



(51) International Patent Classification:

H01L 33/50 (2010.01) H01L 33/44 (2010.01)
H01L 33/20 (2010.01) H01L 33/54 (2010.01)
H01L 33/22 (2010.01)

(21) International Application Number:

PCT/EP2019/082118

(22) International Filing Date:

21 November 2019 (21.11.2019)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

16/199,755 26 November 2018 (26.11.2018) US

(71) Applicant: **OSRAM OPTO SEMICONDUCTORS GMBH** [DE/DE]; Leibnizstr. 4, 93055 Regensburg (DE).

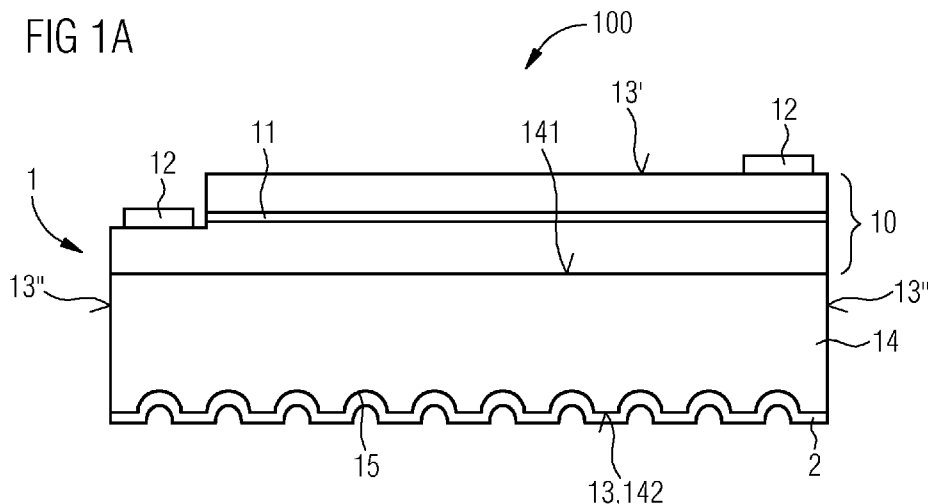
(72) Inventors: **ANC, Maria J.**; 6 Byfield Road, Groveland, Massachusetts 01834 (US). **KUNDALIYA, Darsan**; 7 Lewis Drive, Middleton, Massachusetts 01949 (US). **RAUKAS, Madis**; 29 Downing Road, Lexington, Massachusetts 02421 (US). **O'BRIEN, David**; 5446 NW Bannister Drive, Portland, Oregon 97229 (US).

(74) Agent: **EPING HERMANN FISCHER PATENTANWALTSGESELLSCHAFT MBH**; Schloßschmidstr. 5, 80639 München (DE).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(54) Title: LIGHT-EMITTING DEVICE AND METHOD FOR MANUFACTURING A LIGHT-EMITTING DEVICE



(57) Abstract: A light-emitting device is described, the light-emitting device comprising a light-emitting semiconductor chip having a semiconductor layer sequence comprising at least one light-emitting semiconductor layer and a light-outcoupling surface, and a wavelength conversion layer arranged on the light-outcoupling surface, wherein the wavelength conversion layer comprises quantum dots. Furthermore, a method for manufacturing a light-emitting device is described.

Published:

— *with international search report (Art. 21(3))*

Description

LIGHT-EMITTING DEVICE AND METHOD FOR MANUFACTURING A LIGHT-
EMITTING DEVICE

5

This patent application claims the priority of the US patent application 16/199,755, the disclosure content of which is hereby included by reference.

10 Embodiments of the present invention are related to a light-emitting device and to a method for manufacturing a light-emitting device. In particular, the light-emitting device can have a wavelength conversion layer. The wavelength conversion layer can preferably comprise or substantially consist of
15 quantum dots (QDs).

Quantum dots are narrow-band emitters which are used for wavelength conversion. They can offer benefits of color quality and conversion efficiency for instance in
20 backlighting and solid-state lighting (SSL) applications. Quantum dots are suitable for such applications by providing not only specific optical properties but also a potential for cost-efficient manufacturing. QDs have a broad absorption spectrum in a wavelength range that usually goes from ultra-
25 violet wavelengths up to the first excitonic peak. They are non-scattering and efficient. The peak emission wavelength of QDs can be tuned within just a few nanometers.

Contemporary colloidal QDs in dispersions usually exhibit a
30 high efficiency of typically more than 80% or even more than 90% in large volumes in non-polar solvents and between about 70% and 80% in optimized polymer composites. In colloidal dispersions QDs are usually coated with organic ligands,

passivating the surface, preventing agglomeration and enabling their miscibility with host materials. However, the nature of these ligands affects the feasibility of formulating the QD composites as well as their performance in applications. At present, QD/polymer composites are employed in back lighting and SSL applications as the remote color correcting films. The properties of the QD/polymer composites are satisfactory for such applications where the operation temperature does not exceed 100°C. For applications where the converter may reach temperatures greater than 100°C, other forms of QD films need to be made. According to the state of the art, QD formulations and host materials are used which exhibit greater thermal conductivity and heat endurance.

Typically, optical components with QDs are being fabricated as free standing parts with the application-specific form factor. They may comprise compositions of the QDs with polymers, hybrid organic/inorganic substances, and may also form dense assemblies on a supporting substrate. To prevent degradation of the QD properties in the ambient atmosphere, these components need to be encapsulated. Challenges for the design and fabrication of QD converters intended to work at elevated temperatures originate from the necessity of eliminating organic host materials. In such cases, free standing QD assemblies having the form of densely-packed films or compositions of QDs with inorganic fillers may be applicable. However, the free standing QD parts have to be attached to the light-source in a package, which, in connection with a volume production, introduces fabrication process complexity and increases the costs.

An object of at least one embodiment is to provide a light-emitting device. Another object of at least one embodiment is

- 3 -

to provide a method for manufacturing a light-emitting device.

These objects are, inter alia, achieved with a device and a
5 method according to the independent claims. Further embodiments and configurations are subject matter of the dependent claims.

According to at least one embodiment, a light-emitting device
10 comprises a light-emitting semiconductor chip and a wavelength conversion layer.

According to at least one further embodiment, in a method for manufacturing a light-emitting device, a light-emitting
15 semiconductor chip is provided or produced, and a wavelength conversion layer is arranged on the light-emitting semiconductor chip.

The features and embodiments described herein relate to both
20 the light-emitting device and the method for manufacturing the light-emitting device, respectively.

According to a further embodiment, the light-emitting semiconductor chip has a semiconductor layer sequence. The
25 semiconductor layer sequence comprises at least one light-emitting semiconductor layer. The at least one light-emitting semiconductor layer forms an active region for generating light, so when the light-emitting semiconductor chip is operated, light is produced in the light-emitting
30 semiconductor layer. The light-emitting semiconductor chip further comprises a light-outcoupling surface, via which the light that is produced in the active region is coupled out of the light-emitting semiconductor chip. The wavelength

conversion layer is preferably arranged on the light-outcoupling surface.

The semiconductor layer sequence can be grown particularly preferably on a substrate, which can be denoted as the growth substrate, by means of an epitaxy technique, for instance by means of metalorganic vapor phase epitaxy (MOVPE) or molecular beam epitaxy (MBE). The semiconductor layer sequence as a result comprises semiconductor layers that are arranged one above the other along an arrangement direction given by the growth direction, which can also be denoted as the vertical direction. The layers of the semiconductor layer sequence have a main extension plane that is perpendicular to the arrangement direction. Directions parallel to the main extension plane of the semiconductor layers and thus perpendicular to the vertical direction can be referred to as lateral directions.

The light-emitting semiconductor chip in particular comprises two main surfaces, which are disposed perpendicular to the growth direction. One of the main surfaces is embodied as the light-outcoupling surface, via which the light that is generated during operation of the light-emitting semiconductor chip is emitted. In addition, the light-emitting semiconductor chip comprises a rear face, which is on the opposite side from the light-outcoupling surface and forms the second main surface of the light-emitting semiconductor chip. The light-outcoupling surface and the rear face are connected together via side faces. In addition to light being emitted by the light-outcoupling surface, at least some of the light generated in the light-emitting semiconductor layer during operation may also be emitted via a side face and/or the rear face.

The light-emitting semiconductor chip can have a semiconductor layer sequence based on different semiconductor material systems depending on the light to be generated. A semiconductor layer sequence based on $\text{In}_x\text{Ga}_y\text{Al}_{1-x-y}\text{As}$, for instance, is suitable for a long-wavelength infrared to red emission, a semiconductor layer sequence based on $\text{In}_x\text{Ga}_y\text{Al}_{1-x-y}\text{P}$, for instance, is suitable for red to yellow radiation, and a semiconductor layer sequence based on $\text{In}_x\text{Ga}_y\text{Al}_{1-x-y}\text{N}$, for instance, is suitable for short-wavelength visible radiation, i.e. in particular for green to blue radiation, and/or for UV radiation, where $0 \leq x \leq 1$ and $0 \leq y \leq 1$ in each case. In addition, a semiconductor layer sequence based on an antimonide, for example InSb , GaSb , AlSb or a combination thereof, can be suitable for long-wavelength infrared radiation.

The substrate, in particular in the case of a substrate which is a growth substrate, can comprise or can be an insulating material or a semiconductor material, for instance an aforementioned compound semiconductor material system. In particular, the growth substrate can comprise or be made of sapphire, GaAs , GaP , GaN , InP , SiC , Si and/or Ge .

The growth process can take place in particular in a wafer-based process. In other words, a growth substrate is provided in the form of a wafer, on which the semiconductor layer sequence is grown over a large area. The grown semiconductor layer sequence can be singulated into individual light-emitting semiconductor chips in a further method step, in which the side faces of the light-emitting semiconductor chips can be formed by the singulation. The wavelength conversion layer can preferably be applied before the singulation takes place. In other words, the wavelength

conversion layer can be applied also in a wafer-based process. Alternatively, the wavelength conversion layer can be applied on an already singulated light-emitting semiconductor chip.

5

In addition, the semiconductor layer sequence can be transferred to a carrier substrate prior to singulation, and the growth substrate can be thinned, i.e. removed at least in part or entirely. The carrier substrate can comprise or be
10 made of an electrically insulating or electrically conducting material, for instance a substrate material described above.

The semiconductor layer sequence of the light-emitting semiconductor chip can comprise for instance a conventional
15 p-n junction, a double heterostructure, a single quantum well structure (SQW structure) or a multi-quantum well structure (MQW structure) as the light-emitting semiconductor layer. In addition to the at least one light-emitting semiconductor layer, the semiconductor layer sequence can include further
20 functional layers and functional regions, for instance p-type and n-type charge carrier transport layers, undoped or p-type or n-type confinement, cladding or waveguide layers, barrier layers, planarization layers, buffer layers, protective layers and/or electrodes, and combinations thereof. In
25 particular, for making electrical contact on the light-outcoupling surface and on the rear face, the light-emitting semiconductor chip can comprise for each case an electrical contact element, for instance in the form of an electrode layer which covers a large surface area or a small surface
30 area or which can be a patterned electrode layer. It is also possible that all electrical contacts are provided on a same side of the light-emitting semiconductor chip, for instance on the light-outcoupling surface or on the rear surface. In

particular, the light-emitting semiconductor chip can be embodied as a so-called volume emitter or as a flip-chip, in both cases preferably comprising a semiconductor layer sequence grown on a sapphire substrate, or as a so-called
5 thin-film semiconductor chip, preferably comprising a carrier substrate onto which the semiconductor layer sequence has been transferred after the growth process and preferably further having a thinned or even completely removed growth substrate.

10

The structures described here relating to the light-emitting semiconductor chip as well as the light-emitting semiconductor layer and the further functional layers and regions, in particular the design, function and construction
15 thereof, are known to a person skilled in the art and therefore are not described in greater detail here.

According to a further embodiment, the wavelength conversion layer comprises quantum dots (QDs). As described above, there
20 are benefits of color performance provided by the QDs, in particular a narrow-band emission with a fine-tunable peak position, a broad absorption spectrum and no inherent scattering.

25 According to a further embodiment, the wavelength conversion layer is free of an organic matrix material. In particular, the wavelength conversion layer can substantially consist of the quantum dots. In other words, the wavelength conversion layer is not formed as a composite comprising a matrix
30 material or filler material such as a polymer or other organic materials, which are typically used in the prior art. In contrast, the wavelength conversion layer of the light-emitting device is preferably embodied as an assembly of the

QDs, which are deposited on a surface of the light-emitting semiconductor chip, so that the wavelength conversion layer is formed by the deposition process. Consequently, the wavelength conversion layer is not a free standing component as usually used in the art, but is a part of the light-emitting device that is integrated in the light-emitting device and that cannot be removed without being destroyed. In particular, the QDs are arranged next to each other and/or on top of each other by the deposition process, thereby forming the wavelength conversion layer. The wavelength conversion layer can be deposited preferably by at least one method chosen from drop-casting, inkjet printing, layer transfer. Furthermore, the wavelength conversion layer can be deposited directly on a surface of the light-emitting semiconductor chip, in particular directly on the light-outcoupling surface, so that at least some of the QDs of the wavelength conversion layer can be in direct contact with the light-outcoupling surface of the light-emitting semiconductor chip.

Furthermore, an interlayer can be arranged on a surface of the light-emitting semiconductor chip, in particular on the light-outcoupling surface and preferably directly on the light-outcoupling surface, and the wavelength conversion layer can be deposited on the interlayer, in particular directly on the interlayer. The interlayer can comprise or consist of a transparent material and/or a wavelength conversion material. The wavelength conversion material, which can be different from QDs, can be suitable for converting at least some of the light emitted by the light-emitting semiconductor chip into light of a different wavelength. Preferably, when irradiated with the light of the light-emitting semiconductor chip, the wavelength conversion material of the interlayer can emit light with a wavelength

that is different from the wavelength of the light that is emitted by the wavelength conversion layer. In particular, the interlayer can comprise a ceramic wavelength conversion material, which for instance can be provided as a ceramic layer or as particles dispersed in a matrix material. The wavelength conversion material of the interlayer can comprise for example a material from the group of the garnets, for example yttrium aluminum garnet (YAG) and/or lutetium aluminum garnet (LuAG), and, in particular, doped garnets as for instance Ce-doped garnets. By combining the light-emitting semiconductor chip, the wavelength conversion layer with the QDs and the interlayer with the wavelength conversion material, the light-emitting device can be for instance a white-light-emitting device with an integrated QD layer. The interlayer, preferably comprising or consisting of a wavelength conversion material, can in particular be deposited on the light-outcoupling surface by a pulsed laser deposition (PLD) process.

According to a further embodiment, a surface structure is provided on the light-outcoupling surface and the wavelength conversion layer is deposited directly on the surface structure. The surface structure can comprise indentations like pits and/or crevices and/or grooves as well as elevations like tips and/or peaks and/or dam-like structures. Preferably, the light-outcoupling surface can be provided with the surface structure. In this case, the wavelength conversion layer is deposited directly on the surface structure of the light-outcoupling surface. In the case of an interlayer, preferably an interlayer comprising or consisting of a wavelength conversion material, the interlayer has a surface that is remote from the light-outcoupling surface and that can have the surface structure. In this case, the

wavelength conversion layer is directly deposited on the surface structure of the interlayer.

5 The wavelength conversion layer can be a conformal coating of the surface structure. In other words, the wavelength conversion layer can cover the surface structure in such way that the structure of the wavelength conversion layer on the side remote from the surface structure at least partly resembles the surface structure and thus is at least partly
10 similar to the surface structure. Furthermore, the wavelength conversion layer can at least partly planarize the surface structure by at least partly filling indentations of the surface structure.

15 According to a further embodiment, the light-emitting semiconductor chip comprises a substrate with a first main surface and a second main surface, which are opposite to each other, wherein the semiconductor layer sequence is arranged on the first main surface and the wavelength conversion layer
20 is arranged on the second main surface. In a preferred embodiment, the second main surface is the light-outcoupling surface. The second main surface can have the surface structure. Alternatively, an interlayer as described above is arranged on the light-outcoupling surface formed by the
25 second main surface. Furthermore, the first main surface of the substrate can have a further surface structure and the semiconductor layer sequence is grown on the further surface structure.

30 According to a further embodiment, the substrate with the first main surface is provided and the semiconductor layer sequence is arranged, preferably grown, on the first main surface. In particular, the semiconductor layer sequence is

grown on the substrate in a wafer-based process as described above. Afterwards, the wavelength conversion layer is deposited on the second main surface, which can be the light-outcoupling surface.

5

In cases where the second main surface of the substrate has a surface structure, onto which the wavelength conversion layer is deposited, the surface structure is produced in the second main surface, so that the second main surface is provided
10 with the surface structure before or after the semiconductor layer sequence is arranged on the first main surface.

For instance, the surface structure is provided in the second main surface before the semiconductor layer sequence is
15 arranged on the first main surface. In this case, it can be preferable that the substrate is arranged with the second main surface and thus with the surface structure on a temporary carrier before the semiconductor layer sequence is arranged on the first main surface. The temporary carrier can
20 be removed after the arrangement of the semiconductor layer sequence on the first main surface, thereby exposing the surface structure on the second main surface. Alternatively, the surface structure can be provided on the second main surface after the semiconductor layer sequence is arranged on
25 the first main surface. In this case, it can be preferable that the substrate is thinned before the surface structure is provided in the second main surface and after the semiconductor layer sequence is arranged on the first main surface. By means of the thinning process the second surface
30 can be produced.

According to a further embodiment, the light-outcoupling surface is a surface of the semiconductor layer sequence, in

particular of an outermost semiconductor layer of the semiconductor layer sequence. In this case, the outermost semiconductor layer can have the surface structure.

Alternatively, an interlayer as described above can be
5 arranged on the outermost semiconductor layer.

According to a further embodiment, an encapsulation layer is arranged on the wavelength conversion layer. Preferably, the encapsulation layer is transparent and can be arranged
10 directly on the wavelength conversion layer. This can in particular mean that the encapsulation layer is arranged in direct contact with at least some of the QDs of the wavelength conversion layer. The encapsulation layer can comprise or consist of one or more layers which are
15 responsible for a barrier effect of the encapsulation layer. The one or more layers can comprise one or more inorganic and/or organic materials. Inorganic materials can be applied, for example, by means of atomic layer deposition (ALD), sputtering or plasma-enhanced chemical vapor deposition
20 (PECVD). Suitable inorganic materials can be, for example, transparent inorganic materials such as aluminum oxide, zinc oxide, zirconium oxide, titanium oxide, hafnium oxide, lanthanum oxide, silicon nitride, silicon oxide, silicon oxynitride, silicon carbide, indium tin oxide, indium zinc
25 oxide, aluminum-doped zinc oxide, and mixtures and alloys thereof. Suitable organic materials can be, for example, transparent polymers containing siloxanes, epoxides, imides, carbonates, acrylates and mixtures and combinations thereof. Preferably, the encapsulation layer has a layer sequence
30 having a plurality of layers, for instance a plurality of only inorganic layers or a plurality of inorganic and organic layers, which are alternately arranged on top of each other.

Further features, advantages and expediencies will become apparent from the following description of exemplary embodiments in conjunction with the Figures.

- 5 Figures 1A to 1C show schematic illustrations of a light-emitting device according to an embodiment,
Figures 2A and 2B show electron microscope images of a wavelength conversion layer of light-emitting devices according to further embodiments,
- 10 Figures 3A to 3D show schematic illustrations of method steps of a method for manufacturing a light-emitting device according to a further embodiment,
Figures 4A to 4C show schematic illustrations of method steps of a method for manufacturing a light-emitting device
- 15 according to a further embodiment,
Figures 5 to 7 show schematic illustrations of light-emitting devices according to further embodiments.

In the Figures, elements of the same design and/or function are identified by the same reference numerals. It is to be understood that the embodiments shown in the Figures are illustrative representations and are not necessarily drawn to scale.

25 In the following, specific details are set forth, such as specific features and advantageous effects of a light-emitting device and of a method for manufacturing a light-emitting device, in order to provide a thorough understanding of embodiments of the invention. It will be apparent to one

30 skilled in the art that embodiments of the invention may be practiced without these specific details.

Figure 1A shows a schematic illustration of a light-emitting device 100 according to an embodiment. Figures 1B and 1C show details of the light-emitting device 100 of Figure 1A. The following description equally applies to Figures 1A to 1C.

5

The light-emitting device 100 comprises a light-emitting semiconductor chip 1. The light-emitting semiconductor chip 1 has a semiconductor layer sequence 10 comprising at least one light-emitting semiconductor layer 11 which emits light during the operation of the light-emitting semiconductor chip 1. By means of electrical contacts in the form of electrode layers 12 an electrical current can be applied to the light-emitting semiconductor layer 11 for operating the light-emitting semiconductor chip 1. For instance, the semiconductor layer sequence 10 can be based on InAlGaN and can be configured to produce ultraviolet, blue or green light. Alternatively, the semiconductor layer sequence 10 can be based on another semiconductor material as described in the general part.

20

The light generated in the light-emitting semiconductor layer 11 during operation of the light-emitting semiconductor chip 1 is emitted from the chip 1 via a light-outcoupling surface 13. Opposite the light-outcoupling surface 13, the semiconductor chip 1 has a rear-side surface 13'. The light-outcoupling surface 13 and the rear-side surface 13' are connected to one another by means of side surfaces 13''. The light generated during operation can also be emitted through the side surfaces 13'' and/or through parts of the rear-side surface 13' in addition to the light-outcoupling surface 13.

30

On the light-outcoupling surface 13, a wavelength conversion layer 2 is arranged, which comprises quantum dots (QDs) 20.

Light emitted by the light-emitting semiconductor layer 11 can be absorbed by the QDs 20 and converted to light with a different wavelength. Accordingly, the light produced by the light-emitting semiconductor layer 11 can also be denoted as pump light for the QDs 20. The wavelength conversion layer 2 with the QDs 20 is integrated into the light-emitting semiconductor device 100 as described in further detail below.

Furthermore, the light-emitting semiconductor chip 1 has a substrate 14, which can be a growth substrate or a carrier substrate. The substrate 14 has a first main surface 141 and a second main surface 142. The semiconductor layer sequence 10 is arranged on the first main surface 141, while the second main surface 142 is the light-outcoupling surface 13. In the shown embodiment, the substrate 14 is a growth substrate, onto which the semiconductor layer sequence 10 is grown. The electrode layers 12 can be arranged on the same side of the semiconductor layer sequence 10 which is the rear-side surface 13', so that, by way of example, the light-emitting semiconductor chip 1 is formed as a so-called flip-chip.

On the second main surface 142 of the substrate, and thus on the light-outcoupling surface 13, the light-emitting semiconductor chip 1 has a surface structure 15, onto which the wavelength conversion layer 2 is directly applied. Since in the shown embodiment the second main surface 142 is the light-outcoupling surface 13 and has the surface structure 15, the wavelength conversion layer 2 is applied directly on the light-outcoupling surface 13. Preferably, the surface structure has structure sizes in the order of micrometers.

- 16 -

As shown in the detailed view in Figure 1B, the substrate 14 can have a further surface structure 16 on the first main surface 141. Preferably, the further surface structure is in the order of micrometers. In particular, the first main surface 141 can be a substantially flat and two-dimensionally designed surface, on which a plurality of three-dimensionally designed surface elements is arranged, which project out of the plane formed by the flat surface. The three-dimensionally designed surface elements are formed as elevations, which extend upwards away from the flat surface. The surface elements can be round and in particular circular when viewed along the vertical direction, and therefore the surface elements can be designed as conical elevations. Alternatively, the further surface structure 16 can comprise surface elements which have an angular, for example a hexagonal cross-section when viewed along the vertical direction, and therefore the surface elements can also be designed as pyramidal elevations on the flat surface. Alternatively, the surface elements can be designed as indentations projecting from the flat surface into the substrate 14. Similarly to the previously described elevations, the indentations can, for example, be conical or pyramidal.

In the shown embodiment, the substrate 14 can comprise or be made of sapphire, i.e. aluminum oxide. In particular, the substrate 14 can be designed as a sapphire wafer, on which the semiconductor layer sequence 10 is grown in a large-scale manner. The separation of the wafer with the grown semiconductor layer sequence allows a plurality of light-emitting semiconductor chips to be produced. The flat surface of the first main surface 141 is preferably formed by a crystallographic c surface or (-c) surface of the aluminum

oxide, which is particularly suitable for growing nitride-based semiconductor materials. Accordingly, the surfaces of the surface elements of the further surface structure 16 are formed by a plurality of other crystal surfaces in compliance with their orientation relative to the flat surface.

Alternatively to the embodiment shown, the substrate 14 can, for example, also comprise a first main surface 141 formed by silicon or silicon carbide and can be correspondingly designed, for example, as a silicon wafer or a silicon carbide wafer. Furthermore, another possibility is that the substrate 14 comprises or consists of another material stated in the general section above. Moreover, the first main surface 141 can be embodied without the further surface structure 16.

The wavelength conversion layer 2 can be preferably deposited on the surface structure 15 by a method chosen from drop-casting, inkjet printing, layer transfer. The QDs 20 can be dispersed in a solvent, which can be hexane or chloroform or other non-polar solvents, and the dispersion can be deposited on the surface. Afterwards, the solvent can be evaporated so that substantially only the QDs 20 remain on the surface. As shown in the detailed view in Figure 1C, the wavelength conversion layer 2 substantially consists of the QDs 20 and is free of an organic matrix material or other filler material. Accordingly, the wavelength conversion layer 2 is not formed as a composite having a matrix material or filler material such as polymer or other organic materials. Rather, the wavelength conversion layer 2 is formed by an assembly of the QDs 20, wherein the wavelength conversion layer 2 is formed by the deposition process. Consequently, the wavelength conversion layer 2 is not a free standing component as usually used in the art, but is an integrated

part of the light-emitting device 1 that cannot be removed without being destroyed.

Due to the surface structure 15, a coffee-stain-like effect
5 can be avoided during the evaporation of the solvent, so that a homogeneous covering of the light-outcoupling surface 13 with the QDs 20 can be achieved. The wavelength conversion layer 2 thus forms a conformal coating of the surface structure 15. In other words, the wavelength conversion layer
10 2 covers the surface structure 15 in such way that the structure of the wavelength conversion layer 2 on the side remote from the surface structure 15 at least partly resembles the surface structure 15. It is also possible that the wavelength conversion layer 2 can at least partly
15 planarize the surface structure.

As shown in Figures 1A and 1C, the surface with the surface structure 15 can be a substantially flat and two-
dimensionally designed surface, on which a plurality of
20 three-dimensionally designed surface elements is arranged, which project out of the plane formed by the flat surface or project from the flat surface into the element with the surface structure 15. Thus, the surface elements can for instance be elevations in the form of tips and/or peaks or
25 indentations in the form of pits and/or crevices and/or grooves. When viewed along the vertical direction, the surface elements can have a polygonal or round cross-section. In the shown embodiment, the surface structure 15 comprises half-sphere-shaped crevices. Figure 2A shows an SEM (scanning
30 electron microscope) image of a surface structure with the crevices arranged in a hexagonal order. Figure 2B shows an SEM image of another surface structure with peaks arranged in a hexagonal order. In both cases, it can be clearly seen that

the surface structure is conformally covered by the wavelength conversion layer substantially consisting of the QDs.

5 Since the wavelength conversion layer 2 with the QDs 20 is deposited directly on the surface structure 15 on the light-outcoupling surface 13, which in the case of the embodiment of Figures 1A to 1C is a surface of the substrate 14, the light-emitting semiconductor chip 1 provides a mechanically
10 solid, thermally well conductive carrier for holding the QDs 20 in close vicinity to the light-emitting semiconductor layer 11 that generates the pump light. This arrangement improves upon previously known free standing QD solutions requiring a substrate made from (porous) ceramic, glass or
15 other materials for supporting the QDs. The integrated arrangement of the QDs 20 allows for an on-chip QD converter, which is superior in terms of a decreased light loss due to reduced scattering and provides a high conversion efficiency. In particular, the wavelength conversion layer can be
20 embodied in such way that a full conversion is possible, i.e. that substantially all light emitted by the light-emitting semiconductor layer towards the wavelength conversion layer is converted by the QDs. Furthermore, it provides superior thermal properties with the possibility of active cooling of
25 the entire structure.

Figures 3A to 3D show method steps of a method for manufacturing the light-emitting device 100 according to the embodiment of Figures 1A to 1C. As shown in Figure 3A, in a
30 first step a substrate 14 is provided, which has a first main surface 141 with the further surface structure 16 as explained in connection with Figures 1A to 1C. Alternatively, the substrate 14 can also be provided with a flat first main

surface 141 without the further surface structure 16. In particular, the substrate 14 can be provided as a substrate wafer so that the following method steps can be performed in a wafer-based process. The substrate 14, which can be, for instance, a sapphire substrate as explained above, is a growth substrate, on which the semiconductor layer sequence 10 is grown as shown in Figure 3B. The semiconductor layer sequence 10 has a light-emitting semiconductor layer and can be provided with electrode layers 12 as explained above.

Since the substrate 14 provided as a growth substrate wafer has a thickness that is much bigger than the desired substrate thickness in the final light-emitting semiconductor chip, the substrate 14 is thinned in a further method step in order to reduce the substrate thickness, as shown in Figure 3C. The thinning can be done for instance by etching or grinding. Typically, the thickness of the substrate 14 is reduced to about 150 μm . Alternatively, the final substrate thickness can be greater or smaller, depending on the desired properties of the substrate. Afterwards or in connection with the thinning process, the surface structure 15 is produced on the side of the substrate 14 remote from the first main surface 141, thereby forming the second main surface 142 with the surface structure 15, as shown in Figure 3D. The surface structure 15 can be formed for instance by an etching process. As described above, the second main surface 142 of the substrate 14 forms the light-outcoupling surface 13.

In a further method step the wavelength conversion layer with QDs is then applied to the light-outcoupling surface 13 and the wafer is singulated so that a plurality of light-emitting devices 100 as shown in Figures 1A to 1C is produced.

Figures 4A to 4C show method steps of a method for manufacturing the light-emitting device 100 of Figures 1A to 1C according to a further embodiment. The substrate 14 is provided with a first main surface 141 and a second main surface 142, wherein the second main surface 142 is provided with the surface structure 15 and the first main surface 141 is provided with the further surface structure 16.

Alternatively, the substrate 14 can be provided also with a flat first main surface 141 without the further surface structure 16. Consequently, in contrast to the embodiment of Figures 3A to 3D, the substrate 14 is provided as a wafer with two structured main surfaces and a thickness which corresponds to the desired final substrate thickness in the light-emitting device. Since that thickness is usually too small for a sufficient stability in the following process steps, the substrate 14 is mounted with the second main surface 142 on a temporary carrier 91 by means of a connection layer 92, which can for instance be an adhesive. The assembly formed by the temporary carrier 91 and the substrate 14 has a thickness which can be typically much more than about 150 μm and provides a sufficient stability.

As shown in Figure 4B, the semiconductor layer sequence 10 and the electrode layers 12 are deposited on the first main surface 141 as explained above. Afterwards, as shown in Figure 4C, the temporary carrier 91 and the connection layer 92 are removed by a lift-off process to release the substrate 14 with the chip layers deposited thereon from the temporary carrier 91. As described above, the now uncovered second main surface 142 of the substrate 14 forms the light-outcoupling surface 13. In a further method step the wavelength conversion layer with QDs is applied to the light-outcoupling

surface 13 and the wafer is singulated into a plurality of light-emitting devices 100 as shown in Figures 1A to 1C.

In the following Figures further embodiments of the light-emitting device 100 are shown, which are modifications of the previously described embodiments. The following description therefore mainly concentrates on the difference to the foregoing embodiments.

10 In Figure 5 a further embodiment of the light-emitting device 100 is shown, which has an interlayer 3 that is arranged on a surface of the light-emitting semiconductor chip 1. In particular, the interlayer 3 is arranged on, preferably directly on the light-outcoupling surface 13. The interlayer
15 3 can be deposited for example by a pulsed laser deposition (PLD) process or can be glued to the second main surface 142. As shown in Figure 5, the light-outcoupling surface 13, which is the second main surface 142 of the substrate 14 in the present embodiment, can be flat and without a surface
20 structure. Alternatively, the light-outcoupling surface 13 can have a surface structure and the interlayer 3 can be deposited directly on the surface structure of the light-outcoupling surface 13.

25 The wavelength conversion layer 2 is deposited on the interlayer 3, preferably directly on the interlayer 3. The interlayer 3 has a surface that is remote from the light-outcoupling surface 13 and that has a surface structure 15. As shown, the wavelength conversion layer 2 is directly
30 deposited on the surface structure 15 of the interlayer 3. The surface structure 15 can be embodied as described above.

Preferably, the interlayer 3 comprises or consists of a wavelength conversion material. The wavelength conversion material, which can be different from QDs, can be suitable for converting at least some of the light emitted by the light-emitting semiconductor chip 1 into light with a different wavelength, which can be also different from the wavelength of the light that is emitted by the wavelength conversion layer 2. For instance, the interlayer 3 can comprise a ceramic wavelength conversion material, which can be in the form of a ceramic layer or in the form of particles dispersed in a matrix material. The wavelength conversion material of the interlayer 3 can comprise for example YAG and/or LuAG or another garnet, and can be doped for instance with Ce. The combination of the light-emitting semiconductor chip 1, the wavelength conversion layer 2 with the QDs and the interlayer 3 with the wavelength conversion material can preferably result in a white-light-emitting device 100 with an integrated QD layer.

In Figures 6A and 6B a further embodiment of the light-emitting device 100 is shown, which has an encapsulation layer 4 that is arranged on the wavelength conversion layer 2. Figure 6B shows a detailed view of a part of the light-emitting device 100 of Figure 6A.

Preferably, the encapsulation layer 4 is transparent and can be arranged directly on the wavelength conversion layer 2 as shown in Figures 6A and 6B, so that the encapsulation layer 4 is arranged in direct contact with at least some of the QDs of the wavelength conversion layer 2. The encapsulation layer 4 can comprise or consist of one or more layers which are responsible for a barrier effect of the encapsulation layer 4. The one or more layers can comprise one or more inorganic

and/or organic materials as described above in the general part. Preferably, the encapsulation layer 4 has a layer sequence having a plurality of layers, for instance a plurality of only inorganic layers or a plurality of inorganic and organic layers, which are alternately arranged on top of each other. By way of example, in the detailed view in Figure 6B three layers 41, 42, 43 of the encapsulation layer 4 are shown. Alternatively, the encapsulation layer 4 can have less than or more than three layers.

Throughout the embodiments explained above, the light-outcoupling surface 13 is formed by the second main surface 142 of the substrate 14. In this way it is possible to manufacture the light-emitting device 100 as a conversion light-emitting device utilizing a 1- or 2-side structured-surface substrate, in particular made from sapphire, and an integrated QD film formed by the wavelength conversion layer 2 deposited on one of the structured surfaces of the substrate 14 or of an interlayer 3 on the substrate 14. By introducing a suitable topography on the non-epitaxy side of the substrate it is possible to use the conventional process flow for manufacturing the light-emitting semiconductor chip in combination with the incorporation of the wavelength conversion layer, specifically formed by QDs. As explained above, after fabrication of the light-emitting semiconductor chip, which can be for instance a blue-light-emitting semiconductor chip, the QD film is deposited on the surface structure.

Furthermore, it is also possible that the light-emitting semiconductor chip comprises a carrier substrate, to which the semiconductor layer sequence has been transferred after having grown the semiconductor layers on a growth substrate.

In this case, the light-outcoupling surface can be formed by another surface of the light-emitting semiconductor chip. For example, the light-outcoupling surface 13 can be a surface of the semiconductor layer sequence 10 as shown in the detailed
5 view in Figure 7. The wavelength conversion layer 2 can be deposited directly on a surface structure 15 on the light-outcoupling surface 13 of the semiconductor layer sequence 10. Alternatively, an interlayer, which can comprise a transparent material and/or a wavelength conversion material,
10 can be arranged on the light-outcoupling surface 13 of the semiconductor layer sequence 10 and the wavelength conversion layer 2 can be deposited on the interlayer.

Since in all embodiments the wavelength conversion layer with
15 the QDs is an integral part of the light-emitting device, it is possible to fabricate a solid QD-containing assembly with the possibilities of improved control and stability of the position of the QDs as well as protection and encapsulation of the QDs. Furthermore, the integrated QD containing
20 wavelength conversion layer allows for an improved color adjustment of the light-emitting device. Since the deposition of the wavelength conversion layer with the QDs can be integrated in a conventional design and process flow for manufacturing light-emitting semiconductor chips, a cost
25 reduction in comparison to approaches with free standing QD converters is possible.

Alternatively or additionally to the features described in connection with the Figures, the embodiments shown in the
30 Figures can comprise further features described in the general part of the description. Moreover, features and embodiments of the Figures can be combined with each other, even if such combination is not explicitly described.

- 26 -

The invention is not restricted by the description on the basis of the exemplary embodiments. Rather, the invention encompasses any new feature and also any combination of features, which in particular comprises any combination of
5 features in the patent claims, even if this feature or this combination itself is not explicitly specified in the patent claims or exemplary embodiments.

References

	1	light-emitting semiconductor chip
	2	wavelength conversion layer
5	3	interlayer
	4	encapsulation layer
	10	semiconductor layer sequence
	11	light-emitting semiconductor layer
	12	electrode layer
10	13	light-outcoupling surface
	13'	rear-side surface
	13''	side surface
	14	substrate
	15	surface structure
15	16	further surface structure
	20	quantum dot
	41, 42, 43	layer
	91	temporary carrier
	92	connection layer
20	100	light-emitting device
	141	first main surface
	142	second main surface

Claims

1. Light-emitting device (100), comprising
a light-emitting semiconductor chip (1) having a
5 semiconductor layer sequence (10) comprising at least
one light-emitting semiconductor layer (11) and a light-
outcoupling surface (13),
a wavelength conversion layer (2) arranged on the light-
outcoupling surface, wherein the wavelength conversion
10 layer comprises quantum dots (20).
2. Light-emitting device according to claim 1, wherein the
wavelength conversion layer is free of an organic matrix
material.
15
3. Light-emitting device according to claim 1 or 2, wherein
the wavelength conversion layer substantially consists
of the quantum dots.
- 20 4. Light-emitting device according to any of the preceding
claims, wherein a surface structure (15) is provided on
the light-outcoupling surface and the wavelength
conversion layer is deposited directly on the surface
structure.
- 25 5. Light-emitting device according to any of the preceding
claims, wherein the light-outcoupling surface is a
surface of the semiconductor layer sequence.
- 30 6. Light-emitting device according to any of the preceding
claims,

wherein the light-emitting semiconductor chip comprises a substrate (14) with a first main surface (141) and a second main surface (142),

wherein the semiconductor layer sequence is arranged on the first main surface,
wherein the wavelength conversion layer is arranged on the second main surface.

7. Light-emitting device according to claim 6, wherein the second main surface is the light-outcoupling surface and has the surface structure.

8. Light-emitting device according to claim 6 or 7, wherein the first main surface has a further surface structure (16) and the semiconductor layer sequence is grown on the further surface structure.

9. Light-emitting device according to any of the preceding claims,

wherein an interlayer (3) is arranged on the light-outcoupling surface,
wherein the interlayer has a surface that is remote from the light-outcoupling surface and has the surface structure.

10. Light-emitting device according to claim 9, wherein the interlayer comprises a wavelength conversion material.

11. Light-emitting device according to any of the preceding claims, wherein an encapsulation layer (4) is deposited on the wavelength conversion layer.

12. Light-emitting device according to claim 11, wherein the encapsulation layer comprises a plurality of layers.

13. Method for manufacturing a light-emitting device (100),
wherein a light-emitting semiconductor chip (1) is provided,
the light-emitting semiconductor chip having a
5 semiconductor layer sequence (10) comprising at least
one light-emitting semiconductor layer (11) and a light-
outcoupling surface (13),
wherein a wavelength conversion layer (2) is deposited on the
light-outcoupling surface, wherein the wavelength
10 conversion layer comprises quantum dots (20).

14. Method according to claim 13, wherein the wavelength
conversion layer is deposited by at least one of drop-
casting, inkjet printing, layer transfer.

15. Method according to claim 13 or 14, wherein a surface
structure (15) is provided on the light-outcoupling
surface and the wavelength conversion layer is deposited
directly on the surface structure.

16. Method according to any of claims 13 to 15,
wherein a substrate (14) with a first main surface (141) and
a second main surface (142) is provided,
wherein the semiconductor layer sequence is grown on the
25 first main surface,
wherein the wavelength conversion layer is deposited on the
second main surface.

17. Method according to claim 16, wherein the surface
30 structure is produced in the second main surface.

18. Method according to claim 16 or 17,

- 31 -

wherein the surface structure is provided in the second main surface before the semiconductor layer sequence is arranged on the first main surface,

wherein the substrate is arranged with the second main surface on a temporary carrier (91) before the semiconductor layer sequence is arranged on the first main surface, and

wherein the temporary carrier is removed after the arrangement of the semiconductor layer sequence on the first main surface, thereby exposing the surface structure on the second main surface.

19. Method according to any of claims 16 to 18, wherein the surface structure is provided on the second main surface after the semiconductor layer sequence is arranged on the first main surface.

20. Method according to any of claims 16 to 19, wherein the substrate is thinned before the surface structure is provided on the second main surface and after the semiconductor layer sequence is arranged on the first main surface.

FIG 1A

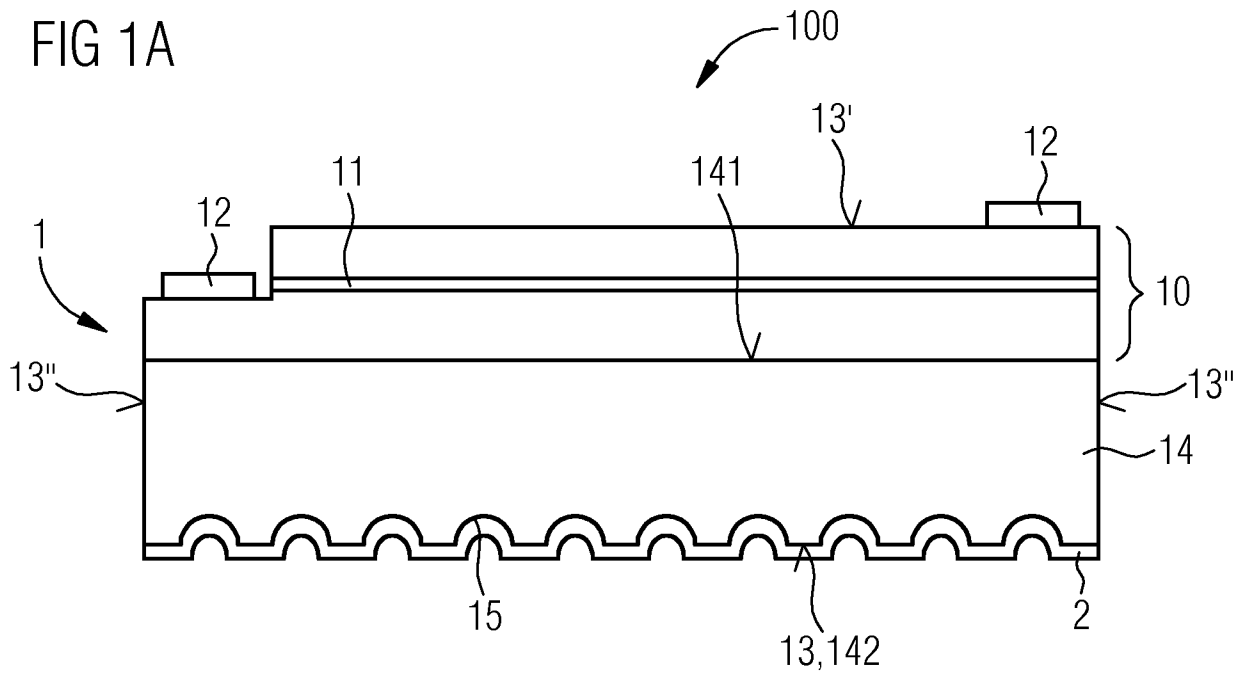


FIG 1B

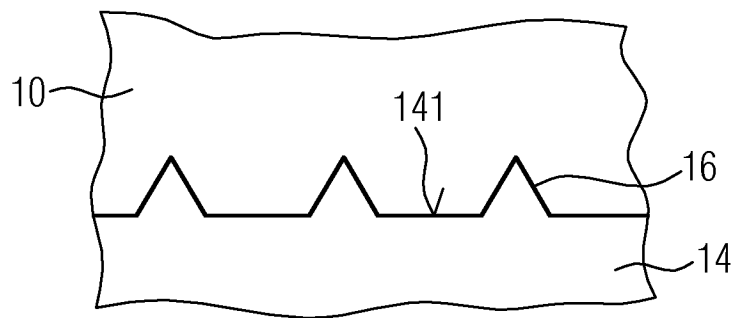


FIG 1C

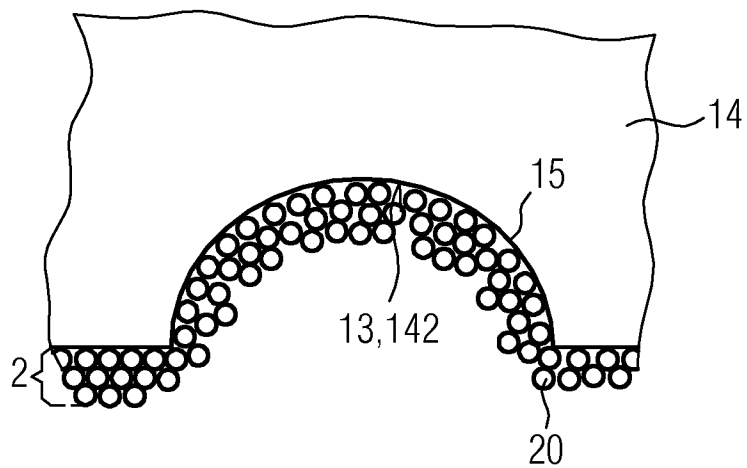


FIG 2A

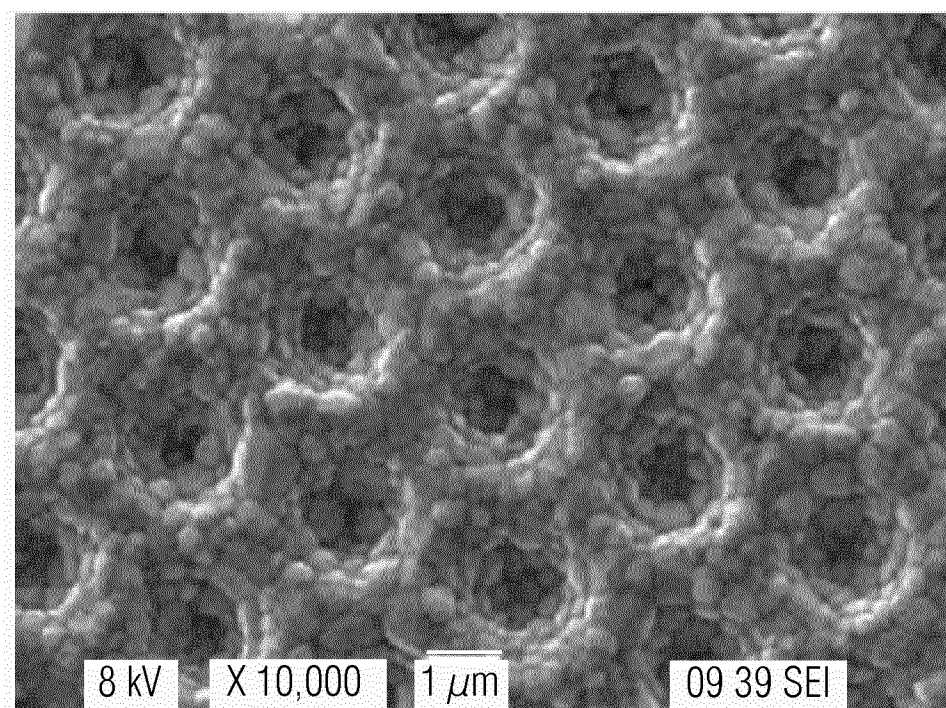


FIG 2B

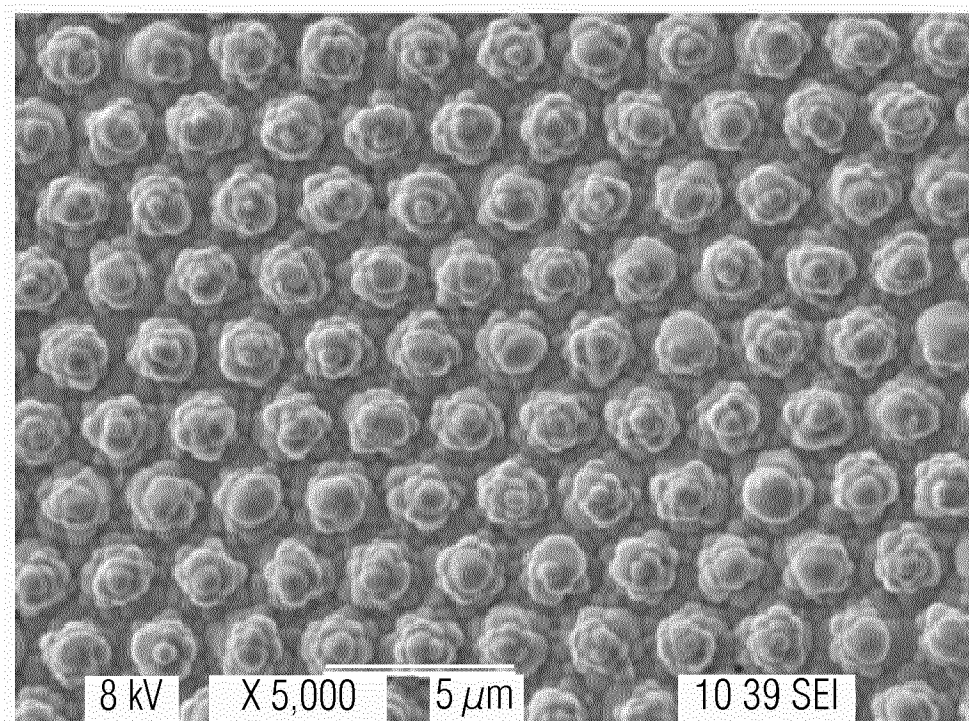


FIG 3A

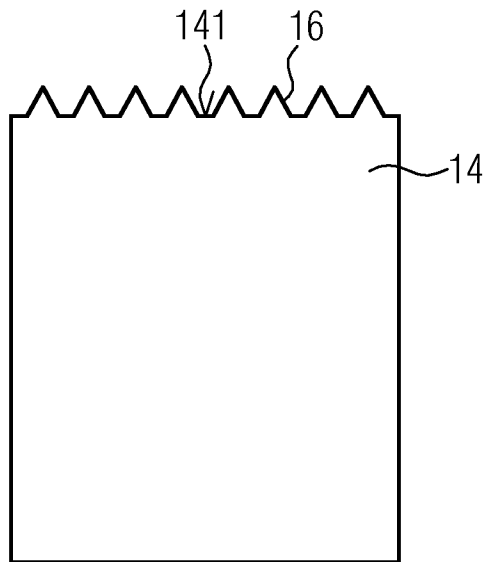


FIG 3B

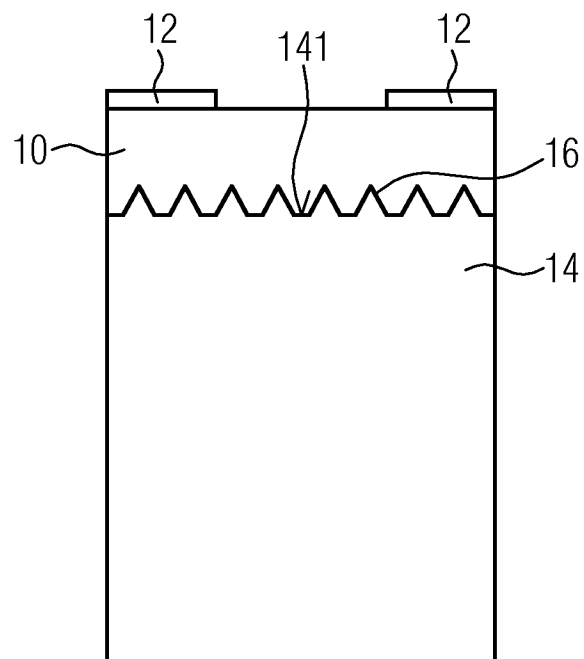


FIG 3C

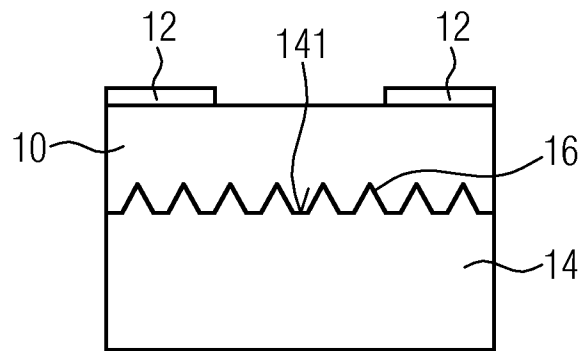


FIG 3D

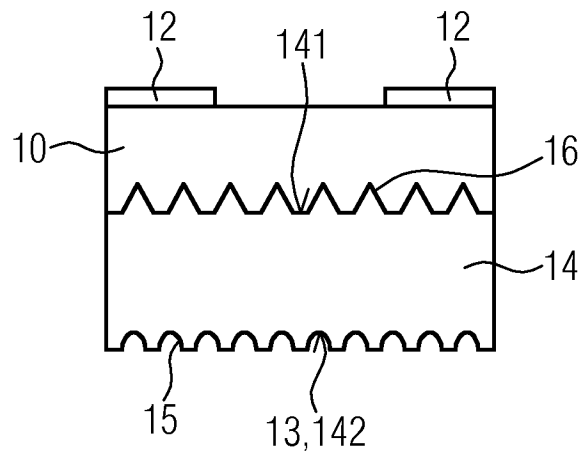


FIG 4A

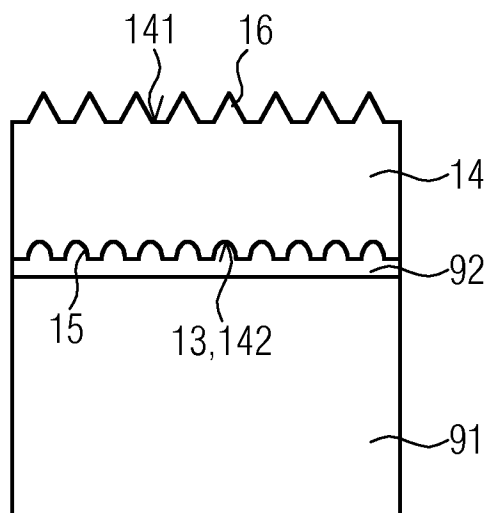


FIG 4B

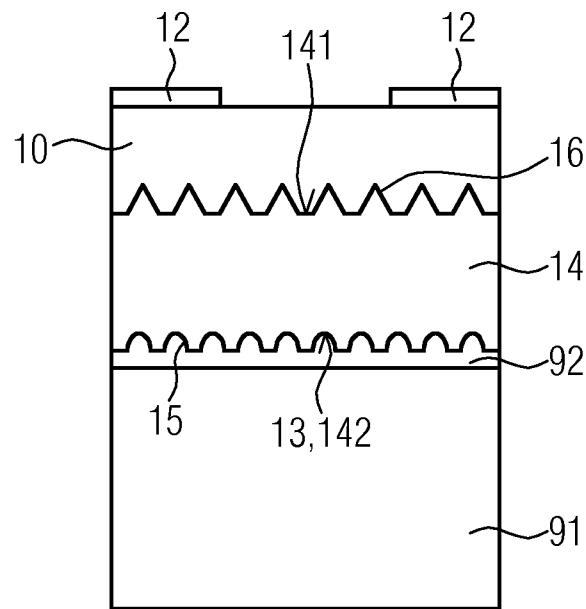


FIG 4C

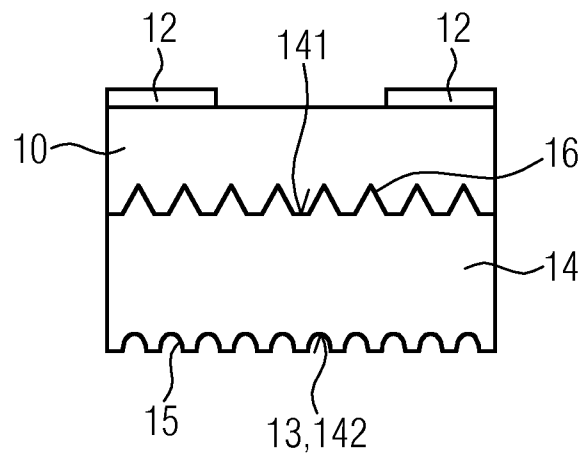


FIG 5

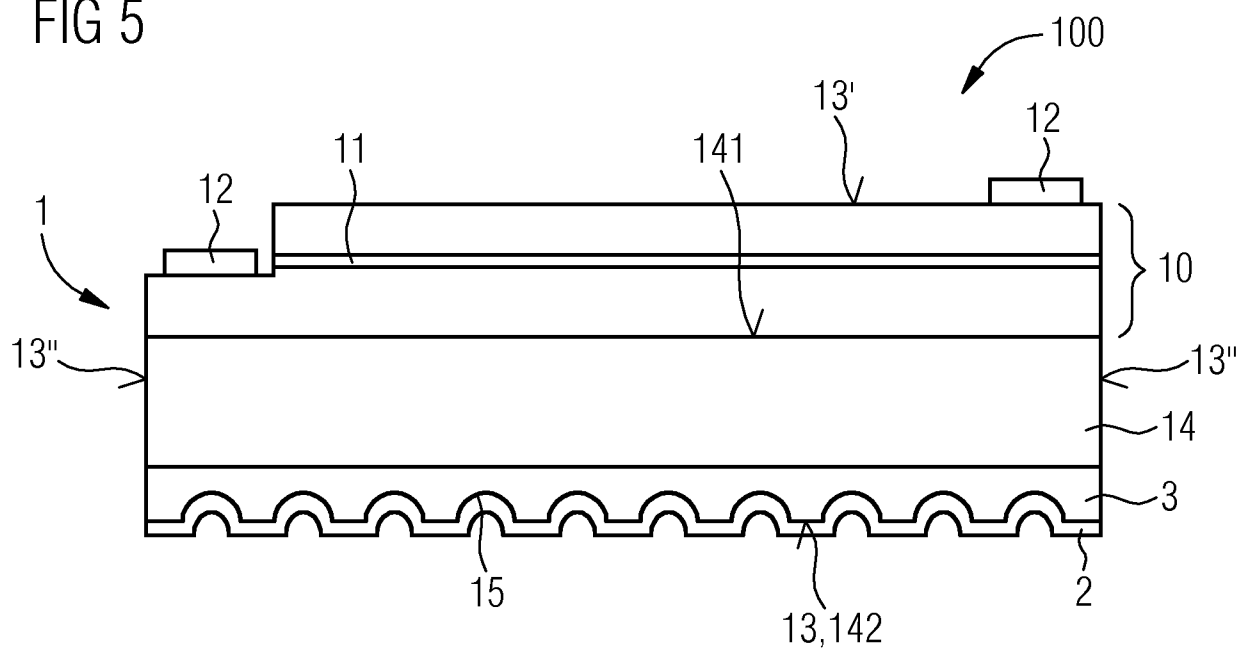


FIG 6A

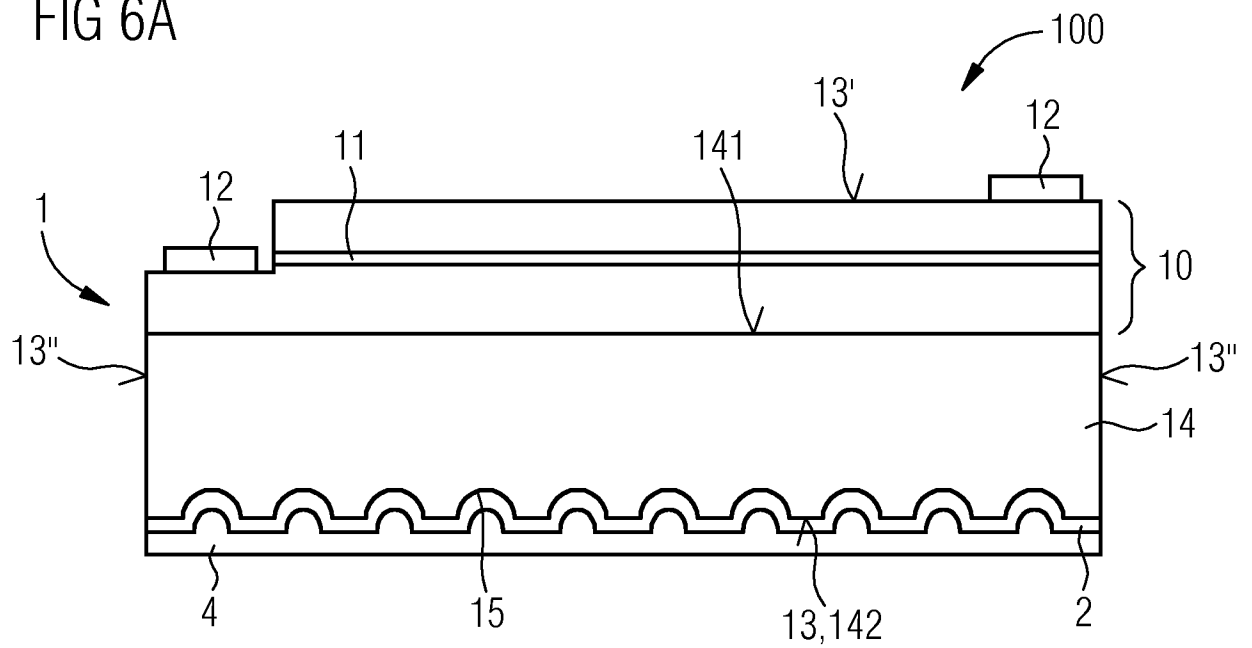


FIG 6B

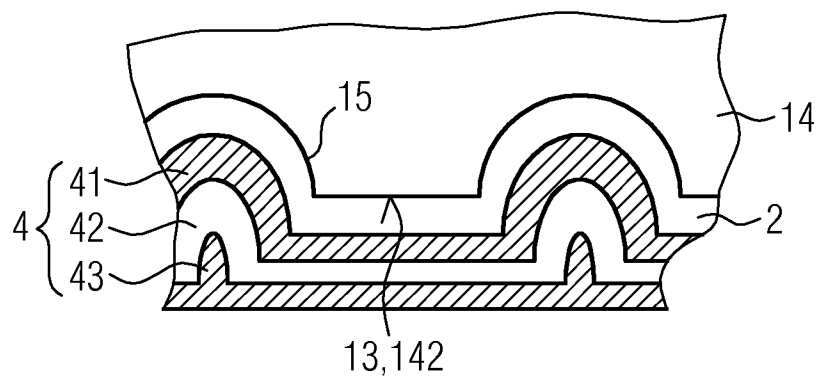
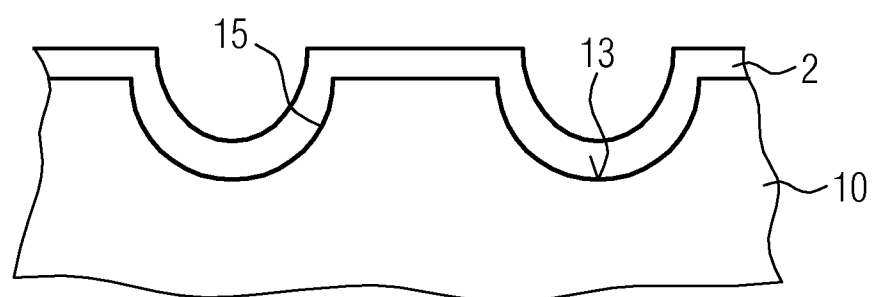


FIG 7



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/082118

A. CLASSIFICATION OF SUBJECT MATTER

INV. H01L33/50

ADD. H01L33/20 H01L33/22 H01L33/44 H01L33/54

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 H01S

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2016/095184 A1 (NAKABAYASHI TAKUYA [JP] ET AL) 31 March 2016 (2016-03-31) paragraphs [0001] - [0157]; figures 1, 2A, 2D	1,4,6-8, 13-20
X	US 2015/021549 A1 (ZHANG FAN [US] ET AL) 22 January 2015 (2015-01-22) the whole document	1-5,13, 15
X	US 2016/197229 A1 (PARK IL WOO [KR] ET AL) 7 July 2016 (2016-07-07) paragraphs [0001] - [0104]; figure 1	1,4,5, 11-15
X	US 2017/133357 A1 (KUO SHU-MING [TW] ET AL) 11 May 2017 (2017-05-11) paragraphs [0001] - [0057]; figure 11	1-5, 11-14
	-/--	



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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

12 February 2020

Date of mailing of the international search report

18/02/2020

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Saynova, Desislava

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2019/082118

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2018/198034 A1 (O'BRIEN DAVID [DE] ET AL) 12 July 2018 (2018-07-12) paragraphs [0001] - [0123]; figure 1 -----	1-3,5, 13,14
X	US 2016/308089 A1 (KIM HYUNG KUN [KR] ET AL) 20 October 2016 (2016-10-20) paragraphs [0001] - [0097], [0150] - [0151], [0160] - [0164]; figures 6, 12, 13 -----	1,4,5, 9-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2019/082118

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2016095184 A1	31-03-2016	JP 6511757 B2 JP 2016072435 A US 2016095184 A1	15-05-2019 09-05-2016 31-03-2016
US 2015021549 A1	22-01-2015	NONE	
US 2016197229 A1	07-07-2016	CN 105762237 A KR 20160084562 A US 2016197229 A1 US 2017330998 A1	13-07-2016 14-07-2016 07-07-2016 16-11-2017
US 2017133357 A1	11-05-2017	US 2017133357 A1 US 2019237452 A1	11-05-2017 01-08-2019
US 2018198034 A1	12-07-2018	DE 102015113052 A1 DE 112016003602 A5 US 2018198034 A1 WO 2017025437 A1	09-02-2017 26-04-2018 12-07-2018 16-02-2017
US 2016308089 A1	20-10-2016	KR 20160124375 A US 2016308089 A1	27-10-2016 20-10-2016