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(54) **A DEVICE FOR MODIFYING LIGHT DISTRIBUTION**

(57) A device for modifying light distribution comprises a reflector surface (310) whose shape is at least partly based on a shape transformation directed to a geometric auxiliary surface (330). The shape transformation comprises i) division of the geometric auxiliary surface into longitudinal geometric surface segments (314', 315'), ii) displacements of at least some of the surface segments sideward so as to achieve a desired shape, and iii) addition of geometric connection-surfaces (316) between surface segments that are at least partly separated from each other by the displacements so as to form a stepped geometric surface corresponding to at least a part of the reflector surface. The geometric auxiliary surface can be selected according to a desired intensity distribution within an illumination pattern formable on a planar surface, whereas the shape obtained with the shape transformation can be selected according to the desired shape of the illumination pattern.

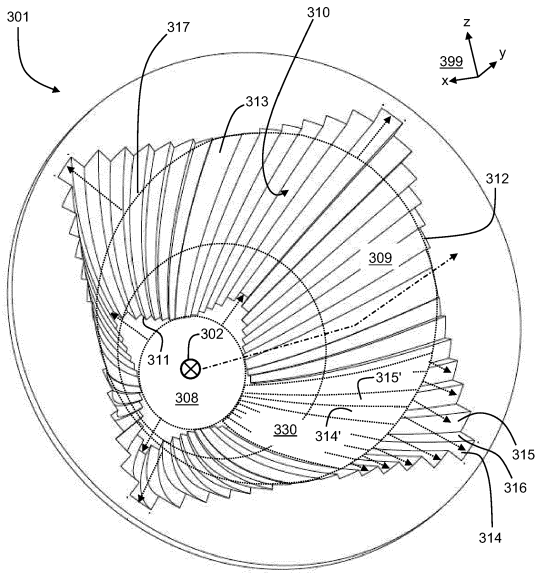


Figure 3b

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## Description

### Field of the disclosure

**[0001]** The invention relates generally to illuminating engineering. More particularly, the invention relates to a device for modifying distribution of light produced by a light source that can be, for example but not necessarily, a light emitting diode "LED".

### Background

**[0002]** Distribution of light produced by a light source can be important or even critical in some applications. The light source can be, for example but not necessarily, a light emitting diode "LED", a filament lamp, or a gas-discharge lamp. Figure 1 a shows a section view of an exemplifying device 101 according to the prior art for modifying the distribution of light produced by a light source 102. The section shown in figure 1 a is taken along a line A-A shown in figure 1b and the section plane is parallel with the yz-plane of a coordinate system 199. In the exemplifying case illustrated in figures 1 a and 1 b, the device 101 for modifying the light distribution comprises a reflector surface 110 whose cross-sections along geometric planes parallel with the xz-plane of the coordinate system 199 are circular. In figure 1a, some of the light beams produced by the light source 102 are depicted with dashed line arrows. Figure 1c illustrates an illumination pattern 105 formed on a planar surface 104 by the light distribution modified by the device 101. In figure 1c, the non-illuminated area is depicted with cross-hatching. The shape of the reflector surface 110 determines at least partly the intensity distribution within the illumination pattern 105. In figure 1c, one of the level curves of the intensity distribution is denoted with a reference number 106. An edge 103 of the reflector surface 110 determines the shape of the illumination pattern 105 so that geometric straight lines drawn from the light source 102 via the edge 103 to the planar surface 104 define a border 107 of the illumination pattern.

**[0003]** Figures 2a, 2b, and 2c illustrate an illumination arrangement that is otherwise similar to the illumination arrangement illustrated in figures 1a-1c but a device 201 for modifying the light distribution comprises a reflector surface 210 whose cross-sections along geometric planes parallel with the xz-plane of a coordinate system 299 are square shaped. Figure 2c illustrates an illumination pattern 205 formed on a planar surface 204 by the light distribution modified by the device 201. In figure 2c, the non-illuminated area is depicted with cross-hatching. The shape of the reflector surface 210 determines at least partly the intensity distribution within the illumination pattern 205. In figure 2c, one of the level curves of the intensity distribution is denoted with a reference number 206. An edge 203 of the reflector surface 210 determines the shape of the illumination pattern 205 so that geometric straight lines drawn from the light source 202 via the edge 203 to the planar surface 204 define a border 207 of the illumination pattern.

**[0004]** As schematically illustrated in figures 1a-1c and 2a-2c, the shape of the reflector surface determines the shape of the illumination pattern and at least partly the intensity distribution within the illumination pattern. Therefore, the shape of the illumination pattern and the intensity distribution are related to each other at least in some extent. In many cases there is, however, a need to produce an illumination pattern so that the shape of the illumination pattern and the intensity distribution can be designed more freely with respect to each other.

### Summary

**[0005]** The following presents a simplified summary in order to provide basic understanding of some aspects of various embodiments of the invention. The summary is not an extensive overview of the invention. It is neither intended to identify key or critical elements of the invention nor to delineate the scope of the invention. The following summary merely presents some concepts of the invention in a simplified form as a prelude to a more detailed description of exemplifying embodiments of the invention.

**[0006]** In this document, the word "geometric" when used as a prefix means a geometric concept that is not necessarily a part of any physical object. The geometric concept can be for example a geometric line, a geometric plane, a non-planar geometric surface, a geometric room, or any other geometric entity that is one, two, or three dimensional.

**[0007]** In accordance with the invention, there is provided a new device for modifying the distribution of light produced by a light source. A device according to the invention comprises:

- a first end comprising a place for the light source,
- a second end for allowing the light to exit from the device, the second end being a distance away from the first end in a longitudinal direction of the device, and
- a reflector surface constituting a light propagation channel between the first and second ends and having and edge delimiting a geometric egress area for allowing the light to exit from the light propagation channel.

**[0008]** The reflector surface is capable of determining at least partly the intensity distribution within an illumination pattern formable on a planar surface by the light distribution modified by the device, and the edge of the reflector surface is capable of determining the shape of the illumination pattern by determining the border of the illumination pattern.

**[0009]** The shape of at least a part of the reflector sur-

face is a result of a shape transformation directed to a geometric auxiliary surface constituting a geometric channel between the first and second ends. The shape transformation comprises: i) division of the geometric auxiliary surface into longitudinal geometric surface segments with geometric section lines directed from the first end to the second end, ii) displacements of at least some of the geometric surface segments substantially sideward with respect to the longitudinal direction so as to obtain a desired shape, and iii) addition of geometric connection-surfaces between ones of the geometric surface segments at least partly separated from each other by the displacements so as to form a stepped geometric surface representing the shape of the at least part of the reflector surface. A displacement of a geometric surface segment can be a shape-conserving displacement in which case all points of the geometric surface segment under consideration are displaced with a same displacement vector. It is also possible that the displacement is not shape-conserving so that different points of the geometric surface segment are displaced with different displacement vectors. In this case, the geometric surface segment under consideration can be warped, stretched, or otherwise deformed.

**[0010]** The above-mentioned geometric auxiliary surface is merely a geometric concept used for describing the shape of the reflector surface and the geometric auxiliary surface is not necessarily a surface of any physical object.

**[0011]** The shape of the geometric auxiliary surface can be selected according to the desired intensity distribution within the illumination pattern formable on the planar surface, whereas the shape produced by the shape transformation can be selected according to the desired shape of the illumination pattern. The geometric auxiliary surface can have for example a smooth shape so that the geometric auxiliary surface and geometric planes perpendicular to the longitudinal direction of the device intersect along closed section curves free from corners. The geometric auxiliary surface can be for example a part of a geometric paraboloid, e.g. a geometric rotation paraboloid. The above-mentioned edge of the reflector surface may have a shape that approximates for example a polygon when the edge is seen along the longitudinal direction of the device. In this case, the shape of the illumination pattern on the planar surface is substantially a polygon. The polygon can be for example a square, a triangle, or a rectangle.

**[0012]** In accordance with the invention, there is provided also a new illuminator system comprising at least one light source and at least one device according to the invention for modifying the distribution of light produced by each light source. The light source can be, for example, a light emitting diode "LED", a filament lamp, or a gas-discharge lamp.

**[0013]** In accordance with the invention, there is provided also a new mold having a form suitable for manufacturing, by mold casting, a piece of solid material, e.g. plastic, having a shape of a device according to the invention. In addition to the mold casting, a process of manufacture of a device according to an exemplifying and non-limiting embodiment of the invention may further comprise coating one or more areas of the above-mentioned piece of solid material with metal or other material so as to obtain desired optical properties.

**[0014]** A number of exemplifying and non-limiting embodiments of the invention are described in accompanied dependent claims.

**[0015]** Various exemplifying and non-limiting embodiments of the invention both as to constructions and to methods of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific exemplifying embodiments when read in connection with the accompanying drawings.

**[0016]** The verbs "to comprise" and "to include" are used in this document as open limitations that neither exclude nor require the existence of also un-recited features. The features recited in dependent claims are mutually freely combinable unless otherwise explicitly stated. Furthermore, it is to be understood that the use of "a" or "an", i.e. a singular form, throughout this document does not exclude a plurality.

## Brief description of the figures

**[0017]** The exemplifying and non-limiting embodiments of the invention and their advantages are explained in greater detail below with reference to the accompanying drawings, in which:

figures 1a, 1 b and 1 c illustrate a device according to the prior art for modifying light distribution,

figures 2a, 2b, and 2c illustrate devices according to the prior art for modifying light distribution,

figures 3a, 3b and 3c illustrate a device according to an exemplifying and non-limiting embodiment of the invention for modifying light distribution,

figure 4 illustrates a device according to an exemplifying and non-limiting embodiment of the invention for modifying light distribution,

figures 5a and 5b illustrate a device according to an exemplifying and non-limiting embodiment of the invention for modifying light distribution, and

figure 6 illustrates an illuminator system according to an exemplifying and non-limiting embodiment of the invention.

**[0018]** Figures 1a, 1b, 1c, 2a, 2b, and 2c have already been explained in the Background-section of this document.

## Description of exemplifying embodiments

**[0019]** The specific examples provided in the description given below should not be construed as limiting the scope and/or the applicability of the appended claims. Lists and groups of examples provided in the description given below are not exhaustive unless otherwise explicitly stated.

**[0020]** Figure 3a shows a front view of a device 301 according to an exemplifying and non-limiting embodiment of the invention for modifying the distribution of light produced by a light source 302. The light source can be for example a light emitting diode "LED", a filament lamp, or a gas-discharge lamp. Figure 3b shows a perspective view of the device 301. The device 301 comprises a first end 308 that comprises a place for the light source 302 and a second end 309 for allowing the light to exit from the device. The second end 309 is a distance away from the first end 308 in the longitudinal direction of the device. In this exemplifying case, the longitudinal direction is parallel with the y-direction of the coordinate system 399. The device 301 comprises a reflector surface 310 that constitutes a light propagation channel between the first and second ends 308 and 309 as illustrated by the perspective view shown in figure 3b. The reflector surface 310 has an edge 311 at the first end 308 of the device and an edge 312 at the second end 309 of the device. In figure 3b, one of the light beams radiated by the light source 302 is depicted with a dash-and-dot line arrow. Figure 3c illustrates an illumination pattern 305 formed on a planar surface 304 by the light distribution modified by the device 301 in an exemplifying situation in which the planar surface 304 is in front of the device 301 and parallel with the xz-plane of the coordinate system 399. In figure 3c, the non-illuminated area is depicted with cross-hatching. The shape of the reflector surface 310 determines at least partly the intensity distribution within the illumination pattern 305. In figure 3c, one of the level curves of the intensity distribution is denoted with a reference number 306. The edge 312 of the reflector surface 310 determines the shape of the illumination pattern 305 so that geometric straight lines drawn from the light source 302 via the edge 312 to the planar surface 304 define a border 307 of the illumination pattern. The light source 302 and the edge 312 are shown in figures 3a and 3b. In this exemplifying case, the edge 312 of the reflector surface 310 has a shape approximating a square and therefore the shape of the illumination pattern 305 on the planar surface 304 is substantially a square.

**[0021]** In this exemplifying case, the shape of the whole reflector surface 310 is a result of a shape transformation directed to a geometric auxiliary surface that constitutes a geometric channel between the first and second ends 308 and 309 of the device 301. In figure 3b, a part of the geometric auxiliary surface is denoted with a reference number 330. In this exemplifying case, the geometric auxiliary surface is rotationally symmetric so that the geometric auxiliary surface and geometric planes perpendicular to the z-direction of the coordinate system 399 intersect along circular section curves. In figures 3a and 3b, some of the circular section curves are depicted with dashed line circles and one of the dashed line circles is denoted with a reference number 317. The geometric auxiliary surface can be for example a part of a geometric paraboloid. Because of the rotational symmetry of the geometric auxiliary surface, the level curves of the intensity distribution are round as illustrated in figure 3c. It is to be noted that figure 3c is merely a schematic illustration and in a real case the level curves of the intensity distribution are not necessarily as circular as in figure 3c but the level curves of the intensity distribution are however closer to circles than in the case illustrated in figures 2a-2c.

**[0022]** The above-mentioned shape transformation is described below with reference to figure 3b. The shape transformation comprises division of the geometric auxiliary surface into longitudinal geometric surface segments with geometric section lines directed from the first end 308 to the second end 309. Three of the geometric surface segments of the geometric auxiliary surface are denoted with reference numbers 313, 314' and 315'. The shape transformation further comprises displacements of some of the geometric surface segments substantially sideward with respect to the longitudinal direction of the device 301 so as to achieve a desired shape. The displacements are depicted with dashed line arrows. The geometric surface segments 314' and 315' after the displacements are depicted with reference numbers 314 and 315. As can be seen from figure 3b, the geometric surface segment 313 is one of the geometric surface segments of the geometric auxiliary surface that are not displaced and thus, concerning the geometric surface segment 313, the reflector surface 310 concurs with the geometric auxiliary surface. The shape transformation further comprises addition of geometric connection-surfaces between those of the geometric surface segments that are at least partly separated from each other by the displacements so as to form a stepped geometric surface representing the shape of the reflector surface 310. One of the geometric connection-surfaces is denoted with a reference number 316.

**[0023]** In the exemplifying case illustrated in figures 3a and 3b, the geometric surface segments of the geometric auxiliary surface are displaced so that the shapes of the geometric surface segments are substantially unchanged, i.e. all points of each geometric surface segment are displaced with a substantially same displacement vector. It is, however, also possible that all points of each geometric surface segment are not displaced with a substantially same displacement vector. For example, the shape transformation applied on the case illustrated in figures 3a and 3b could be as well for example such that the ends of the geometric surface segments that are at the first end 308 of the device are not moved at all, the ends of the geometric surface segments that are at the second end 309 of the device are moved as

illustrated in figure 3b, and points of the geometric surface segments between the ends of the geometric surface segments are moved so that each geometric surface segment gets or retains a desired shape e.g. the shape of a part of a geometric paraboloid. In the above-described case, the shape of the edge of the reflector surface at the first end 308 of the device would be circular when seen along the longitudinal direction of the device, i.e. along the y-direction of the coordinate system 399.

**[0024]** The shape of the edge 312 of the reflector surface 310 can be selected according to the desired illumination pattern obtainable with the aid of the device 301. Instead of the shape illustrated in figures 3a and 3b and approximating a square, the above-described shape transformation can be used for obtaining other shapes too. A shape obtained with the above-described shape transformation can be for example a shape that approximates a polygon other than a square, e.g. a triangle, a non-square rectangle, a pentagon, a hexagon, a heptagon, an octagon, a parallelogram, a trapezium, etc. The polygon does not necessarily need to be convex so that all the angles are below 180 degrees but it is also possible to produce a shape that approximates a polygon having one or more concave angles each being greater than 180 degrees. An example of a polygon having concave angles is a star-shaped polygon. For example, the shape of the edge 311 shown in figures 3a and 3b approximates a polygon having eight angles so that four of the angles are each less than 90 degrees and the rest of the angles are each greater than 180 degrees. Furthermore, the above-described shape transformation can be used for obtaining forms having one or more curved outlines. In the exemplifying case illustrated in figures 3a and 3b, the geometric surface segments of the geometric auxiliary surface are mutually similar. In order to approximate for example a square or another polygon more accurately, the geometric surface segments corresponding to the corner regions of the polygon can be made narrower than the geometric surface segments corresponding to the middle regions of the sides of the polygon.

**[0025]** Figure 4 illustrates a device 401 according to an exemplifying and non-limiting embodiment of the invention for modifying light distribution. The device 401 comprises a first end 408 comprising a place for a light source and a second end 409 for allowing light to exit from the device. The device 401 comprises a reflector surface 410 constituting a light propagation channel between the first and second ends 408 and 409. The reflector surface 410 has an edge 411 at the first end 408 and an edge 412 at the second end 409. In this exemplifying case, the reflector surface 410 comprises annular sections 418, 419, 420, and 421 that are successive in the longitudinal direction of the device 401. As illustrated in figure 4, each transition region between adjacent ones of the annular sections 418-421 forms a step-wise broadening of the light propagation channel constituted by the reflector surface. The shapes of the annular sections 419, 420, and 421 are results of shape transformations of the kind described above with reference to figure 3b. The shape of the annular section 418 that is closest to the first end 408 has a shape that is smooth in the circumferential direction of the annular section 418. The shape of the annular section 418 may correspond for example to a shape of a geometric paraboloid, e.g. a rotational geometric paraboloid.

**[0026]** Figures 5a and 5b illustrate a device 501 according to an exemplifying and non-limiting embodiment of the invention for modifying light distribution. As illustrated in figures 5a and 5b, the device 501 is more asymmetric than the devices 301 and 401 illustrated in figures 3a, 3b, and 4. The device 501 comprises a first end 508 comprising a place for a light source and a second end 509 for allowing light to exit from the device. The device 501 comprises a reflector surface 510 constituting a light propagation channel between the first and second ends 508 and 509. The reflector surface 510 has an edge 511 at the first end 508 and an edge 512 at the second end 509. In this exemplifying case, the reflector surface 510 comprises annular sections 518, 519, 520, and 521 that are successive in the longitudinal direction of the device, i.e. in the direction from the first end 503 to the second end 509. As illustrated in figure 5, each transition region between adjacent ones of the annular sections 518-521 forms a step-wise broadening of the light propagation channel constituted by the reflector surface 510.

**[0027]** The shapes of the annular sections 519, 520, and 521 are results of shape transformations of the kind described above with reference to figure 3b. In figure 5a, the shape of the geometric auxiliary surface used as a starting point of the shape transformation relating to the annular section 521 is illustrated with a closed dashed line curve. One of the displacements related to the shape transformation is depicted with a dashed line arrow in figure 5a. The shape of the annular section 518 that is closest to the first end 508 has a shape that is smooth in the circumferential direction of the annular section 518.

**[0028]** It is worth noting that the edge 512 of the reflective surface 510 does not necessarily need to concur with a geometric plane. Instead, for example, the edge 512 can be arranged to concur with a non-planar geometric surface that, in turn, concurs with dash-and-dot lines 525 shown in figure 5b.

**[0029]** In the exemplifying cases illustrated in figures 3a, 3b, 4, 5a, and 5b, each of the devices for modifying light distribution comprises a structure constituting a cavity whose surface is the reflector surface. The structure constituting the cavity may comprise a body-part made of for example plastic and a metal coating or another suitable coating for providing the reflectiveness of the reflector surface. It is, however, also possible that the device comprises a piece of transparent material that has an outer surface constituting the reflector surface so that the outer surface reflects light arriving from inside the piece of the transparent material. In other words, the outer surface provides total internal reflection "TIR" based on the sufficiently high refractive index of the transparent

material. The transparent material can be for example plastic, glass, or optical silicone.

**[0030]** In addition to the stepped shape caused by the above-explained shape transformation, one or more of the reflector surface areas between the steps can be partly or wholly provided with roughness and/or undulations so as to achieve scattering reflections but it is also possible that the reflective areas are smooth so as to provide mirroring reflections. The undulations may comprise grooves and/or other deviations from a smooth shape. The roughness and/or undulation can be used for achieving e.g. a color mixing effect so that light beams exhibiting different wavelengths become effectively mixed and evenly distributed. It is also possible that a light penetrating surface of a light source is provided with roughness and/or undulations so as to achieve the mixing effect. Furthermore, it is also possible that the light source is covered with a dome made of material penetrable by light and provided with roughness and/or undulations so as to achieve the mixing effect.

**[0031]** Figure 6 illustrates an illuminator system according to an exemplifying and non-limiting embodiment of the invention. The illuminator system comprises light sources 602a, 602b, 602c, and 602d and devices 601 a, 601 b, 601 c, and 601 d according to an embodiment of the invention for modifying the distribution of the light emitted by the light sources. Each of the light sources 602a-602d can be for example a light emitting diode "LED". As illustrated in figure 6, the front side of the illuminator system is substantially covered by the reflective surfaces of the devices 601a-601d. Therefore, darker regions, i.e. regions between the reflective surfaces, are smaller than for example in a case where the reflective surfaces are rotationally symmetric.

**[0032]** The specific examples provided in the description given above should not be construed as limiting the scope and/or the applicability of the appended claims. Lists and groups of examples provided in the description given above are not exhaustive unless otherwise explicitly stated.

## Claims

1. A device (301, 401, 501, 601a-601d) for modifying light distribution, the device comprising:

   - a first end (308, 408) comprising a place for a light source,
   - a second end (309, 409) for allowing light to exit from the device, the second end being a distance away from the first end in a longitudinal direction of the device, and
   - a reflector surface (310, 410) constituting a light propagation channel between the first and second ends and having and edge (312) delimiting a geometric egress area for allowing the light to exit from the light propagation channel,

   wherein the reflector surface is capable of determining at least partly an intensity distribution within an illumination pattern formable on a planar surface by the light distribution modified by the device, and the edge of the reflector surface is capable of determining a shape of the illumination pattern by determining a border of the illumination pattern, **characterized in that** a shape of at least a part of the reflector surface is a result of a shape transformation directed to a geometric auxiliary surface constituting a geometric channel between the first and second ends, the shape transformation comprising: i) division of the geometric auxiliary surface into longitudinal geometric surface segments (314', 315') with geometric section lines directed from the first end to the second end, ii) displacements of at least some of the geometric surface segments (314', 315') substantially sideward with respect to the longitudinal direction, and iii) addition of geometric connection-surfaces (316) between ones of the geometric surface segments (314, 315) at least partly separated from each other by the displacements so as to form a stepped geometric surface representing the shape of the at least part of the reflector surface.

2. A device according to claim 1, wherein the geometric auxiliary surface and geometric planes perpendicular to the longitudinal direction intersect along closed section curves free from corners.

3. A device according to claim 2, wherein the geometric auxiliary surface is a part of a geometric paraboloid.

4. A device according to any of claims 1-3, wherein the edge (312) of the reflector surface has a shape approximating a polygon when seen along the longitudinal direction.

5. A device according to claim 4, wherein the polygon is one of the following: a triangle, a square, a rectangle, a pentagon, a hexagon, a heptagon, an octagon, a parallelogram, a trapezium.

6. A device according to claim 4 or 5, wherein the geometric surface segments of the geometric auxiliary surface corresponding to corner regions of the polygon are narrower in a circumferential direction perpendicular to the longitudinal direction than the geometric surface segments of the geometric auxiliary surface corresponding to middle regions of sides of the polygon.

7. A device according to any of claims 1-6, wherein the reflector surface comprises annular sections (418-421) successive in the longitudinal direction, and each transition region between adjacent ones of the annular sections forms a step-wise broadening of the light propagation channel constituted by the

reflector surface.

**8.** A device according to claim 7, wherein a particular one of the annular sections (418) which is closest to the first end (408) and geometric planes perpendicular to the longitudinal direction intersect along closed section curves free from corners.

**9.** A device according to any of claims 1-8, wherein the device comprises a structure constituting a cavity whose surface constitutes the reflector surface.

**10.** A device according to any of claims 1-8, wherein the device comprises a piece of transparent material having an outer surface constituting the reflector surface, the outer surface being capable of reflecting light arriving at the outer surface from inside the piece of the transparent material.

**11.** An illuminator system comprising:

- at least one device (601a-601d) according to any of claims 1-10 for modifying distribution of light, and
- at least one light source (602a-602d) installed on the at least one device and arranged to produce the light.

**12.** A mold having a form suitable for manufacturing, by mold casting, a piece of solid material having a shape of a device according to any of claims 1-10.

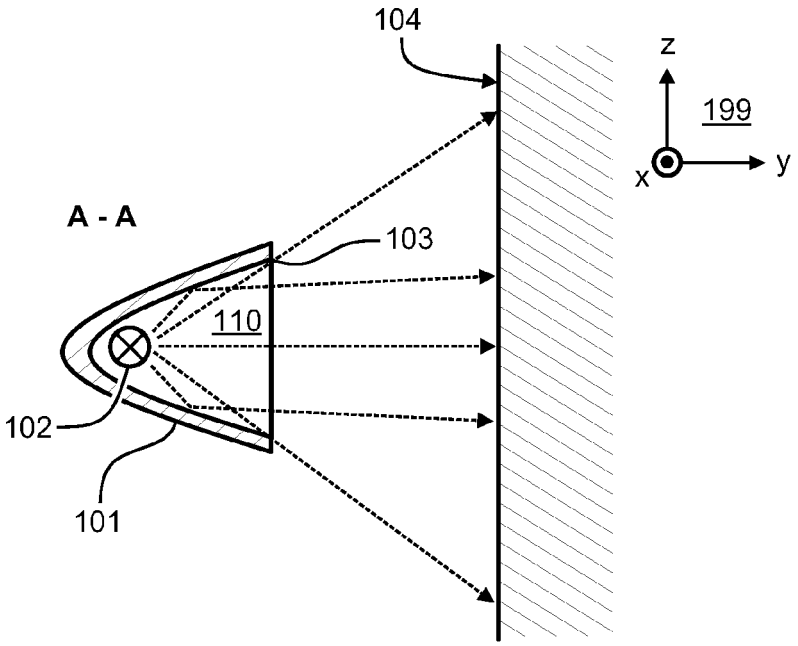



Figure 1a
Prior art

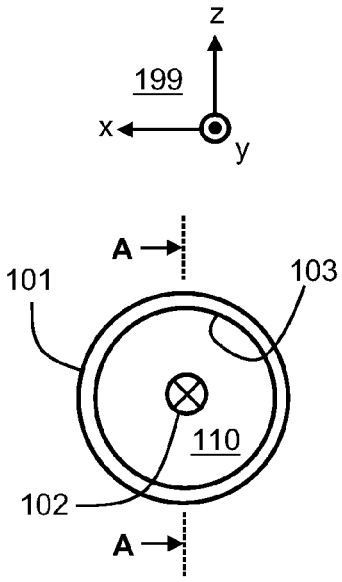



Figure 1b
Prior art

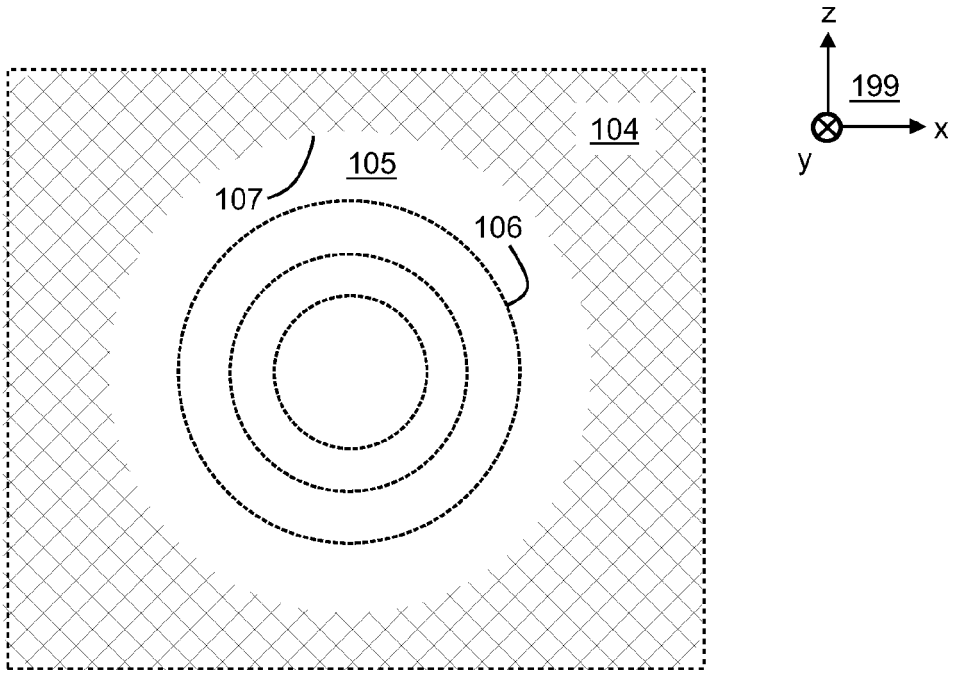



Figure 1c
Prior art

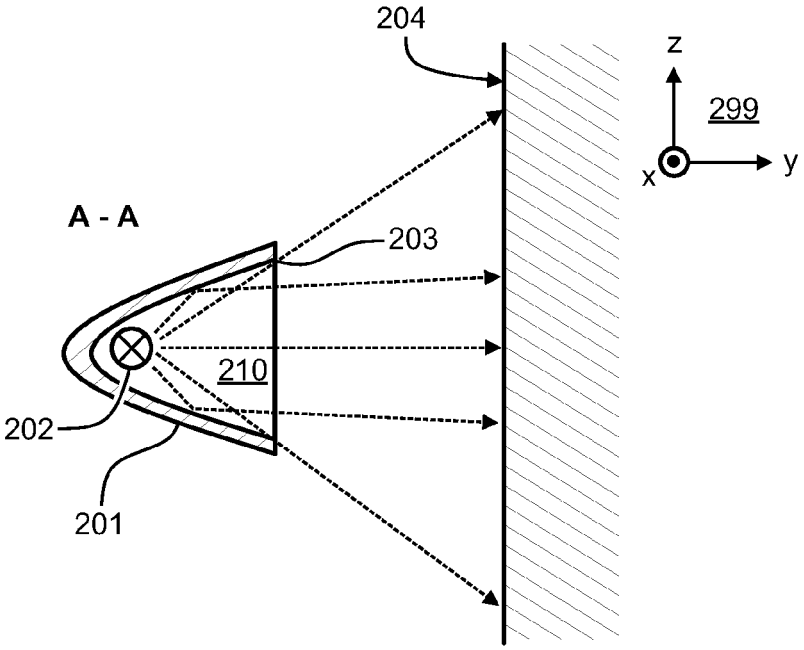



Figure 2a
Prior art

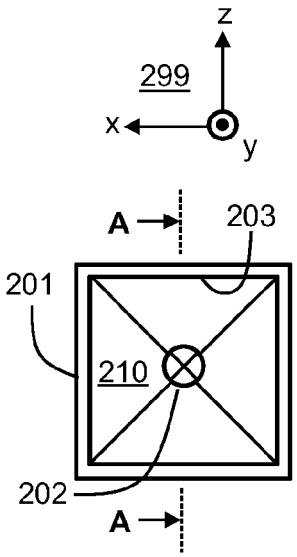



Figure 2b
Prior art

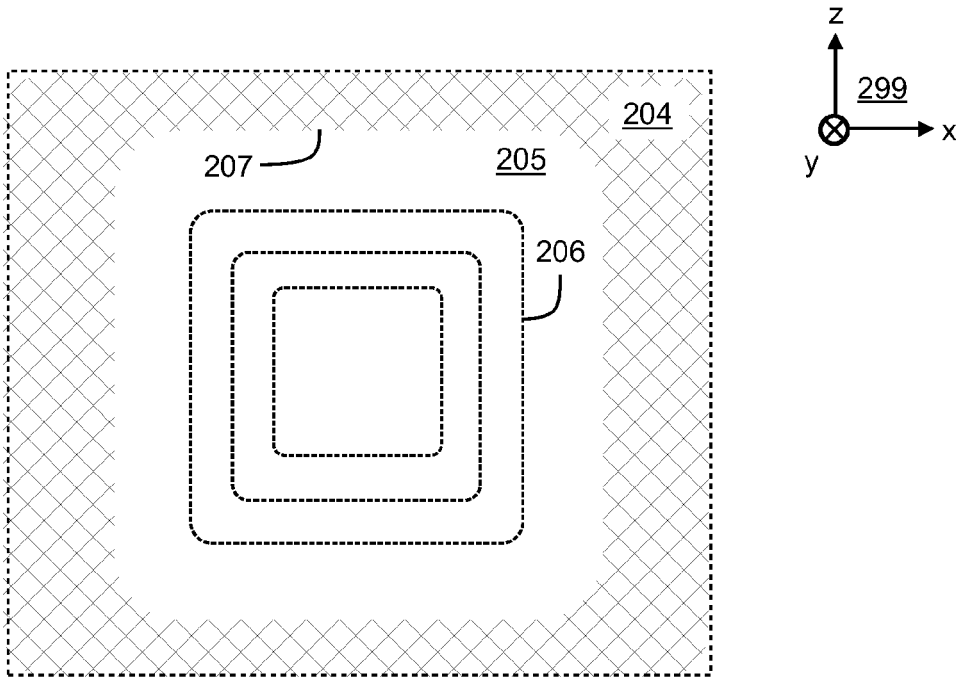



Figure 2c
Prior art

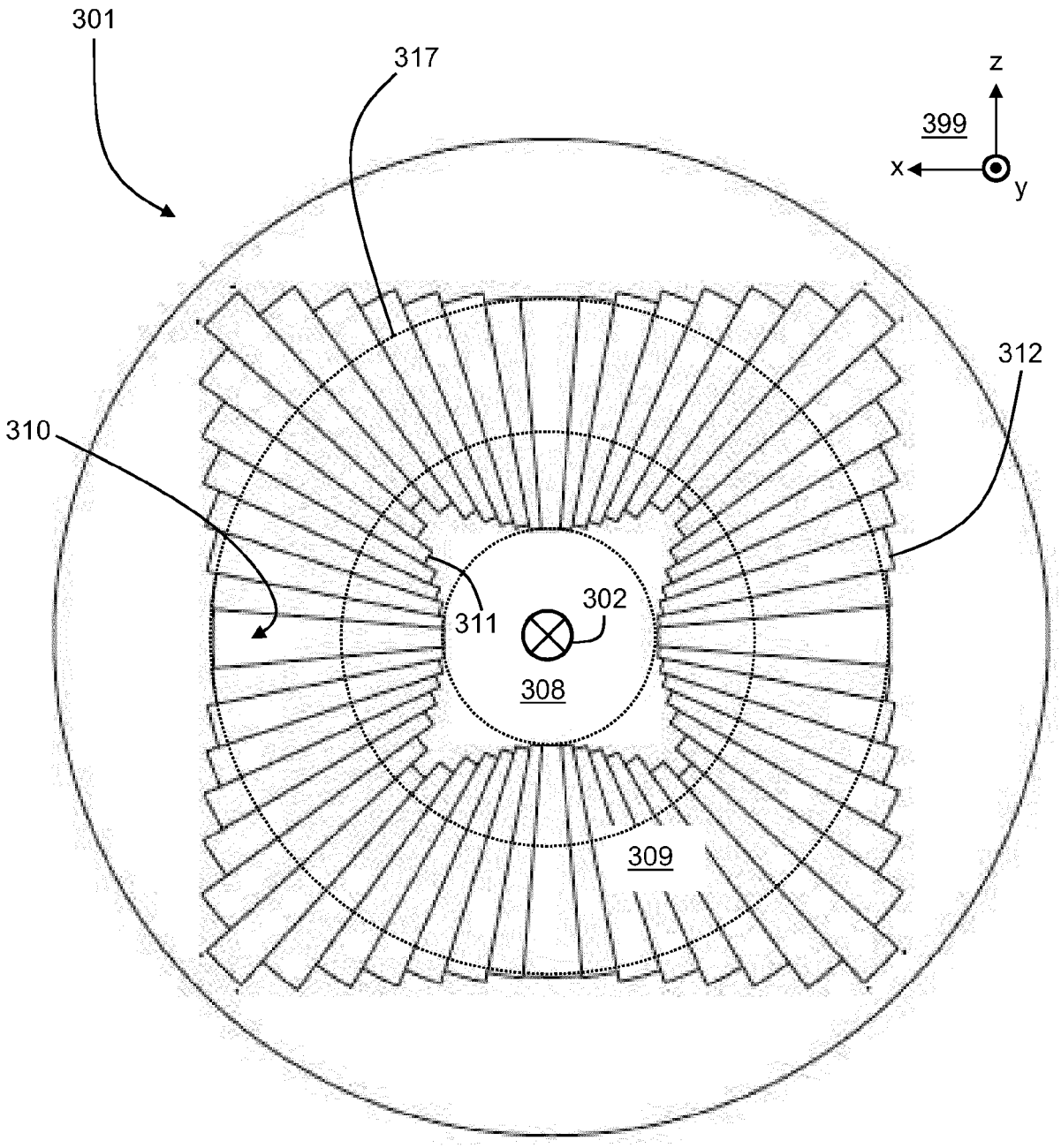
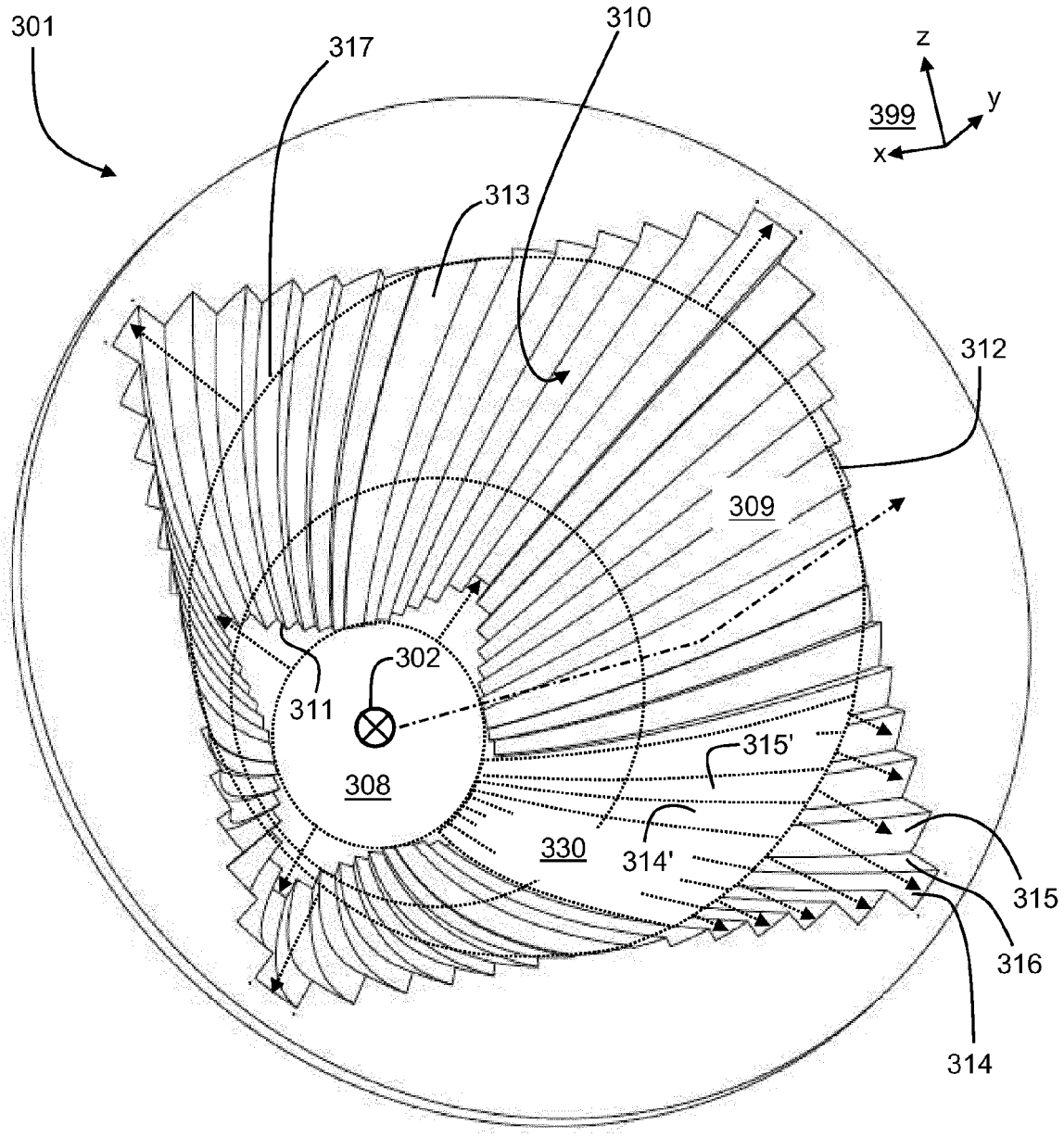



Figure 3a


301
317
310
z
399
y
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313
312
309
302
311
315'
308
330
314'
315
316
314

Figure 3b

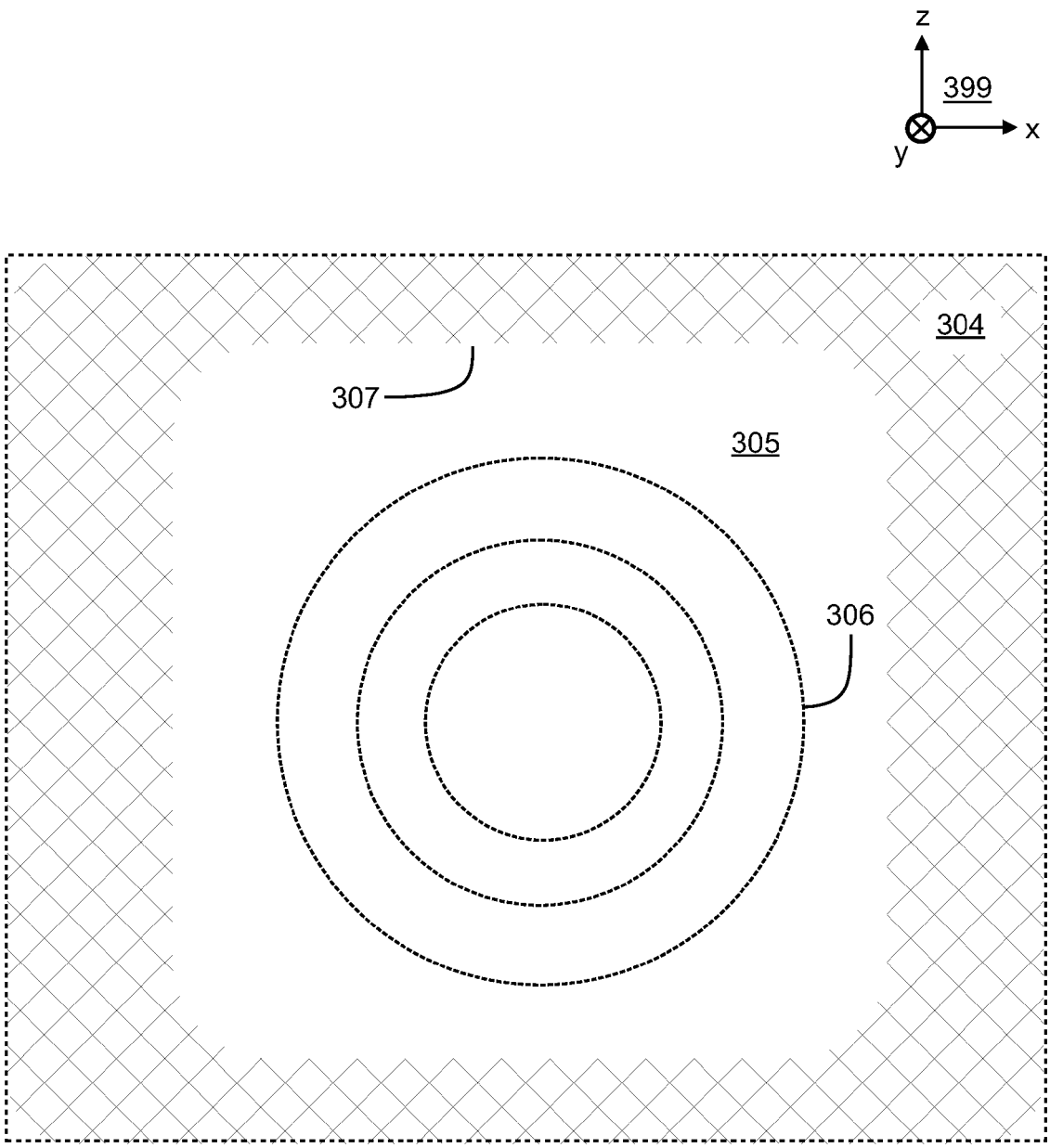


Figure 3c

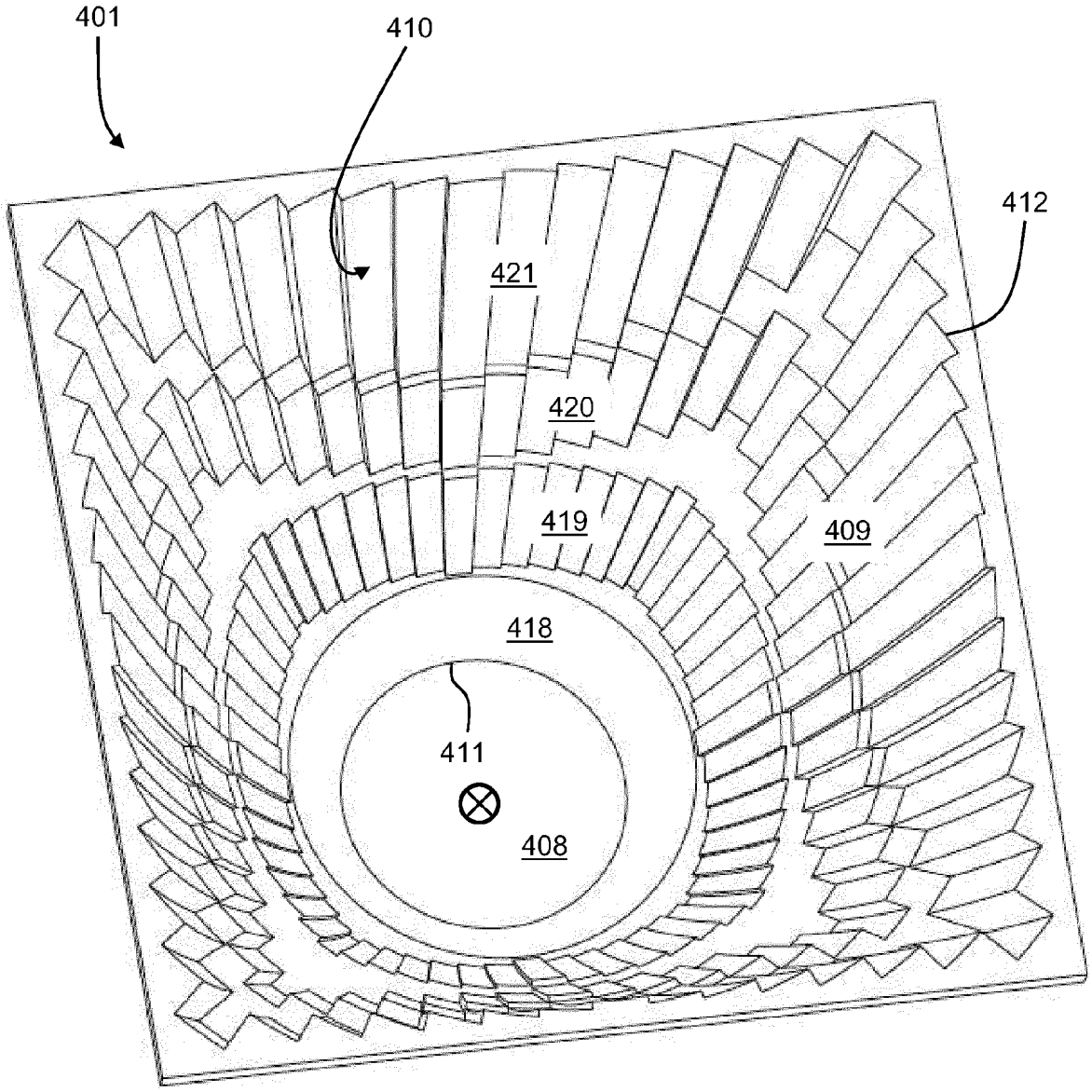


Figure 4

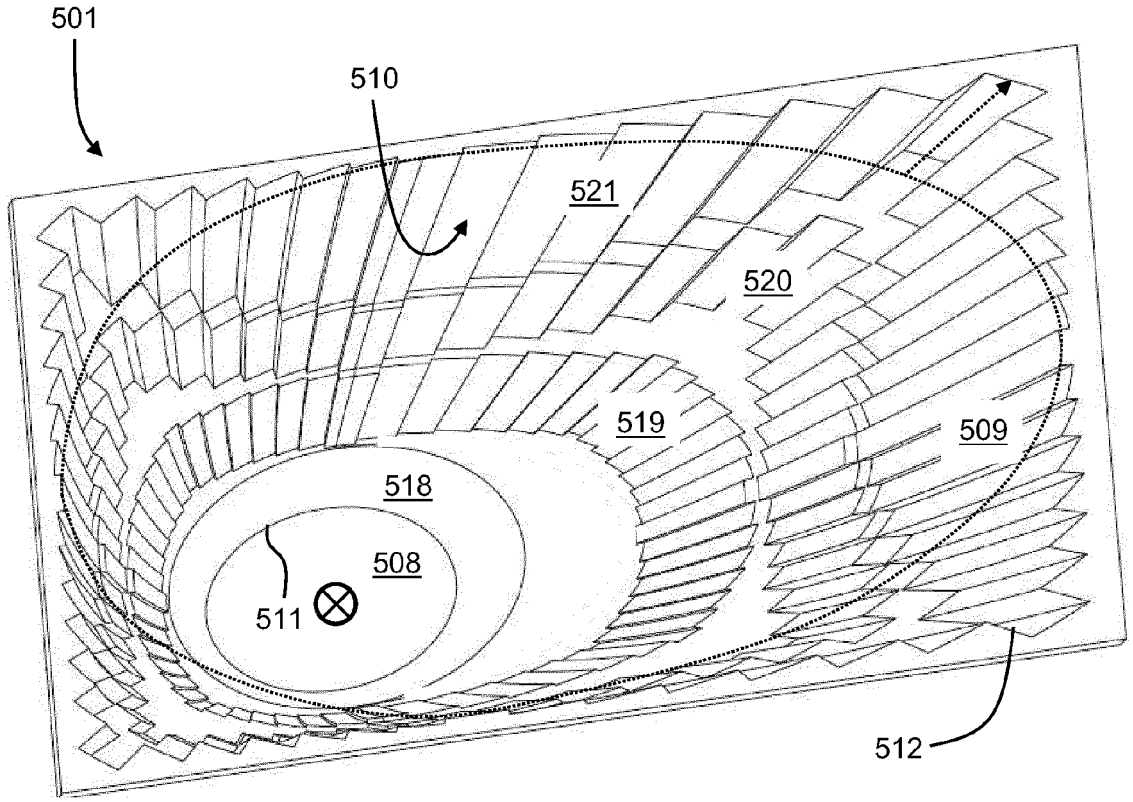


Figure 5a

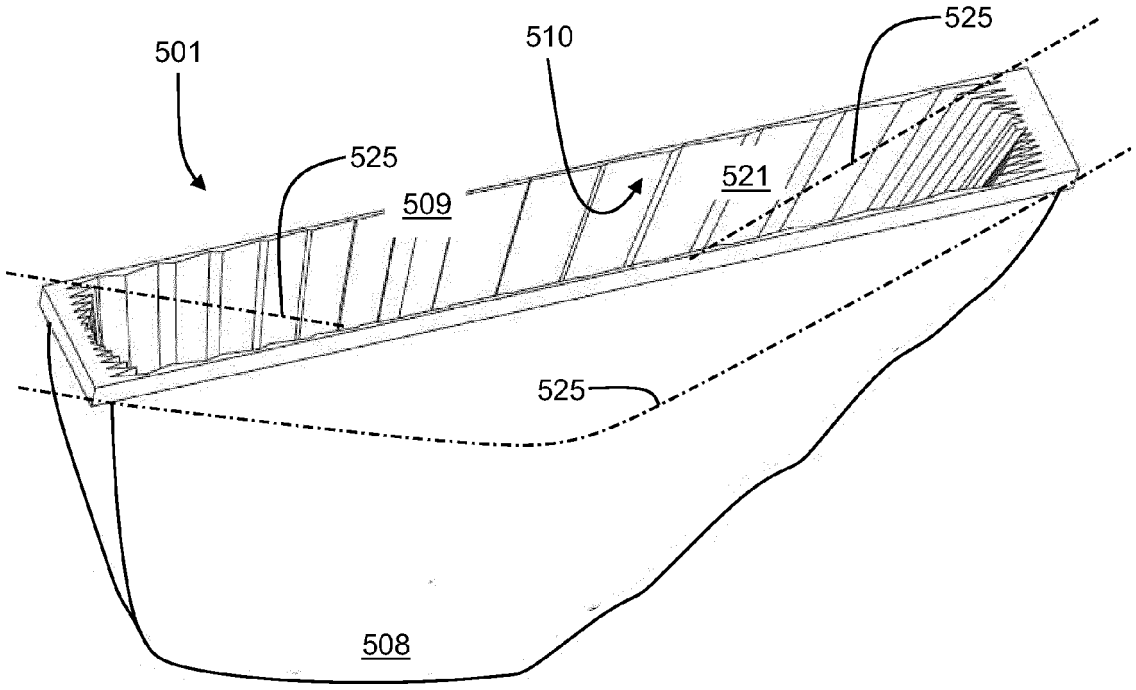


Figure 5b

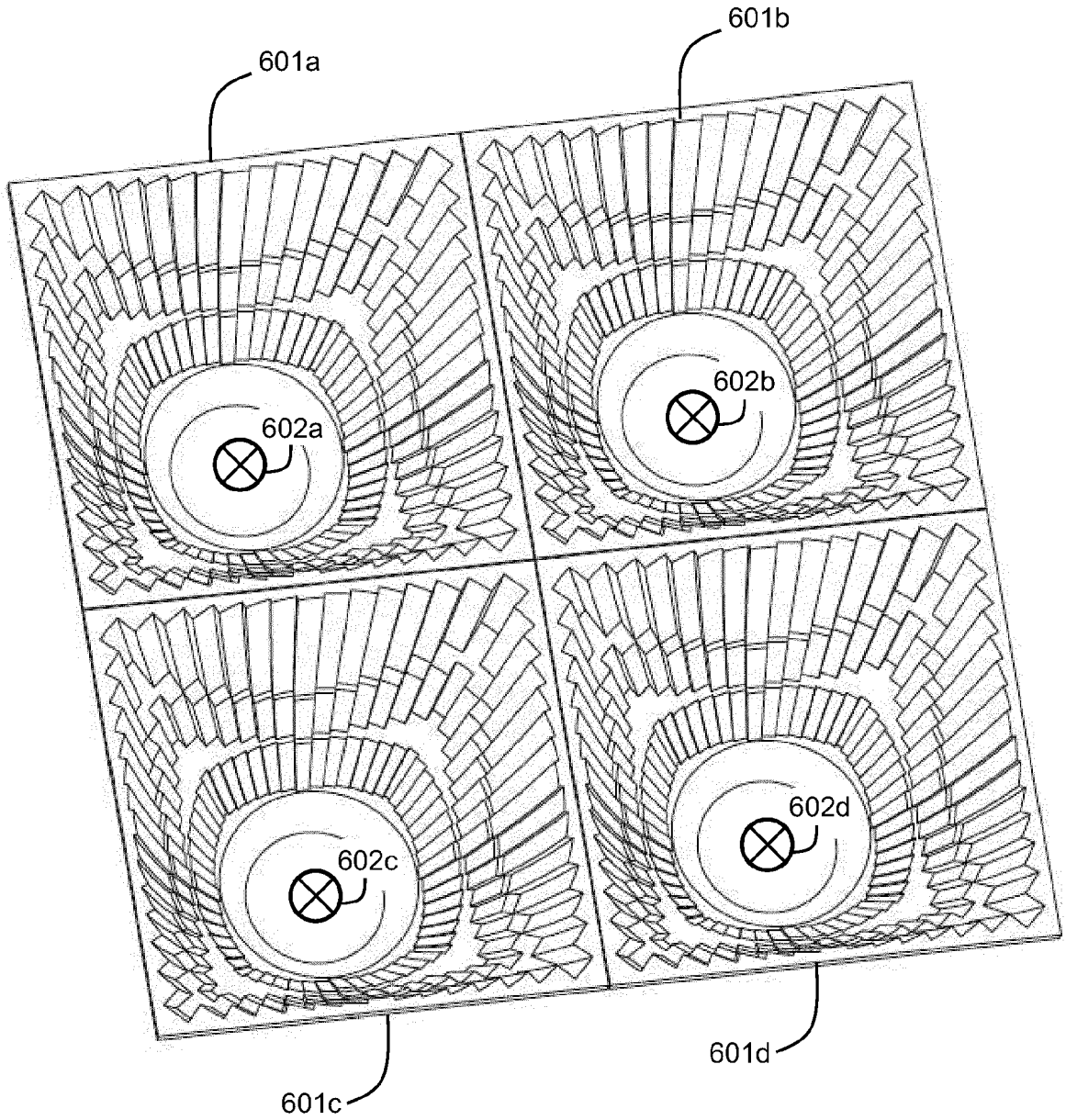


**Figure 6**

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# EUROPEAN SEARCH REPORT

Application Number
EP 15 16 5078

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