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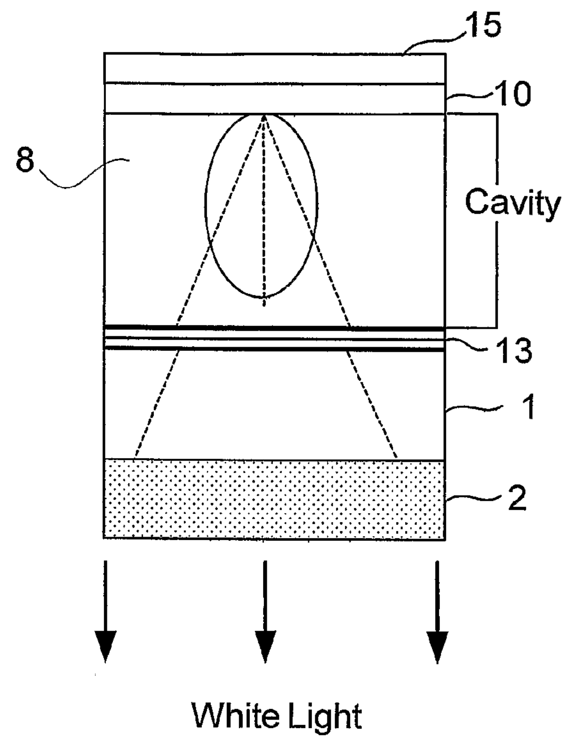
(54) Title: METHOD AND APPARATUS FOR LIGHT EMISSION UTILIZING AN OLED WITH A MICROCAVITY



(57) Abstract: Provided is an OLED device and method of making the OLED device. According to an embodiment, the OLED device incorporates a microcavity structure including a dielectric mirror formed on a glass substrate, an anode formed above the dielectric mirror, an organic film layer formed above the anode, and a reflective electrode formed above the organic film layer such that the cavity is formed in the organic film layer by the dielectric mirror and the reflective electrode. The OLED device with microcavity structure can incorporate one or more phosphors deposited on an underside of the glass substrate such that light of additional wavelengths can be generated by the OLED device.

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— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

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DESCRIPTION

METHOD AND APPARATUS FOR LIGHT EMISSION UTILIZING AN OLED WITH A MICROCAVITY

Cross-Reference to Related Application

The present application claims the benefit of U.S. Provisional Patent Application Serial No. 60/726,865, filed October 14, 2005, which is hereby incorporated by reference herein in its entirety, including any figures, tables, or drawings.

Background of Invention

Organic light emitting diodes (OLEDs) have the potential of being used in solid state lighting to replace conventional light sources such as incandescent light sources. The traditional light sources have efficiencies lower than 15 lm/W, where OLED have the potential of reaching 100 lm/W. Potential uses for OLEDs include lighting products, backlights for LCD panels, and flat panel displays.

A typical OLED device structure is shown in Figure 1. The device has multilayer organic films sandwiched between a metal cathode **10** and an indium tin oxide transparent electrode **20**. Typically, a hole transporting layer **11** is deposited on the top of an ITO electrode **20** followed by the deposition of an emitting layer **12**. Additional layers are sometimes added to the device structure to enhance the performance. One of the issues with OLEDs is that about 80% of the light generated by the device is trapped within the glass substrate **1** and only about 20% of the light can get out.

Brief Summary

Embodiments of the present invention pertain to an organic light emitting diode (OLED) device and method for producing light of one or more desired wavelengths. An embodiment relates to a method for manufacturing an OLED for producing light of one or more desired wavelengths. An embodiment of an OLED device is capable of providing an enhanced light coupling efficiency. An additional embodiment of an OLED device is capable of providing a broad color spectrum.

In a specific embodiment, an OLED device incorporates a dielectric mirror formed on a glass substrate; an anode formed above the dielectric mirror; an organic film layer formed above the anode; a reflective electrode formed above the organic film layer, wherein a cavity is formed in the organic film layer by the dielectric mirror and the reflective electrode; a cathode formed above the reflective electrode; and one or more phosphors deposited on an underside of the glass substrate.

In another aspect of the present invention, there is provided a method for manufacturing an OLED device, including: forming a dielectric mirror on a glass substrate; forming an indium-tin-oxide (ITO) layer above the dielectric layer; growing organic layers above the ITO layer; forming a metal cathode layer, including a reflective electrode above the organic layers; and coating an underside of the glass substrate with one or more phosphors.

Additional advantages, objects, and features of the invention will be set forth in part in the description which follows and in part will become apparent to those having ordinary skill in the art upon examination of the following or may be learned from practice of the invention. The objectives and other advantages of the invention may be realized and attained by the structure particularly pointed out in the written description and claims hereof as well as the appended drawings.

Brief Description of Drawings

Figure 1 shows a typical OLED structure.

Figure 2 shows a comparison between an OLED device without a microcavity and an OLED structure with a microcavity.

Figure 3 shows a comparison of the output spectrum of an OLED device without a microcavity and an OLED structure with a microcavity.

Figure 4 shows a schematic of the operation of a specific embodiment of the subject invention.

Figure 5 shows the structure of a specific embodiment of the subject invention.

Figure 6 shows the structure of a specific embodiment of a dielectric mirror on a glass substrate, with an ITO layer, which can be utilized with the embodiment shown in Figure 5.

Figure 7 shows the emission spectra for perylene red, green, and blue.

It is to be understood that both the foregoing general description and the following detailed description of the present invention are exemplary and explanatory and are intended to provide further explanation of the invention as claimed.

Detailed Disclosure

Embodiments of the present invention pertain to an organic light emitting diode (OLED) device and method for producing light of one or more desired wavelengths. An embodiment relates to a method for manufacturing an OLED for producing light of one or more desired wavelengths. An embodiment of an OLED device is capable of providing an enhanced light coupling efficiency. An additional embodiment of an OLED device is capable of providing a broad color spectrum.

Embodiments of the subject invention can include a blue light emitting organic LED (OLED) structure incorporating a microcavity structure to partially reflect the light generated in the OLED structure back into the OLED structure, so as to create a cavity effect within the device to enhance the output from the OLED. In an embodiment, the microcavity can be created with a reflective material on one end of the OLED and a reflective material at the other end of the OLED. Figure 2B shows an electrode **10** and a reflective layer **15** at one end of the OLED. The electrode **10** and reflective layer **15** can be reversed in position and/or be accomplished with a single layer, such as a layer of reflective metal as the electrode. Likewise, the other end of the OLED can have an electrode and a reflective layer, in either order of position, or have a single layer accomplish both reflection and function as an electrode. In an embodiment similar to the embodiment as shown in Figure 2B, a dielectric mirror **13** can be used at one end of the OLED and a reflective electrode **15** can be used at the other end. Such a dielectric mirror can be referred to as a half mirror and, in an embodiment, can incorporate a quarter wave stack of dielectric thin films.

Referring to Figure 5, in an embodiment, a dielectric mirror **13** can be deposited on a glass substrate **1** prior to deposition of an indium-tin-oxide (ITO) electrode. The dielectric mirror can allow for partial transmission and partial reflection of light generated within the device. By proper tuning on the cavity length, the wavelength of the reflected light can be selected, thus creating a cavity effect within the device. Because of the wavelength selectivity of the reflected light, the resonance within the cavity enhances light coupling efficiency, resulting in enhancement in light output. Typical enhancement of light output can vary between a factor of 3 and a factor of 6. Figure 3 shows the enhancement of light output for a specific embodiment of an OLED in accordance with the invention.

To generate light having a broader color spectrum, such as, for example, white light, from the blue emitting device, one or more phosphors can be placed such that the blue light from the OLED device passes through the phosphor material and causes light of additional wavelengths to be generated. Various embodiments of the invention can incorporate one or more phosphors having colors selected from, but not limited to, red, green, yellow, and orange. In a specific embodiment, a film of yellow phosphor material can be deposited on the substrate glass. Blue light coming out of the glass substrate can excite the phosphors and generate yellow light. In an embodiment, the blue light coming out of the glass substrate can have a wavelength in the range of about 430 nm to about 500 nm. By proper mixture of blue and yellow light, a high efficiency white source can be generated. The phosphor materials can be inorganic phosphors or organic phosphors. Inorganic phosphor particle matter tend to scatter light more and provide a more uniform light emitting devices while organic phosphors tend to give a more directional light sources.

Figure 4 shows a schematic of the operation of a specific embodiment of an OLED in accordance with the subject invention. The subject OLED can incorporate the cavity device of Figure 2, a glass substrate **1**, and a phosphor coating **2**. In one embodiment, a blue light emitting microcavity OLED can be used where the blue light can be down converted to white light using yellow phosphors. In operation, blue light coming out of the glass substrate **1** can excite the yellow phosphors in the phosphor coating **2** to generate a white light.

Referring to Figure 5, a specific embodiment of the invention is shown. Fabrication of the device shown in Figure 5 can begin with a glass substrate **1**. An OLED can be grown on the glass substrate. Prior to growing the OLED, a dielectric mirror **13** can be grown on the glass substrate **1**. This dielectric mirror **13** structure is shown in further detail in Figure 6. The substrates can be degreased with solvents and then cleaned by exposure to oxygen plasma and UV-ozone ambient. All organic and cathode metal layers can be grown in succession without breaking the vacuum.

The dielectric mirror **13** shown in Figure 6 can be grown by alternating layers of TiO_2 (n=2.45) and SiO_2 (n=1.5). These alternating layers can create a Bragg-type reflector, such as a quarter-wave dielectric stack reflector. Other materials and structures can also be used to create the dielectric mirror. The resulting dielectric mirror structure shown in Figure 6 has a peak reflectivity of about 80-95% over a range of wavelengths between 400 nm to 550 nm. In an embodiment, the peak reflectivity of the dielectric mirror is in the range between 70-95%, in a further embodiment in the range between 80-95%, in a further embodiment in the range between 80-90%. A silicon nitride layer can be used as a spacer layer prior to growing an ITO layer, which can be an electrode for the OLED. The thickness of the silicon nitride layer can be controlled to control the length of the cavity. By using such a spacer layer that can have a variable thickness the thickness of the organic film layer can be held approximately constant for devices having different cavity lengths. In this way, the operating voltage of the devices can be approximately the same while the wavelength varies from device to device. Referring back to Figure 5, organic layers can then be grown on the ITO layer to create the OLED. Although a variety of materials can be utilized for the organic layers, in a specific embodiment shown in Figure 5, these organic layers include the following:

EIL, electron injection layer: Cs doped into a matrix of 4,7-diphenyl-1,10-phenanthroline (BPhen)

ETL, electron transport layer: 4-biphenyloxolato Aluminum (bis~2-methyl-8-quinolinato)4-phenylphenolate (BAlq)

EML, emissive layer: host4 *N*,*N*8-dicarbazolyl-3,5-benzene (mCP) doped with phosphorescent iridium complex iridium(III)bis[(4,6- Difluorophenyl)-pyridinato-*N*,*C*2']picolinate (FIrpic)

HTL, Hole transport layer: 4-4'-bis[*N*-(1-naphthyl)-*N*-phenyl-amino]biphenyl (a-NPD)

HIL, hole injection layer, zinc phthalocyanine (ZnPc) doped with 2,3,5,6-tetrafluoro-7,7,8,8-tetracyanoquinodimethane (F_4-TCNQ)

To fabricate the device, first, a 10-nm-thick zinc phthalocyanine as a hole injection layer and a 30-nm-thick NPD hole transport layer were deposited. Next, 6% FIrpic by weight was codeposited with either mCP to form the 30-nm-thick emissive layer. Finally, a 40-nm-thick electron transport layer of BAlq is deposited and used to block holes and confine excitons in the emissive zone. A 30 nm thick EIL consisting of Cs coevaporated with BPhen is deposited. Cathodes consisting of a 1-nm-thick layer of LiF followed by a 100- nm-thick layer of Al were deposited (note that Figure 5 does not show the LiF layer separately). Other metals can be used for this cathode layer. The metal cathode also functions as an end mirror for the microcavity. All organic and cathode metal layers can be grown in succession without breaking the vacuum.

The phosphor coating **2** on the underside of the glass substrate **1** can utilize one or more phosphors, such as organic phosphors and inorganic phosphors. In an embodiment, the phosphor film thickness can range from about 1 micron to about 50 microns. Inorganic phosphors can be used in a polymer binder such as PMMA. Examples include YAG:Ce ($Y_3Al_5O_{12}$:Ce) based phosphors, silicate or nitridosilicate phosphors, $A_2Si_5N_8$ (red-yellow emission) and $ASi_2O_2N_2$ (yellow-green emission where A is an alkaline earth element), and nano-particles of YAG:Ce and CdS:Mn/ZnS. Organic phosphors can be, for example, dissolved in a solvent or can be a polymer. Examples include perylene (3,9-perylenedicarboxylic acid, bis(2-methylpropyl) ester) red and perylene orange dispersed in a PMMA host. Figure 7 shows emission spectra for perylene red, green, and blue (labeled accordingly).

Accordingly, as described above, an OLED including a microcavity structure is capable of emitting a colored light according to the length of the cavity at an enhanced efficiency by the cavity structure.

Also, according to the present invention, a broader color spectrum can be generated by the application of one or more phosphors to the OLED device, so that light from the OLED device passes through the one or more phosphors and causes light of additional wavelengths to be generated.

It will be apparent to those skilled in the art that various modifications and variations can be made in the present invention. Thus, it is intended that the present invention covers the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

All patents, patent applications, provisional applications, and publications referred to or cited herein are incorporated by reference in their entirety, including all figures and tables, to the extent they are not inconsistent with the explicit teachings of this specification. 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

What is claimed is:

1. A device for producing light, comprising:

a first reflective layer formed above a first surface of a glass substrate;

a first electrode formed above the first surface of the glass substrate;

an organic film layer formed above the first electrode;

a second electrode formed above the organic film layer;

a second reflective layer formed above the organic film layer, wherein a cavity is formed by the first reflective layer and the second reflective layer such that light generated in the organic film layer within the cavity is reflected back into the cavity by the second reflective layer and partially reflected back into the cavity by the first reflective layer so as to create a cavity effect; and

a layer incorporating one or more phosphors below a second surface of the substrate glass,

wherein a portion of the light from the cavity incident on the first reflective layer passes through the first reflective layer and passes through the glass substrate, wherein the light exiting the second surface of the substrate glass passes through the layer incorporating one or more phosphors and causes light of additional wavelengths to be generated as output light from the device.

2. The device according to claim 1, wherein the first reflective layer is formed on the first surface of the glass substrate.

3. The device according to claim 1, wherein the first reflective layer is the first electrode.

4. The device according to claim 1, wherein the second electrode is the second reflective layer.

5. The device according to claim 1, further comprising a spacer layer between the first reflective layer and the first electrode.

6. The device according to claim 5, wherein adjusting the width of the spacer layer changes the wavelength with respect to which the cavity effect is created.

7. The device according to claim 1, wherein the organic film layer comprises:

a hole injection layer where holes are injected into;

a hole transport layer formed on the hole injection layer, through which the injected holes travel;

an emissive layer formed on the hole transport layer;

an electron transport layer formed on the emissive layer; and

an electron injection layer formed on the electron transport layer where electrons are injected, wherein injected electrons travel through the electron transport layer and recombine with the injected holes in the emissive layer to generate light in the cavity.

8. The device according to claim 7, wherein the hole injection layer comprises zinc phthalocyanine (ZnPc) doped with 2,3,5,6-tetrafluoro-7,7,8,8-tetracyanoquinodimethane (F4-TCNQ),

wherein the hole transport layer comprises 4-4'-bis[*N*-(1-naphthyl)-*N*-phenyl-amino]biphenyl (a-NPD),

wherein the emissive layer comprises host4 *N*,*N*8-dicarbazolyl-3,5-benzene (mCP) doped with phosphorescent iridium complex iridium(III) bis[(4,6- Difluorophenyl)-pyridinato-*N*,*C*2']picolinate (FIrpic),

wherein the electron transport layer comprises 4-biphenyloxolato Aluminum (bis~2-methyl-8-quinolinato)4-phenylphenolate (BAlq), and

wherein the electron injection layer is Cs doped into a matrix of 4,7-diphenyl-1,10-phenanthroline (BPhen).

9. The device according to claim 1, wherein a spacing between the first reflective and the second reflective is selected such that a desired light wavelength resonates within the cavity.

10. The device according to claim 9, wherein the wavelength of the light with respect to which the cavity effect is created is in the range from about 430 nm to about 500 nm.

11. The device according to claim 1, wherein the output light from the device is substantially white.

12. The device according to claim 9, wherein the resonance within the cavity enhances the output light output between a factor of 3 and a factor of 6.

13. The device according to claim 2, wherein the light exiting the second surface of the glass substrate passing through the one or more phosphors causes light having additional wavelengths associated with one or more colors selected from the group consisting of: red, green, yellow, and orange.

14. The device according to claim 1, wherein the one or more phosphors comprises an inorganic phosphor.

15. The device according to claim 14, wherein the inorganic phosphor uses a polymer binder, wherein the inorganic phosphor is selected from the group consisting of YAG:Ce ($Y_3Al_5O_{12}$:Ce) based phosphors, silicate or nitridosilicate phosphors, $A_2Si_5N_8$ (red-yellow emission) and $ASi_2O_2N_2$ (yellow-green emission where A is an alkaline earth element), and nano-particles of YAG:Ce and CdS:Mn/ZnS.

16. The device according to claim 1, wherein the one or more phosphors comprise an organic phosphor.

17. The device according to claim 16, wherein the organic phosphor is perylene (3,9-perylenedicarboxylic acid, bis(2-methylpropyl) ester) red or perylene orange dispersed in a PMMA host.

18. The device according to claim 1, wherein the first reflective layer comprises a stack of dielectric thin films.

19. The device according to claim 18, wherein the stack dielectric thin films comprises an alternating stack of TiO_2 and SiO_2 layers to form a Bragg-type reflector.

19. A method of producing light, comprising:

forming a first reflective layer above a first surface of a glass substrate;

forming a first electrode above the first surface of the glass substrate;

forming an organic film layer above the first electrode;

forming a second electrode above the organic film layer;

forming a second reflective layer above the organic film layer, wherein a cavity is formed by the first reflective layer and the second reflective layer such that light generated in the organic film layer within the cavity is reflected back into the cavity by the second reflective layer and partially reflected back into the cavity by the first reflective layer so as to create a cavity effect; and

positioning a layer incorporating one or more phosphors below a second surface of the substrate glass,

wherein a portion of the light from the cavity incident on the first reflective layer passes through the first reflective layer and passes through the glass substrate, wherein the light exiting the second surface of the substrate glass passes through the layer incorporating one or more phosphors and causes light of additional wavelengths to be generated as output light from the device.

20. The method according to claim 19, wherein forming an organic film above the first electrode comprises:

forming a hole injection layer above the first electrode;

forming a hole transport layer on the hole injection layer;

forming an emissive layer on the hole transport layer;

forming an electron transport layer on the emissive layer; and

forming an electron injection layer on the electron transport layer, wherein the holes are injected into the hole injection layer and travel through the hole transport layer, wherein electrons are injected into the electron injection layer and travel through the electron transport layer and recombine in the emissive layer with the holes to generate light in the cavity.

21. The method according to claim 19, wherein the second electrode is the second reflective material layer.

22. The method according to claim 19, wherein the output light from the device is substantially white.

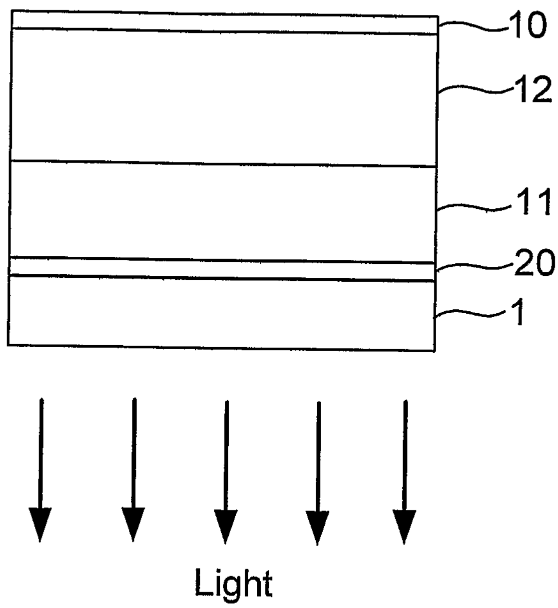


FIG. 1

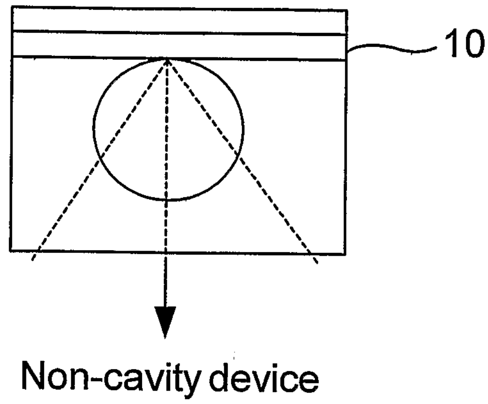


FIG. 2A

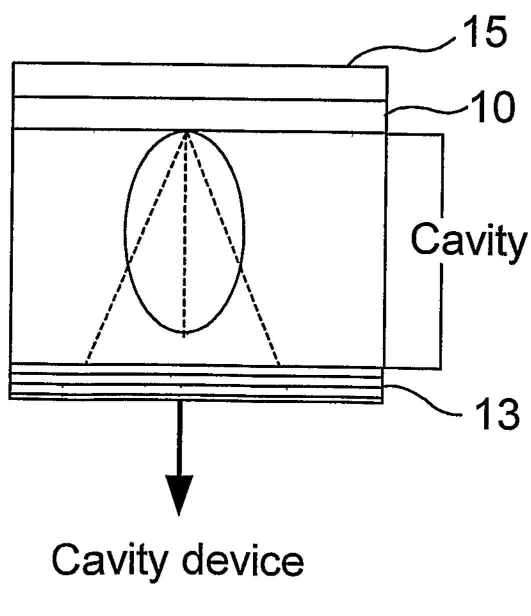


FIG. 2B

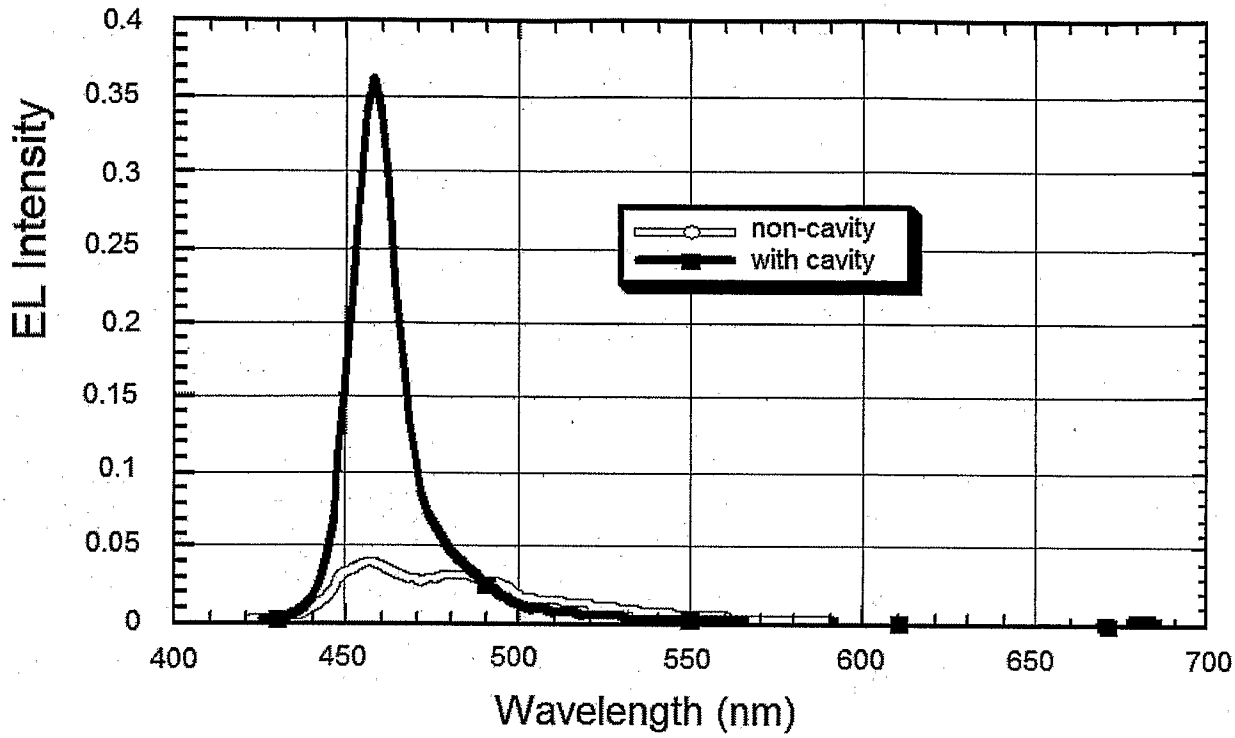

0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
EL Intensity
400
450
500
550
600
650
700
Wavelength (nm)
non-cavity
with cavity

FIG. 3

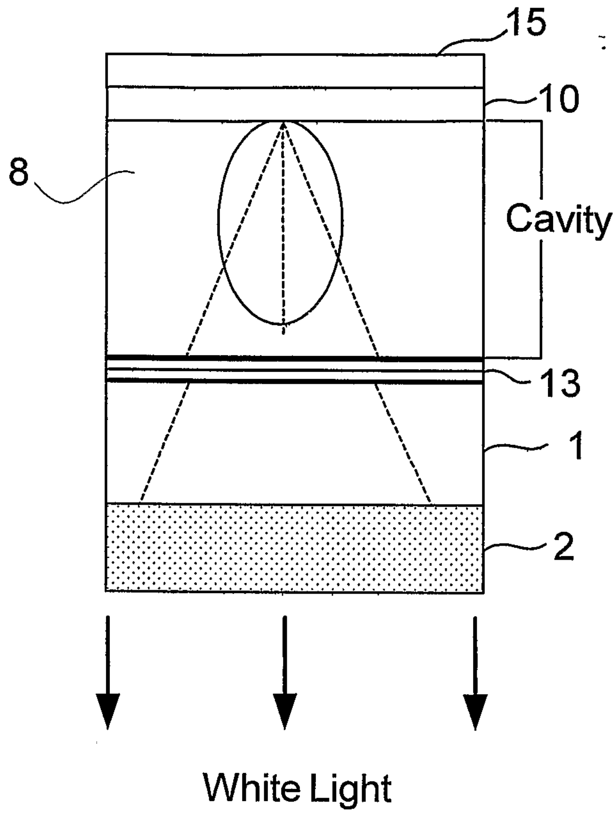


FIG. 4

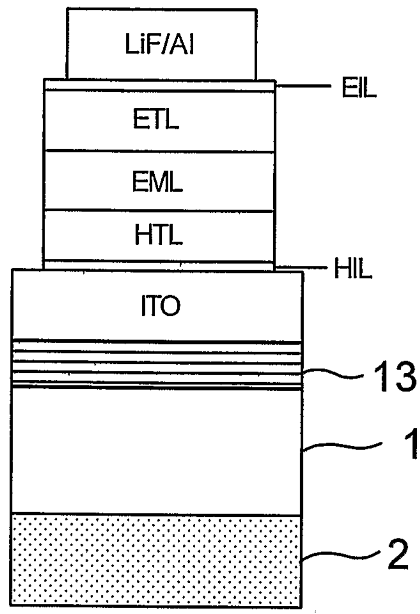
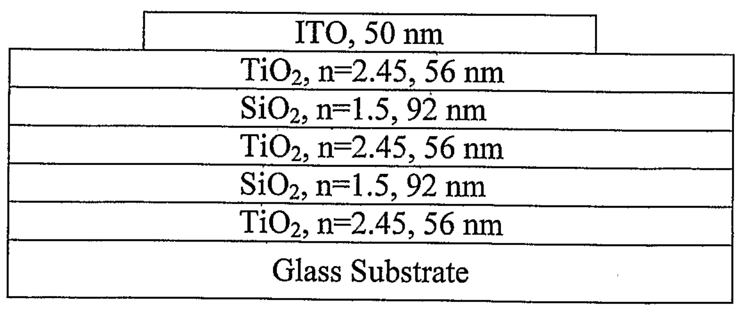

LiF/Al
EIL
ETL
EML
HTL
HIL
ITO
13
1
2

FIG. 5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SiO2, n=1.5, 92 nm
TiO2, n=2.45, 56 nm
SiO2, n=1.5, 92 nm
TiO2, n=2.45, 56 nm
Glass Substrate

FIG. 6

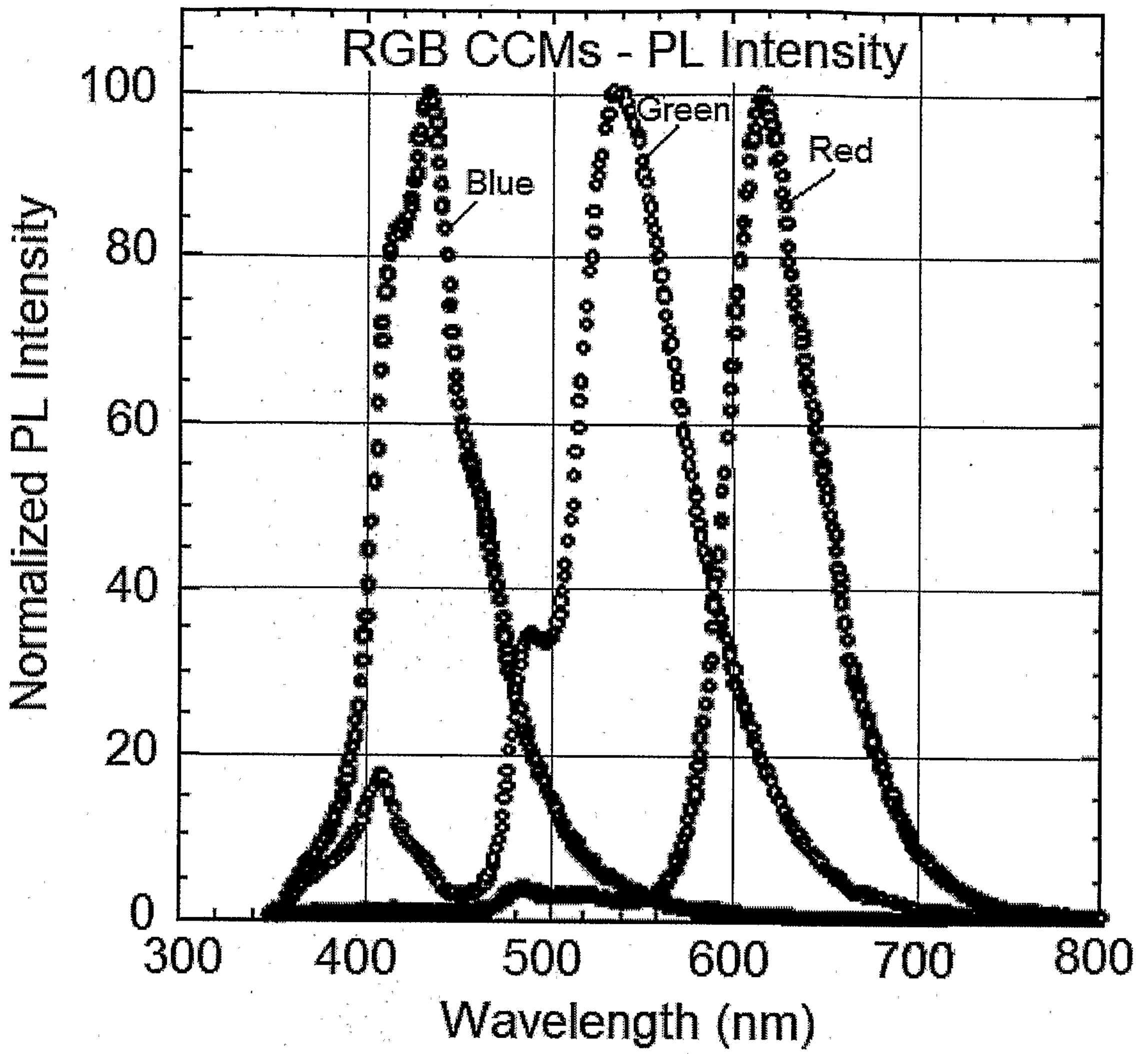
RGB CCMs - PL Intensity
Normalized PL Intensity
100
80
60
40
20
0
300
400
500
600
700
800
Wavelength (nm)
Blue
Green
Red

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/040748

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L51/52

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

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2005/058852 A1 (TYAN YUAN-SHENG [US] ET AL) 17 March 2005 (2005-03-17) paragraphs [0014], [0021], [0022], [0029], [0123], [0135], [0136] -----	1-22
Y	DUGGAL ANIL R ET AL: "Organic light-emitting devices for illumination quality white light" APPLIED PHYSICS LETTERS, AIP, AMERICAN INSTITUTE OF PHYSICS, MELVILLE, NY, US, vol. 80, no. 19, 13 May 2002 (2002-05-13), pages 3470-3472, XP012030809 ISSN: 0003-6951 the whole document -----	1-22
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
22 February 2007	28/02/2007

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Welter, Steve

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2002/175619 A1 (KITA HIROSHI [JP] ET AL) 28 November 2002 (2002-11-28) paragraphs [0047], [0048], [0060] - [0065], [0075] - [0077], [0125], [0132] - [0145]	1-22

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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