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— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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(54) Title: THIN LED FLASH FOR CAMERA

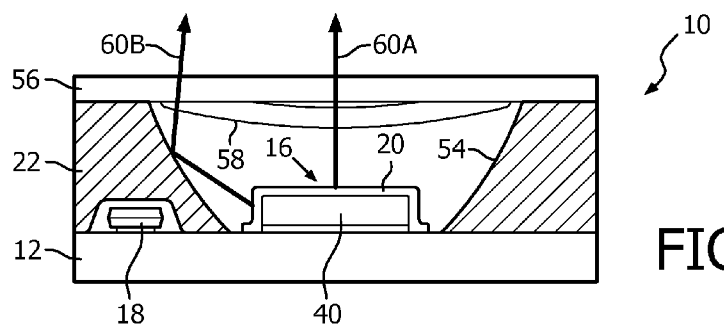

FIG. 3

(57) Abstract: A thin flash module for a camera uses a flexible circuit as a support surface. A blue GaN-based flip chip LED die is mounted on the flex circuit. The LED die has a thick transparent substrate forming a "top" exit window so at least 40% of the light emitted from the die is side light. A phosphor layer conformally coats the die and a top surface of the flex circuit. A stamped reflector having a knife edge rectangular opening surrounds the die. Curved surfaces extending from the opening reflect the light from the side surfaces to form a generally rectangular beam. A generally rectangular lens is affixed to the top of the reflector. The lens has a generally rectangular convex surface extending toward the die, wherein a beam of light emitted from the lens has a generally rectangular shape corresponding to an aspect ratio of the camera's field of view.

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THIN LED FLASH FOR CAMERA

FIELD OF THE INVENTION

This invention relates to packaged phosphor-converted light emitting diodes (pcLEDs) and, in particular, to a packaged pcLED that is useful as a flash for a camera.

BACKGROUND

In modern digital cameras, including smartphone cameras, it is common to provide a flash that uses a pcLED. A common flash is a GaN-based blue LED die mounted in a round reflective cup on a rigid printed circuit board. A layer of YAG phosphor (emits yellow-green) fills the cup. Since the LED die is very thin, almost all light is emitted from the top surface of the die. A circular Fresnel lens is then positioned over the cup to create a generally conical light emission pattern (having a circular cross-section) to illuminate a subject for the photograph. A cover plate, forming part of the camera body, typically has a circular opening for the lens.

Since the field of view of the camera is rectangular, much of the light emitted from the flash, having a circular cross-section, illuminates areas surrounding the subject and is wasted. Such unnecessary illumination may also be bothersome to those not in the picture.

Further, due to the shape of the cup and the phosphor in the cup, the phosphor is not uniform over the LED die, resulting in color non-uniformity vs. angle.

Further, due to the use of the rigid printed circuit board, the thinness of the flash module is limited.

Further, the lens must be spaced away from the top surface of the LED die by a certain minimum distance (e.g., the focal length) in order to properly redirect the light. This minimum distance significantly adds to the thickness of the flash module.

Further, there is substantial back-reflection from the lens back toward the cup and LED die.

Further, the bottom inner edge of the reflector cup facing the sides of the LED die has a thickness that is typically greater than the height of the LED semiconductor layers, so the inner edge of the cup blocks the side light or reflects it back into the LED die.

Further, since almost all light is emitted from the top surface of the LED die, the reflective cup has limited usefulness in shaping the beam, and the resulting beam is not very uniform across the field of view of the camera.

Further, since almost all light is emitted from the top surface of the LED die in a Lambertian pattern, the reflector cup has to have relative high walls to redirect and collimate the "angled" light emitted from the LED die. Any light rays that are not reflected (collimated) spread out at wide angles. The high walls of the reflector limit the minimum thickness of the flash module.

It is known to affix a lens over the LED die for a flash, where the lens has a cavity for the LED die, such as described in patent publication KR2012079665A. The lens has a rectangular top surface and curved side surfaces. However, a significant portion of the light escapes from the sides and is not reflected toward the subject. Also, the prior art lens is relatively thick, resulting in a thick flash module.

What is needed is a thin LED flash module for a camera that more uniformly and efficiently illuminates a subject.

SUMMARY

In one example of the inventive flash module for a camera, a blue flip-chip LED die has a relatively thick transparent substrate on its top surface. This causes a significant portion of the light emission to be from the sides of the LED die, such as 50% of the total light emission.

A conformal coating of phosphor is deposited over the top and side surfaces of the LED die to create a uniform white light.

The pcLED is mounted on a supporting substrate having a metal pattern for connection to the bottom anode and cathode electrodes of the LED die. The substrate has

bottom metal pads for bonding to a camera's printed circuit board. The substrate can be a very thin flex circuit or a rigid substrate such as ceramic.

A rectangular reflector, with rounded corners, is then mounted on the substrate surrounding the rectangular LED die. The rectangular reflector has curved walls for redirecting the side LED light into a generally pyramidal beam, having a rectangular cross-section, where the cross-section aspect ratio is similar to the standard aspect ratio of a camera's field of view. In one embodiment, the reflector is stamped aluminum, where the opening for the LED die has knife edges facing the sides of the LED die so virtually all side light is reflected upward rather than being blocked by the inner edges of the opening. Such a knife edge could not be achieved by a molded reflector cup.

A thin lens is affixed over the top of the reflector, where the lens has a convex side that faces toward the LED die, so the convex portion does not add thickness to the module. The lens not only protects the LED die but increases light extraction due to the convex portion receiving most of the light from the LED die and reflective walls at a substantially normal angle. In contrast to a prior art conventional Fresnel lens, having a flat surface facing the LED die, there is much less back-reflection.

Due to the high percentage of side light being reflected upward by the reflector, the effective optical distance between the lens and the LED die is the sum of the horizontal distance between a side of the LED die and a curved wall of the reflector plus the vertical distance between the curved wall and the lens. Therefore, the lens can be spaced a focal length from the LED die's sides while being much closer to the top surface of the LED die. This allows the flash module to be even thinner. The reflector walls can be more widely spaced from the LED die to further reduce the thinness of the module.

Since a large portion of the light emitted from the LED die is from its sides, the reflector walls can be made relatively shallow, further reducing the thinness of the module.

The convex shape of the lens toward the LED die and the closeness of the lens to the LED top surface cause the lens to intercept a wide angle of the Lambertian light emitted from the top surface of the LED die and slightly redirect it toward the center of the beam, if necessary, to further improve the uniformity of the beam. The convex shape is designed to optimize the uniformity of light across a desired portion of the generally rectangular beam. The lens is not used to significantly shape the beam (but primarily improves uniformity), since the shape of the beam is primarily controlled by the shape of the reflector, in contrast to the prior art.

Accordingly, due to the large percentage of the LED die light being side light and redirected by the rectangular reflector, and the reflected light being blended with the light emitted from the top surface of the LED die, a more uniform rectangular beam of light is emitted by the flash, which generally matches the aspect ratio (e.g., 4:3) of the camera's field of view. Further, the flash module can be made very thin.

Other embodiments are described.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an exploded view of a flash module in accordance with one embodiment of the invention.

Fig. 2 is a cross-sectional compressed view of an LED die, with a conformal phosphor coating, mounted on a flex circuit (or other supporting substrate) that may be used in the module of Fig. 1.

Fig. 3 is a cross-sectional view of the flash module of Fig. 1.

Fig. 4 is a top down view of the flash module of Fig. 1.

Fig. 5 is a bottom view of the flash module of Fig. 1 showing the electrode pattern and thermal pad.

Fig. 6 is a perspective bisected view of the flash module of Fig. 1.

Fig. 7 is a perspective view of the flash module of Fig. 1.

Fig. 8 is a cross-sectional view of an embodiment of the flash module using a flex substrate and identifying various dimensions in millimeters.

Fig. 9 is a back view of a smartphone illustrating the rectangular flash module and camera lens.

Elements that are the same or similar are labeled with the same numeral.

DETAILED DESCRIPTION

Fig. 1 is an exploded view of a flash module 10 in accordance with one embodiment of the invention. A support substrate 12 may be a rigid substrate or a very thin flexible circuit. Using a flexible circuit as the support substrate 12 allows the module 10 to be thinner.

A metal trace 14 pattern is formed on the substrate 12 to define metal pads 15 and 17 for the bottom anode and cathode electrodes of the flip chip LED die 16 and to define metal pads 19 and 21 for the electrodes of an optional transient voltage suppressor (TVS) chip 18.

The bare LED die 16, such as a GaN-based blue LED die, is then electrically and thermally connected to the substrate 12. The TVS chip 18 may also be electrically connected to the substrate 12.

Typically, the LED die 16 is a flip chip die, although other die types, including those with bonding wires, may be used. To minimize the thickness of the flash module 10, the LED die's bottom electrodes are directly bonded to the metal pads 15 and 17 of the metal trace 14. In another embodiment, the bare LED die 16 may be first mounted on a submount with more robust bottom metal pads to simplify handling and enable the LED die 16 to be conformally coated with a phosphor layer 20 after bonding to the submount. Fig. 1 shows an alternative embodiment where the phosphor layer 20 covers only the top surface of the LED die 16 .

If the bare LED die 16 is directly mounted on the substrate 12 (as shown in Fig. 2), the phosphor layer 20 may be deposited over the entire substrate 12 and LED die 16 to coat the top and side surfaces of the LED die 16. The phosphor layer 20 may be phosphor particles, such as YAG phosphor particles or red and green phosphor particles, infused in a silicone binder. The phosphor layer 20 may also serve as an adhesive layer for affixing a reflector 22 to the surface of the substrate 12. In the alternative, a separate adhesive may be used to affix the reflector 22.

Various details of the components in Fig. 1 are described with respect to Figs. 2-8.

Fig. 2 is a cross-sectional compressed view of the LED die 16 with the conformal phosphor layer 20. Although a flip-chip die is shown in the examples, the present invention is applicable to any type of LED die, including vertical LED dies, lateral LED dies, etc.

The LED die 16 includes a bottom anode electrode 23 bonded to the metal pad 15 (defined as a portion of the metal trace 14 of Fig. 1) and includes a bottom cathode electrode 25 bonded to the metal pad 17. The pads 15 and 17 are electrically connected by vias 30 and 31 to associated bottom pads 32 and 34, which may be used to solder the flash module 10 to a camera's printed circuit board. A thermal pad 36 is formed on the bottom surface of the substrate 12, which may be soldered to a heat sink in the printed circuit board.

The LED die 16 semiconductor layers are grown on a relatively thick sapphire substrate 40, which may be as thick as 1 mm. This is thicker than a typical growth substrate, since a manufacturer typically uses the thinnest growth substrate practical for reducing costs and maximizing the top emission. Frequently, in the prior art, the growth substrate is completely removed. The sapphire substrate 40 is much thicker than required for mechanically supporting the LED semiconductor layers. Other material for a growth substrate may instead be used. The top surface and growth surface of the growth substrate 40 may be roughened for increasing light extraction.

A typical width of the LED die 16 is on the order of 1 mm.

N-type layers 42 are epitaxially grown over the sapphire substrate 40, followed by an active layer 44, and p-type layers 46. A portions of the active layer 44 and p-type layers 46 are etched away to gain electrical contact to the n-type layers 42 by means of a via 48 leading to the cathode electrode.

The active layer 44 generates light having a peak wavelength. In the example, the peak wavelength is a blue wavelength, and the layers 42, 44, and 46 are GaN-based.

Alternatively, the growth substrate 40 may be removed and replaced by a transparent support substrate, such as glass, affixed to the semiconductor layers by an adhesive (e.g., silicone) or by other techniques.

By using a thick growth substrate 40 (or other transparent substrate), the light exiting the sides of the LED die 16 is made to be preferably about 50% of the total light emission, with 50% of the total light being emitted from the top surface of the LED die 16. In another embodiment, over 30% of all light emitted by the LED die 16 is from the sides, where the percentage of side light is based on the thickness of the substrate 40. The more side light, the more the reflected light from the reflector 22 is adding to the overall beam and the thinner the flash module can be.

In one embodiment, the thickness of the LED semiconductor layers is less than 100 microns (0.1 mm), and typically less than 20 microns, and the substrate 40 thickness is greater than 0.2 mm and up to 1 mm.

A portion of the blue light leaks through the phosphor layer 20, and the combination of the blue light and phosphor light creates white light for the flash. Since the phosphor layer 20 has a uniform thickness, the color emission will be substantially uniform vs. angle.

The reflector 22 (Fig. 1) is preferable formed by stamping an aluminum sheet. The stamp forms a rectangular opening 52 in the sheet and compresses the surrounding aluminum to form curved sidewalls 54. The term "rectangular," as used herein, includes a square, and includes rectangles with rounded corners. The edges of the opening 52 are knife edges (less than 50 microns thick) to limit any back reflection of the light emitted from the sides of the LED die 16/phosphor. Typically, the opening 52 and curved sidewalls 54 have the same aspect ratio as the camera's field of view, such as 4:3, so the resulting beam will resemble the 4:3 aspect ratio.

The reflector 22 is then coated with a silver layer for high reflectivity, such as by plating, evaporation, sputtering, etc.

The footprint of the reflector 22 may be approximately that of the substrate 12 to minimize the size of the flash module 10. The reflector 22 is then affixed to the substrate 12 using the phosphor layer 20 (containing silicone) as an adhesive. The reflector 22 adds rigidity to the module 10. The phosphor layer 20 is then cured.

A preformed polycarbonate lens 56 is then affixed to the top surface of the reflector 22, such as by silicone. The silicone is then cured to complete the flash module 10. Typically, the lens 56 is rectangular with rounded edges to receive the generally rectangular emission from the reflector 22 and LED die 16.

As shown by the cross-sectional view of the module 10 in Fig. 3, the lens 56 has a flat top surface and a bottom surface. A portion of the bottom surface is a convex surface 58 that faces the LED die 16. Thus, the convex surface does not add to the thickness of the module 10. Typically, the convex surface 58 is rectangular or rectangular with rounded corners, as shown in Fig. 1.

In prior art flash modules using LED dies that generate little side light, the lens had to be spaced relatively far from the top surface of the LED die to properly redirect the light. In one embodiment of present invention, around 40-50% of the light is emitted from the sides of the LED die 16, and the effective optical distance from the LED die 16 to the lens 56 is the sum of the generally horizontal distance from an LED die side to a reflector wall 54 plus the generally vertical distance from the reflector wall 54 to the lens 58. Accordingly, to make the module 10 even thinner, the reflector walls 54 can be further spaced from the LED die 16 while retaining the same effective optical distance between the sides and the lens 58. The lens 56 is designed to improve the uniformity of light across a central portion of the rectangular beam.

In one embodiment, the effective optical distance between the sides of the LED die 16 and the lens 58 is approximately the focal length of the lens 58.

Dry air (or other gas) fills the gap between the lens 56 and the LED die 16 to obtain a large difference in the indices of refraction at the interface of the lens 56 and the gap to achieve the desired refraction by the lens 56.

Fig. 3 shows two sample light rays 60A and 60B. Rays, such as 60A, from the top center surface of the LED die 16 are not substantially redirected by the lens 56. Reflected rays, such as ray 60B, that impinge the convex surface 58 at an angle are slightly redirected toward the center axis to improve the uniformity of the beam across at least a central portion of the 4:3 aspect ratio. The shape of the beam is primarily defined by the shape of the reflector 22, since the reflector 22 reflects virtually all side light and some angled light from the top surface of the LED die 16.

Fig. 3 also shows that the aluminum sheet for forming the reflector 22 is stamped to have a bottom cavity for the TVS chip 18.

By using the phosphor layer 20 (a dielectric) as an adhesive for the aluminum reflector 22, the bottom of the metal reflector 22 does not short out the metal traces 14, and there is no separate step for depositing an adhesive. In another embodiment, the reflector 22 is formed to have a thin dielectric layer on its bottom surface before being mounted on the substrate 12.

Fig. 4 is a top down view of the module 10 of Fig. 3.

Fig. 5 is a bottom view of the module 10 showing the cathode and anode bottom pads 32 and 34, and the thermal pad 36, also shown in Fig. 2.

Fig. 6 is a perspective bisected view of the flash module 10. The phosphor layer 20 over the sides of the LED die 16 is not shown.

Fig. 7 is a perspective view of the flash module 10 of Fig. 1.

Fig. 8 is a cross-sectional view of an embodiment of the flash module 10 using a flex substrate 12 and identifying various dimensions in millimeters. Although the LED die 16 is about 1.0 mm in width, the height of the lens 56 above the top surface of the LED die 16 is only about 0.3 mm, since the optimal separation is based on the travel path of the side light to the lens 56 when being reflected off the reflector 22.

The flex substrate 12 only adds 0.05 mm to the thickness of the module 10. The phosphor layer 20 is shown as being 0.05 mm thick. The reflector 22 is shown as being 0.750 mm thick, and the lens 56 is shown as adding only 0.1 mm to the module 10. The growth substrate 40 (Fig. 2) may be about 0.25-0.5 mm thick. The total height of the flash module 10 of Fig. 8 is less than 1 mm. It is envisioned that all practical flash modules of the invention, using a flex circuit, can be formed to have thicknesses less than 2 mm.

Note that the top surface area of the LED die 16 is about 1 mm^2 and the combined area of the four sides of the LED die, using a 0.5 mm thick substrate 40, is about 2mm^2. For a substrate 40 thickness of 0.25 mm, the side area equals the top surface area. So there is substantial side emission.

Fig. 9 is a back view of a smartphone 66, illustrating the rectangular flash module 10 and camera lens 68.

Accordingly, the present invention reduces the thickness of a flash module, improves the color uniformity across the beam, and increases the efficiency of the flash by creating a generally rectangular beam with a substantially uniform intensity across the relevant portion of the beam and by incurring less reflection of the LED light back toward the LED die.

The present invention may be used for other applications besides camera flashes, such as a flashlight module.

While particular embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from this invention in its broader aspects and, therefore, the appended claims are to encompass within their scope all such changes and modifications as fall within the true spirit and scope of this invention.

CLAIMS

What is claimed is:

1. A light emitting device comprising:

a support structure;

a light emitting diode (LED) die mounted on the support structure,

the LED die having a top surface and side surfaces, the LED die comprising LED semiconductor layers and a transparent substrate, the substrate having a top surface, wherein the side surfaces comprise a combination of sides of the LED semiconductor layers and sides of the substrate, the substrate being thicker than the LED semiconductor layers, wherein light emitted from the side surfaces is at least 30% of all light emitted by the LED;

a phosphor layer covering the top surface and side surfaces;

a reflector surrounding the LED die, the reflector having curved surfaces surrounding the LED die, wherein the curved surfaces extend from a generally rectangular opening for the LED die and reflect the light from the side surfaces of the LED die to form a generally rectangular beam; and

a generally rectangular lens affixed to walls of the reflector, the lens having a generally rectangular convex surface extending toward the LED die, wherein a beam of light emitted from the lens has a generally rectangular shape.

2. The device of Claim 1 wherein the device is a flash for a camera.

3. The device of Claim 2 wherein an aspect ratio of the beam is substantially the same as an aspect ratio of a field of view of the camera.

4. The device of Claim 1 wherein the support structure is a flexible circuit.

5. The device of Claim 1 wherein the reflector comprises a stamped metal reflector, where the opening has a knife edge facing the LED die.

6. The device of Claim 1 wherein the lens has a focal length and wherein a distance from a side of the LED die, taken normal to the side of the LED die, to the reflector plus a distance from the reflector to the lens is approximately the focal length.

7. The device of Claim 1 wherein light from the side surfaces is at least 40% of all light emitted by the LED die.

8. The device of Claim 1 wherein light from the side surfaces is at least 50% of all light emitted by the LED die.

9. The device of Claim 1 wherein the substrate is a growth substrate for the LED semiconductor layers.

10. The device of Claim 1 wherein the LED die is a flip chip.

11. The device of Claim 1 wherein the phosphor layer conformally coats the top surface and side surfaces and has substantially uniform thickness.

12. The device of Claim 1 wherein the phosphor layer comprises phosphor particles infused in a binder, wherein the phosphor layer covers a portion of a top surface of the support structure, and wherein a bottom surface of the reflector is affixed to the support structure by the binder acting as an adhesive.

13. The device of Claim 1 wherein a footprint of the reflector is substantially the same as a footprint of the support structure.

14. The device of Claim 1 wherein a total height of the device is less than 1 mm.

15. The device of Claim 1 wherein a total height of the device is less than 2 mm.

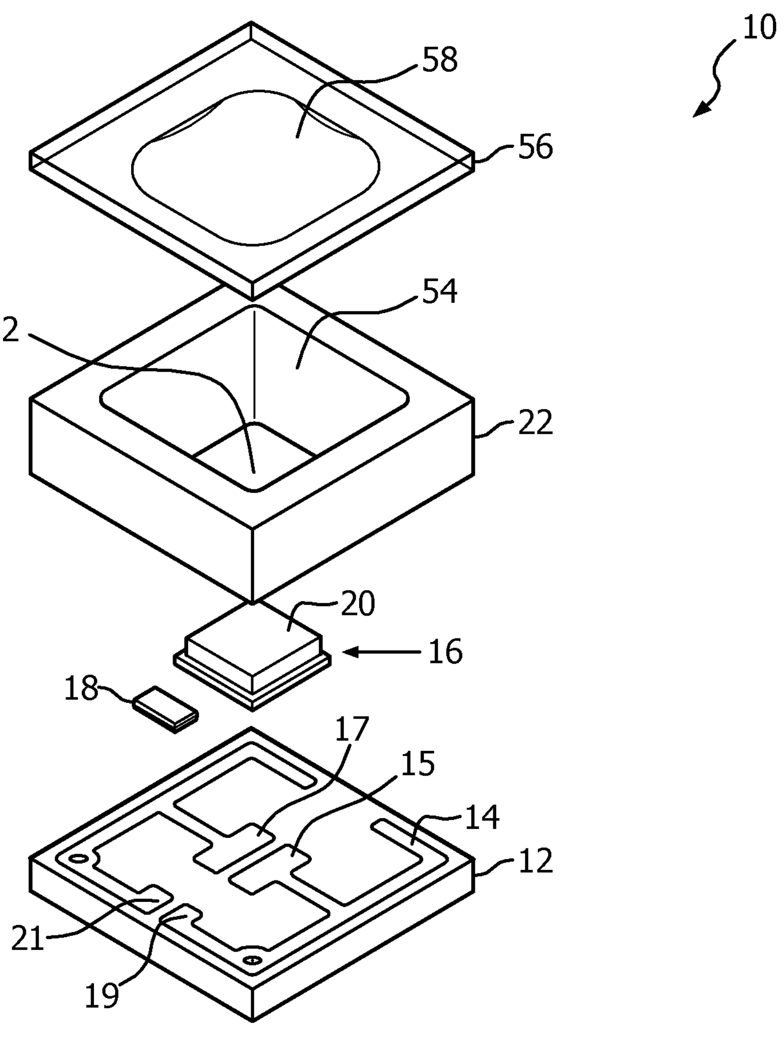

FIG. 1

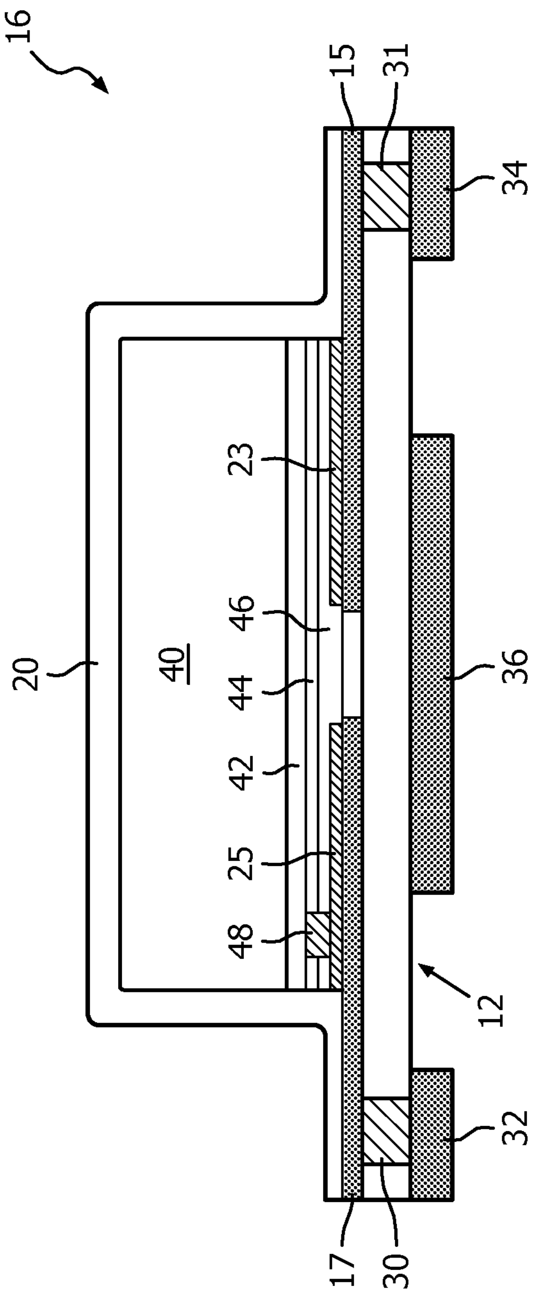

FIG. 2

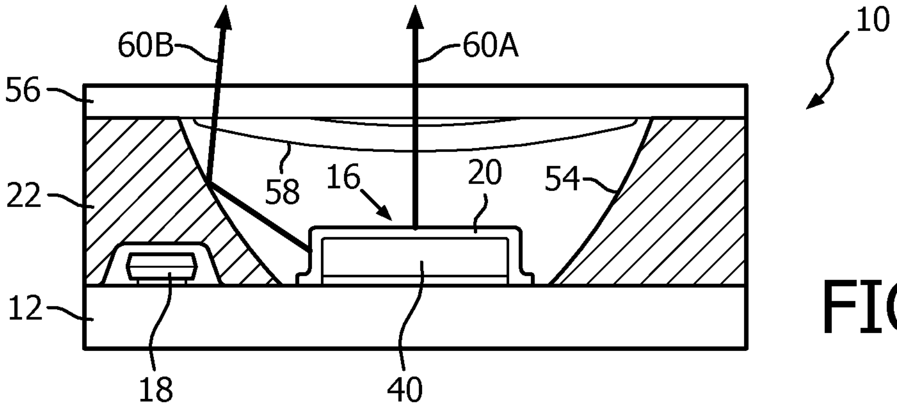

FIG. 3

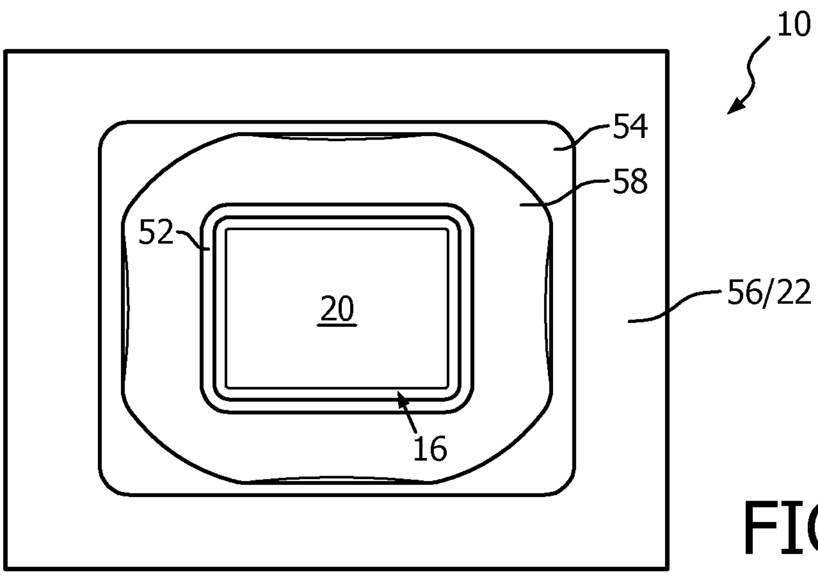

FIG. 4

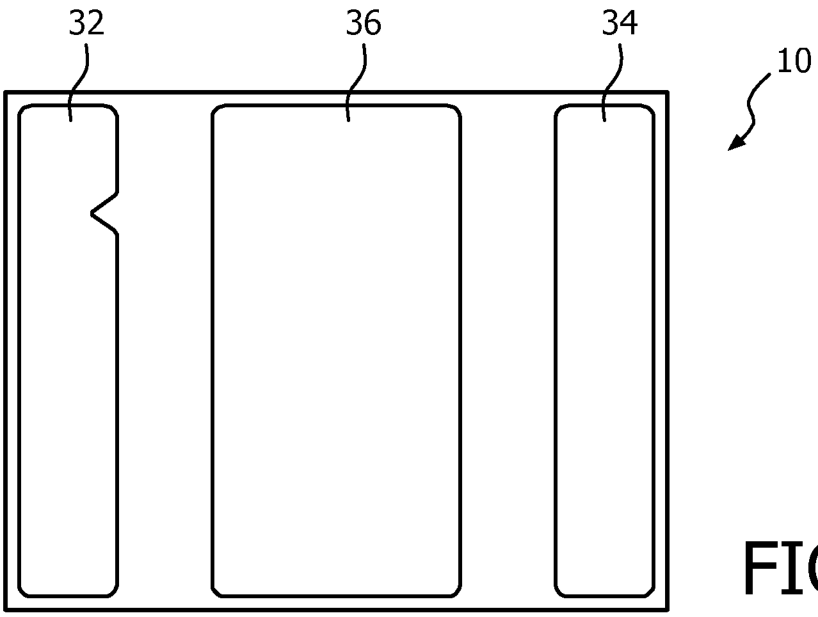

FIG. 5

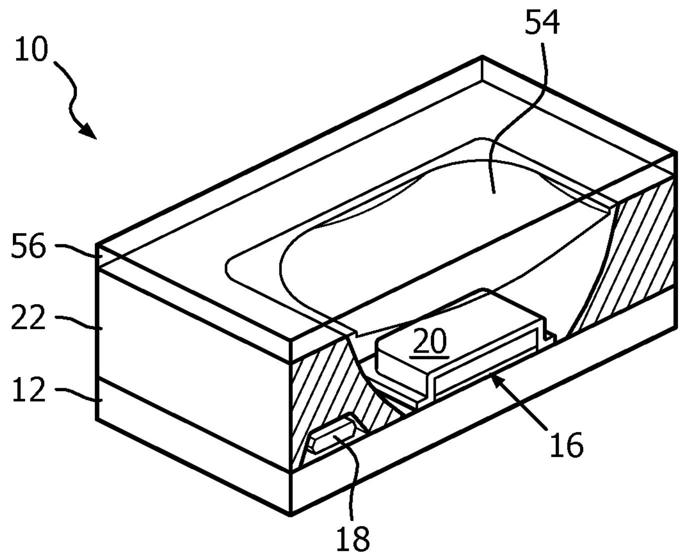

FIG. 6

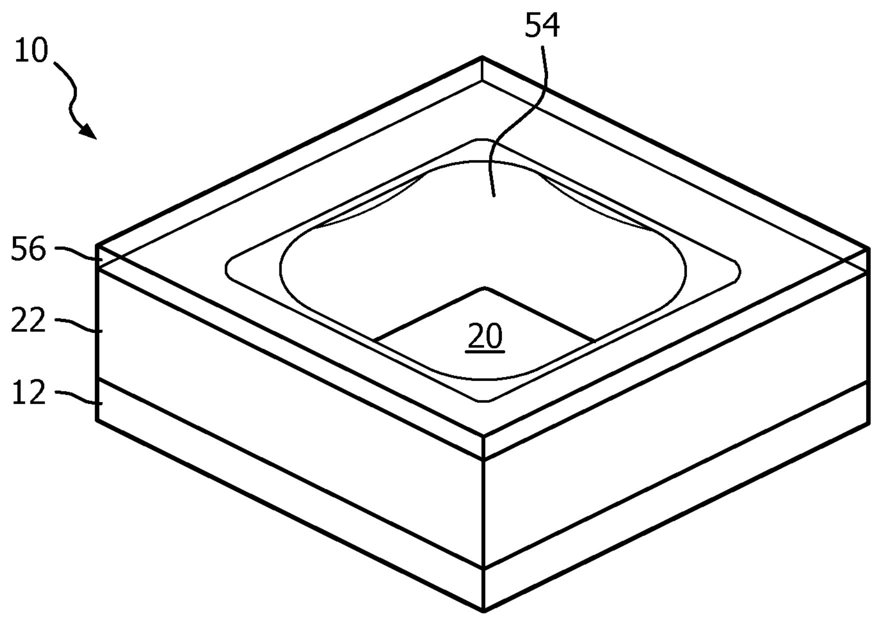

FIG. 7

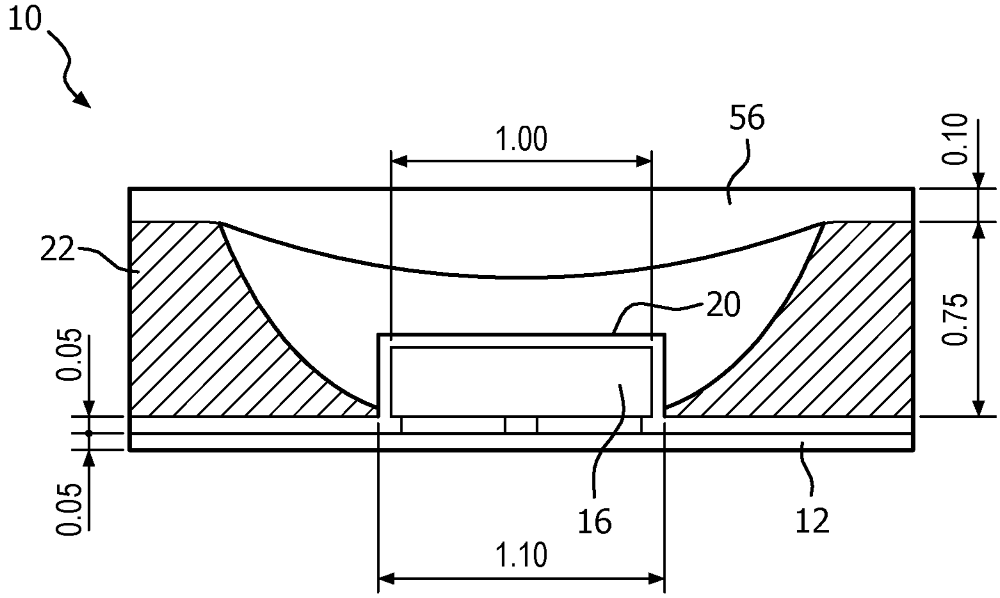

FIG. 8

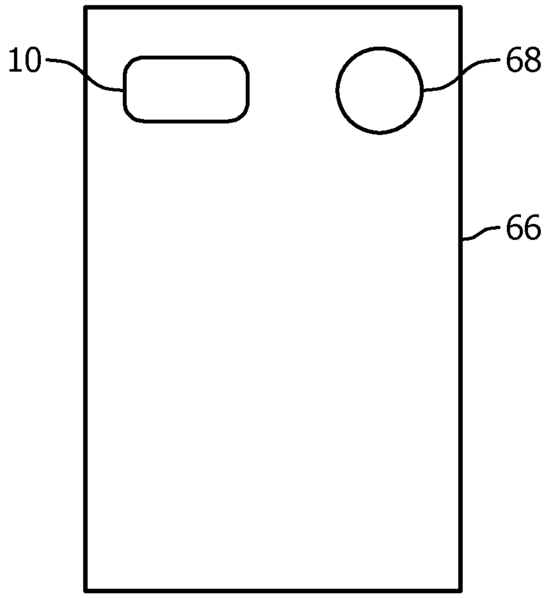

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2014/067204

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L33/58 H01L33/60
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G03B G02B H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, 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	US 2013/148348 A1 (STREPPEL ULRICH [DE]) 13 June 2013 (2013-06-13) paragraphs [0013], [0036], [0067], [0068] figures 3A-C -----	1-4,6-13 5,14,15
X	EP 1 467 417 A2 (CITIZEN ELECTRONICS [JP]) 13 October 2004 (2004-10-13) paragraphs [0039], [0040] figure 8 -----	1
Y	WO 2007/141763 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]; PHILIPS LUMILEDS LIGHTING CO [US]) 13 December 2007 (2007-12-13) page 9, lines 20-24 figure 12 -----	5,14,15

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

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
20 March 2015	27/03/2015

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	Adams, Richard

INTERNATIONAL SEARCH REPORT

Information on patent family members

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