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(71) Applicant: **KONINKLIJKE PHILIPS N.V.** [NL/NL]; High Tech Campus 5, 5656 AE Eindhoven (NL).

(72) Inventors: **GRONENBORN, Stephan**; High Tech Campus 5, 5656 AE Eindhoven (NL). **MOENCH, Holger, Joachim**; High Tech Campus 5, 5656 AE Eindhoven (NL).

(74) Agent: **MÜLLER, Frank** et al.; High Tech Campus 5, 5656 AE Eindhoven (NL).

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(54) Title: LASER ARRANGEMENT COMPRISING A VCSEL ARRAY

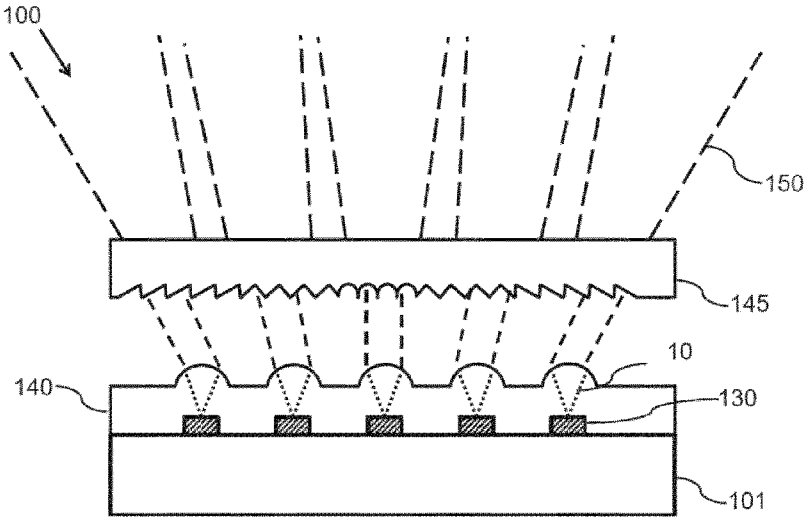


Fig. 2

(57) Abstract: The invention describes a laser arrangement (100) comprising at least one VCSEL array comprising two, three, four or more VCSELs (130) arranged on a common semiconductor substrate (101), wherein the laser arrangement (100) further comprises at least one optical structure (140) and a diffusor structure (145), wherein the optical structure (140) is arranged to reduce a divergence angle of laser light (10) emitted by each VCSEL (130) to a section (147) of the diffusor structure (145) assigned to the respective VCSEL (130), wherein the diffusor structure (145) is arranged to transform the laser light received from the optical structure (140) to transformed laser light (150) such that a continuous illumination pattern (20) can be provided in a reference plane in a defined field-of-view, wherein the diffusor structure (145) is arranged to increase a size of the illumination pattern (20) in comparison to an untransformed illumination pattern which can be provided without the diffusor structure (145). The invention further describes a lighting device comprising such a laser arrangement, a time-of-flight camera (200) comprising such a lighting device and a method of

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manufacturing the laser arrangement (100).

Laser arrangement comprising a VCSEL array

FIELD OF THE INVENTION

The invention relates to a laser arrangement comprising a VCSEL array, a lighting device comprising such a laser arrangement, a time-of-flight camera comprising such a lighting device and a method of manufacturing the laser arrangement.

BACKGROUND OF THE INVENTION

Laser arrangements comprising a VCSEL array can be used for infrared illumination devices. Using short pulses VCSEL arrays are, for example, applied in time-of-flight applications. Such applications comprise e.g. short-range gesture recognition for portable devices and 3D space recognition. VCSEL arrays of about 1mm² area with output power in the 1-10W range are discussed for such applications. A specific field of illumination or view is defined by the application (e.g. a time-of-flight camera observing e.g. 70°x50°).

US 2016/0164261 A1 discloses methods, devices and systems for selectively illuminating different zones of a field of view by a multi-zone illumination device. The multi-zone illuminator may include a plurality of vertical cavity surface emitting lasers (VCSELs), and a plurality of micro-optical devices aligned with apertures of individual or groups of VCSELs, which are configured to be individually activated to provide adjustable illumination to different zones of a field of view of an image sensor.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a laser arrangement comprising a VCSEL array with improved illumination pattern in a reference plane in a field-of-view which can be illuminated by the laser arrangement.

The invention is described in the independent claims. Preferred embodiments are described in the dependent claims or are described in the subsequent portions of the description.

According to a first aspect a laser arrangement comprising at least one VCSEL array is provided. The VCSEL array comprises two, three, four or more VCSELs arranged on a common semiconductor substrate. The laser arrangement further comprises at least one

optical structure and a diffusor structure. The optical structure is arranged to reduce a divergence angle of laser light emitted by each VCSEL to a section of the diffusor structure assigned to the respective VCSEL. The diffusor structure is arranged to transform the laser light received from the optical structure to transformed laser light such that a continuous illumination pattern can be provided in a reference plane in a defined field-of-view. The diffusor structure is further arranged to increase a size of the illumination pattern in comparison to an untransformed illumination pattern which can be provided without the diffusor structure. VCSEL array, optical structure and diffusor structure may be arranged (especially distance between VCSEL array, optical structure and diffusor structure and divergence angles prior and after the optical structure) such that the sections of the diffusor structure assigned to different VCSELs do not overlap in order to enable tailoring of the illumination pattern in the field of view by means of the diffusor structure. This does not exclude that there may some overlap in the outer part of the distribution because VCSEL emission is in a cone with smooth boundaries.

Concentrating or narrowing the beam profile of the laser light emitted by the VCSELs in a first step by means of the optical structure and subsequently spreading of the illumination pattern by means of the diffusor structure in comparison to a raw illumination pattern which could be provided by means of the VCSELs comprised by the VCSEL array without the diffusor structure enables a continuous illumination pattern of the scene in a defined field-of-view of the laser arrangement. Furthermore, the transformed laser light is concentrated in the reference plane such that losses due to transformed laser light outside the intended or defined field-of-view are reduced. The concentration may have the effect that at least 70%, preferably at least 80% and more preferably at least 90% of the transformed laser light illuminates the reference plane in the intended or defined field-of-view. In addition illumination in the corners of especially a large field-of-view (e.g. 100°x80°) may be improved. The illumination pattern is continuous in the sense that there are no steps. An intensity distribution function describing the illumination pattern in the reference plane is differentiable. Examples of such intensity distributions may, for example, be an essentially constant intensity in the reference plane in a defined field-of-view or an essentially constant intensity with respect to the solid angle defined by the respective field-of-view (this results in an intensity distribution in the reference plane which varies with the cube of cosine with respect to the angle to the optical axis connecting the reference plane and the center of the VCSEL array). The sectors illuminated by single VCSELs of the VCSEL array may overlap in the reference plane in the field-of-view. The sectors illuminated by single VCSELs may

completely overlap in the reference plane in order to maximize redundancy. The transformed laser light which can be provided by the laser arrangement may therefore increases system efficiency in combination with laser safety.

The VCSELs are characterized by an active laser light emission area with an area between 3 μm^2 and 10000 μm^2. The pitch or distance between the VCSELs comprised by the VCSEL array may be between 20 µm and 250 µm. The density of the VCSELs and/or the size light emission area may be different depending on the position in the VCSEL array and/or the shape of the optical structure and the diffusor structure illuminated by the respective VCSEL such that the intensity distribution of the illumination pattern can be adapted.

The optical structure may be integrated on wafer level. The optical structure is integrated on wafer level by coupling the common optical structure to a surface of a semiconductor wafer comprising a multitude of VCSEL arrays and corresponding semiconductor substrates before separating the single VCSEL arrays. The optical structure is permanently coupled to the surface of the semiconductor wafer. The optical structure is preferably coupled to the surface of the semiconductor wafer such that it cannot be removed without damaging the respective VCSEL array. The optical structure may consist of a transparent (with respect to the e.g. infrared laser light) optical polymer (e.g. UV-or blue light curable polymers) deposited on top of the semiconductor layer structure of the VCSELs comprised by the VCSEL arrays after processing the VCSELs but before separating the single VCSEL arrays by, for example, dicing. The optical structure may alternatively be etched in the semiconductor substrate of the wafer. Alternatively or in addition a glass wafer comprising optical structures may be bonded, for example, by means of a transparent adhesive or any other suitable bonding technology to the semiconductor wafer comprising the multitude of VCSEL arrays.

The optical structure may be a continuous structure arranged above the light emitting surfaces of the VCSELs. The continuous structure may, for example, be a continuous “block” of polymer or a continuous surface structure etched in the semiconductor substrate or glass wafer.

The optical structure may comprise collimating micro lenses for reducing the divergence angle by collimating the laser light. Each VCSEL of the VCSEL array may be assigned to one specific collimating micro lens such that there is one micro lens per VCSEL. Micro lenses may be combined with a tailored diffusor structure characterized by varying diffusor properties (different diffusor profile) across the diffusor structure in order to improve

illumination pattern and especially to concentrate the illumination pattern in the defined field-of-view. The micro lenses especially in combination with such a tailored diffusor structure may have the advantage that there is a much steeper fall-off at the outer rim of the three-dimensional intensity distribution such that more light is available in the field-of-view. Efficiency may therefore be increased.

The collimating micro lenses may be chirped micro lenses which are characterized by optical axes with varying inclination with respect to, for example, a surface parallel to the semiconductor substrate. Inclination of the optical axes may vary across the whole optical structure. Chirped micro lenses may improve laser safety and shape of the final light distribution or illumination pattern while maintaining the efficiency benefit if the diffusor structure is arranged at some distance to the VCSEL array with the optical structure. This may enable that at different parts of the diffusor structure the incident angle of the light provided by means of the optical structure is well-defined and smaller than the usual divergence angle of the laser light. Each part of the diffusor structure may have a different diffusor profile which is adapted to the respective incident angle of the laser light received from the optical structure. Inclination of the optical axis may alternatively or in addition be combined with tailored positioning of the micro lenses. Tailored positioning (e.g. no regular pattern) may in combination with a tailored diffusor may increase efficiency by concentrating the transformed laser light in the intended field-of-view.

The optical structure may alternatively or in addition comprise a partly reflective mirror structure. The partly reflective mirror structure is arranged to decrease a divergence angle of the VCSEL. The partly reflective mirror structure may be used to stabilize the VCSEL emission to a smaller divergence angle and less mode dynamics. The diffusor structure may be a tailored diffusor to concentrate the transformed laser light in the desired field-of-view. Advantage may be the much steeper fall-off in the slopes of the of the intensity distribution as described above resulting in higher efficiency due to concentration of the transformed laser light in the defined field-of-view. Furthermore, dependency of the beam profile after diffusor structure with respect to changes of driving currents supplied to the VCSELs of the VCSEL array and temperature of the VCSELs of the VCSEL array may be reduced.

Each VCSEL of the VCSEL array may be a top emitter which is arranged to emit the laser light in a direction away from the semiconductor substrate. The optical structure may comprise a material provided on top of a semiconductor layer structure of the VCSEL array. The material is transparent in the wavelength range of the laser light (e.g. in

the wavelength range between 750 nm – 1200 nm). The transparent material may be UV- or blue light curable optical polymer as described above. The transparent material may be provided on top of the mesas of the VCSELs. Alternatively, a planarization layer may be provided in order to provide an essentially plain surface at the level of the light emitting areas of the single VCSELs. The transparent material of the optical structure may be deposited on top of the planarization layer.

The VCSELs of the VCSEL array may alternatively be bottom emitters which are arranged to emit the laser light through the semiconductor substrate. The optical structure may in this case be provided on a surface of the semiconductor substrate which is arranged opposite with respect to processing surface on which the VCSELs are provided.

The optical structure may be integrated, especially etched in the semiconductor substrate of the VCSEL array. The high refractive index of the semiconductor substrate (gallium arsenide n ~ 3.5) enables a relatively flat profile of the optical structure. A planarization layer may be provided after integrating the optical structure in the semiconductor substrate.

The optical structure may alternatively be provided on a glass wafer which is bonded to the semiconductor substrate. The optical structure may, for example, be etched in the glass wafer prior or after bonding to the wafer comprising the semiconductor substrates of the VCSEL array. The glass wafer may, for example, be glued.

The diffusor structure may be coupled to the optical structure by means of a bonding layer. The diffusor structure may be integrated in a transparent carrier like a glass substrate. The transparent carrier is mechanically coupled to the semiconductor substrate. The transparent carrier may, for example, be glued by means of an (in comparison to the refractive index of the semiconductor substrate) low refractive index adhesive to the surface of the optical structure. A planarization layer may be provided on top of the optical structure. The planarization layer may be characterized by a relatively low refractive index in comparison to the refractive index of the semiconductor substrate. The influence with respect to the optical properties of the optical structure may therefore be limited and/or be considered in the design of the optical structure. The diffusor structure may be provided in or on top of the planarization layer. One or more further material layers may, for example, be provided on top of the planarization layer. The diffusor structure may, for example, be provided by means of etching or structuring the one or more further material layers.

At least a part of the VCSELs may be arranged to be individually controlled to emit laser light. Each VCSEL or two, three, four or more groups of VCSELs of the VCSEL

array may be arranged to be individually switched on or off in order to illuminate one or more sectors of the illumination pattern in a defined sequence. The VCSEL array comprises respective electrodes in order to enable individual control of the VCSELs or groups of VCSELs. Individual control of the VCSELs or groups of VCSELs (sub-arrays) may allow electronic adjustment of the illumination pattern (e.g. more light in a sector comprising an otherwise dark corner) or defined illumination sequences.

The sections of the diffusor structure may be arranged such that each VCSEL is arranged to illuminate a sector of the illumination pattern. Each sector may cover a part of the illumination. The sectors may preferably overlap in order to increase redundancy and in an extreme case cover the whole illumination pattern. The sections of the diffusor structure may comprise diffusor subsections wherein the diffusor subsection are arranged to spread the laser light received from the optical structure differently depending on the position of the respective VCSEL in the VCSEL array. The diffusor substructures are characterized by different diffusing properties (as described above) which may be enabled by different surface structures. Such an arrangement may enable a higher contrast between e.g. center of the beam directed to the center of the field-of-view and the large angles, where often a larger intensity is required to compensate for losses in the camera objective (cos^4-law for camera objectives, leading to a decay of the signal on the CCD for objectives with a large field-of-view).

According to a second aspect a light emitting device is provided. The light emitting device comprises at least one laser arrangement as described above and an electrical driver for electrically driving the VCSELs of the VCSEL array. The light emitting device may further comprise a controller for providing control signals for controlling the electrical driver. The controller may, for example, comprise a storage device for storing data and a processing device for executing instructions comprised by the stored data. The stored data may, for example, comprise a sequence of providing an electrical drive current to the VCSELs or groups of VCSELs.

The laser arrangement or light emitting device may be used in consumer devices (e.g. smartphones), vehicles as well as high power industrial applications in order to support

consumer and portable applications as gesture interface or 3D scanner in smart-phones, lap-top, tablet, …

user interface or indoor navigation for robotics, sports, industry, lighting,…

high end for automotive mid-range detection (park assist, safe city driving), and

high power industrial applications.

According to a third aspect a time-of-flight camera is provided. The time-of-flight camera comprises the light emitting device according to any embodiment described above, a light detector, an optical imaging structure and an evaluator. The optical imaging structure is arranged to image transformed laser light reflected by an object to the light detector. The evaluator is arranged to determine a distance to the object by means of the image of the transformed laser light detected by the light detector.

According to a fourth aspect a method of fabricating a VCSEL array according to any embodiment described above is provided. The method comprises the steps of:

providing a semiconductor substrate,

providing at least two VCSELs on the semiconductor substrate,

providing an optical structure,

providing a diffusor structure, and

arranging the optical structure to reduce a divergence angle of laser light emitted by each VCSEL to a section of the diffusor structure assigned to the respective VCSEL, wherein the sections of the diffusor structure are arranged to transform the collimated laser light to transformed laser light such that a continuous illumination pattern can be provided in a reference plane in a defined field-of-view, and to increase a size of the illumination pattern in comparison to an untransformed illumination pattern which can be provided without the diffusor structure.

The steps need not necessarily be performed in the order given above.

The optical structure may be provided and especially integrated on wafer level by several methods, among them grinding, lapping, etching, soft-cushion imprint lithography followed by etching, UV-replication of a master structure on the wafer followed by a etch-transfer of the replicated structure in the semiconductor substrate and the like. Furthermore, wafer bonding of e.g. a glass wafer comprising a multitude of optical structures to the semiconductor wafer may be used. Alternatively, a curable polymer may be provided and subsequently processed by means of processing light (e.g. UV or blue light). Details of such a process are described, for example, on page 2, line 2 to page 5, line 19 of WO 2017/055160 A1. Furthermore, Figures 2-10 and the corresponding description on page 9, line 20 to page 11, line 20 provides a special example of such a process. The disclosure of WO 2017/055160 A1 is incorporated by reference.

The optical structure may be covered by a planarization layer as described above. The planarization layer is characterized by a lower refractive index than a material of the optical structure. The optical structure may be designed with respect to the refractive index of the planarization layer in order to provide the desired illumination pattern. The planarization layer may be used to smooth the surface irregularities caused by the optical structure. The planarization layer may comprise materials like silicone, epoxy, polyimide, SiN and the like. The difference between the refractive index of the semiconductor layer structure (semiconductor substrate or one or more semiconductor layers) which is used to manufacture the optical structure and the refractive index of the planarization layer is sufficient to provide the illumination pattern for a multitude of applications. The planarization layer may protect the optical structure and may simplify further processing steps in order to provide the diffusor structure as described above.

It shall be understood that the laser arrangement of claim 1-12, the lighting device of claim 13 and the method of claim 15 have similar and/or identical embodiments, in particular, as defined in the dependent claims.

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

Further advantageous embodiments are defined below.

BRIEF DESCRIPTION OF THE DRAWINGS

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

The invention will now be described, by way of example, based on embodiments with reference to the accompanying drawings.

In the drawings:

Fig. 1 shows a principal sketch of a cross-section of a first laser arrangement

Fig. 2 shows a principal sketch of a cross-section of a second laser arrangement

Fig. 3 shows a principal sketch of a cross-section of a third laser arrangement

Fig. 4 shows examples of intensity distributions in one defined field-of-view

Fig. 5 shows a principal sketch of an illumination pattern

Fig. 6 shows a principal sketch of a time-of-flight sensor module

Fig. 7 shows a principal sketch of a process flow of a method of fabricating a VCSEL array

In the Figures, like numbers refer to like objects throughout. Objects in the Figures are not necessarily drawn to scale.

DETAILED DESCRIPTION OF EMBODIMENTS

Various embodiments of the invention will now be described by means of the Figures.

Fig. 1 shows a principal sketch of a cross-section of a first laser arrangement 100. The cross-section is taken across a line of VCSELs 130 of the VCSEL array comprised by the laser arrangement 100. Five mesas of top emitting VCSELs 130 provided on top of a semiconductor substrate are shown. Each VCSEL 130 emits laser light with divergence angle of around 20° in air. An optical structure 140 is arranged above the VCSELs 130 such that each VCSEL 130 illuminates one respective area of the optical structure 140. The optical structure is arranged to reduce the divergence angle of around 20° in air to a divergence angle of around 5° in air. The laser light 10 with reduced divergence angle reaches a section of a subsequent diffusor structure 145. The diffusor structure 145 transforms the laser light received from the optical structure 140 such that the transformed laser light 150 is spread in order to provide an illumination pattern 20 (see Fig. 6) with increased size in a reference plane in a field-of-view of the laser arrangement 100 in comparison to an untransformed illumination pattern which would be projected to the reference plane without the diffusor structure 145. The diffusor structure 145 may preferably be arranged to change the beam profile of the laser light received from the optical structure 140 in order to distribute the transformed laser light 150 across a large angle but at the same time restrict the illumination pattern to the predefined field-of-view in order to avoid losses by laser light outside the defined field-of-view (see Fig. 4).

Fig. 2 shows a principal sketch of a cross-section of a second laser arrangement 100. The configuration of the VCSELs 130 and the semiconductor substrate 101 is essentially the same as discussed with respect to Fig. 1. The optical structure 140 consists of a curable optical polymer which is provided on top of a processing surface of the semiconductor substrate 101 and encloses the mesas of the VCSELs 130. The optical structure 140 comprises an array of chirped micro lenses wherein an inclination of the optical axis of the chirped micro lenses with respect to a surface parallel to the semiconductor substrate 101 decreases from the center such that the laser light with reduced divergence angle is tilted to the outside the higher a distance of the respective VCSEL 130 with respect to a VCSEL 130 in the center of the VCSEL array is. The laser light with reduced divergence

angle is subsequently transformed to transformed laser light 150 by means of diffusor structure 145 which is characterized by a tailored structured surface comprising different diffusor substructures. The different diffusor substructures are aligned with the sections 147 (see Fig. 3) receiving the laser light with reduced divergence angle. The different or tailored diffusor substructures may enable a further improvement of the illumination pattern 20 in the field-of-view by enabling a more defined concentration of the transformed laser light in the predefined field-of-view.

Fig. 3 shows a principal sketch of a cross-section of a third laser arrangement 100. The cross-section shows again an example with five VCSELs 130 emitting laser light 10 through the semiconductor substrate 101 (bottom emitter). The optical structure 140 comprises an array of chirped micro lenses similar as discussed with respect to Fig. 2. The array of chirped micro lenses is etched in the bottom surface (surface opposite to the surface on which the VCSELs 130 are processed) of the semiconductor substrate 101. The high refractive index of the GaAs semiconductor substrate 101 of n = 3.5 enables a rather low-profile of the optical structure 140. A glass wafer consisting of a glass with a high refractive index (e.g. n=2 at the emission wavelength of the VCSELs 130) is bonded by means of a bonding layer 142 with a substantially lower refractive index (e.g. n=1.5 at the emission wavelengths of the VCSELs 130) to the semiconductor wafer comprising the VCSEL arrays 100. The bonding layer may, for example, be a polymer material with low optical absorption or a glass material with low softening temperature. The glass wafer comprises diffusor structures 145 which are aligned prior to the bonding process with the VCSEL arrays. The diffusor structure 145 is similar as discussed with respect to Fig. 2. The structured surface comprising the diffusor substructures is arranged on the bonding side of the diffusor structure 145. Design of the structured surface has therefore take into account the refractive index of the bonding layer 142. Arrangement of the structured surface on the bonding side does have the advantage that it is not possible to manipulate the structured surface of the diffusor structure 145 (e.g. by providing an oil droplet on the structured surface). The diffusor structure 145 may alternatively consist of a semiconductor material (e.g. GaAs) with high refractive index. The structured surface of the diffusor structure 145 (consisting of, for example, glass or semiconductor material) may alternatively be arranged on the side opposite to the bonding side which is in contact with the bonding layer 142. High refractive index material may have the advantage that it is more difficult to manipulate the diffusor structure 145 in order to increase laser safety of the laser arrangement 100.

Fig. 4 shows three examples of intensity distributions in one defined field-of-view. The ordinate is assigned to the intensity 51 and the abscissa is assigned to the angle 53 along one cross-section parallel to the surface of the illumination pattern in the field-of-view (e.g. along a horizontal center line of the illumination pattern shown in Fig. 5). The continuous line 61 shows a desirable reference intensity distribution. The intensity distribution 61 is sharply restricted to the angular range of the field-of-view 55. No light is lost outside the field-of-view. In practice and because of the finite divergence angle of the VCSEL it is not possible to realize such desired distribution. A second intensity distribution 63 shows an intensity distribution of typical VCSELs with a divergence angle of 20° in air with diffusor. The divergence of the laser light 10 smears out the profile of the tailored diffusor resulting in less light inside the angular range of the field-of-view 55. The intensity distribution 63 causes optical losses which may be 20% or higher especially if the desired intensity distribution requires a high intensity close to the edges. The improved intensity distribution 65 which can be provided by means of the laser arrangement comprising the optical structure 140 and the diffusor structure 145 decreases the losses by concentrating the transformed light essentially to the angular range of the field-of-view 55 similar as the ideal reference intensity distribution 61 and provides a better defined intensity profile across angular range of the field-of-view 55. The intensity in the center of the intensity distribution 65 is increased and less light is lost outside the field of view. The intensity distribution 65 across the angular range of the field-of-view 55 (and across the total three-dimensional field-of-view) can be tailored by means of the optical structure 140 and the diffusor structure 145 as described above. The tailored intensity distribution 65 may therefore enable an adaption to the camera optics of a time-of-flight camera.

The optical structure 140 in combination with the diffusor structure 145 may transform the laser light 10 to transformed laser light 150 such that the laser light of each VCSEL 130 may be directed to one associated sector 21 of the illumination pattern 20 in the defined field of view as shown in Fig. 5. Which VCSEL 130 is associated to one respective sector 21 depends on, for example, the inclination of an optical axis of a chirped microlens of the optical structure 140 to which the laser light 10 is directed and the corresponding substructure or section 147 of the diffusor structure 145. The associated sectors 21 may preferably overlap or be even identical with the defined field-of-view. The optical structure 140 in combination with the diffusor structure 145 transforms the laser light 10 such that the concentration (no collimation) of the transformed laser light 145 within the field-of-view may be improved and especially the tailored intensity distribution 65 across the field-of-view may

be provided such that the illumination pattern 20 is essentially restricted to the defined field of view and in addition sufficient light is provided at the rim of the field of view (see tailored intensity distribution 65).

Fig. 6 shows a principal sketch of a time-of-flight sensor module 200 which may be comprised in a time-of-flight camera. The time-of-flight sensor module 200 comprises a laser arrangement 100 in accordance with one of the embodiments discussed above. The time-of-flight sensor module 200 further comprises a detector 221 which is arranged to detect very short light pulses. Such short laser pulses may be caused by transformed laser light 150 emitted by the laser arrangement 100 hitting an object 300. A part of the transformed laser light 150 is reflected by the object 300 such that reflected laser light 202 is received by optical device 240 (e.g. camera optics comprising lens or lens arrangement) which images the received laser light to detector 221 (e.g. array of single photon avalanche diodes). The reflected laser light 202 causes a corresponding electrical signal or signals in the detector 221. An electrical driver 230 may be arranged to electrically drive the VCSEL array or optionally each VCSEL or sub-groups of VCSELs of the VCSEL array separately. A controller 250 is connected with the electrical driver 230 in order to control, for example, start and stop time of the laser pulses emitted by the VCSEL array. The controller 250 is further connected with the detector 221 in order to receive the electrical signal or signals caused by the reflected laser light 202 detected by detector 221. The time-of-flight sensor module 200 further comprises an optional interface 235 to transfer start and stop time of the transformed laser light 150 emitted by the corresponding VCSEL or group of VCSELs, information about the illumination pattern 20 in the field-of-view as well as time of reception of the electrical signal or signals caused by the reflected laser light 202. The transferred data can be used to calculate the time-of-flight of the laser light and therefore a distance between the time-of-flight sensor module 200 and the object 300. The time-of-flight sensor module 200 may alternatively comprise an evaluator (not shown) electrically connected with the controller 250 (or may comprise or be comprised by controller 250) in order to determine the distance(s) to the object. Several distance measurements may be used to determine a velocity or even an acceleration of the object 300. The illumination pattern provided by means of the VCSEL array may be adapted to the optical device 240. The intensity may, for example, increase at the rim of the illumination pattern 20 in order to compensate optical losses of the optical device 240 (see tailored intensity distribution 65).

Fig. 7 shows a principal sketch of a process flow of a method of fabricating a VCSEL array 100. In step 410 a semiconductor substrate 101 is provided. The semiconductor

substrate 101 is part of a semiconductor wafer. In the subsequent step 420 at least two VCSELs 130 are provided on a processing side of the semiconductor substrate 101. An optical structure 140 is provided in step 430 such that one optical structure 140 is associated with one corresponding VCSEL array. The diffusor structure 145 is provided in step 440. The optical structure 140 is arranged in step 450 to reduce a divergence angle of laser light 10 emitted by each VCSEL 130 to a section 147 of the diffusor structure 145 assigned to the respective VCSEL 130. The sections 147 of the diffusor structure 145 are arranged to transform the collimated laser light to transformed laser light 150 such that a continuous illumination pattern 20 can be provided in a reference plane, and to increase a size of the illumination pattern 20 in comparison to an untransformed illumination pattern which can be provided without the diffusor structure.

While the invention has been illustrated and described in detail in the drawings and the foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive.

From reading the present disclosure, other modifications will be apparent to persons skilled in the art. Such modifications may involve other features which are already known in the art and which may be used instead of or in addition to features already described herein.

Variations to the disclosed embodiments can be understood and effected by those skilled in the art, from a study of the drawings, the disclosure and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality of elements or steps. 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.

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

LIST OF REFERENCE NUMERALS:

10	laser light
20	illumination pattern
21	sector of illumination pattern
51	intensity
53	angle
55	angular range of field-of-view
61	ideal reference intensity distribution
63	intensity distribution of typical VCSEL with diffusor
65	improved intensity distribution
100	laser arrangement
101	semiconductor substrate
130	VCSEL
140	optical structure
143	bonding layer
145	diffusor structure
147	section of diffusor structure
150	transformed laser light
200	time-of-flight sensor module
202	reflected laser light
221	light detector
230	electrical driver
235	interface
240	optical device
250	controller
300	object
410	step of providing semiconductor substrate
420	step of providing at least two VCSELs
430	step of providing optical structure
440	step of providing diffusor structure
450	step of arranging optical structure and diffusor structure

CLAIMS:

1. A laser arrangement (100) comprising at least one VCSEL array comprising two, three, four or more VCSELs (130) arranged on a common semiconductor substrate (101), wherein the laser arrangement (100) further comprises at least one optical structure (140) and a diffusor structure (145), wherein the optical structure (140) is arranged to reduce a divergence angle of laser light (10) emitted by each VCSEL (130) to a section (147) of the diffusor structure (145) assigned to the respective VCSEL (130), wherein the diffusor structure (145) is arranged to transform the laser light received from the optical structure (140) to transformed laser light (150) such that a continuous illumination pattern (20) can be provided in a reference plane in a defined field-of-view, wherein the diffusor structure (145) is arranged to increase a size of the illumination pattern (20) in comparison to an untransformed illumination pattern which can be provided without the diffusor structure (145), wherein the VCSEL array, optical structure (140) and diffusor structure (145) are arranged such that the sections of the diffusor structure (145) assigned to different VCSELs do not overlap, wherein the diffusor structure (145) is characterized by varying diffusor properties across the diffusor structure (145), wherein the variation of the diffusor properties is arranged to concentrate the illumination pattern (20) in the defined field-of-view.

2. The laser arrangement (100) according to claim 1, wherein the diffusor structure (145) comprises diffusor substructures to vary the diffusor properties which are aligned with the sections (147) receiving the laser light with reduced divergence angle, wherein the diffusor substructures are characterized by different surface structures to spread the laser light (10) received from the optical structure (140) differently depending on the position of the respective VCSEL (130) in the VCSEL array.

3. The laser arrangement (100) according to claim 1 or 2, wherein the optical structure (140) is integrated on wafer level.

4. The laser arrangement (100) according to anyone of the preceding claims, wherein the optical structure (140) comprises collimating micro lenses for reducing the divergence angle by collimating the laser light (10).

5. The laser arrangement (100) according to claim 4, wherein the collimating micro lenses are chirped micro lenses.

6. The laser arrangement (100) according to anyone of claims 1-5, wherein each VCSEL (130) is a top emitter which is arranged to emit the laser light (10) in a direction away from the semiconductor substrate (101), wherein the optical structure (140) comprises a material provided on top of a semiconductor layer structure of the VCSEL array, wherein the material is transparent in the wavelength range of the laser light (10).

7. The laser arrangement (100) according to anyone of claims 1-5, wherein each VCSEL (130) is a bottom emitter which is arranged to emit the laser light (10) through the semiconductor substrate (101), wherein the optical structure is provided on a surface of the semiconductor substrate (101) which is arranged opposite with respect to the VCSELs (130).

8. The laser arrangement (100) according to claim 7, wherein the collimating optical structure (140) is integrated in the semiconductor structure of the VCSEL array (100).

9. The laser arrangement (100) according to claim 7, wherein the optical structure (140) comprises a material provided on top of the semiconductor layer structure of the VCSEL array, wherein the material is transparent in the wavelength range of the laser light (10).

10. The laser arrangement (100) according to anyone of the preceding claims, wherein at least a part of the VCSELs (130) are arranged to be individually controlled to emit laser light (10).

11. The laser arrangement (100) according to anyone of the preceding claims, wherein the sections (147) of the diffusor structure (145) are arranged such that each VCSEL (130) is arranged to illuminate a sector (21) of the illumination pattern (20), wherein each sector (21) overlaps at least with one other sector (21).

12. The laser arrangement according to anyone of the preceding claims, wherein the optical structure (140) comprises a partly reflective mirror structure, wherein the partly reflective mirror structure is arranged to decrease a divergence angle of the VCSEL.

13. A light emitting device comprising at least one laser arrangement (100) array according to anyone of the preceding claims and an electrical driver (230) for providing an electrical drive current to the VCSELs (130).

14. A time-of-flight camera comprising the light emitting device according to claim 13, and a light detector (221) for detecting transformed laser light (150) reflected by an object (300), and wherein and evaluator is arranged to determine a distance to the object (300) by means of the transformed laser light (150) detected by the light detector (221).

15. A method of fabricating a laser arrangement (100), the method comprising the steps of:

providing a semiconductor substrate (101),

providing at least two VCSELs (130) on the semiconductor substrate (101),

providing an optical structure (140),

providing a diffusor structure (145), and

arranging the optical structure (140) to reduce a divergence angle of laser light (10) emitted by each VCSEL (130) to a section (147) of the diffusor structure (145) assigned to the respective VCSEL (130), wherein the sections (147) of the diffusor structure (145) are arranged to transform the laser light received from the optical structure (140) to transformed laser light (150) such that a continuous illumination pattern (20) can be provided in a reference plane in a defined field-of-view, and to increase a size of the illumination pattern (20) in comparison to an untransformed illumination pattern which can be provided without the diffusor structure, wherein the VCSEL array, optical structure (140) and diffusor structure (145) are arranged such that the sections of the diffusor structure (145) assigned to different VCSELs do not overlap, wherein the diffusor structure (145) is characterized by varying diffusor properties across the diffusor structure (145), wherein the variation of the diffusor properties is arranged to concentrate the illumination pattern (20) in the defined field-of-view.

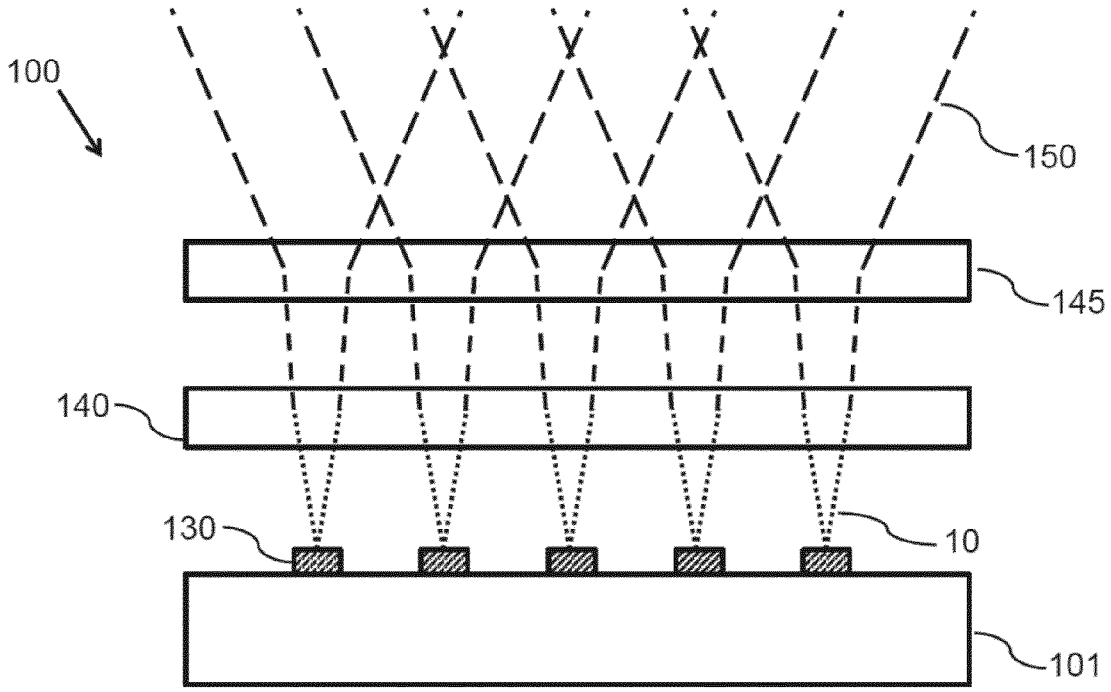


Fig. 1

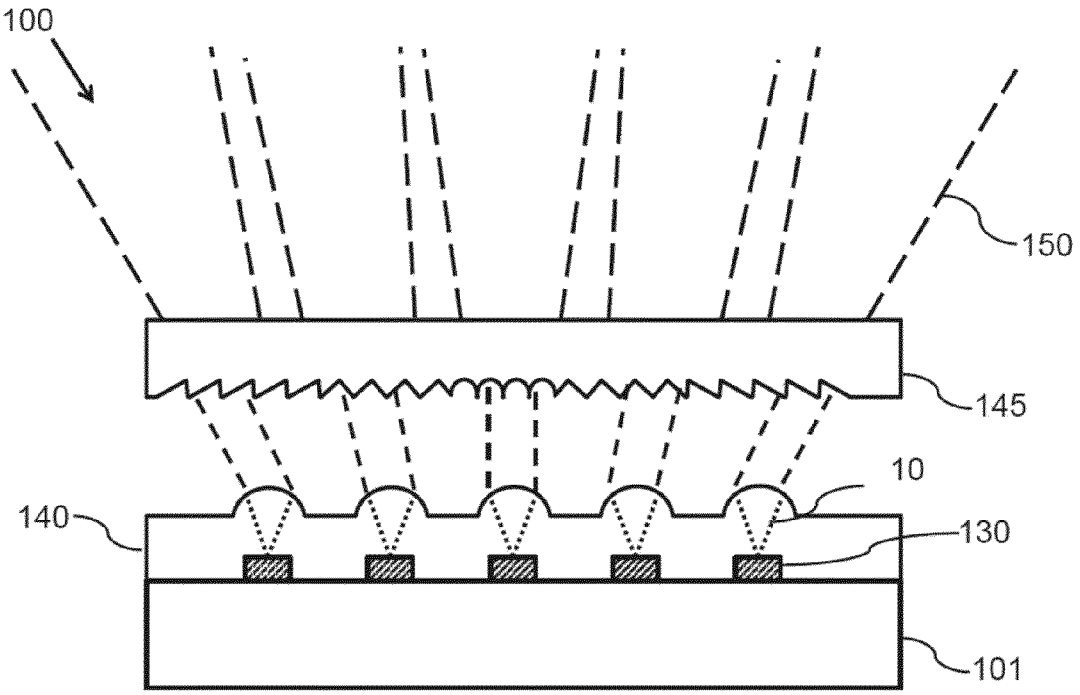


Fig. 2

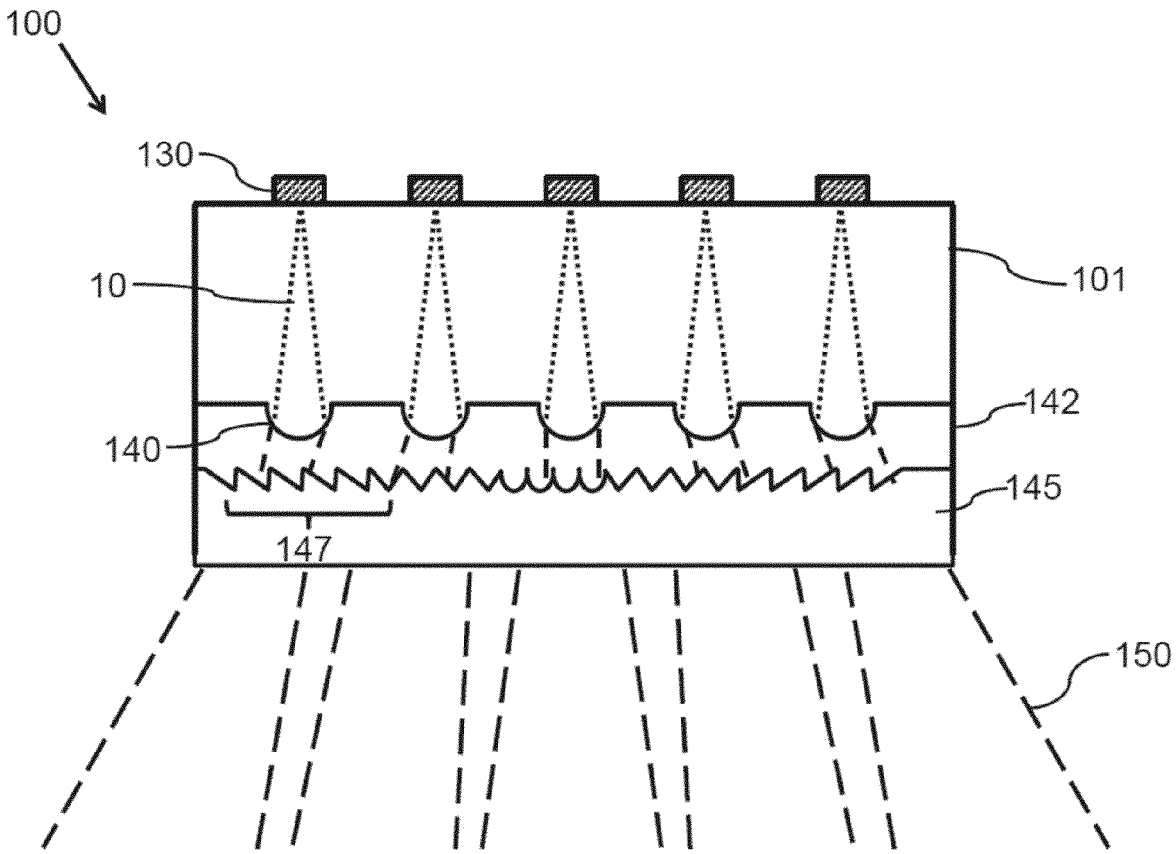


Fig. 3

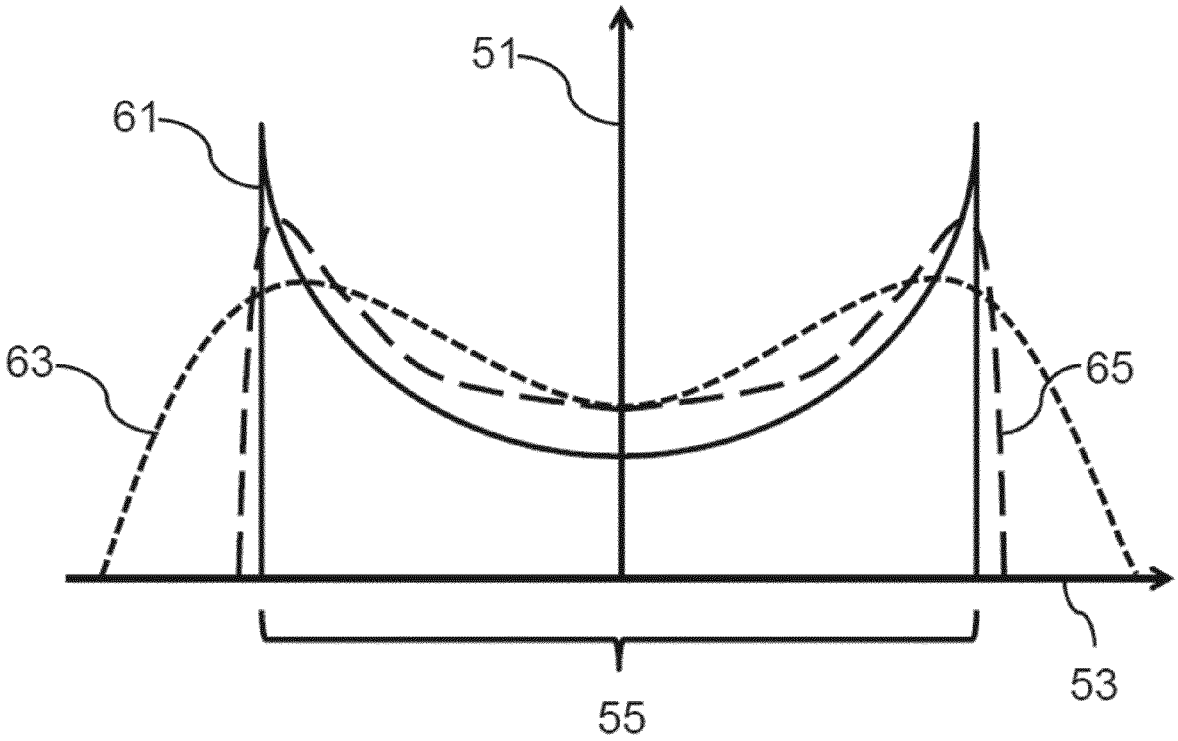


Fig. 4

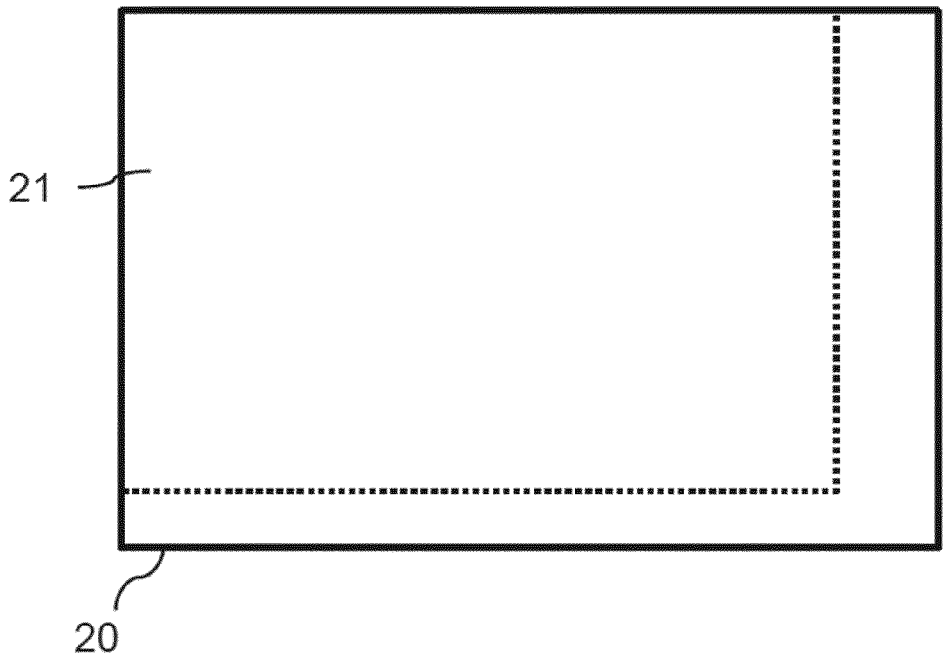


Fig. 5

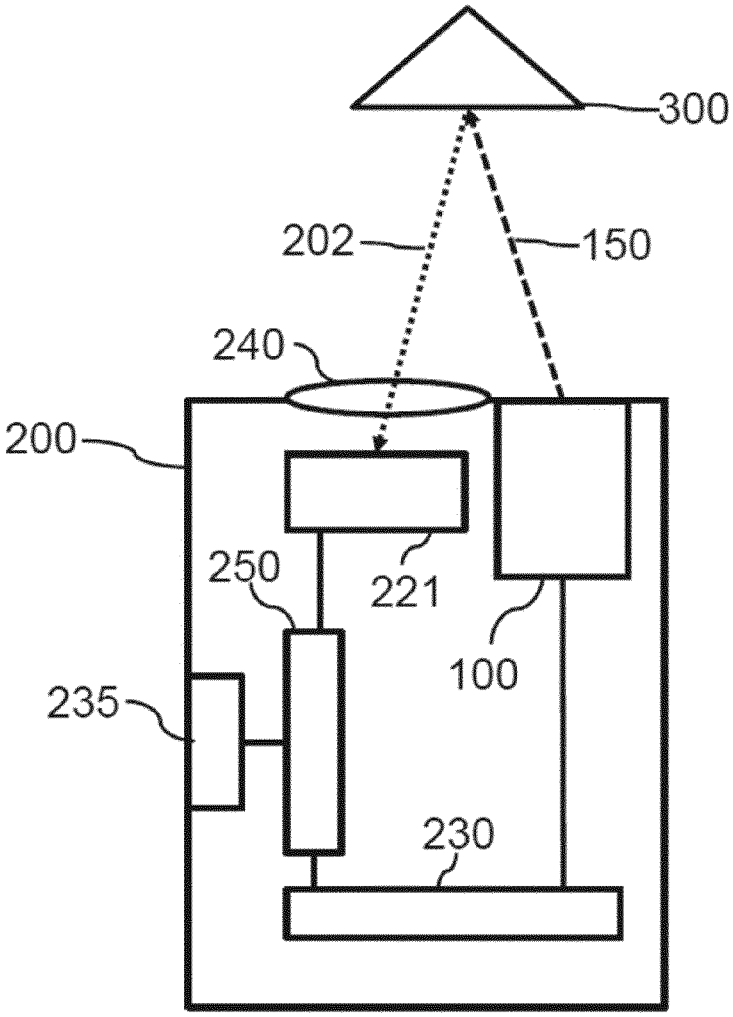


Fig. 6

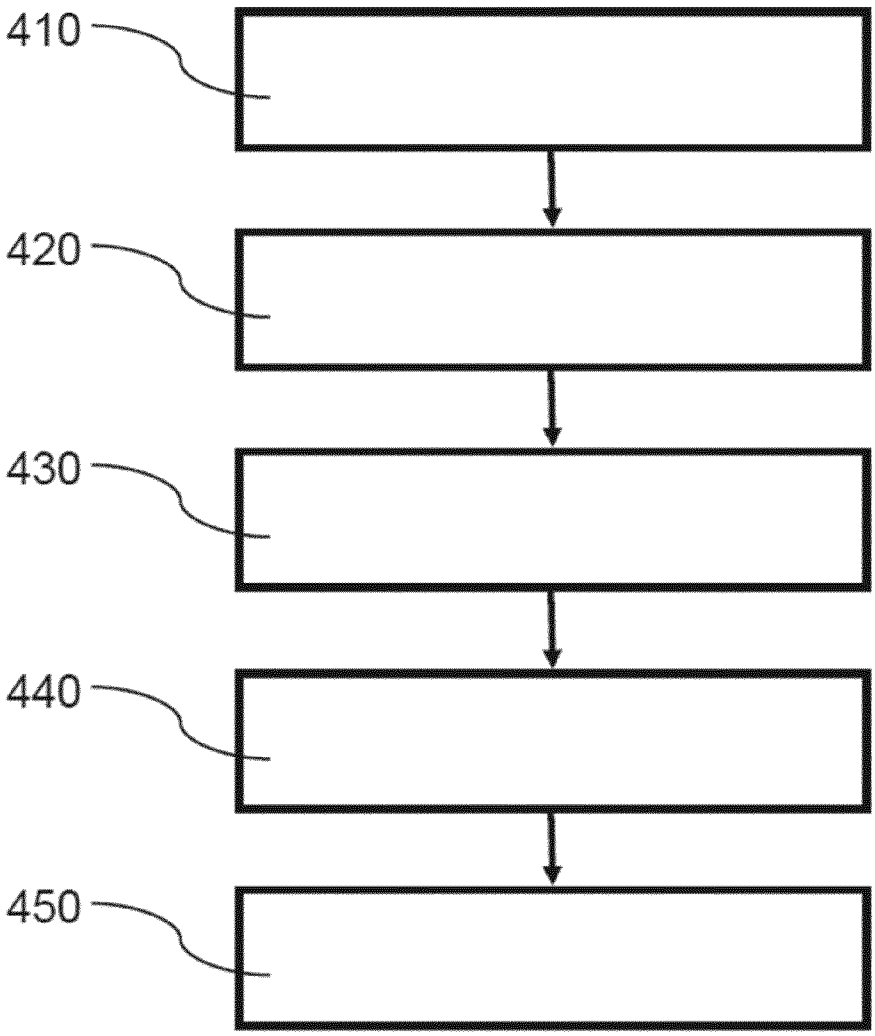


Fig. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/073355

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01S5/183 H01S5/42
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)
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, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2016/164261 A1 (WARREN MIAL E [US]) 9 June 2016 (2016-06-09) ab. fig.12,13 claim 6 fig.7 -----	1-15
A	US 2016/311230 A1 (CONRADS RALF GORDON [DE] ET AL) 27 October 2016 (2016-10-27) abstract; figures 1,3 paragraphs [0078] - [0079] -----	1-15
A	US 2007/071056 A1 (CHEN YE [US]) 29 March 2007 (2007-03-29) abstract; figure 3 -----	1-15

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

☒ See patent family annex.

* Special categories of cited documents :

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 November 2018	27/11/2018

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	Lendroit, Stéphane

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2018/073355

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