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(54) **ORGANIC ELECTROLUMINESCENT MATERIALS AND DEVICES**

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CPC ***H01L 51/0072*** (2013.01); *H01L 51/006* (2013.01); *H01L 51/0073* (2013.01); *H01L 51/0074* (2013.01); *H01L 51/0081* (2013.01); *H01L 51/0085* (2013.01); *H01L 51/5012* (2013.01); *H01L 51/5048* (2013.01); *H01L 51/5096* (2013.01); *H01L 2251/308* (2013.01); *Y10S 428/917* (2013.01)
USPC **428/690**; 428/917; 313/504; 313/505; 313/506; 257/E51.05; 257/E51.026; 257/E51.032; 546/18; 546/79; 546/81; 546/101; 548/304.1; 548/418; 548/440; 548/444

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USPC 428/690, 917; 313/504, 505, 506; 257/40, E51.05, E51.026, E51.032; 546/18, 79, 81, 101; 544/234
See application file for complete search history.

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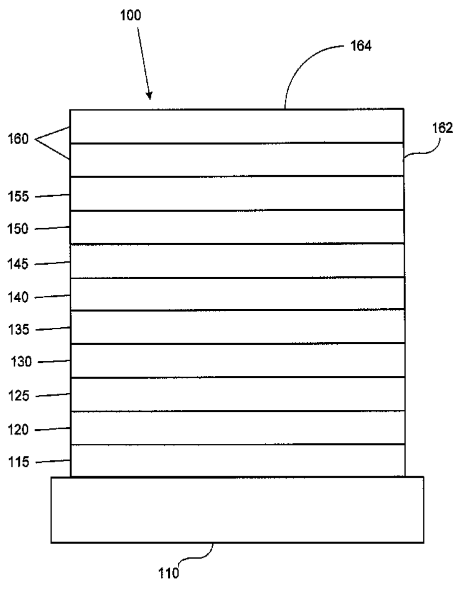
(57) **ABSTRACT**

Compounds comprising a 3,9-linked oligocarbazole moiety and a dibenzothiophene, dibenzofuran, dibenzoselenophene, aza-dibenzothiophene, aza-dibenzofuran, or aza-dibenzoselenophene are provided. The 3,9-linked oligocarbazole and dibenzo or aza-dibenzo moiety are separated by an aromatic spacer. The compounds may be used as non-emissive materials for phosphorescent OLEDs to provide devise having improved performance.

11 Claims, 3 Drawing Sheets



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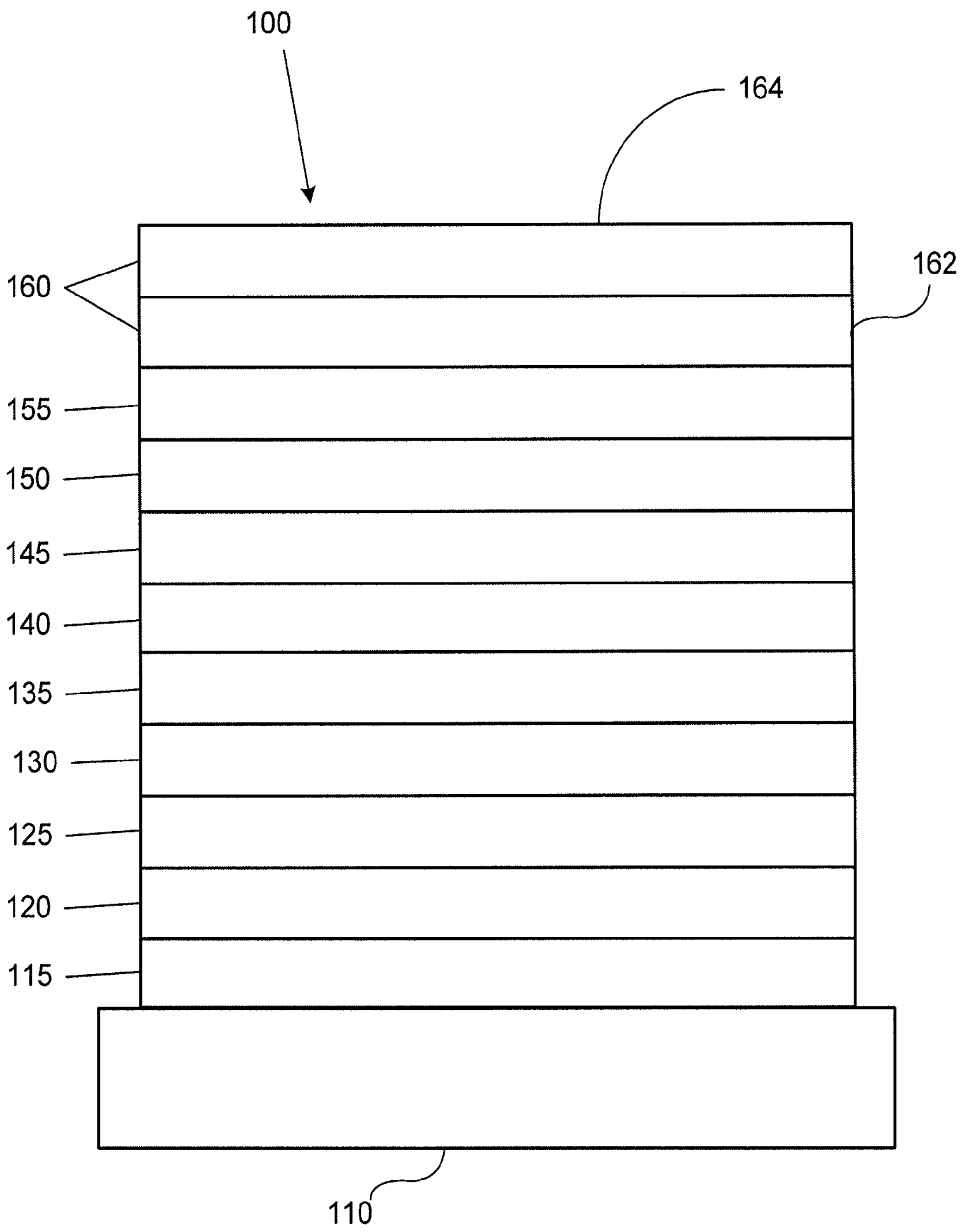


FIGURE 1

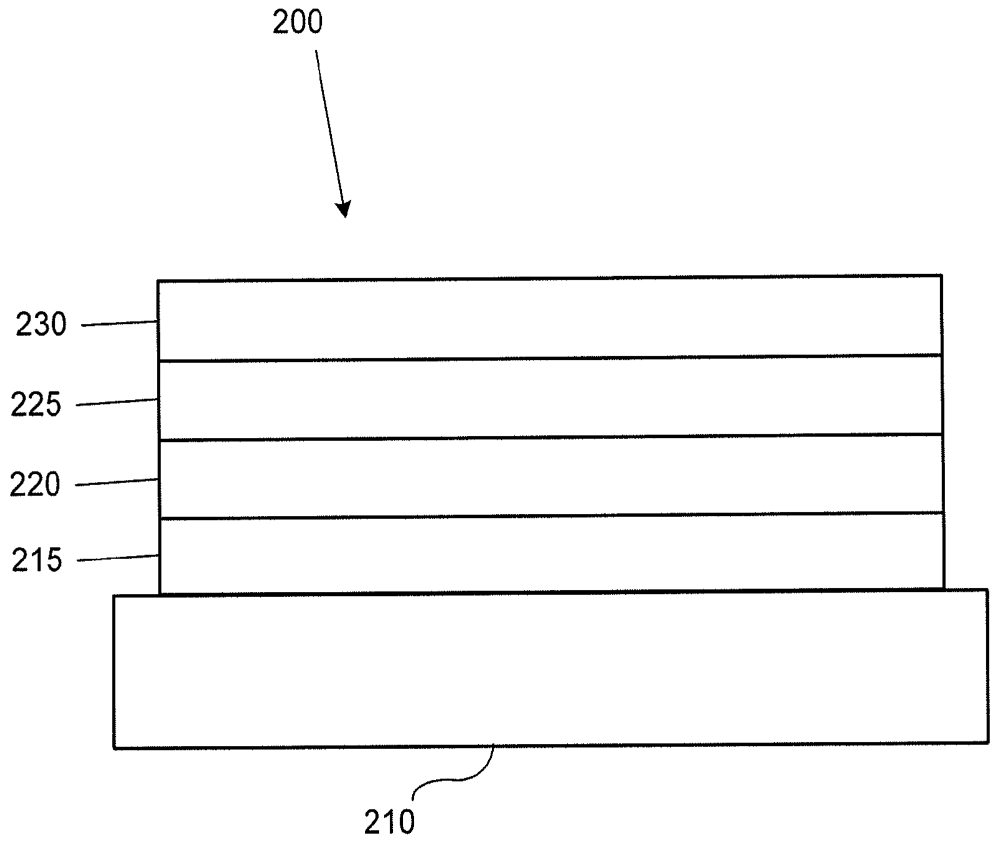


FIGURE 2

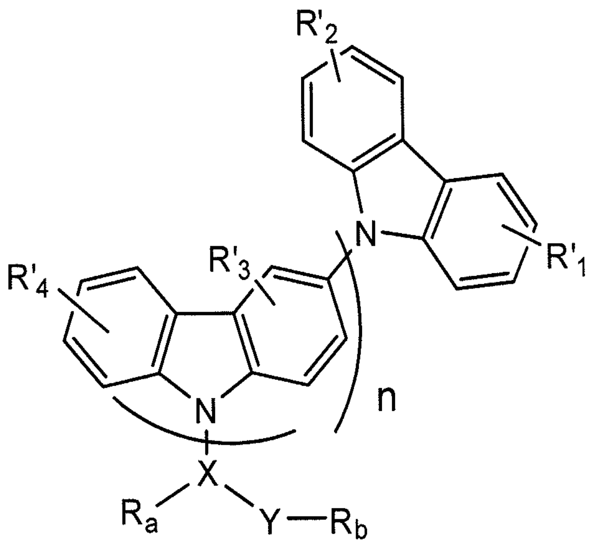


FIGURE 3

ORGANIC ELECTROLUMINESCENT MATERIALS AND DEVICES

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

FIELD OF THE INVENTION

The present invention relates to organic light emitting devices (OLEDs). More specifically, the present invention relates to phosphorescent materials containing a 3,9-linked oligocarbazole and dibenzothiophene or dibenzofuran. These materials may provide devices having improved performance.

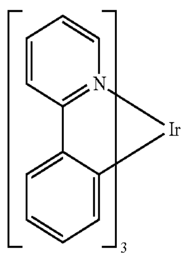
BACKGROUND

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 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 processable" 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.

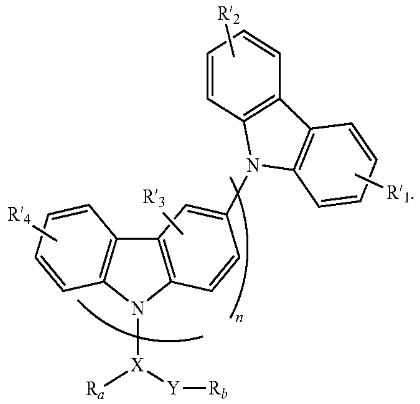
As used herein, and as would be generally understood by one skilled in the art, a first work function is "greater than" or "higher than" a second work function if the first work function has a higher absolute value. Because work functions are generally measured as negative numbers relative to vacuum 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

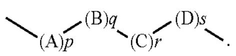
Compounds comprising a 3,9-linked oligocarbazole and a dibenzo or aza-dibenzo moiety are provided. The compound have the formula:

Formula I

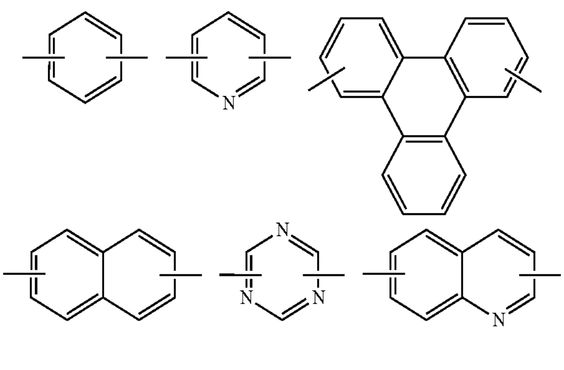


n is 1-20. Preferably, n is 1, 2, or 3. Most preferably, n is 1. Each of R'_1, R'_2, R'_3, and R'_4 independently represent mono, di, tri or tetra substitutions. R'_1, R'_2, R'_3, and R'_4 are independently selected from the group consisting of hydrogen, deuterium, alkyl, alkoxy, amino, alkenyl, alkynyl, arylkyl, aryl, and heteroaryl. R_a and R_b independently represent mono, di, tri, or tetra substitutions. R_a and R_b are independently selected from the group consisting of hydrogen, deuterium, alkyl, alkoxy, amino, alkenyl, alkynyl, arylkyl, aryl, and heteroaryl. X is an aryl or heteroaryl linker further substituted with R_a. Y is dibenzothiophene, dibenzofuran, dibenzoselenophene, aza-dibenzothiophene, aza-dibenzofuran, or aza-dibenzoselenophene that is further substituted with R_b. Preferably, Y is 2-dibenzothiophenyl, 4-dibenzothiophenyl, 2-dibenzofuranyl, or 4-dibenzofuranyl.

In one aspect, X is



A, B, C and D are independently selected from the group consisting of:



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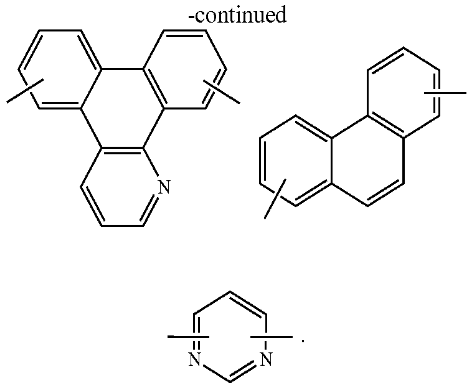
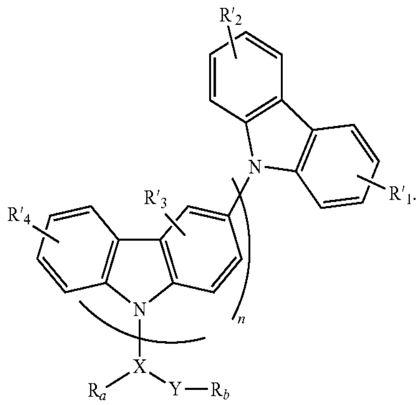


A, B, C and D are optionally further substituted with R_a. Each of p, q, r and s are 0, 1, 2, 3, or 4. p+q+r+s is at least 1.

Specific examples of the compounds are provided. In one aspect, the compound is selected from the group consisting of Compound 1-Compound 83.

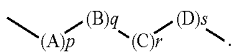
An organic light emitting device is also provided. The device comprises an anode, a cathode, and a first organic layer disposed between the anode and the cathode. The organic layer comprises a compound having the formula:

Formula I

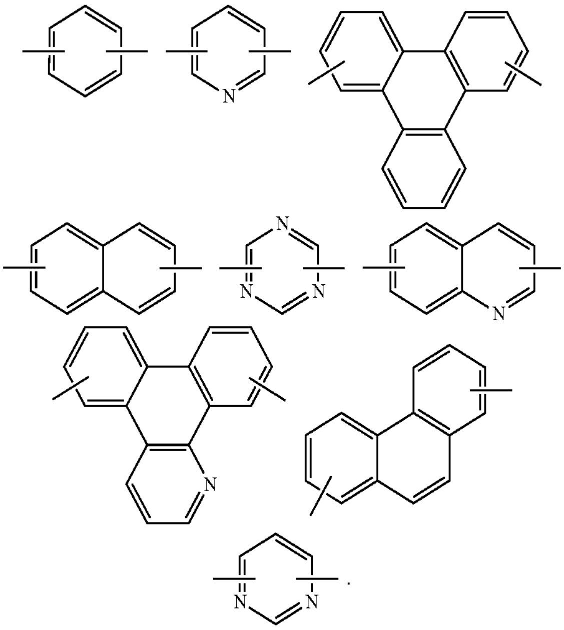


n is 1-20. Preferably, n is 1, 2, or 3. Most preferably, n is 1. Each of R'_1, R'_2, R'_3, and R'_4 independently represent mono, di, tri or tetra substitutions. R'_1, R'_2, R'_3, and R'_4 are independently selected from the group consisting of hydrogen, deuterium, alkyl, alkoxy, amino, alkenyl, alkynyl, arylkyl, aryl, and heteroaryl. R_a and R_b independently represent mono, di, tri, or tetra substitutions. R_a and R_b are independently selected from the group consisting of hydrogen, deuterium, alkyl, alkoxy, amino, alkenyl, alkynyl, arylkyl, aryl, and heteroaryl. X is an aryl or heteroaryl linker further substituted with R_a. Y is dibenzothiophene, dibenzofuran, dibenzoselenophene, aza-dibenzothiophene, aza-dibenzofuran, or aza-dibenzoselenophene that is further substituted with R_b. Preferably, Y is 2-dibenzothiophenyl, 4-dibenzothiophenyl, 2-dibenzofuranyl, or 4-dibenzofuranyl.

In one aspect, X is



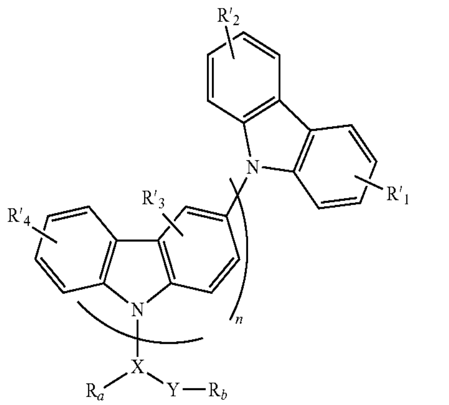
A, B, C and D are independently selected from the group consisting of:



A, B, C and D are optionally further substituted with R_a. Each of p, q, r and s are 0, 1, 2, 3, or 4. p+q+r+s is at least 1.

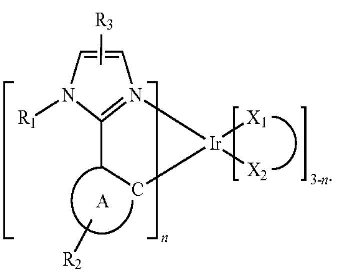
Specific examples of devices comprising the compounds are provided. In one aspect, the compound is selected from the group consisting of Compound 1-Compound 83.

In one aspect, the first organic layer is an emissive layer and the compound having



Formula I is a host.

In another aspect, the first organic layer further comprises an emissive dopant having the formula

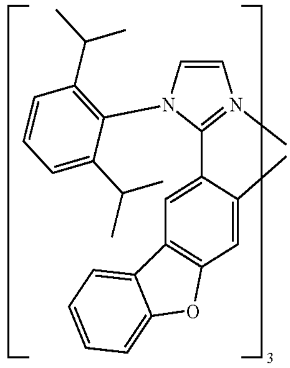


A is a 5 or 6 membered carbocyclic or heterocyclic ring. R_1, R_2, and R_3 independently represent mono, di, tri or tetra

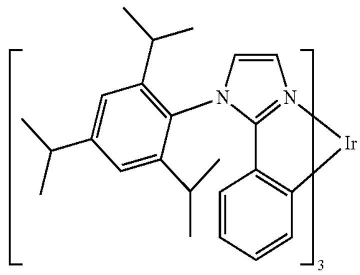
substituents. Each of R_1, R_2, and R_3 are independently selected from the group consisting of hydrogen, deuterium, alkyl, alkoxy, amino, alkenyl, alkynyl, arylkyl, aryl, and heteroaryl. n is 1, 2, or 3. X—Y is an ancillary ligand.

In a further aspect, the emissive dopant is selected from the group consisting of:

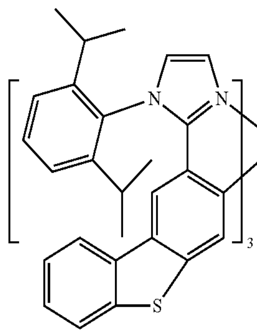
Compound H



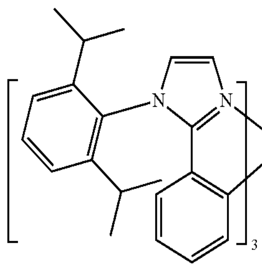
Compound I



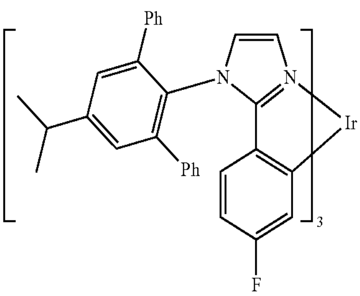
Compound J



Compound K



Compound L



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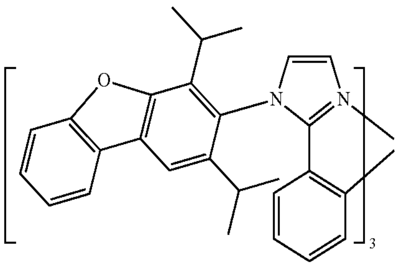
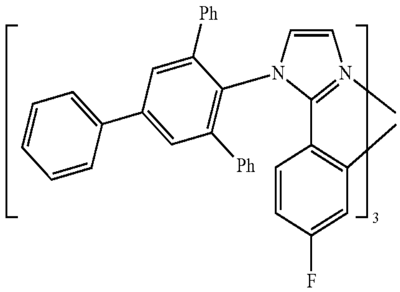
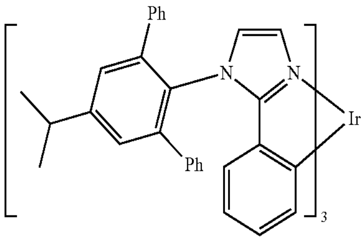
Compound M



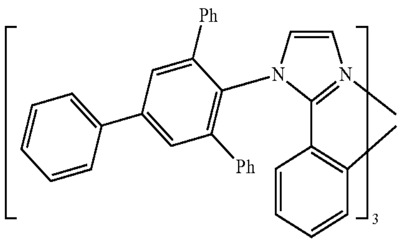
Compound N



Compound O



Compound P



In yet another 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 one aspect, the second organic layer is an electron transporting layer and the compound having Formula I is an electron transporting 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 organic layer is disposed using solution processing.

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

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 containing a3,9-linked oligocarbazole and a dibenzo or aza-dibenzo group.

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 processability 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.

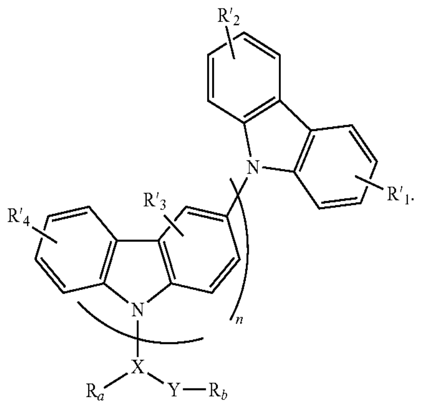
Novel compounds containing a 3,9-linked oligocarbazole and a dibenzo or aza-dibenzo group are provided (illustrated in FIG. **3**). In particular, the compounds comprise a 3,9-linked oligocarbazole moiety and a dibenzothiophene (DBT), dibenzofuran (DBF), dibenzoselenophene, aza-dibenzothiophene (aza-DBT), aza-dibenzofuran (aza-DBF), or aza-dibenzoselenophene, such that the 3,9-linked oligocarbazole moiety and the dibenzo or aza-dibenzo moiety are separated by an aromatic spacer. The compounds may be used as non-emissive materials for phosphorescent OLEDs. For example, the compounds may be used as host materials, electron transporting materials and/or materials in a blocking layer.

A mentioned above, the compounds consist of 3,9-linked oligocarbazole and dibenzo moiety, e.g., DBT or DBF fragments, or aza-dibenzo moiety, e.g., aza-DBT or aza-DBF, separated by aromatic spacers. Without being limited as to any theory regarding how embodiments of the invention work, the HOMO of the compound is controlled by the 3,9-linked oligocarbazole moiety, and the LUMO is controlled by the dibenzo moiety or aza-dibenzo moiety. The aromatic spacer can be designed to extend the conjugation. Without being bound by theory, it is believed that compounds with extended conjugation have improved stability because the charge is delocalized over a greater area. The compound provides good tunability of the HOMO and the LUMO. The compounds showed improved device performance (i.e. efficiency, voltage and lifetime) when used a host for a light blue PHOLED. It is believed that selecting the 3,9-linked oligocarbazole and dibenzo or aza-dibenzo moieties and their connection to one another via the aromatic spacer may keep the triplet value of these compounds in the blue part of the spectrum. These compounds not only can serve as a host, but they also can function as an electron transporting material or material in a blocking layer.

In addition to improved charge balance and charge stability, the compounds provided herein may also provide better film formation. In particular, materials having an asymmetrical structure may offer improved film formation. The improved film formation may be a result of increased tendency to stay amorphous even at elevated temperatures due to the asymmetrical structure of the compound, as evidenced by unexpected results from solution processing devices using the compounds as a host material.

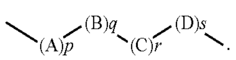
Compounds comprising a 3,9-linked oligocarbazole and a dibenzo or aza-dibenzo moiety are provided. The compound has the formula:

Formula I

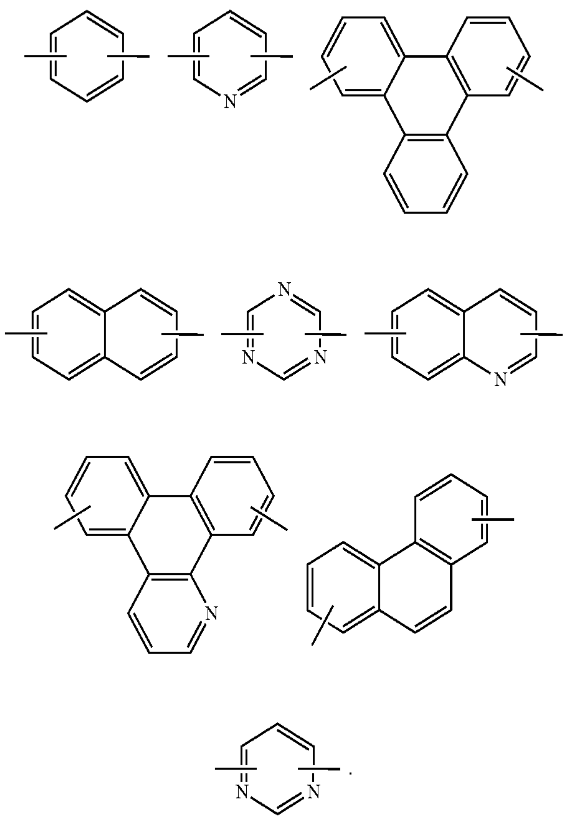


n is 1-20. Preferably, n is 1, 2, or 3. Most preferably, n is 1. Each of R'_1, R'_2, R'_3, and R'_4 independently represent mono, di, tri or tetra substitutions. R'_1, R'_2, R'_3, and R'_4 are independently selected from the group consisting of hydrogen, deuterium, alkyl, alkoxy, amino, alkenyl, alkynyl, arylkyl, aryl, and heteroaryl. R_a and R_b independently represent mono, di, tri, or tetra substitutions. R_a and R_b are independently selected from the group consisting of hydrogen, deuterium, alkyl, alkoxy, amino, alkenyl, alkynyl, arylkyl, aryl, and heteroaryl. X is an aryl or heteroaryl linker further substituted with R_a. Y is dibenzothiophene, dibenzofuran, dibenzoselenophene, aza-dibenzothiophene, aza-dibenzofuran, or aza-dibenzoselenophene that is further substituted with R_b. Preferably, Y is 2-dibenzothiophenyl, 4-dibenzothiophenyl, 2-dibenzofuranyl, or 4-dibenzofuranyl.

In one aspect, X is



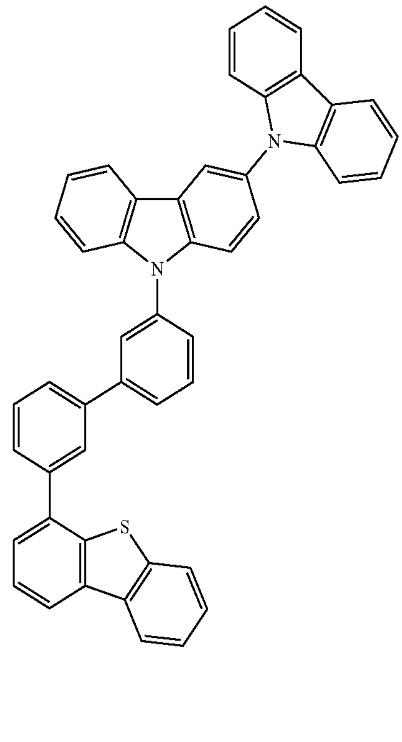
A, B, C and D are independently selected from the group consisting of:



A, B, C and D are optionally further substituted with R_a. Each of p, q, r and s are 0, 1, 2, 3, or 4. p+q+r+s is at least 1.

Specific examples of the compounds are provided. In one aspect, the compound is selected from the group consisting of:

Compound 1



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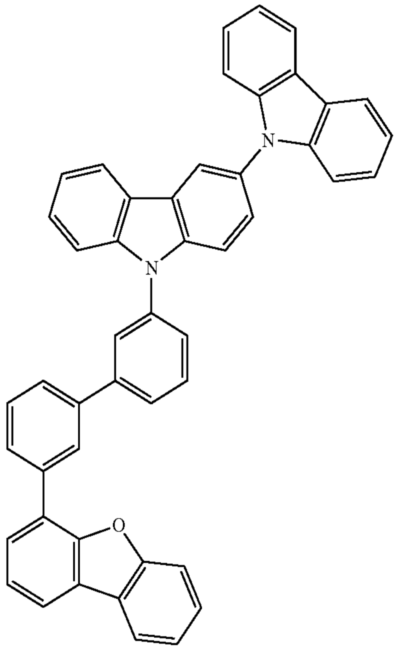
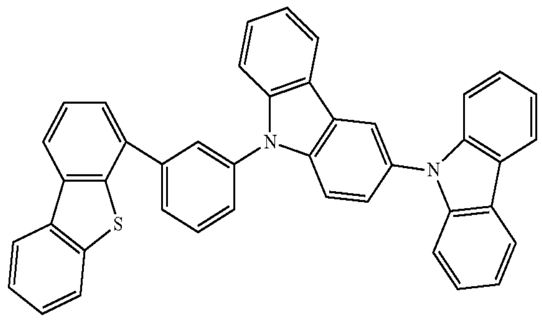
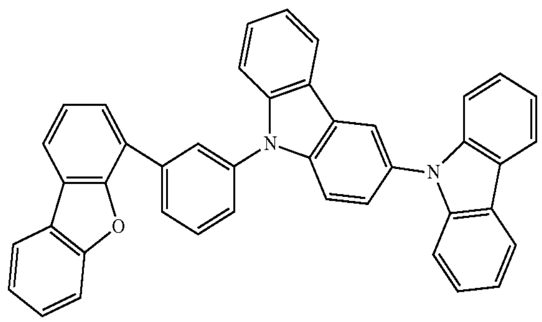
Compound 2



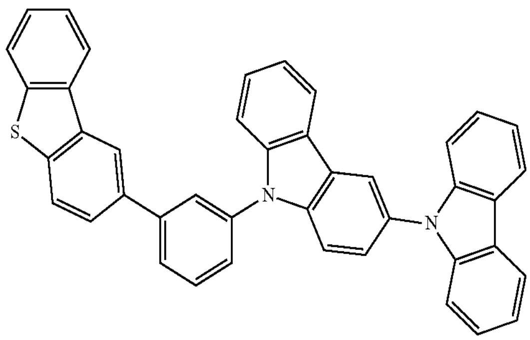
Compound 3



Compound 4



Compound 5



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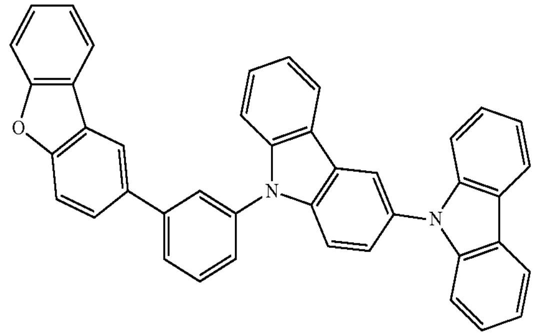
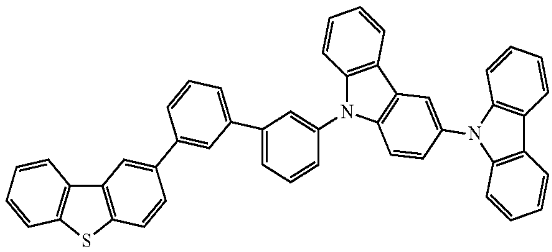
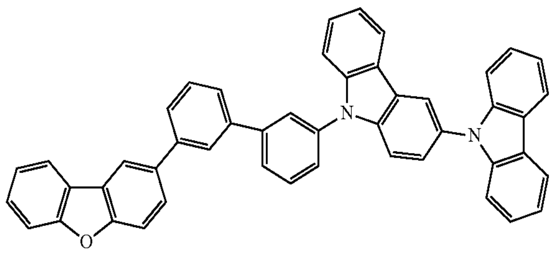
Compound 6



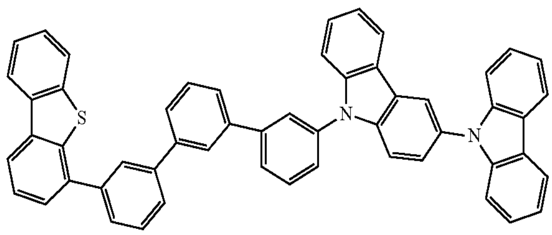
Compound 7



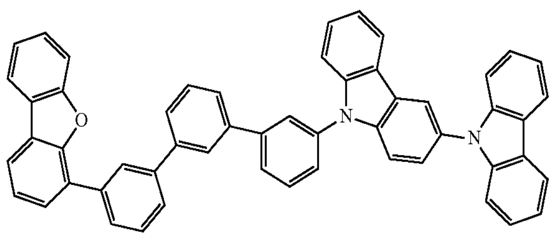
Compound 8



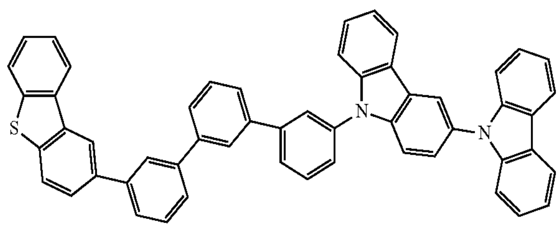
Compound 9



Compound 10



Compound 11



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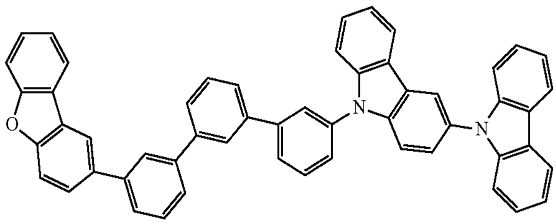
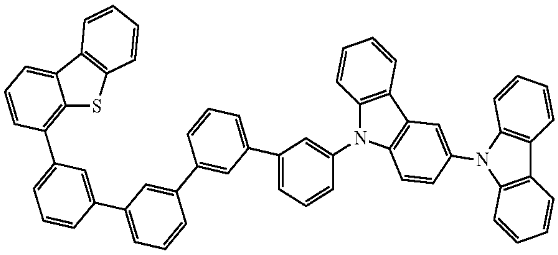
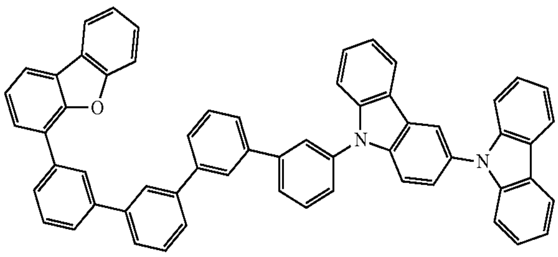
Compound 12



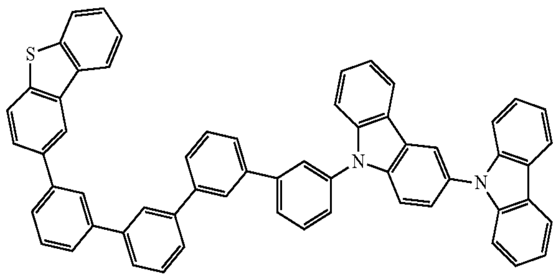
Compound 13



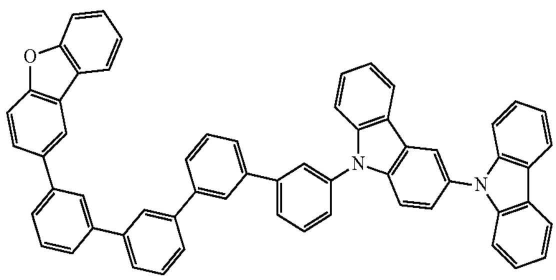
Compound 14



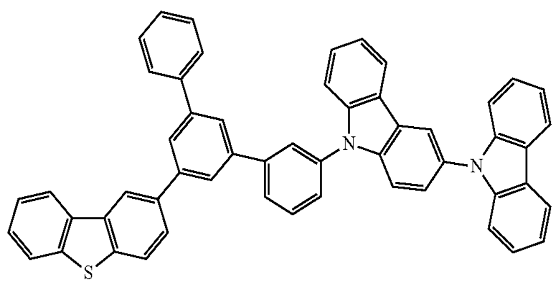
Compound 15



Compound 16



Compound 17



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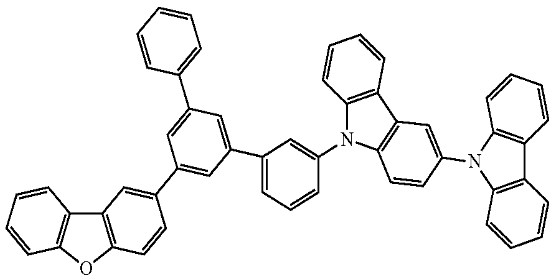

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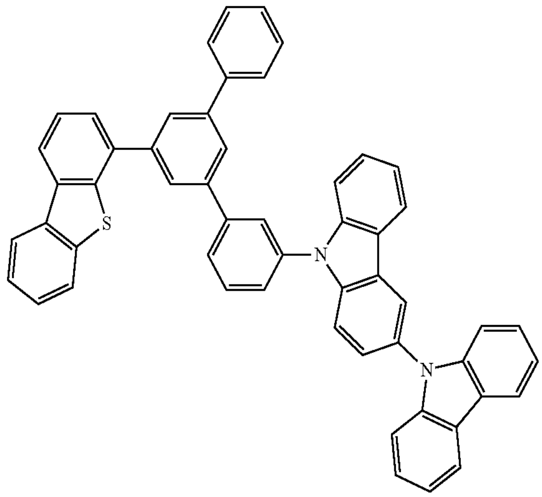
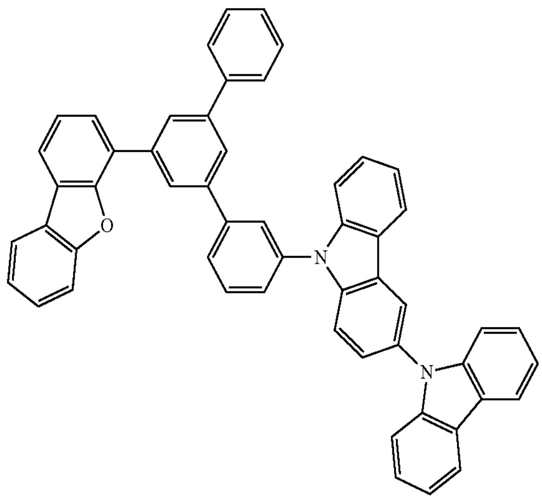


Compound 20



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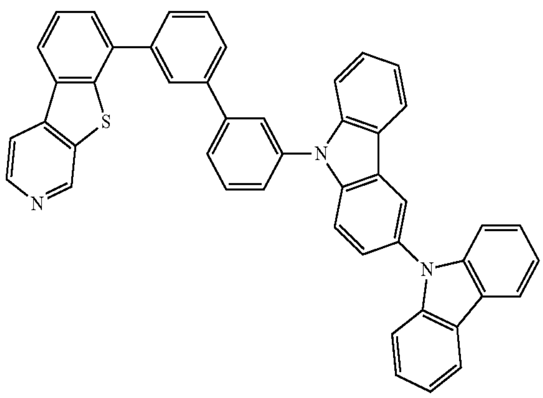

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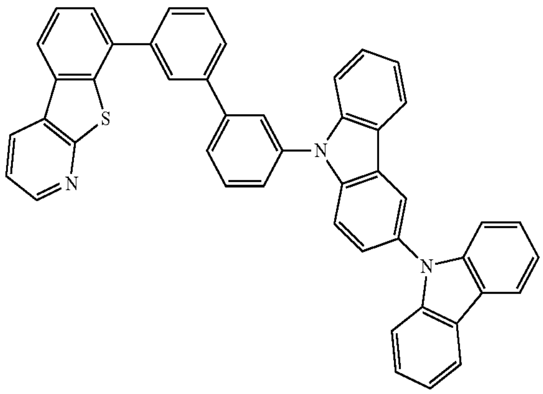

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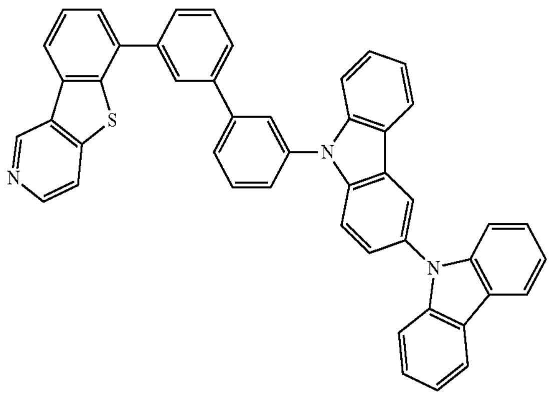

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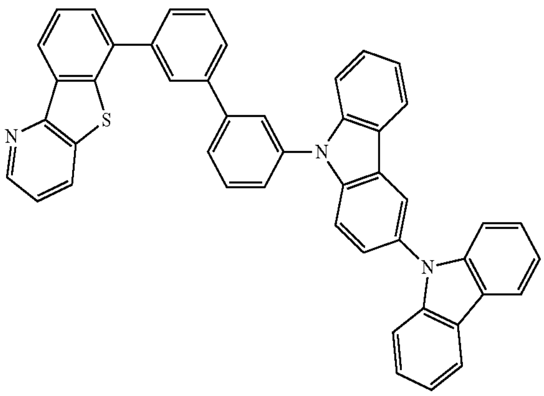

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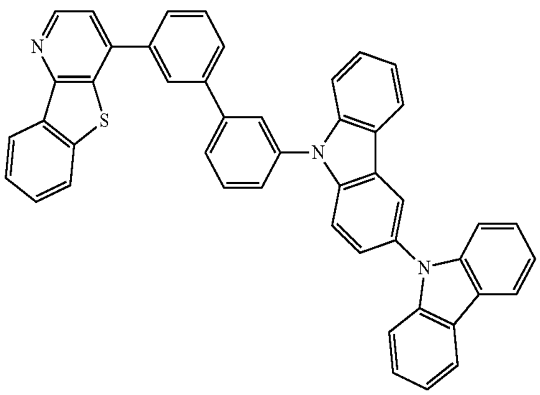

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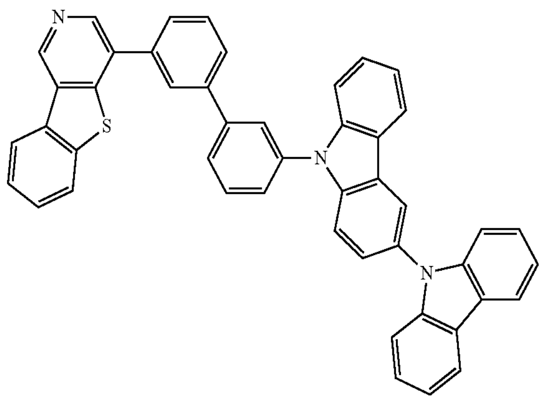
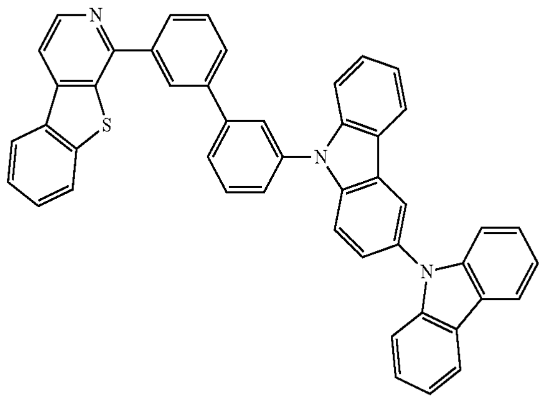
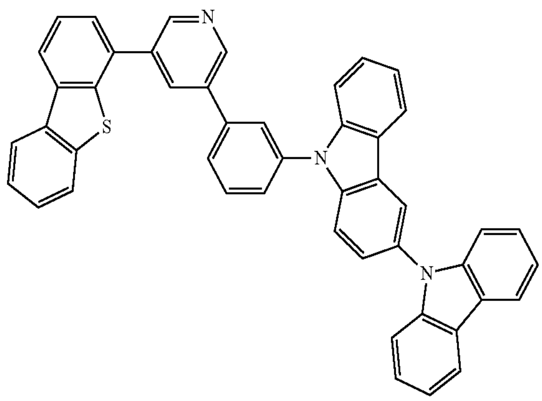
Compound 26



Compound 27



Compound 28



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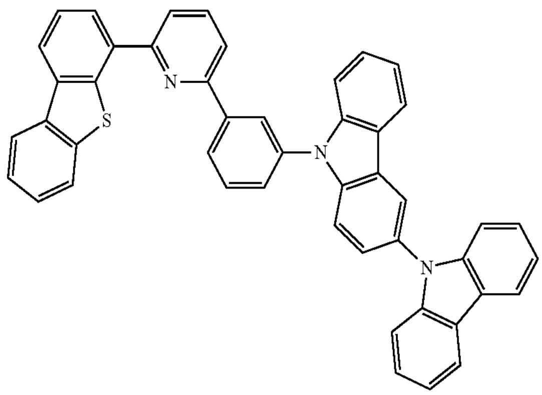

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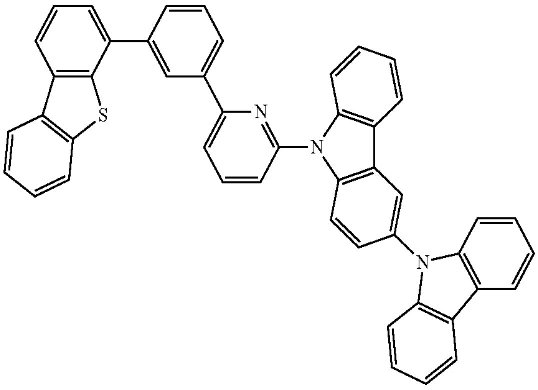
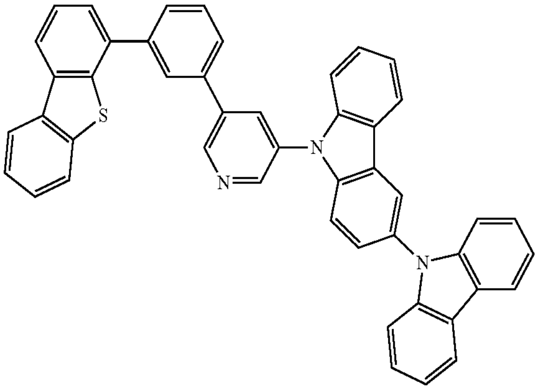


Compound 31



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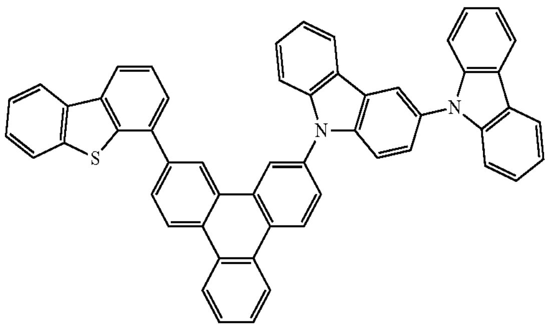
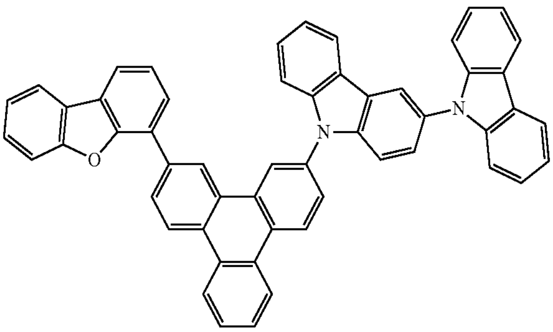


Compound 33



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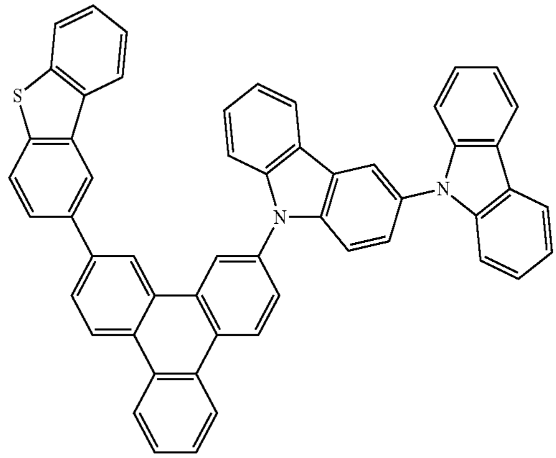
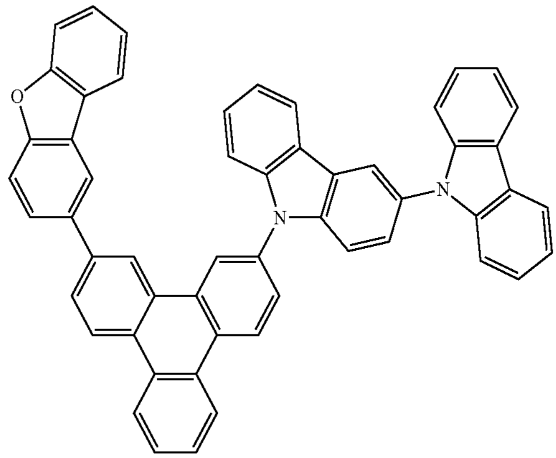
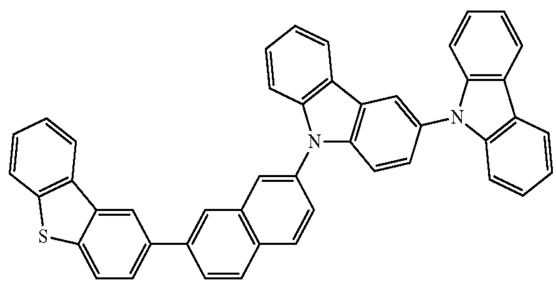
Compound 34



Compound 35



Compound 36



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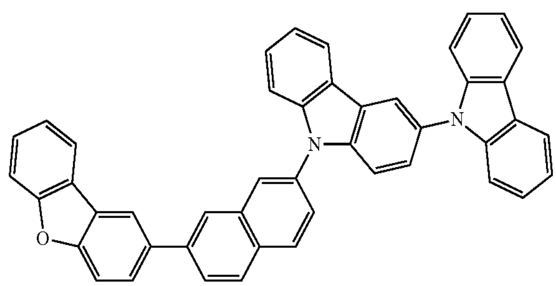

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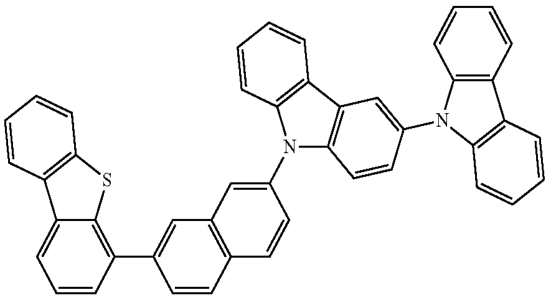
Compound 38



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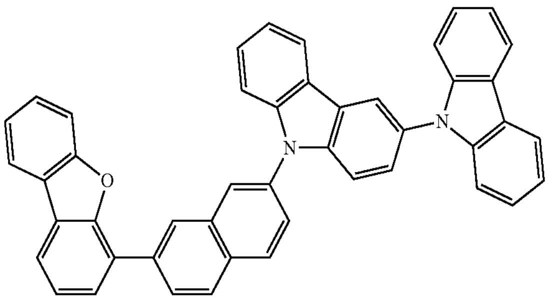

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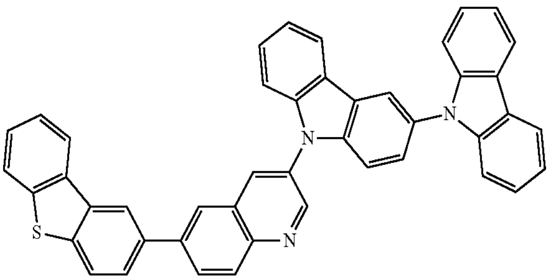
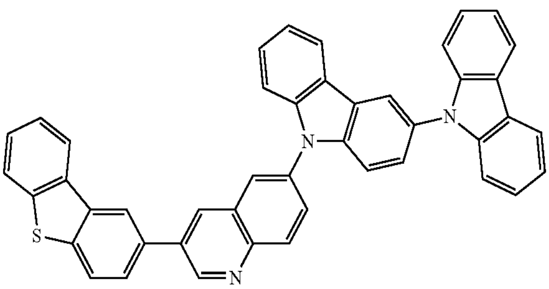
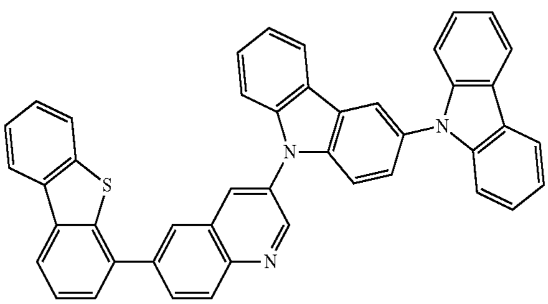


Compound 41



Compound 42



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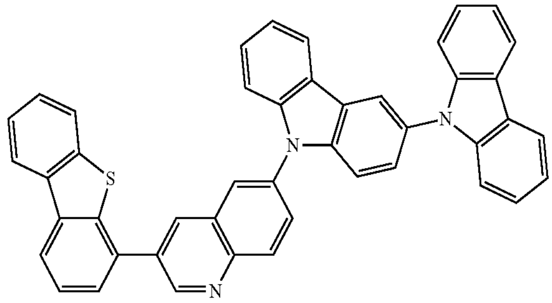
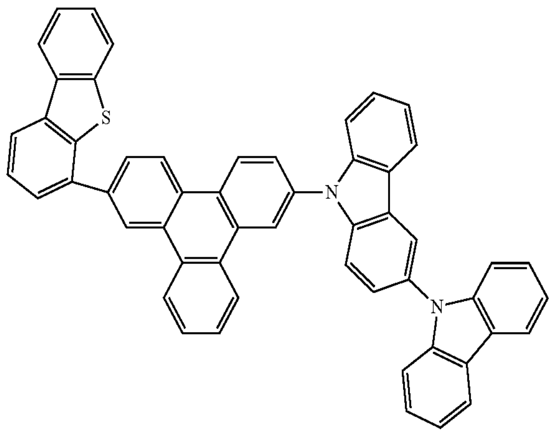
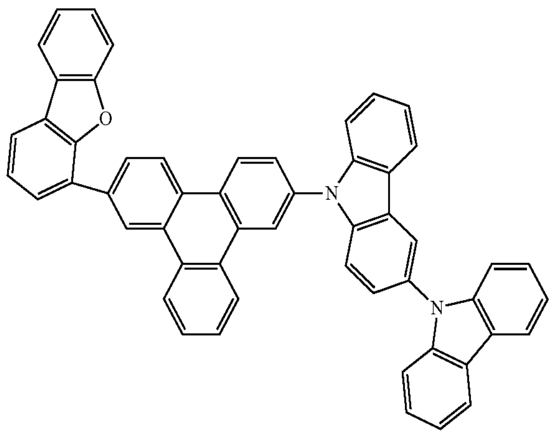
Compound 43



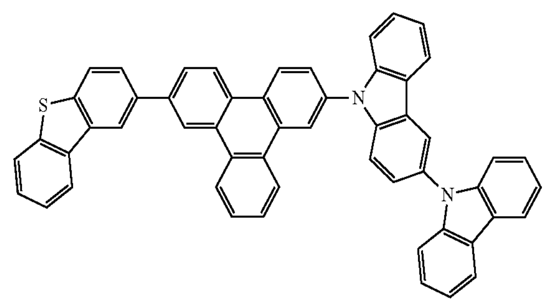
Compound 44



Compound 45



Compound 46



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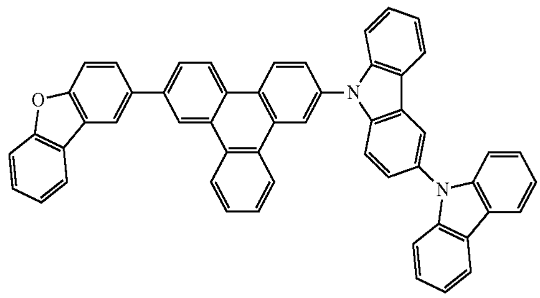
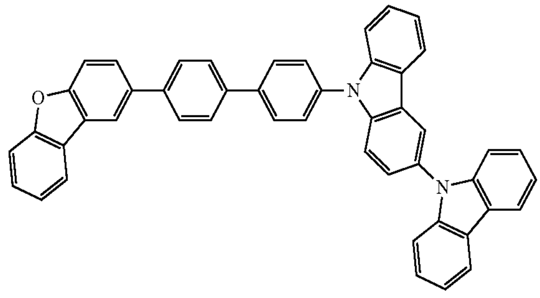
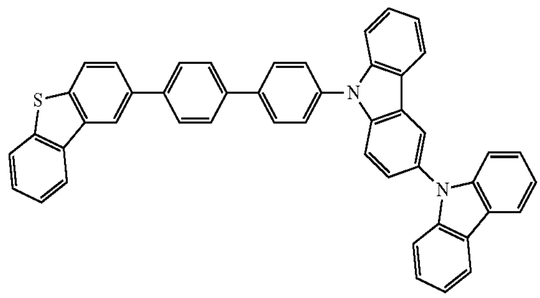


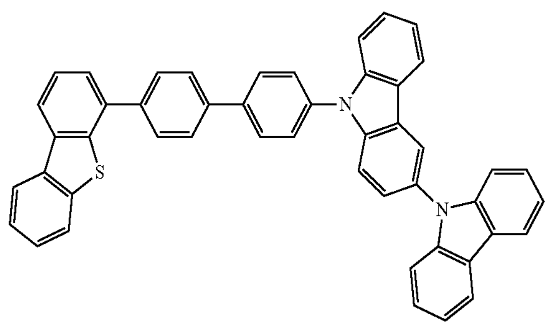
Compound 48



Compound 49



Compound 50



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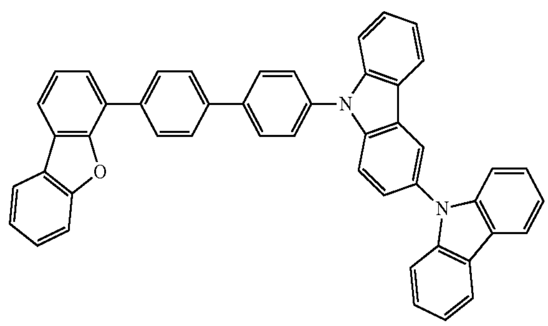

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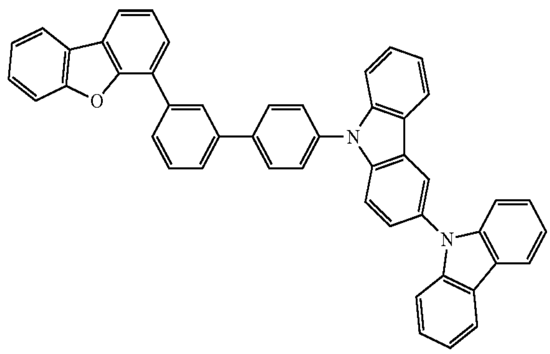

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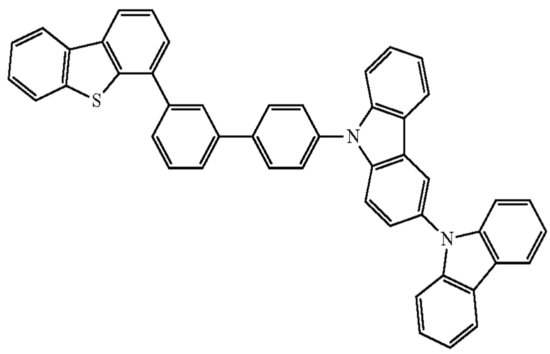
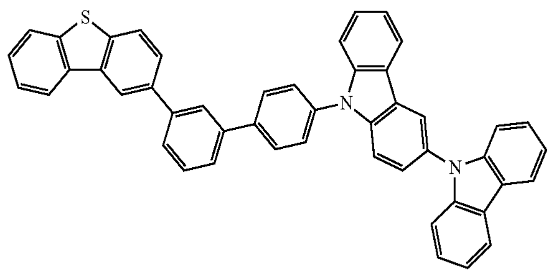
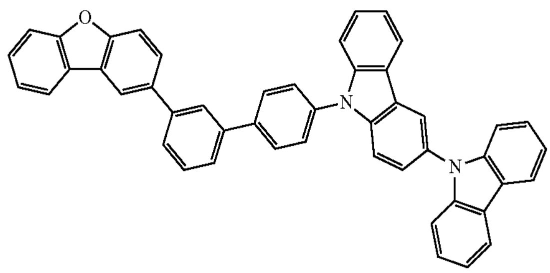


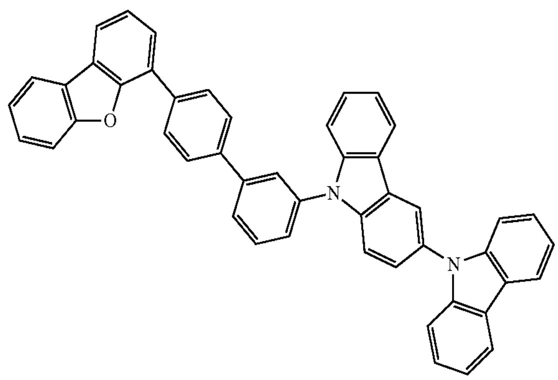
Compound 54



Compound 55



Compound 56



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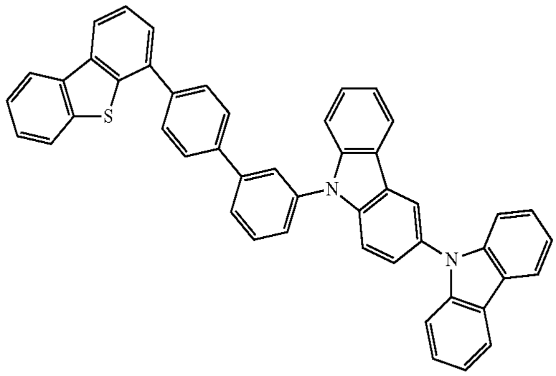
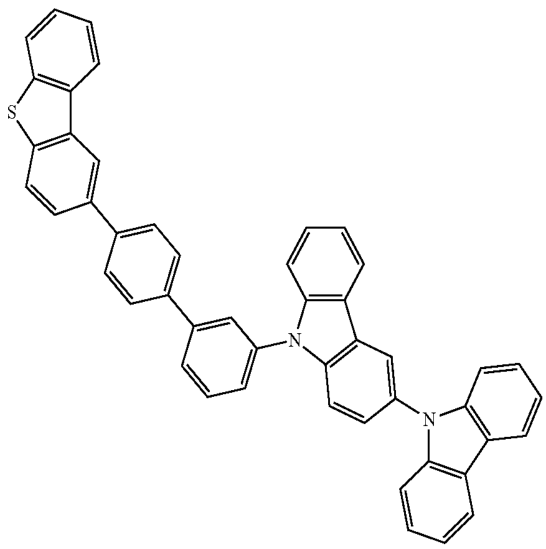
Compound 57



Compound 58



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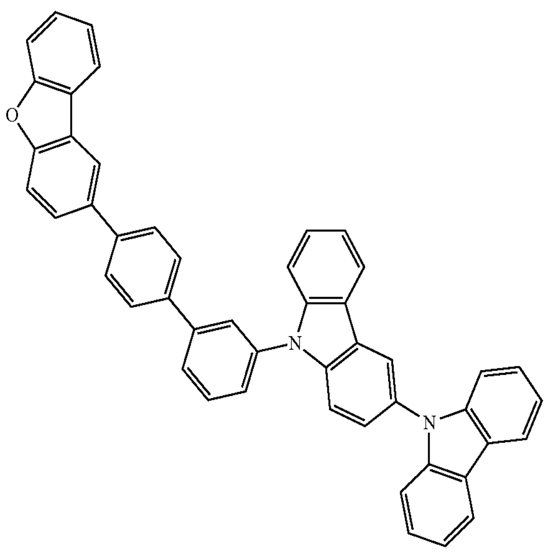

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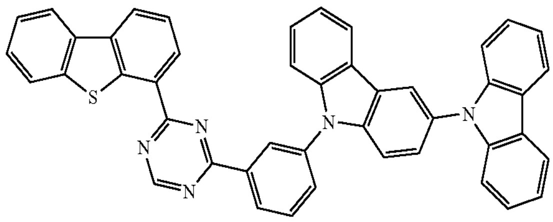

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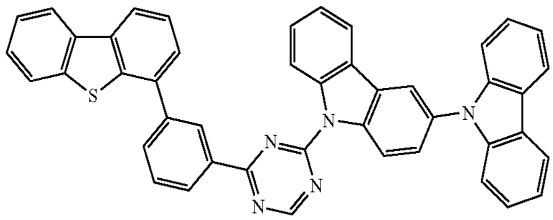
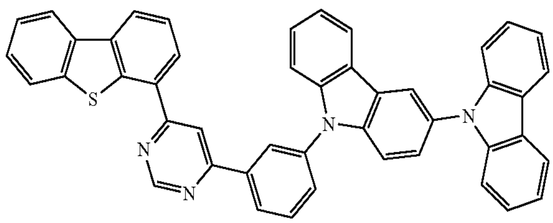
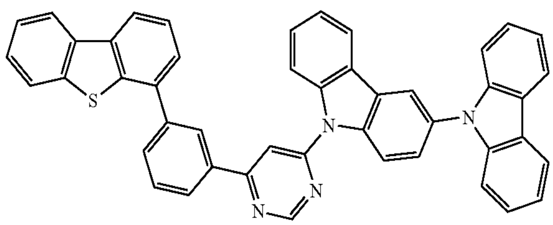


Compound 62



Compound 63



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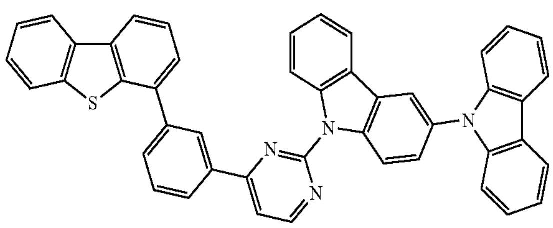

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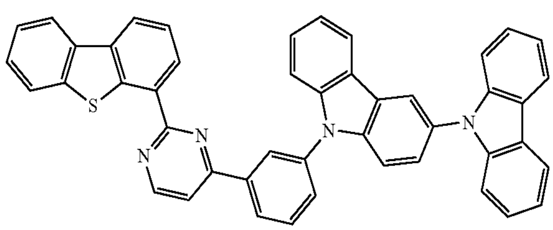

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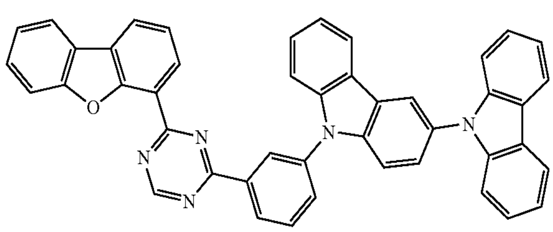

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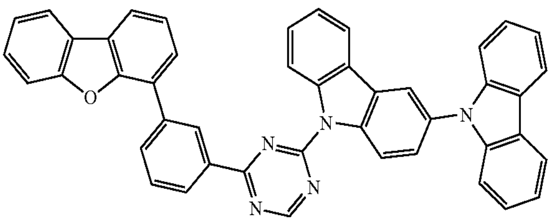

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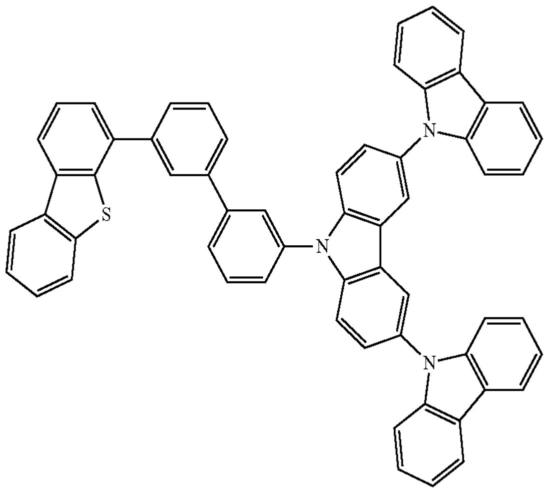

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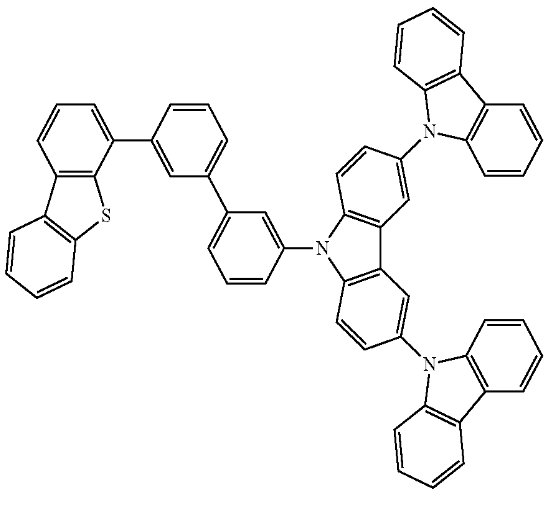

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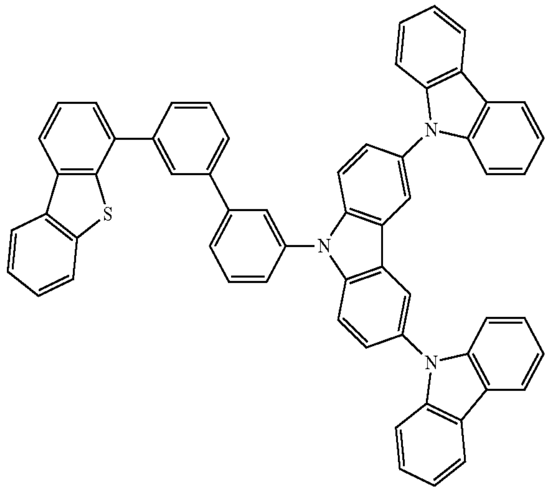

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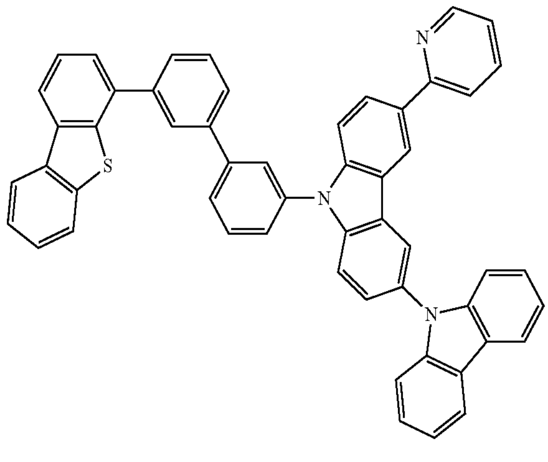
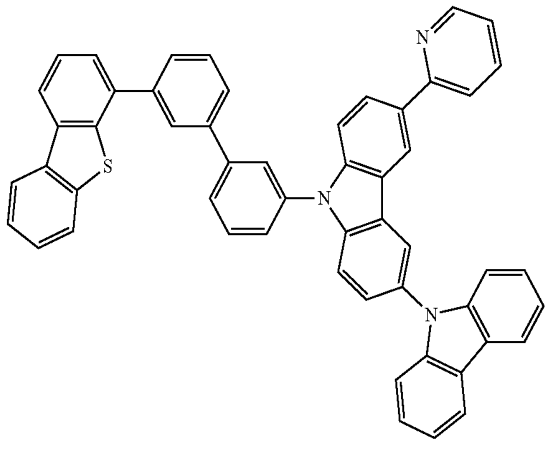


Compound 72



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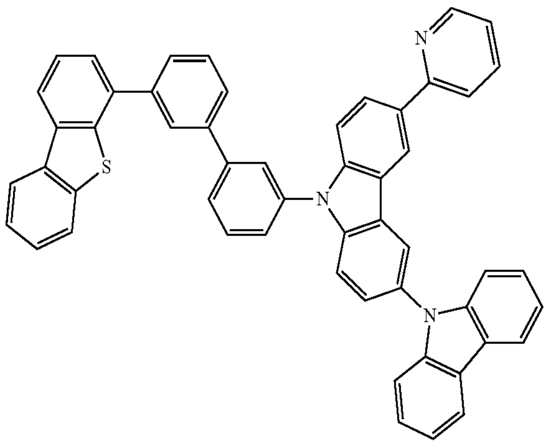
Compound 73



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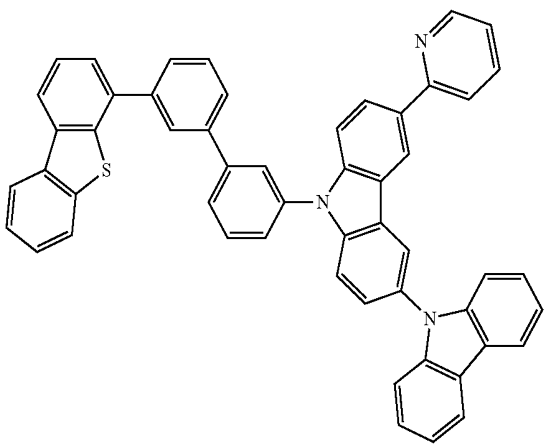

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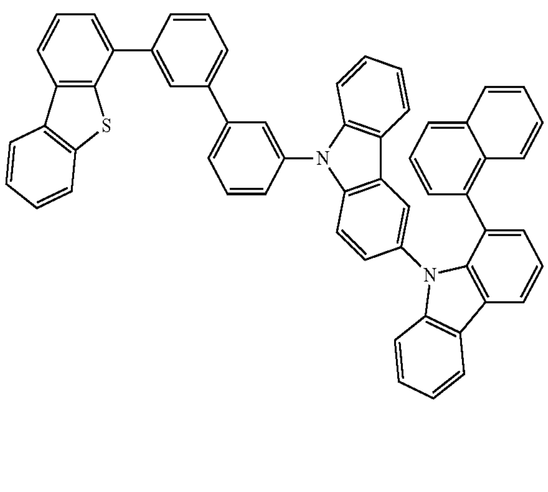

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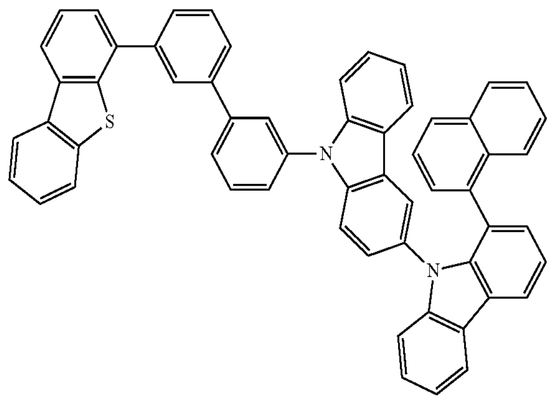

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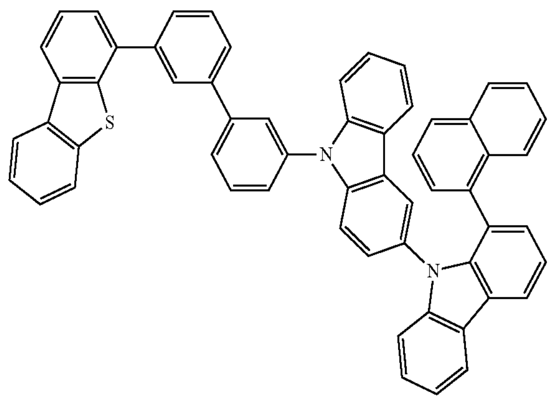

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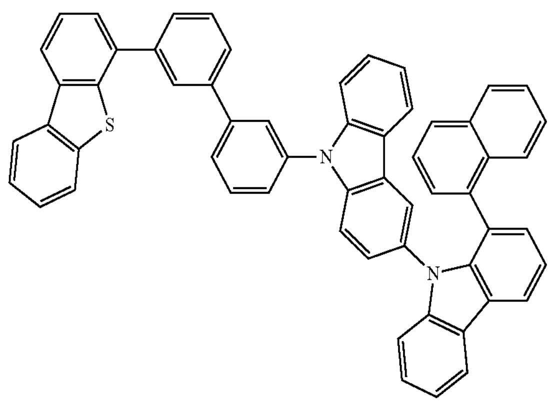
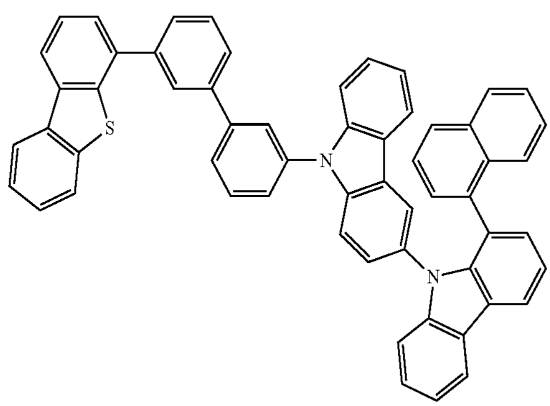


Compound 79



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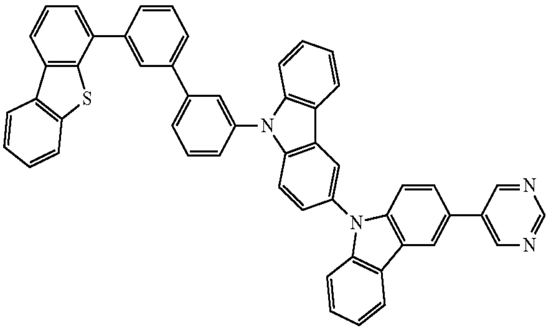
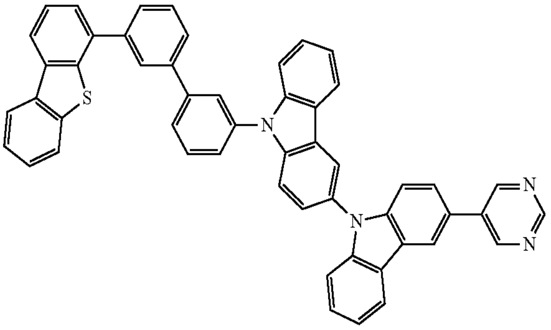
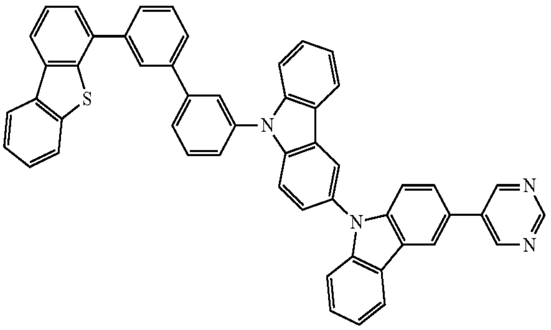
Compound 80



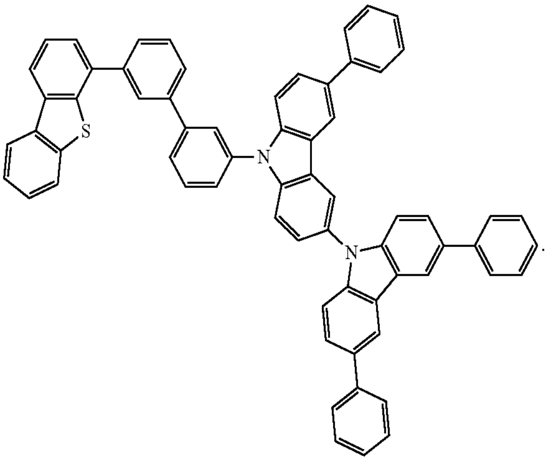
Compound 81



Compound 82

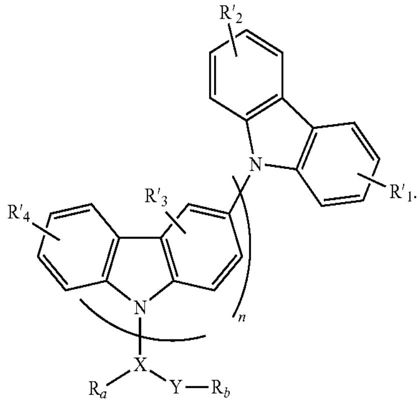


Compound 83



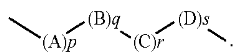
A first device comprising an organic light emitting device is also provided. The organic light emitting device comprises an anode, a cathode, and a first organic layer disposed between the anode and the cathode. The organic layer comprises a compound having the formula:

Formula I

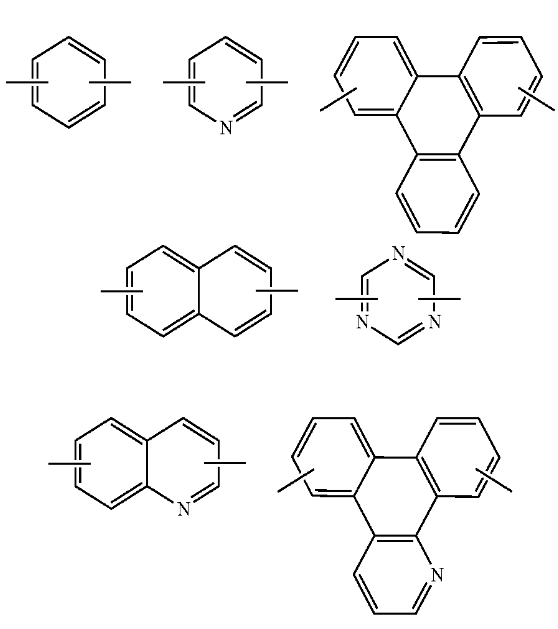


n is 1-20. Preferably, n is 1, 2, or 3. Most preferably, n is 1. Each of R'_1, R'_2, R'_3, and R'_4 independently represent mono, di, tri or tetra substitutions. R'_1, R'_2, R'_3, and R'_4 are independently selected from the group consisting of hydrogen, deuterium, alkyl, alkoxy, amino, alkenyl, alkynyl, arylkyl, aryl, and heteroaryl. R_a and R_b independently represent mono, di, tri, or tetra substitutions. R_a and R_b are independently selected from the group consisting of hydrogen, deuterium, alkyl, alkoxy, amino, alkenyl, alkynyl, arylkyl, aryl, and heteroaryl. X is an aryl or heteroaryl linker further substituted with R_a. Y is dibenzothiophene, dibenzofuran, dibenzoselenophene, aza-dibenzothiophene, aza-dibenzofuran, or aza-dibenzoselenophene that is further substituted with R_b. Preferably, Y is 2-dibenzothiophenyl, 4-dibenzothiophenyl, 2-dibenzofuranyl, or 4-dibenzofuranyl.

In one aspect, X is



A, B, C and D are independently selected from the group consisting of:



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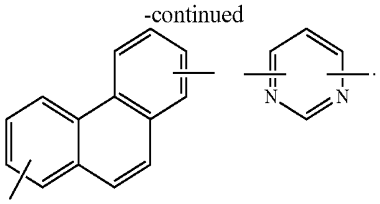
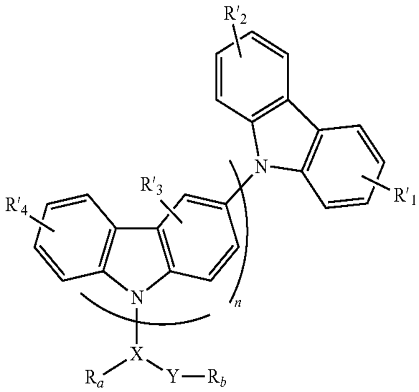


A, B, C and D are optionally further substituted with R_a. Each of p, q, r and s are 0, 1, 2, 3, or 4. p+q+r+s is at least 1.

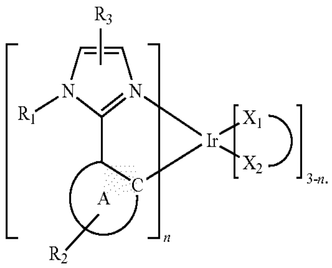
Specific examples of devices comprising the compounds are provided. In one aspect, the compound is selected from the group consisting of Compound 1-Compound 83.

In one aspect, the first organic layer is an emissive layer and the compound having



Formula I is a host.

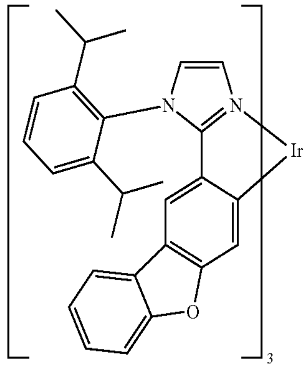
In another aspect, the first organic layer further comprises an emissive dopant having the formula



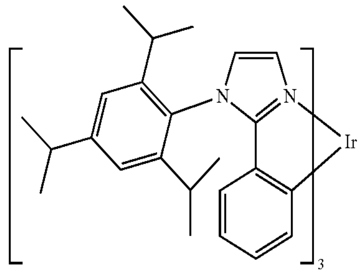
A is a 5 or 6 membered carbocyclic or heterocyclic ring. R_1, R_2, and R_3 independently represent mono, di, tri or tetra substituents. Each of R_1, R_2, and R_3 are independently selected from the group consisting of hydrogen, deuterium, alkyl, alkoxy, amino, alkenyl, alkynyl, arylkyl, aryl, and heteroaryl. n is 1, 2, or 3. X—Y is an ancillary ligand.

In a further aspect, the emissive dopant is selected from the group consisting of:

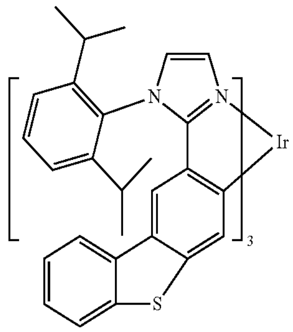
Compound H



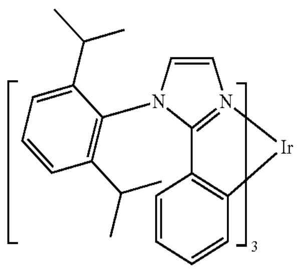
Compound I



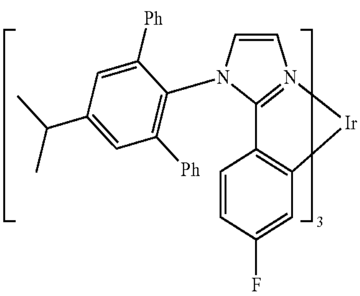
Compound J



Compound K



Compound L



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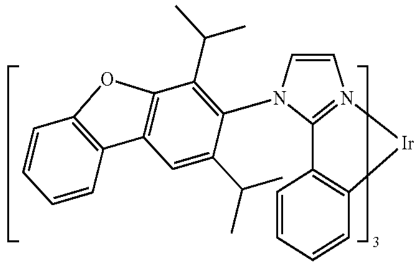
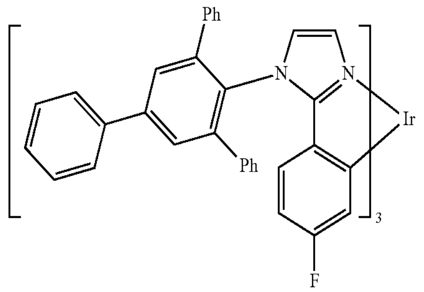
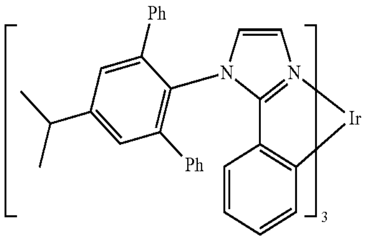
Compound M



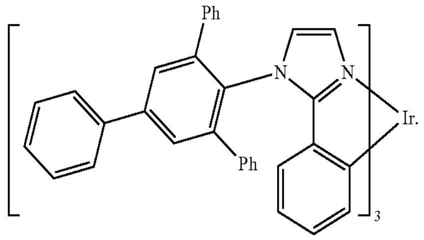
Compound N



Compound O



Compound P



In yet another aspect, the first 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 one aspect, the second organic layer is an electron transporting layer and the compound having Formula I is an electron transporting 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.

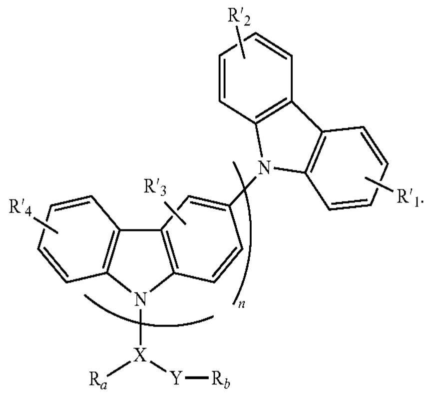
In one aspect, the first organic layer is disposed using solution processing.

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

In addition, there are several other embodiments; however, these additional embodiments are less preferred.

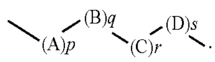
Compounds comprising a carbazole or a 3,9-linked oligocarbazole and a dibenzo or aza-dibenzo moiety are provided. The compounds have the formula:

Formula I

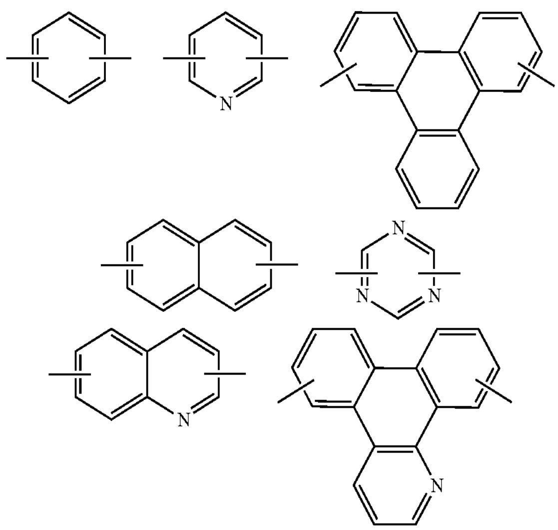


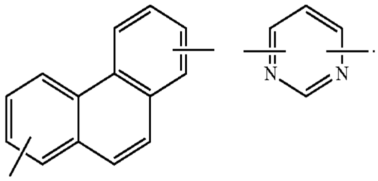
n is 0-20. Preferably, n is 1-20. More preferably, n is 1, 2, or 3. Most preferably, n is 1. Each of R'_1, R'_2, R'_3, and R'_4 independently represent mono, di, tri or tetra substitutions. R'_1, R'_2, R'_3, and R'_4 are independently selected from the group consisting of hydrogen, deuterium, alkyl, alkoxy, amino, alkenyl, alkynyl, arylkyl, aryl, and heteroaryl. R_a and R_b independently represent mono, di, tri, or tetra substitutions. R_a and R_b are independently selected from the group consisting of hydrogen, deuterium, alkyl, alkoxy, amino, alkenyl, alkynyl, arylkyl, aryl, and heteroaryl. X is an aryl or heteroaryl linker further substituted with R_a. Y is dibenzothiophene, dibenzofuran, dibenzoselenophene, aza-dibenzothiophene, aza-dibenzofuran, or aza-dibenzoselenophene that is further substituted with R_b. Preferably, Y is 2-dibenzothiophenyl, 4-dibenzothiophenyl, 2-dibenzofuranyl, or 4-dibenzofuranyl. When n is 0, X is an aryl linker comprising at least two phenylene groups and Y is 4-dibenzothiophene.

In one aspect, X is



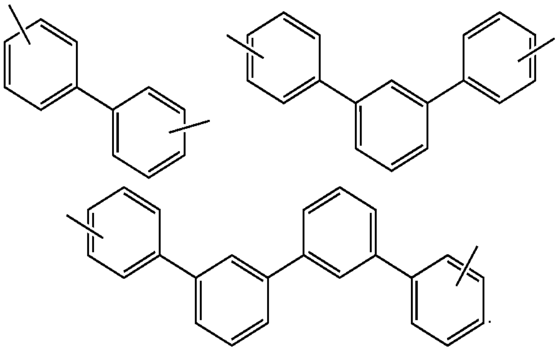
A, B, C and D are independently selected from the group consisting of:





A, B, C and D are optionally further substituted with R_a. Each of p, q, r and s are 0, 1, 2, 3, or 4. p+q+r+s is at least 1.

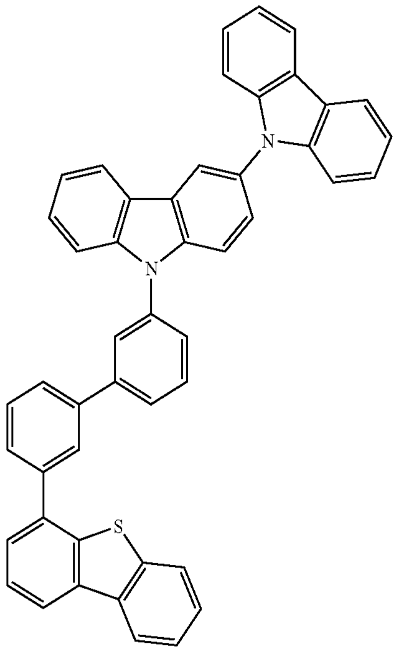
In one aspect, n is 0, X is an aryl linker comprising at least two phenylene groups and Y is 4-dibenzothiophene. In another aspect, X is selected from the group consisting of:



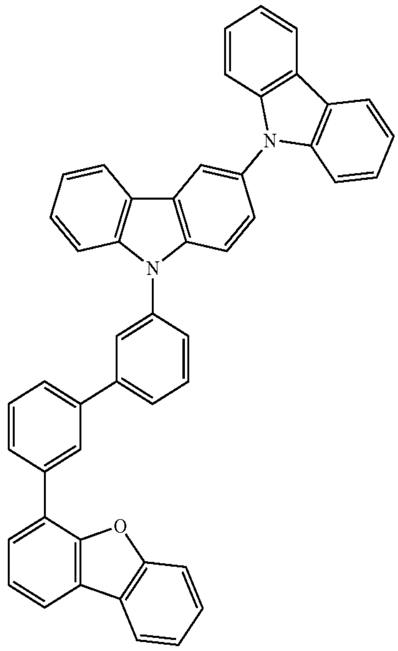
X is further substituted with R_a. Without being bound by theory, it is believed that compounds comprising a carbazole and a 4-dibenzothiophene separated by at least two phenylene groups may be used in various organic layers in a device to provide improved device lifetime. For example, a carbazole and a 4-dibenzothiophene separated by two phenylene rings may be a host material, while a carbazole and a 4-dibenzothiophene separated by three phenylene rings may be a blocking material.

Specific examples of the compounds are provided. In one aspect, the compound is selected from the group consisting of:

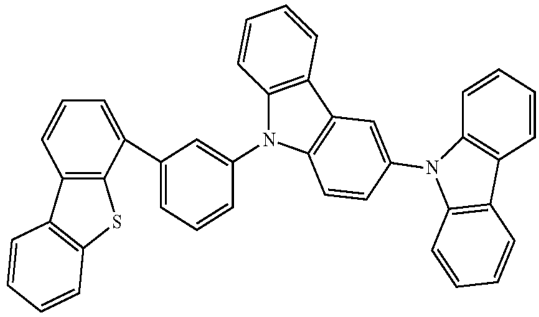
Compound 1



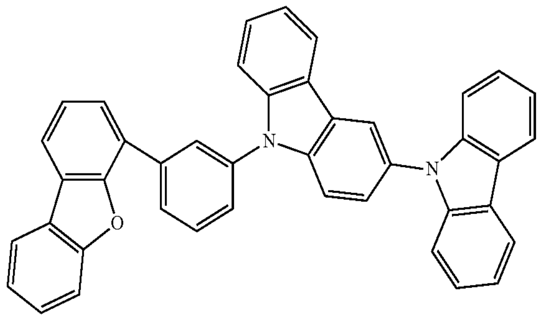
Compound 2



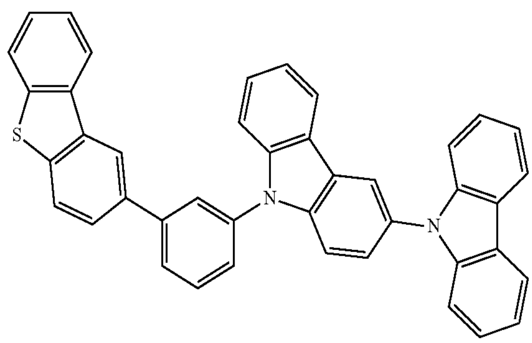
Compound 3



Compound 4



Compound 5



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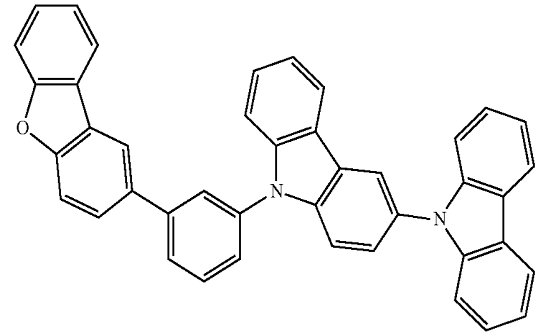
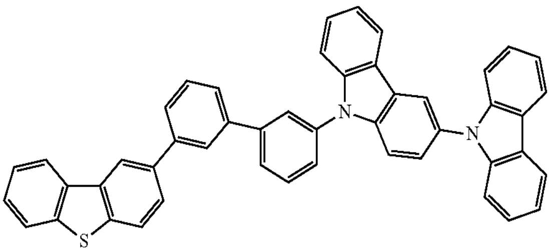
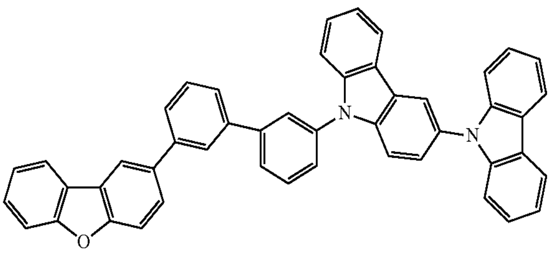
Compound 6



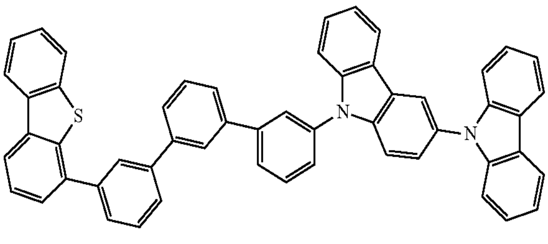
Compound 7



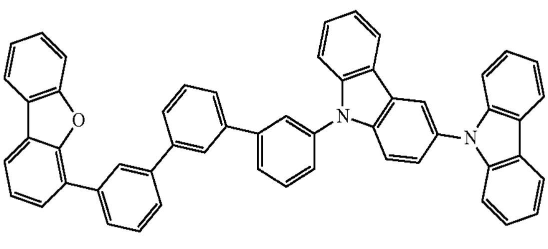
Compound 8



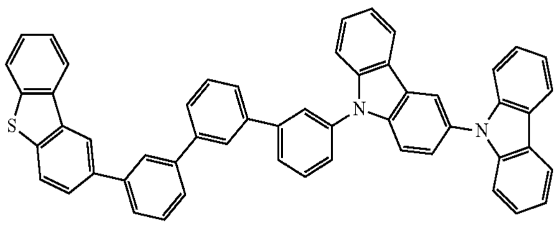
Compound 9



Compound 10



Compound 11



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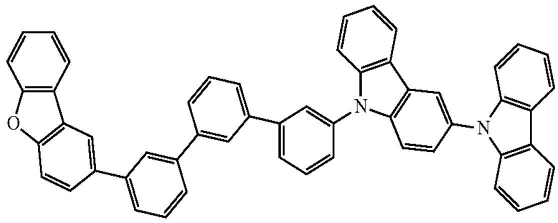
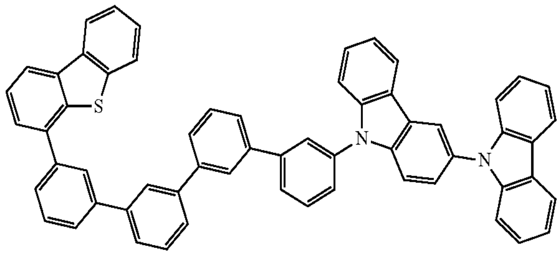
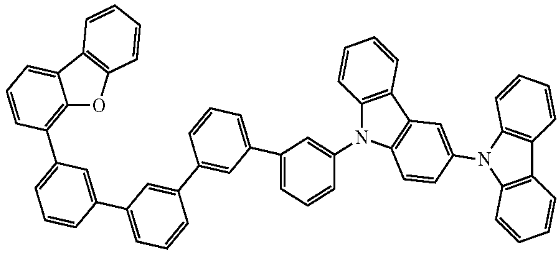
Compound 12



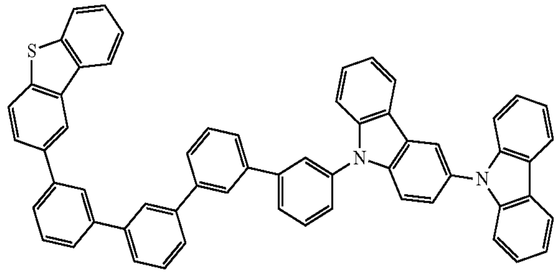
Compound 13



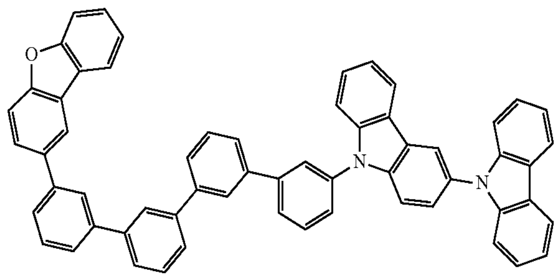
Compound 14



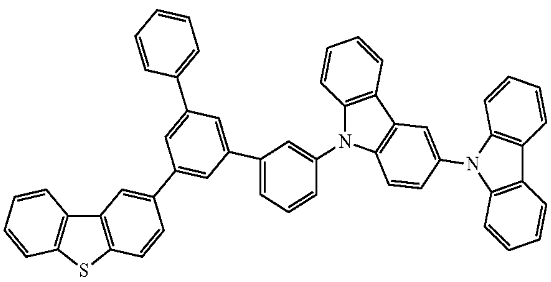
Compound 15



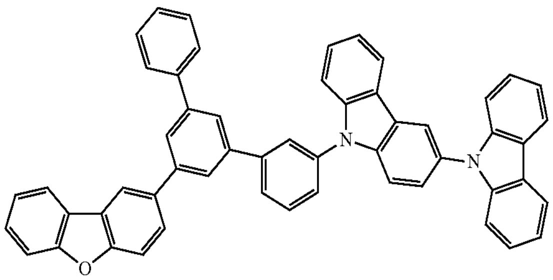
Compound 16



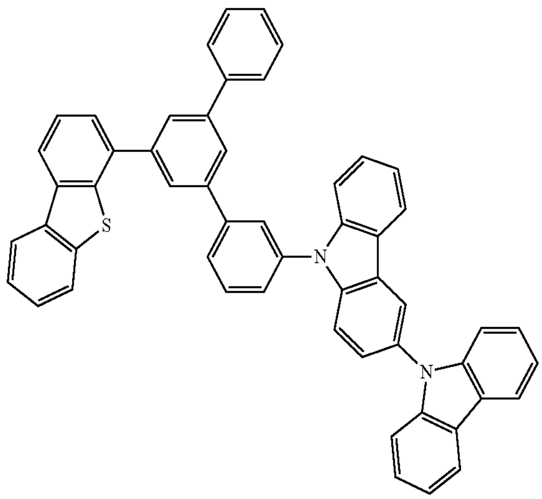
Compound 17



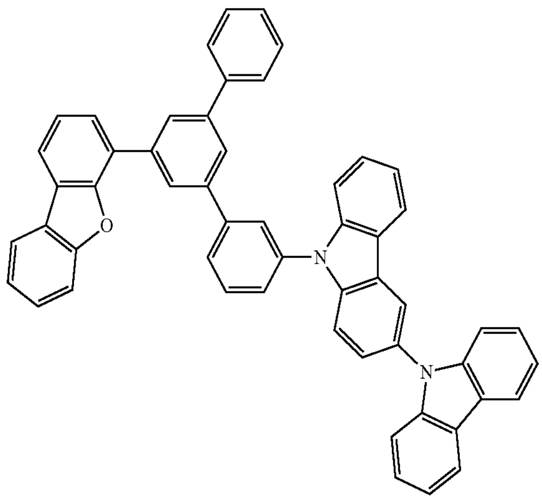
Compound 18



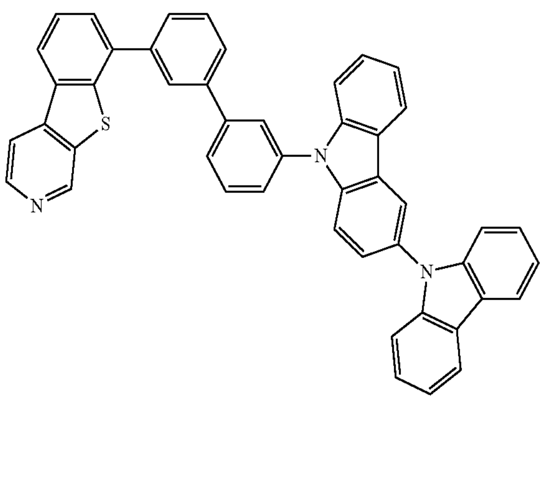
Compound 19



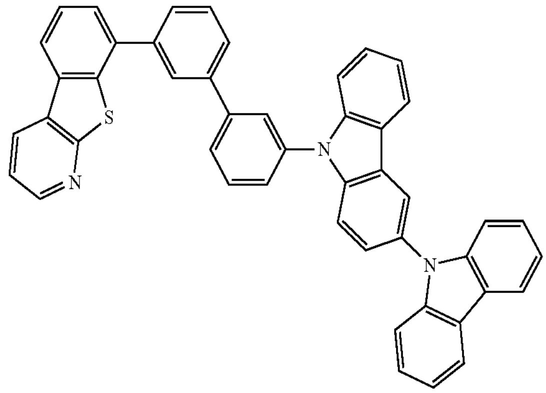
Compound 20



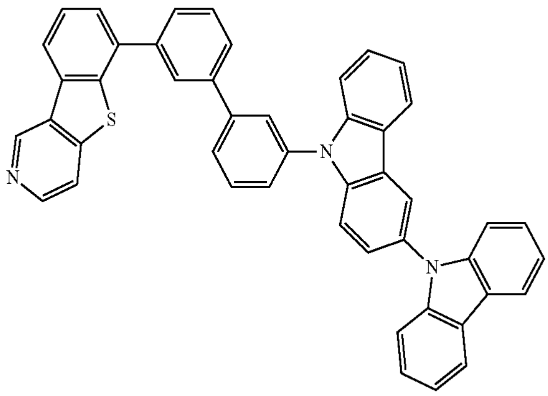
Compound 21



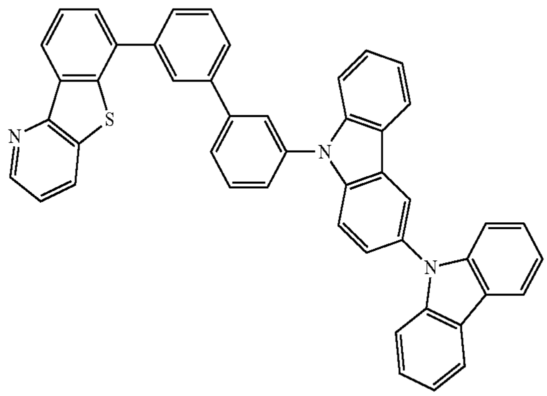
Compound 22



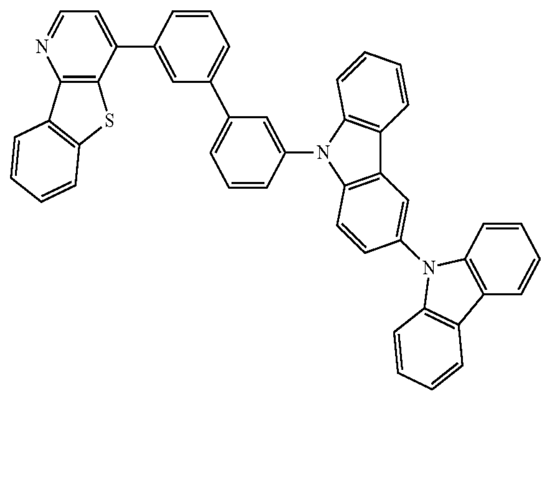
Compound 23



Compound 24



Compound 25



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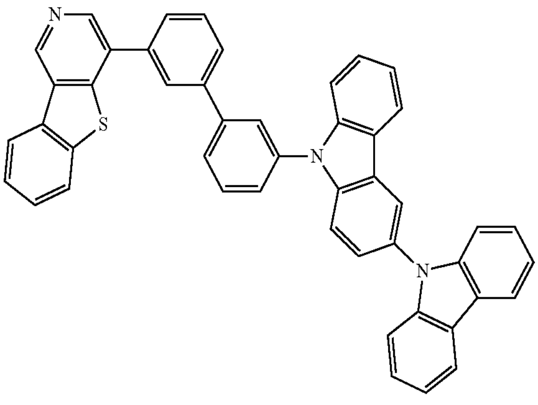
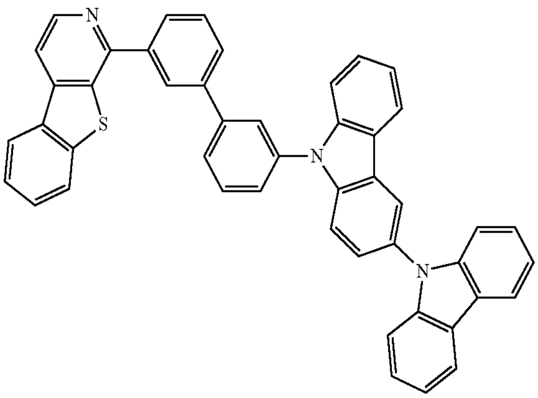
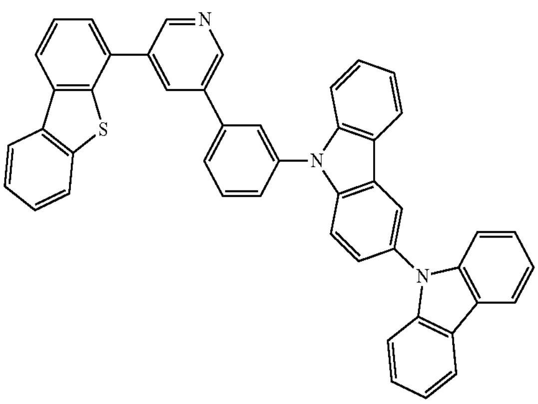
Compound 26



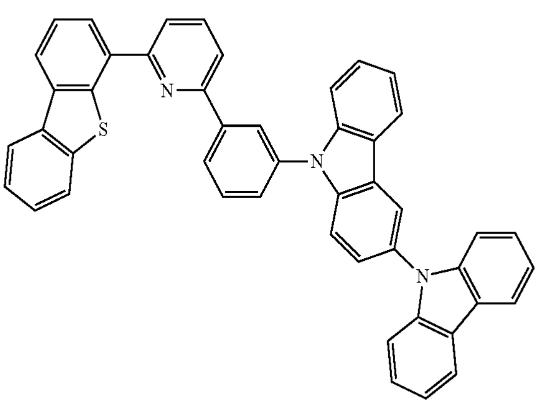
Compound 27



Compound 28



Compound 29



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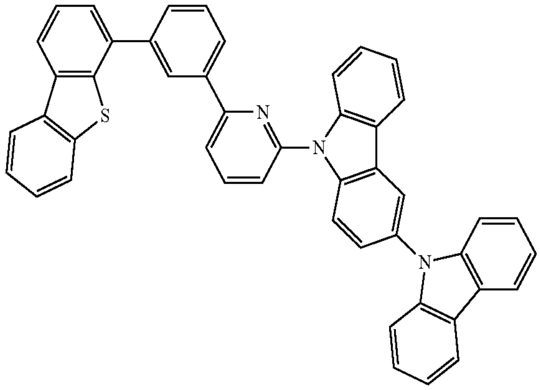
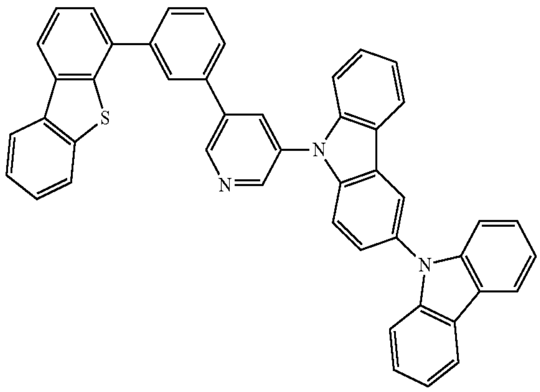
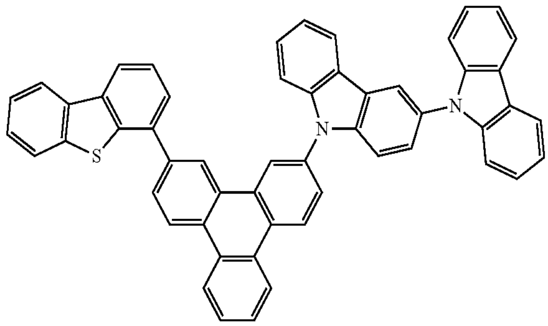
Compound 30



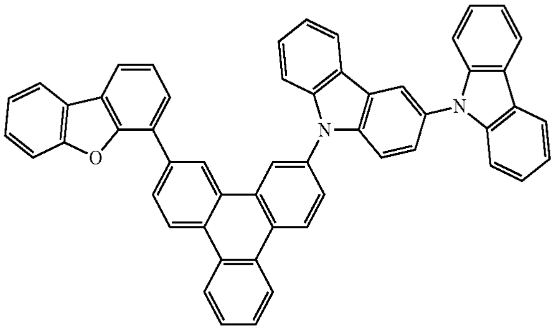
Compound 31



Compound 32



Compound 33



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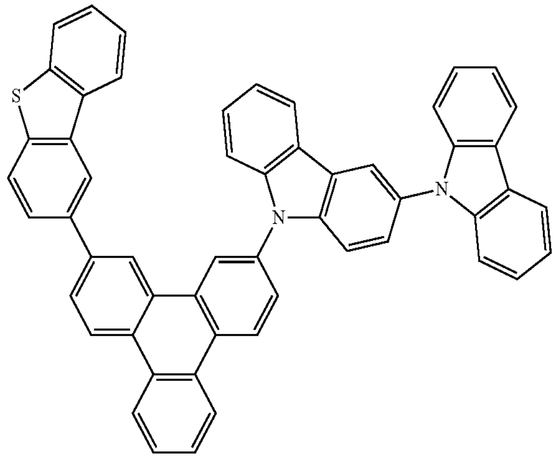
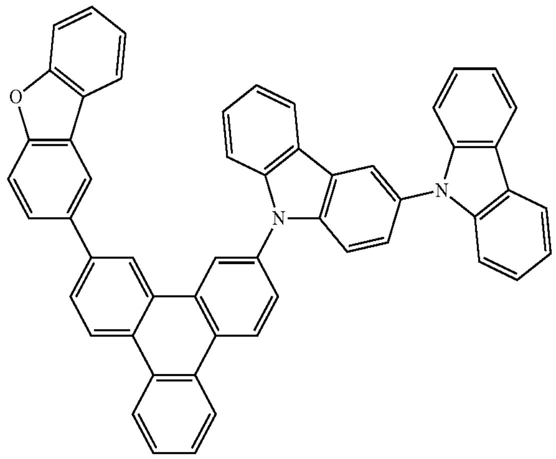
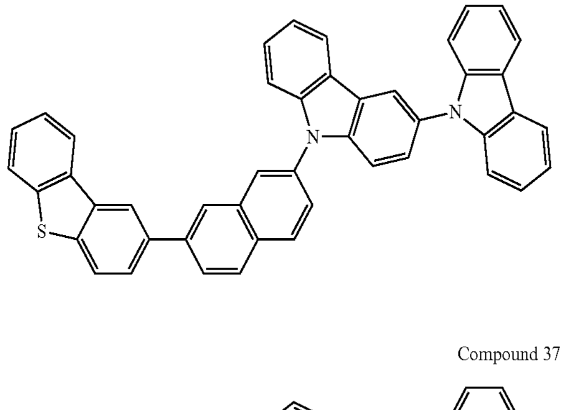
Compound 34



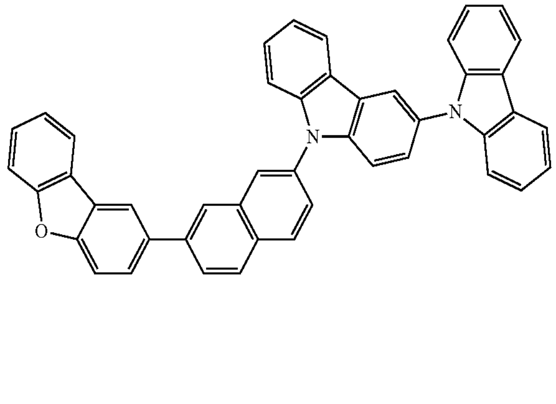
Compound 35



Compound 36



Compound 37



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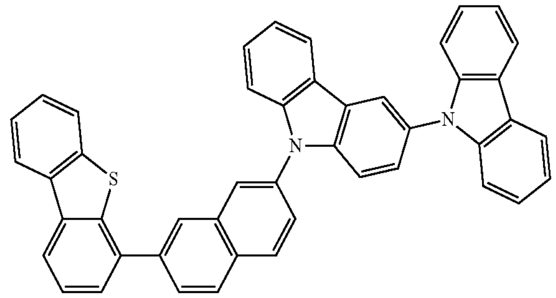
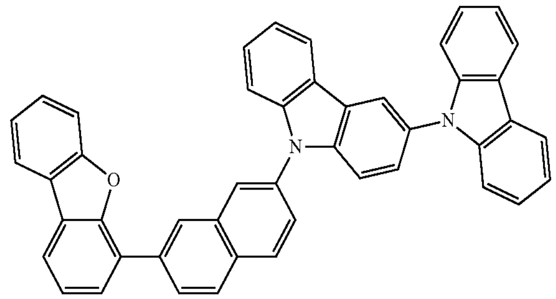
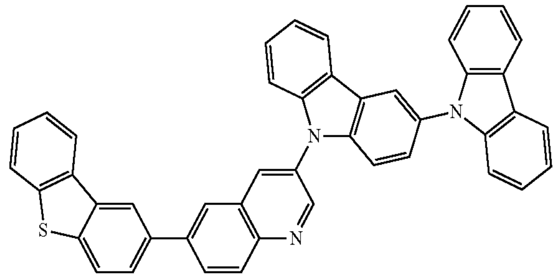
Compound 38



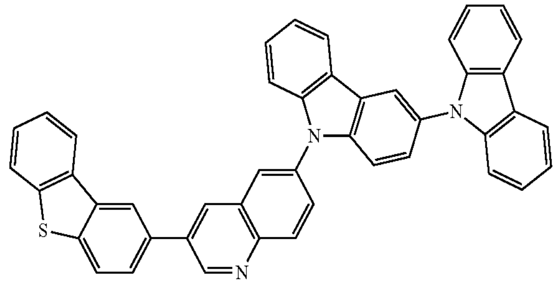
Compound 39



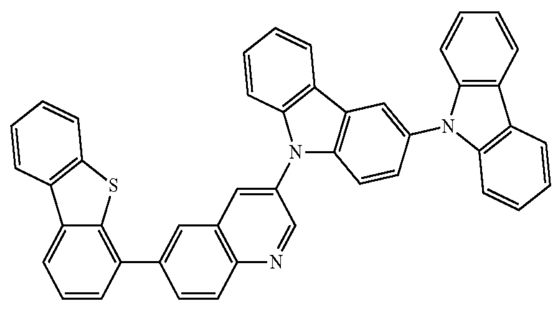
Compound 40



Compound 41

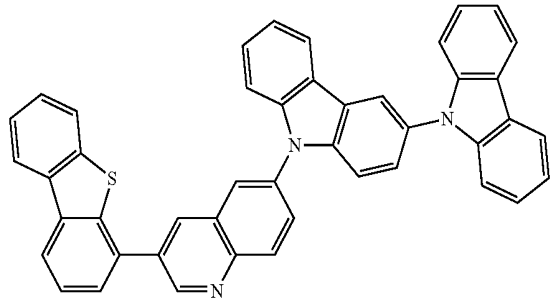


Compound 42

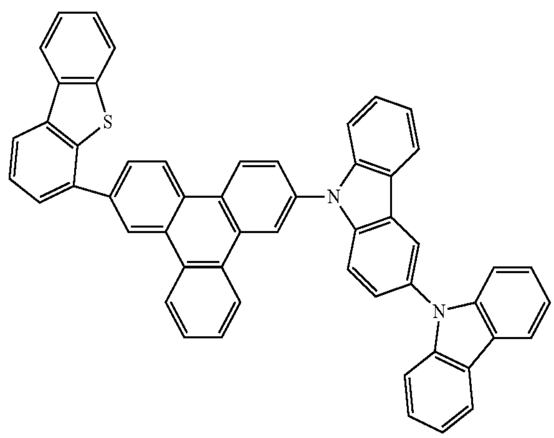


-continued

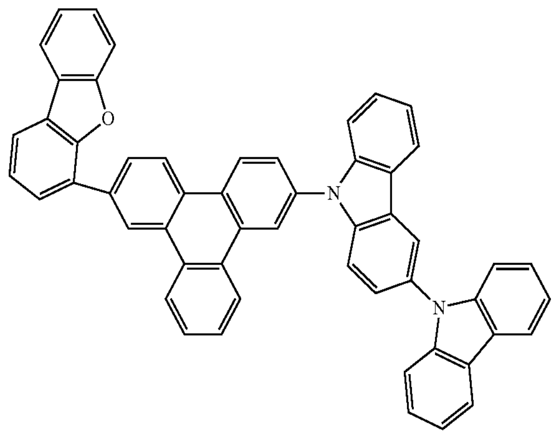
Compound 43



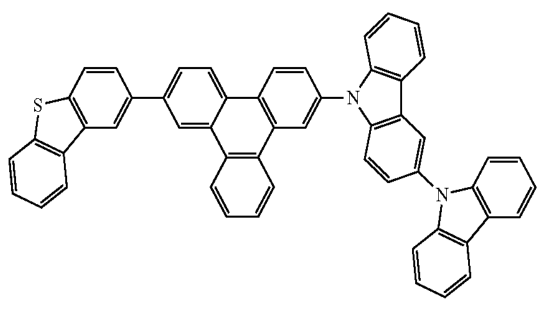
Compound 44



Compound 45



Compound 46



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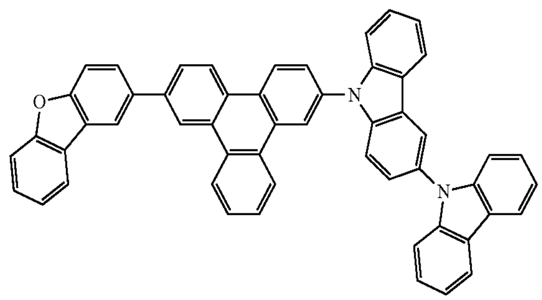
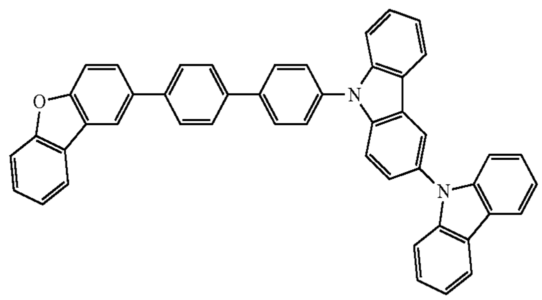
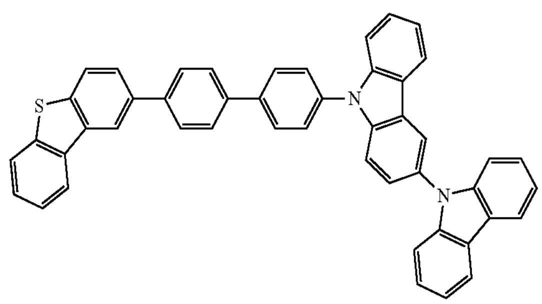
Compound 47



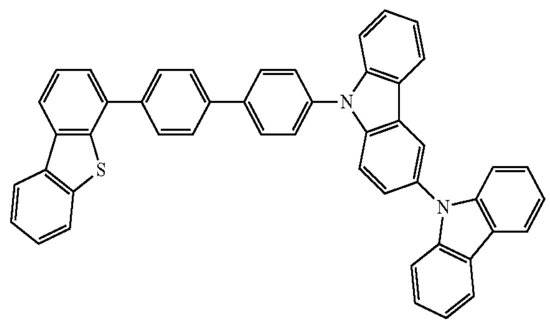
Compound 48



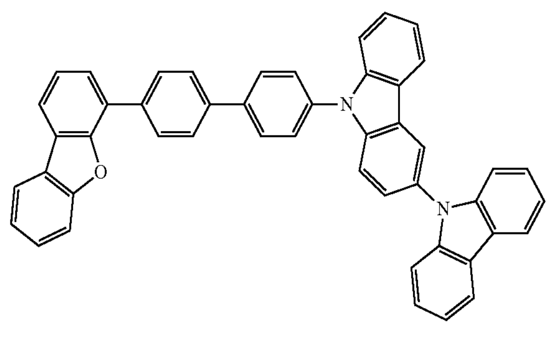
Compound 49



Compound 50



Compound 51



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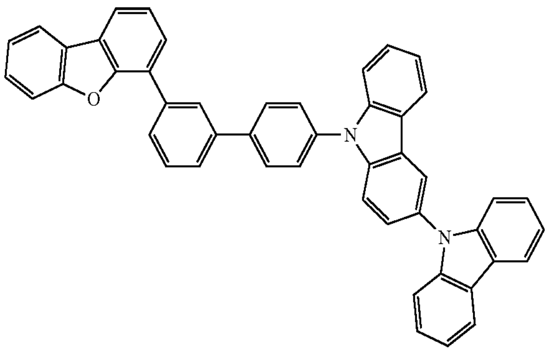
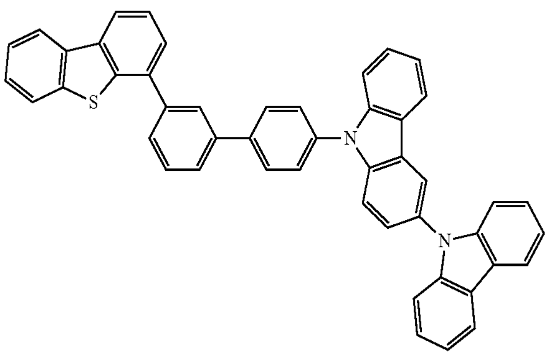
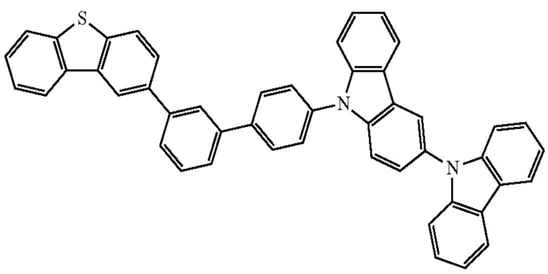
Compound 52



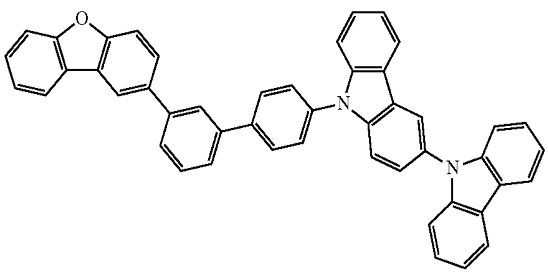
Compound 53



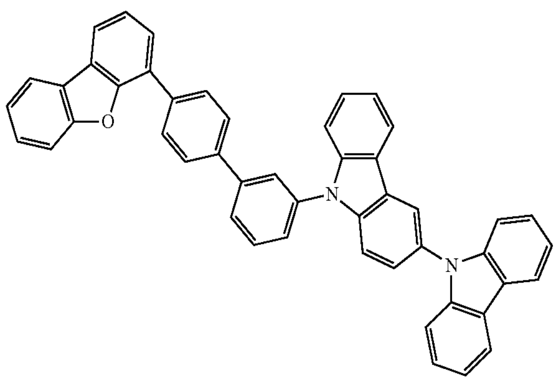
Compound 54



Compound 55



Compound 56



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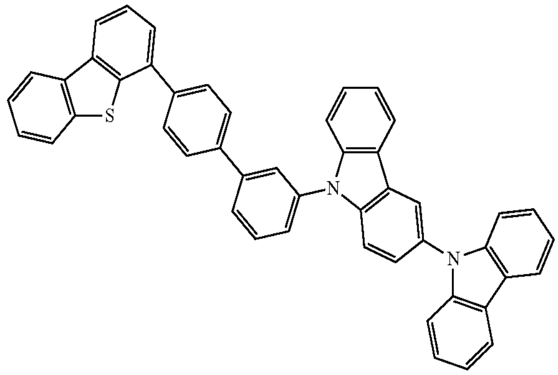
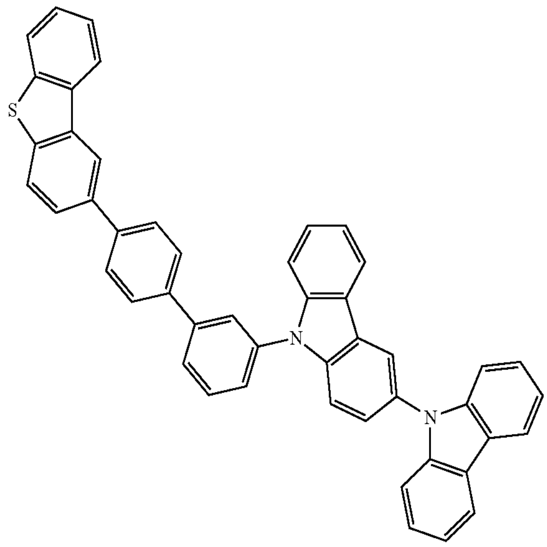
Compound 57



Compound 58



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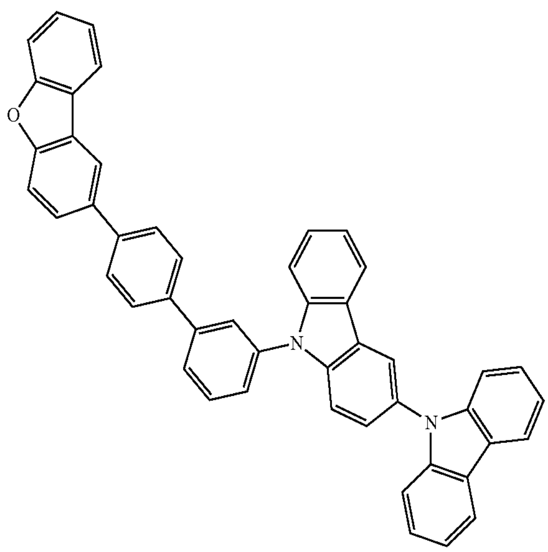

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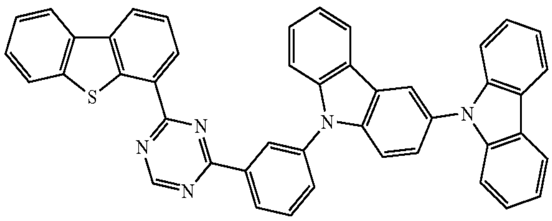
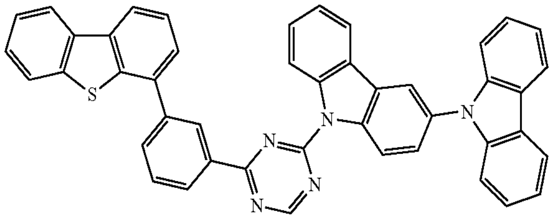
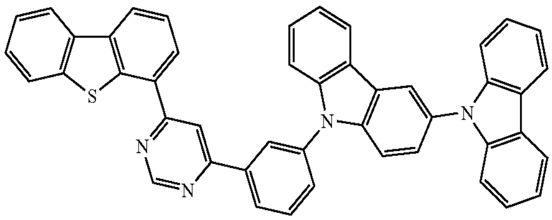
Compound 60



Compound 61



Compound 62



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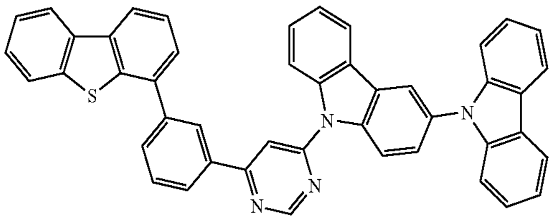
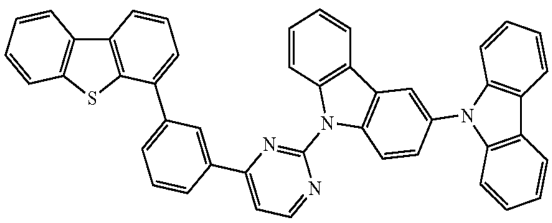


Compound 64



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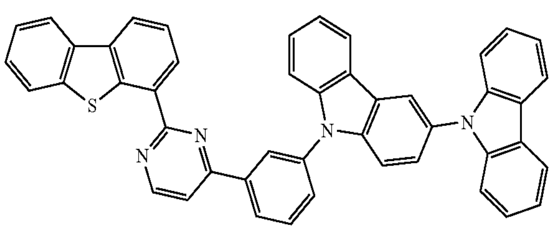
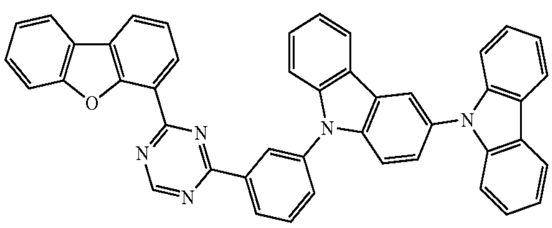


Compound 66



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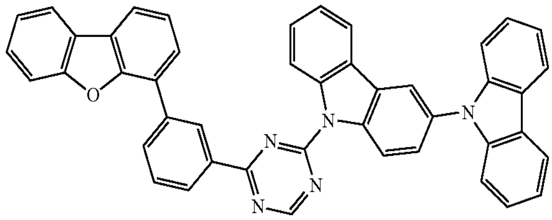
Compound 67



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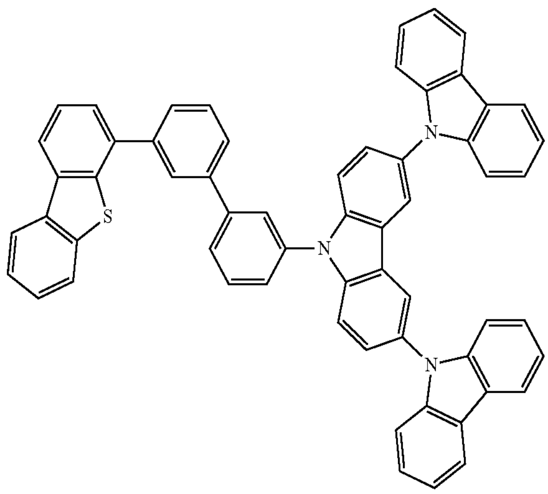
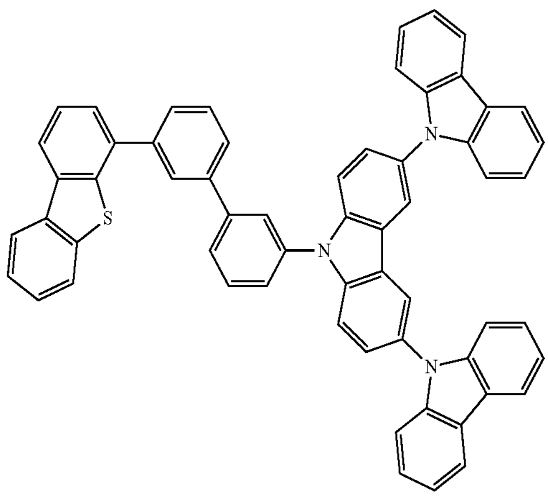


Compound 69



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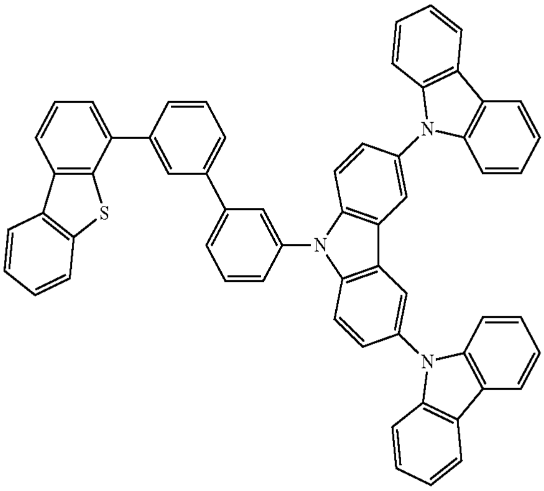
Compound 70



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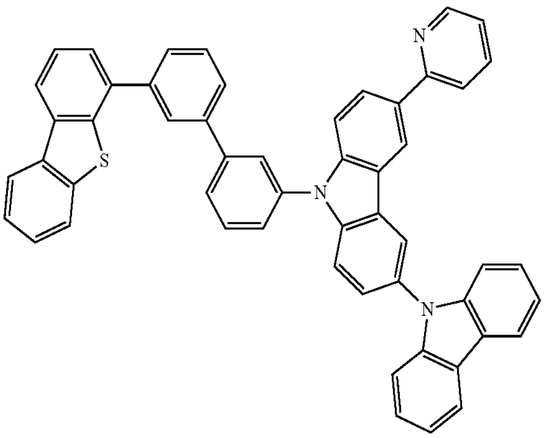
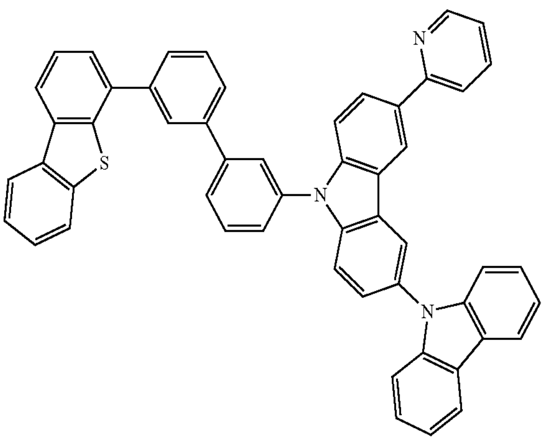


Compound 72



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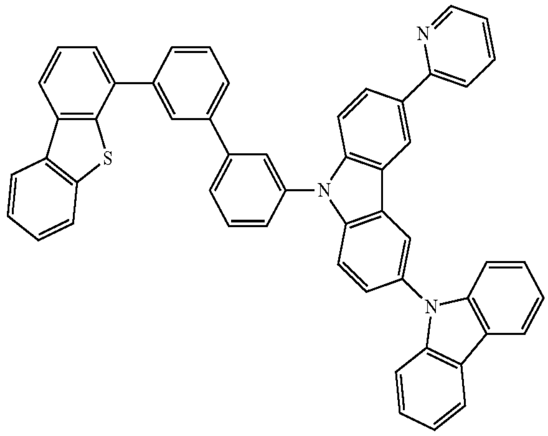
Compound 73



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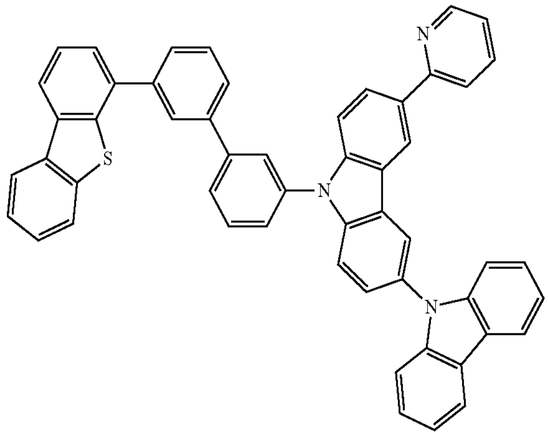

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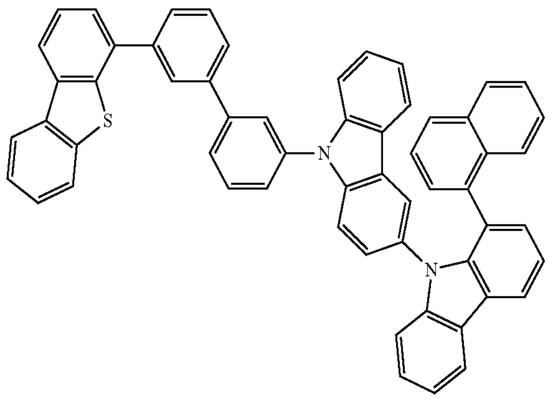
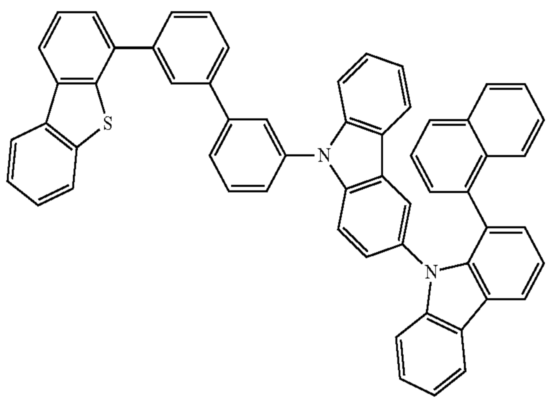


Compound 76



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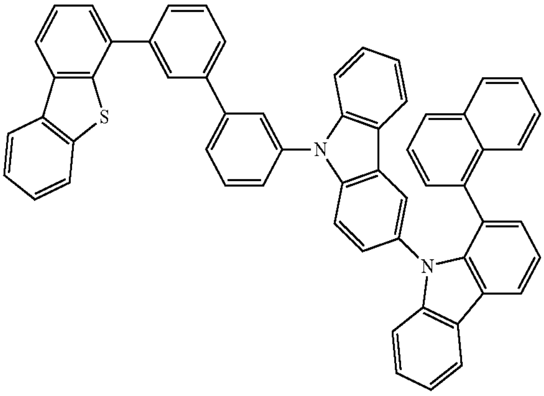
Compound 77



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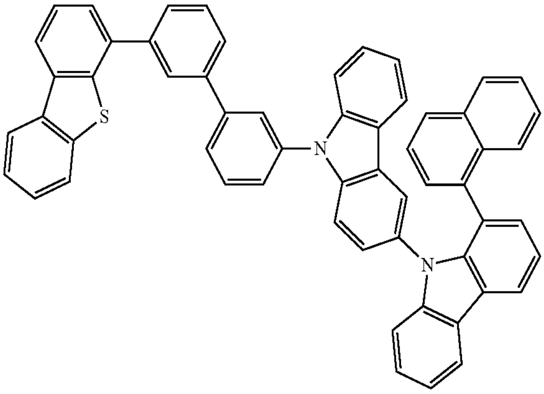
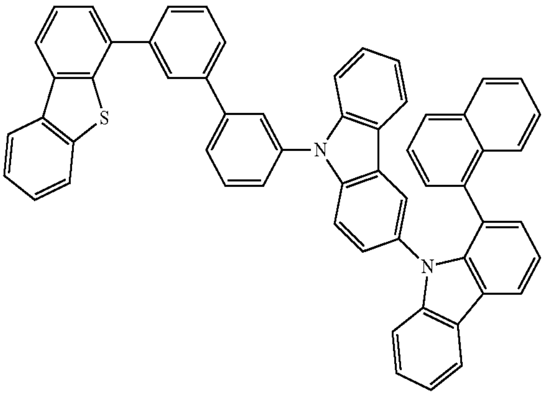
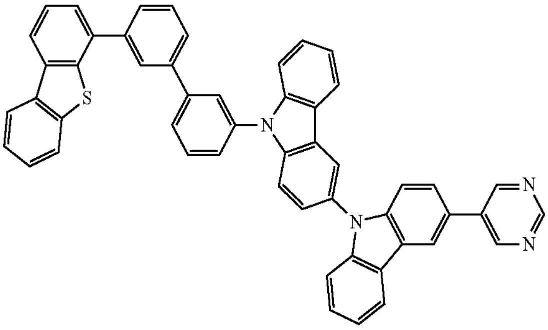


Compound 79



Compound 80



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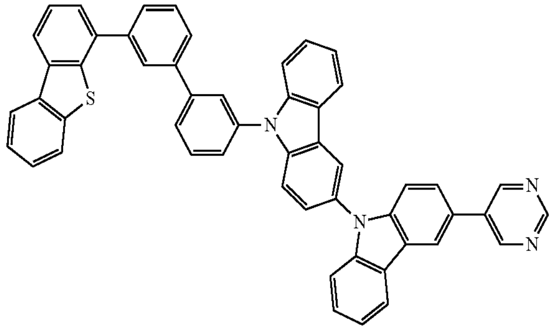
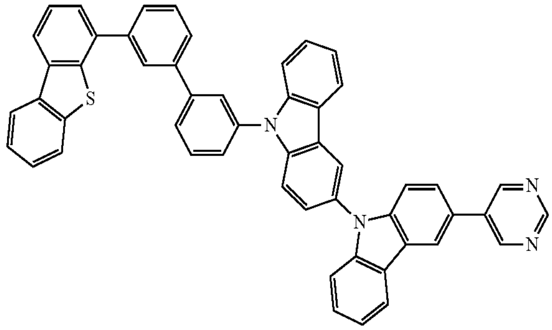
Compound 81



Compound 82



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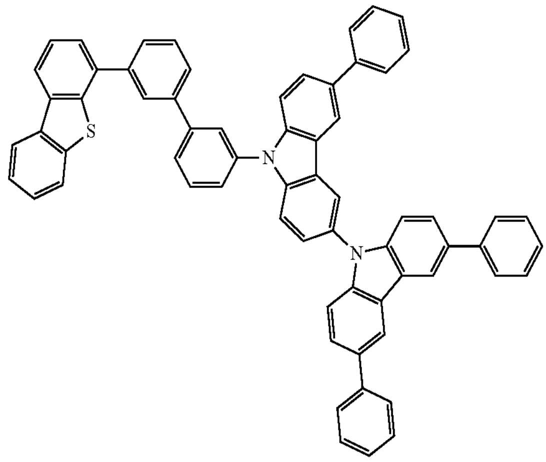
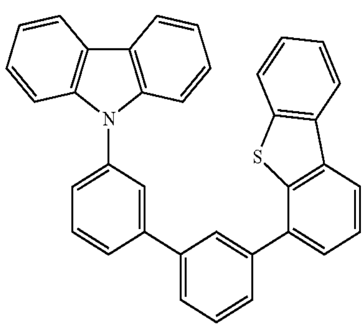


Compound 84



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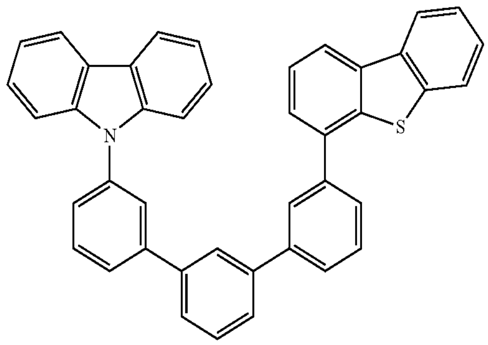
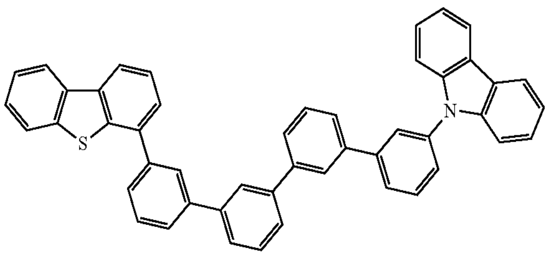
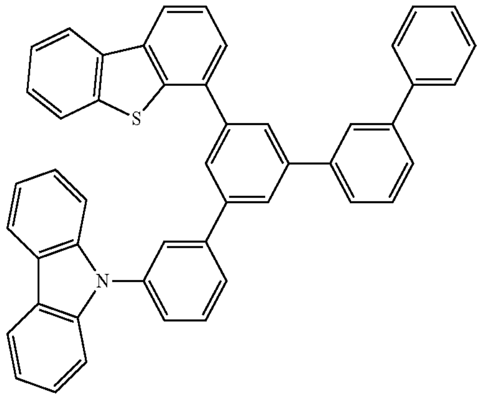
Compound 85



Compound 86



Compound 87



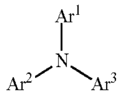
Combination with Other Materials

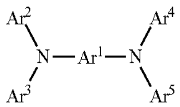
The materials described herein as useful for a particular layer in an organic light emitting device may be used in combination with a wide variety of other materials present in the device. For example, emissive dopants disclosed herein may be used in conjunction with a wide variety of hosts, transport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

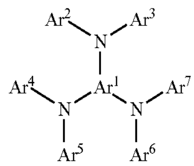
HIL/HTL:

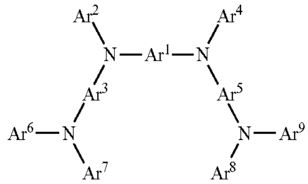
A hole injecting/transporting material to be used in embodiments of the present invention is not particularly limited, and any compound may be used as long as the compound is typically used as a hole injecting/transporting material. Examples of the material include, but are not limited to: a phthalocyanine 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 silane 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.

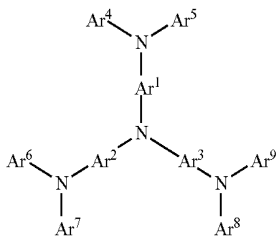
Examples of aromatic amine derivatives used in HIL or HTL include, but are not limited to the following general structures:





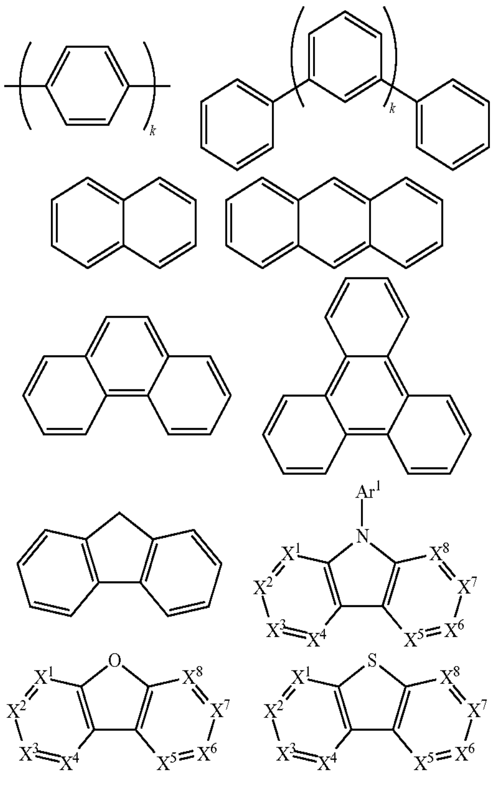






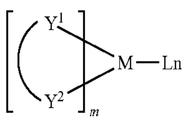
Each of Ar^1 to Ar^9 is selected from the group consisting aromatic hydrocarbon cyclic compounds such as benzene, biphenyl, triphenyl, triphenylene, naphthalene, anthracene, phenalene, phenanthrene, fluorene, pyrene, chrysene, perylene, azulene; group consisting aromatic heterocyclic compounds such as 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, alkyl, alkoxy, amino, alkenyl, alkynyl, arylalkyl, heteroalkyl, aryl and heteroaryl.

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 CH or N; Ar^1 has the same group defined above.

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



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

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

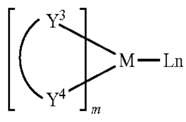
In another aspect, M is selected from Ir, Pt, Os, and Zn.

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:

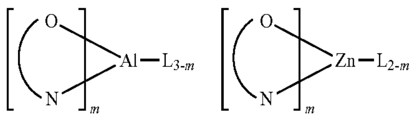
The light emitting layer of the organic EL device of embodiments of the present invention preferably contains at least a metal complex as light emitting material, and may contain a host material using the metal complex as a dopant material. Examples of the host material are not particularly limited, 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; $(Y^3\text{-}Y^4)$ is a bidentate ligand, Y^3 and Y^4 are independently selected from C, N, O, P, and S; L is an ancillary ligand; m is an integer value from 1 to the maximum number of ligands that may be attached to the metal; and m+n is the maximum number of ligands that may be attached to the metal.

In one aspect, the metal complexes are:



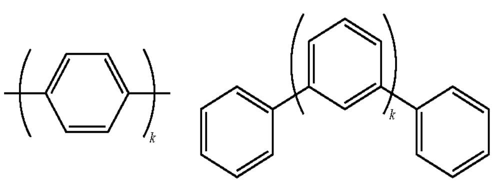
(O—N) is a bidentate ligand, having metal coordinated to atoms O and N.

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

In a further aspect, $(Y^3\text{-}Y^4)$ 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 atom, 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, alkyl, alkoxy, amino, alkenyl, alkynyl, arylalkyl, heteroalkyl, aryl and heteroaryl.

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



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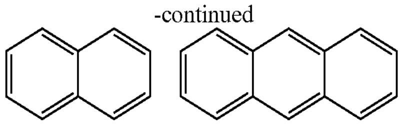
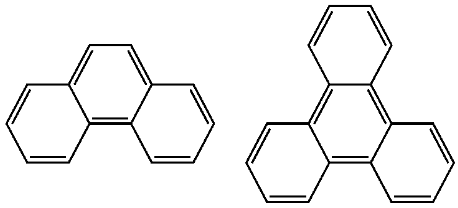
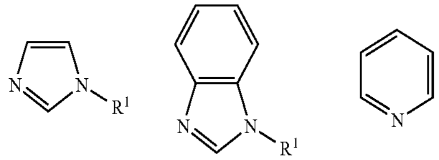
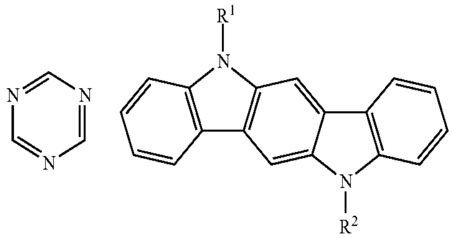
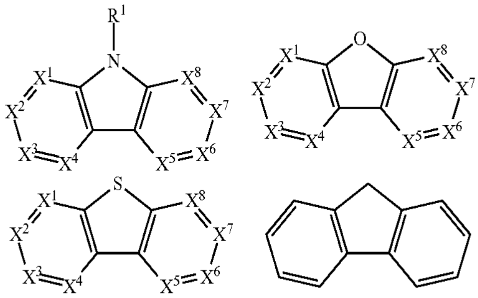
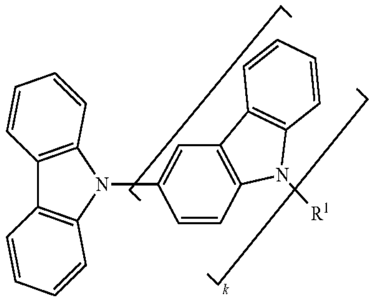


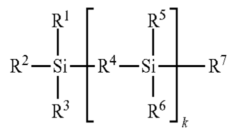


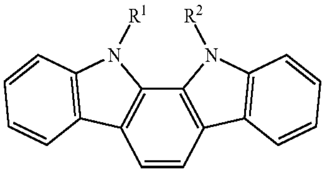












R^1 to R^7 is independently selected from the group consisting of hydrogen, deuterium, alkyl, alkoxy, amino, alkenyl, alkynyl, arylalkyl, heteroalkyl, aryl and heteroaryl, when it is aryl or heteroaryl, it has the similar definition as Ar's mentioned above.

k is an integer from 0 to 20.

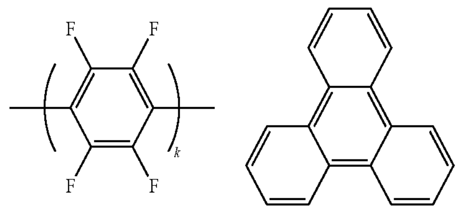
X^1 to X^8 is selected from CH or N.

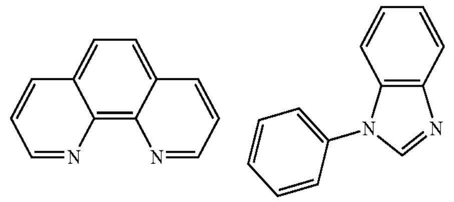
HBL:

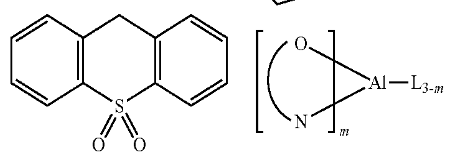
A hole blocking layer (HBL) may be used to reduce the number of holes and/or excitons that leave the emissive layer. The presence of such a blocking layer in a device may result in substantially higher efficiencies as compared to a similar device lacking a blocking layer. Also, a blocking layer may be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





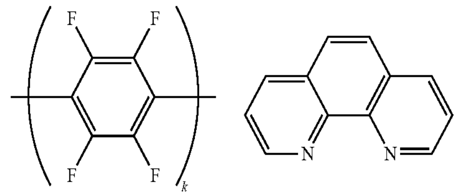


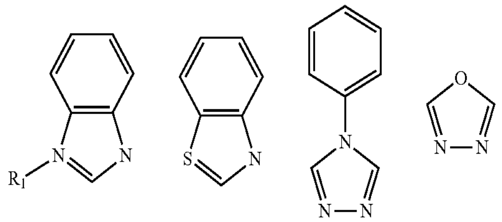
k is an integer from 0 to 20; L is an ancillary ligand, m is an integer from 1 to 3.

ETL:

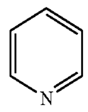
Electron transport layer (ETL) may include a material capable of transporting electrons. Electron transport layer may be intrinsic (undoped), or doped. Doping may be used to enhance conductivity. Examples of the ETL material are not particularly limited, and any metal complexes or organic compounds may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

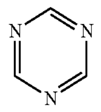
In one aspect, compound used in ETL contains at least one of the following groups in the molecule:

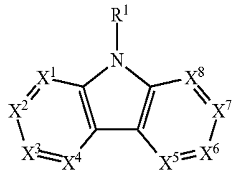


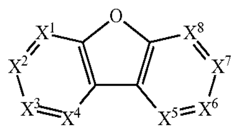


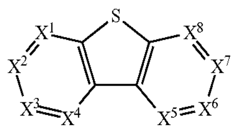
-continued

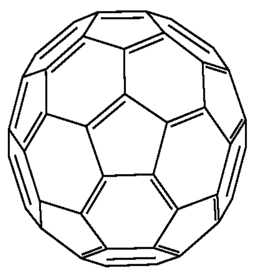


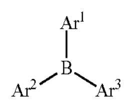












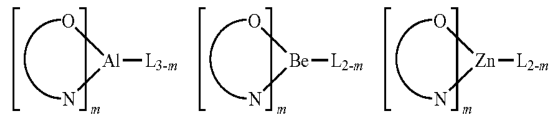
R^1 is selected from the group consisting of hydrogen, deuterium, alkyl, alkoxy, amino, alkenyl, alkynyl, arylalkyl, heteroalkyl, aryl and heteroaryl, when it is aryl or heteroaryl, it has the similar definition as Ar's mentioned above.

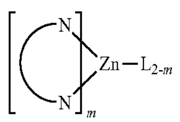
Ar^1 to Ar^3 has the similar definition as Ar's mentioned above.

k is an integer from 0 to 20.

X^1 to X^8 is selected from 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 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 1 below. Table 1 lists non-limiting classes of materials, non-limiting examples of compounds for each class, and references that disclose the materials.

TABLE 1

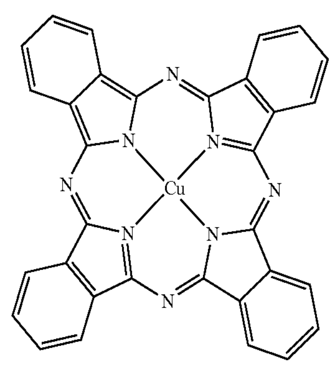
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
	Hole injection materials	
Phthalocyanine and porphryin compounds		Appl. Phys. Lett. 69, 2160 (1996)

TABLE 1-continued

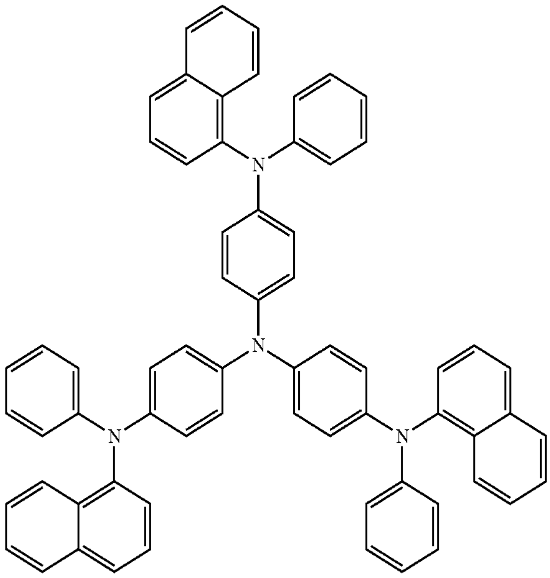
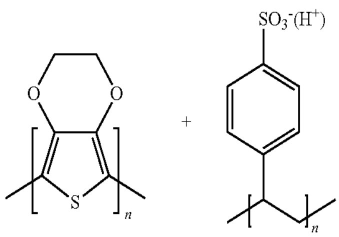
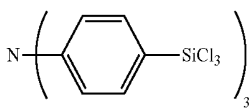
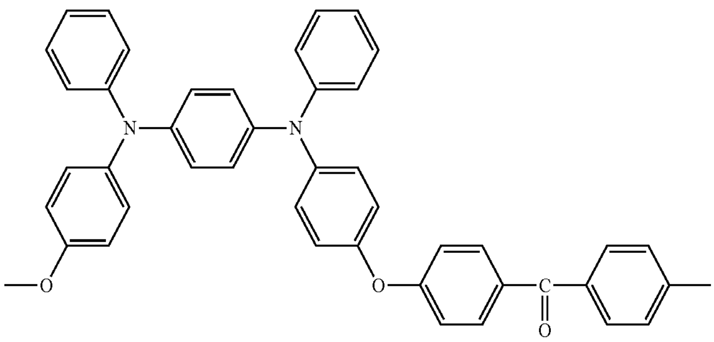
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Starburst triarylamines		J. Lumin. 72-74, 985 (1997)
CF_x Fluoro-hydrocarbon polymer	$\left[CH_xF_y \right]_n$	Appl. Phys. Lett. 78, 673 (2001)
Conducting polymers (e.g., PEDOT:PSS, polyaniline, polypthiophene)		Synth. Met. 87, 171 (1997) WO2007002683
Phosphonic acid and silane SAMs		US20030162053
Triarylamine or polythiophene polymers with conductivity dopants	 and	EA01725079A1

TABLE 1-continued

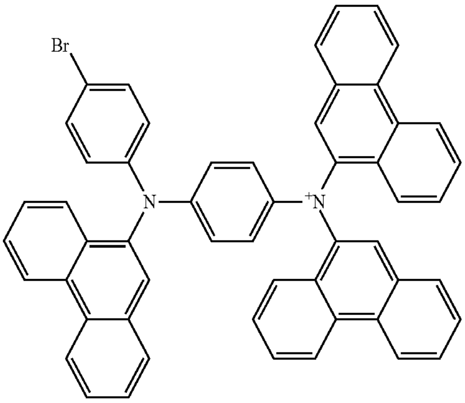
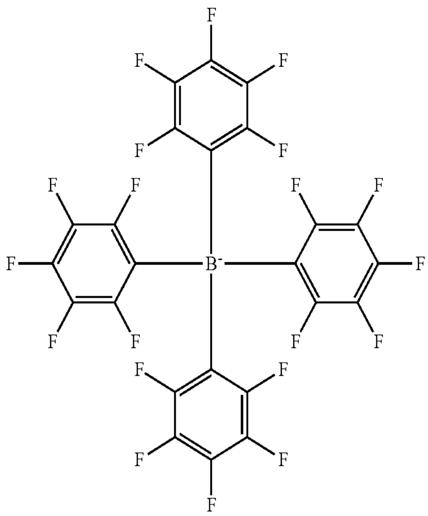
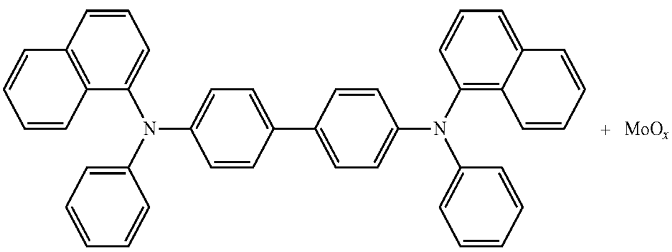
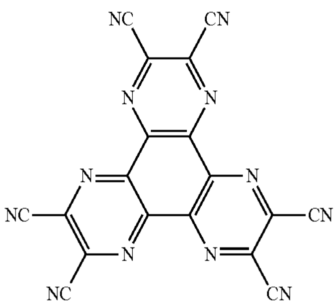
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
	 	
Arylamines complexed with metal oxides such as molybdenum and tungsten oxides		SID Symposium Digest, 37, 923 (2006) WO2009018009
p-type semiconducting organic complexes		US20020158242

TABLE 1-continued

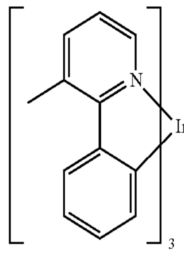
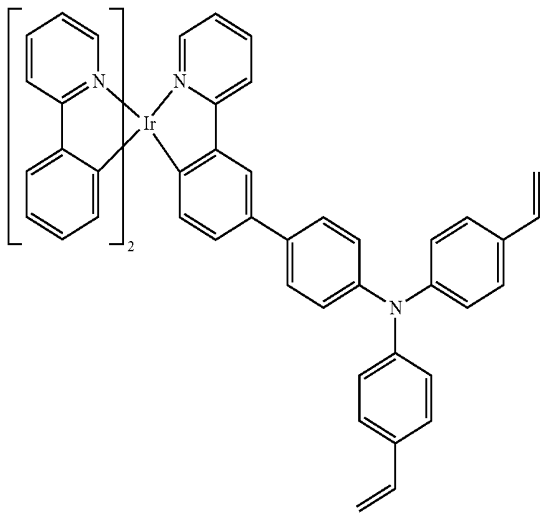
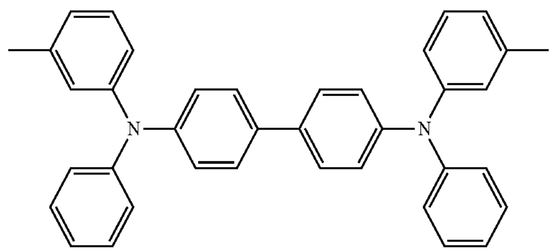
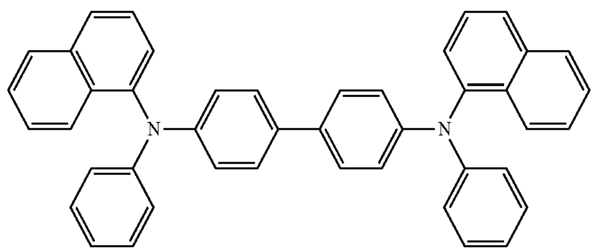
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Metal organometallic complexes		US20060240279
Cross-linkable compounds		US20080220265
Hole transporting materials		
Triarylamines (e.g., TPD, α-NPD)		Appl. Phys. Lett. 51, 913 (1987)
		U.S. Pat. No. 5,061,569

TABLE 1-continued

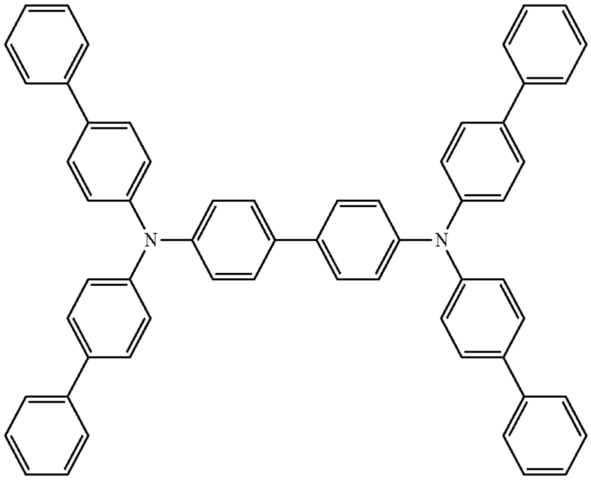
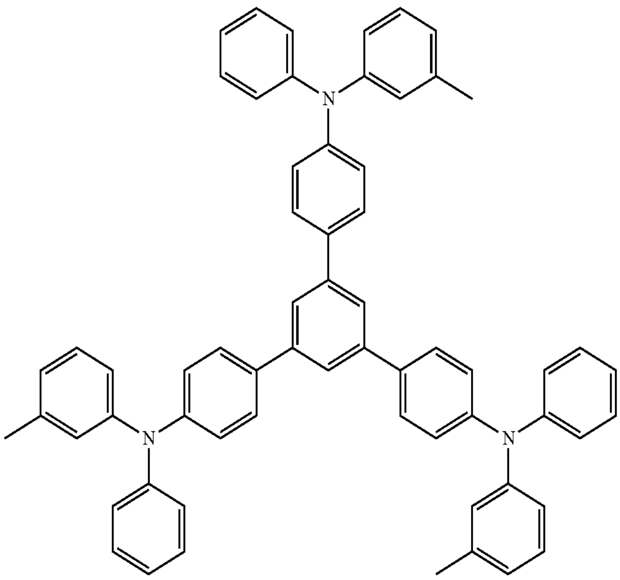
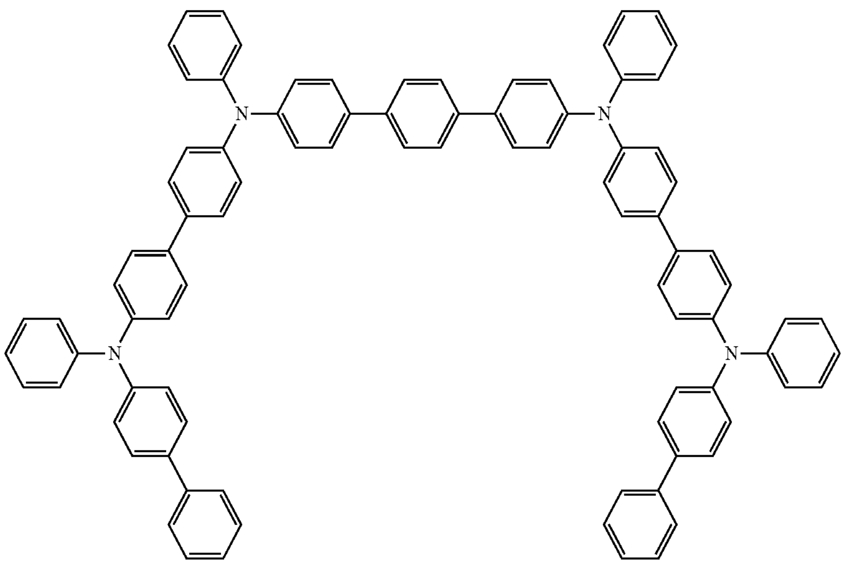
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		EP650955
		J. Mater. Chem. 3, 319 (1993)
		Appl. Phys. Lett. 90, 183503 (2007)

TABLE 1-continued

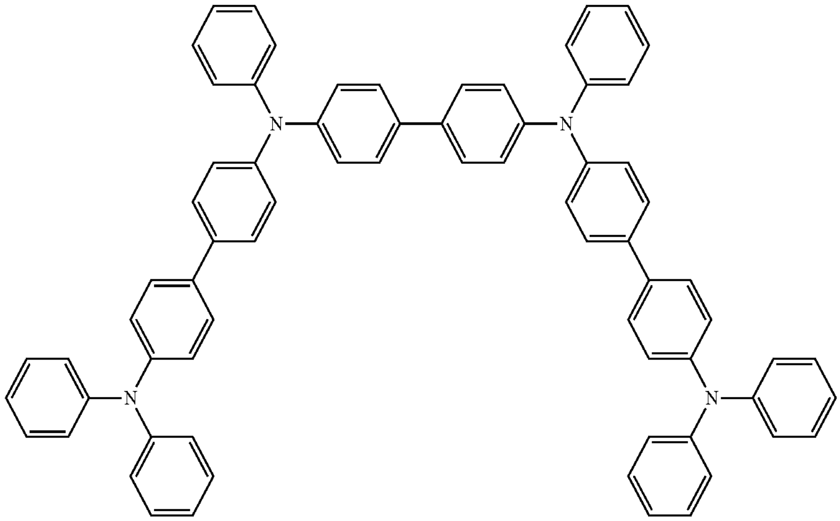
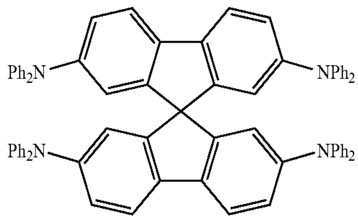
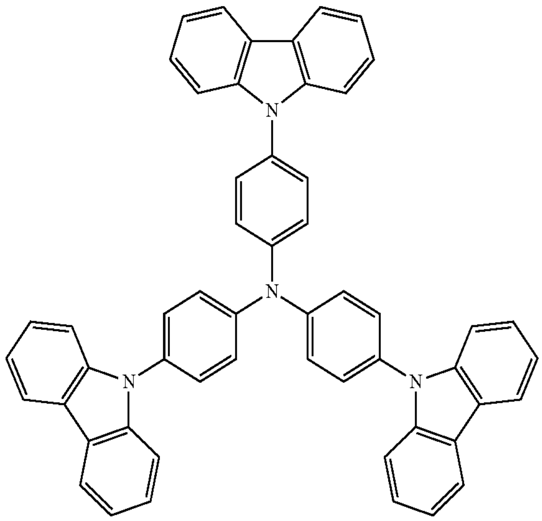
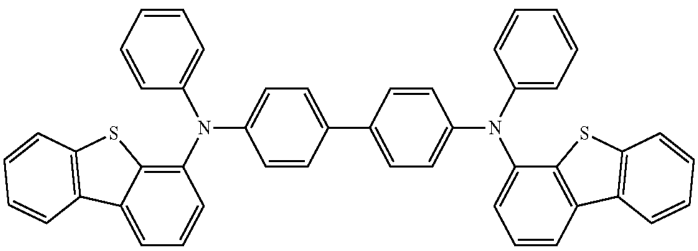
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		Appl. Phys. Lett. 90, 183503 (2007)
Triaylamine on spirofluorene core		Synth. Met. 91, 209 (1997)
Arylamine carbazole compounds		Adv. Mater. 6, 677 (1994), US20080124572
Triarylamine with (di)benzo-thiophene/ (di)benzofuran		US20070278938, US20080106190

TABLE 1-continued

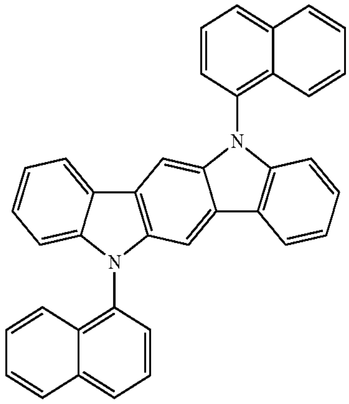
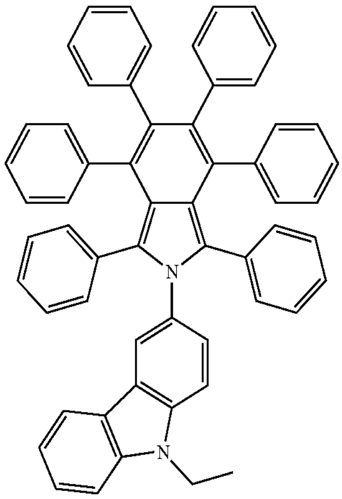
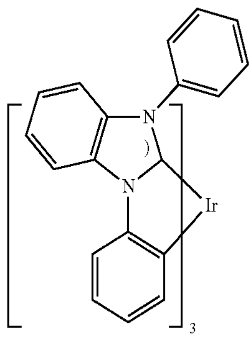
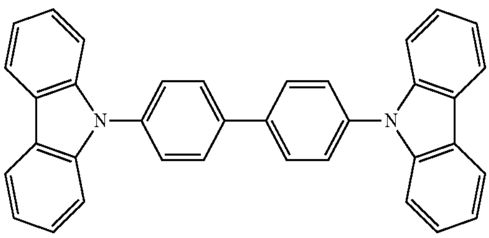
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Indolo-carbazoles		Synth. Met. 111, 421 (2000)
Isoindole compounds		Chem. Mater. 15, 3148 (2003)
Metal carbene complexes		US20080018221
	Phosphorescent OLED host materials Red hosts	
Arylcarbazoles		Appl. Phys. Lett. 78, 1622 (2001)

TABLE 1-continued

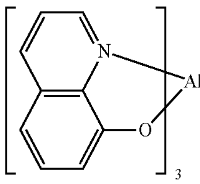
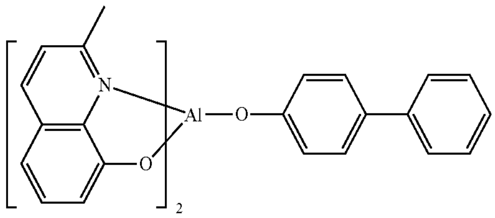
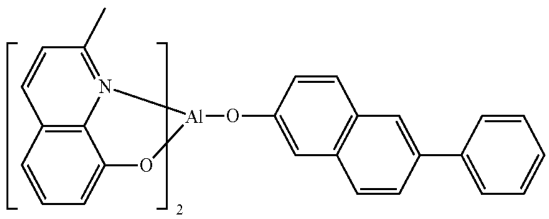
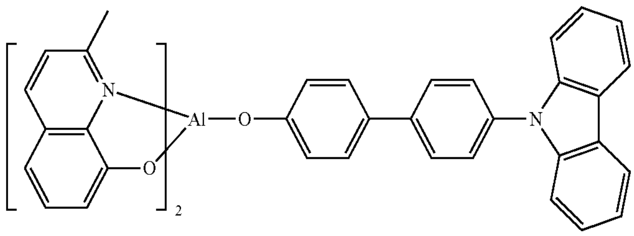
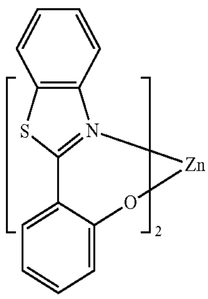
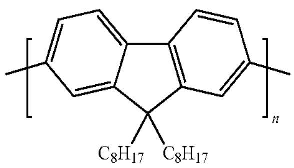
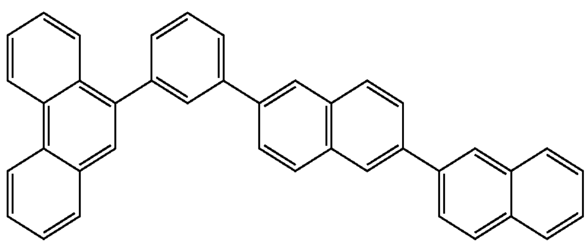
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Metal 8-hydroxy-quinolates (e.g., Alq_3, BAlq)		Nature 395, 151 (1998)
		US20060202194
		WO2005014551
		WO2006072002
Metal phenoxy-benzothiazole compounds		Appl. Phys. Lett. 90, 123509 (2007)
Conjugated oligomers and polymers (e.g., polyfluorene)		Org. Electron. 1, 15 (2000)
Aromatic fused rings		WO2009066779, WO2009066778, WO2009063833, US20090045731, US20090045730, WO2009008311, US20090008605, US20090009065

TABLE 1-continued

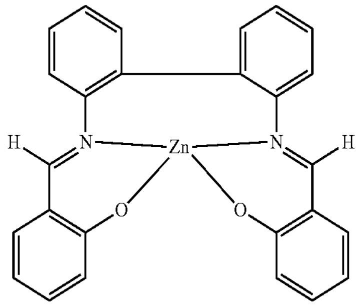
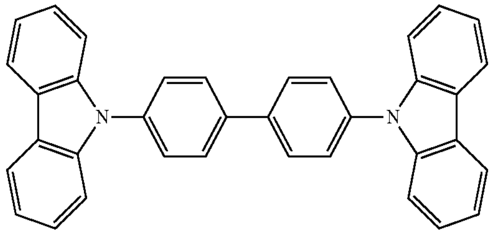
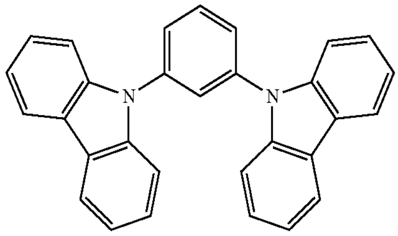
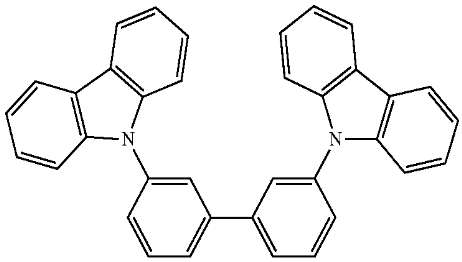
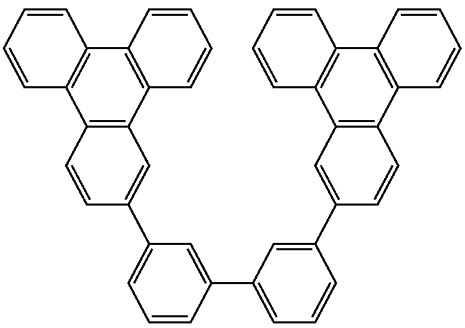
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Zinc complexes		WO2009062578
	Green hosts	
Arylcarbazoles		Appl. Phys. Lett. 78, 1622 (2001)
		US20030175553
		WO2001039234
Aryl-triphenylene compounds		US20060280965

TABLE 1-continued

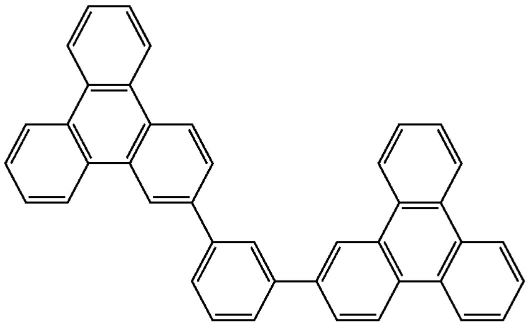
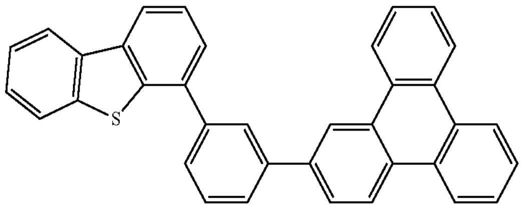
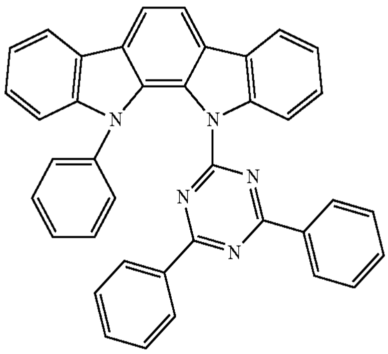
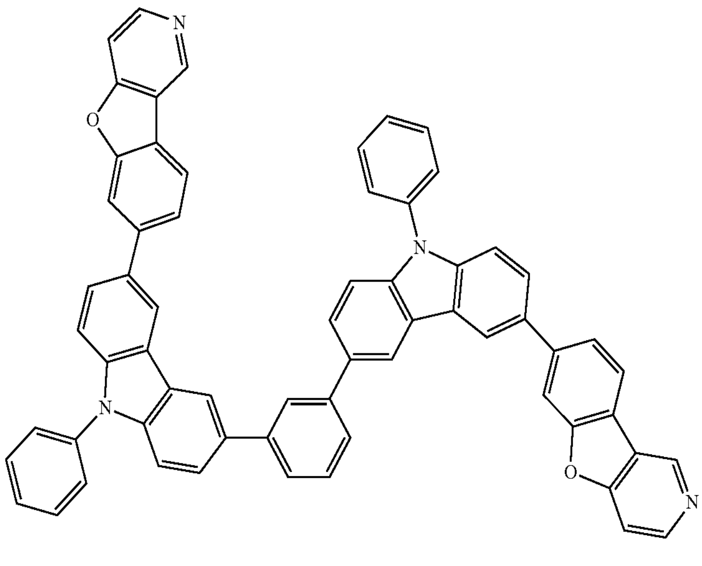
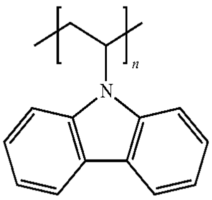
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20060280965
		WO2009021126
Donor acceptor type molecules		WO2008056746
Aza-carbazole/ DBT/DBF		JP2008074939
Polymers (e.g., PVK)		Appl. Phys. Lett. 77, 2280 (2000)

TABLE 1-continued

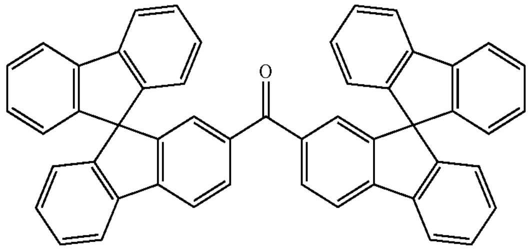
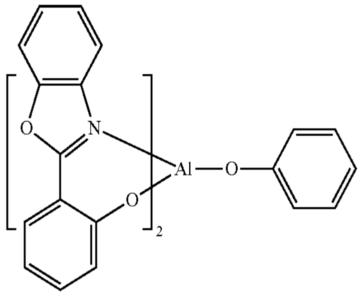
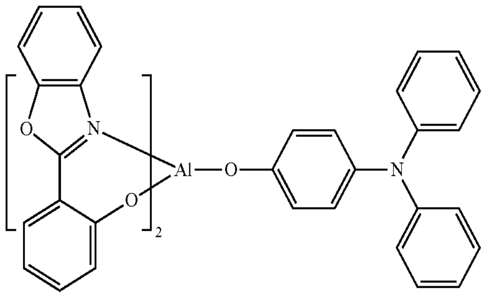
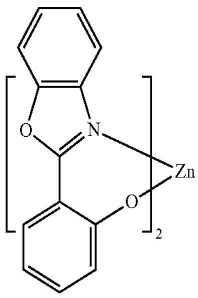
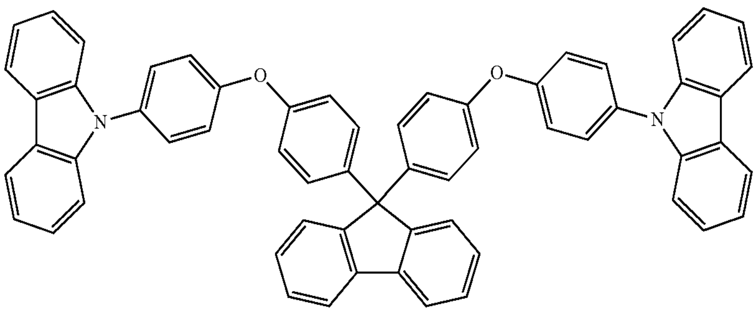
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Spirofluorene compounds		WO2004093207
Metal phenoxy-benzooxazole compounds		WO2005089025
		WO2006132173
		JP200511610
Spirofluorene-carbazole compounds		JP2007254297

TABLE 1-continued

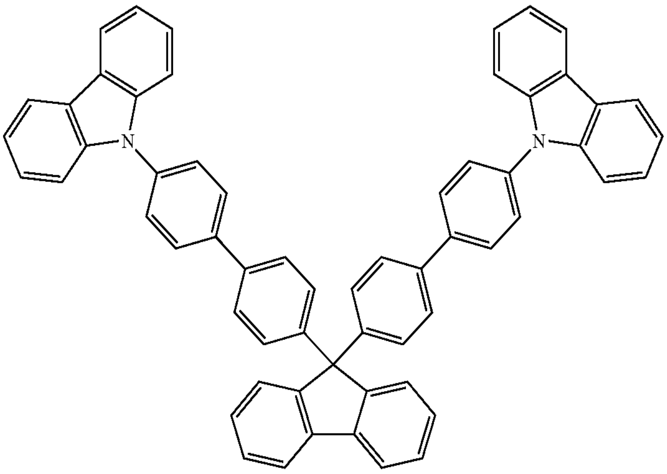
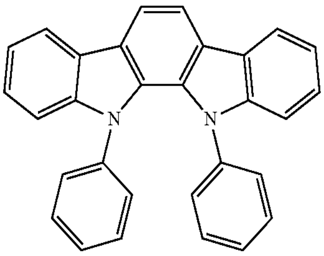
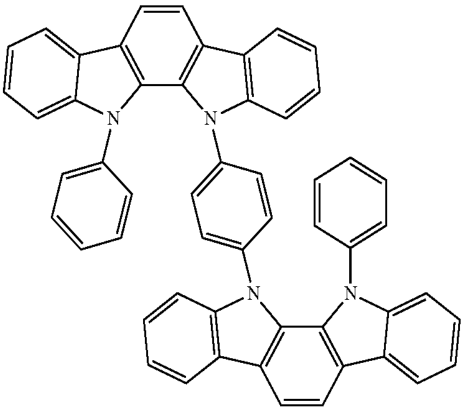
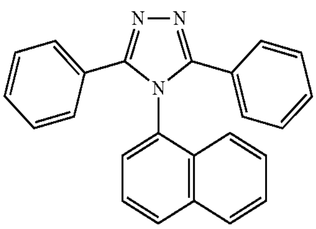
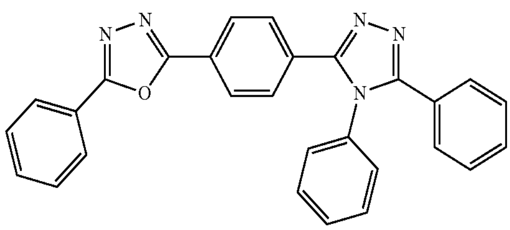
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		JP2007254297
Indolo-carbazoles		WO2007063796
		WO2007063754
5-member ring electron deficient heterocycles (e.g., triazole, oxadiazole)		J. Appl. Phys. 90, 5048 (2001)
		WO2004107822

TABLE 1-continued

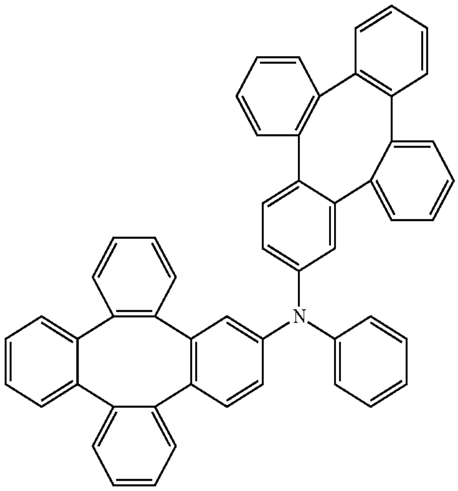
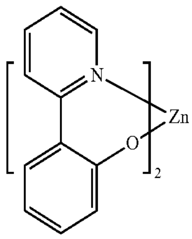
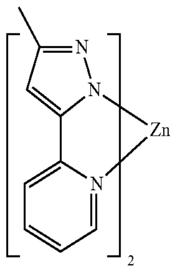
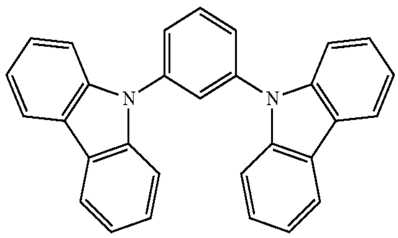
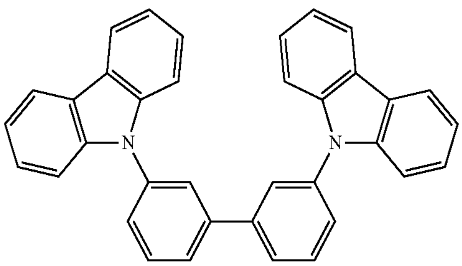
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Tetraphenylene complexes		US20050112407
Metal phenoxy-pyridine compounds		WO2005030900
Metal coordination complexes (e.g., Zn, Al with N^N ligands)		US20040137268, US20040137267
	Blue hosts	
Arylcarbazoles		Appl. Phys. Lett, 82, 2422 (2003)
		US20070190359

TABLE 1-continued

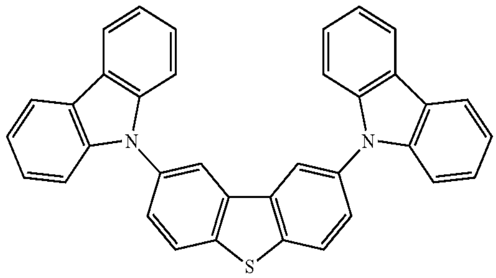
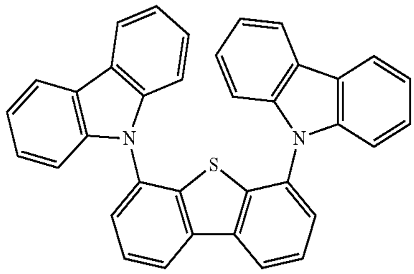
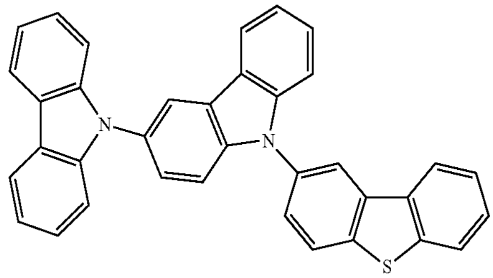
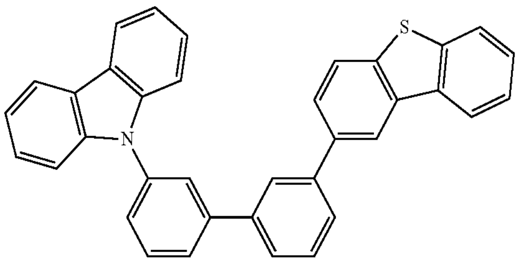
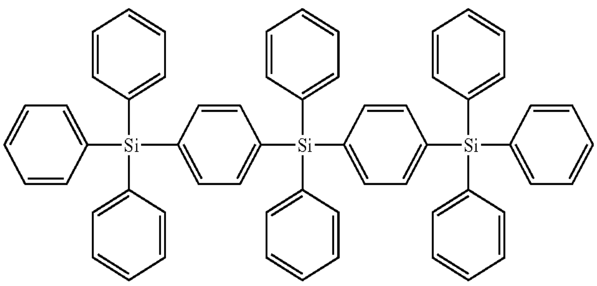
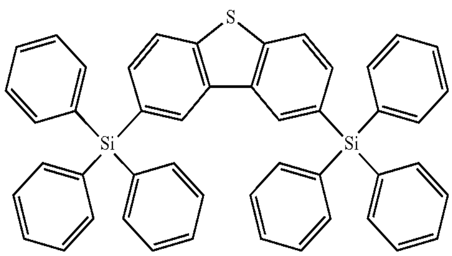
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Dibenzo-thiophene/ Dibenzofuran-carbazole compounds		WO2006114966, US20090167162
		US20090167162
		WO2009086028
		US20090030202, US20090017330
Silicon aryl compounds		US20050238919
		WO2009003898

TABLE 1-continued

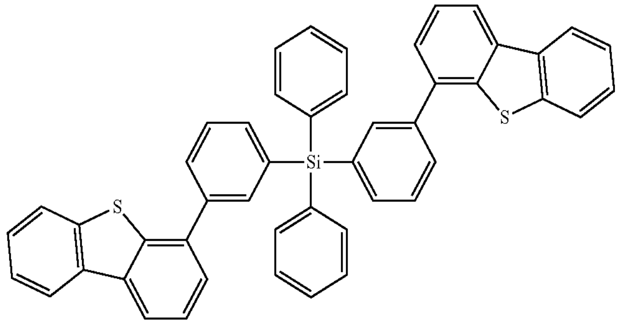
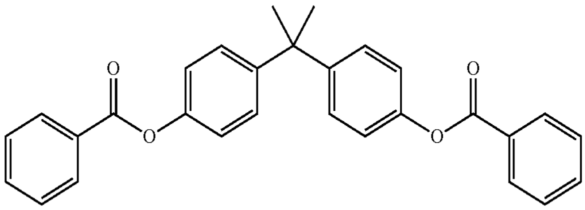
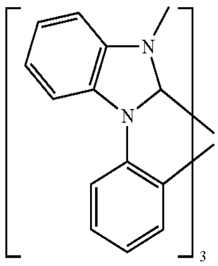
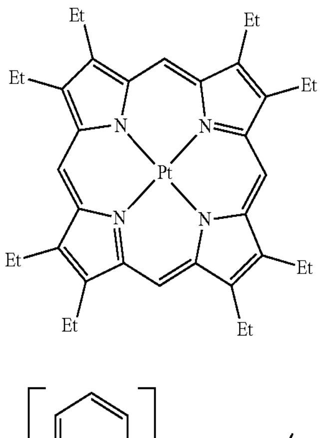
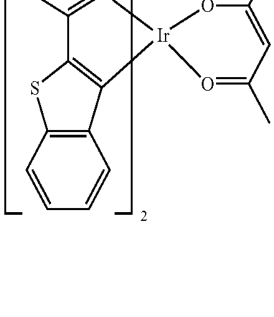
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Silicon/ Germanium aryl compounds		EP2034538A
Aryl benzoyl ester		WO2006100298
High triplet metal organometallic complex		U.S. Pat. No. 7,154,114
	Phosphorescent dopants Red dopants	
Heavy metal porphyrins (e.g., PtOEP)		Nature 395, 151 (1998)
Iridium(III) organometallic complexes		Appl. Phys. Lett. 78, 1622 (2001)

TABLE 1-continued

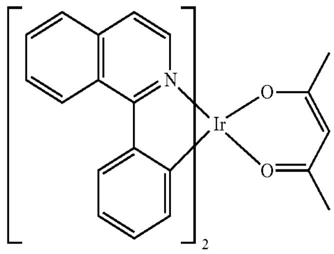
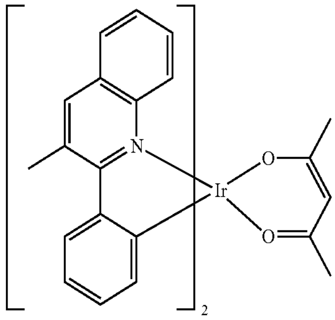
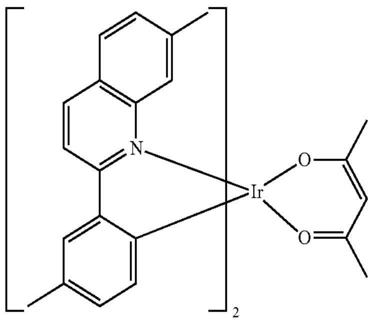
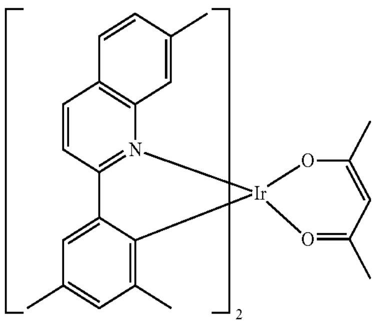
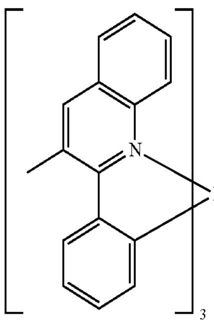
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US2006835469
		US2006835469
		US20060202194
		US20060202194
		US20070087321

TABLE 1-continued

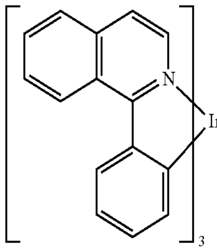
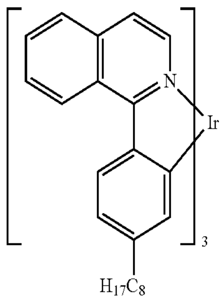
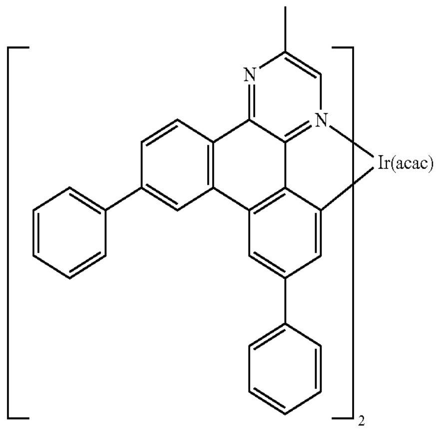
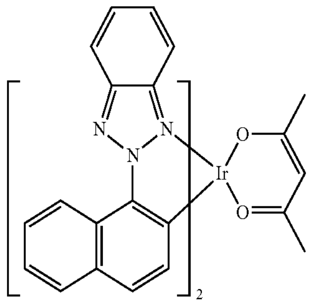
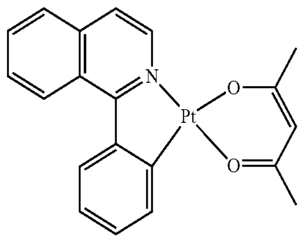
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20070087321
		Adv. Mater. 19, 739 (2007)
		WO2009100991
		WO2008101842
Platinum(II) organometallic complexes		WO2003040257

TABLE 1-continued

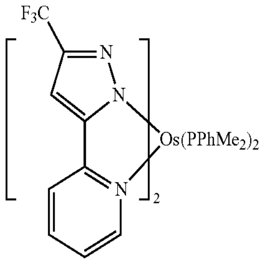
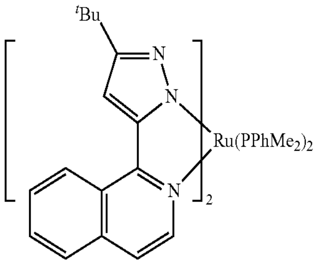
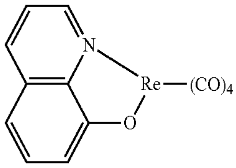
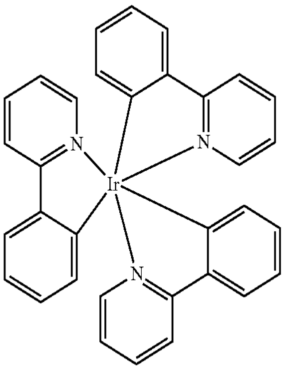
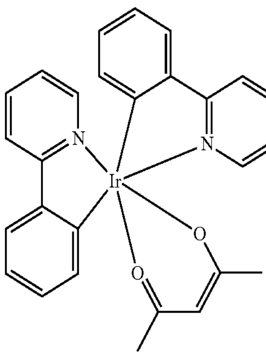
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Osminum(III) complexes		Chem. Mater. 17, 3532 (2005)
Ruthenium(II) complexes		Adv. Mater. 17, 1059 (2005)
Rhenium (I), (II), and (III) complexes		US20050244673
	Green dopants	
Iridium(III) organometallic complexes	 and its derivatives	Inorg. Chem. 40, 1704 (2001)
		US2002034656

TABLE 1-continued

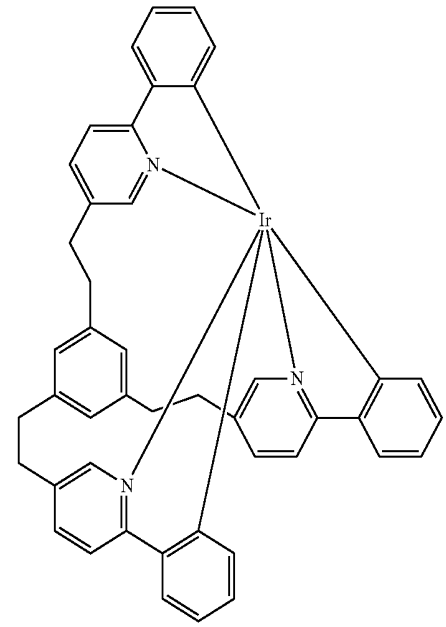
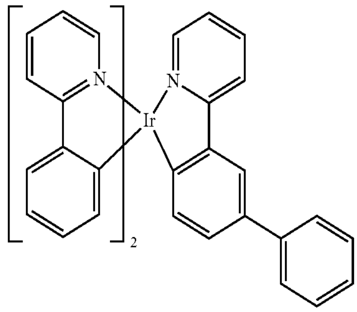
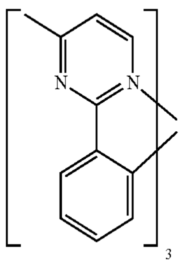
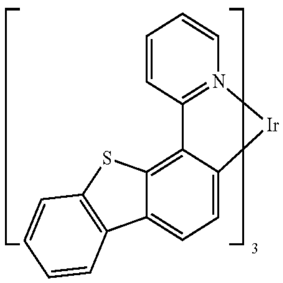
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		U.S. Pat. No. 7,332,232
		US20090108737
		US20090039776
		U.S. Pat. No. 6,921,915

TABLE 1-continued

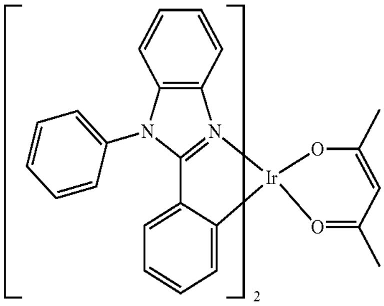
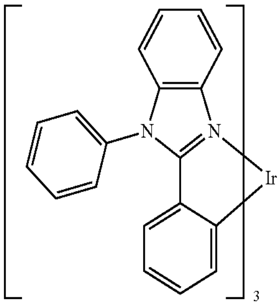
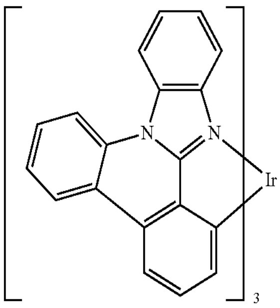
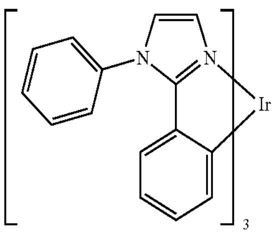
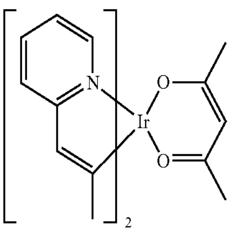
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		U.S. Pat. No. 6,687,266
		Chem. Mater. 16, 2480 (2004)
		US20070190359
		US20060008670 JP2007123392
		Adv. Mater. 16, 2003 (2004)

TABLE 1-continued

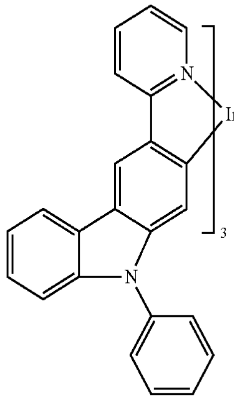
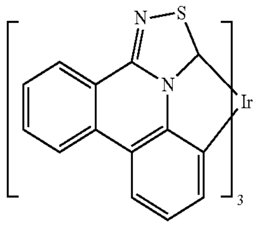
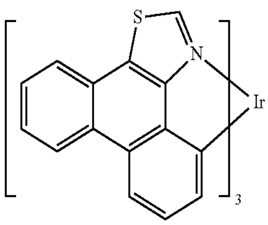
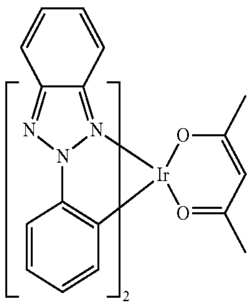
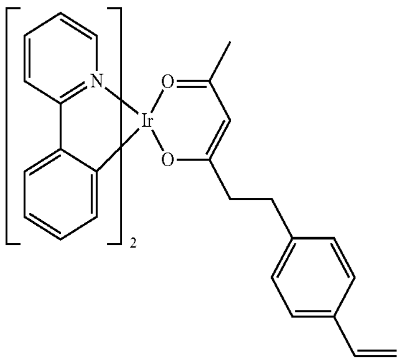
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		Angew. Chem. Int. Ed. 2006, 45, 7800
		WO2009050290
		US20090165846
		US20080015355
Monomer for polymeric metal organometallic compounds		U.S. Pat. No. 7,250,226, U.S. Pat. No. 7,396,598

TABLE 1-continued

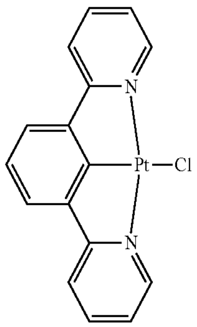
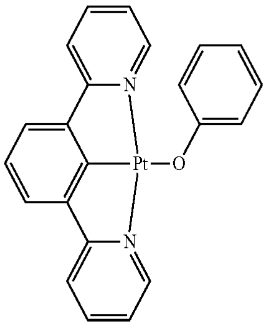
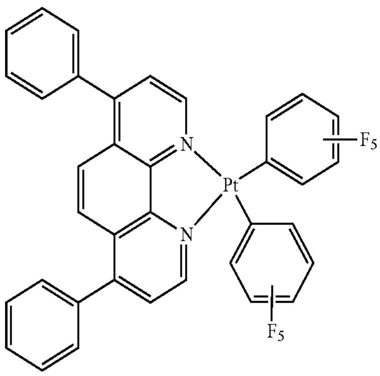
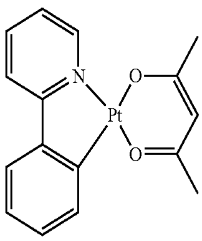
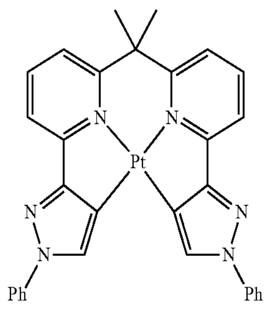
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Pt(II) organometallic complexes, including polydentated ligands		Appl. Phys. Lett. 86, 153505 (2005)
		Appl. Phys. Lett. 86, 153505 (2005)
		Chem. Lett. 34, 592 (2005)
		WO2002015645
		US20060263635

TABLE 1-continued

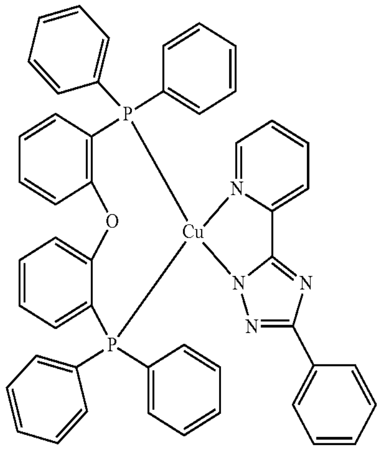
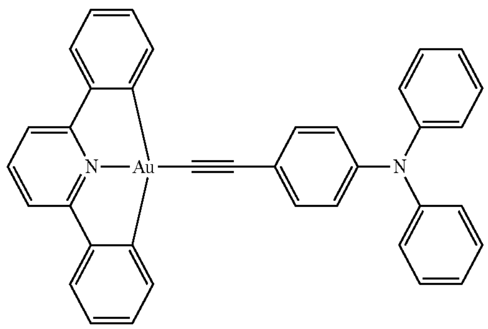
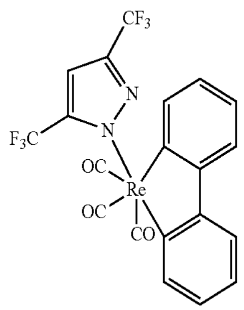
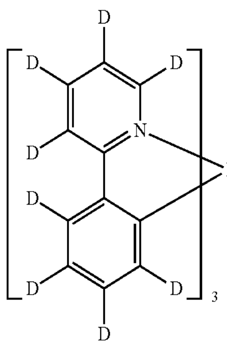
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Cu complexes		WO2009000673
Gold complexes		Chem. Commun. 2906 (2005)
Rhenium(III) complexes		Inorg. Chem. 42, 1248 (2003)
Deuterated organometallic complexes		US20030138657

TABLE 1-continued

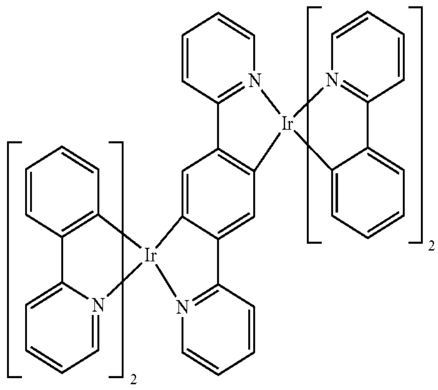
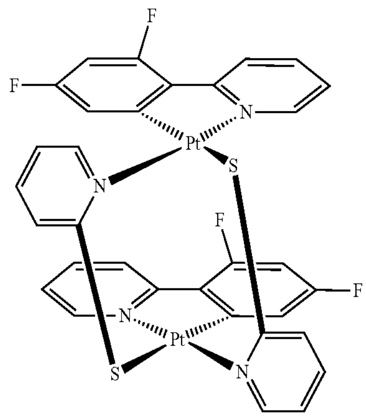
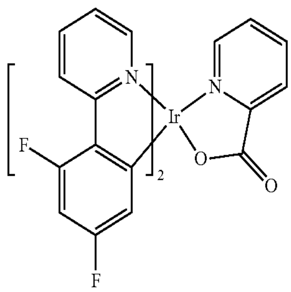
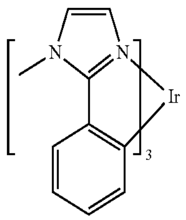
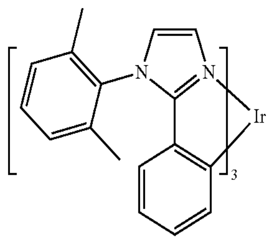
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Organometallic complexes with two or more metal centers		US20030152802
		U.S. Pat. No. 7,090,928
	Blue dopants	
Iridium(III) organometallic complexes		WO2002002714
		WO2006009024
		US20060251923

TABLE 1-continued

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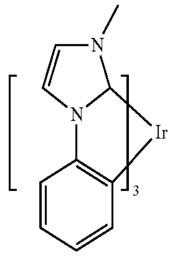
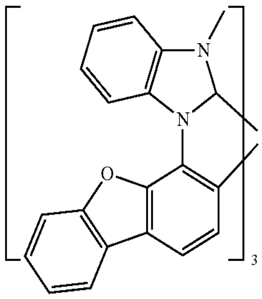
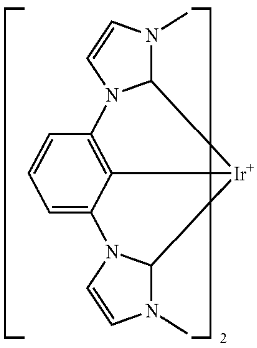
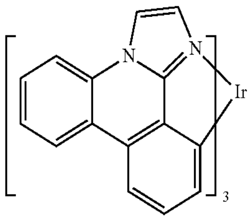
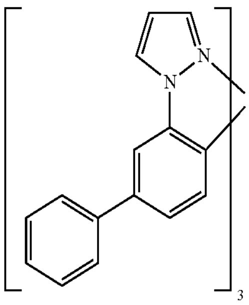
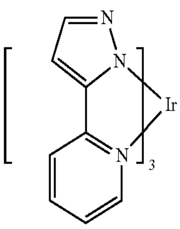
		U.S. Pat. No. 7,393,599, WO2006056418, US20050260441, WO2005019373
		U.S. Pat. No. 7,534,505
		U.S. Pat. No. 7,445,855
		US20070190359, US20080297033
		U.S. Pat. No. 7,338,722
		US20020134984

TABLE 1-continued

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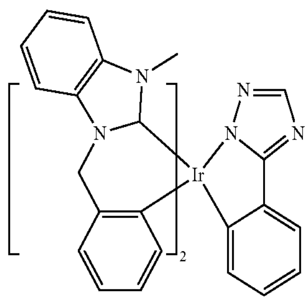
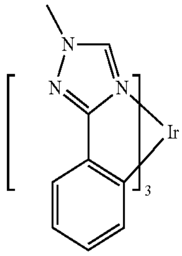
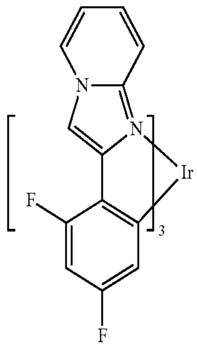
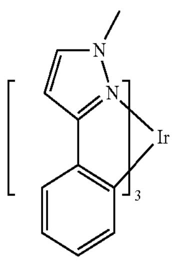
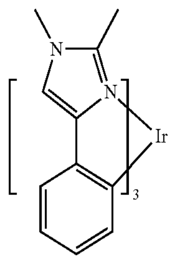
		Angew. Chem. Int. Ed. 47, 1 (2008)
		Chem. Mater. 18, 5119 (2006)
		Inorg. Chem. 46, 4308 (2007)
		WO2005123873
		WO2005123873

TABLE 1-continued

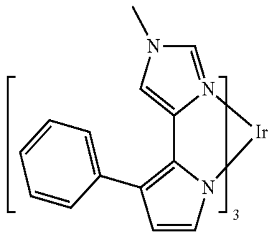
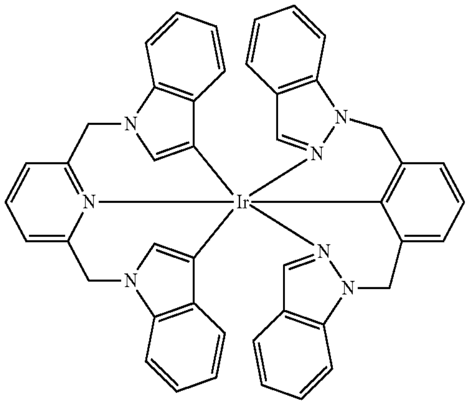
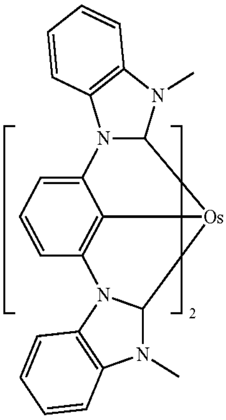
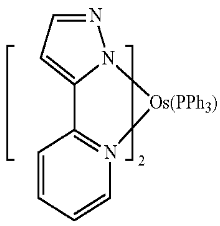
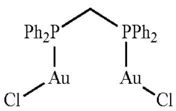
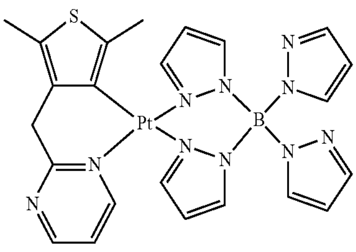
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		WO2007004380
		WO2006082742
Osmium(II) complexes		U.S. Pat. No. 7,279,704
		Organometallics 23, 3745 (2004)
Gold complexes		Appl. Phys. Lett. 74,1361 (1999)
Platinum(II) complexes		WO2006098120, WO20062103874

TABLE 1-continued

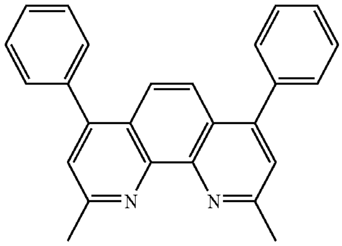
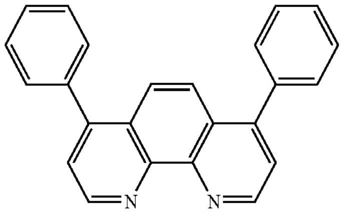
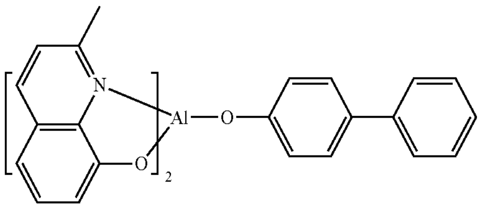
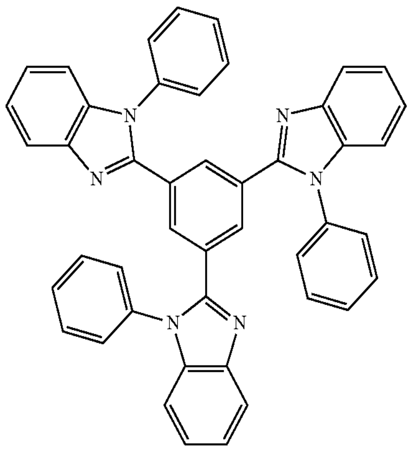
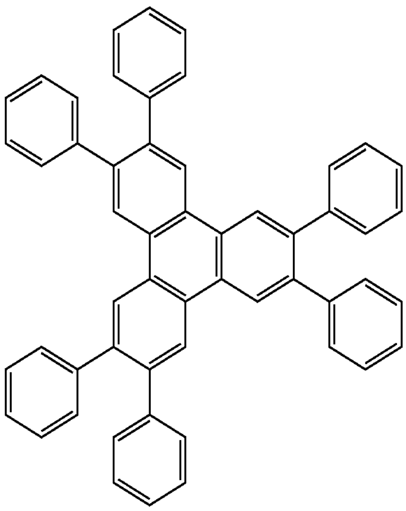
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Exciton/hole blocking layer materials		
Bathocuprine compounds (e.g., BCP, BPhen)		Appl. Phys. Lett. 75, 4 (1999)
		Appl. Phys. Lett. 79, 449 (2001)
Metal 8-hydroxy-quinolates (e.g., BAlq)		Appl. Phys. Lett. 81, 162 (2002)
5-member ring electron deficient heterocycles such as triazole, oxadiazole, imidazole, benzoimidazole		Appl. Phys. Lett. 81, 162 (2002)
Triphenylene compounds		US20050025993

TABLE 1-continued

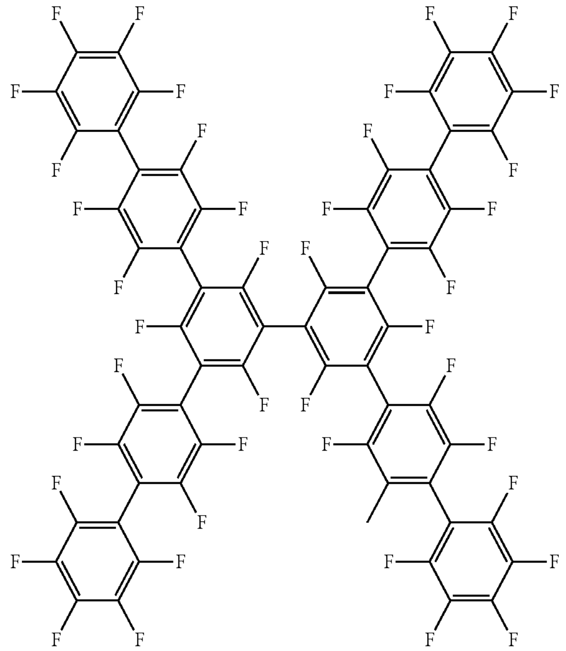
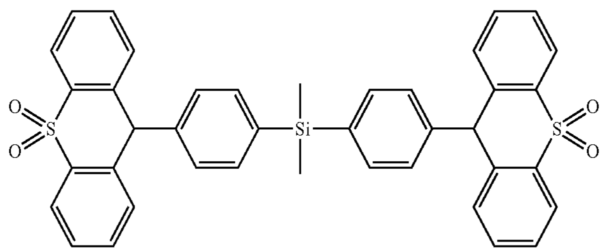
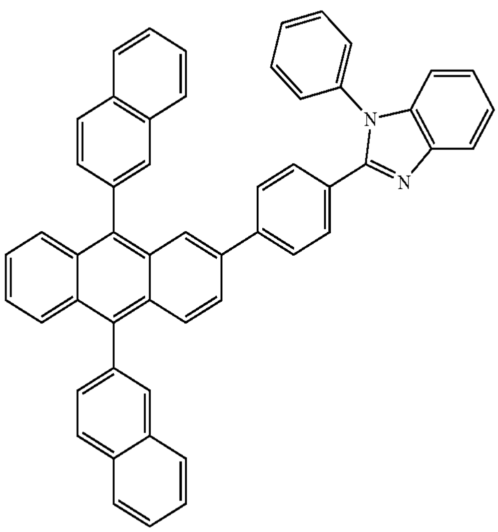
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Fluorinated aromatic compounds		Appl. Phys. Lett. 79, 156 (2001)
Phenothiazine-S-oxide		WO20081232085
	Electron transporting materials	
Anthracene-benzoimidazole compounds		WO2003060956

TABLE 1-continued

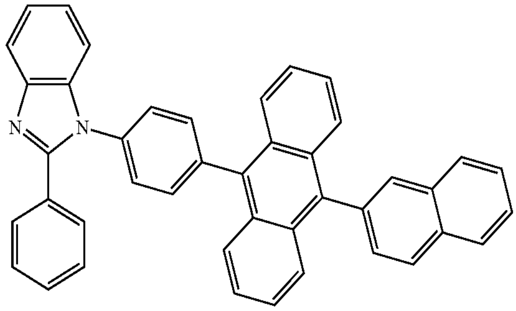
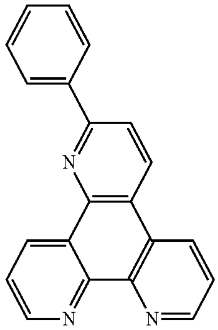
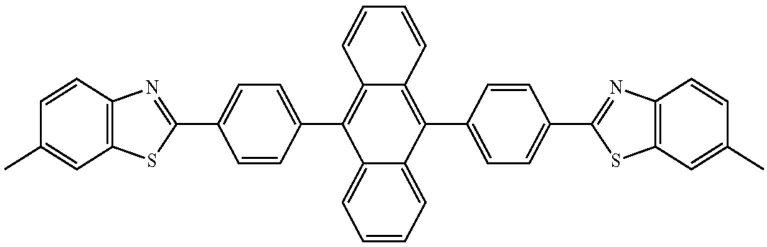
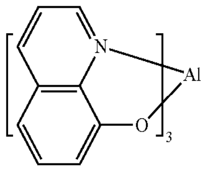
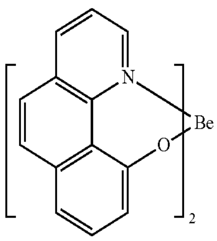
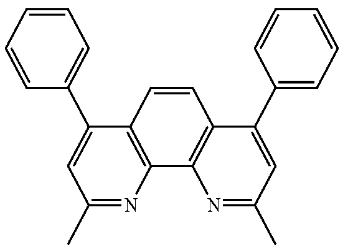
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20090179554
Aza triphenylene derivatives		US20090115316
Anthracene-benzothiazole compounds		Appl. Phys. Lett. 89, 063504 (2006)
Metal 8-hydroxy-quinolates (e.g., Alq_3, Zrq_4)		Appl. Phys. Lett. 51, 913 (1987) U.S. Pat. No. 7,230,107
Metal hydroxy-benoquinolates		Chem. Lett. 5, 905 (1993)
Bathocuprine compounds such as BCP, BPhen, etc		Appl. Phys. Lett. 91, 263503 (2007)

TABLE 1-continued

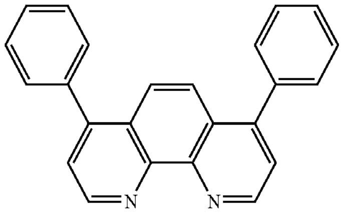
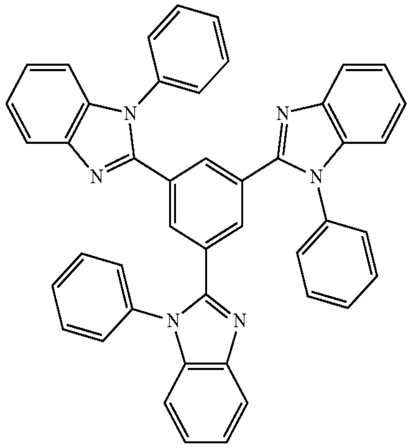
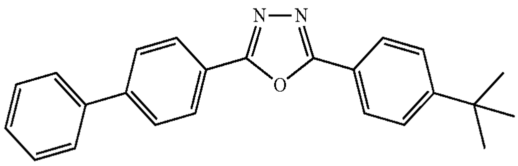
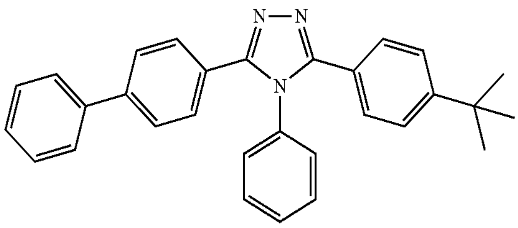
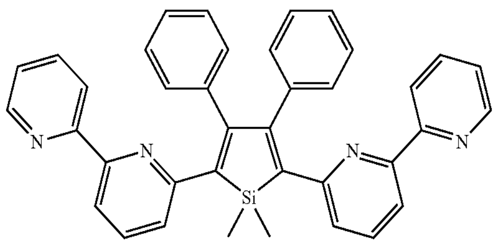
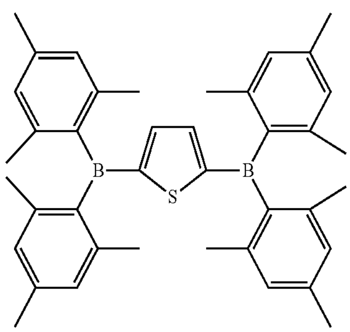
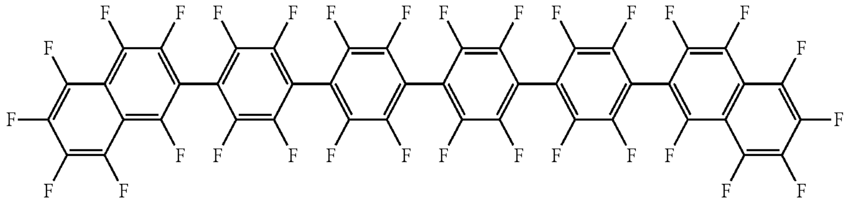
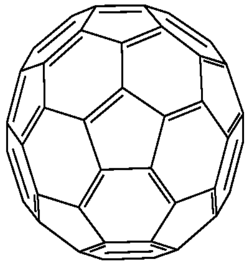
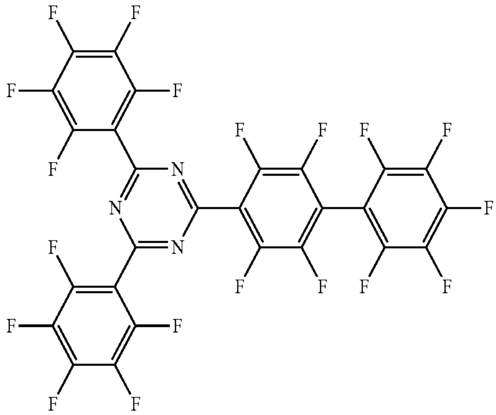
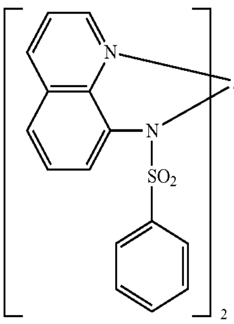
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		Appl. Phys. Lett. 79, 449 (2001)
5-member ring electron deficient heterocycles (e.g., triazole, oxadiazole, imidazole, benzo-imidazole)		Appl. Phys. Lett. 74, 865 (1999)
		Appl. Phys. Lett. 55, 1489 (1989)
		Jpn. J. Apply. Phys. 32, L917 (1993)
Silole compounds		Org. Electron 4, 113 (2003)
Arylborane compounds		J. Am. Chem. Soc. 120, 9714 (1998)

TABLE 1-continued

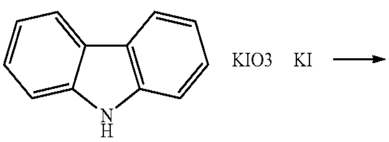
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Fluorinated aromatic compounds		J. Am. Chem. Soc. 122, 1832 (2000)
Fullerene (e.g., C60)		US20090101870
Triazine complexes		US20040036077
Zn (N^N) complexes		U.S. Pat. No. 6,528,187

Experimental

Compound Examples

Synthesis of Compound 1

Step 1



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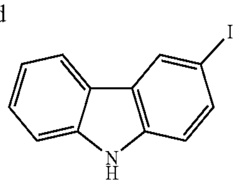
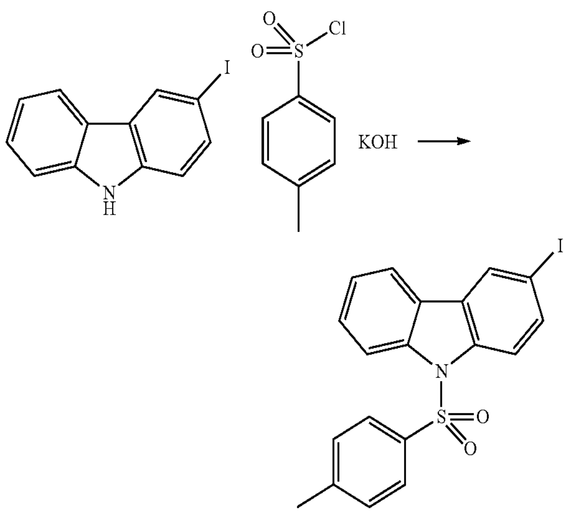


Step 1. The solution of carbazole and potassium iodide in 550 mL of acetic acid was heated up to 120° C. to dissolve the reactants and then allowed to cool back to 100° C. Potassium iodate was added slowly at this temperature and reaction was stirred at 100° C. for 2 h. The reaction then was allowed to cool down to 60° C. and 500 mL of water were added, result

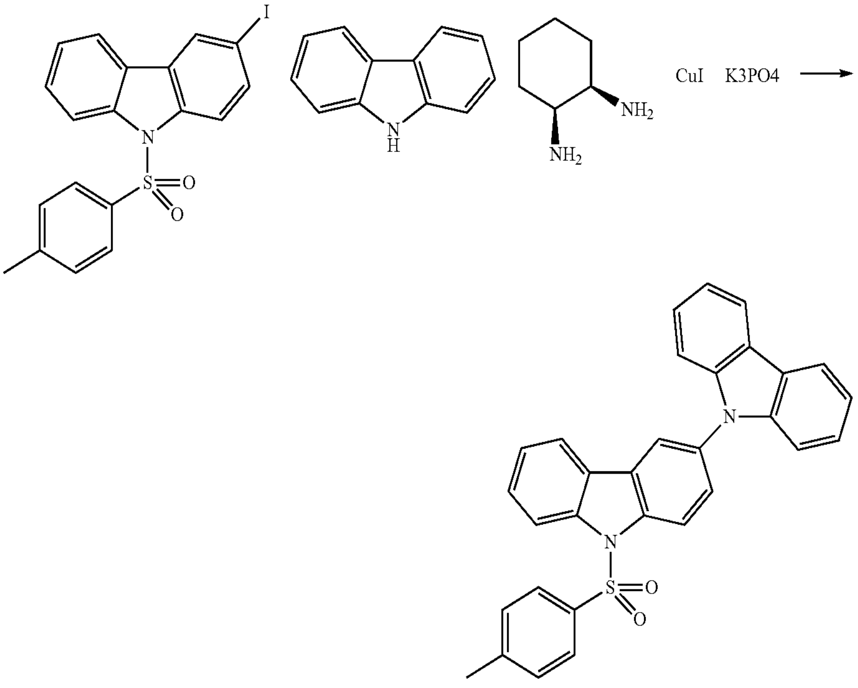
ing formation of grey precipitate. The solid material was filtered and washed with hot water. Then it was dissolved in CH_2Cl_2; this solution was carefully washed with $NaHCO_3$ aq., $NaHSO_3$ aq., brine, then dried over sodium sulfate. The volume was reduced to form slurry mixture, then cool down and kept for at least 30 minutes at room temperature, solid material was filtered, washed fast once with minimum amount of CH_2Cl_2 and dried. It was placed in a 500 mL flask, added 100 mL EtOAc, rotated at the rotavap at 60° C. for 20 minutes without vacuum, then started to pump out solvent to form a slurry mixture, then added 200 mL of hexanes and keep at 55° C. for 15 minutes without vacuum. Then cooled down to room temperature, kept for 30 minutes, briefly sonicated for 3 minutes, filtered solid material and washed it with a lot of hexane. Material was dried in vacuum, providing 24 g (40% yield) of pure.

Step 2

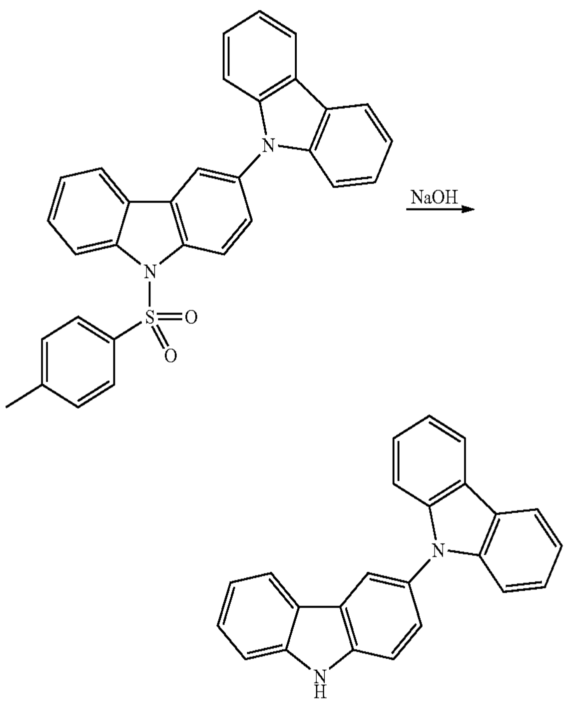


Step 2. 2-Iodocarbazole (29.2 g, 0.1 mol) was dissolved in 200 mL of dry acetone, then potassium hydroxide (7.84 g, 0.14 mol) was added and stirred upon complete solubilization; followed by slow addition of tosyl chloride (22.8 g, 0.12 mol). The reaction was heated to reflux for 3 h. Reaction mixture was cooled down to 60-70° C. and poured into water while stirred at a constant speed; stirring was continued for a while after pouring all amount. A product precipitated on the glass wall; after 30 minutes, water was decanted, the precipitate was washed with water, then with EtOH twice. The residual material was dissolved in CH_2Cl_2, and partially evaporated to see the solid formation, added big volume of EtOH, and continued to evaporate all CH_2Cl_2 (repeated several times). Stirred at 60° C. for 10 minutes then cooled down, kept at 20° C. and filtered, the precipitate was washed with EtOH and dried, providing 40 g (90% yield) of pure 3-Iodo-9-tosyl-9H-carbazole.

Step 3

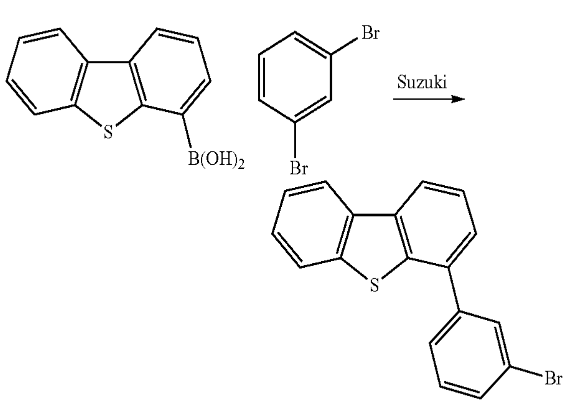


Step 3. 3-Iodo-9-tosyl-9H-carbazole (31.29 g, 0.07 mol), Cu(I) iodide (1.33 g, 0.007 mol), potassium phosphate (29.7 g, 0.14 mol) and carbazole (14.03 g. 0.084 mol) were combined in 3-neck flask, degassed 4 times and cyclohexane-1, 3-diamine (1.14 g, 0.01 mol) in 400 mL of anhydrous toluene was added. Degassed again, fill reaction flask with N_2 and heated to reflux overnight (20 h). The reaction was cooled down to 20° C., filtered through a plug of silica gel toped with celite, washed with toluene; the plug was washed with CH_2Cl_2, combined organic fractions were evaporated. The residue was dissolved in 100 mL of CH_2Cl_2 and 300 mL of EtOH were added; then CH_2Cl_2 was evaporated. The residue in EtOH was at 70° C. for 20 minutes, then was cooled down to 20° C., kept for 2 h and filtered. The solid material was washed with ethanol and dried, providing 30 g (88% yield) of the product.



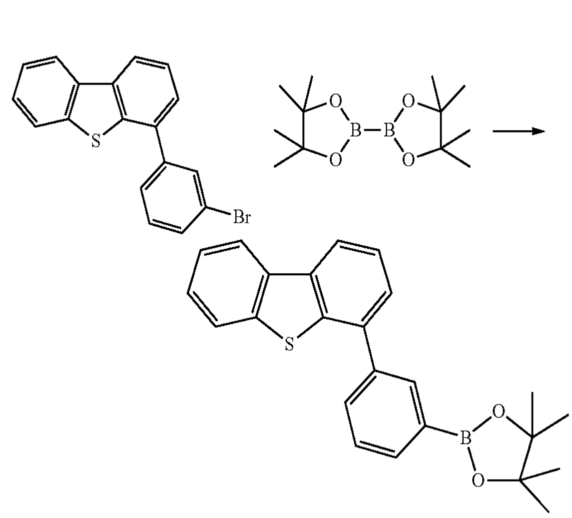
Step 4. The solution of sodium hydroxide (27.4 g) in 150 mL of water was added to 32 g of 9-tosyl-9H-3,9'-bicarbazole, dissolved in 300 mL of THF and 150 mL of methanol. The reaction was allowed to reflux overnight. Then organic solvents were evaporated, added 100 mL of brine and extracted with 3×200 mL of ethyl acetate, combined organic layers, dried over Na_2SO_4 and evaporated. The residue was dissolved in 200 mL of CH_2Cl_2 and absorbed on silica gel. Purified by column chromatography, eluting with gradient mixture of ethyl acetate:hexane from 10:90 to 15:85. The solid was crystallized from ethyl acetate/hexane mixture, providing 17 g (78% yield) of pure material.

Step 5



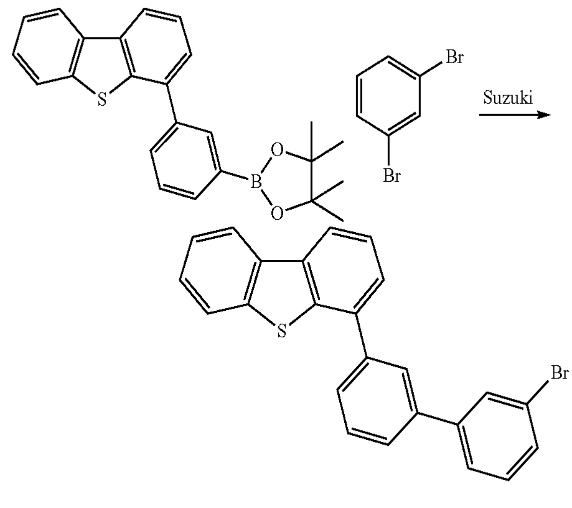
Step 5. Potassium carbonate (18.18 g, 132 mmol) was dissolved in water (75 mL), sonicated, and solution was added to the solution of dibenzo[b,d]thiophen-4-ylboronic acid (10.00 g, 43.8 mmol) and 1,3-dibromobenzene (13.79 ml, 114 mmol) in Toluene (200 mL). Added catalyst (1.013 g, 0.877 mmol), degassed, heated to reflux for 24 h under N_2 atmosphere. Cooled down, evaporated, purified by chromatography on silica gel (250 g), eluting with hexane/CH_2Cl_2 99/1. Chromatographed material was then crystallized from hexane, providing white solid, 10.5 g (67% yield).

Step 6



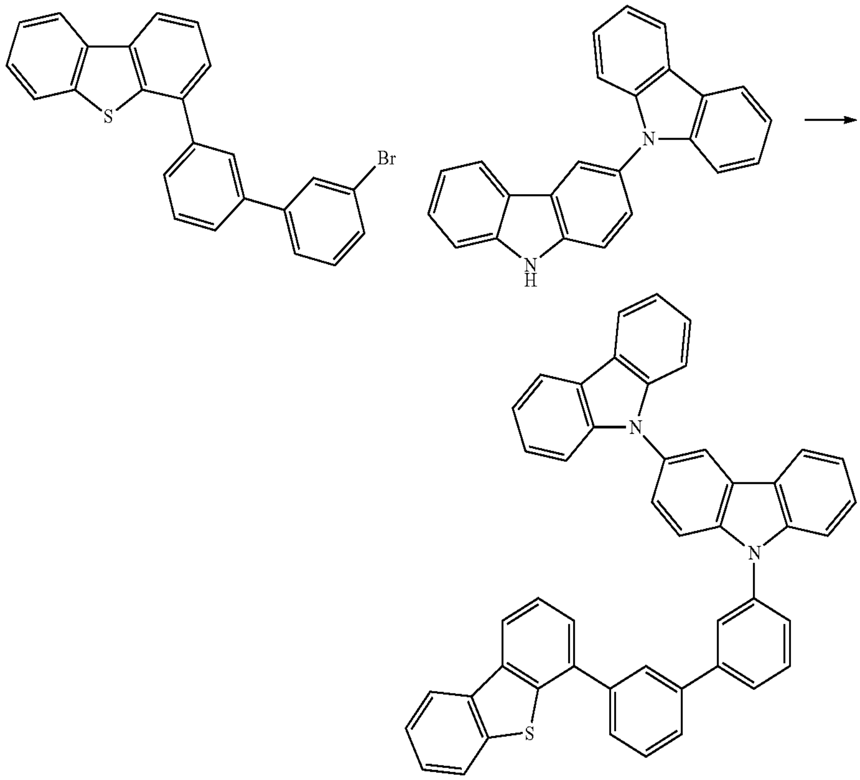
Step 6. 4-(3-Bromophenyl)dibenzo[b,d]thiophene (14.14 g, 41.7 mmol) was dissolved in dioxane (200 mL) to give a colorless solution. 4,4,4',4',5,5,5',5'-Octamethyl-2,2'-bi(1,3,2-dioxaborolane) (12.70 g, 50.0 mmol) was added as one portion, followed by potassium acetate (8.18 g, 83 mmol), $Pd_2(dba)_3$ (0.382 g, 0.417 mmol) and 1,1'-bis(diphenylphosphino)ferrocene (dppf, 0.254 g, 0.834 mmol), then reaction mixture was degassed. Refluxed overnight under N_2, cooled down, diluted with ethyl acetate (150 mL), washed with brine, $NaHSO_3$ and LiCl 10% aq.sol. Filtered, evaporated, the residue was purified by column chromatography (silica 250 g, hex/dcm 9:1), providing 2-(3-(dibenzo[b,d]thiophen-4-yl)phenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane as white solid, 12.8 g (80% yield).

Step 7



Step 7. 2-(3-(dibenzo[b,d]thiophen-4-yl)phenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (14.50 g, 37.5 mmol), 1,3-dibromobenzene (26.6 g, 113 mmol) were dissolved in 200 mL of toluene, added K_2CO_3 aq. solution (16 g in 100 mL), followed by the tetrakis (triphenylphosphine)palladium (0) (0.434 g). Reaction was degassed, filled with N_2, refluxed under N_2 atm. overnight. Organic layer was separated, dried over sodium sulfate, filtered and evaporated. The residue was purified by column chromatography on silica column (200 g, eluted with hexane/CH_2Cl_2 95:5), then crystallized from hexane, providing white solid, 10.1 g (65% yield).

Step 8



Compound 1

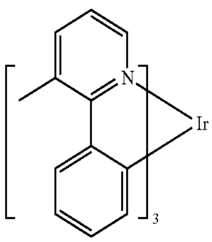
Step 8. 4-(3'-bromo-[1,1'-biphenyl]-3-yl)dibenzo[b,d]thiophene (6.20 g, 14.93 mmol), 9H-3,9'-bicarbazole (4.96 g, 14.93 mmol) were suspended in xylene (dry, 200 ml), added Pd_2 dba_3 (0.273 g, 0.299 mmol), dicyclohexyl(2',6'-dimethoxy-[1,1'-biphenyl]-3-yl)phosphine (0.245 g, 0.597 mmol) and sodium 2-methylpropan-2-olate (2.87 g, 29.9 mmol), degassed, heated to reflux upon vigorous stirring under N_2 atm. for 24 h. Hot reaction mixture was filtered through celite plug, concentrated and loaded on silica column (250 g). Eluted with hexane/CH_2Cl_2 4:1, concentrated fractions, pure by TLC and HPLC. White solid precipitated, it was washed with hexane and crystallized from ethyl acetate, providing Compound 1 as white solid (8.5 g, 85% yield).

Device Examples

Several devices comprising the inventive compounds were fabricated. The anode electrode is ~800 Å of indium tin oxide (ITO). The cathode consisted of 10 Å of LiF followed by 1,000 Å of Al. All devices were encapsulated with a glass lid sealed with an epoxy resin in a nitrogen glove box (<1 ppm of H_2O and O_2) and a moisture getter was incorporated inside the package.

As used herein, the following compounds have the following structures:

Compound A



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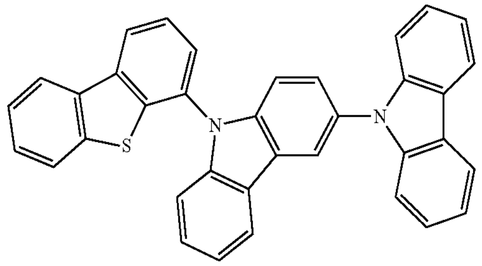
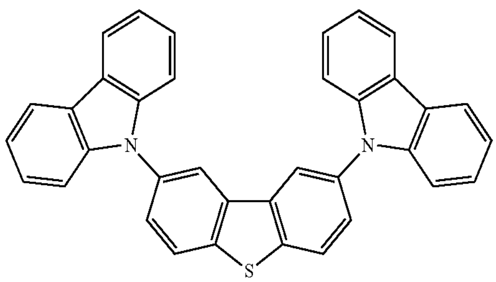
Compound B



Compound C



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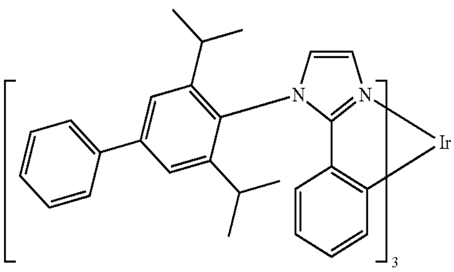
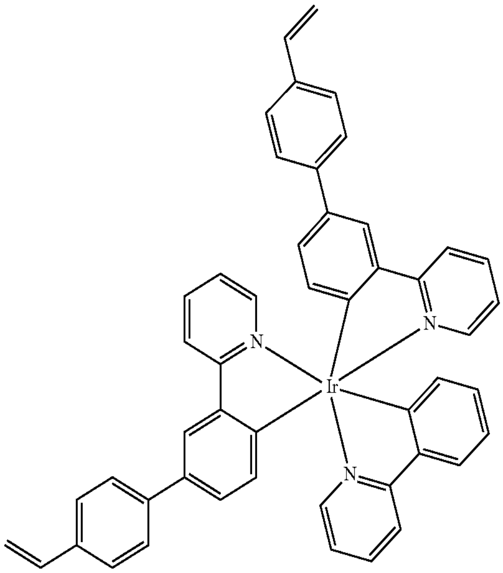
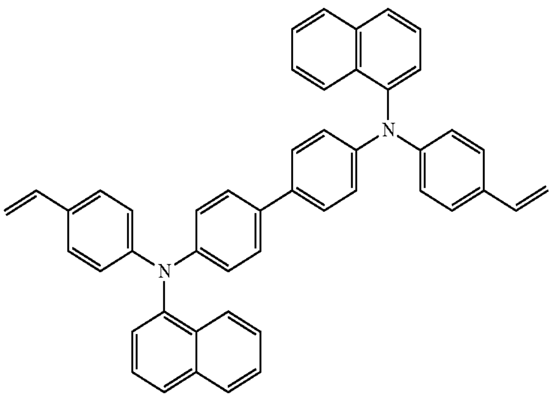
Compound D



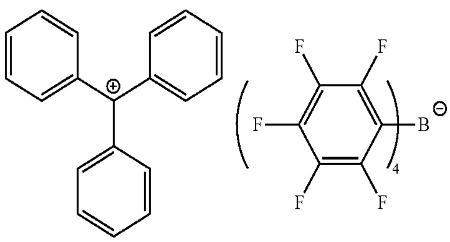
Compound E



Compound F



Compound G



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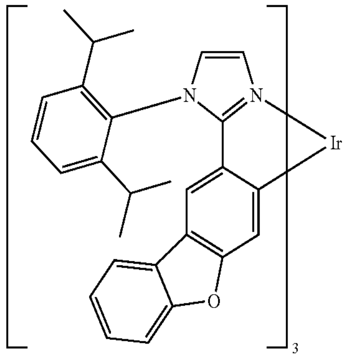
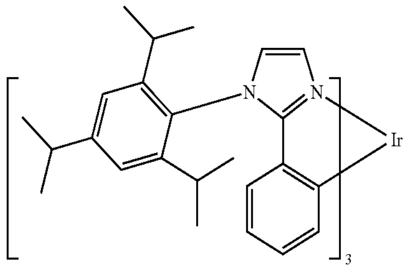
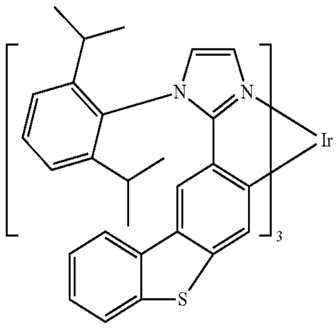
Compound H



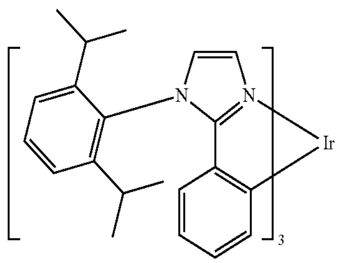
Compound I



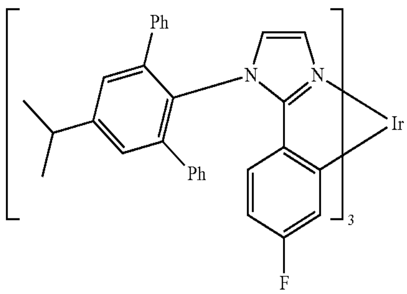
Compound J



Compound K



Compound L



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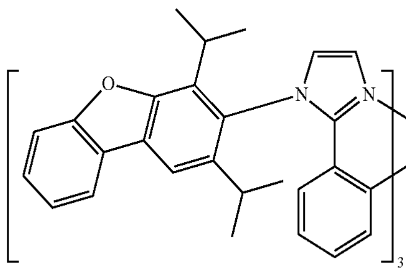
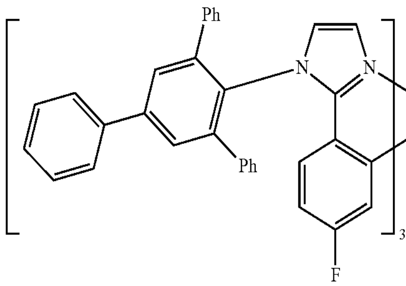
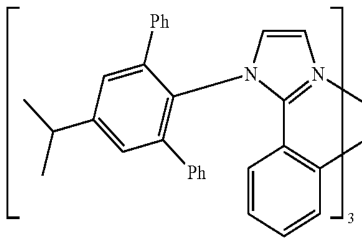
Compound M



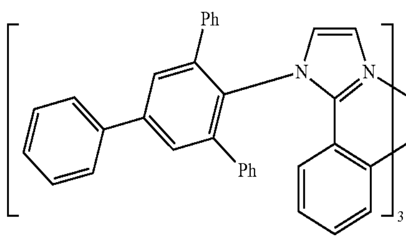
Compound N



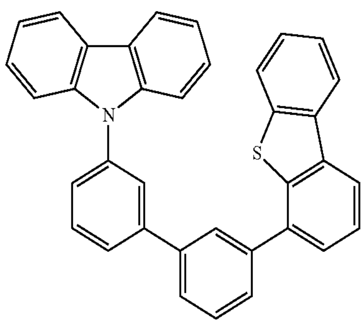
Compound O



Compound P



Compound I



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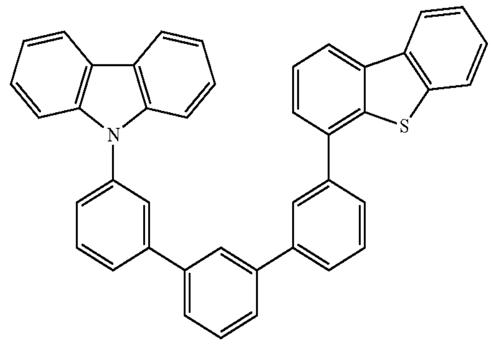
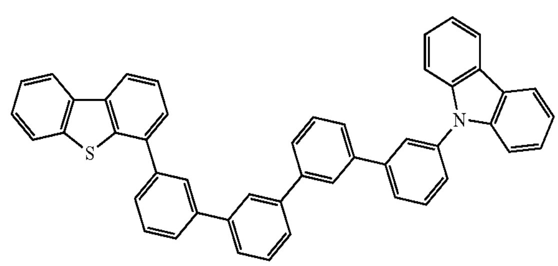
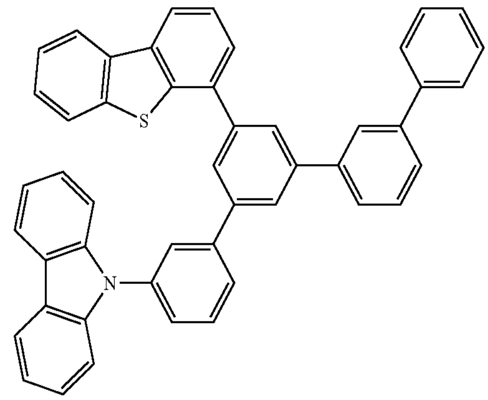
Compound II



Compound III



Compound IV



Solution Processed Devices:

Device Example 1 was fabricated as described below. Compound E and Compound G were dissolved in cyclohexanone. The amount of Compound G in the solution was 10 wt % relative to HIL-1. The total concentration of Compound E and Compound G was 0.5 wt % in cyclohexanone. To form the hole injection layer (HIL), the solution was spin-coated at 4000 rpm for 60 seconds onto a patterned indium tin oxide (ITO) electrode. The resulting film was baked for 30 minutes at 250° C. The film became insoluble after baking. On top of the HIL, a hole transporting layer (HTL) and then emissive layer (EML) were also formed by spin-coating. The HTL was made by spin-coating a 0.5 wt % solution of Compound F in toluene at 4000 rpm for 60 seconds. The HTL film was baked at 200° C. for 30 minutes. After baking, the HTL became an insoluble film. To form the EML, a toluene solution containing 80% of Compound 1 and 20% of Compound D (net concentration of 1 wt % in toluene) was spin-coated on top of the insoluble HTL at 1000 rpm for 60 seconds, and then baked at 80° C. for 60 minutes to remove solvent residues. Then a 50 Å thick layer of Compound C was deposited by vacuum thermal evaporation as the blocking layer (BL). Then a 200 Å thick layer of Alq_3 was deposited by vacuum thermal evaporation as the electron transporting layer (ETL).

Comparative Device Example 1 was fabricated similarly except the host was Compound C instead of Compound 1. The device data is shown in Table 2.

TABLE 2

Example	Host	Dopant (conc.)	ETL2	At 10 mA/cm^2 1931 CIE	Voltage (V)	LE (cd/A)	At L_0 = 2000 cd/m^2 LT_{80} (h)
Device Example 1	Cmpd 1	20%	Cmpd C	(0.18, 0.38)	10	14.4	153
Comparative Device Example 1	Cmpd C	20%	Cmpd C	(0.18, 0.38)	9.5	19.1	39

Vacuum Thermal Evaporation Devices:

Device examples 2 and 3 and Comparative Device examples 2-9 were fabricated by high vacuum (<10^{-7} Torr) thermal evaporation. The organic stack of the Device Examples 2 and 3 and Comparative Device Examples 2-9 in Table 3 consists of sequentially, from the ITO surface, 100 Å of Compound D as the hole injection layer (HIL), 300 Å of α-NPD as the hole transporting layer (HTL), 300 Å of Compound 1, Compound B or Compound C doped with 15 wt % of Compound D as the emissive layer (EML), 50 Å of Compound 1, Compound B, Compound C, Compound III, or Compound IV as the blocking layer (BL) and 400 Å of Alq_3 as the electron transporting layer (ETL). The device structure and result are shown in Table 3.

Table 2 summarizes the data of the solution processed devices. Device Example 1 has significantly higher operation stability over Comparative Device Example 1. LT_{80} (defined as the time required for the initial luminance, L_0, to drop from 100% to 90% under constant current density at room temperature) of Device Example 1 is 153 h, whereas that of Comparative Device Example 1 is 39 h. Although the luminance efficiency (LE) at J=10 mA/cm^2 of Comparative Device Example 1 is higher (19.1 cd/A), Device Example 1 is still quite efficient (14.4 cd/A).

TABLE 3

Examples	Host	Dopant (conc.)	BL	1931 CIE x	1931 CIE y	λ_{max} (nm)	At 1000 cd/m$_2$ LT_{80} (h)	LE (cd/A)	EQE (%)	PE (lm/W)	At L_0 = 2000 cd/m^2 LT_{80} (h)
Device Example 2	Cmpd 1	15%	Cmpd C	0.183	0.407	474	7.2	38	16.2	16.6	1063*
Device Example 3	Cmpd 1	15%	Cmpd 1	0.183	0.409	474	7.8	36.6	15.6	14.8	861*
Comparative Device Example 2	Cmpd C	15%	Cmpd C	0.180	0.397	474	7.1	36.6	15.9	16.3	600*
Comparative Device Example 3	Cmpd B	15%	Cmpd B	0.180	0.387	474	6.8	35.7	15.8	16.5	604
Comparative Device Example 4	Cmpd I	15%	Cmpd C	0.181	0.397	474	7.5	33.8	14.7	14.1	530*
Comparative Device Example 5	Cmpd II	15%	Cmpd C	0.181	0.407	474	7.7	35	14.9	14.4	750
Comparative Device Example 6	Cmpd III	15%	Cmpd C	0.183	0.409	474	7.5	37.1	15.8	15.5	596*
Comparative Device Example 7	Cmpd III	15%	Cmpd III	0.183	0.409	474	8.1	36	15.4	13.9	532*
Comparative Device Example 8	Cmpd IV	15%	Cmpd C	0.185	0.411	474	7.6	36	15.4	14	457*
Comparative Device Example 9	Cmpd IV	15%	Cmpd IV	0.185	0.414	474	8	35.5	15	14.8	407*

*calculated based on lifetest at J = 20 mA/cm^2.

Table 3 summarizes the data of the vacuum thermal evaporation devices. Device Example 2 and Comparative Device Example 2 have the same structure except Device Example 2 has Compound 1 as the host, whereas Comparative Device Example 2 has Compound C as the host. The two devices have similar efficiency (~16% EQE). However, Device Example 2 is significantly more stable compared to Comparative Device Example 2. LT_{80} of Device Example 2 is 1063 h, whereas that of Comparative Device Example 2 is 600 h. Device Example 3 and Comparative Device Example 3 have the same structure except Device Example 3 has Compound 1 as the host and BL, whereas Comparative Device Example 3 has Compound B as the host and BL. The two devices have similar efficiency (~16% EQE). However, Device Example 3 is significantly more stable compared to Comparative Device Example 3.

LT_{80} of Device Example 3 is 861 h whereas that of Comparative Device Example 1 is 604 h. Device Example 2 and Comparative Device Example 4 have the same structure except Device Example 2 has Compound 1 as the host, whereas Comparative Device Example 4 has Compound I as the host. Not only does Device Example 2 has a higher efficiency, it is significantly more stable compared to Comparative Device Example 4. LT_{80} of Device Example 2 is 1063 h, whereas that of Comparative Device Example 4 is 530 h.

The data suggests two superior features of compounds having Formula I. First, Compound 1, with a 3,9-linked oligocarbazole moiety and a dibenzothiophene moiety linked by an aromatic group, results in high device stability compared to compounds with 3,9-linked oligocarbazole moiety and dibenzothiophene moiety directly connected. It is believed that the presence of an aromatic linker has an effect on the conjugation, thus improving the device stability. Second, compounds with carbazole and dibenzothiophene moieties are inferior to compounds with 3,9-linked oligocarbazole and dibenzothiophene moieties, even with an aromatic linker. 3,9-linked oligocarbazole, the main HOMO contributor in the compounds provided herein, is more electron-rich than carbazole. The oxidation and reduction potentials of Compound 1 are 0.74 V and −2.73 V (vs Fc/Fc^+), respectively. The oxidation and reduction potentials of Compound C are 0.91 V and −2.84 V, respectively. The higher HOMO level of Compound 1 may increase hole injection from the HTL and hole transport in the EML. This may result in better device charge balance and/or location of charge recombination, leading to improved device lifetime.

The oxidation and reduction potentials of Compound B are 0.74 V and −2.78 V, respectively. While the HOMO levels of Compound 1 and Compound B are similar, the LUMO level of Compound 1 is slightly lower presumably due to the extra π-system provided by the biphenyl linker. Generally, in compounds containing a 3,9-linked oligocarbazole moiety and a dibenzothiophene moiety with an aromatic linker, the control over π-conjugation, thermal properties and further structural/electronic modification by substituents is better than in corresponding compounds without an aromatic linker. In addition to difference in electronic properties, it is believed that the Compound 1 provides better morphology and morphological stability compared to Compound B and Compound C, leading to improved device lifetime. In particular, materials having an asymmetrical structure, such as the 3,9-linked oligocarbazole structure, may offer improved film formation. The improved film formation is believed to be a result of reduced crystallization due to the asymmetrical structure of the compound. This has been evidenced by unexpected results from solution processing devices using the compounds as a host material.

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 includes 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:

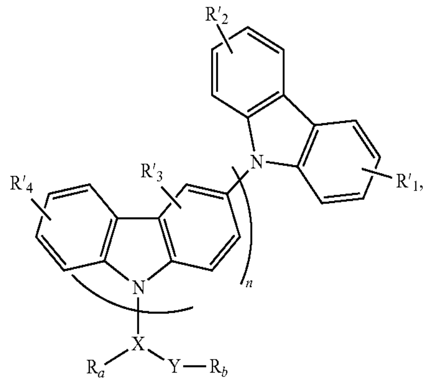
1. A first device, comprising an organic light emitting device comprising:

an anode;

a cathode; and

a first organic layer disposed between the anode and the cathode, comprising a compound having the formula:

Formula I



wherein n is 1;

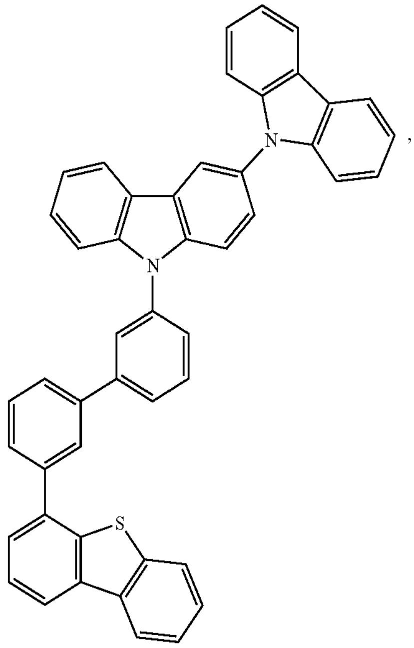
wherein R'_1, R'_2, R'_3, R'_4, R_a, and R_b are hydrogen;

wherein X is biphenyl; and

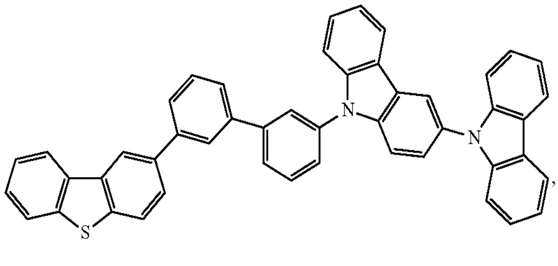
wherein Y is dibenzothiophene.

2. The first device of claim **1**, wherein the compound is

Compound 1



Compound 7



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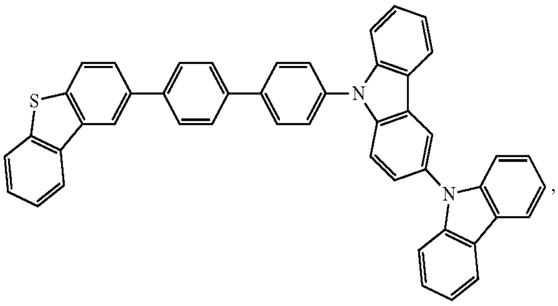
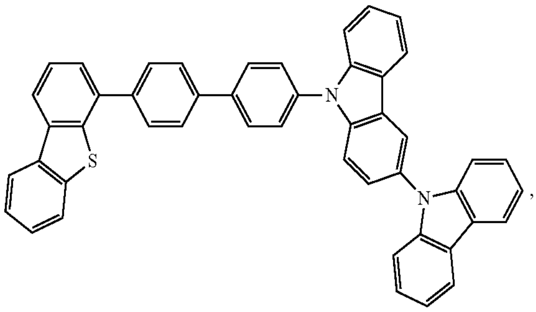
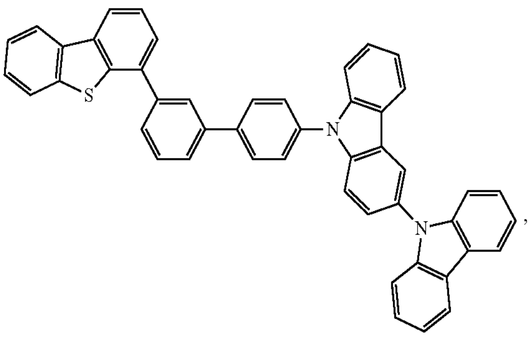
Compound 49



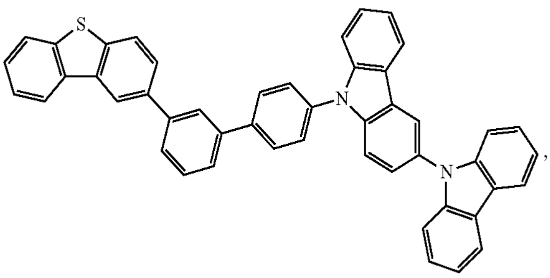
Compound 50



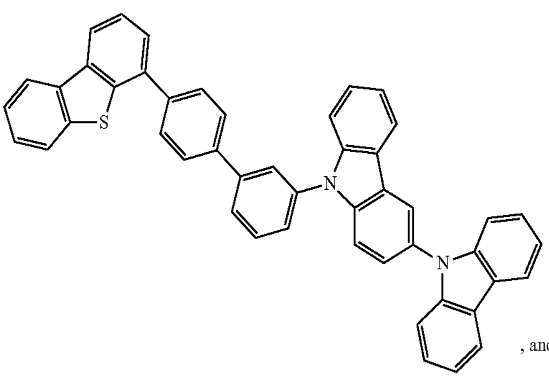
Compound 53



Compound 54



Compound 57



, and

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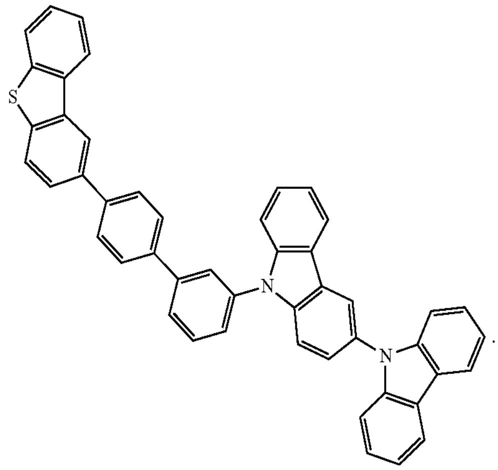
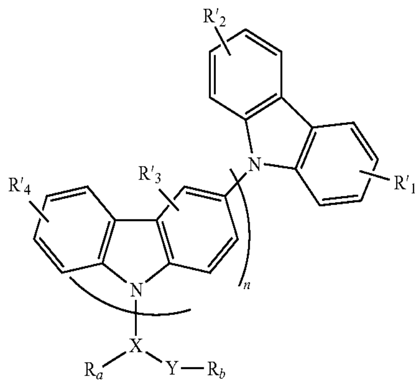
Compound 58

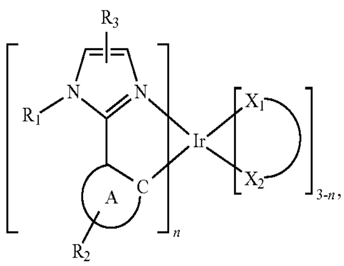


3. The first device of claim 1, wherein the first organic layer is an emissive layer and the compound having



Formula I is a host.

4. The first device of claim 3, wherein the first organic layer further comprises an emissive dopant having the formula



wherein A is a 5 or 6 membered carbocyclic or heterocyclic ring;

wherein R_1, R_2, and R_3 independently represent mono, di, tri or tetra substituents;

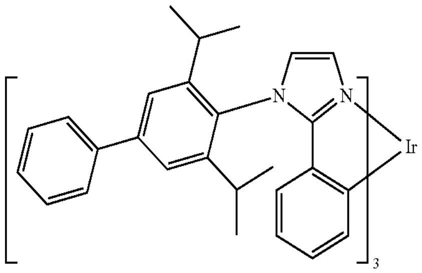
wherein each of R_1, R_2, and R_3 are independently selected from the group consisting of hydrogen, deuterium, alkyl, alkoxy, amino, alkenyl, alkynyl, arylkyl, aryl, and heteroaryl;

wherein n is 1, 2, or 3; and

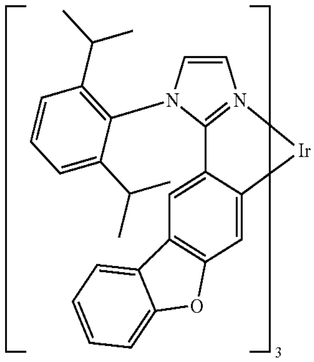
wherein X—Y is an ancillary ligand.

5. The first device of claim 4, wherein the emissive dopant is selected from the group consisting of:

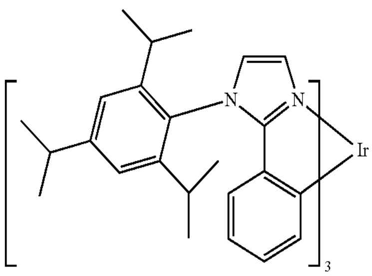
Compound D



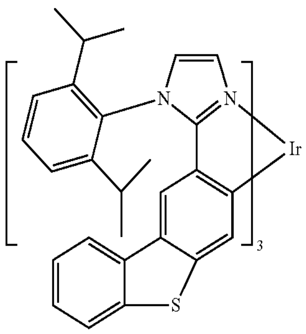
Compound H



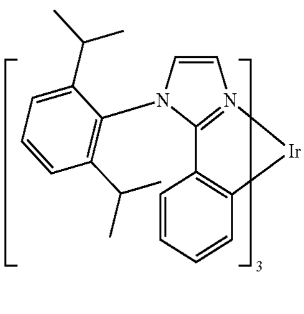
Compound I



Compound J



Compound K



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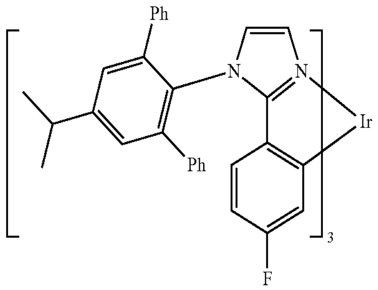
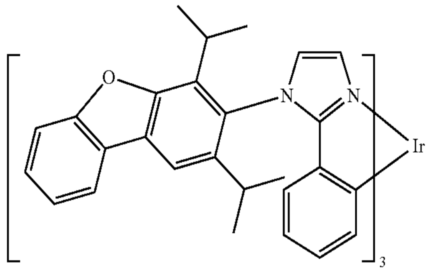
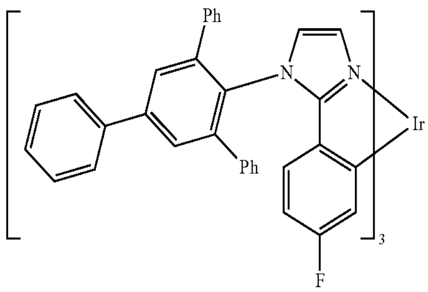
Compound L



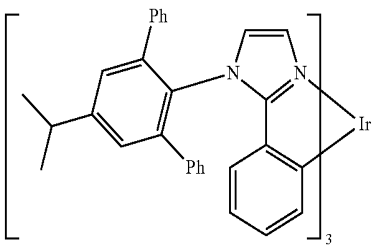
Compound M



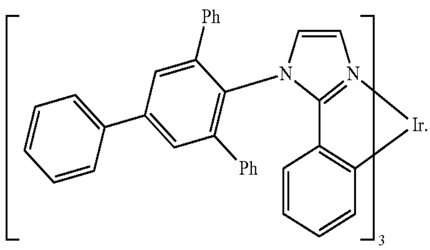
Compound N



Compound O



Compound P



6. The first device of claim 1, 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.

7. The first device of claim 6, wherein the second organic layer is a blocking layer and the compound having Formula I is a blocking material in the second organic layer.

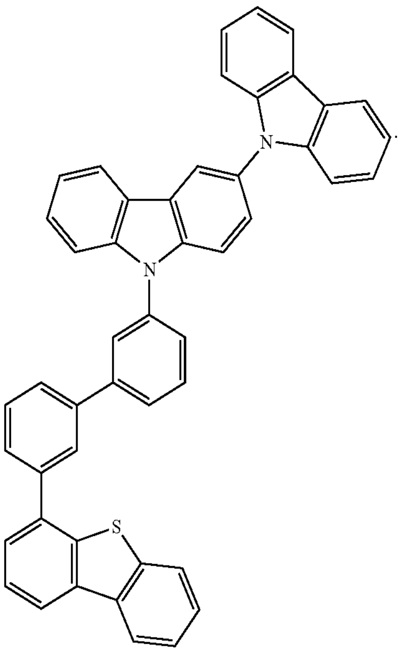
8. The first device of claim 1, wherein the first organic layer is disposed using solution processing.

9. The first device of claim 1, wherein the device is an organic light emitting device.

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

11. The first device of claim **1**, wherein the compound of formula I is:

Compound 1



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专利名称(译)	有机电致发光材料和器件		
公开(公告)号	US8932734	公开(公告)日	2015-01-13
申请号	US12/900925	申请日	2010-10-08
[标]申请(专利权)人(译)	UNIVERSAL DISOLAY CORP		
申请(专利权)人(译)	UNIVERSAL DISOLAY CORPORATION		
当前申请(专利权)人(译)	通用显示器公司		
[标]发明人	DYATKIN ALEXEY		
发明人	DYATKIN, ALEXEY		
IPC分类号	H01L51/50 H01L51/00		
CPC分类号	H01L51/0072 H01L51/006 H01L51/0073 H01L51/0074 H01L51/0081 H01L51/0085 H01L51/5012 H01L51/5048 H01L51/5096 H01L2251/308 Y10S428/917 C07D405/14 C07D409/14 C07D495/04 H01L51/0052 H01L51/0054 H01L51/0071 C09K11/06 H01L51/5016 H01L51/5072		
代理机构(译)	DUANE MORRIS LLP		
审查员(译)	CLARK , GREGORY		
其他公开文献	US20120086329A1		
外部链接	Espacenet USPTO		

摘要(译)

提供了包含3,9-连接的低聚咔唑部分和二苯并噻吩，二苯并呋喃，二苯并硒吩，氮杂 - 二苯并噻吩，氮杂 - 二苯并呋喃或氮杂 - 二苯并硒吩的化合物。 3,9-连接的低聚咔唑和二苯并或氮杂 - 二苯并部分被芳族间隔基分开。该化合物可用作磷光OLED的非发光材料，以提供具有改进性能的设备。