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(54) Title: DYE-DOPED HOLE TRANSPORT LAYER FOR ORGANIC LIGHT EMITTING DIODES

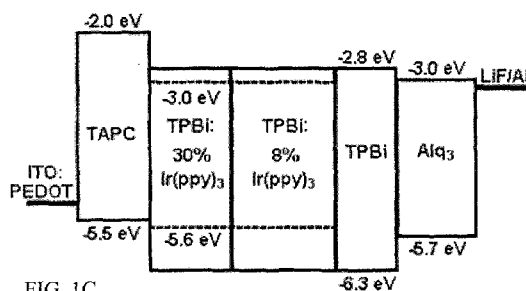


FIG. 1C

(57) Abstract: Embodiments of the invention are directed to an OLED where the quenching from a low triplet energy in the hole transport layer (HTL) at a phosphorescent dye dye-doped HTL/emission layer (EML) interface can be avoided when the triplet energy of the host material of the HTL is high, above -2.6 eV, and the hole transport phosphorescent dye is within a hole transport electron blocking material with the high triplet energy and the EML comprises the hole transport phosphorescent dye. The dye can be in the HTL at levels of 3% or greater.

DYE-DOPED HOLE TRANSPORT LAYER FOR ORGANIC LIGHT EMITTING DIODES

DESCRIPTION

CROSS-REFERENCE TO A RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application Serial No. 62/182,669, filed June 22, 2015, the disclosure of which is hereby incorporated by reference in its entirety, including all figures, tables and drawings.

BACKGROUND OF INVENTION

Organic opto-electronic devices are increasingly more desirable. These devices are constructed of relatively inexpensive materials and the devices can be flexible. These opto-electronic devices include organic light emitting devices (OLEDs), organic phototransistors, organic photovoltaic cells, and organic photodetectors. OLEDs use thin organic films to emit light when voltage is applied for use in displays, lighting, and backlighting. Organic materials used for OLEDs display some advantages over conventional materials, including tuning of the emission wavelength by inclusion of specific dopants. Tuning allows the adaption of pixels to emit "saturated" colors, such as, standards red, green, and blue pixels.

Hole transporting materials are used in hole transporting layers (HTLs) of multilayer organic light-emitting diodes (OLEDs). The HTL is critical to device performance. Typical materials for HTLs have electron-donating nitrogen content and aromatic amine derivatives have been extensively used as hole transporting materials in fluorescent OLEDs. The amine *N,N*-diphenyl-*N,N*-bis(1-naphthyl)-1,1'-biphenyl-4,4'-diamine (NPB) is widely used as a hole transporting layer (HTL) in fluorescent OLEDs. NPB has good hole transporting ability due to good alignment of the highest occupied molecular orbital (HOMO) level with the anode work function. However, use of NPB in phosphorescent OLEDs is problematic because of its inherent low triplet energy (2.3 eV) relative to common dopants. This problem is even more severe for blue emitting phosphorescent OLEDs because of the higher triplet energy of the emitter.

For phosphorescent OLEDs, other materials are preferable for HTLs. An archetype hole transporting material used is the arylamine derivative, 1,1-bis(di-4-tolylaminophenyl)cyclohexane (TAPC). TAPC has been extensively used providing a high efficiency phosphorescent OLED because of its high hole mobility and high triplet energy (2.87 eV).

However, OLEDs based on TAPC HTL suffer from low operational stability that originates from a build-up of trapped charges at the TAPC/emitting layer (EML) interface, which results in a voltage rise and luminance decay during device operation. Short device lifetimes have severely limited the use of TAPC in OLEDs. For the development of an efficient and stable phosphorescent OLED a high triplet energy stable HTL is required. Unfortunately, no arylamine has demonstrated these requirements. Hence, it appears that an alternate approach is required to achieve an operationally stable and efficient OLED.

BRIEF SUMMARY

Embodiments of the invention are directed to an organic light emitting diode that includes a phosphorescent dye in the HTL that is the same as the phosphorescent dye in the EML such that the stability of the device is enhanced over that of an equivalent device absent the dye in the HTL.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 shows energy level diagrams for devices with structures: FIG. 1A without a dye doped HTL; FIG. 1B with a HTL consisting of a dye; and FIG. 1C where the dye is doped at a level above the percolation limit in an electron transport material.

FIG. 2 shows plots of: (a) current density–voltage curves of hole only devices based on a TAPC and TPBi:30% Ir(ppy)₃ layers, (b) and (c) their space charge limited current hole mobility values, and plots indicating the effect of Ir(ppy)₃ doping concentration on hole transport in TPBi:Ir(ppy)₃ layers.

FIG. 3 shows plots of (a, c) luminance–current density–voltage and (b, d) luminance–current efficiency for the device of FIGs. 1A and B, respectively, where the insets of (b) and (d) are the devices' EL spectra.

FIG. 4 shows plots of (a) luminance–current density–voltage and (b) luminance–current efficiency for the device of FIG. 1C, where the inset of (b) is the devices' EL spectra.

FIG. 5 shows plots of (a) luminance–current density–voltage and (b) luminance–current efficiency of an OLED based on 30% Ir(ppy)₃-doped TPBi emitting layer, where the inset of (b) is the devices' EL spectra.

FIG. 6 shows plots of: (a) operational voltage increase under constant current density of 50 mA/cm²; and EL luminance decay curves at (b) 20,000 and (c) 1055 cd/m² for the devices of FIGs. 1A, 1B and 1C.

FIG. 7 shows energy level diagrams for devices with structures: FIG. 7A with a HTL consisting of a dye doped aromatic amine adjacent to a second HTL with the dye in an electron transport material at a level above the percolation limit; and FIG. 7B where the dye is doped in an HTL at a low level in an aromatic amine adjacent to an EML with the same dye.

DETAILED DISCLOSURE

Embodiments of the invention are directed to the use of an organic phosphorescent dye or phosphorescent dye-doped host/dopant system as a charge transport layer in an OLED. The organic phosphorescent dyes used in these OLEDs display high electron/hole mobilities. In an embodiment of the invention a pristine dye is used for a transport layer in the OLED. In another embodiment of the invention, a doped, even a heavily doped phosphorescent dye, is used to transport charge. The dopant dye is included in a hole transport layer (HTL) and emitting layer (EML).

Conventional HTLs are aromatic amines for phosphorescent OLEDs. In an embodiment of the invention, *fac*-tris(2-phenylpyridine)iridium (III) ($\text{Ir}(\text{ppy})_3$), a phosphorescent dye that has hole mobility comparable to conventional organic hole transporting materials, comprises a HTL and can be doped into an organic host that displays a wide band gap. $\text{Ir}(\text{ppy})_3$ has a hole mobility of about $10^{-5} \text{ cm}^2/\text{Vs}$. The $\text{Ir}(\text{ppy})_3$ is doped into the organic matrix at a level that exceeds the percolation limit, such that holes can be injected from the anode, transported via the dopant sites in the dye-doped HTL, and directly injected from the HTL to the dopant sites within an emitting layer (EML) without encountering an injection barrier, as exists when employing an aromatic amine HTL. In this manner, the hole injection barrier can be completely eliminated when holes are injected from the same phosphorescent dye molecule in the HTL and EML. Advantageously, quenching from low triplet energy in the HTL at the dye-doped HTL/EML interface can be avoided when the triplet energy of the host material of the HTL is high. By employing a high triplet energy host, device operating lifetime is significantly improved.

An exemplary OLED fabricated using poly(3,4-ethylenedioxythiophene):poly(styrene sulfonate) (PEDOT:PSS) as a hole injection layer (HIL), TAPC as a HTL, 4,4'-bis-(*N*-carbazolyl)biphenyl (CBP) as a host, 1,3,5-*tris*(2-*N*-phenylbenzimidazolyl)benzene (TPBi) as a host and/or as a hole blocking layer, $\text{Ir}(\text{ppy})_3$ as a dye dopant, *tris*(8-hydroxyquinoline)aluminum (Alq3) as an electron transporting layer (ETL), and lithium

fluoride (LiF) as an electron injection layer (EIL) is illustrated in FIG. 1 along with a state of the art OLED device. The structure of a state of the art device FIG. 1A and two exemplary devices employing a dye are shown in FIGs. 1B and 1C: (A) ITO/PEDOT:PSS/TAPC (40 nm)/CBP:8%Ir(ppy)₃ (30 nm)/TPBi (10 nm)/Alq₃ (30 nm)/LiF (1 nm)/Al (100 nm); (B) ITO/PEDOT:PSS:Ir(ppy)₃ (10 nm)/ TPBi:30% Ir(ppy)₃ (30 nm)/TPBi:8%Ir(ppy)₃ (30 nm)/TPBi (10 nm)/Alq₃ (30 nm)/LiF (1 nm)/Al (100 nm); and (C) ITO/PEDOT:PSS/TAPC (20 nm)/TPBi:30% Ir(ppy)₃ (20 nm)/TPBi:8% Ir(ppy)₃ (30 nm)/TPBi (10 nm)/Alq₃ (30 nm)/LiF (1 nm)/Al (100 nm).

Device A has a HTL of TAPC with Ir(ppy)₃-doped CBP as the emitter layer (EML). Because pristine Ir(ppy)₃ has a high hole mobility (10^{-6} - 10^{-5} cm²/Vs) it is used for hole transport in devices B and C. The hole mobility of Ir(ppy)₃ is comparable to hole mobility of amorphous materials such as NPB and CBP ($\sim 10^{-5}$ cm²/Vs). Device B uses a PEDOT:PSS:Ir(ppy)₃ layer as an HIL and TPBi:30% Ir(ppy)₃ as an HTL, as a doping concentration of 30% is above the percolation threshold. Device C has a TAPC/TPBi:30% Ir(ppy)₃ layer as an HTL such that the dye-doped HTL is in contact with the EML and the TAPC layer is not in contact with the EML. In Devices B and C, TPBi is used as the host for the dye doped HTL as well as the EML. Hole injection from the HTL to the EML is via Ir(ppy)₃, which allows injection without the hole injection barrier common to most devices. TPBi is an electron transporter and the Ir(ppy)₃-doped:TPBi layer behaves as an ambipolar transporting emitting layer.

The hole transporting capability of TAPC and 30% Ir(ppy)₃ doped TPBi layers are determined from hole-only devices (HODs) by measuring their electrical characteristics, including their space charge limited currents (SCLC), and determine their hole mobility values. From the plots shown in FIGs. 2b and 2c, these values are 10^{-6} - 10^{-5} and 10^{-5} - 10^{-3} cm²/Vs for TPBi:30% Ir(ppy)₃ and TAPC layers, respectively. Hole transporting properties for HODs with Ir(ppy)₃ doping concentrations of 0, 8, and 30 % in TPBi on top of TAPC are plotted FIG. 2d, where clearly hole current increases with increasing concentration of Ir(ppy)₃.

FIG. 3 shows luminance-current density-voltage (J - V - L) and luminance-current efficiency characteristics for devices of FIG.s 1A and B; where device B shows a lower current efficiency (55 cd/A) than device A (67 cd/A), implying that the recombination zone is within the Ir(ppy)₃-doped HTL with the lower efficiency, when compared with Device A, being due to concentration quenching. Turn-on voltage reduces from 3.0 V for device A to

2.6 V for device B, which is about the band-gap energy of Ir(ppy)₃ (2.6 eV). The reduced turn-on voltage in device B is attributed to direct injection of holes from the Ir(ppy)₃-doped HTL into the HOMO level of Ir(ppy)₃ without encountering an injection barrier. To improve device efficiency, the recombination zone needs to be removed from the dye-doped HTL. To tune the charge balance and avoid concentration quenching, the Ir(ppy)₃ HIL of FIG. 1B is replaced by a TAPC layer for the device of FIG. 1C, which enhances hole injection.

TPBi is an electron transporting material with its electron mobility ($\sim 10^{-5}$ cm²/Vs) of at least one order of magnitude higher than its hole mobility, and, therefore, is a poor hole transporting material. Due to energy level alignment, the hole injection barrier from TAPC to TPBi (0.8 eV) is greater than the barrier from TAPC to Ir(ppy)₃ (0.1 eV). Hence, holes from the TAPC layer are injected directly into and transported through the hole conduction channel formed by Ir(ppy)₃. For this reason, the device of FIG. 1C displays a turn on voltage similar to the device of FIG. 1B yet retains a current efficiency of 66 cd/A, as shown in FIG. 4, which indicates that the recombination zone is located in the 8% Ir(ppy)₃-doped TPBi EML layer of device C.

A simple OLED using 30% Ir(ppy)₃-doped TPBi as an EML and TAPC as an HTL also indicated that the recombination zone is located in the 8% Ir(ppy)₃-doped TPBi EML layer. As shown in FIG. 5, a current efficiency of 56 cd/A with a turn-on voltage of 2.6 V is observed for the device. As before, the low turn-on voltage for this device indicates direct hole injection from TAPC into Ir(ppy)₃. The 56 cd/A current efficiency for this device is equivalent to that of device B with a 30% Ir(ppy)₃-doped EML, indicating that the emission zone in device B is the 30% Ir(ppy)₃ doped layer.

The short lifetime of OLEDs with TAPC HTLs is attributed to accumulation of immobile positive charges at the HTL/EML interface that leads to a rapid rise of operational voltage and luminance decay. According to embodiments of the invention, hole injection barriers are eliminated; hence, operating lifetimes are significantly improved. Life testing of devices A-C, carried out at constant current densities of 50 mA/cm², reveals the effect of dye-doped HTLs on device operating lifetimes. As shown in FIG. 6, a large difference in operational voltage rise with a different degree of luminance degradation is observed for the three devices. Driven with a constant current density, Device A showed a 63 % increase in voltage after 5 hours of operation, while Device B and C exhibited only 3.3 and 3.7 % increase in voltage during the same period, respectively. Due to direct hole injection from Ir(ppy)₃ to Ir(ppy)₃, hole accumulation at the HTL/EML interface is eliminated, which

significantly increases the operational lifetime in Devices B and C. As shown in FIG. 6, Devices B and C showed a significantly improved luminance LT50 lifetime (the time for the luminance to decay to 50 % of initial luminance) by 8.4 and 11.0 times, respectively, compared to Device A. This improved operational stability is also observed at a lower luminance, as shown in Figure 6c. Luminance decay between Devices A, B and C was compared by measuring the LT90 lifetime (time for the luminance to decay 10%) with an initial luminance of 1,055 cd/m², and the results are 12, 38 and 62 hours for Devices A, B and C, respectively. Assuming an acceleration factor of 1.8, the LT50 lifetimes with an initial luminance of 100 cd/m² are 18,200, 152,800 and 199,600 hours for Device A, B and C, respectively. As the apparent degradation of TAPC-based OLEDs is due to hole accumulation at TAPC/EML interface, embodiments of the invention overcome this problem by utilizing a hole transporting phosphorescent dye-doped layer as the HTL to eliminate the hole injection barrier and to suppress exciton quenching at the HTL/EML interface. A >10X enhancement in operating lifetime can be achieved in this manner while maintaining high electroluminescent efficiency.

In an embodiment of the invention, a first HTL adjacent to an anode, or anode contacting hole injection layer (HIL), is a aromatic amine, such as TAPC, that is dye-doped with the same phosphorescent dye as in a second HTL, for example, as shown in FIG. 7A. By doping the aromatic amine with as little as about 3 % of the dye, as shown in FIG. 7B the holes are dissipated from the aromatic amine to the emissive layer at a sufficient rate such that amine degradation is alleviated. By matching the dye to that of the emitter, the injection barrier can be significantly decreased while the high triplet energy can be retained in the HTL. The HTL can include a matrix that has a triplet energy in excess of -2.5 eV.

In embodiments of the invention, the hole transporting phosphorescent dye can be Ir(ppy)₃, iridium (III) *tris*(2-(4-tolyl)pyridinato-*N,C2'*), or any iridium dyes with hole transfer properties, including, but not limited to: iridium (III) *bis*(2-(4,6-difluorophenyl)pyridinato-*N,C2'*)picolinate; iridium (III) *bis*(2-(2'-benzothienyl)pyridinato-*N,C3'*)(acetylacetonate); iridium (III) *tris*(1-phenylisoquinoline); iridium (III) *bis*(1-phenylisoquinoline)(acetylacetonate); *tris*(2-(2,4-difluorophenyl)pyridine)iridium (III); iridium (III) *bis*(dibenzo[f,h]quinoxaline) (acetylacetonate); iridium (III) *bis*(2-methyldibenzo[f,h]quinoxaline) (acetylacetonate); and *bis*(2-(9,9-dihexylfluorenyl)-1-pyridine)(acetylacetonate) iridium (III). In embodiments of the invention, the hole transporting phosphorescent dye can be another metal containing dye, including, but not limited to, copper(II) phthalocyanine,

indium(III) phthalocyanine chloride, tin(IV) 2,3-naphthalocyanine dichloride, titanyl phthalocyanine, and vanadyl phthalocyanine.

The aromatic amine hole transport materials, in addition to TAPC, 1,1-bis[(di-4-tolylamino)phenyl] cyclohexane, that can be employed include, but are not limited to: NPB, *N,N'*-diphenyl-*N,N'*-(2-naphthyl)-(1,1'-phenyl)-4,4'-diamine; TPD, *N,N'*-diphenyl-*N,N'*-di(*m*-tolyl) benzidine; PF-9HK, poly[(9,9-dioctyl-fluorenyl-2,7-diyl)-*alt-co*-(9-hexyl-3,6-carbazole)]; and 4,4',4''-tris-(*N*-carbazolyl)-triphenylamine (TCTA)CBP, 4,4'-*bis*(*N*-carbazolyl)-1,1'-biphenyl; 1,3-*bis*(*N*-carbazolyl)benzene; 4,4'-*bis*(*N*-carbazolyl)-1,1'-biphenyl; 1,4-*bis*(diphenylamino)benzene; 4,4'-*bis*(3-ethyl-*N*-carbazolyl)-1,1'-biphenyl; *N,N'*-*bis*(3-methylphenyl)-*N,N'*-diphenylbenzidine; *N,N'*-*bis*(phenanthren-9-yl)-*N,N'*-*bis*(phenyl)-benzidine; 4,4'-cyclohexylidenebis[*N,N'*-*bis*(4-methylphenyl)benzenamine]; 4-(dibenzylamino) benzaldehyde-*N,N'*-diphenylhydrazone; 2,2'-dimethyl-*N,N'*-di-[(1-naphthyl)-*N,N'*-diphenyl]-1,1'-biphenyl-4,4'-diamine; 9,9-dimethyl-*N,N'*-di(1-naphthyl)-*N,N'*-diphenyl-9*H*-fluorene-2,7-diamine; *N,N'*-di(1-naphthyl)-*N,N'*-diphenyl-(1,1'-biphenyl)-4,4'-diamine; *N,N'*-di(1-naphthyl)-*N,N'*-diphenyl-(1,1'-biphenyl)-4,4'-diamine; *N,N'*-di(2-naphthyl)-*N,N'*-diphenyl-1,1'-biphenyl-4,4'-diamine; 4-(diphenylamino)benzaldehyde diphenylhydrazone; *N,N'*-diphenyl-*N,N'*-di-*p*-tolylbenzene-1,4-diamine; dipyrazino[2,3-*f*:2',3'-*h*]quinoxaline-2,3,6,7,10,11-hexacarbonitrile; DNTPD, *N*⁴,*N*^{4'}-*bis*[4-[*bis*(3-methylphenyl)amino]phenyl]-*N*⁴,*N*^{4'}-diphenyl-[1,1'-biphenyl]-4,4'-diamine; poly(*N*-ethyl-2-vinylcarbazole); poly(2-vinylcarbazole); poly(1-vinylnaphthalene); poly[*bis*(4-phenyl)(2,4,6-trimethylphenyl)amine]; spiro-MeOTAD, 2,2',7,7'-*tetrakis*(*N,N*-di-*p*-methoxyphenylamino)-9,9'-spirobifluorene, *N,N,N',N'*-*tetrakis*(4-methoxyphenyl)benzidine, *N,N,N',N'*-*tetrakis*(3-methylphenyl)-3,3'-dimethylbenzidine, *N,N,N',N'*-*tetrakis*(2-naphthyl)benzidine, *tetra-N*-phenylbenzidine, *N,N,N',N'*-tetraphenyl naphthalene-2,6-diamine, poly[(9,9-dioctylfluorenyl-2,7-diyl)-*co*-(4,4'-(*N*-(4-sec-butylphenyl) diphenylamine)], *tris*(4-carbazoyl-9-ylphenyl)amine, *tris*[4-(diethylamino)phenyl]amine, 1,3,5-*tris*(diphenylamino)benzene, 1,3,5-*tris*(2-(9-ethylcabazyl-3)ethylene)benzene, 1,3,5-*tris*[(3-methylphenyl)phenylamino]benzene, 4,4',4''-*tris*[2-naphthyl(phenyl)amino]triphenylamine, 4,4',4''-*tris*[phenyl(*m*-tolyl)amino]triphenylamine, tri-*p*-tolylamine, *N*⁴,*N*^{4'}-di(naphthalen-1-yl)-*N*⁴,*N*^{4'}-*bis*(4-vinylphenyl)biphenyl-4,4'-diamine.

The electron transport layer can be any appropriate material in addition to tris-(8-hydroxy quinoline) aluminum (Alq₃), including, but not limited to: tris[3-(3-pyridyl)-mesityl]borane (3TPYMB); 2,9-Dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP); and 4,7-diphenyl-1,10-phenanthroline (BPhen); Inq₃; Gaq₃; Znq₃; Zn(BTZ)₂; and BeBq₂.

METHODS AND MATERIALS

Device fabrication and characterization: OLEDs in this study were prepared on patterned Glass substrates with an ITO anode layer and were cleaned in an ultrasonic bath with acetone and isopropyl alcohol, followed by a 15 min UV-ozone treatment. A 30 nm-thick PEDOT:PSS layer (HIL) was spin-coated onto the ITO layer followed by thermal annealing at 140 °C for 30 minutes. All small molecules and cathodes were evaporated by vacuum thermal deposition under a vacuum pressure of 3.0×10^{-6} Torr. All organic layers were evaporated at a rate of 1.0-2.0 Å/s, and LiF and aluminum (Al) were evaporated at rates of 0.1 and 2.0-3.0 Å/s, respectively.. The active area of devices was 4 mm². Devices were encapsulated with a cap glass by using an UV-curable epoxy in glove box under nitrogen.

The structures of hole only devices (HODs) for the measurement of hole mobility and hole current of doped Irppy₃ in TPBi are ITO/PEDOT:PSS/TAPC (300 nm) or TPBi:30% Ir(ppy)₃ (300 nm)/MoO₃ (5 nm)/Al (100 nm) and ITO/PEDOT:PSS/TPBi: X% Ir(ppy)₃ (80 nm, X = 0, 8 and 30)/MoO₃ (5 nm)/Al (100 nm), respectively.

The structure of the OLED based on EML of 30% Irppy₃ doped TPBi layer is ITO/PEDOT:PSS/TAPC (40 nm)/TPBi:30% Ir(ppy)₃ (30 nm)/TPBi (10 nm)/Alq₃ (30 nm)/LiF (1 nm)/Al (100 nm).

Electrical characterizations were performed using a Keithley 2400 source meter and the luminance was measured using a Konica-Minolta LS 100 luminance meter with a close-up lens. All measurements were carried out in ambient atmosphere and room temperature.

It should be understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application.

CLAIMS

We claim:

1. A phosphorescent OLED, comprising a hole transport phosphorescent dye, wherein a hole transport layer (HTL) comprises the hole transport phosphorescent dye and a hole transport electron blocking material, and an emission layer (EML) comprises the hole transport phosphorescent dye.
2. The phosphorescent OLED according to claim 1, wherein the hole transport electron blocking material has a triplet energy higher than -2.6 eV.
3. The phosphorescent OLED according to claim 1, wherein the hole transport phosphorescent dye is Ir(ppy)₃ and the hole transport electron blocking material comprises TAPC.
4. The phosphorescent OLED according to claim 1, wherein the hole transport phosphorescent dye comprises 3% or more of the HTL.

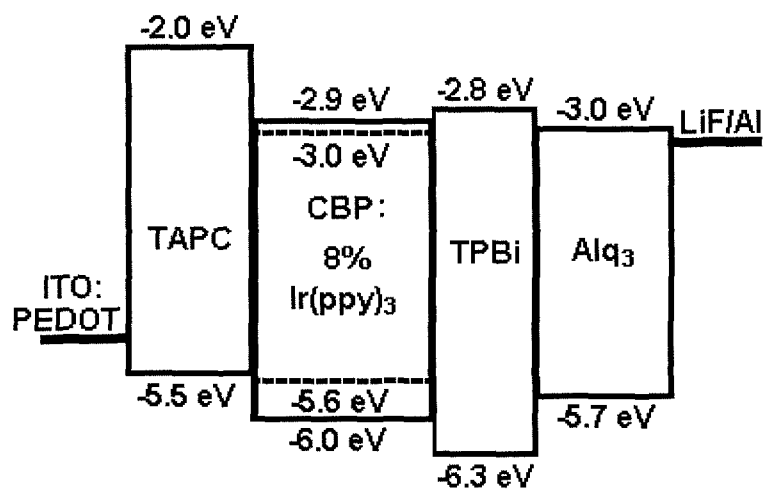


FIG. 1A

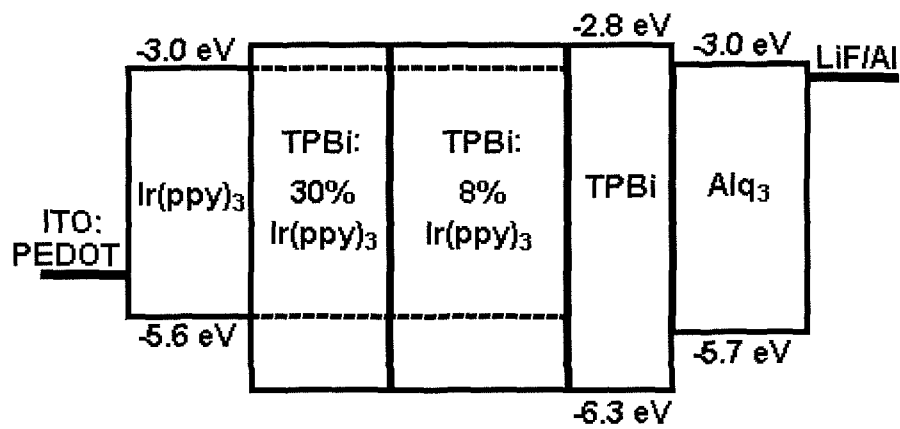


FIG. 1B

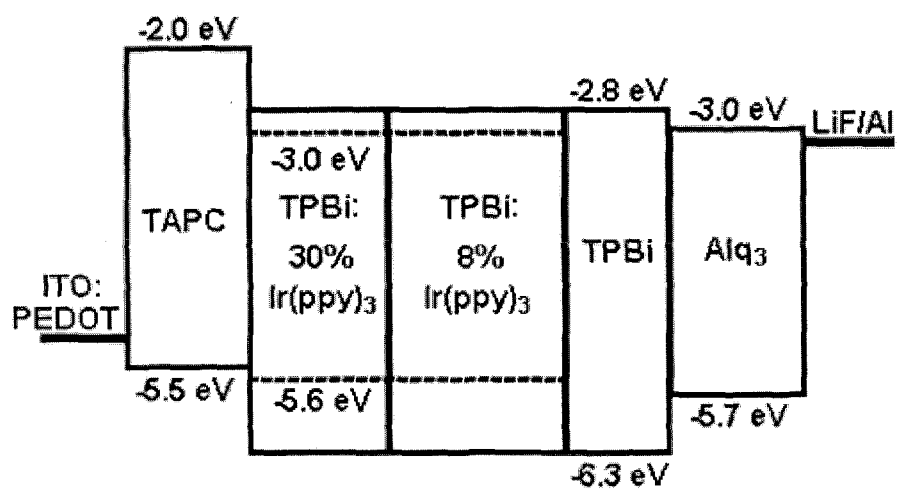


FIG. 1C

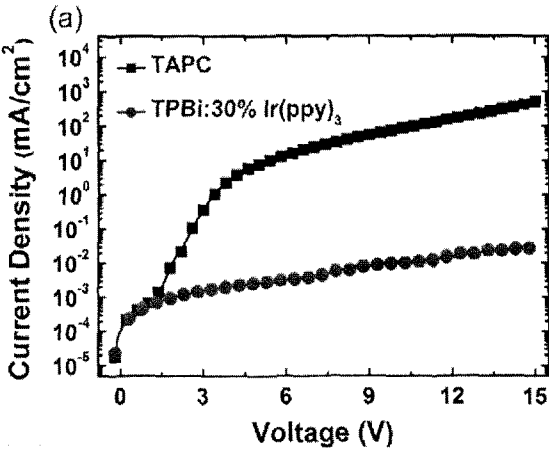


FIG. 2A

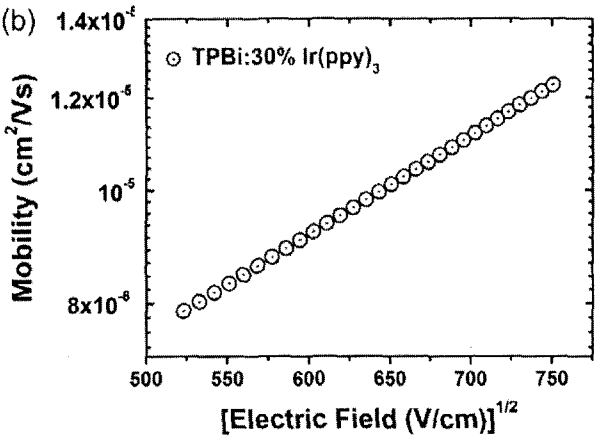


FIG. 2B

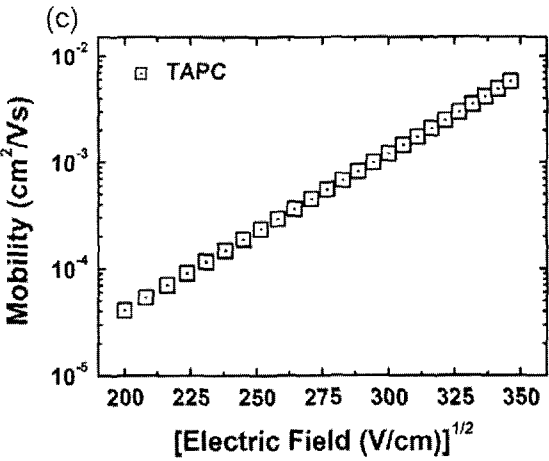


FIG. 2C

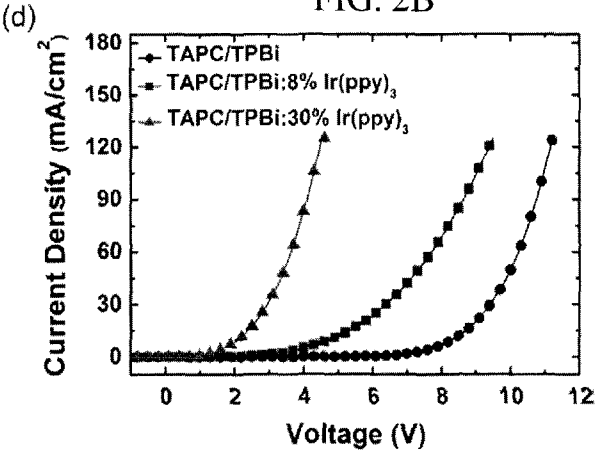


FIG. 2D

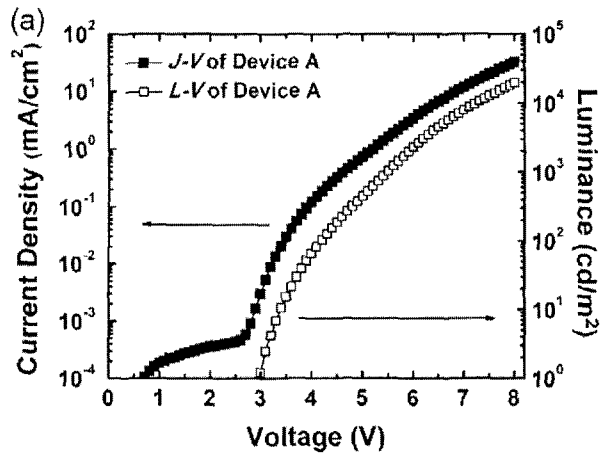


FIG. 3A

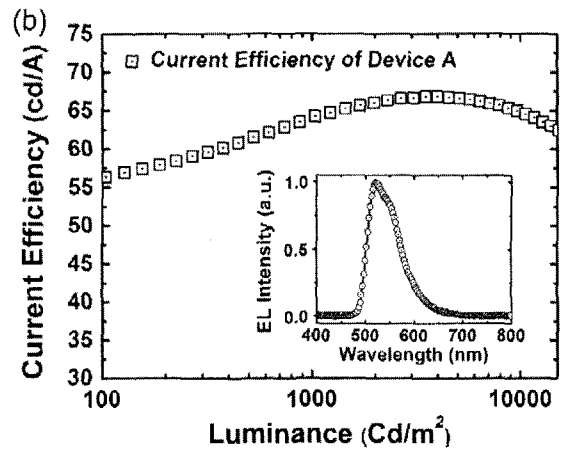


FIG. 3B

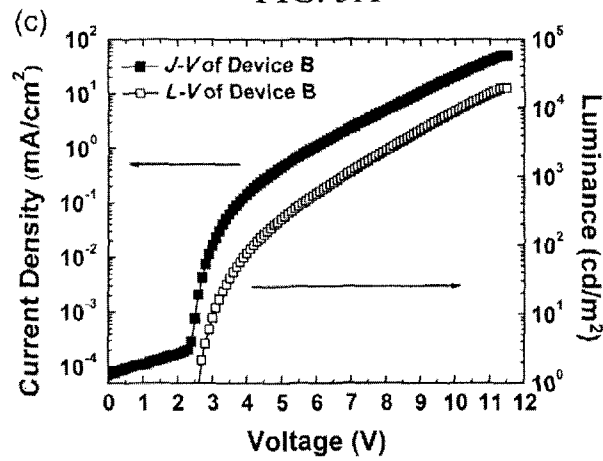


FIG. 3C

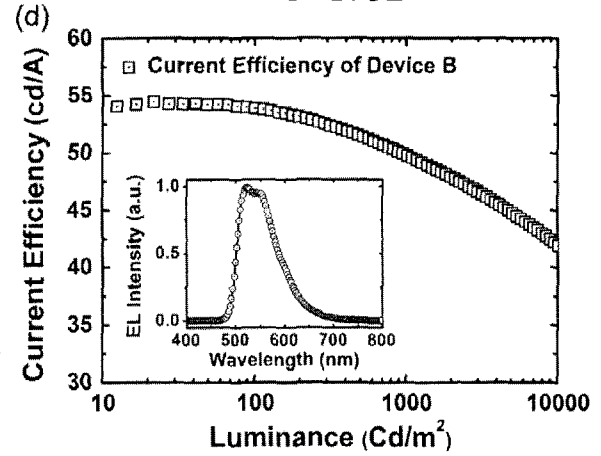


FIG. 3D

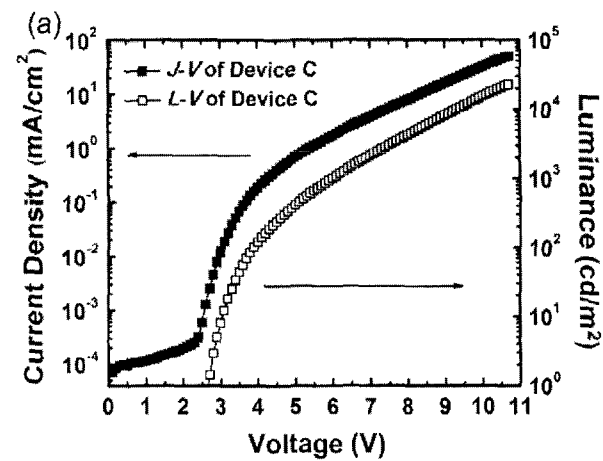


FIG. 4A

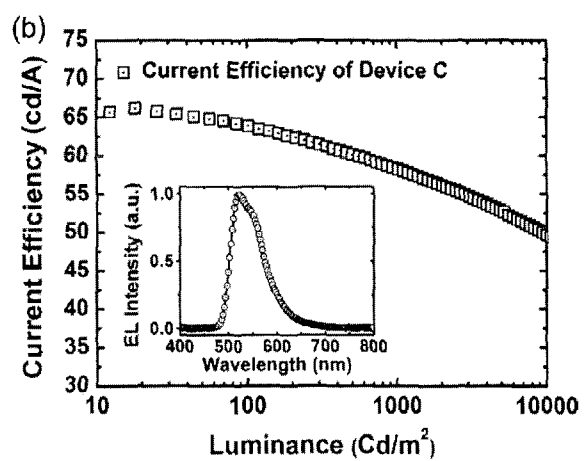


FIG. 4B

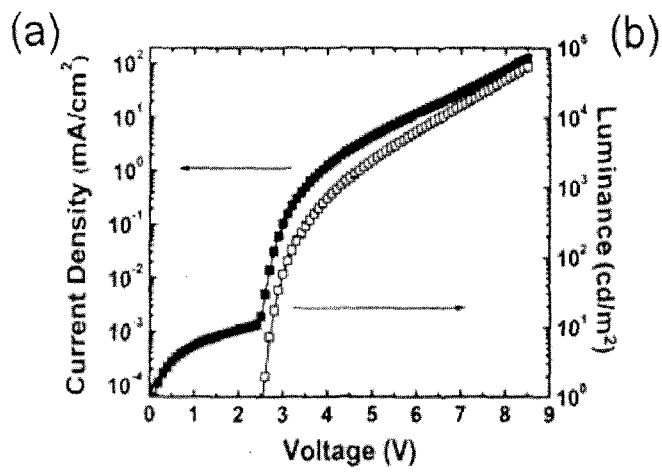


FIG. 5A

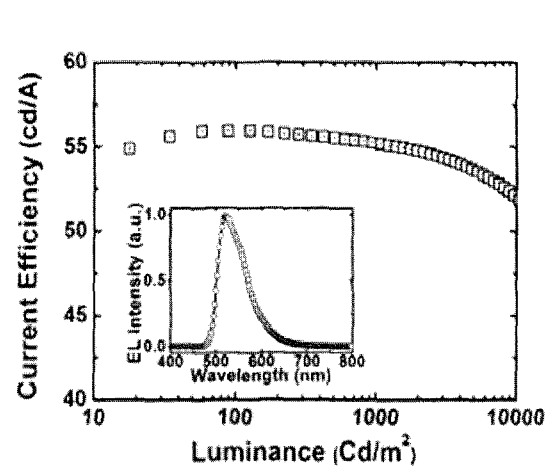


FIG. 5B

FIG. 6A

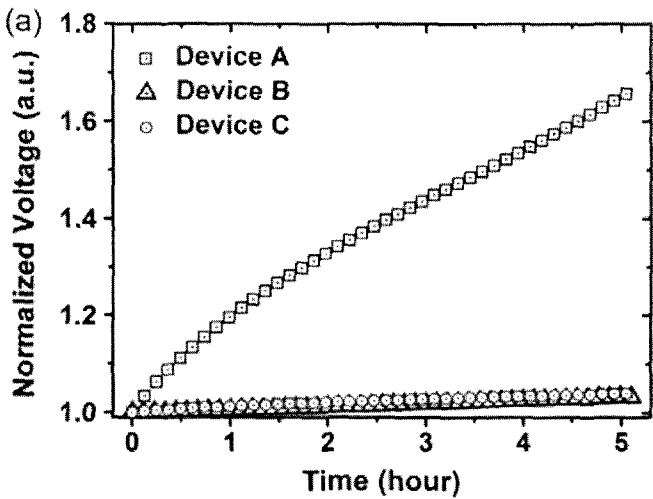


FIG. 6B

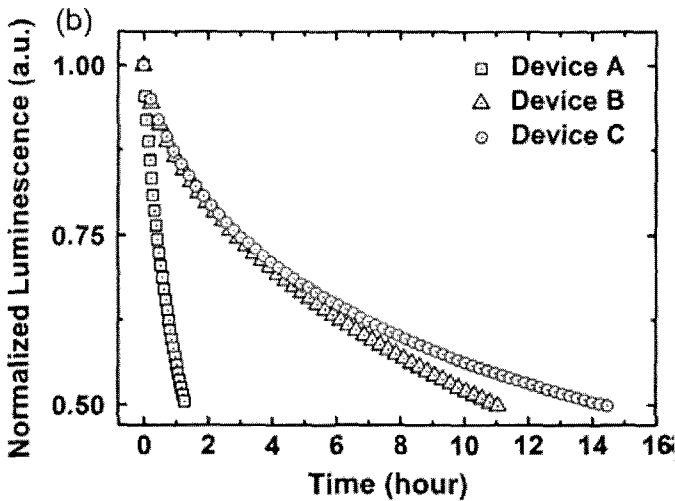
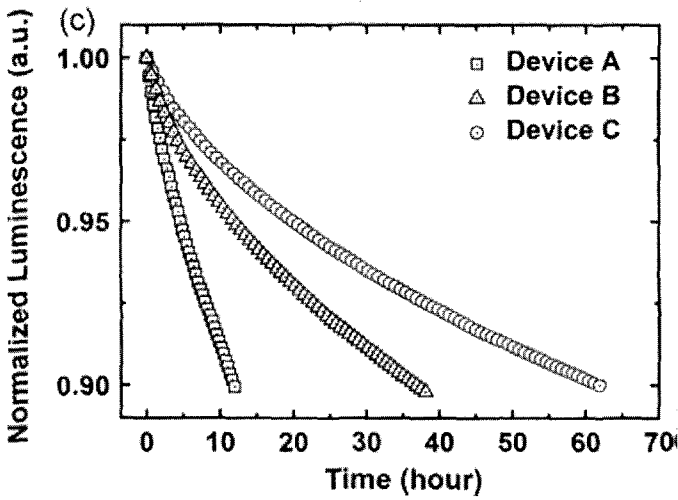


FIG. 6C



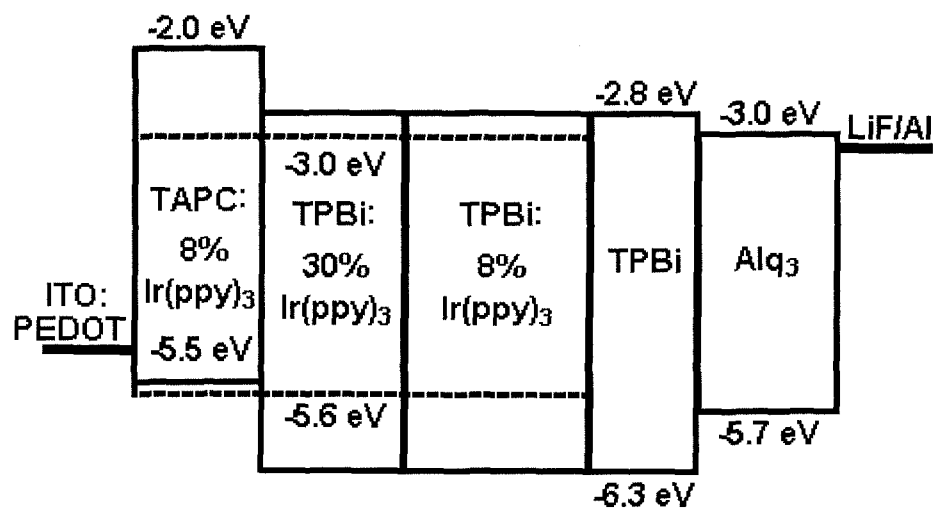


FIG. 7A

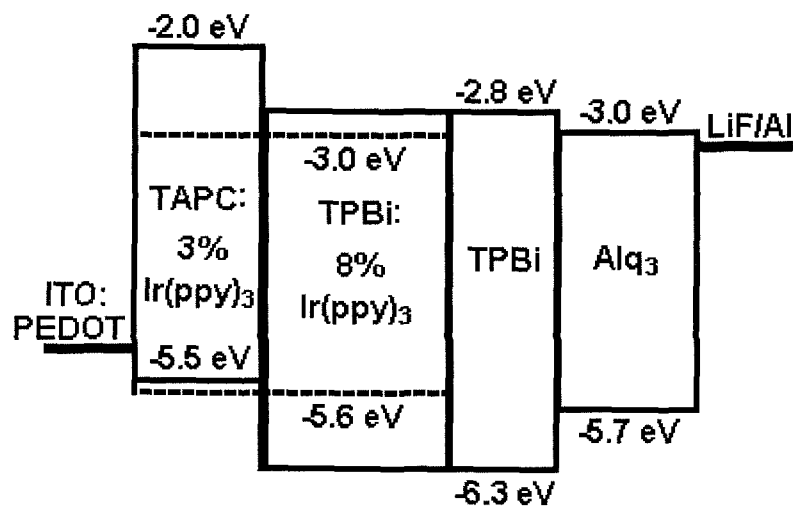


FIG. 7B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/038505**A. CLASSIFICATION OF SUBJECT MATTER****H01L 51/50(2006.01)i**

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

B. FIELDS SEARCHEDMinimum documentation searched (classification system followed by classification symbols)
H01L 51/50; H05B 33/14; H01L 51/54; H01L 51/52; H01L 33/00; C09K 11/06; H01J 1/63Documentation 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 modelsElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: organic light emitting diode(OLED), hole transport layer(HTL), emission layer(EML), hole transport phosphorescent dye, triplet energy, electron blocking**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2006-0231843 A1 (DASHAN QIN et al.) 19 October 2006 See paragraphs [0035], [0106], claim 1 and figure 5.	1-4
Y	US 2006-0134460 A1 (MARINA E. KONDAKOVA et al.) 22 June 2006 See paragraphs [0112]-[0148] and claim 1.	1-4
A	US 2008-0203406 A1 (GUFENG HE et al.) 28 August 2008 See paragraphs [0042]-[0072], claim 1 and figure 6.	1-4
A	US 2010-0033082 A1 (JIE LIU et al.) 11 February 2010 See paragraphs [0042]-[0058], claim 1 and figure 5.	1-4
A	KR 10-2010-0021908 A (SAMSUNG MOBILE DISPLAY CO., LTD.) 26 February 2010 See paragraphs [0022]-[0030], claim 1 and figure 1.	1-4



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

11 October 2016 (11.10.2016)

Date of mailing of the international search report

12 October 2016 (12.10.2016)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/038505

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