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(54) Title: PROCESSING METHOD FOR PROCESSING A SUBSTRATE FOR A LIGHT SOURCE

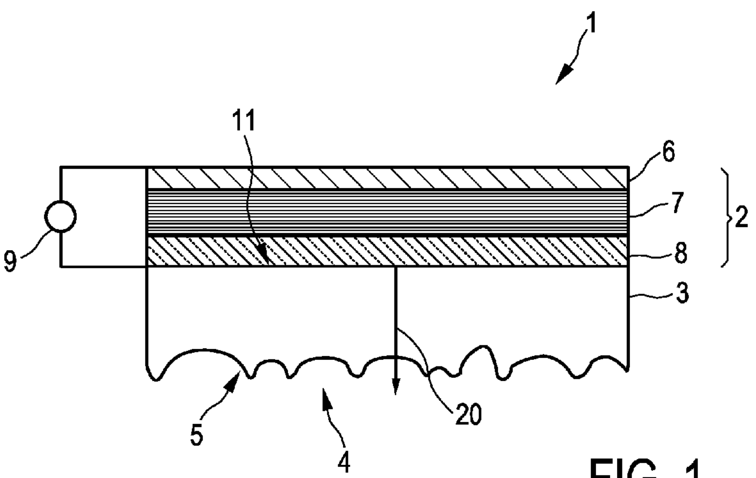

FIG. 1

(57) **Abstract**: The invention relates to a processing method for processing a substrate (3) for a light source. The processing method comprises roughening a surface of the substrate, followed by etching the roughened surface for producing a structured surface (4).Since the surface of the substrate is firstly roughened and then etched, a structured surface can be produced, which comprises rounded surface structures, which are preferentially lens like and concave. If a light generating unit (2) like an organic light emitting diode is provided on this processed substrate with the structured surface (4), the rounded surface structures (5) can increase the out-coupling efficiency of the resulting light source, i.e. the efficiency of extracting light out into air surrounding the light source.

WO 2014/013403 A1

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PROCESSING METHOD FOR PROCESSING A SUBSTRATE FOR A LIGHT SOURCE

FIELD OF THE INVENTION

The invention relates to a processing method and a processing apparatus for processing a substrate for a light source. The invention relates further to a substrate for a light source and to a light source comprising the substrate.

BACKGROUND OF THE INVENTION

US 2005/0231101 A1 discloses an organic light-emitting diode (OLED) comprising a substrate with a plurality of protrusions on a first plane thereof and a first electrode installed on a second plane of the substrate, wherein the second plane is opposed to the first plane. The OLED further comprises organic light-emitting layers on the first electrode and a second electrode on the organic light-emitting layers.

The outcoupling efficiency of coupling light generated by the organic light-emitting layers out of the OLED is relatively low.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a processing method and a processing apparatus for processing a substrate for a light source such that, if the substrate is used by the light source, the outcoupling efficiency of light generated by the light source into the surrounding, in particular, into air, can be improved. It is a further object of the present invention to provide a corresponding substrate and a corresponding light source comprising the substrate.

In a first aspect of the present invention a processing method for processing a substrate for a light source is presented, wherein the processing method comprises roughening a surface of the substrate, followed by etching the roughened surface for producing a structured surface.

Since the surface of the substrate is firstly roughened and then etched, a structured surface can be produced, which comprises rounded surface structures. If a light generating unit is provided on this processed substrate with the structured surface, the rounded surface structures can increase the outcoupling efficiency of the resulting light source, i.e. the efficiency of extracting light out into air surrounding the light source can be improved.

The substrate is preferentially a glass plate, in particular, a standard index glass plate or a float glass plate.

It is preferred that the roughening step includes at least one of sandblasting, grinding, polishing, laser patterning and ion bombardment patterning for roughening the surface. Sandblasting, grinding and polishing can result in random, i.e. statistical, surface structures, whereas laser patterning and ion bombardment patterning can result in regular surface structure patterns, in particular in controlled and equidistant defects on the surface of the substrate.

It is further preferred that the etching step includes using at least one of hydrofluoric acid (HF), hydrochloric acid, ammonium hydrogenic bifluoride, potassiumhydrogen bifluoride, Na-pyrophosphate, tetrafluoroboric acid, hexafluorosilicic acid.

The roughening and etching steps are preferentially adapted such that surface structures are produced on the surface having an average lateral size in the range of 0.5 to 20 μm. It is further preferred that the average lateral size, i.e. the width, of the surface structures is in the range of 1 to 6 μm. The roughening and etching steps can also be adapted such that surface structures are produced on the surface, wherein the lateral size of the produced surface structures is statistically distributed around the average lateral size. For instance, the lateral sizes of the produced surface structures can be statistically distributed such that the distribution defines an average lateral size of 5 μm and a distribution width from 2 to 10 μm, i.e. the smallest lateral size may be 2 μm and the largest lateral size may be 10 μm. Or, the lateral sizes of the produced surface structures can be statistically distributed such that the distribution defines an average lateral size of 2 μm and a distribution width from 1 to 6 μm, i.e. the smallest lateral size may be 1 μm and the largest lateral size may be 6 μm. Moreover, the roughening and etching steps are preferentially adapted such that surface structures are produced on the surface having an average height in the range of 0.5 to 4 μm. The height is preferentially defined as the peak-to-valley distance of the structures. The average height can be similar to or larger than the wavelength of the light of the light source. These preferred dimensions of the surface structures produced by the roughening and etching steps can allow for a further increased outcoupling efficiency, i.e. a further improved efficiency of extracting light out into the surrounding air.

The roughening and etching steps lead to rounded surface structures, which have rounded surfaces. The rounded surface structures can comprise relatively sharp and steep borders. The rounded surface structures are preferentially lens like. It is also preferred that the rounded surface structures are concave.

In a preferred embodiment the roughening and etching steps can be performed such that statistical surface structures are produced. That means the structures can be random structures, which are not regularly arranged and not regularly dimensioned. This can reduce possible color effects. For instance, if the light generating unit is adapted to generate white light being a mixture of red, green and blue light, a good mixing of the different colors can be achieved such that a generally possible variation of the color point with the viewing angle can be reduced.

The processing method preferentially further comprises a step of depositing layers of a light generating unit on a further surface of the substrate, which is opposite to the structured surface, for forming the light source. Preferentially, an anode layer, a cathode layer and intermediate layers in between the anode layer and the cathode layer are deposited on the further surface for forming an OLED. In an embodiment, the anode layer and optionally also the cathode layer are transparent for outcoupling light through the anode layer and optionally the cathode layer. The anode layer is, for example, an indium tin oxide (ITO) layer and the cathode layer can be a metal layer. Thus, an external outcoupling structure can be provided by the structured surface of the substrate for coupling light out of the light source.

Moreover, the processing method may comprise a step of depositing a smoothing layer on the structured surface, after the roughening and etching steps have been performed, wherein the smoothing layer has a refractive index being larger than the refractive index of the substrate. If the light generating unit is an OLED, the refractive index of the smoothing layer is preferentially similar to, in particular, equal to, the average of the refractive indices of the intermediate layers in between the cathode and the anode layer, or to the average of the anode layer and the intermediate layers. In other words, the refractive index of the smoothing layer preferentially matches with the average of the refractive indices of the intermediate layers and optionally of the anode layer, thereby improving the coupling of the light generated by the OLED into the smoothing layer and, thus, the outcoupling efficiency, i.e. the efficiency of extracting the light into air. Preferentially, two refractive indices are regarded as being similar, if the absolute difference between the refractive indices is smaller than 0.1. The smoothing layer can be deposited by using chemical vapor deposition (CVD), wherein grooves of the structured surface are filled with a material having a refractive index being larger than the refractive index of the substrate. For instance, this material can be SiO_xN_y.

For depositing and forming SiO_xN_y via a gas phase reaction CVD is preferentially used with silicon containing gas, oxygen containing gas and nitrogen containing gas as feed gases, i.e. as gaseous starting compounds. For instance, the SiO_xN_y material can be deposited by CVD by using SiH_4, NH_3 and O_2 or N_2O as gaseous starting compounds, diluted in N_2, as described in the article "Rapid Thermal Chemical Vapour Deposition of SiO_xN_y Films" by F. Lebland et al., Applied Surface Science, volume 54, pages 125 to 129 (1992), which is herewith incorporated by reference. By admixture of N_2O the refractive index of the deposited material can be continuously varied between 1.46 and 2.2 by adjusting the relative amounts, i.e. the gas flows, of N_2O and NH_3 in a one step process.

Another possible reaction pathway for depositing SiO_xN_y is using $SiCl_4$ with O_2 and N_2 as gaseous starting compounds for forming SiO_xN_y. Due to the high stability of $SiCl_4$ for temperatures below 600°C a plasma activated CVD process is preferentially performed such as a microwave plasma activated CVD process.

After the smoothing layer has been deposited on the structured surface, the smoothing layer can be smoothed by an additional smoothing step. For instance, an additional thermal and/or polishing treatment or another smoothing treatment can be performed for further smoothing the surface formed by the smoothing layer. This can improve the reliability of the light source and reduce possible dark currents.

In an embodiment, the refractive index of the smoothing layer is equal to or larger than 1.7. It is further preferred that the refractive index of the smoothing layer is equal to or larger than 1.8. In an embodiment, the refractive index of the smoothing layer is within the range of 1.7 to 2.1. For example, the refractive index of the smoothing layer can be 1.85 ± 0.05. It has been found that, if the refractive index of the smoothing layer is within this range, the outcoupling efficiency can be further increased.

In a preferred embodiment, the thickness of the smoothing layer is at least two times larger than the mean height of surface structures on the structured surface, after the surface has been roughened and etched, wherein the thickness of the smoothing layer is preferentially defined as the thickness above the average line of the surface structures or above the waviness profile averaged over neighboring peaks and valleys and wherein the mean height of the surface structures is preferentially defined as the mean peak-to-valley height of the surface structures. In particular, the thickness of the smoothing layer can be two to five times larger than the mean height of the surface structures on the roughened surface. The thickness of the smoothing layer is preferentially larger than 5 µm. For a smoothing layer having a thickness between 5 to 10 μm, the interface roughness, i.e. the mean height of the surface structures, is preferentially within 1 to 3 μm. In this case the average lateral size of the surface structures may be below 10 μm. This can allow for a further improved outcoupling efficiency, i.e. to a further improved efficiency of extracting light into the surrounding air.

The processing method can also be adapted to deposit layers of a light generating unit on the deposited smoothing layer. Also in this case preferentially an anode layer, a cathode layer and intermediate layers in between the anode layer and the cathode layer are deposited, in this embodiment on the smoothing layer, for forming an OLED. The structured surface can therefore also be used to provide an internal outcoupling structure for coupling light out of the light source, wherein the outcoupling structure is provided between the substrate and the smoothing layer.

The substrate is preferentially processed such that the absorption is below 4 percent in the visible range. In particular, the absorption is preferentially below 4 percent in the whole visible range and, for instance, lower than 2.5 percent at a wavelength of 550 nm.

In a further aspect of the present invention a substrate being producible by a processing method as defined in claim 1 is presented. Moreover, in a further aspect of the present invention a light source comprising the substrate as defined in claim 13 is presented.

In an aspect of the present invention a processing apparatus for processing a substrate for a light source is presented, wherein the processing apparatus comprises:

- a roughening unit for roughening a surface of the substrate, and
- an etching unit for etching the roughened surface for producing a structured surface.

It shall be understood that the processing method of claim 1, the substrate of claim 13, the light source of claim 14, and the processing apparatus of claim 15 have similar and/or identical preferred embodiments, in particular, as defined in the dependent claims.

It shall be understood that a preferred embodiment of the invention can also be any combination of the dependent claims with the respective independent claim.

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

Fig. 1 shows schematically and exemplarily an embodiment of a light source comprising a structured surface,

Fig. 2 shows schematically and exemplarily another embodiment of a light source comprising a structured substrate,

Fig. 3 shows a flowchart exemplarily illustrating an embodiment of a processing method for processing a substrate for a light source,

Figs. 4 to 6 show schematically and exemplarily embodiments of structured surfaces of the substrate,

Fig. 7 shows schematically and exemplarily an embodiment of a processing apparatus for processing a substrate for a light source, and

Fig. 8 shows exemplarily diffuse transmittances depending on the wavelength.

DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1 shows schematically and exemplarily a light source 1 comprising a light generating unit 2 on a substrate 3, wherein the light generating unit 2 is adapted to generate light which is coupled out through the substrate 3 into air in the outcoupling direction 20.

The light generating unit 2 is an OLED comprising a cathode layer 6, an anode layer 8 and intermediate layers 7 in between the cathode layer 6 and the anode layer 8. In this embodiment, the cathode layer 6 is a non-transparent metal layer which comprises, for example, copper or silver, and the anode layer 8 is an ITO layer. The intermediate layers 7 can be, for example, two or more layers and include known organic layers which are configured such that light is generated by the intermediate layers 7, if a voltage is applied to the cathode layer 6 and the anode layer 8 via a voltage source 9 schematically shown in Fig. 1. The light generated within the intermediate layers 7 can leave the light generating unit 2 through the anode layer 8 in the outcoupling direction 20. The light source 1 shown in Fig. 1 emits the generated light therefore in the bottom direction. In another embodiment, in addition the cathode layer 6 can be transparent such that the generated light can leave the OLED 2 also through the cathode layer 6. The OLED 2 can therefore be a bottom emitter as shown in Fig. 1, or a bottom and top emitter.

The light generating unit 2 is provided on a planar surface 11 of the substrate 3. The opposite surface 4 of the substrate 3 has been roughened and etched for forming surface structures 5.

The substrate 3 is preferentially a glass plate, in particular, a standard index glass plate or a float glass plate, which has been sandblasted, grinded or polished for initially roughening the surface 4 of the substrate 3, whereupon an etching is performed preferentially with HF. The sandblasting, grinding or polishing followed by the etching leads to random, i.e. statistical, surface structures 5 which comprise rounded surfaces and which are lens like. The rounded surface structures are concave and have relatively sharp and steep boarders. They have preferentially an average lateral size in the range of 0.5 to 20 µm. It is further preferred that the average lateral size, i.e. the width, of the surface structures 5 is in the range of 1 to 6 µm. In particular, the roughening and etching steps can be adapted such that surface structures 5 are produced on the surface 4, wherein the lateral size of the produced surface structures 5 is statistically distributed around the average lateral size. For instance, the lateral sizes of the produced surface structures 5 can be statistically distributed such that the distribution defines an average lateral size of 5 µm and a distribution width from 2 to 10 µm, i.e. the smallest lateral size may be 2 µm and the largest lateral size may be 10 µm. Or, the lateral sizes of the produced surface structures 5 can be statistically distributed such that the distribution defines an average lateral size of 2 µm and a distribution width from 1 to 6 µm, i.e. the smallest lateral size may be 1 µm and the largest lateral size may be 6 µm. Moreover, the roughening and etching steps are adapted such that the produced surface structures 5 on the surface 4 have an average height in the range of 0.5 to 4 µm.

Fig. 2 shows schematically and exemplarily a further embodiment of a light source. In this embodiment the light source 101 comprises a light generating unit 2 with a cathode layer 6, an anode layer 8 and intermediate layers 7 in between the cathode layer 6 and the anode layer 8, which are similar to the corresponding layers described above with reference to Fig. 1. Moreover, also in this embodiment the cathode 6 and the anode 8 are electrically connected to a voltage source 9. Moreover, the light source 101 comprises a substrate 103 being, for instance, a glass substrate like a standard index glass substrate or a float glass substrate, with a structured surface 104 comprising surface structures 105. The surface 104 with the surface structures 105 has also been produced by roughening the surface and then etching the roughened surface. The resulting surface structures 105 are therefore similar to the surface structures 5 described above with reference to Fig. 1. In particular, also in this embodiment the surface structures have rounded surfaces, are lens like and are randomly dimensioned and distributed on the surface 104. Between the surface 104 with the surface structures 105 and the anode layer 8 of the light generating unit 2 a smoothing layer 110 is located, which can also be regarded as being an interface layer and which has a refractive index being larger than the refractive index of the substrate 103. The smoothing layer 110 has been deposited on the surface 104 with the surface structures 105 by using CVD, wherein the grooves formed by the surface structures 105 are filled with a smoothing material having a refractive index being larger than the refractive index of the substrate 103. In this embodiment the smoothing material is SiO_xN_y.

The part of the smoothing layer 110 immediately above the surface structures 105 comprises curved growth lines, which are caused by depositing the filling material forming the smoothing layer 110 on the structured surface 104 of the substrate 103. These growth lines lead to an optically inhomogeneous part of the smoothing layer 110 above the surface structures 105. With increasing distance to the surface structures 105 in the height direction the curved growth lines disappear and the smoothing layer 110 becomes optically homogeneous, thereby forming an optically homogenous layer. The optically homogenous layer may have a thickness in the outcoupling direction 20 being larger than a coherence length of the generated light. Light generated by an OLED has generally a coherence length between 3 μm and 7 μm. The thickness of the optically homogeneous layer may be therefore at least 4 μm, preferentially about 10 μm or larger.

The refractive index of the smoothing layer 110 is preferentially similar to an average of the refractive indices of the intermediate layers 7, i.e. the refractive index of the smoothing layer 110 preferentially matches with the average of the refractive indices of the intermediate layers 7 of the light generating unit 2. In this embodiment, the intermediate layers 7 have an average refractive index of about 1.8. The refractive index of the smoothing layer 110 is therefore also preferentially about 1.8. In other embodiments, the refractive index of the smoothing layer can have another value, wherein generally the refractive index will be equal to or larger than 1.7.

The material forming the smoothing layer 110 is preferentially an inorganic material being transparent to the light generated by the OLED 2. In particular, this material does not absorb the light generated by the OLED 2. The smoothing layer comprises preferentially SiO_xN_y. However, the smoothing layer can also comprise at least one of GeO_2, Ga_2O_3, HfO_2, Ta_2O_5, Si_3N_4 and SiN_y in addition to or instead of SiO_xN_y.

The thickness of the smoothing layer 110 is preferentially at least two times larger than the mean height of the surface structures 105 on the surface 104 of the substrate

103. In particular, the thickness of the smoothing layer 110 is two to five times larger than the mean height of the surface structures 105 on the surface 104. For instance, for a smoothing layer 110 having a thickness between 5 to 10 μm, the interface roughness, i.e. the mean height of the surface structures, is preferentially within 1 to 3 μm. In this case the average lateral size of the surface structures 105 may be below 10 μm.

It should be noted that in Figs. 1 and 2 the dimensions are not to scale.

In the following an embodiment of a processing method for processing a substrate for a light source will exemplarily be described with reference to a flowchart shown in Fig. 3.

In step 201 a substrate is provided. In particular, a glass plate like a standard index glass plate or a float glass plate is provided. In step 202 a surface of the substrate is roughened. For instance, the surface can be sandblasted, grinded or polished for generating surface structures which are statistically dimensioned and distributed on the surface. In step 203 the roughened surface is etched by using, for instance, HF, in order to produce the above described rounded, lens like, concave surface structures. In step 204 a light generating unit can be provided on the substrate for fabricating a light source comprising the substrate. For instance, on a further surface being opposite to the structured surface with the surface structure an anode layer, a cathode layer and intermediate layers in between the anode layer and the cathode layer can be deposited for generating an OLED. Alternatively, a smoothing layer can be provided on the structured surface with the surface structures for smoothing this surface, wherein the smoothing layer has a refractive index being larger than the refractive index of the substrate. After the smoothing layer has been deposited on the structured surface of the substrate, the light generating unit can be provided on the smoothing layer. In particular, the anode layer, the cathode layer and the intermediate layers in between the anode layer and the cathode layer can be deposited on the smoothing layer for forming an OLED.

The surface structure on the substrate is provided by a roughening treatment such as sandblasting, grinding or even polishing, leading to surface defects where the etching can start, which is then followed by an etching treatment either by using HF or another etching fluid or paste. Depending on the prestructuring and etching conditions like the etching time or the defect generation treatment the dimensions and the roughness of the structured surface of the substrate can be varied. Especially HF has the advantageous property that lens like structures like rounded surfaces are created with a statistical dimensional scattering, which are very suited for an efficient light outcoupling with a broad scatter distribution.

For achieving lens like surface structures having dimensions being smaller than 20 μm and amplitudes being smaller than 4 μm firstly a certain defect density is obtained by the roughening step. If the defect density is too small, i.e. if the distance between defects becomes too large, only small lenses are formed around each defect and the rest remains flat. If the etch time is too long, rather large lens like structures are formed. For processing time reasons and for small structures short etch times are preferred. Preferentially, the etch time is between 1 to 3 min.

Fig. 4 shows exemplarily a grinded tin side surface of a float glass substrate which has been etched for 2.5 min by using HF. In this example the grinding has been performed by using SiC particles with an average size of 6.5 μm, which corresponds to the grit classification "grinding 800" of grinding papers. The lens like, rounded, concave surface structures can clearly be seen in this figure. Fig. 5 shows exemplarily a surface of a float glass substrate, after the tin side surface has been grinded and etched for 2.5 min by using HF. In this example the grinding has been performed by using SiC particles with an average size of 3 μm, which corresponds to the grit classification "grinding 1200" of grinding papers. Fig. 6 shows exemplarily a surface of a float glass substrate, after the tin side surface has been polished and etched for 2.5 min by using HF. In this example a polishing has been performed, which corresponds to the grit classification "grinding 1200" of grinding papers.

The roughening and etching steps are preferentially performed such that the resulting surface comprises rounded structures and not sharp spikes. Moreover, the substrate is preferentially processed such that the absorption of the total substrate remains low, wherein the remaining low absorption can be obtained by the additional etching, whereas, for instance, sandblasting and grinding alone would yield an increased absorption.

Preferentially, HF is used as etchant for etching the roughened surface of the substrate. However, rounded, concave, lens like/round facet structures can also be obtained by variants of HF containing etchants or alternate etchants.

Etching by HF means etching in hydrofluoric acid, which is a solution of HF in water. Typical concentrations are 10 to 50 percent of HF. Other possible etching compositions using HF or H and F containing compounds are: a) hydrofluoric acid and sulfuric acid, for instance, H_2O [20 ml] + concentrated H_2SO_4 [80 ml] + HF (40 percent) [100ml]; b) hydrofluoric acid and nitric acid, for instance, H_2O [4 or 7] + HNO_3 (66 percent) [1 or 8] + HF (40 percent) [1 or 5]; c) hydrofluoric acid and nitric acid, for instance, HNO_3 (100 percent) [1] + HF (50 percent) [4]; d) hydrofluoric acid and ammonium fluoride, for instance, HF (40 percent) + NH_4F (40 percent); e) tetrafluoroboric acid, for instance, HBF_4

(50 percent); and f) hexafluorosilicic acid, for instance, H_2SiF_6 (31 percent). Lower concentrations are preferred, in order to produce moderately rough structures. The etching preferentially leads to smoother surfaces on micrometer scale.

Also other recipes can be used, which have a reduced HF content or no HF at all, in order to make the etching process more safe for a user. For instance, following etchants can be used: a) potassiumhydrogen bi-flouride (250 g) with water (1 l) and chloric acid (250 g) and potassiumsulfate (140 g), i.e. HF may be replaced by HCl; b) ammonium hydrogenic bifluoride with the formula NH_4HF_2 mixed with bariumsulfate, HF and water for providing fast etching ink for typical etching times of 15 s; c) 1 percent Na-pyrophosphate solution in water; d) pastes prepared on the basis of ammonium hydrogenic fluoride and which affect silicate in a glass substrate.

Depending on grinding or polishing conditions, i.e., for instance, the dimension of the grains, larger or finer structures can be achieved with the same, preferentially relatively short, etching times. Similar structures can be achieved with sandblasting and etching, but grinding and polishing followed by etching are preferred, because they can provide an increased mechanical stability due to a reduced or not present micro-crack formation.

The processed surface, which can be a scattering interface layer as shown in Fig. 2, can be characterized by lens like structures of an average dimension of, for instance, 5 to 50 μm depending on, for example, polishing and etching conditions. The average, i.e. peak to valley, roughness preferentially varies between 0.5 to 4 μm. The average lateral extension, i.e. the diameter, of the resulting round shapes with relatively sharp and eventually steeper borders can be varied by, for example, selecting a corresponding etching time. In an embodiment, grinded surfaces under rougher grinding conditions like grinding 800 may have surface structures, wherein the average flat lens type sizes vary from i) 2 μm with a distribution width from (2 – 1) μm to (2 + 4) μm, i.e. a distribution width extending from 1 μm to 6 μm, to ii) 5 μm with a distribution width from (5 – 3) μm to (5 + 5) μm, i.e. a distribution width extending from 2 μm to 10 μm.

For light having the wavelength λ the surface, i.e. the structured surface of the substrate without the layer with the relatively high refractive index, may be regarded as smooth, if the condition for the rms roughness, i.e. the root mean squared roughness, Δh holds $\Delta h < (8\cos\alpha)$, where α is the angle of incidence. Preferentially, Δh is therefore larger than $\lambda/(8\cos\alpha)$ or comparable to, for instance, to λ.

The surface structures produced by roughening and etching can be used in different ways. For instance, in the case of bottom emission as shown, for example, in Fig. 1, the rough structured bottom surface may just replace other external outcoupling means such as lens or pyramid arrays and gives improved light emission compared to the blank bottom surface. Moreover, the structured surface can be used as an interface between, for instance a float glass substrate having a relatively low refractive index and an intermediate layer, i.e. a smoothing layer, below an anode layer of a light generating unit as exemplarily shown in Fig. 2. Furthermore, these two options can be combined, i.e. two opposing surfaces of the substrate can be roughened and etched for producing the rounded surface structures on both surfaces, wherein one of these structured surfaces is coated with the smoothing layer for providing an internal outcoupling structure and the other of these structured surfaces forms an outer bottom surface for providing an external outcoupling structure. Moreover, a substrate with a relative high refractive index can be used, which preferentially matches a) the average of the refractive indices of the intermediate layers in between an anode layer and a cathode layer of an OLED or b) the average of the refractive indices of the intermediate layers in between the anode layer and the cathode layer of the OLED and of the anode layer, wherein a first surface of the substrate can be roughened and etched for producing an external outcoupling structure and a second surface of the substrate, which is opposite to the first surface, can be provided with the anode layer, the cathode layer and the intermediate layers in between the anode layer and the cathode layer for providing the OLED on the flat second surface of the substrate.

The preparation of medium to large area, i.e. small molecule, OLEDs, especially of the layer structure consisting of organic materials, is usually carried out by thermal evaporation in vacuum on a light transmitting substrate like float glass. A typical OLED structure consists of a thin transparent anode, a hole transport layer, a light emission zone, an electron transport layer and a cathode layer. Unfortunately typically about 50 percent of the light generated remains in the OLED layer stack because of guided modes, about 25 percent remain in the substrate having a relatively low refractive index and only 20 to 25 percent are coupled into air and can be used for lighting applications.

For monochrome and for white OLED devices the light output into air can be significantly increased by using a substrate having a high refractive index below the OLED. This is based on the fact that by matching the refractive index of this substrate with the average refractive index of the OLED layers of about 1.8 the amount of light in this substrate can be increased by about 50 percent and hence also the amount of light emitted into air by using a suitable light outcoupling structure such as, for instance, a micro lens array or pyramid array. However, the main disadvantage of this approach is that the high refractive index glass substrates used are much more expensive than normal glass substrates having a refractive index of about 1.5 and moreover are much more brittle and have a high chance of breaking during processing. This problem can be overcome, if a normal glass substrate with an optically thick high index layer below the OLED and an additional outcoupling structure near the interface is used, wherein a scattering of the light can be provided at the interface layer between the relatively high refractive index and the relatively low refractive index. Also if the structured surface is used as an external outcoupling structure on the bottom surface of the light source the outcoupling efficiency can be significantly increased.

For depositing and forming SiO_xN_y as the smoothing layer of the structured surface of the substrate CVD is preferentially used with silicon containing gas, oxygen containing gas and nitrogen containing gas as feed gases, i.e. as gaseous starting compounds. For instance, the SiO_xN_y material can be deposited by CVD by using SiH_4, NH_3 and O_2 or N_2O as gaseous starting compounds, diluted in N_2, as described in the article "Rapid Thermal Chemical Vapour Deposition of SiO_xN_y Films" by F. Lebland et al., Applied Surface Science, volume 54, pages 125 to 129 (1992), which is herewith incorporated by reference. By admixture of N_2O the refractive index of the deposited material can be continuously varied between 1.46 and 2.2 by adjusting the relative amounts, i.e. the gas flows, of N_2O and NH_3 in a one step process.

Another possible reaction pathway for depositing SiO_xN_y is using $SiCl_4$ with O_2 and N_2 as gaseous starting compounds for forming SiO_xN_y. Due to the high stability of $SiCl_4$ for temperatures below 600°C a plasma activated CVD process is preferentially performed like a microwave plasma activated CVD process.

In an embodiment, for providing the smoothing layer, in particular, for filling up of grooves between surface structures on the substrate, CVD parameters are used as disclosed in the article "Interface Morphology in Chemical Vapour Deposition on Profiled Substrates", by C. v. d. Brekel et al., Journal of Crystal Growth, 43, pages 488 ff. (1978), which is herewith incorporated by reference. In particular, the CVD process is preferentially surface controlled which means that the dimensionless CVD number is preferentially smaller than 1. Moreover, the deposition rates and deposition temperatures are preferentially in the lower range. For example, the deposition rates can be some nanometers per second, for instance, two nanometers per second, and the deposition temperatures can be in the range of 200 to 400 °C.

The definition of the CVD number is well known and, for example in the isothermal case, given by the product of the mass transport coefficient k_D with the thickness of the boundary layer in the gas phase δ, divided by the diffusion coefficient D_T in accordance with following equation:

$$N(\mathrm{CVD}) = k_D \delta / D_T \quad ,$$

wherein $N(\mathrm{CVD})$ denotes the CVD number. In a further embodiment, the CVD parameters are chosen in accordance with the so-called chemical vapour infiltration (CVI) method, in particular, if deeper holes between the structures have to be filled up by the smoothing layer. Corresponding CVD parameters are disclosed, for example, in the thesis “Mass transport and morphology in CVD processes” by C. v. d. Brekel, pages 33, 42 and 43, Figs. 6 and 7, University of Nijmegen (1978), which is herewith incorporated by reference.

After the smoothing layer has been deposited on the structured surface, the smoothing layer can be smoothed by an additional smoothing step. For instance, an additional thermal and/or polishing treatment or another smoothing treatment can be performed for further smoothing the surface formed by the smoothing layer. This can further improve the efficiency of coupling the light out of the light source.

Fig. 7 shows schematically and exemplarily a processing apparatus for processing a substrate for a light source. The processing apparatus 14 comprises a roughening unit 15 for roughening a surface of the substrate 3. For instance, the roughening unit 15 can be a grinding, polishing or sandblasting unit for roughening the surface of the substrate 3. In Fig. 7 the substrate after the roughening step is indicated by reference number 12. The processing apparatus 14 further comprises an etching unit 16 for etching the roughened surface for producing a structured surface. The structured surface comprises rounded, lens like surface structures. The substrate with the rounded, lens like surface structures after the etching step is indicated in Fig. 7 by reference number 13. The processing apparatus 14 comprises, in this embodiment, also a light generating unit providing unit 17 for providing a light generating unit on a plane surface of the substrate 13 being opposite to the structured surface. Thus, in this embodiment the processing apparatus 14 is adapted to generate a light source with an external outcoupling structure being formed by the roughened and etched surface of the substrate. In another embodiment, the light generating unit providing unit 17 can also be adapted to provide a smoothing layer having a refractive index being larger than the refractive index of the substrate 3 on the structured surface of the substrate 3, wherein on this smoothing layer the layers of the light generating unit can be provided such that the structured surface forms an internal outcoupling structure of the light source. The light generating unit providing unit 17 is preferentially adapted to deposit layers of an OLED on the smoothing layer or on the plane surface of the substrate being opposite to the structured surface for forming an OLED. In particular, the light generating unit providing unit 17 can be adapted to deposit an anode layer, a cathode layer and intermediate layers in between the anode layer and the cathode layer for forming an OLED. In these embodiments the processing apparatus can therefore also be regarded as being a light source fabrication apparatus. In another embodiment the processing apparatus can be adapted to fabricate only the substrate with the surface structures, which may optionally be provided with the smoothing layer and/or the anode layer, which is preferentially an ITO layer. The resulting processed substrate can further be used for fabricating the entire light source by depositing, for instance, further layers of an OLED on the processed substrate.

The substrate is preferentially processed such that the absorption is below 4 percent in the visible range. In particular, the absorption is preferentially below 4 percent in the whole visible range and, for instance, lower 2.5 percent at a wavelength of 550 nm. If the processed substrate also comprises the smoothing layer exemplarily shown in Fig. 2, this absorption requirement is preferentially fulfilled by the complete processed substrate, i.e. by the substrate with the structured surface and the smoothing layer. This absorption is lower than, for instance, the absorption of grinded or sandblasted substrates without etching treatment. This low absorption can lead to efficient multiple scattering and efficient light outcoupling.

The rounded lens like surface structures can lead to a strong diffuse transmission. They can lead, in terms of the bidirectional scattering distribution function (BSDF), to a broad angular distribution extending over the whole angular range, with a relatively small peak in forward direction. Fig. 8 shows exemplarily the diffuse transmission T depending on the wavelength λ for two soda lime substrates which have been grinded and etched by using HF for 2.5 min. The line indicated by reference number 30 corresponds to a substrate having been grinded in accordance with the grit classification “grinding 800”, wherein SiC particles with an average size of 6.5 μm have been used. The line indicated by reference number 31 corresponds to a substrate having been grinded in accordance with the grit classification “grinding 1200”, wherein SiC particles with an average size of 3.0 μm have been used.

In an embodiment, with the above described surface structures and an additional smoothing layer an improved light outcoupling (ILO) factor of two has been achieved for an OLED, in contrast to ILO factors between 1.4 to 1.5 for OLEDs without any outcoupling means, in particular, without an external or internal outcoupling structure provided by a structured surface of the substrate.

The etching times can be in the order of 1 to 5 min, in particular, in the order of 2 to 5 min or 1 to 3 min, for obtaining the lens like structures. Also a softer surface treatment for defect generation (soft sandblasting, grinding with smaller particles like SiC particles having a diameter being smaller than 7 μm or polishing with a paste with smaller particles) is preferred, leading to a relatively low surface roughness, for instance, to a peak-to-valley height being smaller than 1 μm. This can result in an improved filling of the grooves by CVD and this can also better retain the scattering properties. In an embodiment, instead of a statistical defect creation approach also a controlled and equidistant defect generation approach is possible, for instance, by laser patterning, by an ion bombardment pattern, by using multi nozzle modulated sandblasting or by using a regular scratch plate and preparing scratches, in particular, short scratches.

An internal light outcoupling structure of an OLED can be produced by providing a layer having a relatively high refractive index on the structured glass substrate having a relatively low refractive index by using, for instance, CVD or another gas phase deposition method. This layer, i.e. the smoothing layer, is a high n optically thick CVD layer which is preferentially provided with CVD parameters corresponding to a CVD number smaller than one, which corresponds to a relatively low temperature for performing the CVD in a kinetically controlled regime. The resulting layer smoothes the rough surface structure, wherein on top of it a transparent anode layer, in particular, an ITO layer and a respective OLED structure can be deposited.

Although in the above described embodiments the light generating unit is an OLED, the light generating unit can also be another kind of light generating means. For instance, the light generating unit can also be an inorganic light emitting diode, or the light generating unit can be another light generating unit comprising a region with a relatively high refractive index, which is, for example, larger than 1.7, wherein in this high refractive index region light is generated, which can be outcoupled through the structured surface of the substrate into the environment.

Although in the embodiments described above with reference to Figs. 1 and 2 the substrate with the structured surface is optically connected with the light generating unit, in other embodiments the structured surface can also be a separate device, which may already comprise an anode layer, in particular, an ITO layer, and optionally the smoothing layer, wherein this separate substrate can be provided to an OLED producer, which provides the OLED layers on the substrate for producing a light source comprising the OLED with the substrate.

Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims.

In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality.

A single unit or device may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

Method steps for processing the substrate, in particular, for producing the OLED with the processed substrate, performed by one or several units or devices can be performed by any other number of units or devices.

Any reference signs in the claims should not be construed as limiting the scope.

The invention relates to a processing method for processing a substrate for a light source. The processing method comprises roughening a surface of the substrate, followed by etching the roughened surface for producing a structured surface. Since the surface of the substrate is firstly roughened and then etched, a structured surface can be produced, which comprises rounded surface structures, which are preferentially lens like and concave. If a light generating unit like an organic light emitting diode is provided on this processed substrate with the structured surface, the rounded surface structures can increase the outcoupling efficiency of the resulting light source, i.e. the efficiency of extracting light out into air surrounding the light source.

CLAIMS:

1. A processing method for processing a substrate for a light source, the processing method comprises roughening a surface of the substrate, followed by etching the roughened surface (4; 104) for producing a structured surface (4; 104).

2. The processing method as defined in claim 1, wherein the roughening step includes at least one of sandblasting, grinding, polishing, laser patterning and ion bombardment patterning for roughening the surface.

3. The processing method as defined in claim 1, wherein the etching step includes using at least one of hydrofluoric acid, hydrochloric acid, ammonium hydrogenic bifluoride, potassiumhydrogen bifluoride, Na-pyrophosphate, tetrafluoroboric acid, hexafluorosilicic acid.

4. The processing method as defined in claim 1, wherein the roughening and etching steps are adapted such that surface structures are produced on the surface (4; 104) having an average lateral size in the range of 0.5 to 20 µm.

5. The processing method as defined in claim 1, wherein the roughening and etching steps are adapted such that surface structures are produced on the surface (4; 104) having an average height in the range of 0.5 to 4 µm.

6. The processing method as defined in claim 1, wherein the roughening and etching steps are adapted such that rounded surface structures are produced.

7. The processing method as defined in claim 6, wherein the rounded surface structures are concave.

8. The processing method as defined in claim 1, wherein the roughening and etching steps are performed such that statistical surface structures are produced.

9. The processing method as defined in claim 1, wherein the processing method further comprises depositing layers of a light generating unit (2) on a further surface (11) of the substrate, which is opposite to structured surface (4), for forming the light source.

10. The processing method as defined in claim 1, wherein the processing method further comprises depositing a smoothing layer (110) on the structured surface (104), which has a refractive index being larger than the refractive index of the substrate (103), for smoothing the structured surface.

11. The processing method as defined in claim 10, wherein the thickness of the smoothing layer (110) is at least two times larger than the mean height of surface structures (105) on the structured surface (104).

12. The processing method as defined in claim 10, wherein the processing method further comprises depositing layers (6, 7, 8) of a light generating unit (2) on the deposited smoothing layer (110).

13. A substrate being producible by a processing method as defined in claim 1.

14. A light source comprising the substrate (4; 104) as defined in claim 13.

15. A processing apparatus for processing a substrate for a light source, the processing apparatus (14) comprising:

- a roughening unit (15) for roughening a surface of the substrate (3; 103), and
- an etching unit (16) for etching the roughened surface for producing a structured surface (4; 104).

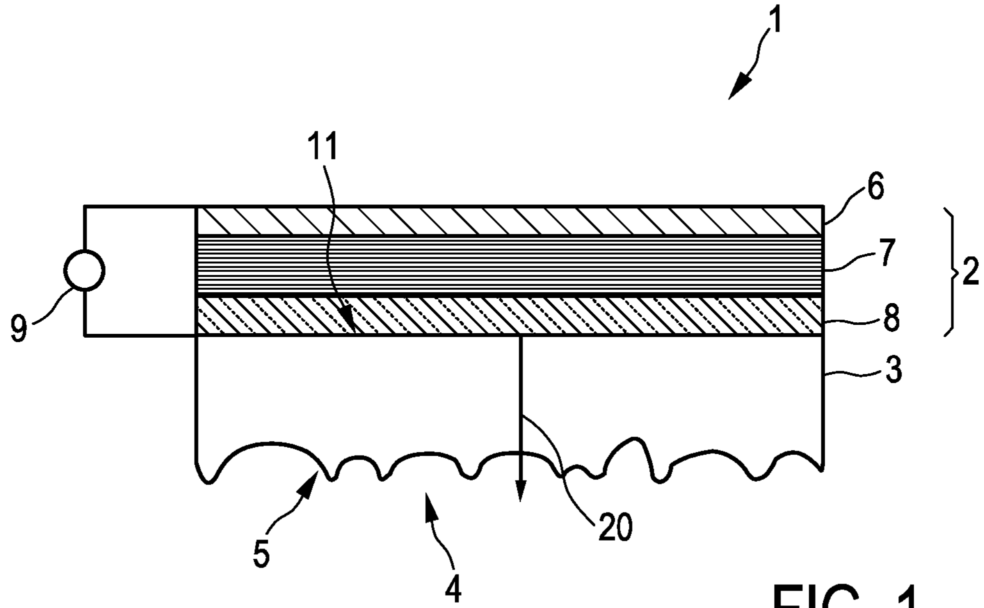

FIG. 1

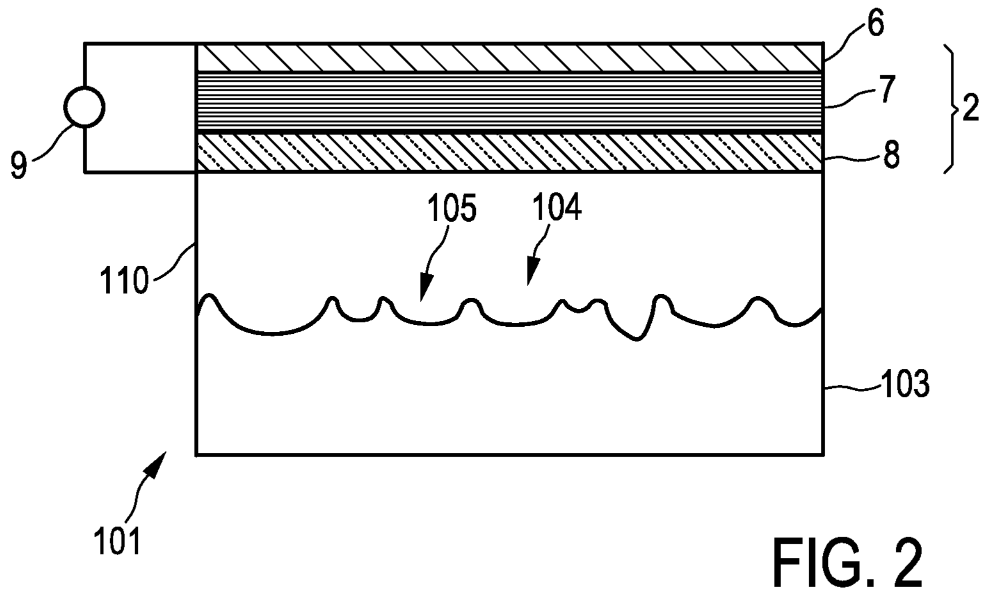

FIG. 2

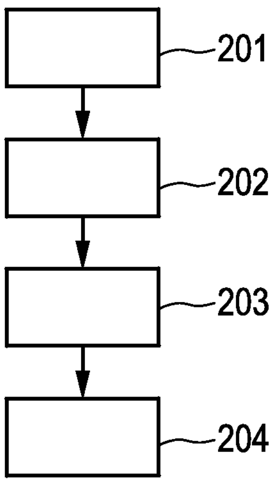

FIG. 3

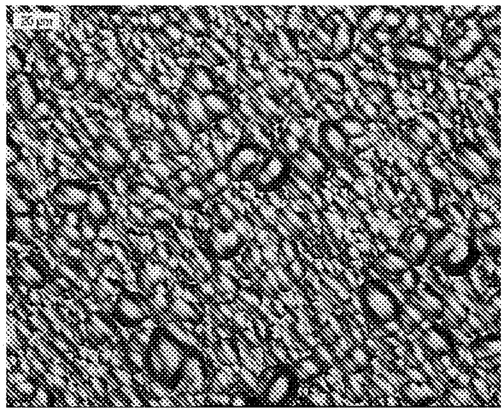

FIG. 4

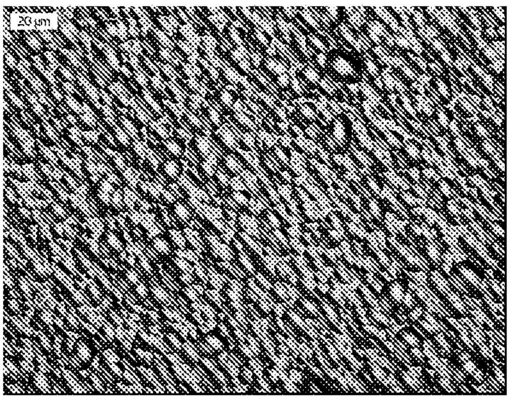

FIG. 5

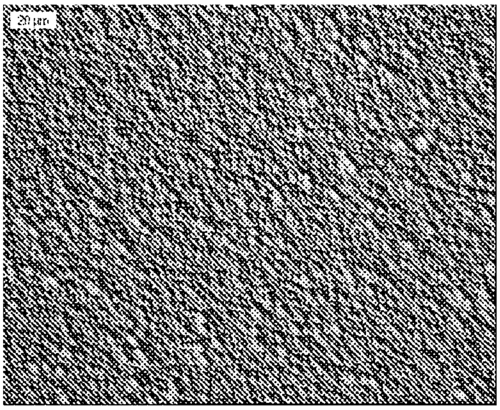

FIG. 6

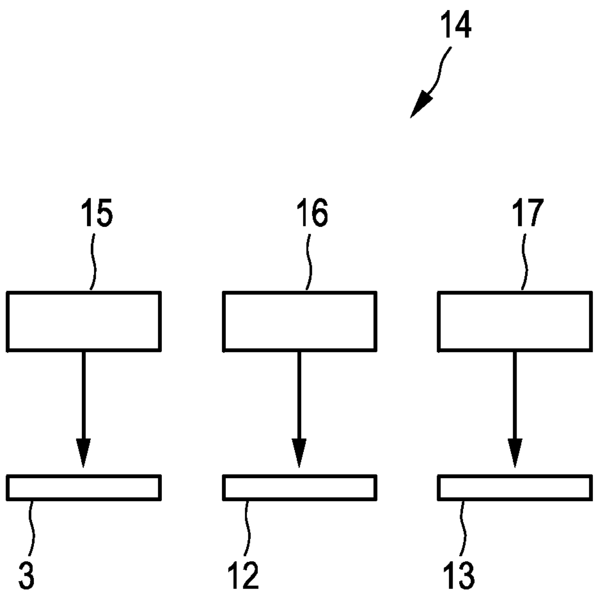

FIG. 7

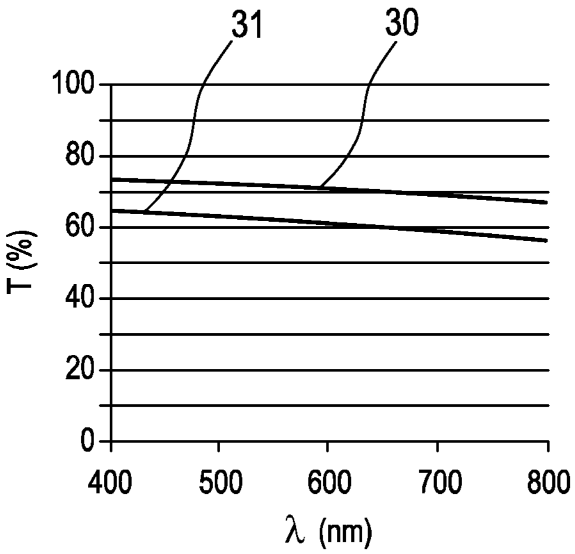

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/055745

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L51/52 H01L51/56 H01L51/00
ADD.

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 practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/091488 A1 (VERMERSCH FRANCOIS-JULIEN [FR] ET AL) 19 April 2012 (2012-04-19) page 5, paragraph 141; claims 1,12; figures 1-3	1-15
X	US 2012/155093 A1 (YAMADA YUKIKA [JP] ET AL) 21 June 2012 (2012-06-21)	13,14
A	claim 1; figure 5	1-12,15

☐ 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

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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	Date of mailing of the international search report
25 November 2013	03/12/2013

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, Fax: (+31-70) 340-3016	Parashkov, Radoslav

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2013/055745

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2012091488 A1	19-04-2012	CN 102449802 A	09-05-2012
		EP 2415096 A2	08-02-2012
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		KR 20120006532 A	18-01-2012
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