(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
13 November 2003 (13.11.2003)

PCT

(10) International Publication Number
WO 03/094255 A2

(51) International Patent Classification[7]: H01L 51/20

(21) International Application Number: PCT/CA03/00653

(22) International Filing Date: 2 May 2003 (02.05.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/377,208	3 May 2002 (03.05.2002)	US
60/377,637	6 May 2002 (06.05.2002)	US
10/383,560	10 March 2003 (10.03.2003)	US

(71) Applicant *(for all designated States except US)*: **LUXELL TECHNOLOGIES INC.** [CA/CA]; 2145 Meadowpine Blvd., Mississauga, Ontario L5N 6R8 (CA).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **JOHNSON, David, J.** [CA/CA]; 60 Chatham Avenue, Toronto, Ontario M4J 1K6 (CA). **WOOD, Richard, P.** [CA/CA]; 121 Wellington Street, Delhi, Ontario N4B 1S6 (CA). **HOFSTRA, Peter, G.** [CA/CA]; 94 Steffler Drive, Guelph, Ontario N1G 3J9 (CA).

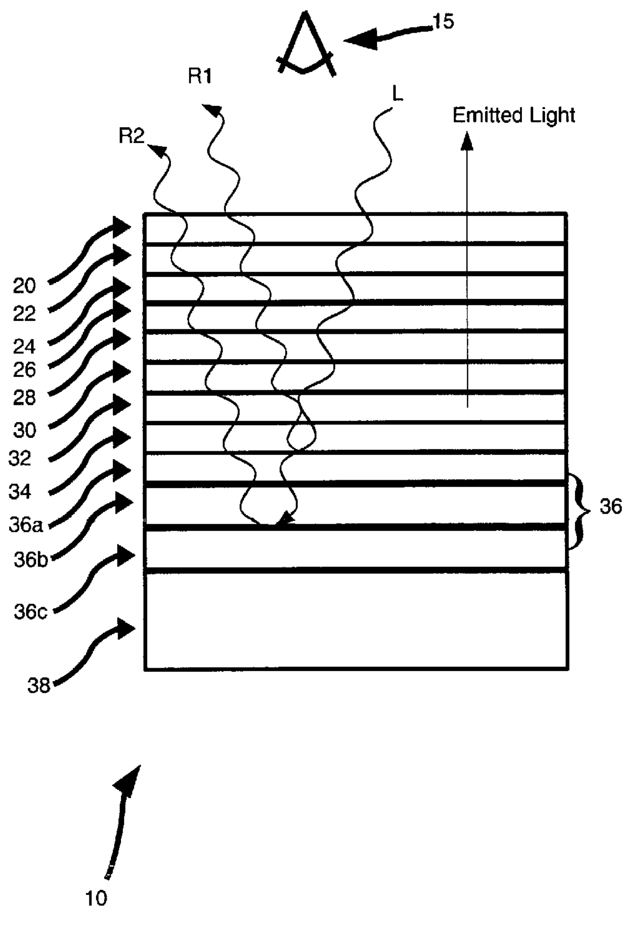
(74) Agents: **CURRIER, T., Andrew** et al.; Lang Michener, BCE Place, Suite 2500, 181 Bay Street, P.O. Box 747, Toronto, Ontario M5J 2T7 (CA).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW),

[Continued on next page]

(54) Title: CONTRAST ENHANCED OLEDS



(57) Abstract: An contrast enhanced OLED device is provided that has a layer of lithium fluoride or lithium oxide deposited within the stack of the device. The lithium fluoride or lithium oxide is deposited in addition to, or in conjunction with, one or more contrast enhancement layers that are also within the stack of the device.

WO 03/094255 A2

Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Contrast Enhanced OLEDs

Priority Claim

[0001] The present application claims priority from United States Provisional Patent Application 60/377,637 filed May 6, 2002; United States Provisional Patent Application 60/377,208 filed May 3, 2002; United States Patent Application 10/383,560, filed March 10, 2003, the contents of which are incorporated herein by reference.

Field of the Invention

[0002] The present invention relates generally to organic light emitting diodes ("OLED") and more particularly relates to contrast enhancement in OLEDs.

Background of the Invention

[0003] In many display and other technologies there is a general need for creating areas that are dark in colour. In OLED displays the rear electrodes often need to be rendered black or dark, to improve the display contrast. This can be addressed by using circular polarizing technology – while circular polarizers do not actually make the electrodes black *per se*, they can absorb light entering the device by controlling the polarization state of the incoming light and the reflected light. Another method of approaching this problem is to use electrodes that are transparent (e.g. ITO, ZnO) and subsequently use black paint or black resin or black polyamide (polymer) on the back of the display, physically behind the electrode, generally on the opposite side of the glass where the ITO is located.

[0004] Another method for achieving a dark display is through the use of optical interference. For example US Patent 5,049,780 to Dobrowolski and US Patent 6,411,019 to Hofstra (both of which are incorporated herein by reference) teach the use of an optical interference member within inorganic and organic thin film electroluminescent devices respectively. While the foregoing circular polarizer and optical interference art can be useful in rendering areas of an electroluminescent display dark, the inventors of the present invention have discovered a need for improved methods of providing an overall dark OLED. In particular, the problem of work-function matching the layers in an OLED can be very challenging, notwithstanding the fact that careful processing can be used to achieve such matching.

Summary of the Invention

[0005] It is therefore an object of the present invention to provide a contrast enhanced OLED that obviates or mitigates at least one of the above-identified disadvantages of the prior art.

[0006] A first aspect of the invention provides an electroluminescent device for displaying an image to a viewer in front of the device, comprising a front anode layer being the front and being substantially transparent to electroluminescent light. The device also comprises an organic electroluminescent layer disposed behind the anode layer and a buffer layer disposed behind the electroluminescent layer. The buffer layer made of a material selected from the group consisting of LiF, LiO, or Li, Ca, or Ba, or compounds of Li, Ca, or Ba. The device also includes a dark layer for reducing reflected ambient light using optical interference. The dark layer is disposed behind the buffer layer. A reflective rear cathode layer is disposed behind the dark layer.

[0007] A second aspect of the invention provides an electroluminescent device for displaying an image to a viewer in front of the device, comprising a front anode layer made from indium tin oxide (ITO) and having a thickness of about 1200 Å. The ITO is the front of the device and is substantially transparent to electroluminescent light. The device also includes a first buffer layer, disposed behind the anode layer, made from CuPc having a thickness of about 250 Å. The device also includes a hole transport layer disposed behind the first buffer layer and made from NPB having a thickness of about 450 Å. An organic electroluminescent layer is disposed behind the hole transport layer and is made from tris(8-quinolinolato aluminum) (Alq3) having a thickness of about 600 Å. An electron transport layer is disposed behind the electroluminescent layer, and there is a second buffer layer disposed behind the electron transport layer. A third buffer layer is disposed behind the electroluminescent layer and is made from a material selected from the group consisting of LiF, LiO, or Li, Ca, or Ba, or from a compounds of Li, Ca, or Ba. The third buffer layer has a thickness of about 10 Å. A dark layer, comprising a partially reflective layer, an absorptive-transmissive layer and a reflecting layer is disposed behind the second buffer layer. A rear cathode layer is disposed behind the dark layer, made from aluminum (Al) having a thickness of about 1500 Å.

[0008] The partially reflective layer can be made from chromium. and have a thickness of between about zero to about 100 Å, or from about zero to about 40 Å, or have a thickness of about 12 Å.

[0009] The absorptive-transmissive layer can be made from chromium silicon monoxide. The absorptive-transmissive chromium silicon monoxide layer can have a thickness of between about 200 Å to about 800 Å, or can have a thickness of between about 400 Å to about 600 Å, or can have a thickness of about 500 Å.

[0010] A third aspect of the invention provides an electroluminescent device for displaying an image to a viewer in front of the device, comprising a front anode layer being the front and being substantially transparent to electroluminescent light. An organic electroluminescent layer is disposed behind the anode layer. A dark layer, comprising a partially reflective layer, an absorptive-transmissive layer and a reflecting layer is disposed behind the organic electroluminescent layer. The partially-reflective layer is co-deposited with a material selected from the group consisting of LiF, LiO, Ca, or Ba, or a compound of Li, Ca or Ba. A reflective rear cathode layer is disposed behind the dark layer.

[0011] Where, for example, the co-deposited material is LiF, it can comprise about 5% to about 60% of the partially-reflective layer, or it can comprise about 30% to about 50% of the partially-reflective layer.

Brief Description of the Drawings

[0012] The present invention will now be described, by way of example only, with reference to the embodiments shown in the attached Figures in which:

[0013] Figure 1 is a schematic diagram of a cross-section of a bottom emitting electroluminescent device in accordance with the first embodiment of the invention.

Detailed Description of the Invention

[0014] A bottom emitting electroluminescent device in accordance with the first embodiment of the invention is indicated generally at 10 in Figure 1. Device 10 comprises a substrate 20 facing a viewer 15, an electroluminescent transmitting anode 22, a first buffer layer 24, a hole transport layer 26, an electroluminescent layer 28, an electron transport layer 30, a second buffer layer 32, a third buffer layer 34, a dark layer 36 composed of three layers 36a, 36b and 36c, and a reflecting cathode layer 38 disposed as shown in Figure 1. Device 10 is connected to a current source (not shown) via anode 22 and cathode 38 in order to drive a constant current through device 10.

[0015] Substrate 20 is glass, plastic or other transparent material of suitable thickness for depositing the layers 22 – 38 using vacuum deposition, spin-coating or other means.

[0016] Electroluminescent transmitting anode 22 is any conducting material which is transparent to at least a portion of emitted electroluminescent light, such as indium tin oxide (ITO) or zinc oxide (ZnO). In the present embodiment, anode 22 is a layer of ITO having a thickness of about twelve-hundred angstroms (1200 Å). Other suitable materials and appropriate thicknesses can be determined by those skilled in the art.

[0017] First buffer layer 24 is made of Cupric Phthalocynine (CuPc) having a thickness of about two hundred and fifty angstroms (250 Å). Other suitable materials and appropriate thicknesses can be determined by those skilled in the art. The function of this layer is to regulate the hole transportation through the device.

[0018] Hole transport layer 26 is made of N,N'-Di(naphthalen-1-yl)-N,N'diphenyl-benzidine (NPB; also known as naphthalene diphenyl benzidine), having a thickness of about four hundred and fifty angstroms (450 Å). Other suitable materials and appropriate thicknesses can be determined by those skilled in the art. The function of this layer is to facilitate hole transportation through the device.

[0019] Electroluminescent layer 28 and electron transport layer 30 is typically deposited as a single layer of an organic electroluminescent material such as Tris-(8-hydroxyquinoline) aluminum (Alq3) having an appropriate thickness. In the present embodiment layer 28 and layer 30 are Alq3 having a combined thickness of about six hundred angstroms (600 Å) although those of skilled in the art will be able to determine other appropriate thicknesses. The function of layer 28 is to emit light, while the function of layer 30 is to facilitate hole transport through device 10.

[0020] Second buffer layer 32 is made from CuPc with an appropriate thickness as known in the art. In the present embodiment, layer 32 is included to protect the electroluminescent layer during sputter deposition of additional layers of device 10. However, where sputter deposition is not used it can be desired to omit layer 32.

[0021] Third buffer layer 34 is for matching the work function of electroluminescent layer 28 and dark layer 36. Third buffer layer 34 is made of lithium fluoride (LiF) having a thickness of about five to about twenty angstroms (5-20 Å), but in a presently preferred embodiment layer 34 has a thickness of about five angstroms (5 Å). Other suitable materials and thicknesses can be determined by those of skill in the art. For example, the thickness of lithium fluoride for third buffer layer 34 can be from about three to about twenty-five angstroms (3 – 25 Å), or it can be from out ten to about fifteen angstroms (10 – 15 Å). As an additional example, third buffer layer 34 can be made from lithium oxide (LiO) and have a thickness of the ranges previously mentioned. It is to be understood that low-work-function based materials can be used, such as Ca or Ba, or compounds thereof from low-work-function based materials.

[0022] It is believed that during deposition of either the LiF or the absorptive-transmissive layer of the dark layer 36, the LiF dissociates into its component species. Since Li alone has a very low work function and readily gives up electrons, an effective electrical match between electroluminescent layer 28 and partially reflective layer 36a (discussed further below) of dark layer 36 can be provided. Each Li atom (or ion) can thereby act as a source to inject electrons into the organic device freeing partially-reflective layer 36a from having to perform this function, in conjunction with performing its partially-reflective function. Thus, the thickness of the LiF layer is chosen to be thick enough so that it does not fully dissociate and can act as an insulator, thus causing increases in the threshold voltage of the device, but thin enough that the level of insulation is not excessive.

[0023] In the present embodiment, dark layer 36 is composed of three layers: a partially-reflective layer 36a, an absorptive-transmissive layer 36b and a reflective layer 36c. Layer 36a is made from chromium and is disposed behind buffer layer 34. Layer 36a can have a thickness of between about zero to about one hundred angstroms (0-100 Å). Layer 36a can also have a thickness of between about zero to about forty angstroms (0-40 Å). In a presently preferred embodiment, chromium layer 36a has a thickness of about twelve angstroms (12 Å).

[0024] Layer 36b, disposed behind layer 36a is made from chromium silicon monoxide preferably having a thickness of between about two hundred to about eight hundred angstroms (200-800 Å). More preferably, layer 36b can have of thickness of between about four hundred to six hundred angstroms (400-600 Å). In a presently preferred embodiment, layer 36b has thickness of about five hundred angstroms (500 Å).

[0025] Layer 36c, disposed behind layer 36b, is also made from chromium preferably having a thickness of between about zero to about fifteen-hundred angstroms (0 A-1500 Å). More preferably, layer 36c has a thickness of about two hundred fifty angstroms (250 Å).

[0026] Cathode layer 38 is aluminum (Al) and has a thickness of about fifteen-hundred angstroms (1500 Å), and in the present embodiment it is reflective. Other suitable materials and appropriate thicknesses can be determined by those skilled in the art.

[0027] In a variation of the foregoing embodiment, partially-reflective layer 36a is made from aluminum, absorptive-transmissive layer 36b is made from aluminum silicon monoxide, and reflective layer 36c is made from aluminum. Layer 36a can have a thickness of between about zero to about fifty angstroms (0-50 Å). Layer 36a can have a thickness of between about ten to about thirty-five angstroms (10-35 Å). In a presently preferred embodiment, aluminum layer 36a has a thickness of about twenty-five angstroms (25 Å).

Layer 36b behind layer 36a is made from aluminum silicon monoxide, preferably, having a thickness of between about two-hundred-and-fifty to about five-hundred angstroms (250-500 Å). More preferably, layer 36b is of thickness of between about two-hundred-and-seventy-five to about four-hundred-and-fifty angstroms (275-450 Å). More preferably, layer 36b is of thickness of between about three-hundred-and-twenty-five to about four-hundred angstroms (325-400 Å). In a presently preferred embodiment, layer 36b has thickness of about three-hundred-and-seventy angstroms (370 Å). Layer 36c, disposed behind layer 36b, is another layer of aluminum, preferably having a thickness between about 1000 Å to about 1500 Å. (When layer 36c is made of aluminum it is contemplated that cathode layer 38 can be eliminated in favour of using layer 36c as the cathode.)

[0028] A wavelength of about five-hundred-and-fifty nanometers (550 nm), the centre of the photopic response of the human eye, is the wavelength chosen for the purpose of determining appropriate thicknesses and materials of layers 22 to 38, as the resulting device 10 can have desirable contrast enhancement properties across the visible light spectrum. The appropriate thicknesses and materials are chosen to minimize the reflection of the device at this wavelength. However, it will occur to those skilled in the art that other wavelengths can be selected, as desired, and the appropriate material thickness can be calculated.

[0029] In operation, incident light L on layer 36a is partially reflected as per reflection R1, and partially transmitted through layers 36a and 36b. The light traveling through layers 36a and 36b is shifted in phase through layer 36b, and reflected off of layer 36c as reflection R2, so that it is out of phase with reflection R1. The phase mismatch of reflection R1 and reflection R2 at the surface of layer 36a cause a destructive interaction of these two reflections R1 and R2, causing at least some reduction in incident light. Where the phase shift is about one-hundred-and-eighty degrees between reflection R1 and reflection R2, there can be a substantial reduction of incident light.

[0030] In a second embodiment, a compound containing the very low work function material (e.g. LiF) can be incorporated directly into partially-reflective layer 36a through co-deposition technique, and thereby eliminate buffer layer 34. The relative amounts of LiF and partially-reflective material can be in the range of from about 5% to about 60% LiF, or can be from about 30% to about 50% LiF. In this embodiment, desired display performance can be achieved without having to deposit an additional layer; additionally, the presence of the LiF can reduce and/or obviate the need to work function match dark layer 36 with electroluminescent layer 28. By so codepositing the LiF with partially-reflective layer 36a, the work function of partially-reflective layer 36a is modified to match electroluminescent layer 28. In this second embodiment, the LiF dissociates during deposition, allowing the Li to act as a source of electrons within the partially reflective layer 36a. With the presence of an excess of LiF, enough non-dissociated insulator is present to impart insulating properties to the layer. If too little LiF is applied, there is not enough Li near the organic surface to make a strong impact on electron injection. The foregoing considerations can be used to choose an appropriate or desired amount of LiF to use.

[0031] While only specific combinations of the various features and components of the present invention have been discussed herein, it will be apparent to those of skill in the art that desired subsets of the disclosed features and components and/or alternative combinations of these features and components can be utilized, as desired. For example, while the specific embodiments of dark layer 36 discussed herein include a number of sub-layers, it is to be understood that other arrangements of dark layer 36 can be effected. In particular, dark layer 36 can include a single layer. In general, it is to be understood that dark layer 36 can be configured or structured in any manner to provide at least some destructive optical interference of incident light L, as previously discussed per reflections R1 and R2 shown in Figure 1. As an example, it is to be understood that reflective layer 36c can be omitted where cathode 38 is reflective.

[0032] The present invention provides a novel contrast enhanced OLED having a buffer layer made from LiO, LiF or the like that allows a flexible range of choices for the dark layer that is placed behind the buffer layer. Since the thickness of the low work function material buffer layer, such as LiF, is very thin, and, as this and related materials are substantially transparent, there is no additional optical effect that need be compensated for in partially reflective layer placed in front of the absorptive-transmissive layer.

[0033] The above-described embodiments of the invention are intended to be examples of the present invention and alterations and modifications may be effected thereto, by those of skill in the art, without departing from the scope of the invention which is defined solely by the claims appended hereto.

We claim:

1. An electroluminescent device for displaying an image to a viewer in front of said device, comprising:

a front anode layer being said front and being substantially transparent to electroluminescent light;

an organic electroluminescent layer, disposed behind said anode layer;

a buffer layer, disposed behind said electroluminescent layer, made of a material selected from the group consisting of LiF, LiO, or Li, Ca, or Ba of compounds thereof;

a dark layer, for reducing reflected ambient light through optical interference disposed behind said buffer layer; and,

a reflective rear cathode layer, disposed behind said dark layer.

2. An electroluminescent device for displaying an image to a viewer in front of said device, comprising:

a front anode layer made from indium tin oxide (ITO) having a thickness of about 1200 Å, being said front and being substantially transparent to electroluminescent light;

a first buffer layer, disposed behind said anode layer, made from CuPc having a thickness of about 250 Å;

a hole transport layer, disposed behind said first buffer layer, made from NPB having a thickness of about 450 Å;

an organic electroluminescent layer, disposed behind said hole transport layer, made from tris(8-quinolinolato aluminum) (Alq3) having a thickness of about 600 Å;

an electron transport layer disposed behind said electroluminescent layer;

a second buffer layer disposed behind said electron transport layer;

a third buffer layer, disposed behind said electroluminescent layer, made from a material selected from the group consisting of LiF, LiO, or Li, Ca, or Ba of compounds thereof, and, having a thickness of about 10 Å;

a dark layer, comprising a partially reflective layer, an absorptive-transmissive layer and a reflecting layer, disposed behind said second buffer layer;

a rear cathode layer, disposed behind said dark layer, made from aluminum (Al) having a thickness of about 1500 Å.

3. The device according to claim 13 wherein said partially reflective layer is made from chromium.

4. The device according to claim 14 wherein said partially reflective chromium layer has a thickness of between about zero to about 100 Å.

5. The device according to claim 15 wherein said partially reflective chromium layer has a thickness of between about zero to about 40 Å.

6. The device according to claim 16 wherein said partially reflective chromium layer has a thickness of about 12 Å.

7. The device according to claim 13 wherein said absorptive-transmissive layer is made from chromium silicon monoxide.

8. The device according to claim 18 wherein said absorptive-transmissive chromium silicon monoxide layer has a thickness of between about 200 Å to about 800 Å.

9. The device according to claim 19 wherein said absorptive-transmissive chromium silicon monoxide layer has a thickness of between about 400 Å to about 600 Å.

10. The device according to claim 20 wherein said absorptive-transmissive chromium silicon monoxide layer has a thickness of 500 Å.

11. The device according to claim 13 wherein said reflecting layer is made from chromium.

12. The device according to claim 22 wherein said reflecting chromium layer has a thickness between about zero to about 1500 Å.

13. The device according to claim 23 wherein said reflecting chromium layer has a thickness of about 250 Å.

14. The device according to claim 13 wherein said partially reflective layer is made from aluminum.

15. The device according to claim 25 wherein said partially reflective aluminum layer has a thickness of between about zero to about 50 Å.

16. The device according to claim 26 wherein said partially reflective aluminum layer has a thickness of between about 10 Å to about 35 Å.

17. The device according to claim 27 wherein said partially reflective aluminum layer has a thickness of about 25 Å.

18. The device according to claims 13 wherein said absorptive-transmissive layer is made from aluminum silicon monoxide.

19. The device according to claim 29 wherein said absorptive-transmissive aluminum silicon monoxide layer has a thickness of between about 250 Å to about 500 Å.

20. The device according to claim 30 wherein said absorptive-transmissive aluminum silicon monoxide layer has a thickness of between about 275 Å to about 450 Å.

21. The device according to claim 31 wherein said absorptive-transmissive aluminum silicon monoxide layer has a thickness of between about 325 Å to about 400 Å.

22. The device according to claim 32 wherein said absorptive-transmissive aluminum silicon monoxide layer has a thickness of about 370 Å.

23. The device according to claim 13 wherein said reflecting layer is made from aluminum having a thickness between about 1000 Å to about 1500 Å.

24. An electroluminescent device for displaying an image to a viewer in front of said device, comprising:

a front anode layer being said front and being substantially transparent to electroluminescent light;

an organic electroluminescent layer, disposed behind said anode layer;

a buffer layer, disposed behind said electroluminescent layer made of a low work function material;

a dark layer, for reducing reflected ambient light through optical interference disposed behind said buffer layer; and, a reflective rear cathode layer, disposed behind said dark layer.

25. An electroluminescent device for displaying an image to a viewer in front of said device, comprising:

a front anode layer being said front and being substantially transparent to electroluminescent light;

an organic electroluminescent layer, disposed behind said anode layer;

a dark layer, comprising a partially reflective layer, an absorptive-transmissive layer and a reflecting layer, disposed behind said organic electroluminescent layer, said partially-reflective layer being co-deposited with a material selected from the group consisting of LiF, LiO, Ca, or Ba; and,

a reflective rear cathode layer, disposed behind said dark layer.

26. The electroluminescent device of claim 25 wherein said co-deposited material is LiF which comprises about 5% to about 60% of said partially-reflective layer.

27. The electroluminescent device of claim 25 wherein said co-deposited material is LiF which comprises about 30% to about 50% of said partially-reflective layer.

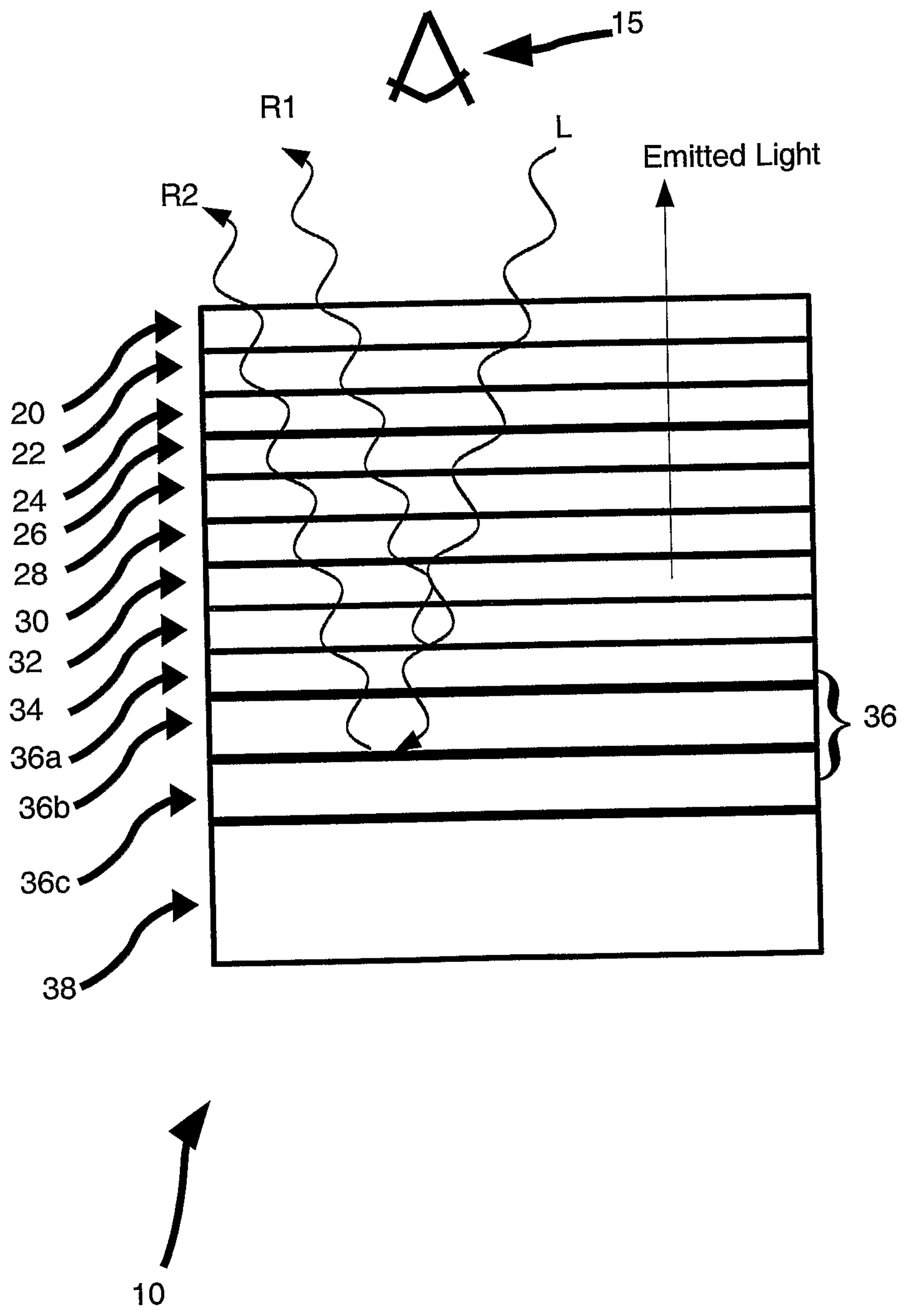

15
R1
L
Emitted Light
R2
20
22
24
26
28
30
32
34
36a
36b
36c
38
36
10

Fig. 1