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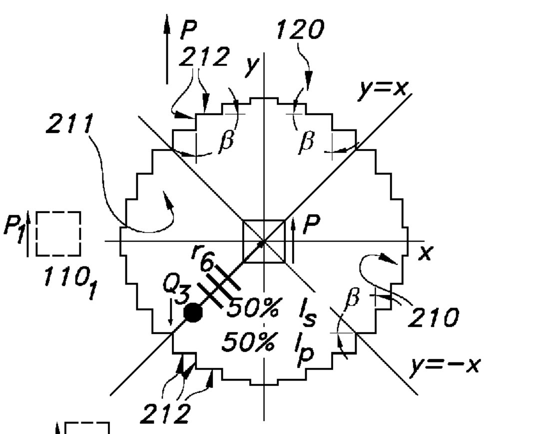

FIG. 7A

(57) **Abstract:** The invention provides a reflector unit (1000) comprising a reflector (200) having a side surface (210) and an optical axis (z), wherein the side surface (210) is tapering from a second end (222) to a first end (221), wherein at least part (211) of the side surface (210) comprises a plurality of segments (212) which define right angles (β) in cross-sectional planes perpendicular to the optical axis (z). The invention also provides a lighting device or spot light comprising such reflector unit.

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POLARIZED LIGHTING DEVICE CONTAINING POLARIZATION PRESERVING REFLECTOR

FIELD OF THE INVENTION

The invention relates to a reflector unit, a lighting unit comprising such reflector unit, as well as to a lighting device comprising such lighting unit.

BACKGROUND OF THE INVENTION

Illumination devices are known, wherein a polarizer is used for providing linearly polarized light. The polarizer is adapted to divide incident light into two linearly polarized components of opposite polarization characteristics. One of the components passes through the polarizer, while the other component is absorbed by the polarizer. In for example U.S. Pat. No. 3,566,099, this issue is addressed by providing a light projection assembly having a reflective-transmissive polarizer arranged over the mouth of a parabolic reflector, wherein one of the components passes through the polarizer and the other component is reflected back into the reflector. The reflected component, being oppositely polarized in relation to the transmitted component, is made to pass through a quarter-wave plate which is positioned directly behind the polarizer. The quarter-wave plate converts the reflected component into circularly polarized light, which is then reflected on the surface of the reflector and reversed into the opposite direction of polarization. As the reversed component passes back through the quarter-wave plate, it will emerge as light linearly polarized in the same direction as that of the original component transmitted by the polarizer and thus will pass through the polarizer reinforcing the transmitted component.

SUMMARY OF THE INVENTION

Polarized light illumination devices are desired for numerous applications like high efficiency LCD products (LCD projection systems, LCD televisions, LCD based computer displays, LCD desktop monitors, portable computers, tablet computers, smartphones), spot lights (studio spot lights, museum spot lights, retail spot lights, architectural spotlights, reading lights, pool lights), low glair luminaires (street luminaires, office luminaires, shop luminaires, museum lights) and more.

Polarized spotlights may be beneficial in illumination systems where either reflection from surfaces needs to be minimized, such as e.g. reflections from glossy surfaces like printed materials, photo's, posters, glass windows, pool surfaces, museum pieces, shop vitrines, stadium lights, studio spot lights, theater lights, etc., or where it is a desire to increase the reflection of light from surfaces (e.g. to create extra sparkling effects), like in shop environments (e.g. jewelry shops, car show rooms).

Absorption type polarizers might be used to absorb the unwanted mode of polarization, however, since the absorbed mode of polarization is lost, such solutions drastically reduces the system efficacy. To obtain acceptable lumen efficacy levels, polarization conversion optical subsystems are desired to convert the unpolarized light from an unpolarized light source into a polarized light beam with a minimal amount of light losses. Unpolarized light emitting sources such as LEDs have much higher efficiencies than polarized light emitting sources. Such polarization conversion subsystems make use of non-absorbing polarization dependent effects, like polarization dependent refraction, polarization dependent scattering or polarization dependent reflectors, where polarization dependent reflectors are most commonly used to provide such solutions as applied in LCD projectors and applied in backlight systems for direct view LCD products like LCD televisions, LCD monitors, laptop computers, tablets and mobile phones. Such solutions reflective polarizing elements may include a liquid crystal polymer based reflective polarizers (like cholesteric polarizers and uniaxial birefringent layer based polarizers such as the 3M DBEF (Dual Brightness Enhancement Film), interference layers based polarizing beam splitters (cube based PBS and multi PBS systems) and wire grid based reflective polarizers such as Moxtek polarizers. Therefore, in embodiments the reflective polarizer may comprise a dual brightness enhancement film, or a wire grid polarizer, or a cholesteric reflector.

Further, reflector shapes, like a parabolic reflector, may provide solutions to redirect and focus a reflected polarization mode into the desired directions; however such reflectors appear to have a relatively low optical efficiency.

Hence, it is an aspect of the invention to provide an alternative reflector, which preferably further at least partly obviates one or more of above-described drawbacks. The present invention may have as object to overcome or ameliorate at least one of the disadvantages of the prior art, or to provide a useful alternative.

This invention provides solutions to prevent the direction of polarization of the light rays to be changed when the light rays reflect at 2D curved reflector shapes like a parabolic reflector, such that the light rays may pass the reflective polarizer located at the output surface of such (polarized light) illumination system with a minimum amount of reflections leading to highest optical efficiencies.

Especially, the invention provides in a an aspect a reflector unit ("unit") comprising a reflector, especially for shaping (unpolarized) light source light of a light source into a beam of (polarized) light source light, the reflector having an optical axis, wherein a side surface of the reflector is tapering from a second end to a first end, wherein at least part of the side surface comprises a plurality of n segments wherein in specific embodiments the segments are configured to form straight intersection lines of the segments with a cross-sectional plane perpendicular to the optical axis (at a specific height along the optical axis), and wherein in specific embodiments these intersection lines of adjacent segments are configured perpendicular to each other. In specific embodiments the tapering of the reflector may be achieved by curving the segments within the height direction of the reflector. In specific embodiments, the segments may consist of planar facets, where the tapering of the reflector is achieved by providing or defining a stair-case configuration of these facets within its segment. Hereby, a segmented reflector is provided. Hence, in embodiments the invention provides a reflector having segmented side walls, which segments are perpendicular in cross-sectional planes perpendicular to the optical axis of the reflector, and which segments are tapered in the height direction over the optical axis of the reflector. The segments may in embodiments either may be curved within the height direction of the reflector or may consist of planar facets which are provided in a stair-case configuration within the height direction of the reflector. Hence, at least part of the side surface is segmented. The side surface may herein also be indicated as segmented side surface or facetted side surface. Therefore, in an aspect the invention may (especially) provide a reflector unit comprising a reflector having a side surface and an optical axis, wherein the side surface is tapering from a second end to a first end, wherein at least part of the side surface comprises a plurality of segments which define right angles in cross-sectional planes perpendicular to the optical axis. Especially, wherein $n>4$, like at least 8, such as at least 12. For a good beam shaping, $n>4$, especially at least 8, even more especially at least 12, such as up to 4000, like up to 800, like in the range of 8-256, though larger than 4000 is not excluded herein. The larger the number of segments, the easier it may be to have the reflector approximate a reflector having a circular cross-section (perpendicular to the optical axis).

With such reflector unit it is possible to create a desired beam shape and together with a reflective polarizer and (optionally) with a polarization rotating element, a beam of polarized light may be created with relatively high optical efficiency (starting with unpolarized light source). The loss of light for converting an unpolarized light source into a polarized light beam with such reflector unit may be relatively low.

As indicated above, the invention provides a reflector unit. The reflector unit comprises a reflector, but may optionally include further optics. Such further optics may be configured within the reflector and/or downstream of the reflector. Suitable optics may include e.g. a lens, refractive based or TIR (Total Internal reflection) based structures. Examples of lenses may include one or more of spherical, aspherical, biconvex, plano-convex, biconcave, plano-concave lenses, Fresnel lenses, holographic lenses, or any combination of these. Examples of refractive based structures may be micro lens structures, prism based structures, or variable prism based structures. Examples of TIR based structures may be prismatic structures configured to (partly) guide the incident light via TIR based reflective side-walls. Further, such optical structures may be an integral part of the reflector, especially in embodiments wherein the reflector is a solid body (of light transparent material).

The terms “upstream” and “downstream” relate to an arrangement of items or features relative to the propagation of the light from a light generating means (here the especially the light source), wherein relative to a first position within a beam of light from the light generating means, a second position in the beam of light closer to the light generating means is “upstream”, and a third position within the beam of light further away from the light generating means is “downstream”.

Further, in embodiments the reflector unit may include an end window of a light transparent material. Especially, such end window has substantially no impact on the polarization of the light escaping from the reflector.

The reflector is especially used to shape a beam of light from the light source light of a light source, such that together with the reflector unit a beam of light can be created. Hence, the reflector (unit) can also be indicated as beam shaping element. Especially, there may be two types of beam shaping elements.

In specific embodiments, the beam shaping element may comprise a hollow reflector with reflector cavity, with a first side and a second side, wherein the second side comprises a reflector opening for escape of the beam of light source light from the hollow reflector. The light source can be configured upstream of the first side, or within the reflector closer to the first side than to the second side.

Alternatively, in specific embodiments the beam shaping element may comprise a solid reflector with reflector body (of solid light transmissive material), with a first side and a second side, wherein the second side comprises a reflector face (or end face) for escape of the beam of light source light from the reflector body. The light source may be configured upstream of the first side and the second side; the second side is configured downstream of the first side. The first side and/or the second side may be planar or may be curved. Further, such first side and/or second side may comprise one or more optical structures.

A solid reflector may in embodiments also be configured as lens, for instance, when the solid reflector has a curved end face.

The reflector may e.g. be a collimator, like a parabolic collimator or an elliptical reflector. Hence, in embodiments the reflector consist of segmented side walls that are parabolic shaped along the optical axis (or height direction) of the reflector. A Bezier shape of the segmented side walls may also be possible. A tapered shape of the segmented side walls may also be possible.

Therefore, the reflector has an optical axis. Further, a side surface of the reflector is tapering from a second end to a first end. Especially, this side face may essentially define a length of the reflector. Or, the distance between the first and second end may define the length. The side surface may bridge the distance between the first end and the second end. Especially, the side surface essentially surrounds the optical axis over the length between the first end and second end. The term “surrounding” does not necessarily refer to a perfect circular surrounding. As further elucidated below, the optical axis may over part of its length be surrounded with a stair-case like side face. In other embodiments, the optical axis may over part of its length be surrounded with a segmented side face.

Hence, at least part of the side surface (directed to the optical axis) comprises a plurality of segments. Especially, the part of the side surface that comprises these segments is an integral part, or comprises a (even numbered) plurality of parts that are configured symmetrical relative to the optical axis, or comprises a plurality of optical axis surround parts. Especially, however, the part of the side surface that comprises these segments is an integral part; here below, such integral part is further described.

In general, the part of the side surface that comprises these segments is (thus) especially essentially surrounding the optical axis. Further, the part of the side surface that comprises these segments is over at least 40%, such as at least 50%, like at least 70%, of the length along the optical axis, wherein the maximum length is defined as the length along (or projected on) the optical axis of the side surface. Especially, the entire side surface may comprise such segments.

In specific embodiments, the segments consist of a number of planar facets that are square or rectangular. Also different types of segments and/or facets may be applied. The facets may in embodiments have lengths and widths. The lengths and widths may vary or may be identical for all of the facets. Especially, a part of the side surface close to the first end, and a part of the side surface close to the second end may include facets that have other lengths and/or width that the part of the side surface in between. Typical lengths and widths of the facets, in case applied, may (independently) be selected from the range of 1 mm - 10 cm. For most lighting applications, these dimensions may independently be selected from the range of 2 mm – 5 cm. Especially, the segments are segments that are parabolic shaped over the height direction of the reflector; i.e. one dimensionally curved with a parabolic curvature. Especially, the facets, in case applied, are planar facets. In this way, undesired redirection of the rays of the light source light is minimized. Especially, the facets, in case applied, are essentially flat facets, in order to reduce specular reflection at the facets.

Hence, in embodiments the segments are planar or one dimensionally curved. With such embodiments, the intersection lines of the segments with a cross-sectional plane perpendicular to the optical axis are straight lines. Further, the intersection lines of adjacent facets with the cross-sectional plane are configured perpendicular to each other. Hence, in embodiments the segments may be planar shaped, may be curved shaped, such as parabolic shaped, etc. In embodiments, the segments are staircase staggered. Note that a combination of differently shaped segments may also be possible.

In a specific embodiment, of the reflector a side surface of the reflector is tapering from a second end to a first end, wherein at least part of the side surface comprises a plurality of segments wherein in specific embodiments a subset of the total number of segments are configured parallel to the optical axis, wherein in specific embodiments a (second) subset of the total number of (second) segments are configured perpendicular to the optical axis, and wherein in specific embodiments adjacent segments are configured perpendicular to each other. Hereby, a staircase-like tapering is provided. Hence, the invention also provides a reflector having a staircase-like tapered side face with segments providing or defining such staircase that are essentially parallel or essentially perpendicular to an optical axis of the reflector. Hence, in embodiments a first subset of a total number of segments are configured parallel to the optical axis and a second subset of the total number of second segments are configured perpendicular to the optical axis, and wherein adjacent segments are configured perpendicular to each other, which is herein also indicated as staircase embodiment.

As indicated above, the reflector may comprise a plurality of n segments which (intersection lines with cross-sectional planes perpendicular to the optical axis) define right angles in cross-sectional planes perpendicular to the optical axis, wherein n>4. Such number of segments may be essentially over the length (or height) of the reflector. However, in other embodiments, the reflector may have a staircase shape. In such embodiments, there may be a substantial number of segments. Especially, the reflector is configured such that there is at least a single cross-sectional plane (perpendicular to the optical axis) that intersect with n>4, like at least 8, such as at least 12 segments. For instance, assume that at a specific height along the optical axis a cross-sectional plane would intersect 12 segments, and at another height another cross-sectional plane would intersect 12 other segments, this would imply that there are at least 24 segments. This may e.g. apply for staircase embodiments. Note that it may be especially useful in view of beam shaping, when at a specific height along the optical axis a cross-sectional plane would intersect 8 segments. As will be clear to a person skilled in the art, the term “cross-sectional planes” especially refers to virtual planes.

The reflector unit has preferably n≥8. More preferably n≥12 or even more preferably n≥28. Most preferably n≥60. The higher the n, the smoother the beam.

The reflector unit has preferably a high level of symmetry i.e. 4+y*n faces wherein n=8 and y is a positive integer i.e. 1, 2, 3, … . A reflector unit which has a high level of symmetry enables a beam shape which has a high level of symmetry.

The reflector unit has preferably n=12 or n=20, more preferably n=28 or n=36 or n=44, most preferably n=52 or n=60 or n=68 or n=76 or n=84 or n=92 or n=100.

Preferably at least 80% of all segments which define right angles (β) in cross-sectional planes perpendicular to the optical axis (z), more preferably at least 90% of all segments which define right angles (β) in cross-sectional planes perpendicular to the optical axis (z), most preferably all segments which define right angles (β) in cross-sectional planes perpendicular to the optical axis (z).

The accuracy of alignment between the reflective polarizer and the reflector unit is preferably within 1°, more preferably within 0.5°.

The right angles are thus especially the mutual angles of the segments. More precisely, it refers to the mutual angles of the intersection lines of the segments with the with cross-sectional planes perpendicular to the optical axis. Hence, the right angle refers to the mutual angle between adjacent segments at the same height and which are configured essentially parallel to the optical axis.

As indicated above the reflector may be hollow or may be massive ("solid body"). Especially in embodiments wherein the reflector comprises a hollow reflector, the segments may comprise a metallic coating, such as especially having a high specular reflectivity. For instance, the metallic coating may be an aluminum coating or a silver coating. In specific embodiment, such metal coating may be covered with a transparent material to protect the metal for aging. Alternatively, in an embodiment the reflector comprises a hollow reflector, the segments may comprise an interference coating having a high specular reflectivity, where the interference coating consist of a stack of transparent layers having alternated refractive indices. In this way, a reflective side surface may be obtained.

In yet other embodiments, the reflector comprises (thus) a light transparent material. Especially, in such embodiments the reflector is a total internal reflection (TIR) reflector. Such reflector may especially be configured such that the light rays originating from the light source cannot leave the side walls of the transparent embodiment due to total internal reflections. Also such reflector may comprise a light reflective coating (at the side surface(s) of the solid body of light transparent material.

Hence, the reflector, such as especially the segments, may comprise, a light reflective coating, especially a specular light reflective coating, such as in embodiments a metallic coating.

The reflector unit is especially useful for shaping unpolarized light source light of a light source into a beam of polarized light source light. To this end the reflector unit may include further optics to convert the unpolarized light of the light source into polarized light.

Therefore, especially, the light source provides unpolarized light. The term "light source" may refer to a semiconductor light-emitting device, such as a light emitting diode (LEDs), a resonant cavity light emitting diode (RCLED), a vertical cavity laser diode (VCSELs), an edge emitting laser, etc. The term "light source" may also refer to an organic light-emitting diode, such as a passive-matrix (PMOLED) or an active-matrix (AMOLED). In a specific embodiment, the light source comprises a solid state light source (such as a LED or laser diode). In an embodiment, the light source comprises a LED (light emitting diode). The term LED may also refer to a plurality of LEDs. Further, the term "light source" may in embodiments also refer to a so-called chips-on-board (COB) light source. The term "COB" especially refers to LED chips in the form of a semiconductor chip that is neither encased nor connected but directly mounted onto a substrate, such as a PCB. Hence, a plurality of semiconductor light sources may be configured on the same substrate. In embodiments, a

COB is a multi LED chip configured together as a single lighting module. The term “light source” may also relate to a plurality of light sources, such as 2-2000 solid state light sources.

The term light source may also refer to non-semiconductor based light source, like incandescent lamps, gas discharge lamps, high intensity gas discharge lamps like metal halide lamps, UHP-mercury lamps or Xenon discharge lamps, flash lights or Extreme UV lamps, such as used for photolithography.

The term light source may also refer to a light that is extracted from a light conversion element, where the light conversion element is pumped with pump light originating from one or more light sources as described above.

The light source may be configured to provide white light or colored light. When a plurality of (different) light sources is applied, the optical properties of the beam of light may be controlled, such as one or more of color point, color temperature, etc.

As indicated above, especially the reflector unit comprises a reflective polarizer. Such reflective polarizer may especially be configured for providing a polarized beam of light source light. The reflective polarizer is especially configured closer to the second end than to the first end. Hence, in embodiments the reflector unit may further comprise a reflective polarizer configured at the second end. Hence, upstream of the reflective polarizer the light may be unpolarized or include different polarizations. Downstream of the reflective polarizer, i.e. especially downstream of the reflector, the light source light (of the beam) is polarized. The polarization may be s or p polarization.

An example of such reflective polarized is e.g. a dual brightness enhancement (DBEF) film, which may especially consisting of a lamination of a large stack of birefringent polymer layers, such as e.g. described in EP0428213 or by Su Pan et al., in Optics Express, vol. 25, no 15 (24 July 2017), p. 14799-17510, which are herein incorporated by reference. Therefore, in embodiments the reflective polarizer comprises a dual brightness enhancement (DBEF) film.

Alternatively, such reflective polarizer may consist of a wideband cholesteric polarizer, such as e.g. described in EP0606939, or a wideband wire grid (Moxtek) polarizer, such as e.g. described in EP1192486, which are herein incorporated by reference.

Such reflective polarizer selects a specific polarization and reflects at least part of the light having another polarization. Hence, the reflective polarizer is especially a downstream optics, such as configured at the second end.

As indicated above, the reflector unit may further (also) comprise a polarization rotator configured upstream of reflective polarizer. Especially suitable for the polarization rotator are one or more ¼ λ layers, like 1-3 of such ¼ λ layers. Therefore, in embodiments the polarization rotator comprises a stack of ¼ λ layers, such as at least two ¼ λ layers, like three ¼ λ layers.

The polarization rotator may especially be configured upstream of the reflective polarizer. Several positions may be possible, as further explained below. In this case a specific polarization direction is chosen by the reflective polarizer and light of the opposite (unwanted) polarization is reflected. Due to the passages through the polarization rotator, the light with the unwanted direction of polarization is rotated to the desired direction of polarization that is accepted by the reflective polarizer and can escape from the reflector unit and contributes also to the intensity of the beam of (polarized) light source light. In this way, the reflector efficiency is larger.

In embodiments, intersection lines of the segments with the cross-sectional planes perpendicular to the optical axis are configured parallel or perpendicular to a polarization axis of the reflective polarizer. These configurations provide the highest efficiencies. In other embodiments, intersection lines of the segments with the cross-sectional planes perpendicular to the optical axis are configured under an angle of 45° with a polarization axis of the reflective polarizer. This configuration is less efficient than configurations wherein intersection lines of the segments with the cross-sectional planes perpendicular to the optical axis are configured parallel or perpendicular to a polarization axis of the reflective polarizer, but more efficient than other angles such as for example 17 °.

The reflector may especially be used for a lighting unit, wherein the light source light of a light source is converted into a beam of light source light by the reflector. Hence, in yet a further aspect the invention provides a lighting unit comprising the reflector unit as defined herein, and a light source module, wherein the light source module is configured closer to the first end than to the second end, wherein the light source module comprises the light source having a light emitting surface portion. Especially, the light emitting surface portion is within a cavity defined by the reflector.

Hence, the light source is especially a solid state light source. In specific embodiments, the light emitting surface portion is configured perpendicular to the optical axis. Especially, the lighting unit may further comprise a reflective polarizer especially configured for providing a polarized beam of light source light. Yet further, especially the lighting unit may further comprise a polarization rotator for changing a polarization direction of at least part of the light source light that is reflected by the reflective polarizer. Therefore, in an aspect the invention provides a lighting unit comprising the reflector unit as defined herein, and a light source module, wherein the light source module is configured closer to the first end than to the second end, wherein the light source module comprises a light source having a light emitting surface portion and configured to generate light source light, and wherein the lighting unit may in specific embodiments further comprise a reflective polarizer, especially configured for providing a polarized beam of light source light. The reflector is especially used to shape the beam and the polarizer is especially used to provide such beam with an essentially a predetermined polarization of the light (rays) in the beam of light source light.

The light source may especially be configured such that part of the light source light can escape from the reflector without being reflected at the side surface of the reflector.

Further, especially the light source module further comprises a reflective surface portion. In such embodiments, especially the light emitting surface portion and the reflective surface portion are configured perpendicular to the optical axis.

Herein, terms like “perpendicular” or “parallel” may refer to configurations that may also deviate at maximum about 5° thereof. Hence, the terms “perpendicular” or “right angle” may refer to an angle selected from the range of 85-95°, like 89-91°, such as especially selected from the range of 89.5-90.5°, like 90°+/- 0.2°. Likewise, such ranges may apply around 0° or 180°. Tolerances of +/-5°, such as +/-1°, like +/-0.5°, like especially +/-0.2° may be possible. Hence, terms like “perpendicular” or “parallel” may also be interpreted as “essentially perpendicular” or “essentially parallel”, respectively, as known to a person skilled in the art.

Especially, the lighting unit may thus further comprise the polarization rotator as defined above. This polarization rotator may essentially be placed at two alternative positions. In embodiments, the polarization rotator is configured at the second end. For instance, the polarization rotator is a layer directly upstream of the reflective polarizer.

Therefore, in embodiments the polarization rotator is configured as layer adjacent to and upstream of the reflective polarizer.

In alternative embodiments, the polarization rotator is configured at the reflective surface portion. Hence, in embodiments the light emitting surface portion and the reflective surface portion are configured perpendicular to the optical axis z, and the polarization rotator is configured closer to the reflective surface portion than to the second end. The polarization rotator may thus be configured at (i.e. especially in physical contact with) the reflective surface portion or nearby, such as within about 10 mm, such as within about 5 mm, from the reflective surface portion. As there may be a plurality of reflective surface portions, there may also be a plurality of (identical) polarization rotators. The polarization rotator(s) especially change the polarization of the light reflected at the reflective polarizer.

Especially, the polarization rotator is configured for changing a polarization direction of at least part of the light source light that is reflected by the reflective polarizer.

Alternative (or additional) to a polarization rotator, also a depolarization element may be applied. For instance, LED dies may have such depolarization effect on light reflected to the LED die.

As indicated above, the term “light source” may also refer to a plurality of light sources. Likewise, the term “surface portion” may also refer to a plurality of surface portions, and the term “light emitting surface portion” may also refer to a plurality of light emitting surface portions. Therefore, in specific embodiments the lighting unit may comprise a plurality of sets of light emitting surface portions and reflective surface portions. In further specific embodiments, the light emitting surface portions and reflective surface portions of each set are configured symmetrical to the optical axis.

In specific embodiments, a lighting unit is provided, comprising at least one light emitting module adapted to emit light. The light emitting module comprises at least one light emitting surface portion and at least one corresponding reflective surface portion. Furthermore, the optical system comprises at least one reflector arranged relatively to a corresponding one of the at least one light emitting module so as to receive at least some light emitted by the at least one light emitting module, and a polarizer which is arranged relatively to the reflector so as to receive at least some of the light emitted by the at least one light emitting module. The polarizer is adapted to transmit light having at least a first polarization direction, and to reflect light having at least a second polarization direction. At least some of the reflected light is directed, for example via reflection at the reflector, back towards the at least one light emitting module. Each of the at least one light emitting surface portion and the at least one reflective surface portion is arranged asymmetrically with respect to an optical axis of the at least one reflector, and each of the at least one light emitting surface portion and the corresponding at least one reflective surface portion is arranged point symmetrically to each other with respect to a point coinciding with the optical axis of the at least one reflector. Thereby, at least some of the light reflected by the polarizer impinges on the at least one reflective surface portion, wherefrom at least some of the impinging light is reflected towards the polarizer, through which at least some of the impinging light is transmitted.

The amount of polarized light emitted from the unit, or the efficiency of the unit, is for example dependent on the degree or extent of light reflection within the reflector. By for example using a transmissive-reflective polarizer, which transmits light having a desired or required first direction of polarization and reflects at least some of the light that is not transmitted through the polarizer back into the reflector, an improved 'recycling' of the light generated by the light emitting module may be enabled. Further, by providing a light emitting module within the reflector, which e.g. may be circularly symmetric with respect to its optical axis, which light emitting module has a reflective surface portion and a light emitting surface portion which are arranged point symmetrically to each other with respect to a point coinciding with the optical axis and wherein the at least one light emitting surface portion and the at least one reflective surface portion are arranged asymmetrically with respect to the optical axis, the degree of light reflection within the reflector may be increased as compared to utilizing a light emitting module not having any reflective surface portion or not exhibiting such a point symmetric arrangement of the reflective surface portion relatively to the light emitting surface portion. The point symmetry of the optical system of the at least one reflective and light emitting surface portions and the asymmetric placement of the at least one reflective and light emitting surface portions with respect to the optical axis enables at least some of the light that is reflected back by the polarizer towards the light emitting module to impinge on the reflective surface portion arranged point symmetrically to the corresponding light emitting surface portion from which the light was emitted. Thereby, at least some of the light having the undesired, second polarization direction may be 'recycled' by means of the symmetrically arranged reflective surface portions of the light emitting module relatively to the light emitting surface portions, which are arranged asymmetrically with respect to the optical axis, and the efficiency of the optical system may hence be improved. By arranging the reflective surface portions such that at least some of the reflected light having the second polarization direction impinges on the reflective surface portion rather than on the light emitting surface portion of the light emitting module, the amount of light impinging on or absorbed by non-reflective surface portions of the light emitting module may advantageously be reduced. Since the polarization of the light, e.g. direction of polarization of the light, reflected by the polarizer may be changed upon reflection on a reflecting surface or surfaces, e.g. on the reflective surface portions of the light emitting module and/or on the reflector, at least some of the recycled light may eventually be transmitted through the polarizer as light having the desired direction of polarization. Further embodiments are also described in US2015346505/WO2014180718A1, which is (are) herein incorporated by reference.

In yet a further aspect, the invention also provides a lighting device comprising one or more lighting units as defined herein. The lighting device may be part of or may be applied in e.g. office lighting systems, household application systems, shop lighting systems, home lighting systems, accent lighting systems, spot lighting systems, theater lighting systems, fiber-optics application systems, projection systems, self-lit display systems, pixelated display systems, segmented display systems, warning sign systems, medical lighting application systems, indicator sign systems, decorative lighting systems, portable systems, automotive applications, (outdoor) road lighting systems, urban lighting systems, green house lighting systems, horticulture lighting, LCD backlighting or photolithography. When a plurality of (different) light sources is applied, the optical properties of the beam of light may be controlled, such as one or more of color point, color temperature, etc. Therefore, in embodiments the lighting device may also include or be functionally coupled to a control system configured to control the light sources of the plurality of light sources.

In a specific aspect, the invention provides a luminaire or a lamp comprising one or more lighting units as defined herein. Hence, in embodiments the invention provides also a spot light. The reflector of the reflector unit and/or an additional beam shaping element may be used to shape the beam of light of the spot light. As indicated above, the reflector may also be indicated as beam shaping element. Hence, the term “beam shaping element” may in embodiments also refer to a plurality of beam shaping elements.

In embodiments, the beam shaping element, such as the reflector and/or another beam shaping element, may be configured to shape the light source light into the beam of light source light having a beam angle selected from the range of 2-120°, especially 5-90°, such as 5-40°. In this way, e.g. a spot light may be provided. Especially, the beam angle is defined by the full width half maximum intensities. Hence, e.g. the value of 40° may be defined as between -20° and + 20° from the optical axis. Instead of the term “spot light” also the term “spot light device” may be applied. A spot light is a possible embodiment of the lighting unit. Hence, in specific embodiments the lighting device may include a directional lighting device. Such device may have at least 80% light output with a solid angle π sr, corresponding to a cone with an angle of 120°. A directional lighting device is a possible embodiment of the lighting unit. Instead of, or in addition to a spot light, also other types of devices may be applied, such as often indicated as “luminaire”, or “light engine” or “fixture” or “module”.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, and in which:

Fig. 1 schematically depicts for explanatory purposes a cross sectional side view of an optical system, comprising a light emitting module and a transmissive-reflective polarizer;

Fig. 2 schematically depicts for explanatory purposes a cross-sectional view of a massive reflector;

Figs. 3a-3d each schematically depicts a top or frontal view of a light emitting module having at least one light emitting surface portion with a corresponding reflective surface portion;

Figs. 4a and 4b show the front view of a solid parabolic reflector 120 having a refractive index of e.g. n=1.5. Fig. 4b shows a cross sections of the solid parabolic reflector 120 through its optical axis z.

Figs. 4c shows the mirror-images of light source 110, for the light rays being reflected at point Q_1 (Image 110_1), for the light rays being reflected at point Q_2 (Image 110_2), and for the light rays being reflected at point Q_3 (Image 110_3);

Figs. 5a-5b schematically depict for explanatory purposes the polarizations with a reflector having a mirror like reflective side surface with a metal coating;

Figs. 6a and 6b show for explanatory reasons the polarizations with an unpolarized light source emitting unpolarized light towards the exit surface of the parabolic reflector where it hits a reflective polarizer positioned at the exit plane of the parabolic reflector;

Figs. 6c-6d show the cross sections over the y,z-axis with light rays r_3 and r_4 selected in the plane x=0, where light ray r_3 hits the reflector at point Q_2. Fig. 6b is in the x-direction and Fig. 6d is in the y-direction. Figs. 6e and 6f show the other situations;

Figs. 7a-7c show cross-sections of an embodiment of a segmented reflector.

The schematic drawings are not necessarily to scale.

DETAILED DESCRIPTION OF THE EMBODIMENTS

A solution is possible where the light, after being reflected by a reflective polarizer, hits metallic surfaces in the illumination device, preventing the light to be depolarized. Stacks of λ/4 films may be applied to change the direction of polarization from an unwanted towards a desired mode. Such solutions may minimize the number of reflections required to convert all the light from an unwanted into the desired mode of polarization and are favorable to be used in illumination systems like spot lights. An example of such solution may be found in WO2014180718A1 (Fig. 1). The polarized spot light 100 consist of a LED based light source 110 which consist of at least 1 LED light sources positioned in plane 110. The exit plane of the spot lighting device 100 is covered by a reflective polarizer 130 that transmits a wanted mode of polarization L_2 and reflects the unwanted mode of polarization L_3. The unwanted mode of polarization L_3 is reflected back to plane 110 where a reflector 112 is positioned. Reflector 112 reflects the light rays L_3 as light rays L_4 back to the reflective polarizer 130. During these reflections, the light passes a polarization rotating element 140, which polarization rotating element may consist of a λ/4 film or a stack of λ/4 films, after the polarization direction of the light is changed from the unwanted into the wanted mode (or at least part of the light is changed from the unwanted into the wanted mode), after the light may pass the reflective polarizer 130 towards the objects (or space) to be illuminated. Reference α indicates the beam angle; reference z indicates the optical axis.

Fig. 1 schematically depicts an explanatory example of a reflector unit 1000 comprising a reflector 200 for shaping light source light 11 of a light source 10 into a beam 20 of light source light 11, the reflector 200 having an optical axis z, wherein a side surface 210 of the reflector 200 is tapering from a second end 222 to a first end 221. However, in this explanatory example, the side surface 210 does not comprise segments 212. Reference L1 indicates the length or height of the reflector 200.

Fig. 1 especially depicts a hollow reflector 200, such as a hollow parabolic reflector. Fig. 2 schematically depicts an explanatory example wherein the reflector 200 comprises a light transparent material 201, and wherein the reflector 200 is a total internal reflection reflector. Both figures in fact also schematically depict explanatory examples of a lighting unit 2000 comprising the reflector unit 1000 and a light source 10, such as a light source module 110 comprising such light source 10. The reflector unit 1000 is configured to beam shape the light source light 11 of the light source(s) 10 (of the light source module 110; if any).

Note that in both embodiments as schematically depicted in Figs. 1 and 2, the light emitting surface portion 114 is within a cavity defined by the reflector. In the hollow reflector, it is in the reflector cavity, see Fig. 1. In the massive reflector, there may be a cavity at the first end 221, wherein the light emitting surface portion 114 may be configured.

Figs 3a-3b from application WO2014180718A1 show a preferred positioning of the (LED) light source 114 and reflecting surface 112 in plane 110, which positioning is such that the (unwanted) light reflected by the reflective polarizer 130 hits the reflecting surface 112 and will not be incident on a light source 114, since most of the light that will hit a light source 114 will be absorbed by that light source. Figs. 3 c and 3d of application WO2014180718A1 show alternative embodiments where multiple LED's 114 are positions at surface 110 such that the light, after being reflected at reflective polarizer 130, will hit a reflecting surface 112 and will not be incident on an LED light source 114.

For such parabolic reflector based systems it will be beneficial to improve the control of the polarization directions of the light rays that have been reflected at the reflecting polarizer 130, such that the polarization direction of these light rays will have been converted from the unwanted direction (the linear polarization direction of the light rays as reflected from the reflective polarizer 130) towards the wanted mode of polarization (the linear direction of polarization of the transmissive mode of the reflective polarizer 130) at the moment these light rays hits the reflective polarizer for the second time. In that case all that light will pass the reflective polarizer with a minimum amount of reflections within the polarized light illumination device 100 leading to highest optical efficiency. Secondary, when the polarization directions are fully controlled, the polarization modifying element 140 (consisting of a $\lambda/4$ film or a stack of $\lambda/4$ films) may be positioned on top of the reflecting surface 112 instead near the reflective polarizer 130 as shown in Fig. 1, leading to smaller sizes of the polarization rotating element 140 and such to lower cost. In such embodiment the reflective polarizer 130 will split the light into its 2 linear polarized light components I_{wanted} and $I_{unwanted}$, will transmit the wanted polarization mode I_{wanted} and will reflect the unwanted polarization mode $I_{unwanted}$, after the polarization direction of the unwanted mode $I_{unwanted}$ is preserved until these light rays hits the reflecting surface 112. Since the reflecting surface 112 is covered by a $\lambda/4$ film 140, the linear polarized light will be converted in circular polarized light at the moment the light passes $\lambda/4$ film 140. At the moment that circular polarized light hits the reflecting surface 112, the rotation direction of that circular polarized light will convert (right handed circular polarized light will convert in left handed circular polarized light and vice versa), after the light rays will traverse through the $\lambda/4$ film 140 for the second time, such the circular polarized light will be converted back to linear polarized light by the λ/4 film 140. Since the direction of rotation of the circular polarized light has been changed while the light rays reflect at the reflecting surface 112, the light is converted to linear light of the opposite, or wanted, direction, such these light rays will be transmitted by the reflective polarizer 140 as a wanted mode of polarization. Indications like Pol close to an arrow indicate that the arrow shows the polarization direction of the polarized light.

Such solutions however would require a (linear) polarization preserving parabolic reflector, while a standard parabolic reflector, as explained below, does not. Figs. 4a and 4b show the front view of a solid parabolic reflector 120 having a refractive index of e.g. n=1.5. Fig. 4b shows a cross sections of the solid parabolic reflector 120 through its optical axis z and y=0. Figs 4a-4b shows a polarized light emitting lighting device 100 emitting linear polarized light with polarization direction P in the direction of the y-axis, which might be an LED covered by a linear (absorption type) polarizer. Fig. 4b shows a light ray r_1 emitted by the light emitting device towards point Q_1 located at the parabolic reflector 120 after light ray r_1 is reflected by parabolic reflector 120 as light ray r_2 towards the object and/or environment to be illuminated. Fig. 4c shows the mirror-images of light source 110, for the light rays being reflected at point Q_1 (Image 110_1), for the light rays being reflected at point Q_2 (Image 110_2), and for the light rays being reflected at point Q_3 (Image 110_3). As shown in Fig. 4c, the polarization direction of mirror-image 110_3 is rotated over 90° (rotated from the y axis direction towards the x-axis direction), while the polarization of the mirror-images 110_1 and 110_2 are maintained.

Ray tracings using Light Tools of such a specific embodiment demonstrates the light loss due to this effect. For a solid parabolic reflector (CPC) using no polarizers, 99.9 % of the emitted light will leave the CPC at its exit surface. For a solid parabolic reflector (CPC) using crossed polarizers (a polarizer on top of the light source and a crossed oriented polarizer (the analyzer) on top of the exit surface of the CPC), although the polarizers are crossed, 42.6 % of the emitted light will pass the analyzer located at the exit plane of the CPC, which transmission is caused by the rotations of the plane of polarization as indicated in Figs. 4a-4c. For a solid parabolic reflector (CPC) using parallel polarizers (a polarizer on top of the light source and a parallel oriented polarizer (the analyzer) on top of the exit surface of the CPC), although the polarizers are parallel, only 59.2 % of the emitted light will pass the analyzer located at the exit plane of the CPC, which light loss is caused by the rotations of the plane of polarization as indicated in Figs. 4a-4c.

Additional phase change effects may occur in case a metal parabolic reflector is used instead of a solid CPC. In case of a reflection of light at a boundary of a high refractive index to a lower refractive index (as shown in Fig. 4b) such phase change remains absent, however in case of a metal reflector (Fig. 5a) phase changes will occur at the moment polarized light reflects at the metallic surface. Because the phase shift for p-polarized and s-polarized light is different, these phase changes will cause the light to become elliptical polarized in case both components (p-polarized and s-polarized) are present, as is the case at plane p_3 in Fig. 5b, while the direction of polarization (the main axis of the elliptical polarized light) is simultaneously is rotated with respect of the polarization direction of the source light pol (direction of the y axis).

There may remain two special circumstances where linear polarized light reflects as linear polarized light, which is the case when only p or s polarized light is incident on the metallic surface, such the light leaving the parabolic reflector like originating from the mirror-images 110_1 or 110_2 remain their initial state of polarization.

In embodiments, a reflective polarizer at the exit surface of the parabolic reflector may be applied.

Figs. 6a and 6b shows an embodiment with an unpolarized light source 110 emitting unpolarized light towards the exit surface of the parabolic reflector 120 where it hits a reflective polarizer 130 positioned at the exit plane of the parabolic reflector, which reflective polarizer 130 may consist of a large stack of linear oriented, birefringent layers such as a 3M DBEF film. The reflective polarizer film130 split the incident light into its 2 linear polarizing components and is oriented such that the reflected light is polarized in the y direction as indicated in Figs 6a-6b resp. (the black dot, indicated pol, in Fig. 6b indicates a polarization direction in the y axis in this particular cross section). The (linear polarized) light rays reflected by the reflective polarizer 130 are bounced back into the parabolic reflector where they may be reflected by the walls of the parabolic reflector towards the plane 110 where the light source is located. The light source 110 at plane 110 is however positioned such, that the light rays reflected at the reflective polarizer 130 is focused at a mirror surface located in the plane 110 as indicated in Figs 3a-3d. Note that the angle of reflection at the parabolic reflector 120 is determined by the tangent plane of the parabolic reflector at point Q_1 where light ray r_1 hits the parabolic reflector 120. Lines p_1 and p_{11} in the figures represent the cross section of that tangent plane p_1 in those particular cross sections. Fig. 6b show the cross sections over the x,z-axis with light rays r_1 and r_2 selected in the plane y=0, where light ray r_1 hits the reflector at point Q_1. Since light ray r_1 is (only) s-polarized, the light after reflection (light ray r_2) remains s-polarized and all light rays in the plane y=0 will remain linear polarized and maintain their direction of polarization while reflected at the walls of the parabolic reflector 120. Fig. 6d show the cross sections over the y,z-axis with light rays r_3 and r_4 selected in the plane x=0, where light ray r_3 hits the reflector at point Q_3. In this view, the polarization direction of the reflected light is parallel to the y-axis. Since light ray r_3 is (only) p-polarized, the light after reflection (light ray r_4) remains p-polarized and all light rays in the plane x=0 will remain linear polarized and maintain their direction of polarization while reflected at the walls of the parabolic reflector 120.

In all other circumstances, as shown in Figs. 6e and 6f, the plane of polarization of the light rays will rotate while, in case of a metal reflector, the (linear polarized) light needs to be split into its 2 components (its p- polarized and its and s-polarized component), after these 2 components are reflected with a different phase shift, such that the light has become elliptically polarized after reflection. Since many light rays will deviate from the x=0 or y=0 plane, a large amount of the original polarization direction of the linear incident light will be lost, leading to multiple reflections before the light may leave the system through the reflective polarizer 130, reducing the system efficacy of such polarized light illumination device, as simulated in the ray tracing according to Fig. 6.

Therefore, a parabolic reflector solution is provided which maintains the polarization of the light when the individual light rays are being reflected at the parabolic reflector. Figs 7a-7b shows a typical embodiment according to the invention. Instead of a standard parabolic reflector, the reflector 200 is segmented, such that any y=x cross section along the z-axis consist of reflecting planes that are either parallel or perpendicular to the polarization axis of the reflective polarizer 130. As a result the mirror image 110_3 of the light source 110 does not rotate with respect to the original. Next, in case of a metal reflector, a light ray r_5 will bounce twice at a (metallic) parabolic reflector 200, once at a metal surface oriented parallel to the axis of polarization and once at a metal surface oriented perpendicular to the axis of polarization. Such, in case the segments are relatively small, at each reflection only p or s polarized light is reflected, such the light keeps its direction of polarization at each reflection while also the effects of phase shifts remain negligible.

A polarized light illumination system may consist of such segmented reflector 200, a lighting device 110 and a (linear) reflective polarizer 130. The reflective polarizer 130 might consist of a large stack of linear oriented, birefringent layers such as a 3M DBEF film, being transmissive for the wanted mode of (linear) polarized light and being reflective for the opposite mode (the unwanted mode of polarization) of linear polarized light. The segmented walls of the reflector are oriented parallel or perpendicular to the polarization axis of the (linear) reflective polarizer 130 as shown in Figs. 7a-7b. The segmented reflector consists of a reflector having segmented walls, such that the neighboring segments are perpendicular. The shaped segments may be parabolic shaped in the z-direction of the reflector. The segmented reflector may consist of a metal reflector, pressed from a sheet of metal, a bended sheet of metal or a molded metal part. The segmented reflector may consist of a highly light reflective material or may consist of a molded body, such as a molded part from plastic or glass, covered with a highly light reflective layer such as a high reflective metal coating or a stack of layers forming an interference based mirror, the reflective coating preferably located at the inner side of the reflector.

The segmented reflector may be consist of a solid transparent body consisting of a highly transparent optical material such as glass, optical glass or an optical polymer material, often called a Compound Parabolic Concentrator (CPC).

In case the reflector consists of a solid transparent body, to minimize the amount of depolarization due to stress birefringence the material has preferably a low stress optical coefficient. Furthermore, to minimize the amount of depolarization due to stress birefringence in the transparent body, that transparent body should be formed such that the stress profile in the CPC is orientation around the z-axis of Figs. 7a-7b, such that the light hardly will notice the differences in refractive indices due to stress birefringence in the transparent material. The lighting device 110 preferably consists of a light reflective plane and at least one light emitting device having its output surface parallel to the light reflective plane of the lighting device 110 as indicated in Figs. 3a till 3d and as laid down in WO2014180718A1.

For a parabolic reflector (CPC) according to the invention using no polarizers, 99.8 % of the emitted light will leave the CPC at its exit surface. For a solid parabolic reflector (CPC) according to the invention, using parallel polarizers (a polarizer on top of the light source and a parallel oriented polarizer (the analyzer) on top of the exit surface of the CPC), (note that the polarizers are parallel), 98.5 % of the emitted light will pass the analyzer located at the exit plane of the CPC, which is 1.67 (98.5/59.2) times the amount using a normal parabolic reflector.

High optical efficiency will be achieved when the individual light rays may pass the reflective polarizer 120 with a minimum amount of reflections in the system.

That will be the case when the parabolic reflector preserves the state of polarization and the light reflected at the reflective polarizer 120, for the first time, is completely converted to the opposite state of polarization when the light hits the reflective polarizer 120 for the second time (after being recycled via the parabolic reflector 130 and the light illumination device 110 (which consist of a reflective surface located in the plane 110 and at least one light emitting device located in that plane 110 as indicated in Figs. 3a-3d). To rotate the plane of polarization a polarization rotating device is required, which might consist of a λ/4 film or a stack of λ/4 films. A stack of λ/4 films has the advantage that the conversion of the plane of polarization over 90° may be made almost achromatic, such all wavelengths within the visible range will rotate over 90° with an optical efficiency higher that 99%, which may be obtained with a stack of 3 λ/4 films, each film having the correct phase shift (dΔn), and oriented under the correct angles and oriented under the correct angle with the direction of polarization of the incident (linear) polarized light.

A first possible location to position the stack of λ/4 films may be on top of the metallic reflecting surface in the illumination device 110. After the (unpolarized) light hits the reflective polarizer 130 for the first time, the light is split into its 2 (linear) polarized direction: (1) The wanted mode of (linear) polarization will pass the reflective polarizer 130 towards the object or space to be illuminated; (2) The unwanted mode of (linear) polarization will reflect at the reflective polarizer 130 and be bounced towards the parabolic reflector 120.

Since the light reflected back into the parabolic reflector 120 (the parabolic reflector designed according to the invention), the state of polarization and its direction will be maintained when the light is reflected by the parabolic reflector 120 towards the mirror surface located in plane 110 of the illumination device 110. Before the light hits the reflector located in the plane 110, the light will pass the stack of λ/4 films, after the light has been changed from a linear state of polarization into a circular state of polarization. Assumed that the individual λ/4 films are properly oriented, all the light within the visible range will be changed from the linear state of polarization into circular polarized light; e.g. right-handed circular polarized light, after that circular polarized light will hit the metallic reflective surface oriented in the plane 110.

During the reflection at the metallic reflective surface in the plane 110, right-handed circular polarized light will change its direction of rotation, such that the light will be reflected as left-handed polarized light from the reflecting surface in the plane 110 after the light will be incident on the stack of λ/4 films for the second time.

Since the light now has become left-handed circular polarized, the light will be modified by the stack of λ/4 films into linear polarized light, but now of the opposite direction as previous, such this light has been changed from the "unwanted" into the “wanted” mode, after the light may be reflected by the (polarization maintaining) parabolic reflector 120 after it hits the reflective polarizer 130 for the second time, but now with the “wanted” mode of polarization such it will now pass the reflective polarizer 120 to (also) illuminate the object or space to be illuminated.

A second possible position for the stack of λ/4 films is located at the exit plane of the parabolic reflector 120 (between the parabolic reflector 120 and the reflective polarizer 130). After the (unpolarized) light hits the reflective polarizer 130 for the first time, the light is split into its 2 (linear) polarized direction: (1) The wanted mode of (linear) polarization will pass the reflective polarizer 130 towards the object or space to be illuminated; (2) The unwanted mode of (linear) polarization will reflect at the reflective polarizer 130 and be bounced towards the parabolic reflector 120. Before the light enters the parabolic reflector 120, it will pass the stack of λ/4 films, after the light has been changed from a linear state of polarization into a circular state of polarization. Assumed that the individual λ/4 films are properly oriented, all the light within the visible range will be changed from the linear state of polarization into circular polarized light; e.g. right-handed circular polarized light.

The circular polarized light will enter the parabolic reflector 120 where it may hit the walls of the reflector, after it will be incident on the illumination device 110, where it will hit the metallic reflective surface oriented in the plane 110. During the reflection at the metallic reflective surface in the plane 110, right-handed circular polarized light will change its direction of rotation, such that the light will be reflected as left-handed polarized light from the reflecting surface in the plane 110 after the light may hit the wall of the parabolic reflector 120 and will be incident on the stack of λ/4 films for the second time.

Since the light now has become left-handed circular polarized, the light will be modified by the stack of λ/4 films into linear polarized light, but now of the opposite direction as previous, such this light has been changed from the “unwanted” into the “wanted” mode, such the light will now pass the reflective polarizer 120 to also illuminate the object or space to be illuminated. This solution however assumes that the state of polarization of the circular polarized light will not change when the light is reflected at the walls of the reflector 120 which will be the case if the reflector 120 consist of a body consisting of a highly transparent material and the light at the walls will reflect due to TIR (Total Internal Reflection) at its walls.

In a further embodiment the light emitting element 110 already emits (linear) polarized light. In such case, the reflective polarizer 130 and the λ/4 films may be omitted, or these elements may be part of the polarized light emitting element 110, such these components (the reflective polarizer 130 and the stack of λ/4 films) can be kept much smaller and as such provide the polarization function for lower cost. Using a parabolic reflector 120 according the invention will maintain the (linear) state of polarization such the parabolic reflector 120 will emit (linear) polarized light to illuminate the objects and/or space to be illuminated. The polarized light emitting element 110 may consist of a polarized light emitting light source, such as a laser light source, or may consist of an unpolarized light emitting device combined with a polarization conversion system. The polarized light emitting element 110 may consist of a LED covered with a reflective polarizer, such the unwanted mode of polarization is reflected back into the LED device where it may be recycled. The polarized light emitting element 110 may consist of such an LED covered with a reflective polarizer, having a λ/4 film or a stack of λ/4 films located between the reflective polarizer and the light emitting surface of the LED. The polarized light emitting element 110 may consist of such an LED covered with a reflective polarizer, having a λ/4 film or a stack of λ/4 films sandwiched between the reflective polarizer and the light emitting surface of the LED, such all these components are in optical contact. The polarized light emitting element 110 may consist of a LED covered with a reflective polarizer, where the reflective polarizer is shaped, such the unwanted mode of polarization is reflected by the reflective polarizer and imaged at a mirror surface located in plane 110, next to the LED. Such polarized light emitting element 110 may consist of such an LED covered with a (curved) reflective polarizer, having a λ/4 film or a stack of λ/4 films located between the reflective polarizer and the light reflecting surface located at the reflective plane 110. Such polarized light emitting element 110 may consist of such an LED covered with a (curved) reflective polarizer, having a λ/4 film or a stack of λ/4 films in optical contact with the reflective surface at the reflective plane 110. Such polarized light emitting element 110 may consist of at least one Light Emitting Diode (LED) covered with a curved reflective polarizer at its light emitting surface, where the at least one LED is positioned according to Figs. 3a till 3d.

Applications of the invention may be as or in retail spot lights, museum spot lights, studio spot lights, polarized light reading lights, low glair luminaires, street luminaires, office luminaires, stadium lights, studio spot lights, theater lights, shop luminaires, museum lights, architectural spotlights, lights at (swimming) pools, polarized light spot lights, polarized light illumination systems, polarized light luminaires, LCD projection systems, photolithography applications etc.

Referring to Fig. 7b, at least part 211 of the side surface 210 comprises a plurality of segments. This is not shown in detail in Fig. 7b, but the cross-sectional view of

Fig. 7a shows these segments, indicated with reference 212. The tapering of the reflector may be achieved by curving the segments within the height direction of the reflector, which curving may be parabolic shaped in the height direction resp. in the direction of the optical axis z.

Fig. 7c shows an embodiment wherein the entire side surface 210 is facetted; the part 211 is essentially the entire side surface as (basically also) shown in Fig. 7a. As shown in Figs. 7a, 7c, a subset of the total number of facets 212 are configured parallel to the optical axis z, a subset of the total number of facets 212 are configured perpendicular to the optical axis z, and adjacent facets 212 are configured perpendicular to each other, thereby providing a staircase like tapering. Fig. 7c also shows the staircase like side surface 210. In fact, layers are provided with angles of 90°. The embodiment of Fig. 7c also shows that there may be embodiments wherein a (second) subset of second segments, indicated with reference 212b are configured essentially perpendicular to the optical axis and/or are configured essentially parallel to the cross-sectional planes perpendicular to the optical axis z. The segments 212 essentially parallel to the optical axis z are indicates as segments 212 or first segments 212a.

Fig. 7c schematically depicts an embodiment wherein a side surface of the reflector is tapering from a second end to a first end, wherein at least part of the side surface comprises a plurality of segments wherein a subset of the total number of segments are configured parallel to the optical axis, wherein a (second) subset of the total number of (second) segments are configured perpendicular to the optical axis, and wherein adjacent segments are configured perpendicular to each other. Hereby, a staircase-like tapering is provided. Hence, the invention also provides a reflector having a staircase-like tapered side face with segments providing or defining such staircase that are essentially parallel or essentially perpendicular to an optical axis of the reflector.

Fig. 7c shows an embodiment wherein a number of layers of segments 212 are provided over the length L1 of the reflector 200. Here, seven layers may be identified (the number of segments 212a along the length axis or optical axis z.

Figs. 7a schematically depicts a cross-section; In general, more than four facets 212 may be applied, see also Fig. 7a. In this way, the beam shape may be smoother.

$n>4$. Preferably $n\geq8$. More preferably $n\geq12$ or even more preferably $n\geq28$. Most preferably $n\geq60$. The higher the n, the smoother the beam.

The reflector unit is has preferably a high level of symmetry i.e. 4+y*n faces wherein n=8 and y is a positive integer i.e. 1, 2, 3, … . A reflector unit which has a high level of symmetry enables a beam shape which has a high level of symmetry.

Preferably n = 12 or n=20, more preferably n=28 or n=36 or n=44, most preferably n=52 or n=60 or n=68 or n=76 or n=84 or n=92 or n=100.

The reflector unit 200 depicted in Fig.7a shows n=60. This means it provides a smooth beam and the beam shape has a high level of symmetry.

As indicated above, Fig. 7a shows a cross-sectional view. Hence, for cross-sections perpendicular to the optical axis z in Fig. 7, cross-sections like shown in Fig. 7a will be found along at least part of the height L_1 of the reflector 20. Likewise, cross-sectional planes perpendicular planes perpendicular to the optical axis z in Fig. 7c will provide, along at least part of the height L_1, cross-sections like shown in Fig. 7a. Hence, flat segments 212 (see Fig. 7c) and one dimensionally curved segments 212 (see Fig. 7b) may be applied. Fig. 7a shows that the embodiments such as schematically depicted in Figs. 7b-7c may comprise a plurality of segments 212 which define right angles β in cross-sectional planes perpendicular to the optical axis z. Hence, Figs. 7a-7c show embodiments of the reflector 200 having a side surface 210 and an optical axis z, wherein the side surface 210 is tapering from a second end 222 to a first end 221, wherein at least part 211 of the side surface 210 (in the schematically depicted embodiments essentially the entire side surface 210) comprises a plurality of segments 212 which define right angles β in cross-sectional planes perpendicular to the optical axis z. As shown in Fig. 7a, intersection lines of the segments 212 with a plane perpendicular to the optical axis z, i.e. a cross-sectional plane, are configured to form straight lines, and the intersection lines of adjacent facets 212 with the plane are configured perpendicular to each other. In Fig. 7a, each quadrant included 16 segments 212. Hence, there are 60 segments (as the quadrants share segments 212). Hence, at a specific height along the optical axis where this cross-sectional plane is defined, (already) 60 segments can be identified. Note that there may only be 60 segments in total (i.e. over the entire height) or there may be much more, such as in the case of a staircase like embodiment.

In embodiments, the intersection lines of the segments 212 in the cross-section plane may have identical lengths, though this is not necessarily the case.

Fig. 7a also shows that a large number of segments 212 allows an approximation of a reflector 200 having a circular cross-section.

Hence, especially the segments are configured such that the polarization is either p or s, but upon reflection at the reflective surface of the reflector, the polarization does not change.

Hence, especially, the segments 212 may especially be configured such that they are either perpendicular to a polarization axis or parallel to a polarization axis.

The term “plurality” refers to two or more.

The term “substantially” herein, such as in “substantially all light” or in “substantially consists”, will be understood by the person skilled in the art. The term “substantially” may also include embodiments with “entirely”, “completely”, “all”, etc. Hence, in embodiments the adjective substantially may also be removed. Where applicable, the term “substantially” may also relate to 90% or higher, such as 95% or higher, especially 99% or higher, even more especially 99.5% or higher, including 100%. The term “comprise” includes also embodiments wherein the term “comprises” means “consists of”. The term “and/or” especially relates to one or more of the items mentioned before and after “and/or”. For instance, a phrase “item 1 and/or item 2” and similar phrases may relate to one or more of item 1 and item 2. The term "comprising" may in an embodiment refer to "consisting of" but may in another embodiment also refer to "containing at least the defined species and optionally one or more other species".

Furthermore, the terms first, second, third and the like in the description and in the claims, are used for distinguishing between similar elements and not necessarily for describing a sequential or chronological order. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments of the invention described herein are capable of operation in other sequences than described or illustrated herein.

The devices herein are amongst others described during operation. As will be clear to the person skilled in the art, the invention is not limited to methods of operation or devices in operation.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. Use of the verb "to comprise" and its conjugations does not exclude the presence of elements or steps other than those stated in a claim. Unless the context clearly requires otherwise, throughout the description and the claims, the words “comprise”, “comprising”, and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense; that is to say, in the sense of “including, but not limited to”. The article "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The invention may be implemented by means of hardware comprising several distinct elements, and by means of a suitably programmed computer. In the device claim enumerating several means, several of these means may be embodied by one and the same item of hardware. 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.

The invention further applies to a device comprising one or more of the characterizing features described in the description and/or shown in the attached drawings. The invention further pertains to a method or process comprising one or more of the characterizing features described in the description and/or shown in the attached drawings.

The various aspects discussed in this patent can be combined in order to provide additional advantages. Further, the person skilled in the art will understand that embodiments can be combined, and that also more than two embodiments can be combined. Furthermore, some of the features can form the basis for one or more divisional applications.

CLAIMS:

1. A reflector unit (1000) configured to shape unpolarized light source light of a light source (10) into a beam of polarized light source light and comprising a reflective polarizer (130) and a reflector (200), the reflector having a side surface (210) and an optical axis (z), wherein the side surface (210) is tapering from a second end (222) to a first end (221), wherein at least part (211) of the side surface (210) comprises a plurality of n segments (212) which define right angles (β) in cross-sectional planes perpendicular to the optical axis (z), wherein n>4.

2. The reflector unit (1000) according to claim 1, wherein the segments (212) are planar or parabolic shaped over the height direction of the reflector, and wherein n≥8.

3. The reflector unit (1000) according to any one of the preceding claims, wherein a first subset of a total number of segments (212a) are configured parallel to the optical axis (z) and a second subset of the total number of second segments (212b) are configured perpendicular to the optical axis (z), and wherein adjacent segments (212a,212b) are configured perpendicular to each other.

4. The reflector unit (1000) according to any one of the preceding claims 1-3, wherein the reflector (200) comprises a light transparent material (201), and wherein the reflector (200) is a total internal reflection reflector.

5. The reflector unit (1000) according to any one of the preceding claims 1-3, wherein the reflector (200) comprises a hollow reflector (200), and wherein the facets (212) comprise a light reflective coating.

6. The reflector unit (1000) according to any one of the preceding claims, wherein the reflective polarizer (130) is configured at the second end (222).

7. The reflector unit (1000) according to claim 6, wherein intersection lines of the segments (212) with the cross-sectional planes perpendicular to the optical axis (z) are configured parallel or perpendicular to a polarization axis of the reflective polarizer (130) or wherein intersection lines of the segments (212) are configured under an angle of 45° with a polarization axis of the reflective polarizer (130).

8. The reflector unit (1000) according to any one of the preceding claims 6-7, wherein the reflective polarizer (130) comprises a dual brightness enhancement film, or a wire grid polarizer, or a cholesteric reflector, and wherein the reflector unit (1000) further comprises a polarization rotator (140) configured upstream of the reflective polarizer (130).

9. The reflector unit (1000) according to claim 8, wherein the polarization rotator (140) comprises one or more ¼ λ layers.

10. A lighting unit (2000) comprising the reflector unit (1000) according to any one of the preceding claims 1-9, and a light source module (110), wherein the light source module (110) is configured closer to the first end (221) than to the second end (222), wherein the light source module (110) comprises the light source (10) having a light emitting surface portion (114) and configured to generate light source light (11), wherein the lighting unit (2000) further comprises the reflective polarizer (130) for providing a polarized beam (20) of light source light (11).

11. The lighting unit (2000) according to claim 10, further comprising a polarization rotator (140), wherein the polarization rotator (140) is configured as layer adjacent to and upstream of the reflective polarizer (130), wherein the polarization rotator (140) is configured for changing a polarization direction of at least part of the light source light (11) that is reflected by the reflective polarizer (130), and wherein $n \geq 12$.

12. The lighting unit (2000) according to claim 11, wherein the light source module (110) further comprises a reflective surface portion (112), wherein the light emitting surface portion (114) and the reflective surface portion (112) are configured perpendicular to the optical axis (z), wherein the polarization rotator (140) is configured closer to the reflective surface portion (112) than to the second end (222).

13. The lighting unit (2000) according to any one of the preceding claims 10-12, wherein the light source module (110) further comprises a reflective surface portion (112), wherein the light emitting surface portion (114) and the reflective surface portion (112) are configured perpendicular to the optical axis (O), wherein the lighting unit (2000) comprises a plurality of sets of light emitting surface portions (114) and reflective surface portions (112), wherein the light emitting surface portions (114) and reflective surface portions (112) of each set are configured symmetrical to the optical axis (z).

14. A lighting device comprising one or more lighting units (2000) according to any one of the preceding claims 10-13.

15. A luminaire or a lamp comprising one or more lighting units (2000) according to any one of the preceding claims 10-13.

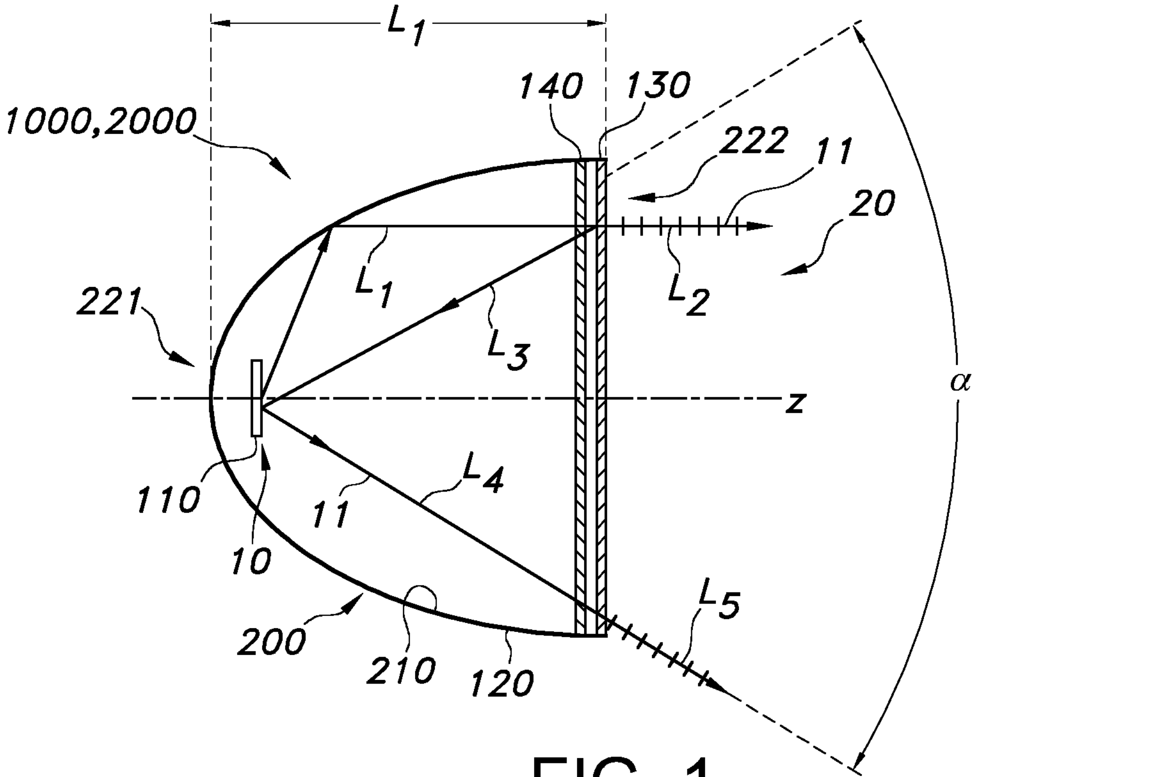
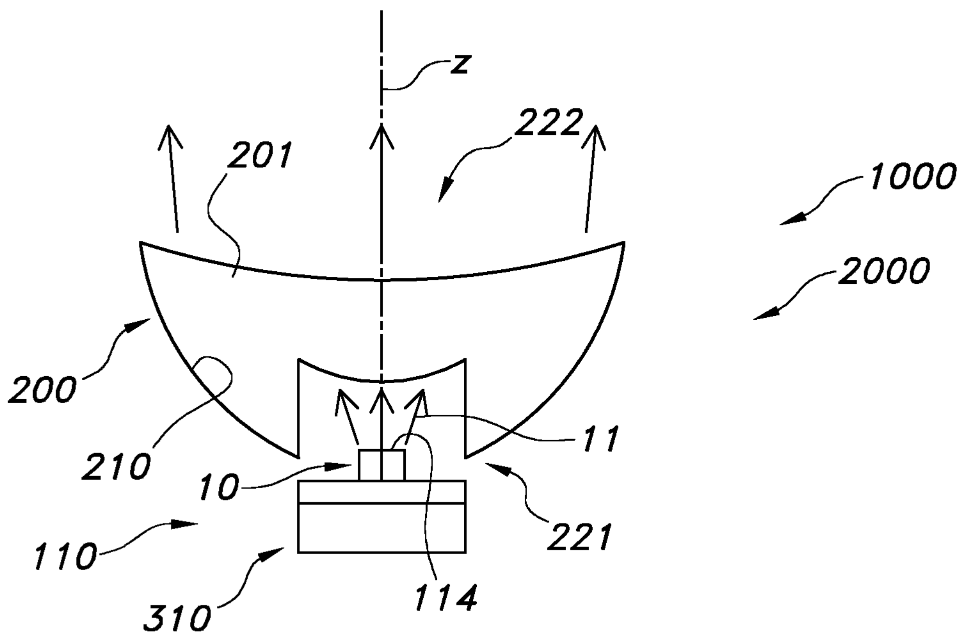

L1
140
130
1000,2000
222
11
20
L1
L2
221
L3
α
z
110
L4
11
10
L5
200
210
120

FIG. 1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201
1000
2000
200
210
11
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221
110
114
310

FIG. 2

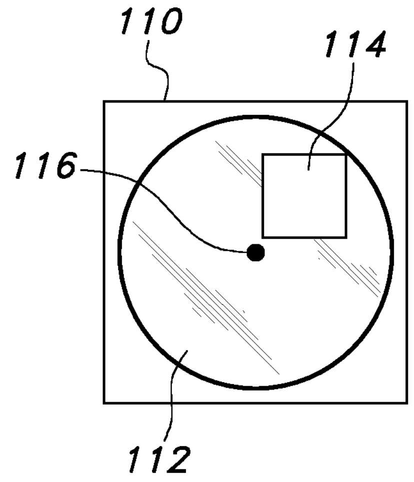


FIG. 3A

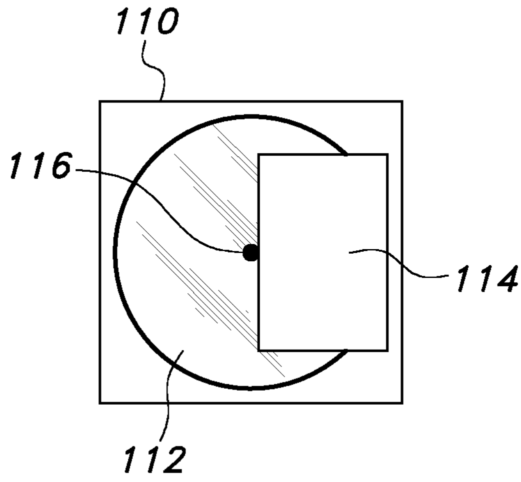


FIG. 3B

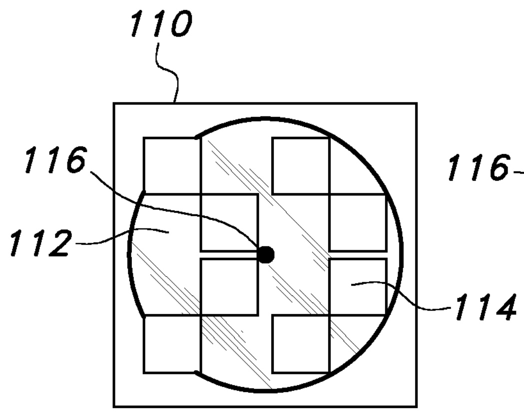


FIG. 3C

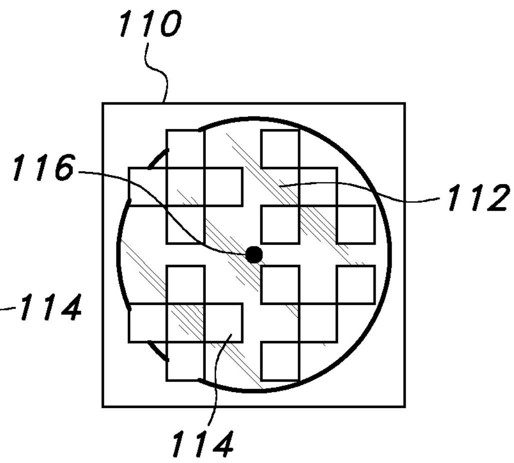


FIG. 3D

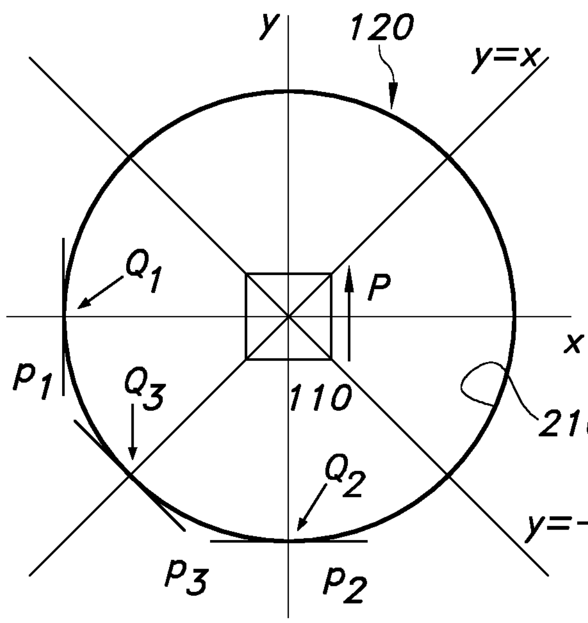


FIG. 4A

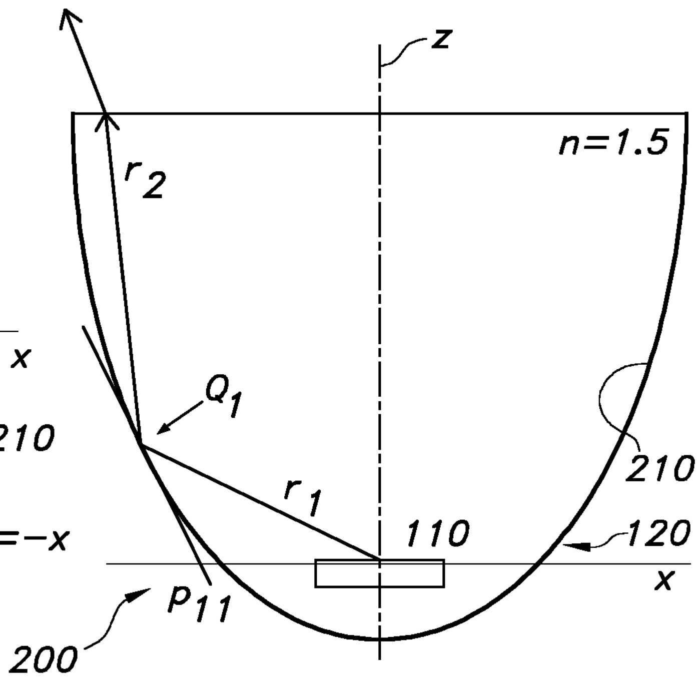


FIG. 4B

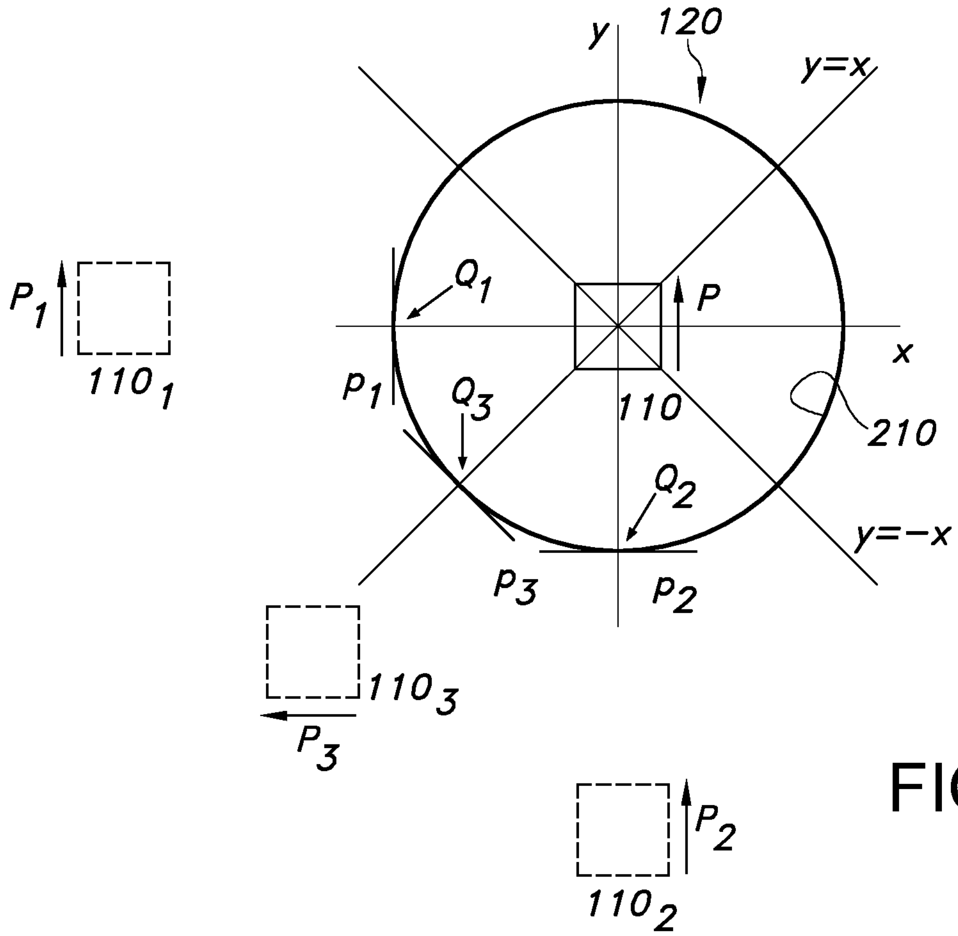


FIG. 4C

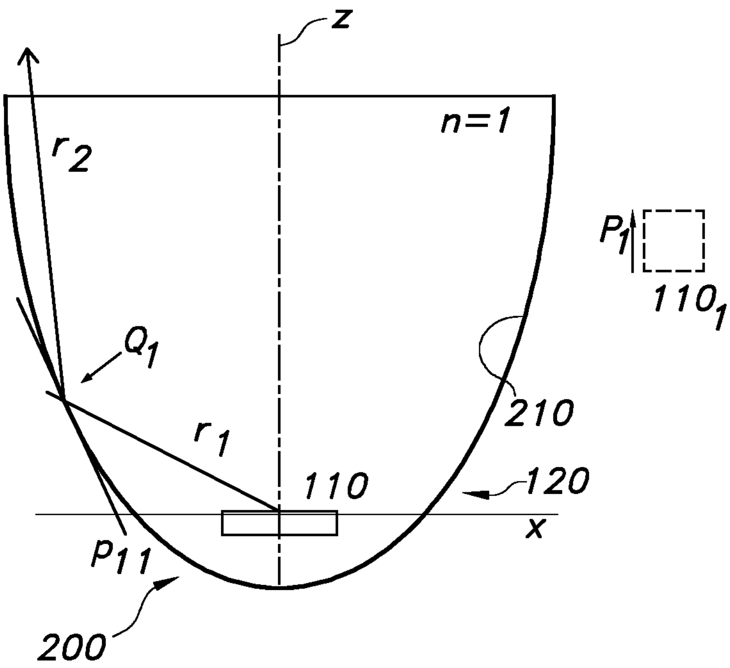


FIG. 5A

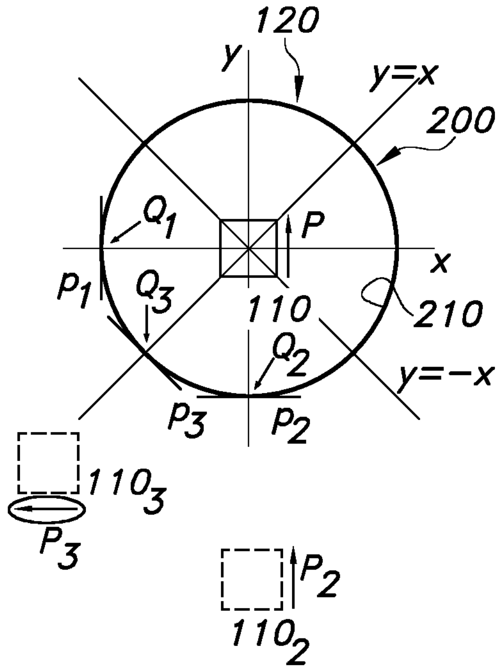


FIG. 5B

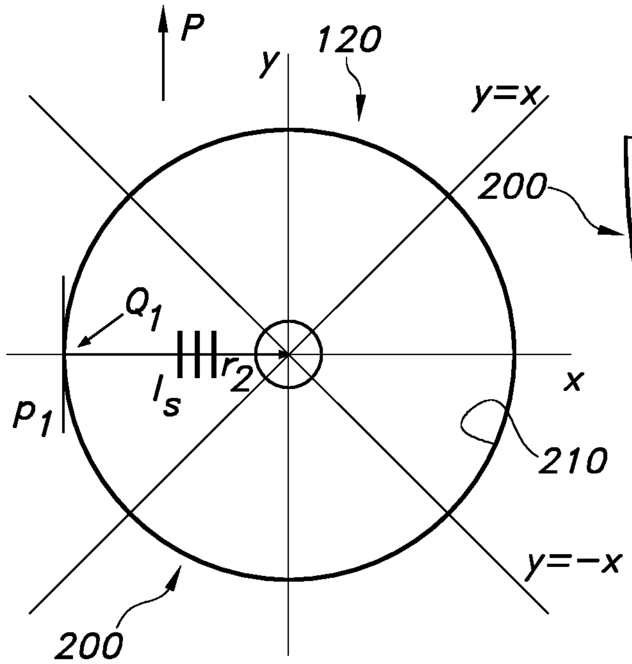


FIG. 6A

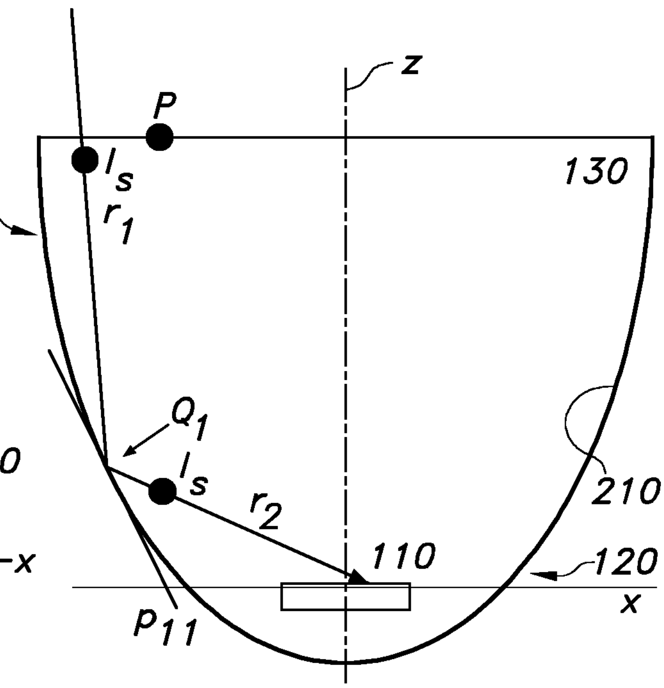


FIG. 6B

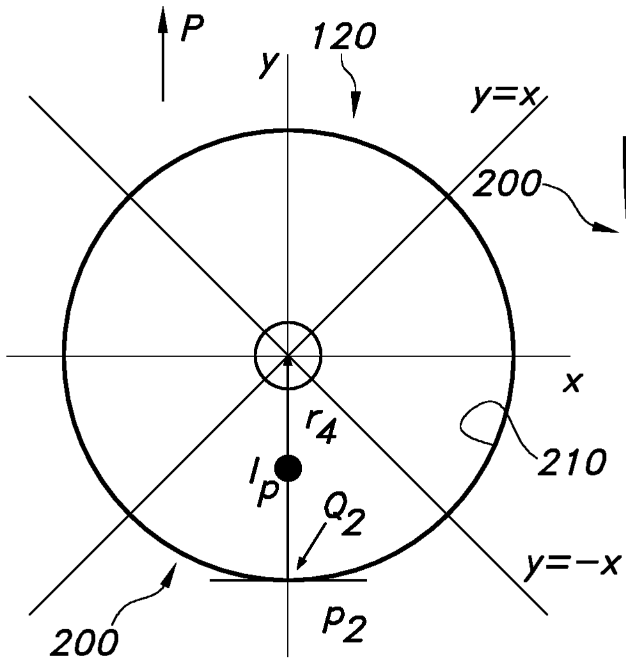


FIG. 6C

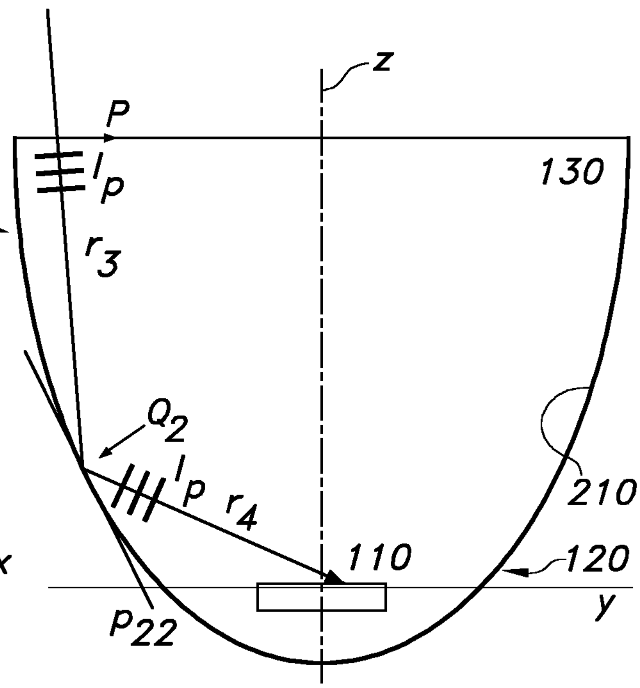


FIG. 6D

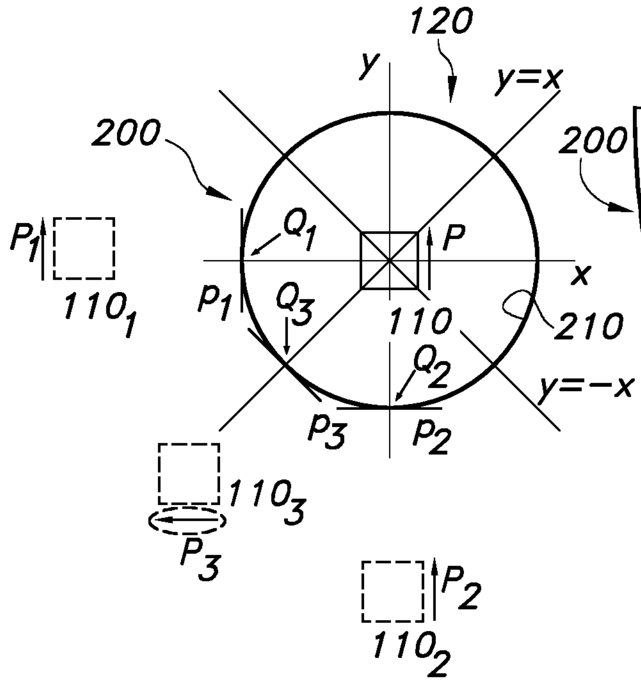


FIG. 6E

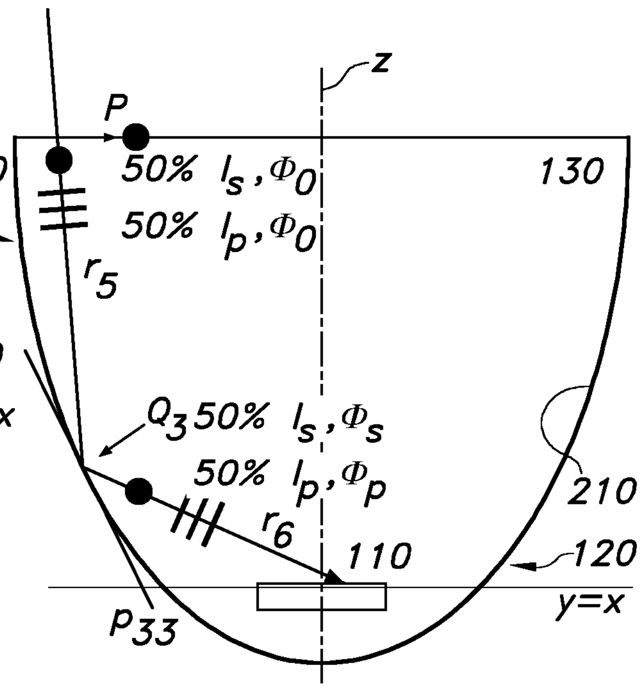
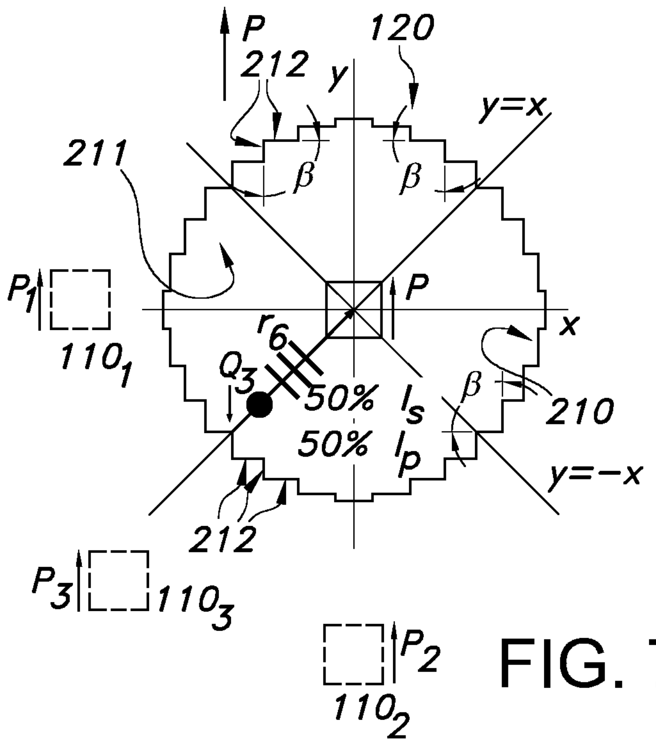


FIG. 6F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212
120
y
y=x
211
β
β
P
P1
x
110 1
r6
Q3
50% Is
β
210
50% Ip
y=-x
212
P3
110 3
P2
110 2

FIG. 7A

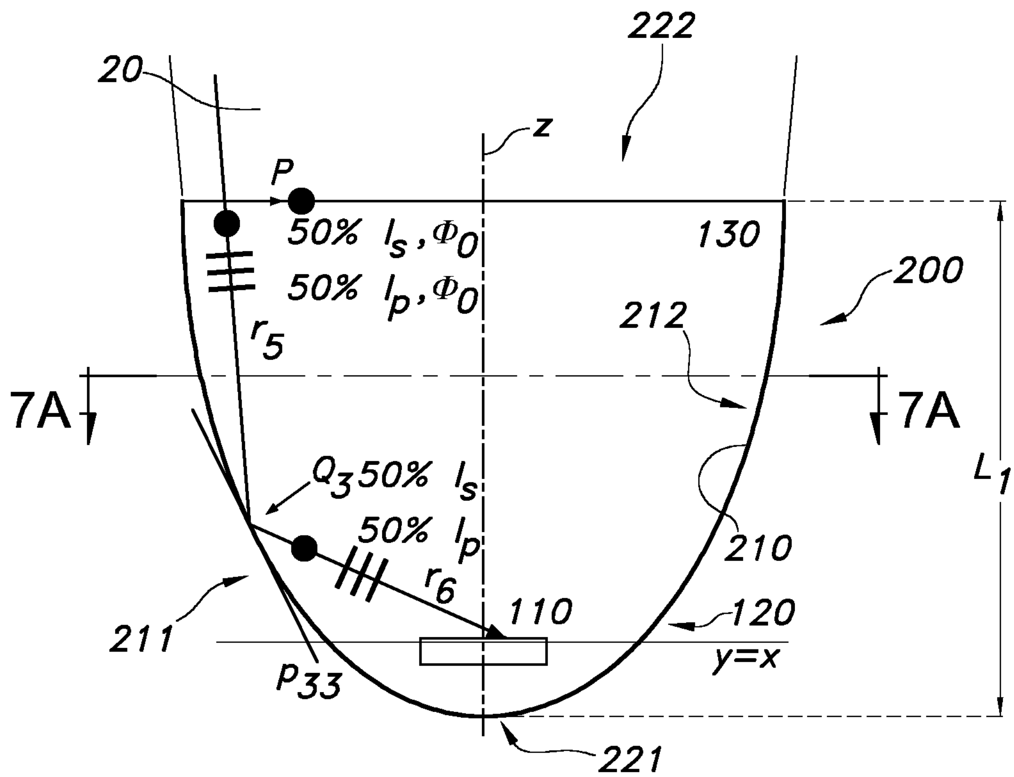
222
20
z
P
50% Is, Φ0
130
50% Ip, Φ0
200
r5
212
7A
7A
L1
Q3 50% Is
50% Ip
210
r6
110
120
211
y=x
P33
221

FIG. 7B

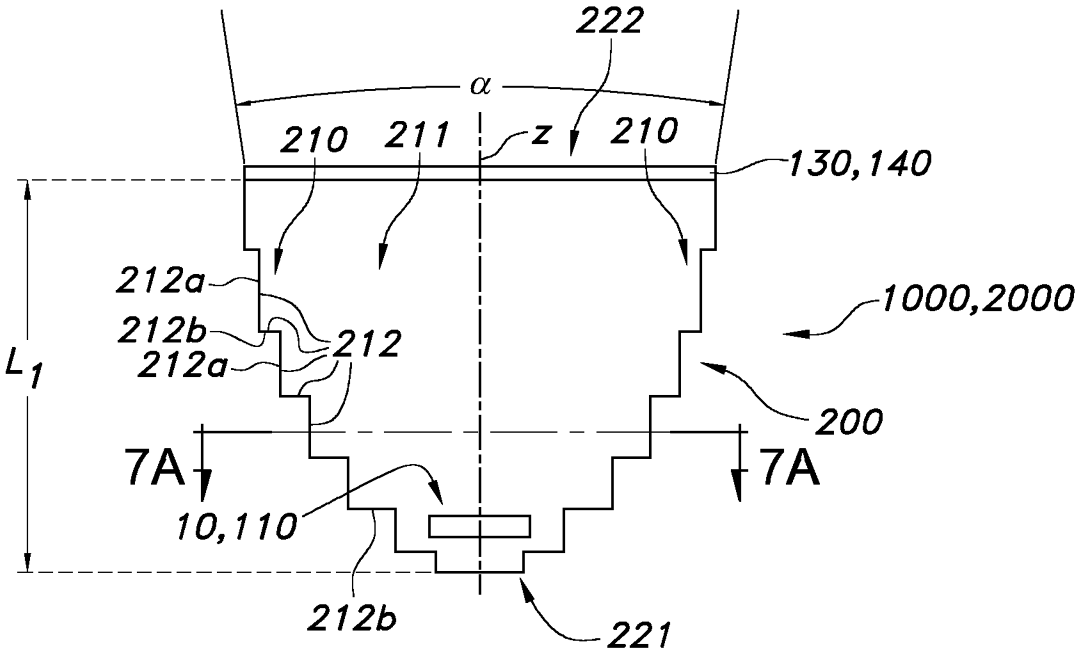
222
α
210
211
z
210
130,140
212a
212b
212
212a
L1
1000,2000
200
7A
7A
10,110
212b
221

FIG. 7C

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/051361

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B27/28 G02B19/00 F21V7/04
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)
G02B F21V

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 3 086 026 A1 (LEDIL OY [FI]) 26 October 2016 (2016-10-26) the whole document -----	1-15
Y	US 6 536 923 B1 (MERZ BERND [DE]) 25 March 2003 (2003-03-25) the whole document -----	1-15
Y	US 2015/346505 A1 (DE VAAN ADRIANUS JOHANNES STEPHANUS MARIA [NL] ET AL) 3 December 2015 (2015-12-03) cited in the application paragraphs [0037] - [0049]; figures 1-3 -----	1-15

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

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 March 2019	26/03/2019

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	Wolf, Steffen

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2019/051361

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