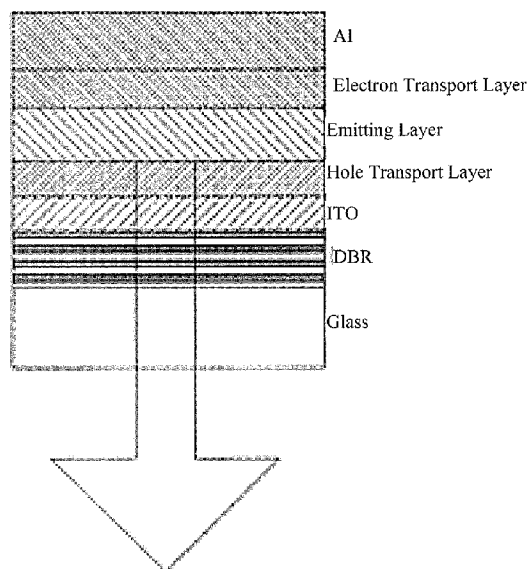




- (51) International Patent Classification:
H05B 33/20 (2006.01)
- (21) International Application Number:
PCT/US2013/058151
- (22) International Filing Date:
5 September 2013 (05.09.2013)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
61/697,474 6 September 2012 (06.09.2012) US
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- (81) Designated States (*unless otherwise indicated, for every
kind of national protection available*): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KN, KP, KR,
KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME,
MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM,
TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM,
ZW.

[Continued on next page]

(54) Title: WHITE LIGHT EMITTING DIODE DEVICES



(57) Abstract: A white light generating device has at least four pixels where each pixel is a different colored light emitting device (LED) such that the combination of the pixels produces a white light of a desired color temperature upon demand. The LEDs can be organic light emitting devices (OLEDs) or inorganic LEDs. The LEDs can have a microcavity structure for enhanced light output and additionally permitting a broader range of color temperatures than can generally be achieved without the microcavity structure. The color temperature provided by the white light generating device can be changed to achieve different effects. By having at least four colors, more natural aesthetics of illuminated surfaces is achieved, as the reflected light from non-white surfaces is similar to that of reflected natural light.

Figure 3



(84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

DESCRIPTION

WHITE LIGHT EMITTING DIODE DEVICES

5 CROSS-REFERENCE TO RELATED APPLICATION

The present application claims the benefit of U.S. Provisional Application Serial No. 61/697,474, filed September 6, 2012, which is hereby incorporated by reference herein in its entirety, including any figures, tables, or drawings.

10 BACKGROUND OF INVENTION

Organic light emitting diodes (OLED) are a very promising next generation lighting source for general lighting applications because of the possible high luminance efficiency, being a large area light source, rather than the single point sources with inorganic LED, the potential for cost effective roll-to-roll manufacturing, and the ability to make flexible lighting panels. Mass production of white OLED lighting is envisioned to begin in late 2012 or early 15 2013, assuming that the technology issues of forming the lighting devices with high luminance efficiency and low cost are overcome.

In general, the generation of white light from OLEDs has been pursued by one of three different methods. The first method employs a single emissive layer comprising a mixture of different emissive materials, which, although simple to manufacture, is difficult to 20 tune in color while maintaining good device performance. The second method uses a stacked red-green-blue emissive material, which allows a facile tuning of the color mix but is complex to manufacture and generally suffers from color stability, as the different layers age at different rates. The third method involves the placement of a color conversion material on an emission face of a single OLED, for example, a yellow phosphor, a down conversion 25 material, on the surface of a blue OLED. Although this overcomes the color stability problem, the devices generally suffer from a low absorption efficiency of the color conversion material.

In a single color OLED device the light output into air can be increased by the construction of a microcavity, which comprises either a semitransparent electrode and/or a 30 sequence of high and low index layers with optimized thicknesses between a transparent electrode of the OLED and the light exiting substrate, where, generally, two very high index

layers sandwiching a low index layer is sufficient to form an effective microcavity. When a white light OLED is prepared using a mixture or stack of emissive materials, the improvement of luminous power efficacy by a microcavity can be applied only to a single color in a wavelength range of about 90 nm, with the light emission outside of this wavelength range being reduced in intensity.

Additionally, these designs for white light OLEDs do not permit varying the color temperature on demand. The color temperature of sunlight varies from a low of 2500 K during mornings and evenings, to a high of 8000K during daytime. A color tunable OLED illumination display is taught by Rogojevic *et al.*, U.S. Patent Application Publication No. 2008/0137008, which teaches devices with three stacked layers, where each layer has a multiplicity of pixels, one third of which is emissive active for a chosen color, but where upon proper alignment of the three layers the color pixels of one layer align vertically with inactive pixels of the other layers. The layers could be independently addressed to provide color temperatures from about 5500 K to about 6500 K, or about 2800 K to about 5500 K. The ability to present natural reflective rendering was not apparently disclosed. Gaertner *et al.*, U.S. Patent Application Publication No. 2012/0153320, teaches a light emitting device where two or three alternating stripes of different color electroluminescent OLEDs are constructed for microcavity effects such that the device can have enhanced light output. An ability to change the color temperature of the emitted light is not disclosed. The level of the hormone melatonin in our brain circulates in sync with the daily cycle of the sunlight's color temperature. For example, during the day, the level of melatonin decreases, helping people remain awake, while at night the level of melatonin increases, helping people relax. Recent studies show that the color temperature of artificial lighting critically affects the normal 24 hours circadian rhythms and a low color temperature of lighting at night is favored physiologically and psychologically. Hence, white light OLEDs that are efficient and allow variation of the color temperature remains a goal for OLED lighting.

BRIEF SUMMARY

An embodiment of the invention is directed to a color temperature-tunable white OLED lighting having a microcavity structure that improves the luminance efficiency. The white OLED lighting comprises separate pixels that emit blue, green, red and yellow (or orange) light. The microcavity structure of each pixel significantly narrows the

electroluminescence (EL) spectrum of emitting light. The separate blue, green, red, and yellow (or orange) pixels allow independent control of the EL intensity at each pixel. Independent control permits a range of color temperatures to be achieved with the emitting light. The white OLED lighting with the microcavity structure can express all kinds of the color temperature in a single lighting panel and change the color temperature from 1000 K to 8000 K by choice, or automatically, for example, to match the daily cycle of color temperature exhibited by sunlight. Additionally, the microcavity structure within the OLEDs improves the luminance efficiency by an enhancement of the outcoupling efficiency. Finally, high efficient and color temperature-tunable white OLEDs can be fabricated with the microcavity structure.

BRIEF DESCRIPTION OF DRAWINGS

Figure 1 shows a drawing of a prior art white light OLED where three different organic emitting layers are stacked.

Figure 2 shows a drawing of a white light device comprising four pixels that are four OLEDs where features are shown without the structures for microcavity effects as in embodiments of the invention.

Figure 3 shows OLEDs with a DBR that can be used in the white light device according to an embodiment of the invention.

Figure 4 shows a) a top emitting OLED, and b) a bottom emitting OLED that includes a thin film electrode to provide a microcavity effect and can be used in white light devices according to embodiments of the invention.

Figure 5 shows composite spectra for a) blue, b) green, and c) red OLEDs without DBRs (broad emission) and with DBRs (narrow emission), which can be used in white light devices according to embodiments of the invention.

Figure 6 shows plots of a CIE plot with indices of the blue, green, and red emitting devices with a DBR (apexes of a large triangle) and without a DBR (apexes of a smaller triangle) where the color temperature of white light available from these combinations are displayed on a curve plotted in the center of the triangles.

Figure 7 shows plots of current efficiencies of a green emitting OLED with a DBR (empty diamonds) and without a DBR (filled diamonds) as a function of luminance.

DETAILED DISCLOSURE

In contrast to typical white light OLEDs that comprise sequentially deposited blue, green and red emitting layers, as shown in Figure 1, white light LED devices, according to an embodiment of the invention, comprise separate colored LED pixels, where four or more colors are generated. The EL spectrum of emitting light from the device is fixed to single color temperature. White light OLEDs, according to an embodiment of the invention, comprise a structure that is illustrated in Figure 2, where drive voltages can be separately applied to at least four individual colored pixels. In an embodiment of the invention, the color temperature of white light can be controlled by combination of each OLED's intensity where each OLED pixel of the white light OLED is a microcavity OLED to enhance the output of light from each of the different colored pixels comprising the white light source. The microcavity OLED has a structure that comprises an optical medium, including an electroluminescent layer, sandwiched with a perfectly reflective layer and a partially transmissive layer (partially reflective layer). Because of multiple reflections of the generated light between the two reflective layers, a resonant wavelength preferably escapes the microcavity with a narrower wavelength distribution than that generated in the electroluminescent layer. The thickness of the optical medium determines the resonant wavelength in the microcavity structure, which can be adjusted, within limits, to produce the desired output wavelength distribution at a higher intensity than is possible absent the microcavity structure.

OLED emitter materials produce relatively broad electroluminescence (EL) spectra with wide full width at half maximum (FWHM). Because of the broad spectra, the simple device of Figure 1, or even one similar to Figure 2 employing three pixels, has a limited range of the color temperatures for the emitted white light. The microcavities of the OLEDs, for the white light OLED device according to an embodiment of the invention, are composed of an optical medium that is sandwiched by a perfectly reflective layer and a partially transmissive layer. By multiple reflections of emitting light between two reflectors, a specific resonant wavelength escapes the microstructure, thereby narrowing the EL spectrum of emitting light. The thickness of the optical medium determines the resonant wavelength in the microcavity structure.

For OLEDs, as illustrated in Figure 2, hole transport layers can be selected from any appropriate material, including, but not limited to: 1,1-bis[(di-4-tolylamino)phenyl]

cyclohexane (TAPC); *N,N'*-diphenyl-*N,N'*-(2-naphthyl)-(1,1'-phenyl)-4,4'-diamine (NPB); *N,N'*-diphenyl-*N,N'*-di(*m*-tolyl) benzidine (TPD); poly[(9,9-dioctyl-fluorenyl-2,7-diyl)-*alt-co*-(9-hexyl-3,6-carbazole)] (PF-9HK); and 4,4',4''-tris-(*N*-carbazolyl)-triphenylamine (TCTA). The organic light emitting layers can be selected from any appropriate material, including, but not limited to: poly-[2-methoxy, 5-(2'-ethyl-hexyloxy) phenylene vinylene] (MEH-PPV); *tris*(8-hydroxy quinoline) aluminum (Alq₃); iridium (III) *bis*[(4,6-difluorophenyl)-pyridinate-*N,C2'*]picolinate (FIrpic) (blue dopant); [iridium(III)*bis*(2-methyldibenzo[*f,h*]quinoxaline) (acetylacetonate)] (Ir(MDQ)2(acac)) (red dopant); *tris*(phenyl pyridine)iridium (Ir(ppy)₃) (green dopant); oxadiazole pendant poly(phenylene vinylene); oligo(9,9-di-*n*-octylfluorene-2,7-vinylene); poly(4-4'-diphenylene diphenylvinylene) (PDPV); poly(9,9-dialkylfluorenes) or poly(*bis*acetylide thiophenes) with 2,1,3-benzothiadiazole (BTD) or quinoxaline; diphenyloxadiazole pendant polystyrene; 5,6,11,12-tetraphenylnaphthacene; *bis*(4',6'-Difluoro-phenylpyridinato)-4,9-bis-[4-(2,2-diphenyl-vinyl)-phenyl]-naphtho[2,3-*c*] [1,2,5]thiadiazole; 4,4'-*bis*'2,2'-diphenylvinyl'-1,1'-spirobiphenyl (Spiro-DPVBi); and FIrpic, Ir(ppy)₃, and/or Ir(MDQ)2(acac) doped into 4,4'-*bis*(carbazol-9-yl)-biphenyl (CBP), *N,N'*-dicarbazolyl-3,5-benzene (mCP), 1,3,5-*tris*(*N*-phenylbenzimidazole-2-yl)benzene (TPBI) or *N,N'*-diphenyl-*N,N'*-bis(1-naphthyl)-(1,1'-biphenyl)-4,4'-diamine (NPB). Electron transport layers can be inserted between the electroluminescent layer and the cathode, and can be selected from any appropriate material, including, but not limited to: *tris*[3-(3-pyridyl)-mesityl]borane (3TPYMB); 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP); 4,7-diphenyl-1,10-phenanthroline (BPhen); and *tris*(8-hydroxy quinoline) aluminum (Alq₃).

Figure 3 shows a microcavity OLED that employs a dielectric bragg reflector (DBR) on the light exiting face of a transparent electrode and a thick Al cathode layer that functions effectively as a perfectly reflective layer. The exemplary DBR consists of two pairs of quarter-wave stacks of alternative high refractive index materials, such as, titanium oxide (TiO₂) or Tantalum oxide (Ta₂O₅) and low refractive index materials, such as, silicon oxide (SiO₂) or LiF. Other DBRs of more layers and/or of different materials can be used. Figures 4a) and b) show bottom emitting and top emitting microcavity OLEDs, respectively, where a thin semitransparent metal electrode layer is employed as a partially transmitting layer to create the microcavity effect. The thin semitransparent metal electrode layer can be gold (Au), silver (Ag), copper (Cu), Molybdenum (Mo), or nickel (Ni), to function as a

semitransparent metal anode layer, or Ag, magnesium silver alloy (MgAg), calcium (Ca)/Ag bilayer, aluminum (Al), Ca/Al, or Lithium Fluoride (LiF)/Al to function as a thin semitransparent metal cathode layer.

The colored lights exiting the white light device can pass through at least one diffuser positioned appropriately with respect to the OLEDs on the light exiting face. The diffuser is positioned at a distance from the OLEDs that optimally mixes and diffuses the light emerging from the device. The diffuser element may comprise a transparent material with a textured surface. The diffuser can be, but is not limited to, a transparent material having one or both surfaces textured, a layer comprising a multiplicity of positive or negative lens structures, Fresnel lens structures, a curved layer, a layer comprising suspended particles of a high index within a lower index medium, or any combination of such structures. The diffuser is positioned at a finite distance from the OLEDs. The optimal distance at which the diffuser is position depends on the size, arrangement, and emission spectra of the OLEDs, where the optimal position can allow a uniform appearance of the light when viewed.

Figures 5a), b), and c) shows EL spectra of blue, green, and red emitting OLEDs with a DBR and without a DBR, such as that shown in Figure 3, for OLEDs employing the emitters Firpic, Ir(ppy)₃, and Ir(MDQ)₂(acac), respectively. The DBR OLEDs display a narrow FWHM in their EL spectra, relative to the OLEDs without DBR, because of the microcavity effects with the DBRs. The narrowed EL spectra of the DBR OLEDs allow control of a wide range of color temperatures for emitted white light. However, when only three narrow colors reflected light from objects in a room that absorb or transmit the specific wavelengths of the individual OLEDs results in a false color of these objects, which is an unsatisfactory effect for the aesthetics desired of the environment illuminated by the white OLEDs by the combination of three individual OLED pixels. This occurs, even though the combination of three colors, as plotted with the Commission Internationale de L'Eclairage (CIE) coordinates of blue, green, and red, as shown in Figure 6, permits the emission of a very broad perceived pallet of colors. This emitted color pallet can be greater for a device employing the DBR OLEDs (larger triangle) than the device without DBR (smaller triangle). The RGB OLED devices with DBR permits emission of a greater proportion of the color temperatures of natural white light, which is plotted almost entirely within the wider triangle area shown in Figure 6, where nearly all color temperatures of white light, 1000 K to 40000 K, can be achieved with colors provided due to the OLEDs with the microcavity effects,

including the higher color temperatures that are not achievable from the same emitters in OLEDs without DBRs.

The current efficiencies for the OLED devices with DBR are significantly improved by the microcavity effect over that of devices without DBR. Figure 7 shows the current efficiencies of the green emitting OLED with DBR and without DBR. The current efficiency was enhanced by about 140% by inclusion of the DBR. Although embodiments of the invention have been presented for white light devices comprising OLEDs, the devices can be formed using at least four inorganic LEDs as the light emitters of different colors or combinations of inorganic and organic emitters. For example, the colored inorganic semiconductors suitable for inclusion in the device include, but are not limited to, InGaN / GaN, ZnS, GaP:N, AlInGaP, GaAsP, GaAsP:N, InGaP, AlGaAs, and GaAs. The white light devices comprising inorganic LEDs can be formed using pixels that comprise quantum dot light emitters. The use of quantum dots permits the retention of many advantages of OLED emitters, such the preparation of a flexible device. With all of these devices, by having a good approximation of the components of white light provided by at least four independently addressable pixels of different colors having microcavity effects, the device can provide a wide range of selected color temperatures on demand with a high efficiency.

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.

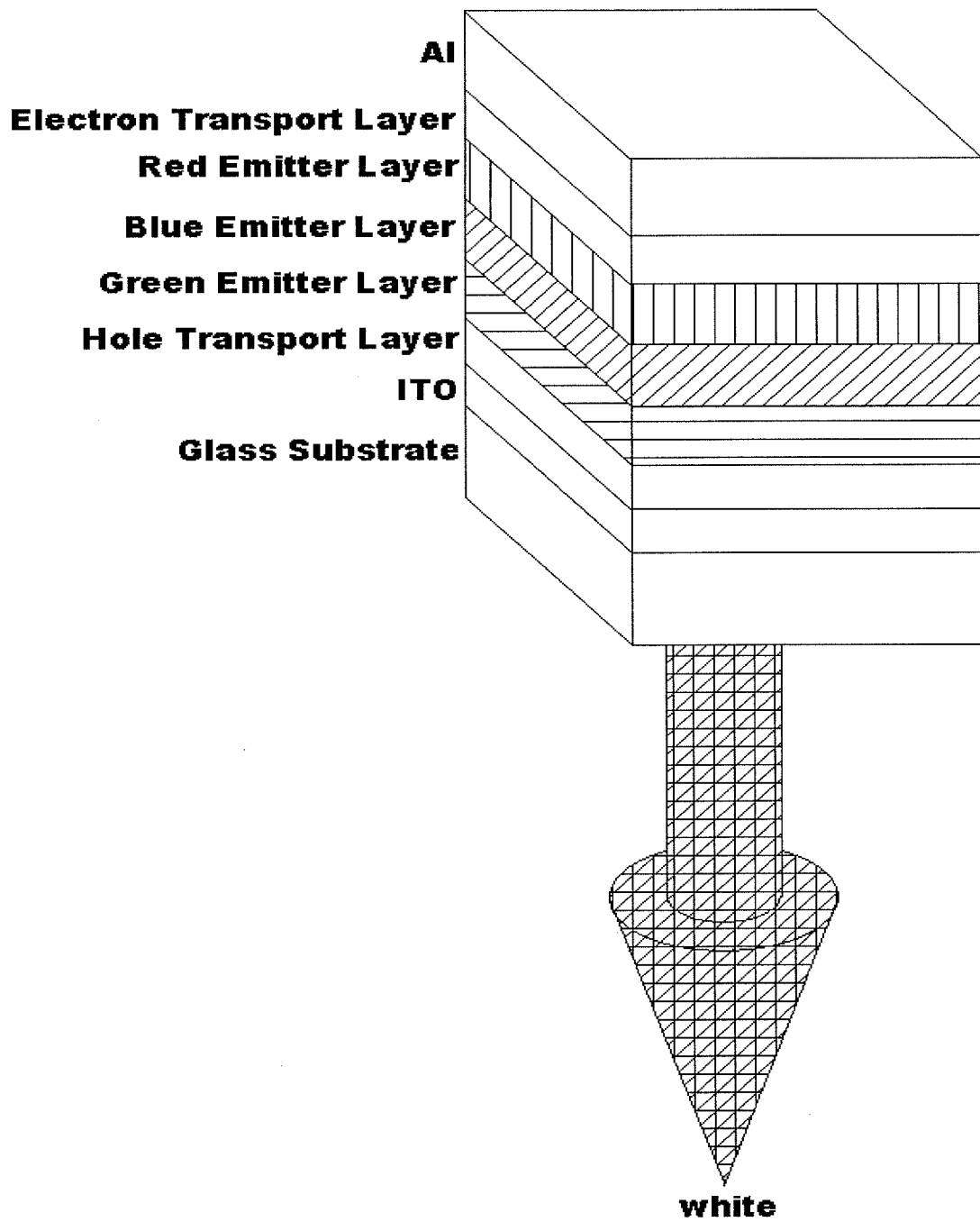
It should be understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application.

CLAIMS

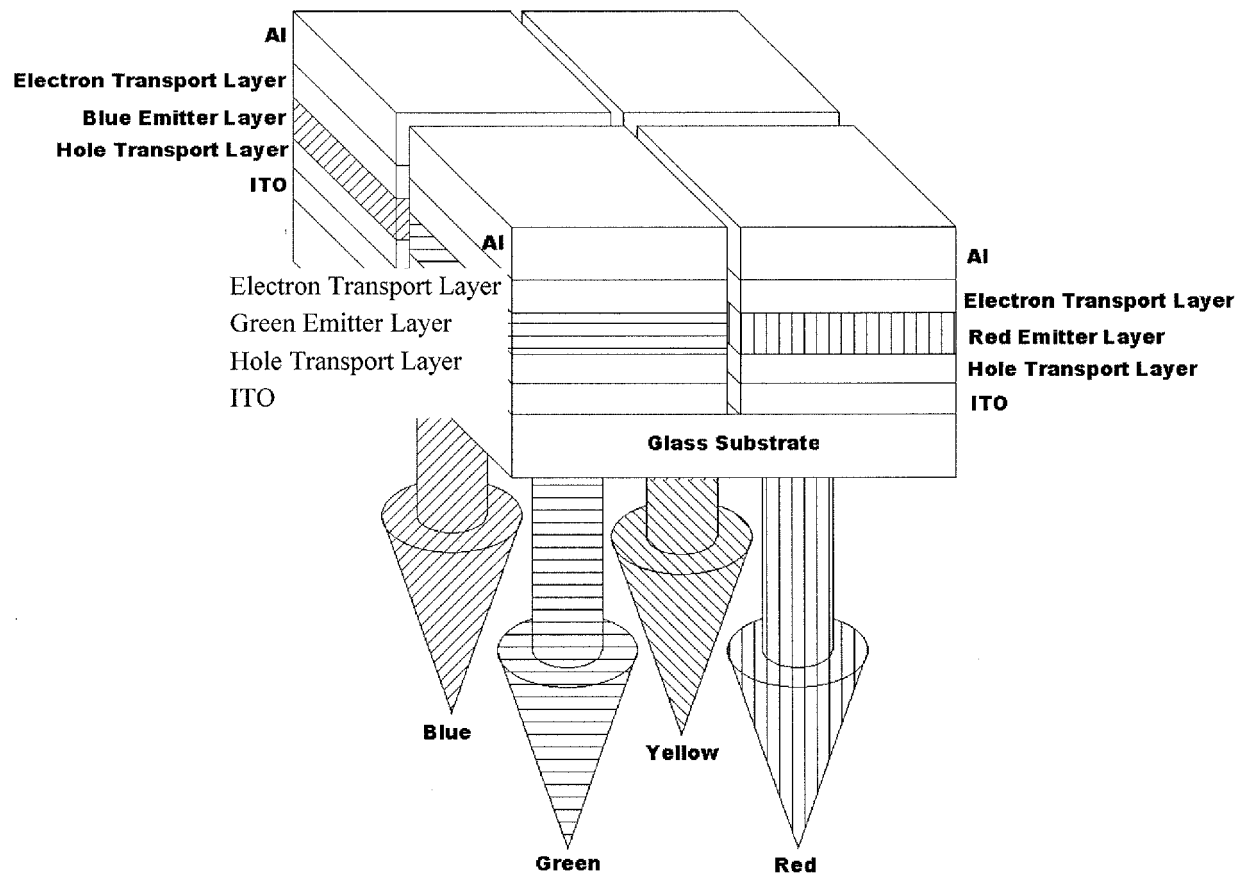
We claim:

1. A white light generating device, comprising at least four pixels comprising light emitting devices (LEDs); wherein each of said LED emits a different color, and wherein each of said LEDs has a microcavity structure.
2. The white light generating device of claim 1, wherein said LEDs are organic light emitting diode OLEDs.
3. The white light generating device of claim 1, wherein said LEDs comprise a transparent anode or a transparent cathode and a dielectric bragg reflector (DBR).
4. The white light generating device of claim 1, wherein said LEDs comprise a semi-transparent anode or a semi-transparent cathode.
5. The white light generating device of claim 1, wherein said pixels are independently addressable, wherein emissions of said white light generating device emits any of a range of color temperatures on demand.
6. The white light generating device of claim 1, wherein said range of color temperatures is 1000 K to 40000 K.
7. The white light generating device of claim 1, further comprising a diffuser.

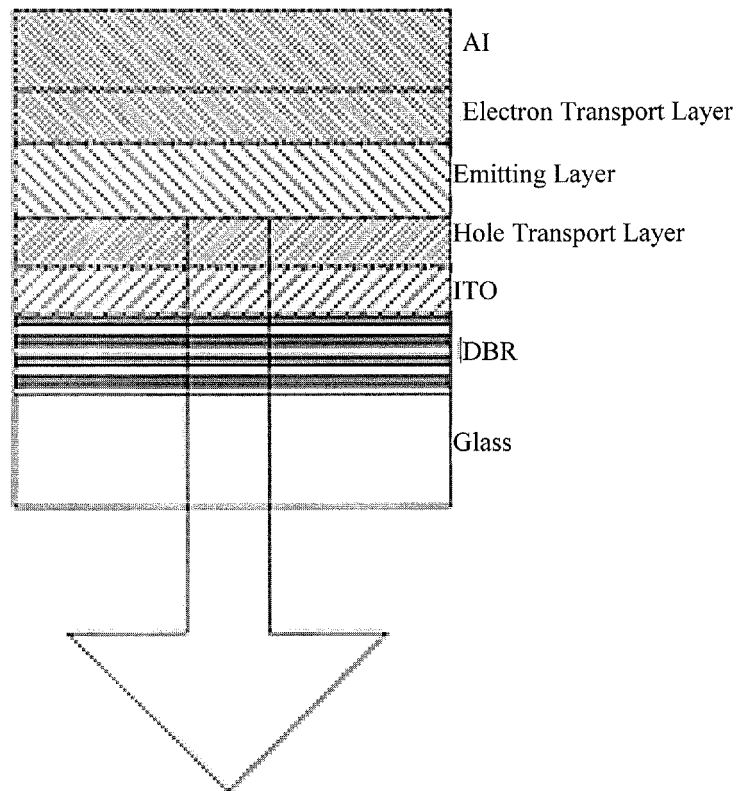
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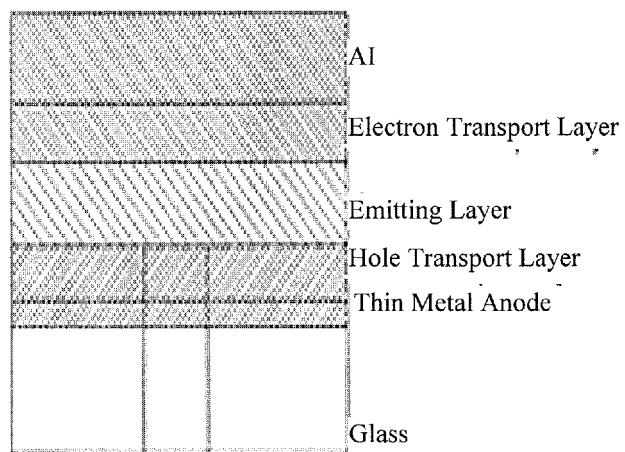
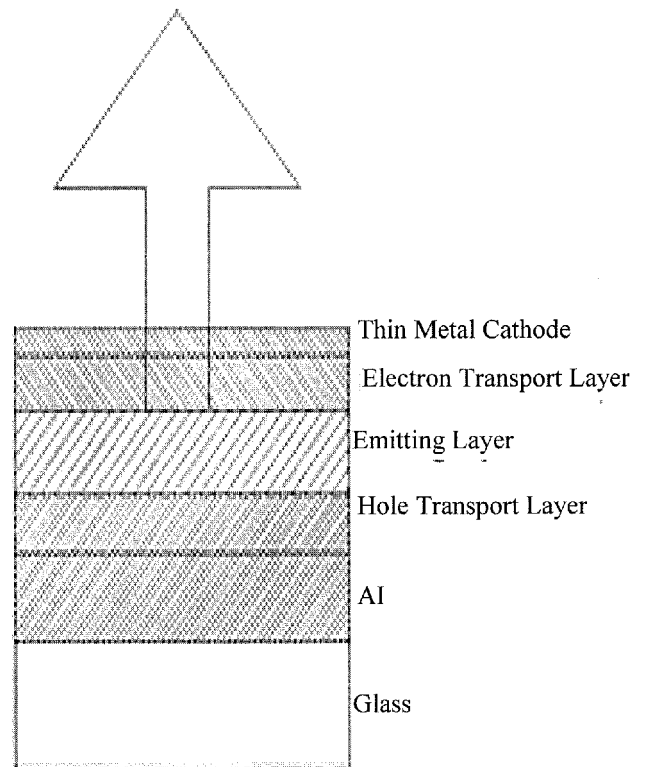
*Figure 1*

2/7

*Figure 2*

3/7

*Figure 3*

*Figure 4A**Figure 4B*

Blue

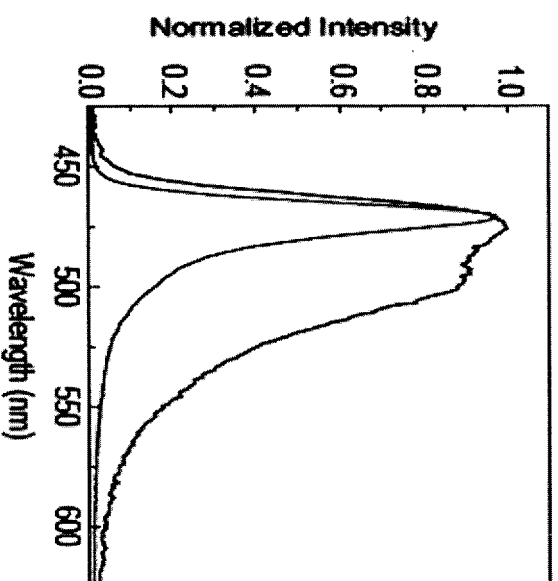


Figure 5A

Green

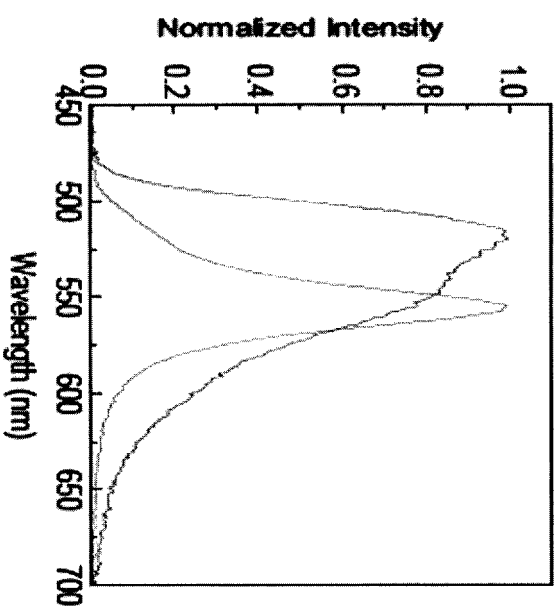


Figure 5B

Red

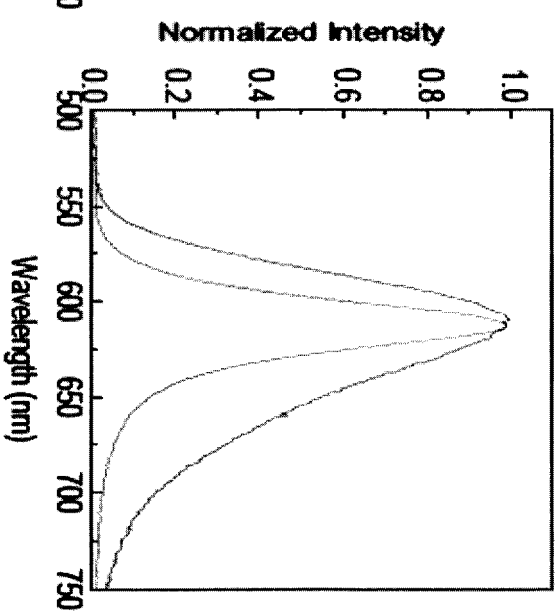
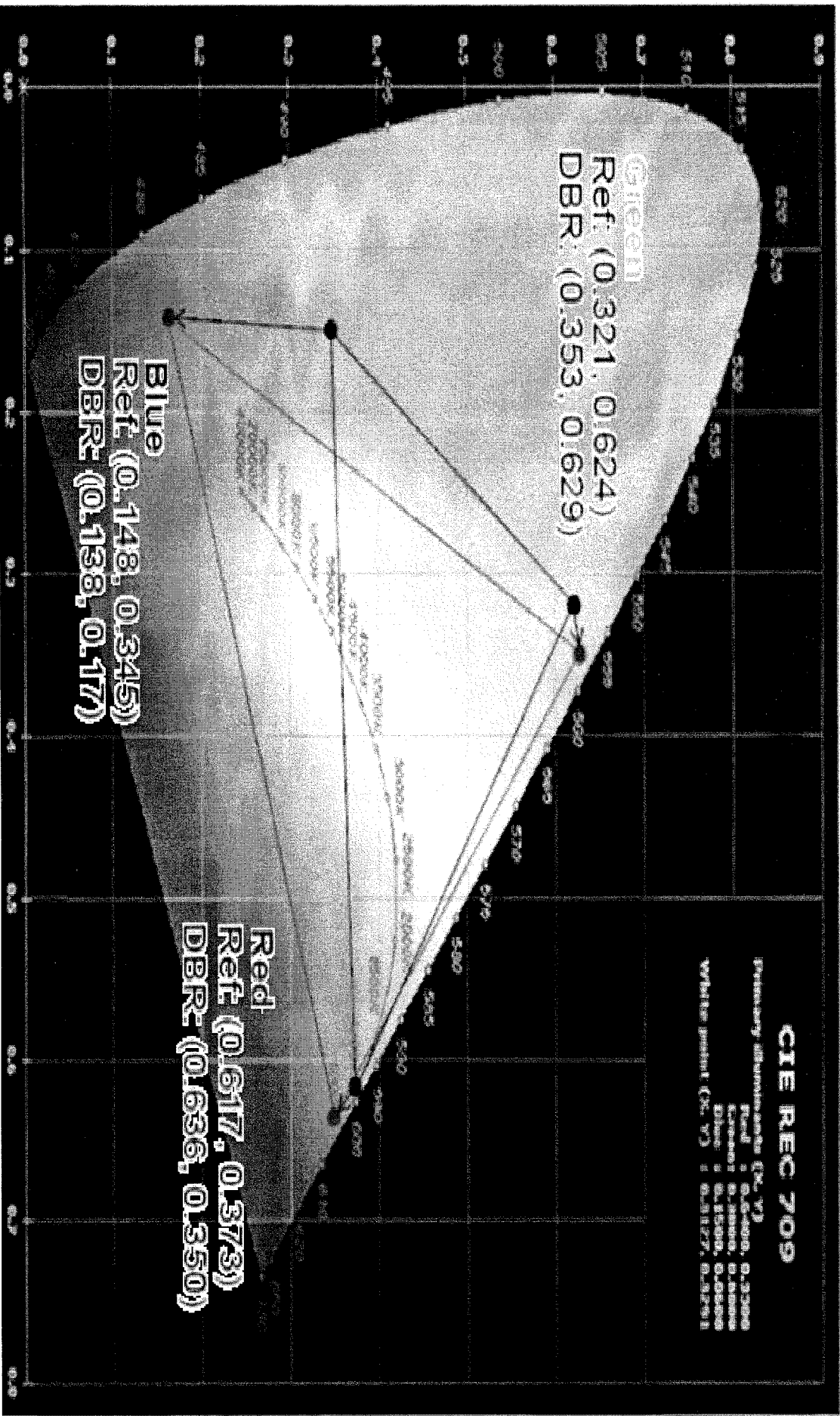


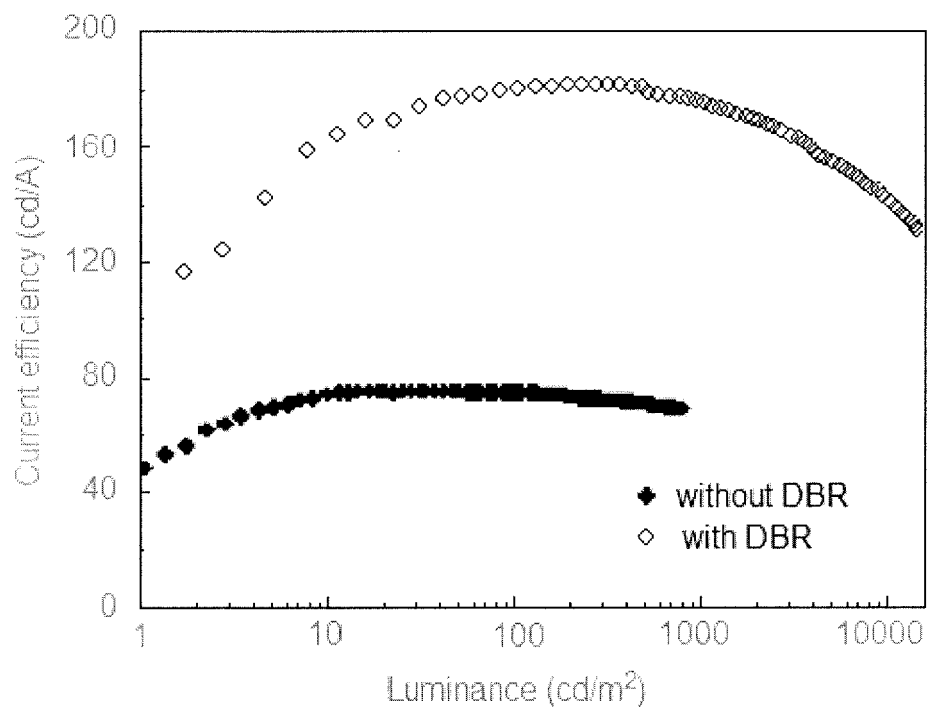
Figure 5C



Values around the CIE locus are the wavelengths in nm.
Grayline within the chromatic diagram shows color temperatures in Kelvin.

Figure 6

7/7

*Figure 7*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/058151**A. CLASSIFICATION OF SUBJECT MATTER****H01L 51/52(2006.01)i, H05B 33/20(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 51/52; H05B 33/00; H01L 27/32; H05B 33/14; G09G 3/32; H01L 51/50; H05B 33/20

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: white light generating device, OLED, microcavity, color temperature

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005-0225232 A1 (MICHAEL L. BOROSON et al.) 13 October 2005 See paragraphs [0030]-[0103]; and figure 3.	1-6
Y		7
Y	US 2012-0153320 A1 (GEORG F. GAERTNER et al.) 21 June 2012 See abstract; paragraphs [0021]-[0027]; and figure 1.	7
A	WO 2011-106306 A2 (UNIVERSITY OF FLORIDA RESEARCH FOUNDATION, INC.) 01 September 2011 See paragraphs [0028]-[0032]; and figures 9-11.	1-7
A	KR 10-2011-0036076 A (E. I. DUPONT DE NEMOURS AND COMPANY) 06 April 2011 See paragraphs [0064]-[0069]; and figure 4.	1-7
A	US 7333080 B2 (MICHAEL E. MILLER et al.) 19 February 2008 See column 6, line 66 - column 12, line 26; and figures 5-7.	1-7



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search

26 December 2013 (26.12.2013)

Date of mailing of the international search report

27 December 2013 (27.12.2013)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2013/058151

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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