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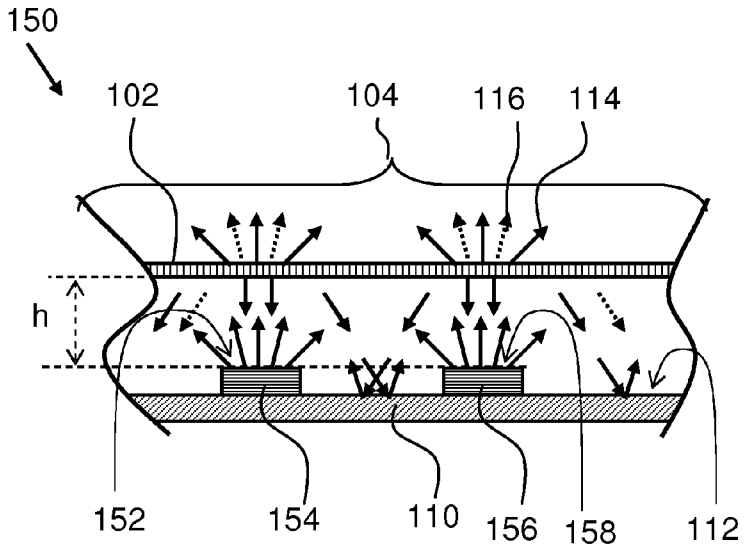


Fig. 1b

(57) Abstract: A light emitting module (150), a lamp and luminaire are provided. The light emitting module (150) emits light through a light exit window (104) and comprises a base (110), a solid state light emitter (154, 158) and a luminescent layer (102). The base (110) has a light reflective surface (112) which faces towards the light exit window (104). The light reflective surface (112) has a first reflection coefficient which is defined by a ratio between the amount light that is reflected by the light reflective surface and the amount of light that impinges on the light reflective surface. The solid state light emitter (108) is provided in between the base (110) and the light exit window (104) and emits light of a first color range (114) towards at least a part of the light exit window (104). The solid state light emitter (108) has a top surface (106) facing towards the light exit window (104) and having a second reflection coefficient. The second reflection coefficient is defined by a ratio between the amount light that is reflected by the solid state emitter (108) and the amount of light that impinges on the top surface (106) of the solid state light emitter (108). The luminescent layer (102) comprises luminescent material which converts at least a part of the light of the first color range (114) into light of the second color range (116). The light exit window (104) comprises at least a part of the luminescent layer (102). The value of the first reflection coefficient is larger than the second reflection coefficient plus 0.2 times the difference between 1 and the second reflection coefficient.

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A light emitting module, a lamp and a luminaire

FIELD OF THE INVENTION

The invention relates to light emitting modules which comprises a luminescent material.

BACKGROUND OF THE INVENTION

Published patent application US2009/0322208A1 discloses a light emitting device. A Light Emitting Diode (LED) is provided within a conical cavity formed by a recessed housing. At the front side of the recessed housing the conical cavity is covered with a transparent thermal conductor layer on which a refractory phosphor layer is provided. At the backplane of the recessed housing is provided a heat sink and the side walls of the recessed housing are covered with a metal frame. The conical cavity may be filled with a material such as silicone.

The LED emits light towards the phosphor layer. A portion of the emitted light may be reflected or scattered back into the cavity by the phosphor layer. Another portion of the emitted light is converted by the phosphor layer into light of another color. When the phosphor emits the light of the another color, this light is emitted in all directions, and thus a part of the light of the another color is emitted into the cavity. Light which is reflected back into the cavity or light of the another color which is emitted into the cavity partly impinges on a base of the cavity, partly impinges on a wall of the cavity, and partly impinges on the LED. At the surfaces of the LED and at the surfaces of the cavity the light is partly reflected and partly absorbed. Especially the absorption of light results in an inefficiency of the light emitting device.

Other light module manufactures also provide lighting modules which comprise a cavity with a base. These modules often have a plurality of light emitters on the base. In certain embodiments of these light emitting modules the phosphor layer is provided directly on top of the light emitters, and in other embodiments the phosphor layer is a so-termed remote phosphor layer which means that there is a relative large distance between the light emitter and the phosphor layer. In these modules also a relatively large amount of light, which is generated by the light emitters, is absorbed by the light emitters themselves and the

surfaces of the base and walls of the cavity when the light is reflected or scattered back or is emitted by the phosphor into the cavity.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a light emitting module which is relatively efficient.

A first aspect of the invention provides light emitting module as claimed in claim 1. A second aspect of the invention provides a lamp as claimed in claim 14. A third aspect of the invention provides a luminaire as claimed in claim 15. Advantageous embodiments are defined in the dependent claims.

A light emitting module in accordance with the first aspect of the invention emits light through a light exit window. The light emitting module comprises a base, a solid state light emitter and a luminescent layer. The base has a light reflective surface which faces towards the light exit window. The light reflective surface has a first reflection coefficient which is defined by a ratio between the amount light that is reflected by the light reflective surface and the amount of light that impinges on the light reflective surface. The solid state light emitter is provided in between the base and the light exit window and emits light of a first color range towards at least a part of the light exit window. The solid state light emitter has a top surface facing towards the light exit window and having a second reflection coefficient. The second reflection coefficient is defined by a ratio between the amount light that is reflected by the solid state emitter and the amount of light that impinges on the top surface of the solid state light emitter. The luminescent layer comprises luminescent material which converts at least a part of the light of the first color range into light of the second color range. The light exit window comprises at least a part of the luminescent layer. The value of the first reflection coefficient is larger than the second reflection coefficient plus 0.2 times the difference between 1 and the second reflection coefficient.

Light of the first color range which impinges on the luminescent layer is partly reflected back towards the solid state light emitter and the base due to reflections by a surface of the luminescent layer and due to internal reflections and due to back scattering in the luminescent layers, and may partly be transmitted through the luminescent layer and may partly be converted to light of the second color range. The light of the second color range is emitted by the luminescent material in all directions and a part of this light is also emitted towards the solid state light emitter or towards the light reflective surface of the base.

The solid state light emitter has a limited second reflection coefficient due to its construction, which means that a significant portion of the light which impinges on the solid state emitter is absorbed by the solid state light emitter. The top surface of the solid state light emitter chip reflects a relatively small portion of the light which impinges on the top surface, and a relatively large portion of that light is transmitted into the core of the solid state light emitter chip. The back surface and the epi / quantum well area inside the solid state light emitter chip absorb a significant portion of the light and, as a consequence, a limited amount of light, which enters into the core of the solid sate light emitter chip, is emitted back into the ambient of the solid state light emitter chip. Often the word 'die' is used for solid state light emitter chip and both terms refer to the semiconductor device in which the light is generated. The semiconductor device includes the semiconductor material which actually generates the light, and also included electrode, segmentation, vias, back side mirrors, and for example, protection layers. It is to be noted that in some applications solid state light emitters are grown on a light transmitting substrate, for example, sapphire. After the manufacturing, the substrate may still be present on the solid state light emitter die and the light which is generated in the solid state light emitter is emitted through the growth substrate. The word 'die' does not refer to the growth substrate and in the context of the invention the growths substrate is not seen as an element of the solid state light emitter. Further, the top surface is the surface of the semiconductor chip which emits most of the light, and in line with the invention, the light emission through the top surface is in the direction of the light exit window.

The first reflection coefficient is at least higher than the second reflection coefficient and consequently the light reflective surface of the base absorbs less light than the solid state emitter. This is advantageous because more light is reflected by the base and as such more light may be emitted through the light exit window in the ambient of the light emitting module. It actually means that light which is reflected by the light reflective surface is recycled instead of absorbed. The efficiency of the light emitting module as a whole improves. It was noticed that, if the first reflection coefficient is not sufficiently higher than the second reflection coefficient, the efficiency of the light emitting module as a whole did not substantially improve. Further, a significant improvement was noticed above a certain difference in reflection coefficients. Thus, according to the invention, the first reflection coefficient is at least larger than the second reflection coefficient plus 0.2 times the difference between 1 and the second reflection coefficient. In other words, the first reflection of the light reflective base is better than the actual reflection of the solid state light emitter with an

amount that is at least 20% of the difference between full reflection and actual amount of reflection by the solid state light emitter. If it is assumed that *R1* is the first reflection coefficient and *R2* is the second reflection coefficient, the criterion is represented by the subsequent formula: $R1 > R2+0.2(1-R2)$. Thus, if the second reflection coefficient is 0.5, the first reflection coefficient should be larger than 0.6, and if the second reflection coefficient is 0.75, the first reflection coefficient should be larger than 0.8.

It should be noted that the reflection coefficients are average numbers over a whole surface to which they relate. The light reflective surface of the base may comprise, for example, areas which are less reflective than other areas, such as by using different materials on the base. Further, the reflection of light of different wavelengths may differ, however, it is assumed that the reflection coefficient is a weighted averaged over a spectral range which comprises light of first color range and of the second color range.

In some cases the solid state light emitter is attached to a substrate, for example, a ceramic substrate, and the combination of the substrate and the solid state light emitter are attached to another carrier layer. This carrier layer may for instance be a metal core printed circuit board (MCPCB) also called insulated metal substrate (IMS) or a conventional PCB, such as FR4, or another ceramic carrier, such as alumina or aluminiumnitride. In such situations, the base of the light emitting module is the combination of the another carrier layer and the substrate to which the solid state light emitter is attached. In other words, the base is the combination of materials and/or layers on which the solid state light emitters are provided. Consequently, in this specific case, the first reflection coefficient is the weighted average of reflection coefficient of the substrates and the carrier layer.

In specific embodiments, the light emitter may be a combination of a plurality of solid state light emitters with their light emitting surfaces positioned very close to each other in one plane. Very close means that the distance between the individual solid state light emitters is in the order of tens of micrometers, but not more than 0.2mm. Such closely positioned solid state light emitters are seen in the context of this invention as a single light emitter. The top surface is the combination of top surfaces of the individual solid state light emitters of the very closely positioned solid state light emitters. It is to be noted that the very close placement relates to the dies of the solid state light emitters and not to the very close placement of packages of solid state light emitter.

In another embodiment, the value of the first reflection coefficient at least larger than the second reflection coefficient plus 0.5 times the difference between 1 and the second reflection coefficient. This results in a light emitting module which is even more

efficient. In a practical embodiment, the first reflection coefficient at least larger than the second reflection coefficient plus 0.8 times the difference between 1 and the second reflection coefficient. The most efficient situation is present by the case where the second reflection coefficient approaches 1.

In an embodiment the solid state light emitter is provided on the light reflective surface. However, in other embodiments the solid state light emitter may be positioned on a network of wires which are provided in between the base and the light exit window. In such an embodiment, the wires carry the solid sate light emitters and provide power to the solid sate light emitters. The wire may contain a metal core and a protective plastic cladding and only be electrically attached at point of contact to the substrate or carrier of the emitter, e.g. by a solder joint connection.

In an embodiment, the light emitting module comprises a plurality of solid state light emitters which are provided on an imaginary plane which is in between the base and the light exit window. Each one of the solid state light emitters emits light in a specific color range towards at least a specific part of the light exit window and each one of the solid state emitters has a top surface facing towards the light exit window. The second reflection coefficient is defined as the average value of the reflection coefficients of the plurality of solid state light emitters.

The light emitting module is able to emit more light if more than one solid light emitter is provided. More light, seen in absolute values, will be reflected within the light emitting module and consequently emitted back towards the solid state light emitters and the light reflective surface of the base. Thus, if the light reflective surface has a better reflectivity than the solid state light emitters, more light, seen in absolute values, may be recycled by reflecting the light via the reflective surface back to the luminescent layer (and through the light exit window). Further, the light emitting module with a plurality of solid state light emitters has the same advantages as the light emitting module with a single solid state light emitter.

It is to be noted that, that in some applications solid state light emitters are grown on a light transmitting substrate and that, after the manufacturing, the substrate may still be present on the solid state light emitter die and light which is generated in the solid state light emitter is emitted through the growth substrate. The term ‘top surface’ does not refer to a surface of the growth substrate, but to a surface of solid state light emitter die. In the context of the invention the growths substrate is not seen as an element of the solid state light emitter.

In a further embodiment, a gap is present between the top surface of the solid state light emitter and the luminescent layer or the top surfaces of the plurality of solid state light emitters and the luminescent layer. The gap has to be interpreted broadly. The meaning is that the luminescent layer is not in direct contact with the top surface or top surfaces of the at least one solid state light emitter. The gap may be filled with air, but a substantially transparent material may also be present in the gap.

If the luminescent layer is not in direct contact with the top surface of the solid state light emitter or solid sate light emitters, a relatively larger amount of light will be reflected and emitted towards the light reflective surface. If, according to the invention, the light reflective surface has a higher reflectivity than the solid state light emitter, more light will be reflected back to the luminescent layer and, consequently, a higher light output will be obtained.

The inventors have found that the optical effect of a higher reflectivity is not the only factor which contributes to a higher light output. If there is a gap between the solid state light emitter(s) and the luminescent layer, the solid state light emitter does not become as warm as it would be when the luminescent layer is positioned on top of, or very close to, the solid state light emitter(s). This improves the efficiency of the solid state light emitters and may allow a higher current loading before a critical temperature is reached in the solid state light emitter or solder joint of the solid state light emitter chip. Hence, a higher absolute light output is realized. Also, if the luminescent layer is not directly thermally coupled to the solid state light emitter(s) it does not receive the heat from the solid state light emitter(s). It depends on the quality of thermal interface towards the base and a possible heatsink to which the module is connected how well the luminescent layer can be cooled. The light conversion from the first spectral range towards the second spectral range converted light energy partly to heat, typically denoted as 'Stokes shift' losses. Furthermore, in practice the Quantum Efficiency (QE) of the luminescent material(s) is limited, e.g. to 0.9 giving rise to further thermal heat-up of the luminescent layer. It is part of the invention to come to an efficient cooling of the luminescent layer. The efficiency of the luminescent material is higher if the temperature of the luminescent material is kept within acceptable limits. This can be achieved by limiting the light flux loading on the luminescent material, but more preferably the thermal resistance between the luminescent layer and the base and between the luminescent layer and the heatsink is optimized to achieve a low thermal resistance. This can be achieved by various means, such as by coupling the luminescent layer to a heat conductive wall at the circumference of the exit window, or by applying a heat conductive material between the

emitters and the base and the luminescent material, such as a heat conductive glass or ceramic or by applying heat spreading layers or structures on the luminescent layer, such as a carrier substrate to which the luminescent layer is attached with heat conductive properties. Thus, with such measures, the gap between the solid state light emitter(s) and the luminescent layer results in the photothermal effect of a more efficient luminescent layer. Further, the gap between the solid state light emitter(s) and the luminescent layer results in a more uniform distribution of light flux through the luminescent layer instead of a relatively high light flux in a very specific area of the luminescent layer. Luminescent materials tend to be sensitive to photosaturation, which means that above a certain light flux, the luminescent material converts light at a lower efficiency. Thus, by having a gap between the solid state light emitter(s) and the luminescent layer photosaturation of the luminescent material is prevented and efficiency is improved.

Thus, a specific combination of the first reflection coefficient being higher than the second reflection coefficient according to the presence of the gap, leads to a higher light output than one expects only on basis of the optical effect of more reflection by the light reflective surface of the base.

In the above discussion it becomes clear that the efficiency of the light emitting module increase and that the light is more spread out over the whole light exit window preventing hot spots, and thus that the light output is more uniform.

In another embodiment, the shortest distance between the top surface of the solid light emitter and the part of the light exit window is a value in a range with a minimal value of 0.25 times a largest linear size of the top surface and a maximum value of 5 times the largest linear size of the top surface. The largest linear size of the top surface is defined as the longest distance from a point on the top surface to another point on the top surface along a straight line. If the light emitting module has a plurality of solid state light emitters, the average value of the shortest distances between the top surface of the plurality of light emitters and the parts of the light exit window is a value in the range with a minimal value of 0.25 times the average value of the largest linear size of the top surfaces of the plurality of solid state light emitters and a maximum value of 5 times the average value of the largest linear size of the top surfaces of the plurality of solid state light emitters.

The top surface may be any shape, for example, a square, rectangle, circle or ellipse. For the square or the rectangle, the longest linear distance is the length of a diagonal of the square or the rectangle. For the circle, the longest linear distance is the length of a diameter of the circle.

The inventors have found that the distance between the solid state light emitter(s) and the luminescent layer should have a minimum value above which the relatively large light output of the light emitting module is obtained. Below this minimum value the light emitting module operates less efficiently and too much light is reflected to the solid state light emitter(s). Further, the inventors have found that when the distance between the solid state light emitter(s) and the luminescent layer becomes too large, the light output starts to decrease and is therefore not advantageous. The decrease is the result of more absorption of light because the light has a longer traveling path through the light emitting module.

The inventors have found that the specific combination of the first reflection coefficient being higher than the second reflection coefficient according to the previously specified criterion and the criterion of the distance between the top surface of the solid state light emitter(s) and the luminescent layer being in the specific range, leads to a relatively high light output.

In an embodiment, the range has a minimum value of 0.5 times the largest linear size of the top surface or the average value of the largest linear sizes of the top surfaces and a maximum value of 2.5 times the largest linear size of the top surface or the average value of the largest linear sizes of the top surfaces.

In a further embodiment, the area of the top surface of the solid state light emitter or the sum of the areas of the plurality of solid state light emitters is at least smaller than the area defined by 0.55 times the area of the light reflective surface of the base. In other words, not more than 55% of the light reflective surface is covered by the die of the solid state light emitter(s). If more than 55% is covered, it has been found by the inventors that the efficiency of the light emitting module decreases relatively fast with an increasing coverage percentage. If less than 55% is covered, it has been found that the efficiency of the light emitting module has an acceptable value.

In an embodiment, the light emitting module comprises a wall interposed between the base and the light exit window. The base, the wall and the light exit window enclose a cavity. The wall has a light reflective wall surface facing towards the cavity and the light reflective wall surface has a third reflection coefficient. The third reflection coefficient is defined by a ratio between the amount light that is reflected by the light reflective wall surface and the amount of light that impinges on the light reflective wall surface. The value of the third reflection coefficient is at least larger than the second reflection coefficient plus 0.2 times the difference between 1 and the second reflection coefficient. The reflectivity of the walls should be large enough and the criterion for the third reflection coefficient is in

conformance with the criterion for the first reflection coefficient. Thus, as discussed previously, the light emitting module is more efficient if the walls of the light emitting module have the third reflection coefficient as specified. It is to be noted, in line with the first and second reflection coefficient, that the third reflection coefficient is a weighted average of reflection of light of a predefined spectrum of light. It is to be noted that the walls may have a further function, such as conducting heat from the luminescent layer towards the base. The base is often coupled to a heat sink and the luminescent layer may become relatively hot as the result of heat generation while light of the first color range is converted to light of the second color range.

It is to be noted that, according to the invention, all different optimization parameters of, for example, the reflectivity of the base with respect to the reflectivity of the solid state light emitter, the distance between the top surface of the solid state light emitter and the luminescent layer with respect to the largest linear size of the top surface, the maximum area of the base covered by the solid state light emitter, and the reflectivity of the walls with respect to the reflectivity of the solid state light emitter, may be combined all together, or every combination of the reflectivity of the base with respect to the reflectivity of the solid state light emitter may be combined with any combination of the other parameters.

In an embodiment, the wall comprises at least one of the following materials: aluminium, copper, ceramic like alumina, thermally conductive plastics such as polyamides or spectralon.

In another embodiment, at least one of the light reflective surface of the base and the light reflective wall surface comprises a light reflective coating or a light reflective foil. A light reflective coating may be used to increase the reflectivity of the respective light reflective surfaces, thereby improving the efficiency of the light emitting module. In an embodiment, the light reflective surface of the base and the wall diffusely scatter light, which may be obtained by means of a white coating. In another embodiment, the light reflective surface of the base and the wall may be specularly reflecting, which may be obtained by means of a metal mirror (e.g. protected silver or aluminium). In a further embodiment, the light reflective surface of the base and the wall may be a combination of a diffusely scattering material and a specularly reflecting material.

In a further embodiment, the light reflective wall surface is tilted with respect to a normal axis of the base for increasing the reflection of light towards the light exit window. In another further embodiment, the light reflective wall surface is curved for increasing the reflection of light towards the light exit window. Such a tilted wall surface or

curved wall surface results in a convex cavity, seen from the interior of the cavity. Further, the tilting or the curving is such that the edges of the light reflective wall surface that touch the base are closer to each other than the edges of the light reflective wall surface that touch the luminescent layer. The convex cavity with such a tilted or curved light reflective wall surface better reflects the light which impinges on the light reflective wall surface towards the luminescent layer (and thus the light exit window). It is at least partly prevented that light is reflected by the light reflective wall surface to the interior of the cavity which results in more absorption at another reflection point or by the solid sate light emitter. Consequently, the efficiency of the light emitting module increases.

In an embodiment, the luminescent layer forms the light exit window. The luminescent layer has an edge, and the edge of the luminescent layer is in contact with the base. A construction according to the embodiment prevents the use of walls between the luminescent layer and the base, which may be advantageous in certain applications. Further, it may results in a wider angular light output distribution.

In another embodiment, the light emitting module comprises a substantially transparent material arranged between the one or more solid state light emitter(s) and the luminescent layer, the transparent material being optically coupled to the one or more solid state light emitter(s). The substantially transparent material assists the outcoupling of light from the solid state light emitter die. The material of the solid state light emitter has in general a relatively high refractive index, and as such a significant amount of light is caught within the solid state light emitter die because of total internal reflection (TIR). The substantially transparent material has a refractive index that is closer to the refractive index of the solid state light emitter than the refractive index of, for example, air, and as a consequence more light is emitted into the transparent material and, consequently, finally out of the light emitting module. The transparent material may have a refractive index close to the refractive index of the solid state light emitter. If the solid state light emitter is of the type of InGaN materials, the refractive index of the emitter is close to 2.4 and a high refractive index glass or ceramic attached to the emitter surface will extract most light from the chip. The transparent material may comprise various materials applied in various layers or as mixtures. For instance, a high refractive index ceramic substrate may be bonded with a high index glass or a high index resin to the solid state light emitter chip. The substantially transparent material may be, for example, a dome or a flat encapsulant placed on the solid state light emitter. In an embodiment, the refractive index of the transparent material is higher

than 1.4. In another embodiment, the refractive index of the transparent material is higher than 1.7.

In a further embodiment, the substantially transparent material is optically and thermally coupled to the luminescent layer. For example, the whole space between the base and the luminescent layer is filled with the transparent material, and thus, the transparent material is also optically coupled to the luminescent layer resulting in less reflection at the interface between the luminescent layer and the cavity. Consequently, more light is emitted into the environment of the light emitting module. Further, if the transparent material is in contact with the luminescent layer, the transparent material is also thermally coupled to the luminescent layer and assists in the heat conduction from the luminescent layer towards, for example, the base. It results in a less warm luminescent layer, which is, in general, more efficient and has a longer lifetime. Hence, the transparent material provides an enhanced thermal contact between the luminescent material and the base compared to an air gap. As air has a thermal conductivity of about 0.025 W/mK, a silicone resin with thermal conductivity of about 0.3 W/mK will provide a better thermal interface, whereas a glass substrate like sodalime glass of about 1.0 W/mK thermal conductivity is even better, whereas a borosilicate glass or a fused silica glass of about 1.3 W/mK, a translucent polycrystalline alumina substrate of about 30 W/mK, and a sapphire substrate of 42 W/mK are much better.

In another embodiment, the substantially transparent material comprises at least one of: a transparent resin, a transparent gel, a transparent liquid, a transparent glass, a transparent polymer, and a transparent ceramic. Transparent refers to the absence of substantial light absorption in the spectral region of the first and second wavelength range. Some limited levels of scattering may be allowed in the transparent layers, especially if this scattering is of a forward scattering type. Hence, some scattering centers may be allowed in the substantially transparent material in between the luminescent material and the base.

In a further embodiment, the luminescent material comprises at least one of: an inorganic phosphor, an organic phosphor, a ceramic phosphor and a quantum dot phosphor, or another fluorescent material. It is to be noted that the luminescent layer may comprise a carrier layer, for example a glass substrate, and a layer of luminescent material, or that the luminescent layer comprise randomly distributed particles of the luminescent material in a carrier layer, or in the case of a ceramic phosphor, substantially the whole luminescent layer is the luminescent material. It is also noted that the luminescent layer may consist of various separate luminescent layers stacked or closely spaced. Different

luminescent materials may be used in the different layers. However, the luminescent materials may also be mixed together in the same layers(s).

In an embodiment, the light exit window further comprises at least one of: a diffuser layer for obtaining a diffuse light emission, for obtaining a spatially, color and color over-angle uniform light emission, and for obtaining a color mixed light emission. A dichroic layer may be comprises for correcting color over angle variations or light uniformity. In addition to influencing the light emission characteristics by the luminescent layer, other optical layers may also be used to influence the characteristics of the light that is emitted through the light exit window into the environment of the light emitting module.

According to a second aspect of the invention a lamp is provided which comprises the light emitting module according to the first aspect of the invention. The lamp may comprise a plurality of light emitting modules. The lamp may comprises a retrofit light bulb, a retrofit parabolic aluminized reflector (PAR) lamp, a spot lamp, a downlighter lamp or a retrofit light tube.

According to a third aspect of the invention, a luminaire is provided which comprises a light emitting module according to the first aspect of the invention or which comprises a lamp according to the second aspect of the invention. The luminaire may comprise a plurality of light emitting modules.

The lamp and luminaire according to, respectively, the second aspect and third aspect of the invention provide the same benefits as the light emitting module according to the first aspect of the invention and have similar embodiments with similar effects as the corresponding embodiments of the light emitting module.

In this context, light of a color range typically comprises light having a predefined spectrum. The predefined spectrum may, for example, comprise a primary color having a specific bandwidth around a predefined wavelength, or may, for example, comprise a plurality of primary colors. The predefined wavelength is a mean wavelength of a radiant power spectral distribution. In this context, light of a predefined color also includes non-visible light, such as ultraviolet light. The light of a primary color, for example, includes Red, Green, Blue, Yellow and Amber light. Light of the predefined color may also comprise mixtures of primary colors, such as Blue and Amber, or Blue, Yellow and Red. It is to be noted that the first color range may also comprise light which is invisible for the human eye, such are ultra violet light or infrared light.

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

It will be appreciated by those skilled in the art that two or more of the above-mentioned embodiments, implementations, and/or aspects of the invention may be combined in any way deemed useful.

Modifications and variations of the light emitting module, lamp, and/or luminaire, which correspond to the described modifications and variations of the light emitting module, can be carried out by a person skilled in the art on the basis of the present description.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

Fig. 1a and 1b schematically show cross-sections of embodiments of a light emitting module according to the first aspect of the invention,

Fig. 2a and 2b schematically show a top-view of embodiments of a light emitting module according to the first aspect of the invention,

Fig. 3a schematically shows an embodiment of a light emitting module comprising a cavity,

Fig. 3b schematically shows an embodiment of a light emitting module having a cylindrical shape,

Fig. 4 schematically shows a cross-section of the embodiment of the light emitting module comprising the cavity,

Fig. 5a and 5b schematically show a plurality of cross-sections of embodiments of the light emitting module according to the first aspect of the invention,

Fig. 6 schematically shows a plurality of cross-sections of embodiments of light emitting modules with a luminescent layer forming the light exit window and the edge of the luminescent layer touching the base,

Fig. 7a and 7b schematically show cross-sections of embodiments of a flexible light emitting module,

Fig. 8a and 8b show two graphs with the results of simulations of the light emitting module,

Fig. 9a and 9b show two other graphs with the results of simulations of the light emitting module,

Fig. 10a shows two embodiments of lamps according to the second aspect of the invention,

Fig. 10b shows an embodiment of a luminaire according to the third aspect of the invention,

Fig. 11 schematically shows a three dimensional view of an embodiment of a light emitting module,

Fig. 12 schematically shows a cross-cut of the light emitting module of Fig. 11, and

Fig. 13 schematically shows a cross-cut of another embodiment of another light emitting module,

It should be noted that items denoted by the same reference numerals in different Figures have the same structural features and the same functions, or are the same signals. Where the function and/or structure of such an item have been explained, there is no necessity for repeated explanation thereof in the detailed description.

The figures are purely diagrammatic and not drawn to scale. Particularly for clarity, some dimensions are exaggerated strongly

DETAILED DESCRIPTION OF THE EMBODIMENTS

A first embodiment is shown in Fig. 1a. Fig. 1a shows a cross-section of a light emitting module 100 according to the first aspect of the invention. The light emitting module 100 has a light exit window 104. The light exit window 104 is formed by a luminescent layer 102 which comprises luminescent material. The luminescent material converts at least a part of light of a first color range 114 which impinges on the luminescent material into light of a second color range 116. At another side of the light emitting module 100 is provided a base 110 which has a light reflecting surface 112 which faces towards the light exit window 104. On the base 110 is provided a solid state light emitter 108 which emits, in use, light of the first color range 114 towards a part of the light exit window 104. The base is typically provided with electrode structures to contact the dies or plurality of dies to provide electrical power. The electrode structures are not shown in the Figures.

The light reflective surface 112 has a first reflection coefficient *R1*, which is defined by a ratio between an amount of light that is reflected by the light reflective surface 112 and an amount of light that impinges on the light reflective surface 112. The solid state light emitter 108 has a second reflection coefficient *R2*, which is defined by a ratio between an amount of light that is reflected by the solid state light emitter 108 and an amount of light that impinges on solid state light emitter 108. It is noted that the reflection coefficients are both an average of the reflection coefficients related to light of different

wavelengths, for example, an (weighted) average over light of the first color range 114 and light of the second color range 116.

The luminescent layer 102 is not positioned directly on top of the solid state light emitter 108, but they are arranged at a distance *h* from each other. If the solid state light emitter 108 emits light of the first color range 114, at least a part of the light of the first color range 114 is reflected by the luminescent layer 102 towards the base 110 and the solid state light emitter 108. The part of the light of the first color range 114 is reflected by the luminescent layer 102 because of reflection at a surface at which the light impinge, or because of internal reflection or backscattering. The light which is reflected back partly impinges on the solid state light emitter 108 and partly impinges on the light reflective surface 112 of the base 110.

Another part of the light of the first color range 114 may be transmitted through the luminescent layer 102 into the environment of the light emitting module 100. A further part of the light of the first color range 114 is converted by the luminescent material into light of the second color range 116. The luminescent material emits the light of the second color range 116 in a plurality of direction and, consequently, a part of the light of the second color range 116 is emitted into the environment of the light emitting module 100, and another part of the light of the second color range 116 is emitted towards the base 110 and the solid state light emitter 108.

The light which impinges on a top surface 106 of the solid state light emitter 108 is partly reflected and partly transmitted into the semiconductor material of the solid state light emitter 108. Inside the solid state light emitter a part of the light is absorbed and some other part light is reflected back towards the top surface 106 and emitted back towards the light exit window 104. The value of the second reflection coefficient *R2* defines which part of the impinging light is reflected back, and the value *1-R2* defines how much of the impinging light is absorbed by the solid sate light emitter 108. The solid state light emitter 108 has a relatively low second reflection coefficient *R2*.

The light which is reflected, scattered or emitted by the luminescent layer towards the base 110 and which does not impinge on the solid state light emitter 108 is to a large extent reflected by the light reflective surface 112 of the base 110, however, a small amount of light may still be absorbed at the surface or in the underlying layers. The first reflection coefficient *R1* defines which part of the impinging light is reflected back by the light reflective surface 112, and the value *1-R1* defines how much of the impinging light is absorbed by the light reflective surface 112.

The value of the first reflection coefficient *R1* and the second reflection coefficient *R2* is always a value between 0 and 1. It is to be noted that the amount of light which is generated by the solid state light emitter 108 is not taken into account when determining in the second reflection coefficient *R2*. The part of light which is reflected is a part of the amount of light which impinges on the solid state light emitter 108.

According to the invention, the value of the first reflection coefficient *R1* is at least larger than the value of the second reflection coefficient *R2* plus 0.2 times the difference between 1 and the second reflection coefficient *R2*. Thus, $R1 > R2 + 0.2(1-R2)$. Thus, the light reflective surface 112 is, on average, more light reflective than the solid state light emitter 108 with a value that is at least 20% of the difference between a full reflective solid state light emitter and the actual reflectivity of the used solid state light emitter 108.

Because a substantial amount of light is reflected, scattered or emitted by the luminescent layer 102 in a direction away from the luminescent layer 102 towards the base 110, it is advantageous to reuse this light by reflecting the light back to the light exit window 104 to improve the efficiency of the light emitting module 100. The second light reflection coefficient *R2* can often not be chosen because it is a fixed characteristic of a specific solid state light emitter 108 that has to be used in the light emitting module 100. Therefore, in order to improve the efficiency of the light emitting module 100, it is advantageous to have a light reflective surface 112 which better reflects than the solid state light emitter 108. Further, it has been found that a significant efficiency improvement may be obtained if $R1 > R2 + 0.2(1-R2)$.

It should be noted that the reflection coefficients are average numbers over a whole surface to which they relate. The light reflective surface of the base may comprise, for example, areas which are less reflective than other areas. Further, the reflection of light of different wavelengths and at different angles of incidence may differ, however, it is assumed that the reflection coefficient is averaged over a spectral range and over a angle of incidence distribution, for example, over the spectral range of daylight, or over a spectral range which comprises specific quantities of first color range and of the second color range. Measuring a reflectivity coefficient is often performed by pointing a collimated light beam of the spectral range to the object of which the reflectivity has to be measured and measuring the amount of reflected light. This is typically done at several angles of incidence and the reflection coefficient is a weighted average of the obtained reflection coefficients at different angles of incidence, wherein the weight depends on the amounts of light which impinge at the various angles of incidence on the object in the light emitting module.

In some cases the solid state light emitter is attached to a substrate, for example, a ceramic substrate, and the combination of the substrate and the solid state light emitter are attached to another carrier layer. This carrier layer may for instance be a metal core printed circuit board (MCPCB) also called insulated metal substrate (IMS) or a conventional PCB, such as FR4, or another ceramic carrier, such as alumina or aluminiumnitride. In such situations, the base of the light emitting module is the combination of the another carrier layer and the substrate to which the solid state light emitter is attached. In other words, the base is the combination of materials and/or layers on which the solid state light emitters are provided. Consequently, in this specific case, the first reflection coefficient is the weighted average of reflection coefficient of the substrates and the carrier layer. It is not necessary that the substrate to which the solid state light emitter is attached or the carrier substrate is completely flat. Typically there will be metal electrodes present on the substrates with a physical height, such as conductive copper tracks to supply power to the emitters. Also, there may be heat spreading layer applied to the surface. Part of the substrate of carrier may be locally thicker to achieve an additional support structure, e.g. for clamping the module or attaching collimators to the module or to define a rim, e.g. to separate optical functions from electrical functions. Other electrical components may be present on the substrate or carrier, such as capacitors, temperature sensors like NTCs, resistors, ESD protection diodes, Zehner diodes, varistors or integrated circuits (ICs). These components may likely be placed outside the circumference of the optical exit window, but in principle could also be placed inside the circumference of the optical exit window. In the latter case they will contribute to the average reflectance of the base. These components may be covered with a reflective layer to minimize optical losses.

Fig. 1b shows another embodiment of a light emitting module 150 according to a first aspect of the invention. Light emitting module 150 has a similar structure as light emitting module 100, however, a plurality of solid state light emitter 154, 156 are provided which emit light of the first color range 114 towards the luminescent layer 102. With respect to the light emitting module 150, the second light reflection coefficient *R2* is defined as the average light reflection coefficient of the light reflection coefficients of the plurality of solid state light emitters 154, 156.

As seen in Fig. 1b, the ratio between the area of the light reflective surface 112 of the base 110 and the area of the solid state light emitter 154, 156 is smaller than such a ratio of the light emitting module 100. Thus, in the light emitting module 150 a relatively larger amount of light impinges on the solid state light emitter 154, 156, and thus it is even

more important that the light reflective layer 112 has better first reflection coefficient *R1* than the second light reflection coefficient *R2* of the solid state light emitters 154, 156 to compensate for the absorption of light by the plurality of solid state light emitters 154, 156. The efficiency of the light emitting module 150 is much higher if $R1 > R2 + 0.2(1-R2)$.

It is to be noted that in other embodiments, the different solid state light emitter 154, 156 emits different color ranges. Further, the luminescent layer 102 may comprises different luminescent materials each having a different conversion characteristic such that the light which is transmitted through the light exit window 104 comprises more than only the first color range 114 and the second color range 116.

In Fig. 1a and Fig. 1b each one of the solid state light emitters 108, 154, 156 have a top surface 106, 152, 158 which is facing towards the light exit window 104 and the luminescent layer 102. The top surfaces 106, 152, 158 are surfaces through which light of the first color range 114 is dominantly emitted towards the luminescent layer. The shortest distance between the top surfaces 106, 154, 158 of the solid state light emitters 108, 154, 156 and the luminescent layer 102 is the distance h.

Each one of the top surfaces 106, 154, 156 have a largest linear size being defined as the largest linear distance along a line on the top surface 106, 154,156. If the top surfaces are circular, the largest linear size is the length of the diameter of the circle. If the top surface has the shape of a square or a rectangle, the largest linear size is the length of the diagonal of the square or of the rectangle. The inventors have realized that, if distance h is too small, too much light impinges back on the solid state light emitters 108, 154, 156 such that too much light is absorbed by the solid state light emitters 108, 154, 156. And the inventors have realized that, if distance h is larger than a specific value, the amount of light is emitted back to the solid state emitters 108, 154, 156 compared to the amount of light which is emitted back to the light reflective surface, is such that no significant efficiency improvement may be obtained when the distance h is further increased. Thus, the inventors have found that the shortest distance h between the top surfaces 106, 152, 158 and the luminescent layer 102 should be in a range that has as minimum value 0.25 times the largest linear size of the top surfaces 106, 154, 156 and has as a maximum value 5 times the largest linear size of the top surfaces 106, 154, 156.

In light emitting module 150 a plurality of light emitters 154, 156 are provided, and each one of the plurality of light emitters 154, 156 may have a different distance to the luminescent layer 102. If the shortest distances are different, the average of the shortest distances should be in the range defined by [$0.25 Largest_linear_size,$

5Largest_linear_size]. If the solid state light emitters 154, 156 each have a different shape and/or size of their top surfaces 154, 158, the largest linear size is defined as the average of the largest linear sizes of the top surfaces of the plurality of solid state light emitters 154, 156.

The inventors have found that the optical effect of more reflection by the light reflective surface is not the only factor which contributes to a higher light output. If there is a distance *h* between the solid state light emitter(s) 108, 154, 156 and the luminescent layer 102, the solid state light emitter(s) 108, 154, 156 does not become as warm as it would be when the luminescent layer 102 is positioned on top of, or very close to, the solid state light emitter(s) 108, 154, 156. In this case, the luminescent layer 102 is not thermally coupled to the solid state light emitter(s) 108, 154, 156 and does not provided or receive the heat of the solid state light emitter(s) 108, 154, 156. The efficiency of the luminescent material is higher if the temperature of the luminescent material is kept within acceptable limits. Further, the efficiency of the solid state light emitter(s) 108, 154, 156 is higher if the temperature of the solid state light emitter(s) 108, 154, 156 is kept within acceptable limits. Thus, the distance *h* between the solid state light emitter(s) 108, 154, 156 and the luminescent layer 102 results in the photothermal effect of a more efficient luminescent layer 102. Further, the distance *h* between the solid state light emitter(s) 108, 154, 156 and the luminescent layer 102 results in a more uniform relatively small light flux through the luminescent layer 102 instead of a relatively high light flux in a very specific area of the luminescent layer 102. Luminescent materials tend to be sensitive to photosaturation, which means that above a certain flux, the luminescent material converts light at a lower efficiency. Also some luminescent materials or binders of these materials, such as organic phosphors or organic binders, tend to be sensitive to photodegradation, which means that above a certain flux, the luminescent material or the binder starts to degrade which typically results in a lowering of efficiency. Thus, by creating a distance *h* between the solid state light emitter(s) 108, 154, 156 and the luminescent layer 102 photosaturation of the luminescent material and photodegradation effects are prevented. Also the distance *h* aids in achieving a more uniform light output distribution in the exit window and aids to mix color distributions between the first spectral range(s) and the second spectral range(s). So both the spatial and angular color homogeneity is improved. This may be further enhanced with a diffuser or dichroic layer.

The solid state light emitter(s) 108, 154, 156 may be light emitting diode(s) (LEDs), organic light emitting diode(s) (OLEDs), or, for example, laser diode(s).

Fig. 2a and Fig. 2b present top-views of light emitting modules 200, 250 according to the first aspect of the invention. The presented top-views are seen if one looks towards a surface of the base of the light emitting modules 200, 250 on which the solid state light emitters are provided. One looks towards the base via the light exit window. It is to be noted that the luminescent layer is not drawn in Fig. 2a and 2b.

In Fig. 2a a light reflective surface 204 of a base and a top-surface 206 of a solid state light emitter is drawn. Arrow 202 indicates a largest linear size of the top surface 206 of the solid state light emitter. The area of the top surface 206 of the solid state emitter is L_wL_h. The area of the light reflective surface 204 of the base is B_wB_h – it is to be noted that the area of the light reflective surface 204 includes the area that is covered by the solid state light emitter. According to an aspect of the invention, the area of the top surface 206 is at least smaller than 0.55 of the area of the light reflective surface of the base. In other words, not more than 55% of the area of the light reflective surface is covered by the slid sate light emitter. It was found by the inventors that the efficiency of the light emitting module 200 increased to a large extent if the discussed criterion is followed. If the area of the top surface 206 is larger than 55% of the area of the light reflective surface 204, the efficiency increase is not large enough or even a light output decrease may occur.

In Fig. 2b is presented: a light reflective surface 254, a first top surface 256 of a first solid state light emitter, and a second top surface 258 of a second solid state light emitter. A largest linear distance of the rectangular first solid state emitter is indicated by arrow 252. The area of the first top surface 256 of the first solid state light emitter is $L1_wL1_h$. The second top surface 258 of the second solid state light emitter is circular and its diameter is indicated with arrow 260. The area of the second top surface 258 of the second solid state light emitter is $¼\pi(L2_d)^2$. The area of the light reflective surface 254 of the base is B_wB_h. According to an aspect of the invention the sum of the areas of the first top surface 256 and of the second top surface 258 is at least smaller than 55% of the area of the light reflective surface.

Fig. 3a presents an embodiment of a light emitting module 300 which comprises a cavity 316. The light emitting module 300 comprises a base 309 which has a light reflective surface 306 inside the cavity 316. On the light reflective surface 306 is provided a solid state light emitter 312 which emits light in a first color range towards the light exit window. The light exit window is formed by a luminescent layer 308. In between the base 309 and the luminescent layer 308 are provided walls 310, 314. The inner surfaces 302, 304 of the walls 310, 314 are light reflective and have a third reflection coefficient *R3*.

The third reflection coefficient is the ratio between an amount of light which is reflected by the light reflective surface 302, 304 of the walls and an amount of light which impinges on the light reflective surface 302, 304of the walls. The solid state light emitter has a second reflection coefficient *R2*. The light reflective surface 306 of the base 309 has a first reflection coefficient *R1*. The definition of the first and the second reflection coefficient are given in the description of Figs. 1a and 1b.

The walls 310, 314 may consist of various materials. The wall material may provide a high reflectivity such as when using a scattering ceramic such as reflective alumina, zirconia, YAG or other ceramics, a scattering glass, a scattering pigmented polymer, such as white polyamide; or scattering fluorpolymers, like Spectralon or a scattering silicone resin. The walls 310, 314 may also consist of a metal material such as aluminium or silver. The metal may be a metal foil or film, such a highly reflective commercial metal mirrors with the trade name of Alanod.

The wall material may also be of low reflectivity and covered with a reflective layer. In this case the wall may be another material like a thermally conductive polymer, such as a carbon filled plastic, e.g. a polyamide, or metallic materials like copper, nickel, stainless steel or ceramic materials such as aluminium nitride (AlN). These materials typically have a high thermal conductivity which is beneficial, e.g. copper = ~400 W/mK, AlN = ~140 W/mK. The reflective layer may be a coating, a film or a thin layer, such as thin metal coating such as protected silver or aluminium. The thin metal layer may be evaporated or sputtered on the wall material. The walls 310, 314 may come in a variety of shapes such as, for example, circular such as a ring, cylindrical, squared or triangular. The wall may contain surface structures such as fins in order to facility cooling.

The wall material may also consist of a thin film layer, such as the reflector coating or film only. In this case the wall reflector may cover the edges of a solid material present between the base and the luminescent material, such as the circumference of a glass or ceramic substrate. Light which is reflected or scattered by the luminescent layer and which is emitted by the luminescent layer is also reflected towards the walls 310, 314 and is reflected by the light reflective surface 302, 304. As such light, which is not immediately transmitted through the light exit window into the ambient, is reflected via the light reflective surfaces 302, 304 of the walls 310, 314 and/or the light reflective surface 306 of the base 309. Thus, the light which is not immediately transmitted into the ambient is recycled and contributes to an efficient light emitting module. In accordance with the criterion which defines the relation between the first reflection coefficient *R1* and the second reflection

coefficient *R2* should be at least larger than *R2 + 0.2(1-R2)*. The same applies to the third reflection coefficient *R3*.

Fig. 3b shows another embodiment of a light emitting module 350 according to the first aspect of the invention. The light emitting module 350 is similar to light emitting module 300 of Fig. 3a, however, there are some minor difference. Light emitting module 350 has a circular base 358 with a light reflective surface 354 which is faced towards a cavity. The cavity is enclosed by the base 358, a cylindrical wall 362 and a luminescent layer 352. A surface of the cylindrical wall 362 which faces towards cavity is a light reflective wall surface 356. On the light reflective surface 354 of the base are provided a plurality of light emitting diodes (LEDs) which emit light of a first color range towards the light exit window of the cavity. The light exit window of the cavity is formed by a luminescent layer 352 which comprises luminescent material for converting a part of the light of the first color range towards light of a second color range.

A cross-section of the light emitting module 300 of Fig. 3a along line A-A' is presented in Fig. 4. The light exit window is indicated with 402. The light exit window 402 is a portion of the luminescent layer 308 because a part of the luminescent layer 308 is arranged on top of the walls 404, 314 which have a certain thickness. Alternatively, there may be a recess in the wall edge to which the luminescent layer 308 may be fitted as a support of the luminescent layer 308. An adhesive may be used to attach the luminescent layer 308 to the top of the wall or into the recess in the wall. When a recess is used to attach the luminescent layer 308 there is an additional benefit of achieving thermal contact of the side face of the luminescent layer 308 to the wall.

The criteria for the first reflection coefficient and the third reflection coefficient are: *R1 > R2 + 0.2(1-R2)* and *R3 > R2 + 0.2(1-R2)*. The solid state light emitter 312 has a top surface 412. The area of the top surface 412 covers less than 55% of the area of the light reflective surface 306 of the base 309. The shortest distance between the top surface 412 of the solid state light emitter 312 and the luminescent layer 308 is indicated with *h*. The value of distance *h* is in a range with has as minimum value 0.25 times the longest linear size of the top surface 412 of the solid state light emitter 312, and has a maximum value of 5 times the longest linear size of the top surface 412 of the solid sate light emitter 312.

It is noted that, if the solid state light emitter 312 does not cover more than 55% of the light reflective surface 306, if *R1 > R2 + 0.2(1-R2)* and *R3 > R2 + 0.2(1-R2)*, and if the distance *h* is in the above presented range, the light emitting module 300 is a very efficient light emitting module. Only absorption by the solid state light emitter contributes

significantly to the inefficiency, while all other distances, sizes and reflection coefficients are optimized for maximum light output The effect of the absorption by the solid sate light emitters becomes minimal when a relatively low percentage of the light reflective surface is covered by the solid state light emitters, for example, a percentage below 20%. The light emitting module 300 may be even more efficient is in the above presented formulas the factor 0.2 is higher, for example 0.5 or 0.8. If the values of the reflection coefficients *R1, R2* become relatively high, for example, approaching unity, the configuration of the light emitting module becomes very efficient especially if the solid state light emitters cover much less than 55% of the light reflective surface 306 and very little of the light extracted from the solid state light emitters is being lost.

The luminescent layer 308 is placed on a top edge of the walls 404, 314 and as such they luminescent layer 308 is thermally coupled to the walls 404, 314. The luminescent layer 308 becomes warm because of the absorption of energy by the luminescent material while it converts light of the first color range towards light of the second color range. The thermal coupling between the luminescent layer 308 and the walls 404, 314 allows the walls 404, 314 to conduct the heat of the luminescent layer towards the base 309, which may comprises an interface for coupling the base 309 to a heat sink. This mechanism provides an effective heat management of the light emitting module 300 and prevents that the luminescent layer 308 becomes too warm, which enhances the efficiency and the lifetime of the luminescent material. Further, the cavity 316 may be filled with a substantially optically transparent material. If the whole cavity is filled with the transparent material, the transparent material is also thermally coupled to the luminescent layer 308 and may conduct heat away from the luminescent layer towards the walls 404, 314 and the base 309 in a much more efficient way than when an air gap is used. As will be discussed in the context of Fig. 5a the transparent material has further advantages such as the increase of light outcoupling from the solid state light emitter 412.

The substantially transparent material is typically a solid material, such as a solidified or cured silicone resin with a thermal conductivity of about 0.3 W/mK. Many types of such materials exist, ranging from hard silicone resins, to soft silicone resins, to flexible elastic silicone resins or gel type of resins. Other materials may include epoxy resins, many types of optically transparent polymers known to those skilled in the art. In other embodiments, wide range of glass type of materials may be used, such as sodalime glass of about 1.0 W/mK thermal conductivity or borosilicate glass or a fused silica glass of about 1.3 W/mK. Also, ceramic materials may be used such as translucent polycrystalline alumina

substrates of about 30 W/mK, sapphire substrates of 42 W/mK thermal conductivity. Combinations of such materials may also be used. For example, solid glass or ceramic substrates may be bonded to the emitters and/or the base. Optionally the optical and thermal contact is only achieved with the emitter surface such as to extract more light from the emitter and an air gap is still present between the solid material and the base. This may help to spread out the light more effectively by lightguiding in the solid material to enhance light uniformity. For optimal thermal contact, the solid substrates may also be attached to the base, for instance using an adhesive. The solid substrate performs the function of a heat spreading layer and thermal interface material when it is also coupled to the luminescent layer. The solid material may also be present on the emitter, such as a piece of sapphire or silicon carbide SiC, which may be the growth substrate on to which the emitter die was formed. Furthermore a dome shape or lens shape optical body may be present on the die, typically of a size at least 2 times larger than the longest linear size, which may, for example, be from a silicone resin of a glass material. The dome or lens shaped body may be covered with another transparent material.

The substantially transparent material preferably has a relatively high refractive index if in optical contact to the emitter die. As typical solid state light emitters, like GaN or InGaN or AlInGaN, have a high refractive index of about 2.4, a high refractive index contact to the die extracts more light from the die by reducing total internal reflection in the solid state light emitter chip. Most transparent materials come with a refractive index ranging from 1.4 to 1.6, typically 1.5. Some examples of high refractive index materials suitable for attaching to the emitter are high refractive index glasses, like LaSFN9, or ceramic materials like sapphire (n~1.77), alumina (n~1.77), YAG (n~1.86), zirconia (n~2.2) or silicon carbide (SiC, n ~2.6). A high refractive index optical bond may be used to attach the substrates, such as a high index glass or a high index resin. The high index resin may consist of a low index binder filled with high refractive index nano-particles, such as silicone resin filled with nano-TiO_2 particles smaller than 100 nm in diameter. In some types of emitter dies the typical growth substrates such as sapphire and silicon carbide may still be present on the die. It is than preferably to cover these dies with a high refractive index material, such as described above.

Alternatively also liquid materials may be used, such as silicone oils (n~1.4) or mineral oils (n~1.5) or a wide variety of liquids, such as aliphatic or aromatic hydrocarbons, or liquids of high refractive index, know to those skilled in the art. When a liquid is used a tight sealing around the edges of the exit window is preferred to prevent leakage from the

light emitting module. Fig. 5a presents several alternative embodiments of the light emitting module according to the first aspect of the invention. Light emitting module 500 comprises a base 518, a plurality of light emitting diodes (LEDs) 514 provided on substrates 516, walls 510, a first luminescent layer 506 and a second luminescent layer 504 provided on the walls and forming a light exit window. The LEDs 514 emit light of a first color range and all LEDs 514 have an equal size with a longest linear size *d*. The first luminescent layer comprises luminescent material for converting light of the first color range into light of a second color range. The second luminescent layer comprises another luminescent material for converting light of the first color range into light of a third color range. The walls 510, the base 518 and first luminescent layer 506 enclose a cavity which is filled with a transparent material 502. Thus, the transparent material is interposed between the LEDs 514 and the first luminescent layer 506. The transparent material is optically coupled to the LEDs 514 and optically and thermally coupled to the first luminescent layer 506. The distance between the light emitters and the first luminescent layer 506 is indicated with *h*. The surfaces of the walls 510 which face towards the cavity are provided with a light reflective coating 508. The spaces between the LEDs 514 and the light transmitting material 502 are filled with a light reflective material 512, thereby covering the base 518 and the substrates 516. The light reflective surface is formed by the surface of the light reflective material 512 which is interposed between the LEDs 514. The light reflective material has a first reflection coefficient *R1*. The LEDs have a second reflection coefficient *R2*. The light reflective coating 508 has a third reflection coefficient *R3*. Further, the area A_r of the light reflective surface is a part of the surface of the base 518 that is enveloped by the walls 510. The total area of the top surfaces of the plurality of LEDs 514 is A_l. The parameters of the light emitting module 500 relate according to the subsequent formulas to each other:

$$R1 > R2+0.2(1-R2) \quad (1)$$

$$R3 > R2+0.2(1-R2) \quad (2)$$

$$0.25\,d <= h <= 5\,d \quad (3)$$

$$A_l < 0.55\,A_r \quad (4)$$

Instead of a light reflective coating also a light reflective foil or film may be used that can be attached to or transferred to the base and or walls. An adhesive may be used for the attachment, such as a pressure sensitive adhesive. The reflective coating layer may be a dielectric layer as is typically used in an MCPCB carrier to isolate the surface electrodes from the metal carrier or a solder mask typically used in an MCPCB or PCB carrier to screen-off the surface electrodes. As the substrate 516 is covered with a reflective layer and is

hence optically screened off, it may consist of a material with poor reflectivity such as aluminiumnitride (AlN). AlN has the advantage of having a very high thermal conductivity of about 140 W/mK. Hence, optical functions can be screened off from thermal functions by the use of a reflective coating or foil allowing individual optimization of both functions which is advantageous.

The light reflective coating or film may consist of a diffusely reflecting material, such as a coating consisting of a binder filled with a scattering pigment or various scattering pigments. Suitable binders are silicone materials or silicate materials or alkylsilicate materials or epoxy materials or polyimide materials or fluorpolymers or polyamides or polyurethanes or other polymeric materials. The coating may also consist of highly reflective BariumSulphate (BaSO4) based material. Examples of scattering pigments are TiO2 pigments, ZrO2 pigments, Al2O3 pigments, but many other scattering particles or pores may be used as well, known to those skilled in the art. The reflective coating or film may also consist of metal layers, such as aluminium or silver. The metal may be a metal foil or film, such a highly reflective commercial metal mirrors with the trade name of Alanod. The thin metal layer may be evaporated or sputtered on the wall material.

Light emitting module 520 is similar to light emitting module 500, however, the walls 522 are of a light reflective material, and as such no additional coating is applied to the walls 522. Further, only one luminescent layer 506 is applied. The substrates 524 on which the LEDs 514 are provided are also of a light reflective material, and as such only the spaces between the substrates 524 are filled with light reflective particles 512.

Light emitting module 530 is another variation in which so-termed domed LEDs 514 are used. The LEDs 514 are provided on a substrate 516 and domes of a light transmitting material 502 are placed on top of the LEDs. The dome of the light transmitting material 502 is optically coupled to die of the LED. Further, the cavity is filled with a further light transmitting material 532. The further light transmitting material 532 is optically coupled to the domes of the light transmitting material 502 and is optically coupled to the first luminescent layer 506. This facilitates thermal transfer of heat from generated in the luminescent layer towards the base and the heatsink to which the base is typically attached.

Light emitting module 540 is similar to light emitting module 500, however, the walls 542 are tilted with respect to a normal axis to the base 518. The walls 542 are tilted in a way such that light which impinges on the tilted walls 542 is reflected towards the first luminescent layer 506 instead of a direction towards the base 518. The tilted walls 542 prevent that light rays are reflected many times between the walls 542 and base, which

prevents unnecessary light absorption, namely, every reflection is not perfect and at every reflection a small amount of light is absorbed.

Light emitting module 550 is a variant of light emitting module 540. The walls 552 of light emitting module 550 are curved in a way such that more light, which impinges on the curved walls 552, is reflected towards the first luminescent layer 506 and thus towards the light exit window. Furthermore, the substrate surfaces 516 are not coated but the spacing 512 between the substrates is coated with a reflective material. The substrate 516 may consist of a reflective material, such as a scattering ceramic, such as alumina that includes scattering pores and/or scattering particles, such as zirconia particles. Thus the reflectance of the light reflective surface of the base 518 is an average of the reflectance of the substrate 516 and the spacing 512 weighted over the area.

Light emitting module 560 is another variation. The cavity is filled with a substantially transparent material 562 and has at the light exit side of the light emitting module a curved surface. The first luminescent layer 506 is provided on top of the transparent material 562. As seen, the shortest distances between the LEDs 514 and the first luminescent layer 506 differ. Two LEDs are positioned at a distance *h1* from the first luminescent layer, and two LEDs are positioned at a distance *h2* form the first luminescent layer. The above presented formula (3) changes to:

$$0.25\ d <= (h1+h2)/2 <= 5\ d \quad (5)$$

Thus, the average value of the shortest distances of the LEDs 514 and the first luminescent layer 506 should be the range from 0.25 times the longest linear size *d* of the LEDs and 5 times the longest linear size *d* of the LEDs.

In yet another embodiment, which is not shown, the solid state emitter dies are bonded directly to the carrier board without the additional intermediate substrate. This further reduces thermal resistance between the die and the board and the die and the heatsink to which the board is typically attached.

Fig. 5b presents three alternative light emitting modules 570, 580, 590, 595. Light emitting module 570 is similar to light emitting module 520 and has inside the cavity an additional luminescent layer 572. Thus, a layer with another type of luminescent material is applied to the light reflective walls 522 and the light reflective surface of the base 518. The another luminescent material converts light of the first color range towards light of the third color range. Not all light which impinges on the additional luminescent layer 527 is converted, and some light is emitted towards the light reflective walls 522 and the light

reflective surface of the base 518 and is subsequently reflected back towards the cavity and thus towards the light exit window.

Light emitting module 580 is similar to light emitting module 500. A first difference is that only a single luminescent layer 506 is provided at the light exit window. During manufacturing the luminescent layer 506 is applied to a transparent substrate 582, which is for example glass. The substrate 582 with the luminescent layer 506 is cut into pieces, for example with a saw, and piece of the substrate 582 with the luminescent layer 506 is provided on the walls 510 of the light emitting module 580.

Light emitting module 590 is similar to light emitting module 580, however, the cavity is not filled with a substantially transparent material, but with a piece of the transparent substrate 582 with the luminescent layer 506. The piece is bonded with, for example, a transparent resin 592 to the light reflective wall surfaces and the light reflective surface of the base 518. The transparent substrate 582 is, for example, 2 mm tick and provides as such a height difference between the top surfaces of the LEDs 514 and the luminescent layer 506 of about 2mm.

Light emitting module 595 is similar to light emitting module 520. However, other types of LEDs are used. The base 598 is a metal core PCB (MCPCB). LEDs without a relatively large substrate may be mounted directly on the MCPCB. LEDs which are suitable for such applications are LEDs which are manufactured with the so-termed CSP or COB technologies. COB refers to chip-on-board wherein the LED chip is soldered directly on the MCPCB. CSP refers to Chip Scale Packages where a carrier is provided to the wafer on which the LED is manufactured, and the wafer is diced to obtain CSP LEDs. Such CSP LEDs are presented in light emitting module 595. In CSP LEDs the carrier 597 has the same size as the LED chip 596.

In Fig. 6 other schematically drawn cross-cuts of embodiments of a light emitting module 600, 620, 630, 640, 650, 660 are presented. The light emitting modules 600, 620, 630, 640, 650, 660 do not have walls between a luminescent layer 604, 622, 632, 642, 652, 662 and the base, but they have the luminescent layer 604, 622, 632, 642, 652, 662 of which the edge touches the light reflective surface or base 610, 664. The luminescent layer 604, 622, 632, 642, 652, 662 as a whole form the whole light exit window of the light emitting modules 600, 620, 630, 640, 650, 660. The light emitting modules 600, 620, 630, 640, 650, 660 do not only emit light in a direction substantially parallel to a normal axis to the base 610, 664, but emit light in various light emission angles with respect to the normal axis of the base. In the drawing of light emitting module 620 an edge 624 of the luminescent

layer 622 is indicated. As seen the edge 620 is in contact with the light reflective surface of the base 610.

The light emitting module 600 comprises a base 610, on which substrates 608 with LEDs 606 are provided. The substrates 608 and LEDs 606 are surrounded by a light reflective material 612 which forms a light reflective surface. The light emitting top surfaces of the LEDs 606 are optically coupled to a transparent material 602 which is also in contact with the luminescent layer 604. Light emitting modules 620, 630, 640 have luminescent layers 622, 632, 642 of another shape.

Light emitting module 650 has a base 610, on which a single chip-scale packaged LED 656 is provided. Often the abbreviation CSP-LED is used for the chip-scaled packaged LED 656 – such a chip-scaled packaged LED 656 does not comprise an extra substrate as shown in previous embodiments. Around the LED 656 a light reflective material 612 is applied which creates a light reflective surface facing towards the luminescent layer 652. On top of the LED 656 and the light reflective material 612 is placed a dome 654 of a transparent material on which the luminescent layer 652 is arranged. The radius r is the shortest distance between the LED 656 and the luminescent layer 652. The above discussed formula (3) changes to:

$$0.25\ d <= r <= 5\ d \qquad (6)$$

Light emitting module 660 does not comprise a dome of transparent material but a box shaped transparent material 663. Further, the base 664 is made of a light reflective material and as such no additional layer of light transmitting material is provided on the surface of the base 664 which is facing towards the luminescent layer 662. Other shapes and combinations may be envisioned as well.

The schematically shown light emitting modules 500, 520, 530, 540, 550, 560, 600, 620, 630, 640, 650, 660 may be circularly symmetric but may also be asymmetric out of the plane of the depicted cross-section. For instance, the module may be elongated in the depth direction to the plane of the paper such as to form an elongated, tube, rod, or cylinder like shape. Multiple emitters may form an emitter array in the depth direction. Such a shape may for instance be used in an LED streetlamp or LED retrofit fluorescent/TL lamp. LED emitter arrays of tens up to hundreds of LEDs may in principle be used.

In Fig. 7a is presented a light emitting module 700 which is manufactured on a flexible base foil 712. Solid state light emitters 706 which are provided on a small substrate 708, which is equipped with electrode connection pads (not shown), are provided on the flexible base foil 712, and the area in between the substrates 708 is filled with a light

reflective material 710. The light emitters 706 are optically coupled to a layer of a flexible transparent material 704. On top of the flexible light transmitting material 704 is provided a luminescent layer 702 comprising at least one luminescent material. As seen in Fig. 7a, the light emitting module 700 comprises a plurality of solid state light emitters 706. In an embodiment a relatively large two-dimensional array of solid state emitters is provided to obtain a relatively large light exit window. In conformity with previous embodiments, the shortest distance between the solid state light emitter 706 and the luminescent layer 702 should be in a range that depends on the longest linear size of the top surface of the solid state light emitters 706, and the average reflectivity of the light reflective surface of the base 712, formed by the combination of the substrates 708 and the light reflective material 710, should be substantially larger than the reflectivity of the solid state light emitter 706. Further, the solid state light emitters should only cover a relatively small part of the light reflective surface formed by the light reflective material 710 and the substrates 708. It is to be noted that the reflection coefficient *R1* of the light reflective surface is defined as the average reflectivity of the whole light reflective surface. Thus, the reflection coefficient *R1* is a weighted average between the reflection coefficient of the substrates and the reflection coefficient of the light reflective material, wherein the weights are formed by the part of the total area that is covered by the specific material.

In Fig. 7b another embodiment of a flexible light emitting module 750 is presented. Light emitting module 750 is similar to light emitting module 700, however, the base only exists of a light reflective foil 754 which is applied to a side of a transparent material 704. On another side of the flexible transparent material 704, which is opposite to the side to which the light reflective foil 754 is applied, a luminescent layer 702 is arranged. Within the transparent material wires 752 are provided which support substrates 708 on which solid state light emitters 706 are provided. The wires 752 provide electrical power to the solid state light emitters 706. The shortest distance from a top surface of the solid state light emitters to the luminescent layer 702 is indicated with *h*. The distance between the solid state light emitters 706 and the luminescent layers 702 should be larger than 0.25 times the average longest linear size of the top surfaces of the solid state light emitters and smaller than 5 times the average longest linear size of the top surface of the solid state light emitters. It is to be noted that this criterion also applies to the light emitting module 700. Further, in conformity with previously discussed embodiments, the first reflection coefficient *R1* of the light reflective foil 754 should relate to the second reflection coefficient *R2* of the solid state light emitters 706 according to: $R1 > R2 + 0.2(1-R2)$. Also in this case the coverage of the

light reflective foil 754 by the solid state light emitters should be less than 55%. In this case, wherein the solid state light emitters are not immediately provided on the light reflective foil 754, the coverage must be determined from a top view. If one looks through the luminescent layer 702 towards to light reflective foil 754 one has to determine which part of the light reflective foil 754 is covered by the solid state light emitters 706.

Fig. 8a and 8b show two graphs with the results of simulations of the light emitting module. With a light-ray tracing software packages an optical model was built of the light emitting modules according to the first aspect of the invention. The model comprises 16 blue-emitting LEDs with dies that have a top surface of 1x1mm each. Thus, the longest linear size of the top surfaces of these LEDs is about 1.4mm. The LED dies have a diffuse reflectance with a weighted average over the first and second spectral range of 71%, which corresponds to a typical surface roughened GaN type of LED die. The cavity had a circular shape with a diameter of 22 mm. The dies are relatively uniformly distributed over the base substrate. The die surface covered about 4% of the light reflective surface of the base. The LEDs are distributed on a highly reflective substrate and are surrounded with highly reflective walls forming a cavity. The light exit window of the cavity is covered by luminescent layer comprising a ceramic phosphor and an additional coating layer with particles of another phosphor in silicon. The light that is emitted by the modeled light emitting module through its light exit window has a warm white color point. The effect of the distance between the LEDs and the luminescent layers in combination with different reflectivity parameters on the light output is shown in Fig. 8a. The upper line shows that when the base and the walls are highly reflective, the maximum light output is reached at about 1 mm distance and at longer distances the light output slightly decreases. Between 0 and 0.5 mm the light output sharply increases. Thus, between 0.5 and 5 mm the light output is relatively high, and the light emitting module is operating at the highest possible efficiency, given the chosen reflection parameters. The effect of the distance between the LEDs and the luminescent layer in combination with different coverage values on the light output of the light emitting module is shown in Fig. 8b. The coverage value is the percentage of the light reflective surface that is covered by the LED dies. In Fig 8b it is also seen that, when increasing the distance between the LED dies and the luminescent layer, in a range of 0 and 0.5mm, the light output sharply increases, that a maximum light output is obtained at about 0.5mm to 1mm distance, and that after 1mm the light output decreases. Especially, if the coverage percentage is relatively large, the light output decreases relatively fast more significantly with the increase of the distance between the LED dies and the luminescent

layer. Thus, a relatively small coverage percentage and a distance between the LEDs and the luminescent layers of about 0.5 – 1 mm is optimal for optical efficiency reasons.

Fig. 9a and 9b show two other graphs with the results of simulations of the light emitting module. The optical model is slightly different from the model used in the simulation of which the results are presented in Fig. 8a and 8b. In these simulations, the shape of the cavity is modeled as a cylindrical shape with a highly reflective base and walls, and the cavity comprises only a single LED on the base of the cavity which has a square top surface of 1x1mm. Thus, if the radius of the cavity increases, the percentage of the light reflective surface of the base that is covered by the LED decreases. The simulations of which the results are presented in Fig. 9a are performed at different combinations of cavity radii, reflection coefficients and distances between the LED and the luminescent layers. It is seen in Fig. 9a that, if the cavity radius is relatively small (2mm), and thus a relatively large amount of the light reflective surface of the substrate (base) is covered by the LED, the light output is significantly lower. Above a certain cavity radius (4mm and more), the influence of the coverage of the light reflective surface of the substrate (base) is small. Further, after a specific distance between the LED die and the luminescent layer, the light output does not increase substantially, and thus, there is for optical efficiency reasons an optimum distance of about 0.6-1.2mm, if LED dies of 1x1mm are used. And, as expected, the higher the light reflectivity of the walls and the substrate is, the higher the light output is. Fig. 9b shows the influence of the coverage of the light reflective surface of the base by the LED die in combination with different reflection coefficients of the light reflective surface of the substrate (Rsubstrate) and the walls (Rwalls). As expected, the more area of the light reflective surface is covered with the LED die, the lower the light output is, because the LED die absorbs a relatively large amount of light which impinges on the LED die.

Fig. 10a shows an embodiment of a lamp 1000 according to the second aspect of the invention. The lamp 1000 comprises a retrofit light bulb 1002 which is connected to a lamp base 1006 which includes a heat sink, a power driver and electrical connections. On the lamp base 1006 is provided a light emitting module 1004 according to the first aspect of the invention. It is to be noted that embodiments of the lamp are not limited to lamps that have the size of a traditional light bulb. Other shapes, likes tube, are possible as well. Alternative lamp types, such a spot lamps or downlighter may be used as well. The lamps may comprise a plurality of light emitting modules as well.

Fig. 10a shows another embodiment of a lamp 1020. Lamp 1020 is a spot lamp which comprises a reflector 1022 for collimating the light which is emitted by a light

emitting module 1004. The light emitting module 1004 is thermally coupled to a heat sink 1024 for conducting the heat away from the light emitting module 1004 and providing the heat to the ambient of the lamp 1020. The heat sink 1024 may be passively and actively cooled.

Fig. 10b shows an embodiment of a luminaire 1050 according to the third aspect of the invention. The luminaire 1050 comprises a light emitting module 1052 according to the first aspect of the invention. In other embodiments, the luminaire 1050 comprises a lamp according to the second aspect of the invention.

The lamp according to the second aspect of the invention and the luminaire according to the third aspect of the invention, have similar embodiments with similar effects as the light emitting module of the first aspect of the invention.

A first embodiment is shown in Fig. 11. A light emitting module 1100 is shown in a three dimensional view. The light emitting module 1100 comprises a housing 1108, a luminescent layer 1106 and a solid state light emitter 1112. The housing 1108 forms a cavity 1114 which has light reflective walls 1102, 1104 and a light reflective base 1105. Further, the housing 1108 is of a heat conducting material. At a first side of the housing a light exit window is covered by the luminescent layer 1106. In the embodiment of Fig. 11 the luminescent layer 1106 thermally is connected to the housing 1108 at the edges of the luminescent layer 1108. For example, a heat conducting paste or heat conducting adhesive may be used to connect the luminescent layer 1108 to the housing 1108. At the second side of the housing 1108, which is substantially opposite the first side of the housing 1108, an interface 1110 to a heat sink (not shown) is provided. The solid state light emitter 1112 is provided within the cavity 1114 and is applied to the light reflective base 1105. The contact between the solid state light emitter 1112 and the light reflective base 1105 is such that the solid state light emitter 1112 is thermally coupled to the housing 1108. The solid state light emitter 1112 may be glued with a heat conducting adhesive, for example a metal particle filled adhesive, to the light reflective base 1105. The base of the cavity and / or the walls may contain thermal vias to further improve heat transfer. For example, the base may be made of an aluminum oxide ceramic that contains through holes which are metalized with copper. The copper has a higher thermal conductivity (approx. 400 W/mK compared to the aluminum oxide (20-30 W/mK). The solid state light emitter 1112 may also be connected with electrical vias through the base of the cavity to a power source. The electrical vias may also conduct heat.

The solid state light emitter 1112 emits light of a first color range into the cavity. Most of the light is directly emitted towards the luminescent layer, but a part may impinge on the light reflective walls 1102, 1104. The luminescent layer 1106 may directly transmit a part of received light into the ambient of the light emitting module 1100 and may reflect a small amount of the light back into the cavity 1114. Further, the luminescent layer 1106 comprises luminescent material which converts a part of the light of the first color range into light in a second color range. The generated light in the second color range is emitted in different directions. A part of the light in the second color range is emitted into the ambient of the light emitting module 1100 and another part of the light in the second color range is emitted into the cavity.

All the light which is not directly transmitted into the ambient of the light emitting module 1100 and impinges on the light reflective walls 1102, 1104 and the light reflective base 1105, is reflected by the walls 1102, 1104 and the base 1105. After one or more reflections the light is "recycled" and impinges on the luminescent layer 1106, which may transmit this light into the ambient of the light emitting module 1100. Light which impinges on the solid state light emitter 1112 is only partly reflected because solid state light emitters have typically limited reflection coefficient.

The total area of the light reflective walls 1102, 1104 plus the light reflective base 1105 which is defined as *total_area*. The area of the light reflective walls 1102, 1104 and/or the area of the light reflective base 1105 which is covered by the solid state light emitter 1112 is defined as *area_covered*. A ratio between the area of the light reflective walls 1102, 1104 and base 1105 covered by the solid state light emitter 1112 and the area of the light reflective walls 1102, 1104 and base 1105 not covered by the solid state light emitter 1112 may be defined as:

$$R = \frac{area_covered}{total_area - area_covered} \qquad (1)$$

If $R < 0.2$ a significant part of the light which is not directly transmitted into the ambient of the light emitting module 1100 is efficiently "recycled" and as such the output flux of light is relatively high.

The luminescent layer 1106 may comprise phosphors for converting light in the first color range into light of the second color range. The second color range is preferable different from the first color range – however, the ranges may partially overlap. The

phosphor may be a white phosphor like YAG:CE for partial conversion of blue light to yellow such that a combined substantial white emission may be obtained. In another embodiment the phosphor may be a full conversion phosphor like BSSNE:Eu or ECAS:Eu for fully converting blue light to amber or red, respectively. The luminescent layer 1106 may comprise a combination of phosphors, e.g. YAG:Ce and ECAS:Eu to obtain a warmer white emission.

The conversion of the light in the first color range into light of the second color range has a high efficiency, however, some light is absorbed and converted into heat. Especially with high power solid state light emitters 1112 the amount of absorbed energy may be relatively high. The efficiency of the luminescent layer 1106 may degrade if the luminescent layer 1106 becomes too hot. Further, the luminescent layer 1106 may comprise materials which degrade at high temperatures such that their light emission characteristics degrade as well. In the light emitting module 1100 the generated heat is transferred via the housing 1108 towards a heat sink. As such the luminescent layer 1106 does not become too hot.

The luminescent layer 1106 may be a ceramic phosphor which is manufactured to a fused macroscopic body via sintering of powder particles of phosphor or from precursor powders that form the phosphor in a reactive sintering process. Such a ceramic phosphor is produced in plates and are mechanically diced to give a proper size matching the light exit window of the housing 1108. It is to be noted that a single sheet of luminescent material, like a sheet of the ceramic phosphor, may cover a plurality of neighboring cavities.

A ceramic phosphor is a relative good thermal conductor. The thermal conductivity depends on the type of ceramic phosphor and the residual porosity. As an example typical thermal conductivity for a ceramic YAG phosphor is 9-13 W/mK at room temperature. A typical thermal conductivity of a powder phosphor layer in a binder resin such as a silicone or organic polymer is dominated by the binder with a thermal conductivity of about 0.15-0.3 W/mK. The ceramic phosphor layer may be around 10 – 300 micron in thickness, typically about 100 micron and is therefore rigid, self-supporting, hence no additional supporting substrate is need for the luminescent layer.

The luminescent layer 1106 may also be a substrate of glass on which a layer of a translucent resin comprising phosphor particles deposited. For example, a powder phosphor particles which are dispersed in a binder, typically a silicone resin. Preferably

however, the binder is a better heat conducting materials such as a glass or sol-gel derived silicate or alkylsilicate with a typical heat conductivity around 1 W/mK.

The housing 1108 is heat conducting and the walls and base facing toward the cavity are light reflective. Thus, the housing 1108 may be manufactured of a metal which is light reflective and heat conducting, for example silver, copper or aluminium or an alloy of metals, but may also be a heat conducting ceramic material, for example aluminium oxide or aluminium nitride, which have respectively an heat transmission factor of 20-30 W/mK or 70-210 W/mK, respectively. If the material of which the housing is manufactured has a too low reflection coefficient, the walls and the base of the cavity 1114 may be coated with a light reflective coating. The housing is not necessarily manufactured of one material or in one part. For example, the base may be of another material than the walls and they may be glued together with an appropriate adhesive. For example, the base is ceramic like aluminum oxide that is plated with a metal layer, such as copper and covered with a light reflective coating such as a TiO2 pigment filled silicate or silicone. The base may however also be a printed circuit board (PCB) such as an FR4 board or a metal core PCB (MCPCB) with a white surface coating. The surface coating may be a solder mask of the PCB.

The light emitting module 1100 provides a good thermal coupling between the solid state light emitter 1112 and the heat coupling interface 1110 to the heat sink. The solid state light emitter 1112 may be applied directly to the housing 1108 which is of a heat conducting material and as such a good thermal coupling is obtained. It is to be noted that the solid state light emitter 1112 may be thermally connected to the interface 1110 to a heat sink by additional means, like thermal vias to further improve heat transfer towards the interface 1110.

The solid state light emitter 1112 may be a Light Emitting Diode (LED), an Organic Light Emitting Diode (OLED), Polymer Light Emitting Diode (PLED) or a laser diode.

In an embodiment of the light emitting module 1100, an additional layer is placed on top of the luminescent layer 1106 which acts as a diffuser such that the light emitting module 1100 emits light in a plurality of output directions with improved angular color uniformity. The phosphor layer will convert light travelling more or less perpendicular through the phosphor layer less than light travelling at large angles with the normal. When a partial converted phosphor layer is used this induces more LED light (typically of blue color) to be emitted near the normal angle than at large angles. This leads to unacceptable color variations with angle. The diffuser scrambles the light prior to emission towards the ambient

to improve the color-over-angle uniformity. The diffuser is preferably dominantly forward scattering.

Alternatively a dichroic or interference layer may be present on top of the luminescent layer to correct the color-over-angle errors in the light emitted through the luminescent layer. The dichroic layer consists of a multitude of thin layers with alternative higher and lower refractive indices with which the light interferes. The optical characteristics of the dichroic are such that blue light is reflected more near the normal, and less or not at larger angles in a gradual way. The excess of a blue LED light near the normal through the phosphor is then compensated by a higher backreflection by the dichroic. The backreflected blue light will partly excite the phosphor and be color converted and may partly be recycled in the cavity. The dichroic layer may be present as a thin film on a carrier substrate, such as a glass, and connected to the phosphor. The connection may be made using an adhesive.

Alternatively the phosphor may be present as a coating on the same substrate as the dichroic at the opposite side. The carrier substrate of the dichroic may be a heat conducting transparent substrate such as a ceramic.

Further, the cavity 1114 may comprises a plurality of solid state light emitters 1112. The plurality of solid state light emitters 1112 may comprise different types of solid state light emitters 1112 which emit different colors into the cavity. By combining different colors of solid state light emitter a specific distribution of output light of different colors may be obtained. As far as the light of the different solid state light emitters 1112 is not directly emitted through the luminescent layer 1106, the light is mixed in the cavity 1114 to obtain a more uniform color output distribution across the light exit window. The luminescent material may convert one of the colors of the light emitted by one of the solid state light emitters 1112, or the luminescent material may comprise several types of luminescent material such that a plurality of colors emitted by the solid state light emitters 112 is converted into other colors.

Fig. 12 shows a cross-cut 1200 of the light emitting module 1100 of Fig.1 along a vertical plane through B-B' of Fig. 11. The cross-cut 1200 shows the housing 1108, the cavity 1114, the luminescent layer 1106, the interface 1110 to a heat sink 1210, the light reflective base 1105 and the light reflective walls 1102, 1206. Further, the light exit window 1202 is indicated in the cross-cut 1200. In Fig. 2 a specific type of solid state light emitter 1212 is shown which is connected to the electrical power by means of two wires 1208. Light Emitting Diodes (LEDs) have often top-bond wires 1208. The wires 1208 are connected to the solid state light emitter 1212 at a top surface 1211 of the solid state light

emitter 1212. The top surface 1211 is a surface of the solid state light emitter 1212 which is closest to the luminescent layer 1106 and where the light is emitted into the cavity 1114.

As seen in Fig. 12 the interface 1110 to the heat sink 1210 is provided at the back side of the light emitting module 1100. It is to be noted that the back side is substantially opposite the side where the luminescent layer 1106 is present and that a part of the housing which forms the back side also forms the base of the cavity 114. As seen in Fig. 12 the solid state light emitter 1212 is applied to the light reflective base 1105 of the cavity 1114. The contact between the solid state light emitter 1212 and the housing 1108 is such that a good thermal coupling is obtained between the solid state light emitter 1212 to the housing 1108 and as such between the solid state light emitter 1212 and the heat sink 1210.

Alternatively, the solid state light emitter 1212 may be mounted in a through hole in the light reflect base such that light is emitted into the cavity 1114 and such that the solid state light emitter 1212 has a good thermal contact with the housing 1108.

In a specific embodiment of the light emitting module 1100 the cavity 1114 may be filled with a transparent resin 1204. The transparent resin 1204 is injected into the cavity such that a good optical connection is made between the transparent resin 1204 and the top surface 1211 solid state light emitter 1212. After injection the transparent resin 1204 may cure or react to become more solid, ether a hard solid or a gel. Alternatively, the transparent material may be a liquid. If the luminescent layer 1106 is applied to the housing when the transparent resin 1206 is still in a more fluid state, a good optical coupling between the transparent resin 1206 and the luminescent layer 1106 may be obtained. The optical coupling between the solid state light emitter 1212 and the transparent resin 1204 provide a good outcoupling of light from the solid state light emitter 1212. If the transparent resin 1204 is optically coupled to the luminescent layer 1106, no air gap is available between the transparent resin 1204 and the luminescent layer 1106. Thus, reflection of light at interfaces between air and the transparent resin 1204 and the luminescent layer 1106 may be prevented.

The transparent resin 1204 may be a resin that has a relatively high refractive index, preferably above 1.4. A silicone resin typically has a refractive index in the range of 1.4 to 1.57. Polyamides have a higher refractive index (1.6-1.8). There are also high refractive index glass materials available such as in the range of 1.7 to 2.2. The glass can be molten at elevated temperature to fill the cavity. Preferably, the transparent material 1204 which is optically coupled with solid state light emitter 1212 and/or with the luminescent layer 1106 has a refractive index that is as close as possible to the refractive index of the solid state light emitter 1212 and/or the refractive index of the luminescent layer. The cavity may

be filled with a mixture of materials or with by combining various substantially transparent materials. For instance, a high refractive index material like sapphire may fill up a substantial part of the cavity, preferably in connection with the LED surface. A remaining part of the cavity may be filled up with another material like a low index silicone resin. Alternatively the remaining part of the cavity may be filled up with a high refractive index glass. Hence, multiple materials with differing refractive index may be used to fill the cavity.

In other words, the refractive index of the solid state light emitter 1212 is relatively high. In a typical example of a Light Emitting Diode manufactured from InGaN the refractive index is about 2.4. If the refractive index of the transparent material 1204 is closer to the refractive index of the solid state light emitter 1212, more light is outcoupled from the solid state light emitter 1212. Sometimes the top surface of the solid state light emitter 1212 still comprises a thin layer of a substrate on which the solid state light emitter 1212 was manufactured. The substrate is, for example, sapphire, which has a refractive index of 1.77. A relatively good outcoupling of light is obtained between sapphire and the transparent material 1204 having a refractive index that is larger than 1.4. A proper material for the transparent material 1204 may be a relative hard material, for example, a silicone resin, or a soft material, like a silicone gel or past, or a liquid such as a silicone oil. If the material inside the cavity is a liquid, the mobility of the liquid aids in transferring and homogenizing heat by convection.

Typical ceramic phosphors, like YAG:Ce and amber colored barium strontium silicium nitride (BSSNE:Eu) have a refractive index of about 1.86 and 2, respectively. Thus, a transparent resin with a refractive index higher than 1.4 may provide a relatively good optical coupling between these specific LEDs and the discussed specific ceramic phosphors. Extra scattering centers, like scattering particles, may be incorporated preferably with forward scattering characteristics.

In the cross-cut 1200 of Fig. 12 is indicated a distance d which is the shortest distance between the top surface 1211 of the solid state light emitter 1212 and the luminescent layer 1106. The distance d has to be in the range 0.2mm to 10 mm. The minimum distance d is determined by the length of the wires and by the fact that the cavity 1114 has to have a minimum size to obtain a good reflection of light without the absorption of the light the by solid state light emitter 1212. The minimum size of the cavity is important to obtain a ratio R according to (1) which is small enough. An upper bound of the range for the distance d may be defined by stress which occurs in curing and reacting transparent resins after the injection of the transparent resin. The larger distance d is, the

larger the amount of stress will be. If the stress is too high, the optical coupling between the transparent resin may be reduced and the top-bond wires 1208 risks to become defective or become disconnected from the solid state light emitter 1211.

The light reflective walls 1102, 1206 and the light reflective base 1105 have a thickness. In order to obtain a compact light emitting module 1200, the thickness has to be relatively small and at least thin enough to conduct the heat generated in the luminescent layer 1106 towards the heat sink 1210. In an embodiment, the thickness of the light reflective walls 1102, 1206 and the light reflective base 1105 is smaller than 5% of the shortest distance from each one of the light reflective walls 1102, 1206 towards an opposite light reflective wall 1102, 1206.

As seen in Fig. 12 the light reflective walls 1102, 1206 have an orientation which is substantially perpendicular to the orientation of the light reflective base 1105. In an embodiment, the corners where the light reflective walls 1102, 1206 are in contact with the light reflective base 1105 may be rounded to obtain a smooth transition from the base to the walls. At least a substantial part of the light reflective walls 1102, 1206 are oriented perpendicular to a substantial part of the light reflective base 1105.

It is to be noted that the shape of the light emitting module 1100, 1200 is not limited to a box shape. The light emitting module 1100, 1200 may also have a cylindrical shape, wherein the light reflective walls 1102, 1206 have the form of a pipe and wherein the light reflective base 1105 shuts off one side of the pipe. The shape light emitting module 1100, 200 may also differ a little bit from the cylindrical shape, for example by having a slightly conical shape. However, this reduces the size of the cavity in comparison to the outer dimensions of the light emitting module 1100, 1200 and as such it is preferred that the shape does not deviate much from the cylindrical shape.

A wire-bond top connection 1208 is a wire which is electrically connected to an electrical contact area at the top surface 1211 of the LED 1212 which is usually metalized and the wire provides electrical energy to the LED 1212. The top surface 1211 of the LED 1212 is often the light emitting surface of the LED 1212 as well. The light emitting surface of the LED 1212 is defined as the non-obstructed emissive surface area of the LED 1212 where the light generated by the LED 1212 is emitted into the cavity 1114. In the context of this document the top surface 1211 of the LED 1212 is the surface which faces towards the luminescent layer 1106.

Using a luminescent layer 1106, which is implemented as a ceramic phosphor, or which is implemented as a phosphor layer deposited on for example a glass substrate, in

combination with a LED 1212 with a wire-bond top connection 1208 has proved to be difficult. The wires 1208 obstruct the direct provision of such a ceramic phosphor layer on top of the light emitting surface. A solution may be to drill precision holes in the ceramic phosphor through which the wire is led, which is a relative expensive process. However, it is difficult to prevent light leakage via the precisions holes along the wire. This results in a reduced color control. Especially when the luminescent layer 1106 has to convert all the light of in the first color range, the light leakage results in an unacceptable reduced color saturation. Further, the holes would typically be drilled with laser ablation which comes with the risk of damaging the phosphor near the drilled holes such that the ablation by-products absorb light and a part of the phosphor is deactivated.

The embodiment provides an effective and efficient solution for converting light of LEDs 1212 with one or more wire bond top connections 1208 into another color. The cavity 1114 provides space for the wires 1208, and because of the reflections of the light inside the cavity no shadow of the wires 1208 is visible at the light exit window 1202. It is to be noted that the cavity 1114 of the embodiment is relative large with respect to the size of the light emitting module 1200 and as such less shadows of wires may be available compared to the known light emitting modules in which the cavity is relative small. If the cavity 1114 is relatively large, the light may become more homogeneous compared to relative small cavities.

The use of the wire-bond top-connection 1208 together with a transparent resin 1204, which is arranged between the LED 1212 and the luminescent layer 1106, is advantageous. The transparent resin 1204 may be injected into the cavity 1114 after assembling the LED 1212 to the housing 1108. During injection the transparent resin 1204 is in a liquid state and may flow towards each corner of the cavity. The wires 1208 are not an obstacle for the injected transparent resins and as such a good contact may be made between the transparent resin 1204 and the whole top surface 1211 of the LED 1212. Thus, the transparent resin 1204 increases the outcoupling of light from the LED 1212. Further, if the transparent resin 1204 is hardened the wire-bound top connections 1208 are fastened by the resin 1204 and is less sensitive to damage, for example, if the light emitting module 1200 is subject to vibrations.

Further, compared to LEDs on which the luminescent layer is applied directly, the amount of light which is emitted into the ambient of the light emitting module is increased because of the better outcoupling of light from the LED by the transparent resin and the reduction of light which would be emitted and reflected back on the LED by a

ceramic phosphor that is in direct contact with the LED. Thus, although the outer dimensions of the light emitting module are larger than the outer dimensions of a LED on which the luminescent layer is applied directly, the light output flux increases as well.

Fig. 13 shows another embodiment of the light emitting module according to the first aspect of the invention. Light emitting module 1300 comprises a housing comprising a base 1311 and walls 1309 around a cavity 1114 and the light exit window of the cavity 1114 is covered with a luminescent layer 1106. The walls 1309 of the housing forms light diffusely reflective walls 1306, 1310 and the base 1311 forms a light diffusely reflective base 1312 of the cavity 1114. Diffusely reflective means that light which impinges on the wall or the base is reflected in several directions, which is for example shown at point 1308 and point 1320. Light beam 1314 impinges at point 1308 on the diffusely reflective wall 1306 and at point 1308 parts of the light beam 1314 are reflected in a plurality of different directions. Light beam 1318 impinges on the light reflective base 1320 at point 1320 and is reflected in a plurality of different directions.

For example, the interior of the cavity, or the walls 1309 and/ or the base 1311, are made of an alumina ceramic material with a relatively high porosity to induce a high reflectivity that can be close to 100%. Alternatively the interior of the walls 1309 and/or the base 1311 may be coated with a diffusely reflecting layer such as a silicone, silicate or alkylsilicated layer filled with scattering particles such as titanium dioxide, zirconium oxide or aluminium oxide particles or a mixture thereof.

In the cavity 1114 is provided a solid state light emitter 1316 which emits light in at least one sideward direction. The sideward emission is typically obtained by providing two additional layers on top of a general purpose solid state light emitter, which are a layer of a transparent material 1302 and a layer of a light reflective material 1304.

A Light Emitting Diode (LED), which is a solid state light emitter, is often manufactured on substrate of transparent sapphire. After manufacturing, in many cases, the layer of sapphire is removed. However, when the sapphire is not removed, or only partial removed, the addition of a light reflective coating to a surface of the sapphire layer which is substantially opposite to the LED results in the manufacturing of the sideward emitting solid state light emitter 1316. Alternatively, a piece of glass or sapphire may be adhered to the LED.

The walls 1309 and base 1311 may be manufactured of the one and the same material and glued together. In another embodiment, the walls 1309 and base 1311 are different materials. It is to be noted that the base 1311, as drawn, may extend beyond the

walls 1309, for example, when one base is shared by a plurality of neighboring light emitting modules, for example, when the base is a heat conducting Printed Circuit Board.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims.

In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. Use of the verb "comprise" and its conjugations does not exclude the presence of elements or steps other than those stated in a claim. The article "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The invention may be implemented by means of hardware comprising several distinct elements, and by means of a suitably programmed computer. In the device claim enumerating several means, several of these means may be embodied by one and the same item of hardware. 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.

CLAIMS:

1. A light emitting module (100, 150, 300, 350, 500, 600, 700, 750) for emitting light through a light exit window (104, 402) of the light emitting module (100, 150, 300, 350, 500, 600, 700, 750), the light emitting module (100, 150, 300, 350, 500, 600, 700, 750) comprising:

- a base (110, 309, 358, 518, 610, 712) having a light reflective surface (112, 306, 354) facing towards the light exit window (104, 402), the light reflective surface (112, 306, 354) having a first reflection coefficient (R1), the first reflection coefficient (R1) being defined by a ratio between the amount light that is reflected by the light reflective surface (112, 306, 354) and the amount of light that impinges on the light reflective surface (112, 306, 354),

- a solid state light emitter (108, 154, 156, 312, 360, 514, 606) provided in between the base (110, 309, 358, 518, 610, 712) and the light exit window (104, 402), the solid state light emitter (108, 154, 156, 312, 360, 514, 606) being configured for emitting light of a first color range (114) towards at least a part of the light exit window (104, 402), the solid state light emitter (108, 154, 156, 312, 360, 514, 606) having a top surface (106, 152, 158, 412) facing towards the light exit window (104, 402) and having a second reflection coefficient (R2), the second reflection coefficient (R2) being defined by a ratio between the amount light that is reflected by the solid state light emitter (108, 154, 156, 312, 360, 514, 606) and the amount of light that impinges on the top surface (106, 152, 158, 412) of the solid state light emitter (108, 154, 156, 312, 360, 514, 606),

- a luminescent layer (102, 308, 352, 506, 604, 702), the luminescent layer (102, 308, 352, 506, 604, 702) comprising luminescent material for converting at least a part of the light of the first color range (114) into light of the second color range (116), the light exit window (104, 402) comprising at least a part of the luminescent layer (102, 308, 352, 506, 604, 702),

wherein the value of the first reflection coefficient (R1) is larger than the second reflection coefficient (R2) plus 0.2 times the difference between 1 and the second reflection coefficient (R2).

2. A light emitting module (100, 150, 300, 350, 500, 600, 700, 750) according to claim 1 comprising a plurality of solid state light emitters (108, 154, 156, 312, 360, 514, 606) being provided on an imaginary plane which is in between the base (110, 309, 358, 518, 610, 712) and the light exit window (104, 402), wherein each one of the solid state light emitters (108, 154, 156, 312, 360, 514, 606) is configured for emitting light in a specific color range towards at least a specific part of the light exit window (104, 402), each one of the solid state light emitters has a top surface (106, 152, 158, 412) facing towards the light exit window (104, 402), and the second reflection coefficient (R2) is defined as the average value of the reflection coefficients of the plurality of solid state light emitters (108, 154, 156, 312, 360, 514, 606).

3. A light emitting module (100, 150, 300, 350, 500, 600, 700, 750) according to claim 1 or 2, wherein a gap (h, h1, h2) is present between the top surface (106, 152, 158, 412) of the solid state light emitter (108, 154, 156, 312, 360, 514, 606) or the top surfaces (106, 152, 158, 412) of the plurality of solid state light emitters (108, 154, 156, 312, 360, 514, 606) and the luminescent layer (102, 308, 352, 506, 604, 702).

4. A light emitting module (100, 150, 300, 350, 500, 600, 700, 750) according to claim 3,
wherein, if the light emitting module (100, 150, 300, 350, 500, 600, 700, 750) comprises a single solid state light emitter (108, 154, 156, 312, 360, 514, 606), a shortest distance (h, h1, h2) between the top surface (106, 152, 158, 412) and the light exit window (104, 402) is a value in a range with a minimal value of 0.25 times a largest linear size (202, 252, 260) of the top surface (106, 152, 158, 412) and a maximum value of 5 times the largest linear size (202, 252, 260) of the top surface (106, 152, 158, 412), or wherein, if the light emitting module (100, 150, 300, 350, 500, 600, 700, 750) comprises a plurality of solid state light emitters (108, 154, 156, 312, 360, 514, 606), an average of shortest distances between the plurality of top surfaces (106, 152, 158, 412) and the light exit window (104, 402) is a value in a range with a minimal value of 0.25 times an average largest linear size of the top surface (106, 152, 158, 412) and a maximum value of 5 times the average largest linear size of the top surface (106, 152, 158, 412),
wherein the largest linear size (202, 252, 260) of the top surface (106, 152, 158, 412) being defined as the longest distance from a point on the top surface (106, 152, 158, 412) to another point on the top surface (106, 152, 158, 412) along a straight line.

5. A light emitting module (100, 150, 300, 350, 500, 600, 700, 750) according to claim 1 or 2, wherein, when referring to claim 1, the area of the top surface (106, 152, 158, 412) is at least smaller than the area defined by 0.55 times the area of the light reflective surface (112, 306, 354) of the base (110, 309, 358, 518, 610, 712), or wherein, when referring to claim 2, a sum of the areas of the top surfaces (106, 152, 158, 412) of the plurality of light emitters (108, 154, 156, 312, 360, 514, 606) is at least smaller than the area defined by 0.55 times the area of the light reflective surface (112, 306, 354) of the base (110, 309, 358, 518, 610, 712).

6. A light emitting module (100, 150, 300, 350, 500, 600, 700, 750) according to claim 1 or 2 comprising a wall (310, 314, 362, 404) interposed between the base (110, 309, 358, 518, 610, 712) and the light exit window (104, 402), the base (110, 309, 358, 518, 610, 712), the wall (310, 314, 362, 404) and the light exit window (104, 402) enclosing a cavity (316), the wall (310, 314, 362, 404) having a light reflective wall surface (302, 304, 406) facing towards the cavity (316), the light reflective wall surface (302, 304, 406) having a third reflection coefficient (R3), the third reflection coefficient (R3) being defined by a ratio between the amount light that is reflected by the light reflective wall surface (302, 304, 406) and the amount of light that impinges on the light reflective wall surface (302, 304, 406), wherein the value of the third reflection coefficient (R3) is at least larger than the second reflection coefficient (R2) plus 0.2 times the difference between 1 and the second reflection coefficient (R2).

7. A light emitting module (100, 150, 300, 350, 500, 600, 700, 750) according to claim 1 or claim 6, wherein, when referring to claim 1, the light reflective surface (112, 306, 354) of the base comprises a light reflective coating or light reflective foil, and wherein, when referring to claim 6, at least one of the light reflective surface of the base (110, 309, 358, 518, 610, 712) and the light reflective wall surface (302, 304, 406) comprises a light reflective coating or a light reflective foil.

8. A light emitting module (100, 150, 300, 350, 500, 600, 700, 750) according to claim 6, wherein the light reflective wall surface (302, 304, 406) is tilted with respect to a normal axis of the base (110, 309, 358, 518, 610, 712) for increasing the reflection of light towards the light exit window (104, 402), or wherein the light reflective wall surface (302,

304, 406) is curved for increasing the reflection of light towards the light exit window (104, 402).

9. A light emitting module (100, 150, 300, 350, 500, 600, 700, 750) according to claim 1, wherein the luminescent layer (102, 308, 352, 506, 604, 702) forms the light exit window (104, 402), the luminescent layer (102, 308, 352, 506, 604, 702) having an edge (624), and the edge (624) of the luminescent layer (102, 308, 352, 506, 604, 702) is in contact with the base (110, 309, 358, 518, 610, 712).

10. A light emitting module (100, 150, 300, 350, 500, 600, 700, 750) according to claim 1 or 2, comprising, when referring to claim 1, a substantially transparent material (502, 602, 704) arranged between the solid state light emitter (108, 154, 156, 312, 360, 514, 606) and the luminescent layer (102, 308, 352, 506, 604, 702), the transparent material (502, 602, 704) being optically coupled to the solid state light emitter (108, 154, 156, 312, 360, 514, 606), or comprising, when referring to claim 2, a substantially transparent material (502, 602, 704) arranged between the plurality of solid state light emitters (108, 154, 156, 312, 360, 514, 606) and the luminescent layer (102, 308, 352, 506, 604, 702), the transparent material (502, 602, 704) being optically coupled to the plurality of solid state light emitters (108, 154, 156, 312, 360, 514, 606).

11. A light emitting module (100, 150, 300, 350, 500, 600, 700, 750) according to claim 10, wherein the substantially transparent material (502, 602, 704) is further optically and thermally coupled to the luminescent layer (102, 308, 352, 506, 604, 702).

12. A light emitting module (100, 150, 300, 350, 500, 600, 700, 750) according to claim 1, wherein the luminescent material comprises at least one of: an inorganic phosphor, an organic phosphor, a ceramic phosphor and a quantum dot phosphor.

13. A light emitting module (100, 150, 300, 350, 500, 600, 700, 750) according to claim 1, wherein the light exit window (104, 402) further comprises at least one of:

- a diffuser layer for obtaining a diffuse light emission, for obtaining a spatially, color and color over-angle uniform light emission, and for obtaining a color mixed light emission, and
- a dichroic layer for correcting color over angle variations or light uniformity.

14. A lamp (1000, 1020) comprising a light emitting module (100, 150, 300, 350, 500, 600, 700, 750) according to claim 1.

15. A luminaire (1050) comprising a light emitting module (100, 150, 300, 350, 500, 600, 700, 750) according to claim 1 or comprising a lamp (1000, 1020) according to claim 14.

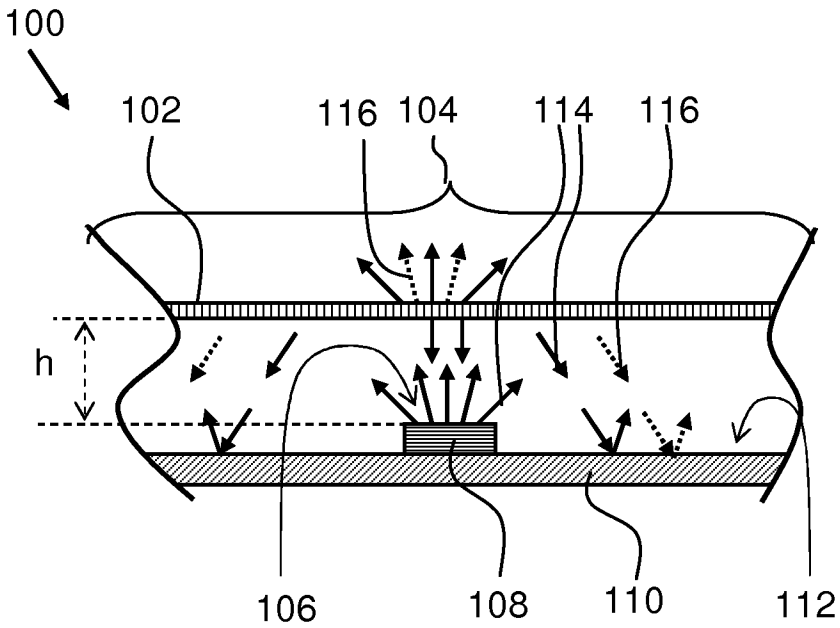

100
102
116
104
114
116
h
106
108
110
112

Fig. 1a

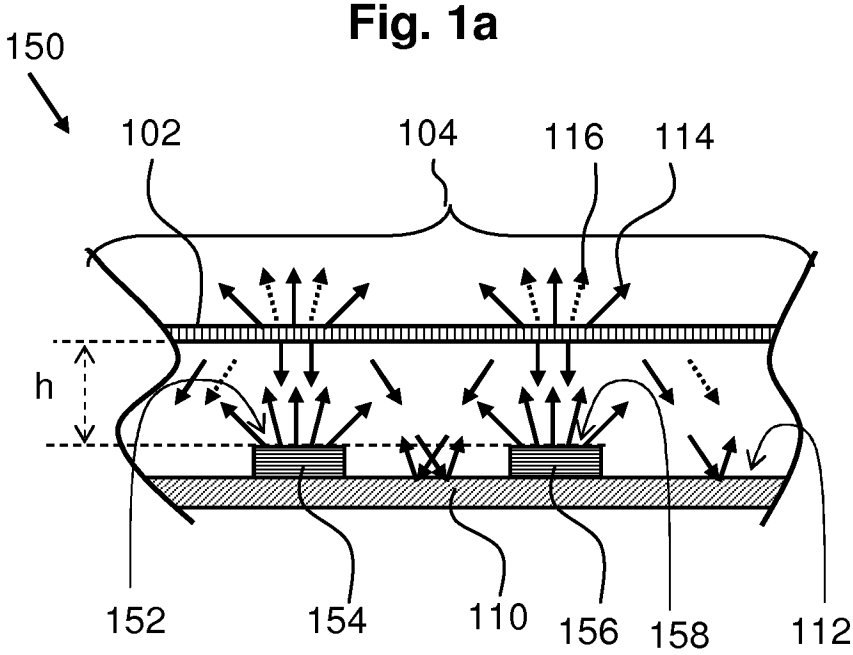

150
102
104
116
114
h
152
154
110
156
158
112

Fig. 1b

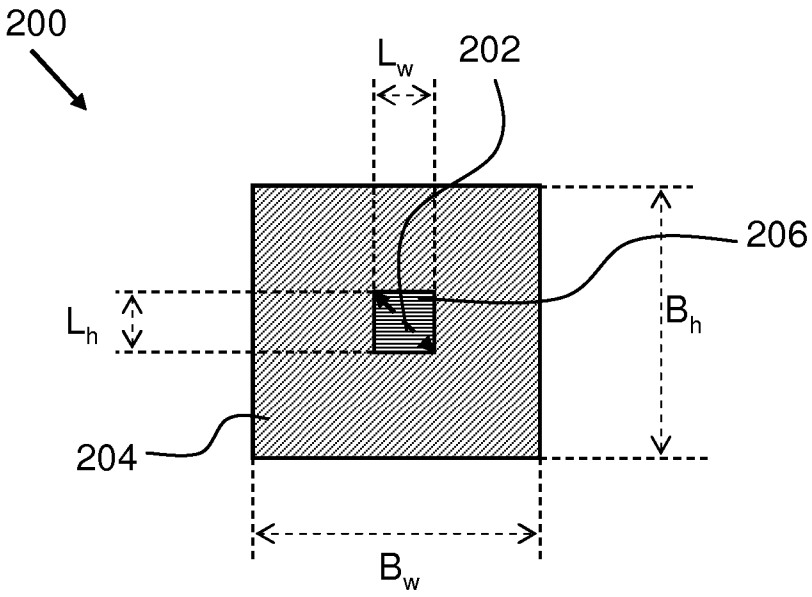

200
L_w
202
206
L_h
B_h
204
B_w

Fig. 2a

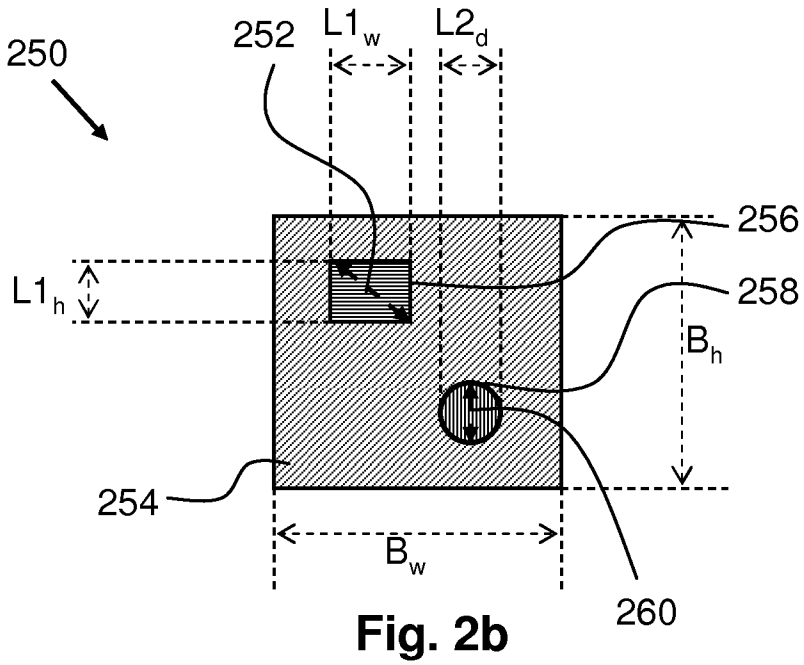

250
252
$L1_w$
$L2_d$
256
$L1_h$
258
B_h
254
B_w
260

Fig. 2b

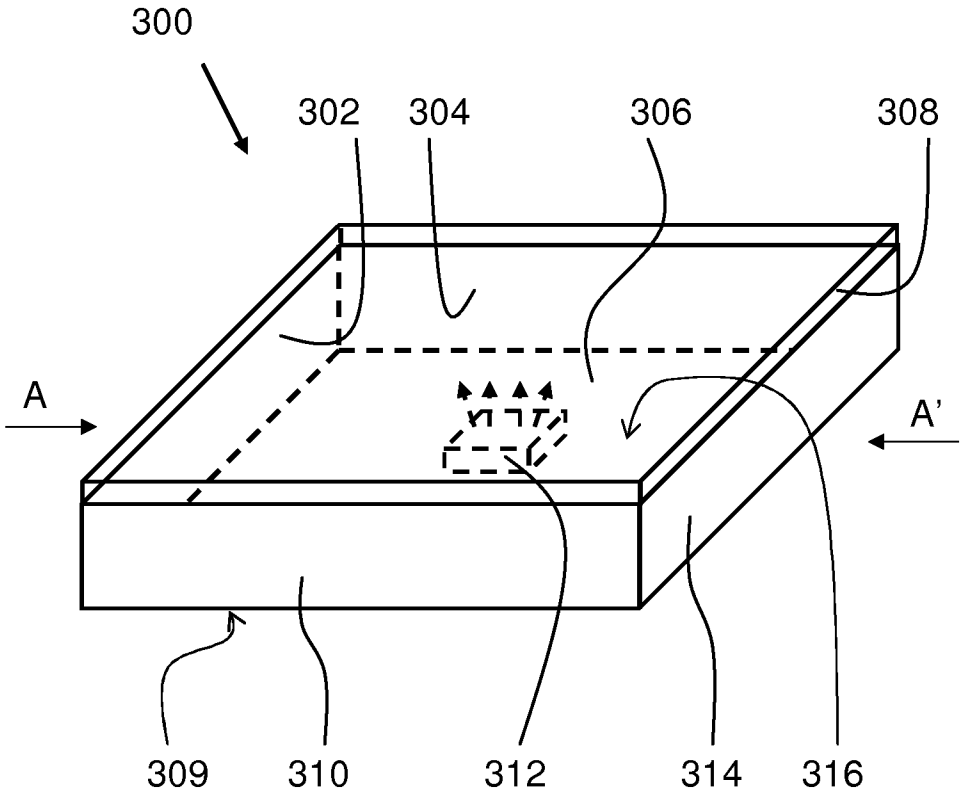

300
302
304
306
308
A
A'
309
310
312
314
316

Fig. 3a

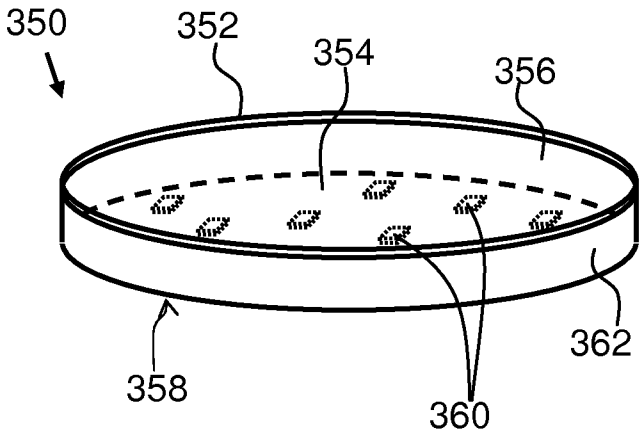

350
352
354
356
358
360
362

Fig. 3b

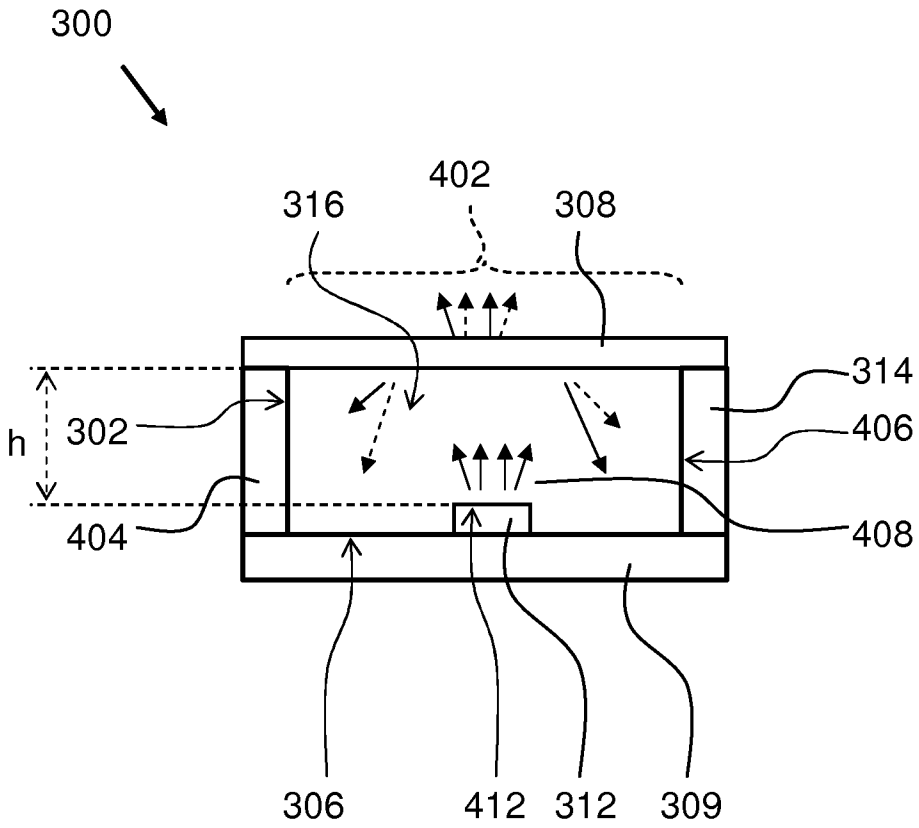


Fig. 4

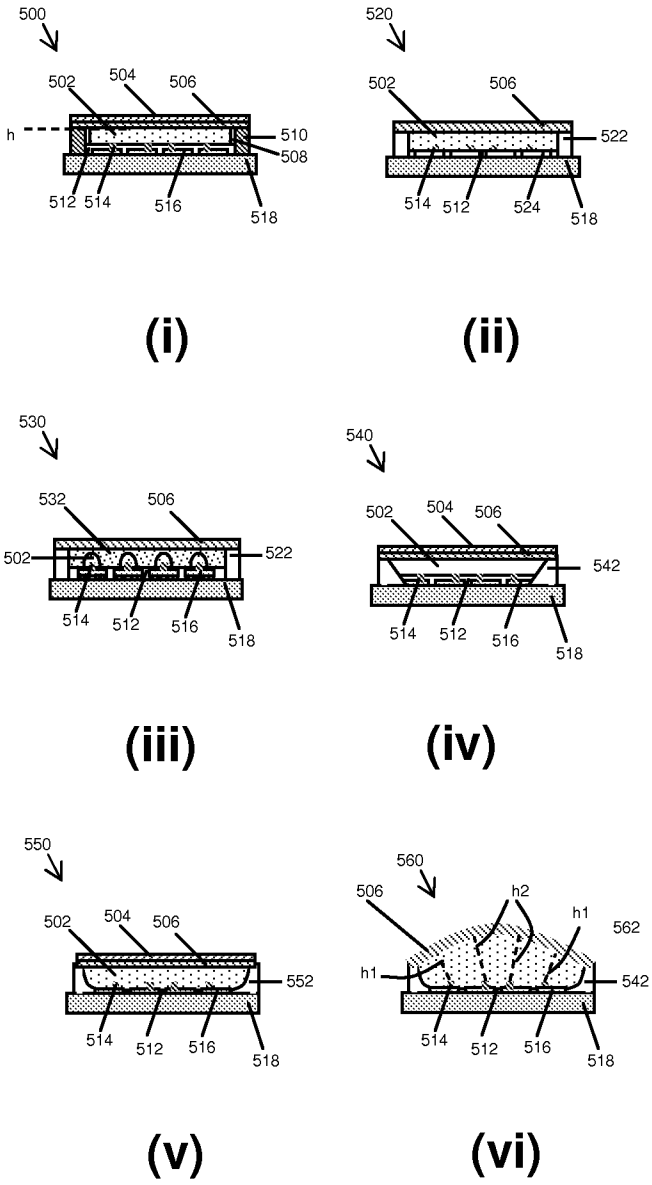

500
502
504
506
h
510
508
512
514
516
518
(i)
520
502
506
522
514
512
524
518
(ii)
530
532
506
502
522
514
512
516
518
(iii)
540
502
504
506
542
514
512
516
518
(iv)
550
502
504
506
552
514
512
516
518
(v)
560
506
h2
h1
562
h1
542
514
512
516
518
(vi)

Fig. 5a

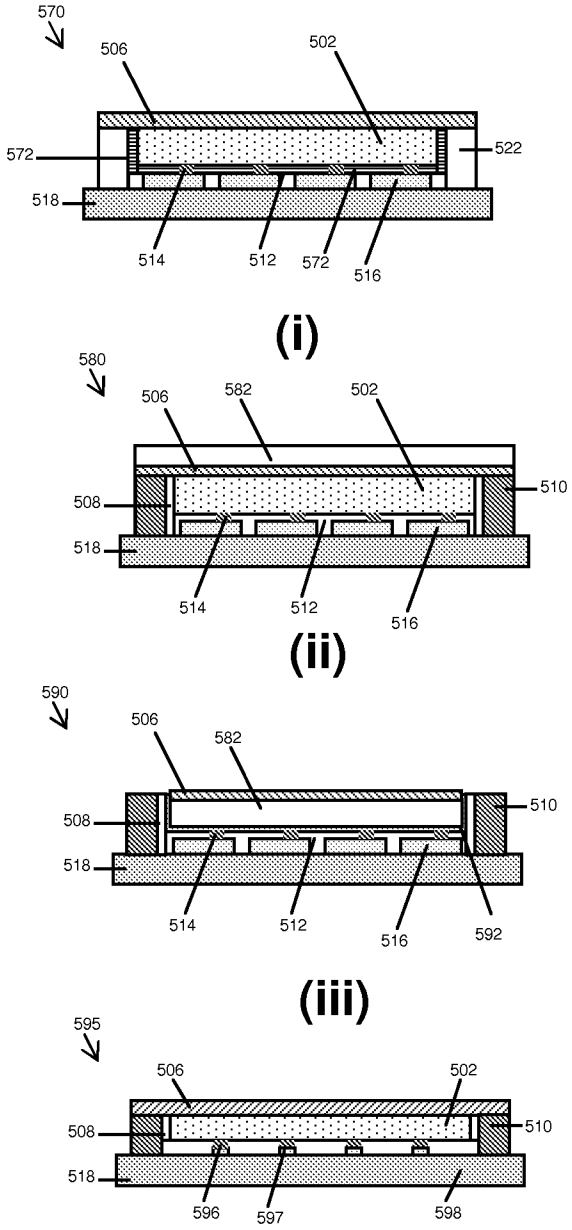

570
506
502
572
522
518
514
512
572
516
(i)
580
506
582
502
510
508
518
514
512
516
(ii)
590
506
582
510
508
518
514
512
516
592
(iii)
595
506
502
510
508
518
596
597
598
(iv)

Fig. 5b

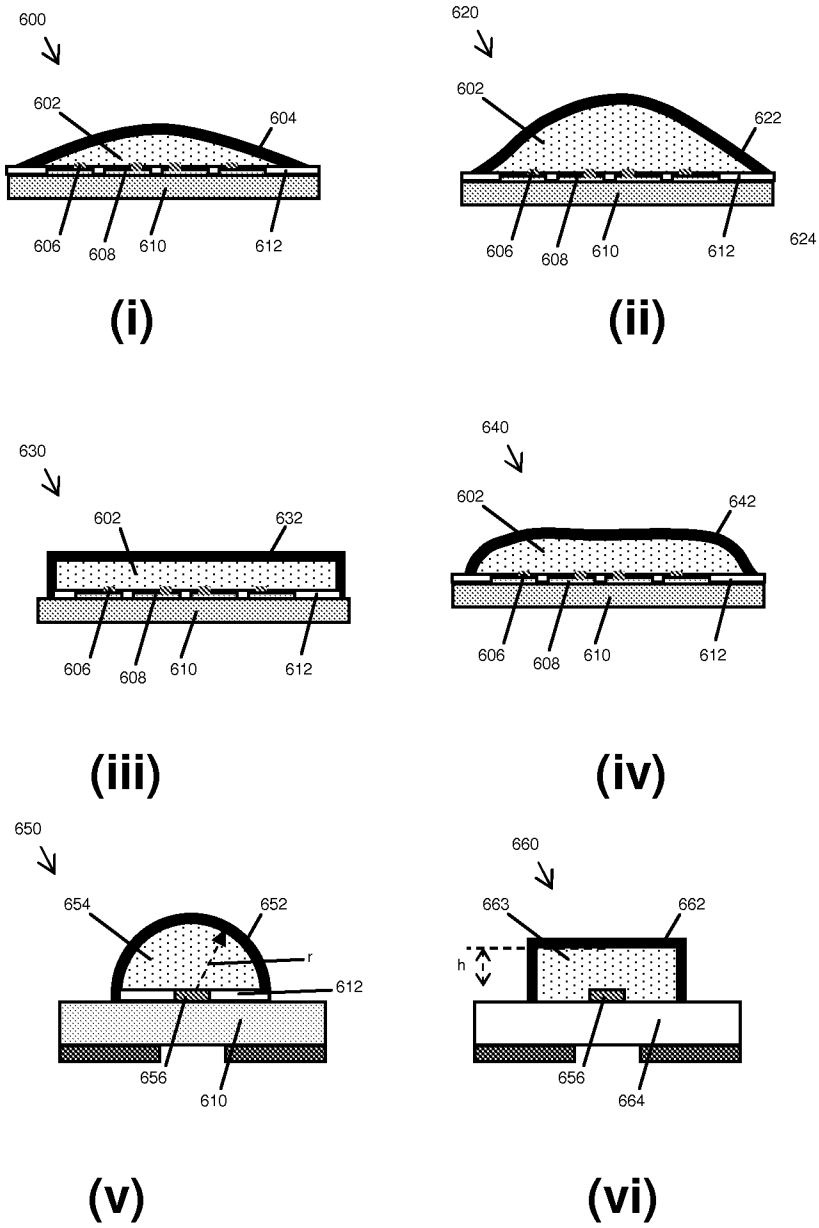

600
602
604
606
608
610
612
(i)
620
602
622
624
606
608
610
612
(ii)
630
602
632
606
608
610
612
(iii)
640
602
642
606
608
610
612
(iv)
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656
610
(v)
660
663
662
h
656
664
(vi)

Fig. 6

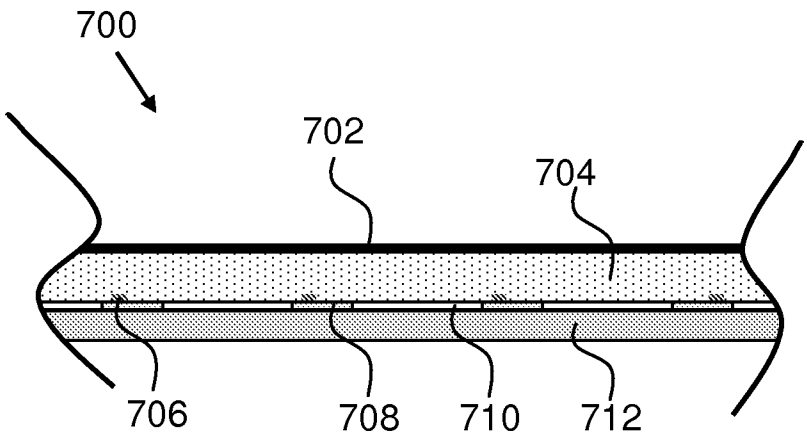


Fig. 7a

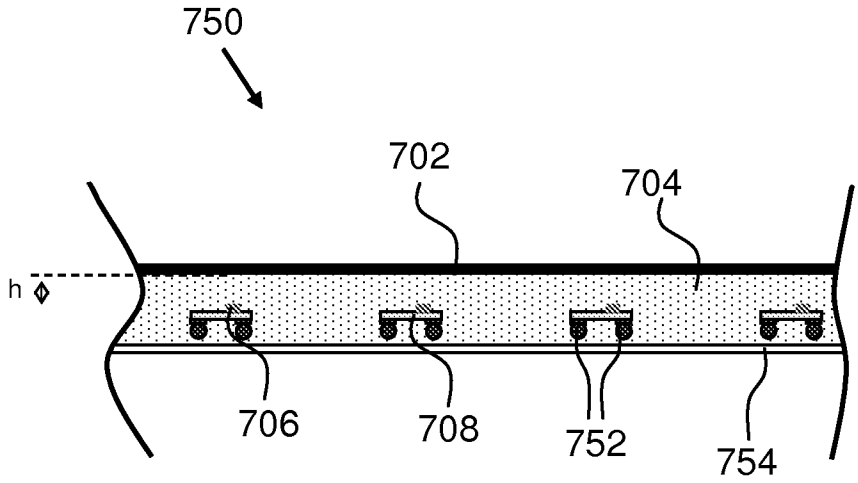


Fig. 7b

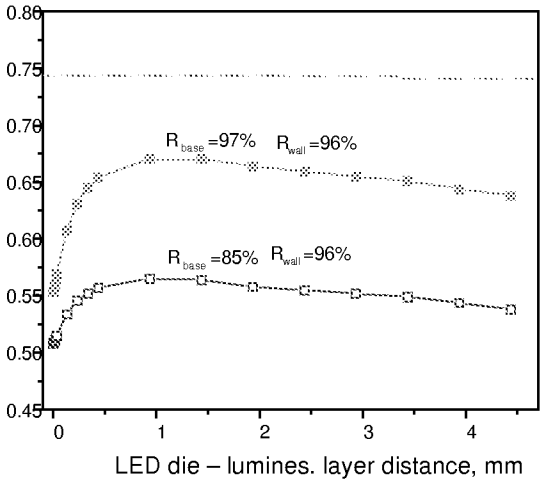

0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0
1
2
3
4
R base =97% R wall =96%
R base =85% R wall =96%
LED die – lumines. layer distance, mm

Fig. 8a

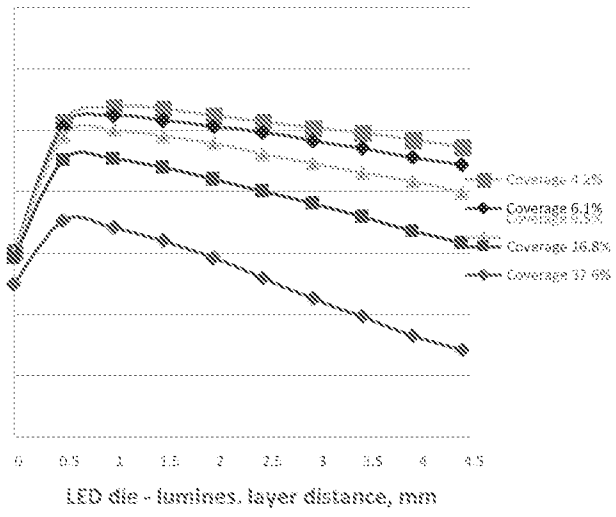

Coverage 4.2%
Coverage 6.1%
Coverage 16.8%
Coverage 37.6%
LED die - lumines. layer distance, mm

Fig. 8b

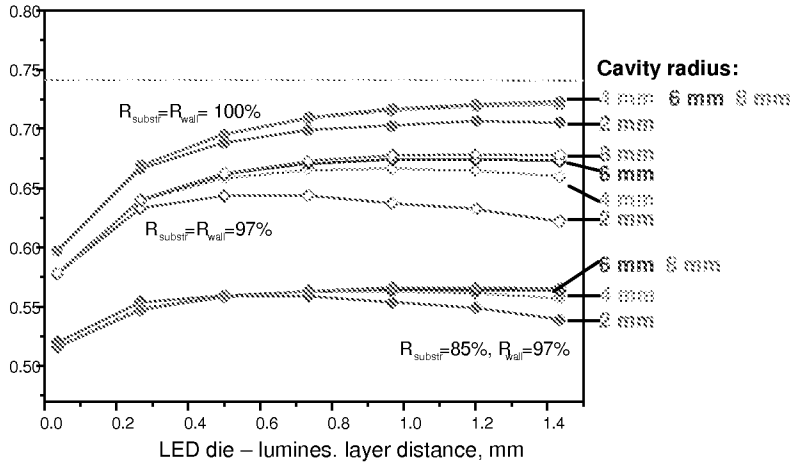

0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
LED die – lumines. layer distance, mm
Cavity radius:
6 mm
8 mm
$R_{substr}=R_{wall}$= 100%
$R_{substr}=R_{wall}$=97%
R_{substr}=85%, R_{wall}=97%

Fig. 9a

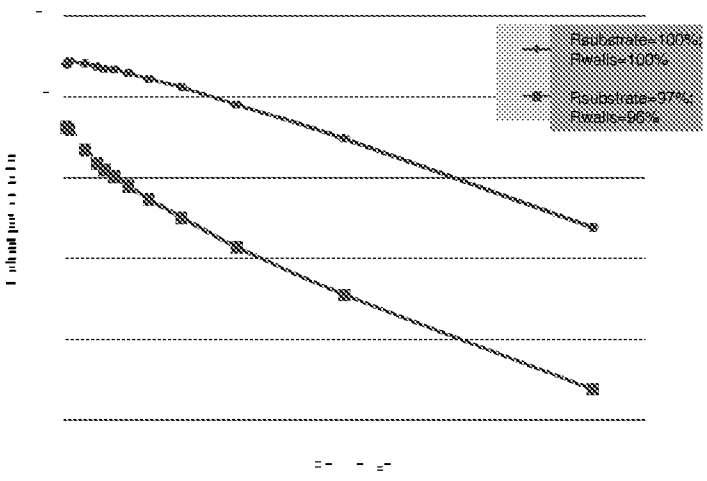

Rsubstrate=100%
Rwalls=100%
Rsubstrate=97%
Rwalls=95%

Fig. 9b

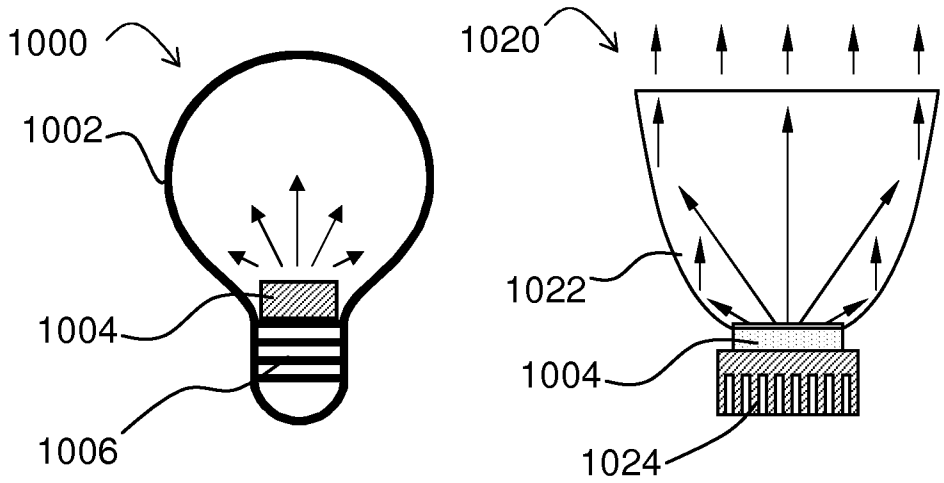


Fig. 10a

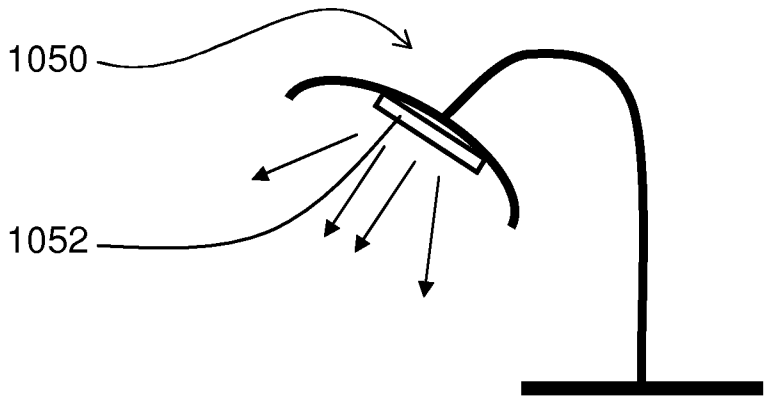


Fig. 10b

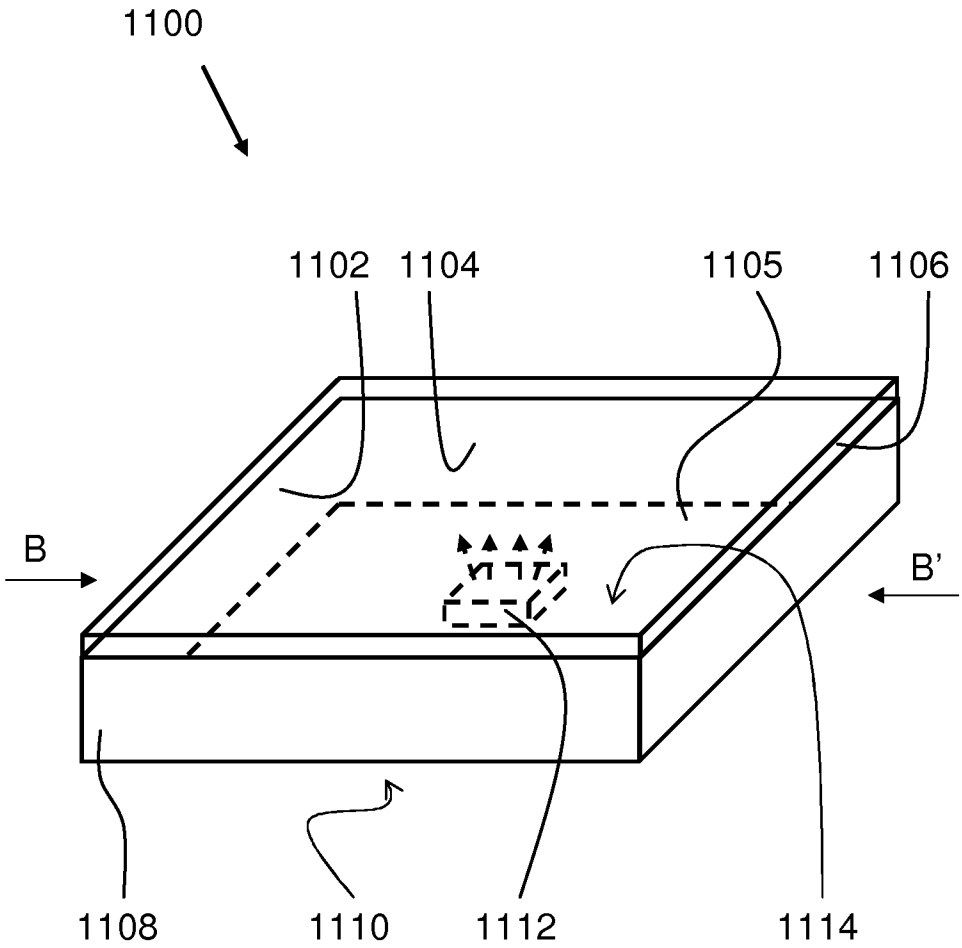


Fig. 11

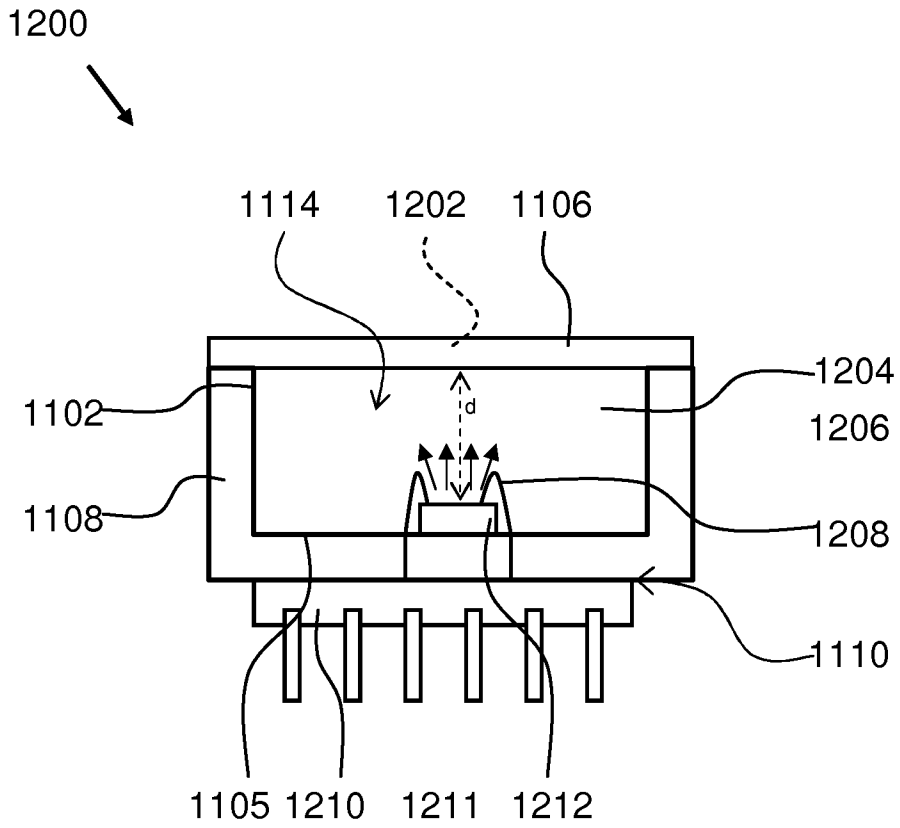

1200
1114
1202
1106
1204
1102
1206
d
1108
1208
1110
1105
1210
1211
1212

Fig. 12

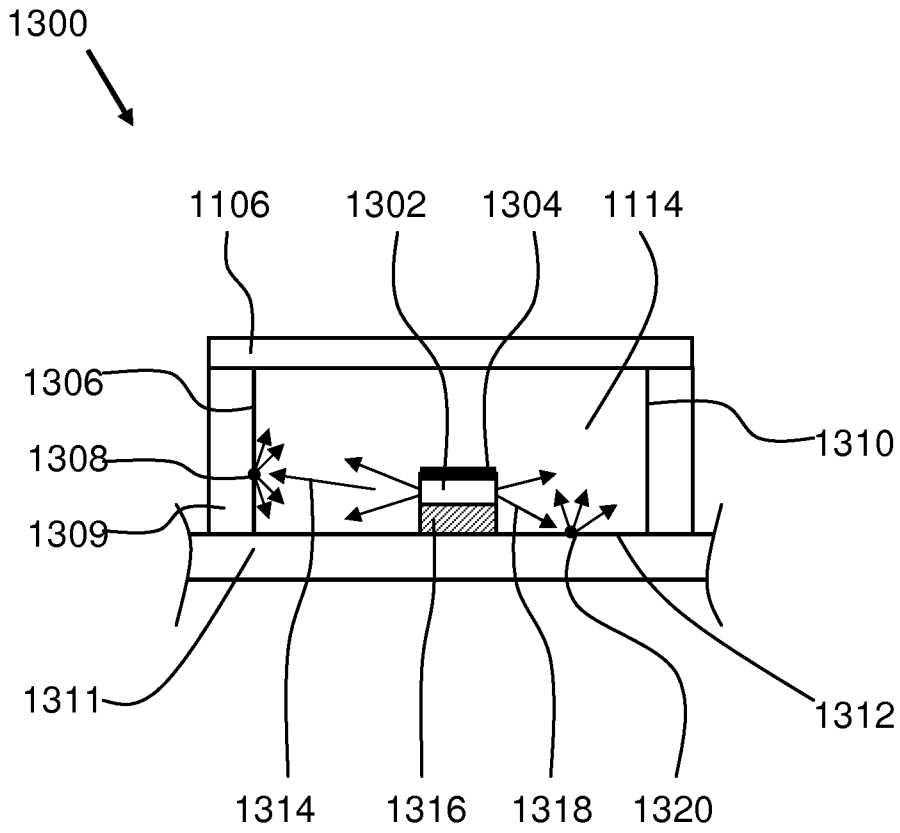

1300
1106
1302
1304
1114
1306
1308
1309
1310
1311
1312
1314
1316
1318
1320

Fig. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2011/050952

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L33/60 H01L33/50
ADD. H01L33/48 H01L33/64

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, COMPENDEX, INSPEC, IBM-TDB, 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 Y	EP 1 686 630 A2 (SAMSUNG ELECTRONICS CO LTD [KR]; RENSSELAER POLYTECH INST [US]) 2 August 2006 (2006-08-02) abstract; figures 2C,3,5C,5D,6,7 paragraphs [0003], [0004], [0007], [0014], [0020] - [0022] ----- -/--	1,3-8, 10-12, 14,15 2,8,13

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 July 2011	29/07/2011

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	Marani, Roberta

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2011/050952

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	LUO HONG ET AL: "Analysis of high-power packages for phosphor-based white-light-emitting diodes", APPLIED PHYSICS LETTERS, AIP, AMERICAN INSTITUTE OF PHYSICS, MELVILLE, NY, US, vol. 86, no. 24, 8 June 2005 (2005-06-08), pages 243505-243505, XP012065894, ISSN: 0003-6951, DOI: DOI:10.1063/1.1949282	1,3-6,8, 10-12, 14,15
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