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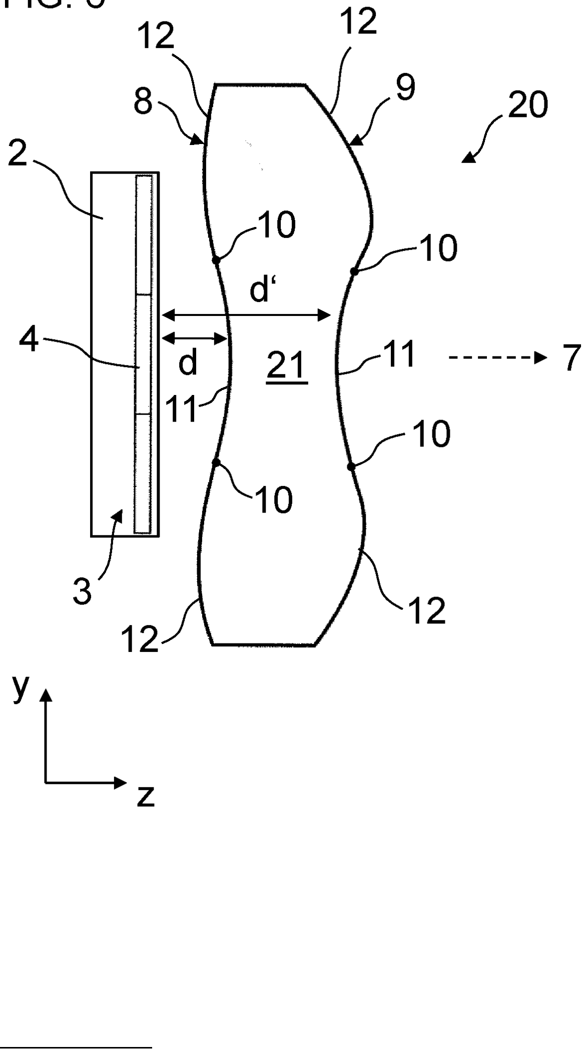
(54) LIGHT MODULE FOR A VEHICLE HEADLAMP HAVING LED LIGHT SOURCE AND VEHICLE HEAD LAMP

(57) The invention describes a light module (1) for a vehicle head lamp (14), comprising an LED light source (2) for generating light, the LED light source (2) comprising an LED array (3) having a plurality of LEDs (4), a collimating optic (5, 21, 26, 31), and an imaging optic (6). The collimating optic (5, 21, 26, 31) is arranged in a light path (7) between the LED light source (2) and the imaging optic (6) such that the collimating optic (5, 21, 26, 31) collects the light generated by the LED light source (2) and collimates it to the imaging optic (6). The imaging optic (6) is configured to generate an image of the plurality of LEDs (4) in a far field of the light generated by the LED light source (2). The collimating optic (5, 21, 26, 31) comprises a light entry surface (8) and a light exit surface (9), at least one of which having, with respect to a first spatial direction (y), a curvature comprising at least two inflection points (10). The curvature of a first surface section (11) extending between the two inflection points (10) of the respective one or more of the light entry and exit surfaces (8, 9) is concave.

The invention further describes a vehicle head lamp (14) comprising such a light module (1).

FIG. 6



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Description

FIELD OF THE INVENTION

[0001] The invention relates to a light module comprising an LED light source and, particularly, to an LED light module for a vehicle head lamp. The invention further relates to a vehicle head lamp comprising such a light module.

BACKGROUND OF THE INVENTION

[0002] Light emitting diodes (LEDs) are rapidly gaining popularity because of their longevity and low energy credentials. Advances in manufacturing have led to the emergence of chip-sized LED packages or modules in which at least one LED, however, typically, a plurality of LEDs are packaged together and are presented as a single die. Such packages are therefore sometimes referred to as single die emitters (SDE) or micro LED arrays (MLA). Due to the Lambertian luminous distribution and brightness produced by such packages, they are considered a key enabler of LED-based solutions in a number of application domains, including automotive lighting and projection lighting.

[0003] Such LED modules typically produce a Lambertian luminous distribution centred about an optical axis of the package. In some application domains including but not limited to automotive front lighting, e.g. automotive head lamps, the use of such packages must therefore be combined with additional optical elements in order to reshape and redirect the luminous distribution in the desired direction, often to comply with the appropriate regulations concerning allowable beam profiles generated by different types of head lamps, e.g. full beams, dipped or low beams, and so on.

[0004] US 8,764,259 B2 discloses a lighting assembly including a semiconductor light source, a support with a recess within which the semiconductor light source is positioned, and a collimator having light entry and light exit openings joined together by at least one side wall. The collimator is moveable relative to the support. The collimator is attached to the support such that the light entry opening of the collimator and the recess are joined so that light emitted by the semiconductor light source within the recess enters the collimator through the light entry opening and exits essentially only through the light exit opening of the collimator for any position of the collimator over its range of motion. This assembly is relatively bulky and costly.

[0005] While there is a variety of techniques that may be used to control the light distribution pattern from an LED light module or a vehicle's head lamp assembly, these techniques provide limited adaptability, e.g. by providing only two states of operation: high beams and low beams. Accordingly, what is needed is a light module as well as a vehicle head lamp which are capable of providing a variety of distribution patterns along with improved performance, where performance is assessed on the qualities of illumination homogeneity, compactness (miniaturization), manufacturing ease, cost, and output efficiency.

SUMMARY OF THE INVENTION

[0006] It is an object of the present invention to provide a light module comprising an LED light source and a vehicle head lamp comprising such a light module which are capable of providing a variety of distribution patterns along with improved illumination/intensity homogeneity, compact and miniaturized design, manufacturing ease, cost, and output efficiency.

[0007] The invention is defined by the independent claims. The dependent claims define advantageous embodiments.

[0008] According to a first aspect, a light module for a vehicle head lamp is provided that comprises an LED light source for generating light, wherein the LED light source comprises an LED array having a plurality of LEDs. Further, the light module comprises a collimating optic and an imaging optic. The collimating optic is arranged in a light path (also referred to as an *optical path* which is the path that light takes in travelling an optical medium or system) between the LED light source and the imaging optic such that the collimating optic collects the light generated by the LED light source and collimates it to the imaging optic, i.e. the collimating optic collects the light from a plurality, preferably essentially from all, of the light generating LEDs.

[0009] The imaging optic is configured to generate an image of the plurality of LEDs in a far field of the light generated by the LED light source. In general, the far field of the light is considered a field in space comparatively far away from the light source, e.g. at least several few meters up to several 10 meters, e.g. about 25 meters, or even 100 meters.

[0010] Further, according to the invention, the collimating optic comprises a light entry surface facing the LED light source, and a light exit surface facing the imaging optic, wherein one or more of the light entry surface and the light exit surfaces comprise, with respect to a first spatial direction y (herein also referred to as a *height or vertical direction* of the light module), a curvature comprising at least two inflection points. It is to be noted that, with respect to the first spatial direction y, at the inflection points the respective one or more of the light entry and exit surfaces changes its nature of curvature, e.g. from convex to concave and vice versa.

[0011] Further, according to the invention, the curvature of a first surface section extending between the two inflection points of the respective one or more of the light entry and exit surfaces is concave.

[0012] In other words, as the first surface section between the two inflection points has a concave curvature with respect to the first spatial direction y, other second surface sections of the respective light entry and exit surfaces adjoining the first surface section must have a curvature with an opposite direction, i.e. in this case a convex curvature, following from the definition of an inflection point (i.e. change of curvature). It is to be understood that, in the sense of the present invention, the term *concave* means a curvature that is directed towards the inside or interior of the collimating optic and a body forming the collimating optic, respectively. Consequently, according to the present invention, a *convex* curvature is a curvature being directed towards the exterior or outside of the collimating optic.

[0013] The herein-described combination and specific arrangement of the LED array, the collimating optic having its defined shape, and the imaging optic according to the invention bring about the advantage that a variety of distribution patterns can be generated in the far field of the light generated by the plurality of LEDs as a function of their actual individual activation state. Thus, it is possible to improve either the illumination and light intensity homogeneity in the far field, respectively, and still shape the light intensity distribution in the far field as a function of the light intensity generated by individual LEDs. Furthermore, the overall output efficiency of the light module is also improved as essentially all the light generated by the light source is projected into the far field. The imaging of the LEDs in the far field according to the invention yields the light intensity distribution desired, i.e., a distribution showing only a comparatively smooth decline of light intensity from the centre of the far field (i.e. the optical axis) towards the outer periphery of the entire light beam generated by the plurality of LEDs together in order to provide illumination of a rather wide field of view, yet still being capable of sharply imaging each individual LED in the far field (i.e. yielding a high imaging contrast of individual LEDs). Therefore, deactivating and activating individual LEDs will show a tight-bounded light intensity change in the far field. Thus, for example, by switching off the respective LEDs, blinding of oncoming traffic will be effectively avoided while still sufficient illumination on the right hand side and left hand side of the oncoming traffic will be ensured.

[0014] Still further, imaging errors or aberrations of the individual LEDs in the far field introduced by the collimating optic could be (entirely) corrected or at least mitigated by the imaging optic.

[0015] Yet further, the light entry surface of the collimating optic may be arranged comparatively close to the LED array (or even/almost abutting the LED array), thus being capable of collecting essentially the overall light generated by the LEDs of the LED array as the entire LED array may be covered with only one single collimating optic, for example. Moreover, the close arrangement also improves precise mapping of (different) optical components to respective LEDs of the LED array. In other words, the collimating optic may extend across the entire LED array. This facilitates a compact design of the light module and further improves manufacturing ease and cost.

[0016] The other light entry surface or light exit surface could not have any inflection point with respect to (at least) the first spatial direction y, i.e. the respective light entry or exit surface not having any inflection point may be entirely planar or may entirely have a convex or concave curvature, thus still yielding further improvements with respect to manufacturing ease and cost.

[0017] As already stated above, the imaging optic may be configured and arranged such that it (entirely) corrects or at least minimizes (mitigates) imaging aberrations in the far field caused by the collimating optic, thus improving light/intensity distribution in the far field.

[0018] Yet further, the light entry surface of the collimating optic may be a continuous surface (i.e. not comprising any disruptions, discontinuities, recesses, projections and the like) with respect to one or more of the first spatial direction y and a second spatial direction x (herein also referred to as a *lateral/width/horizontal direction* of the light module) being perpendicular to the first spatial direction y. Being a single continuous surface, the light entry surface of the collimating optic covers a plurality or all individual LEDs of the LED array in the same manner (e.g. regarding distance, angle and the like), thus facilitating a tight neighbouring or even abutting arrangement of all the individual LEDs of the LED array enabling highly miniaturized and compact designs of the light module.

[0019] The LED array may be a micro LED array, i.e. a LED array having the plurality of individual LEDs arranged in very close proximity to each other (e.g. arranged on the same semiconductor substrate), i.e. almost or even abutting each other. The micro LED array facilitates a highly compact design of the light module along with a high overall output efficiency of the LED light source.

[0020] Still further, a cross section of the collimating optic may be constant along the second spatial direction x being perpendicular to the first spatial direction y, wherein the cross section is essentially aligned parallel to an yz-plane extending in the first spatial direction y and a third spatial direction z being perpendicular to both the first and second spatial directions x, y. Thus, besides improving manufacturing ease and cost, also light/intensity distribution in the far field are enhanced in a desired manner.

[0021] Furthermore, the collimating optic may comprise a collimating body being extrudable. In particular, the collimating body of the collimating optic may be one single (integral) material body which may be made of a polycarbonate or a glass material, for example. Also, a silicone material may be used to manufacture the collimating body, though polycarbonate and glass materials are particularly preferred materials. In any case, being able to manufacture the collimating optic by extrusion highly improves manufacturing ease and cost.

[0022] The LED array may be arranged in the form of a matrix comprising a plurality of adjoining LED rows with each LED row having a plurality of adjoining LEDs arranged therein.

[0023] The LED array may comprise 3 to 5 rows with each row comprising 20 to 40 LEDs, without being limited thereto. For example, 2 rows of LEDs or more than 5 rows of LEDs, e.g. 6, 7, 8 or still more rows of LEDs, may be provided. Also, less than 20 LEDs per row or more than 40 LEDs per row may be provided. Additionally, if a micro LED array is used as the LED array, the number of LEDs arranged in one row may even attain 10 times the numbers given above. However, in order to achieve the results described herein, the quantities specified in the accompanying claims represent particularly advantageous and thus especially preferred embodiments of the invention exhibiting optimal performance as to the compactness, manufacturing ease, cost, and output efficiency of the light module.

[0024] According to a second aspect of the invention, a vehicle head lamp comprising a light module in accordance with any embodiment described above is provided.

[0025] The vehicle head lamp may comprise a housing in which the light module is accommodated.

[0026] As further components of vehicle head lamps as well as their arrangement are well-known, a more detailed description thereof will be omitted for the sake of conciseness and readability of this specification.

[0027] It is to be understood that further preferred embodiments of the invention can also be any combination of features defined in the dependent claims with the features of the respective independent claim.

[0028] Further advantageous embodiments are defined below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

[0030] The invention will now be described, by way of example, based on embodiments with reference to the accompanying drawings.

[0031] In the drawings:

- Fig. 1 illustrates a side view of an embodiment of a light module according to the invention.
- Fig. 2 shows a perspective view of individual components of the light module of Fig. 1.
- Fig. 3 illustrates an enlarged perspective view of the arrangement of the light source and the collimating optic of the light module of Fig. 1.
- Fig. 4 shows a longitudinal section through the components of the light module illustrated in Fig. 3.
- Fig. 5 shows another perspective view of the collimating optic shown in Fig. 3.
- Fig. 6 depicts part of another embodiment of a light module according to the invention.
- Fig. 7 shows part of still another embodiment of a light module according to the invention.
- Fig. 8 shows part of yet another embodiment of a light module according to the invention.
- Fig. 9 depicts two light intensity graphs with respect to a first spatial direction y achieved with the light module shown in Fig. 1.
- Fig. 10 depicts two light intensity graphs with respect to a second spatial direction x achieved with the light module shown in Fig. 1.
- Fig. 11 shows a side view of an embodiment of a vehicle head lamp according to the invention.

[0032] In the Figures, like numbers refer to like objects throughout. Objects in the Figs. are not necessarily drawn to scale.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0033] Various embodiments of the invention will now be described by means of the Figures.

[0034] Fig. 1 schematically shows a side view of an embodiment of a light module 1 according to the invention. In particular, the presently described embodiment of the light module 1 may be used for a vehicle head lamp (cf. also Fig. 11).

[0035] The light module 1 shown in Fig. 1 comprises an LED light source 2 for generating light, wherein the LED light source 2 comprises an LED array 3 having a plurality of LEDs 4. Three individual LEDs 4 are visible in the side view of Fig. 1, each one marking a row of a plurality of LEDs 4 as will become apparent further below along with the explanation of Fig. 3, for example. Thus, the LED light source 2 comprises more than only three individual LEDs 4. In the embodiment of Fig. 1, the LED array 3 is a micro LED array (i.e. individual LEDs 4 being arranged in very close proximity to each other, e.g. gaps between neighbouring LEDs may be in the range of μm or even (directly) abutting each other). However, the invention is not limited to a micro LED array design.

[0036] The embodiment of the light module 1 shown in Fig. 1 further comprises a collimating optic 5 and an imaging optic 6. As is apparent from Fig. 1, the collimating optic 5 is arranged in a light path 7 (optical path) between the LED light source 2 and the imaging optic 6 such that the collimating optic 5 collects the light generated by the LED light source 2 and collimates it to the imaging optic 6.

[0037] In the present embodiment, the collimating optic 5 comprises one single collimating body, preferably an extrudable body. Especially preferred materials for the collimating optic/body 5 are polycarbonate materials or glass materials, though a silicone material may also be used.

[0038] The imaging optic 6 is configured to generate an image of the plurality of LEDs 4 in a far field of the light generated by the LED light source 2, i.e. far to the right hand side of the imaging optic 6 shown in Fig. 1, e.g. about 20 m to 30 m distant from the light module 1. The imaging optic 6 is further configured and arranged such that it corrects or at least mitigates/minimizes imaging aberrations in the far field caused by the collimating optic 5. To this end, a light entry surface 61 of the imaging optic 6 and a light exit surface 62 of the imaging optic 6 are shaped accordingly. Preferably, the light entry and exit surfaces 61, 62 of the imaging optic 6 are smooth and/or continuous surfaces.

[0039] The collimating optic 5 comprises a light entry surface 8 facing the LED light source 2 and a light exit surface 9 facing the imaging optic 6.

[0040] In the following description of the light module 1, Figs. 2 to 5 are referenced collectively. Fig. 2 shows a perspective view of individual components of the light module of Fig. 1 as mentioned above, i.e. the LED array 3, the plurality of LEDs 4, the collimating optic 5, and the imaging optic 6. Fig. 3 illustrates an enlarged perspective view of the arrangement of the LED light source 2 (not shown but accommodating the visible individual LEDs 4 as the LED array 3) and the collimating optic 5 of the light module 1 of Fig. 1. Fig. 4 shows a longitudinal section through the components of the light module 1 illustrated in Fig. 3, and Fig. 5 shows another perspective view of the collimating optic 5 shown in Fig. 3.

[0041] s is well observable in Fig. 4, in the present embodiment of the light module 1, the light entry surface 8 of the collimating optic 5 has a curvature with respect to a first spatial direction y (herein also referred to as the height or vertical direction of the light module 1). Moreover, the curvature of the light entry surface 8 comprises at least two inflection points 10, in the present embodiment exactly (only) two inflection points 10. Furthermore, a first surface section 11 extending between the two inflection points 10 of the light entry surface 8 has a greater shortest distance d from the LED array 3 than second surface sections 12 of the light entry surface 8 adjoining the first surface section 11. It is to be understood that the shortest distance d is a distance between any point of the first surface section 11 of the light entry surface 8 of the collimating optic 5 and an opposing surface of the LED array 3 having the shortest possible length therebetween.

[0042] Thus, the first surface section 11 of the light entry surface 8 of the collimating optic 5 can be described as a concave surface section with respect to the spatial direction y, whereas the second adjoining surface sections 12 can be described as convex surface sections of the collimating optic 5 with respect to the spatial direction y. In other words, the first surface section 11 of the light entry surface 8 having the concave curvature effects a light refraction with respect to the light entering the collimating optic 5 through its light entry surface 8 like a diverging lens, whereas the second (adjoining) surface sections 12 of the light entry surface 8 having the convex curvature effect a light refraction with respect to the light entering the collimating optic 5 through its light entry surface 8 like converging lenses.

[0043] Furthermore, according to the present embodiment of Fig. 4, the light exit surface 9 of the collimating optic 5 does not have any inflection point with respect to at least the first spatial direction y. Rather, in the presented case, it has an entirely convex curvature with respect to the spatial direction y.

[0044] As is well observable in Figs. 2, 3, and 5, the light entry surface 8 of the collimating optic 5 is a continuous surface with respect to the first spatial direction y and the second spatial direction x being perpendicular to the first spatial direction y, i.e. the light entry surface 8 does not comprise any disruptions, discontinuities, recesses, projections and the like with respect to the first and second spatial directions x and y.

[0045] Furthermore, in the present embodiment of the light module 1, the cross section of the collimating optic 5 is constant along the second spatial direction x, wherein the cross section is aligned parallel to an yz-plane extending in the first spatial direction y and a third spatial direction z being perpendicular to both the first and second spatial directions x, y, for example as illustrated in Figs. 3 and 4.

[0046] Furthermore, Figs. 3 and 4 clearly depict that the collimating optic 5 of the present embodiment, in particular its light entry surface 8, is arranged in close proximity to the LED array 3. Advantageously, according to the invention there is no need to arrange other (additional) optically active elements between the individual LEDs 4 and the light entry surface 8 of the collimating optic 5. The light entry surface 8 extends across the entire LED array 3, i.e., in the present embodiment, all individual LEDs 4 are covered by the continuous light entry surface 8 of the single collimating optic 5.

[0047] From Fig. 3 it will further become clear that in the present embodiment of the light module 1 the LED array 3 is arranged in the form of a matrix comprising a plurality of adjoining LED rows 13 with each LED row 13 having a plurality of adjoining LEDs 4 arranged therein. In particular, Fig. 3 shows three LED rows 13 each having 30 individual LEDs 4 arranged therein in close proximity to each other, without being limited to such quantities. More or less LED rows 13 and/or more or less LEDs 4 may be provided without departing from the principles of the present invention.

[0048] Fig. 6 depicts part of another embodiment of a light module 20 (imaging optic not shown) according to the invention. The main difference between the light module 20 shown in Fig. 6 and the light module 1 shown in Fig. 1 is a collimating optic 21 instead of the collimating optic 5. As apparent from Fig. 6, the collimating optic 21 comprises light entry and exit surfaces 8 and 9, respectively, wherein both the light entry surface 8 and the light exit surface 9 each have a curvature with respect to the first spatial direction y comprising two inflection points 10. Moreover, the first surface section 11 extending between the two inflection points 10 of the light entry surface 8 has a greater shortest distance d from the LED array 3 than second surface sections 12 of the light entry surface 8 adjoining the first surface section 11 on the light entry surface 8. However, the first surface section 11 extending between the two inflection points 10 of the light exit surface 9 has a smaller shortest distance d' from the LED array 3 than second surface sections 12 of the light exit surface 9 adjoining the first surface section 11 on the light exit surface 9.

[0049] In other words, the curvature of the first surface section 11 of the light entry surface 8 as well as the curvature of the first surface section 11 of the light exit surface 9 are both concave with respect to the first spatial direction y. The curvature of the second (adjoining) surface sections 12 of the light entry surface 8 and the curvature of the second (adjoining) surface sections 12 of the light exit surface 9 are both convex with respect to the first spatial direction y.

[0050] Fig. 7 shows part of still another embodiment of a light module 25 (imaging optic not shown) according to the invention. The major difference between the light module 25 shown in Fig. 7 and the light module 1 shown in Fig. 1 is a collimating optic 26 instead of the collimating optic 5. As observable from Fig. 7, the collimating optic 26 comprises a light entry surface 8 being entirely planar. This embodiment of the collimating optic 26 shown in Fig. 7 may be particularly suitable for the manufacturing thereof using a glass material. Consequently, the light entry surface 8 of the collimating optic 26 does not have any inflection point with respect to at least the first spatial direction y. However, in the present embodiment of the light module 25, the light exit surface 9 of the collimating optic 26 has a curvature with respect to the first spatial direction y comprising two inflection points 10. In particular, the first surface section 11 extending between the two inflection points 10 of the light exit surface 9 has a smaller shortest distance d' from the LED array 3 than second surface sections 12 of the light exit surface 9 adjoining the first surface section 11 on the light exit surface 9.

[0051] Again, the curvature of the first surface section 11 of the light exit surface 9 can be described as a concave curvature with respect to the first spatial direction y. The curvature of the second (adjoining) surface sections 12 of the light exit surface 9 can be described as a convex curvature with respect to the first spatial direction y on the other hand.

[0052] Fig. 8 shows part of yet another embodiment of a light module 30 according to the invention (imaging optic not shown). The essential difference between the light module 30 shown in Fig. 8 and the light module 1 shown in Fig. 1 is a collimating optic 31 instead of the collimating optic 5. As shown in Fig. 8, the collimating optic 31 comprises a light entry surface 8 entirely having a convex curvature with respect to the first spatial direction y. Consequently, the light entry surface 8 of the collimating optic 31 does not have any inflection point with respect to at least the first spatial direction y. However, in the present embodiment of the light module 30, the light exit surface 9 of the collimating optic 31 has a curvature with respect to the first spatial direction y comprising two inflection points 10 in a similar way as the light exit surface 9 of the collimating optic 26 of the light module 25 shown in Fig. 7. Therefore, the curvature of the surface section 11 of the light exit surface 9 is concave, whereas the curvature of the second (adjoining) surface sections 12 of the light exit surface 9 are convex.

[0053] Fig. 9 depicts two graphs a) and b) showing a light intensity I as a function of the first spatial direction y (height or vertical direction) yielded in the far field using the light module 1 shown in Fig. 1.

[0054] In Fig. 9a the light intensity distribution in the far field is shown for the y direction when all LEDs 4 of all three LED rows 13 of the LED array 3 are active, i.e. generating light. As clearly depicted in Fig. 9a, each of the three LED rows 13 generates an illumination maximum M1, M2, M3 in the far field.

[0055] In Fig. 9b the light intensity distribution in the far field is shown for the y direction when the second one of the three LED rows 13 (i.e. the middle row) of the LED array 3 is entirely deactivated, i.e. not generating any light. Due to the high intensity contrast of the LED projection in the far field yielded with the light module 1 according to the invention the light intensity I of the middle (second) LED row 13 visible in Fig. 9a (cf. maximum M2) is essentially entirely reduced to zero in Fig. 9b while still remaining the light intensities of the remaining two active LED rows (cf. maxima M1 and M3) essentially on the same intensity level as in Fig. 9a. Thus, exact shaping of different light intensity distributions in the far field with respect to the first spatial direction y (height direction) is achieved by the light module 1 according to the invention.

[0056] Fig. 10 depicts two graphs a) and b) showing light intensity I as a function of the second spatial direction x (width or horizontal direction) yielded using the light module 1 shown in Fig. 1.

[0057] In Fig. 10a the light intensity distribution in the far field is shown for the x direction when all individual LEDs 4 of each of the three LED rows 13 of the LED array 3 are active, i.e. generating light. In this case, each LED column consisting of three individual LEDs 4 arranged on top of each other (i.e. one individual LED 4 in each of the three LED rows 13) generates an illumination maximum in the far field as is clearly shown in Fig. 10a, one of which is denoted with Mx. From Fig. 10a it is apparent that a smooth intensity distribution across a large width range (x direction) from about -14 m to +14 m around a centred optical axis at 0 m is achieved applying the teachings of the present invention. Yet, deactivating of individual LED columns (i.e. one individual LED 4 in each of the three LED rows 13 being arranged on top of each other) immediately leads to sharp and defined light intensity minima or drop-outs DO at the respective spatial locations x, e.g. in Fig. 10b below -10 m, between -8 m and -5 m, between -2 m and 0 m, and at 5 m. Thus, exact shaping of different light intensity distributions in the far field also with respect to the second spatial direction x (width/horizontal direction) is achieved by the light module 1 according to the invention.

[0058] Fig. 11 shows a side view of an embodiment of a vehicle head lamp 14 according to the second aspect of the invention. The vehicle head lamp 14 comprises a light module 1 according to any of the embodiments described herein, e.g. any one of the presented light modules 1, 20, 25, 30. In the embodiment shown in Fig. 11 light module 1 is accommodated within a housing 15 of the vehicle head lamp 14.

[0059] It is to be understood that the LED light source 2 is supplied by electrical power accordingly, e.g. via an electric cable 16 which in turn may be connected to an electrical energy source (not shown) and an electric control unit (also not shown), respectively.

[0060] 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.

[0061] 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.

[0062] 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.

[0063] Any reference signs in the claims should not be construed as limiting the scope thereof.

REFERENCE SIGNS:

[0064]

1	Light module
2	LED light source
3	LED array
4	LED
5	Collimating optic
6	Imaging optic
7	Light path
8	Light entry surface of collimating optic 5
9	Light exit surface of collimating optic 5
10	Inflection point
11	Concave first surface section between inflection points 10
12	Convex second surface section adjoining first surface section 11
13	Row of individual LEDs
14	Vehicle head lamp
15	Housing
16	Electric cable
20	Light module
21	Collimating optic
25	Light module
26	Collimating optic
30	Light module
31	Collimating optic
61	Light entry surface of imaging optic 6
62	Light exit surface of imaging optic 6
d, d'	Shortest distance between LED array 3 and light entry surface 8 of collimating optic 5
DO	Intensity drop-out
I	Light intensity
M1	Light intensity maximum of LED row 1
M2	Light intensity maximum of LED row 2
M3	Light intensity maximum of LED row 3
Mx	Light intensity maximum of a column x of LEDs arranged above each other
y	First spatial direction (height direction)
x	Second spatial direction (lateral direction)
z	Third spatial direction (longitudinal direction)

Claims

1. A light module (1) for a vehicle head lamp (14), comprising
an LED light source (2) for generating light,
the LED light source (2) comprising an LED array (3) having a plurality of LEDs (4),
a collimating optic (5, 21, 26, 31), and
an imaging optic (6),
the collimating optic (5, 21, 26, 31) being arranged in a light path (7) between the LED light source (2) and the imaging optic (6) such that the collimating optic (5, 21, 26, 31) collects the light generated by the LED light source (2) and collimates it to the imaging optic (6),
the imaging optic (6) being configured to generate an image of the plurality of LEDs (4) in a far field of the light generated by the LED light source (2),
wherein the collimating optic (5, 21, 26, 31) comprises a light entry surface (8) facing the LED light source (2), and a light exit surface (9) facing the imaging optic (6), one or more of the light entry surface (8) and the light exit surface (9) having, with respect to a first spatial direction (y), a curvature comprising at least two inflection points (10),
wherein the curvature of a first surface section (11) extending between the two inflection points (10) of the respective one or more of the light entry and exit surfaces (8, 9) is concave.

2. The light module (1) as claimed in claim 1, wherein the light entry surface (8) or the light exit surface (9) does not have any inflection point with respect to the first spatial direction (y).

3. The light module (1) as claimed in claim 1, wherein the imaging optic (6) is configured and arranged such that it corrects or at least minimizes imaging aberrations in the far field caused by the collimating optic (5, 21, 26, 31).

4. The light module (1) as claimed in claim 1, wherein the light entry surface (8) of the collimating optic (5, 21, 26, 31) is a continuous surface with respect to one or more of the first spatial direction (y) and a second spatial direction (x) being perpendicular to the first spatial direction (y).

5. The light module (1) as claimed in claim 1, wherein a cross section of the collimating optic (5, 21, 26, 31) is constant along a second spatial direction (x) being perpendicular to the first spatial direction (y), the cross section being aligned parallel to an yz-plane extending in the first spatial direction (y) and a third spatial direction (z) being perpendicular to both the first and second spatial directions (x, y).

6. The light module (1) as claimed in claim 1, wherein the collimating optic (5, 21, 26, 31) comprises a collimating body being extrudable.

7. The light module (1) as claimed in claim 1, wherein the collimating optic (5, 21, 26, 31) is made of a polycarbonate or a glass material.

8. The light module (1) as claimed in claim 1, wherein the LED array (3) is a micro LED array.

9. The light module (1) as claimed in claim 1, wherein the LED array (3) is arranged in the form of a matrix comprising a plurality of adjoining LED rows (13) with each LED row (13) having a plurality of adjoining LEDs (4) arranged therein.

10. The light module (1) as claimed in claim 8 or 9, wherein the LED array (3) comprises 3 to 5 rows with each row comprising 20 to 40 LEDs.

11. A vehicle head lamp (14) comprising the light module (1, 20, 25, 30) according to any one of claims 1 to 10.

FIG. 1

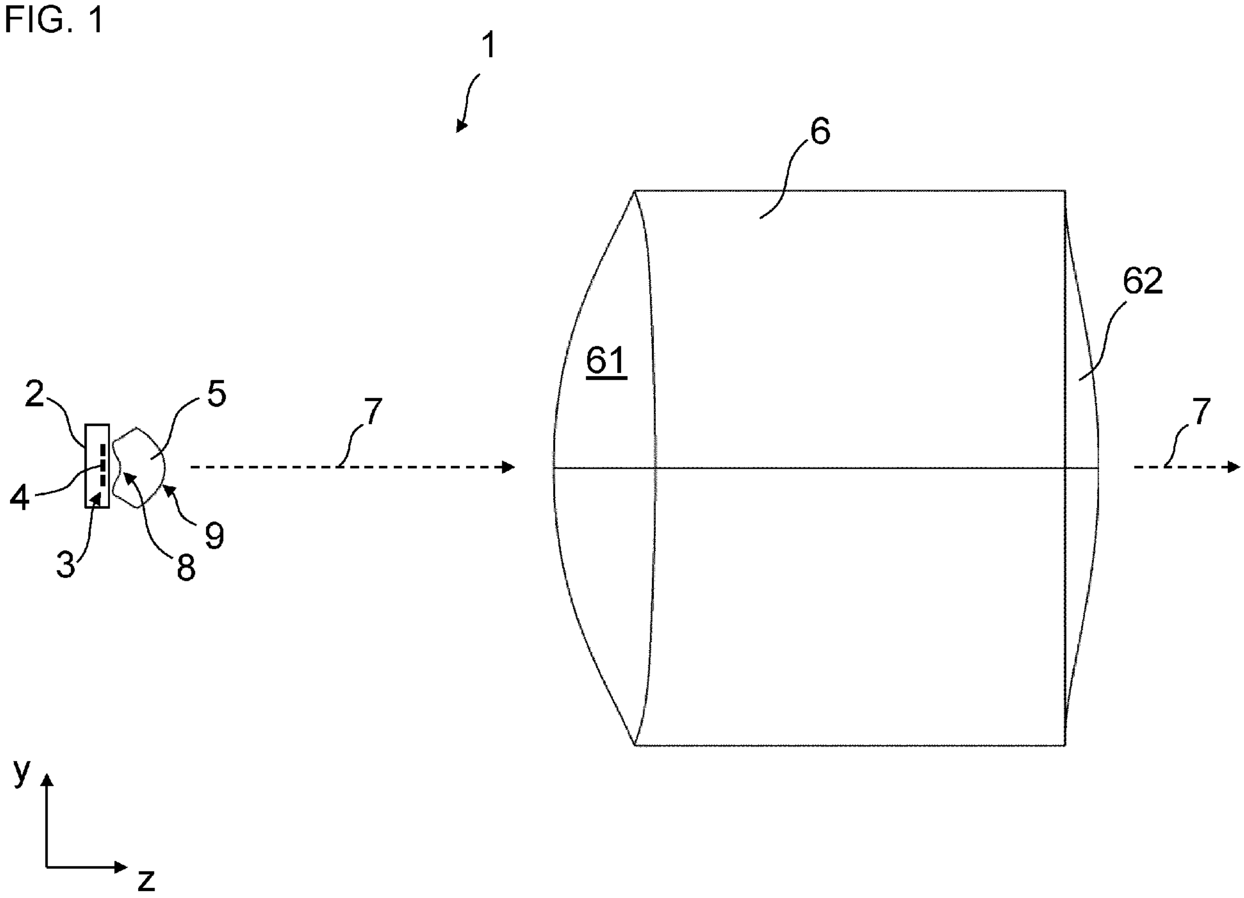


FIG. 2

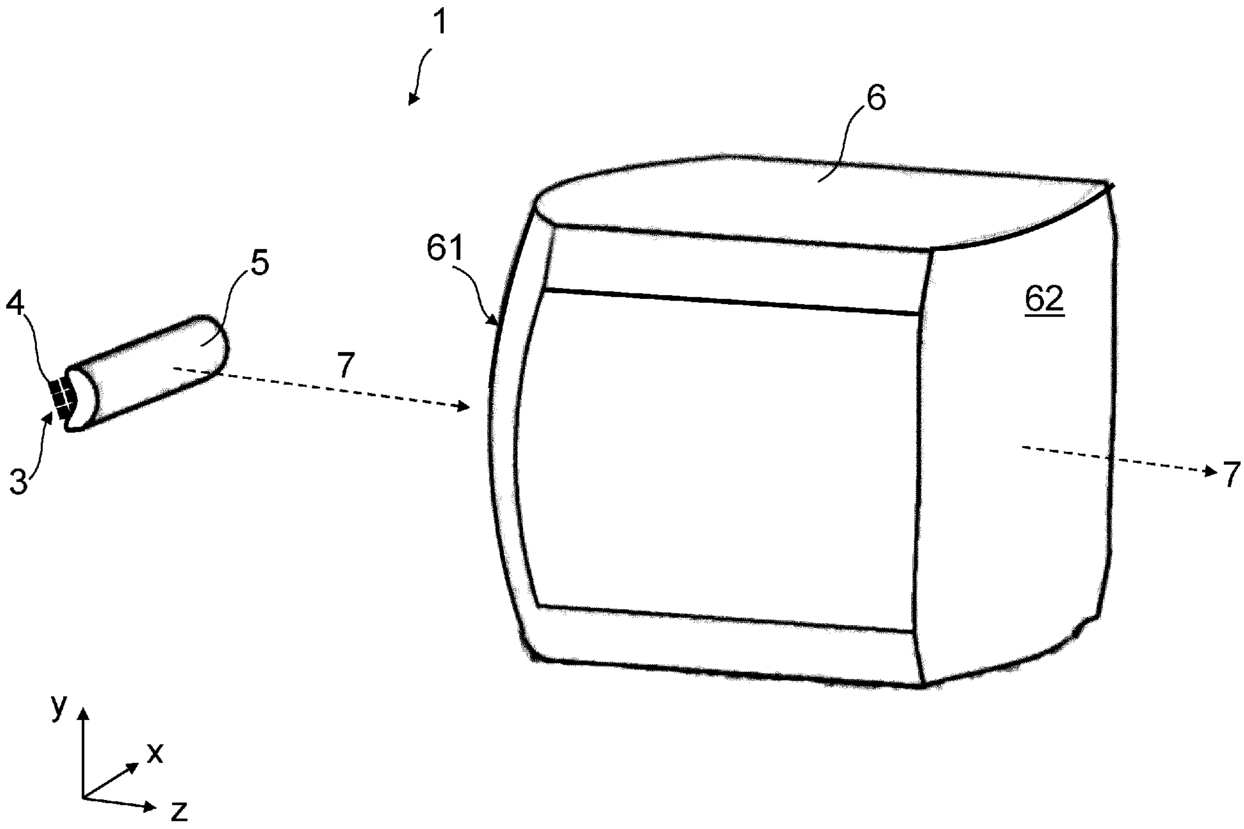


FIG. 3

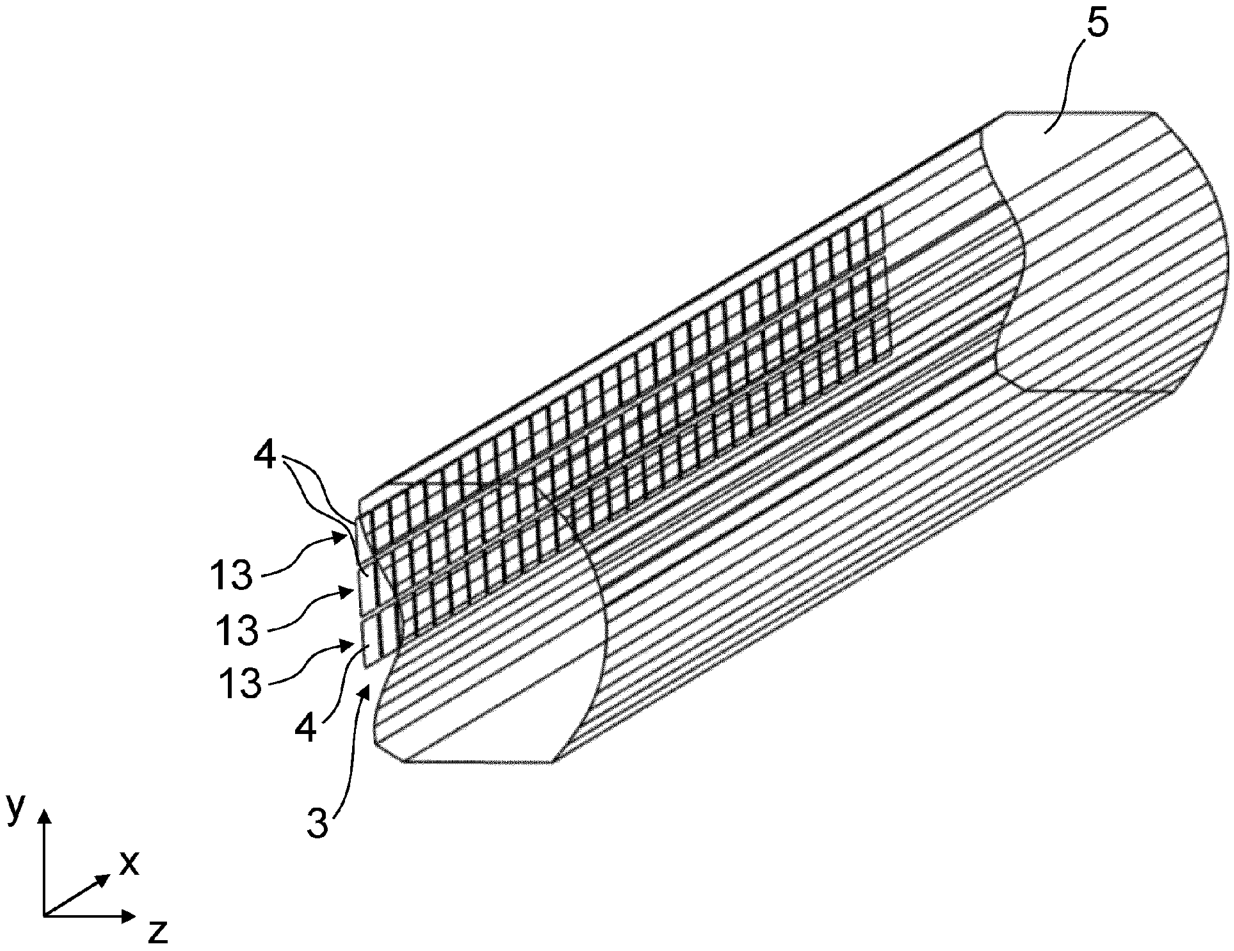


FIG. 4

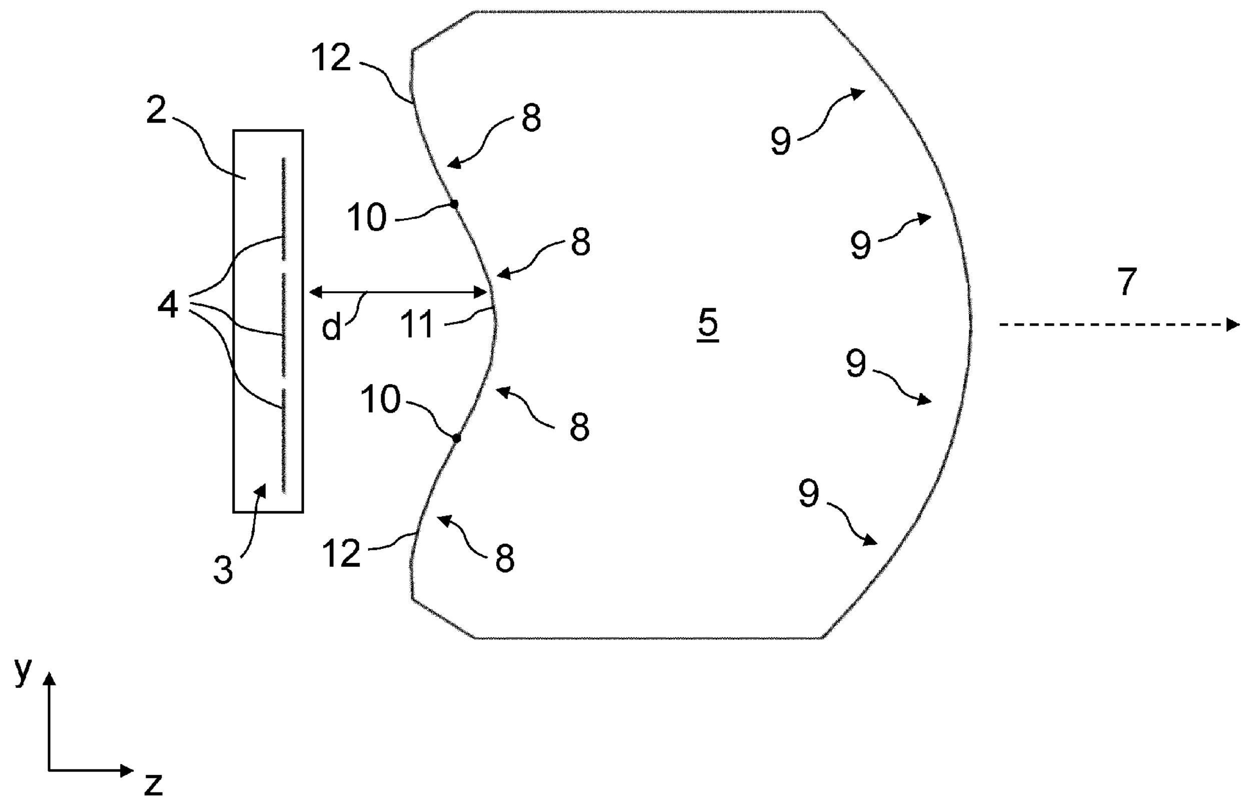


FIG. 5

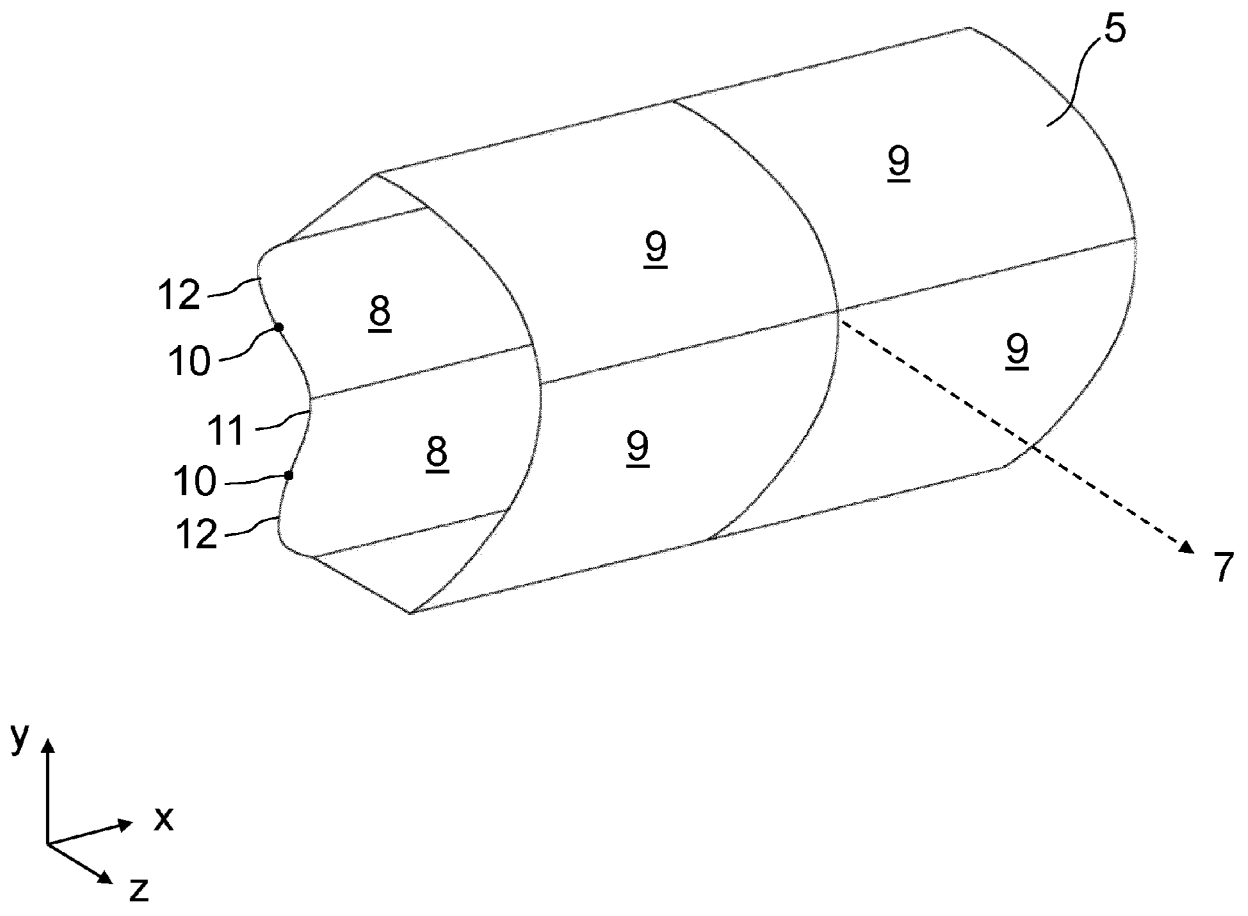


FIG. 6

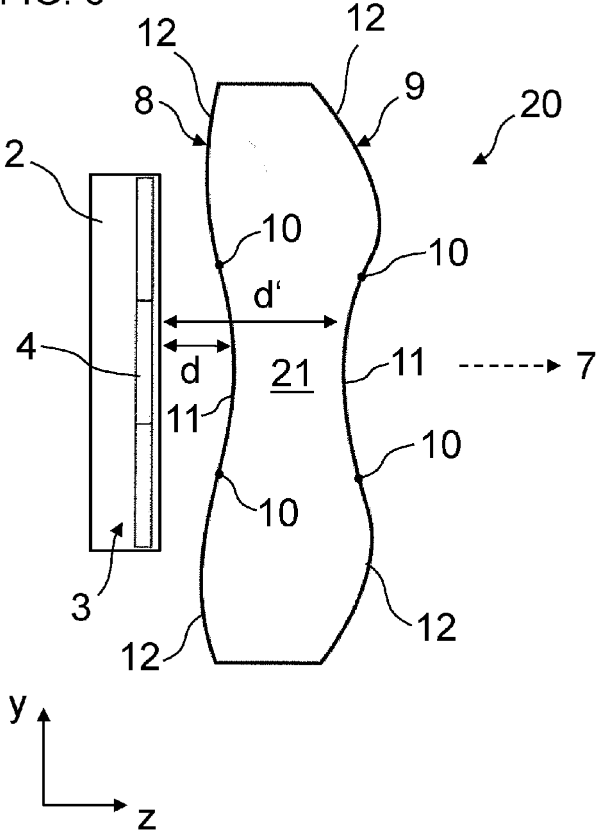

12
12
8
9
20
2
10
10
d'
4
d
21
11
7
11
10
10
3
12
12
y
z

FIG. 7

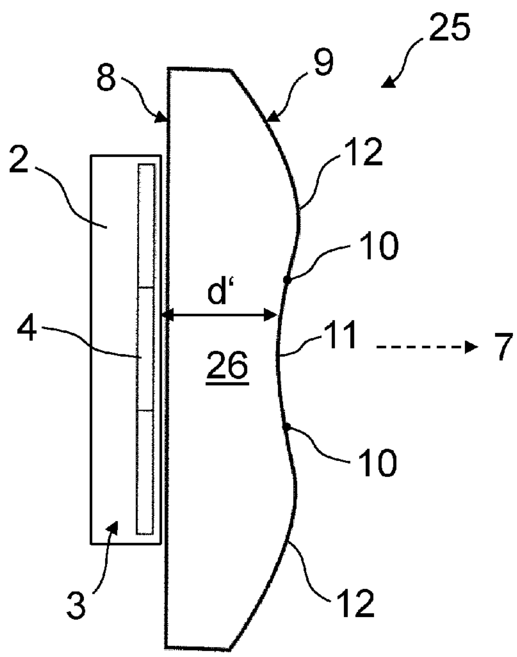

25
8
9
2
12
10
d'
4
11
7
26
10
3
12

FIG. 8

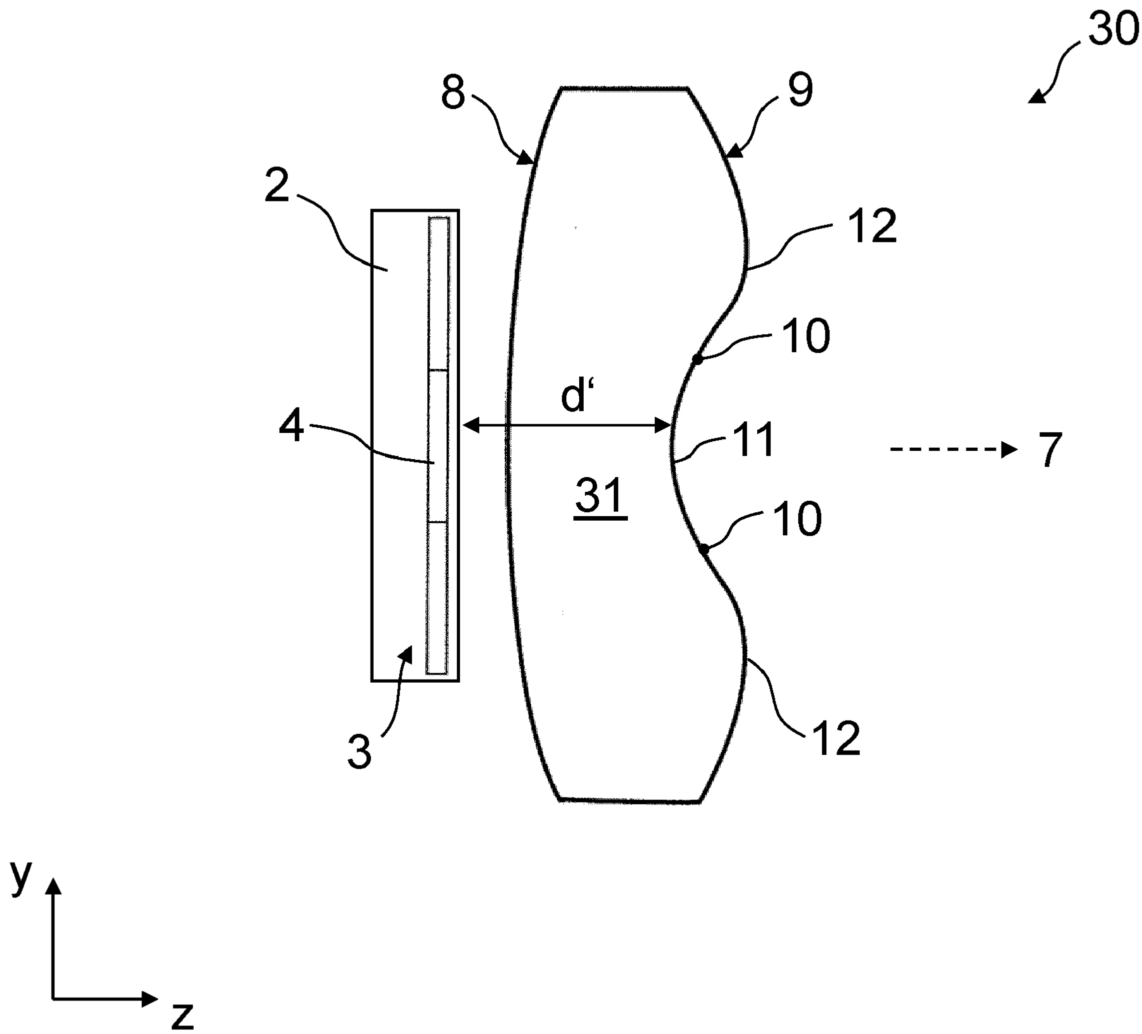
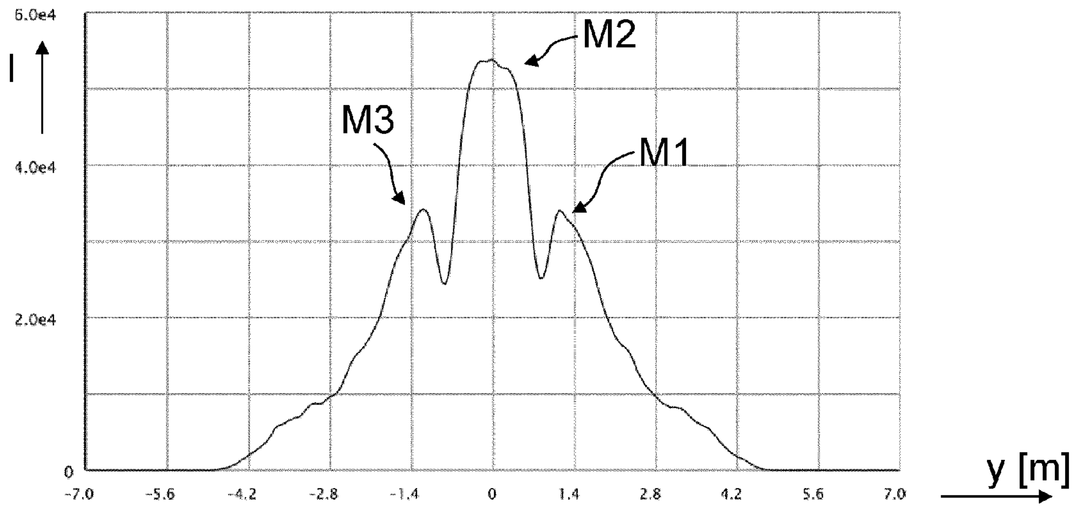


FIG. 9

(a)


I
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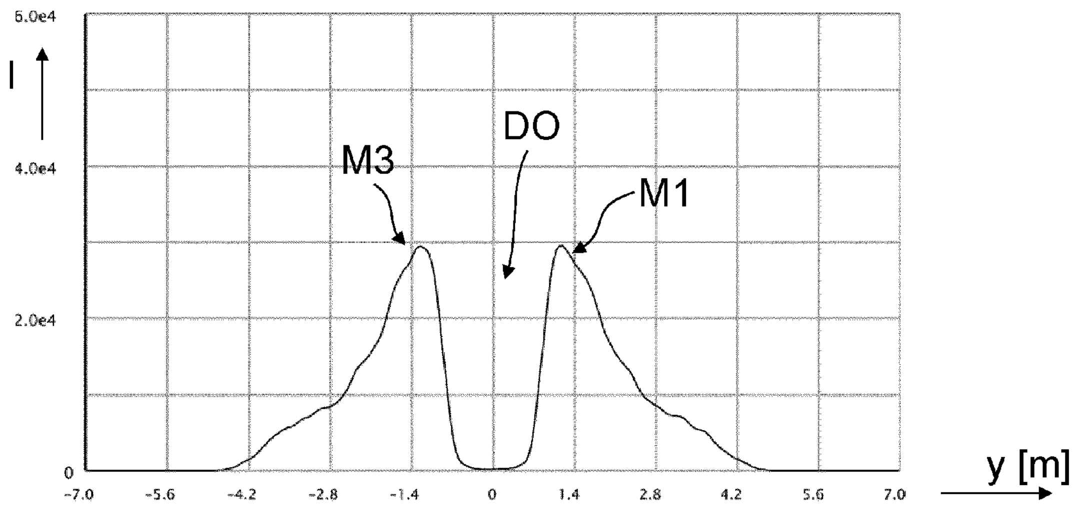
4.0e4
2.0e4
0
M2
M3
M1
-7.0
-5.6
-4.2
-2.8
-1.4
0
1.4
2.8
4.2
5.6
7.0
y [m]

(b)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-5.6
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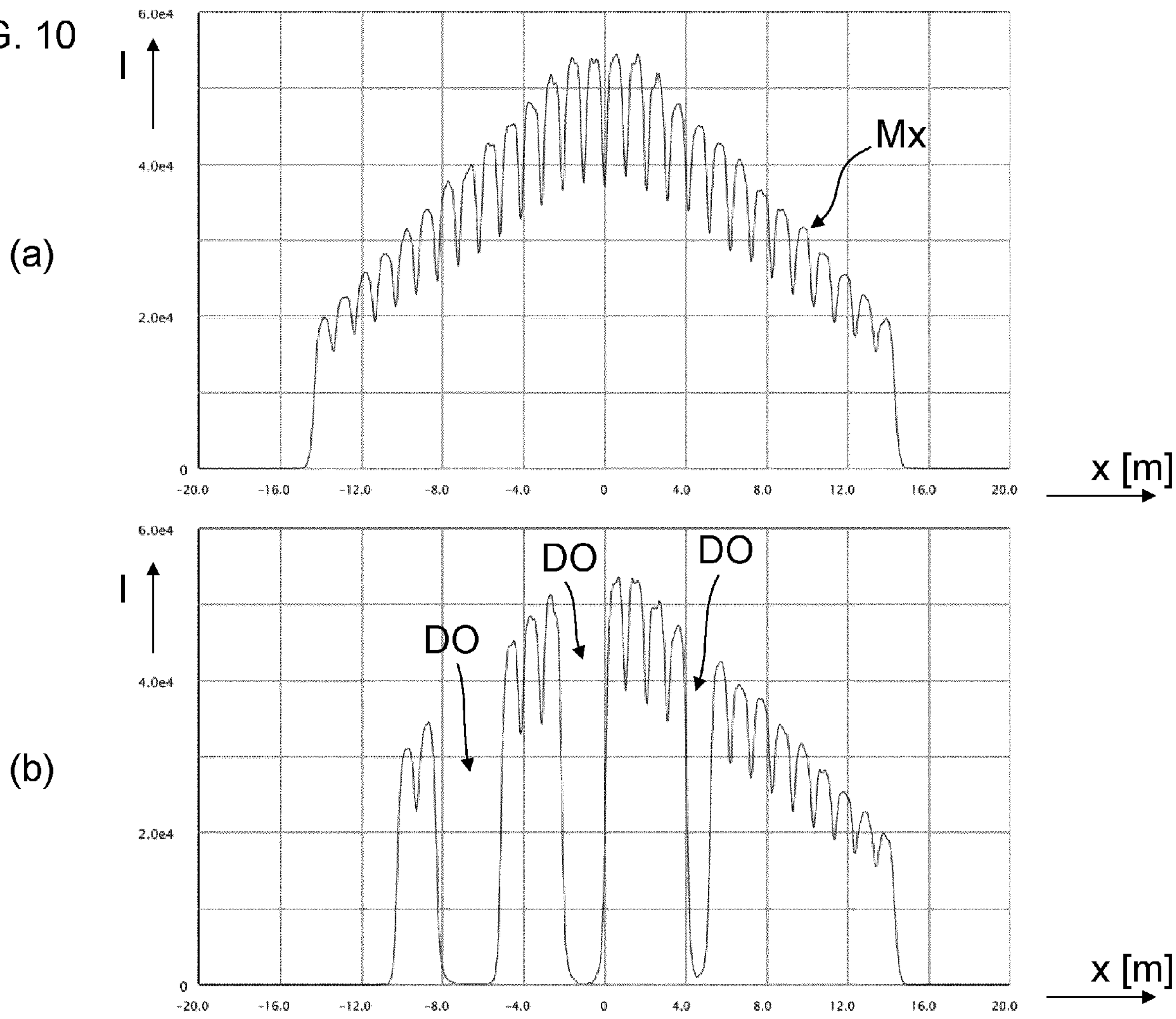
-1.4
0
1.4
2.8
4.2
5.6
7.0
y [m]

FIG. 10


(a)
I
Mx
x [m]
(b)
I
DO
DO
DO
x [m]
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4.0e4
2.0e4
0
-20.0
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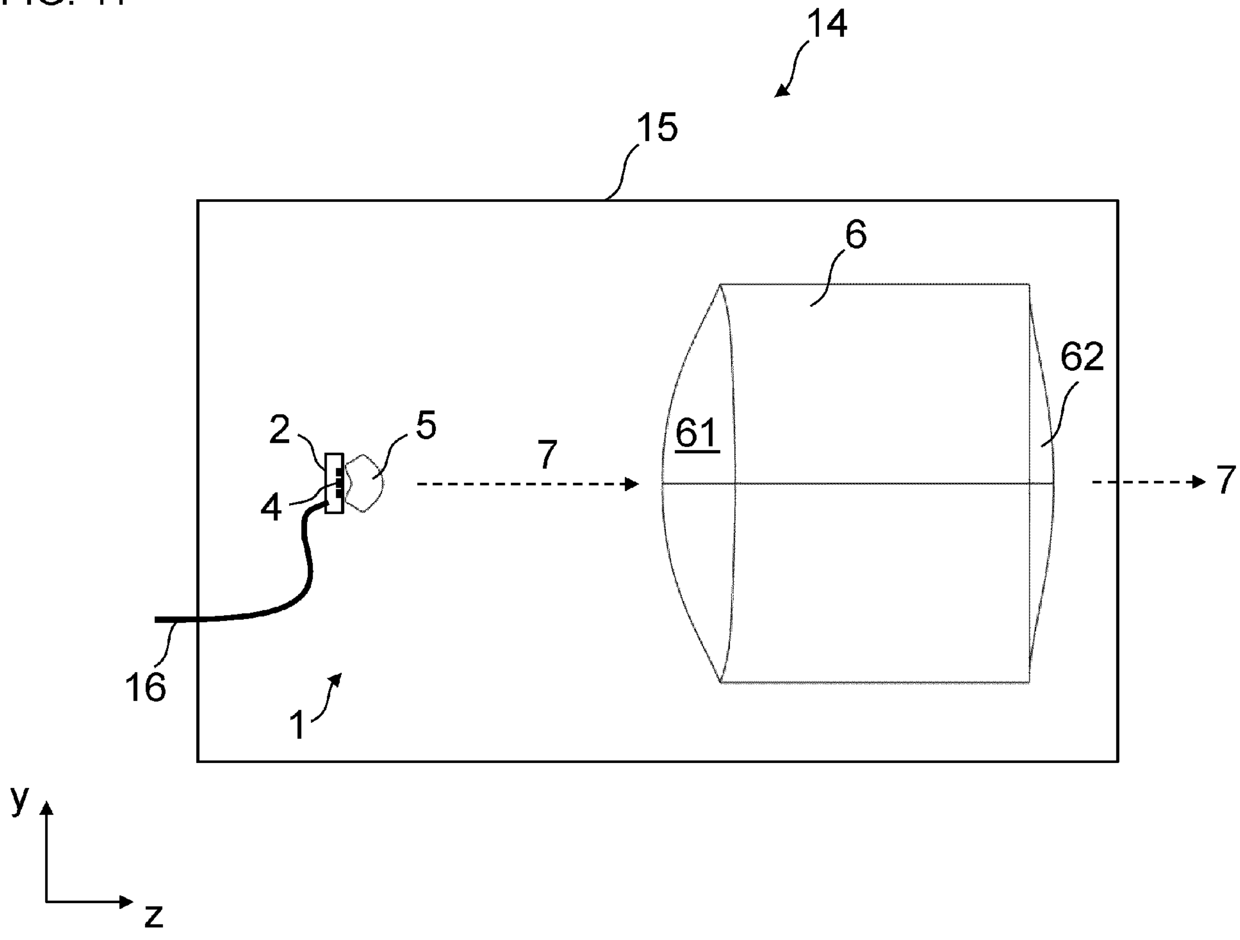
-8.0
-4.0
0
4.0
8.0
12.0
16.0
20.0

FIG. 11



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EUROPEAN SEARCH REPORT

Application Number
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2

Place of search	Date of completion of the search	Examiner
Munich	5 August 2020	Panatsas, Adam

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