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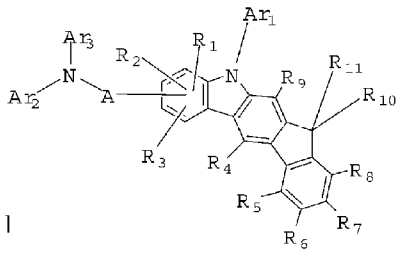
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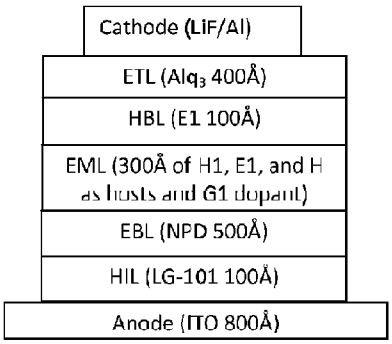
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(54) Title: PHOSPHORESCENT ORGANIC LIGHT EMITTING DEVICES HAVING A HOLE-TRANSPORTING HOST IN THE EMISSIVE REGION



[I]

FIG. 2



(57) Abstract: An improved OLED includes an emissive layer disposed between a cathode and an anode where the emissive layer includes a multi-component host material and a phosphorescent emitter material. The host material includes at least a first host compound and a second host compound, where the first host compound is hole-transporting host compound having the general formula wherein R_1, R_2, R_3, R_4, R_5, and R6 may be the same or different fluorine atom, chlorine atom, a deuterium atom, a cyano group, a trifluoromethyl group, a nitro group, linear or branched alkyl group (C1-C6), cyclo-alkyl group (C5-C10), linear or branched alkoxy group (C1-C6), cyclo-alkoxy group (C5~C10), substituted or unsubstituted aromatic hydrocarbon group, substituted or unsubstituted aromatic heterocyclic group, substituted or unsubstituted fused polycyclic aromatic group, r_1, r_4, r_5 = 0, 1, 2, 3, or 4, r_2, r_3, r_6; = 0, 1, 2 or 3, n = 0 or 1, and Ar_1, Ar_2, and Ar_3 may be the same or different, substituted or unsubstituted aromatic hydrocarbon group, substituted or unsubstituted aromatic heterocyclic group, substituted or unsubstituted fused polycyclic aromatic group, deuterium substituted aromatic hydrocarbon group, deuterium substituted aromatic heterocyclic group, or deuterium substituted fused polycyclic aromatic group.

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PHOSPHORESCENT ORGANIC LIGHT EMITTING DEVICES HAVING A HOLE-TRANSPORTING HOST IN THE EMISSIVE REGION

FIELD

[0001] The present invention relates to an organic electroluminescent (EL) device such as an organic light emitting device (hereinafter abbreviated as an OLED) and materials capable of being used in such an OLED.

BACKGROUND

[0002] OLEDs which comprise an organic thin film layer which includes a light emitting layer located between an anode and a cathode are known in the art. In such devices, emission of light may be obtained from exciton energy, produced by recombination of a hole injected into a light emitting layer with an electron.

[0003] OLEDs make use of thin organic films that emit light when a voltage is applied across the device. Generally, OLEDs are comprised of several organic layers in which at least one of the layers can be made to electro-luminesce by applying a voltage across the device. When a voltage is applied across a device, the cathode effectively reduces the adjacent organic layers (*i.e.*, injects electrons), and the anode effectively oxidizes the adjacent organic layers (*i.e.*, injects holes). Holes and electrons migrate across the device toward their respective oppositely charged electrodes. When a hole and an electron localize on the same molecule, recombination is said to occur, and an exciton is formed. An exciton is a localized electron-hole pair having an excited energy state. Light is emitted (*i.e.*, electroluminescence) when the exciton relaxes via a photo-emissive mechanism in luminescent compounds. In some cases, the exciton may be localized on an excimer or an exciplex.

[0004] Despite the recent discoveries such as the use of efficient heavy metal phosphors and the resulting advancements in OLED technology, there remains a continued need for longer device stability and higher efficiency. An improved OLED device that exhibit improved lifetimes and efficiencies is disclosed herein along with the associated materials that may be used to construct such OLED.

[0005] 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. As used herein, "small molecule" refers to any organic material that is not a polymer, *i.e.*,

organic material having molecules with a defined molecular weight, and "small molecules" may actually be quite large. Small molecules may include repeat units in some circumstances, e.g. oligomers. 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.

[0006] 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.

[0007] As used herein, "solution processible" means capable of being dissolved, dispersed, or transported in and/or deposited from a liquid medium, either in solution or suspension form.

[0008] 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.

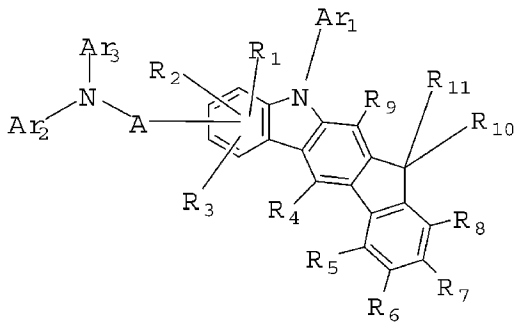
[0009] As used herein, and as would be generally understood by one skilled in the art, a first "Highest Occupied Molecular Orbital" (HOMO) or "Lowest Unoccupied Molecular Orbital" (LUMO) energy level is "greater than" or "higher than" a second HOMO or LUMO energy level if the first energy level is closer to the vacuum energy level. Since ionization potentials (IP) are measured as a negative energy relative to a vacuum level, a higher HOMO energy level corresponds to an IP having a smaller absolute value (an IP that is less negative). Similarly, a higher LUMO energy level corresponds to an electron affinity (EA) having a smaller absolute value (an EA that is less negative). On a conventional energy level diagram,

with the vacuum level at the top, the LUMO energy level of a material is higher than the HOMO energy level of the same material. A "higher" HOMO or LUMO energy level appears closer to the top of such a diagram than a "lower" HOMO or LUMO energy level.

[0010] 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.

SUMMARY

[0011] The present disclosure provides OLEDs having a multi-component emissive layer. In one aspect, an OLED of the present disclosure comprises an anode electrode, a cathode electrode, and an organic electroluminescent layer disposed between the anode electrode and the cathode electrode. The organic electroluminescent layer comprising a host material and a phosphorescent emitter dopant material. The host material comprises at least a first host compound, and a second host compound, wherein the first host compound has an indeno-carbazole ring structure represented by the following general formula H1



(H1)

wherein A represents a divalent group of a substituted or unsubstituted aromatic hydrocarbon, a divalent group of a substituted or unsubstituted aromatic heterocyclic ring, or a divalent group of substituted or unsubstituted fused polycyclic aromatics; Ar_1, Ar_2, and Ar_3 may be the same or different, and represent a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted aromatic heterocyclic group, or a substituted or unsubstituted fused polycyclic aromatic group, where A and Ar_2, or Ar_2 and Ar_3 may bind to each other via a single bond or via substituted or unsubstituted methylene, an oxygen atom,

or a sulfur atom to form a ring; R_1 to R_9 may be the same or different, and represent a hydrogen atom, a deuterium atom, a fluorine atom, a chlorine atom, cyano, nitro, linear or branched alkyl of 1 to 6 carbon atoms that may have a substituent, cycloalkyl of 5 to 10 carbon atoms that may have a substituent, linear or branched alkenyl of 2 to 6 carbon atoms that may have a substituent, linear or branched alkyloxy of 1 to 6 carbon atoms that may have a substituent, cycloalkyloxy of 5 to 10 carbon atoms that may have a substituent, a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted aromatic heterocyclic group, a substituted or unsubstituted fused polycyclic aromatic group, or substituted or unsubstituted aryloxy, which may bind to each other via a single bond, substituted or unsubstituted methylene, an oxygen atom, or a sulfur atom to form a ring; and R_{10} and R_{11} may be the same or different, and represent linear or branched alkyl of 1 to 6 carbon atoms that may have a substituent, cycloalkyl of 5 to 10 carbon atoms that may have a substituent, linear or branched alkenyl of 2 to 6 carbon atoms that may have a substituent, linear or branched alkyloxy of 1 to 6 carbon atoms that may have a substituent, cycloalkyloxy of 5 to 10 carbon atoms that may have a substituent, a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted aromatic heterocyclic group, a substituted or unsubstituted fused polycyclic aromatic group, or substituted or unsubstituted aryloxy, which may bind to each other via a single bond, substituted or unsubstituted methylene, an oxygen atom, or a sulfur atom to form a ring.

[0012] In another aspect, the OLED described above further comprises an exciton/electron blocking layer disposed between the electroluminescent layer and the anode, wherein the exciton/electron blocking layer blocks at least one of excitons or electrons and comprises a material that is the compound represented by the general formula H1.

[0013] The inventors have discovered that the OLED incorporating the teachings of the present disclosure exhibits an unexpectedly improved color saturation in the emission spectrum.

BRIEF DESCRIPTION OF THE DRAWING

[0014] The figures are not necessarily drawn to scale.

[0015] FIG. 1 is a schematic illustration of an OLED architecture.

[0016] FIG. 2 is a schematic illustration of an OLED architecture according to an embodiment of the present disclosure in which the hole transporting compound of the present disclosure is used as a hole-transporting host in a four-component emissive layer.

[0017] FIG. 3 is a schematic illustration of an OLED architecture according to another embodiment, in which the hole-transporting compound is used as a hole-transporting host in a four-component emissive layer and as an exciton/electron blocking layer.

[0018] FIG. 4 is an energy level diagram for the device of FIG. 2 in which the hole-transporting compound is used as a hole transporting host in the four-component emissive layer.

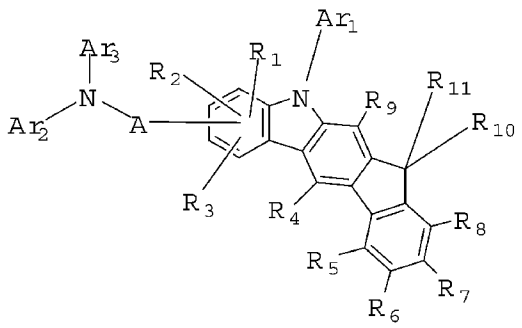
[0019] FIG. 5 is an energy level diagram for the device of FIG. 3 in which the hole-transporting compound is used as a hole transporting host in the four-component emissive layer and as an exciton/electron blocking layer.

[0020] FIG. 6 is a schematic illustration of an inverted OLED.

DETAILED DESCRIPTION

[0021] In the present disclosure, HIL refers to a hole injection layer; HTL refers to a hole transport layer; EBL refers to an exciton/electron blocking layer that may be capable of blocking excitons or electrons or both; EML refers to an emissive layer; HBL refers to a hole blocking layer; and ETL refers to an electron transport layer. The terms electroluminescent and emissive are used interchangeably.

[0022] The present disclosure describes an OLED comprising an organic electroluminescent layer comprising a phosphorescent emitter dopant dispersed in a host material wherein the host material comprises a first host compound, and a second host compound. The first host compound is a hole-transporting host compound represented by the general formula H1



(H1)

wherein A represents a divalent group of a substituted or unsubstituted aromatic hydrocarbon, a divalent group of a substituted or unsubstituted aromatic heterocyclic ring, or a divalent group of substituted or unsubstituted fused polycyclic aromatics; Ar_1, Ar_2, and Ar_3 may be the same or different, and represent a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted aromatic heterocyclic group, or a substituted or unsubstituted fused polycyclic aromatic group, where A and Ar_2, or Ar_2 and Ar_3 may bind to each other via a single bond or via substituted or unsubstituted methylene, an oxygen atom, or a sulfur atom to form a ring; R_1 to R_9 may be the same or different, and represent a hydrogen atom, a deuterium atom, a fluorine atom, a chlorine atom, cyano, nitro, linear or branched alkyl of 1 to 6 carbon atoms that may have a substituent, cycloalkyl of 5 to 10 carbon atoms that may have a substituent, linear or branched alkenyl of 2 to 6 carbon atoms that may have a substituent, linear or branched alkyloxy of 1 to 6 carbon atoms that may have a substituent, cycloalkyloxy of 5 to 10 carbon atoms that may have a substituent, a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted aromatic heterocyclic group, a substituted or unsubstituted fused polycyclic aromatic group, or substituted or unsubstituted aryloxy, which may bind to each other via a single bond, substituted or unsubstituted methylene, an oxygen atom, or a sulfur atom to form a ring; and R_{10} and R_{11} may be the same or different, and represent linear or branched alkyl of 1 to 6 carbon atoms that may have a substituent, cycloalkyl of 5 to 10 carbon atoms that may have a substituent, linear or branched alkenyl of 2 to 6 carbon atoms that may have a substituent, linear or branched alkyloxy of 1 to 6 carbon atoms that may have a substituent, cycloalkyloxy of 5 to 10 carbon atoms that may have a substituent, a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted aromatic heterocyclic group, a substituted or unsubstituted fused polycyclic aromatic group, or substituted or unsubstituted aryloxy, which may bind to each other via a single bond, substituted or unsubstituted methylene, an oxygen atom, or a sulfur atom to form a ring.

[0023] The resulting OLED exhibits improved color saturation in the emission spectrum. According to an aspect of the present disclosure, the host material can also include a third host compound. The second and third host compounds are described below.

[0024] **FIG. 1** shows an OLED **100**. The OLED **100** may include a substrate **110**, an anode **115**, a hole injection layer **120**, a hole transport layer **125**, and 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**. The cathode **160** can be a compound cathode having more than one conductive layers, such as a first conductive layer **162** and a second conductive layer **164** as shown. The OLED **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. patent No. 7,279,704 at columns 6-10, the disclosure of which is incorporated herein by reference in its entirety.

[0025] Structures and materials not specifically described may also be used, such as OLEDs comprised of polymeric materials (PLEDs) such as disclosed in U.S. patent 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. patent 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 this disclosure. For example, the substrate may include an angled reflective surface to improve outcoupling, such as a mesa structure as described in U.S. patent No. 6,091,195 to Forrest *et al.*, and/or a pit structure as described in U.S. patent No. 5,834,893 to Bulovic *et al.*, which are incorporated by reference in their entireties.

[0026] 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. patent No. 6,013,982 and No. 6,087,196, which are incorporated by reference in their entireties, organic vapor phase deposition (OVPD), such as described in U.S. patent 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 No. 7,431 ,968, 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. patent No. 6,294,398 and No. 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 be better suited for solution processing 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.

[0027] 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 °C to 30 °C, and more preferably at room temperature (20-25 °C).

[0028] 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.

[0029] The terms halo, halogen, alkyl, cycloalkyl, alkenyl, alkynyl, aralkyl, heterocyclic group, aryl, aromatic group, and heteroaryl are known to the art, and are defined in U.S. patent No. 7,279,704 at columns 31-32, the disclosure of which is incorporated herein by reference in its entirety. The host material of the emissive layer in an organic light-emitting device provides a solid medium for the transport and recombination of charge carriers injected from the anode and the cathode. Compounds used for the host material can be categorized according to their charge transport properties. Some host compounds are predominantly electron-transporting and some others are predominantly hole-transporting. Although host compounds may be characterized as transporting predominantly one type of charge, the compound may also transport charges of both types.

Emitter dopant:

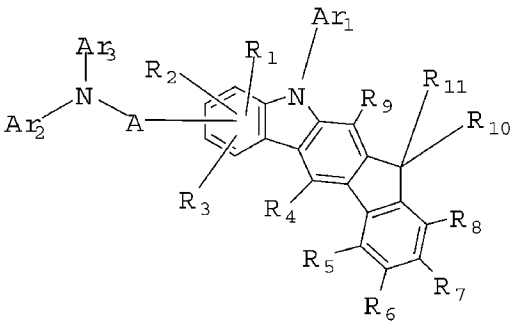
[0030] Any suitable phosphorescent dopant may be used in the emissive layer. Some examples are provided in **Table 5** below. In one embodiment, the phosphorescent dopant is a phosphorescent emitter material comprising a phosphorescent organometallic compound that emits phosphorescent radiation from a triplet molecular excited state when a voltage is applied across the material. The selection of the host materials will vary depending on the selection of the phosphorescent emitter dopant. In some embodiments, the electroluminescent layer contains additional dopants.

[0031] According to an embodiment, the phosphorescent emitter material is an organometallic compound selected from the group consisting of phosphorescent organometallic platinum compounds, organometallic iridium compounds and organometallic osmium compounds. The phosphorescent organometallic compound can include a carbon-metal bond. The organometallic platinum compounds, iridium compounds and osmium compounds can each include an aromatic ligand.

[0032] The phosphorescent organometallic compounds can comprise heteroleptic complexes with extended conjugation on the heterocyclic ring. Examples of such heteroleptic iridium compounds are described in PCT publication No. WO 2010/028151, published on March 11, 2010, the disclosure of which is incorporated herein by reference in its entirety.

The Hole-transporting Host Compound:

[0033] The first host compound is represented by the following general formula H1:

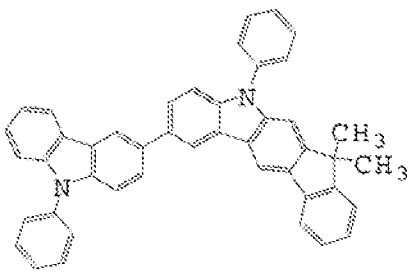


H1

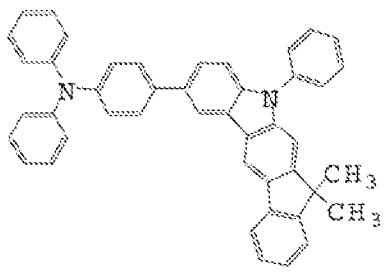
wherein A represents a divalent group of a substituted or unsubstituted aromatic hydrocarbon, a divalent group of a substituted or unsubstituted aromatic heterocyclic ring, or a divalent group of substituted or unsubstituted fused polycyclic aromatics; Ar_1, Ar_2, and Ar_3 may be the same or different, and represent a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted aromatic heterocyclic group, or a substituted or

unsubstituted fused polycyclic aromatic group, where A and Ar_2, or Ar_2 and Ar_3 may bind to each other via a single bond or via substituted or unsubstituted methylene, an oxygen atom, or a sulfur atom to form a ring; R_1 to R_9 may be the same or different, and represent a hydrogen atom, a deuterium atom, a fluorine atom, a chlorine atom, cyano, nitro, linear or branched alkyl of 1 to 6 carbon atoms that may have a substituent, cycloalkyl of 5 to 10 carbon atoms that may have a substituent, linear or branched alkenyl of 2 to 6 carbon atoms that may have a substituent, linear or branched alkyloxy of 1 to 6 carbon atoms that may have a substituent, cycloalkyloxy of 5 to 10 carbon atoms that may have a substituent, a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted aromatic heterocyclic group, a substituted or unsubstituted fused polycyclic aromatic group, or substituted or unsubstituted aryloxy, which may bind to each other via a single bond, substituted or unsubstituted methylene, an oxygen atom, or a sulfur atom to form a ring; and R_{10} and R_{11} may be the same or different, and represent linear or branched alkyl of 1 to 6 carbon atoms that may have a substituent, cycloalkyl of 5 to 10 carbon atoms that may have a substituent, linear or branched alkenyl of 2 to 6 carbon atoms that may have a substituent, linear or branched alkyloxy of 1 to 6 carbon atoms that may have a substituent, cycloalkyloxy of 5 to 10 carbon atoms that may have a substituent, a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted aromatic heterocyclic group, a substituted or unsubstituted fused polycyclic aromatic group, or substituted or unsubstituted aryloxy, which may bind to each other via a single bond, substituted or unsubstituted methylene, an oxygen atom, or a sulfur atom to form a ring.

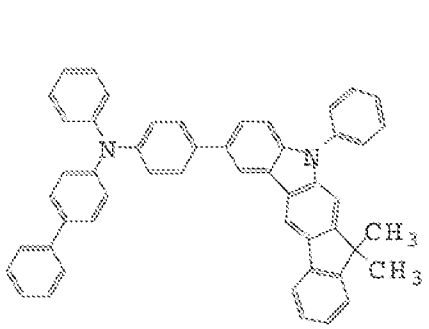
[0034] Examples of specific compounds having the structure of formula H1 are shown below. The first host compound can be selected from the group consisting of the compounds shown below, wherein D represents deuterium:



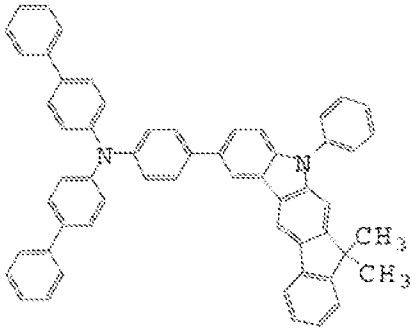
Compound H1-1



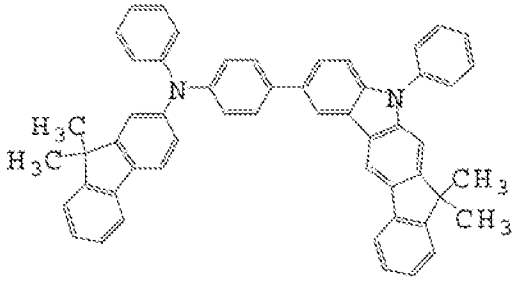
Compound H1-2



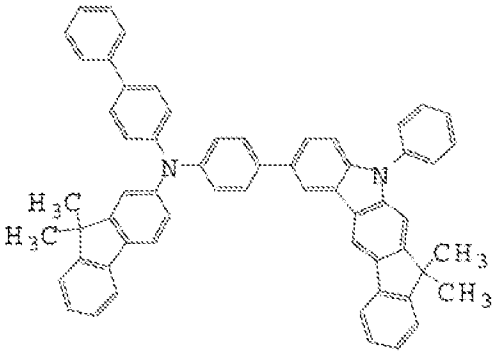
Compound H1-3



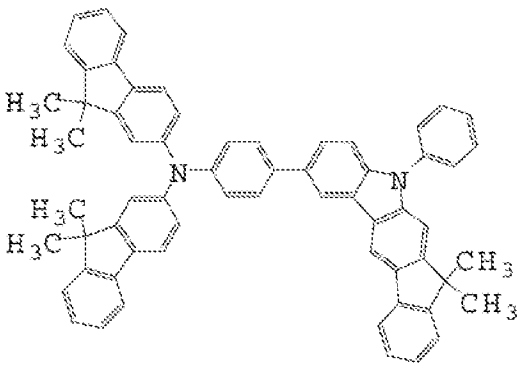
Compound H1-4



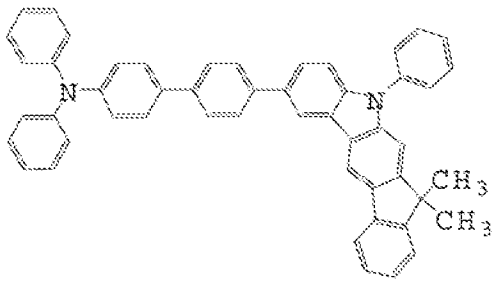
Compound H1-5



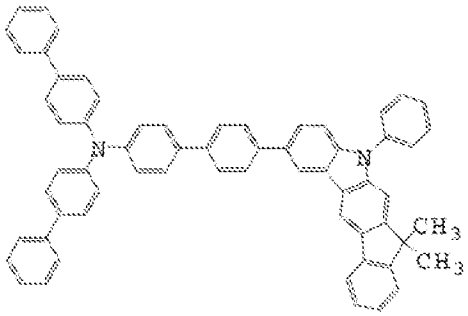
Compound H1-6



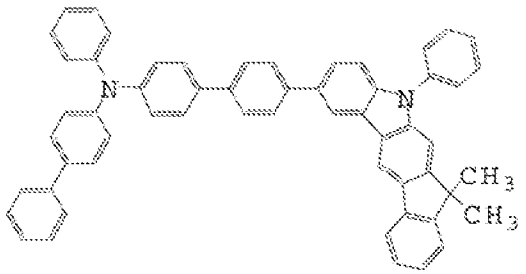
Compound H1-7



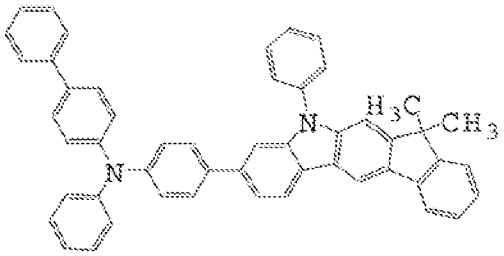
Compound H1-8



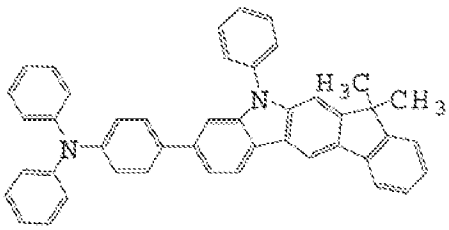
Compound H1-9



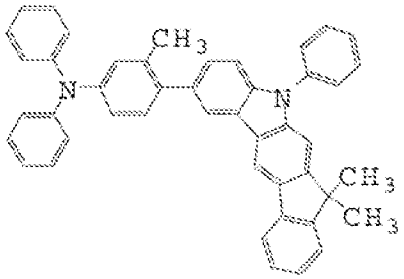
Compound H1-10



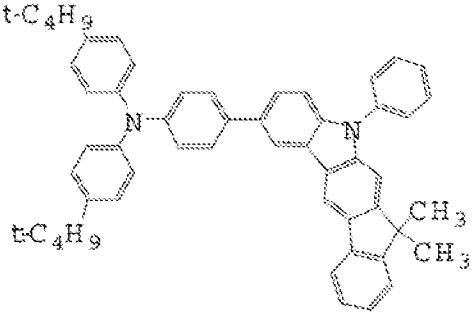
Compound H1-11



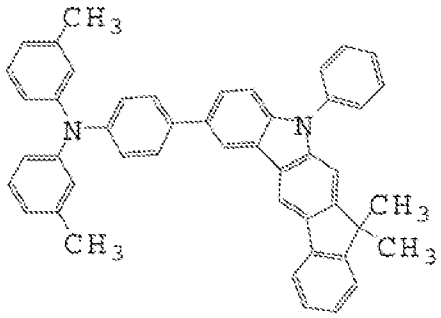
Compound H1-12



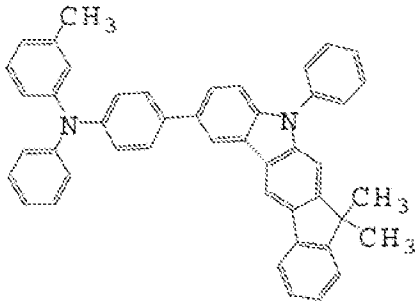
Compound H1-13



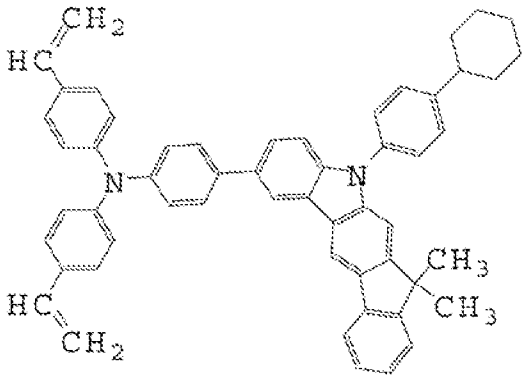
Compound H1-14



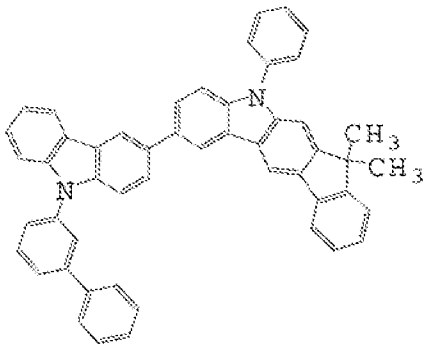
Compound H1-15



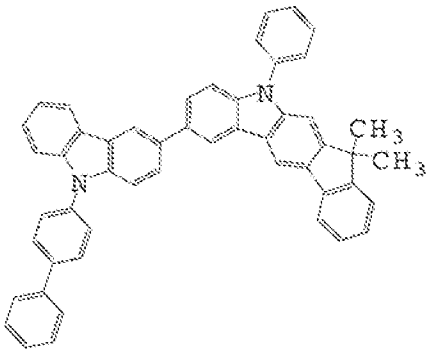
Compound H1-16



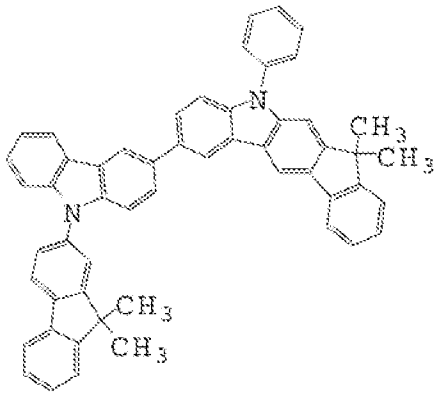
Compound H1-17



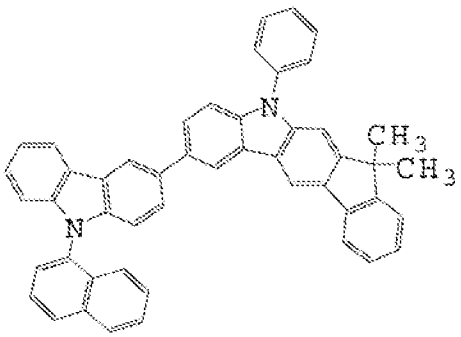
Compound H1-18



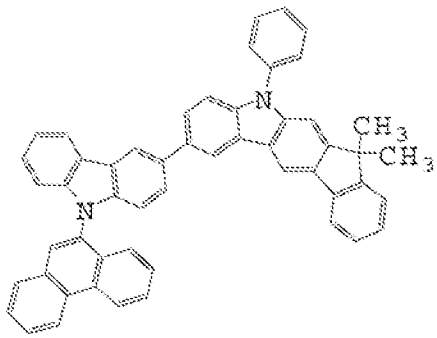
Compound H1-19



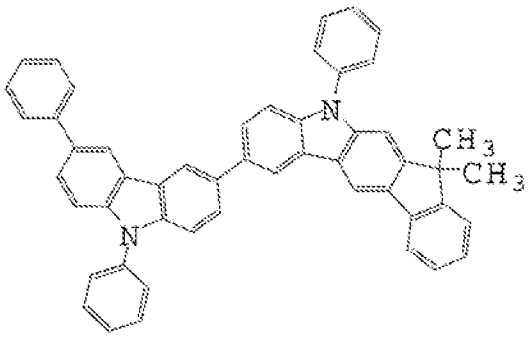
Compound H1-20



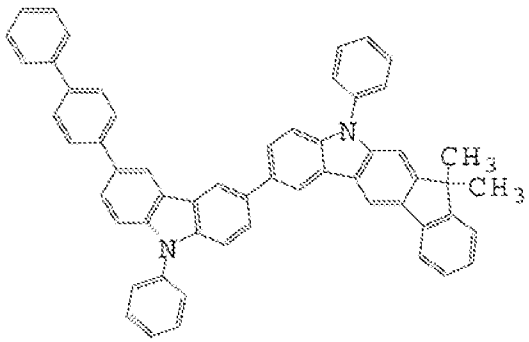
Compound H1-21



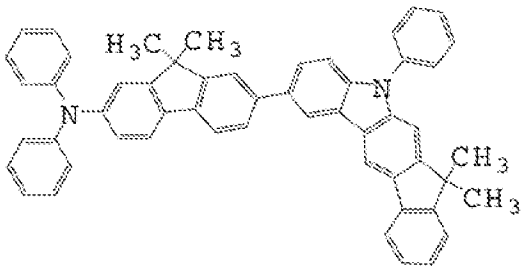
Compound H1-22



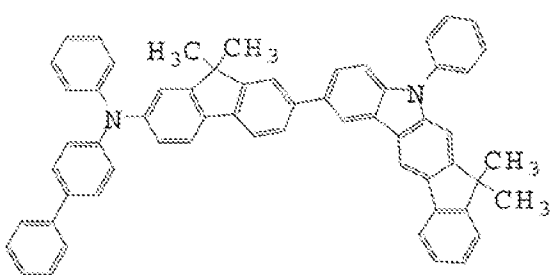
Compound H1-23



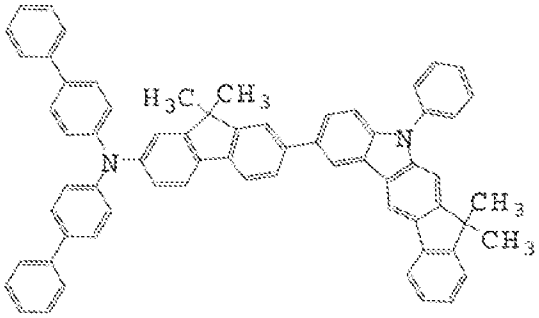
Compound H1-24



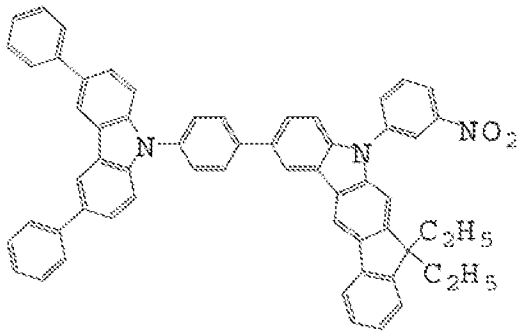
Compound H1-25



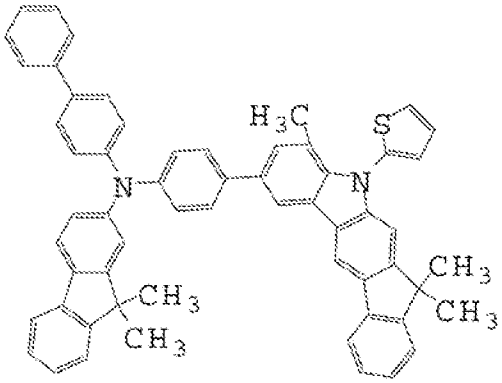
Compound H1-26



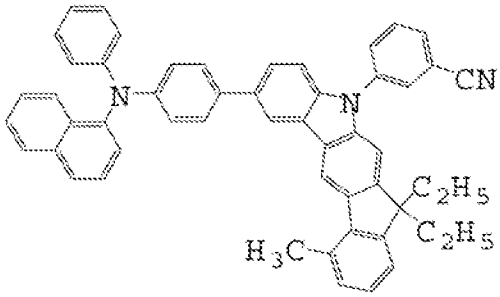
Compound H1-27



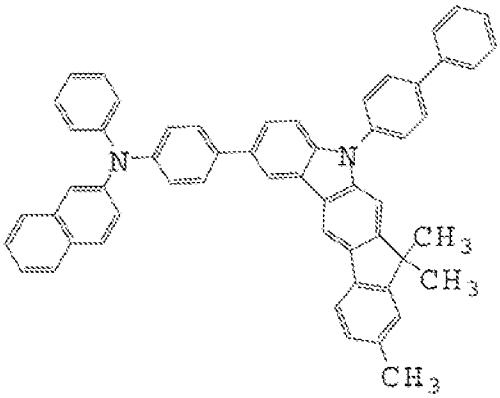
Compound H1-28



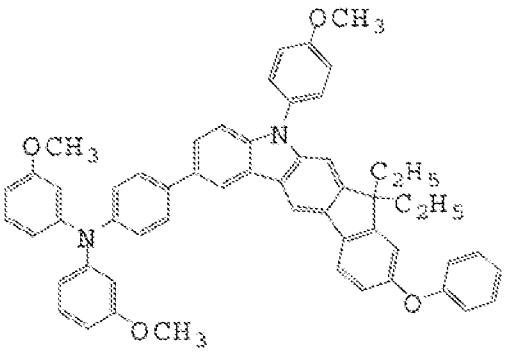
Compound H1-29



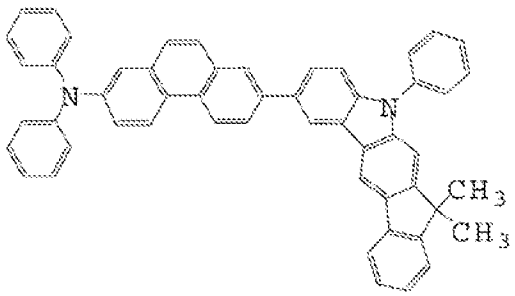
Compound H1-30



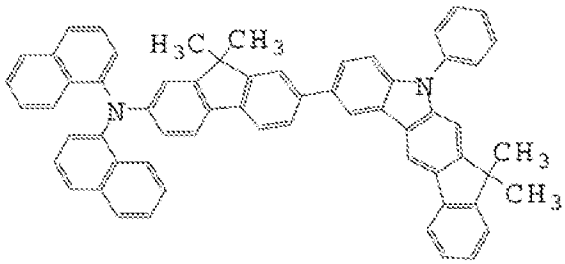
Compound H1-31



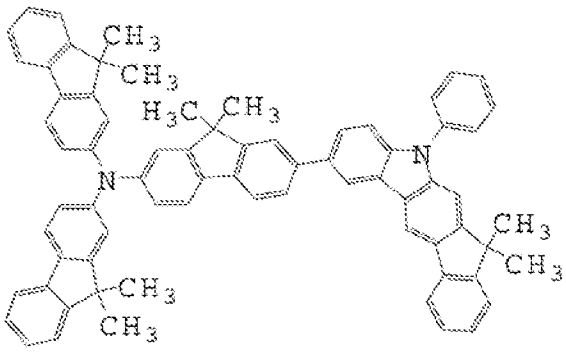
Compound H1-32



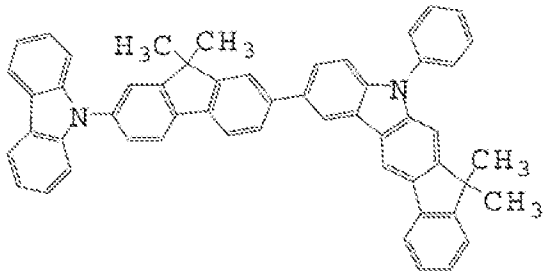
Compound H1-33



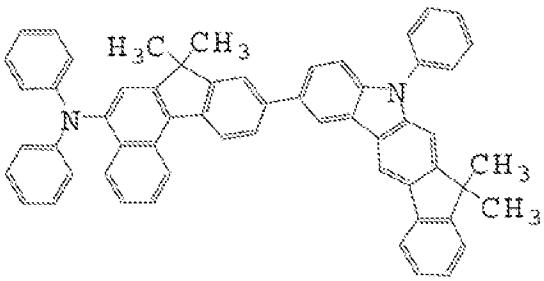
Compound H1-34



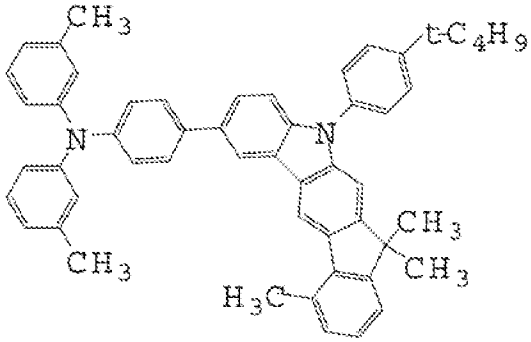
Compound H1-35



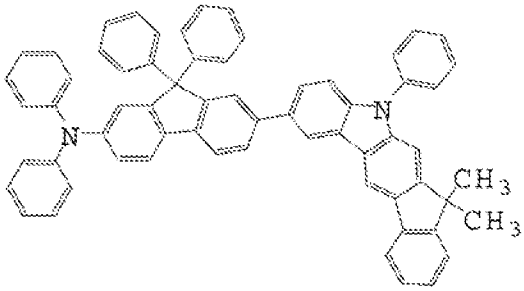
Compound H1-36



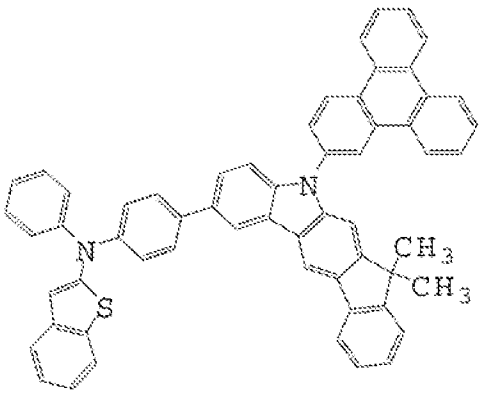
Compound H1-37



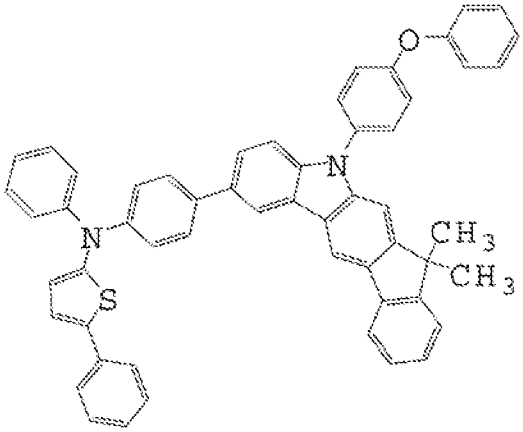
Compound H1-38



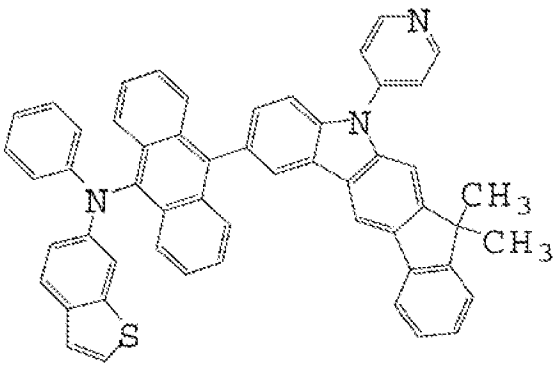
Compound H1-39



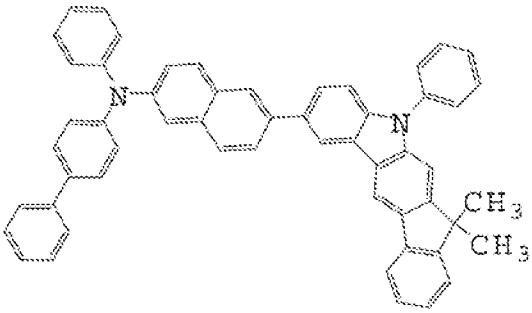
Compound H1-40



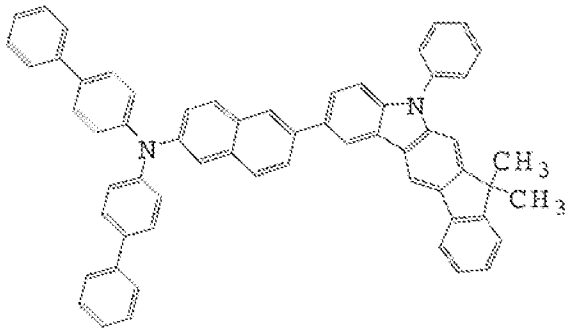
Compound H1-41



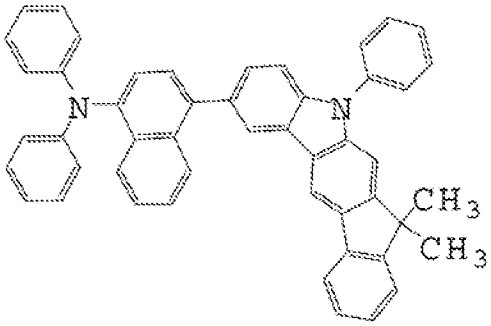
Compound H1-42



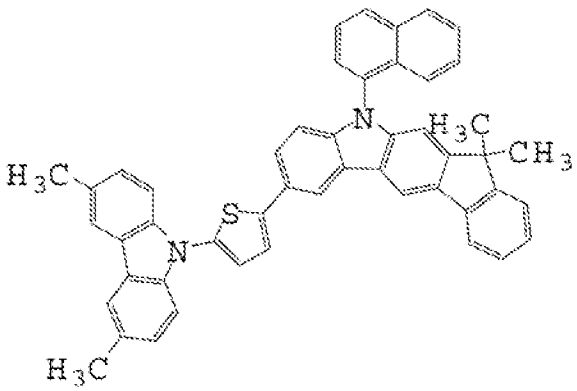
Compound H1-43



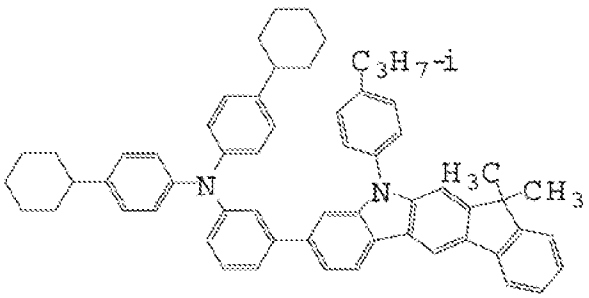
Compound H1-44



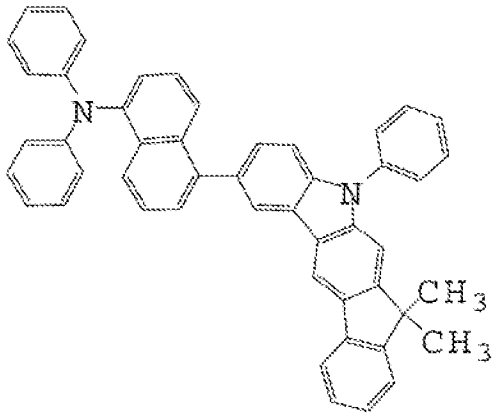
Compound H1-45



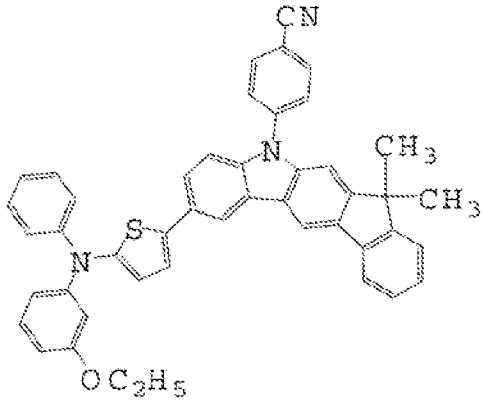
Compound H1-46



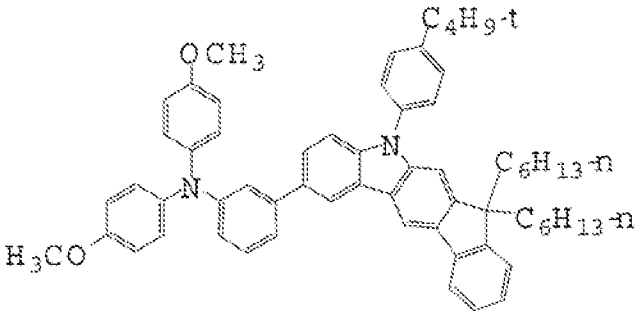
Compound H1-47



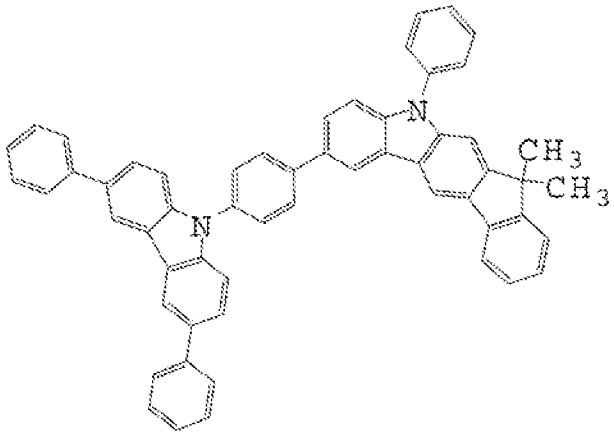
Compound H1-48



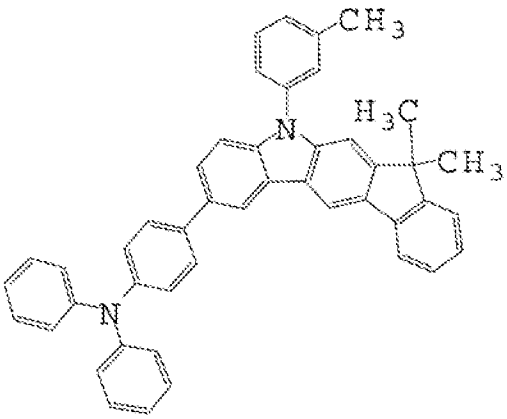
Compound H1-49



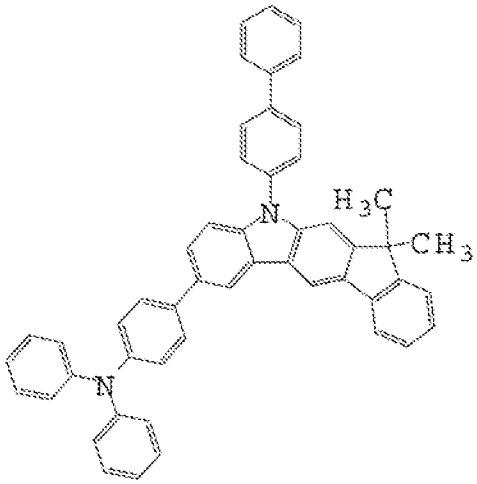
Compound H1-50



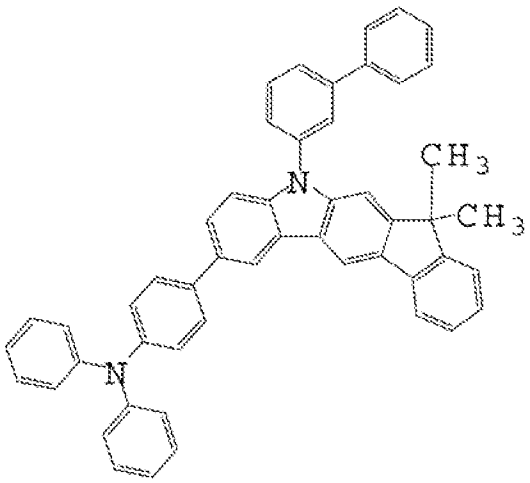
Compound H1-51



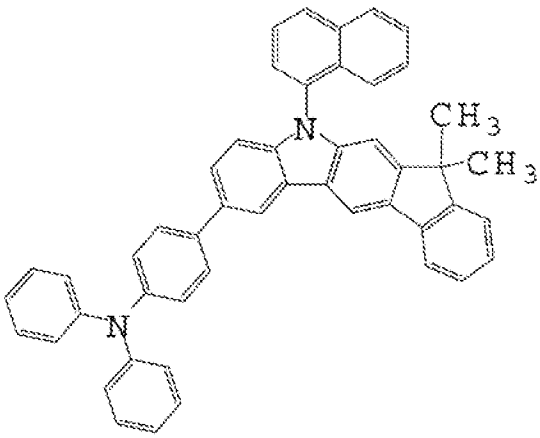
Compound H1-52



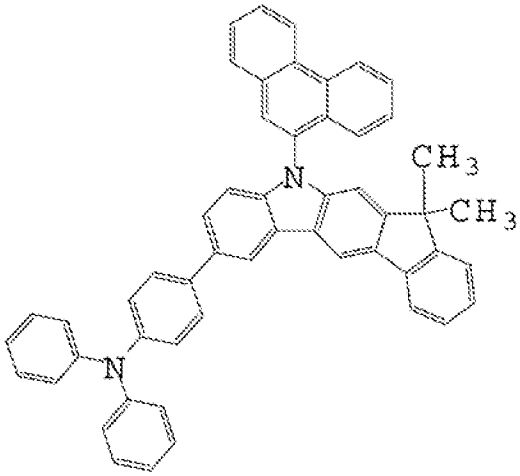
Compound H1-53



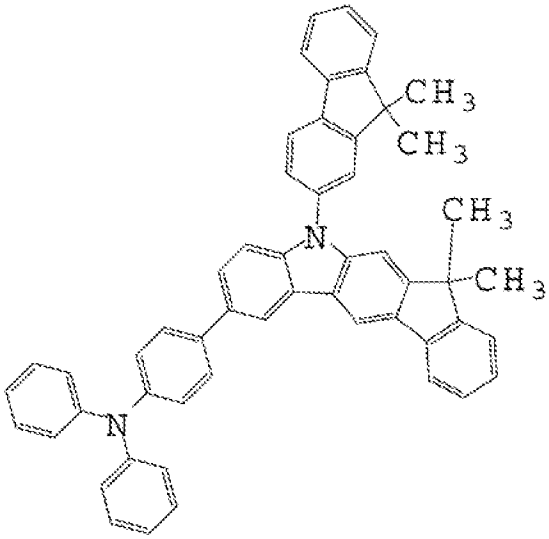
Compound H1-54



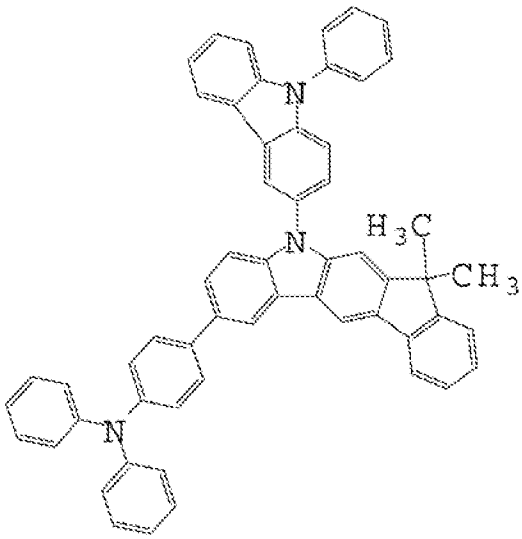
Compound H1-55



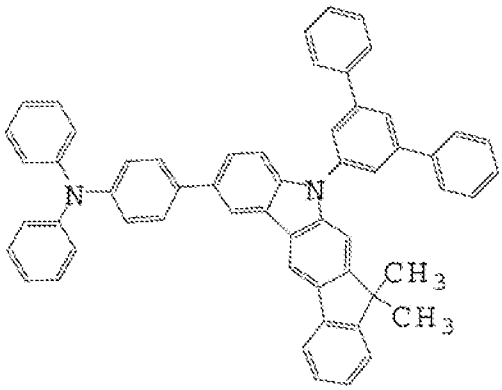
Compound H1-56



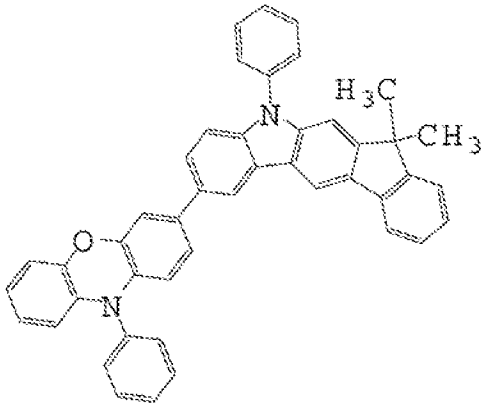
Compound H1-57



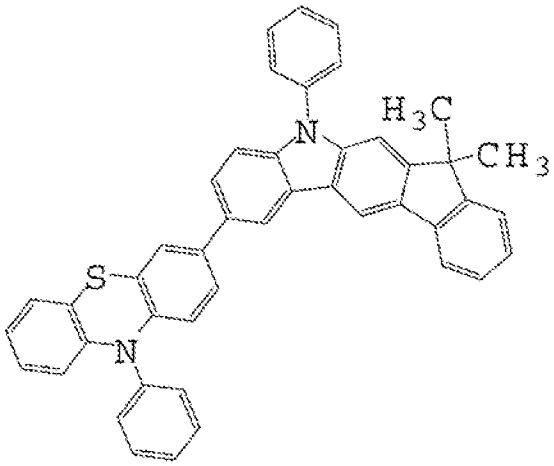
Compound H1-58



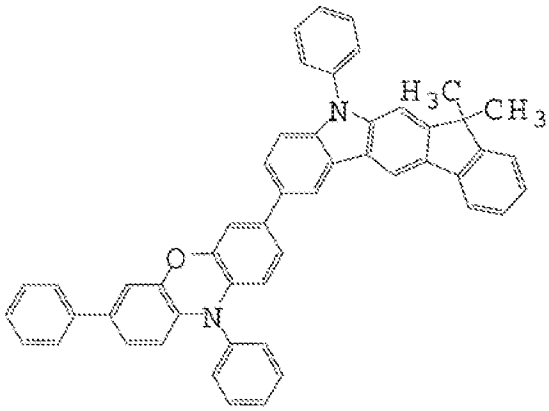
Compound H1-59



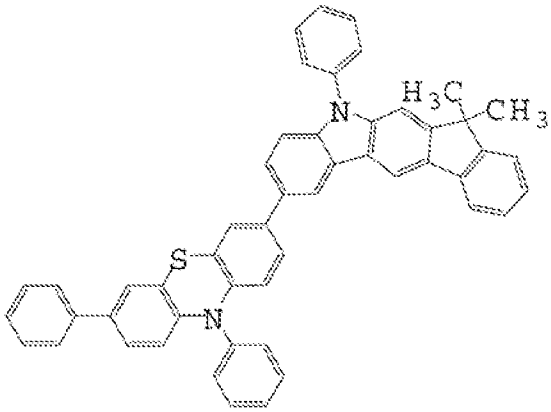
Compound H1-60



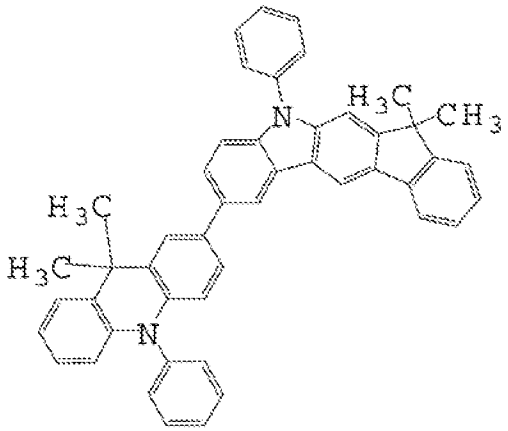
Compound H1-61



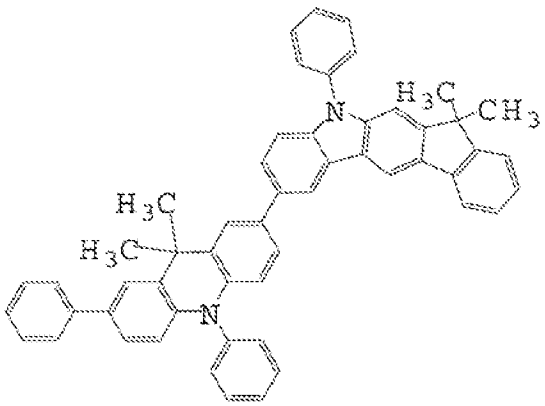
Compound H1-62



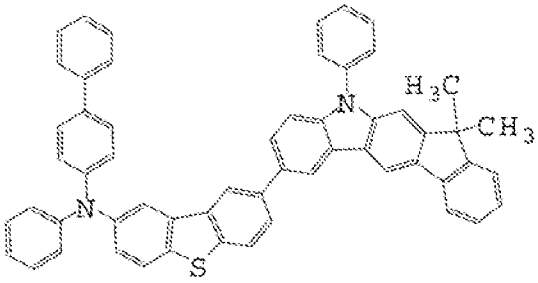
Compound H1-63



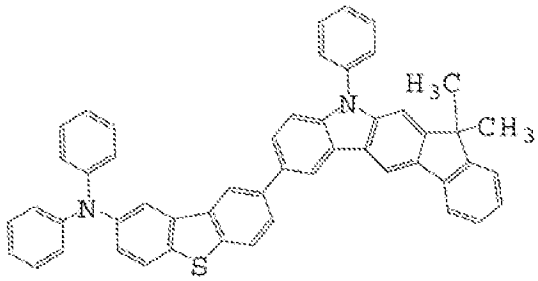
Compound H1-64



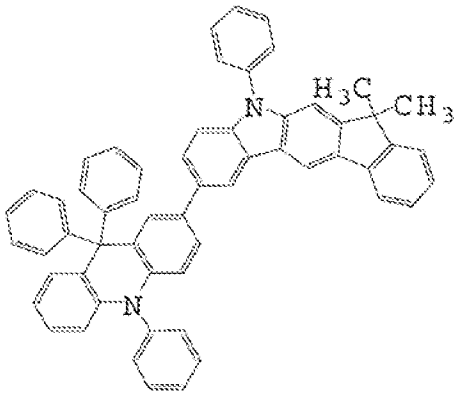
Compound H1-65



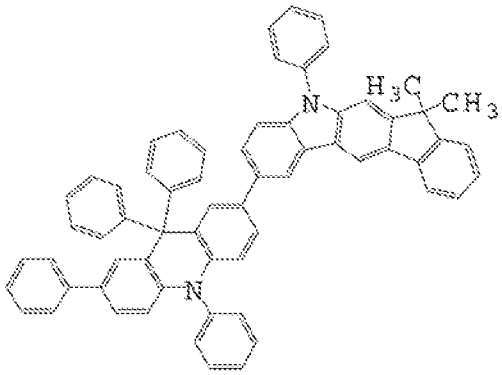
Compound H1-66



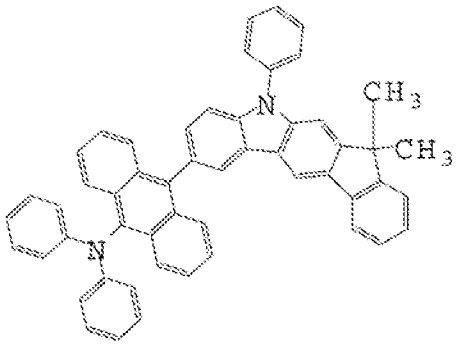
Compound H1-67



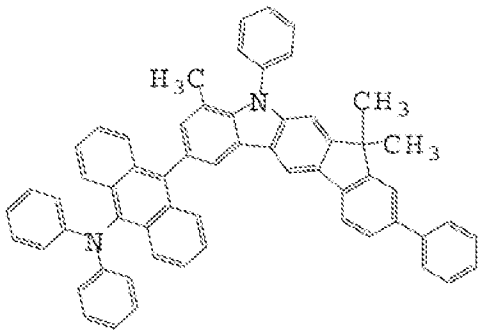
Compound H1-68



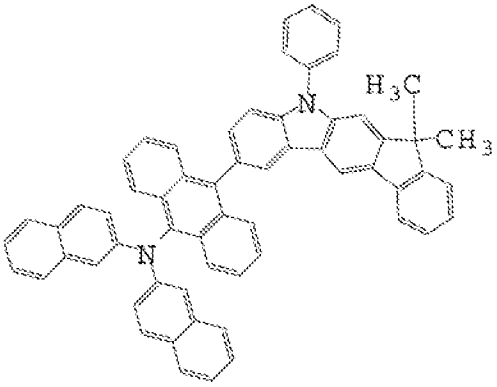
Compound H1-69



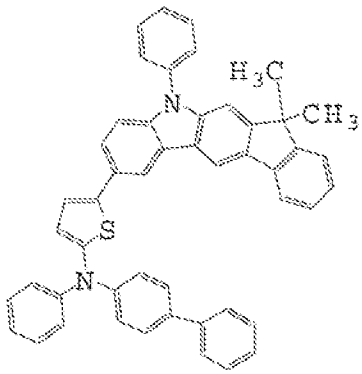
Compound H1-70



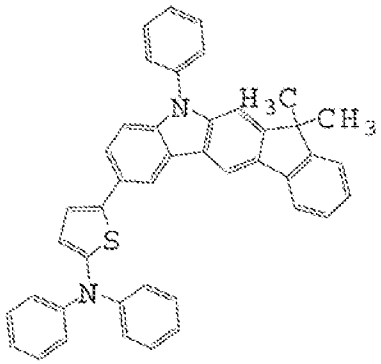
Compound H1-71



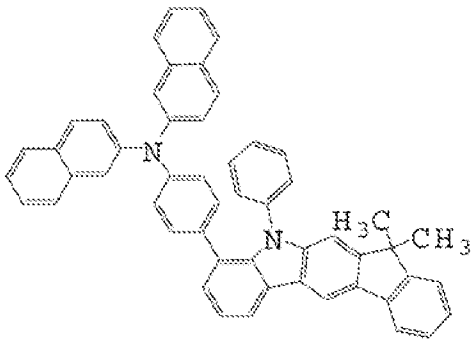
Compound H1-72



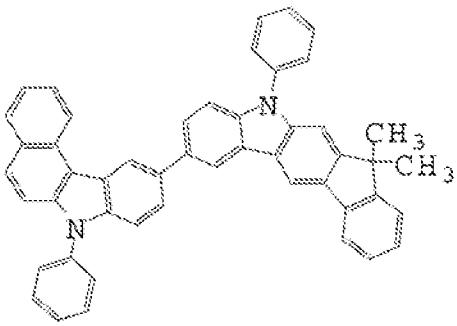
Compound H1-73



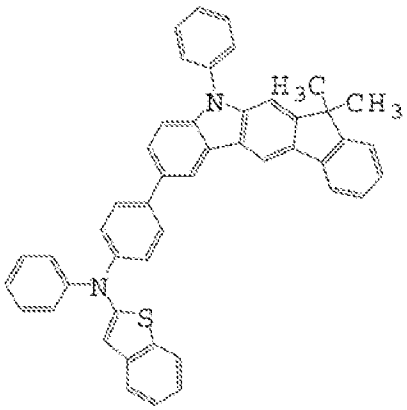
Compound H1-74



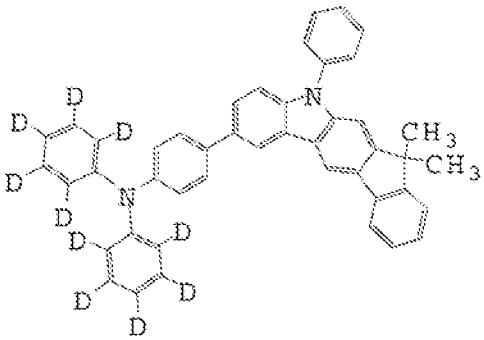
Compound H1-75



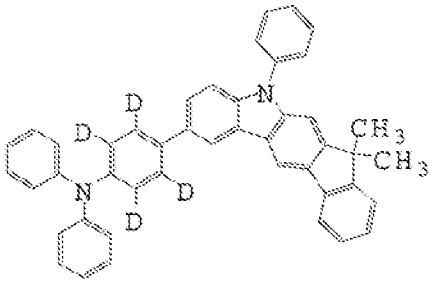
Compound H1-76



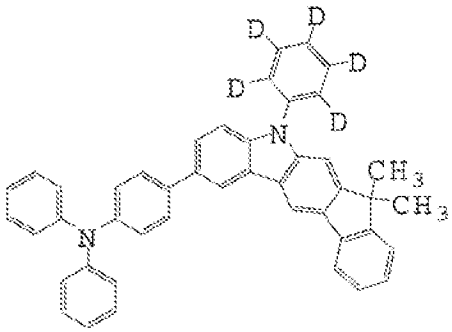
Compound H1-77



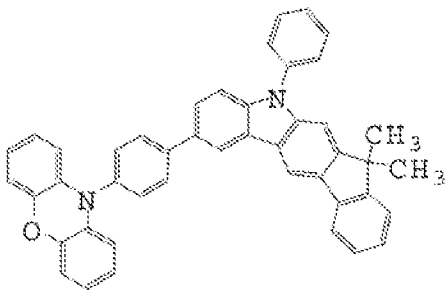
Compound H1-78



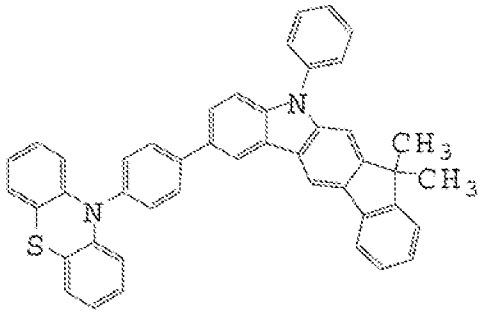
Compound H1-79



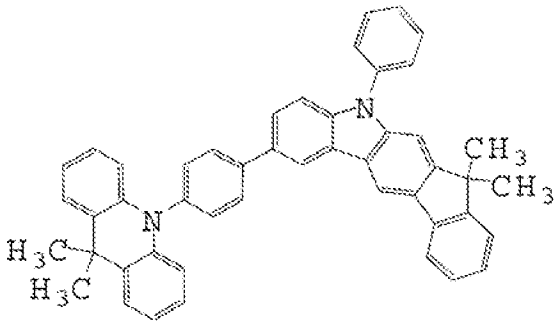
Compound H1-80



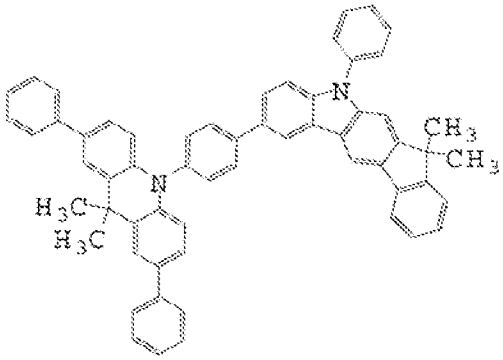
Compound H1-81



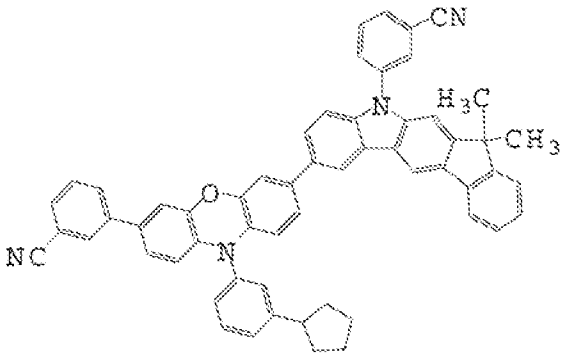
Compound H1-82



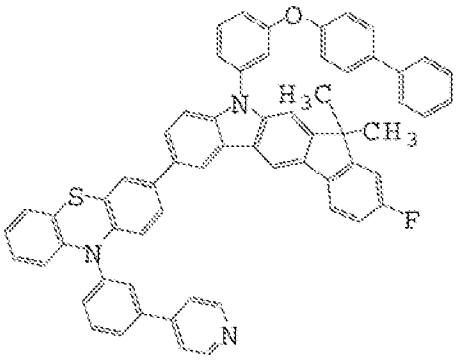
Compound H1-83



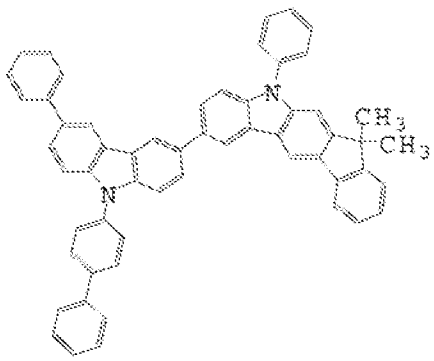
Compound H1-84



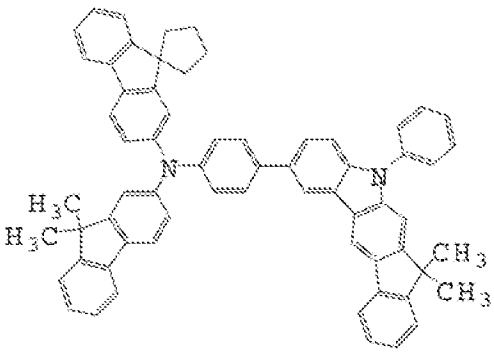
Compound H1-85



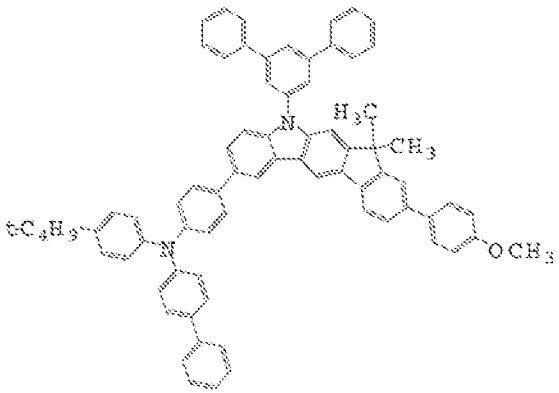
Compound H1-86



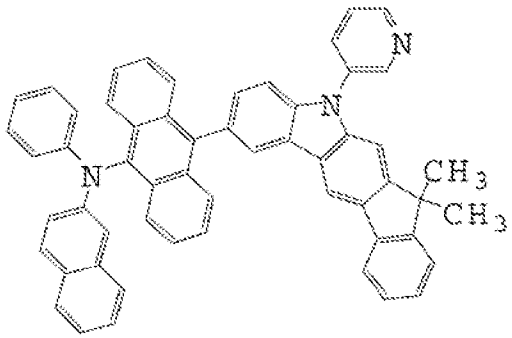
Compound H1-87



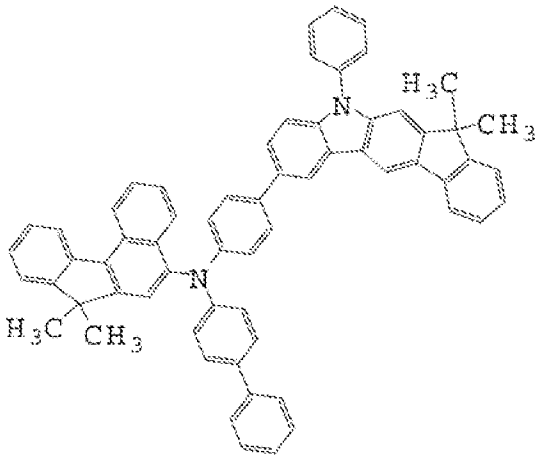
Compound H1-88



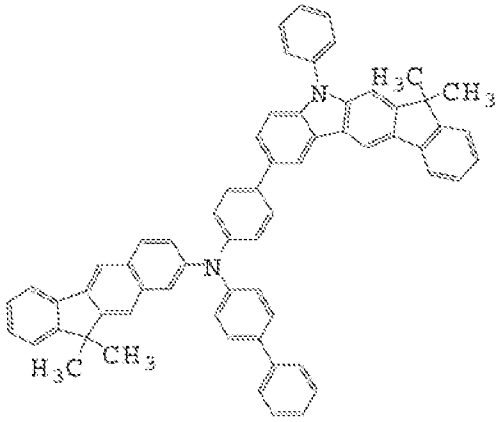
Compound H1-89



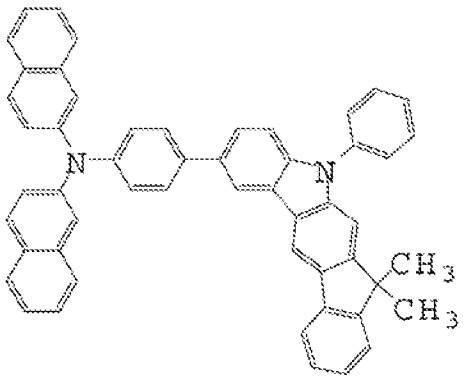
Compound H1-90



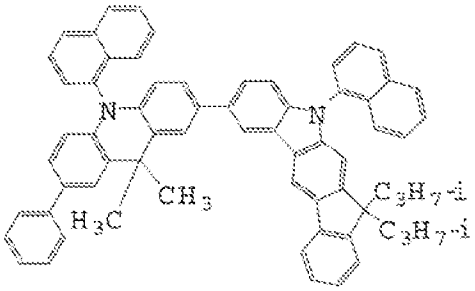
Compound H1-91



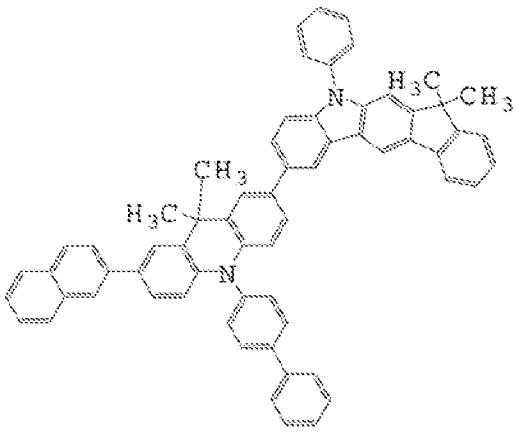
Compound H1-92



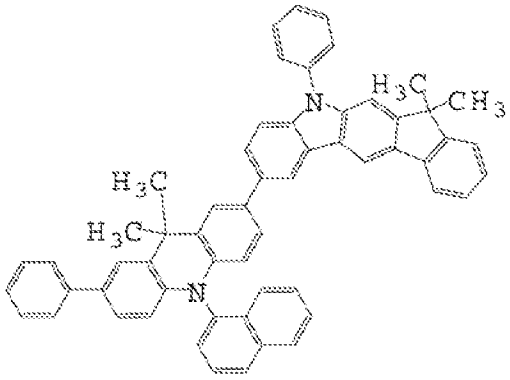
Compound H1-93



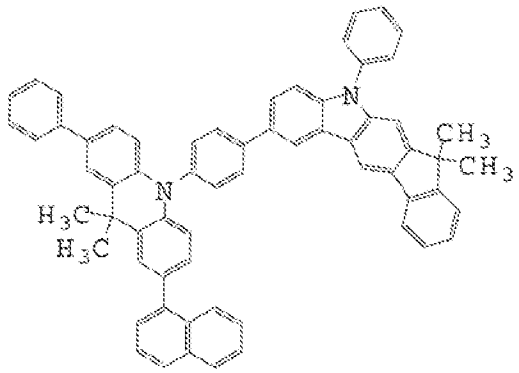
Compound H1-94



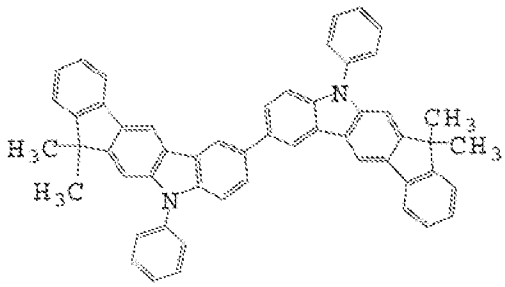
Compound H1-95



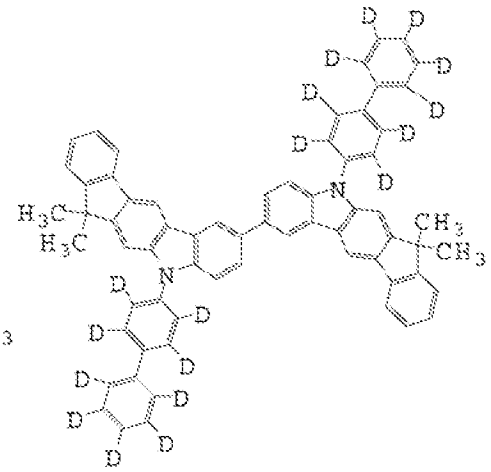
Compound H1-96



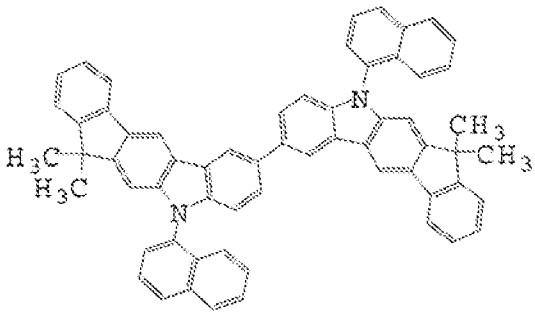
Compound H1-97



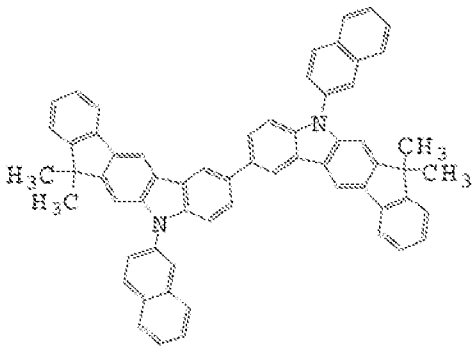
Compound H1-98



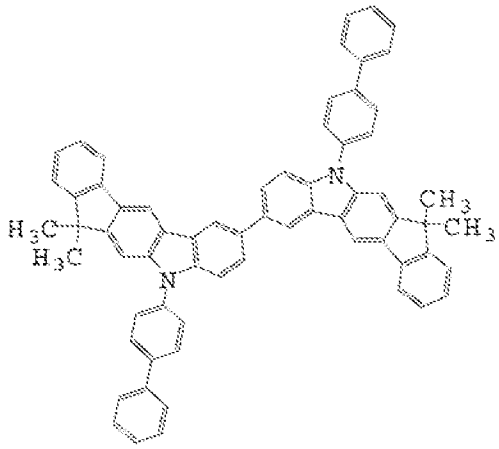
Compound H1-99



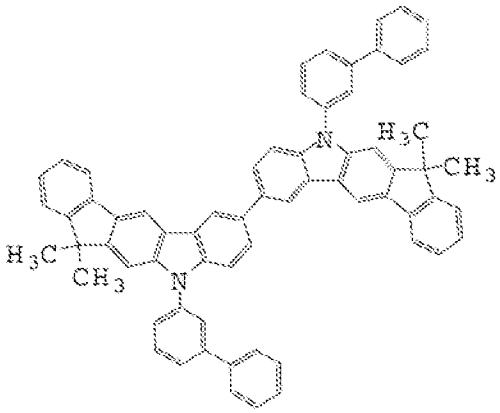
Compound H1-100



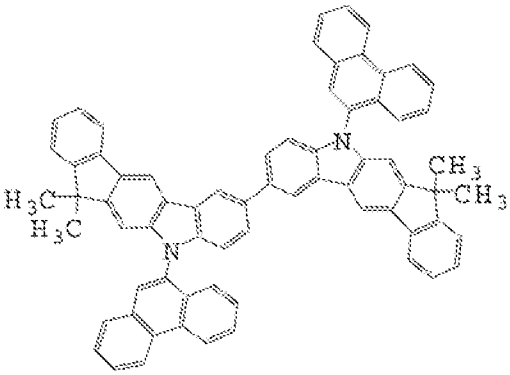
Compound H1-101



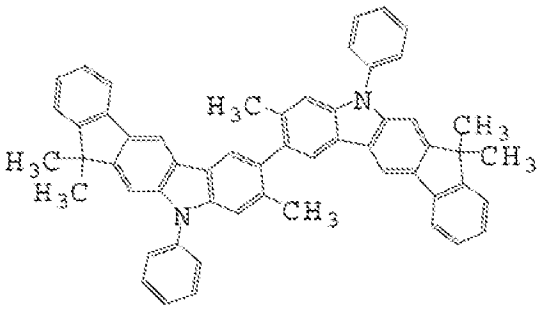
Compound H1-102



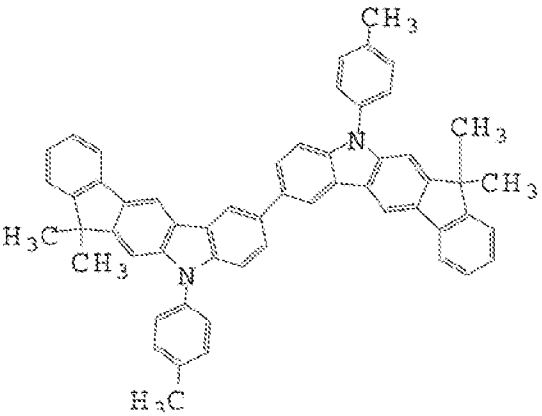
Compound H1-103



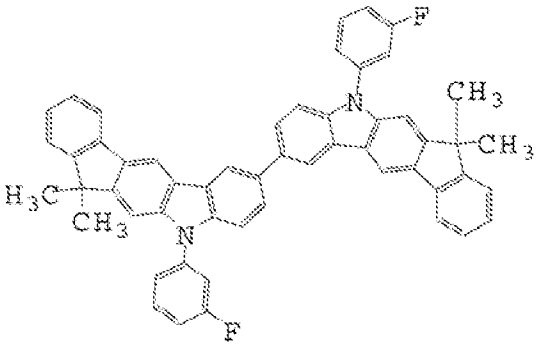
Compound H1-104



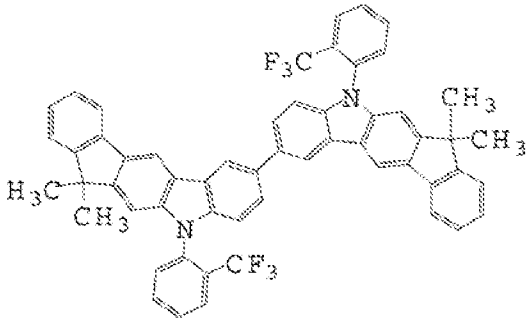
Compound H1-105



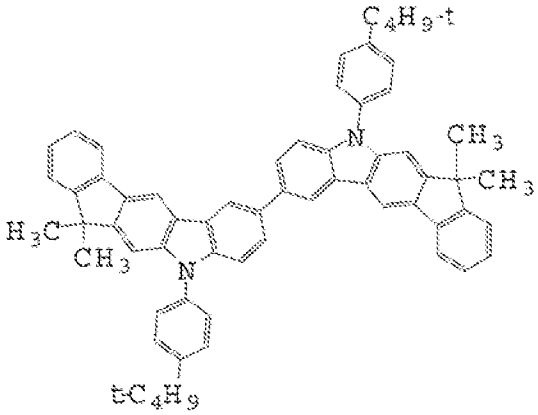
Compound H1-106



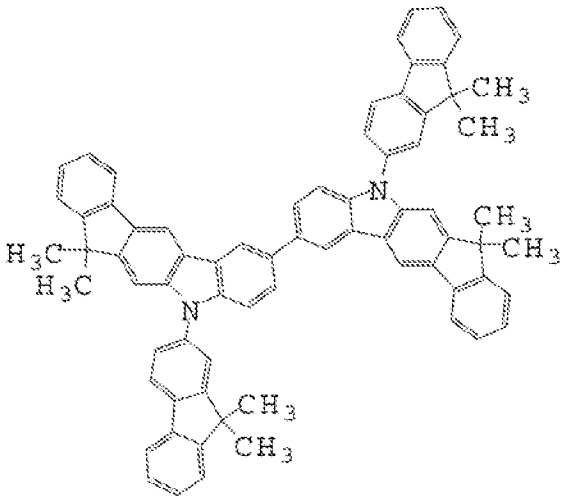
Compound H1-107



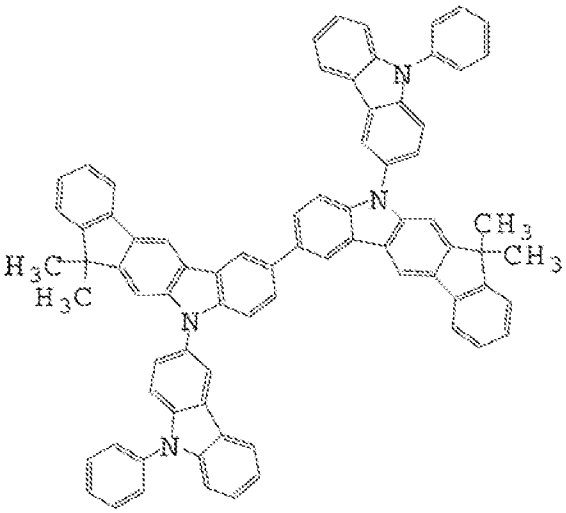
Compound H1-108



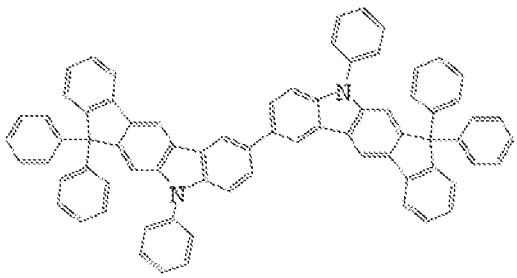
Compound H1-109



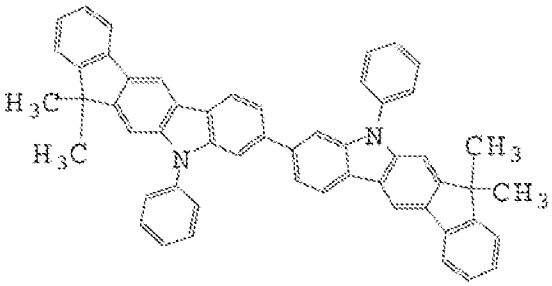
Compound H1-110



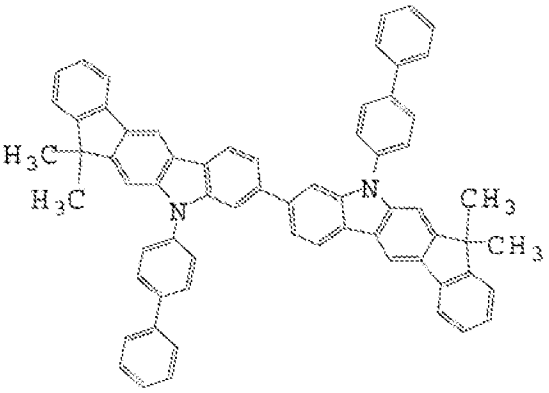
Compound H1-111



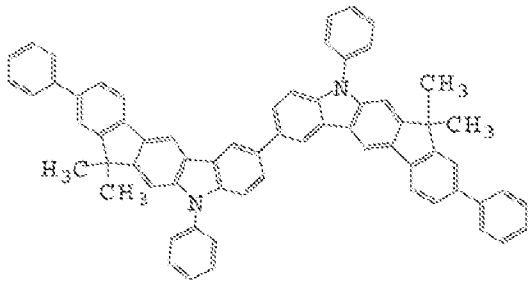
Compound H1-112



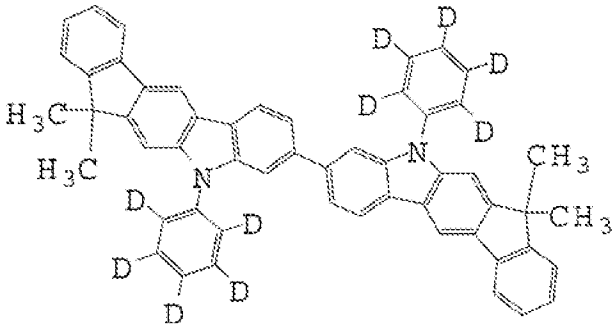
Compound H1-113



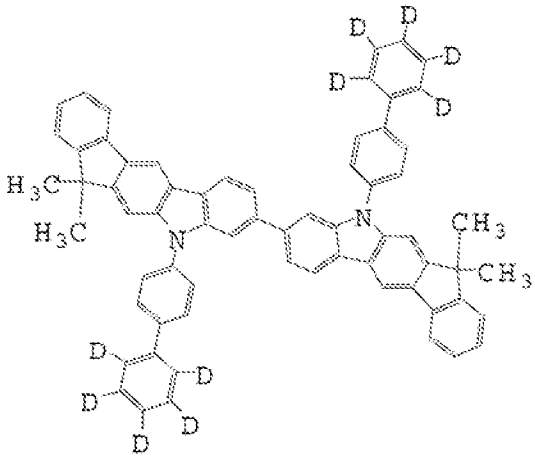
Compound H1-114



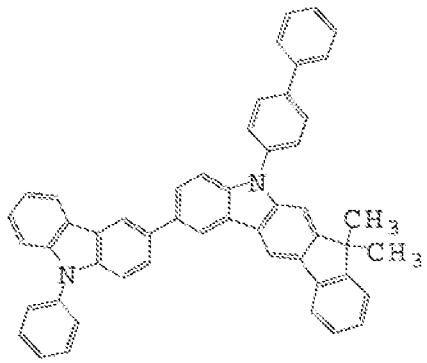
Compound H1-115



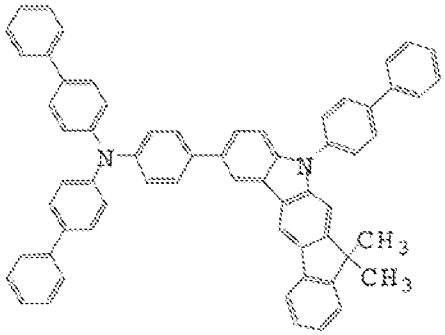
Compound H1-116



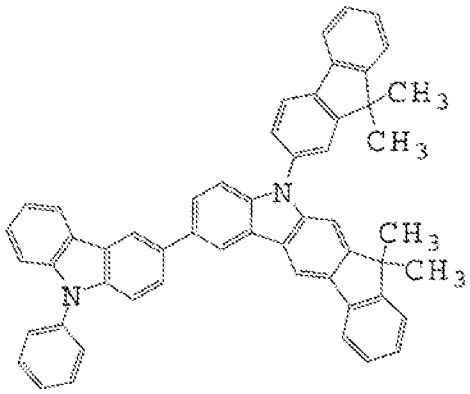
Compound H1-117



Compound H1-118



Compound H1-119



Compound H1-120

[0035] Preferably, the HOMO level of the first host compound is relatively close to the HOMO level of the emitter dopant, which allows offloading of the hole transporting function from the emitter dopant material. This enhances the lifetime of the emitter dopant material in the OLED. Because the first host compound is a hole-transporting type, the HOMO level of the first host compound is higher (less electronegative) than the HOMO energy levels of the other host compounds. The right energy level alignment allow separate charges and excitons in the device emissive layer, minimize triplet-polaron annihilation and non-radiative quenchers formation. This improves the OLED's color saturation in the emission spectrum.

[0036] Synthesis of examples of the first host compound H1:

[0037] Example 1 - Synthesis of Compound H1-1

Synthesis of 12,12-dimethyl-10-phenyl-7-(9-phenyl-9H-carbazol-3-yl)-10,12-dihydroindeno[2,1-b]carbazole: N-(9,9-dimethyl-9H-fluorene-2-yl)-2-bromo-aniline (18.5 g), potassium acetate (6.98 g), and DMF (95 ml) were added to a nitrogen-substituted reaction vessel and aerated with nitrogen gas for 1 hour. The mixture was heated after adding tetrakis(triphenylphosphine)palladium (1.18 g) and stirred at 100 °C for 11 hours. After the mixture was cooled to a room temperature, the reaction liquid was added to water (300 ml) and extraction was performed with toluene (300 ml). An organic layer obtained was washed with water (200 ml) twice, dehydrated with anhydrous magnesium sulfate, and concentrated under reduced pressure to obtain a crude product. The crude product was purified by column chromatography (carrier: silica gel; eluent: toluene/n-hexane) to obtain a pale yellow powder of 12,12-dimethyl-10,12-dihydroindeno[2,1-b]carbazole (7.9 g; yield 55.2%).

[0038] The resulting 12,12-dimethyl-10,12-dihydroindeno[2,1-b]carbazole (7.8 g), iodobenzene (3.7 ml), sodium bisulfite (0.43 g), a copper powder (0.17 g), 3,5-di(tert-

butyl)salicylic acid (0.69 g), potassium carbonate (5.71 g), and dodecylbenzene (10 ml) were added to a nitrogen-substituted reaction vessel, heated, and stirred at 170 °C for 10 hours. The mixture was cooled to 100 °C, extracted by adding toluene (100 ml), concentrated under reduced pressure, and crystallized using n-hexane (30 ml) to obtain a pale yellow powder of 12,12-dimethyl-10-phenyl-10,12-dihydroindeno[2,1-b]carbazole (8.73 g; yield 88.3%).

[0039] The resulting 12,12-dimethyl-10-phenyl-10,12-dihydroindeno[2,1-b]carbazole (7.5 g) and DMF (53 ml) were added to a reaction vessel. N-bromosuccinimide (3.72 g) was added under ice-cooled conditions, and the mixture was stirred for 9 hours and then left for one night. Water (260 ml) was added, and the mixture was subjected to filtration to obtain a brownish white powder of 7-bromo-12,12-dimethyl-10-phenyl-10,12-dihydroindeno[2,1-b]carbazole (8.67 g; yield 94.6%).

[0040] The resulting 7-bromo-12,12-dimethyl-10-phenyl-10,12-dihydroindeno[2,1-b]carbazole (2.0 g), 9-phenyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-9H-carbazole (1.68 g), a toluene/ethanol (4/1, v/v) mixed solvent (15 ml), and a 2M potassium carbonate aqueous solution (3.4 ml) were added to a nitrogen-substituted reaction vessel and aerated with nitrogen gas for 30 min under ultrasonic irradiation. The mixture was heated after adding tetrakis(triphenylphosphine)palladium (0.26 g), and stirred at 73 °C for 5 hours. After the mixture was cooled to a room temperature, toluene (30 ml) and water (20 ml) were added to perform liquid separation in order to collect an organic layer. The organic layer was washed with saturated brine, dehydrated with anhydrous magnesium sulfate, and concentrated under reduced pressure to obtain a crude product. The crude product was purified by column chromatography (carrier: silica gel; eluent: toluene/n-hexane) to obtain a white powder of 12,12-dimethyl-10-phenyl-7-(9-phenyl-9H-carbazol-3-yl)-10,12-dihydroindeno[2,1-b]carbazole (1.5 g; yield 54.7%).

[0041] The structure of the resulting white powder was identified by NMR. ^{1}H-NMR (THF-d_8) detected 32 hydrogen signals, as follows. δ(ppm) = 8.66(1H), 8.64(1H), 8.59(1H), 8.23-8.29(1H), 7.88-7.90(1H), 7.83-7.85(1H), 7.78-7.80(1H), 7.66-7.71(8H), 7.42-7.53(7H), 7.37-7.40(1H), 7.31-7.33(1H), 7.26-7.29(1H), 7.21-7.24(1H), 1.51(6H).

[0042] Example 2 - Synthesis of Compound H1-118

Synthesis of 10-(biphenyl-4-yl)-12,12-dimethyl-7-(9-phenyl-9H-carbazol-3-yl)-10,12-dihydroindeno[2,1-b]carbazole: 12,12-dimethyl-10,12-dihydroindeno[2,1-b]carbazole synthesized in Example 1 (35.5 g), 4-bromobiphenyl (35.0 g), sodium bisulfite (6.0 g), a

copper powder (2.4 g), 3,5-di(tert-butyl)salicylic acid (9.4 g), potassium carbonate (31.2 g), and dodecylbenzene (52 ml) were added to a nitrogen-substituted reaction vessel, heated, and stirred at 190 °C for 26 hours. After cooled to 120 °C, the mixture was stirred after adding toluene (35 ml), and a crude product was collected by filtration. After adding toluene (1.6 L) to the crude product, the crude product was heated and extracted at 110 °C. After cooled to a room temperature, the crude product was concentrated under reduced pressure. The product was crystallized with methanol (120 ml) to obtain a white powder of 10-(biphenyl-4-yl)-12,12-dimethyl-10,12-dihydroindeno[2,1-b]carbazole (48.5 g; yield 88.1%)

[0043] The resulting 10-(biphenyl-4-yl)-12,12-dimethyl-10,12-dihydroindeno[2,1-b]carbazole (42.5 g) and DMF (2.5 L) were added to a reaction vessel, and the mixture was heated up to 70 °C and dissolved. After cooled to a room temperature, N-bromo-succinimide (17.4 g) was added, and the mixture was stirred for 7 hours. Water (2.5 L) was added, and filtration was performed to obtain a white powder of 10-(biphenyl-4-yl)-7-bromo-12,12-dimethyl-10,12-dihydroindeno[2,1-b]carbazole (34.9 g; yield 69.5%).

[0044] The resulting 10-(biphenyl-4-yl)-7-bromo-12,12-dimethyl-10,12-dihydroindeno[2,1-b]carbazole (16.5 g), 9-phenyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-9H- carbazole (14.2 g), a toluene/ethanol (4/1, v/v) mixed solvent (250 ml), and a 2M potassium carbonate aqueous solution (48 ml) were added to a nitrogen-substituted reaction vessel and aerated with nitrogen gas for 30 min under ultrasonic irradiation. The mixture was heated after adding tetrakis(triphenylphosphine)palladium (1.9 g), and stirred at 73 °C for 5 hours. After the mixture was cooled to a room temperature, a precipitated crude product was collected by filtration. 1,2 Dichlorobenzene (450 ml) was added to the crude product, and the crude product was dissolved while being heated, and after removing insoluble matter by filtration, a filtrate was concentrated under reduced pressure. Purification by crystallization using 1,2-dichlorobenzene (150 ml) and n-hexane (300 ml) was performed to obtain a white powder of 10-(biphenyl-4-yl)-12,12-dimethyl-7-(9-phenyl-9H-carbazol-3-yl)-10,12-dihydroindeno[2,1-b]carbazole (9.8 g; yield 45.2%).

[0045] The structure of the resulting white powder was identified by NMR. ^{1}H-NMR (THF-d_8) detected 36 hydrogen signals, as follows. δ(ppm) = 8.69(1H), 8.64(1H), 8.59(1H), 8.28(1H), 7.99(2H), 7.89(1H), 7.85-7.78(6H), 7.66(4H), 7.56-7.49(6H), 7.44-7.37(4H), 7.32(1H), 7.27(1H), 7.23(1H), 1.52(6H).

[0046] Example 3 - Synthesis of H1-119

Synthesis of 12,12-dimethyl-10-(9,9-dimethyl-9H-fluorene-2-yl)-7-(9-phenyl-9H-carbazol-3-yl)-10,12-dihydroindeno[2,1-b]carbazole: 12,12-Dimethyl-10,12-dihydroindeno[2,1-b]carbazole synthesized in Example 1 (5.5 g), 2-bromo-9,9-dimethyl-9H-fluorene (6.4 g), sodium bisulfite (0.3 g), a copper powder (0.1 g), 3,5-di(tert-butyl)salicylic acid (0.5 g), potassium carbonate (4.0 g), and dodecylbenzene (5 ml) were added to a nitrogen-substituted reaction vessel, heated, and stirred at 180 C for 29 hours. The mixture was cooled to 100 C, and insoluble matter was removed by filtration after adding toluene (80 ml), and a filtrate was concentrated. Crystallization using n-hexane (20 ml) was performed to obtain an ocher powder of 12,12-dimethyl-10-(9,9-dimethyl-9H-fluorene-2-yl)-10,12-dihydroindeno[2,1-b]carbazole (7.4 g; yield 80.0%).

[0047] The resulting 12,12-dimethyl-10-(9,9-dimethyl-9H-fluorene-2-yl)-10,12-dihydroindeno[2,1-b]carbazole (7.0 g) and DMF (140 ml) were added to a reaction vessel. The mixture was heated up to 100 °C, dissolved, and cooled. N-bromo-succinimide (2.6 g) was added under ice-cooled conditions, and the mixture was stirred for 1 hour at a room temperature. Water (500 ml) was added, and the mixture was subjected to filtration to obtain a pale red powder of 7-bromo-12,12-dimethyl-10-(9,9-dimethyl-9H-fluorene-2-yl)-10,12-dihydroindeno[2,1-b]carbazole (5.7 g; yield 70.3%).

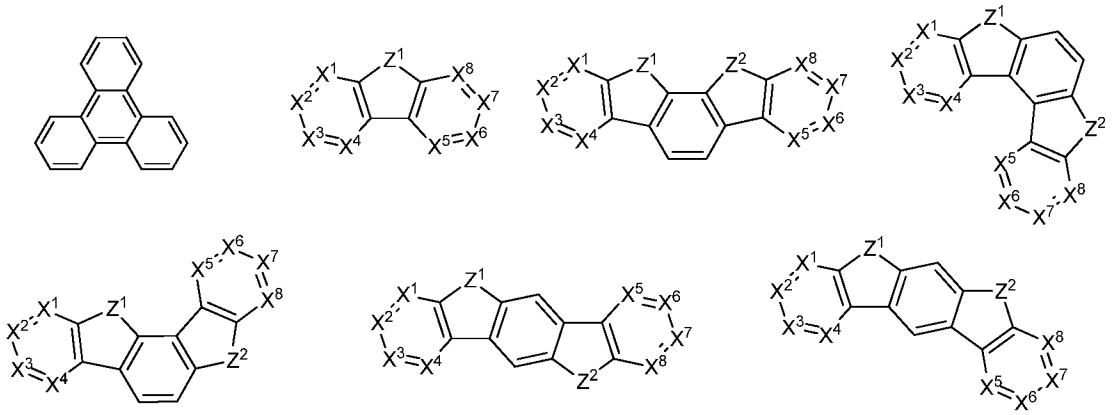
[0048] The resulting 7-bromo-12,12-dimethyl-10-(9,9-dimethyl-9H-fluorene-2-yl)-10,12-dihydroindeno[2,1-b]carbazole (4.0 g), 9-phenyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-9H-carbazole (3.2 g), a toluene/ethanol (4/1, v/v) mixed solvent (50 ml), and a 2M potassium carbonate aqueous solution (10 ml) were added to a nitrogen-substituted reaction vessel and aerated with nitrogen gas for 30 min under ultrasonic irradiation. The mixture was heated after adding tetrakis(triphenylphosphine)palladium (0.4 g), and stirred at 71°C for 7 hours. After the mixture was cooled to a room temperature, water (20 ml) was added to perform liquid separation in order to collect an organic layer. The organic layer was dehydrated with anhydrous magnesium sulfate and concentrated under reduced pressure to obtain a crude product. The crude product was purified by column chromatography (carrier: silica gel; eluent: toluene/cyclohexane) to obtain a white powder of 12,12-dimethyl-10-(9,9-dimethyl-9H-fluorene-2-yl)-7-(9-phenyl-9H-carbazole-3-yl)-10,12-dihydroindeno[2,1-b]carbazole (3.4 g; yield 65.7%).

[0049] The structure of the resulting white powder was identified by NMR. ^{1}H-NMR (THF-d_8) detected 40 hydrogen signals, as follows. δ(ppm) = 8.67(1H), 8.65(1H), 8.60(1H),

8.28(1H), 8.08(1H), 7.90-7.82(5H), 7.69-7.66(5H), 7.58-7.49(5H), 7.43(2H), 7.39(2H), 7.36(1H), 7.33(1H), 7.28(1H), 7.23(1H), 1.61(6H), 1.51(6H).

Second and Third Host Compounds:

[0050] Each of the second and third host compounds is a wide band gap host compound that is more electron-transporting compared to the compound H1 and can contain at least one of the following groups in the molecule:



wherein X^1 to X^8 is selected from C or N; and wherein Z^1 and Z^2 is S or O. Preferably, the second host compound and the third host compound are different compounds.

[0051] According to an aspect of the present disclosure, any substituent in the second and third host compounds is preferably an unfused substituent independently selected from the group consisting of C_nH_{2n+1}, OC_nH_{2n+I}, OAr_1, $N(C_nH_{2n+1})_2$, $N(Ar_1)(Ar_2)$, $CH=CH-C_nH_{2n+1}$, $C=CHC_nH_{2n+1}$, Ar_1, Ar_1-Ar_2, C_nH_{2n}-A_{r1}, or no substitution, wherein n is 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10, and wherein Ar_1 and Ar_2 are independently selected from the group consisting of benzene, biphenyl, naphthalene, triphenylene, carbazole, and heteroaromatic analogs thereof.

[0052] According to another embodiment, the second host compound can be a compound comprising a triphenylene containing benzo-fused thiophene. Triphenylene is a polyaromatic hydrocarbon with high triplet energy, yet high [pi]- conjugation and a relatively small energy difference between the first singlet and first triplet levels. This would indicate that triphenylene has relatively easily accessible HOMO and LUMO levels compared to other aromatic compounds with similar triplet energy (*e.g.*, biphenyl). The advantage of using triphenylene and its derivatives as hosts is that it can accommodate red, green and even blue phosphorescent dopants to give high efficiency without energy quenching. Triphenylene hosts may be used to provide high efficiency and stability phosphorescent OLEDs

(PHOLEDs). See Kwong and Alleyene, *Triphenylene Hosts in Phosphorescent Light Emitting Diodes*, 2006, 60 pp, US 2006/0280965 Al. Benzo-fused thiophenes may be used as hole transporting organic conductors. In addition, the triplet energies of benzothiophenes, namely dibenzo[*b*,*d*]thiophene (referred to herein as "dibenzothiophene"), benzo[*b*]thiophene and benzo[*c*]thiophene are relatively high. A combination of benzo-fused thiophenes and triphenylene as hosts in PHOLEDs may be beneficial. More specifically, benzo-fused thiophenes are typically more hole transporting than electron transporting, and triphenylene is more electron transporting than hole transporting. Therefore combining these two moieties in one molecule may offer improved charge balance which may improve device performance in terms of lifetime, efficiency and low voltage. Different chemical linkage of the two moieties can be used to tune the properties of the resulting compound to make it the most appropriate for a particular phosphorescent emitter, device architecture, and/or fabrication process. For example, *m*-phenylene linkage is expected to result in higher triplet energy and higher solubility whereas *p*-phenylene linkage is expected to result in lower triplet energy and lower solubility.

[0053] Similar to the characterization of benzo-fused thiophenes, benzo-fused furans are also typically hole transporting materials having relatively high triplet energy. Examples of benzo-fused furans include benzofuran and dibenzofuran. Therefore, a material containing both triphenylene and benzofuran may be advantageously used as emitter host or hole blocking material in PHOLED. A compound containing both of these two groups may offer improved electron stabilization which may improve device stability and efficiency with low voltage. The properties of the triphenylene containing benzofuran compounds may be tuned as necessary by using different chemical linkages to link the triphenylene and the benzofuran.

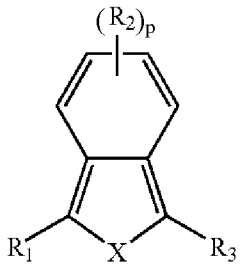
[0054] The compounds for the second host compound may be substituted with groups that are not necessarily triphenylenes, benzo-fused thiophenes, and benzo-fused furans. Preferably, any group that is used as a substituent of the compound has a triplet energy high enough to maintain the benefit of having triphenylene benzo-fused thipohenes or benzo-fused furans (*i.e.* the triplet energy of the substituent maintains the high triplet energy of benzo-fused thiophenes, benzo-fused furans and triphenylenes). Examples of such groups that may be used as substituents of the compound may include any unfused substituent independently selected from the group consisting of C_nH_{2n+1}, OC_nH_{2n+I}, OAr_1, $N(C_nH_{2n+1})_2$, $N(Ar_1)(Ar_2)$, $CH{=}CH\text{-}C_nH_{2n+1}$, $C{=}CHC_nH_{2n+1}$, Ar_1, $Ar_1\text{-}Ar_2$, $C_nH_{2n}\text{-}A_{r1}$, or no substitution, wherein n is 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10, and wherein Ar_1 and Ar_2 are independently selected from the group

consisting of benzene, biphenyl, naphthalene, triphenylene, carbazole, and heteroaromatic analogs thereof. The compounds for the host material described herein have a high enough triplet energy to be suitable for use in a device having phosphorescent blue emissive materials.

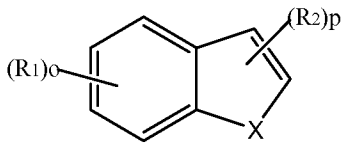
[0055] The substituents of the compounds described herein are unfused such that the substituents are not fused to the triphenylene, benzo-fused furan or benzo-fused thiophene moieties of the compound. The substituents may optionally be inter-fused (*i.e.* fused to each other).

[0056] Materials provided herein may also offer improved film formation in the device as fabricated by both vapor deposition and solution processing methods. In particular, materials offering improved fabrication have a central pyridine ring to which the benzo-fused thiophenylene and triphenylene, or benzofuran and triphenylene, are attached. The improved film formation is believed to be a result of the combination of polar and non-polar rings in the compound.

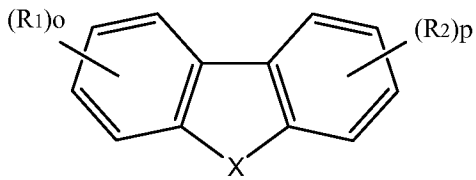
[0057] According to another embodiment, the second and/or third host compounds are triphenylene-containing benzo-fused thiophenes or benzo-fused furans. Examples of triphenylene-containing benzo-fused thiophenes or benzo-fused furans include compounds having the structure of the following formulae (H-IV), (H-V), and (H-VI):



(H-IV)



(H-V)



(H-VI)

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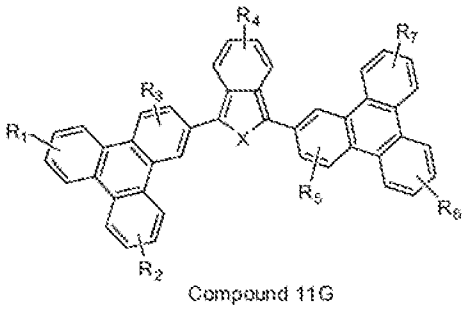
In the formula (H-IV), X is S or O; R_1, R_2 and R_3 are unfused substituents that are independently selected from the group consisting of C_nH_{2n+1}, OC_nH_{2n+1}, OAr_1, $N(C_nH_{2n+1})_2$, $N(Ar_1)(Ar_2)$, $CH=CH-C_nH_{2n+1}$, $C=CHC_nH_{2n+1}$, Ar_1, Ar_1-Ar_2, $C_nH_{2n}-A_{r1}$, and hydrogen; n is 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10; Ar_1 and Ar_2 are independently selected from the group consisting of benzene, biphenyl, naphthalene, triphenylene, carbazole, and heteroaromatic analogs thereof; p is 1, 2, 3, or 4; and at least one of R_1, R_2 and R_3 includes a triphenylene group.

[0058] In the formula (H-V), X is S or O; R_1, and R_2 are unfused substituents that are independently selected from the group consisting of C_nH_{2n+1}, OC_nH_{2n+1}, OAr_1, $N(C_nH_{2n+1})_2$,

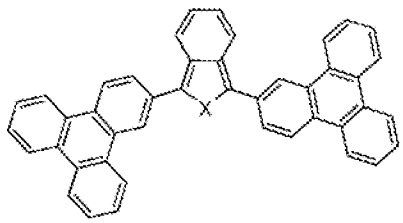
$N(Ar_1)(Ar_2)$, $CH=CH-C_nH_{2n+1}$, $C=CHC_nH_{2n+1}$, Ar_1, Ar_1-Ar_2, $C_nH_{2n}-A_{r1}$, and hydrogen; n is 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10; Ar_1 and Ar_2 are independently selected from the group consisting of benzene, biphenyl, naphthalene, triphenylene, carbazole, and heteroaromatic analogs thereof; o is 1, 2, 3, or 4, and p is 1 or 2; and at least one of R_1, and R_2 includes a triphenylene group.

[0059] In the formula (H-VI), X is S or O; R_1, and R_2 are unfused substituents that are independently selected from the group consisting of C_nH_{2n+1}, OC_nH_{2n+1}, OAr_1, $N(C_nH_{2n+1})_2$, $N(Ar_1)(Ar_2)$, $CH=CH-C_nH_{2n+1}$, $C=CHC_nH_{2n+1}$, Ar_1, Ar_1-Ar_2, $C_nH_{2n}-A_{r1}$, and hydrogen; n is 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10; Ar_1 and Ar_2 are independently selected from the group consisting of benzene, biphenyl, naphthalene, triphenylene, carbazole, and heteroaromatic analogs thereof; o and p is 1, 2, 3, or 4; and at least one of R_1, and R_2 includes a triphenylene group.

[0060] Examples of compounds having the structure of the formula (H-IV) include:



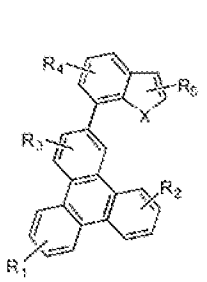
Compound 11G



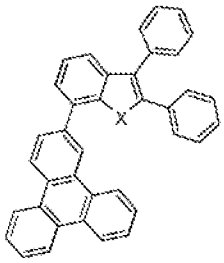
Compound 11

where X is S or O. Preferably, X is S. R_1 to R_n are independently selected from the group consisting of C_nH_{2n+1}, OC_nH_{2n+I}, OAr_1, $N(C_nH_{2n+1})_2$, $N(Ar_1)(Ar_2)$, $CH=CH-C_nH_{2n+1}$, $C=CHC_nH_{2n+1}$, Ar_1, Ar_1-Ar_2, $C_nH_{2n}-A_{r1}$, or no substitution. Each of R_1 to R_n may represent mono, di, tri, or tetra substitutions., n is 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10. Ar_1 and Ar_2 are independently selected from the group consisting of benzene, biphenyl, naphthalene, triphenylene, carbazole, and heteroaromatic analogs thereof. At least one of R_1, R_2, and R_3 includes a triphenylene group.

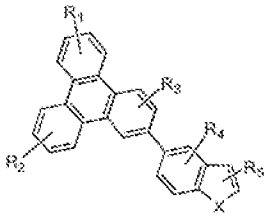
[0061] Examples of compounds having the structure of the formula (H-V) include:



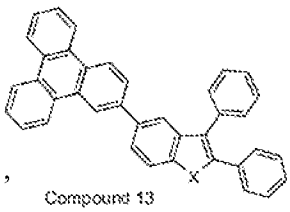
Compound 12G ,



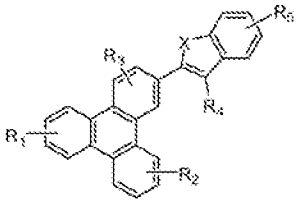
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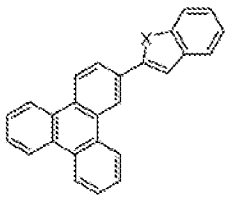
Compound 13G ,



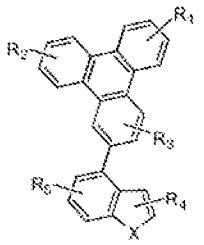
Compound 13 ,



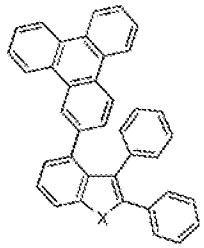
Compound 14G ,



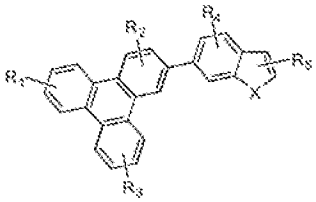
Compound 14 ,



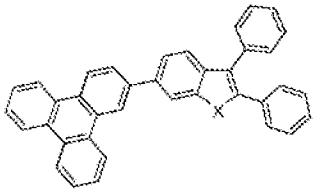
Compound 16G ,



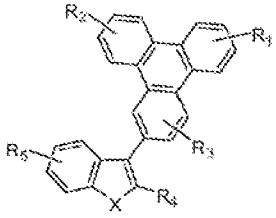
Compound 16 ,



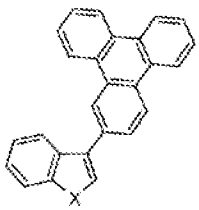
Compound 17G ,



Compound 17 ,



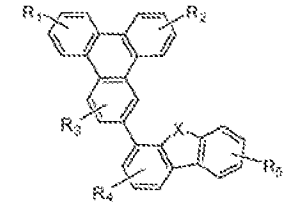
Compound 18G , and



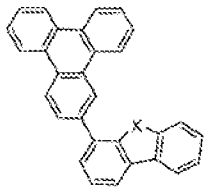
Compound 18 .

where X is S or O. Preferably, X is S. R_1 to R_n are independently selected from the group consisting of C_nH_{2n+1}, OC_nH_{2n+I}, OAr_1, $N(C_nH_{2n+1})_2$, $N(Ar_1)(Ar_2)$, $CH=CH-C_nH_{2n+1}$, $C=CHC_nH_{2n+1}$, Ar_1, Ar_1-Ar_2, $C_nH_{2n}-A_{r1}$, or no substitution. Each of R_1 to R_n may represent mono, di, tri, or tetra substitutions, and n is 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10. Ar_1 and Ar_2 are independently selected from the group consisting of benzene, biphenyl, naphthalene, triphenylene, carbazole, and heteroaromatic analogs thereof. At least one of R_1, R_2, and R_3 includes a triphenylene group.

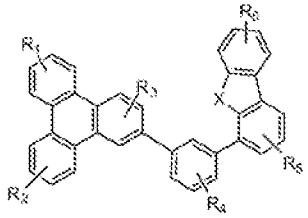
[0062] Examples of compounds having the structure of the formula (H-VI) include:



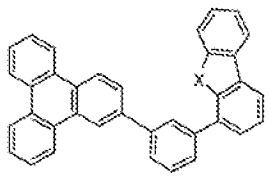
Compound 1G



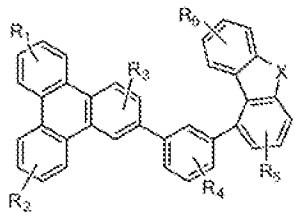
Compound 1



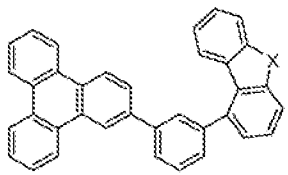
Compound 2G



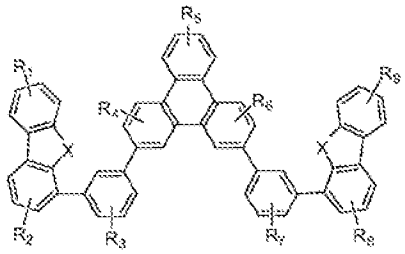
Compound 2



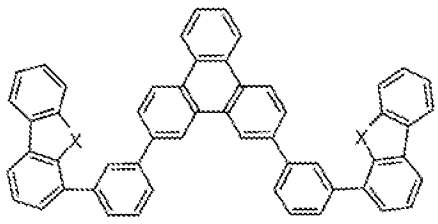
Compound 3G



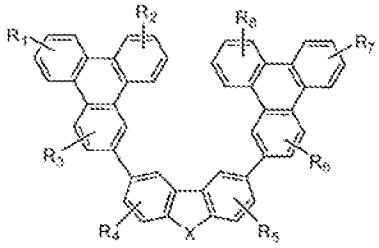
Compound 3



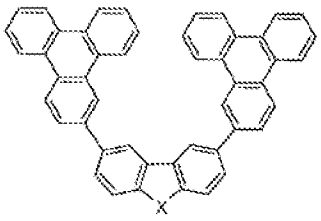
Compound 4G



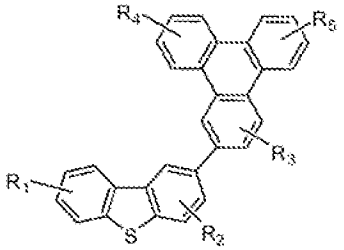
Compound 4



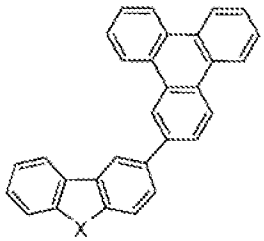
Compound 5G



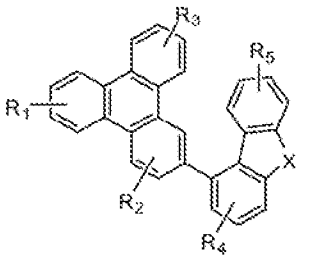
Compound 5



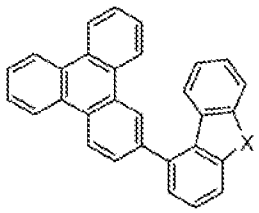
Compound 6G



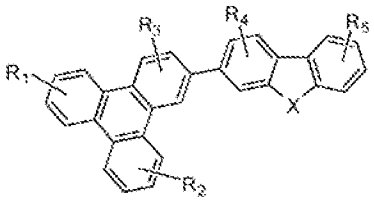
Compound 6



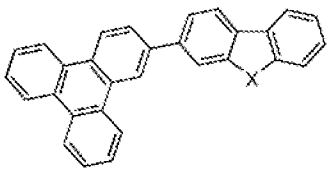
Compound 7G



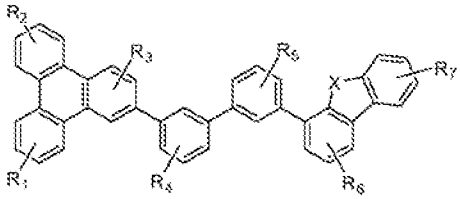
Compound 7



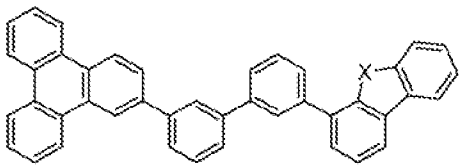
Compound 8G



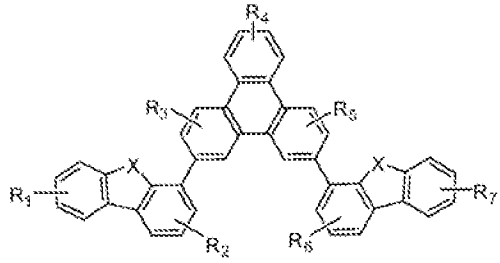
Compound 8



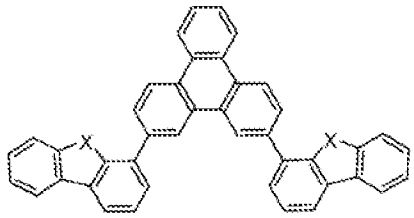
Compound 9G



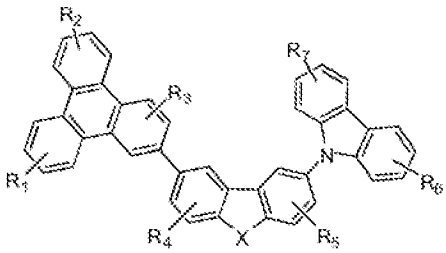
Compound 9



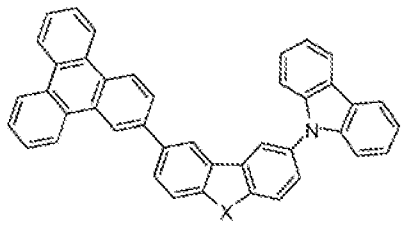
Compound 10G



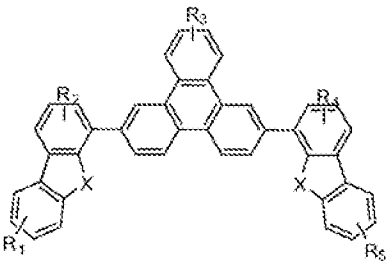
Compound 10



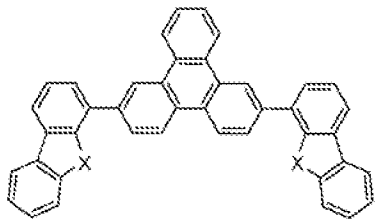
Compound 15G



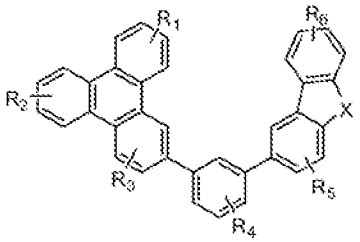
Compound 15



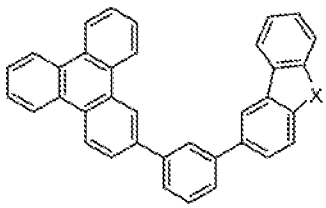
Compound 19 G



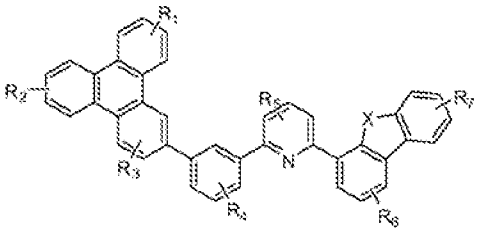
Compound 19



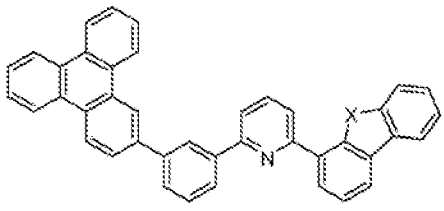
Compound 20 G



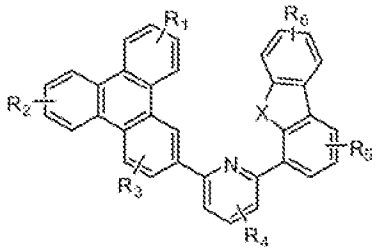
Compound 20



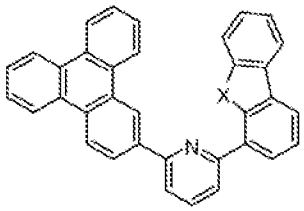
Compound 21 G



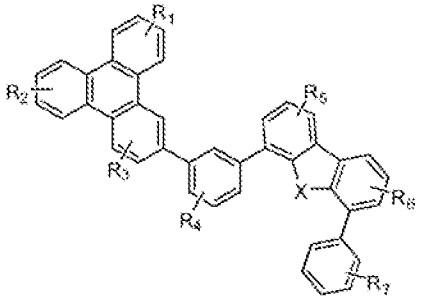
Compound 21



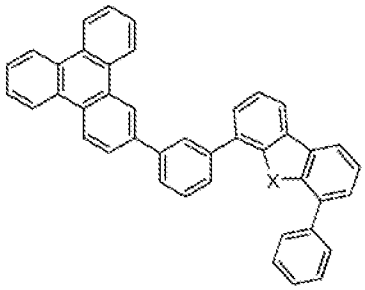
Compound 22 G



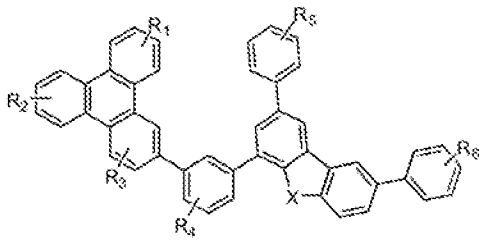
Compound 22



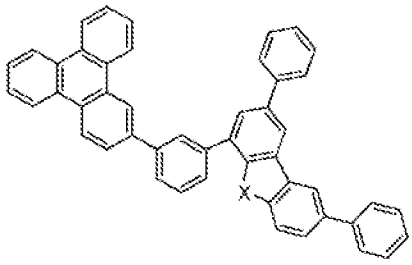
Compound 23 G



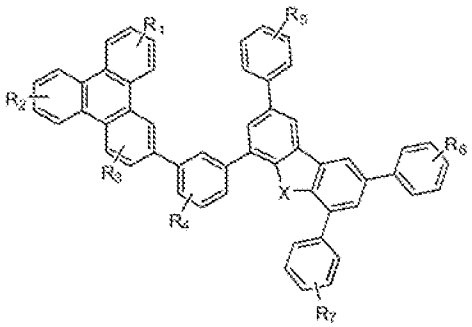
Compound 23



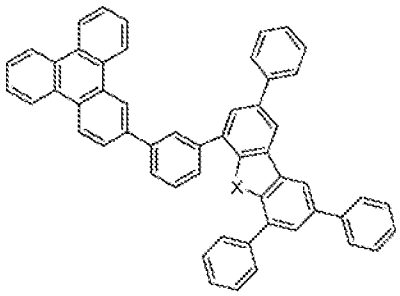
Compound 24 G



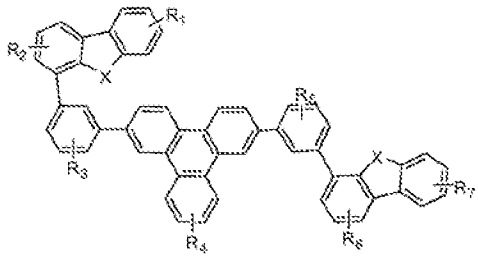
Compound 24



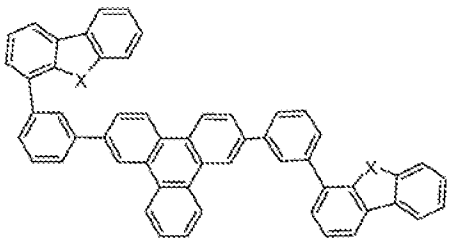
Compound 25 G



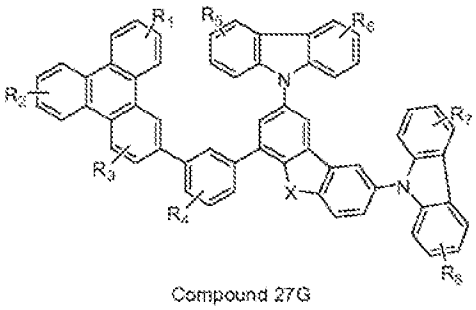
Compound 25



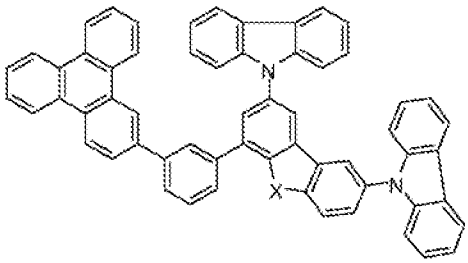
Compound 26G



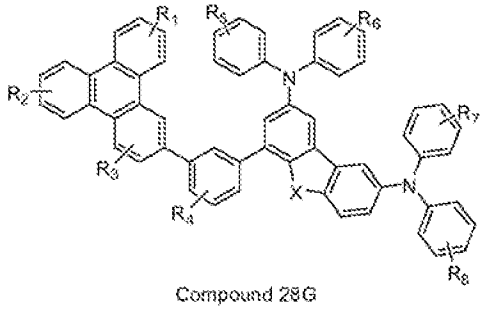
Compound 26



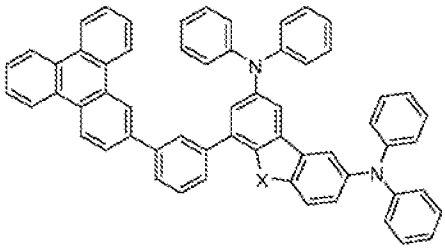
Compound 27G



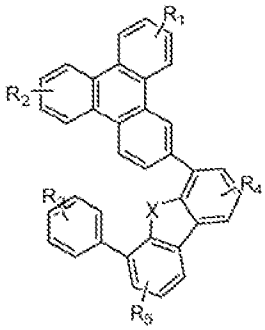
Compound 27



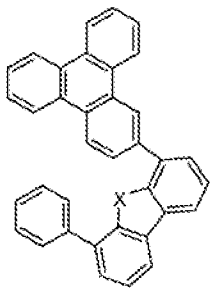
Compound 28G



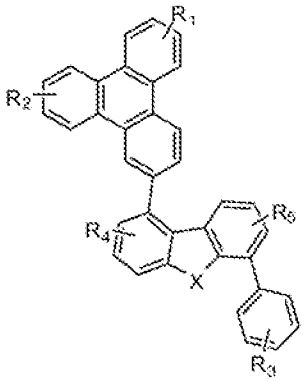
Compound 28



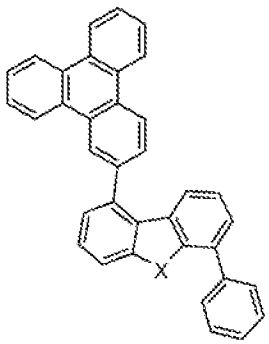
Compound 29G



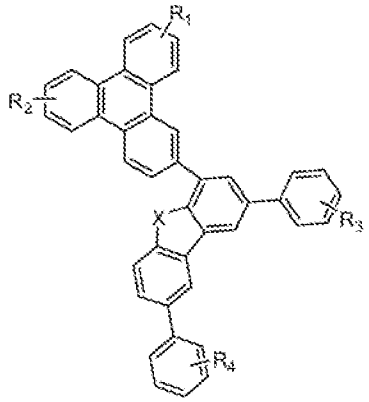
Compound 29



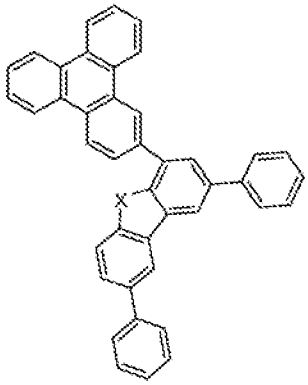
Compound 30G



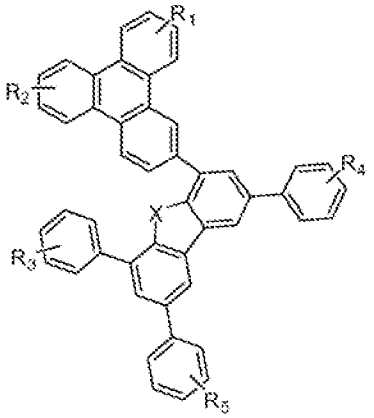
Compound 30



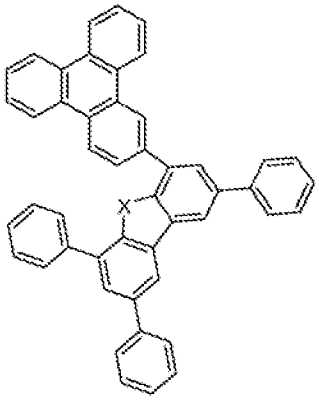
Compound 31G



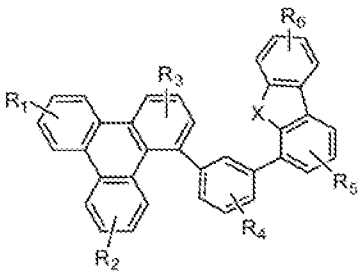
Compound 31



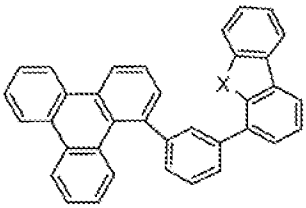
Compound 32G



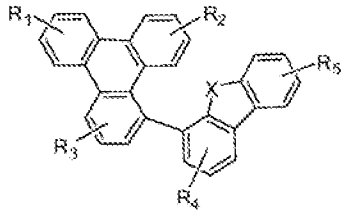
Compound 32



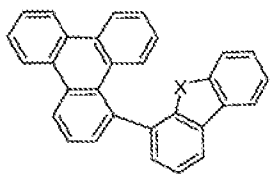
Compound 33G



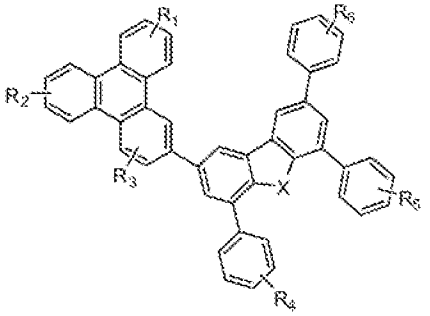
Compound 33



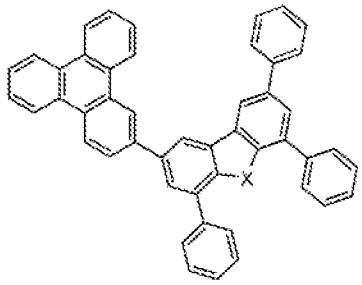
Compound 34G



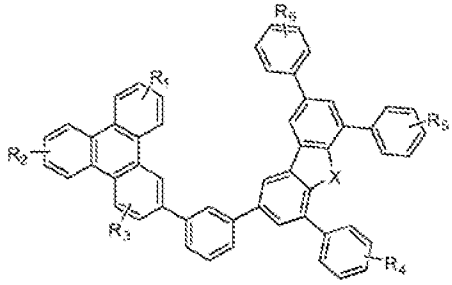
Compound 34



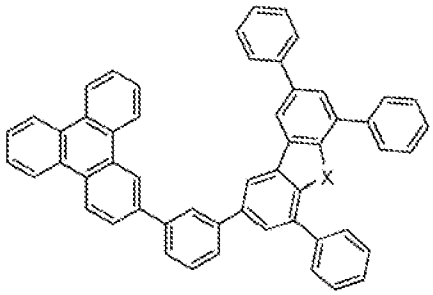
Compound 35G



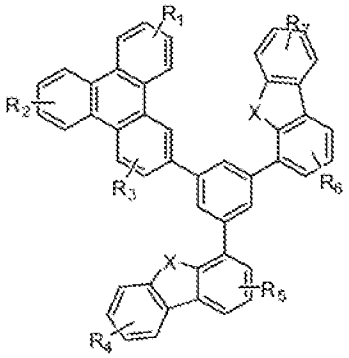
Compound 35



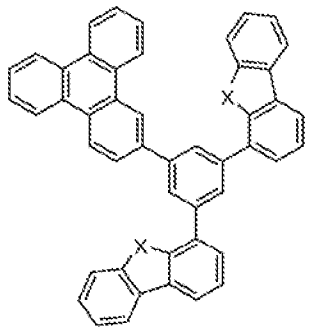
Compound 36G



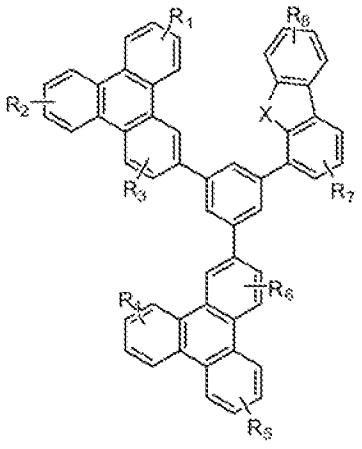
Compound 36



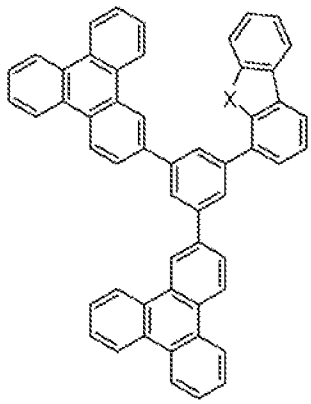
Compound 37G



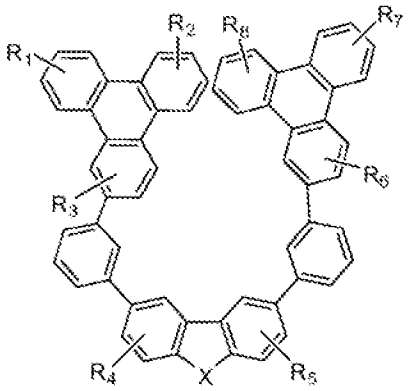
Compound 37



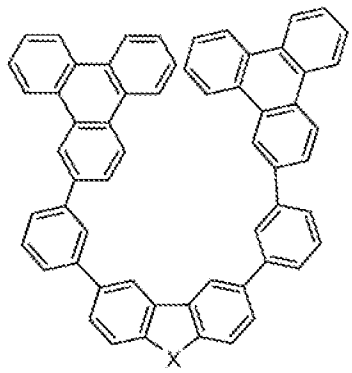
Compound 38G



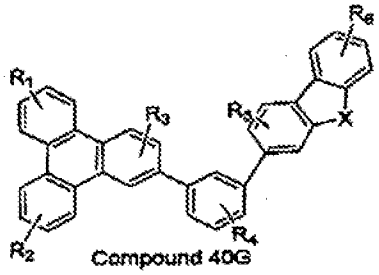
Compound 38



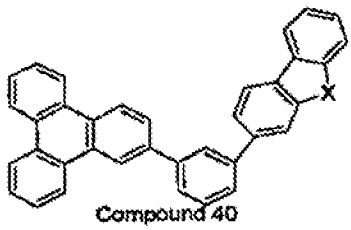
Compound 39G



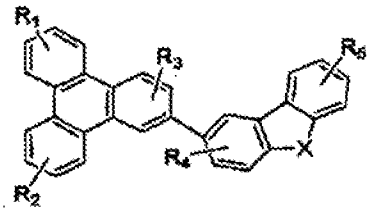
Compound 39



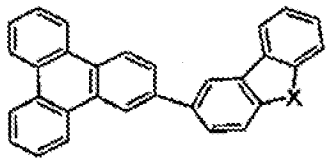
Compound 40G



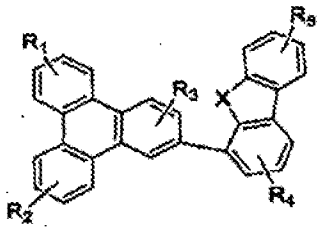
Compound 40



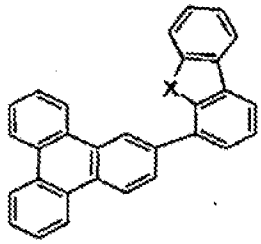
Compound 41G



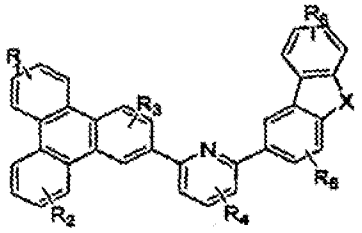
Compound 41



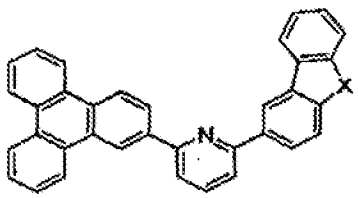
Compound 42G



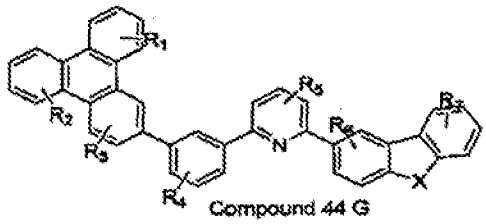
Compound 42

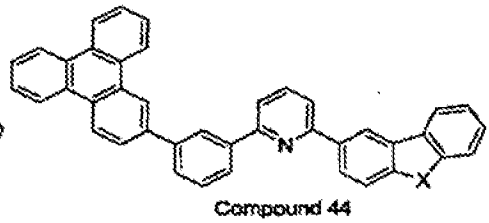


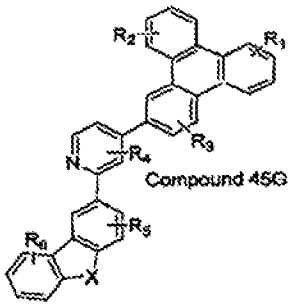
Compound 43 G

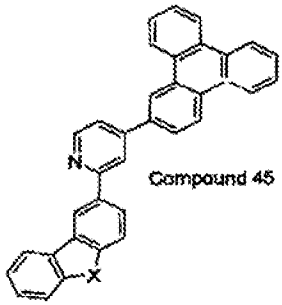


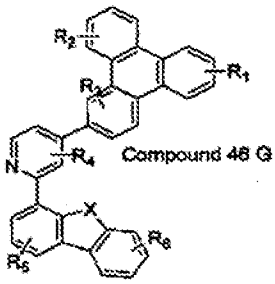
Compound 43

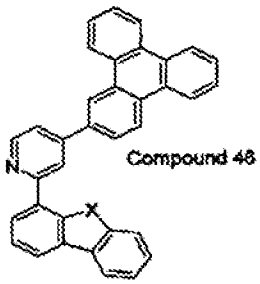

Compound 44 G

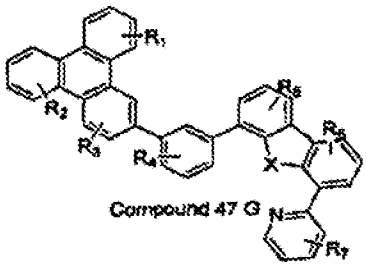

Compound 44

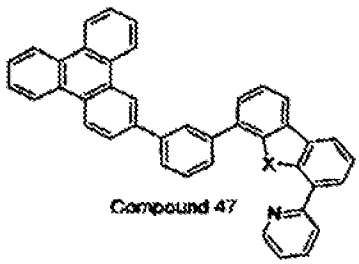

Compound 45G

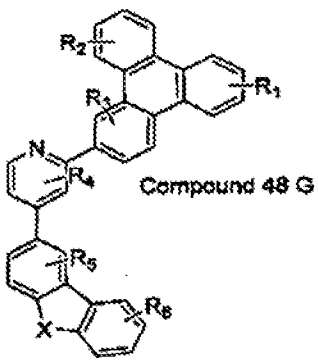

Compound 45

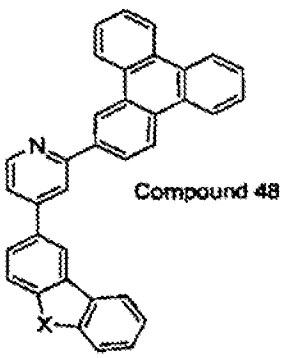

Compound 46 G


Compound 46


Compound 47 G


Compound 47


Compound 48 G


Compound 48

where X is S or O. In a preferred embodiment, X is S. R_1 to R_n are independently selected from the group consisting of C_nH_{2n+1}, OC_nH_{2n+I}, OAr_1, $N(C_nH_{2n+1})_2$, $N(Ar_1)(Ar_2)$, CH=CH-C_nH_{2n+1}, C=CHC_nH_{2n+1}, Ar_1, Ar_1-Ar_2, C_nH_{2n}-A_{r1}, or no substitution. Each of R_1 to R_n may represent mono, di, tri, or tetra substitutions. n is 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10. Ar_1 and Ar_2 are independently selected from the group consisting of benzene, biphenyl, naphthalene, triphenylene, carbazole, and heteroaromatic analogs thereof. At least one of R_1, R_2, and R_3 includes a triphenylene group.

[0063] All of the host compound materials disclosed herein are compounds that have triplet energies greater than the triplet energy of the phosphorescent dopant. This energy configuration allows confinement of the triplet excited states on the dopant. The use of the additional host materials in the emissive layer may reduce the interaction of the excitons with the charge carriers, thereby reducing exciton quenching, which may improve device efficiency and/or lifetime.

[0064] The wide band gap host compounds for the second host compound in the emissive layer have a HOMO-LUMO band gap of at least 2.0 eV. Depending on the phosphorescent dopant that is used, in some cases, the wide band gap host compound has a HOMO-LUMO band gap of at least 2.5 eV, and in some cases, at least 3.0 eV. In some cases, the HOMO-LUMO band gap of the wide band gap host compound is equal to or greater than that of the hole-transporting first host compound. The wide band gap host compound does not readily transport charges of either type in the emissive layer. In particular, the wide band gap host compound has a lower hole mobility than the hole-transporting first host compound. The host compounds are preferably capable of mixing well with the other components of the emissive layer and capable of promoting the formation of an amorphous film.

[0065] The synthesis information for the examples of the second host compounds described above can be found in PCT publication Nos. WO 2009/021126 published on 12 February 2009, the contents of which are incorporated herein by reference, and WO 2010/083359 published on 22 July 2010, the contents of which are incorporated herein by reference.

[0066] The compounds for the emissive layer may be deposited using any suitable deposition technique, including vapor-phase deposition techniques such as vacuum thermal evaporation. The different compounds in the emissive layer may be deposited separately or in combination. For example, each compound may be deposited at individually controlled

rates, or alternatively, two or more of the host compounds may be pre-mixed and then be evaporated together.

[0067] The components of the multi-component emissive layer discussed herein can be used in the following quantities defined as wt. % of the total emissive layer materials. According to one embodiment, the phosphorescent dopant can be provided in 0.5-20 %, more preferably in 1-10 %, most preferably 3-7%. The first host compound preferably constitutes no more than 25 % and more preferably about 10-20 %. The second host compound preferably constitutes about 50-90% and more preferably about 60-80%. The third host compound preferably constitutes about 10-50% and more preferably about 20-40%. The relative amounts of the emitter dopant and the host materials in the emissive layer will vary depending upon the particular application.

Exciton/Electron Blocking Layer:

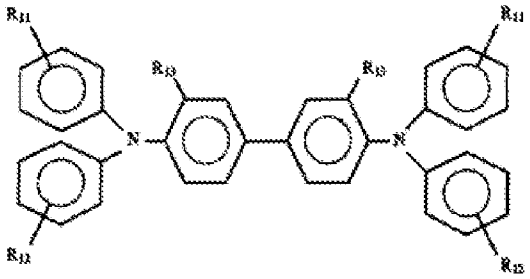
[0068] According to another aspect, the OLED of the present disclosure can further comprise an exciton/electron blocking layer (EBL), formed of the material that is the compound represented by the general formula H1 described above, disposed between the emissive layer and the anode. The EBL blocks at least one or both of excitons or electrons.

[0069] The material for the EBL can be selected from the group consisting of the following examples of compounds having the general formula H1: Compound H1-1; Compound H1-2; Compound H1-3; Compound H1-4; Compound H1-5; Compound H1-6; Compound H1-7; Compound H1-8; Compound H1-9; Compound H1-10; Compound H1-11; Compound H1-12; Compound H1-13; Compound H1-14; Compound H1-15; Compound H1-16; Compound H1-17 through Compound H1-120 described herein.

Hole Transport Layer:

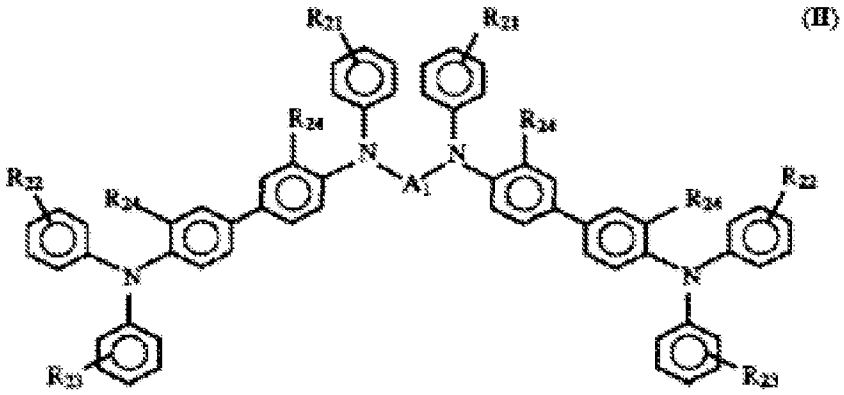
[0070] The OLED according to another aspect of the present disclosure further comprises at least one hole transport layer disposed between the emissive layer and the anode. The at least one hole transport layer is a material comprising at least one of the compounds having a formula selected from the following formulae (HTL-I) to (HTL-VI) listed below:

(HTL-I) is



wherein R_{11} and R_{12} may be the same or different and are independently selected from the group consisting of a hydrogen atom, a deuterium atom, a lower alkyl group, a lower alkoxy group, a phenyl group, a phenyl group having a lower alkyl group or deuterium substituent, and a phenyl group having a deuterium atom or a lower alkoxy group substituent with the proviso at least one of R_{11} and R_{12} is a deuterium atom, a normal butyl group, an isobutyl group, a secondary butyl group, a tertiary butyl group, a phenyl group, a phenyl group having a lower alkyl group substituent, or a phenyl group having a lower alkoxy group substituent; and R_{13} represents a hydrogen atom, a deuterium atom, a lower alkyl group, a lower alkoxy group or a chlorine atom;

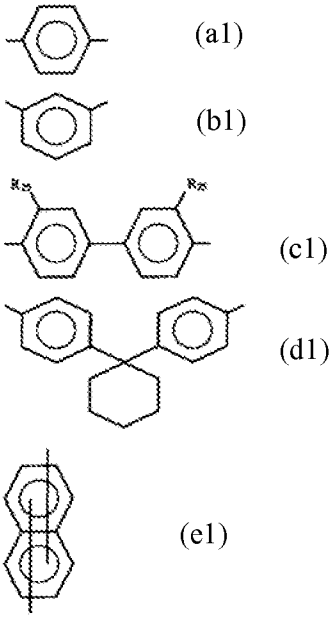
(HTL-II) is

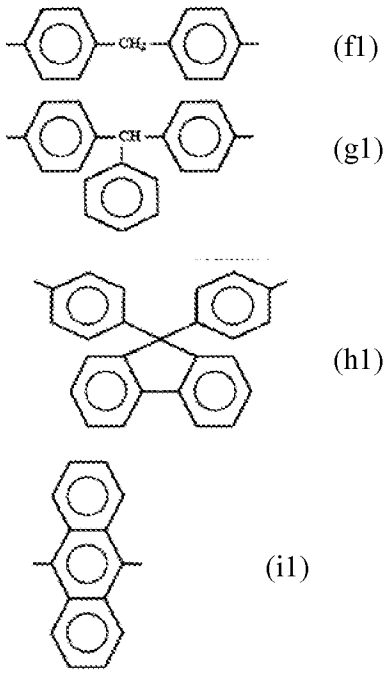


(II)

wherein R_{21}, R_{22} and R_{23} may be the same or different and each independently represents a hydrogen atom, a deuterium atom, a lower alkyl group, a lower alkoxy group, an unsubstituted phenyl group, or a phenyl group having a lower alkyl group or a lower alkoxy group as a substituent(s); R_{24} represents a hydrogen atom, a deuterium atom, a lower alkyl group, a lower alkoxy group or a chlorine atom; and

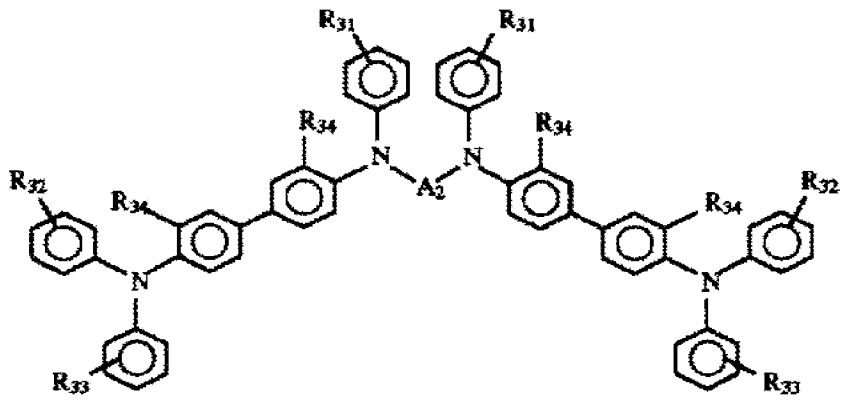
A_1 represents a group represented by any one of the following structural formulae (a1) to (i1);





in which R_{25} represents a hydrogen atom, a deuterium atom, a lower alkyl group, a lower alkoxy group or a chlorine atom;

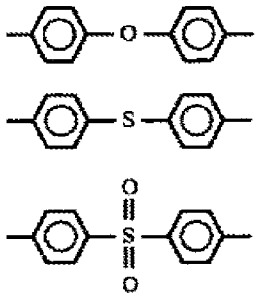
(HTL-III) is



wherein R_{31}, R_{32} and R_{33} may be the same or different and each independently represents a hydrogen atom, a deuterium atom, a lower alkyl group, a lower alkoxy group, an unsubstituted phenyl group, or a phenyl group having a deuterium atom, a lower alkyl group or a lower alkoxy group as a substituent(s); R_{34} represents a hydrogen atom, a deuterium

atom, a lower alkyl group, a lower alkoxy group or a chlorine atom; and

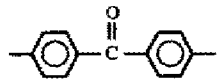
A_2 represents a group represented by any one of the following formulae (j1) to (n1);



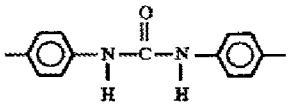
(j1)

(k1)

(l1)

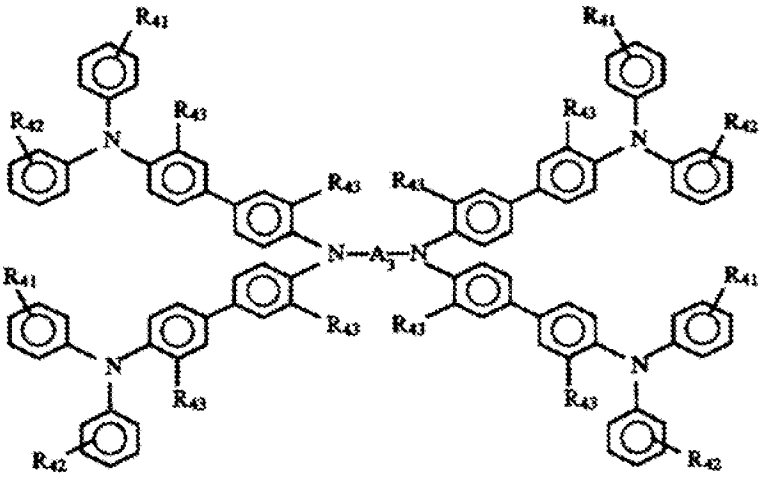


(m1)



(n1) ;

(HTL-IV) is



wherein R_{41} and R_{42} may be the same or different and each independently represents a hydrogen atom, a deuterium atom, a lower alkyl group, a lower alkoxy group, an unsubstituted phenyl group or a phenyl group having a deuterium atom, a lower alkyl group or a lower alkoxy group as a substituent(s); R_{43} represents a hydrogen atom, a deuterium atom, a lower alkyl group, a lower alkoxy group or a chlorine atom; and

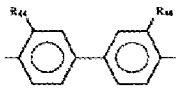
A_3 represents a group represented by anyone of the following structural formulae (a2) to (i2);



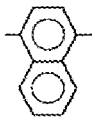
(a2)



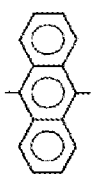
(b2)



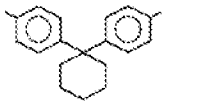
(c2)



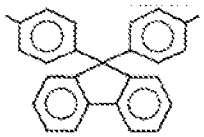
(d2)



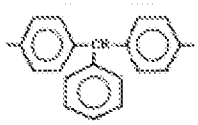
(e2)



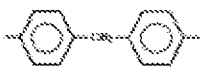
(f2)



(g2)



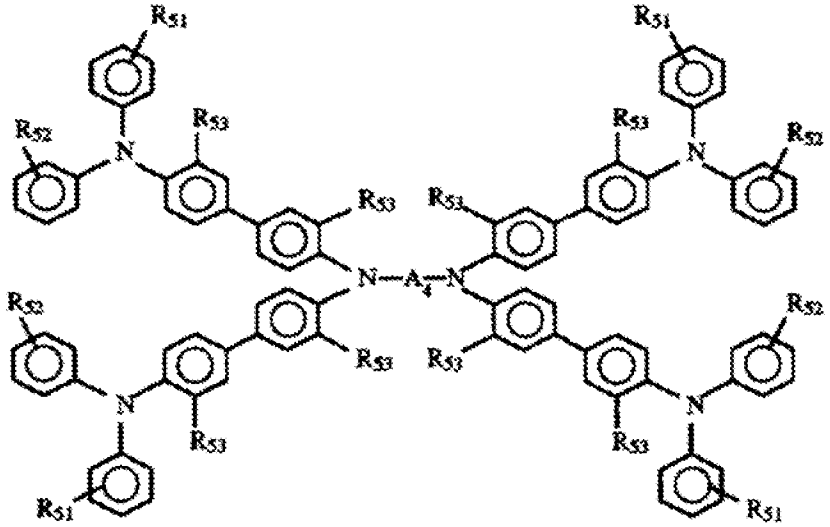
(h2)



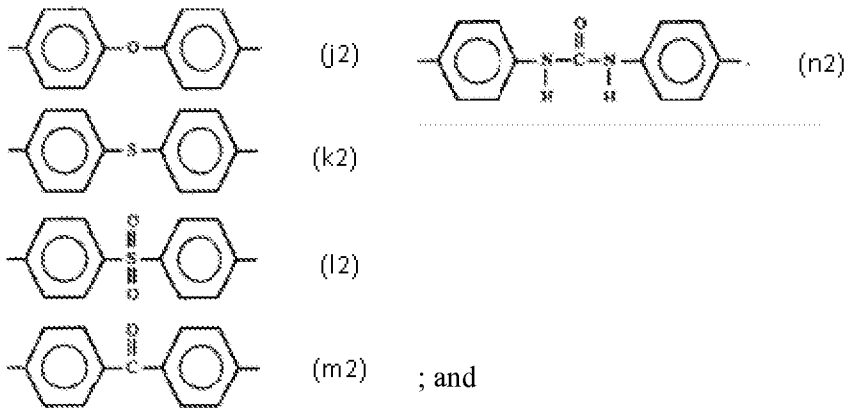
(i2)

in which R_{44} represents a hydrogen atom, a deuterium atom, a lower alkyl group, a lower alkoxy group or a chlorine atom;

(HTL-V) is

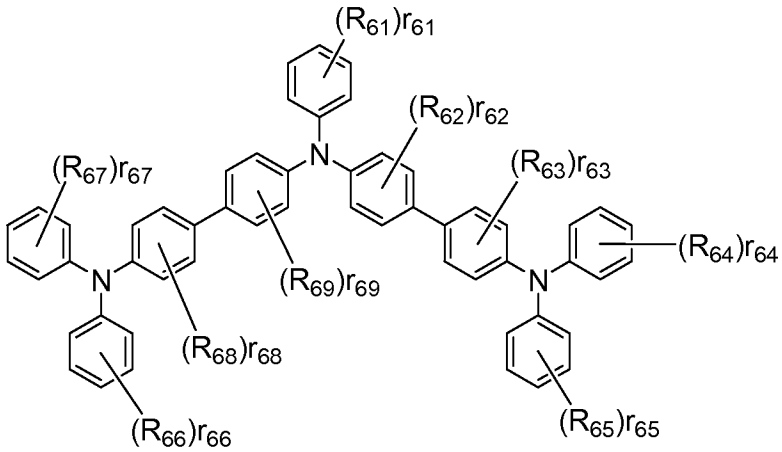


wherein R_{51} and R_{52} may be the same or different and each independently represent a hydrogen atom, a deuterium atom, a lower alkyl group, a lower alkoxy group, an unsubstituted phenyl group or a phenyl group having a deuterium atom, a lower alkyl group or a lower alkoxy group as a substituent(s); R_{53} represents a hydrogen atom, a deuterium atom, a lower alkyl group, a lower alkoxy group or a chlorine atom; and
A_4 represents a group represented by anyone of the following structural formulae (j2) to (n2);



; and

(HTL-VI) is

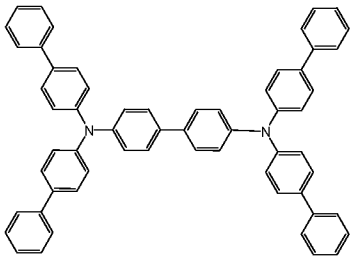


where R_{61} to R_{69}, which may be the same or different, independently represent a hydrogen atom, a deuterium atom, a lower alkyl group, a lower alkoxy group, an unsubstituted aromatic hydrocarbon group, a phenyl group having a deuterium atom, a lower alkyl group or a lower alkoxy group; r_{61} to r_{69}, which may be the same or different, represent 0, 1 or 2.

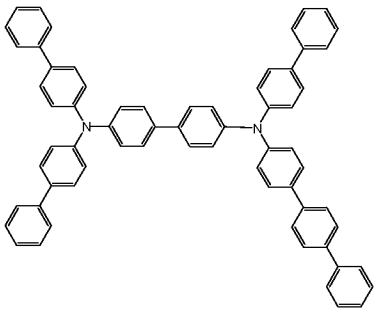
[0071] The terms "lower alkyl group" and "lower alkoxy group" as used herein mean "C_{1-4} alkyl group" and "C_{1-4} alkoxy group," respectively.

[0072] The synthesis information for the compounds of the formulae (HTL-I) to (HTL-VI) and the specific examples of the compounds of formulae (HTL-I) to (HTL-VI) are provided in United States patent No. 5,707,747 to Tomiyama et al., the contents of which are incorporated herein by reference.

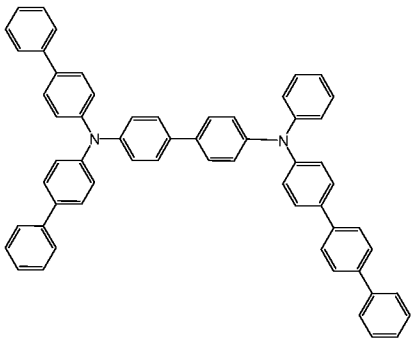
[0073] Examples of compounds having the structure of formula (HTL-I) to (HTL-VI) include:



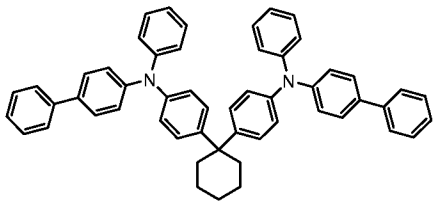
Compound-1a,



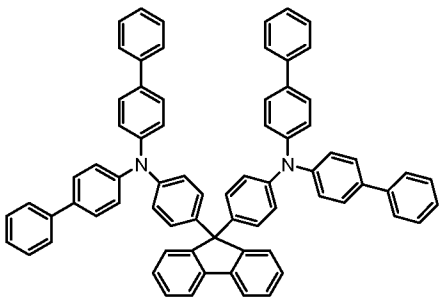
Compound-2a,



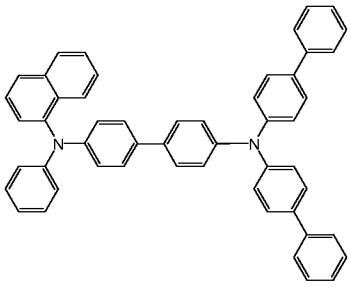
Compound-3a,



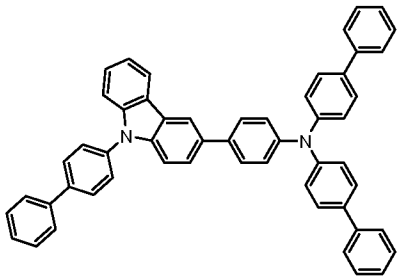
Compound-4a,



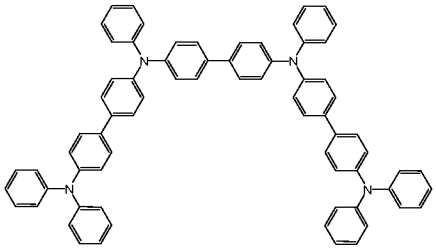
Compound-5a,



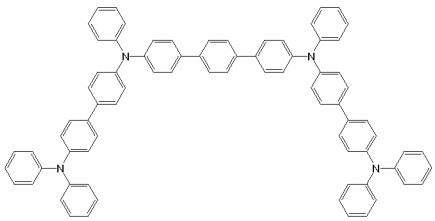
Compound-6a,



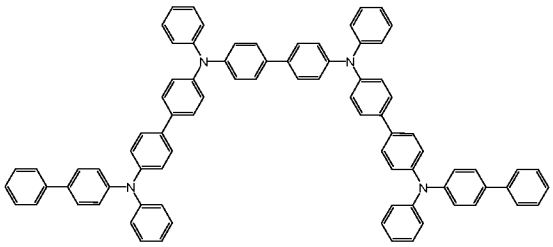
Compound-7a,



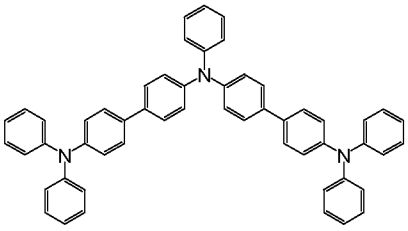
Compound-8a,



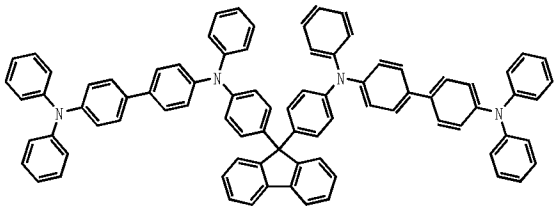
Compound-9a,



Compound-10a,



Compound-11a, and



Compound-12a.

Substrate:

[0074] The OLED of the present invention may be prepared on a substrate for supporting the OLED. The substrate is preferably a flat substrate in which light in the visible region of about 400 to about 700 nm has a transmittance of at least about 50 %. The substrate may include a glass plate, a polymer plate and the like. In particular, the glass plate may include soda lime glass, barium•strontium-containing glass, lead glass, aluminosilicate glass, borosilicate glass, barium borosilicate glass, quartz and the like. The polymer plate may include polycarbonate, acryl, polyethylene terephthalate, polyether sulfide, polysulfone and the like.

Electrodes:

[0075] The anode **3** in the OLED **100** of the present invention assumes the role of injecting holes into the hole injecting layer, the hole transporting layer or the light emitting layer. Typically the anode has a work function of 4.5 eV or more. Specific examples of a material suitable for use as the anode include indium tin oxide alloy (ITO), tin oxide (NESA), indium zinc oxide, gold, silver, platinum, copper and the like. The anode can be prepared by forming a thin film from electrode substances, such as those discussed above, by a method such as a vapor deposition method, a sputtering method and the like.

[0076] When light is emitted from the light emitting layer, the transmittance of light in the visible light region in the anode is preferably larger than 10 %. The sheet resistance of the anode is preferably several hundred Ω/square or less. The film thickness of the anode is selected, depending on the material, and is typically in the range of from about 10 nm to about 1 μm, and preferably from about 10 nm to about 200 nm.

[0077] The cathode **11** comprises preferably a material having a small work function for the purpose of injecting an electron into the electron injecting layer, the electron transporting layer or the light emitting layer. Materials suitable for use as the cathode include, but are not limited to indium, aluminum, magnesium, magnesium-indium alloys, magnesium-aluminum

alloys, aluminum-lithium alloys, aluminum-scandium-lithium alloys, magnesium-silver alloys and the like. For transparent or top-emitting devices, a TOLED cathode such as disclosed in U.S. Patent No. 6,548,956 is preferred.

[0078] The cathode can be prepared, as is the case with the anode, by forming a thin film by a method such as a vapor deposition method, a sputtering method and the like. Further, an embodiment in which light emission is taken out from a cathode side can be employed as well.

Inverted OLED:

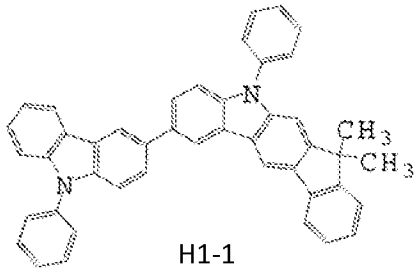
[0079] **FIG. 6** shows an inverted OLED **400** according to another embodiment of the present disclosure. The device includes a substrate **410**, a cathode **415**, an emissive layer **420**, a hole transport layer **425**, and an anode **430**. OLED **400** may be fabricated by depositing the layers described, in order. Because the most common OLED configuration has a cathode disposed over the anode, and device **400** has cathode **415** disposed under anode **430**, device **400** may be referred to as an inverted OLED. OLED **400** also illustrates an example of an OLED in which some of the layers illustrated in the OLED **100** of **FIG. 1** are omitted from the device architecture.

[0080] The simple layered structures of OLEDs **100, 200, 300** and **400** are provided by way of non-limiting examples 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 certain layers may be omitted entirely, based on the design, performance, and cost factors. Other layers not specifically described herein may also be included.

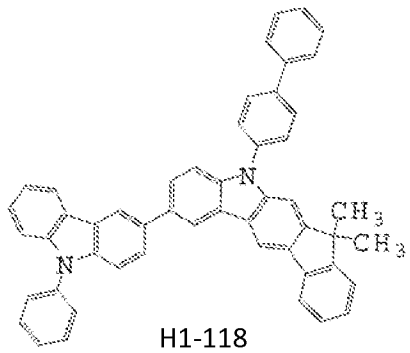
[0081] Although many of the examples provided herein described various layers as comprising a single material, it is understood that combinations of materials, or more generally a mixture, may be used. Also, the layers may have various sub-layers. The names given to the various layers herein are not intended to be strictly limiting. For example, in device **400**, hole transport layer **425** transports holes and injects holes into emissive layer **420**, 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.

EXAMPLES

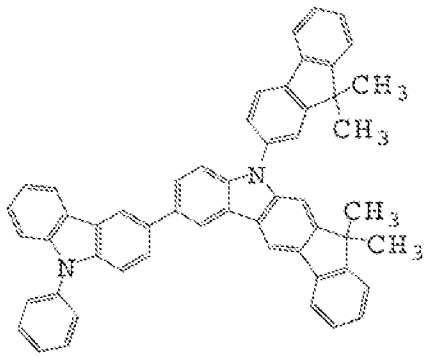
[0082] The invention will be described in further detail with reference to the following example devices and comparative example devices. However, the invention is not limited by the following examples. The chemical structures of the particular organic compounds H1-1, H1-118, H1-119, H, E1, G1, NPD and Alq_3 used in making the example devices are shown below.



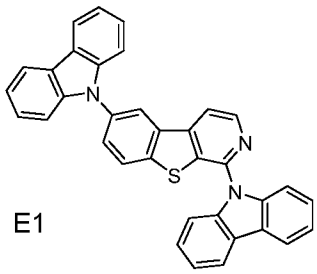
H1-1



H1-118

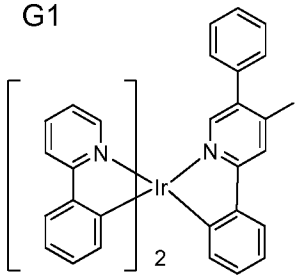


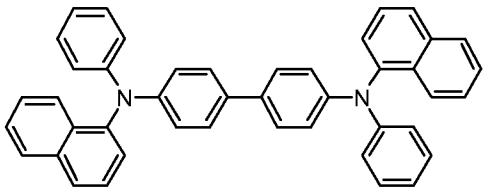
H1-119



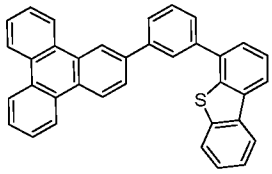
E1

G1

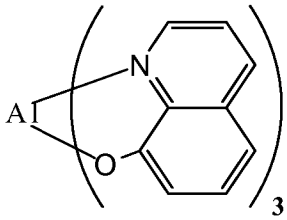




NPD



H



Alq_3

[0083] Compound H1 as a host - Example Devices #1, #2 and #3: Experimental green PHOLEDs having a four-component emissive layer and having the architecture shown in **FIG. 2** was constructed. The example devices #1, #2 and #3 had an ITO anode (800 Å) and a LiF/Al cathode. Disposed between the two electrodes were: 100 Å thick hole injection layer (HIL) made of the compound LG-101 (from LG Chemical), a 500 Å thick electron blocking layer (EBL) made of NPD, a 300 Å thick four-component emissive layer (EML), a 100 Å thick hole blocking layer (HBL) made of the compound E1, and a 400 Å thick electron transport layer (ETL) made of Alq_3. The four-component EML in these experimental devices were formed with three host compounds. The first host compound was the hole-transporting type host compound having the general formula H1, the second host compound was compound H as a wide band-gap matrix host, and the third host compound was E1 as an electron-transporting host. As shown in the experimental device data summary of **Table 3**, the particular hole-transporting host compounds in devices #1, #2 and #3 were H1-1, H1-119, and H1-118, respectively. The compound G1 was the green emitter dopant. The HOMO-LUMO energy levels of these compounds are provided in **Table 1** below.

Table 1. Energy levels of the EML components

Compound	LUMO [eV]	HOMO [eV]	Triplet Energy [eV]
H	2.34	5.96	2.63
E1	2.63	5.73	2.95
H1-1	2.10	5.59	2.80
H1-118	2.20	5.56	2.79
H1-119	2.33	5.58	2.77
G1	2.46	5.1	2.40

The functions of the organic compounds used in the exemplary devices according to the present disclosure are provided in **Table 2** below.

Table 2. Functions of the organic compounds

Compound	H1-1	H1-1	H1-118	H1-118	H1-119	H1-119
Layer location	exciton/electron blocking layer	Emissive Layer	exciton/electron blocking layer	Emissive Layer	exciton/electron blocking layer	Emissive Layer
Function	Exciton and/or Electron blocker	Hole-transporting host	Exciton and/or Electron blocker	Hole-transporting host	Exciton and/or Electron blocker	Hole-transporting host

Table 2 (cont'd).

Compound	H	E1	E1	G1
Layer location	Emissive Layer	Emissive Layer	Hole Blocking Layer	Emissive Layer
Function	Wide band gap matrix host	Electron-transporting host	Hole Blocker	Emitter Dopant

[0084] The amount of each of the components of the emissive layer used are provided in **Table 3** below. The amounts are provided in wt.% of the emissive layer. For example, in the Example Device #1, the concentrations of the first host compound H1-1, the second host compound H, the third host compound E1, and the emitter dopant G1 were 15 wt.%, 60 wt.%, 20 wt.%, and 5 wt.%, respectively.

[0085] The energy level diagram for the four-component EML of a device of **FIG. 2** that incorporates the hole-transporting type compound H1 as one of the hosts in the EML according to an embodiment is shown in **FIG. 4**. The energy level diagram for the four-component EML portion of the Example Device #4 is shown in **FIG. 5**. The HOMO level of compound H1-1 is 5.59 eV, which is higher (or less electronegative) than the HOMO levels of the other host compounds H and E1 which are 5.96 and 5.73, respectively. The host compounds H and E1 are thus more electron-transporting than the hole-transporting type compounds H1-1, H1-118 and H1-119. The HOMO levels of compounds H1-1, H1-118, and H1-119 are relatively close to HOMO level of the emitter dopant G1 (5.1 eV), and as discussed above, this allows the hole-transporting host compounds such as H1-1, H1-118, and H1-119 to offload the hole transporting function from the emitter dopant which extends the life of the emitter dopant material.

[0086] In the Example Devices #1 through #8 with high 15 wt.% of compounds H1-1, H1-118, and H1-119 and low 5 wt.% of G1 in the EML, the majority of holes are believed to be transported by the hole-transporting host compounds H1-1, H1-118, and H1-119 which enhances separation of the charge carriers and excitons and minimizes concentration

quenching and polaron-exciton interaction. The triplet energy of compound H1-1 (2.80 eV) is higher than the triplet energy of G1 (2.4 eV) and does not cause the emission quenching.

[0087] Compound H1 as a host and an EBL - Example Devices #4 through #8:
Example devices #4, #5, #6, #7 and #8 had the architecture **300** shown in **FIG. 3**. The EML of example devices #4, #5, #6, #7 and #8 had a four-component composition consisting of the hole-transporting compound having the general formula H1 (15 wt.%) as the first host compound, the compound H (60 wt.%) as the second host compound, and the compound E1 (20 wt.%) as the third host compound, and the emitter dopant compound G1 (5 wt.%).

[0088] The measured CIE 1931 coordinates, λ_{max} and FWHM (Full Width at Half Maximum) of the emission spectrum from the example devices are shown in **Table 3**. The example devices #1 through #8 with compounds H1-1, H1-119 or H1-118 as a component in the EML exhibited better color saturation compared to the comparative reference device CE. As shown in **Table 3**, two groups of example devices were evaluated: (1) a first group using the hole-transporting type compound of the present disclosure as one of the host compounds in the emissive layer with NPD as EBL (example devices #1, #2 and #4); and (2) a second group using the compound of the present disclosure as one of the host compounds in the emissive layer and also as the EBL (example devices #5, #6, #8, #9, and #14). The indeno-carbazole derivative compounds represented by the general formula H1 were used as a host with the matrix host, H, the electron-transporting host, E1, and provided the hole-transporting host function. The comparative example device CE had only two host compounds, the matrix host H and the electron-transporting host E1, and NPD as the EBL. The superior color saturation was achieved with all of the example devices. The example devices exhibited narrower FWHM than the comparative example device. The inventors believe that this may be an evidence of an increased microcavity effect induced by the addition of the hole-transporting host to the EML. This would suggest that in addition to the compound H1's transport functions, its refractive index may improve the reflectance characteristics in the EML, leading to spectral narrowing and enhanced intensity of emission. These beneficial effects were unexpected because such effects are generally not predictable based on the chemical structures of the compounds.

Table 3. Example Devices Experimental Data

		Emissive Layer Components					CIE 1931			
	EBL	First Host [wt%]	Second Host [wt%]	Third Host [wt%]	Emitter [wt%]	HBL	x	y	λ max [nm]	FWHM [nm]
Example Device #1	NPD	H1-1 [15]	H [60]	E1 [20]	G1 [5]	E1	0.316	0.628	520	64
Example Device #2	NPD	H1-119 [15]	H [60]	E1 [20]	G1 [5]	E1	0.316	0.631	520	64
Example Device #3	NPD	H1-118 [15]	H [60]	E1 [20]	G1 [5]	E1	0.322	0.626	522	68
Example Device #4	H1-1	H1-1 [15]	H [60]	E1 [20]	G1 [5]	E1	0.315	0.630	520	64
Example Device #5	H1-119	H1-1 [15]	H [60]	E1 [20]	G1 [5]	E1	0.316	0.630	520	64
Example Device #6	H1-119	H1-1 [15]	H [60]	E1 [20]	G1 [5]	E1	0.318	0.630	522	64
Example Device #7	H1-119	H1-119 [15]	H [60]	E1 [20]	G1 [5]	E1	0.315	0.631	522	64
Example Device #8	H1-118	H1-118 [15]	H [60]	E1 [20]	G1 [5]	E1	0.330	0.623	522	70
CE	NPD	--	H [68]	E1 [20]	G1 [12]	E1	0.344	0.616	528	72

[0089] The HOMO, LUMO levels and the triplet energy levels are provided in **Table 1** above. The very shallow LUMO level of compounds H1-1, H1-118, and H1-119 (2.10, 2.20, and 2.33 eV, respectively) blocks electrons from leaking into HTL and high triplet energy of the compounds H1-1, H1-118, and H1-119 (2.80, 2.79, and 2.77 eV, respectively) blocks excitons from leaking into HTL. The excitons and electrons in the device with compounds, such as H1-1, H1-118, or H1-119, as the exciton/electron blocking layer are better confined within the emissive layer. Thus, it combines both charge-exciton separation in the emissive layer and electron and exciton blocking in the exciton/electron blocking layer.

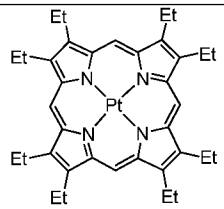
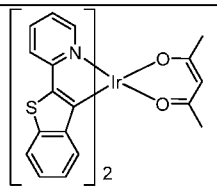
[0090] All organic layers were deposited under high-vacuum conditions ($1x10^{-7}$ Torr). The PHOLED was transferred directly from vacuum into an inert environment glove-box, where it was encapsulated using a UV-curable epoxy, and a glass lid with a moisture getter.

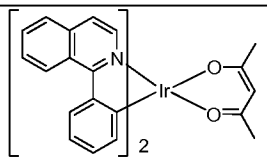
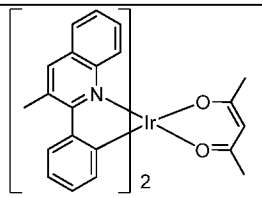
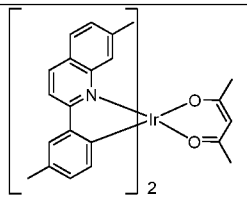
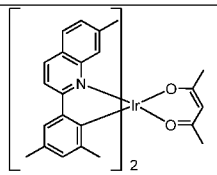
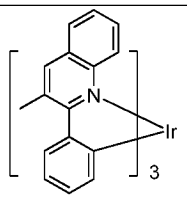
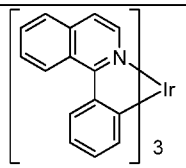
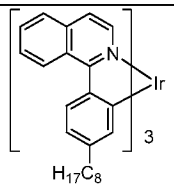
[0091] Unless otherwise specified, any of the layers of the various embodiments of the invention described herein may be deposited by any suitable method. For the organic layers, preferred methods include thermal evaporation, ink-jet, such as described in U.S. Pat. Nos. 6,013,982 and 6,087,196, which are incorporated by reference in their entireties, organic vapor phase deposition (OVPD), such as described in U.S. Pat. No. 6,337,102 to Forrest et

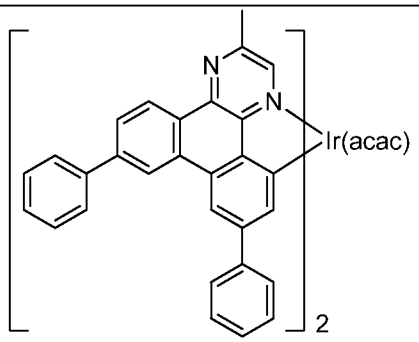
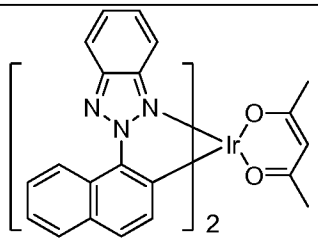
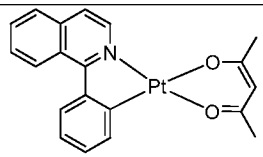
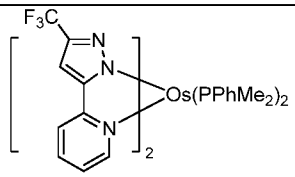
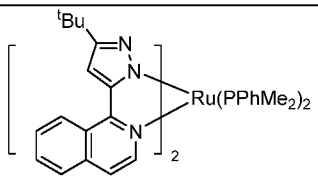
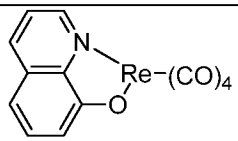
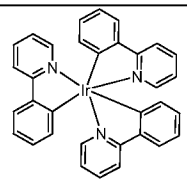
al., which is incorporated by reference in its entirety, and deposition by organic vapor jet printing (OVJP), such as described in U.S. patent application Ser. No. 10/233,470, which is incorporated by reference in its entirety. Other suitable deposition methods include spin coating and other solution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

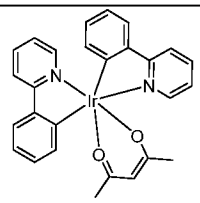
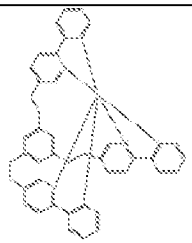
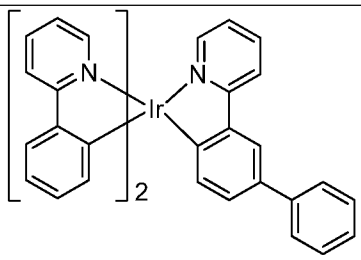
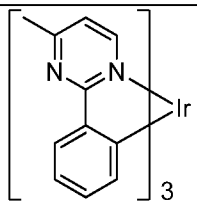
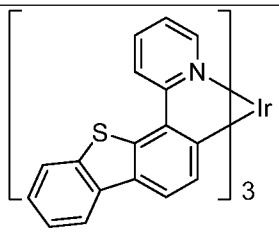
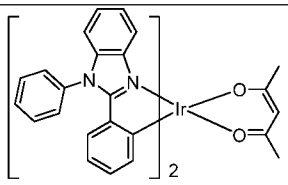
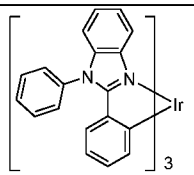
[0092] The structures illustrated herein are an example only and the OLED according to the disclosed invention is not limited to the particular structure and can include more layers or fewer layers or different combinations of the layers.

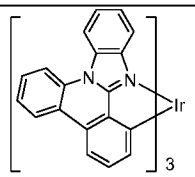
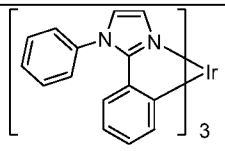
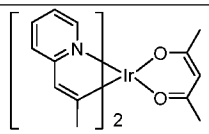
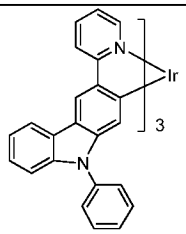
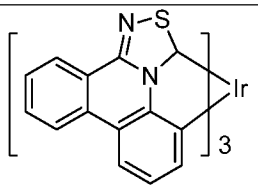
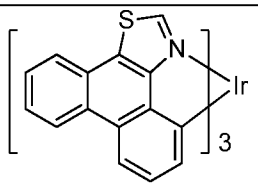
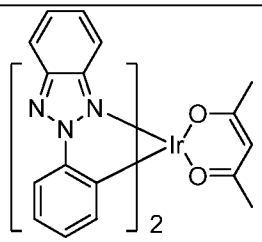
[0093] **Table 5**. Examples of phosphorescent dopants.

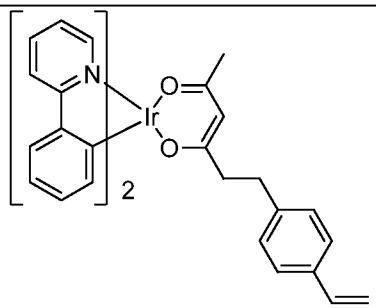
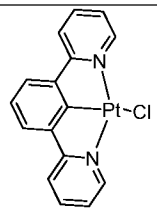
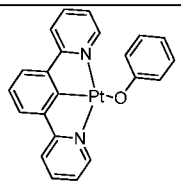
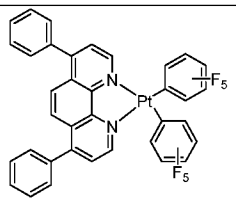
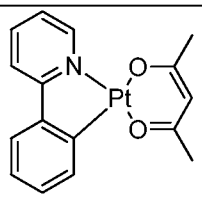
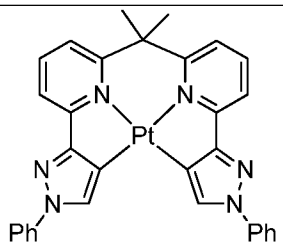
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Red dopants		
Heavy metal porphyrins (e.g., PtOEP)		Nature 395, 151 (1998)
Iridium(III) organometallic complexes		Appl. Phys. Lett. 78, 1622 (2001)

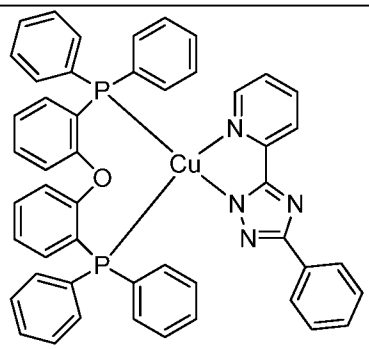
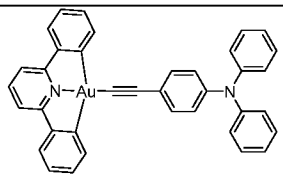
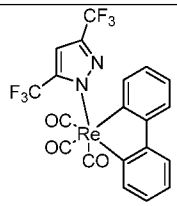
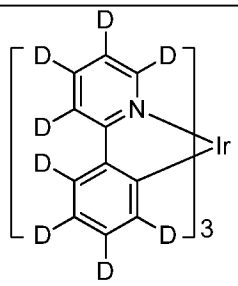
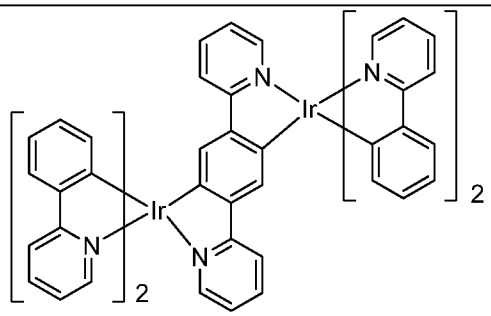
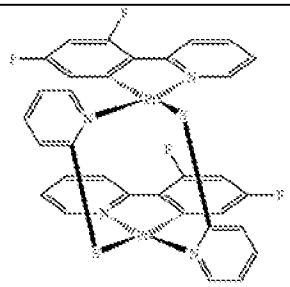
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US 2006/835469
		US 2006/835469
		US 2006/0202194
		US 2006/0202194
		US 2007/0087321
		US 2007/0087321
		Adv. Mater. 19, 739 (2007)

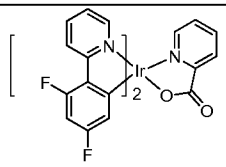
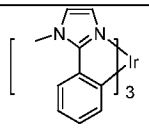
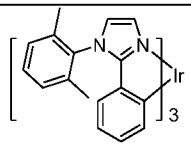
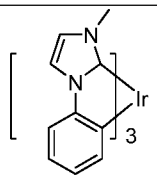
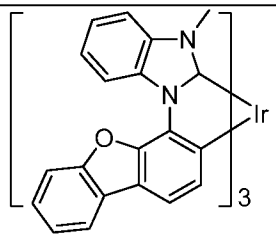
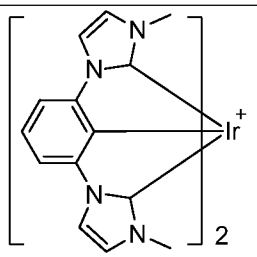
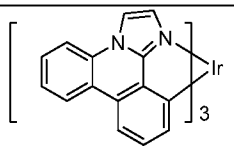
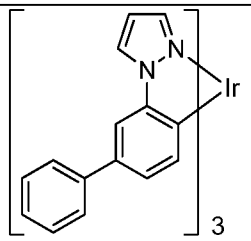
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		WO 2009/100991
		WO 2008/101842
Platinum(II) organometallic complexes		WO 2003/040257
Osminum(III) complexes		Chem. Mater. 17, 3532 (2005)
Ruthenium(II) complexes		Adv. Mater. 17, 1059 (2005)
Rhenium (I), (II), and (III) complexes		US 2005/0244673
Green dopants		
Iridium(III) organometallic complexes	 and its derivatives	Inorg. Chem. 40, 1704 (2001)

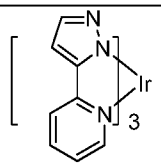
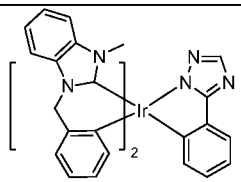
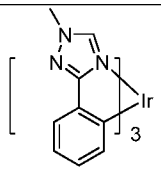
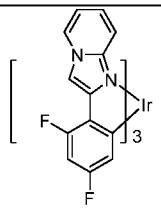
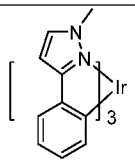
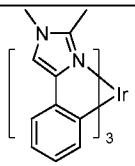
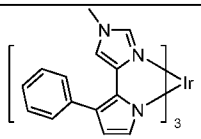
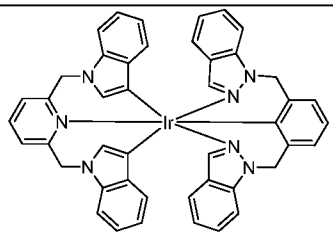
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		US 2002/0034656
		US 7332232
		US 2009/0108737
		US 2009/0039776
		US 6921915
		US 6687266
		Chem. Mater. 16, 2480 (2004)

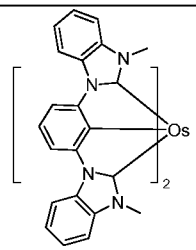
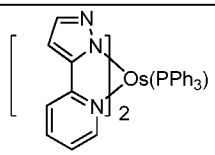
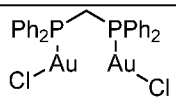
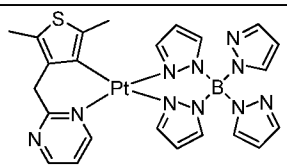
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		US 2007/0190359
		US 2006/0008670 JP 2007-123392
		Adv. Mater. 16, 2003 (2004)
		Angew. Chem. Int. Ed. 2006, 45, 7800
		WO 2009/050290
		US 2009/0165846
		US 2008/0015355

MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Monomer for polymeric metal organometallic compounds		US 7250226, US 7396598
Pt(II) organometallic complexes, including polydentated ligands		Appl. Phys. Lett. 86, 153505 (2005)
		Appl. Phys. Lett. 86, 153505 (2005)
		Chem. Lett. 34, 592 (2005)
		WO 2002/015645
		US 2006/0263635

MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Cu complexes		WO 2009/000673
Gold complexes		Chem. Commun. 2906 (2005)
Rhenium(III) complexes		Inorg. Chem. 42, 1248 (2003)
Deuterated organometallic complexes		US 2003/0138657
Organometallic complexes with two or more metal centers		US 2003/0152802
		US 7090928

MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Blue dopants		
Iridium(III) organometallic complexes		WO 2002/002714
		WO 2006/009024
		US 2006/0251923
		US 7393599, WO 2006/056418, US 2005/0260441, WO 2005/019373
		US 7534505
		US 7445855
		US 20070190359, US 2008/0297033
		US 7338722

MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US 2002/0134984
		Angew. Chem. Int. Ed. 47, 1 (2008)
		Chem. Mater. 18, 5119 (2006)
		Inorg. Chem. 46, 4308 (2007)
		WO 2005/123873
		WO 2005/123873
		WO 2007/004380
		WO 2006/082742

MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Osmium(II) complexes		US 7279704
		Organometallics 23, 3745 (2004)
Gold complexes		Appl. Phys. Lett.74,1361 (1999)
Platinum(II) complexes		WO 2006/098120, WO 2006/103874

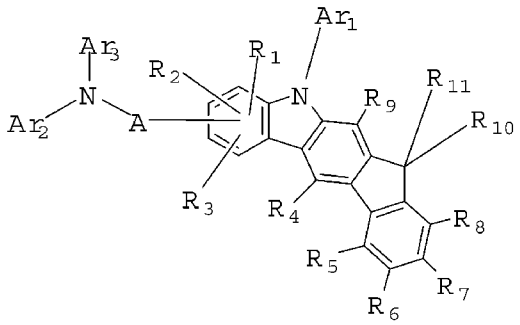
WHAT IS CLAIMED IS:

1. An organic light emitting device comprising an anode, a cathode and a plurality of organic layers provided between them, the plurality of organic layers comprising:

an emissive layer comprising a host material and a phosphorescent emitter material, the host material comprising:

a first host compound; and

a second host compound wherein the first host compound has an indeno-carbazole ring structure represented by the following general formula H1,



(H1)

wherein A represents a divalent group of a substituted or unsubstituted aromatic hydrocarbon, a divalent group of a substituted or unsubstituted aromatic heterocyclic ring, or a divalent group of substituted or unsubstituted fused polycyclic aromatics;

Ar_1, Ar_2, and Ar_3 may be the same or different, and represent a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted aromatic heterocyclic group, or a substituted or unsubstituted fused polycyclic aromatic group, where A and Ar_2, or Ar_2 and Ar_3 may bind to each other via a single bond or via substituted or unsubstituted methylene, an oxygen atom, or a sulfur atom to form a ring;

R_1 to R_9 may be the same or different, and represent a hydrogen atom, a deuterium atom, a fluorine atom, a chlorine atom, cyano, nitro, linear or branched alkyl of 1 to 6 carbon atoms that may have a substituent, cycloalkyl of 5 to 10 carbon atoms that may have a substituent, linear or branched alkenyl of 2 to 6 carbon atoms that may have a substituent, linear or branched alkyloxy of 1 to 6 carbon atoms that may have a substituent, cycloalkyloxy of 5 to 10 carbon atoms that may have a substituent, a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted aromatic heterocyclic group, a substituted or unsubstituted fused polycyclic aromatic group, or substituted or unsubstituted aryloxy, which may bind to each other via a single bond, substituted or unsubstituted methylene, an

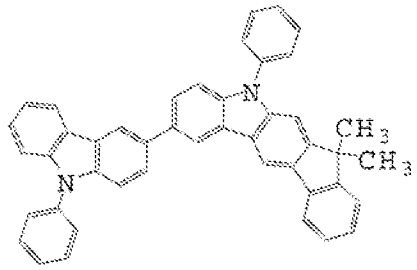
oxygen atom, or a sulfur atom to form a ring; and

R_{10} and R_{11} may be the same or different, and represent linear or branched alkyl of 1 to 6 carbon atoms that may have a substituent, cycloalkyl of 5 to 10 carbon atoms that may have a substituent, linear or branched alkenyl of 2 to 6 carbon atoms that may have a substituent, linear or branched alkyloxy of 1 to 6 carbon atoms that may have a substituent, cycloalkyloxy of 5 to 10 carbon atoms that may have a substituent, a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted aromatic heterocyclic group, a substituted or unsubstituted fused polycyclic aromatic group, or substituted or unsubstituted aryloxy, which may bind to each other via a single bond, substituted or unsubstituted methylene, an oxygen atom, or a sulfur atom to form a ring.

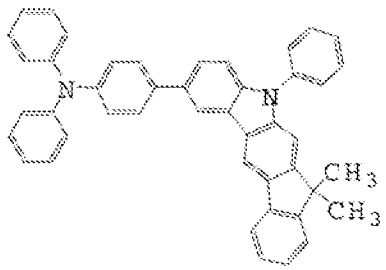
2. The organic light emitting device of claim 1, wherein the first host compound constitutes no more than 25 wt.% of the emissive layer.

3. The organic light emitting device of claim 1, wherein the first host compound constitutes 10 - 20 wt.% of the emissive layer.

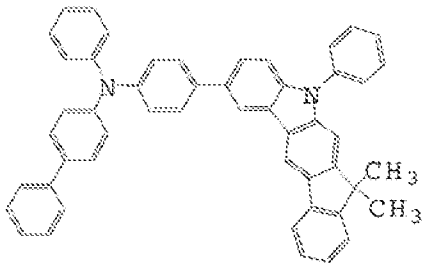
4. The organic light emitting device of claim 1, wherein the first host compound is selected from the group consisting of:



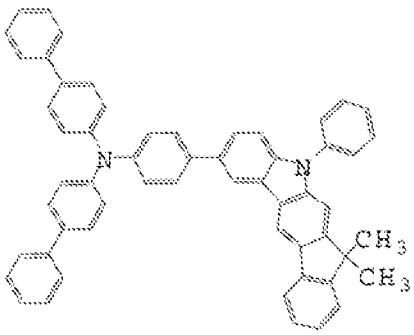
Compound H1-1



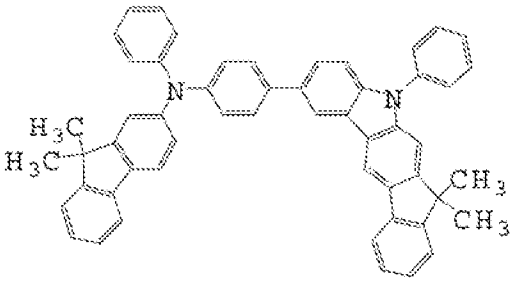
Compound H1-2



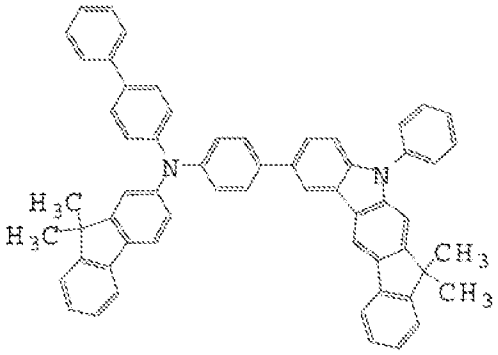
Compound H1-3



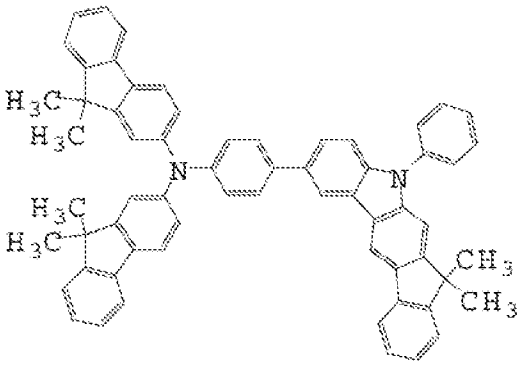
Compound H1-4



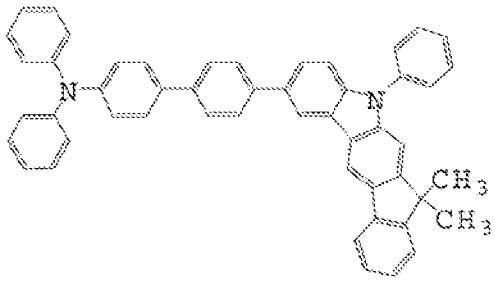
Compound H1-5



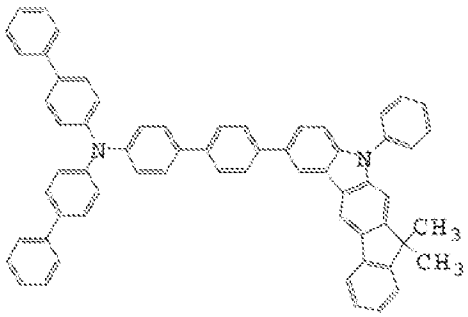
Compound H1-6



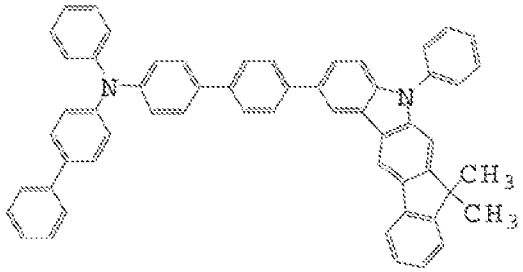
Compound H1-7



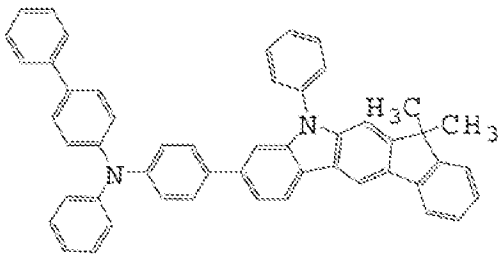
Compound H1-8



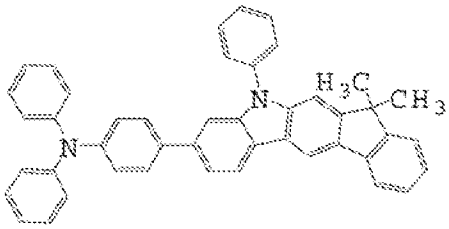
Compound H1-9



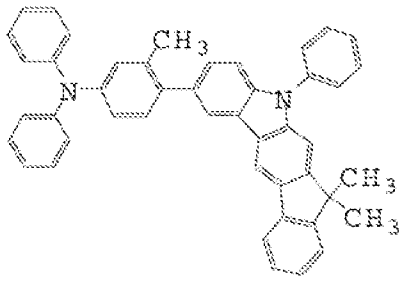
Compound H1-10



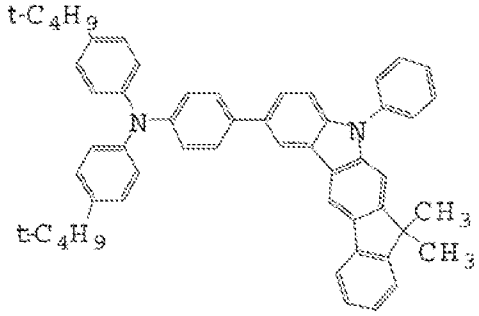
Compound H1-11



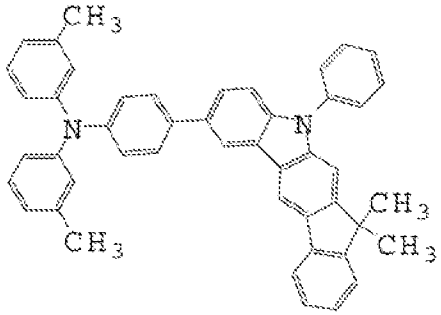
Compound H1-12



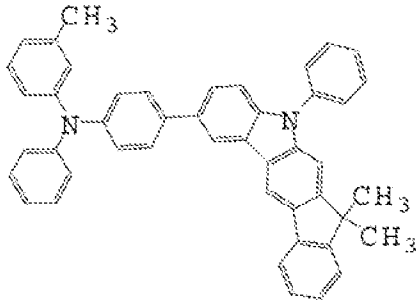
Compound H1-13



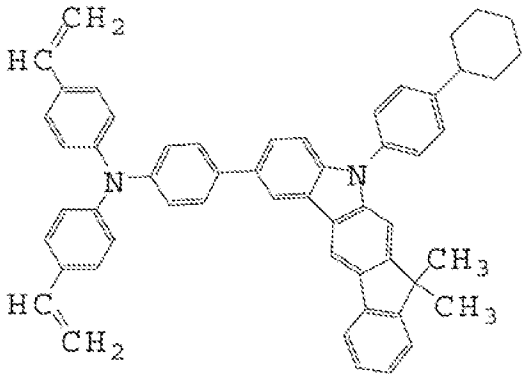
Compound H1-14



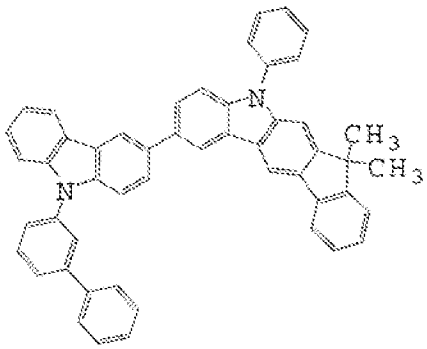
Compound H1-15



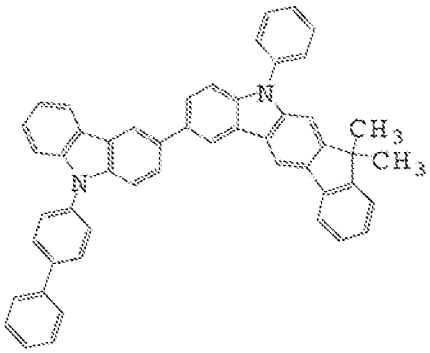
Compound H1-16



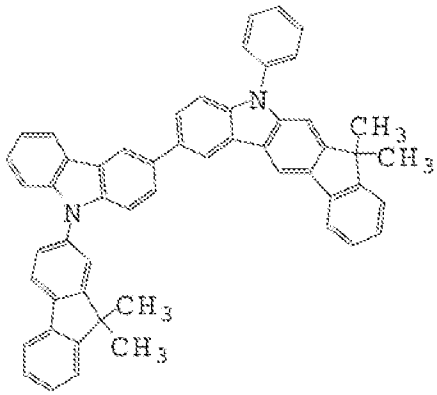
Compound H1-17



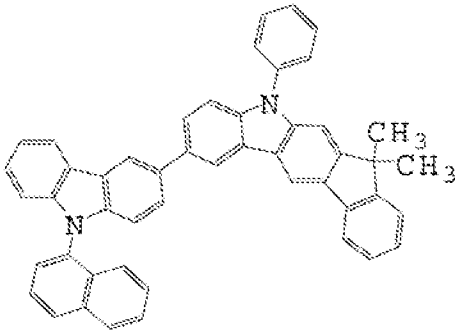
Compound H1-18



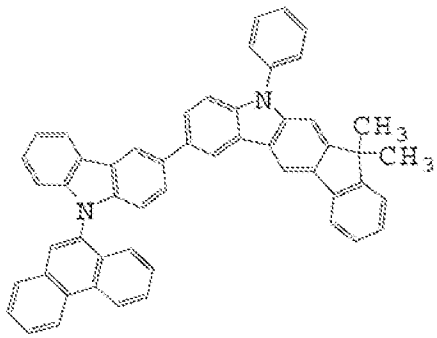
Compound H1-19



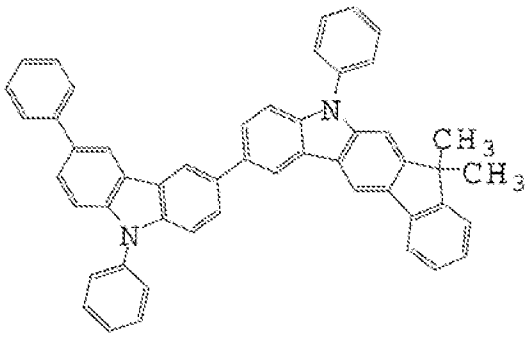
Compound H1-20



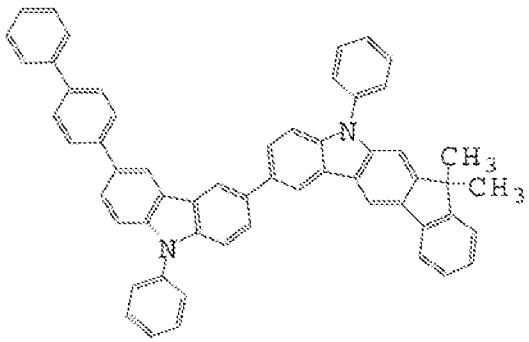
Compound H1-21



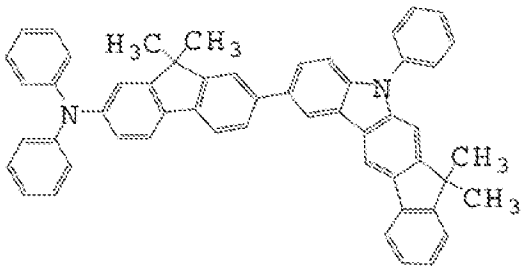
Compound H1-22



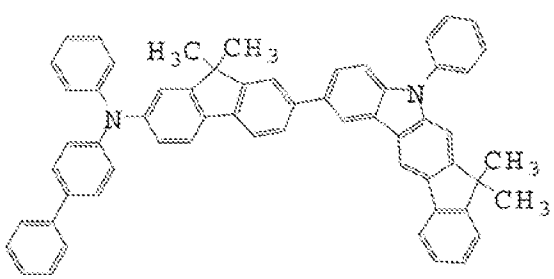
Compound H1-23



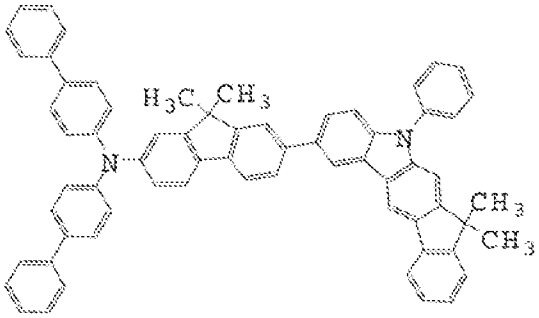
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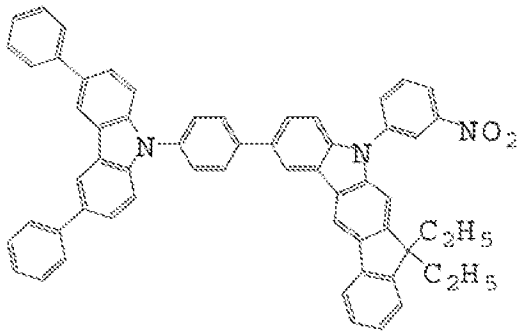
Compound H1-25



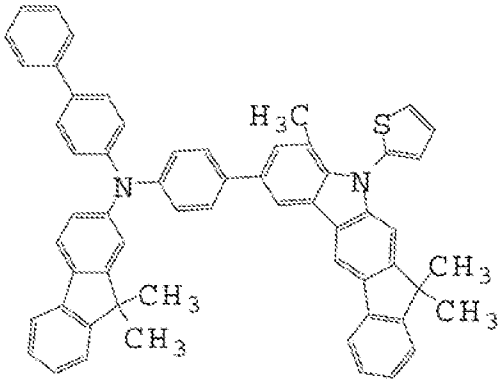
Compound H1-26



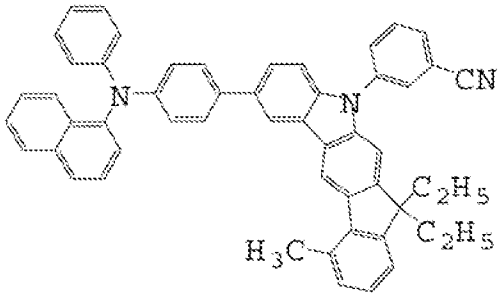
Compound H1-27



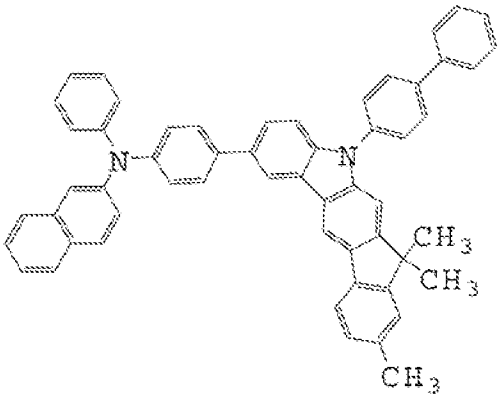
Compound H1-28



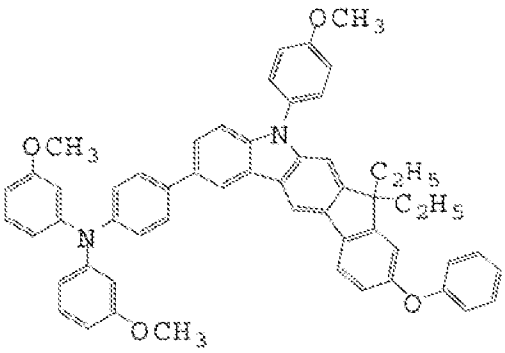
Compound H1-29



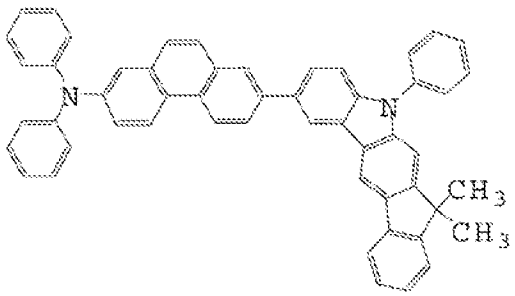
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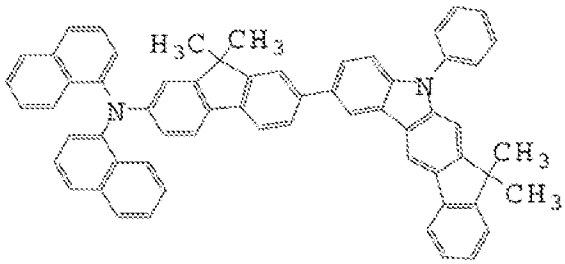
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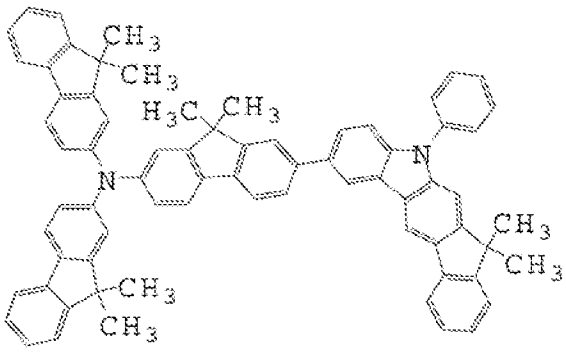
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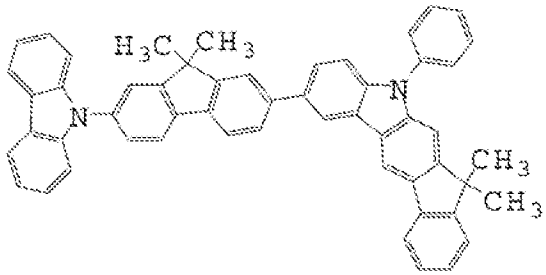
Compound H1-33



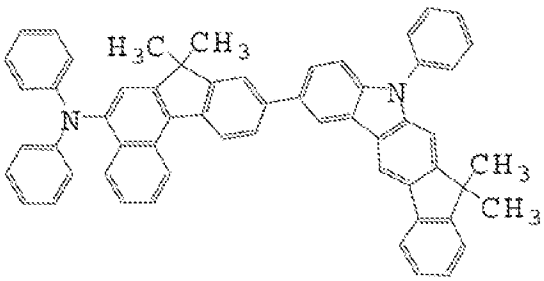
Compound H1-34



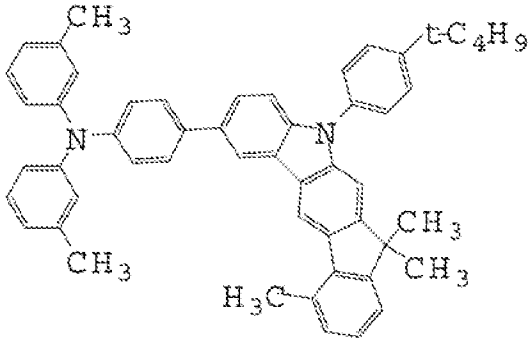
Compound H1-35



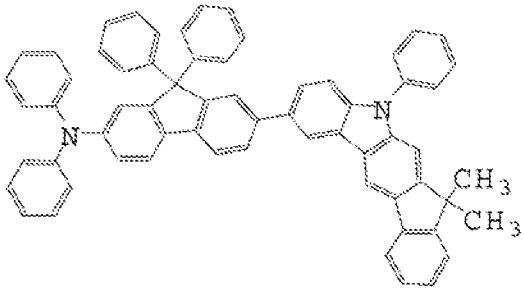
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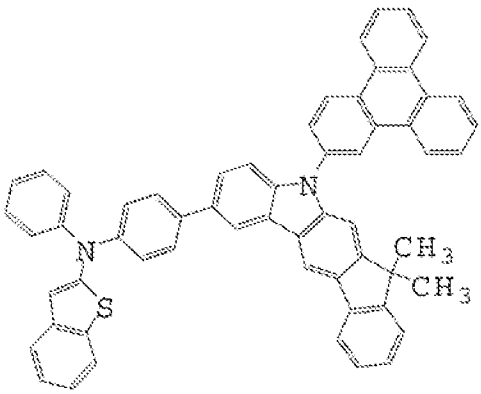
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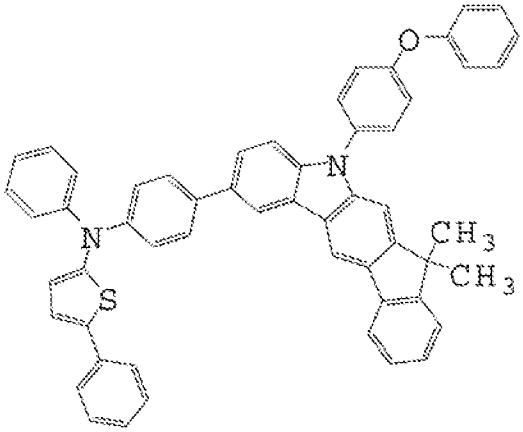
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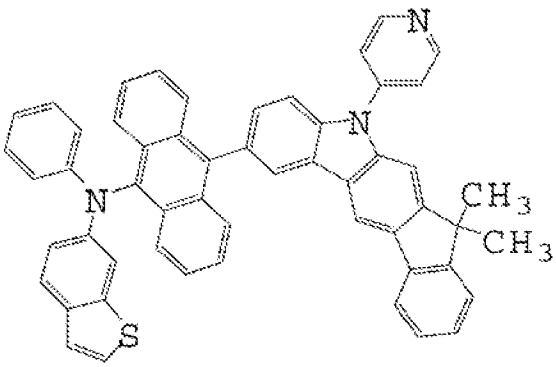
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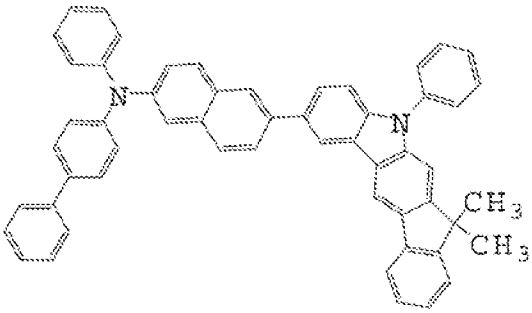
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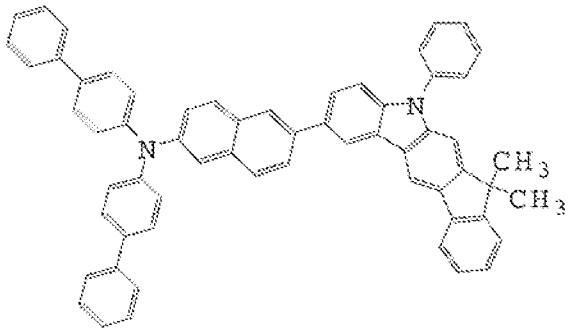
Compound H1-41



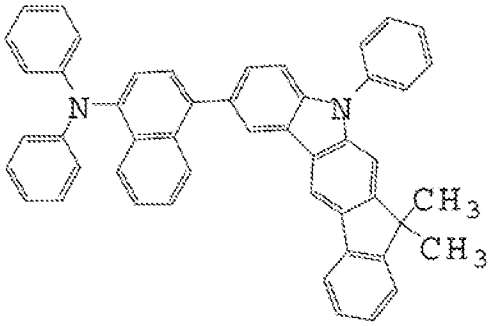
Compound H1-42



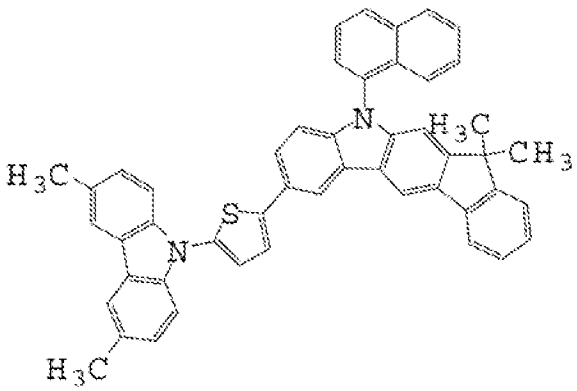
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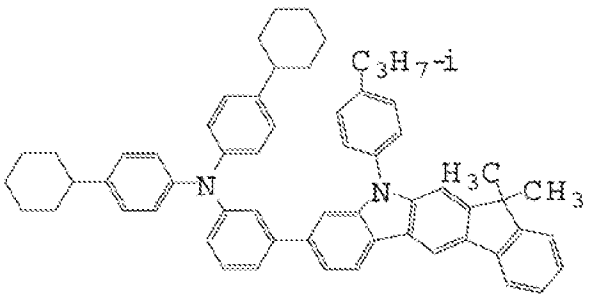
Compound H1-44



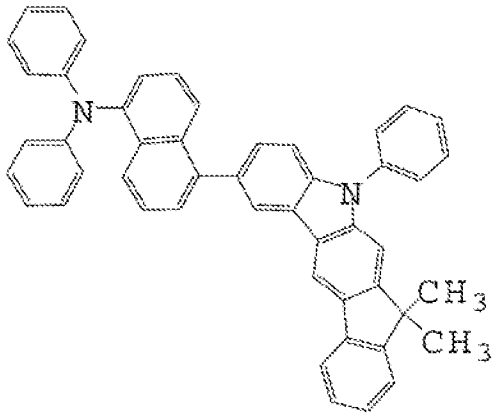
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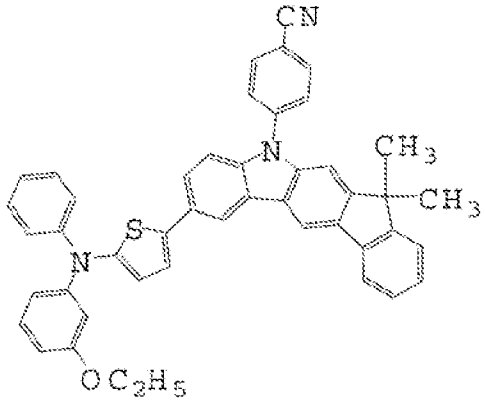
Compound H1-46



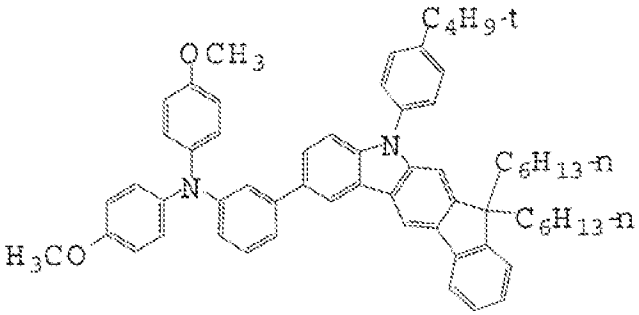
Compound H1-47



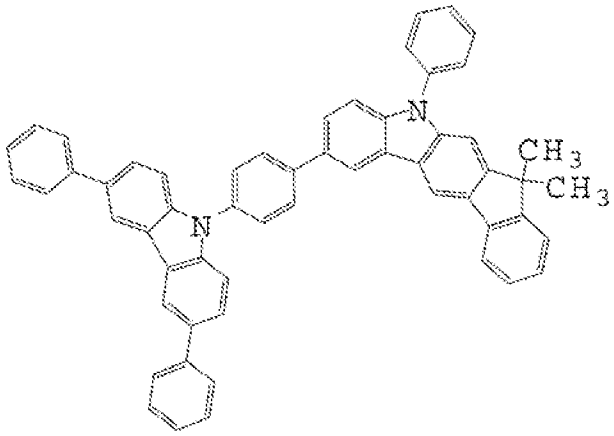
Compound H1-48



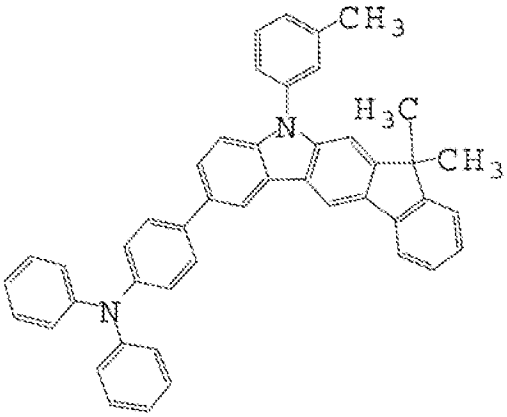
Compound H1-49



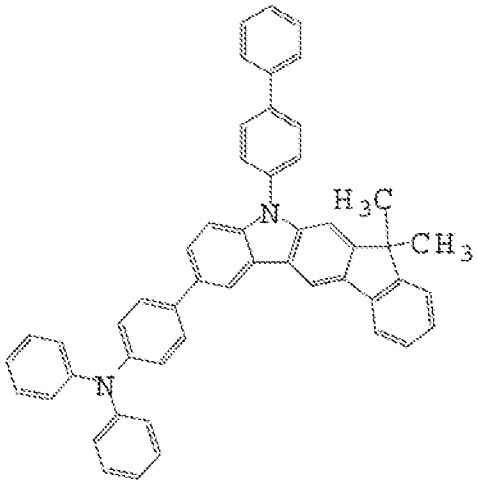
Compound H1-50



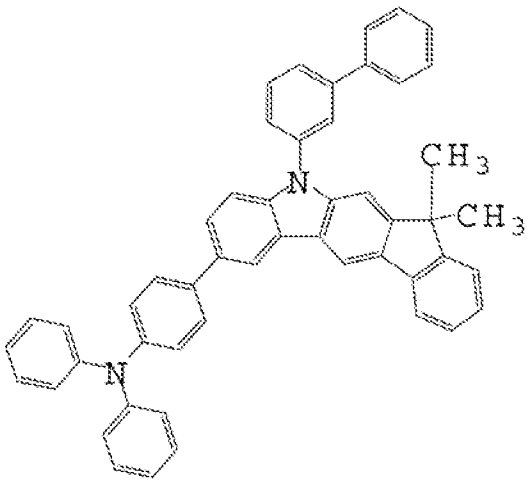
Compound H1-51



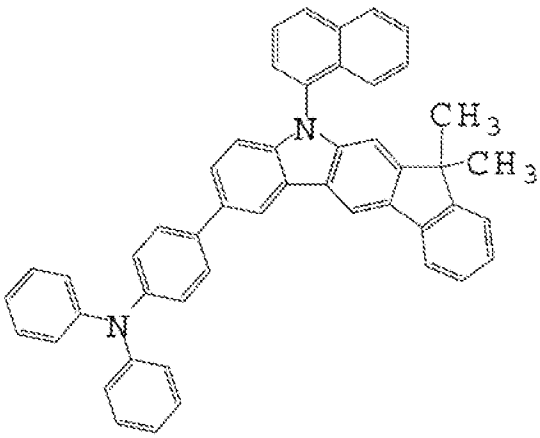
Compound H1-52



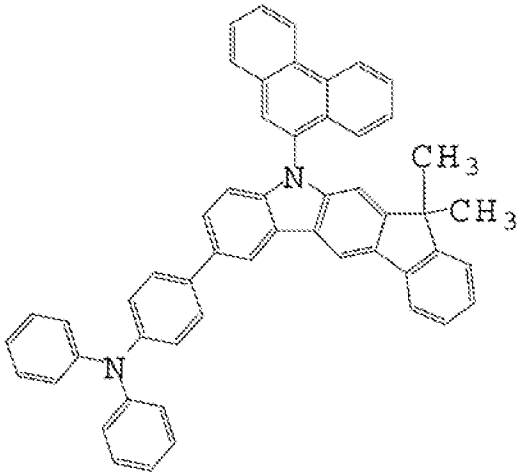
Compound H1-53



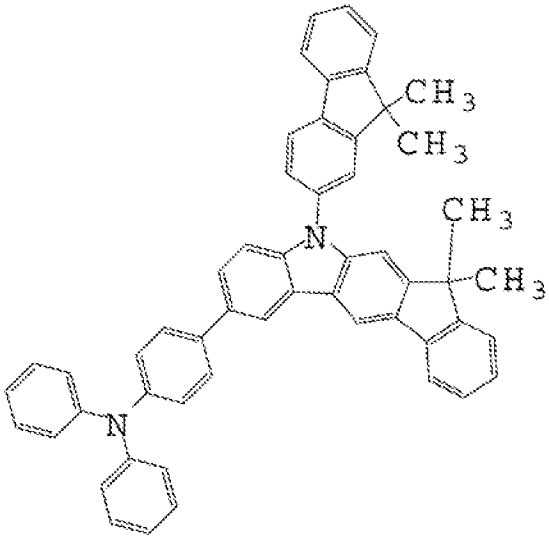
Compound H1-54



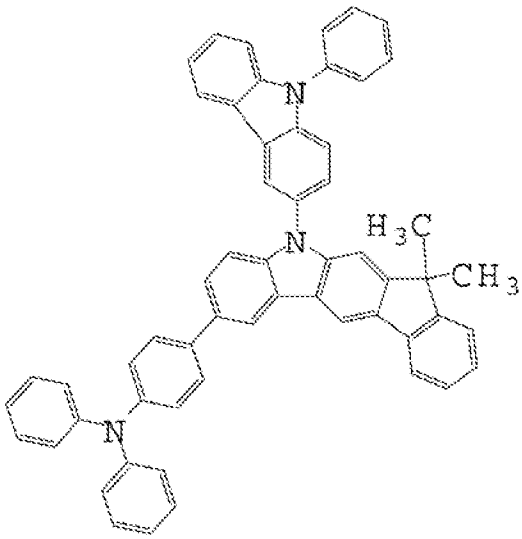
Compound H1-55



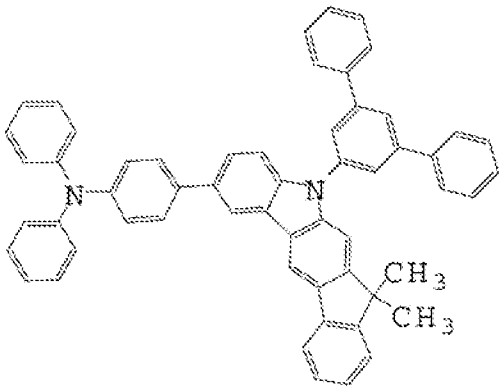
Compound H1-56



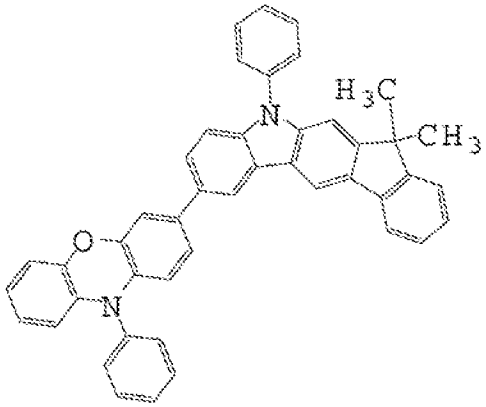
Compound H1-57



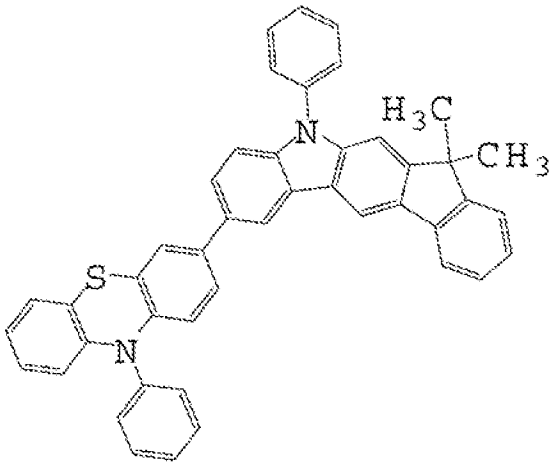
Compound H1-58



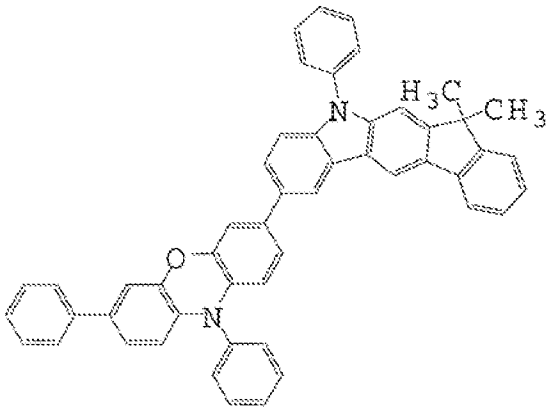
Compound H1-59



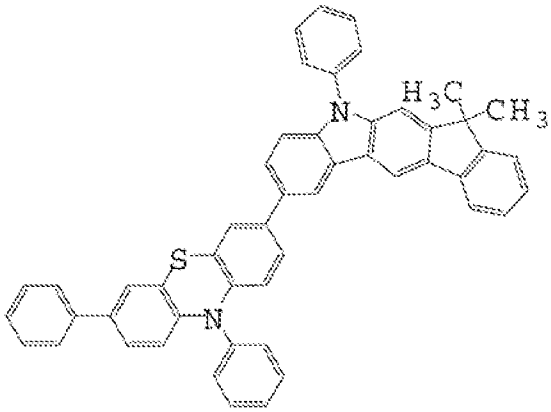
Compound H1-60



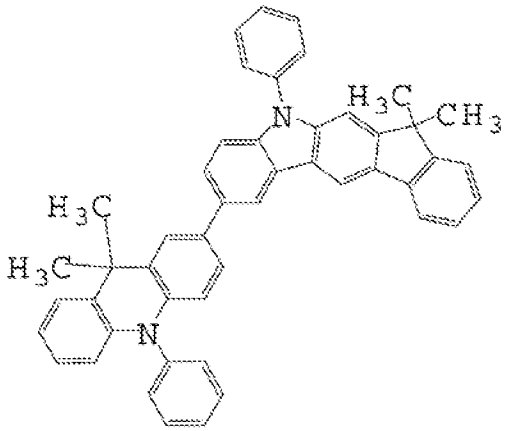
Compound H1-61



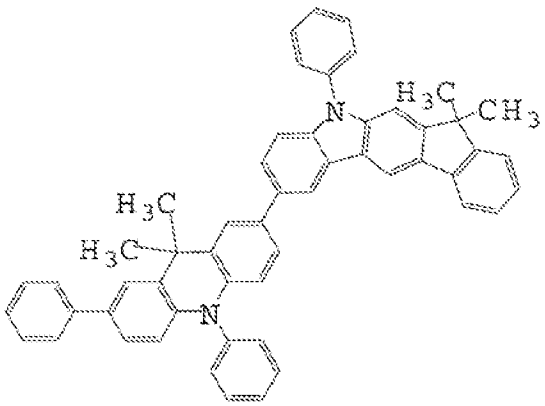
Compound H1-62



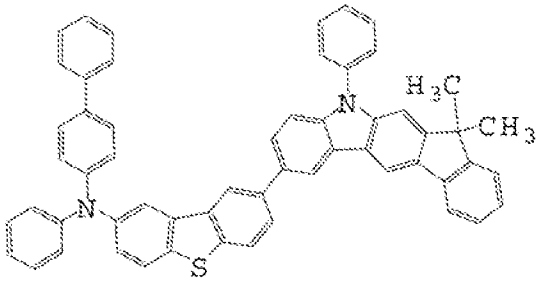
Compound H1-63



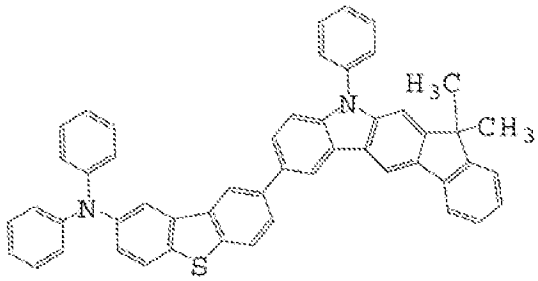
Compound H1-64



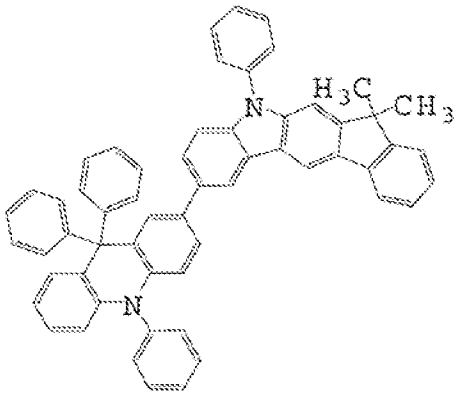
Compound H1-65



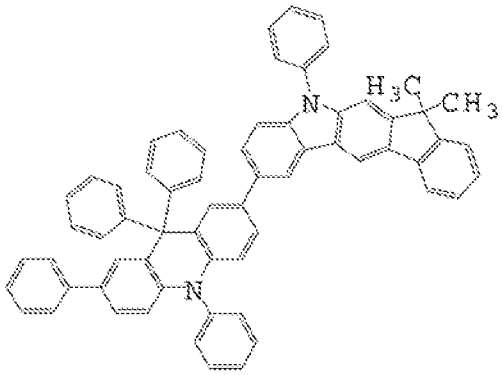
Compound H1-66



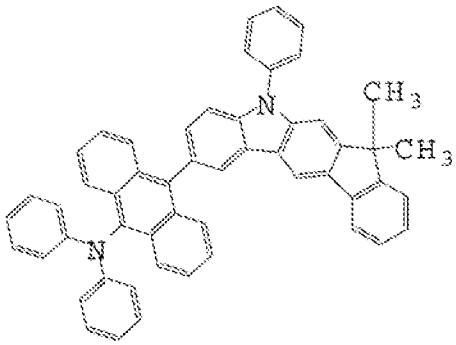
Compound H1-67



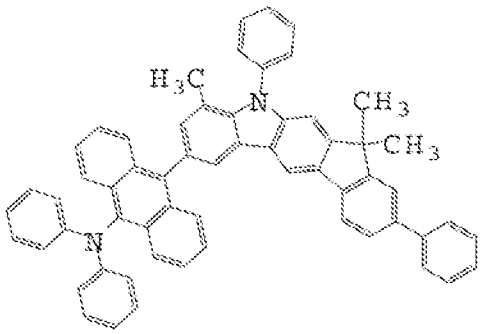
Compound H1-68



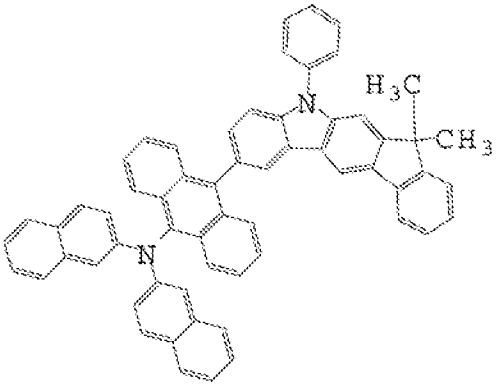
Compound H1-69



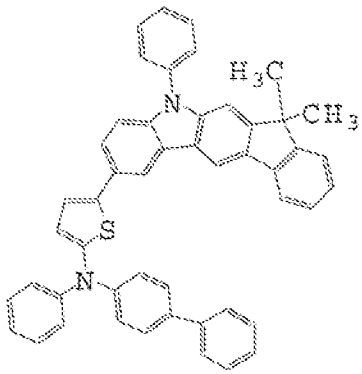
Compound H1-70



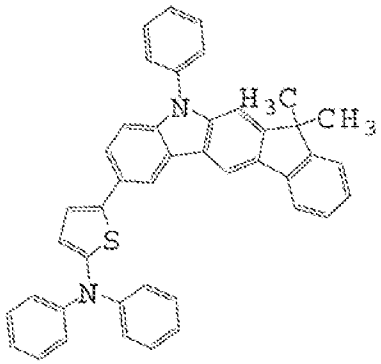
Compound H1-71



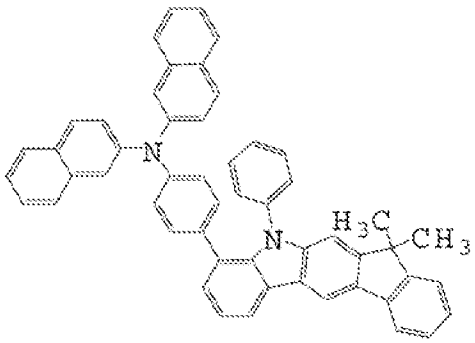
Compound H1-72



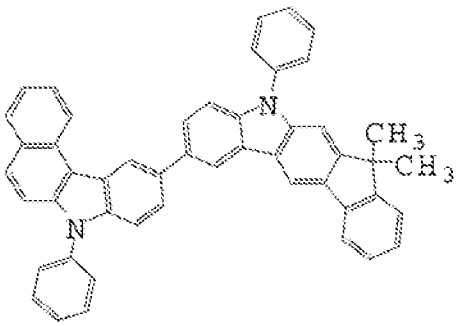
Compound H1-73



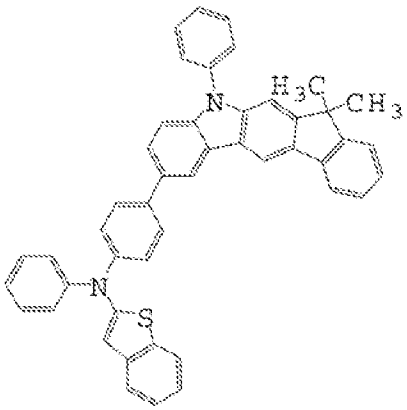
Compound H1-74



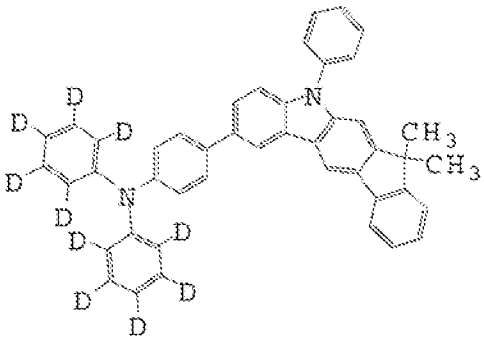
Compound H1-75



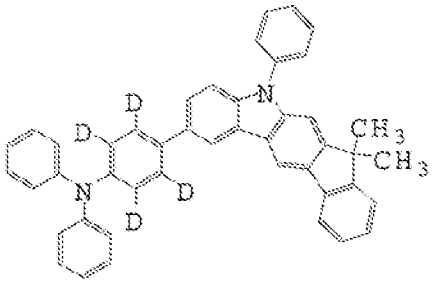
Compound H1-76



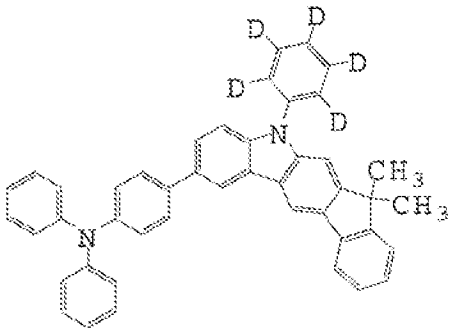
Compound H1-77



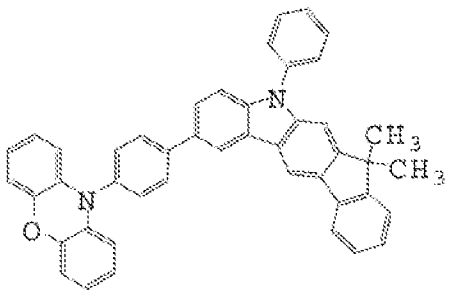
Compound H1-78



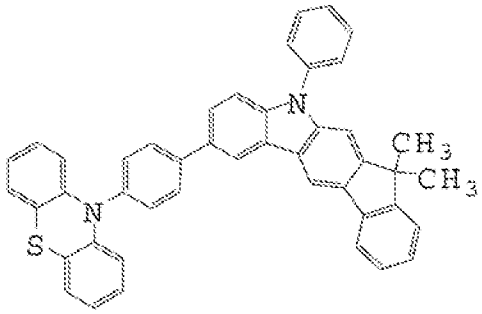
Compound H1-79



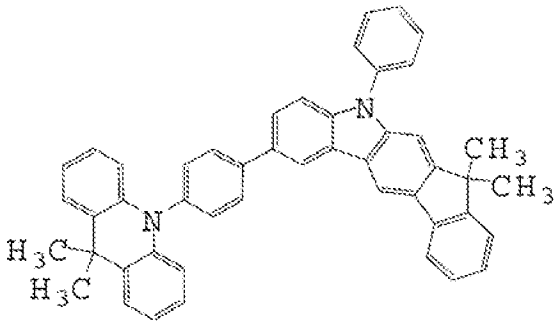
Compound H1-80



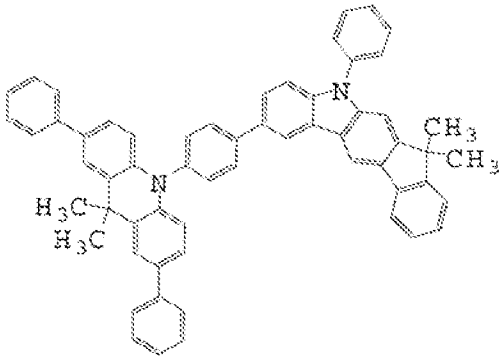
Compound H1-81



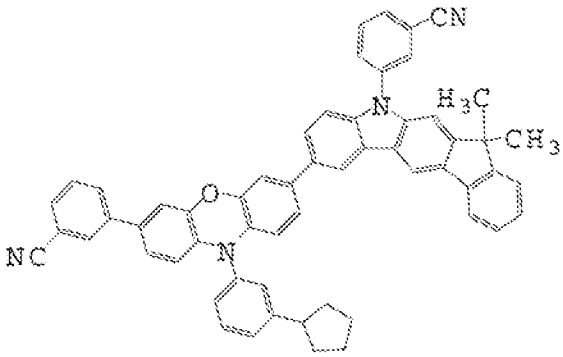
Compound H1-82



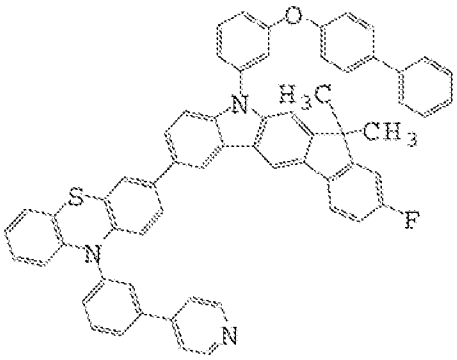
Compound H1-83



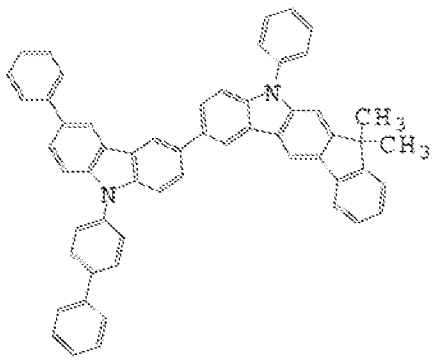
Compound H1-84



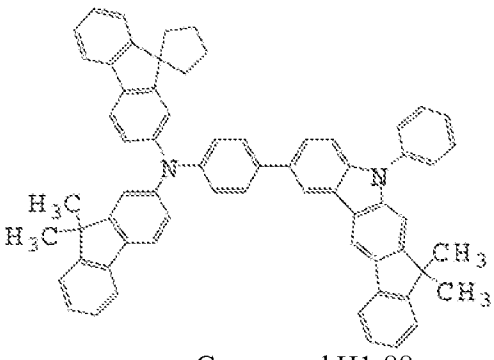
Compound H1-85



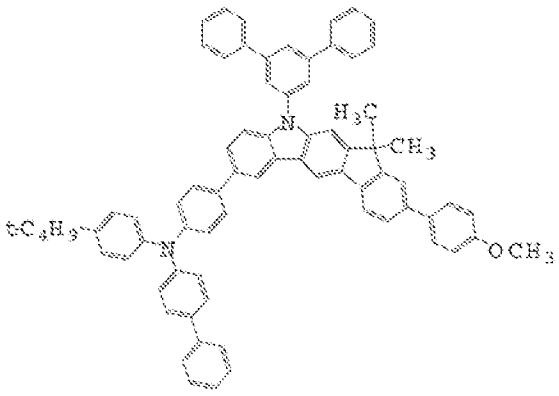
Compound H1-86



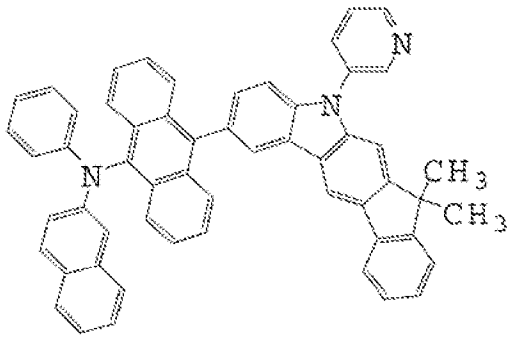
Compound H1-87



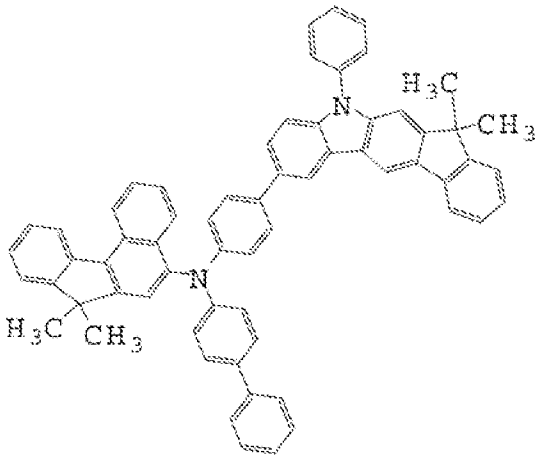
Compound H1-88



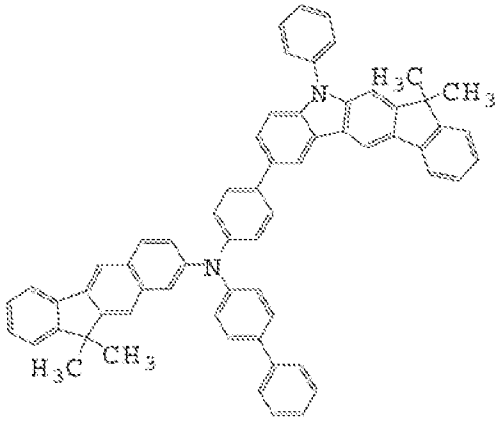
Compound H1-89



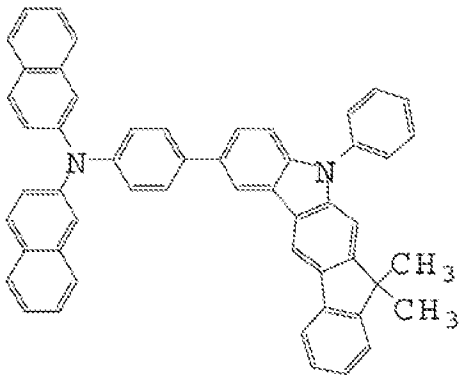
Compound H1-90



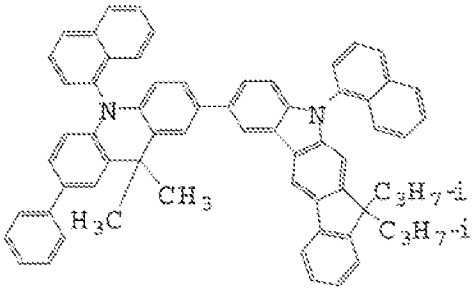
Compound H1-91



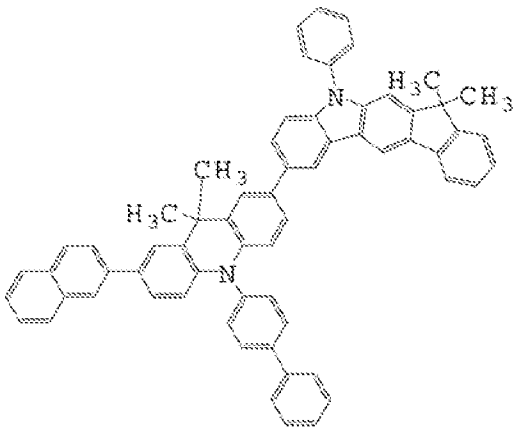
Compound H1-92



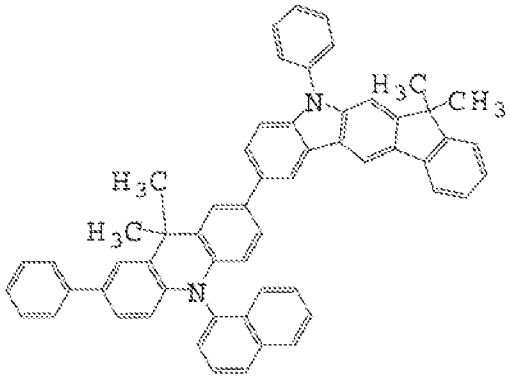
Compound H1-93



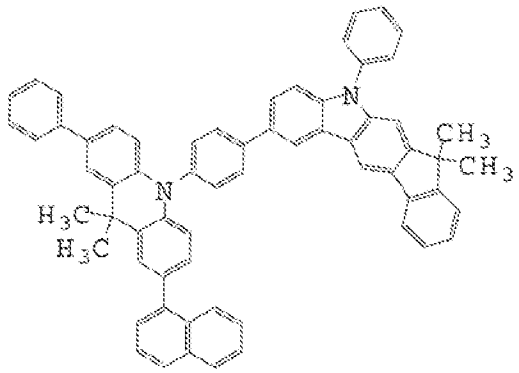
Compound H1-94



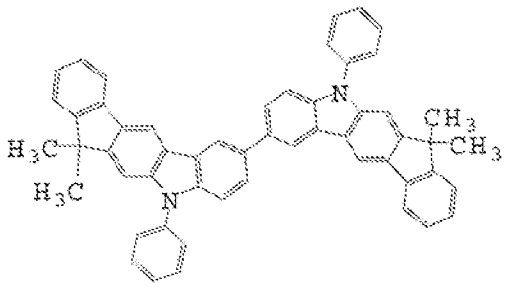
Compound H1-95



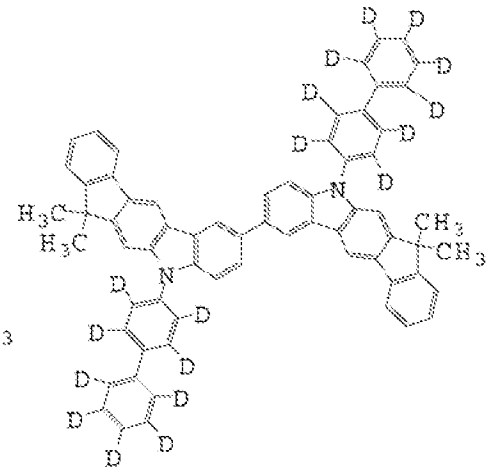
Compound H1-96



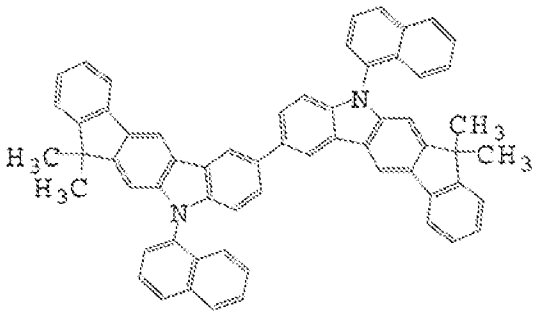
Compound H1-97



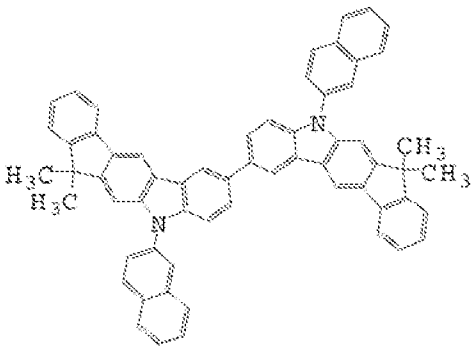
Compound H1-98



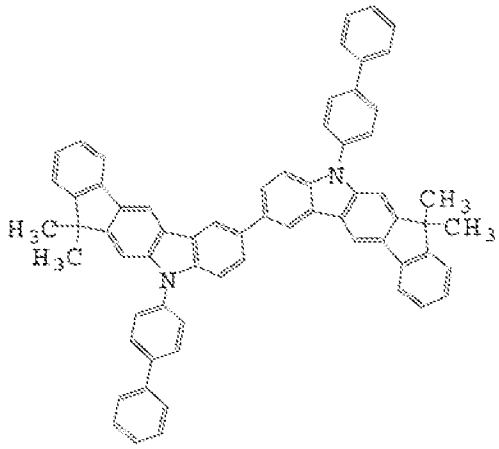
Compound H1-99



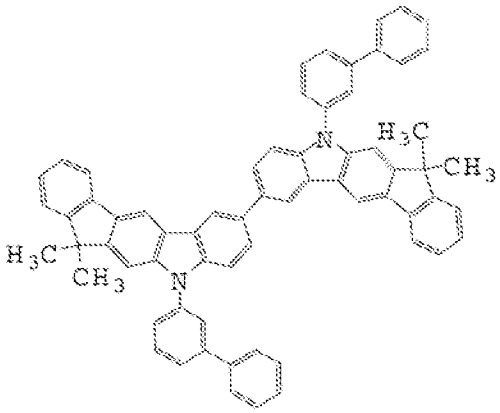
Compound H1-100



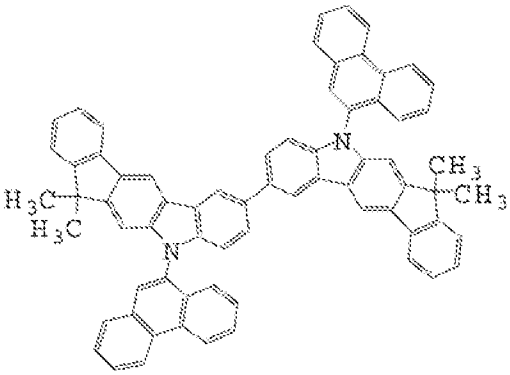
Compound H1-101



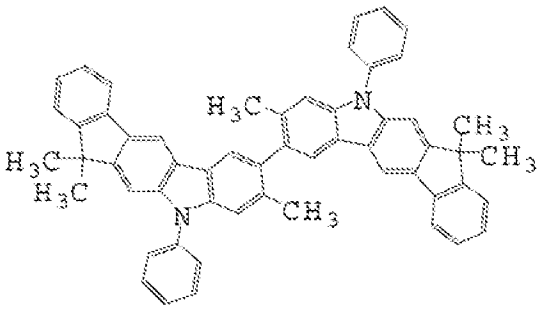
Compound H1-102



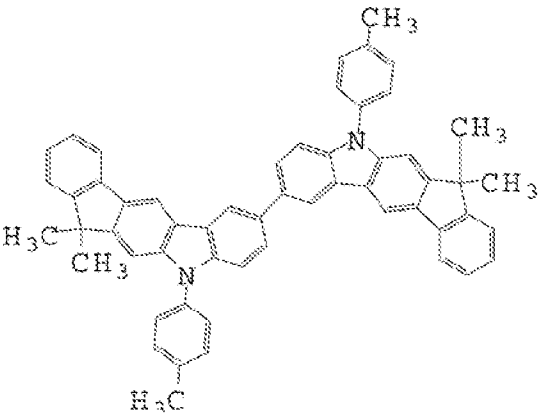
Compound H1-103



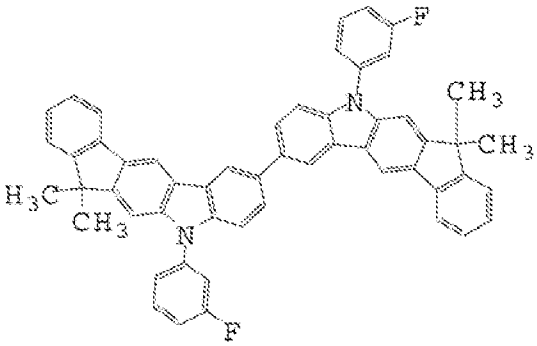
Compound H1-104



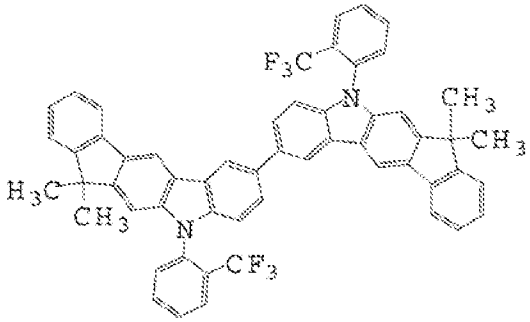
Compound H1-105



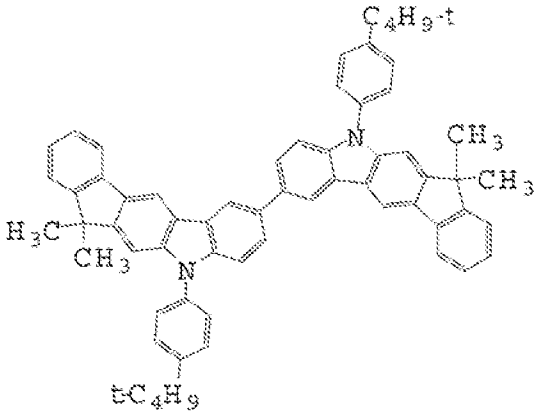
Compound H1-106



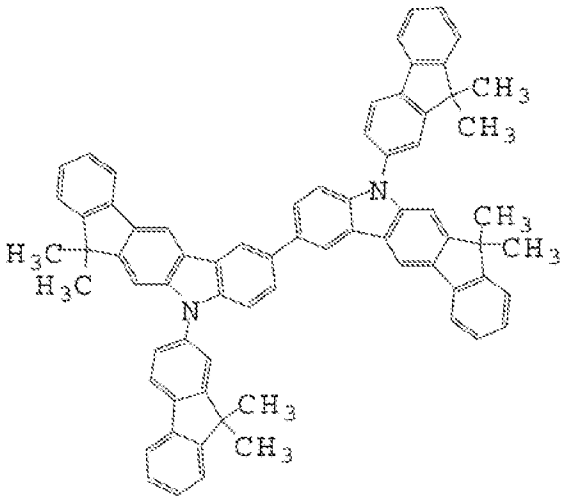
Compound H1-107



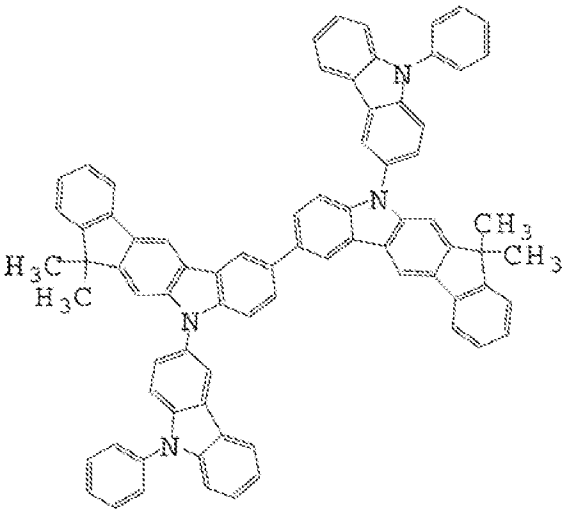
Compound H1-108



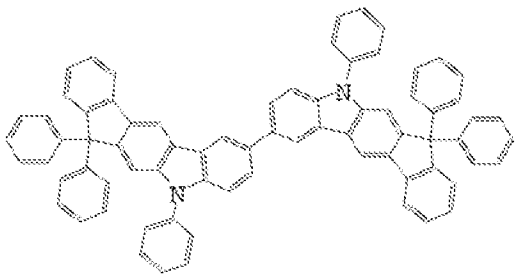
Compound H1-109



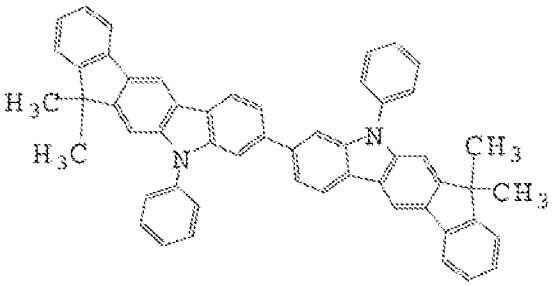
Compound H1-110



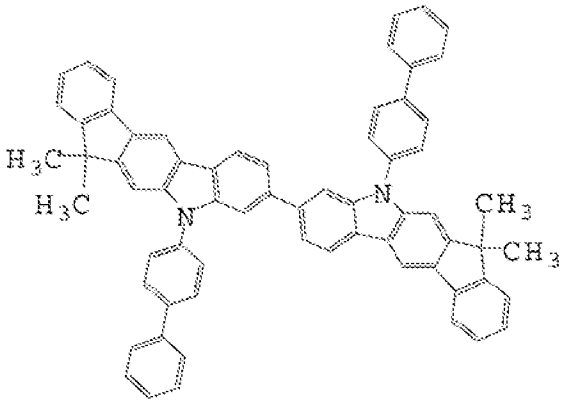
Compound H1-111



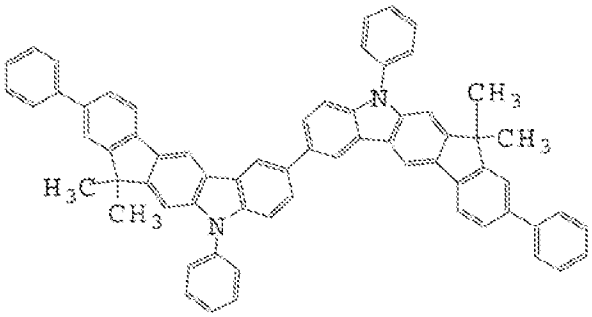
Compound H1-112



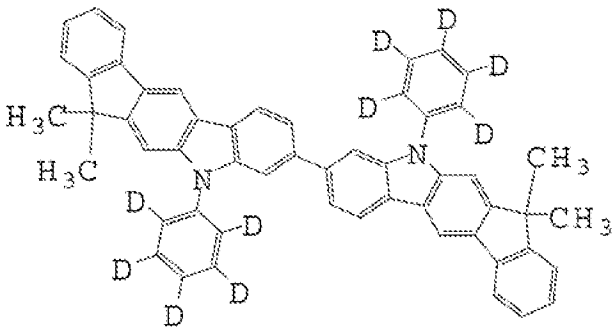
Compound H1-113



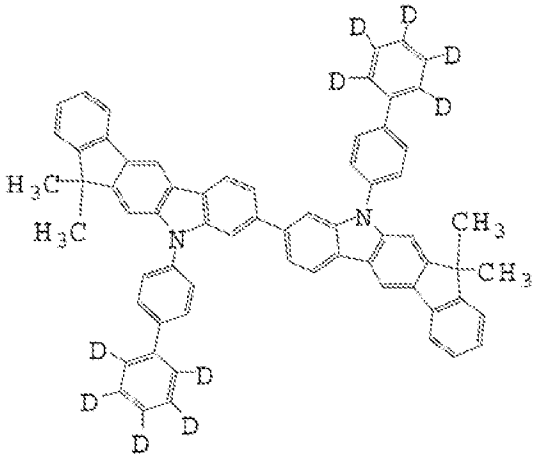
Compound H1-114



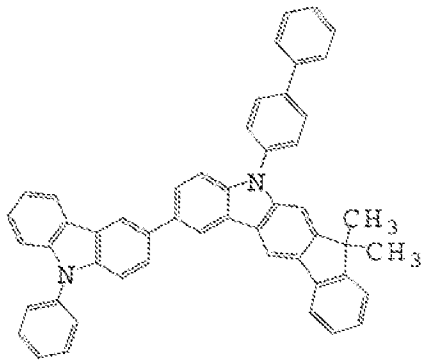
Compound H1-115



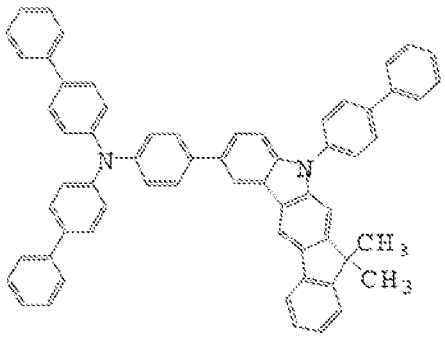
Compound H1-116



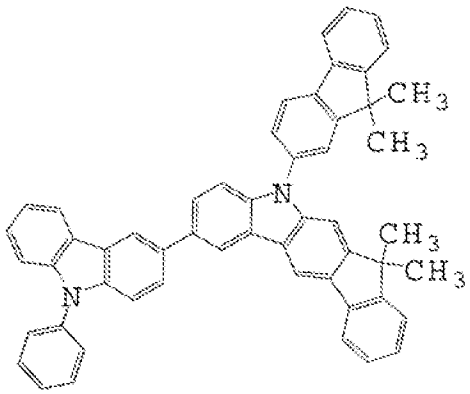
Compound H1-117



Compound H1-118

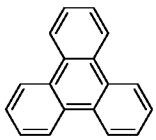


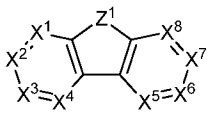
Compound H1-119 , and

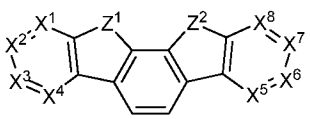


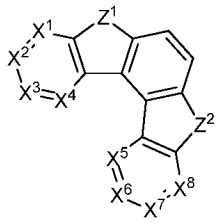
Compound H1-120 .

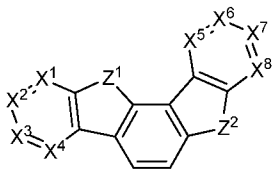
5. The organic light emitting device of claim 1, wherein the second host compound contains at least one of the following groups:

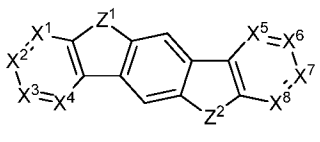


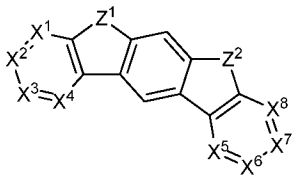










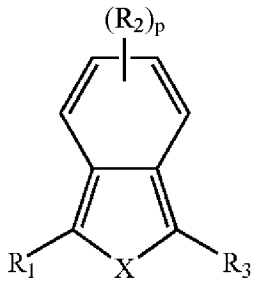


wherein X^1 to X^8 is selected from C or N; and

wherein Z^1 and Z^2 is S or O.

6. The organic light emitting device according to claim 5, wherein any substituent in the second host compound is an unfused substituent independently selected from the group consisting of C_nH_{2n+1}, OC_nH_{2n+I}, OAr_1, $N(C_nH_{2n+1})_2$, $N(Ar_1)(Ar_2)$, $CH=CH-C_nH_{2n+1}$, $C=CHC_nH_{2n+1}$, Ar_1, Ar_1-Ar_2, $C_nH_{2n}-A_{r1}$, or no substitution, wherein n is 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10, and wherein Ar_1 and Ar_2 are independently selected from the group consisting of benzene, biphenyl, naphthalene, triphenylene, carbazole, and heteroaromatic analogs thereof.

7. The organic light emitting device according to claim 1, wherein the second host compound is represented by the structure of formula (H-IV):



(H-IV)

wherein X is S or O;

wherein R_1, R_2, and R_3 are unfused substituents independently selected from the group consisting C_nH_{2n+1}, OC_nH_{2n+1}, OAr_1, $N(C_nH_{2n+1})_2$, $N(Ar_1)(Ar_2)$, $CH=CH-C_nH_{2n+1}$, $C=CHC_nH_{2n+1}$, Ar_1, Ar_1-Ar_2, $C_nH_{2n}-A_{r1}$, and hydrogen;

wherein n is 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10;

wherein Ar_1 and Ar_2 are independently selected from the group consisting of benzene, biphenyl, naphthalene, triphenylene, carbazole, and heteroaromatic analogs thereof;

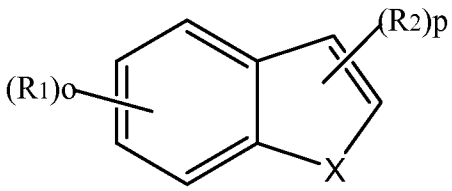
wherein p is 1, 2, 3, or 4; and

wherein at least one of R_1, R_2 and R_3 includes a triphenylene group.

8. The organic light emitting device according to claim 7, wherein X is S.

9. The organic light emitting device according to claim 7, wherein X is O.

10. The organic light emitting device according to claim 1, wherein the second host compound is represented by the structure of formula (H-V):



(H-V)

wherein X is S or O;

wherein R_1 and R_2 are unfused substituents independently selected from the group consisting C_nH_{2n+1}, OC_nH_{2n+1}, OAr_1, $N(C_nH_{2n+1})_2$, $N(Ar_1)(Ar_2)$, $CH=CH-C_nH_{2n+1}$, $C=CHC_nH_{2n+1}$, Ar_1, Ar_1-Ar_2, $C_nH_{2n}-A_{r1}$, and hydrogen, and

wherein n is 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10;

wherein Ar_1 and Ar_2 are independently selected from the group consisting of benzene, biphenyl, naphthalene, triphenylene, carbazole, and heteroaromatic analogs thereof;

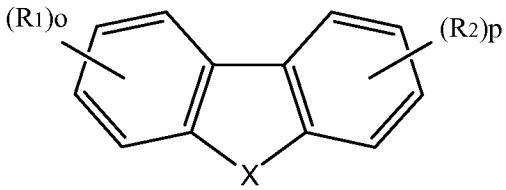
wherein o is 1, 2, 3 or 4, and p is 1 or 2; and

wherein at least one of R_1 and R_2 includes a triphenylene group.

11. The organic light emitting device according to claim 10, wherein X is S.

12. The organic light emitting device according to claim 10, wherein X is O.

13. The organic light emitting device according to claim 6, wherein the second host compound is represented by the structure of formula (H-VI):



(H-VI)

wherein X is S or O; and

wherein R_1 and R_2 are independently selected from the group consisting C_nH_{2n+1}, OC_nH_{2n+1}, OAr_1, $N(C_nH_{2n+1})_2$, $N(Ar_1)(Ar_2)$, $CH=CH-C_nH_{2n+1}$, $C=CHC_nH_{2n+1}$, Ar_1, Ar_1-Ar_2, $C_nH_{2n}-A_{r1}$, and hydrogen; and

wherein n is 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10;

wherein Ar_1 and Ar_2 are independently selected from the group consisting of benzene, biphenyl, naphthalene, triphenylene, carbazole, and heteroaromatic analogs thereof;

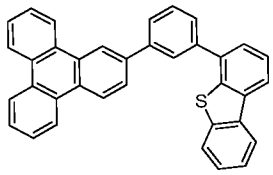
wherein o and p is 1, 2, 3, or 4; and

wherein at least one of R_1 and R_2 includes a triphenylene group.

14. The organic light emitting device according to claim 13, wherein X is S.

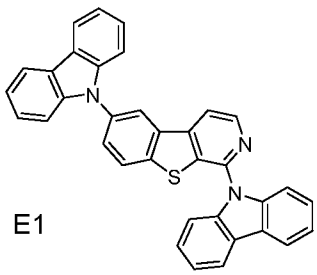
15. The organic light emitting device according to claim 13, wherein X is O.

16. The organic light emitting device according to claim 13, wherein the second host compound has the formula H:



(H) .

17. The organic light emitting device according to claim 1, further comprising a third host compound in the emissive layer, wherein the third host compound is



E1

18. The organic light emitting device according to claim 1, wherein the phosphorescent emitter material is an organometallic compound selected from the group consisting of phosphorescent organometallic platinum compounds, organometallic iridium compounds and organometallic osmium compounds.

19. The organic light emitting device according to claim 18, wherein the phosphorescent organometallic platinum compound has an aromatic ligand.

20. The organic light emitting device according to claim 18, wherein the phosphorescent organometallic iridium compound has an aromatic ligand.

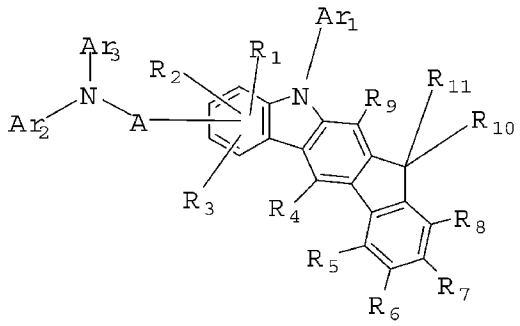
21. The organic light emitting device according to claim 18, wherein the phosphorescent organometallic osmium compound has an aromatic ligand.

22. An organic light emitting device comprising an anode, a cathode and a plurality of organic layers provided between them, the plurality of organic layers comprising:

an emissive layer comprising a host material and a phosphorescent emitter material, wherein the host material comprising:

a first host compound; and

a second host compound, wherein the first host compound has an indeno-carbazole ring structure represented by the following general formula H1,



(H1);

wherein A represents a divalent group of a substituted or unsubstituted aromatic hydrocarbon, a divalent group of a substituted or unsubstituted aromatic heterocyclic ring, or a divalent group of substituted or unsubstituted fused polycyclic aromatics;

Ar_1, Ar_2, and Ar_3 may be the same or different, and represent a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted aromatic heterocyclic group, or a substituted or unsubstituted fused polycyclic aromatic group, where A and Ar_2, or Ar_2 and Ar_3 may bind to each other via a single bond or via substituted or unsubstituted methylene, an oxygen atom, or a sulfur atom to form a ring;

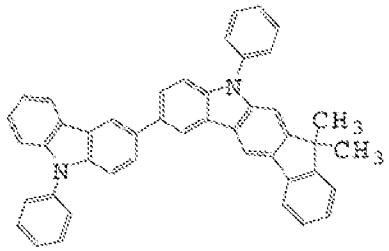
R_1 to R_9 may be the same or different, and represent a hydrogen atom, a deuterium atom, a fluorine atom, a chlorine atom, cyano, nitro, linear or branched alkyl of 1 to 6 carbon atoms that may have a substituent, cycloalkyl of 5 to 10 carbon atoms that may have a substituent, linear or branched alkenyl of 2 to 6 carbon atoms that may have a substituent, linear or branched alkyloxy of 1 to 6 carbon atoms that may have a substituent, cycloalkyloxy of 5 to 10 carbon atoms that may have a substituent, a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted aromatic heterocyclic group, a substituted or unsubstituted fused polycyclic aromatic group, or substituted or unsubstituted aryloxy, which may bind to each other via a single bond, substituted or unsubstituted methylene, an oxygen atom, or a sulfur atom to form a ring; and

R_{10} and R_{11} may be the same or different, and represent linear or branched alkyl of 1 to 6 carbon atoms that may have a substituent, cycloalkyl of 5 to 10 carbon atoms that may have a substituent, linear or branched alkenyl of 2 to 6 carbon atoms that may have

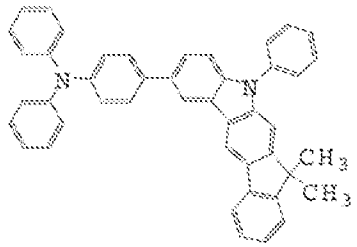
a substituent, linear or branched alkyloxy of 1 to 6 carbon atoms that may have a substituent, cycloalkyloxy of 5 to 10 carbon atoms that may have a substituent, a substituted or unsubstituted aromatic hydrocarbon group, a substituted or unsubstituted aromatic heterocyclic group, a substituted or unsubstituted fused polycyclic aromatic group, or substituted or unsubstituted aryloxy, which may bind to each other via a single bond, substituted or unsubstituted methylene, an oxygen atom, or a sulfur atom to form a ring ; and

an exciton/electron blocking layer disposed between the emissive layer and the anode, wherein the exciton/electron blocking layer comprises a blocking compound having the indeno-carbazole ring structure represented by the general formula H1, the exciton/electron blocking layer blocks at least one of excitons or electrons, and wherein the first host compound and the blocking compound can be the same or different.

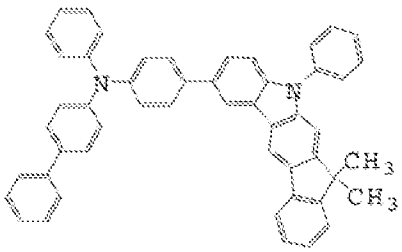
23. The organic light emitting device according to claim 22, wherein the first host compound and the blocking compound are independently selected from the group consisting of:



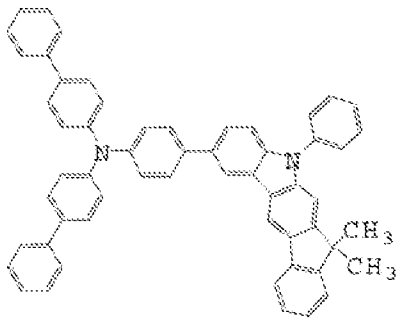
Compound H1-1



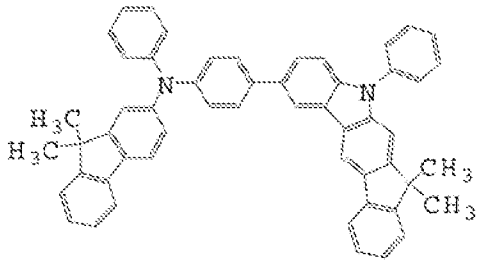
Compound H1-2



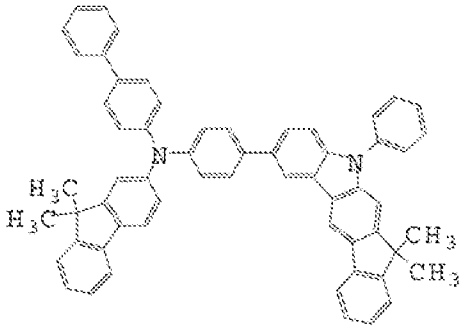
Compound H1-3



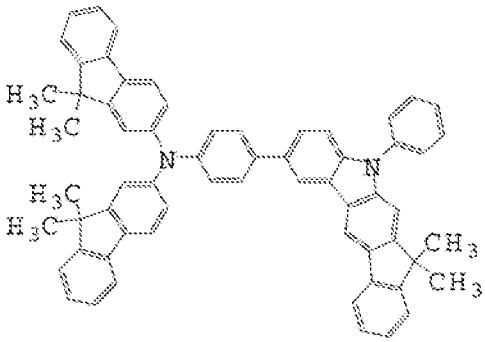
Compound H1-4



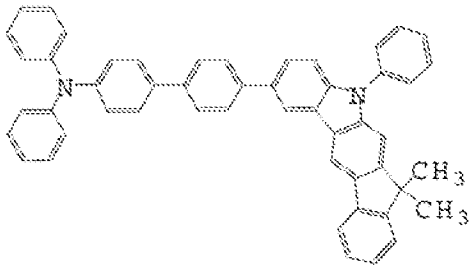
Compound H1-5



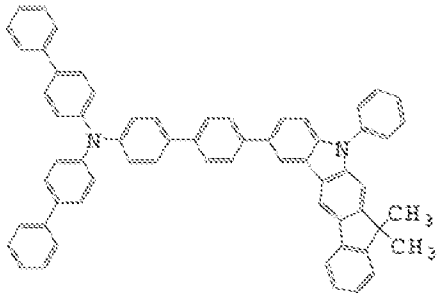
Compound H1-6



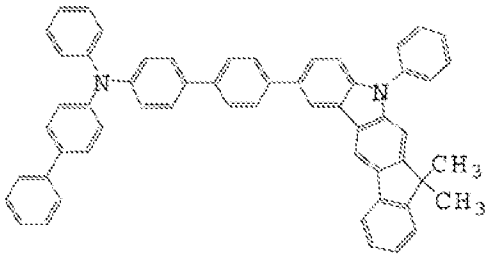
Compound H1-7



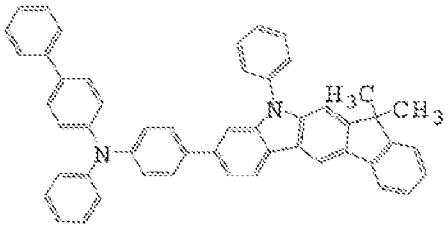
Compound H1-8



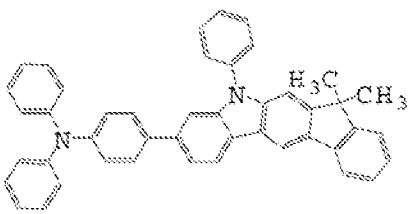
Compound H1-9



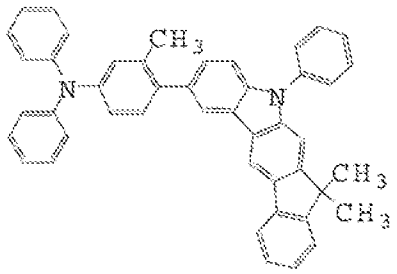
Compound H1-10



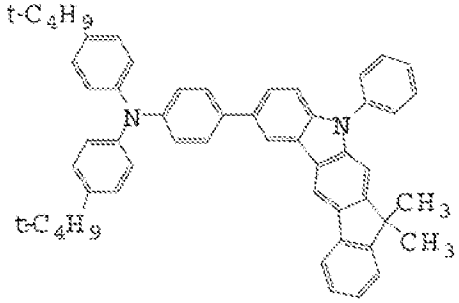
Compound H1-11



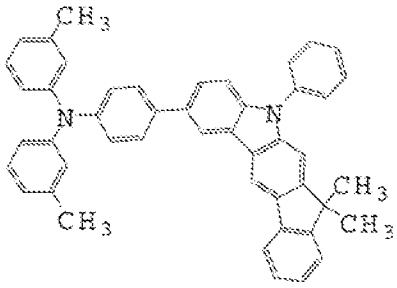
Compound H1-12



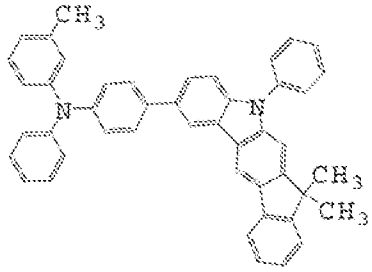
Compound H1-13



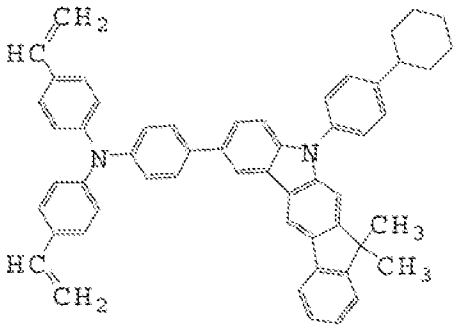
Compound H1-14



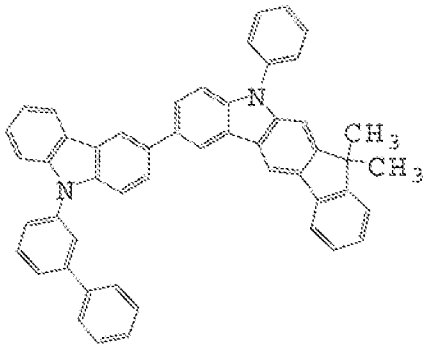
Compound H1-15



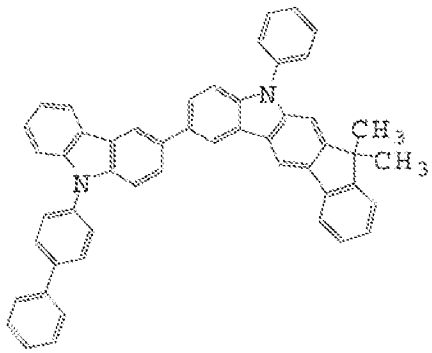
Compound H1-16



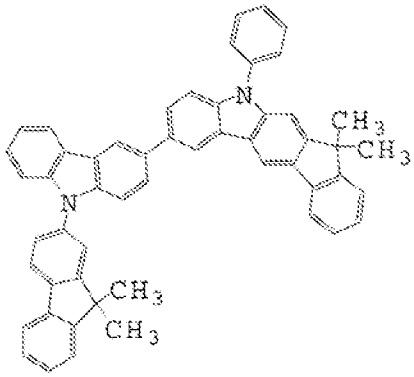
Compound H1-17



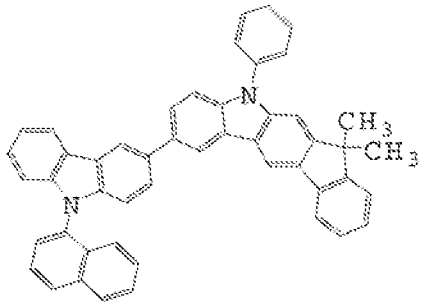
Compound H1-18



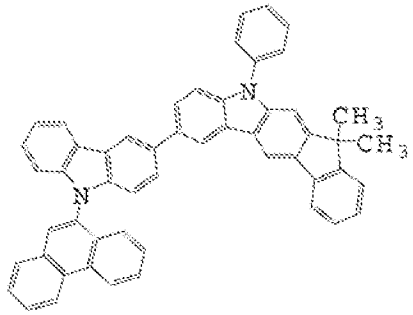
Compound H1-19



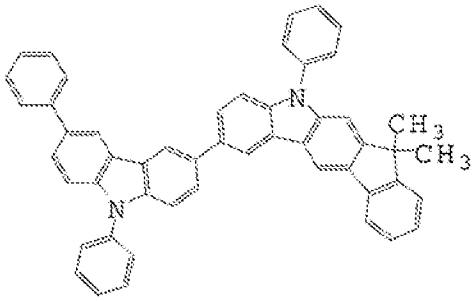
Compound H1-20



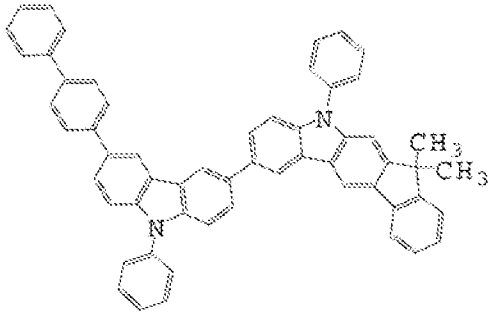
Compound H1-21



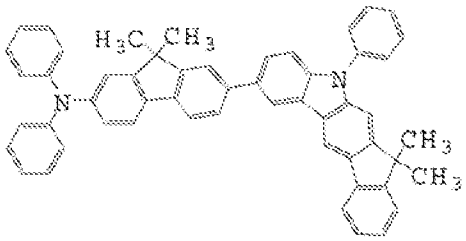
Compound H1-22



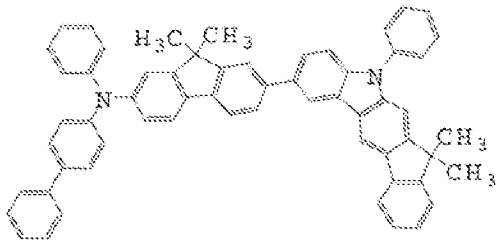
Compound H1-23



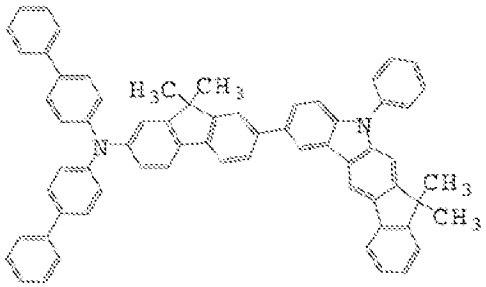
Compound H1-24



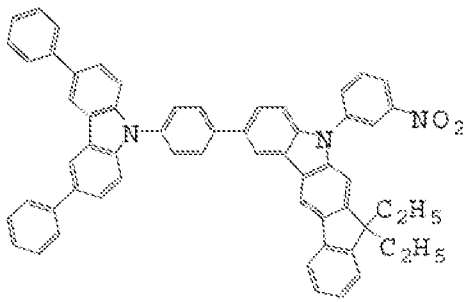
Compound H1-25



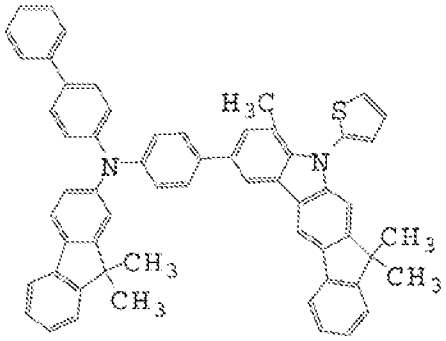
Compound H1-26



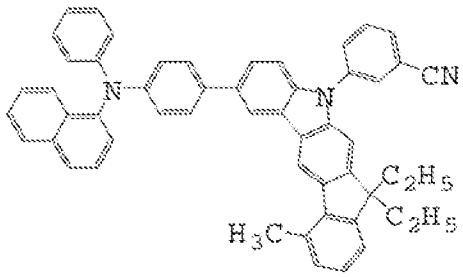
Compound H1-27



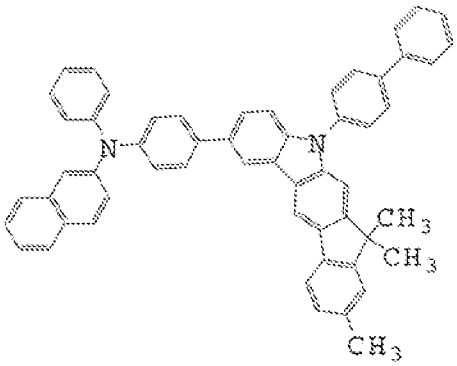
Compound H1-28



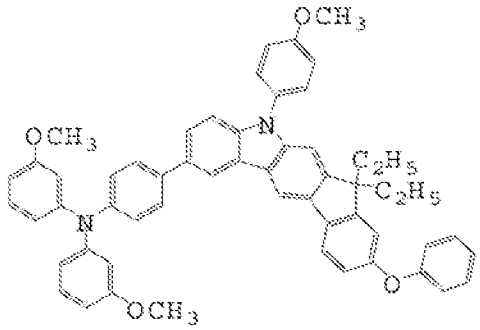
Compound H1-29



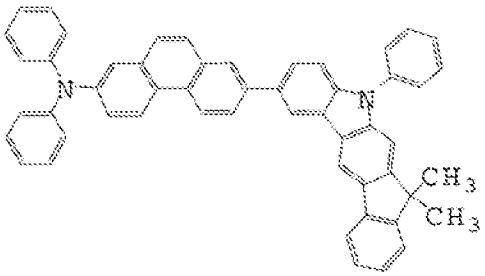
Compound H1-30



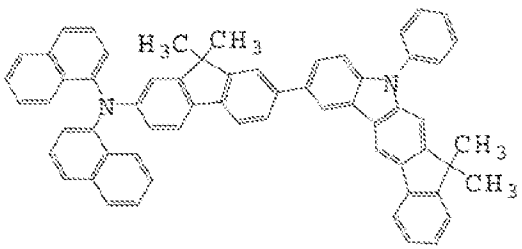
Compound H1-31



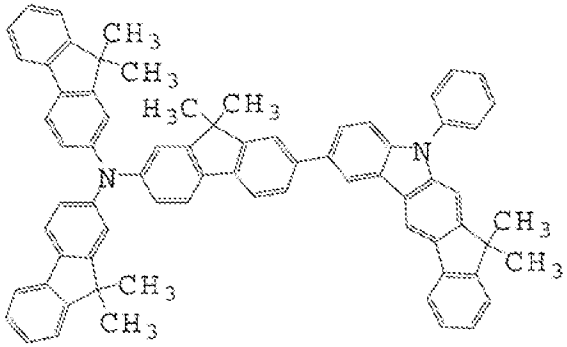
Compound H1-32



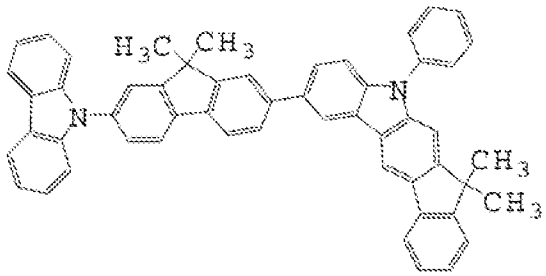
Compound H1-33



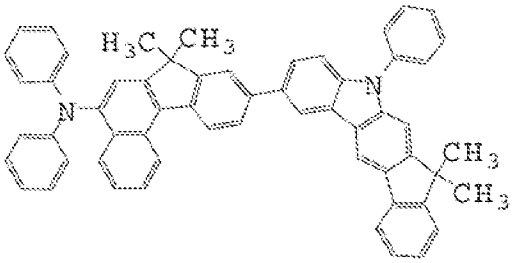
Compound H1-34



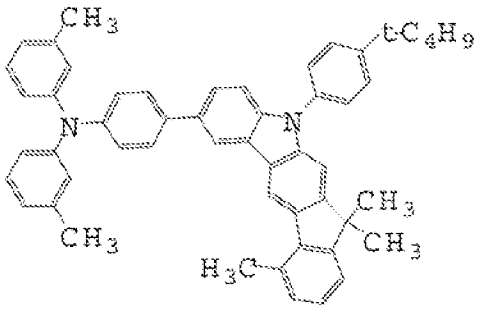
Compound H1-35



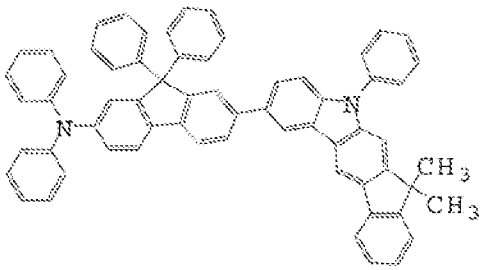
Compound H1-36



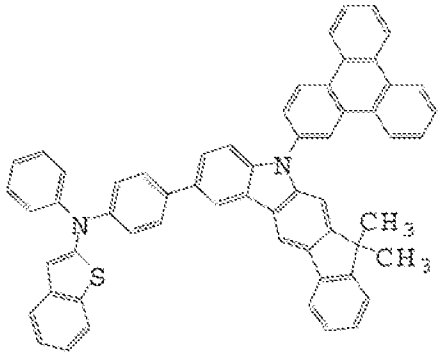
Compound H1-37



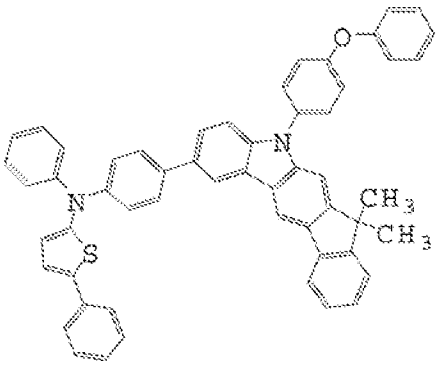
Compound H1-38



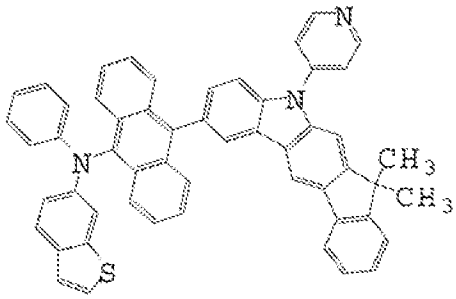
Compound H1-39



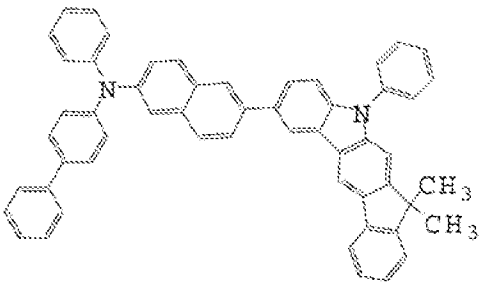
Compound H1-40



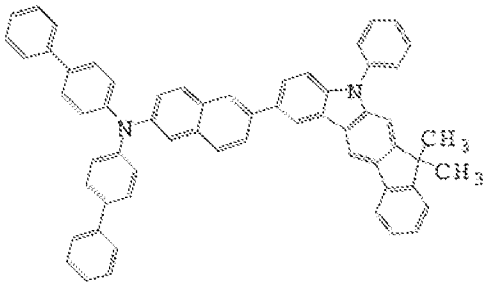
Compound H1-41



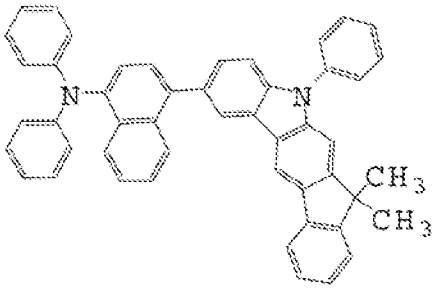
Compound H1-42



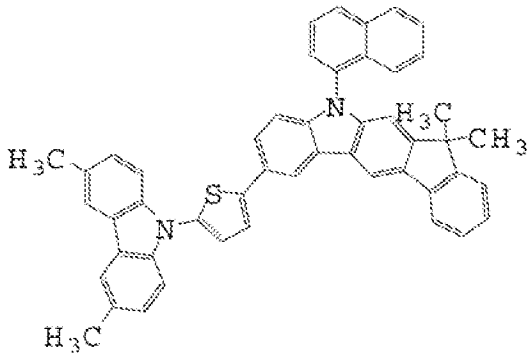
Compound H1-43



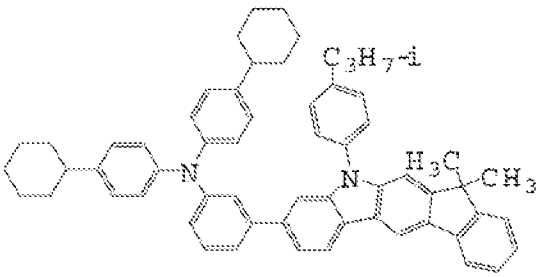
Compound H1-44



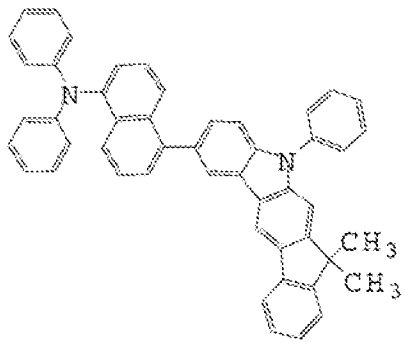
Compound H1-45



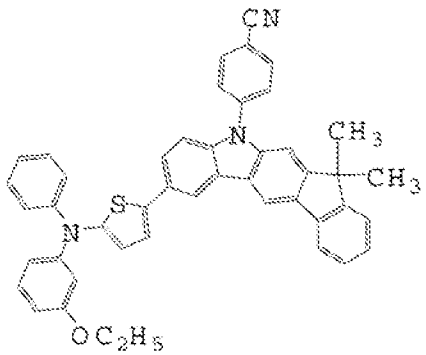
Compound H1-46



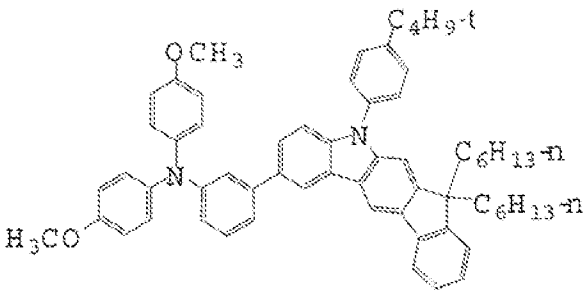
Compound H1-47



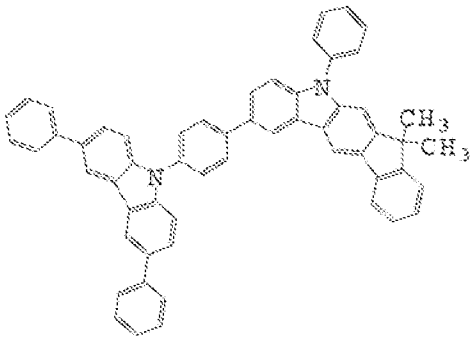
Compound H1-48



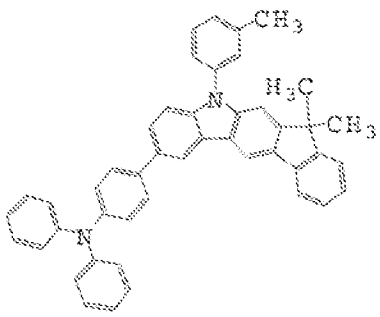
Compound H1-49



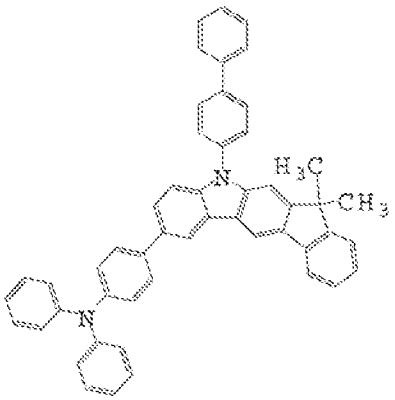
Compound H1-50



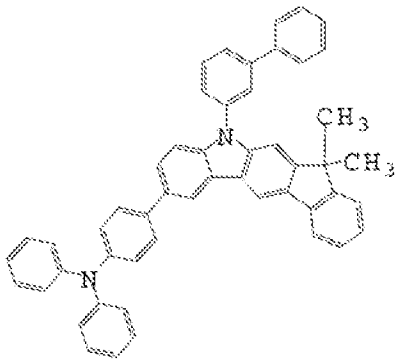
Compound H1-51



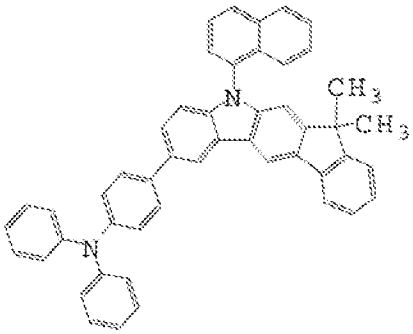
Compound H1-52



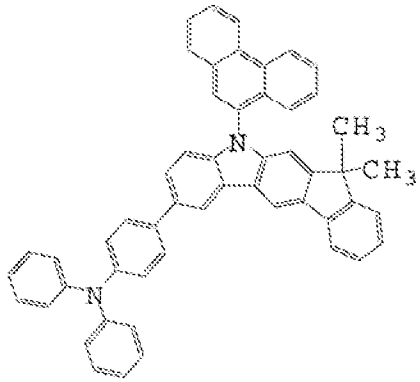
Compound H1-53



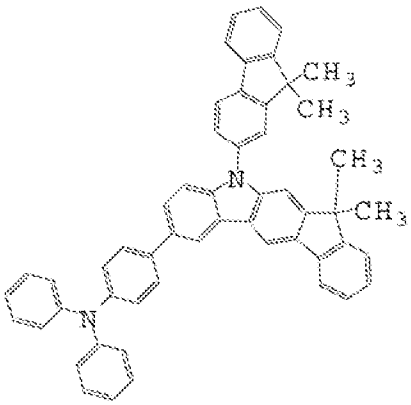
Compound H1-54



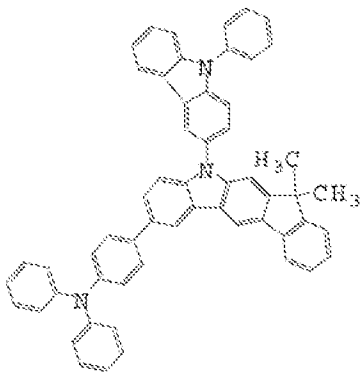
Compound H1-55



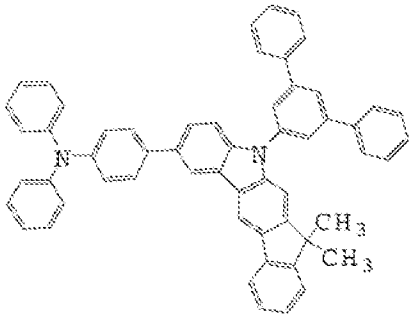
Compound H1-56



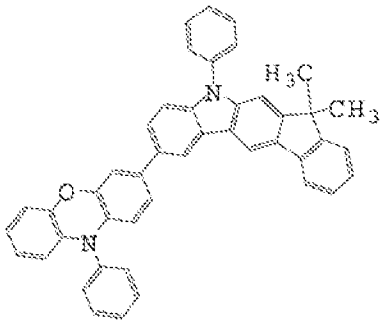
Compound H1-57



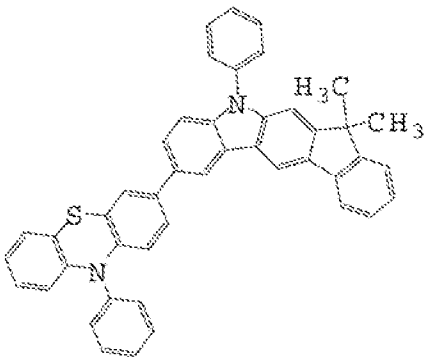
Compound H1-58



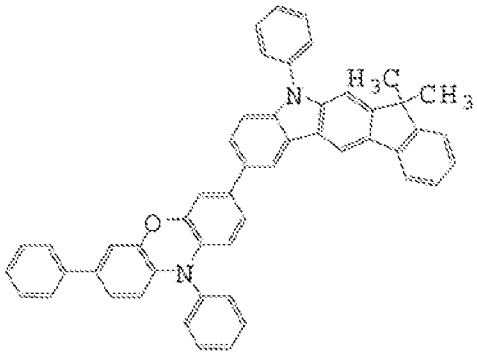
Compound H1-59



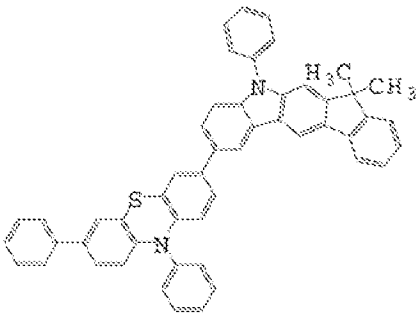
Compound H1-60



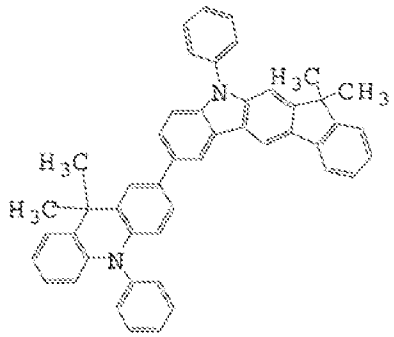
Compound H1-61



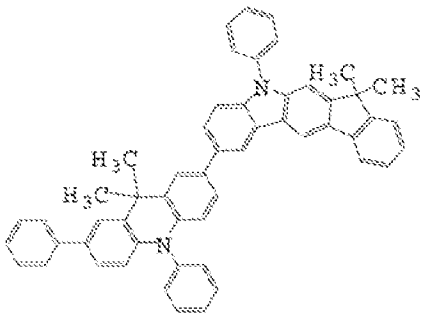
Compound H1-62



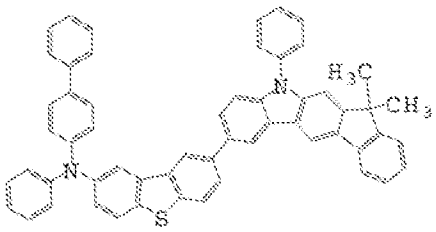
Compound H1-63



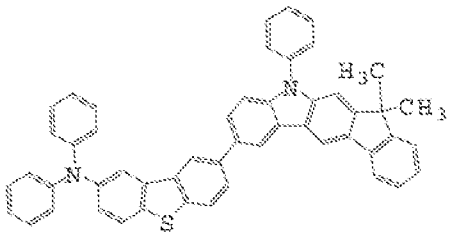
Compound H1-64



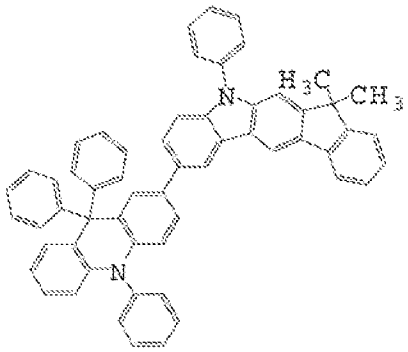
Compound H1-65



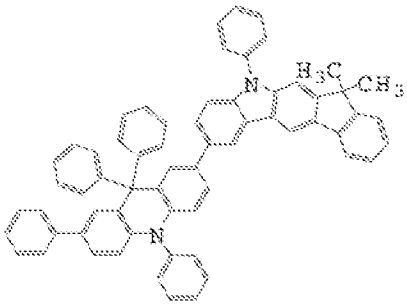
Compound H1-66



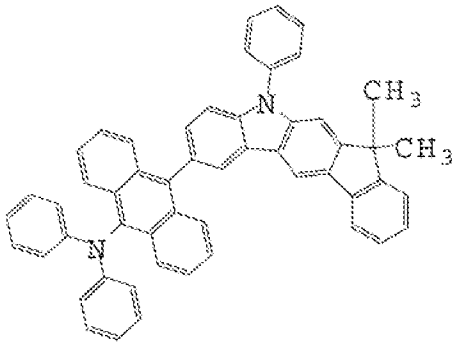
Compound H1-67



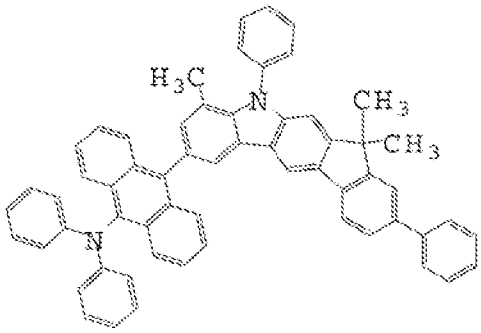
Compound H1-68



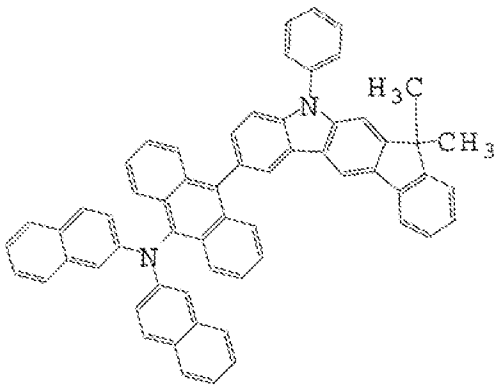
Compound H1-69



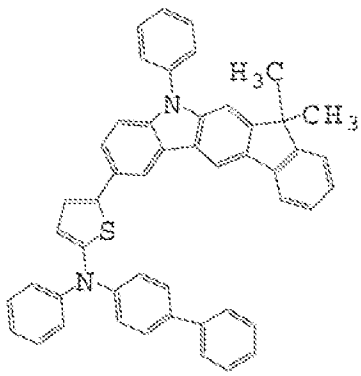
Compound H1-70



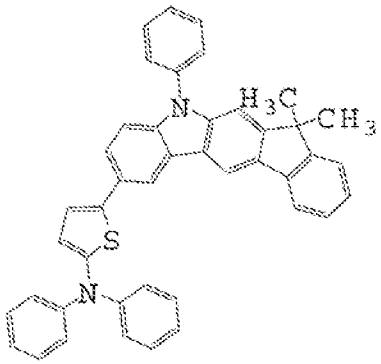
Compound H1-71



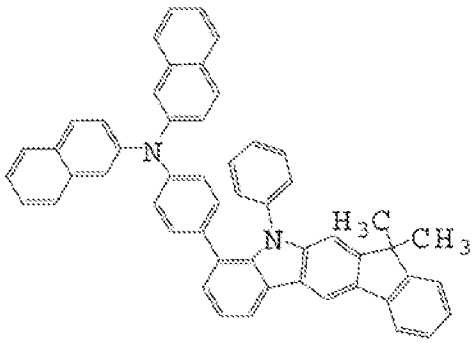
Compound H1-72



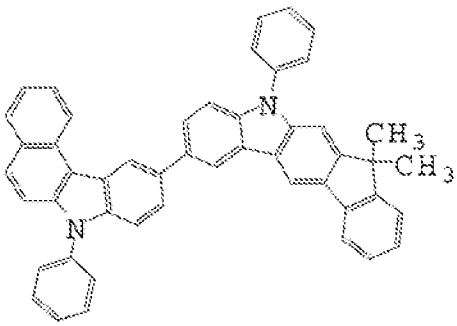
Compound H1-73



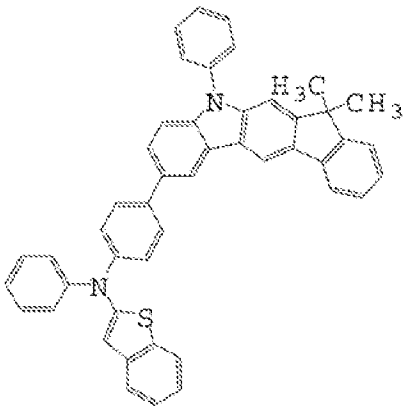
Compound H1-74



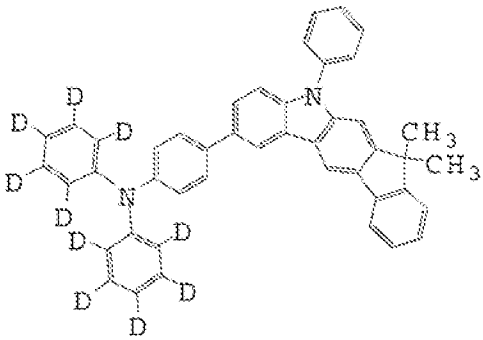
Compound H1-75



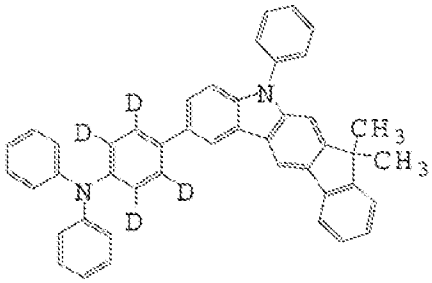
Compound H1-76



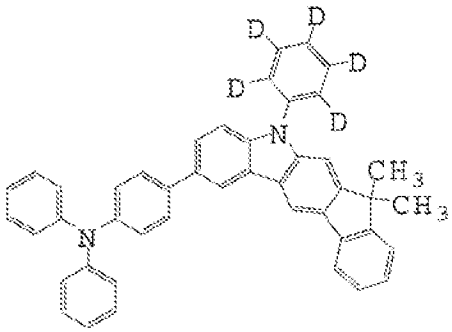
Compound H1-77



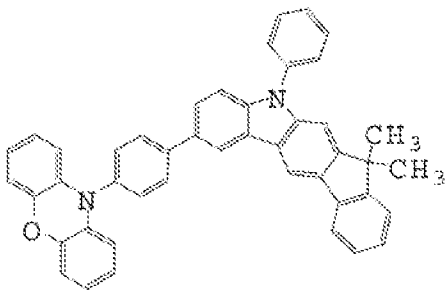
Compound H1-78



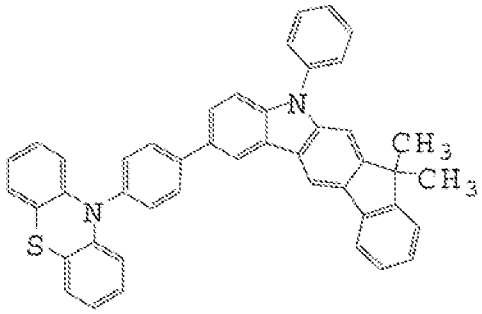
Compound H1-79



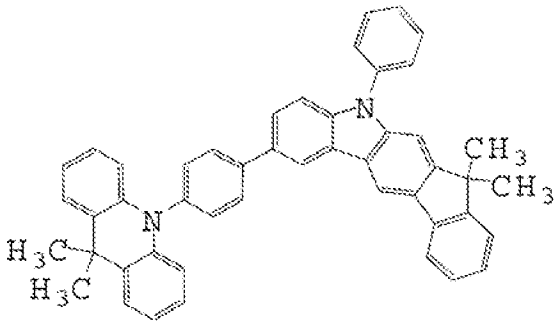
Compound H1-80



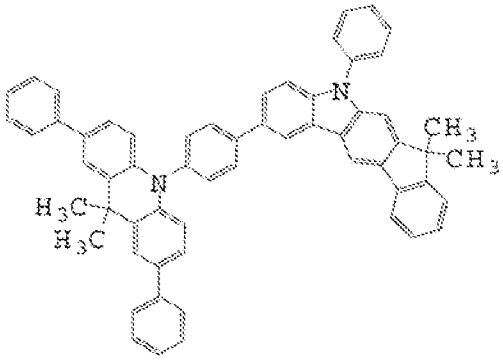
Compound H1-81



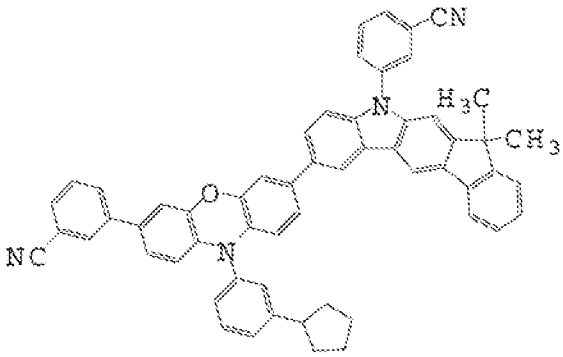
Compound H1-82



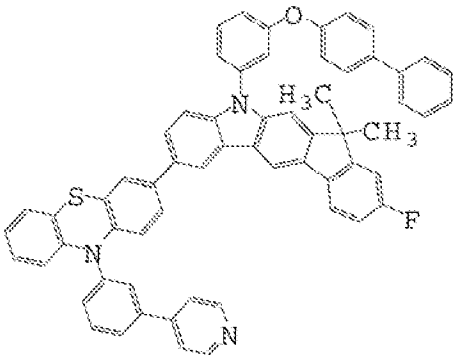
Compound H1-83



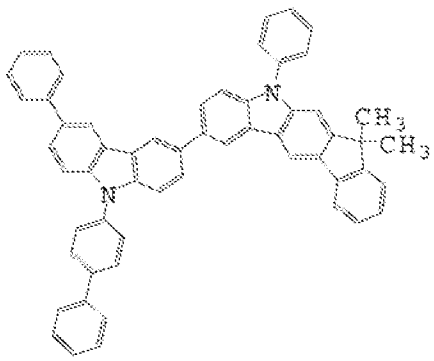
Compound H1-84



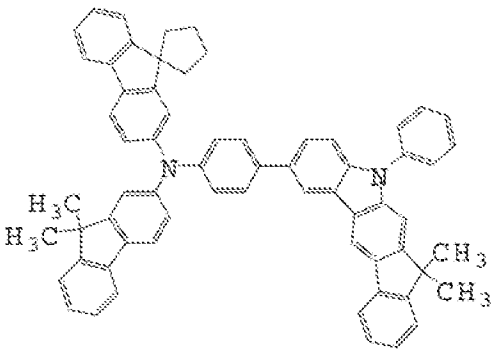
Compound H1-85



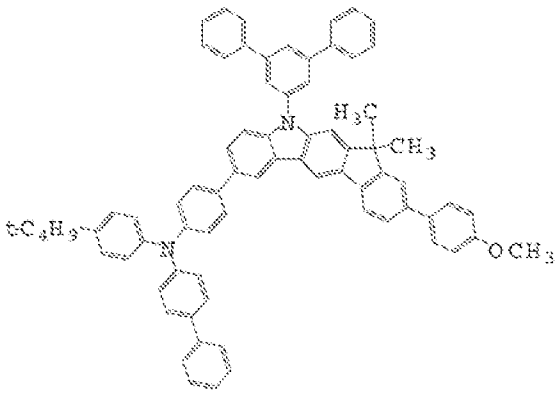
Compound H1-86



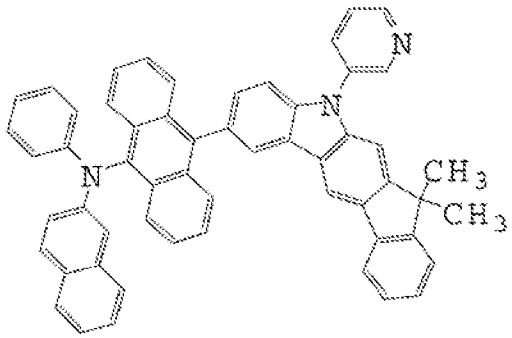
Compound H1-87



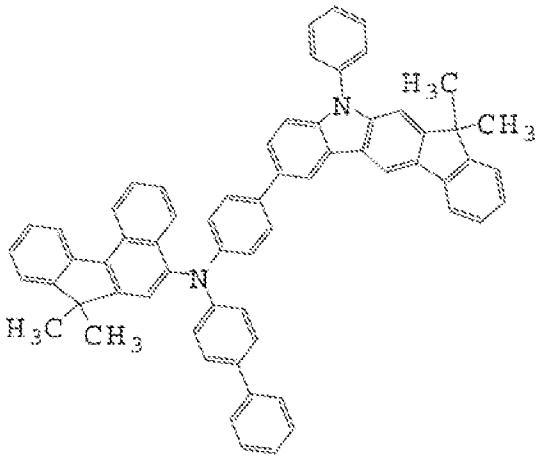
Compound H1-88



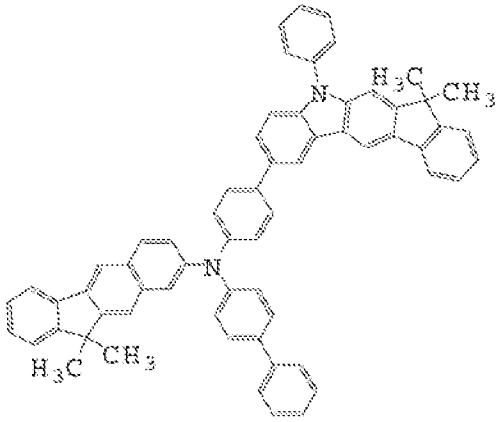
Compound H1-89



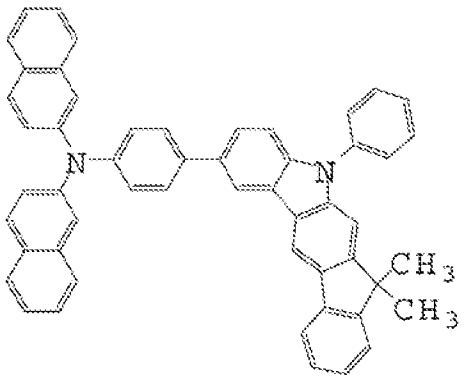
Compound H1-90



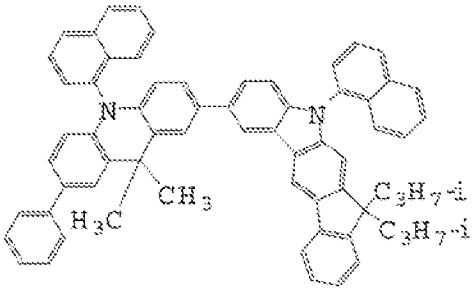
Compound H1-91



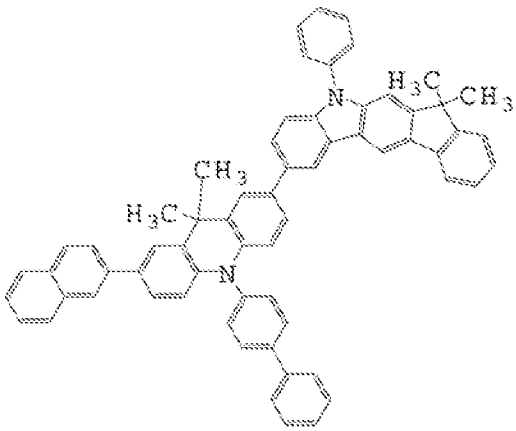
Compound H1-92



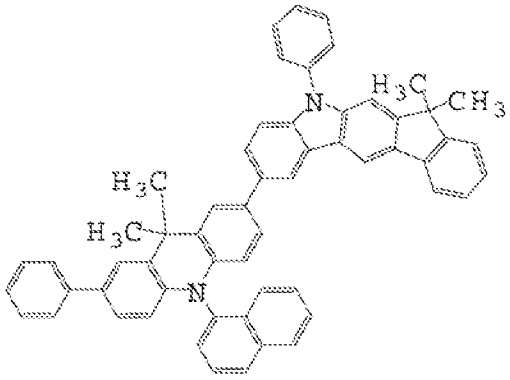
Compound H1-93



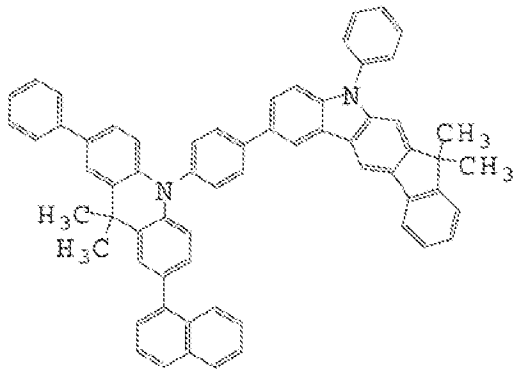
Compound H1-94



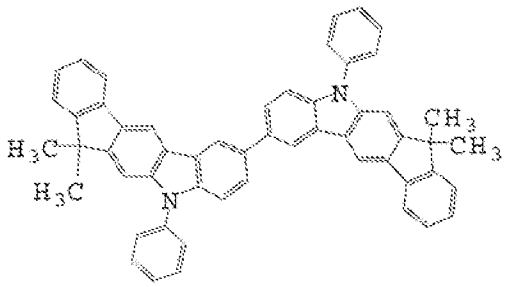
Compound H1-95



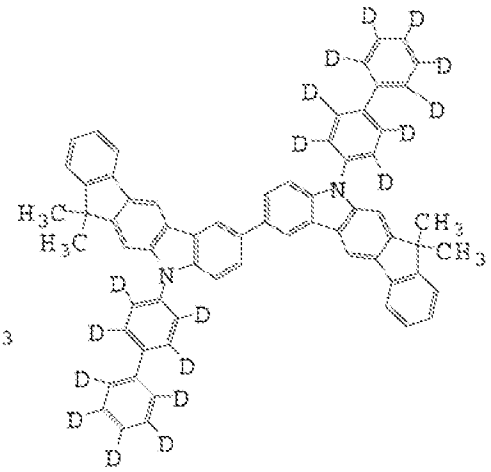
Compound H1-96



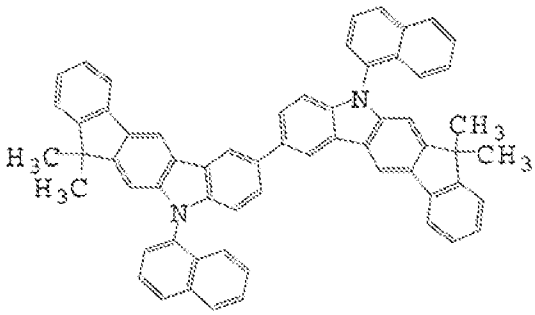
Compound H1-97



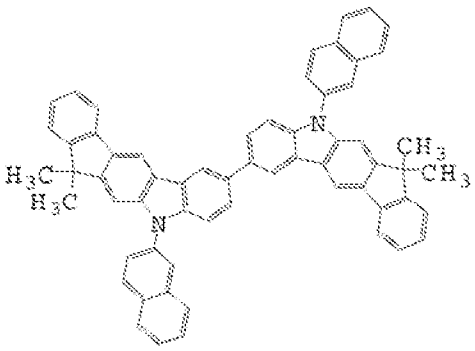
Compound H1-98



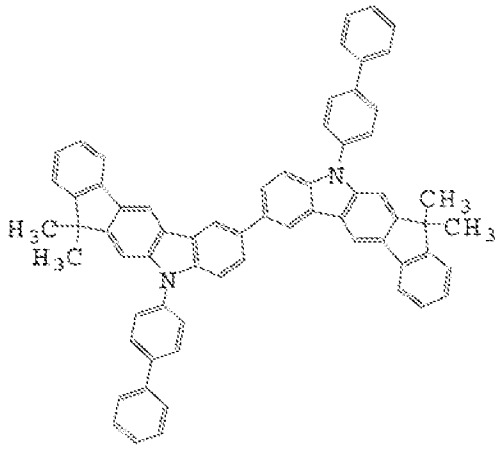
Compound H1-99



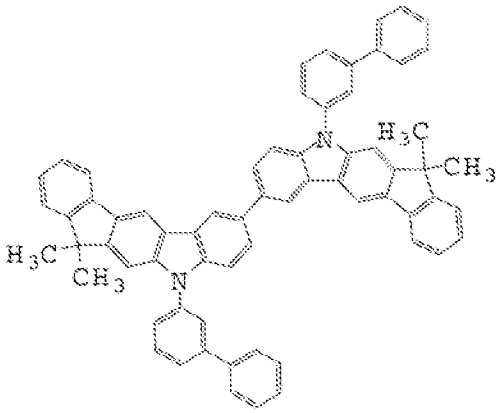
Compound H1-100



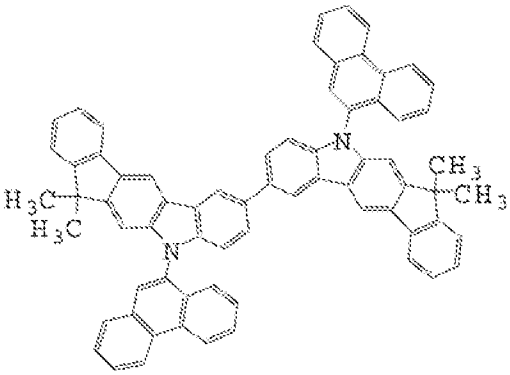
Compound H1-101



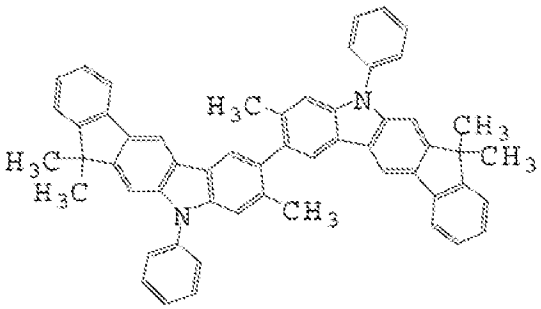
Compound H1-102



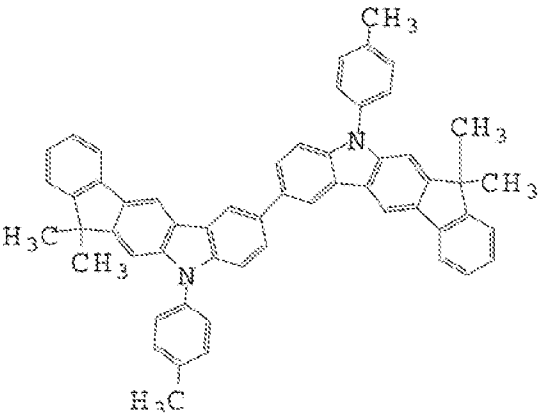
Compound H1-103



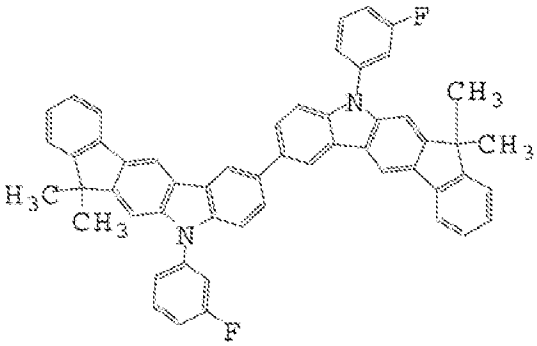
Compound H1-104



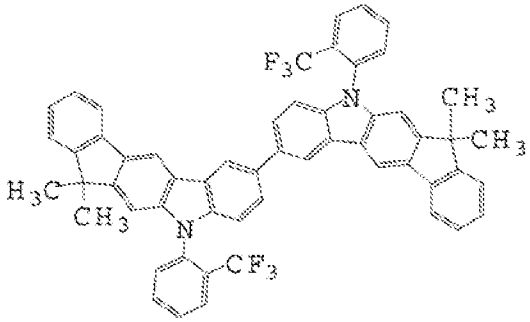
Compound H1-105



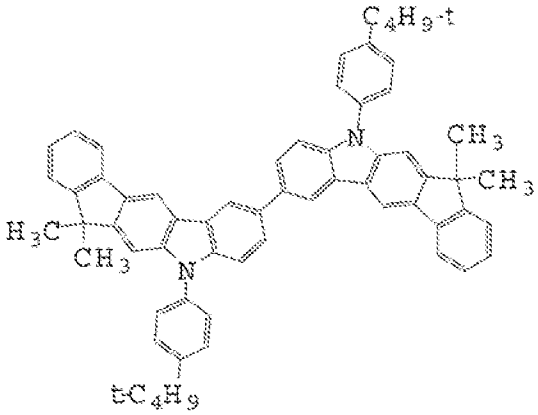
Compound H1-106



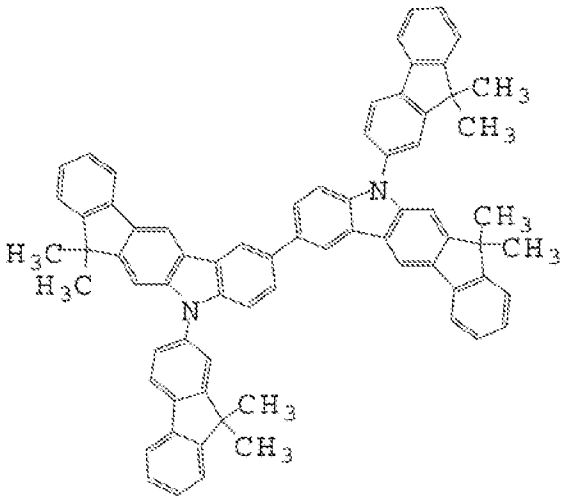
Compound H1-107



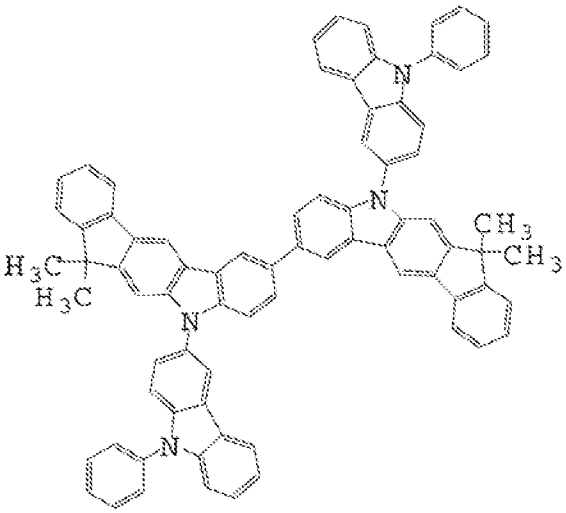
Compound H1-108



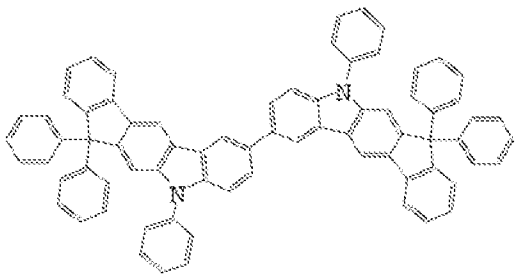
Compound H1-109



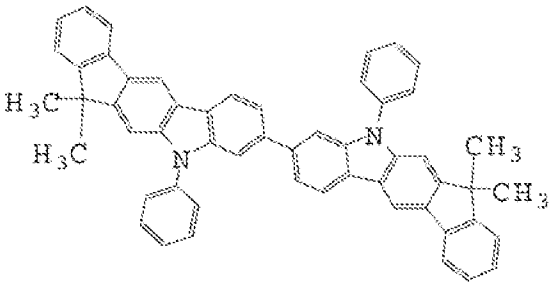
Compound H1-110



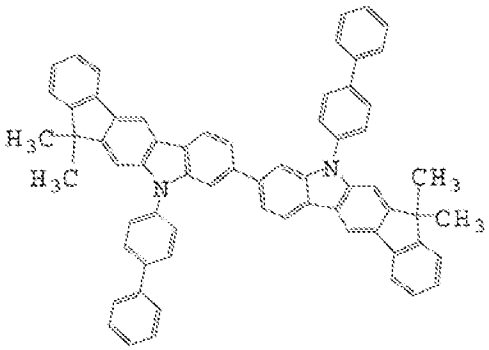
Compound H1-111



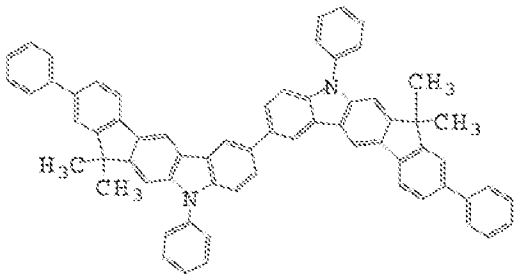
Compound H1-112



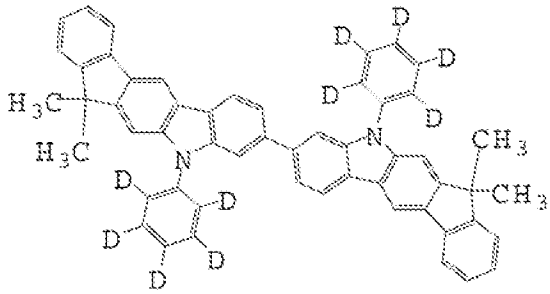
Compound H1-113



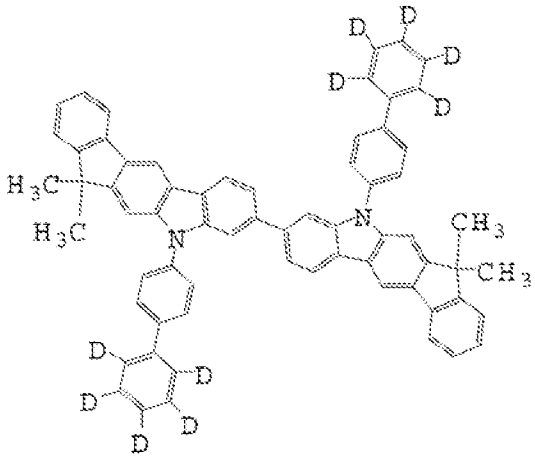
Compound H1-114



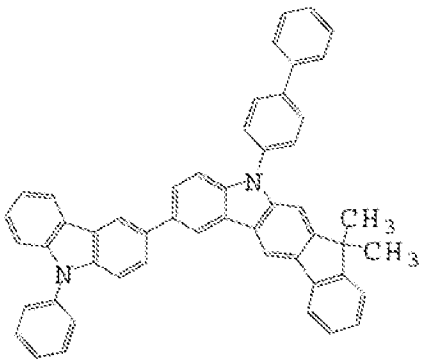
Compound H1-115



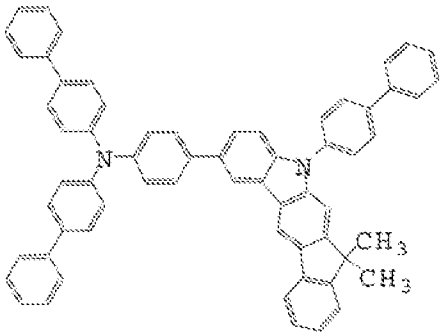
Compound H1-116



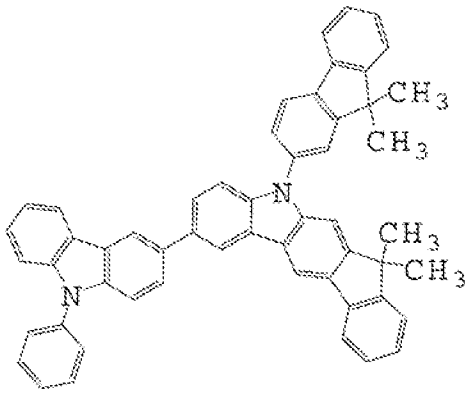
Compound H1-117



Compound H1-118

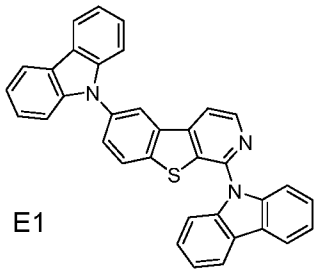


Compound H1-119 , and



Compound H1-120 .

24. The organic light emitting device according to claim 22, further comprising a third host compound in the emissive layer, wherein the third host compound is



E1

25. The organic light emitting device according to claim 22, wherein the exciton/electron blocking layer blocks both excitons and electrons.

26. The organic light emitting device according to claim 22, wherein the phosphorescent emitter material is an organometallic compound selected from the group consisting of phosphorescent organometallic platinum compounds, organometallic iridium compounds and organometallic osmium compounds.

27. The organic light emitting device according to claim 26, wherein the phosphorescent organometallic platinum compound has an aromatic ligand.

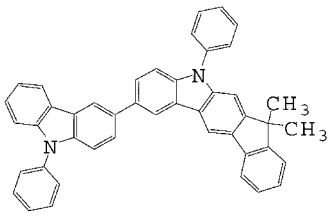
28. The organic light emitting device according to claim 26, wherein the phosphorescent organometallic iridium compound has an aromatic ligand.

29. The organic light emitting device according to claim 26, wherein the phosphorescent organometallic osmium compound has an aromatic ligand.

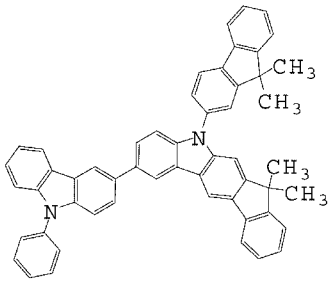
30. An organic light emitting device comprising an anode, a cathode and a plurality of organic layers provided between them, the plurality of organic layers comprising:

an emissive layer comprising a host material and a phosphorescent emitter material, the host material comprising:

a first host compound and a second host compound, wherein the first host compound is selected from a group consisting of

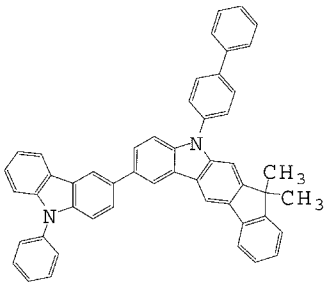


,



, and

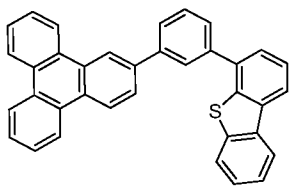
H1-1 H1-119



;

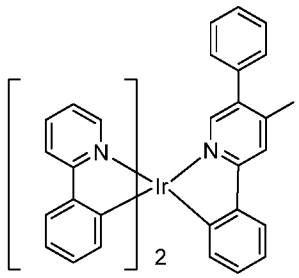
H1-118

wherein the second host compound is represented by the formula H



(H) ; and

the phosphorescent emitter material is a compound represented by the formula G1



(G1) .

31. The organic light emitting device of claim 30, wherein the first host compound constitutes no more than 25 wt.% of the emissive layer.

32. The organic light emitting device of claim 31, wherein the first host compound is 10-20 wt.% of the emissive layer.

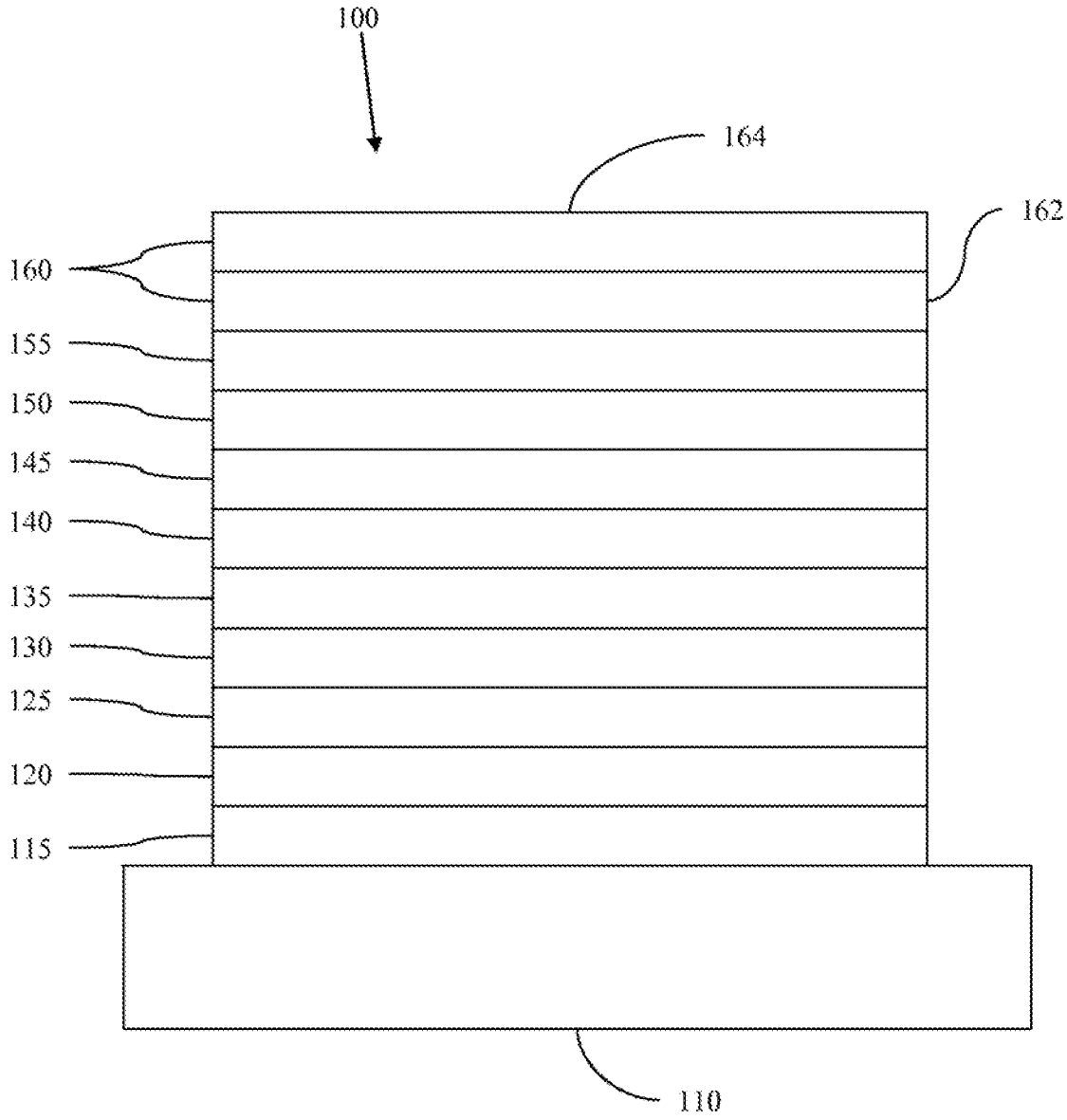


FIG. 1

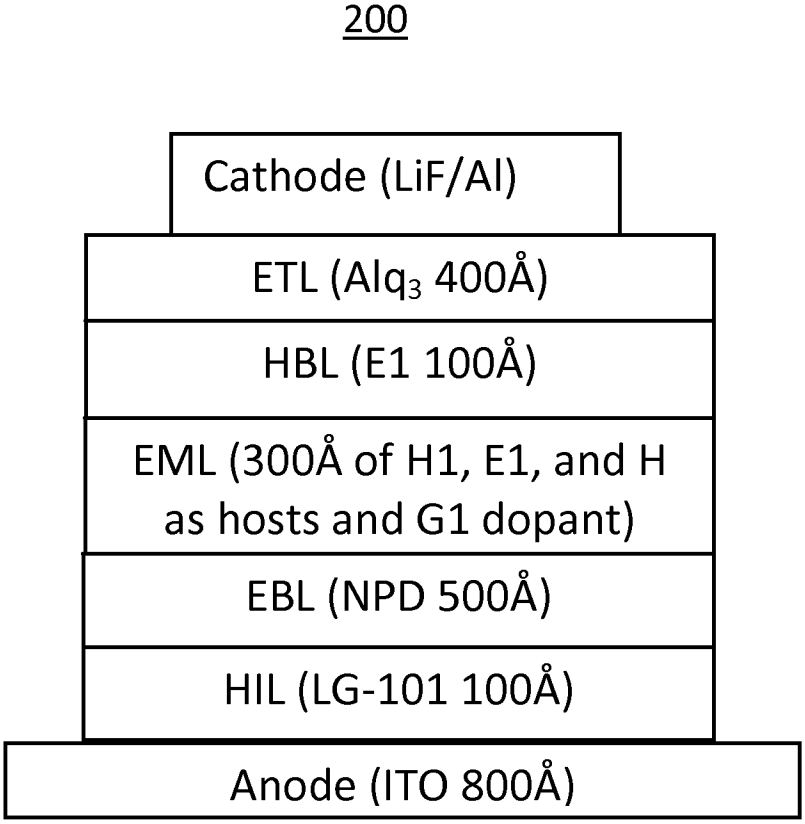

200
Cathode (LiF/Al)
ETL (Alq_3 400Å)
HBL (E1 100Å)
EML (300Å of H1, E1, and H as hosts and G1 dopant)
EBL (NPD 500Å)
HIL (LG-101 100Å)
Anode (ITO 800Å)

FIG. 2

300

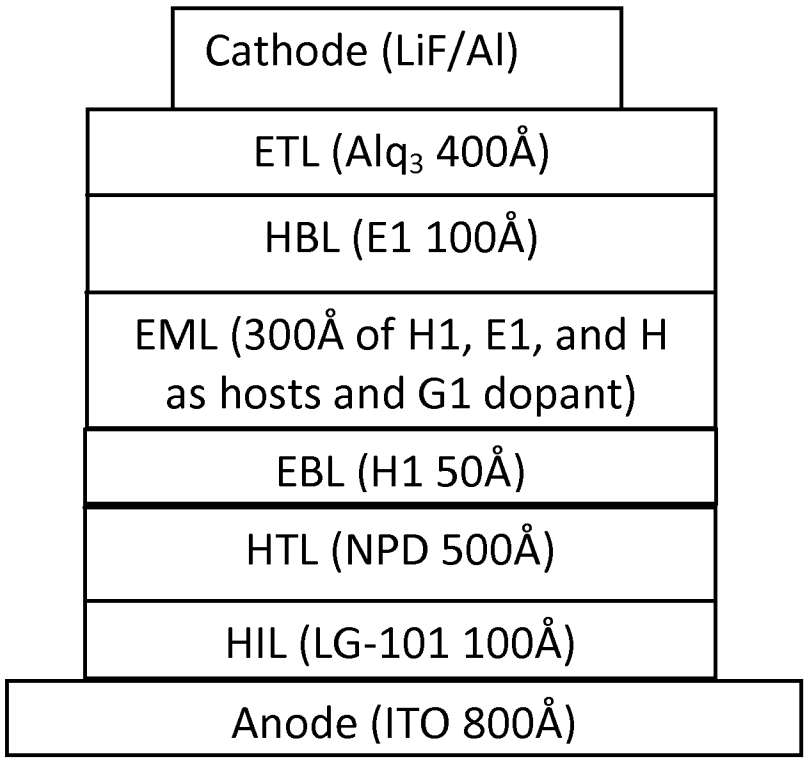

Cathode (LiF/Al)
ETL (Alq_3 400Å)
HBL (E1 100Å)
EML (300Å of H1, E1, and H as hosts and G1 dopant)
EBL (H1 50Å)
HTL (NPD 500Å)
HIL (LG-101 100Å)
Anode (ITO 800Å)

FIG. 3

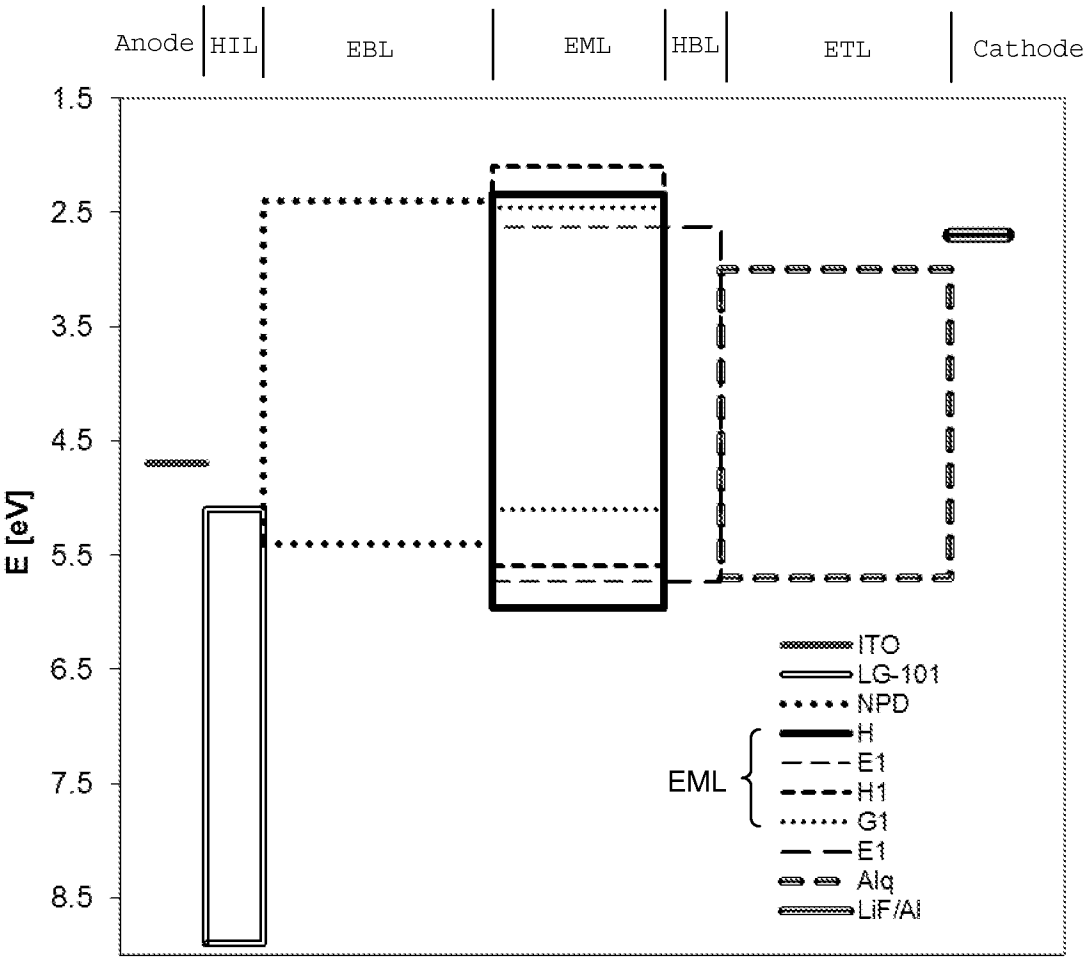

Anode
HIL
EBL
EML
HBL
ETL
Cathode
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
E [eV]
ITO
LG-101
NPD
EML
H
E1
H1
G1
E1
Alq
LiF/Al

FIG. 4

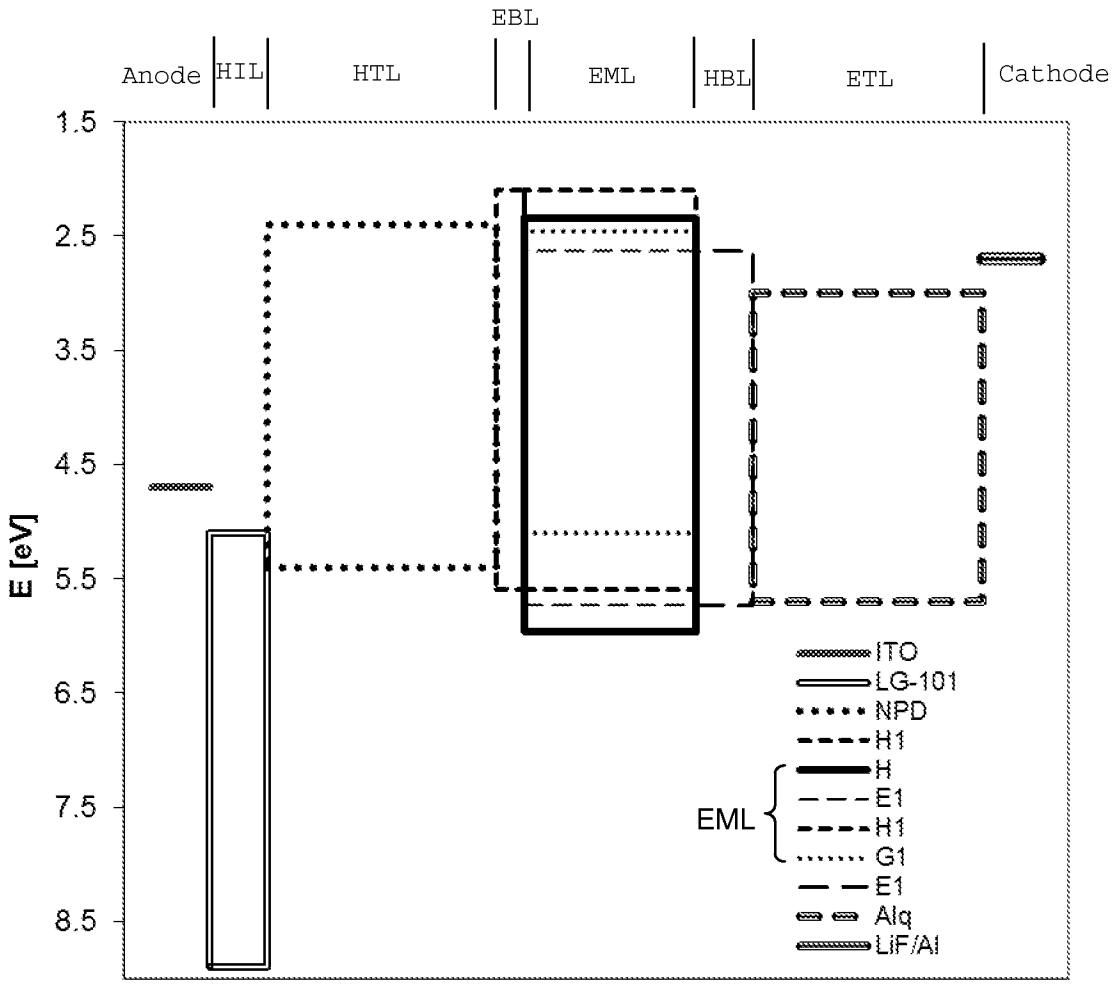

EBL
Anode
HIL
HTL
EML
HBL
ETL
Cathode
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
E [eV]
ITO
LG-101
NPD
H1
EML
H
E1
H1
G1
E1
Alq
LiF/Al

FIG. 5

400

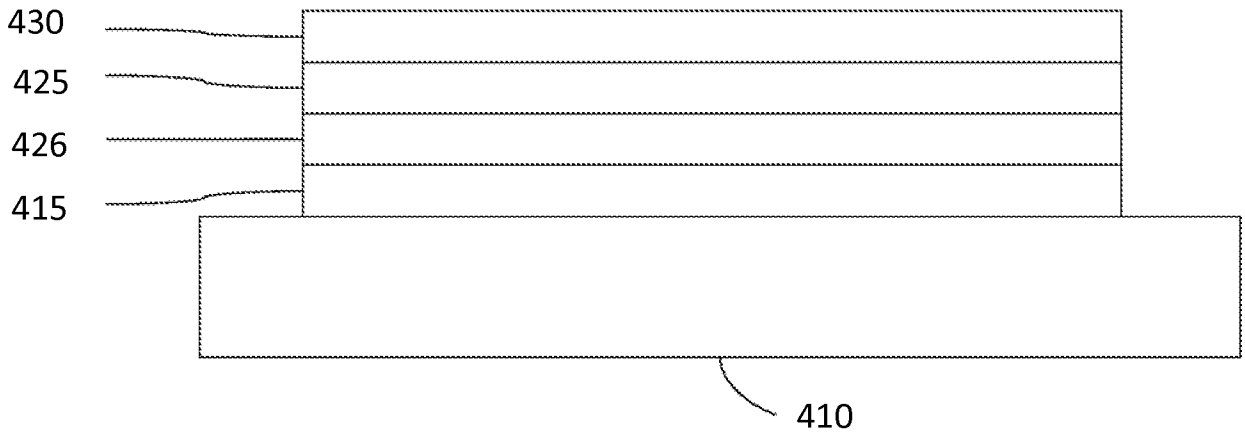


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/046802

A. CLASSIFICATION OF SUBJECT MATTER

H01L 51/54(2006.01)i, H05B 33/14(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01L 51/54; C07D 403/14; C07D 491/02; H01L 51/00; H01L 51/52; C07F 15/00; C07D 333/76; C07D 495/02; C09K 11/06; C07D 307/91; H05B 33/14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: organic light emitting device, host, phosphorescent emitter, indeno-carbazole ring structure, blocking layer

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013-0126856 A1 (NORIMASA YOKOYAMA et al.) 23 May 2013 See paragraphs [0024], [0054], [0073]-[0079], [0105], [0113], [0123]; and figure 9.	1-4,18-23,25-29
Y		5-17,24,30-32
Y	WO 2009-021126 A2 (UNIVERSAL DISPLAY CORPORATION) 12 February 2009 See paragraphs [0016], [0017], [0045].	5-16,30-32
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☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 March 2014 (13.03.2014)	**14 March 2014 (14.03.2014)**

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Information on patent family members

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International application No.
PCT/US2013/046802

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