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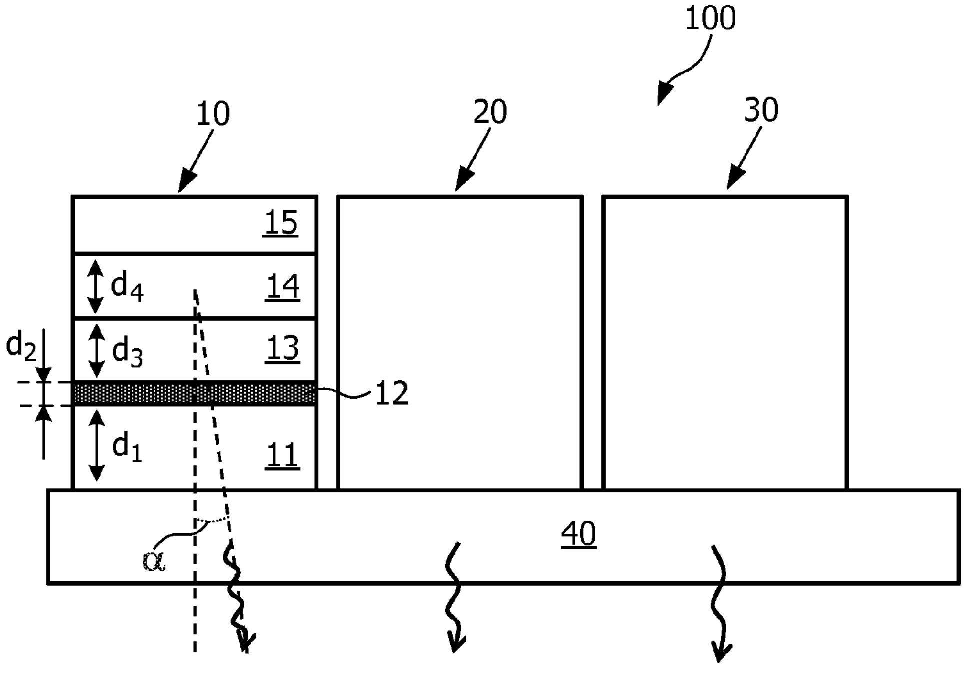
(54) Title: WHITE OLED WITH HIGH LUMEN EFFICACY



(57) Abstract: The invention relates to a white-emitting OLED (100) comprising a blue-emitting component (10) with a y-color coordinate smaller than 0.15. The OLED may further comprise a yellow, red and/or green light-emitting component (20, 30) and have a color temperature in the range between 2000 and 6000 K. A particular design of the blue-emitting component (10) comprises a layered structure of a glass substrate (40), an ITO anode (11), an Ag-layer (12), a HTL (13), a blue light-emitting layer (14), and a cathode (15). The blue-emitting layer (14) is preferably realized in a micro-cavity to allow a tuning of the wavelength.

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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*

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.

White OLED with high lumen efficacy

The invention relates to a white-emitting Organic Light Emitting Device (OLED) comprising at least two light-emitting components of different color.

From the US 6 869 695 B2 (which is incorporated into the present application by reference), a white-emitting OLED is known that comprises two emitters in a single emissive region, wherein one of the emitters is aggregated. The US 2004 32205 A1 discloses an OLED that comprises a plurality of regions containing light-emitting components of different colors, wherein the areas of said regions are selected with particular ratios to increase the efficiency of the device. In general, the overall lumen efficacy of OLEDs is however limited by the blue component, which performs far inferior compared to commercially available green and red emitters.

Based on this situation it was an object of the present invention to provide a white-emitting OLED with high lumen efficacy.

This objective is achieved by a white-emitting OLED according to claim 1. Preferred embodiments are disclosed in the dependent claims.

The white-emitting OLED according to the present invention comprises the following components:

a) A blue-emitting component with a y-color coordinate smaller than about 0.15, wherein the color coordinates mentioned here and in the following refer to the CIE 1931 definition and wherein the term "smaller" is to be understood here and in the following in the sense of "smaller or equal" (≤). The x-coordinate of the blue-emitting component may in principle have any value of the remaining, physically possible range (i.e. within the CIE 1931 color diagram). Preferably, the x-coordinate is however limited to values smaller than 0.25, preferably smaller than 0.20.

b) At least one further light-emitting component with a color that is different from the color of the blue-emitting component. The color(s) of the further light-emitting component(s) should be selected such that, in combination with the blue-emitting component, the generation of an overall white emission is possible.

While the y-color coordinates of usual blue-emitting components of white OLEDs typically range between 0.15 and 0.25, the y-color coordinate of the blue-emitting component according to the invention has a comparatively small value of less than 0.15. As will be shown in a more detail with respect to the Figures, this application of a saturated blue emitter allows a considerable improvement of the efficacy and power consumption of the overall device.

Beside the blue-emitting component the white-emitting OLED may comprise one further light-emitting component of yellow color. In another embodiment, the white-emitting OLED may comprise besides the blue-emitting component two further light-emitting components of red and green color, respectively. In these embodiments, a satisfactory broad emission spectrum can be generated with reasonable effort. It is therefore preferred that the at least one further light-emitting component has one of the following colors: yellow (defined by the color coordinates $0.4 \leq x \leq 0.6$, $0.4 \leq y \leq 0.6$), red ($0.5 \leq x \leq 0.7$, $0.25 \leq y \leq 0.4$), or green ($0.1 \leq x \leq 0.5$, $0.4 \leq y \leq 0.8$).

The blue-emitting component and/or the further light-emitting component preferably comprise luminous polymers and/or amorphous films of organic molecules. Examples of polymers and organic molecules that can be used can be found in the literature (e.g. Chihaya Adachi, Marc A. Baldo, Mark E. Thompson, and Stephen R. Forrest, "Nearly 100% internal phosphorescence efficiency in an organic light emitting device", JOURNAL OF APPLIED PHYSICS, VOLUME 90, NUMBER 10-15, (2001), which is incorporated into the present application by reference).

In a preferred embodiment of the invention, the upper limit of the y-color coordinate of the blue-emitting component is further restricted to be smaller than 0.1, preferably smaller than 0.08, most preferably smaller than 0.05.

Though the y-color coordinate of the blue-emitting component can be arbitrarily small, it is preferably larger than 0.01.

The Correlated Color Temperature (CCT) that can be achieved with the proposed white-emitting OLED preferably ranges between 2000 and 6000 K. Moreover, the OLED is preferably tunable with respect to its color temperature such that several discrete values or a continuous sub-interval of the mentioned color temperature range can be covered by it.

While the emitting components (i.e. the blue-emitting and the further light-emitting components) might be merged in the same region of the OLED, it is preferred that they are arranged in separate regions. Said regions may particularly be arranged side by side or on top of each other with respect to the direction of the overall light emission.

In one particular realization of the white-emitting OLED, the blue-emitting component comprises a blue color filter, i.e. a filter which suppresses wavelengths outside the interval 380 nm – 550 nm, preferably outside the interval 400 nm – 500 nm. The filter may for example be realized by a pigment or by dielectric layers. With said filter, the emission of a broader spectrum can be restricted in such a way that the desired y-color coordinate of the blue-emitting component is achieved.

In another realization of the white-emitting OLED, the blue-emitting component comprises a micro-cavity. As is described in literature (e.g. T. Shiga, H. Fujikawa and Y. Taga, "Design of multiwavelength resonant cavities for white organic light-emitting diodes", J. Appl. Phys. 93,1 (2003) 19), the wavelength of an emitter layer can be tuned by placing it in a micro-cavity of suitable dimensions.

According to another embodiment of the invention, the blue-emitting component comprises a sequential arrangement of a cathode, a (blue) light-emitting and electron transport layer, and a hole transport layer (abbreviated HTL in the following). The thickness of the light-emitting and electron transport layer preferably ranges between 50 nm and 70 nm. The thickness of the HTL preferably ranges between 50 nm and 200 nm.

In a further development of the aforementioned embodiment, the HTL is arranged upon a transparent anode, preferably an anode of indium tin oxide (abbreviated ITO in the following). A hole transporting layer may, for example, comprise a mixture of polyethylene dioxythiophene (PDOT) and poly(styrene sulfonate).

Furthermore, a silver (Ag) layer may optionally be disposed between the HTL and the aforementioned anode, wherein the thickness of said Ag-layer preferably ranges between 10 and 40 nm.

The white-emitting OLED may further comprise a glass substrate on which the above-mentioned (or other) structures are arranged.

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiment(s) described hereinafter. These embodiments will be described by way of example with the help of the accompanying drawings in which:

Figure 1 shows schematically one embodiment of a white-emitting OLED according to the present invention;

Figure 2 shows the x-color coordinate (circles) and the y-color coordinate (squares) of the blue-emitting component of the OLED of Figure 1 as a function of the emission angle α;

Figure 3 shows the CIE 1931 x,y-color coordinate diagram of a white-emitting OLED according to the present invention;

Figure 4 shows the relative electrical power of the white-emitting OLED of Figure 3 for constant lumen output as a function of the y-color coordinate of the blue-emitting component for different color temperatures of the lamp;

Figure 5 shows the color rendering index Ra as a function of the y-color coordinate of the blue-emitting component for the OLED of Figures 3 and 4;

Figure 6 illustrates the power emitted into the glass substrate by a dipole in a micro-cavity in dependence on the wavelength and angle.

Like reference numbers in the Figures refer to identical or similar components.

Organic Light Emitting Devices (OLEDs) can be realized with broad emission spectra in the visible range. Although white light can be generated applying adequate broad spectra, the overall lumen efficacy is limited by the blue component, which performs far inferior compared to commercially available green and red emitters. The present invention therefore proposes an OLED light source with a saturated blue emitter (i.e. with a y-color coordinate < 0.15) in combination with e.g. red and green emitters. The application of saturated blue emitters offers several advantages:

- efficacy increase of 10% by increasing the so-called lumen equivalent of the RGB white emission spectrum for a CCT > 2000 K;
- increase of the resulting color rendering index (Ra);
- efficacy increase of up to 40% in combination with a so-called Triplet emitting green emitter (remark: the combination of a Singlet blue emitter with Triplet green and red so far is the only viable solution for white light generation with sufficient lifetime for lighting applications).

The required blue emission spectra can be generated with adequate micro-cavity structures, combining thin active organic layers with suitable reflection layers close to anode and cathode of the device. Alternatively blue color filters (pigments and/or dielectric layers) can be applied, on the expense of the overall efficacy gain.

In the following, the above concepts will be explained in more detail.

The development of production processes and of luminescent materials with high efficiency and lifetime are still topics of high importance in OLED research. Phosphorescent Triplet-emitters play a key role in this respect for the achievement of a high efficiency. A particular example of such a material is the green emitter material IRPYY (cf. Chihaya Adachi, Marc A. Baldo, Mark E. Thompson, Stephen R. Forrest, "Nearly 100% internal phosphorescence efficiency in an organic light emitting device", JOURNAL OF APPLIED PHYSICS VOLUME 90, NUMBER 10 (2001)). This material achieves a lifetime of more than 10.000 hours and is nowadays commercially available. Similarly, phosphorescent emitters with high lifetime are commercially available for the red spectral range.

In contrast to this, the lifetime of the blue emitter materials is generally lower, wherein luminescent emitters (Singlet-emitters) are significantly better in the blue range than the Triplet-emitters that are presently available. Moreover, the presently achieved external quantum efficiency of phosphorescent blue emitter materials is significantly lower than that of green or red phosphorescent emitters (further details regarding white OLEDs can be found in the literature, e.g. Adv. Materi. 2002, 14, no.15, 1032, "White Light Emission Using Triplet Eximers in Electrophosphorescent OLEDs").

Based on the described situation, it was an object of the present invention to provide white-emitting organic thin film EL (emitter layer) devices with improved efficiency and color rendering. As already mentioned, this objective is in general achieved by a white-emitting OLED that comprises a blue emitter, wherein the color coordinates of said blue emitter are restricted such that y is smaller than 0.15 (referring to the CIE 1931 definition).

Figure 1 shows one particular embodiment of such a white-emitting OLED 100. In this example, the OLED 100 comprises three light-emitting components 10, 20 and 30 of the colors blue, green and red, respectively. All three light-emitting components are disposed on a glass substrate 40, wherein only the structure of the blue-emitting component 10 is shown in more detail. It should be noted that further light-emitting components (e.g. more copies of the three components 10, 20, 30) could optionally be disposed on the glass substrate 40.

The blue-emitting component 10 consists, starting from the lowest depicted layer on top of the glass substrate 40, of the following elements:

- an ITO layer 11 serving as an anode, wherein a typical thickness d_1 of this layer is for example 140 nm;
- an Ag-layer 12, wherein the thickness d_2 of this layer typically ranges between about 17 and 30 nm and may particularly have a value of 20 nm in the shown example; the Ag-layer may for example be produced by vapor deposition on the ITO layer;
- a low index hole transport layer HTL 13, wherein a typical thickness d_3 of this layer is for example 200 nm;

- a blue-emitting layer 14, wherein a typical thickness d_4 of this layer is for example 50 nm; the blue-emitting layer 14 may for example consist of poly[9,9-(2'-ethylhexyl)fluorene] (PEHF);
- a metal cathode 15.

A micro-cavity is realized in this design between the mirrored surfaces of the cathode 15 on the one hand side and the Ag-layer 12 plus ITO layer 11 on the other hand side.

Organic electroluminescent materials that can be used in the blue-emitting layer 14 (or in organic light emitting diodes in general) include:

(a) Organic molecules such as Alq3 (8-hydroxyquinolene aluminum) or paraphenylenevinylene. These are often blended with a charge transporting matrix to increase electrical conductivity. Many such molecular compounds exist, but their common feature is an electronic excited state that when decaying, emits a photon in the visible.

(b) Organic conjugated polymers such as PPV (poly(phenylene vinylene)) and polyfluorenes. The conjugated polymer may be a cross-linked polymer, star polymer, dendrimer or a linear chain polymer. They also have an electronic excited state which decays emitting a photon in the visible, but the exciton is less well defined and may extend over several repeat units of the polymer chain. Charge transport also occurs in the polymers.

(c) Organo-metallics: These are complexes of organic ligand groups and metal ions, e.g. lanthanide atoms. These can be both photoluminesent and electroluminescent and the excitation is transported via an organic ligand to the lanthanide. The lanthanide decays emitting a photon, but in a very narrow spectral bandwidth. The pure color is beneficial to color displays. Also the lifetime of the exciton is much longer, which may make laser action easier to achieve. Organolanthanides are a subclass of transition metal phosphorescents.

(d) There are many combinations and blends of the above.

Figure 2 shows in a diagram the x-color coordinates (circles) and the y-color coordinates (squares) of the blue-emitting component 10 of Figure 1 as a function of the emission angle α. The different curves of this diagram correspond to different thicknesses d_2 of the Ag-layer 12, wherein said thickness d_2 increases in the direction of the arrow from 17 to 30 nm. For a given thickness d_2 of the Ag-layer 12, the y-color coordinate is primarily determined by the thickness d_4 of the blue-emitting layer 14; with increasing thickness d_4 of the blue-emitting layer 14, the y-color coordinate also increases. The micro-cavity design of the blue-emitting layer 14 therefore allows to tune the y-color coordinate within a certain range. Without a micro-cavity, the y-color coordinate of the used emitter would be about 0.22.

Figure 3 shows the x-y color coordinate diagram for a white-emitting OLED according to the present invention, for example the OLED of Figures 1 and 2. The points on the curve within the diagram correspond to the black body line for CCT < 5000 K and to the CIE white line for CCT > 5000 K, respectively, wherein dots indicate Correlated Color Temperatures (CCT) in steps of 500 K. The diagram further shows by black squares the color coordinates of the blue-emitting component 10 ($x=0.126$, $y=0.095$), the green emitting component 20 ($x=0.392$, $y=0.572$) and the red emitting component 30 ($x=0.644$, $y=0.355$), respectively.

Figure 4 depicts the relative electrical power P_{rel} of the white-emitting OLED 100, which is required for the generation of a certain light flux (lumen), as a function of the y-color coordinate of the blue emitter 10. The color points of the red and green emitter are assumed to remain constant with the values mentioned above for Figure 3. Different curves in this diagram correspond to different Correlated Color Temperatures of the lamp, as indicated by the arrow. The blue-emitting component is in this example a Singlet-emitter, the green component a Triplet-emitter, and the red component may be a Triplet or a Singlet-emitter. The diagram shows that power consumption decreases with decreasing values of the y-color coordinate.

Figure 5 illustrates the influence of the blue emission on the color rendering index of the OLED 100, expressed as the Ra value (i.e. the mean of the R1 to R8 values according to the definition of color rendering indices, CRI, by the International Commission on Illumination, CIE). The diagram shows that the Ra value approaches a maximum at about $y = 0.05$, i.e. in the preferred interval of the blue emitter y-color coordinates.

The desired y-color coordinates of the blue-emitting component 10 can be achieved with usual blue-emitting materials by the construction of a micro-cavity that restricts the emission to a small range of wavelengths. Figure 6 shows in this respect the wavelength and the angular dependency of the power emitted by a dipole in a micro-cavity into the glass substrate (lines refer to points of equal power). The emission power of a dipole in a micro-cavity may have one or more maxima depending on the thickness of the active layers between the reflective anode and cathode contacts. Due to the reflectivity of the anode and the cathode, approximately no power is emitted in the shown example into an angle larger than 41° (i.e. the angle of total reflection in glass).

In summary, the invention discloses white OLEDs characterized by at least one of the following features:

- y-color coordinate of the blue emitter lies between 0.01 and 0.15
- three emitting regions with colors red, green, and blue;
- two emitting regions with colors yellow and blue;
- different emitting regions being arranged side by side;
- different emitting regions being disposed on top of each other;
- color temperature CCT ranging between 2000 and 6000 K;
- blue emitter comprises a micro-cavity;
- blue emitter comprises a blue color filter, e.g. a pigment or dielectric layers.

Finally it is pointed out that in the present application the term "comprising" does not exclude other elements or steps, that "a" or "an" does not exclude a plurality, and that a single processor or other unit may fulfill the functions of several means. The invention resides in each and every novel characteristic feature and each and every combination of characteristic features. Moreover, reference signs in the claims shall not be construed as limiting their scope.

CLAIMS:

1. A white-emitting OLED (100), comprising

a) a blue-emitting component (10) with a y-color coordinate smaller than 0.15;

b) at least one further light-emitting component (20, 30) of a different color.

2. The white-emitting OLED (100) according to claim 1, characterized in that the y-color coordinate of the blue-emitting component (10) is smaller than 0.1, preferably smaller than 0.08, most preferably smaller than 0.05.

3. The white-emitting OLED (100) according to claim 1 or 2, characterized in that the y-color coordinate of the blue-emitting component (10) is larger than 0.01.

4. The white-emitting OLED (100) according to any of claims 1 to 3, characterized in that its correlated color temperature ranges between 2000 and 6000 K.

5. The white-emitting OLED (100) according to any of claim 1 to 4, characterized in that the blue-emitting component (10) is arranged in a first region and the further light-emitting component, which emits light of other colors, in a separate second region.

6. The white-emitting OLED (100) according to claim 5,

characterized in that the separate regions are arranged side by side or on top of each other with respect to the direction of the light emission.

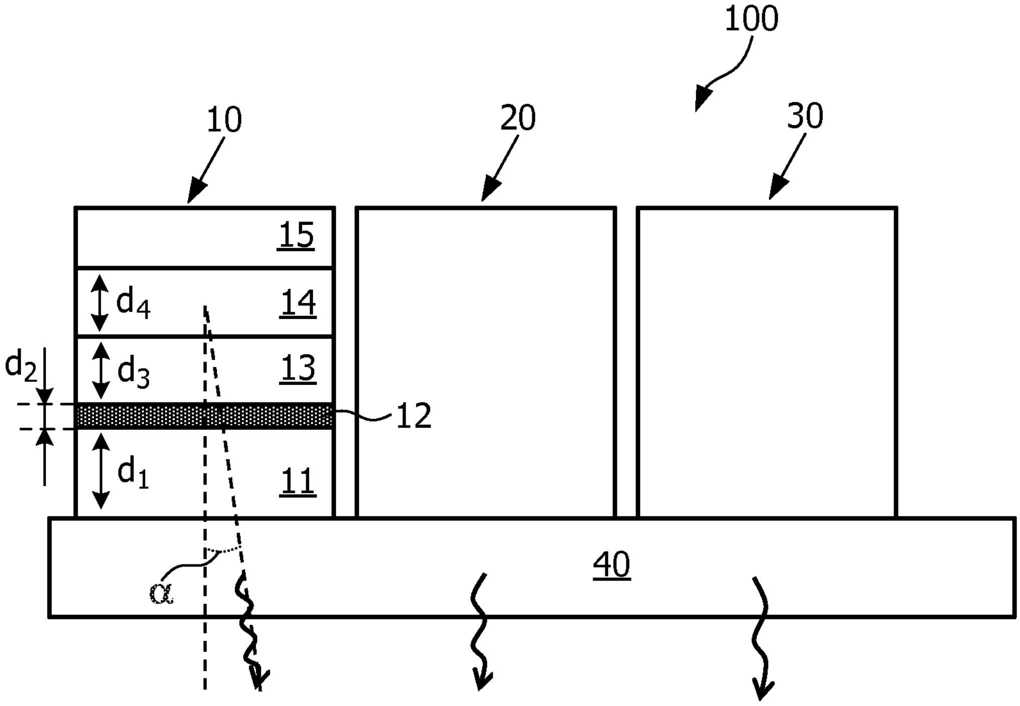
7. The white-emitting OLED (100) according to any of claims 1 to 6, characterized in that the blue-emitting component (10) comprises a blue color filter or a micro-cavity.

8. The white-emitting OLED (100) according to any of claims 1 to 7, characterized in that the blue-emitting component (10) comprises a sequential arrangement of a cathode (15), a light-emitting layer (14), a HTL (13) and an anode (11).

9. The white-emitting OLED (100) according to claim 8, characterized in that the thickness (d_4) of the light-emitting layer (14) ranges between 50 and 70 nm and/or the thickness (d_3) of the HTL (13) ranges between 50 and 200 nm.

10. The white-emitting OLED (100) according to claim 8 or 9, characterized in that an Ag-layer (12) is disposed between the HTL (13) and the anode (11).

11. The white-emitting OLED (100) according to claim 10, characterized in that the thickness (d_2) of the Ag-layer (12) ranges between 10 and 40 nm.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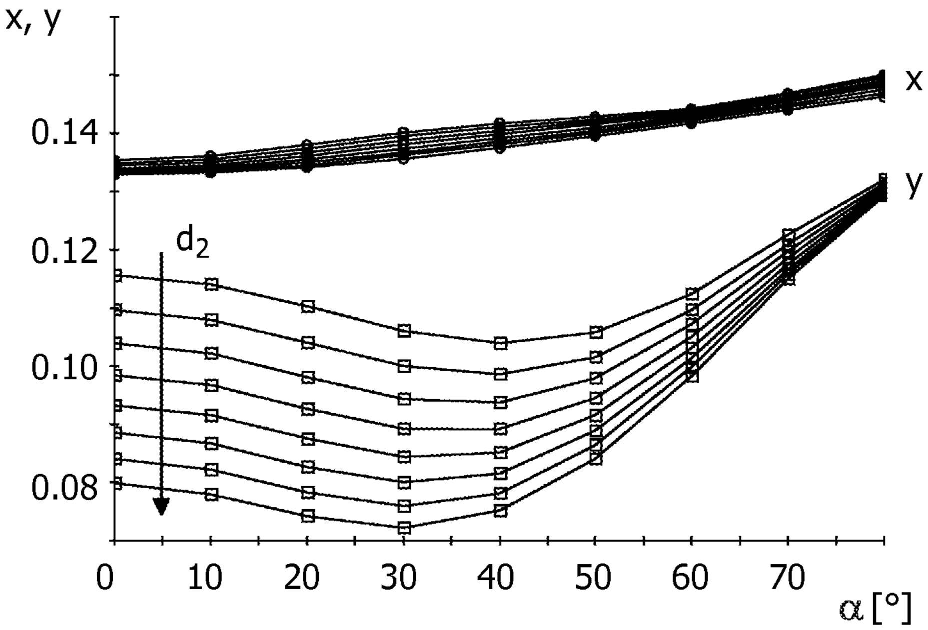
40
d4
d3
d2
d1
α

FIG. 1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0.10
0.08
x
y
d2
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20
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40
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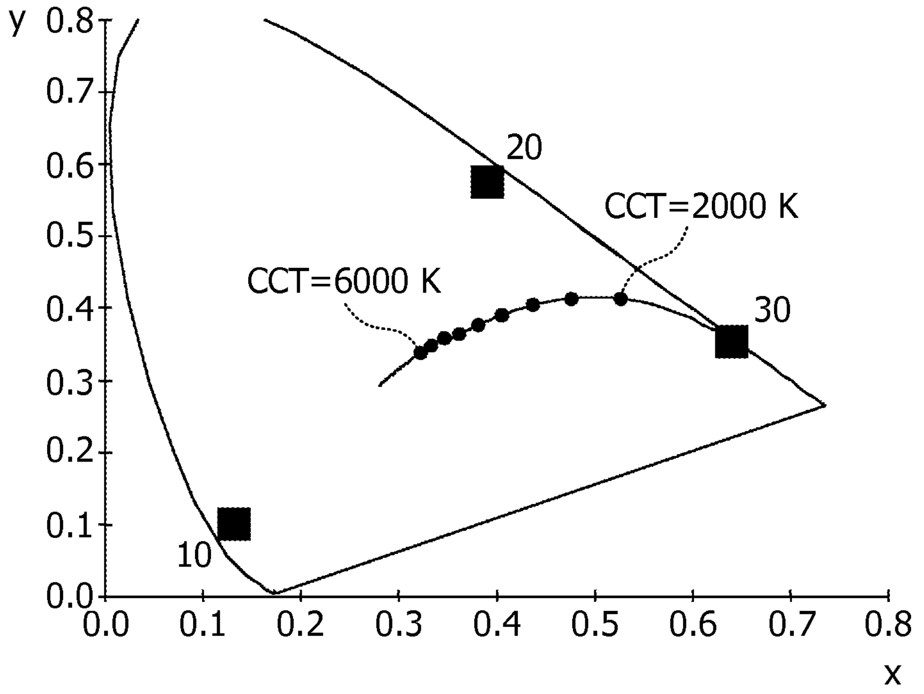
α [°]

FIG. 2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0.6
0.7
0.8
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CCT=6000 K
30
10

FIG. 3

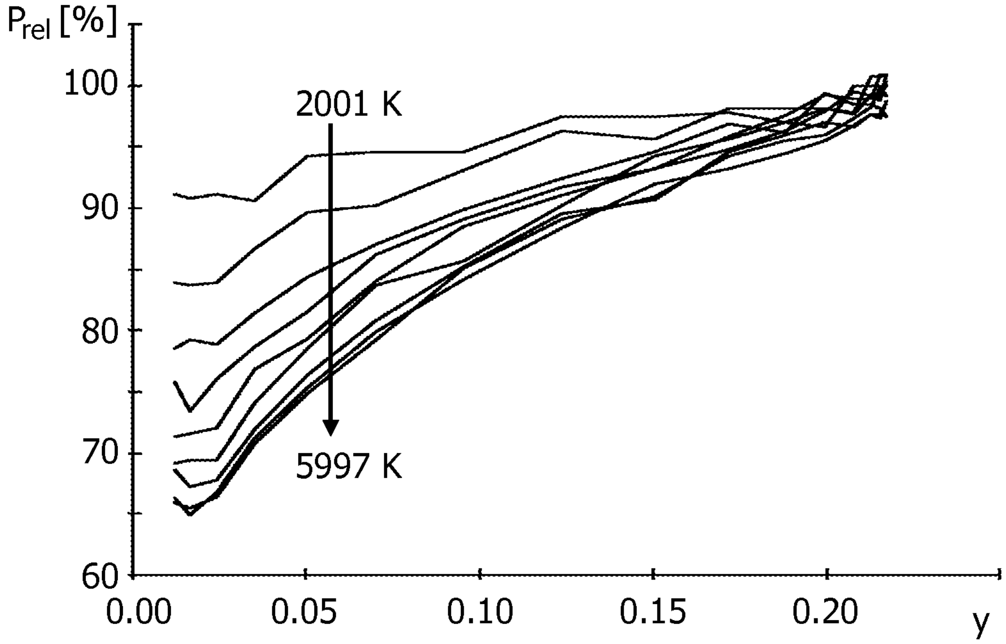
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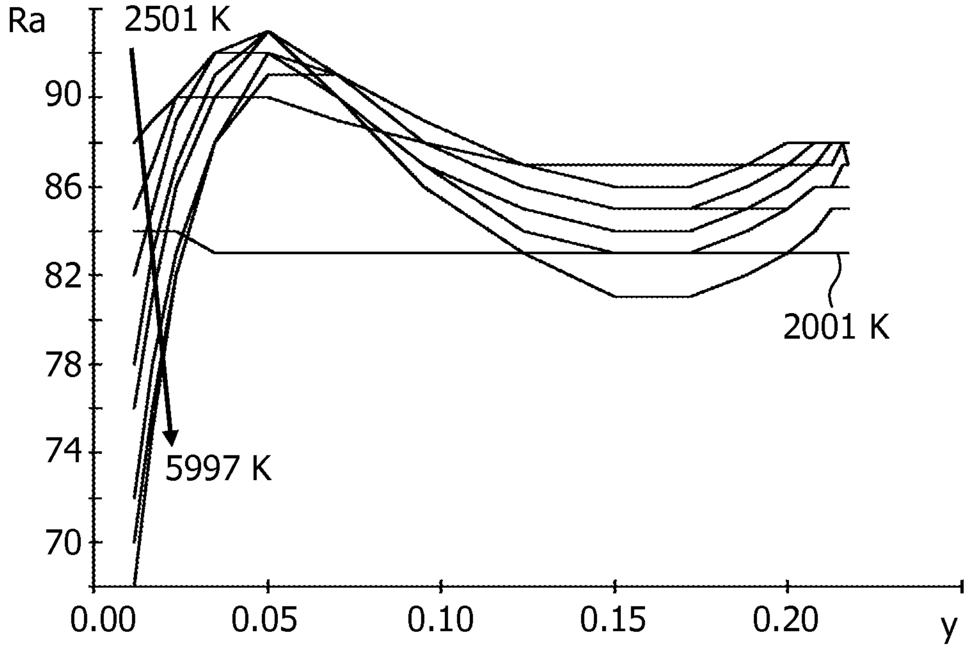
FIG. 4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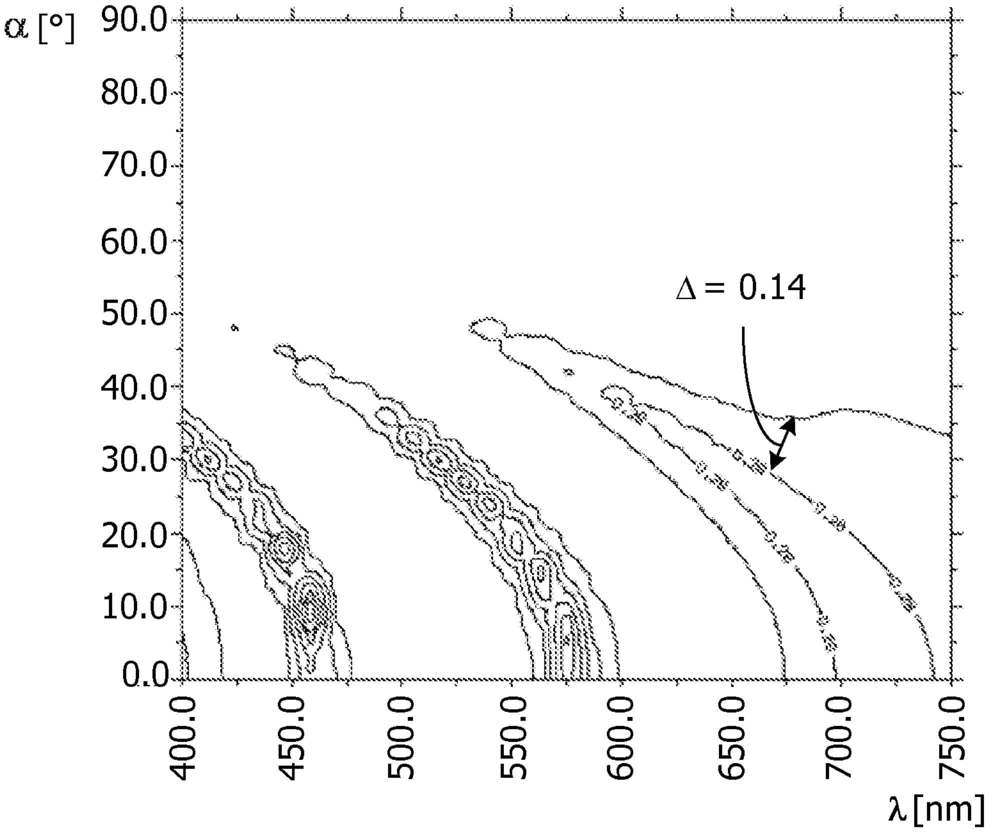
y

FIG. 5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λ[nm]

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2007/051975

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L27/32 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.
X	US 2005/280008 A1 (RICKS MICHELE L [US] ET AL) 22 December 2005 (2005-12-22)	1-9
Y	paragraphs [0032], [0033], [0036], [0195] - [0203], [0209] - [0221], [0244]; figures 2,3b,4b,6b; table 2 -----	10,11
X	US 2006/105198 A1 (SPINDLER JEFFREY P [US] ET AL) 18 May 2006 (2006-05-18) paragraphs [0006] - [0010], [0026] - [0030], [0159], [0185]; figures 1,5 ----- -/--	1-8

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search 23 October 2007	Date of mailing of the international search report 05/11/2007
Name and mailing address of the ISA/ 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	Authorized officer Bakos, Tamás

International application No
PCT/IB2007/051975

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	ISHIBASHI T ET AL: "ACTIVE MATRIX ORGANIC LIGHT EMITTING DIODE DISPLAY BASED ON SUPER TOP EMISSION TECHNOLOGY" May 2006 (2006-05), JAPANESE JOURNAL OF APPLIED PHYSICS, JAPAN SOCIETY OF APPLIED PHYSICS, TOKYO, JP, PAGE(S) 4392-4395 , XP001502200 ISSN: 0021-4922 page 4392, column 2, paragraph 2; figures 2,4 -----	1-7
Y	WO 2005/112521 A (IDEMITSU KOSAN CO [JP]; HACHIYA SATOSHI [JP]; KUMA HITOSHI [JP]; HOSOK) 24 November 2005 (2005-11-24) abstract -& US 2006/232196 A1 (HACHIYA SATOSHI [JP] ET AL) 19 October 2006 (2006-10-19) paragraphs [0038], [0040], [0042], [0043], [0047], [0055], [0065], [0074], [0075]; figure 4 -----	10,11

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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