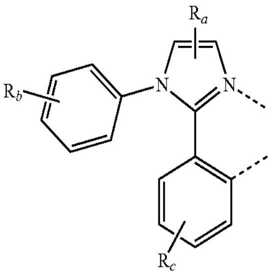
Formula I

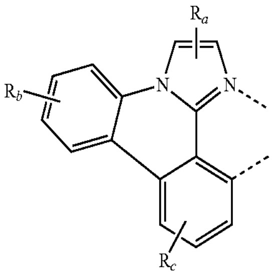


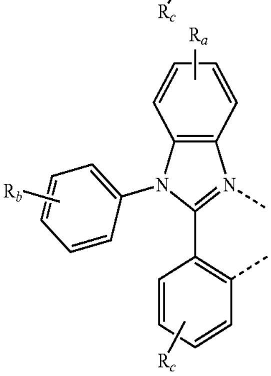
Ar and Ar' are independently selected from the group consisting of phenyl, biphenyl, napthyl, dibenzothiolyl, and dibenzofuranyl, which are optionally further substituted. Z is selected from Si and Ge. L_1 comprises aryl or heteroaryl groups, and any heteroatoms in the heteroaryl groups are nitrogen. L_2 is a single bond or comprises aryl or heteroaryl groups, and any heteroatoms in the heteroaryl groups are nitrogen. L_1 and L_2 can be optionally further substituted. In one embodiment, the substituents on L_1, L_2, Ar, and Ar' can be hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

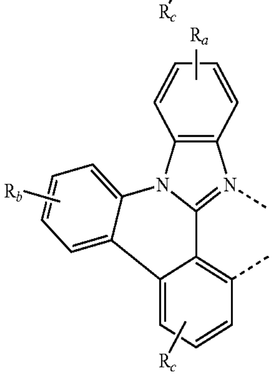
Group A contains a group selected from the group consisting of dibenzofuran, dibenzothiophene, azadibenzofuran, azadibenzothiophene, dibenzoselenophene and azadibenzoselenophene, which are optionally further substituted, and wherein the substitution is optionally fused to at least one benzo ring. Group B contains a group selected from the group consisting of carbazole and azacarbazole, which are optionally further substituted, and wherein the substitution is optionally fused to the carbazole or azacarbazole group.

In one embodiment, the organic layer is an emissive layer and the compound of Formula I is a host. In another embodiment, the organic layer further comprises an emissive dopant. In one embodiment, the emissive dopant is a transition metal complex having at least one ligand selected from the group consisting of:









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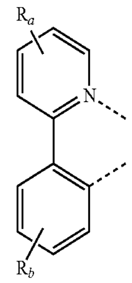

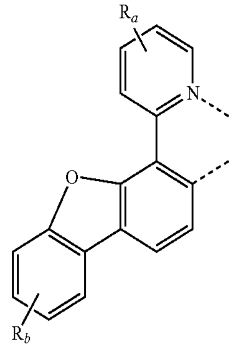

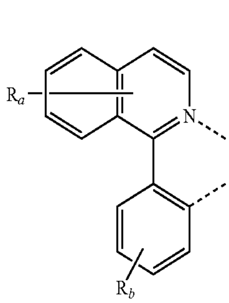

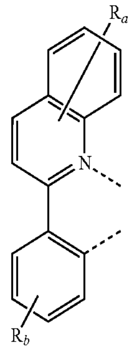

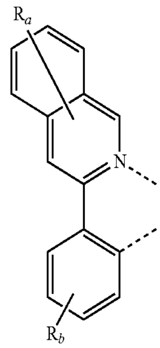

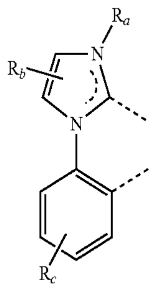

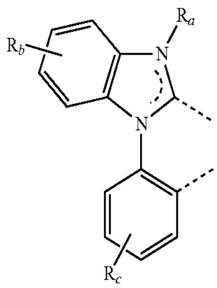

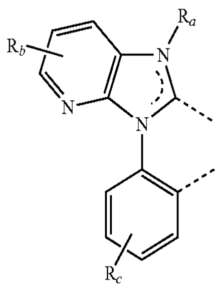

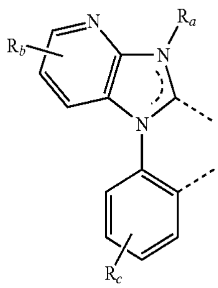

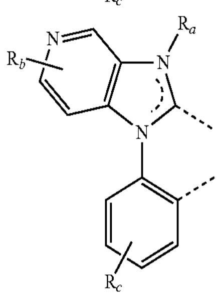

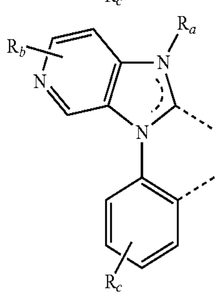

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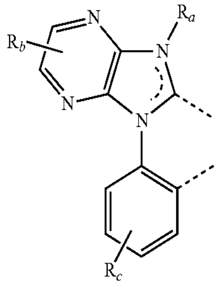
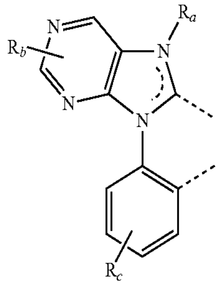
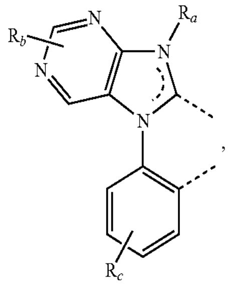






wherein R_a, R_b, and R_c may represent mono, di, tri or tetra substitutions. R_a, R_b, and R_c are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, and wherein two adjacent substituents of R_a, R_b, and R_c are optionally joined to form a fused ring.

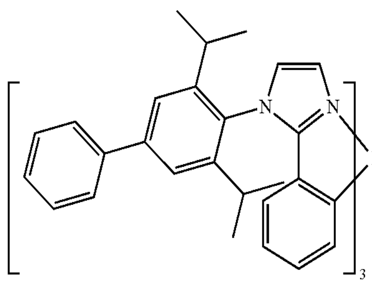
In one embodiment, the device further comprises a second organic layer that is a non-emissive layer and the compound having Formula I is a material in the second organic layer. In another embodiment, the second organic layer is a blocking layer and the compound having Formula I is a blocking material in the second organic layer. In one embodiment, the organic layer is deposited using a solution process.

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

Device Examples

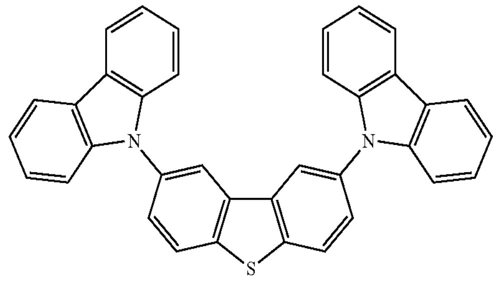
The structures of the materials used in the device examples is show in Table 1 below.

TABLE 1

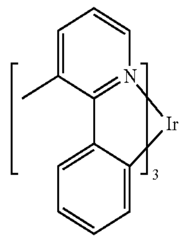


Compound D

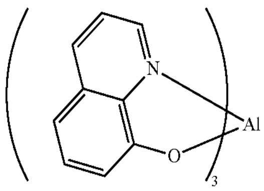
TABLE 1-continued



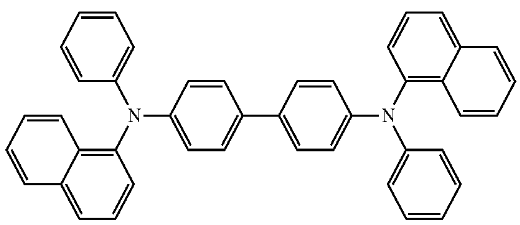
Compound BL



Compound HIL



Alq

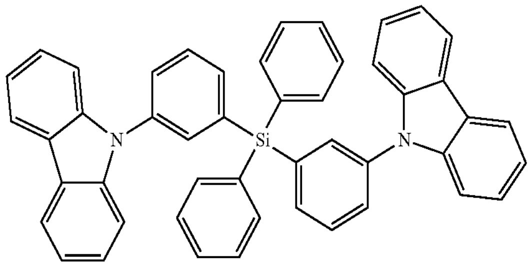


Compound NPD

The organic stack of the OLED device used in the Examples and Comparative Device Examples has the following structure: from the ITO surface, 100 Å of Compound HIL as the hole injection layer, 300 Å of NPD as the hole transporting layer (HTL), 300 Å of a compound of Formula I, CC-1 or CC-2 doped with 15 wt % of Compound D as the emissive layer (EML), 50 Å of Compound BL as the Blocking Layer (BL) and 400 Å of Alq as the ETL1. The device structure is shown in FIG. **4**.

Comparative Compounds CC-1 and CC-2 have the following structures:

CC-1



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CC-2

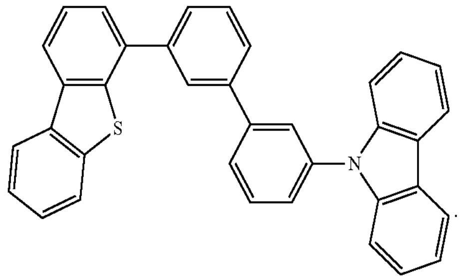


TABLE 2

			1931 CIE		λ_{max}	At 1000 nits V	LE	EQE	PE	At 20 mA/cm^2
Example	Host	BL	x	y	[nm]	[V]	[cd/A]	[%]	[lm/W]	$LT_{80\%}$ [h]
Device Example 1	Compound 23	Compound BL	0.179	0.391	474	7.4	37.8	16.6	16.1	76
Device Example 2	Compound 24	Compound BL	0.172	0.376	474	6.7	43	19.6	20.2	86
Device Example 3	Compound 25	Compound BL	0.179	0.395	474	6.5	43.1	18.9	20.7	90
Device Example 4	Compound 26	Compound BL	0.175	0.389	474	6.5	44.6	19.8	21.4	81
Device Example 5	Compound 27	Compound BL	0.178	0.392	474	7.2	38.5	17.0	16.8	83
Device Example 6	Compound 28	Compound BL	0.176	0.385	474	6.7	43.1	19.2	20.2	100
Device Example 7	Compound 29	Compound BL	0.173	0.378	474	7.3	40.8	18.5	17.5	70
Device Example 8	Compound 30	Compound BL	0.174	0.380	474	6.7	43.7	19.8	20.5	55
Device Example 9	Compound 31	Compound BL	0.176	0.389	474	6.4	47.3	21.0	23.2	63
Device Example 10	Compound 32	Compound BL	0.177	0.394	474	6.8	43	19.0	19.8	34
Device Example 11	Compound 33	Compound BL	0.183	0.408	474	6.9	39.9	17.1	18.2	58
Device Example 12	Compound 34	Compound BL	0.176	0.386	474	6.6	42	18.7	19.9	72
Device Example 13	Compound 35	Compound BL	0.182	0.410	476	6.6	44.1	18.8	21.0	35
Device Example 14	Compound 36	Compound BL	0.179	0.405	474	6.7	46.3	20.0	21.8	37
Device Example 15	Compound 37	Compound BL	0.179	0.394	474	6.7	42.5	18.7	20.0	43
Device Example 16	Compound 38	Compound BL	0.176	0.387	474	6.5	45.7	20.3	22.0	55
Device Example 17	Compound 23	Compound 23	0.174	0.385	472	7.1	43	19.2	19.1	75
Device Example 18	Compound 24	Compound 24	0.171	0.371	474	7.5	41.3	19.0	17.2	80
Device Example 19	Compound 25	Compound 25	0.177	0.389	474	7.6	40.5	17.9	16.8	78
Device Example 20	Compound 26	Compound 26	0.186	0.426	476	9.6	43.7	18.1	14.3	83
Device Example 21	Compound 27	Compound 27	0.176	0.387	474	8.2	40.1	17.8	15.4	87
Device Example 22	Compound 28	Compound 28	0.174	0.380	474	7.5	43.1	19.4	18.0	86
Device Example 23	Compound 29	Compound 29	0.173	0.378	474	7.3	40.8	18.5	17.5	67
Device Example 24	Compound 30	Compound 30	0.172	0.376	474	7.6	43.3	19.7	17.9	47
Device Example 25	Compound 31	Compound 31	0.174	0.383	474	7.4	42.2	19.0	17.9	60
Device Example 26	Compound 32	Compound 32	0.175	0.390	474	8.2	40.1	17.9	15.4	30

TABLE 2-continued

Example	Host	BL	1931 CIE x	1931 CIE y	λ_{max} [nm]	At 1000 nits V [V]	At 1000 nits LE [cd/A]	At 1000 nits EQE [%]	At 1000 nits PE [lm/W]	At 20 mA/cm^2 $LT_{80\%}$ [h]
Device Example 27	Compound 33	Compound 33	0.180	0.402	474	8.6	37.5	16.3	13.7	125
Device Example 28	Compound 34	Compound 34	0.173	0.380	474	8.3	39.7	17.9	15.1	88
Device Example 29	Compound 35	Compound 35	0.181	0.408	476	7.1	43.6	18.8	19.3	33
Device Example 30	Compound 36	Compound 36	0.177	0.402	474	7.2	46.3	20.1	20.2	39
Device Example 31	Compound 37	Compound 37	0.177	0.390	474	7.1	43	19.1	19.0	40
Device Example 32	Compound 38	Compound 38	0.173	0.381	474	7.8	42.4	19.1	17.0	54
Comparative Device Example 1	CC-1	Compound BL	0.177	0.387	474	6.8	42.5	18.8	19.7	40
Comparative Device Example 2	CC-2	Compound BL	0.179	0.396	474	7.2	35.4	15.4	15.5	176

Table 2 is a summary of the device data. The devices with aryl silane hosts show high efficiency and long lifetimes. Compared to the host without aryl silane moiety, CC-2, the aryl silane hosts demonstrates much improved efficiency (Device Examples 1-16 vs. Comparative Device Example 2). Without being bound by theory, these results are attributable in part to the breakage of conjugation by the silane bridge and retention of high triplet energy for individual molecules. Additionally, the steric hindrance introduced by the tetraphenylsilane unit can also prevent unfavorable intermolecular stacking that can decrease the triplet energy in the solid state. A high triplet energy of the host effectively confines the excitons on emitters, leading to high efficiency.

Furthermore, devices with the asymmetric aryl silane hosts have comparable to much improved lifetime than those with the symmetric aryl silane hosts (Device Examples 1-16 vs Comparative Device Example 1). This is attributable to the asymmetric nature of, for example, Compound 23, which not only lowers the operation voltage, but also helps to balance charge fluxes. The balanced electron/hole fluxes spread the charge recombination zone, which preserves a high efficiency at high brightness by suppressing or reducing exciton quenching. An expanded charge recombination zone also extends the device lifetime by allowing a larger population of molecules to have charge transport, exciton formation, and light emission roles. It is also demonstrated that the compounds of Formula I are useful as blocking layer components (Device Examples 17-32), producing OLEDs having high efficiencies and long lifetimes. Since compounds of Formula I can serve both as hosts and hole blocking layers, these materials are expected to reduce device fabrication cost.

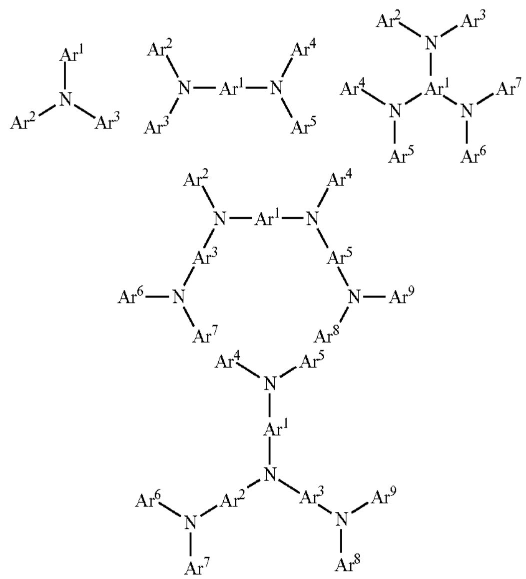
Combination with Other Materials

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

HIL/HTL:

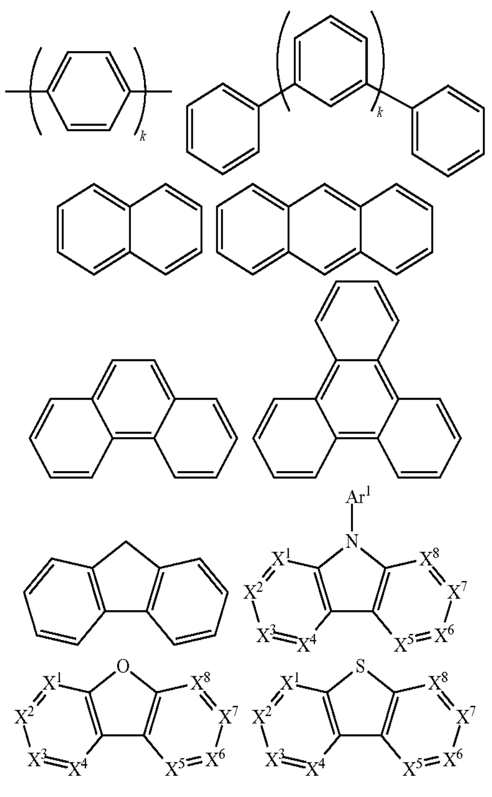
A hole injecting/transporting material to be used in the present invention is not particularly limited, and any compound may be used as long as the compound is typically used as a hole injecting/transporting material. Examples of the material include, but not limit to: a phthalocyanine or porphryin derivative;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

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



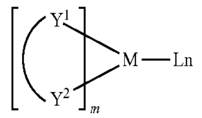
Each of Ar^1 to Ar^9 is selected from the group consisting aromatic hydrocarbon cyclic compounds such as benzene, biphenyl, triphenyl, triphenylene, naphthalene, anthracene, phenalene, phenanthrene, fluorene, pyrene, chrysene, perylene, azulene; group consisting aromatic heterocyclic compounds such as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

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



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

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



M is a metal, having an atomic weight greater than 40; (Y^1-Y^2) is a bindentate ligand, Y1 and Y^2 are independently selected from C, N, O, P, and S; L is an ancillary ligand; m is an integer value from 1 to the maximum number of ligands that may be attached to the metal; and m+n is the maximum number of ligands that may be attached to the metal.

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

In another aspect, (Y^1-Y^2) is a carbene ligand.

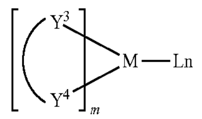
In another aspect, M is selected from Ir, Pt, Os, and Zn.

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

Host:

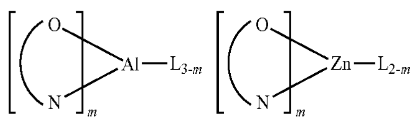
The light emitting layer of the organic EL device of the present invention preferably contains at least a metal complex as light emitting material, and may contain a host material using the metal complex as a dopant material. Examples of the host material are not particularly limited, and any metal complexes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

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



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

In one aspect, the metal complexes are:



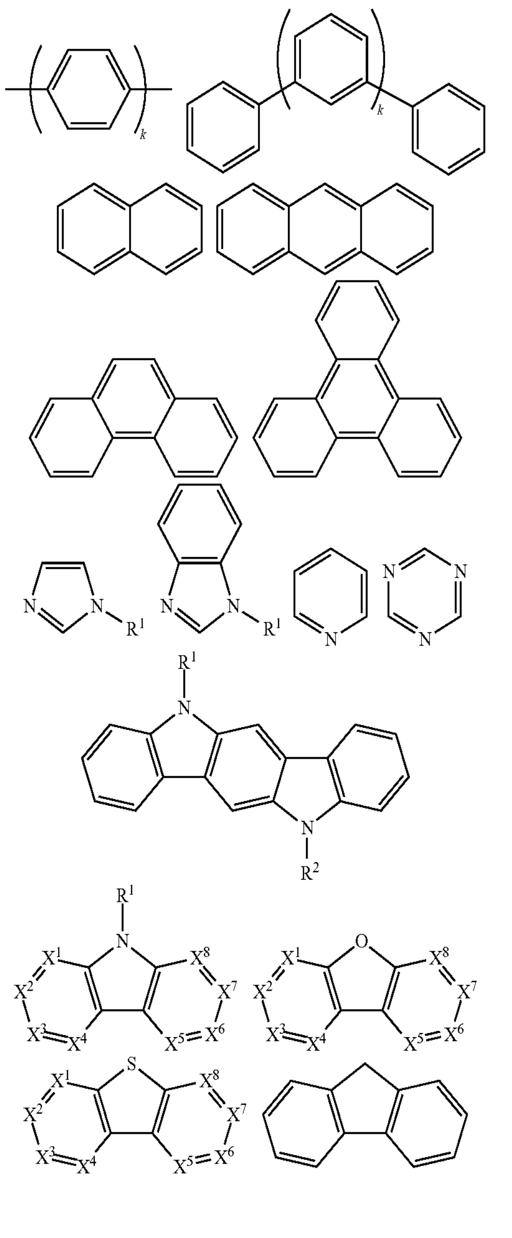
(O—N) is a bidentate ligand, having metal coordinated to atoms O and N.

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

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

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

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



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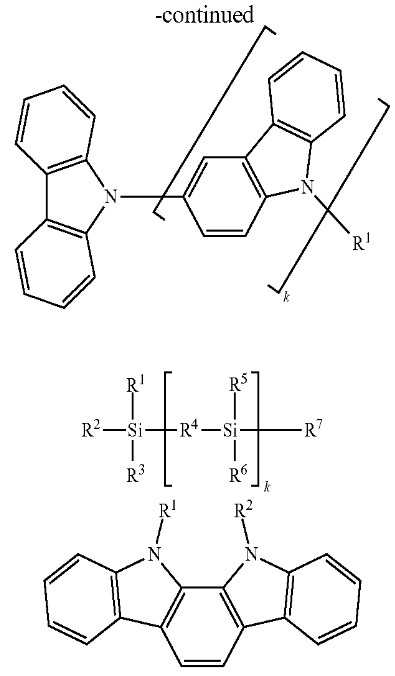


R^1 to R^7 is independently selected from the group consisting of hydrogen, alkyl, alkoxy, amino, alkenyl, alkynyl, arylalkyl, heteroalkyl, aryl and heteroaryl, when it is aryl or heteroaryl, it has the similar definition as Ar's mentioned above.

k is an integer from 0 to 20.

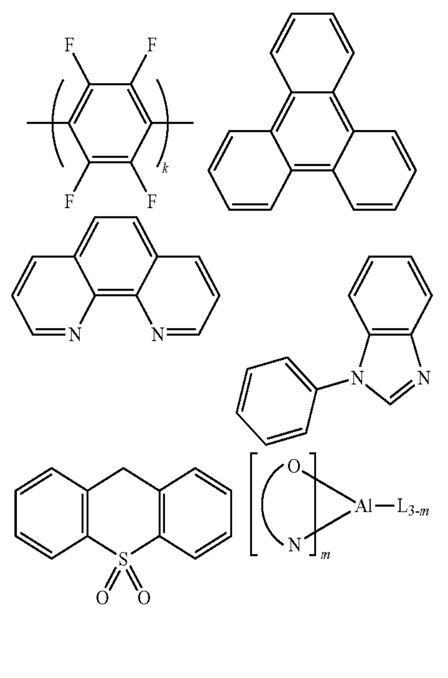
X^1 to X^8 is selected from C (including CH) or N.

HBL:

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

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

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

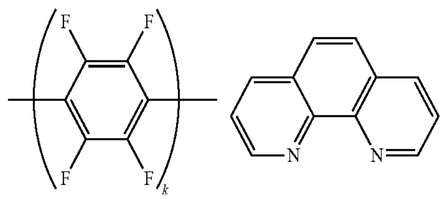


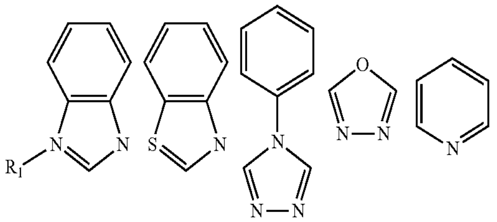
k is an integer from 0 to 20; L is an ancillary ligand, m is an integer from 1 to 3.

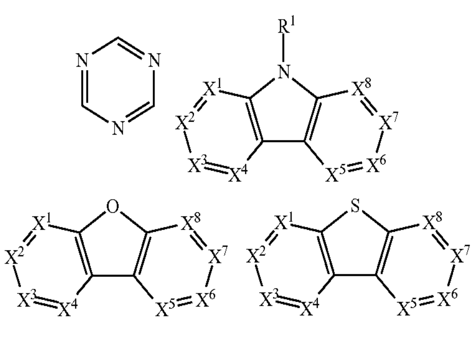
ETL:

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

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







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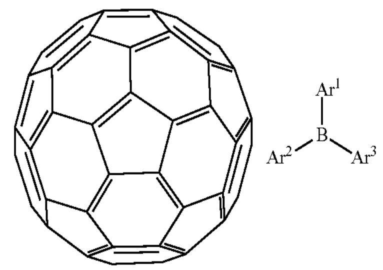


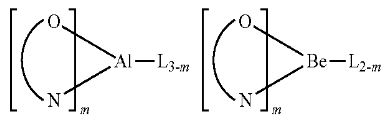
R^1 is selected from the group consisting of hydrogen, alkyl, alkoxy, amino, alkenyl, alkynyl, arylalkyl, heteroalkyl, aryl and heteroaryl, when it is aryl or heteroaryl, it has the similar definition as Ar's mentioned above.

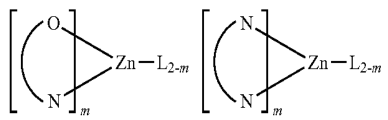
Ar^1 to Ar^3 has the similar definition as Ar's mentioned above.

k is an integer from 0 to 20.

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

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





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

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

In addition to and/or in combination with the materials disclosed herein, many hole injection materials, hole transporting materials, host materials, dopant materials, exiton/hole blocking layer materials, electron transporting and electron injecting materials may be used in an OLED. Non-limiting examples of the materials that may be used in an OLED in combination with materials disclosed herein are listed in Table 3 below. Table 3 lists non-limiting classes of materials, non-limiting examples of compounds for each class, and references that disclose the materials.

TABLE 3

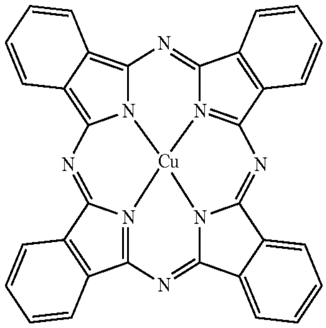
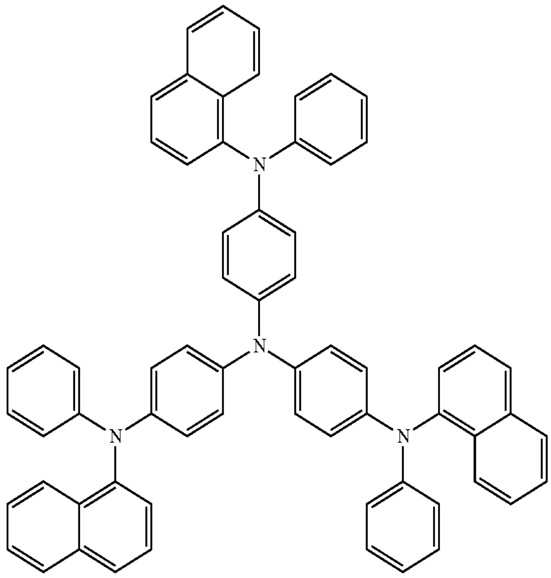
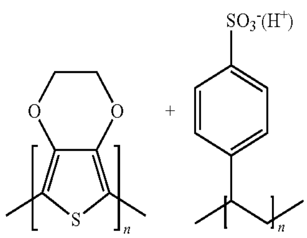
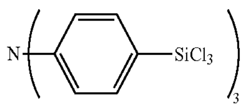
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
	Hole injection materials	
Phthalocyanine and porphyrin compounds		Appl. Phys. Lett. 69, 2160 (1996)
Starburst triarylamines		J. Lumin. 72-74, 985 (1997)
CF_x Fluorohydrocarbon polymer	$-[CH_xF_y]_n-$	Appl. Phys. Lett. 78, 673 (2001)
Conducting polymers (e.g.,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

TABLE 3-continued

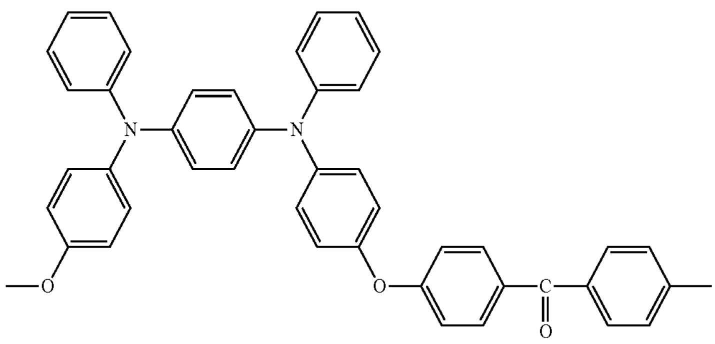
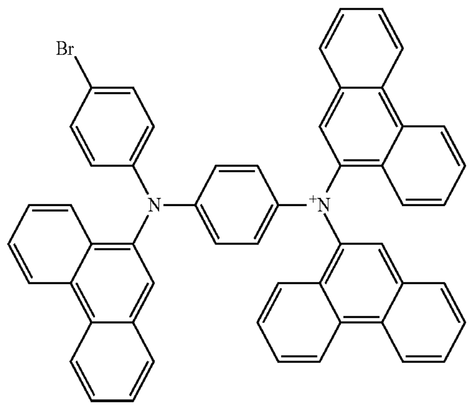
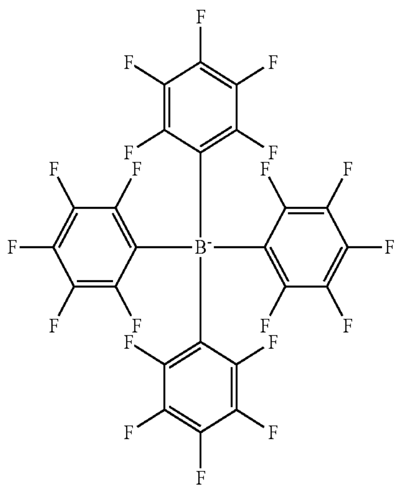
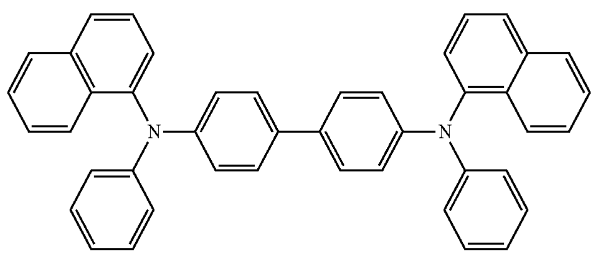
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Triarylamine or polythiophene polymers with conductivity dopants	 and  	EA01725079A1
Arylamines complexed with metal oxides such as molybdenum and tungsten oxides	 + MoO_x	SID Symposium Digest, 37, 923 (2006) WO2009018009

TABLE 3-continued

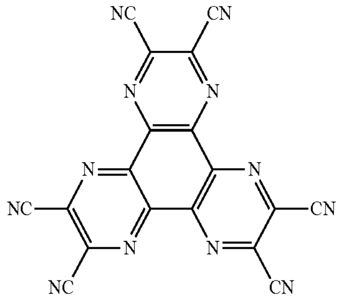
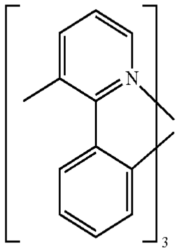
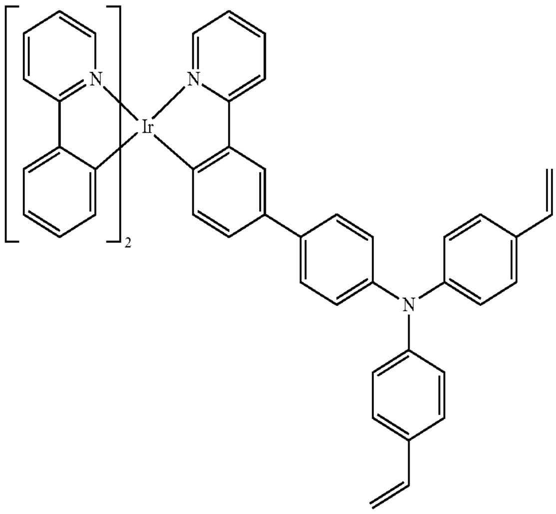
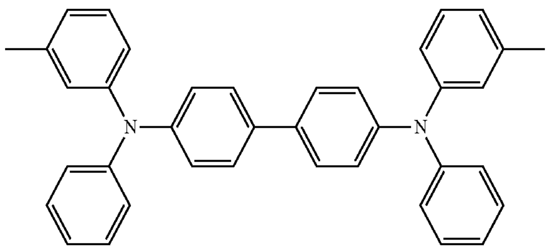
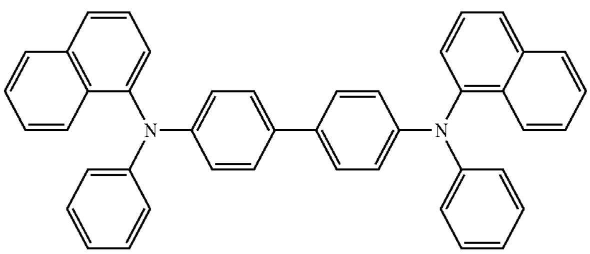
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
p-type semiconducting organic complexes		US20020158242
Metal organometallic complexes		US20060240279
Cross-linkable compounds		US20080220265
	Hole transporting materials	
Triarylamines (e.g., TPD, α-NPD)		Appl. Phys. Lett. 51, 913 (1987)
		US5061569

TABLE 3-continued

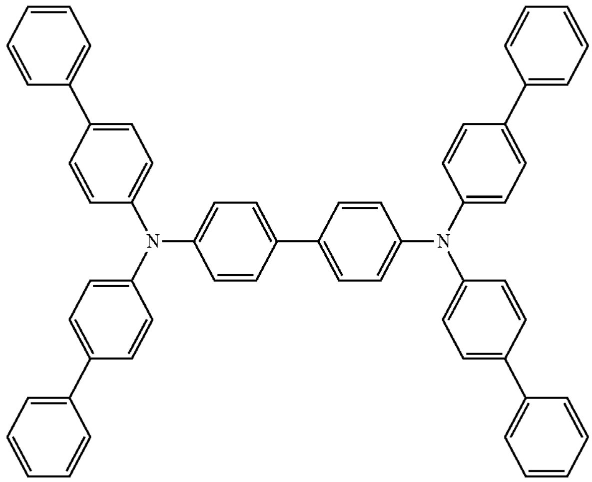
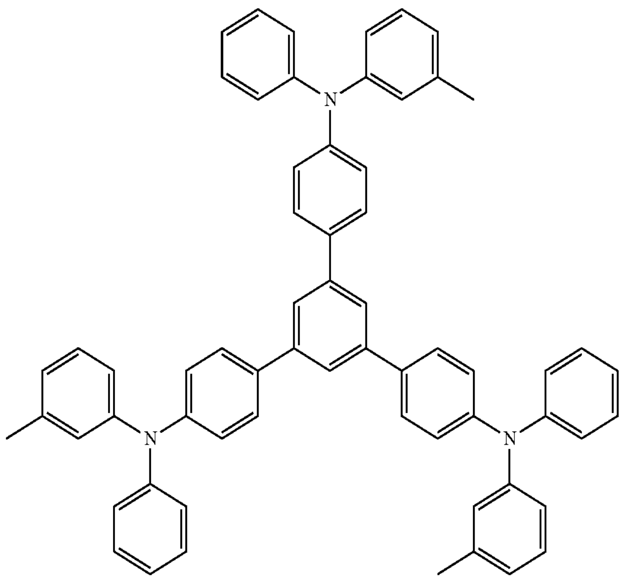
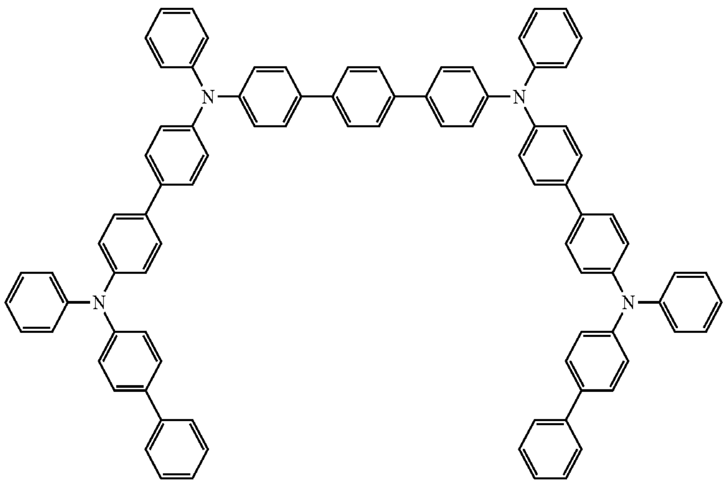
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		EP650955
		J. Mater. Chem. 3, 319 (1993)
		Appl. Phys. Lett. 90, 183503 (2007)

TABLE 3-continued

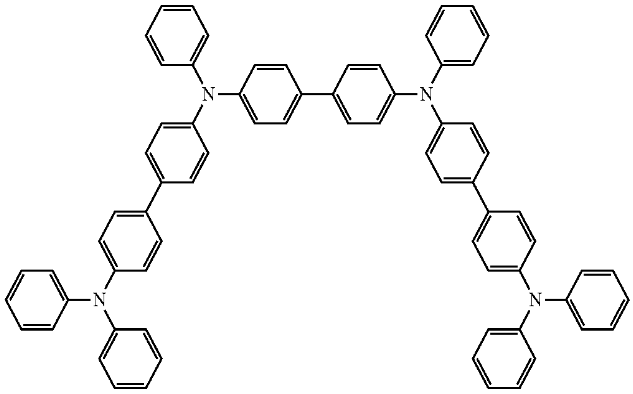
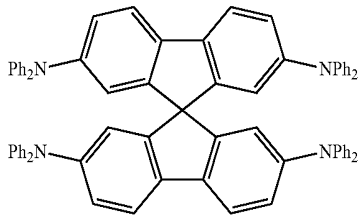
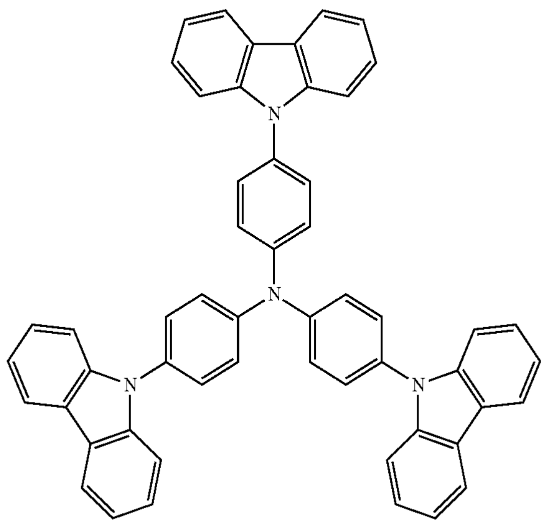
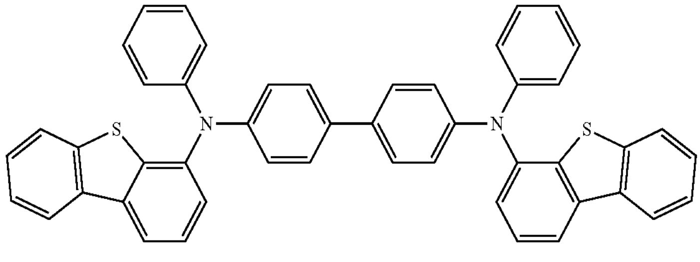
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		Appl. Phys. Lett. 90, 183503 (2007)
Triarylamine on spirofluorene core		Synth. Met. 91, 209 (1997)
Arylamine carbazole compounds		Adv. Mater. 6, 677 (1994), US20080124572
Triarylamine with (di)benzothiophene/(di) benzofuran		US20070278938, US20080106190

TABLE 3-continued

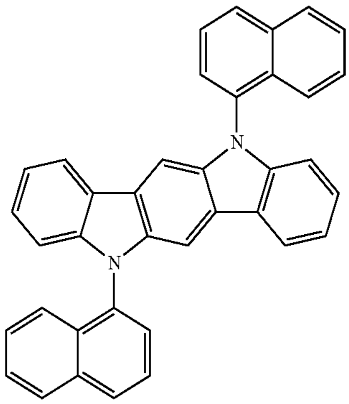
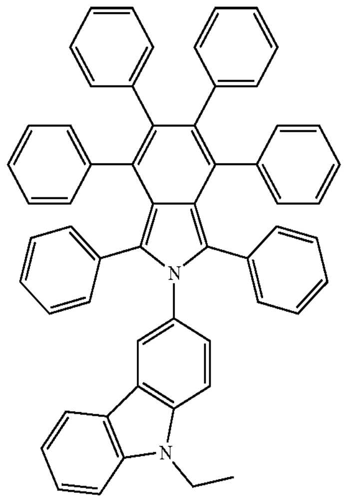
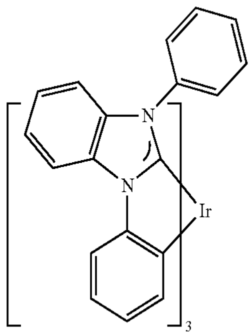
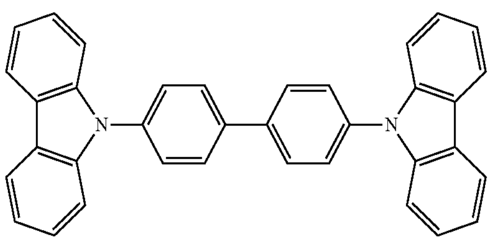
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Indolocarbazoles		Synth. Met. 111, 421 (2000)
Isoindole compounds		Chem. Mater. 15, 3148 (2003)
Metal carbene complexes		US20080018221
	Phosphorescent OLED host materials Red hosts	
Arylcarbazoles		Appl. Phys. Lett. 78, 1622 (2001)

TABLE 3-continued

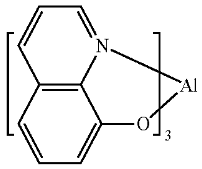
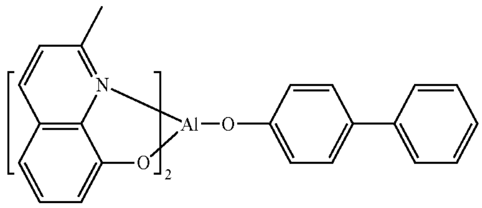
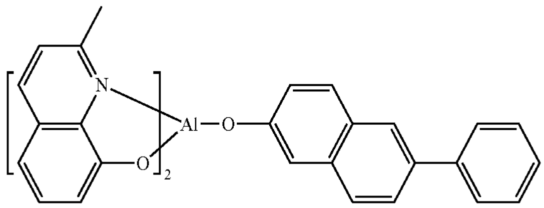
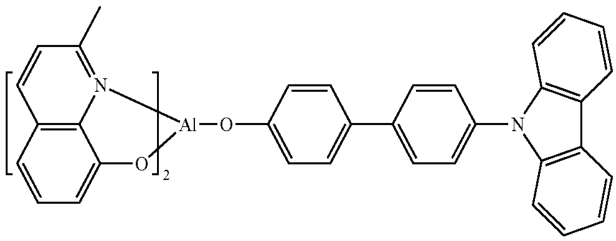
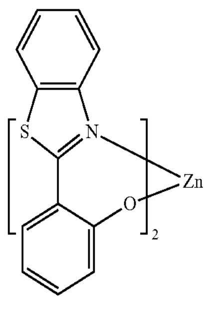
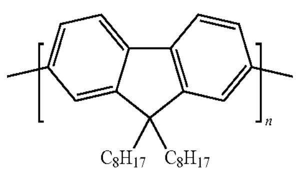
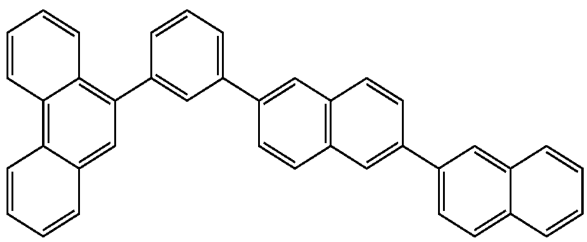
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Metal 8-hydroxy-quinolates (e.g., Alq_3, BAlq)		Nature 395, 151 (1998)
		US20060202194
		US2005014551
		WO2006072002
Metal phnoxybenzothiazole compounds		Appl. Phys. Lett. 90, 123509 (2007)
Conjugated oligomers and polymers (e.g., polyfluorene)		Org. Electron. 1, 15 (2000)
Aromatic fused rings		WO2009066779, WO2009066778, WO2009063833, US20090045731, US20090045730, WO2009008311, US20090008605, US20090009065

TABLE 3-continued

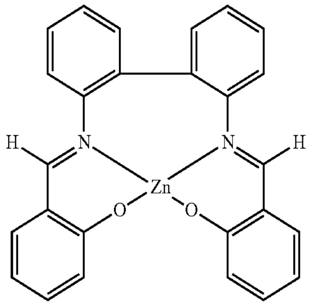
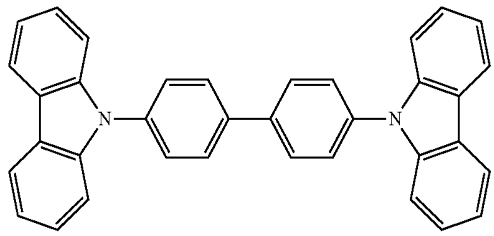
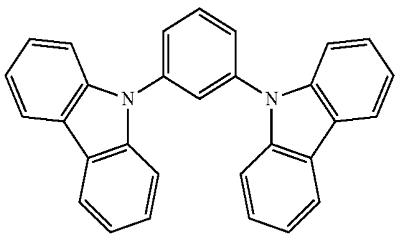
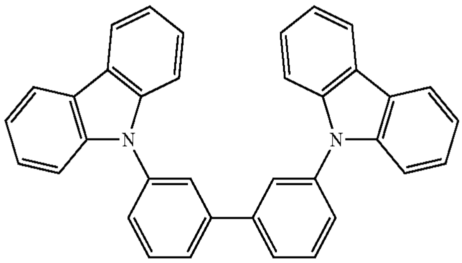
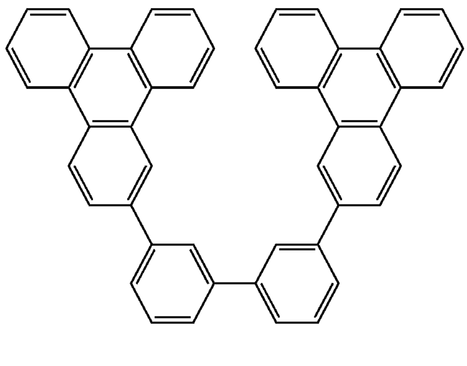
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Zinc complexes		WO2009062578
	Green hosts	
Arylcarbazoles		Appl. Phys. Lett. 78, 1622 (2001)
		US20030175553
		WO2001039234
Aryltriphenylene compounds		US20060280965

TABLE 3-continued

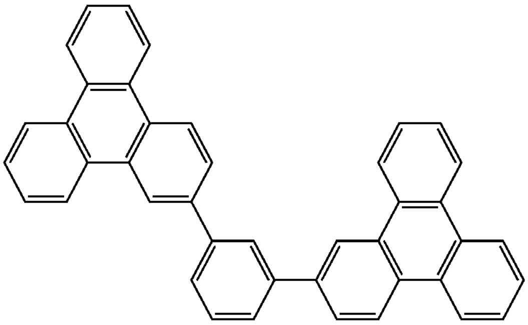
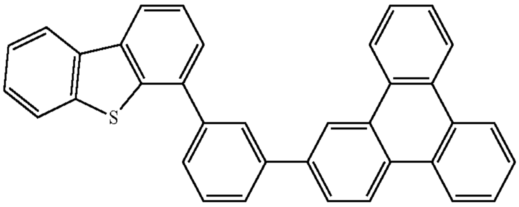
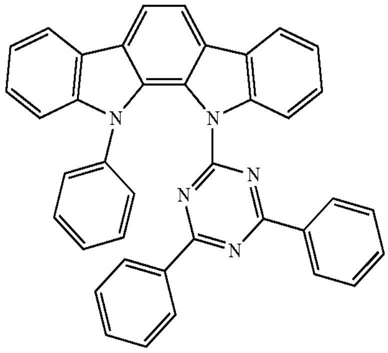
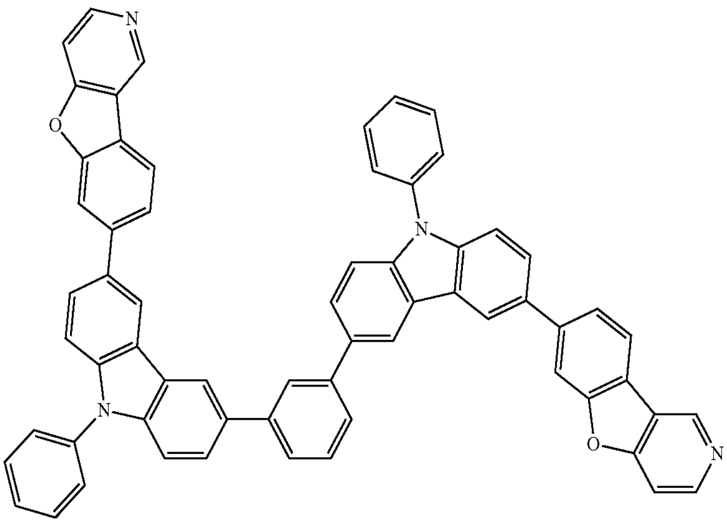
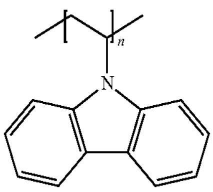
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20060280965
		WO2009021126
Donor acceptor type molecules		WO2008056746
Aza-carbazole/DBT/ DBF		JP2008074939
Polymers (e.g., PVK)		Appl. Phys. Lett. 77, 2280 (2000)

TABLE 3-continued

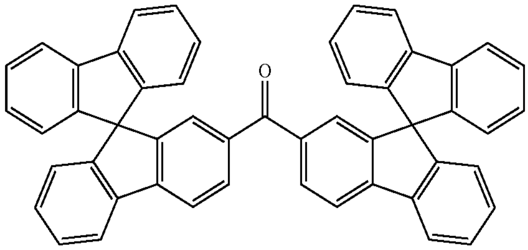
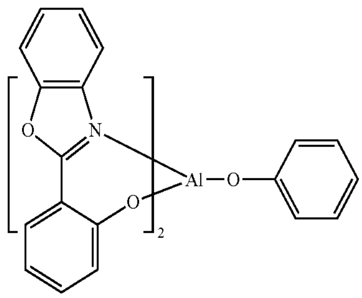
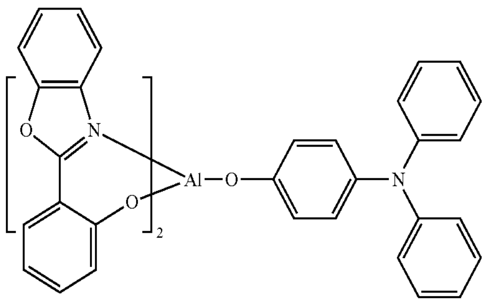
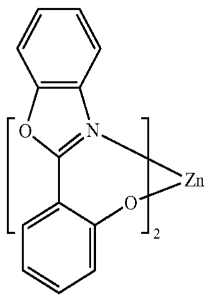
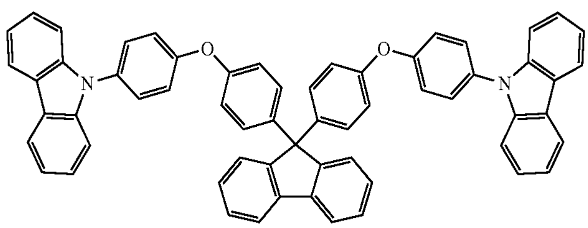
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Spirofluorene compounds		WO2004093207
Metal phenoxybenzooxazole compounds		WO2005089025
		WO200613273
		JP200511610
Spirofluorene-carbazole compounds		JP2007254297

TABLE 3-continued

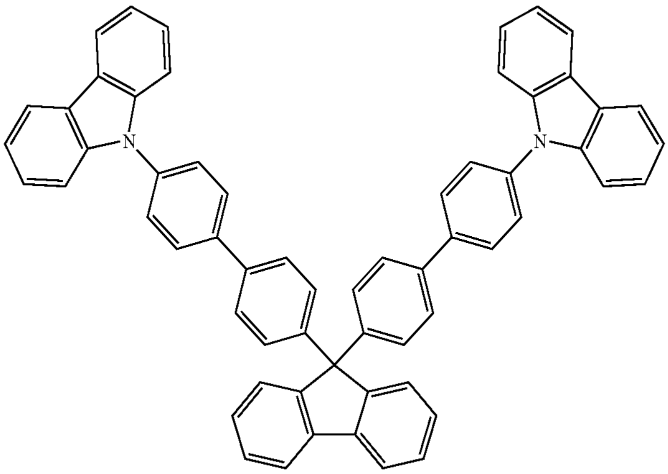
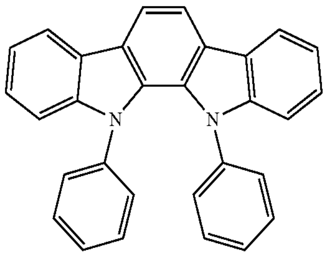
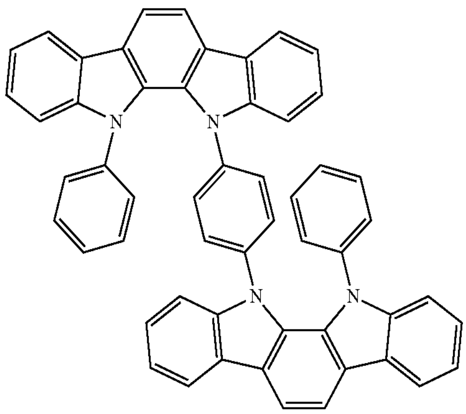
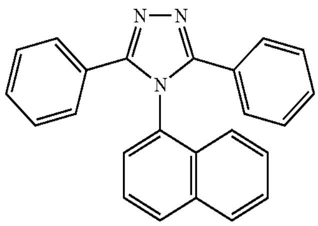
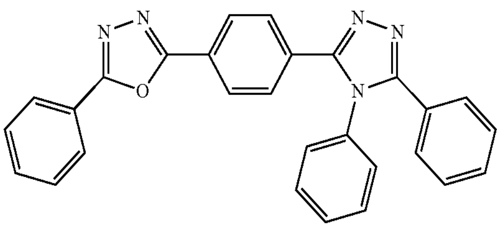
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		JP2007254297
Indolocabazoles		WO2007063796
		WO2007063754
5-member ring electron deficient heterocycles (e.g., triazole, oxadiazole)		J. Appl. Phys. 90, 5048 (2001)
		WO2004107822

TABLE 3-continued

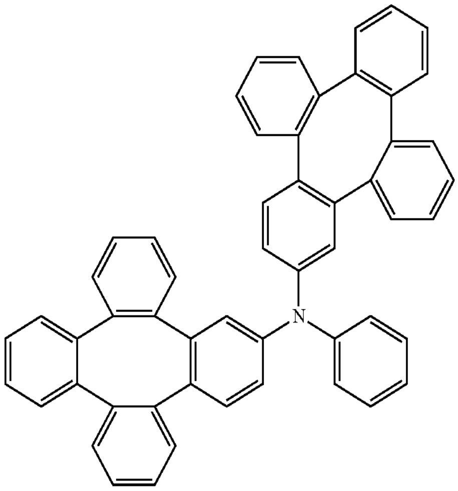
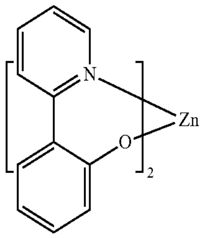
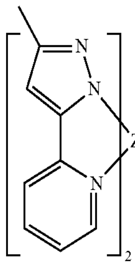
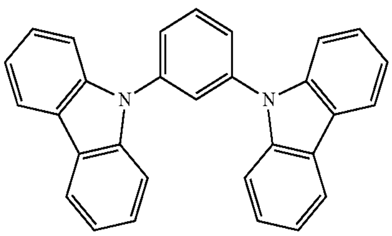
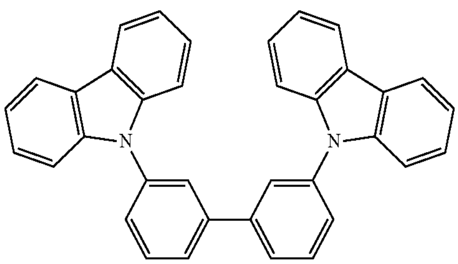
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Tetraphenylene complexes		US20050112407
Metal phenoxypyridine compounds		WO2005030900
Metal coordination complexes (e.g., Zn, Al, with N^N ligands		US20040137268, US20040137267
	Blue hosts	
Arylcarbazoles		Appl. Phys. Lett, 82, 2422 (2003)
		US20070190359

TABLE 3-continued

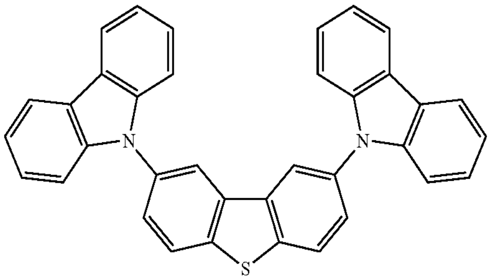
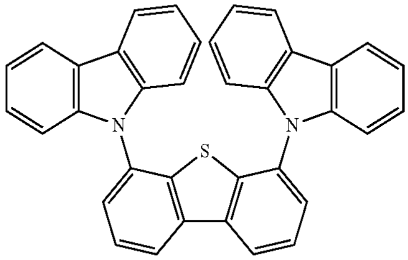
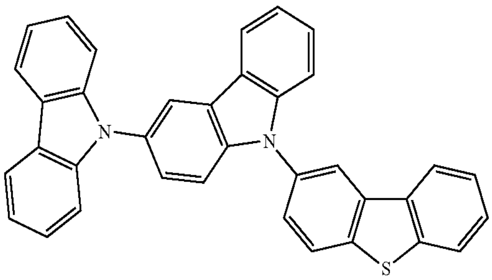
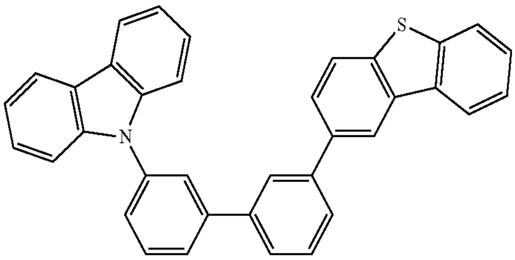
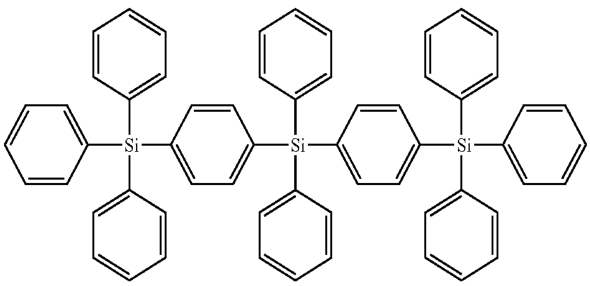
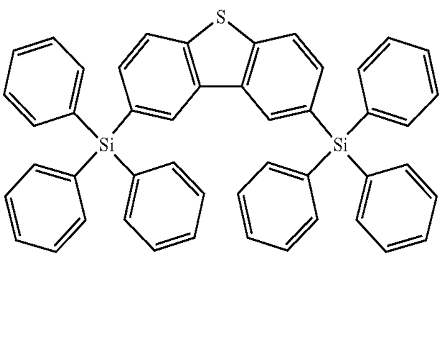
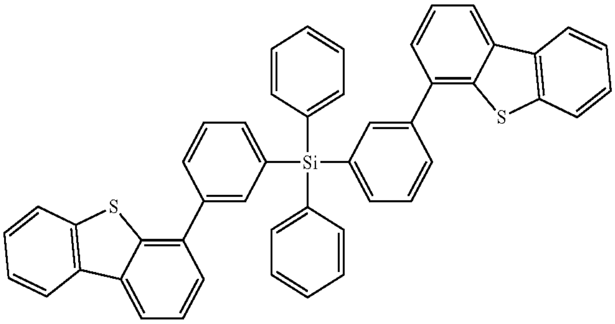
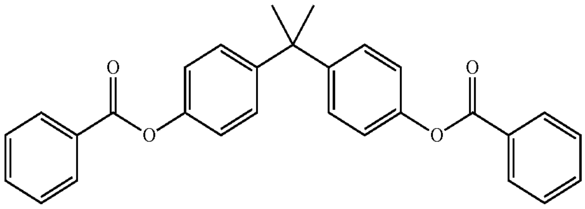
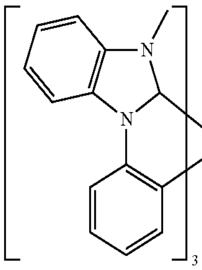
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Dibenzothiophene/Dibenzofuran-carbazole compounds		WO2006114966, US20090167162
		US20090167162
		WO2009086028
		US20090030202, US20090017330
Silicon aryl compounds		US20050238919
		WO2009003898

TABLE 3-continued

MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Silicon/Germanium aryl compounds		EP2034538A
Aryl benzoyl ester		WO2006100298
High triplet metal organometallic complex		US7154114

Phophorescent dopants

Red dopants

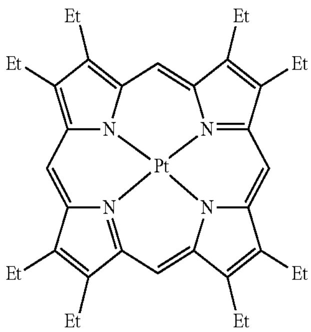
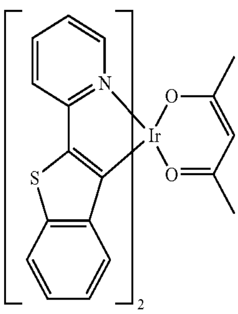
Heavy metal porphyrins (e.g., PtOEP)		Nature 395, 151 (1998)
Iridium(III) organometallic complexes		Appl. Phys. Lett. 78, 1622 (2001)

TABLE 3-continued

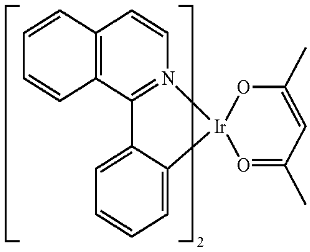
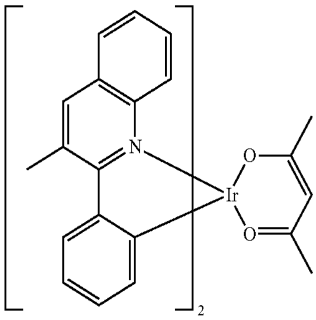
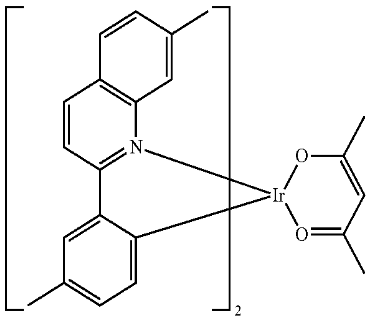
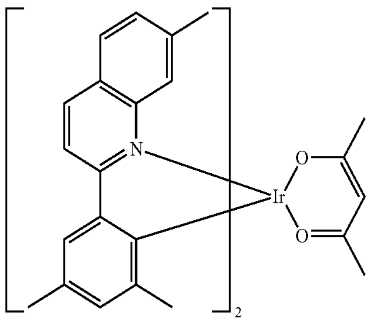
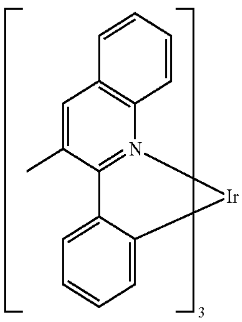
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US2006835469
		US2006835469
		US20060202194
		US20060202194
		US20070087321

TABLE 3-continued

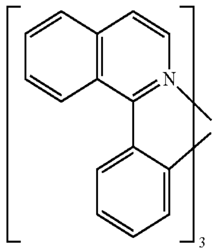
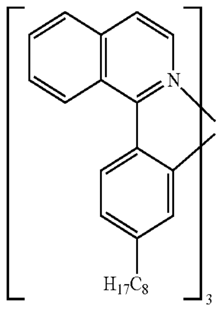
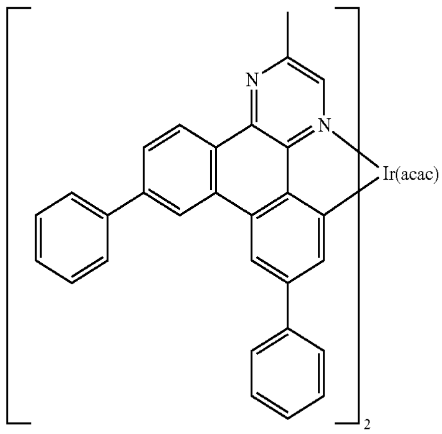
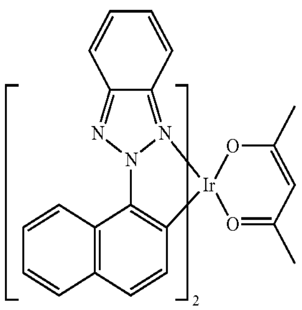
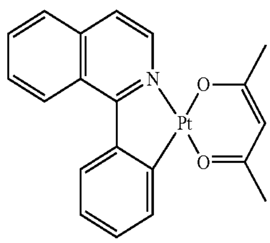
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20070087321
		Adv. Mater. 19, 739 (2007)
		WO2009100991
		WO2008101842
Platinum(II) organometallics complexes		WO2003040257

TABLE 3-continued

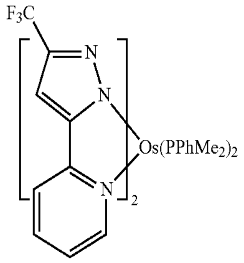
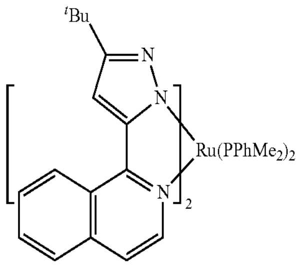
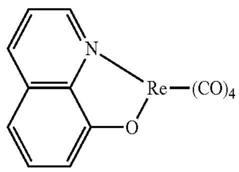
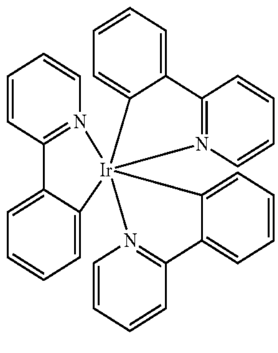
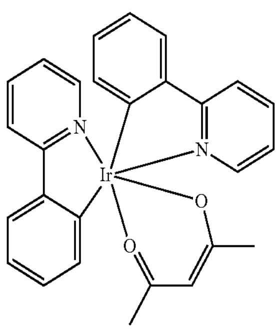
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Osminum(III) complexes		Chem. Mater. 17, 3532 (2005)
Ruthenium(II) complexes		Adv. Mater. 17, 1059 (2005)
Rhenium (I), (II), and (III) complexes		US20050244673
	Green dopants	
Iridium(III) organometallic complexes	 and its derivatives	Inorg. Chem. 40, 1704 (2001)
		US20020034656

TABLE 3-continued

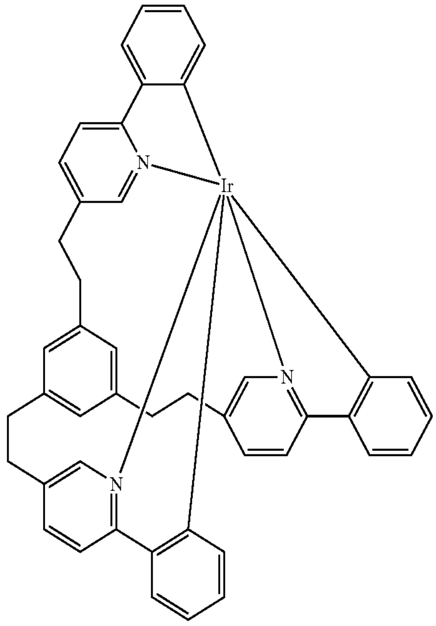
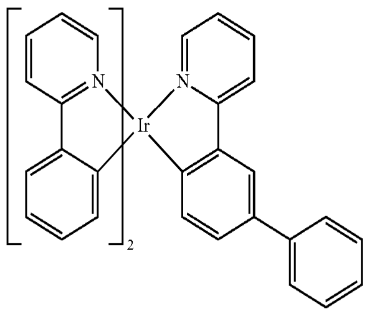
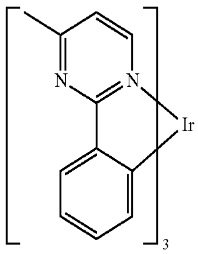
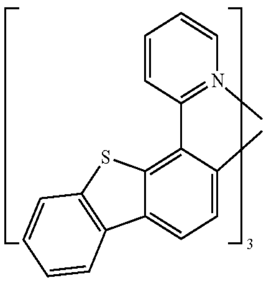
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US7332232
		US20090108737
		US20090039776
		US6921915

TABLE 3-continued

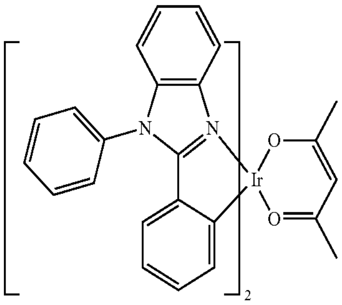
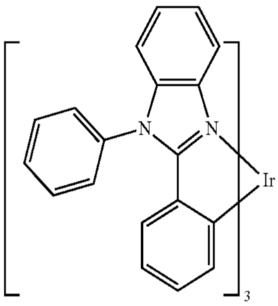
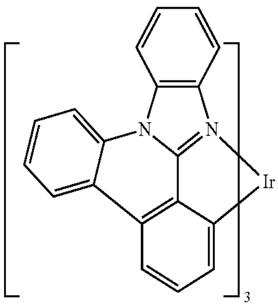
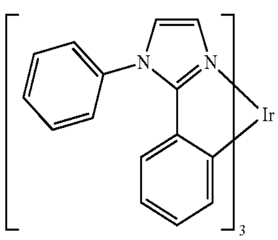
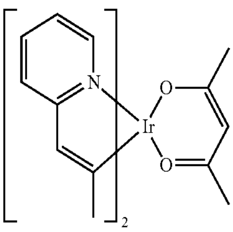
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US6687266
		Chem. Mater. 16, 2480 (2004)
		US20070190359
		US 20060008670 JP2007123392
		Adv. Mater. 16, 2003 (2004)

TABLE 3-continued

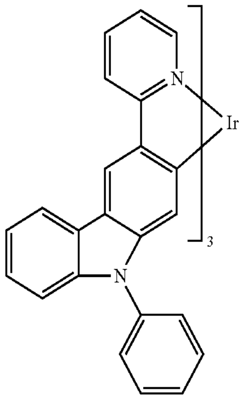
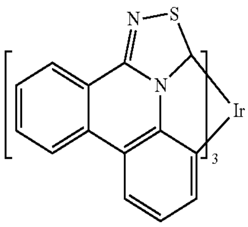
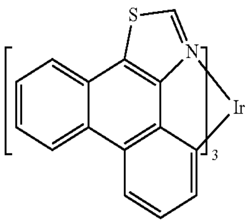
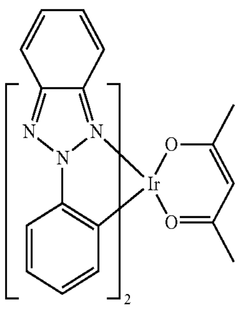
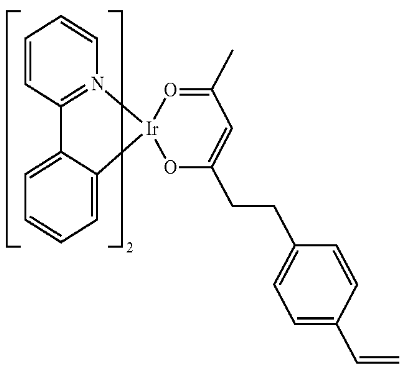
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		Agnew. Chem. Int. Ed. 2006, 45, 7800
		WO2009050290
		US20090165846
		US20080015355
Monomer for polymeric metal organometallic compounds		US7250226, US7396598

TABLE 3-continued

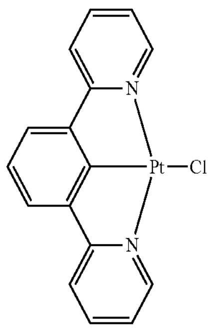
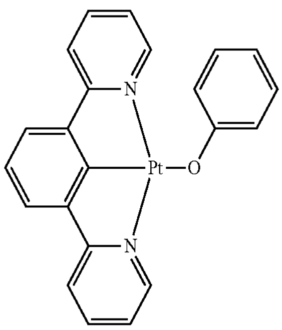
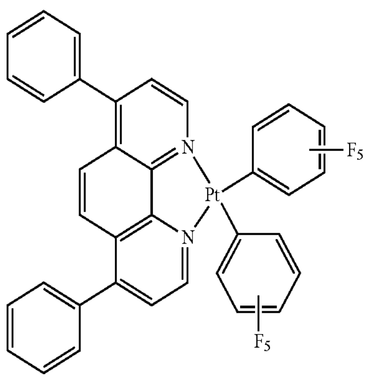
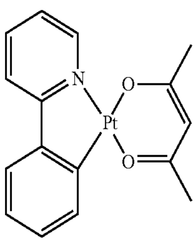
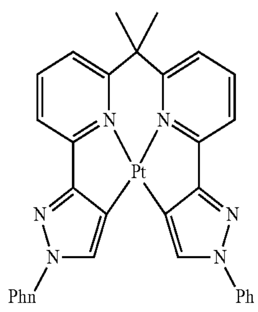
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Pt(II) organometallic complexes, including polydentated ligands		Appl. Phys. Lett. 86, 153505 (2005)
		Appl. Phys. Lett. 86, 153505 (2005)
		Chem. Lett. 34, 592 (2005)
		WO2002015645
		US20060263635

TABLE 3-continued

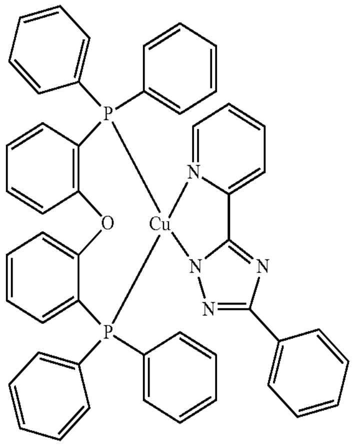
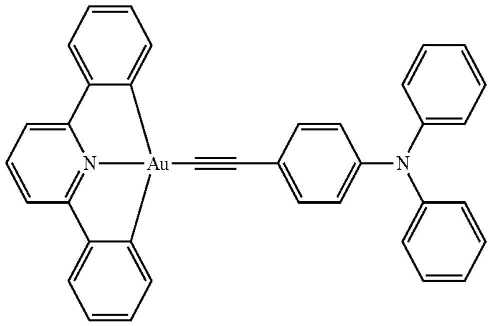
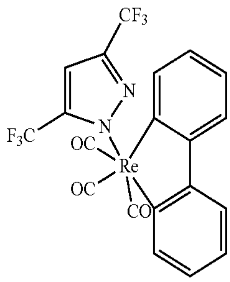
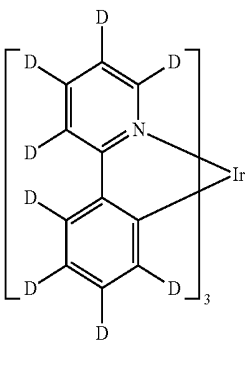
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Cu complexes		WO2009000673
Gold complexes		Chem. Commun. 2906 (2005)
Rhenium(III) complexes		Inorg. Chem. 42, 1248 (2003)
Deuterated organo-metallic complexes		US20030138657

TABLE 3-continued

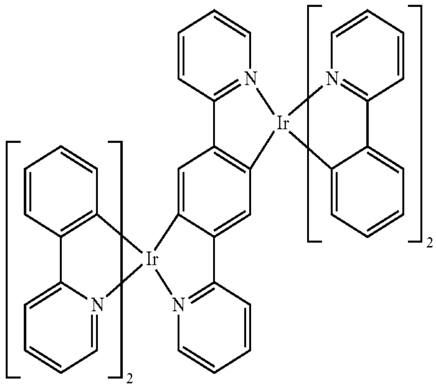
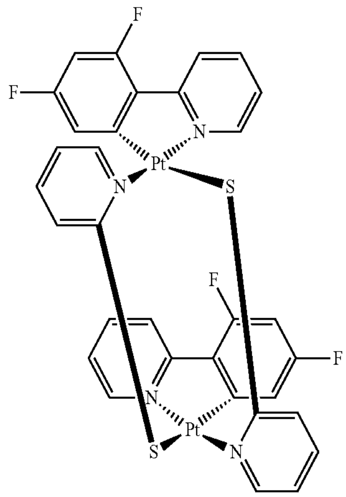
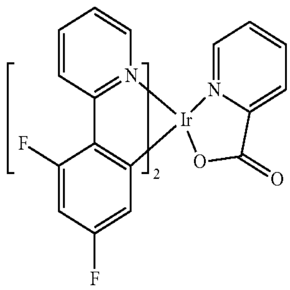
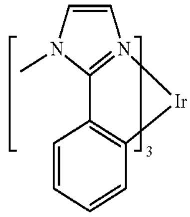
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Organometallic complexes with two or more metal centers		US20030152802
		US7090928
	Blue dopants	
Iridium(III) organo-metallic complexes		WO2002002714
		WO2006009024

TABLE 3-continued

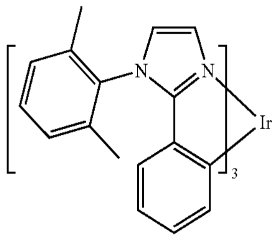
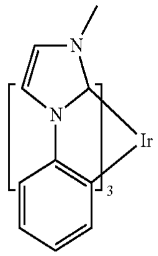
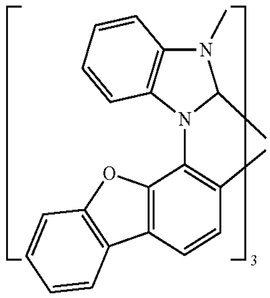
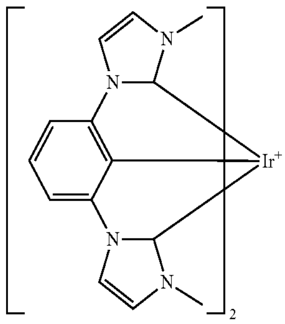
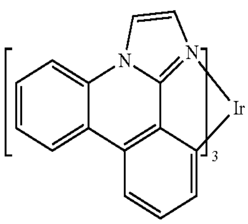
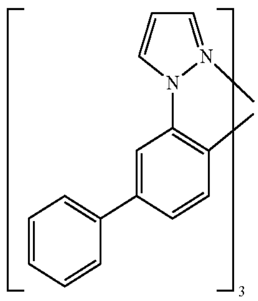
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20060251923
		US7393599, WO2006056418, US20050260441, WO2005019373
		US7534505
		US7445855
		US20070190359, US20080297033
		US7338722

TABLE 3-continued

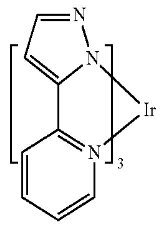
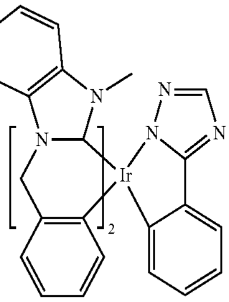
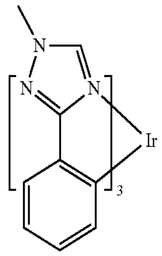
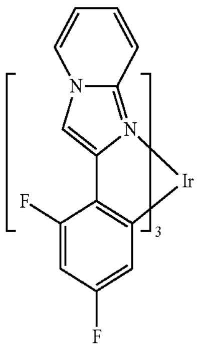
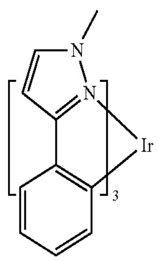
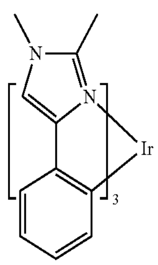
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20020134984
		Agnew. Chem. Int. Ed. 47, 1 (2008)
		Chem. Mater. 18, 5119 (2006)
		Inorg. Chem. 46, 4308 (2007)
		WO2005123873
		WO2005123873

TABLE 3-continued

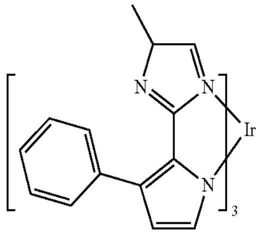
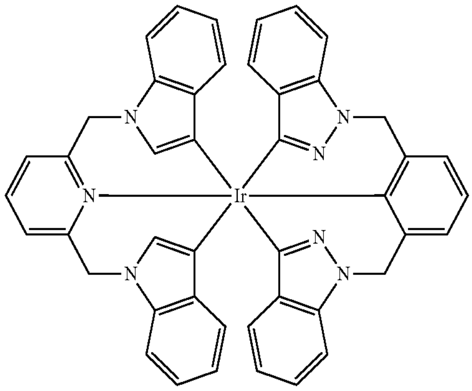
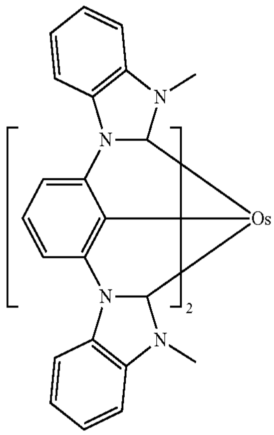
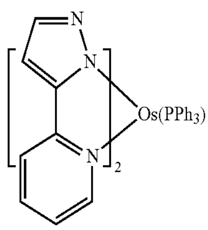
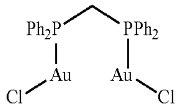
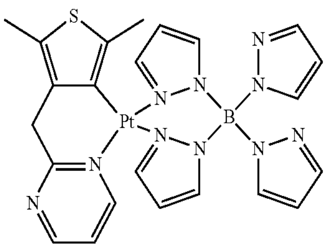
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		WO2007004380
		WO2006082742
Osmium(II) complexes		US7279704
		Organometallics 23, 3745 (2004)
Gold complexes		Appl. Phys. Lett. 74, 1361 (1999)
Platinum(II) complexes		WO2006098120, WO2006103874

TABLE 3-continued

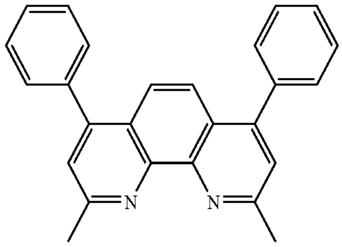
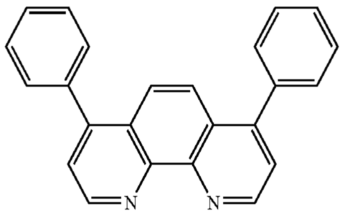
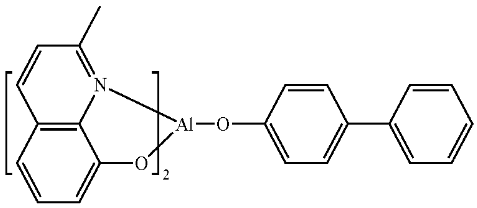
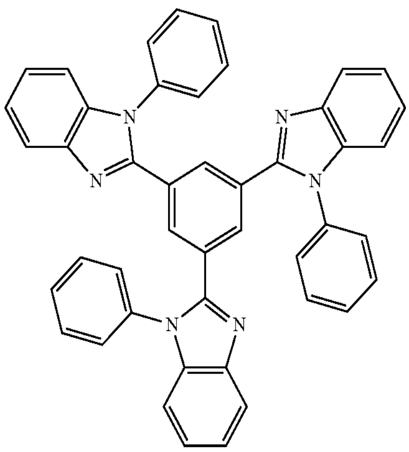
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
	Exciton/hole blocking layer materials	
Bathocuprine compounds (e.g., BCP, BPhen)		Appl. Phys. Lett. 75, 4 (1999)
		Appl. Phys. Lett. 79, 449 (2001)
Metal 8-hydroxy-quinolates (e.g., BAlq)		Appl. Phys. Lett. 81, 162 (2002)
5-member ring electron deficient heterocycles such as triazole, oxadi-azole, imidazole, benzoimidazole		Appl. Phys. Lett. 81, 162 (2002)

TABLE 3-continued

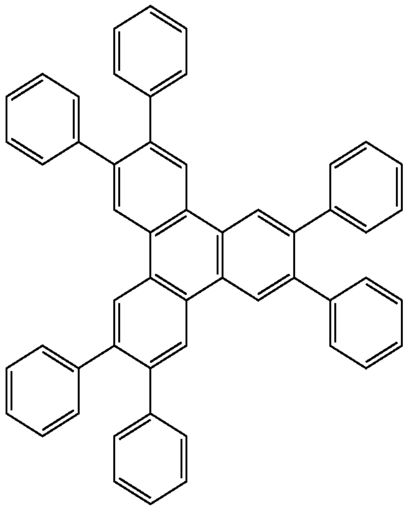
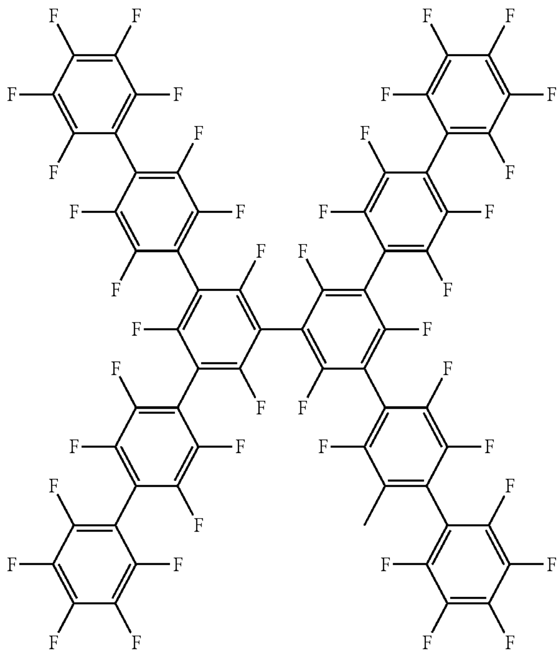
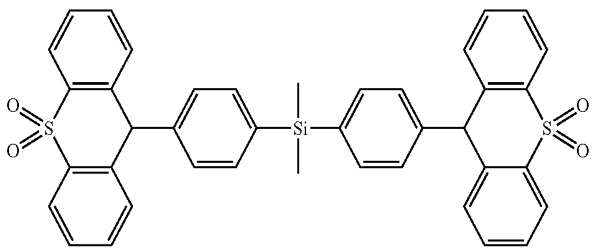
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Triphenylene compounds		US20050025993
Fluorinated aromatic compounds		Appl. Phys. Lett. 79, 156 (2001)
Phenothiazine-S-oxide		WO2008132085

TABLE 3-continued

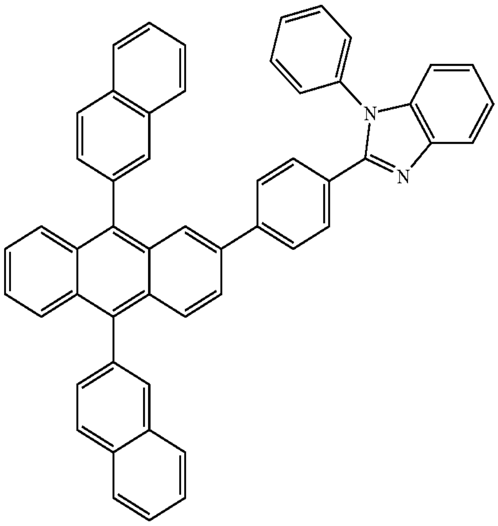
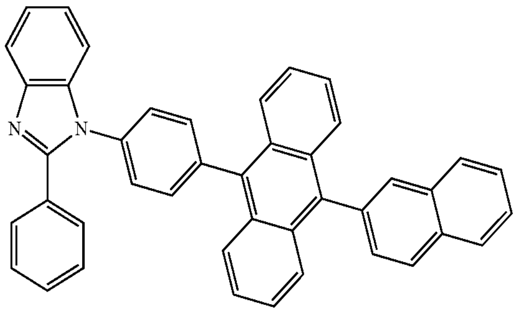
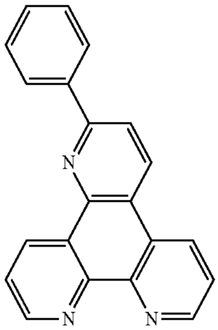
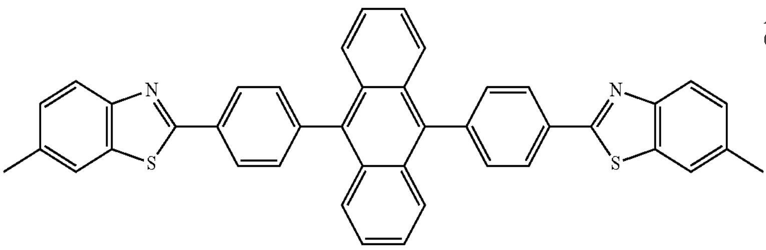
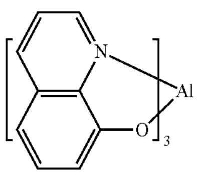
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
	Electron transporting materials	
Anthracene-benzoimidazole compounds		WO2003060956
		US20090179554
Aza triphenylene derivatives		US20090115316
Anthracene-benzothiazole compounds		Appl. Phys. Lett. 89, 063504 (2006)
Metal 8-hydroxy-quinolates (e.g., Alq_3, Zrq_4)		Appl. Phys. Lett. 51, 913 (1987) US7230107

TABLE 3-continued

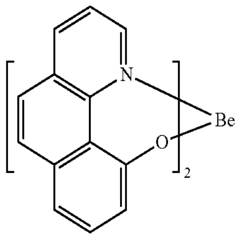
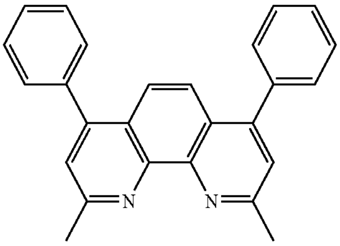
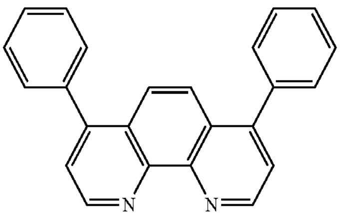
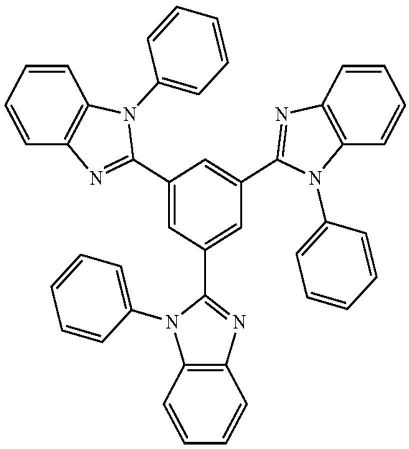
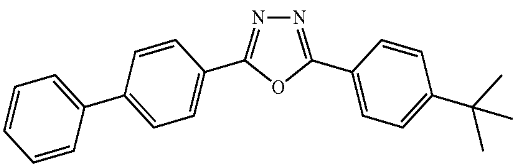
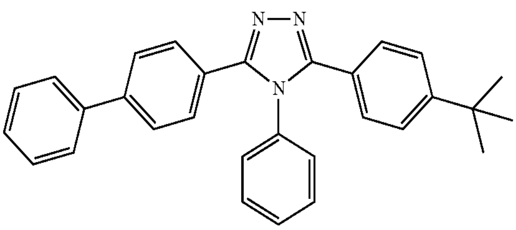
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Metal hydroxybenoquinolates		Chem. Lett. 5, 905 (1993)
Bathocuprine compounds such as BCP, BPhen, etc		Appl. Phys. Lett. 91, 263503 (2007)
		Appl. Phys. Lett. 79, 449 (2001)
5-member ring electron deficient heterocycles (e.g., triazole, oxadi-azole, imidazole, benzoimidazole)		Appl. Phys. Lett. 74, 865 (1999)
		Appl. Phys. Lett. 55, 1489 (1989)
		Jpn. J. Apply. Phys. 32, L917 (1993)

TABLE 3-continued

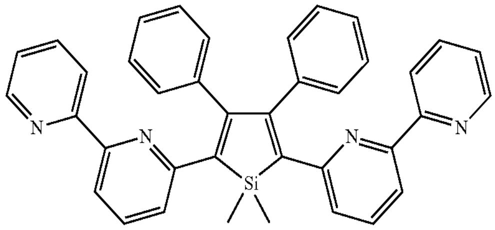
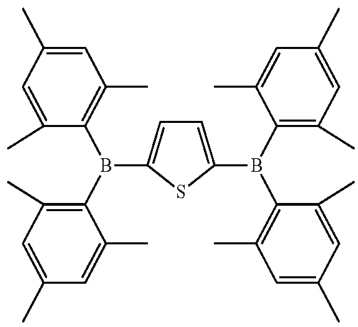
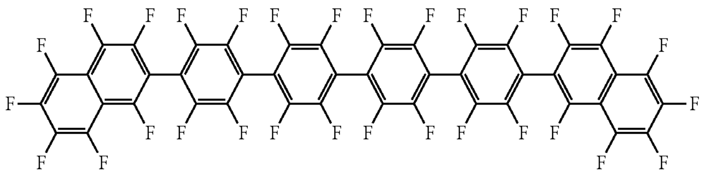
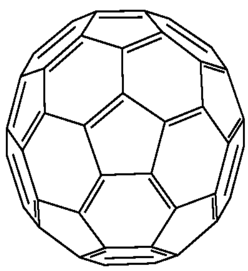
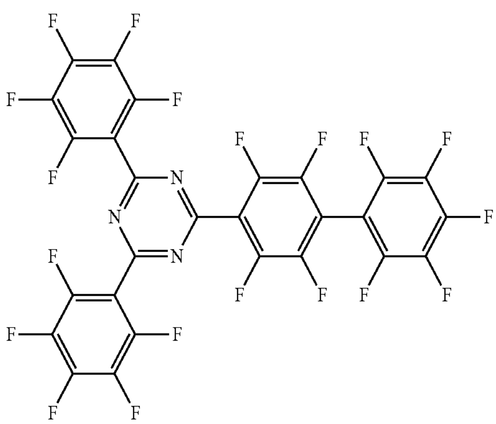
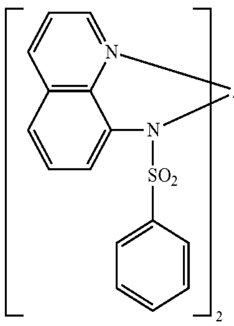
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Silole compounds		Org. Electron. 4, 113 (2003)
Arylborane compounds		J. Am. Chem. Soc. 120, 9714 (1998)
Fluorinated aromatic compounds		J. Am. Chem. Soc. 122, 1832 (2000)
Fullerene (e.g., C60)		US20090101870
Triazine complexes		US20040036077

TABLE 3-continued

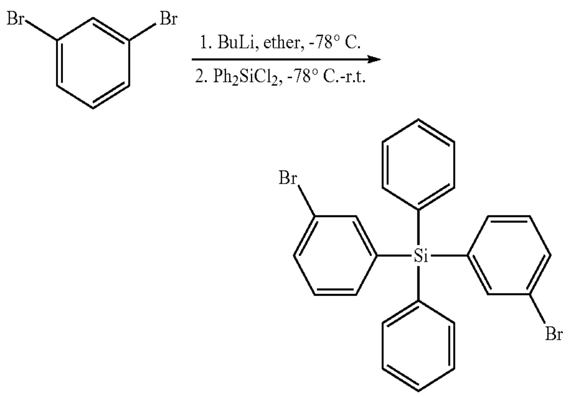
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Zn (N^N) complexes		US6528187

EXPERIMENTAL

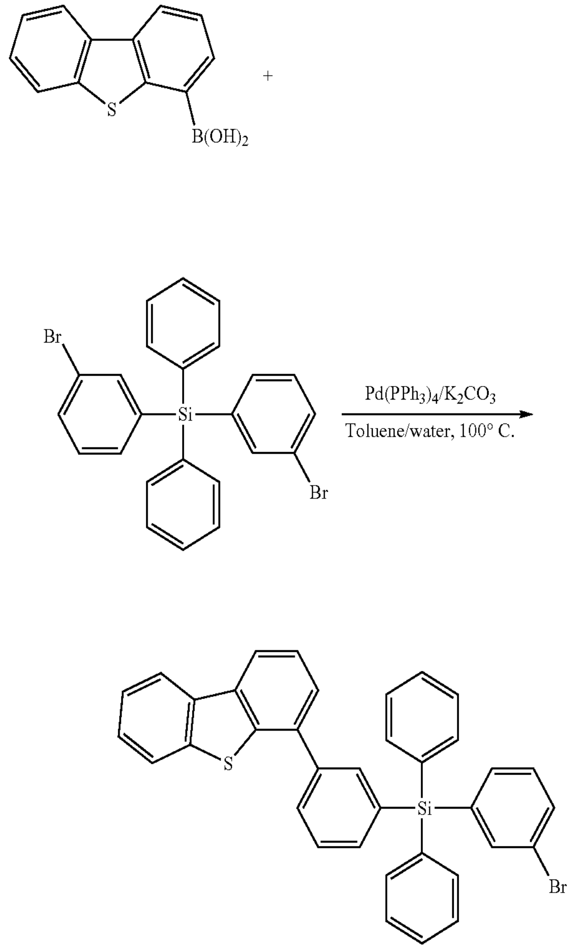
Chemical abbreviations used throughout this document are as follows: dba is dibenzylideneacetone, EtOAc is ethyl acetate, PPh_3 is triphenylphosphine, dppf is 1,1'-bis(diphenylphosphino)ferrocene, DCM is dichloromethane, SPhos is dicyclohexyl(2',6'-dimethoxy-[1,1'-biphenyl]-3-yl)phosphine, THF is tetrahydrofuran.

Example 1

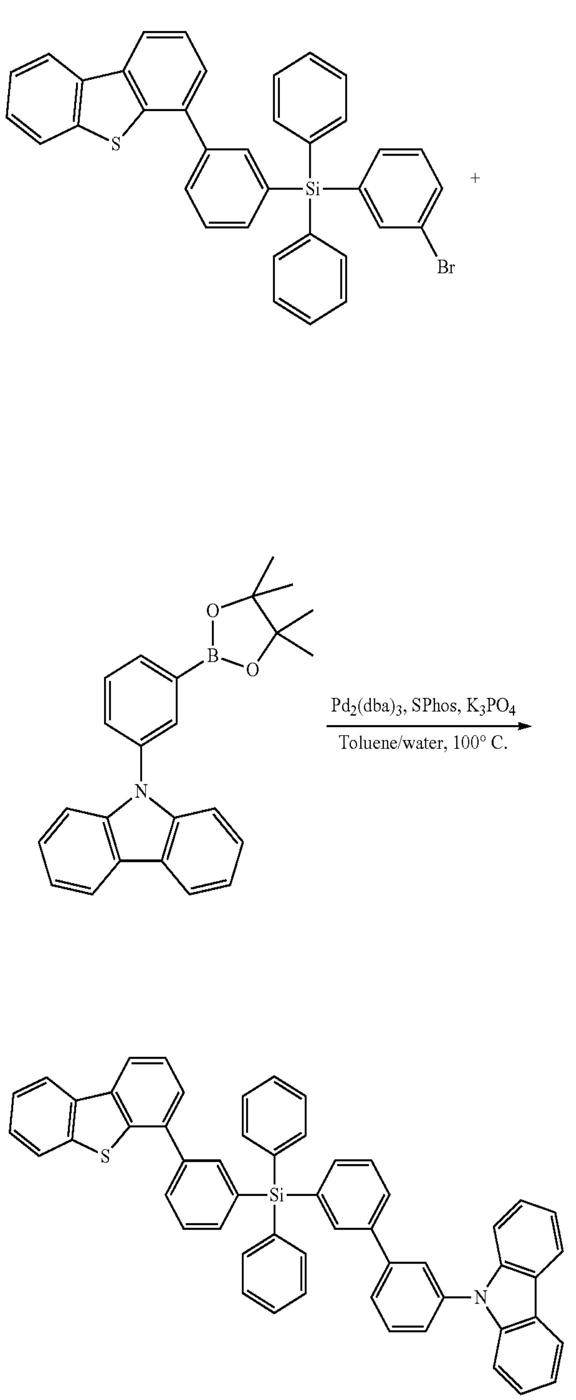
Synthesis of Compound 23



Butyllithium (53.2 mL, 133 mmol, 2.5M in hexane) was added dropwise into a solution of 1,3-dibromobenzene (15.38 mL, 127 mmol) in ether (300 mL) at −78° C. The reaction mixture was stirred at this temperature before dichlorodiphenylsilane (11.90 mL, 57.8 mmol) in ether (20 mL) was added dropwise to yield a clear yellow solution. The solution was allowed to warm up to room temperature overnight and quenched with water. The organic phase was washed with brine and water, dried over Na_2SO_4. Upon evaporation of the solvent, the residue was purified by column chromatography on silica gel with hexane/DCM (9.8/0.2, v/v) as eluent, and recrystallized from methanol to yield bis(3-bromophenyl)diphenylsilane (25 g, 87%) as white crystals.



A mixture solution of dibenzo[b,d]thiophen-4-boronic acid (1.84 g, 8.04 mmol), bis(3-bromophenyl)diphenylsilane (9.97 g, 20.17 mmol), $Pd(PPh_3)_4$ (0.19 g, 0.16 mmol) and potassium carbonate (6.69 g, 48.4 mmol,) in toluene (60 mL) and water (20 mL) was heated at 100° C. under nitrogen overnight. After cooling to room temperature, the reaction mixture was quenched with water, extracted with DCM, washed with brine and water, and dried over Na_2SO_4. Upon evaporation of the solvent, the residue was purified by column chromatography on silica gel with hexane:DCM (9.5:0.5 to 9:1, v/v) as eluent. The crude product was dissolved in DCM, precipitated with methanol, and filtered to yield (3-bromophenyl)(3-(dibenzo[b,d]thiophen-4-yl)phenyl)diphenylsilane (3.0 g, 62%) as a white solid.



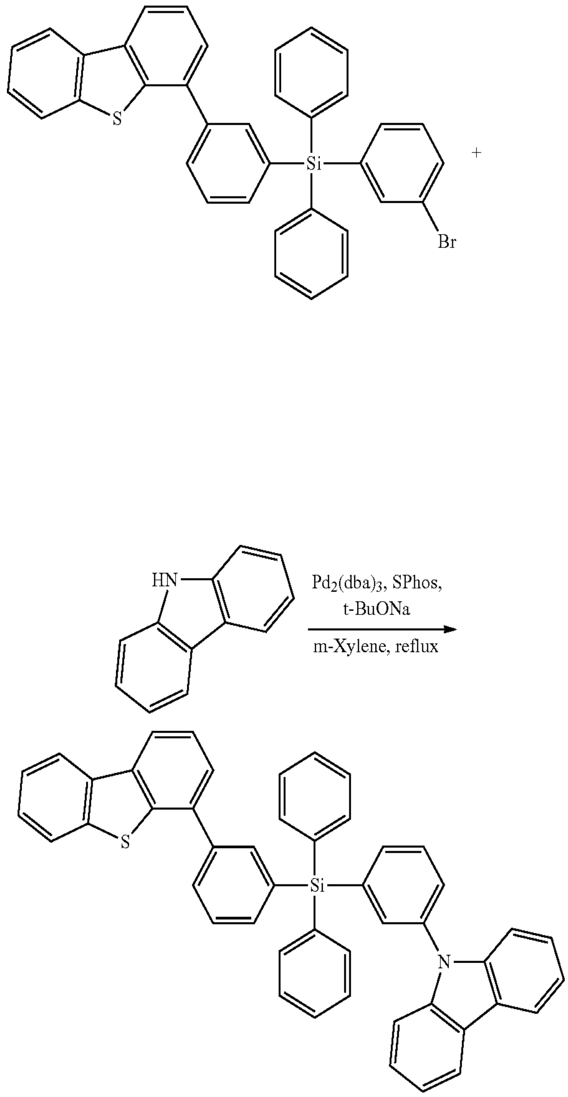
Compound 23

A mixture solution of (3-bromophenyl)(3-(dibenzo[b,d]thiophen-4-yl)phenyl)diphenylsilane (3 g, 5.02 mmol), 9-(3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)-9H-carbazole (2.039 g, 5.52 mmol), tris(dibenzylideneacetone)dipalladium(0) ($Pd_2(dba)_3$) (0.092 g, 0.100 mmol), dicyclohexyl(2',6'-dimethoxy-[1,1'-biphenyl]-3-yl)phosphine (SPhos) (0.082 g, 0.201 mmol), and potassium phosphate tribasic (K_3PO_4) (1.066 g, 5.02 mmol) in toluene (40 mL) and water (4 mL) was heated at 100° C. under nitrogen overnight. The reaction mixture was quenched with water, extracted with DCM, washed with brine and water, and dried over Na_2SO_4. Upon evaporation of the solvent, the residue was purified by column chromatography with hexane:DCM (9.25:0.75, v/v) as eluent. The crude product was dissolved in

DCM, precipitated with methanol, and filtered to yield Compound 23 (2.2 g, 66%) as a colorless glass.

Example 2

Synthesis of Compound 24

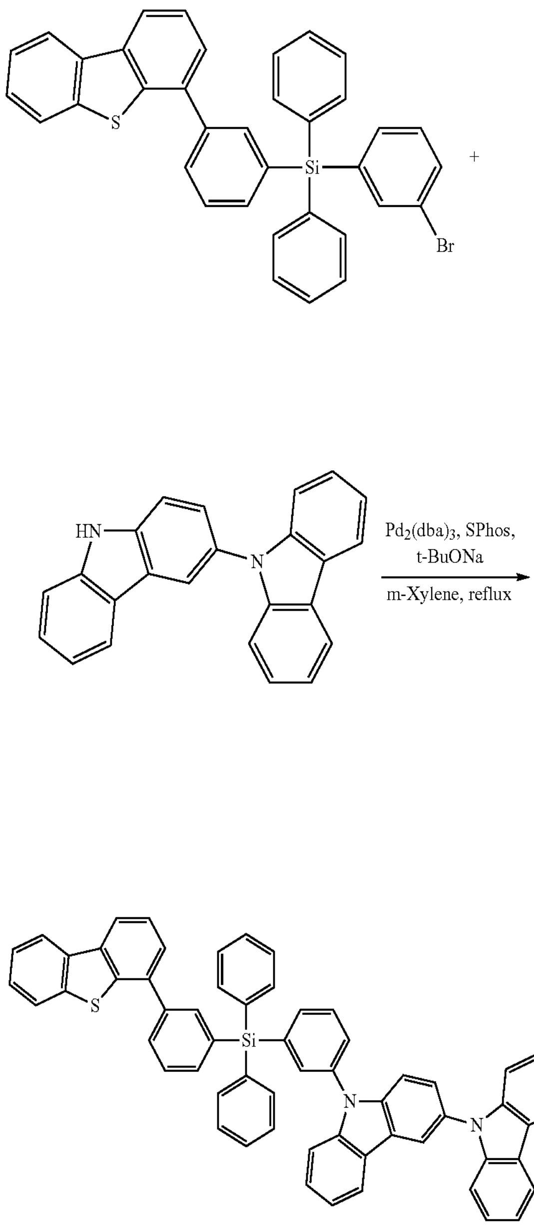


Compound 24

A suspension of (3-bromophenyl)(3-(dibenzo[b,d]thiophen-4-yl)phenyl)diphenylsilane (3.5 g, 5.86 mmol), 9H-carbazole (0.979 g, 5.86 mmol), $Pd_2(dba)_3$ (0.107 g, 0.117 mmol), SPhos (0.096 g, 0.234 mmol), and sodium tert-butoxide (0.563 g, 5.86 mmol) in m-xylene (50 mL) was refluxed under nitrogen overnight. After cooling to room temperature, the reaction mixture was filtered through a short plug of Celite, and washed with toluene. The combined organic solution was washed with water and dried over Na_2SO_4. Upon evaporation of the solvent, the crude product was purified by column chromatography on silica gel with hexane:DCM (9.25:0.75, v/v) as eluent. The crude product was dissolved in DCM, precipitated with methanol, and filtered to yield Compound 24 (2.5 g, 62%) as a colorless glass.

Example 3

Synthesis of Compound 25

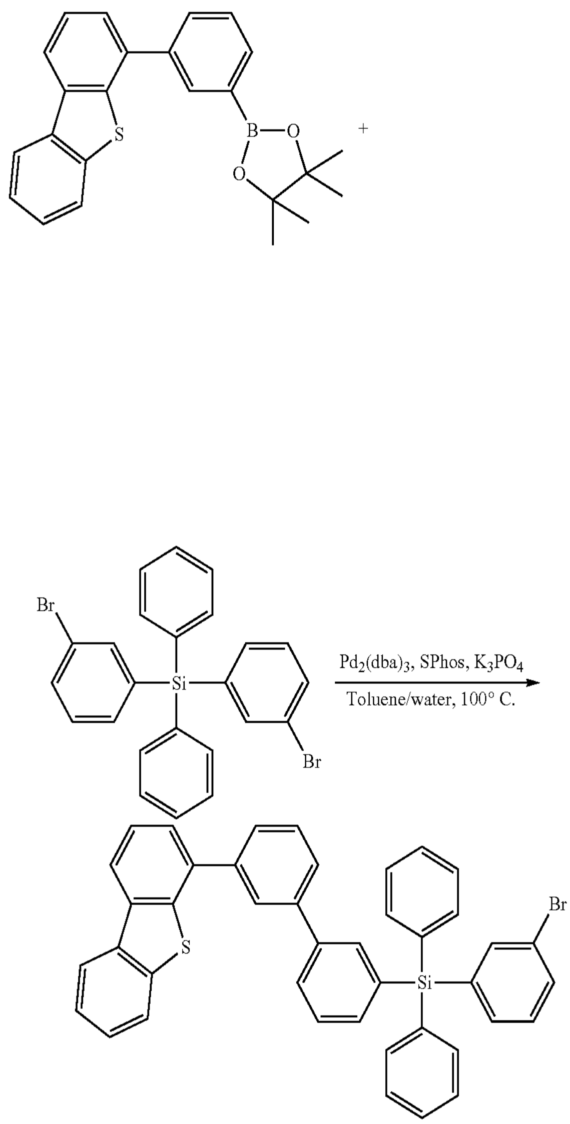


Compound 25

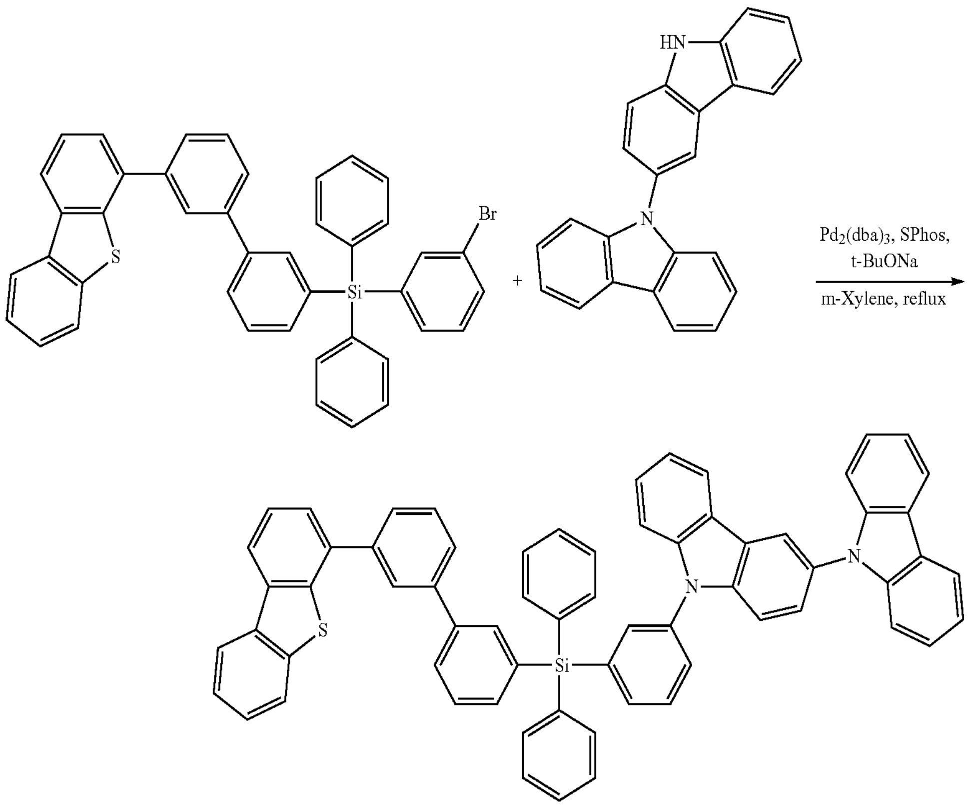
A suspension of (3-bromophenyl)(3-(dibenzo[b,d]thiophen-4-yl)phenyl)diphenylsilane (3.5 g, 5.86 mmol), 9H-3,9'-bicarbazole (1.947 g, 5.86 mmol), $Pd_2(dba)_3$ (0.107 g, 0.117 mmol), SPhos (0.096 g, 0.234 mmol), and sodium tert-butoxide (0.563 g, 5.86 mmol) was added to m-xylene (100 mL) and refluxed under nitrogen overnight. After cooling to room temperature, the reaction mixture was filtered through a short plug of Celite and washed with toluene. The combined organic solution was washed with water, dried over Na_2SO_4. Upon evaporation of the solvent, the residue was purified by column chromatography on silica gel with hexane:DCM (8.5:1.5, v/v) as eluent. The crude product was dissolved in DCM, precipitated with ethanol, and filtered to yield Compound 25 (3.0 g, 60%) as a colorless glass.

Example 4

Synthesis of Compound 26



A mixture solution of 2-(3-(dibenzo[b,d]thiophen-4-yl)phenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (6.0 g, 15.53 mmol), bis(3-bromophenyl)diphenylsilane (19.19 g, 38.8 mmol), $Pd_2(dba)_3$ (0.28 g, 0.31 mmol), SPhos (0.26 g, 0.62 mmol) and K_3PO_4 (3.30 g, 15.53 mmol) in xylene (150 mL) and water (15 mL) was refluxed under nitrogen at 120° C. overnight. After cooling to room temperature, the reaction mixture was quenched with water, extracted with DCM, washed with brine and water, and dried over Na_2SO_4. Upon evaporation of the solvent, the residue was purified by column chromatography on silica gel with hexane:DCM (9.5:0.5 to 9:1, v/v) as eluent. The crude product was dissolved in DCM, precipitated with methanol, and filtered to yield (3-bromophenyl)(3'-(dibenzo[b,d]thiophen-4-yl)-[1,1'-biphenyl]-3-yl)diphenylsilane (3.2 g, 30.6%) as a white powder.

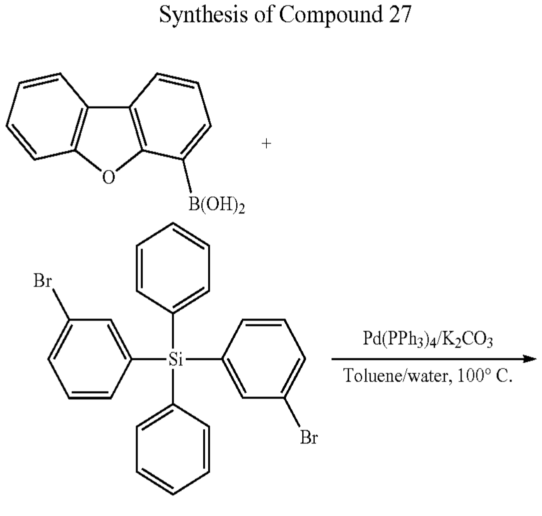


Compound 26

A suspension of (3-bromophenyl)(3'-(dibenzo[b,d]thiophen-4-yl)-[1,1'-biphenyl]-3-yl)diphenylsilane (4.5 g, 6.68 mmol), 9H-3,9'-bicarbazole (2.66 g, 8.02 mmol), $Pd_2(dba)_3$ (0.122 g, 0.134 mmol), SPhos (0.110 g, 0.267 mmol), and sodium tert-butoxide (1.284 g, 13.36 mmol) in m-xylene (100 mL) was refluxed at 140° C. under nitrogen overnight. After cooling to room temperature, the reaction mixture was filtered through a short plug of Celite and washed with toluene. The combined organic solution was washed with water, dried over Na_2SO_4. Upon evaporation of the solvent, the residue was purified by column chromatography on silica gel with hexane:DCM (8:2, v/v) as eluent. The crude product was dissolved in DCM, precipitated with ethanol, and filtered to yield Compound 26 (3.8 g, 62%) as a white powder.

Example 5

Synthesis of Compound 27



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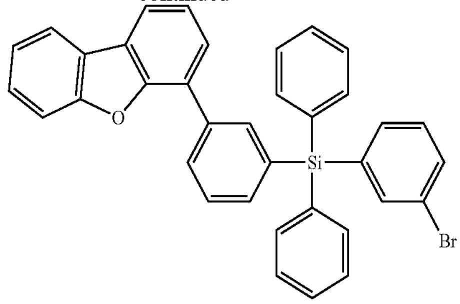
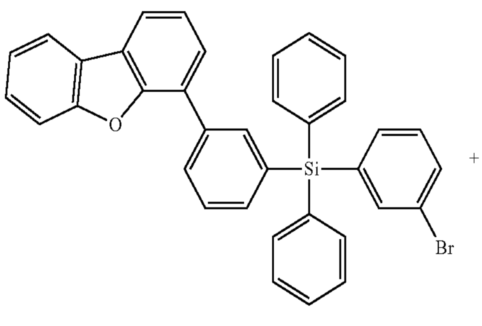


A mixture solution of dibenzo[b,d]furan-4-yl boronic acid (2.5 g, 11.79 mmol), bis(3-bromo-phenyl)diphenylsilane (14.57 g, 29.5 mmol), $Pd(PPh_3)_4$ (0.136 g, 0.118 mmol) and K_2CO_3 (3.26 g, 23.58 mmol) in 150 mL of toluene and 50 mL water was refluxed under nitrogen overnight. After cooling to room temperature, the organic phase was separated and evaporated to dryness. The residue was purified by column chromatography on silica gel with hexane:DCM (9.5:0.5, v/v) as eluent to yield (3-bromophenyl)(3-(dibenzo[b,d]furan-4-yl)phenyl)diphenylsilane (4.4 g, 64%) as a white solid.



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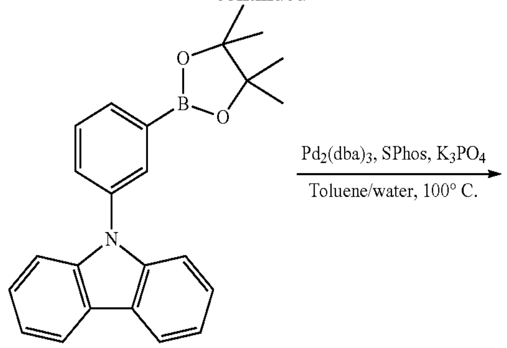
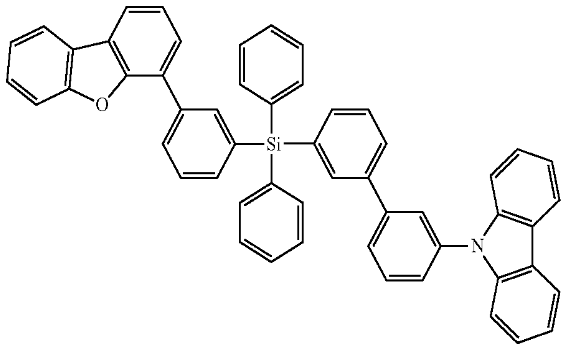


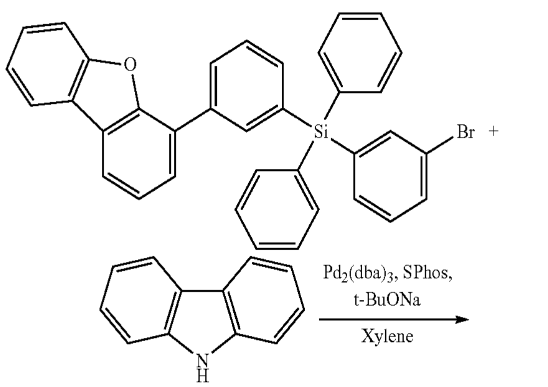


Compound 27

A mixture solution of (3-bromophenyl)(3-(dibenzo[b,d]furan-4-yl)phenyl)diphenylsilane (4.42 g, 7.60 mmol), 9-(3-(4,4,5,5-tetramethyl-1,3-dioxolan-2-yl)phenyl)-9H-carbazole (2.82 g, 7.60 mmol), K_3PO_4 (3.50 g, 15.20 mmol), $Pd_2(dba)_3$ (0.070 g, 0.076 mmol), SPhos (0.062 g, 0.152 mmol) in toluene (200 ml) and water (5 mL) was refluxed under nitrogen overnight. After cooling to room temperature, the organic phase was isolated and evaporated to dryness. The residue was purified by column chromatography on silica gel with hexanes/DCM (75:25, v/v) and sublimation under vacuum (<10^{-5} torr) to yield Compound 27 (1.9 g) as a colorless glass.

Example 6

Synthesis of Compound 28



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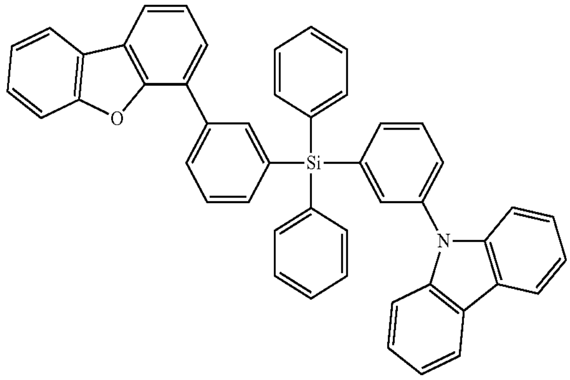
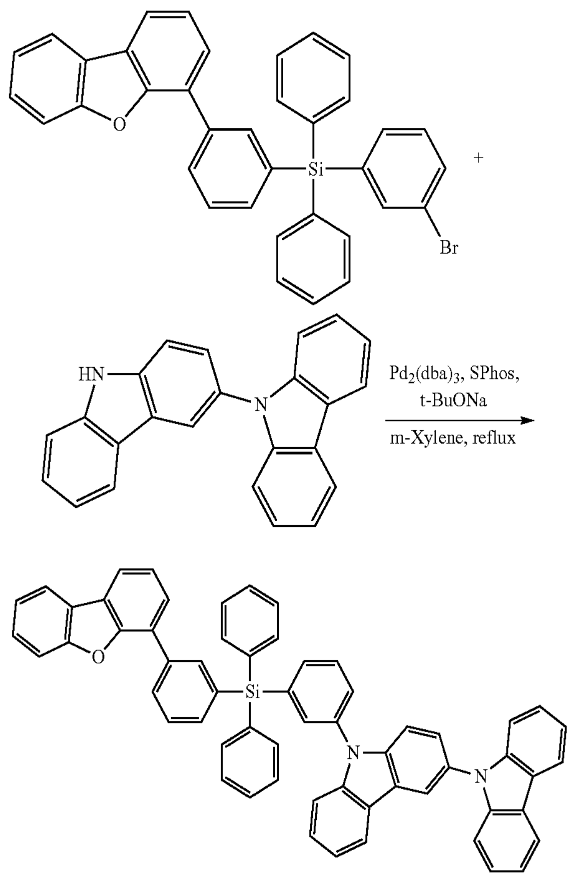


Compound 28

A suspension of 9H-carbazole (1.107 g, 6.62 mmol), (3-bromophenyl)(3-(dibenzo[b,d]furan-4-yl)phenyl)diphenylsilane (3.50 g, 6.02 mmol), $Pd_2(dba)_3$ (0.055 g, 0.060 mmol), SPhos (0.049 g, 0.120 mmol) and sodium tert-butoxide (1.157 g, 12.04 mmol) in anhydrous xylene (200 mL) was refluxed under nitrogen overnight. After cooling to room temperature, the reaction mixture was diluted with DCM and filtered through a short plug of silica gel. Upon evaporation of the solvent, the residue was purified by column chromatography on silica gel with hexane:DCM (4/1, v/v) as eluent to yield Compound 28 (3.3 g, 82% yield) as a white solid.

Example 7

Synthesis of Compound 29

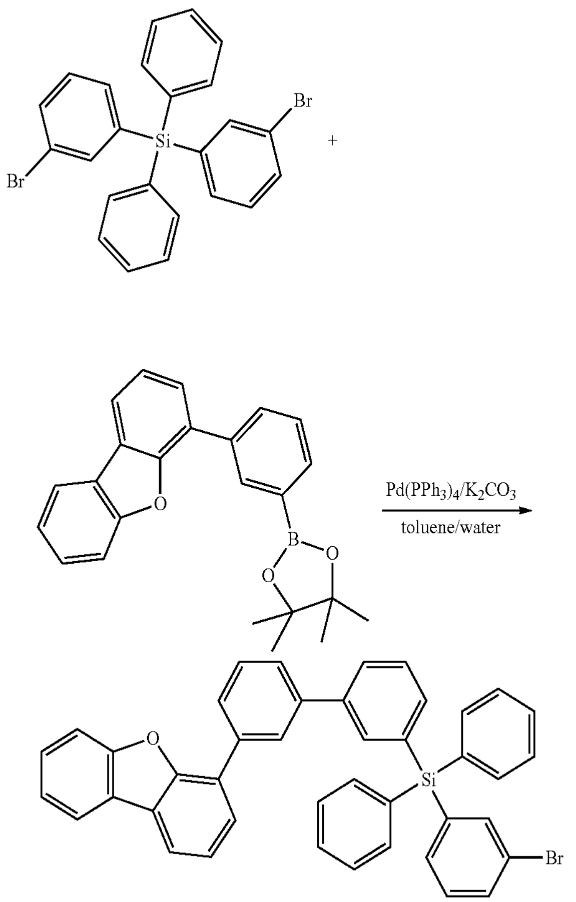


Compound 29

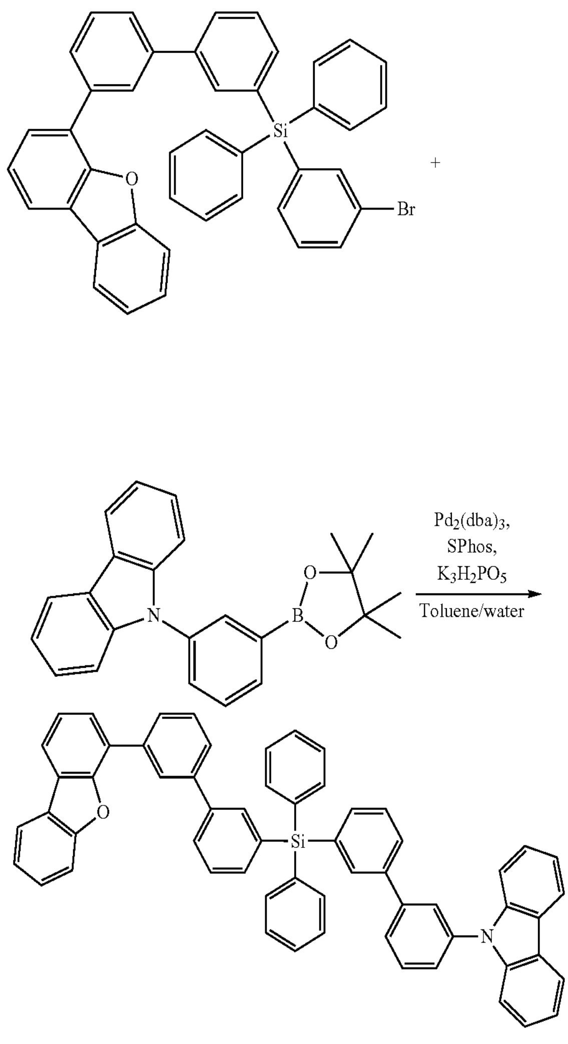
A suspension of (3-bromophenyl)(3-(dibenzo[b,d]furan-4-yl)phenyl)diphenylsilane (2.5 g, 4.30 mmol), 9H-3,9'-bicarbazole (1.715 g, 5.16 mmol), $Pd_2(dba)_3$ (0.079 g, 0.086 mmol), SPhos (0.071 g, 0.172 mmol), and sodium tert-butoxide (0.826 g, 8.60 mmol) in xylene (50 mL) was refluxed at 140° C. under nitrogen overnight. After cooling to room temperature, the reaction was quenched with water and extracted with toluene. The organic phase was isolated, washed with water, and dried over $MgSO_4$. Upon evaporation of the solvent, the residue was purified by column chromatography on silica gel with hexane:DCM (8:2, v/v) as eluent, precipitation from DCM to ethanol to yield Compound 29 (2.86 g, 80%) as a white solid.

Example 8

Synthesis of Compound 30



A mixture solution of bis(3-bromophenyl)diphenylsilane (8.01 g, 16.21 mmol), 2-(3-(dibenzo[b,c]furan-4-yl)phenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (3.00 g, 8.10 mmol), K_2CO_3 (2.240 g, 16.21 mmol), $Pd(PPh_3)_4$ (0.15 g, 0.162 mmol) in toluene (200 mL) and water (50 mL) was refluxed under nitrogen overnight. After cooling to room temperature, the organic phase was isolated and evaporated to dryness. The residue was purified by column chromatography on silica gel with hexane:DCM (9/1 to 3/1, v/v) as eluent to yield (3-bromophenyl)(3'-(dibenzo [b,d]furan-4-yl)-[1,1'-biphenyl]-3-yl)diphenylsilane (3.2 g, 60%) as a white solid.

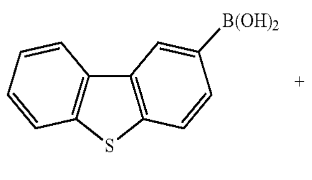


Compound 30

A mixture solution of (3-bromophenyl)(3'-(dibenzo[b,d]furan-4-yl)-[1,1'-biphenyl]-3-yl)diphenylsilane (2.82 g, 4.29 mmol), 9-(3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)-9H-carbazole (1.583 g, 4.29 mmol), $Pd_2(dba)_3$ (0.039 g, 0.043 mmol), SPhos (0.035 g, 0.086 mmol), $K_3H_2PO_5$ (2.96 g, 12.86 mmol) in toluene (150 mL) and water (5 mL) was heated at 100° C. under nitrogen overnight. After cooling to room temperature, the organic phase was isolated and evaporated to dryness. The residue was purified by column chromatography on silica gel with hexane:DCM (4/1, v/v) as eluent to yield Compound 30 (3.1 g, 88%) as a white solid.

Example 9

Synthesis of Compound 31



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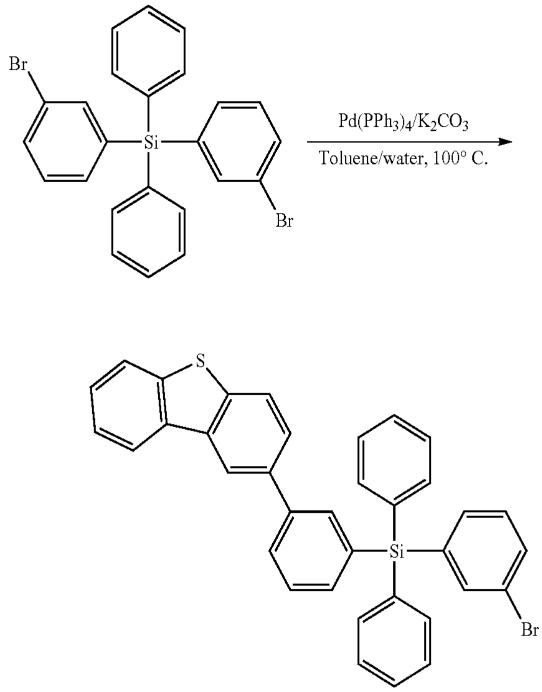
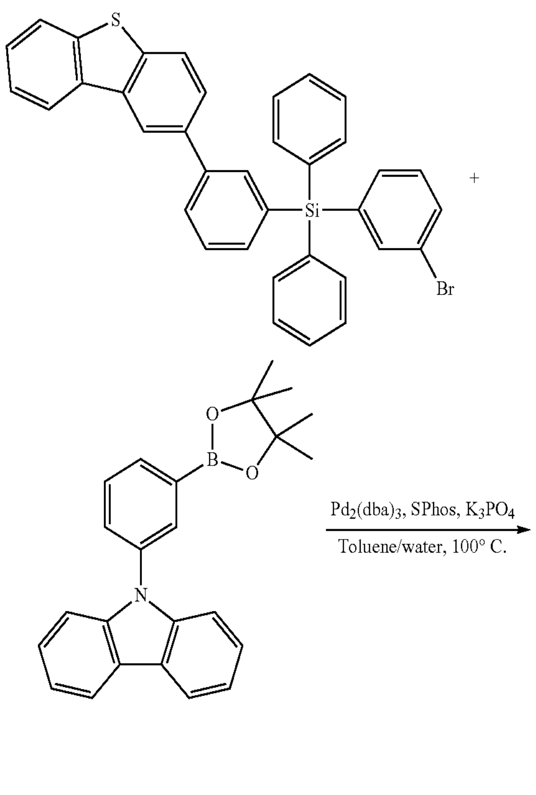


A mixture solution of bis(3-bromophenyl)diphenylsilane (10.84 g, 21.92 mmol), dibenzo[b,d]thiophen-2-yl boronic acid (2.000 g, 8.77 mmol), $Pd(PPh_3)_4$ (0.101 g, 0.088 mmol) and K_2CO_3 (2.424 g, 17.54 mmol) in toluene (200 mL) and water (50 mL) was refluxed under nitrogen overnight. After cooling to room temperature, the organic phase was isolated and evaporated to dryness. The residue was purified by column chromatography on silica gel with hexane:DCM (9:1, v/v) as eluent to yield (3-bromophenyl)(3-(dibenzo[b,d]thiophen-2-yl)phenyl)diphenylsilane (3.16 g, 60% yield) as a white solid.



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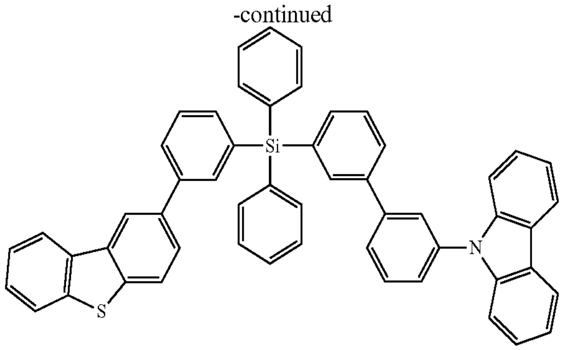
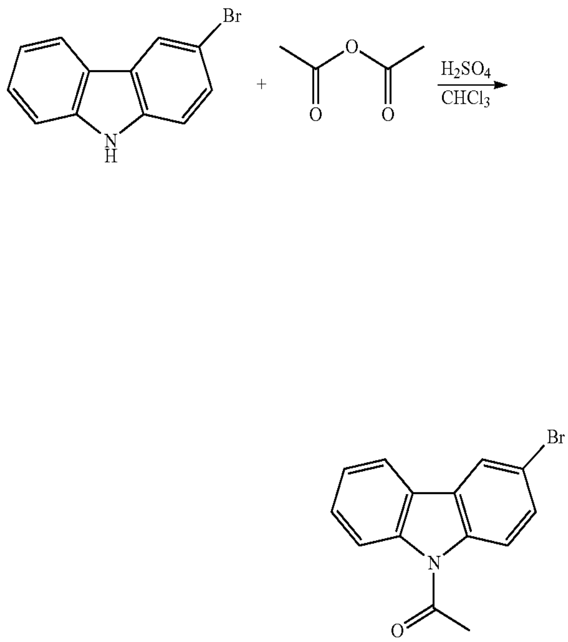


Compound 31

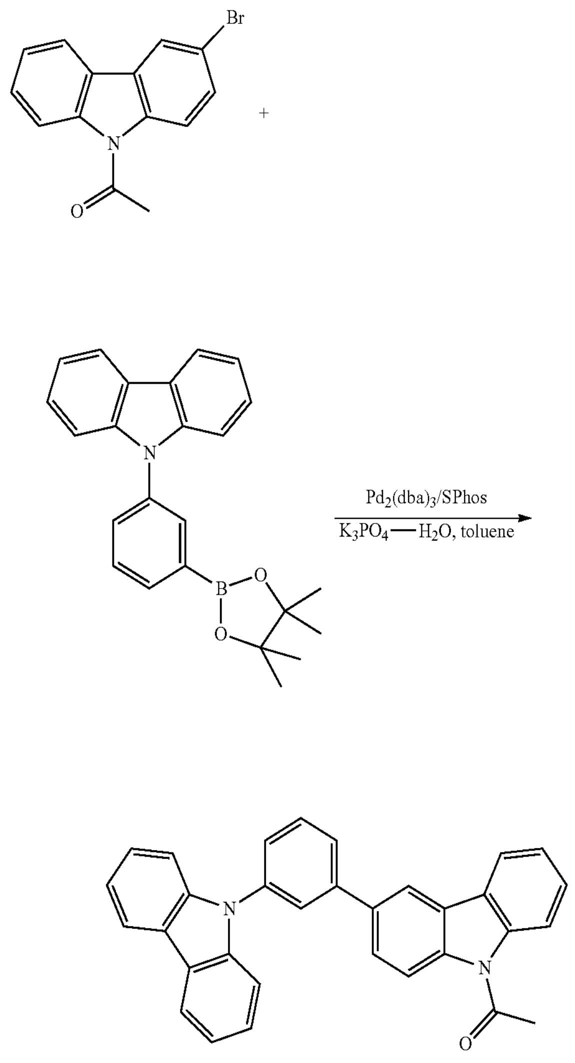
A suspension of (3-bromophenyl)(3-(dibenzo[b,d]thiophen-2-yl)phenyl)diphenylsilane (3.16 g, 5.29 mmol), 9-(3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)-9H-carbazole (1.952 g, 5.29 mmol), $Pd_2(dba)_3$ (0.048 g, 0.053 mmol), SPhos (0.043 g, 0.106 mmol) and K_3PO_4 (2.435 g, 10.57 mmol) in toluene (200 mL) and water (5 mL) was heated at 60° C. under nitrogen overnight. After cooling to room temperature, the organic phase was isolated and evaporated to dryness. The residue was purified by column chromatography on silica gel with hexane:DCM (9:1 to 7:3, v/v) as eluent to yield Compound 31 (3.2 g, 80%) as a white solid.

Example 10

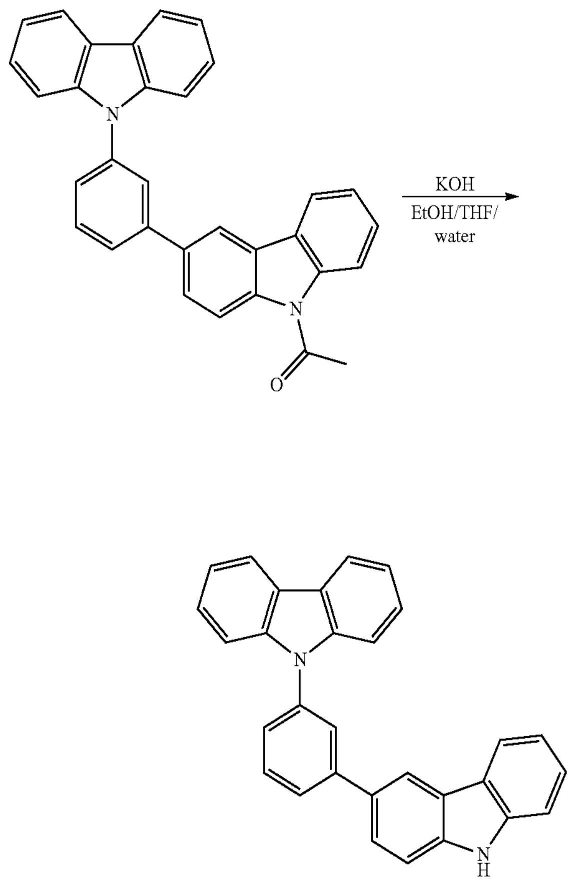
Synthesis of Compound 32



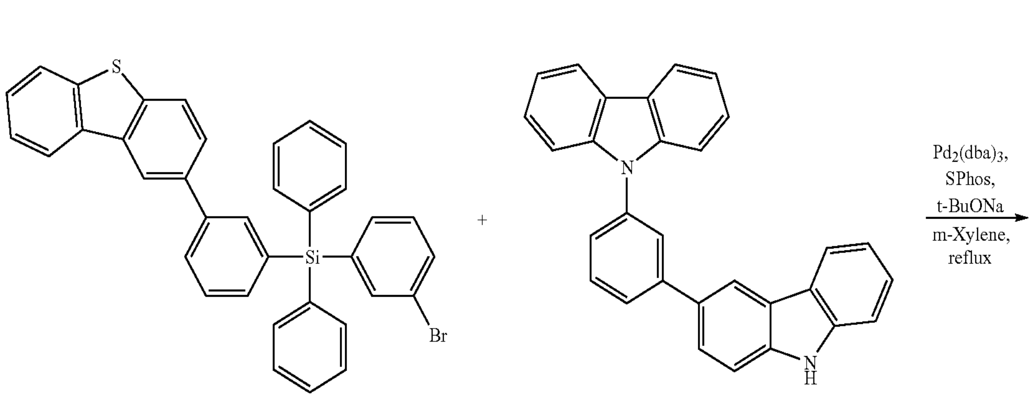
A solution of 3-bromo-9H-carbazole (10.00 g, 40.6 mmol), acetic anhydride (8.30 g, 81 mmol) together with 2 drops of H_2SO_4 in chloroform (150 mL) was refluxed overnight. After cooling to room temperature, the solution was washed with water. Upon evaporation of the solvent, the crude product was purified by crystallization from hexane/DCM and hexane/EtOAc to yield 1-(3-bromo-9H-carbazol-9-yl)ethanone (6.1 g, 51% yield) as a light yellow solid.



A solution of 1-(3-bromo-9H-carbazol-9-yl)ethanone (2.000 g, 6.94 mmol), 9-(3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)-9H-carbazole (2.56 g, 6.94 mmol), $Pd_2(dba)_3$ (0.064 g, 0.069 mmol), SPhos (0.057 g, 0.139 mmol) and potassium phosphate tribasic hydrate (4.80 g, 20.82 mmol) in toluene (100 mL) and water (10 mL) was stirred at 70° C. under nitrogen overnight. After cooling to room temperature, the organic phase was isolated. Upon evaporation of the solvent, the residue was purified by column chromatography on silica gel with hexane:DCM (1:4, v/v) as eluent to yield 1-(3-(3-(9H-carbazol-9-yl)phenyl)-9H-carbazol-9-yl)ethanone (2.9 g, 94%) as a white solid.



A mixture of 1-(3-(3-(9H-carbazol-9-yl)phenyl)-9H-carbazol-9-yl)ethanone (3.50 g, 7.77 mmol) and potassium hydroxide (1.308 g, 23.31 mmol) in EtOH (250 mL), THF (100 mL), and water (25 mL) was refluxed for 3 h. The organic solvent was evaporated, and the aqueous phase was extracted with EtOAc. The extracts were combined and passed through a short plug of silica gel and concentrated. Upon addition of hexane, the product 3-(3-(9H-carbazol-9-yl)phenyl)-9H-carbazole (3.0 g, 95%) precipitated as white shining crystals.



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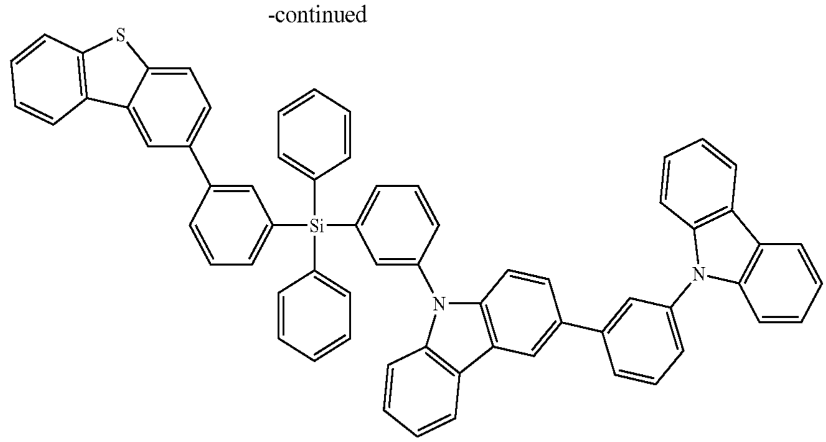
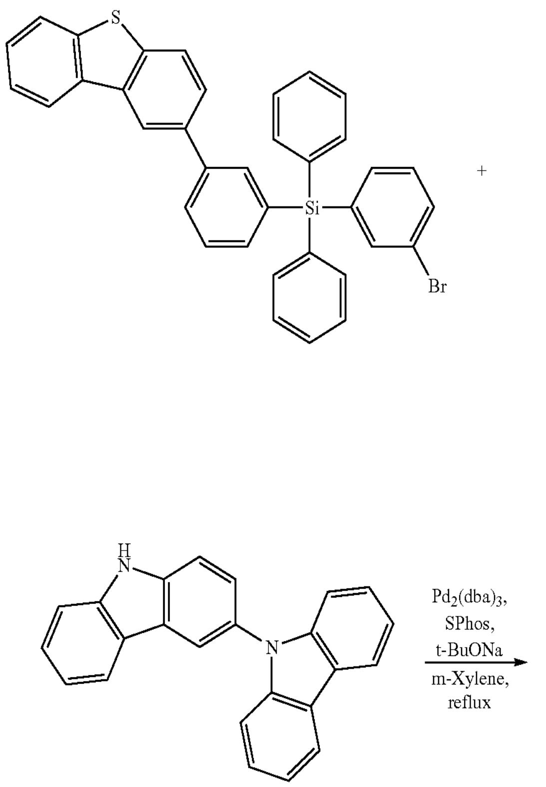


Compound 32

A suspension of 3-(3-(9H-Carbazol-9-yl)phenyl)-9H-carbazole (2.000 g, 4.90 mmol), (3-bromophenyl)(3-(dibenzo[b,d]thiophen-2-yl)phenyl)diphenylsilane (2.93 g, 4.90 mmol), sodium tert-butoxide (0.941 g, 9.79 mmol), $Pd_2(dba)_3$ (0.090 g, 0.098 mmol) and SPhos (0.040 g, 0.098 mmol) in xylene (200 mL) was refluxed under nitrogen for 18 h. After cooling to room temperature, the solvent was evaporated and the crude product was purified by column chromatography on silica gel with hexane:DCM (3/1, v/v) as eluent to yield Compound 32 (3.0 g, 66%) as a white solid.

Example 11

Synthesis of Compound 33



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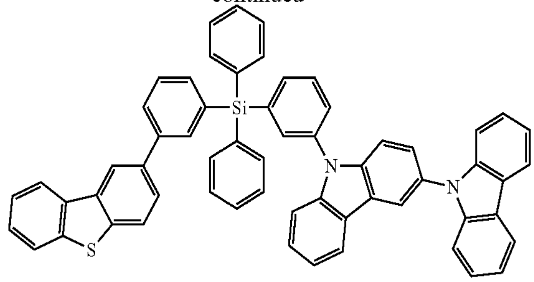
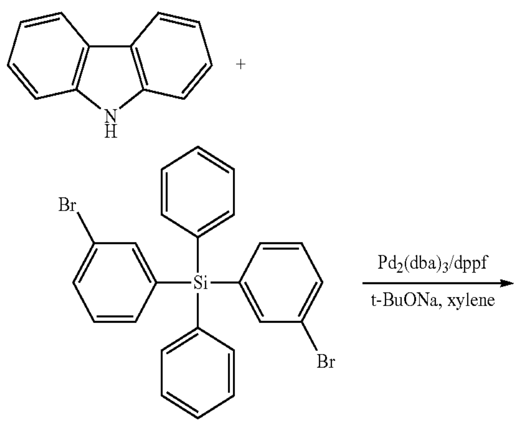


Compound 33

A suspension of (3-bromophenyl)(3-(dibenzo[b,d]thiophen-2-yl)phenyl)diphenylsilane (3 g, 5.02 mmol), 9H-3,9'-bicarbazole (1.835 g, 5.52 mmol), $Pd_2(dba)_3$ (0.092 g, 0.100 mmol), SPhos (0.082 g, 0.201 mmol), and sodium tert-butoxide (0.965 g, 10.04 mmol) in m-xylene (50 mL) was refluxed at 140° C. under nitrogen. After cooling to room temperature the reaction was quenched with water, extracted with toluene, and dried over $MgSO_4$. Upon evaporation of the solvent, the crudue product was purified by column chromatography with hexane:DCM (8:2, v/v) as eluent to yield Compound 33 as a white powder (3.4 g, 80%).

Example 12

Synthesis of Compound 34



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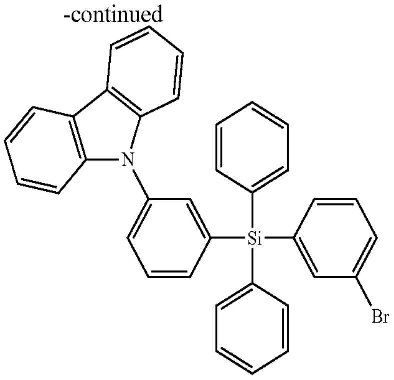
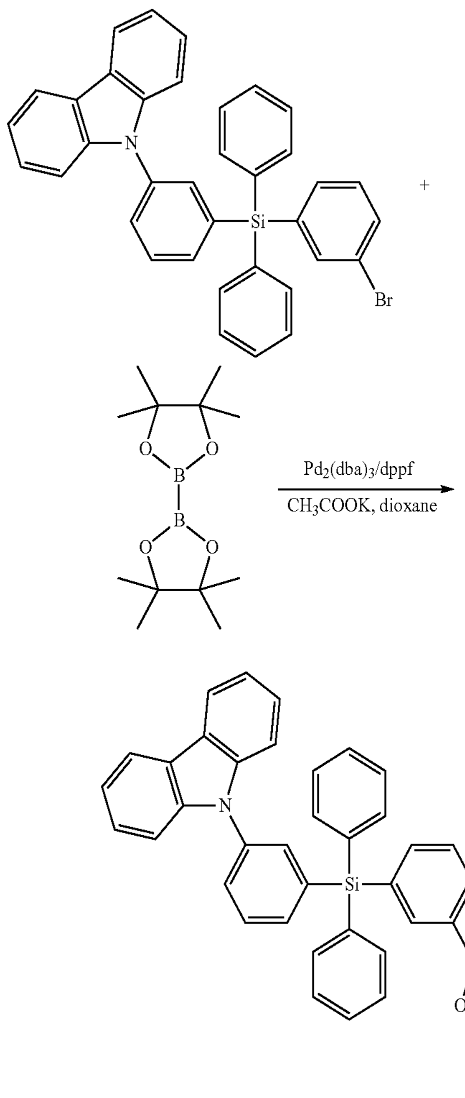
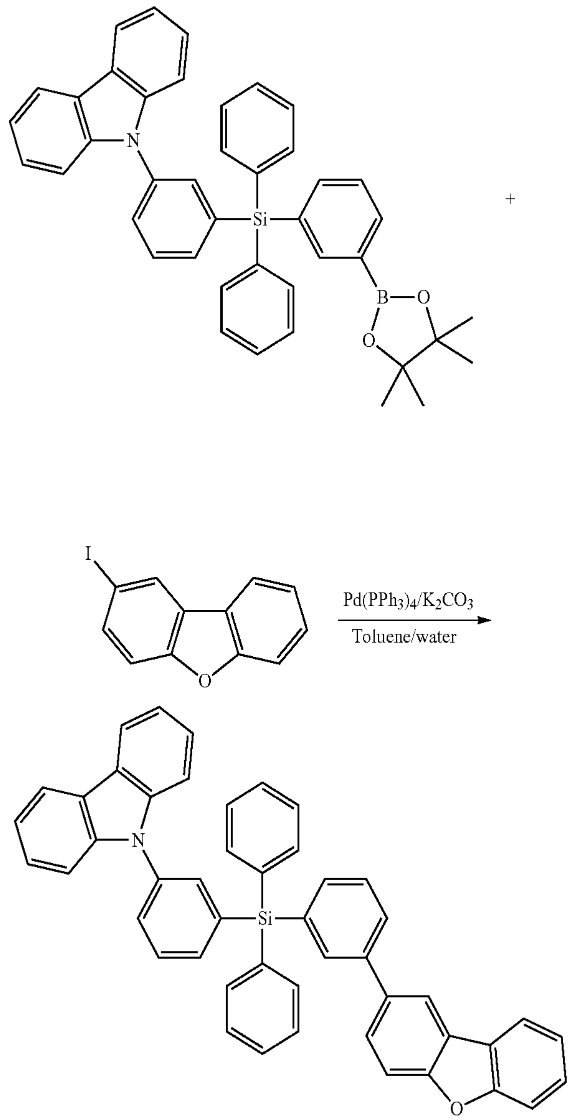


A suspension of 9H-carbazole (3.60 g, 21.53 mmol), bis(3-bromophenyl)diphenylsilane (21.28 g, 43.1 mmol), $Pd_2(dba)_3$ (0.394 g, 0.431 mmol), 1,1'-Bis(diphenylphosphino)ferrocene (dppf, 0.394 g, 0.431 mmol) and sodium tert-butoxide (4.14 g, 43.1 mmol) in xylene (150 mL) was refluxed under nitrogen overnight. After cooling to room temperature, the organic solution was isolated by filtration. Upon evaporation of the solvent, the crude product was purified by column chromatography on silica gel with hexane: EtOAc (9:1, v/v) as eluent to yield 9-(3-((3-bromophenyl)diphenylsilyl)phenyl)-9H-carbazole (6.1 g, 49%) as white solid



A solution of 9-(3-((3-bromophenyl)diphenylsilyl)phenyl)-9H-carbazole (6.00 g, 10.33 mmol), 4,4,4',4',5,5,5',5'-octamethyl-2,2'-bi(1,3,2-dioxaborolane) (3.15 g, 12.40 mmol), potassium acetate (1.014 g, 10.33 mmol), $Pd_2(dba)_3$ (9.46 g, 10.33 mmol) and dppf (6.31 g, 10.33 mmol) in dioxane (200 mL) was refluxed under nitrogen overnight. After cooling to room temperature, the black reaction mixture was diluted with water, extracted with EtOAc and dried over Na_2SO_4. Upon evaporation of the solvent, the crude product was purified by column chromatography on silica gel with hexane:EtOAc (9:1, v/v) as eluent to yield 9-(3-(diphenyl(3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)silyl)phenyl)-9H-carbazole (3.26 g, 50%) as a white solid.

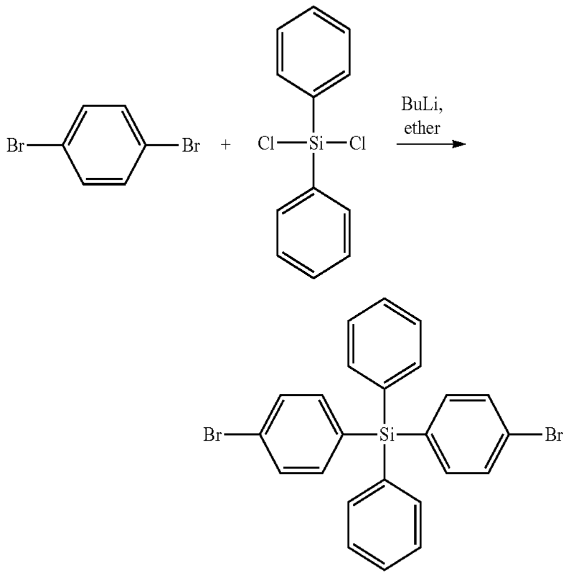


Compound 34

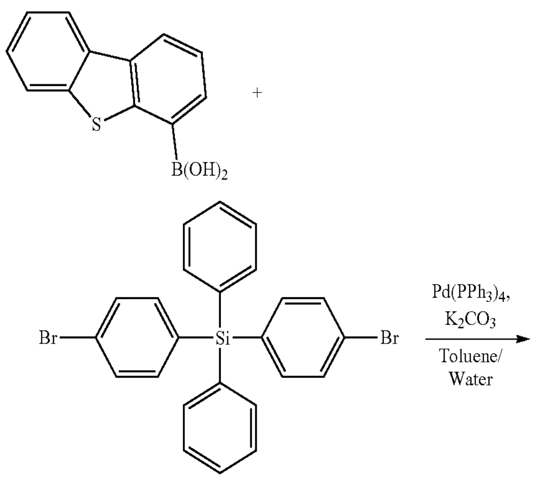
A solution of 9-(3-(diphenyl(3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)silyl)phenyl)-9H-carbazole (3.25 g, 5.18 mmol), 2-iododibenzo[b,d]furan (1.523 g, 5.18 mmol), K_2CO_3 (1.431 g, 10.36 mmol) and $Pd(PPh_3)_4$ (0.096 g, 0.083 mmol) in toluene (100 mL) and water (5 mL) was refluxed under nitrogen overnight. After cooling to room temperature, the organic phase was isolated. Upon evaporation of the solvent, the residue was purified by column chromatography on silica with hexane:DCM (7:3, v/v) as eluent to yield Compound 34 (2.55 g, 74%) as a white solid.

Example 13

Synthesis of Compound 35



Into a solution of 1,4-dibromobenzene (34 g, 144 mmol) in diethyl ether (600 mL) was added 2.5M butyllithium solution in hexane (60.3 mL, 151 mmol) dropwise at −78° C. The solution was stirred at −78° C. for 3.5 hours before dichlorodiphenylsilane (13.49 mL, 65.5 mmol) dissolved in 20 ml of diethyl ether was added dropwise. The reaction mixture was allowed to warm up to room temperature overnight and was quenched with water. The organic phase was isolated, filtered to remove solids, and dried over Na_2SO_4. After evaporation of the solvent, the residue was purified by column chromatography on silica gel with hexane:toluene as eluent and precipitation from toluene to methanol to yield bis(4-bromophenyl)diphenylsilane (12 g, 37%) as a white powder.



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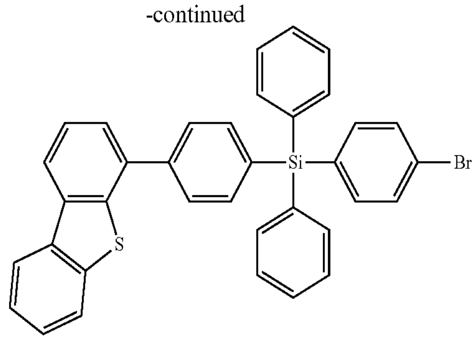
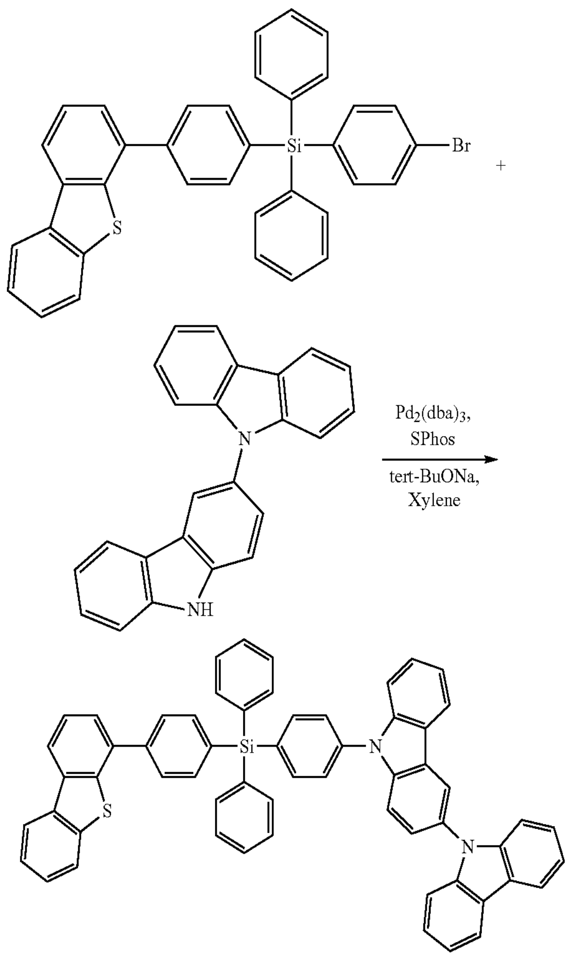


A mixture solution of dibenzo[b,d]thiophen-4-ylboronic acid (2.5 g, 10.96 mmol), bis(4-bromophenyl)diphenylsilane (11.92 g, 24.11 mmol), $Pd(PPh_3)_4$ (0.253 g, 0.219 mmol), and K_2CO_3 (9.09 g, 65.8 mmol) in toluene (90 mL) and water (30 mL) was stirred at 90° C. under nitrogen overnight. After cooling to room temperature, the organic phase was isolated, and the aqueous phase was extracted with toluene. The combined organic solution was dried over Na_2SO_4. Upon evaporation of the solvent, the residue was purified by column chromatography on silica gel with hexane:DCM(9/1, v/v) as eluent to yield (4-bromophenyl)(4-(dibenzo[b,d]thiophen-4-yl)phenyl)diphenylsilane (5.2 g, 79%) as a white powder.

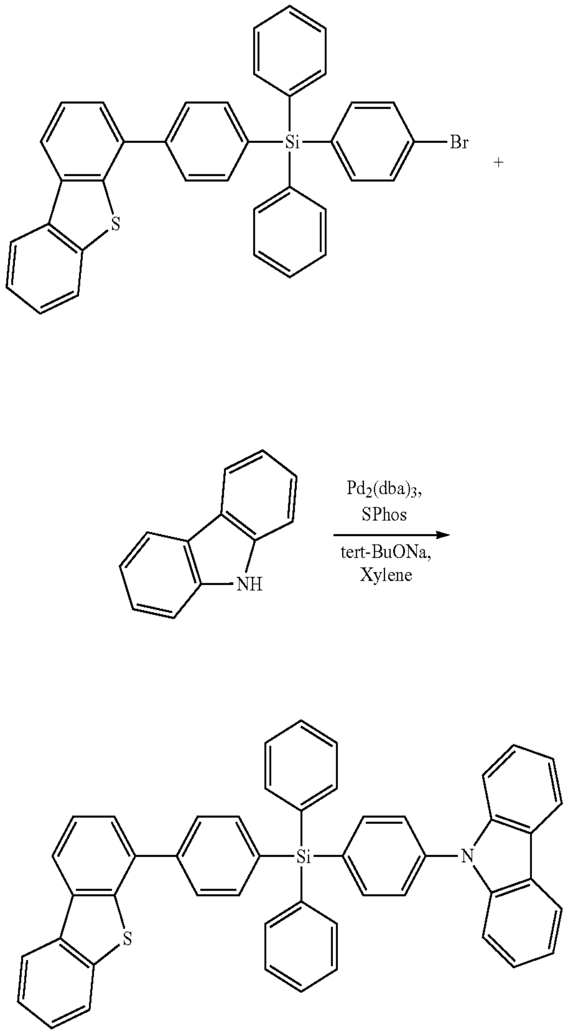


Compound 35

A suspension of (4-bromophenyl)(4-(dibenzo[b,d]thiophen-4-yl)phenyl)diphenylsilane (2.83 g, 4.74 mmol), 9H-3,9'-bicarbazole (1.731 g, 5.21 mmol), $Pd_2(dba)_3$ (0.087 g, 0.095 mmol), SPhos (0.078 g, 0.189 mmol), and sodium tert-butoxide (0.910 g, 9.47 mmol) in xylene (50 mL) was refluxed at 140° C. overnight. After cooling to room temperature, it was passed through a short plug of Celite, washed with toluene and DCM. The combined solution was evaporated, and the residue was purified by column chromatography on silica gel with hexane:DCM(7.5:2.5, v/v) as eluent to yield Compound 35 (3.76 g, 94%) as a white powder.

Example 14

Synthesis of Compound 36

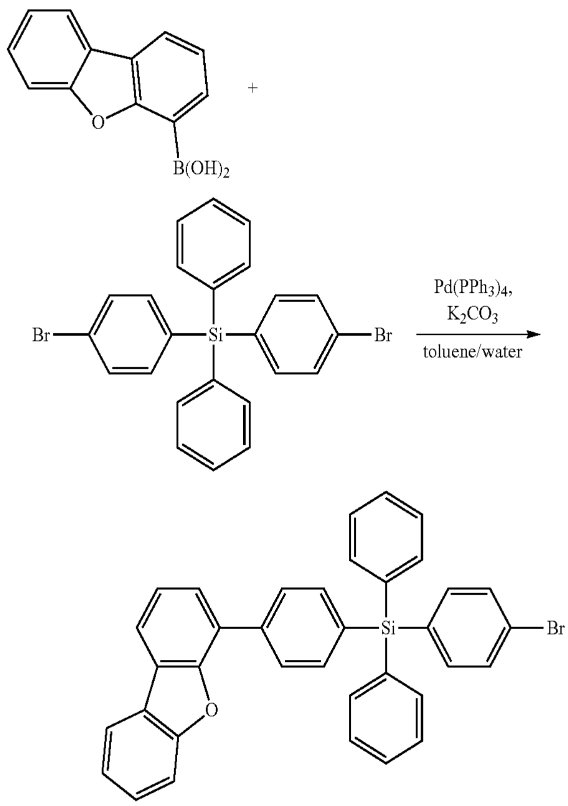


Compound 36

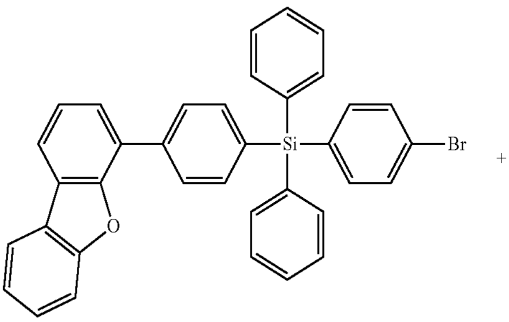
A suspension of (4-bromophenyl)(4-(dibenzo[b,d]thiophen-4-yl)phenyl)diphenylsilane (2.83 g, 4.74 mmol), 9H-carbazole (0.808 g, 4.83 mmol), $Pd_2(dba)_3$ (0.087 g, 0.095 mmol), SPhos (0.078 g, 0.189 mmol), and sodium tert-butoxide (0.910 g, 9.47 mmol) in m-xylene (50 mL) was heated at 140° C. for 5 h. After cooling to room temperature, the solution was washed with aqueous ammonium chloride and water, dried over Na_2SO_4, and passed through a short plug of Celite. Upon evaporation of the solvent, the residue was purified by column chromatography on silica gel with hexane:DCM (8:2, v/v) as eluent to yield Compound 36 (1.50 g, 46.3%) as a white powder.

Example 15

Synthesis of Compound 37



A solution of dibenzo[b,d]furan-4-ylboronic acid (2.60 g, 12.26 mmol), with bis(4-bromophenyl)diphenylsilane (12.12 g, 24.53 mmol), $Pd(PPh_3)_4$ (0.283 g, 0.245 mmol) and K_2CO_3 (5.08 g, 36.8 mmol) in toluene (200 mL) and water (50 mL) was refluxed under nitrogen overnight. After cooling to room temperature, the organic phase was isolated. Upon evaporation of the solvent, the residue was purified by column chromatography on silica gel with hexane:DCM (9:1, v/v) as eluent to yield (4-bromophenyl)(4-(dibenzo[b,c]furan-4-yl)phenyl)diphenylsilane (3.14 g, 44%) as a white solid.



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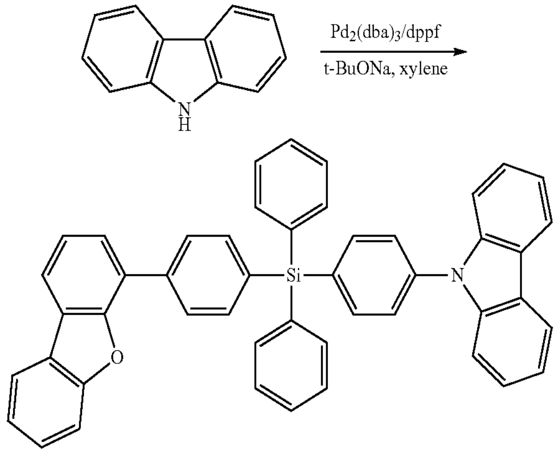
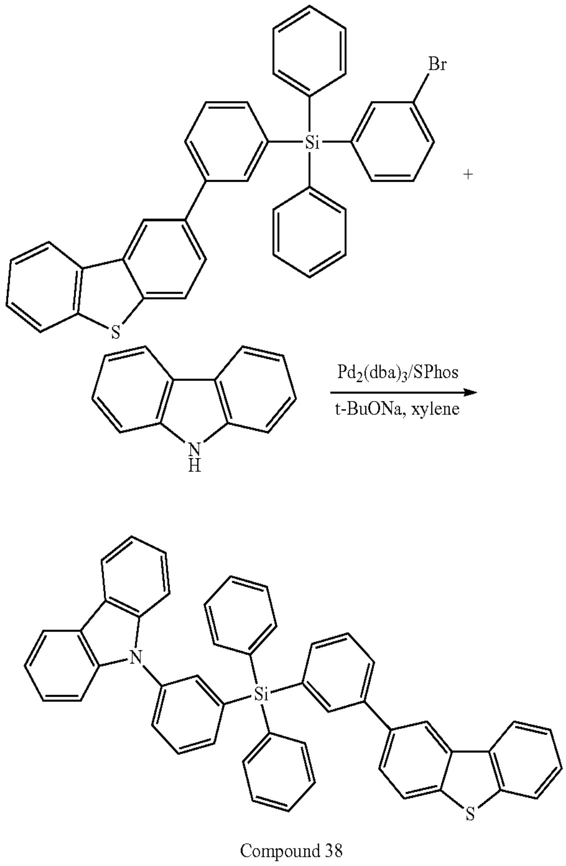


Compound 37

A suspension of (4-bromophenyl)(4-(dibenzo[b,d]furan-4-yl)phenyl)diphenylsilane (3.15 g, 5.42 mmol), 9H-carbazole (0.996 g, 5.96 mmol), sodium tert-butoxide (1.041 g, 10.83 mmol) $Pd_2(dba)_3$ (0.099 g, 0.108 mmol) and dppf (0.066 g, 0.108 mmol) in xylene (150 mL) was refluxed under nitrogen for 24 h. After cooling to room temperature, the reaction mixture was filtered. Upon evaporation of the solvent, the residue was purified by column chromatography on silica with hexane:EtOAc (4:1, v/v) as eluent to yield Compound 37 (3.4 g, 94%) as a white solid.

Example 16

Synthesis of Compound 38



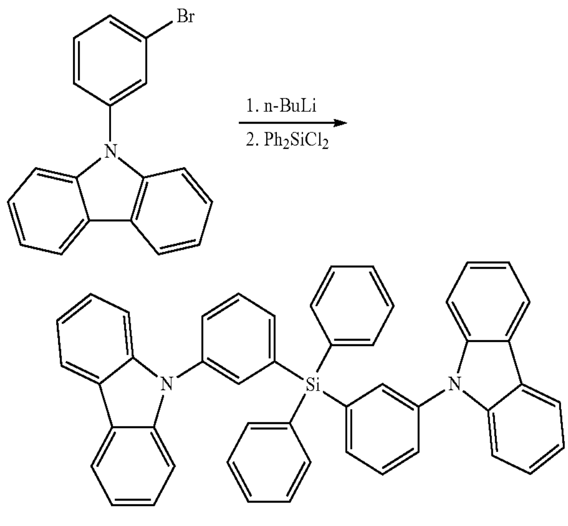
Compound 38

A suspension of (3-bromophenyl)(3-(dibenzo[b,d]thiophen-2-yl)phenyl)diphenylsilane (3.81 g, 6.38 mmol), 9H-carbazole (1.173 g, 7.01 mmol), $Pd_2(dba)_3$ (0.117 g, 0.128 mmol), SPhos (0.105 g, 0.255 mmol), and sodium tert-butoxide (1.225 g, 12.75 mmol in xylene (200 mL) was refluxed under nitrogen overnight. After cooling to room temperature, the organic solution was isolated by filtration. Upon evaporation of the solvent, the residue was purified by column chromatography on silica gel with hexane:DCM (4:1 to 1:1, v/v) as eluent to yield Compound 38 (2.2 g, 50%) as a white solid.

Comparative Examples

Comparative Examples 1

Synthesis of Comparative Compound CC-1

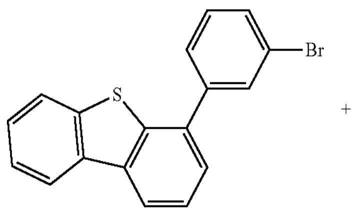


CC-1

Into a solution of 9-(3-bromophenyl)-9H-carbazole (5 g, 15.52 mmol) in THF (50 mL) was added n-butyllithium (9.7 mL, 15.5 mmol, 1.6 M in hexane) dropwise at −78° C., and the mixture was stirred for 2 h at −78° C. In a separate flask, dichlorodiphenylsilane (1.5 mL, 7.1 mmol) was dissolved in 10 mL of THF and added dropwise to reaction mixture, which was then allowed to warm to room temperature overnight. Ethyl acetate (50 mL) and water (50 mL) were added and the layers separated. The aqueous layer was washed twice more with EtOAc and combined organics were washed with water and brine. Upon evaporation of the solvent, the residue was purified by column chromatography on silica gel with hexane:DCM (7/3, v/v) as eluent, recrystallization from hexane, and sublimation twice under vacuum ($<10^{-5}$ Torr) to yield CC-1 (1.7 g) as white crystals.

Comparative Examples 2

Synthesis of Comparative Compound CC-2



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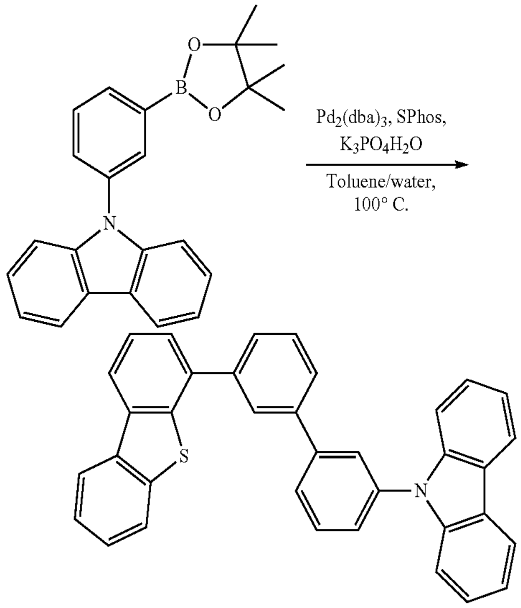


CC-2

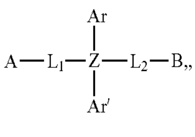
A solution of 4-(3-bromophenyl)dibenzo[b,d]thiophene (7.15 g, 21.08 mmol), 9-(3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)-9H-carbazole (7.78 g, 21.08 mmol), SPhos (0.173 g, 0.422 mmol), $Pd_2(dba)_3$ (0.192 g, 0.211 mmol) and potassium phosphate monohydrate (9.71 g, 42.2 mmol) in toluene (200 mL) and water (10 mL) was refluxed under nitrogen overnight. After cooling to room temperature, the organic phase was isolated and evaporated to dryness. The residue was purified by column chromatography on silica gel with hexane:DCM (9:1 to 1:1, v/v) as eluent, recrystallization from heptane, and sublimation under vacuum to yield CC-2 (6.4g, 61%) as white crystals.

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

The invention claimed is:

1. A compound of Formula I comprising:

Formula I



wherein Ar and Ar' are independently selected from the group consisting of phenyl, biphenyl, napthyl, dibenzothiolyl, and dibenzofuranyl, which are optionally further substituted;

wherein Z is selected from Si and Ge;

wherein L_1 comprises aryl or heteroaryl groups, wherein any heteroatoms in the heteroaryl groups are nitrogen;

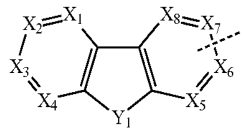
wherein L_2 comprises aryl or heteroaryl groups, wherein any heteroatoms in the heteroaryl groups are nitrogen;

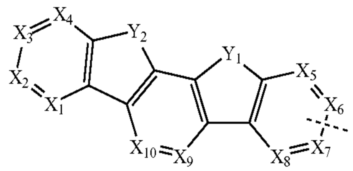
wherein L_1 and L_2 are optionally further substituted;

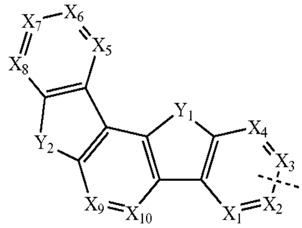
wherein A contains a group selected from the group consisting of dibenzofuran, dibenzothiophene, azadibenzofuran, azadibenzothiophene, dibenzoselenophene and azadibenzoselenophene, which are optionally further substituted, and wherein the substitution is optionally fused to at least one benzo ring; and

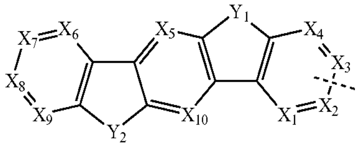
wherein B contains a group selected from the group consisting of carbazole and azacarbazole, which are optionally further substituted, and wherein the substitution is optionally fused to the carbazole or azacarbazole group.

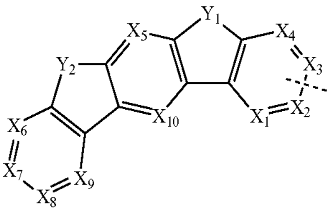
2. The compound of claim **1**, wherein A is selected from the group consisting of:

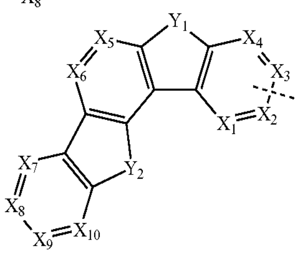


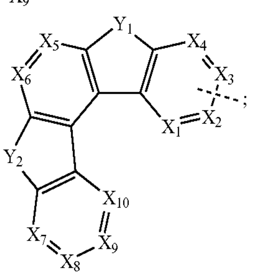




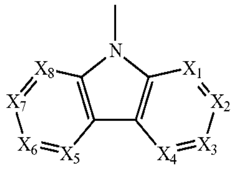


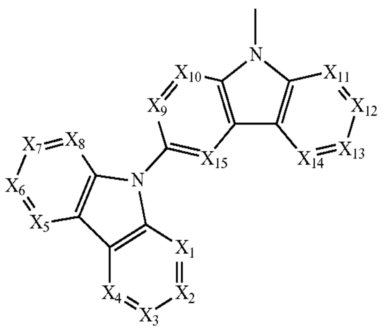


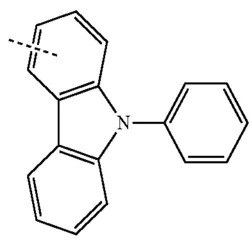


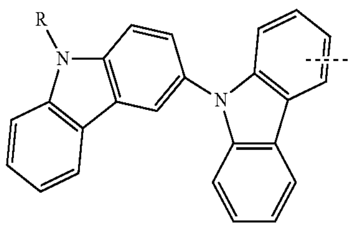


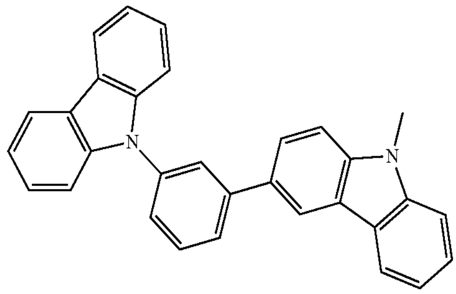
wherein B is selected from the group consisting of:

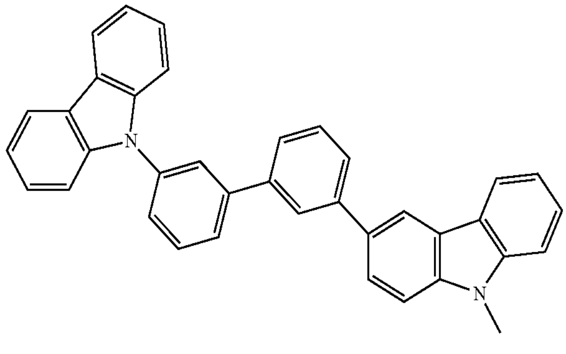












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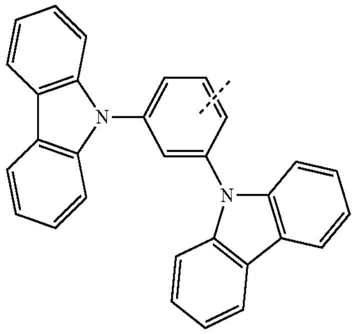

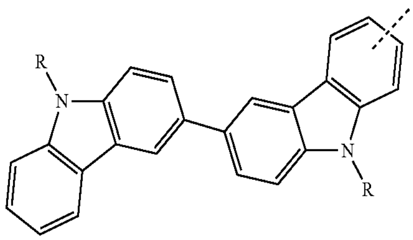

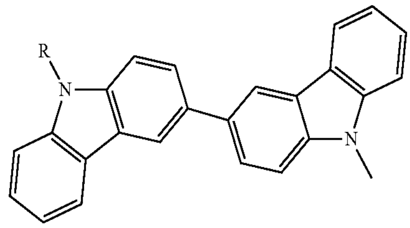

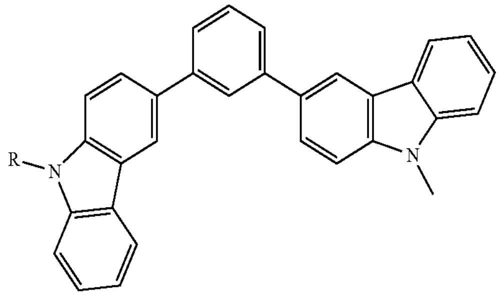

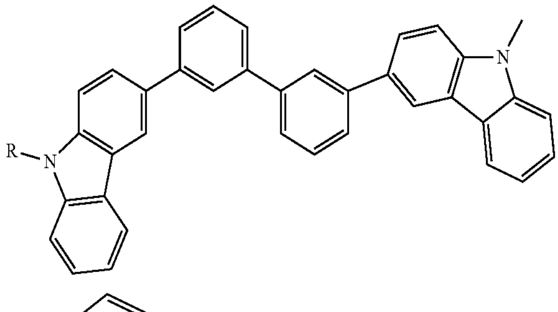

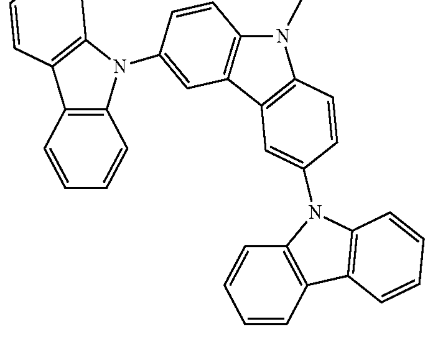

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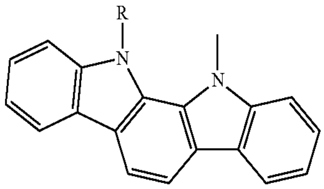

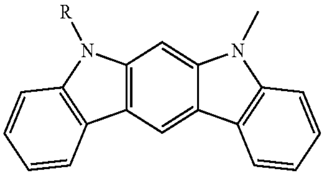

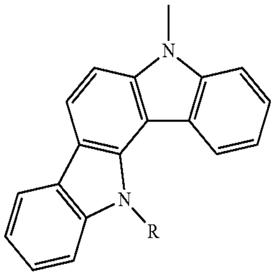

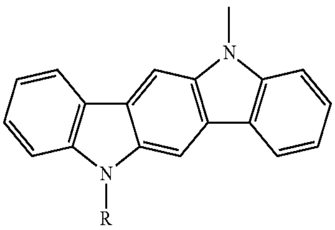

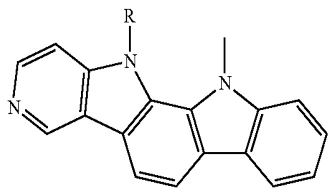

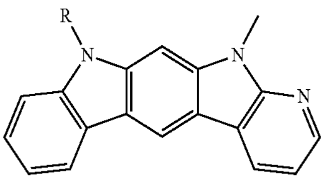

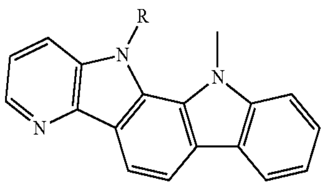

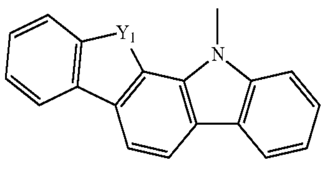

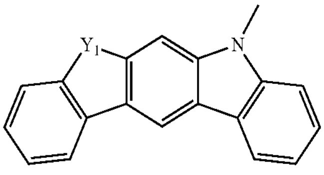

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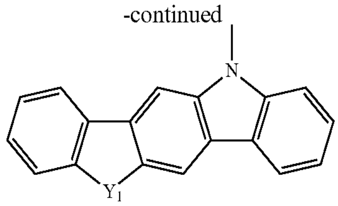
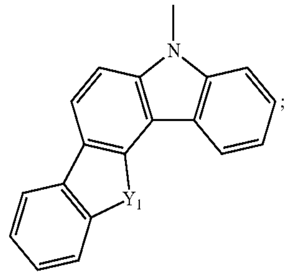


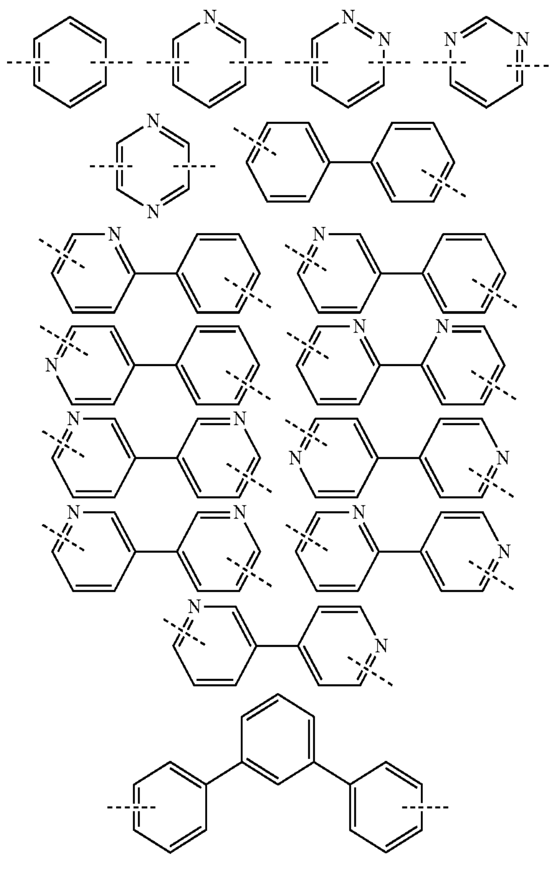


wherein Y_1 and Y_2 are independently selected from the group consisting of O, S, and Se;

wherein X_1 to X_{10} are independently selected from the group consisting of CR and N, and wherein each benzo ring contains at most one N;

wherein R is selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

3. The compound of claim **1**, wherein L_1 and L_2 are independently selected from the group consisting of:



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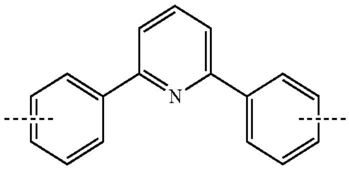

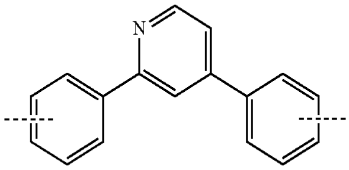

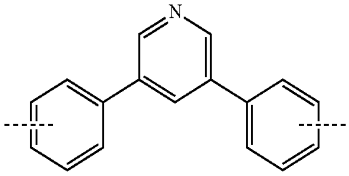

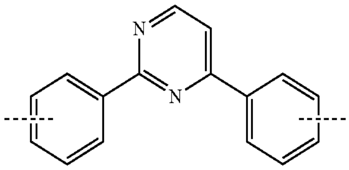

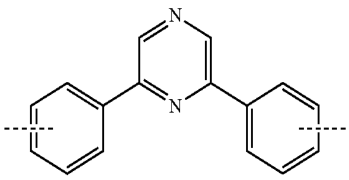

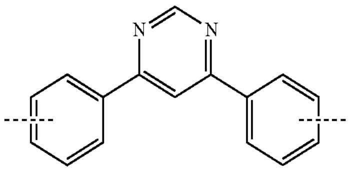

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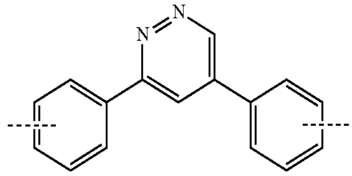


4. The compound of claim **1**, wherein L_1 and L_2 contain at least one phenyl bonded directly to Z.

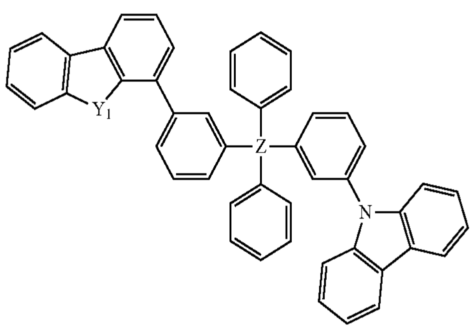
5. The compound of claim **1**, wherein Ar and Ar' are phenyl.

6. The compound of claim **1**, wherein Ar, Ar', A and B are independently substituted with at least one group selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

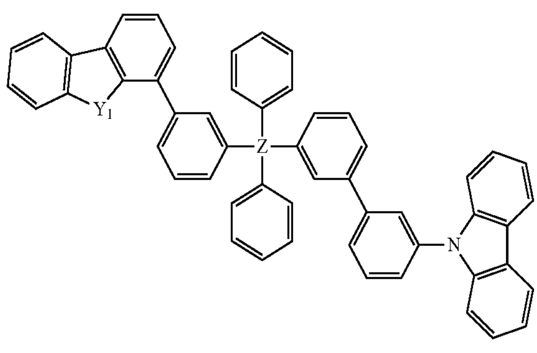
7. The compound of claim **6**, wherein aryl comprises phenyl, biphenyl, triphenyl, terphenyl, naphthalene, phenalene, phenanthrene, fluorene or chiysene; and wherein heteroaryl comprises dibenzothiophene, dibenzofuran, benzofuran, benzothiophene, pyrazole, imidazole, triazole, oxazole, thiazole, oxadiazole, oxatriazole, dioxazole, thiadiazole, pyridine, pyridazine, pyrimidine, pyrazine, triazine, indole, azaindole, benzimidazole, indazole, benzoxazole, benzisoxazole, benzothiazole, quinoline, isoquinoline, cinnoline, quinazoline, quinoxaline, naphthyridine, phthalazine, pteridine, xanthene, phenothiazine, phenoxazine, benzofuropyridine, furodipyridine, benzothienopyridine and thienodipyridine.

8. The compound of claim **1**, wherein the compound is selected from the group consisting of

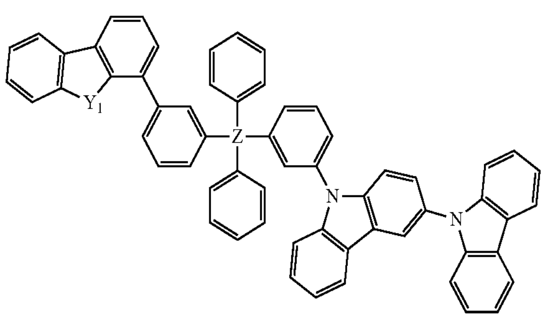
Compound 1



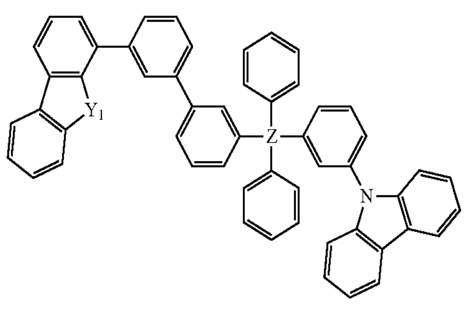
Compound 2



Compound 3



Compound 4



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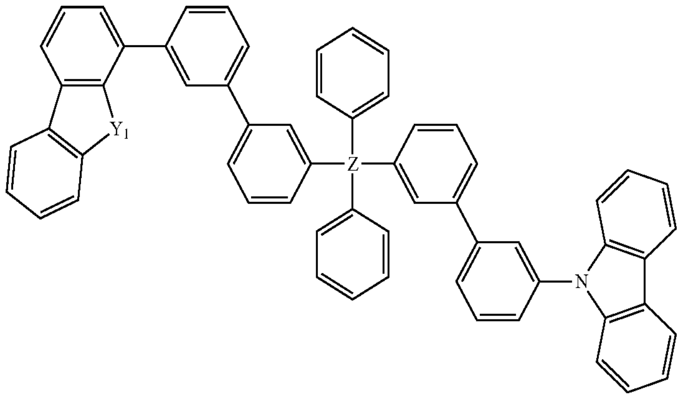
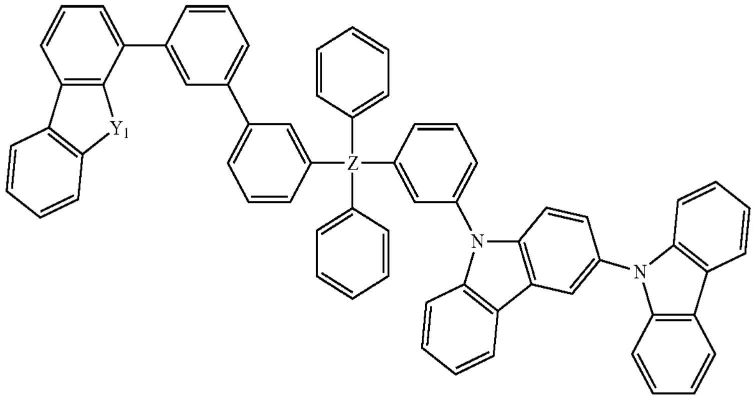
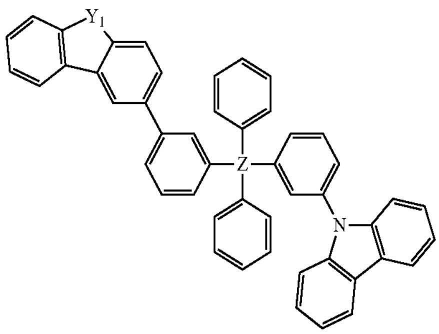
Compound 5



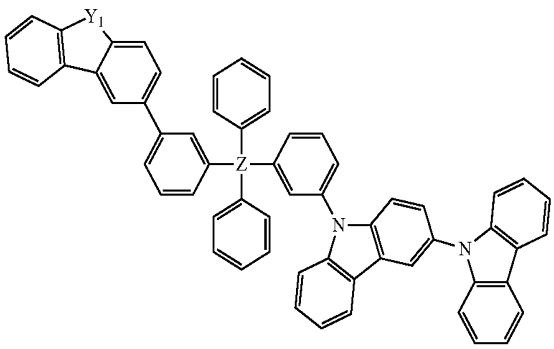
Compound 6



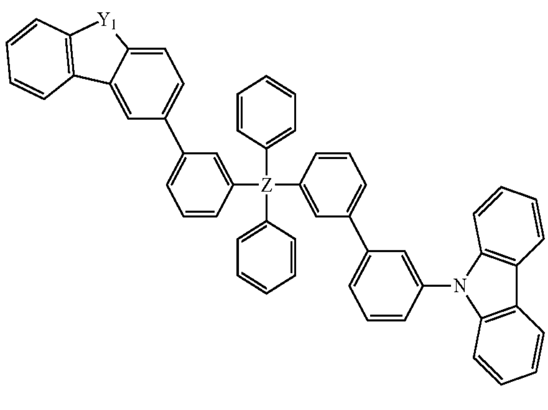
Compound 7



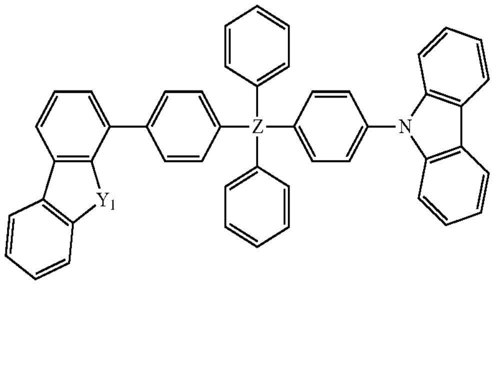
Compound 8



Compound 9



Compound 10



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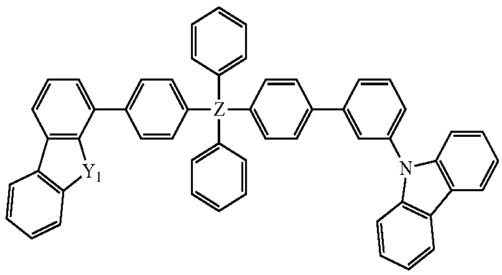
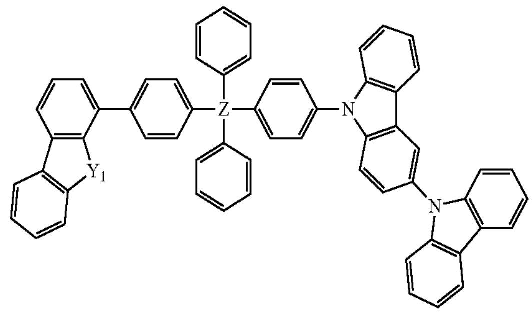
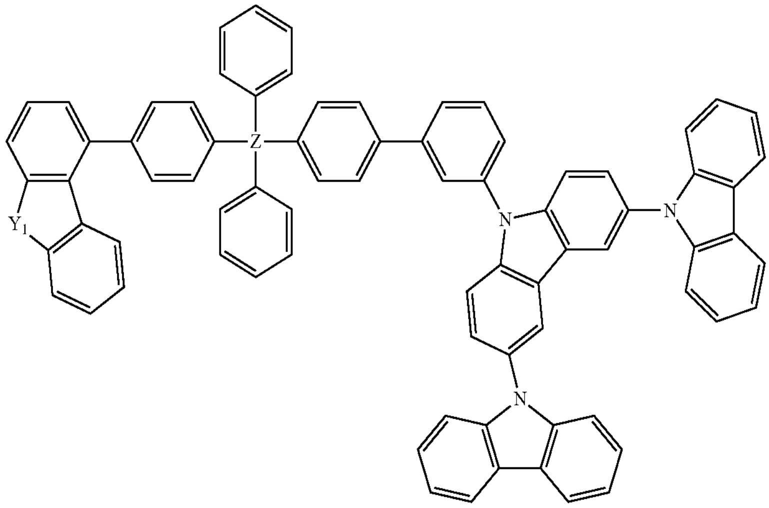
Compound 11



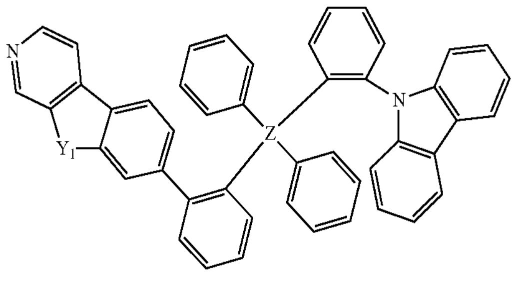
Compound 12



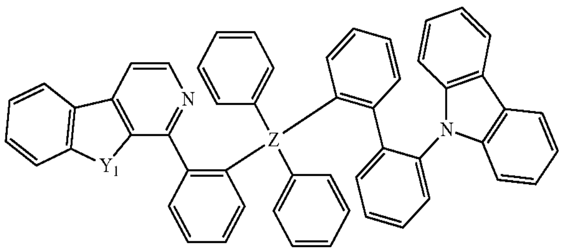
Compound 13



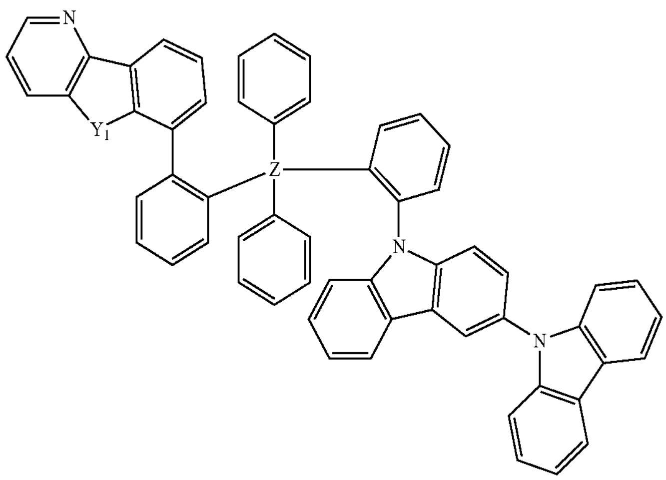
Compound 14



Compound 15



Compound 16



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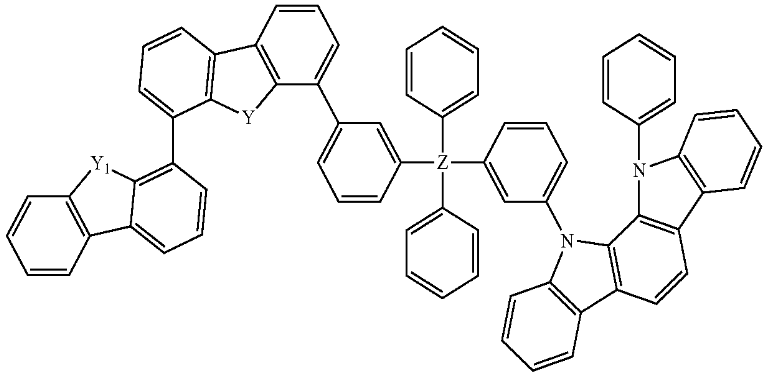
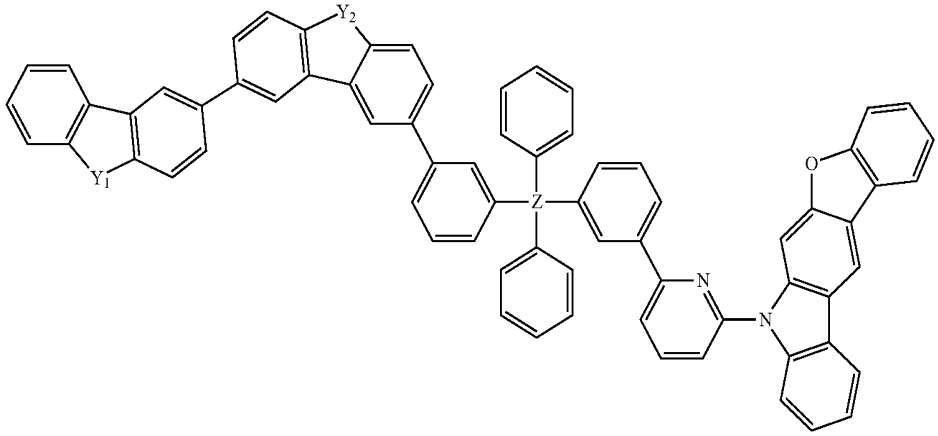
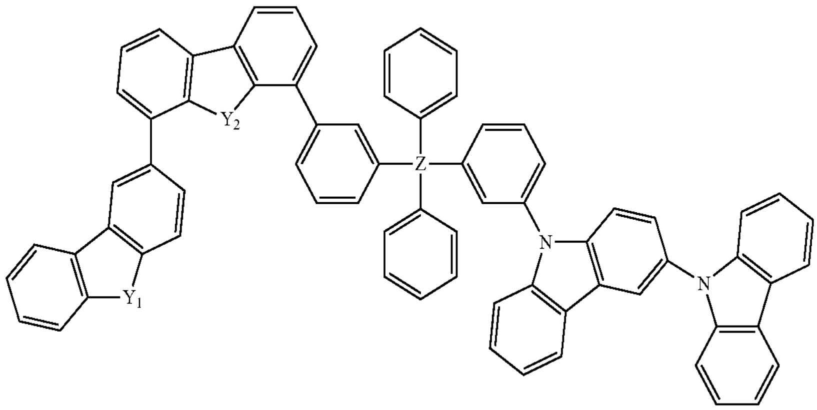
Compound 17



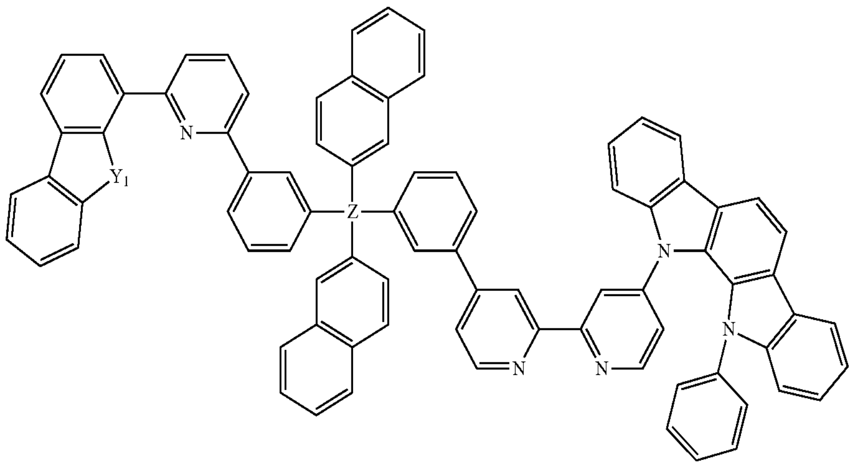
Compound 18



Compound 19



Compound 20



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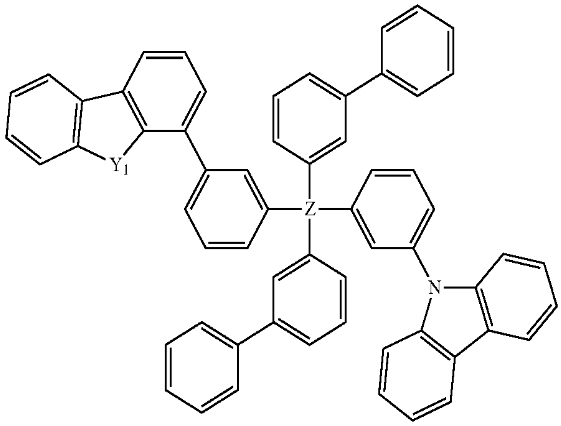
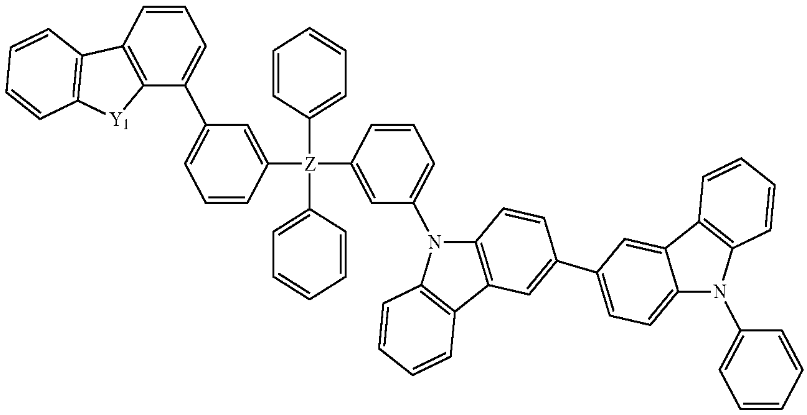
Compound 21



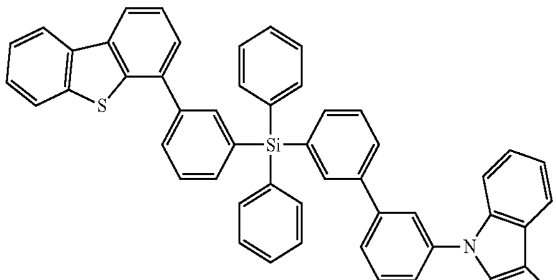
Compound 22



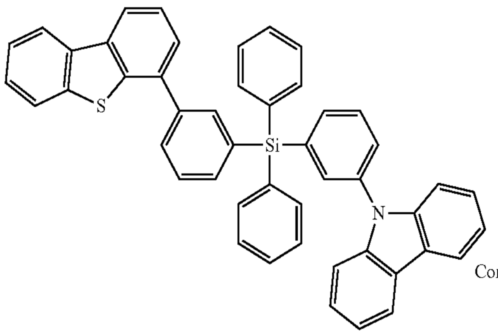
wherein Y_1 and Y_2 are independently selected from the group consisting of O, S and Se; and wherein Z is selected from the group consisting of Si and Ge.

9. The compound of claim **1**, wherein the compound is selected from the group consisting of

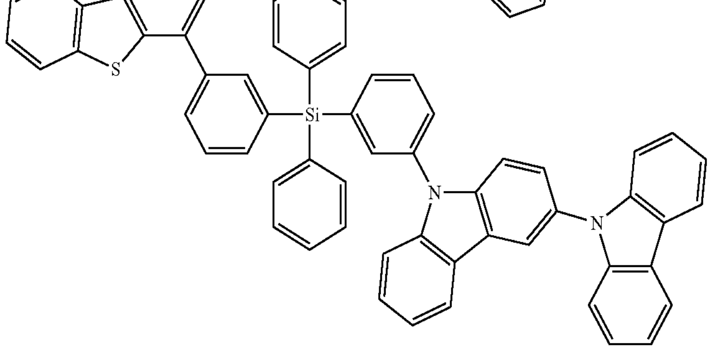
Compound 23



Compound 24



Compound 25



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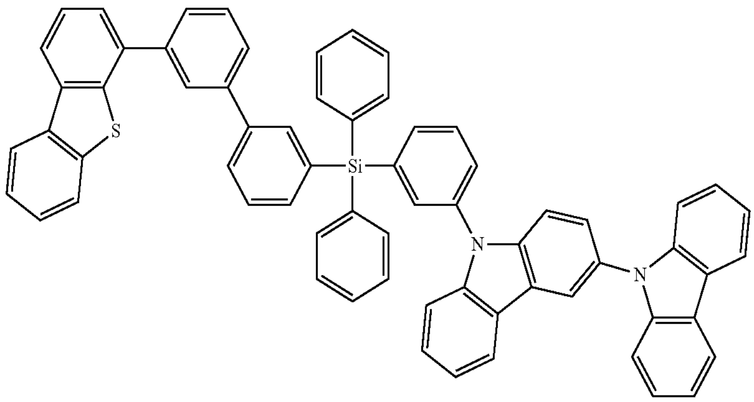
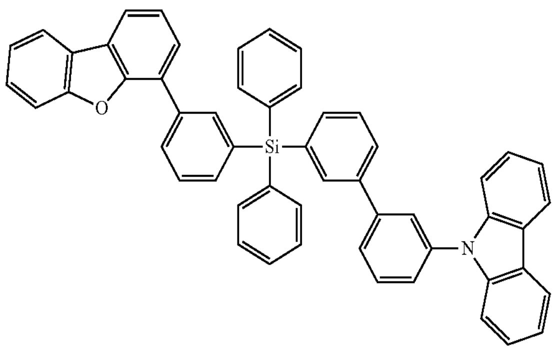
Compound 26



Compound 27



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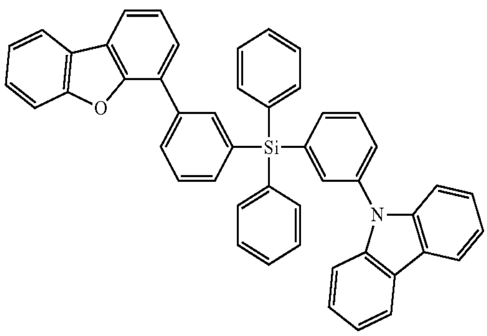
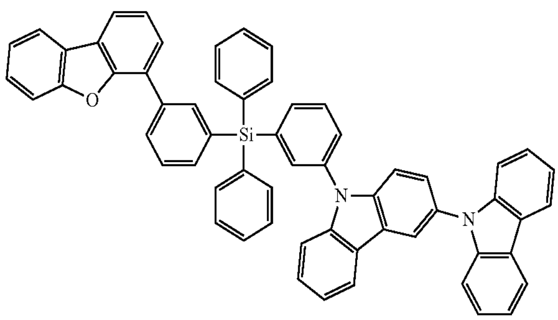
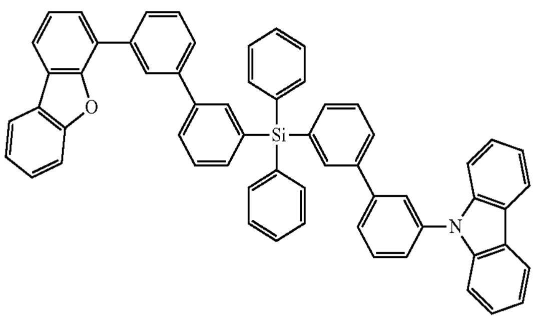


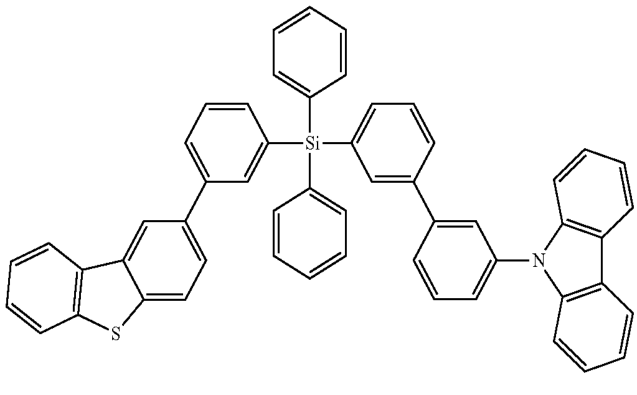
Compound 29



Compound 30



Compound 31



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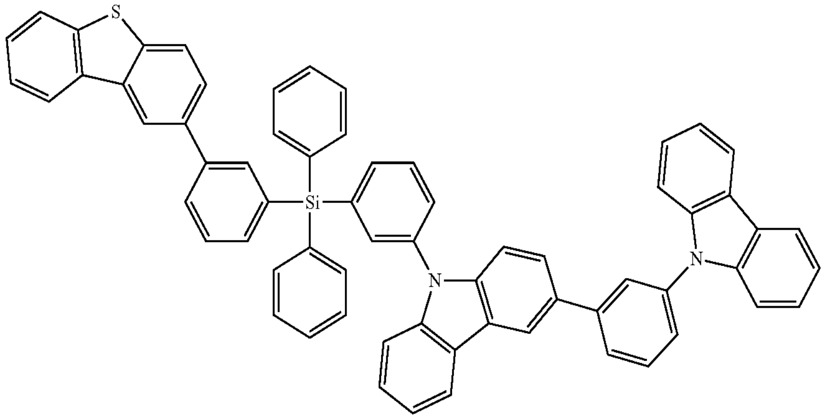
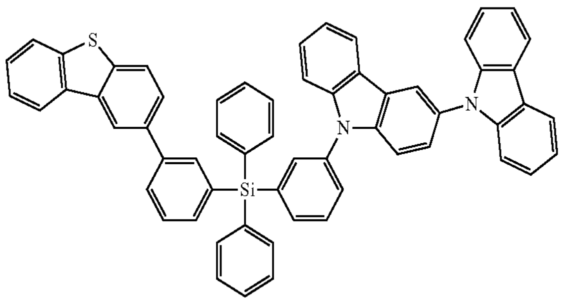
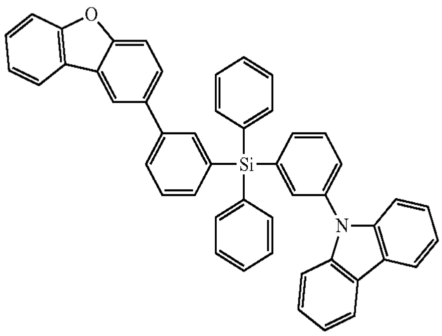
Compound 32



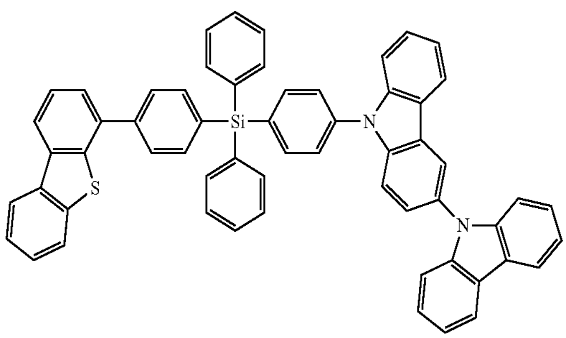
Compound 33



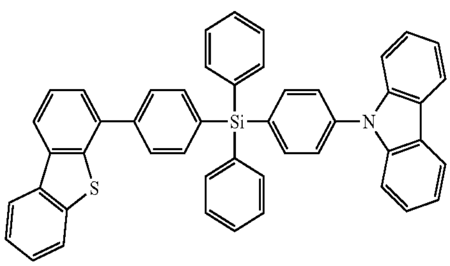
Compound 34



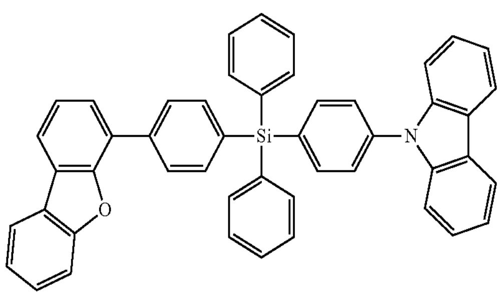
Compound 35



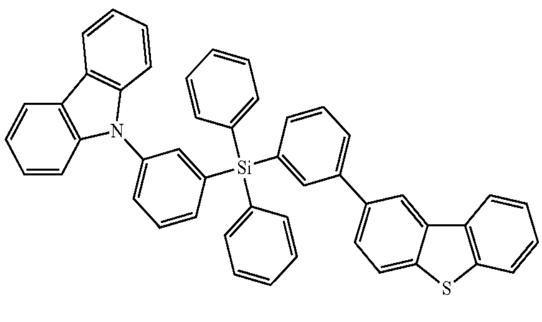
Compound 36



Compound 37



Compound 38



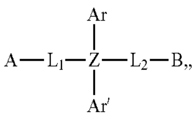
10. A first device comprising an organic light emitting device, further comprising:

an anode;

a cathode; and

an organic layer, disposed between the anode and the cathode, comprising a compound having the Formula I:

Formula I



wherein Ar and Ar' are independently selected from the group consisting of phenyl, biphenyl, napthyl, dibenzothiolyl, and dibenzofuranyl, which are optionally further substituted;

wherein Z is selected from Si and Ge;

wherein L_1 comprises aryl or heteroaryl groups, wherein any heteroatoms in the heteroaryl groups are nitrogen;

wherein L_2 comprises aryl or heteroaryl groups, wherein any heteroatoms in the heteroaryl groups are nitrogen;

wherein L_1 and L_2 are optionally further substituted;

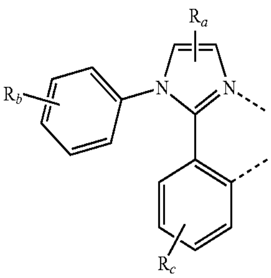
wherein A contains a group selected from the group consisting of dibenzofuran, dibenzothiophene, azadibenzofuran, azadibenzothiophene, dibenzoselenophene and azadibenzoselenophene, which are optionally further substituted, and wherein the substitution is optionally fused to at least one benzo ring; and

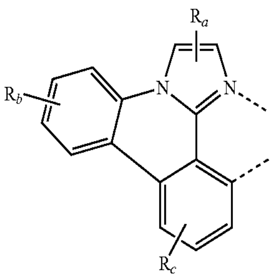
wherein B contains a group selected from the group consisting of carbazole and azacarbazole, which are optionally further substituted, and wherein the substitution is optionally fused to the carbazole or azacarbazole group.

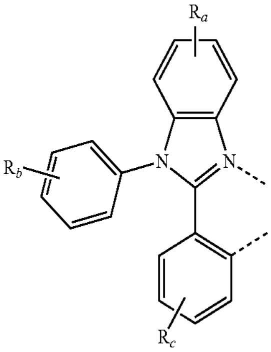
11. The first device of claim **10**, wherein the organic layer is an emissive layer and the compound of Formula I is a host.

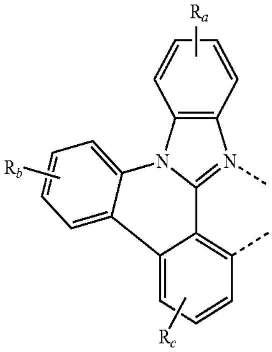
12. The first device of claim **10**, wherein the organic layer further comprises an emissive dopant.

13. The first device of claim **12**, wherein the emissive dopant is a transition metal complex having at least one ligand selected from the group consisting of:









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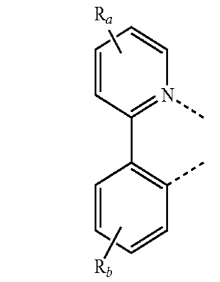

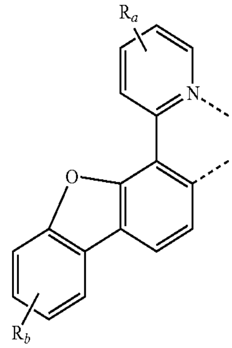

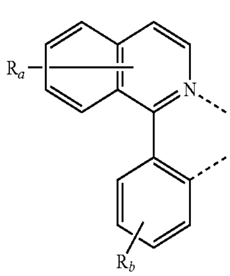

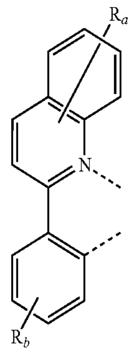

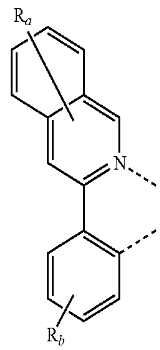

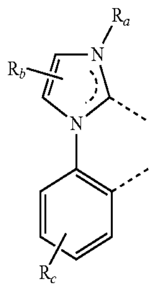

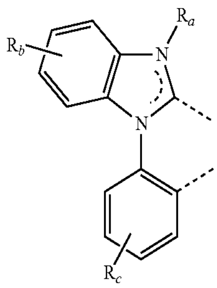

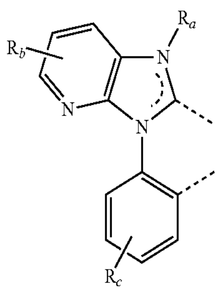

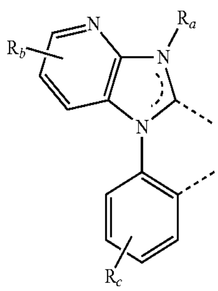

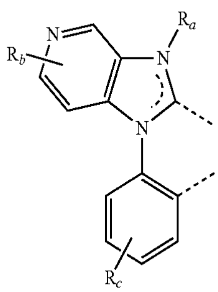

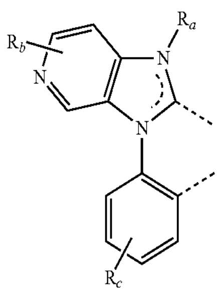

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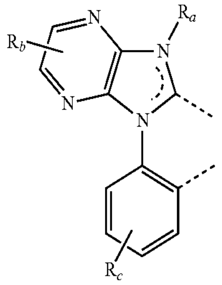
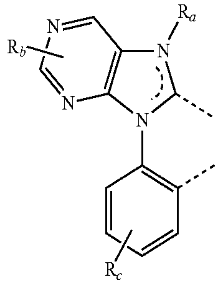
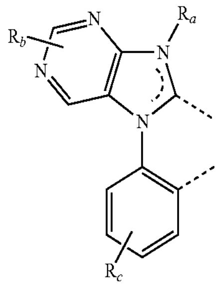






,

wherein R_a, R_b, and R_c may represent mono, di, tri or tetra substitutions;

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

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

14. The first device of claim **10**, wherein the device further comprises a second organic layer that is a non-emissive layer and the compound having Formula I is a material in the second organic layer.

15. The first device of claim **10**, wherein the organic layer is deposited using a solution process.

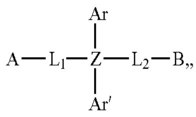
16. A first device comprising an organic light emitting device, further comprising:

an anode;

a cathode; and

an organic layer, disposed between the anode and the cathode, comprising a compound having the Formula I:

Formula I



wherein Ar and Ar' are independently selected from the group consisting of phenyl, biphenyl, napthyl, dibenzothiolyl, and dibenzofuranyl, which are optionally further substituted;

wherein Z is selected from Si and Ge;

wherein L_1 comprises aryl or heteroaryl groups, wherein any heteroatoms in the heteroaryl groups are nitrogen;

wherein L_2 is a single bond or comprises aryl or heteroaryl groups, wherein any heteroatoms in the heteroaryl groups are nitrogen;

wherein L_1 and L_2 are optionally further substituted;

wherein A contains a group selected from the group consisting of dibenzofuran, dibenzothiophene, azadibenzofuran, azadibenzothiophene, dibenzoselenophene and azadibenzoselenophene, which are optionally further substituted, and wherein the substitution is optionally fused to at least one benzo ring;

wherein B contains a group selected from the group consisting of carbazole and azacarbazole, which are optionally further substituted, and wherein the substitution is optionally fused to the carbazole or azacarbazole group;

wherein the device further comprises a second organic layer that is a non-emissive layer and the compound having Formula I is a material in the second organic layer; and

wherein the second organic layer is a blocking layer and the compound having Formula I is a blocking material in the second organic layer.

17. The first device of claim **10**, wherein the first device is a consumer product.

18. The first device of claim **10**, wherein the first device is an organic light-emitting device.

19. The first device of claim **14**, wherein the second organic layer is a blocking layer and the compound having Formula I is a blocking material in the second organic layer.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 8,748,012 B2
APPLICATION NO. : 13/067345
DATED : June 10, 2014
INVENTOR(S) : Lichang Zeng, Alexey B. Dyatkin and Gregg Kottas

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims:

In column 144, line 25, of claim 7, “chiysene” should be -- chrysene --

Signed and Sealed this
Twelfth Day of August, 2014

Michelle K. Lee

Michelle K. Lee
Deputy Director of the United States Patent and Trademark Office

专利名称(译)	用于OLED的主体材料		
公开(公告)号	US8748012	公开(公告)日	2014-06-10
申请号	US13/067345	申请日	2011-05-25
[标]申请(专利权)人(译)	环球展览公司		
申请(专利权)人(译)	通用显示器公司		
当前申请(专利权)人(译)	通用显示器公司		
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摘要(译)

描述了新的芳基硅和芳基锗主体材料。当用作OLED的发光层中的主体时，这些化合物改善了OLED器件的性能。