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(54) Title: LASER PHOSPHOR LIGHTING DEVICE PROVIDING BEAM SHAPING USING CONCENTRIC FIBERS

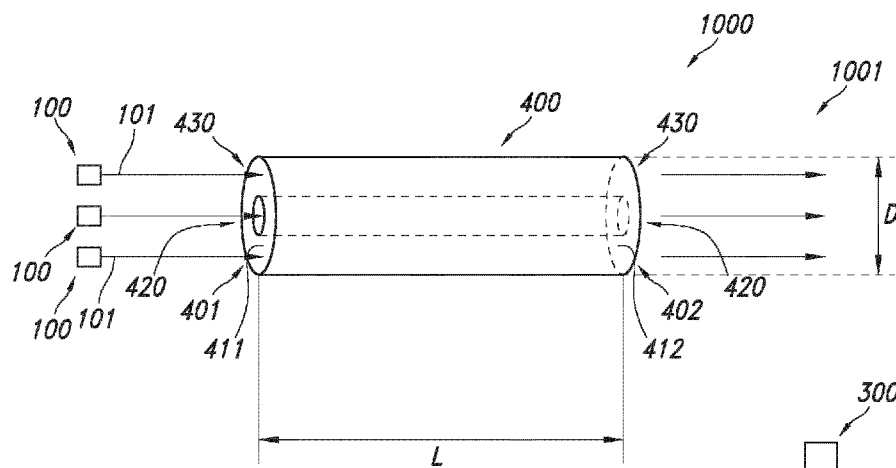


FIG. 1A

(57) Abstract: The invention provides a light generating system (1000) comprising k_1 light sources (100) and a lightguide (400), wherein: (a) the k_1 light sources (100) are configured to generate light (101); wherein $k_1 > 2$; (b) the lightguide (400) comprises m_1 concentric arranged lightguide regions (410), including a core (420) and one or more shells (430), wherein the lightguide (400) comprises a light outcouple end (402); wherein $m_1 > 2$; (c) each of the m_1 concentric arranged lightguide regions (410) comprises a light incouple side (411) and a light outcouple side (412); wherein the light outcouple end (402) comprises the light outcouple sides (412); (d) at least two of the light incouple sides (411) are configured in a light receiving relationship each with at least one light source (100), including the light incouple side (411) of at least one of the one or more shells (430).



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Laser phosphor lighting device providing beam shaping using concentric fibers

FIELD OF THE INVENTION

The invention relates to a light generating system as well as to a light generating device comprising such light generating system.

5 BACKGROUND OF THE INVENTION

Optical fibers are known in the art. US2018/0064322, for instance, describes an illumination system for a surgical device, the illumination system comprising: a tubular body made of a light permeable material, the tubular body comprising a peripheral wall, a distal end, a proximal end, and at least one lumen extending between the distal end and the proximal end; a light source that generates light having at least one wavelength between 200 nm and 2000 nm; and at least one light diffusing optical fiber disposed in the at least one lumen, the at least one light diffusing optical fiber having a core, primary cladding, and a plurality of nano-sized structures, the optical fiber further including an outer surface, and an end optically coupled to the light source; wherein the fiber is configured to scatter guided light via the nano-sized structures away from the core and through the outer surface, to form a light-source fiber portion having a length that emits substantially uniform radiation over its length.

US2020/326044A1 discloses a lighting device comprising a luminescent element comprising one or more elongated light transmissive bodies. Each elongated light transmissive body comprises a side face, wherein the elongated light transmissive body comprises a luminescent material configured to convert at least part of a light source light selected from one or more of the UV, visible light, and IR received by the elongated light transmissive body along its side face into luminescent material radiation.

25 SUMMARY OF THE INVENTION

While white LED sources can give an intensity of e.g. up to about 300 lm/mm²; static phosphor converted laser white sources can give an intensity even up to about 20.000 lm/mm². Ce doped garnets (e.g. YAG, LuAG) may be the most suitable luminescent convertors which can be used for pumping with blue laser light as the garnet matrix has a

very high chemical stability. Further, at low Ce concentrations (e.g. below 0.5%) temperature quenching may only occur above about 200 °C. Furthermore, emission from Ce has a very fast decay time so that optical saturation can essentially be avoided. Assuming e.g. a reflective mode operation, blue laser light may be incident on a phosphor. This may in
5 embodiments realize almost full conversion of blue light, leading to emission of converted light. It is for this reason that the use of garnet phosphors with relatively high stability and thermal conductivity is suggested. However, also other phosphors may be applied. Heat management may remain an issue when extremely high-power densities are used.

High brightness light sources can be used in applications such as projection,
10 stage-lighting, spot-lighting and automotive lighting. For this purpose, laser-phosphor technology can be used wherein a laser provides laser light and e.g. a (remote) phosphor converts laser light into converted light. The phosphor may in embodiments be arranged on or inserted in a heatsink for improved thermal management and thus higher brightness.

One of the problems that may be associated with such (laser) light sources is
15 the heat management of the (ceramic) phosphor. Other problems associated with such laser light sources may be the desire to create compact high power devices. Yet further, there may be a desire to create a dynamic light source, with variable emitter size which can be used in applications requiring a (dynamic) (electronic) beam control.

Hence, it is an aspect of the invention to provide an alternative light generating
20 system, 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.

Amongst others, herein a lighting device, such as a laser phosphor lighting device, is proposed for providing beam shaping. In embodiments, concentric optics such, as
25 concentric cylindrical fibers, are used to create a ring-shaped source and in embodiments to project rings of (laser) light onto the phosphor. In embodiments, at least two (laser) light sources may be used which may in embodiments individually be controlled using a controller ("control system"). In embodiments, first (laser) light, of a first (laser) light source, may be coupled into the 'core', while second (laser) light, of a second (laser) light source, may be
30 coupled into the 'shell'. By adapting the (laser) light of the first (laser) light source with respect to the second (laser) light of the second (laser) light source (further) beam shaping may be obtained. Suitable optics can be arranged downstream (at the vicinity) of the phosphor (element).

In an aspect, the invention provides a light generating system ("system") comprising k_1 light sources and a lightguide (or "light guide"). Especially, the k_1 light sources are configured to generate light. Further, in embodiments $k_1 \geq 1$, especially $k_1 \geq 2$. In embodiments, the lightguide comprises m_1 concentric arranged lightguide regions, including a core and one or more shells. Further, especially the lightguide comprises a light outcouple end. Further, in embodiments $m_1 \geq 2$. Especially, in embodiments each of the m_1 concentric arranged lightguide regions comprises a light incouple side and a light outcouple side. In specific embodiments, the light outcouple end comprises the (m_1) light outcouple sides. Further, in specific embodiments at least one of the (m_1) light incouple sides may be configured in a light receiving relationship with at least one light source, even more especially more than one light source, including the light incouple side of at least one of the one or more shells. Therefore, in embodiments the invention provides a light generating system comprising k_1 light sources and a lightguide, wherein: (a) the k_1 light sources are configured to generate light; wherein $k_1 \geq 1$, especially $k_1 \geq 2$; (b) the lightguide comprises m_1 concentric arranged lightguide regions, including a core and one or more shells, wherein the lightguide comprises a light outcouple end; wherein $m_1 \geq 2$; (c) each of the m_1 concentric arranged lightguide regions comprises a light incouple side and a light outcouple side; wherein the light outcouple end comprises the light outcouple sides; and (d) at least one of the light incouple sides is configured in a light receiving relationship with more than one light source, including the light incouple side of at least one of the one or more shells. The light incouple side is at one end of the lightguide region. Especially, in embodiments $k_1 \geq 2$, and at least two of the (m_1) light incouple sides are configured in a light receiving relationship each with at least one light source (of the k_1 light sources), including the light incouple side of at least one of the one or more shells. Especially, the lightguide regions and light sources are configured such, that the light of each light source mainly enters one of the lightguide regions. The core and the one or more shells comprise a light transmissive material comprising a light transmissive organic material or a light transmissive inorganic material. The core and the one or more shells are arranged to have at least 90 % of the light coupled in at one side of the core or the one or more shells to escape at another end of the respective core or the respective one or more shells.

It appears that with e.g. concentric cylindrical fibers (laser) light may be very well mixed or homogenized and may be provided as e.g. an emission ring at an outcouple end of the fiber. Furthermore, this allows the light sources to be arranged at a distance from the phosphor, for instance to reduce thermal issues, though other embodiments may also be

possible. In specific embodiments, more than two concentric cylindrical fibers, i.e. more than a core and a shell, such as a core and two shells, may be used to create advanced beam shaping. In specific embodiments, more than one light source, such as more than one laser may be used for getting light in a shell. In specific embodiments, more light sources may be used for outer shells than for inner shells. In embodiments, the light sources, such as lasers, may emit light of different wavelengths. In other embodiments, the light sources, such as lasers, may emit light of the same wavelengths. The inventors discovered that surprisingly (ring-shaped) shells can be used to create uniform ring-shaped sources. For instance, the light source light of different (laser) light sources appear to be well homogenized when introduced in the shell. Hence, the invention provides in embodiments a homogenizer for light (of a plurality of light sources). Further, a dynamic light source may be provided, with variable emitter size. Also with such system, dynamic beam control is possible.

As indicated above, the light generating system comprises in embodiments k1 light sources and a lightguide. The k1 light sources are configured to generate light (in an operational mode). During operation, one or more of the k1 light sources may generate light.

The term “light source” may also relate to a plurality of light sources, such as 2-200 (solid state) LED light sources. Hence, 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 light semiconductor light source may be configured on the same substrate. In embodiments, a COB is a multi LED chip configured together as a single lighting module.

The light source has a light escape surface. Referring to conventional light sources such as light bulbs or fluorescent lamps, it may be outer surface of the glass or quartz envelope. For LED's it may for instance be the LED die, or when a resin is applied to the LED die, the outer surface of the resin. In principle, it may also be the terminal end of a fiber. The term escape surface especially relates to that part of the light source, where the light actually leaves or escapes from the light source. The light source is configured to provide a beam of light. This beam of light (thus) escapes from the light exit surface of the light source.

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 (essentially identical (or different)) light sources, such as 2-2000 solid state light sources. In embodiments, the light source may comprise one or more micro-optical elements (array of micro lenses) downstream of a single solid-state light source, such as a LED, or downstream of a plurality of solid-state light sources (i.e. e.g. shared by multiple LEDs). In embodiments, the light source may comprise a LED with on-chip optics. In embodiments, the light source comprises a pixelated single LEDs (with or without optics) (offering in embodiments on-chip beam steering).

The term “laser light source” especially refers to a laser. Such laser may especially be configured to generate laser light source light having one or more wavelengths in the UV, visible, or infrared, especially having a wavelength selected from the spectral wavelength range of 200-2000 nm, such as 300-1500 nm. The term “laser” especially refers to a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. Especially, in embodiments the term “laser” may refer to a solid-state laser. In specific embodiments, the terms “laser” or “laser light source”, or similar terms, refer to a laser diode (or diode laser).

Hence, in embodiments the light source comprises a laser light source. In embodiments, the terms “laser” or “solid state laser” may refer to one or more of cerium doped lithium strontium (or calcium) aluminum fluoride (Ce:LiSAF, Ce:LiCAF), chromium doped chrysoberyl (alexandrite) laser, chromium ZnSe (Cr:ZnSe) laser, divalent samarium doped calcium fluoride (Sm:CaF₂) laser, Er:YAG laser, erbium doped and erbium–ytterbium codoped glass lasers, F-Center laser, holmium YAG (Ho:YAG) laser, Nd:YAG laser, NdCrYAG laser, neodymium doped yttrium calcium oxoborate Nd:YCa₄O(BO₃)₃ or Nd:YCOB, neodymium doped yttrium orthovanadate (Nd:YVO₄) laser, neodymium glass (Nd:glass) laser, neodymium YLF (Nd:YLF) solid-state laser, promethium 147 doped phosphate glass (147Pm³⁺:glass) solid-state laser, ruby laser (Al₂O₃:Cr³⁺), thulium YAG

(Tm:YAG) laser, titanium sapphire (Ti:sapphire; $\text{Al}_2\text{O}_3:\text{Ti}^{3+}$) laser, trivalent uranium doped calcium fluoride ($\text{U}:\text{CaF}_2$) solid-state laser, Ytterbium doped glass laser (rod, plate/chip, and fiber), Ytterbium YAG (Yb:YAG) laser, Yb_2O_3 (glass or ceramics) laser, etc.

In embodiments, the terms “laser” or “solid state laser” may refer to one or more of a semiconductor laser diode, such as GaN, InGaN, AlGaInP, AlGaAs, InGaAsP, lead salt, vertical cavity surface emitting laser (VCSEL), quantum cascade laser, hybrid silicon laser, etc.

A laser may be combined with an upconverter in order to arrive at shorter (laser) wavelengths. For instance, with some (trivalent) rare earth ions upconversion may be obtained or with non-linear crystals upconversion can be obtained. Alternatively, a laser can be combined with a downconverter, such as a dye laser, to arrive at longer (laser) wavelengths.

As can be derived from the below, the term “laser light source” may also refer to a plurality of (different or identical) laser light sources. In specific embodiments, the term “laser light source” may refer to a plurality N of (identical) laser light sources. In embodiments, $N=2$, or more. In specific embodiments, N may be at least 5, such as especially at least 8. In this way, a higher brightness may be obtained. In embodiments, laser light sources may be arranged in a laser bank (see also above). The laser bank may in embodiments comprise heatsinking and/or optics e.g. a lens to collimate the laser light.

The laser light source is configured to generate laser light source light (or “laser light”). The light source light may essentially consist of the laser light source light. The light source light may also comprise laser light source light of two or more (different or identical) laser light sources. For instance, the laser light source light of two or more (different or identical) laser light sources may be coupled into a light guide, to provide a single beam of light comprising the laser light source light of the two or more (different or identical) laser light sources. In specific embodiments, the light source light is thus especially collimated light source light. In yet further embodiments, the light source light is especially (collimated) laser light source light. The phrases “different light sources” or “a plurality of different light sources”, and similar phrases, may in embodiments refer to a plurality of solid-state light sources selected from at least two different bins. Likewise, the phrases “identical light sources” or “a plurality of same light sources”, and similar phrases, may in embodiments refer to a plurality of solid-state light sources selected from the same bin.

The light source is especially configured to generate light source light having an optical axis (O), (a beam shape,) and a spectral power distribution. The light source light

may in embodiments comprise one or more bands, having band widths as known for lasers. In specific embodiments, the band(s) may be relatively sharp line(s), such as having full width half maximum (FWHM) in the range of less than 20 nm at RT, such as equal to or less than 10 nm. Hence, the light source light has a spectral power distribution (intensity on an energy scale as function of the wavelength) which may comprise one or more (narrow) bands.

The beams (of light source light) may be focused or collimated beams of (laser) light source light. The term “focused” may especially refer to converging to a small spot. This small spot may be at the discrete converter region, or (slightly) upstream thereof or (slightly) downstream thereof. Especially, focusing and/or collimation may be such that the cross-sectional shape (perpendicular to the optical axis) of the beam at the discrete converter region (at the side face) is essentially not larger than the cross-section shape (perpendicular to the optical axis) of the discrete converter region (where the light source light irradiates the discrete converter region). Focusing may be executed with one or more optics, like (focusing) lenses. Especially, two lenses may be applied to focus the laser light source light, or other type of light source light. Collimation may be executed with one or more (other) optics, like collimation elements, such as lenses and/or parabolic mirrors. In embodiments, the beam of (laser) light source light may be relatively highly collimated, such as in embodiments $\leq 2^\circ$ (FWHM), more especially $\leq 1^\circ$ (FWHM), most especially $\leq 0.5^\circ$ (FWHM). Hence, $\leq 2^\circ$ (FWHM) may be considered (highly) collimated light source light. Optics may be used to provide (high) collimation (see also above). However, other embodiments may also be possible (see also below). Hence, between the light source(s) and the lightguide (regions) intermediate optics may be configured.

Referring to e.g. solid state lasers, the uncollimated laser light source light may have an opening angle α , which may be up to about even 45° . As indicated above, for the present invention it may be desirable to provide more collimated light to the light incouple sides. In specific embodiments, the k1 light sources, including optional optics, are configured to generate the light with a full width half maximum selected from the range of $0.5-70^\circ$, such as up to about 36° . In embodiments, the k1 light sources, including optional optics, are configured to generate the light with a full width half maximum selected from the range of at least 2° , like at least about 5° , such as selected from the range of $5-70^\circ$, like selected from the range of $5-40^\circ$. Note that the opening angle may vary over the cross-section of a beam of light source light. For instance, a beam may have a circular cross-section

(defined by the FWHM) but may in embodiments also have an elliptical cross-section (defined by the FWHM).

In embodiments, the light sources may be selected from the group comprising a laser light source and a super-luminescent diode. Hence, one or more light sources may
5 comprise laser light sources and/or one or more light sources may comprise super-luminescent diode. Alternatively or additionally, one or more light sources may comprise luminescent concentrator lighting devices, such as e.g. described in US2020218001, WO2017207464, or WO2006/054203, which are herein incorporated by reference.

Alternatively or additionally, in specific embodiments, the light sources may
10 be fiber light sources, which are based on the collection in a single fiber of light of a plurality of light sources, such as laser light sources or LEDs. In specific embodiments, the light sources may be selected from the group consisting of light sources have an intensity of at least 1 W/mm^2 , wherein the area refers to an area of the light emitting surface of the light source, such as a die. Especially, the light sources may be selected from the group consisting
15 of light sources having an intensity of at least 1 W/mm^2 in the blue spectral wavelength range.

Especially, in embodiments the light sources comprise laser light sources.

As indicated above, $k_1 \geq 1$, especially $k_1 \geq 2$. The upper limit may be high, but may in embodiments be e.g. $k_1 \leq 200$. However, other values for k_1 are herein not excluded.

20 In specific embodiments, $k_1 \geq 3$, such as $k_1 \geq 4$. For instance, k_1 may be selected from the range of 4-200.

In embodiments, the lightguide may comprise m_1 concentric arranged lightguide regions, including a core and one or more shells. The lightguide comprise light transmissive material, that is transmissive for the light of one or more, especially all of the
25 light sources. Hence, the material may be chosen such, and the length (see also below) may be chosen such, that light source light entering the lightguide at one side of the core or of a shell may escape at another end of the respective core or shell, especially at least 50%, even more especially at least 80%, even more especially at least 90%. In embodiments, at least 95% of the light coupled in at one side of the core or shell may escape at another end of the
30 respective core or shell, even more especially at least 95%, such as especially at least 98%. Here, the percentages refer to the power of the light (i.e. Watts). In embodiments, the light guide regions comprise a solid material. In embodiments, the light guide regions comprise a non-luminescent material.

Herein the terms “incouple”, “outcouple”, and similar terms, may especially refer the propagation of light from one medium to another medium, such as respectively into the lightguide (region) and again out the lightguide region.

Therefore, the core may comprise core material and the shell(s) may comprise shell material that is especially light transmissive, even more especially transparent for light of one or more of the light sources.

The light transmissive material may comprise one or more materials selected from the group consisting of a transmissive organic material, such as selected from the group consisting of PE (polyethylene), PP (polypropylene), PEN (polyethylene naphthalate), PC (polycarbonate), polyurethanes (PU), polymethylacrylate (PMA), polymethylmethacrylate (PMMA) (Plexiglas or Perspex), polymethacrylimide (PMI), polymethylmethacrylimide (PMMI), styrene acrylonitrile resin (SAN), cellulose acetate butyrate (CAB), silicone, polyvinylchloride (PVC), polyethylene terephthalate (PET), including in an embodiment (PETG) (glycol modified polyethylene terephthalate), PDMS (polydimethylsiloxane), and COC (cyclo olefin copolymer). Especially, the light transmissive material may comprise an aromatic polyester, or a copolymer thereof, such as e.g. one or more of polycarbonate (PC), poly (methyl) methacrylate (P(M)MA), polyglycolide or polyglycolic acid (PGA), polylactic acid (PLA), polycaprolactone (PCL), polyethylene adipate (PEA), polyhydroxy alkanoate (PHA), polyhydroxy butyrate (PHB), poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV), polyethylene terephthalate (PET), polybutylene terephthalate (PBT), polytrimethylene terephthalate (PTT), polyethylene naphthalate (PEN). Especially, the light transmissive material may comprise polyethylene terephthalate (PET). Hence, the light transmissive material is especially a polymeric light transmissive material.

However, in another embodiment the light transmissive material may comprise an inorganic material. Especially, the inorganic light transmissive material may be selected from the group consisting of glasses, (fused) quartz, transmissive ceramic materials, and silicones. Also hybrid materials, comprising both inorganic and organic parts may be applied. Especially, the light transmissive material comprises one or more of PMMA, transparent PC, or glass.

The lightguide comprises a core and a shell. Hence, whatever cross-sectional symmetry the core may have, like triangular, square, rectangular, pentagonal, hexagonal, or other n-gonal shapes (i.e. e.g. with $n \geq 7$, such as $n=8$ or $n=12$), or round, the shell circumferentially surrounds the core.

Note that the term “circumferentially” does not necessarily include circular (shapes). Especially, the core may have an essentially circular cross-section. Further, the shell and the core may essentially have the same type of circumferential shape, like triangular, square, rectangular, pentagonal, hexagonal, or other n-gonal shapes (i.e. with $n \geq 7$, such as $n=8$ or $n=12$), or round. For instance, the core may have a circular shape, and the shell may be a ring, or the core may have a square shape, and the shell may be a larger square with a (central) opening. Hence, in specific embodiments the lightguide may have a circular or n-gonal cross-sectional shape, wherein $3 \leq n \leq 24$, especially $3 \leq n \leq 12$. Especially, such as in embodiments $6 \leq n \leq 12$. Here, e.g. square or hexagonal, may thus e.g. be indicated as “4-gonal” or “6-gonal”, respectively.

Hence, in embodiments the core may be an axial region and the one or more shells may essentially completely surround the core (and optionally one or more inner shells).

In specific embodiments, a reflector (layer) may be arranged between the core and the shell. Alternatively or additionally, in embodiments the core and the shell may have different indices of refraction. For instance, in embodiments the core and the shell may comprise different transparent materials. In specific embodiments, the shell may enclose a hollow core. Alternatively or additionally, in embodiments the core and the shell may have no (direct) physical contact. Hence, in embodiments two adjacent lightguide regions may at least partly be optically separated.

For instance, in embodiments a reflector may be arranged between two adjacent lightguide regions. In other embodiments there may be no physical contact between two adjacent lightguide regions, which may substantially reduce optical contact. Especially, the distance may be at least equal to about the wavelength of interest (see below). Therefore, in specific embodiments one or more of the following may apply: (a) the lightguide further comprises a reflector configured between two adjacent lightguide regions, and (b) two adjacent lightguides are not in optical contact, especially not in physical contact.

In embodiments, lightguide regions may not be in optical contact when the distance between the lightguide regions is at least about the wavelength of interest. For instance, an average distance may be at least the wavelength of interest. In embodiments, the (average) distance is at least 800 nm, such as at least 1000 nm. For IR applications, the distance may be at least 1500 nm.

A distance between lightguide regions may e.g. be created with distance holders. In such embodiments, adjacent surfaces of adjacent lightguide regions may have no physical contact, and may have a distance of the wavelength of interest. Further, less than

20% of the area of each of the adjacent surfaces may be occupied with a distance holder, such as less than 10%.

In yet other embodiments, two adjacent lightguide regions may have different indices of refraction. Also, in this way two adjacent lightguide regions may at least partly be optically separated. Especially, the inner lightguide regions may have larger indices of refraction than outer lightguide regions. For instance, assuming a core-shell lightguide, or a core-shell-shell lightguide, the indices of refraction may be n_1 and n_2 , or n_1 , n_2 , and n_3 , respectively, wherein $n_1 > n_2$, and $n_1 > n_2 > n_3$, respectively. Especially, the indices of refraction apply to the wavelength of interest.

The wavelength of interest may e.g. be the centroid wavelength of the light of one of the light sources that propagates through one of the lightguide regions. When light sources with light having different spectral power distributions are applied, there are different types of light propagating through a lightguide region or through two adjacent lightguide regions. In such embodiments, especially the centroid wavelength of the light having the largest centroid wavelength may be selected.

In embodiments, an inner lightguide region of the two adjacent lightguide regions may have a first index of refraction n_1 , wherein an outer lightguide region of the two adjacent lightguide regions may have a second index of refraction n_2 , wherein the second index of refraction n_2 is in embodiments at least 0.01% smaller than the first index of refraction n_1 . For instance, n_1 may be 1.6, and n_2 may be 1.584. More general, n_{a+1} may be at least 0.01% smaller than n_a , wherein a is at least 1, and wherein n_a refers to a more inner lightguide region of the two adjacent lightguide regions, with the more inner lightguide region at least partly being enclosed by the more outer lightguide region of the two adjacent lightguide regions. Especially, the second index of refraction n_2 is in embodiments at least 0.05% smaller than the first index of refraction n_1 . In specific embodiments, the second index of refraction n_2 is in embodiments at maximum about 1%, such as at maximum about 0.5% smaller than the first index of refraction n_1 ; though other embodiments may also be possible.

In specific embodiments, $n_1 - n_2 \geq 0.03$. Even more especially, in specific embodiments, $n_1 - n_2 \geq 0.05$. Polymers may e.g. have indices of refraction of about 1.4-1.6. Inorganic materials may have similar or higher indices of refraction. Therefore, in specific embodiments two adjacent lightguide regions have an index of refraction difference of at least 0.03, even more especially at least 0.05, wherein an inner lightguide region of the two

adjacent lightguide regions has a higher index of refraction than an outer lightguide region of the two adjacent lightguide regions.

In specific embodiments, the differences of the refractive indices as indicated above may at least apply at 589.29 nm.

5 Note that when there is (in embodiments) no physical contact between adjacent lightguides, the indices of refraction of the adjacent lightguides may be the same, or may also be different (such as indicated above). Further, when there are more than two sets of adjacent lightguide regions, optical separation between different sets of adjacent lightguide regions may also be achieved via different options, such as one with a reflector in between
10 and one with different indices of refraction, like e.g. a core and a shell having different indices of refraction, and that shell and another shell separated by a reflector (see also above).

 The lightguide may also comprise a plurality of shells. A first shell on the core may be indicated as shell k , and a next shell on shell k may be indicated as shell $k+1$, etc. Each shell with a lower number than a shell with a number $+1$, whatever cross-sectional
15 symmetry that shell with lower number may have, like triangular, square, rectangular, pentagonal, hexagonal, or other n -gonal shapes (i.e. with $n \geq 7$, such as $n=8$ or $n=12$), or round, is circumferentially surrounded by that shell with a number $+1$. The shell with the highest number may be circumferentially surrounded by a cladding.

 As indicated above, the lightguide may in embodiments comprise m_1
20 concentric arranged lightguide regions, including a core and one or more shells. Hence, with $m_1=2$, the lightguide comprises a core and a shell, and with $m_1=3$, the lightguide comprises a core and a first shell and a second shell. Hence, the term lightguide regions refers to a core and one or more shells. As indicated above, $m_1 \geq 2$. In embodiments, there may be 1-4 shells, such as 2-3 shells. In specific embodiments, $m_1 \geq 3$. Hence, in specific embodiments m_1 may
25 be selected from the range of 2-5, especially 2-4, though other numbers may also be possible.

 Assuming for instance an optical fiber with a core and a shell, and optionally on the shell a cladding, wherein light source light is provided in the core and/or the shell, then $m_1=2$, i.e. the core and shell are lightguide regions. Would the cladding be configured in a light receiving relationship each with at least one light source, then the cladding may herein
30 be considered as (shell) lightguide region. Would a configuration with a core, a reflective shell, a first shell, a reflective shell, and a further (second) shell be provided, the reflective shells are not light transmissive lightguide regions (but reflectors). Hence, for such configuration $m_1=3$ (core, first shell, second shell).

As indicated above, in specific embodiment the core may be hollow. In alternative embodiments, the core may comprise a light transmissive material (like the other lightguide regions may comprise a (different) light transmissive material). Further, a reflector may be arranged between the shells. In other embodiments, two or more shells may have different indices of refraction. For instance, in embodiments two or more shells may comprise different transparent materials.

The lightguide may comprise a first and a second end, which may define a length of the lightguide. However, it is herein not excluded that the core and shell(s) may have two or more different lengths. Especially, however, the core and shell(s) have essentially identical lengths.

At one end ("second end") the light may escape from one or more of the lightguide regions. Hence, in embodiments the lightguide comprises a light outcouple end (or second end). Here, light may escape from the lightguide and enter another medium, which may e.g. be a luminescent material, an optical element, or a medium like air.

Especially, each of the $m1$ concentric arranged lightguide regions comprises a light incouple side and a light outcouple side. Note that in case of a hollow core, the light incouple side is essentially an opening defined by the first shell (likewise this may apply for the light outcouple side). The light incouple side may especially be one end of the lightguide region. Hence, there may be $m1$ light incouple sides and n light outcouple sides.

Especially, in embodiments the light outcouple end of the lightguide comprises the $(m1)$ light outcouple sides. Hence, light introduced in the lightguide via one or more light incouple sides of the $m1$ lightguide regions may escape from the lightguide at the light outcouple end via the respective light outcouple sides of the $m1$ lightguide regions.

Especially, in embodiments at least one of the $(m1)$ light incouple sides is configured in a light receiving relationship with at least one light source, even more especially more than one light source. Hence, at least one of the $(m1)$ light incouple sides may be configured downstream from one or more light source, especially more than one light source. When providing the light source light of a single light source to e.g. a shell, the light of the light source may (within the shell) be distributed over the shell, leading to homogenization. When providing the light source light of two light sources to e.g. a shell, the light of the two light sources may be distributed over the shell, leading to homogenization. Hence, especially a shell may be used to homogenize (and/or mix light).

Therefore, at least one of the $(m1)$ light incouple sides is configured in a light receiving relationship with at least one light source, especially more than one light source,

wherein especially in embodiments the at least one of the (m1) light incouple sides (which are configured in a light receiving relationship), including the light incouple side of at least one of the one or more shells. Therefore, in specific embodiments at least one shell (of the one or more shells) may be configured in a light receiving relationship with at least two light sources.

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”. In embodiments, the term “light-receiving relationship” and “downstream” may essentially be synonyms.

The terms "radiationally coupled" or “optically coupled” may especially mean that (i) a light generating element, such as a light source, and (ii) another item or material, are associated with each other so that at least part of the radiation emitted by the light generating element is received by the item or material. In other words, the item or material is configured in a light-receiving relationship with the light generating element. At least part of the radiation of the light generating element will be received by the item or material. This may in embodiments be directly, such as the item or material in physical contact with the (light emitting surface of the) light generating element. This may in embodiments be via a medium, like air, a gas, or a liquid or solid light guiding material. In embodiments, also one or more optics, like a lens, a reflector, an optical filter, may be configured in the optical path between light generating element and item or material.

As the core and shell(s) may have different features or may be separated from each other (with e.g. reflective layers), at least part of the light source light introduced in a lightguide region may (essentially) escape from the same lightguide region. This may also be due to the beam angle of the light source light that is provided to the light incouple side. The smaller the beam angle, the higher the reflection (within the core or shell), until the light outcouple side is reached. There, a substantial part of the light that is provided at the light incouple side of the same lightguide region may escape. Hence, over the length of the lightguide, contamination with light from the core or another shell may be very small, or even (essentially) absent (e.g. in the case of reflectors). Further, the light source light of a light source may essentially only be provided to a single region. Especially, this may be

achieved by focusing the light source light essentially at the light incouple side of a specific lightguide region.

Hence, when a lightguide region is configured in a light receiving relationship with a (laser) light source, especially at least 70%, such as at least 80%, even more especially at least 90% of the (optical) power of the light source light of that light source that irradiates the one or more light incouple sides is received by that specific lightguide region.

Hence, in embodiments, one or more, especially two or more of the lightguide are configured in a light receiving relationship with different sets of each one or more light sources. In other words, one or more light sources may be configured to provide light to a specific lightguide region, but especially those one or more light sources (and optional intermediate optics) may be configured such that at least 70%, such as at least 80%, or even more, such as at least 90%) of the light that reaches the lightguide regions, is received by one of the lightguide regions. Again, the percentages refer to the power of the light (i.e. Watts).

Hence, the phrase “at least two of the light incouple sides are configured in a light receiving relationship each with at least one light source, including the light incouple side of at least one of the one or more shells”, and similar phrases, may especially indicate that there are at least two light incouple sides (and thus at least two lightguide regions). Further, it may especially indicate that at least two of the at least two light incouple sides receive light from the light sources. A first light incouple side (of a lightguide region), of the at least two light incouple sides, may receive light from one or more light sources, and a second light incouple side (of another lightguide region), of the at least two light incouple sides, may receive light from one or more other light sources. Hence, each light incouple side may be in a light receiving relationship with a respective set of light sources. A light incouple side of a (shell) lightguide region may also be in a light receiving relationship with a plurality of sets of light sources. Nevertheless, one or more other (shell) lightguide regions will then be in a light receiving relationships with respective other set(s) of light sources. In this way, each lightguide region may receive light source light of one or more respective light sources. Further, the above phrase may also indicate that of the at least two light incouple sides, at least one is of a shell.

The light generating system especially comprises at least a single light source, such as a laser light source. Even more especially, one of the one or more shells is configured in a light receiving relationship with that single light source. Especially, the light generating may comprise two or more light sources. In embodiments, as indicated above, at least one of

the (m1) light incouple sides is configured in a light receiving relationship with at least one light source, including the light incouple side of at least one of the one or more shells.

When there is more than one light source, different embodiments may be possible. For instance, two or more of the light sources may be radiatively coupled with the same lightguide region and/or two or more of the light sources are radiatively coupled with different lightguide regions. Alternatively or additionally, two or more of the light sources are essentially identical light sources in terms of spectral power distribution and/or two or more of the light sources differ in terms of spectral power distribution of the light source light generated by the two or more of the light sources.

As indicated above, especially a shell may be used to homogenize and/or mix light of two or more light sources.

Hence, in embodiments at least two essentially the same light sources in terms of spectral power distributions may be configured in a light receiving relationship with the same lightguide region. In this way, homogenized light may be produced, which may have (in embodiments) the shape of a ring with a substantial even intensity distribution over the ring. Hence, in specific embodiments two or more of the at least two light sources are configured to generate light having the same spectral power distributions. Therefore, in specific embodiments two or more of the at least two light sources may be configured to generate light having essentially the same color points. For instance, in embodiments two or more of the two or more light sources may be solid state light sources, such as LEDs or lasers, of the same bin.

Alternatively or additionally, in embodiments at least two different light sources in terms of spectral power distributions may be configured in a light receiving relationship with the same lightguide region. In this way, homogenized and mixed light may be produced, which may have the shape of a ring with a substantial even intensity distribution over the ring. Hence, in specific embodiments two or more of the at least two light sources are configured to generate light having different spectral power distributions. Therefore, in specific embodiments two or more of the at least two light sources may be configured to generate light having different color points. For instance, in embodiments two or more of the two or more light sources may be solid state light sources, such as LEDs or lasers, of different bins. In specific embodiments, two or more of the at least two light sources are configured to generate light having centroid wavelengths that differ in embodiments with at least 10 nm, such as at least 20 nm, or even at least 30 nm, such as a difference selected from the range of 30-200 nm.

In specific embodiments, colors or color points of a first type of light and a second type of light may be different when the respective color points of the first type of light and the second type of light differ with at least 0.01 for u' and/or with at least 0.01 for v' , even more especially at least 0.02 for u' and/or with at least 0.02 for v' . In yet more specific
 5 embodiments, the respective color points of first type of light and the second type of light may differ with at least 0.03 for u' and/or with at least 0.03 for v' . Here, u' and v' are color coordinate of the light in the CIE 1976 UCS (uniform chromaticity scale) diagram.

In other specific embodiments, colors or color points of a first type of light and a second type of light may be essentially the same when the respective color points of the
 10 first type of light and the second type of light differ with at maximum 0.03 for u' and/or with at maximum 0.03 for v' , even more especially at maximum 0.02 for u' and/or with at maximum 0.02 for v' . In yet more specific embodiments, the respective color points of first type of light and the second type of light may differ with at maximum 0.01 for u' and/or with at maximum 0.01 for v' . Here, u' and v' are color coordinate of the light in the CIE 1976
 15 UCS (uniform chromaticity scale) diagram.

The term “centroid wavelength”, also indicated as λ_c , is known in the art, and refers to the wavelength value where half of the light energy is at shorter and half the energy is at longer wavelengths; the value is stated in nanometers (nm). It is the wavelength that divides the integral of a spectral power distribution into two equal parts as expressed by the
 20 formula $\lambda_c = \sum \lambda * I(\lambda) / (\sum I(\lambda))$, where the summation is over the wavelength range of interest, and $I(\lambda)$ is the spectral energy density (i.e. the integration of the product of the wavelength and the intensity over the emission band normalized to the integrated intensity). The centroid wavelength may e.g. be determined at operation conditions.

In embodiments, two or more lightguide regions, especially their light
 25 incouple sides, may be configured in a light receiving relationship with a plurality of essentially the same light sources in terms of spectral power distributions. Note, however, that different lightguide regions may be radiationally coupled with different (sets of) light sources (see also above). This may provide a light generating system with an increased intensity at the centroid wavelength of the light source light of this plurality of essentially the
 30 same light sources.

Alternatively or additionally, two or more lightguide regions, especially their light incouple sides, may be configured in a light receiving relationship with a plurality of light sources comprising at least two different light sources in terms of spectral power distributions. Note, however, that different lightguide regions may be radiationally coupled

with different (sets of) light sources (such as different (sets of) lasers). This may provide a light generating system with an increased intensity at the respective centroid wavelength of the light source light of these plurality of light sources and/or mixed light, as one or more of the lightguide regions may each individually be radiationally coupled with (one or more sets of each) at least two different light sources in terms of spectral power distributions.

In specific embodiments, the system may be configured to provide each lightguide region essentially the same (spectral) power per area of light incouple side. Hence, in embodiments the intensity of the light source light that escapes from the different light outcouple sides may also essentially have the same (spectral) power per area of light outcouple side. In this way, the lightguide outcouple end maybe used to provide an essentially equal irradiance of a surface (such as of e.g. a luminescent material; see also below). Essentially equal may e.g. refer to ratios within the range of 0.9-1.1. Note that the invention is not limited to such embodiments.

In specific embodiments, the lightguide may comprise a core, and at least two shells. At least two of the shells, especially their light incouple sides, may be configured in a light receiving relationship with different sets of each at least a single light source, even more especially with different sets of each at least two light sources. For instance, this would allow homogenization of light of two or more essentially the same light sources in terms of spectral power distribution via a first shell, and homogenization of light of two or more essentially the same light sources in terms of spectral power distribution via a second shell, wherein the light sources for the different shells mutually differ in spectral power distributions. For instance, UV and blue, or short wavelength blue and long wavelength blue, etc. However, also essentially the same light sources may be applied for two or more shells. Therefore, in embodiments $m \geq 3$. Further, in specific embodiments at least two shells may be configured in a light receiving relationship with different sets of each at least two light sources. As indicated above, the sets may be the same in terms of spectral power distribution or may mutually differ in terms of spectral power distribution.

The phrase “wherein at least two shells are configured in a light receiving relationship with different sets, with each set comprising at least one light source”, or the phrase “wherein at least two shells are configured in a light receiving relationship with different sets, with each set comprising at least two light sources”, and similar phrases may especially indicated each of the at least two shells may be configured in a light receiving relationship with a respective set of light sources. A light incouple side of a (shell) lightguide region may also be in a light receiving relationship with a plurality of sets of light sources.

Nevertheless, one or more other (shell) lightguide regions will then be in a light receiving relationships with respective other set(s) of light sources. In this way, each lightguide region may receive light source light of one or more respective light sources, such as at least two light sources. Hence, the k_1 light sources may be divided in at least two unique sets of light sources, wherein each set comprises at least one light source, wherein each light source may be comprised by (only) a single set. A light incouple side may be configured in a light receiving relationship with one or more sets. However, especially each set may be configured, together with optional optics, to provide light source light to a specific lightguide region. Of course, in embodiments also two or more sets may be configured, together with optional optics, to provide light source light to a specific lightguide region.

Referring to the lightguide, the lightguide may have an equivalent circular diameter (D) with essentially any suitable value. Especially, however, the equivalent circular diameter may be relatively small, such as selected from the range of about 0.05-10 mm, though larger values may also be possible. Hence, especially in embodiments the lightguide may have an equivalent circular diameter (D) selected from the range of 0.05-10 mm.

The equivalent circular diameter (or ECD) of an (irregularly shaped) two-dimensional shape is the diameter of a circle of equivalent area. For instance, the equivalent circular diameter of a square with side a is $2 \cdot a \cdot \sqrt{1/\pi}$. For a circle, the diameter is the same as the equivalent circular diameter. Would a circle in an xy -plane with a diameter D be distorted to any other shape (in the xy -plane), without changing the area size, than the equivalent circular diameter of that shape would be D .

Especially, the equivalent circular diameter may be selected from the range of about 0.1-10 mm, such as about 0.2-10 mm. For instance, in embodiments the core may have an equivalent circular diameter of at least about 50 μm , such as at least about 75 μm , and each shell of the one more shells may each have a thickness individually selected from at least about 50 μm , such as at least about 75 μm . When there is more than one shell, in embodiments all shells may have the same thickness and in other embodiments two or more shells may have different thicknesses. The lightguide may have a length (see also below); the equivalent circular diameter (D) may be configured perpendicular to the length.

Especially, in embodiments the cross-sectional core dimensions and the cross-sectional shell dimensions may stay constant over the respective lengths of the lightguide regions. Alternatively, however, in (other) embodiments the cross-sectional core dimensions and the cross-sectional shell dimensions may taper.

The length of the lightguide regions may be selected such, that a good homogenization may take place. In first order approximation, this length may relate on the equivalent circular diameter of the lightguide. Especially, the length of the lightguide regions may especially be at least twice the equivalent circular diameter of the lightguide, such as at least three times the diameter, like at least 5 times the equivalent circular diameter of the lightguide. With such length, homogenization may be relatively good. Long lightguide regions may be less desirable, as this may also lead to some loss and may complicate small devices. Hence, the length of the lightguide regions may be at maximum about 25 times the equivalent circular diameter of the lightguide, such as at maximum 20 times the equivalent circular diameter of the lightguide, such as up to about 15 times the equivalent circular diameter of the lightguide. Therefore, especially the lightguide may have a length, defined relative to the light outcouple end of $a \cdot D$, wherein a is selected from the range of 5-15, and wherein D is the equivalent circular diameter. Especially, in embodiments the length may be at least about 0.5 mm.

The length of the lightguide regions may be defined along an axis of elongation. Over at least part of the lengths of the lightguide regions, the axes of elongation may be parallel. In general, the lightguide regions may have (outer) equivalent circular diameters smaller than the length of the lightguide regions. Therefore, in embodiments an outer equivalent circular diameter of the lightguide may be smaller than the length of the lightguide, such as equal to or smaller than 50% of the length of the lightguide, like equal to or smaller than 20% of the length of the lightguide, or even smaller (see also above). A shell may have an outer equivalent circular diameter and an inner equivalent circular diameter.

As indicated above, in specific embodiments between adjacent lightguide regions, a reflector may be configured. Hence, between the core and the shell a reflector may be arranged. When there are more than one shell, between adjacent shells of one or more sets of two shells a reflector may be configured. Especially, the reflector may have essentially the same length as the adjacent shells or the adjacent core and shell. Therefore, in embodiments the light generating system may further comprise a reflector configured between two adjacent lightguide regions. For instance, a reflector may be provided via a vapor deposition process on the core or on a shell, before a shell of further shell is provided, respectively, to the core or more inner shell. For instance, via CVD or plasma CVD an Al coating may be provided. A metal coating, such as an Al coating, may also be provided via sputtering.

The light escaping from the lightguide may be used as such, e.g. for lighting purposes, or for other purposes, such as communication, disinfection, etc. The light escaping

from the lightguide may also be used, or at least part thereof, to illuminate a luminescent material, to convert at least part of the light escaping from the lightguide into luminescent material light. Therefore, the light generating system further comprises a luminescent material, wherein the luminescent material is configured in a light-receiving relationship with the light outcouple end, and wherein the luminescent material is configured to convert at least part of the light into luminescent material light. The term “in a light-receiving relationship” does, as indicated above, not exclude the presence of intermediate optical elements, such as lenses, collimators, reflectors, dichroic mirrors, etc. Hence, the luminescent material may especially be configured downstream of the light outcouple end, or at least downstream of at least part of one or more light outcouple sides of one or more lightguide regions, or remote (i.e. a non-zero distance) from the one or more light outcouple sides of the one or more lightguide regions.

Especially, in embodiments the light generating system may be configured to generate system light. In an operational mode of the light generating system the system light may comprise the luminescent material light.

The system, or apparatus, or device may execute an action in a “mode” or “operation mode” or “mode of operation”. Likewise, in a method an action or stage, or step may be executed in a “mode” or “operation mode” or “mode of operation” or “operational mode”. The term “mode” may also be indicated as “controlling mode”. This does not exclude that the system, or apparatus, or device may also be adapted for providing another controlling mode, or a plurality of other controlling modes. Likewise, this may not exclude that before executing the mode and/or after executing the mode one or more other modes may be executed.

The term “luminescent material” especially refers to a material that can convert first radiation, especially one or more of UV radiation and blue radiation, into second radiation. In general, the first radiation and second radiation have different spectral power distributions. Hence, instead of the term “luminescent material”, also the terms “luminescent converter” or “converter” may be applied. In general, the second radiation has a spectral power distribution at larger wavelengths than the first radiation, which is the case in the so-called down-conversion. In specific embodiments, however the second radiation has a spectral power distribution with intensity at smaller wavelengths than the first radiation, which is the case in the so-called up-conversion. In embodiments, the “luminescent material” may especially refer to a material that can convert radiation into e.g. visible and/or infrared light. For instance, in embodiments the luminescent material may be able to convert one or

more of UV radiation and blue radiation, into visible light. The luminescent material may in specific embodiments also convert radiation into infrared radiation (IR). Hence, upon excitation with radiation, the luminescent material emits radiation. In general, the luminescent material will be a down converter, i.e. radiation of a smaller wavelength is converted into radiation with a larger wavelength ($\lambda_{\text{ex}} < \lambda_{\text{em}}$), though in specific embodiments the luminescent material may comprise up-converter luminescent material, i.e. radiation of a larger wavelength is converted into radiation with a smaller wavelength ($\lambda_{\text{ex}} > \lambda_{\text{em}}$).

In embodiments, the term “luminescence” may refer to phosphorescence. In embodiments, the term “luminescence” may also refer to fluorescence. Instead of the term “luminescence”, also the term “emission” may be applied. Hence, the terms “first radiation” and “second radiation” may refer to excitation radiation and emission (radiation), respectively. Likewise, the term “luminescent material” may in embodiments refer to phosphorescence and/or fluorescence. The term “luminescent material” may also refer to a plurality of different luminescent materials. Examples of possible luminescent materials are indicated below.

In embodiments, luminescent materials are selected from garnets and nitrides, especially doped with trivalent cerium or divalent europium, respectively. The term “nitride” may also refer to oxynitride or nitridosilicate, etc.

In specific embodiments the luminescent material comprises a luminescent material of the type $\text{A}_3\text{B}_5\text{O}_{12}:\text{Ce}$, wherein A in embodiments comprises one or more of Y, La, Gd, Tb and Lu, especially (at least) one or more of Y, Gd, Tb and Lu, and wherein B in embodiments comprises one or more of Al, Ga, In and Sc. Especially, A may comprise one or more of Y, Gd and Lu, such as especially one or more of Y and Lu. Especially, B may comprise one or more of Al and Ga, more especially at least Al, such as essentially entirely Al. Hence, especially suitable luminescent materials are cerium comprising garnet materials. Embodiments of garnets especially include $\text{A}_3\text{B}_5\text{O}_{12}$ garnets, wherein A comprises at least yttrium or lutetium and wherein B comprises at least aluminum. Such garnets may be doped with cerium (Ce), with praseodymium (Pr) or a combination of cerium and praseodymium; especially however with Ce. Especially, B comprises aluminum (Al), however, B may also partly comprise gallium (Ga) and/or scandium (Sc) and/or indium (In), especially up to about 20% of Al, more especially up to about 10 % of Al (i.e. the B ions essentially consist of 90 or more mole % of Al and 10 or less mole % of one or more of Ga, Sc and In); B may especially comprise up to about 10% gallium. In another variant, B and O may at least partly be replaced by Si and N. The element A may especially be selected from the group consisting of

yttrium (Y), gadolinium (Gd), terbium (Tb) and lutetium (Lu). Further, Gd and/or Tb are especially only present up to an amount of about 20% of A. In a specific embodiment, the garnet luminescent material comprises $(Y_{1-x}Lu_x)_3B_5O_{12}:Ce$, wherein x is equal to or larger than 0 and equal to or smaller than 1. The term “:Ce”, indicates that part of the metal ions (i.e. in the garnets: part of the “A” ions) in the luminescent material is replaced by Ce. For instance, in the case of $(Y_{1-x}Lu_x)_3Al_5O_{12}:Ce$, part of Y and/or Lu is replaced by Ce. This is known to the person skilled in the art. Ce will replace A in general for not more than 10%; in general, the Ce concentration will be in the range of 0.1 to 4%, especially 0.1 to 2% (relative to A). Assuming 1% Ce and 10% Y, the full correct formula could be

$(Y_{0.1}Lu_{0.89}Ce_{0.01})_3Al_5O_{12}$. Ce in garnets is substantially or only in the trivalent state, as is known to the person skilled in the art.

In embodiments, the luminescent material (thus) comprises $A_3B_5O_{12}$ wherein in specific embodiments at maximum 10% of B-O may be replaced by Si-N.

In specific embodiments the luminescent material comprises $(Y_{x1-x2-x3}A'_{x2}Ce_{x3})_3(Al_{y1-y2}B'_{y2})_5O_{12}$, wherein $x1+x2+x3=1$, wherein $x3>0$, wherein $0<x2+x3\leq 0.2$, wherein $y1+y2=1$, wherein $0\leq y2\leq 0.2$, wherein A' comprises one or more elements selected from the group consisting of lanthanides, and wherein B' comprises one or more elements selected from the group consisting of Ga, In and Sc. In embodiments, $x3$ is selected from the range of 0.001-0.1. In the present invention, especially $x1>0$, such as >0.2 , like at least 0.8.

Garnets with Y may provide suitable spectral power distributions.

In specific embodiments at maximum 10% of B-O may be replaced by Si-N. Here, B in B-O refers to one or more of Al, Ga, In and Sc (and O refers to oxygen); in specific embodiments B-O may refer to Al-O. As indicated above, in specific embodiments $x3$ may be selected from the range of 0.001-0.04. Especially, such luminescent materials may have a suitable spectral distribution (see however below), have a relatively high efficiency, have a relatively high thermal stability, and allow a high CRI (in combination with the first light source light and the second light source light (and the optical filter)). Hence, in specific embodiments A may be selected from the group consisting of Lu and Gd. Alternatively or additionally, B may comprise Ga. Hence, in embodiments the luminescent material comprises $(Y_{x1-x2-x3}(Lu,Gd)_{x2}Ce_{x3})_3(Al_{y1-y2}Ga_{y2})_5O_{12}$, wherein Lu and/or Gd may be available. Even more especially, $x3$ is selected from the range of 0.001-0.1, wherein $0<x2+x3\leq 0.1$, and wherein $0\leq y2\leq 0.1$. Further, in specific embodiments, at maximum 1% of B-O may be replaced by Si-N. Here, the percentage refers to moles (as known in the art); see

e.g. also EP3149108. In yet further specific embodiments, the luminescent material comprises $(Y_{x1-x3}Ce_{x3})_3Al_5O_{12}$, wherein $x1+x3=1$, and wherein $0<x3\leq 0.2$, such as 0.001-0.1.

In specific embodiments, the light generating device may only include luminescent materials selected from the type of cerium comprising garnets. In even further specific embodiments, the light generating device includes a single type of luminescent materials, such as $(Y_{x1-x2-x3}A'_{x2}Ce_{x3})_3(Al_{y1-y2}B'_{y2})_5O_{12}$. Hence, in specific embodiments the light generating device comprises luminescent material, wherein at least 85 weight%, even more especially at least about 90 wt.%, such as yet even more especially at least about 95 weight % of the luminescent material comprises $(Y_{x1-x2-x3}A'_{x2}Ce_{x3})_3(Al_{y1-y2}B'_{y2})_5O_{12}$. Here, wherein A' comprises one or more elements selected from the group consisting of lanthanides, and wherein B' comprises one or more elements selected from the group consisting of Ga In and Sc, wherein $x1+x2+x3=1$, wherein $x3>0$, wherein $0<x2+x3\leq 0.2$, wherein $y1+y2=1$, wherein $0\leq y2\leq 0.2$. Especially, $x3$ is selected from the range of 0.001-0.1. Note that in embodiments $x2=0$. Alternatively or additionally, in embodiments $y2=0$.

In specific embodiments, A may especially comprise at least Y, and B may especially comprise at least Al.

In embodiments, the luminescent material may alternatively or additionally comprise one or more of $M_2Si_5N_8:Eu^{2+}$ and/or $MAISiN_3:Eu^{2+}$ and/or $Ca_2AlSi_3O_2N_5:Eu^{2+}$, etc., wherein M comprises one or more of Ba, Sr and Ca, especially in embodiments at least Sr. In embodiments, the luminescent may comprise one or more materials selected from the group consisting of $(Ba,Sr,Ca)S:Eu$, $(Ba,Sr,Ca)AlSiN_3:Eu$ and $(Ba,Sr,Ca)_2Si_5N_8:Eu$. In these compounds, europium (Eu) is substantially or only divalent, and replaces one or more of the indicated divalent cations. In general, Eu will not be present in amounts larger than 10% of the cation; its presence will especially be in the range of about 0.5 to 10%, more especially in the range of about 0.5 to 5% relative to the cation(s) it replaces. The term “:Eu”, indicates that part of the metal ions is replaced by Eu (in these examples by Eu^{2+}). For instance, assuming 2% Eu in $CaAlSiN_3:Eu$, the correct formula could be $(Ca_{0.98}Eu_{0.02})AlSiN_3$. Divalent europium will in general replace divalent cations, such as the above divalent alkaline earth cations, especially Ca, Sr or Ba. The material $(Ba,Sr,Ca)S:Eu$ can also be indicated as $MS:Eu$, wherein M is one or more elements selected from the group consisting of barium (Ba), strontium (Sr) and calcium (Ca); especially, M comprises in this compound calcium or strontium, or calcium and strontium, more especially calcium. Here, Eu is introduced and replaces at least part of M (i.e. one or more of Ba, Sr, and Ca). Further, the material $(Ba,Sr,Ca)_2Si_5N_8:Eu$ can also be indicated as $M_2Si_5N_8:Eu$, wherein M is one or more

elements selected from the group consisting of barium (Ba), strontium (Sr) and calcium (Ca); especially, M comprises in this compound Sr and/or Ba. In a further specific embodiment, M consists of Sr and/or Ba (not taking into account the presence of Eu), especially 50 to 100%, more especially 50 to 90% Ba and 50 to 0%, especially 50 to 10% Sr, such as

- 5 Ba_{1.5}Sr_{0.5}Si₅N₈:Eu (i.e. 75 % Ba; 25% Sr). Here, Eu is introduced and replaces at least part of M, i.e. one or more of Ba, Sr, and Ca). Likewise, the material (Ba,Sr,Ca)AlSiN₃:Eu can also be indicated as MAlSiN₃:Eu, wherein M is one or more elements selected from the group consisting of barium (Ba), strontium (Sr) and calcium (Ca); especially, M comprises in this compound calcium or strontium, or calcium and strontium, more especially calcium. Here,
- 10 Eu is introduced and replaces at least part of M (i.e. one or more of Ba, Sr, and Ca). Eu in the above indicated luminescent materials is substantially or only in the divalent state, as is known to the person skilled in the art.

- In embodiments, a red luminescent material may comprise one or more materials selected from the group consisting of (Ba,Sr,Ca)S:Eu, (Ba,Sr,Ca)AlSiN₃:Eu and
- 15 (Ba,Sr,Ca)₂Si₅N₈:Eu. In these compounds, europium (Eu) is substantially or only divalent, and replaces one or more of the indicated divalent cations. In general, Eu will not be present in amounts larger than 10% of the cation; its presence will especially be in the range of about 0.5 to 10%, more especially in the range of about 0.5 to 5% relative to the cation(s) it replaces. The term “:Eu”, indicates that part of the metal ions is replaced by Eu (in these
- 20 examples by Eu²⁺). For instance, assuming 2% Eu in CaAlSiN₃:Eu, the correct formula could be (Ca_{0.98}Eu_{0.02})AlSiN₃. Divalent europium will in general replace divalent cations, such as the above divalent alkaline earth cations, especially Ca, Sr or Ba.

- The material (Ba,Sr,Ca)S:Eu can also be indicated as MS:Eu, wherein M is one or more elements selected from the group consisting of barium (Ba), strontium (Sr) and
- 25 calcium (Ca); especially, M comprises in this compound calcium or strontium, or calcium and strontium, more especially calcium. Here, Eu is introduced and replaces at least part of M (i.e. one or more of Ba, Sr, and Ca).

- Further, the material (Ba,Sr,Ca)₂Si₅N₈:Eu can also be indicated as
- M₂Si₅N₈:Eu, wherein M is one or more elements selected from the group consisting of
- 30 barium (Ba), strontium (Sr) and calcium (Ca); especially, M comprises in this compound Sr and/or Ba. In a further specific embodiment, M consists of Sr and/or Ba (not taking into account the presence of Eu), especially 50 to 100%, more especially 50 to 90% Ba and 50 to 0%, especially 50 to 10% Sr, such as Ba_{1.5}Sr_{0.5}Si₅N₈:Eu (i.e. 75 % Ba; 25% Sr). Here, Eu is introduced and replaces at least part of M, i.e. one or more of Ba, Sr, and Ca).

Likewise, the material (Ba,Sr,Ca)AlSiN₃:Eu can also be indicated as MAISiN₃:Eu, wherein M is one or more elements selected from the group consisting of barium (Ba), strontium (Sr) and calcium (Ca); especially, M comprises in this compound calcium or strontium, or calcium and strontium, more especially calcium. Here, Eu is introduced and replaces at least part of M (i.e. one or more of Ba, Sr, and Ca).

Eu in the above indicated luminescent materials is substantially or only in the divalent state, as is known to the person skilled in the art.

Blue luminescent materials may comprise YSO (Y₂SiO₅:Ce³⁺), or similar compounds, or BAM (BaMgAl₁₀O₁₇:Eu²⁺), or similar compounds.

The term “luminescent material” herein especially relates to inorganic luminescent materials. Instead of the term “luminescent material” also the term “phosphor”. These terms are known to the person skilled in the art.

Alternatively or additionally, also other luminescent materials may be applied. For instance quantum dots and/or organic dyes may be applied and may optionally be embedded in transmissive matrices like e.g. polymers, like PMMA, or polysiloxanes, etc. etc.

Quantum dots are small crystals of semiconducting material generally having a width or diameter of only a few nanometers. When excited by incident light, a quantum dot emits light of a color determined by the size and material of the crystal. Light of a particular color can therefore be produced by adapting the size of the dots. Most known quantum dots with emission in the visible range are based on cadmium selenide (CdSe) with a shell such as cadmium sulfide (CdS) and zinc sulfide (ZnS). Cadmium free quantum dots such as indium phosphide (InP), and copper indium sulfide (CuInS₂) and/or silver indium sulfide (AgInS₂) can also be used. Quantum dots show very narrow emission band and thus they show saturated colors. Furthermore the emission color can easily be tuned by adapting the size of the quantum dots. Any type of quantum dot known in the art may be used in the present invention. However, it may be preferred for reasons of environmental safety and concern to use cadmium-free quantum dots or at least quantum dots having a very low cadmium content.

Instead of quantum dots or in addition to quantum dots, also other quantum confinement structures may be used. The term “quantum confinement structures” should, in the context of the present application, be understood as e.g. quantum wells, quantum dots, quantum rods, tripods, tetrapods, or nano-wires, etcetera.

Organic phosphors can be used as well. Examples of suitable organic phosphor materials are organic luminescent materials based on perylene derivatives, for example compounds sold under the name Lumogen® by BASF. Examples of suitable

compounds include, but are not limited to, Lumogen® Red F305, Lumogen® Orange F240, Lumogen® Yellow F083, and Lumogen® F170.

Different luminescent materials may have different spectral power distributions of the respective luminescent material light. Alternatively or additionally, such different luminescent materials may especially have different color points (or dominant wavelengths).

As indicated above, other luminescent materials may also be possible. Hence, in specific embodiments the luminescent material is selected from the group of divalent europium containing nitrides, divalent europium containing oxynitrides, divalent europium containing silicates, cerium comprising garnets, and quantum structures. Quantum structures may e.g. comprise quantum dots or quantum rods (or other quantum type particles) (see above). Quantum structures may also comprise quantum wells. Quantum structures may also comprise photonic crystals.

The (inorganic) luminescent material may in embodiments be provided as single crystal, or as ceramic body, or a luminescent material dispersed in another material, like polymeric material (of a polymeric body). Organic luminescent materials and/or quantum dots may also be dispersed in another material, like polymeric material (of a polymeric body).

The luminescent material may be configured in the reflective mode or in the transmissive mode. In the transmissive mode, it may be relatively easy to have light source light admixed in the luminescent material light, which may be useful for generating the desirable spectral power distribution. In the reflective mode, thermal management may be more easy, as a substantial part of the luminescent material may be in thermal contact with a thermally conductive element, like a heatsink or heat spreader. In the reflective mode, a part of the light source light may in embodiments be reflected by the luminescent material light and may be admixed in the luminescent material light.

In specific embodiments, it may be desirable to separate the luminescent material light and the light source light (whether in reflective mode or transmissive mode) that is used or intended to generate the luminescent material light (but was e.g. transmitted or reflected). For instance, this may allow a better control of the optical properties of the light that escapes from the system ("system light").

Hence, in specific embodiments the light generating system may further comprise a dichroic element, configured to transmit or reflect the light and configured to reflect or transmit the luminescent material light, wherein the dichroic element is configured

between the light outcouple end and the luminescent material. Alternatively or additionally, the dichroic element may be configured downstream of the luminescent material. Especially, the dichroic element may be a dichroic mirror or reflector.

The dichroic element may be an embodiment of a color separation element, such as described in US7070300, which is herein incorporated by reference. Especially, the color separation element may be selected from the group of a dichroic mirror, a dichroic cube, and a diffractive optical element. Optionally, the color separation element may be provided using a hologram.

It may be desirable that the system light in an operational mode of the system comprises both luminescent material light and light source light. For instance, this may be the case in embodiments wherein the light source light is e.g. blue light, and the luminescent material light comprises e.g. yellow light, or yellow and red light, or green and red light. Then, the blue light may be admixed (deliberately) to provide white light. Therefore, when light source light is reflected or transmitted by the luminescent material, dependent upon the mode, light source light may be desirable propagate together with the luminescent material light.

Alternatively, or additionally, the luminescent material light may be IR radiation, such as selected from the range of 780-2000 nm, like up to about 1500 nm.

For instance, in specific embodiments the luminescent material may be configured in the transmissive mode, wherein the luminescent material is configured to transmit part of the light, and wherein in an operational mode of the light generating system the system light comprises the luminescent material light and the light.

Alternatively or additionally, at least part of the light source light may bypass the luminescent material, and downstream thereof be admixed with the luminescent material light.

Alternatively or additionally, a first lightguide may be used to irradiate a luminescent material, and a light source and/or other lightguide may be used to provide light that is admixed with the luminescent material light.

In embodiments, in an operational mode, the system may be configured to generate white light, at least comprising the luminescent material light. In yet other embodiments, the system may be configured to generate white light, at least comprising the light source light that escapes from the light outcouple end.

The term “white light” herein, is known to the person skilled in the art. It especially relates to light having a correlated color temperature (CCT) between about 1800 K

and 20000 K, such as between 2000 and 20000 K, especially 2700-20000 K, for general lighting especially in the range of about 2700 K and 6500 K. In embodiments, for backlighting purposes the correlated color temperature (CCT) may especially be in the range of about 7000 K and 20000 K. Yet further, in embodiments the correlated color temperature (CCT) is especially within about 15 SDCM (standard deviation of color matching) from the BBL (black body locus), especially within about 10 SDCM from the BBL, even more especially within about 5 SDCM from the BBL.

The terms “visible”, “visible light” or “visible emission” and similar terms refer to light having one or more wavelengths in the range of about 380-780 nm. Herein, UV may especially refer to a wavelength selected from the range of 200-380 nm.

The terms “light” and “radiation” are herein interchangeably used, unless clear from the context that the term “light” only refers to visible light. The terms “light” and “radiation” may thus refer to UV radiation, visible light, and IR radiation. In specific embodiments, especially for lighting applications, the terms “light” and “radiation” refer to (at least) visible light.

The terms “violet light” or “violet emission” especially relates to light having a wavelength in the range of about 380-440 nm. The terms “blue light” or “blue emission” especially relates to light having a wavelength in the range of about 440-495 nm (including some violet and cyan hues). The terms “green light” or “green emission” especially relate to light having a wavelength in the range of about 495-570 nm. The terms “yellow light” or “yellow emission” especially relate to light having a wavelength in the range of about 570-590 nm. The terms “orange light” or “orange emission” especially relate to light having a wavelength in the range of about 590-620 nm. The terms “red light” or “red emission” especially relate to light having a wavelength in the range of about 620-780 nm. The term “pink light” or “pink emission” refers to light having a blue and a red component. The term “cyan” may refer to one or more wavelengths selected from the range of about 490-520 nm. The term “amber” may refer to one or more wavelengths selected from the range of about 585-605 nm, such as about 590-600 nm.

As indicated above, downstream of at least part of the light outcouple end, a luminescent material may be configured. Alternatively, downstream of at least part of the light outcouple end, a non-luminescent diffuse scattering material may be configured. Alternatively, downstream of at least part of the light outcouple end, a non-luminescent translucent material may be configured. In yet other embodiments, downstream of at least part of the light outcouple end, a luminescent translucent material may be configured. In yet

other embodiments, downstream of at least part of the light outcouple end, a non-luminescent transparent material may be configured, such as a single crystal or ceramic body or a light transmissive polymeric body (see also above).

The light source may be controlled via e.g. a control system. Especially when more than one light source is applied, it may be useful to control the more than one light sources. This may allow e.g. one or more of intensity control, beam shape control, spectral and power distribution control.

In specific embodiments, the light generating system may further comprise a control system configured to (individually) control the k1 light sources. Especially, in embodiment the light generating system may further comprise a control system configured to (individually) control the k1 light sources in dependence of one or more of an input signal of a user interface, a sensor signal (of a sensor), and a timer. The control system may also be configured to individually control sets of light sources, wherein each set comprises at least a light source.

For instance, the system may be controlled in different modes, wherein the intensity of the light provided to the different lightguide regions may be controlled.

The term “controlling” and similar terms especially refer at least to determining the behavior or supervising the running of an element. Hence, herein “controlling” and similar terms may e.g. refer to imposing behavior to the element (determining the behavior or supervising the running of an element), etc., such as e.g. measuring, displaying, actuating, opening, shifting, changing temperature, etc. Beyond that, the term “controlling” and similar terms may additionally include monitoring. Hence, the term “controlling” and similar terms may include imposing behavior on an element and also imposing behavior on an element and monitoring the element. The controlling of the element can be done with a control system, which may also be indicated as “controller”. The control system and the element may thus at least temporarily, or permanently, functionally be coupled. The element may comprise the control system. In embodiments, the control system and element may not be physically coupled. Control can be done via wired and/or wireless control. The term “control system” may also refer to a plurality of different control systems, which especially are functionally coupled, and of which e.g. one control system may be a master control system and one or more others may be slave control systems. A control system may comprise or may be functionally coupled to a user interface.

The control system may also be configured to receive and execute instructions from a remote control. In embodiments, the control system may be controlled via an App on

a device, such as a portable device, like a Smartphone or I-phone, a tablet, etc. The device is thus not necessarily coupled to the lighting system, but may be (temporarily) functionally coupled to the lighting system.

Hence, in embodiments the control system may (also) be configured to be controlled by an App on a remote device. In such embodiments the control system of the lighting system may be a slave control system or control in a slave mode. For instance, the lighting system may be identifiable with a code, especially a unique code for the respective lighting system. The control system of the lighting system may be configured to be controlled by an external control system which has access to the lighting system on the basis of knowledge (input by a user interface of with an optical sensor (e.g. QR code reader) of the (unique) code. The lighting system may also comprise means for communicating with other systems or devices, such as on the basis of Bluetooth, WIFI, LiFi, ZigBee, BLE or WiMAX, or another wireless technology.

The system, or apparatus, or device may execute an action in a “mode” or “operation mode” or “mode of operation”. Likewise, in a method an action or stage, or step may be executed in a “mode” or “operation mode” or “mode of operation” or “operational mode”. The term “mode” may also be indicated as “controlling mode”. This does not exclude that the system, or apparatus, or device may also be adapted for providing another controlling mode, or a plurality of other controlling modes. Likewise, this may not exclude that before executing the mode and/or after executing the mode one or more other modes may be executed.

However, in embodiments a control system may be available, that is adapted to provide at least the controlling mode. Would other modes be available, the choice of such modes may especially be executed via a user interface, though other options, like executing a mode in dependence of a sensor signal or a (time) scheme, may also be possible. The operation mode may in embodiments also refer to a system, or apparatus, or device, that can only operate in a single operation mode (i.e. “on”, without further tunability).

Hence, in embodiments, the control system may control in dependence of one or more of an input signal of a user interface, a sensor signal (of a sensor), and a timer. The term “timer” may refer to a clock and/or a predetermined time scheme.

In yet a further aspect, the invention also provides a lamp or a luminaire comprising the light generating system as defined herein. The luminaire may further comprise a housing, optical elements, louvres, etc. etc. The lamp or luminaire may further comprise a housing enclosing the light generating system. The lamp or luminaire may

comprise a light window in the housing or a housing opening, through which the system light may escape from the housing. In yet a further aspect, the invention also provides a projection device comprising the light generating system as defined herein. Especially, a projection device or “projector” or “image projector” may be an optical device that projects an image (or moving images) onto a surface, such as e.g. a projection screen. The projection device may include one or more light generating systems such as described herein.

Therefore, in an aspect the invention further provides a light generating device selected from the group of a lamp, a luminaire, a projector device, a disinfection device, and an optical wireless communication device, comprising the light generating system as defined herein.

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:

Figs. 1A-1D schematically depict some aspects and variants;

Figs. 2A-2D schematically depict some further embodiments and variants;

Figs. 3A-3E schematically depict some further embodiments and variants;

Fig. 4 schematically depict some possible applications and embodiments.

The schematic drawings are not necessarily to scale.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Fig. 1 schematically depicts an embodiment of a light generating system 1000. The system 1000 comprises k_1 light sources 100 and a lightguide 400.

The k_1 light sources 100 are configured to generate light 101, such as UV or blue. They may generate all the same spectral power distribution or two or more of these may be configured to generate light with different spectral power distribution. Especially, $k_1 \geq 1$. Here, $k_1 = 3$, by way of example.

In embodiments, wherein $k_1 \geq 2$, two or more of the at least two light sources 100 are configured to generate light 101 having the same spectral power distributions. In other embodiments, wherein $k_1 \geq 2$, two or more of the at least two light sources 100 are configured to generate light 101 having centroid wavelengths that differ with at least 10 nm.

The lightguide 400 comprises m_1 concentric arranged lightguide regions 410, including a core 420 and one or more shells 430. Especially, $m_1 \geq 2$; here $m_1 = 2$. Further, the

lightguide 400 comprises a light outcouple end 402. Reference 401 refers to a (possible) first end of the light guide 400.

The lightguide regions 410 may have axes of elongation A_x , here, as there are two lightguide regions 410, they are indicated with A_1 and A_2 . Here, the axes of elongation essentially coincide.

Especially, each of the m_1 concentric arranged lightguide regions 410 comprises a light incouple side 411 and a light outcouple side 412. The light outcouple end 402 comprises the (m_1) light outcouple sides 412.

As schematically depicted, at least one of the (m_1) light incouple sides 411 is configured in a light receiving relationship with at least one light source 100, including the light incouple side 411 of at least one of the one or more shells 430.

Especially, as shown at least one shell 430 (of the one or more shells 430) is configured in a light receiving relationship with at least two light sources 100.

In embodiments, the light sources 100 may be selected from the group comprising a laser light source and a super-luminescent diode, though other embodiments may also be possible (see also above).

Reference L indicates the length of the lightguide 400. Especially, the length may be defined starting from the light outcouple end 402. In embodiments, the lightguide 400 has a length, defined relative to the light outcouple end 402 of $a \cdot D$ (for D , the equivalent circular diameter, see below). Especially, a is selected from the range of 5-15.

Referring to Fig. 1A, and also Fig. 1B (see further below), the lightguide 400 may in embodiments have an equivalent circular diameter D selected from the range of 0.05-10 mm.

The light generating system 1000 may further comprise a control system 300 configured to (individually) control the k_1 light sources 100 in dependence of one or more of an input signal of a user interface, a sensor signal of a sensor, and a timer.

The light sources 100 used herein, optionally in combination with optics, may provide relatively narrow beams of light source light. This may facilitate propagation in the respective lightguide region.

Especially, the k_1 light sources 100, including optional (intermediate) optics 510, may be configured to generate the light 101 with a full width half maximum, in embodiments selected from the range of for instance 5-70° (see also above), see also Fig. 1D.

Fig 1B schematically depict a view on the first end 401 of the light guide 400 (see on the left, I), and also a view on the second end or light outcouple end 402 of the light

guide 400 (see on the right, II). Reference D indicates the diameter in these embodiments. Especially, D is constant over the length L. In general, reference D refers to the equivalent circular diameter.

The embodiments in Fig. 1C show a cross-sectional view of an embodiment of the lightguide which has a circular cross-section (for all lightguide regions) on the left (I), and on the right, embodiment II a cross-sectional view of an embodiment of the lightguide which has an n-gonal, with $n=8$, i.e. octagonal cross-section (for all lightguide regions).

Hence, in embodiments the lightguide 400 may have a circular or n-gonal cross-sectional shape, wherein $3 \leq n \leq 12$.

Fig. 1D schematically depicts a cross-section of a beam. In the top of this drawing, schematically an intensity plot is drawing, with at the center the optical axis O (perpendicular to the plane of drawing), which is 100% intensity, and circles indicating 50%, 10%, and 0% intensity. Here, the intensity plot, lower part of the drawings, is perpendicular to the optical axis O. The 50% circle may indicate the full width half maximum. In the lower part of the drawing, an intensity plot of a cross-section including the optical axis is shown. Note that the beam is not necessarily fully symmetric, which could lead to different cross-sectional distribution. Angles α indicates the opening angles, defined by the full width half maximum. The percentages especially refers to the percentage of maximum (optical) power (Watt) of the light. Fig. 1D schematically depicts a kind of symmetric Gaussian distribution. However, the distribution is not necessarily symmetric and/or the distribution is also not necessarily Gaussian.

Fig. 2A schematically depicts an embodiment with a core 420 and two shells 430. One light source 100 addresses the core, and for each shell two light sources 100 are used to irradiate the light incouple sides 411. The axes of elongation are indicated with references A1, A2, and A3.

Reference 500 refers to an optical element. Reference 510 refers to a lens. The optical element 500 may be used to focus the light source light 101 on the respective light incouple sides 411 of the respective lightguide regions 410.

The light sources 100 may be lasers, e.g. configured in thermal contact with a heatsink or other thermally conductive element. Here, schematically a laser bank is depicted.

Fig. 2A schematically depicts an embodiment wherein $m1 \geq 3$. Further, Fig. 2A schematically depicts an embodiment wherein at least two shells 430 are configured in a light receiving relationship with different sets of each at least two light sources 100. Further, Fig. 2A schematically depicts an embodiment wherein the light generating system 1000 further

comprises a reflector 440 configured between two adjacent lightguide regions 410. The reflector may e.g. be an Al coating.

Hence, in embodiments the lightguide regions may be (essentially) optically isolated, by sufficiently lower refractive index layers for the shell layers, or by using a (metal) reflector coating.

Of course, the lightguide 400 may also comprise in embodiments a cladding (not depicted), but that is known to a person skilled in the art.

Fig. 2B schematically depicts an embodiment wherein a plurality of optical fibers as light sources 100 are applied, such as a fiber bundle. Here, also an optical element 500, such as a lens 510, is applied.

Fig. 2C schematically depicts an embodiment wherein a plurality of optical fibers as light sources 100 are applied, such as a fiber bundle, but wherein these are directly upstream of the lightguide element 400, without intermediate optics.

Fig. 2D schematically shows how with a core-shell-shell system a plurality of light patterns may be generated, though more light patterns than schematically depicted may be possible. Note that dependent upon the distance from the outcouple end, the light patterns may merge.

Embodiment I shows a light spot of light 101a when only light source light is provided to a core. Embodiment II shows a light spot of light 101b when only light source light is provided to a shell adjacent to a core; and essentially no light is provided to the core. Embodiment III shows a light spot of light 101c when only light source light is provided to a shell adjacent to the shell that is adjacent to the core, and essentially no light to the core or the shell between the core and the shell to which the light 101c is provided. Embodiment IV shows the light spot when light is provided to the core and both shells. The light, indicated with references 101a, 101b, 101c, just to distinguish, may in specific embodiments have mutually different color points (see also above).

Figs. 3A-3C schematically depict a number of embodiments including a luminescent material 200.

Amongst others, Fig. 3A schematically depicts an embodiment of the light generating system 1000 further comprising a luminescent material 200, wherein the luminescent material 200 is configured in a light-receiving relationship with the light outcouple end 402. Especially, the luminescent material 200 is configured to convert at least part of the light 101 into luminescent material light 201.

Here, a variant is depicted wherein the light escaping from the outcouple end 402 is collimated with optics 500, such as a lens 510, passes optics 500, here a color separator, such as a dichroic element 520, via transmission (reflection could also be possible), is subsequently focused via other optics 500, such as another lens 510, and reaches the luminescent material 200. The luminescent material light 201 propagates the way back in the direction of the dichroic element 520, or other type of color separator and is reflected (transmission could also be possible).

The light generating system 1000 is configured to generate system light 1001. In an operational mode of the light generating system 1000 the system light 1001 comprises the luminescent material light 201.

Hence, in Fig. 3A (and also Fig. 3C), an embodiment is schematically depicted wherein the light generating system 1000 further comprises a dichroic element 520, configured to transmit or reflect the light 101 and configured to reflect or transmit the luminescent material light 201. Especially, the dichroic element 520 is configured between the light outcouple end 402 and the luminescent material 200.

In embodiments, the luminescent material 200 comprises a luminescent material of the type $A_3B_5O_{12}:Ce$, wherein A comprises one or more of Y, La, Gd, Tb and Lu, and wherein B comprises one or more of Al, Ga, In and Sc.

Other configurations may also be possible. Fig. 3B schematically depicts an embodiment wherein the luminescent material 200 is configured in the transmissive mode. Here, optical element 500 may e.g. be selected from the group of a TIR collimator, a reflector, or other optical element which may be used for beam shaping in combination with a light source of variable size.

In specific embodiments, the luminescent material 200 may be configured to transmit part of the light 101. In such embodiments, in an operational mode of the light generating system 1000 the system light 1001 comprises the luminescent material light 201 and the light 101. In other embodiments, it may be less desired that light 101 is transmitted. In such embodiments, an optical filter, like e.g. a dichroic filter, may be configured downstream of the luminescent material 200.

Fig. 3C is essentially the same as Fig. 3A, but in addition, downstream of the luminescent material 200, second light 121 of a second light source 120 is admixed. To this end, optics 500 may be applied, such as a dichroic element 520.

Fig. 3D schematically depicts an embodiment wherein a plurality of systems 1000 (indicated with references 1000a, 1000b, ...) are combined and the system light 1001

(indicated with references 1001a, 1001b, ...) of the systems is combined with (again) a lightguide 400. This is an embodiment of a possible light generating device 1200, which in an operational mode may provide device light 1201 comprising the light 1001a, 1001b, ... of systems 1000a, 1000b, ...

5 Fig. 3E schematically depicts another embodiment wherein a plurality of systems 1000 (indicated with references 1000a, 1000b, ...) are combined and the system light 1001 (indicated with references 1001a, 1001b, ...) of the systems is combined to provide device light 1201.

References 1000a, 1000b, etc., are used to distinguish different systems.

10 Fig. 4 schematically depicts an embodiment of a luminaire 2 comprising the light generating system 1000 as described above. Reference 301 indicates a user interface which may be functionally coupled with the control system 300 comprised by or functionally coupled to the light generating system 1000. Fig. 4 also schematically depicts an embodiment of lamp 1 comprising the light generating system 1000. Reference 3 indicates a projector
15 device or projector system, which may be used to project images, such as at a wall, which may also comprise the light generating system 1000.

Hence, the invention also provides a light generating device 1200 selected from the group of a lamp 1, a luminaire 2, a projector device 3, a disinfection device, and an optical wireless communication device, comprising the light generating system 1000 as
20 defined herein. Other applications than shown in Fig. 4 may also be possible.

The light generating system 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,
25 indicator sign systems, decorative lighting systems, portable systems, automotive applications, (outdoor) road lighting systems, urban lighting systems, green house lighting systems, horticulture lighting, digital projection, or LCD backlighting. The light generating system (or luminaire) may be part of or may be applied in e.g. optical communication
30 systems or disinfection systems.

The term “plurality” refers to two or more.

The terms “substantially” or “essentially” herein, and similar terms, will be understood by the person skilled in the art. The terms “substantially” or “essentially” may also include embodiments with “entirely”, “completely”, “all”, etc. Hence, in embodiments

the adjective substantially or essentially may also be removed. Where applicable, the term “substantially” or the term “essentially” 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” also includes embodiments wherein the term

5 “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”
10 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
15 invention described herein are capable of operation in other sequences than described or illustrated herein.

The devices, apparatus, or systems may herein amongst others be 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, apparatus, or systems in operation.

20 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.

25 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”.

30 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 a device claim, or an apparatus claim, or a system 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.

5 The invention also provides a control system that may control the device, apparatus, or system, or that may execute the herein described method or process. Yet further, the invention also provides a computer program product, when running on a computer which is functionally coupled to or comprised by the device, apparatus, or system, controls one or more controllable elements of such device, apparatus, or system.

10 The invention further applies to a device, apparatus, or system 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.

15 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 light generating system (1000) comprising k_1 light sources (100) and a lightguide (400), wherein:
- the k_1 light sources (100) are configured to generate light (101); wherein $k_1 \geq 2$;
 - 5 - the lightguide (400) comprises m_1 concentric arranged lightguide regions (410), including a core (420) and one or more shells (430), wherein the lightguide (400) comprises a light outcouple end (402); wherein $m_1 \geq 2$;
 - each of the m_1 concentric arranged lightguide regions (410) comprises a light incouple side (411) and a light outcouple side (412); wherein the light outcouple end (402)
10 comprises the light outcouple sides (412); wherein the light incouple side (411) is at one end of the lightguide regions (410);
 - at least two of the light incouple sides (411) are configured in a light receiving relationship each with at least one light source (100), including the light incouple side (411) of at least one of the one or more shells (430);
 - 15 - wherein the core (420) and the one or more shells (430) comprise a light transmissive material comprising a light transmissive organic material or a light transmissive inorganic material;
 - wherein the core (420) and the one or more shells (430) are arranged to have at least 90 % of the light coupled in at one side of the core (420) or of the one or more shells
20 (430) to escape at another end of the respective core (420) or of the respective one or more shells (430);
 - wherein the light generating system (1000) further comprises a luminescent material (200), wherein the luminescent material (200) is configured in a light-receiving relationship with the light outcouple end (402), and wherein the luminescent material (200) is
25 configured to convert at least part of the light (101) into luminescent material light (201), wherein the light generating system (1000) is configured to generate system light (1001), wherein in an operational mode of the light generating system (1000) the system light (1001) comprises the luminescent material light (201).

2. The light generating system (1000) according to claim 1, wherein at least one shell (430) is configured in a light receiving relationship with at least two light sources (100); and wherein the light sources (100) are selected from the group comprising a laser light source and a super-luminescent diode.

5

3. The light generating system (1000) according to claim 2, wherein two or more of the at least two light sources (100) are configured to generate light (101) having the same spectral power distributions.

10

4. The light generating system (1000) according to claim 2, wherein two or more of the at least two light sources (100) are configured to generate light (101) having centroid wavelengths that differ with at least 10 nm.

15

5. The light generating system (1000) according to any one of the preceding claims, wherein $m \geq 3$; and wherein at least two shells (430) are configured in a light receiving relationship with different sets, with each set comprising at least two light sources (100).

20

6. The light generating system (1000) according to any one of the preceding claims, wherein the lightguide (400) has a circular or n-gonal cross-sectional shape, wherein $3 \leq n \leq 12$.

25

7. The light generating system (1000) according to any one of the preceding claims, wherein the lightguide (400) has an equivalent circular diameter (D) selected from the range of 0.05-10 mm; and wherein the lightguide (400) has a length, defined relative to the light outcouple end (402) of $a \cdot D$, wherein a is selected from the range of 5-15.

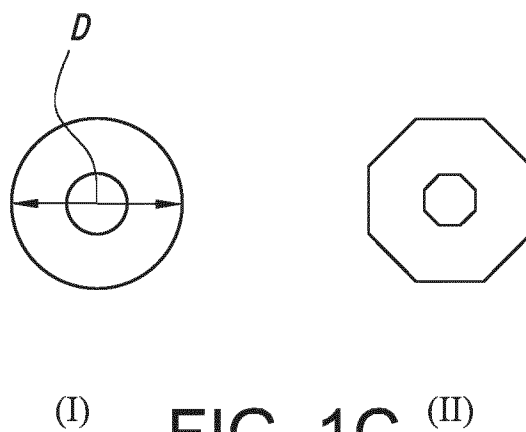
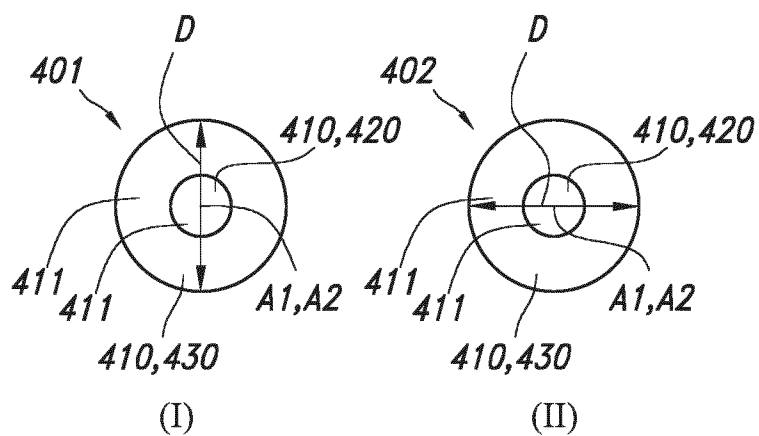
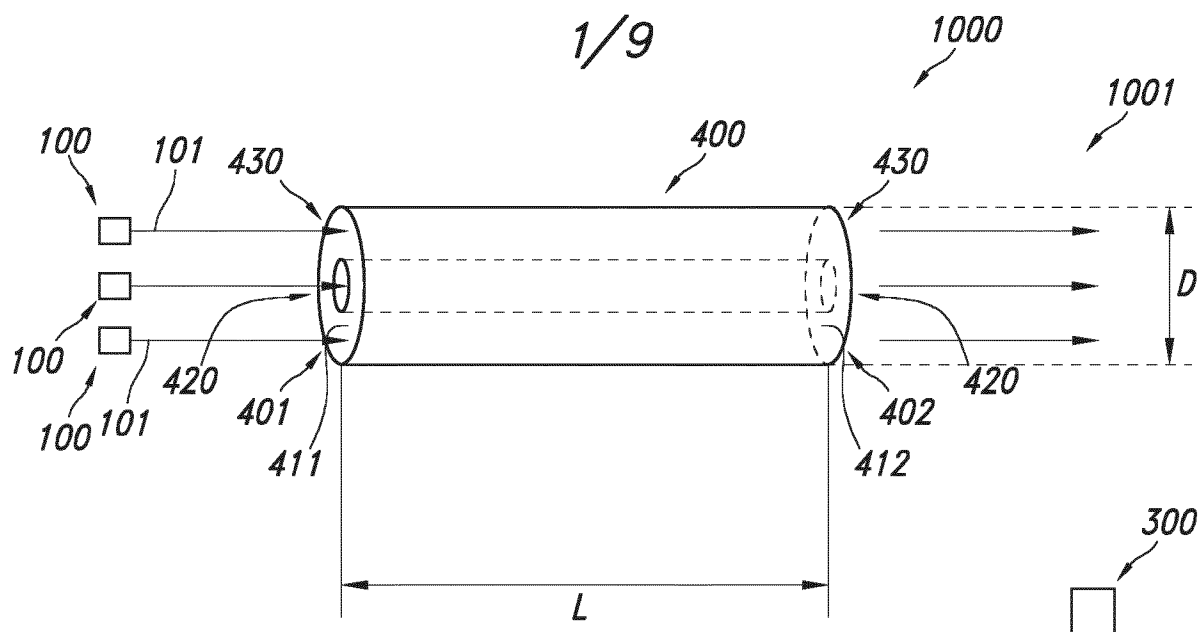
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8. The light generating system (1000) according to any one of the preceding claims, wherein one or more of the following applies: (a) the lightguide (400) further comprises a reflector (440) configured between two adjacent lightguide regions (410), and (b) two adjacent lightguide regions (410) are not in optical contact.

9. The light generating system (1000) according to any one of the preceding claims, wherein an inner lightguide region (410) of the two adjacent lightguide regions (410)

has a first index of refraction n_1 , wherein an outer lightguide region (410) of the two adjacent lightguide regions (410) has a second index of refraction n_2 , wherein the second index of refraction n_2 is at least 0.01% smaller than the first index of refraction n_1 .

- 5 10. The light generating system (1000) according to any one of the preceding claims, wherein the k_1 light sources (100), including optional optics (510), are configured to generate the light (101) with a full width half maximum selected from the range of 5-70°.
11. The light generating system (1000) according to any one of the preceding
10 claims, wherein the light guide regions (410) comprise a solid and a non-luminescent material. .
12. The light generating system (1000) according to claim 11, further comprising
15 a dichroic element (520), configured to transmit or reflect the light (101) and configured to reflect or transmit the luminescent material light (201), wherein the dichroic element (520) is configured between the light outcouple end (402) and the luminescent material (200).
13. The light generating system (1000) according to any one of the preceding
20 claims 10-12, wherein the luminescent material (200) comprises a luminescent material of the type $A_3B_5O_{12}:Ce$, wherein A comprises one or more of Y, La, Gd, Tb and Lu, and wherein B comprises one or more of Al, Ga, In and Sc.
14. The light generating system (1000) according to any one of the preceding
25 claims, further comprising a control system (300) configured to control the k_1 light sources (100) in dependence of one or more of an input signal of a user interface, a sensor signal, and a timer.
15. A light generating device (1200) selected from the group of a lamp (1), a
30 luminaire (2), a projector device (3), a disinfection device, and an optical wireless communication device, comprising the light generating system (1000) according to any one of the preceding claims.



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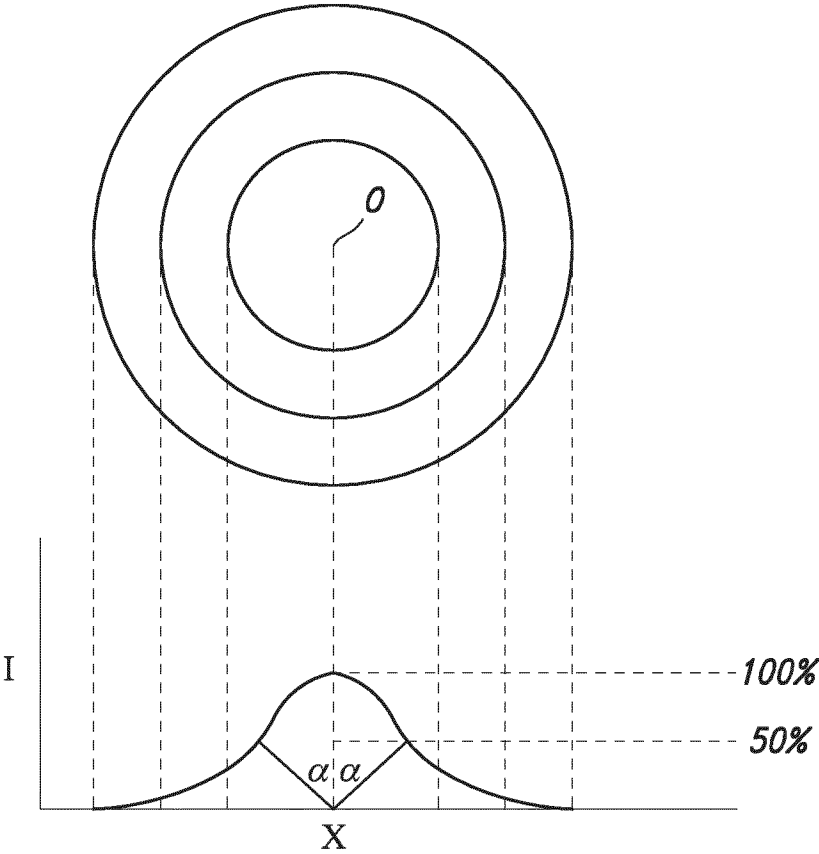


FIG. 1D

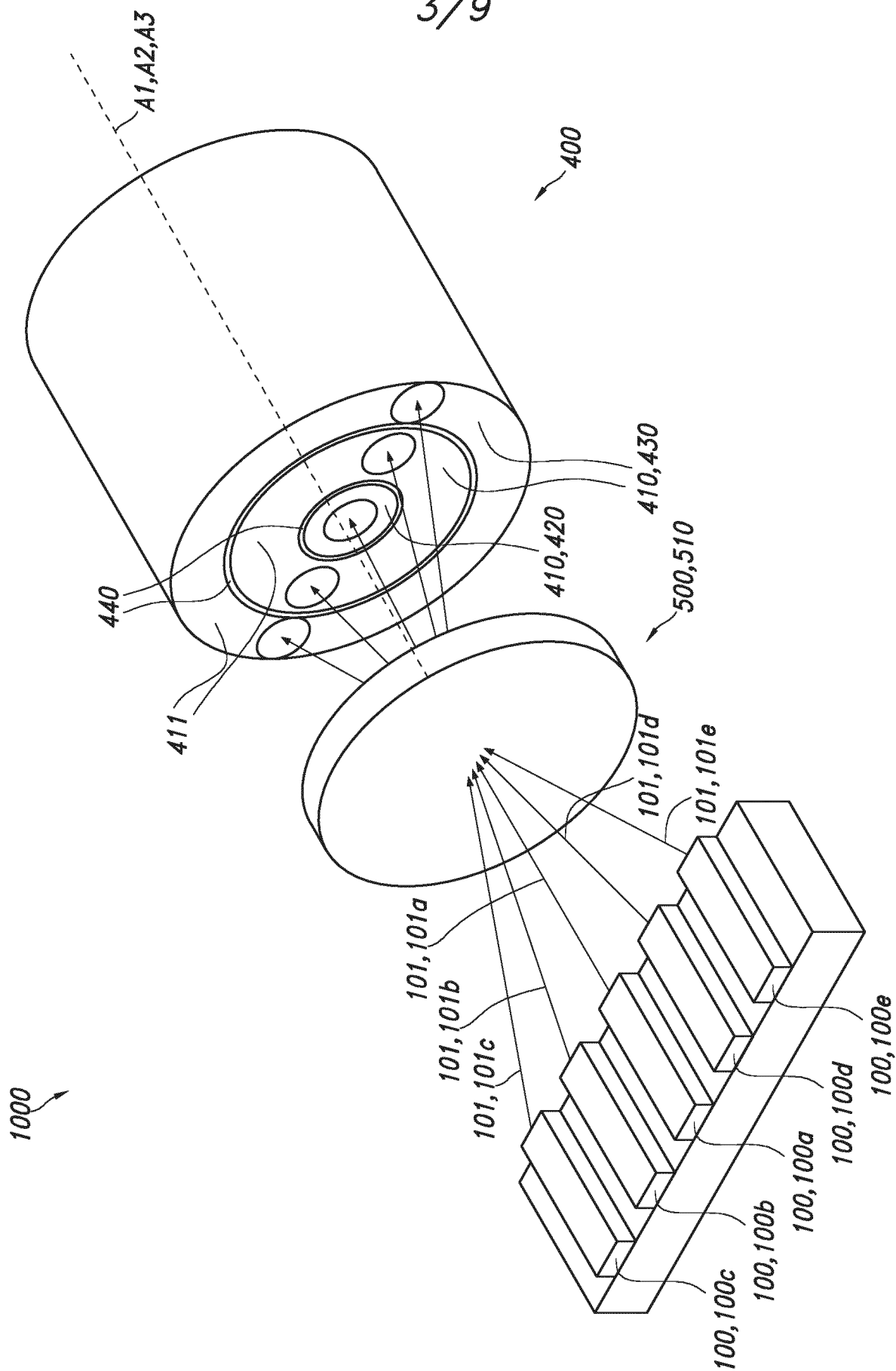


FIG. 2A

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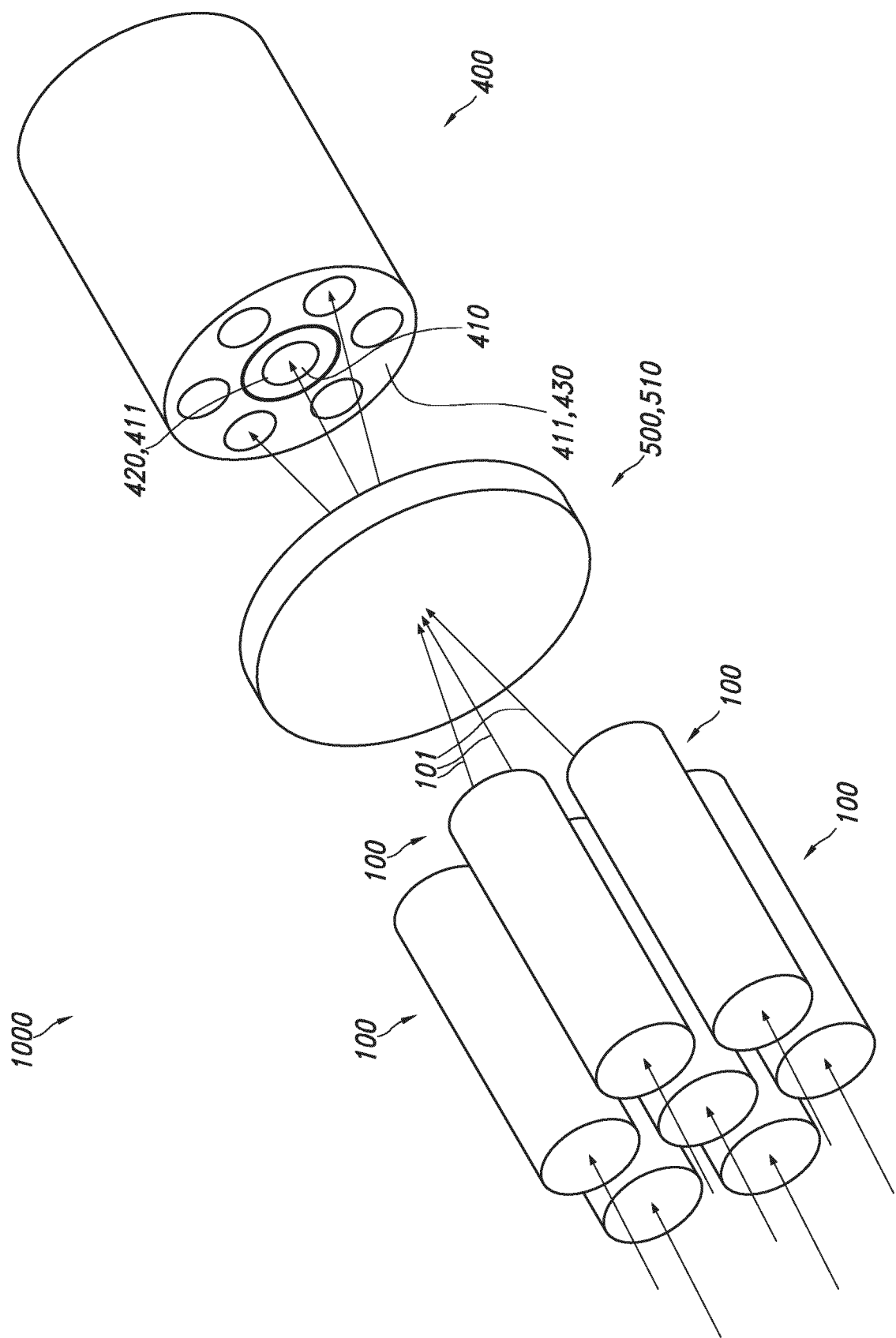


FIG. 2B

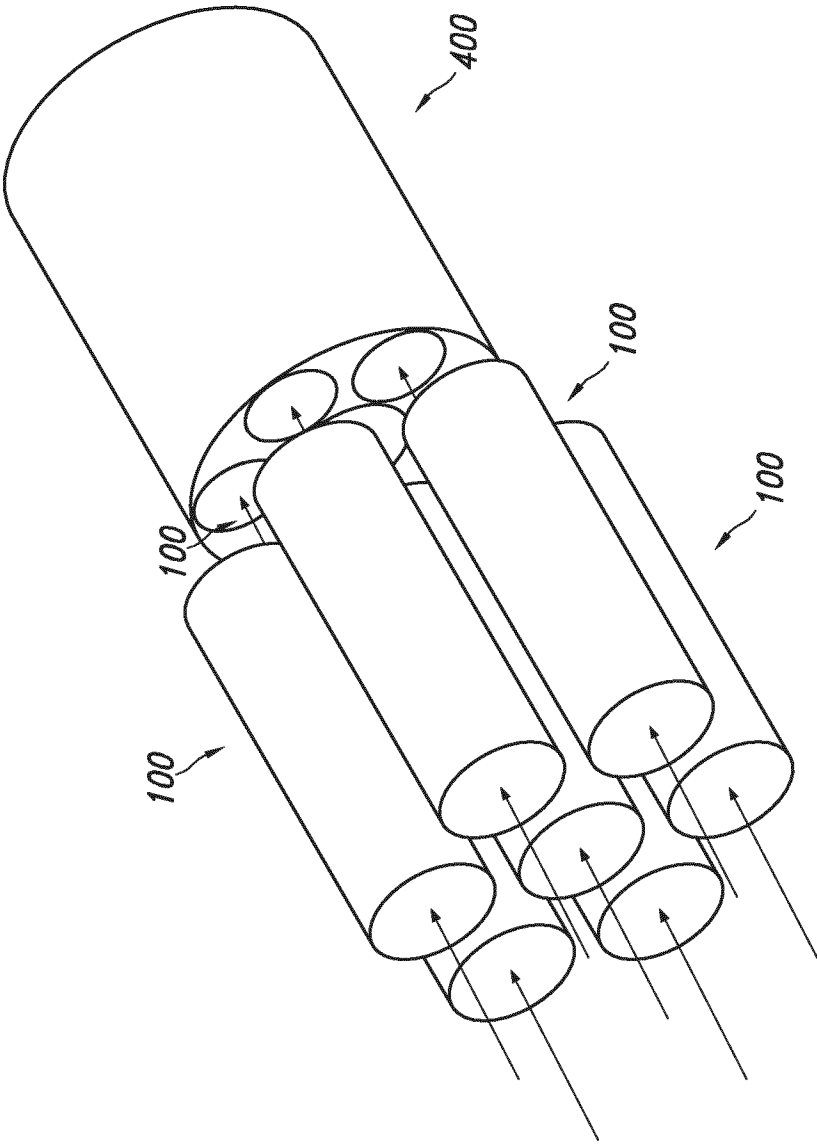


FIG. 2C

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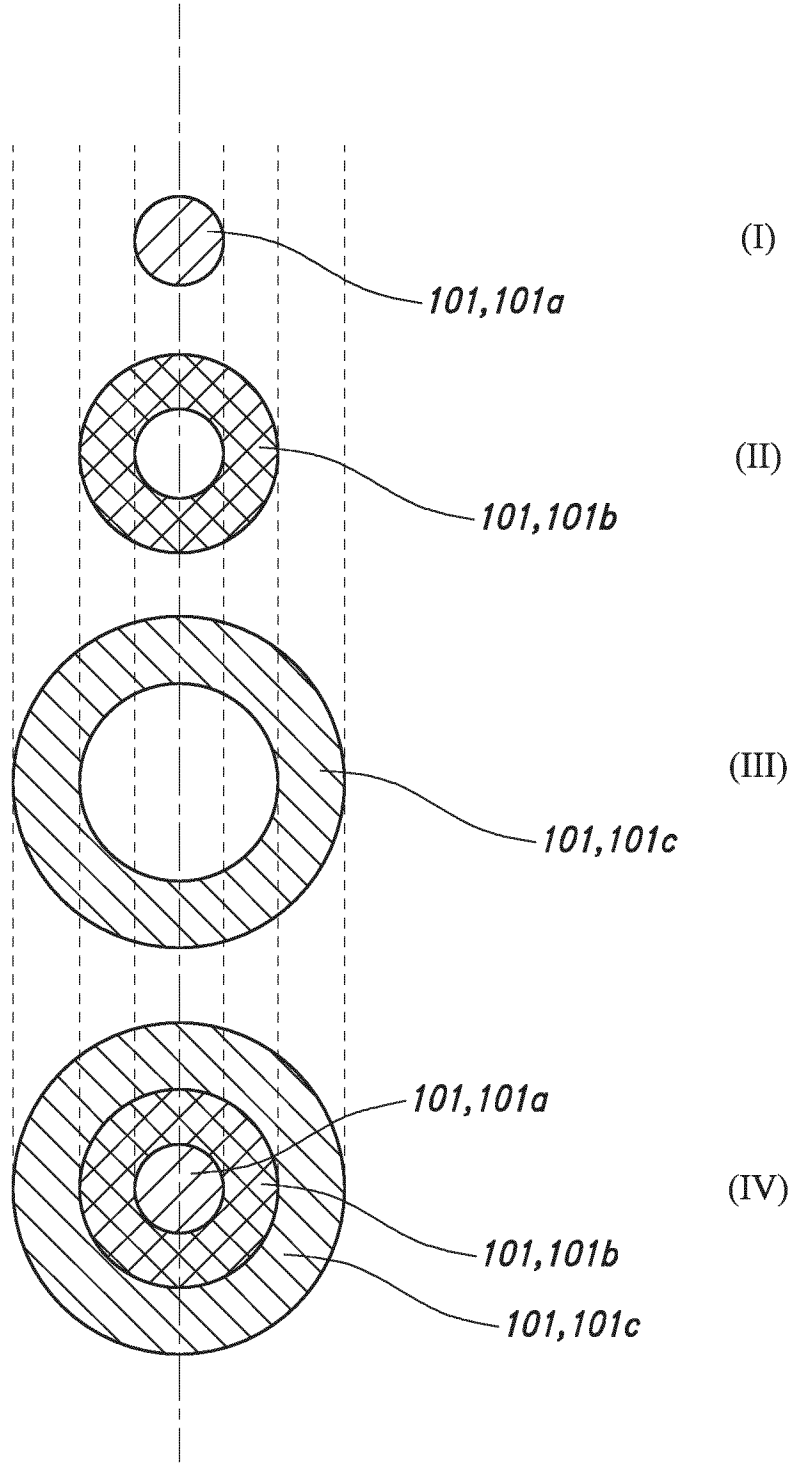


FIG. 2D

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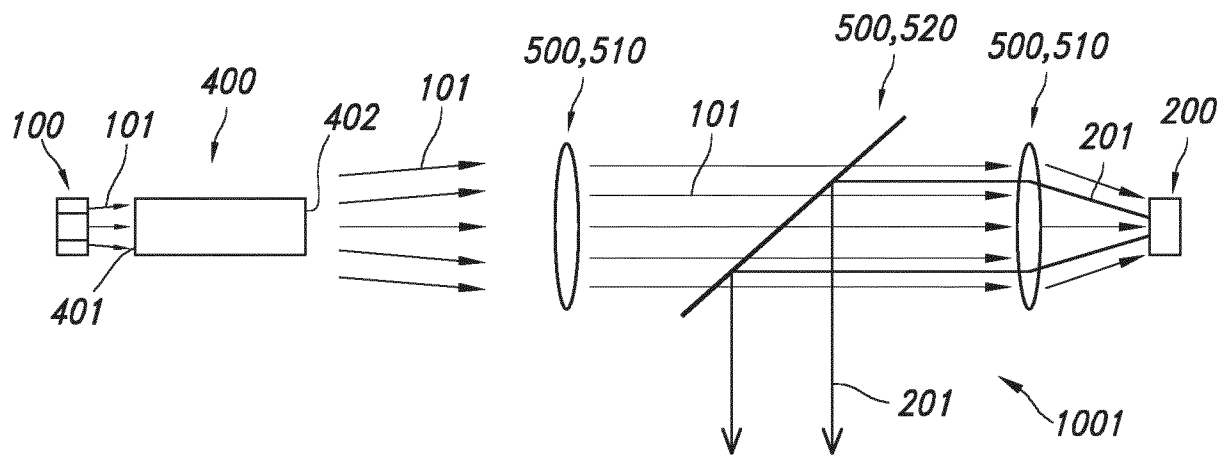


FIG. 3A

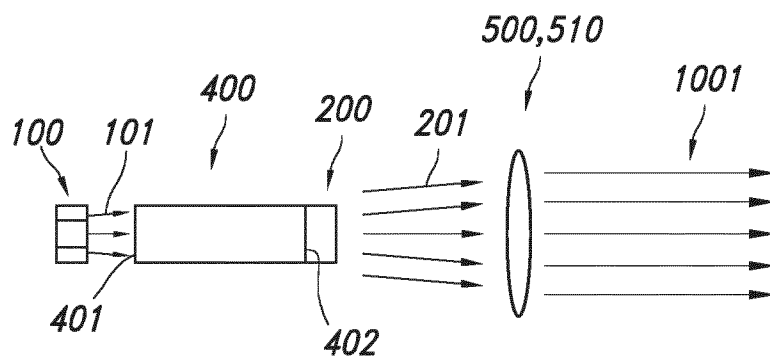


FIG. 3B

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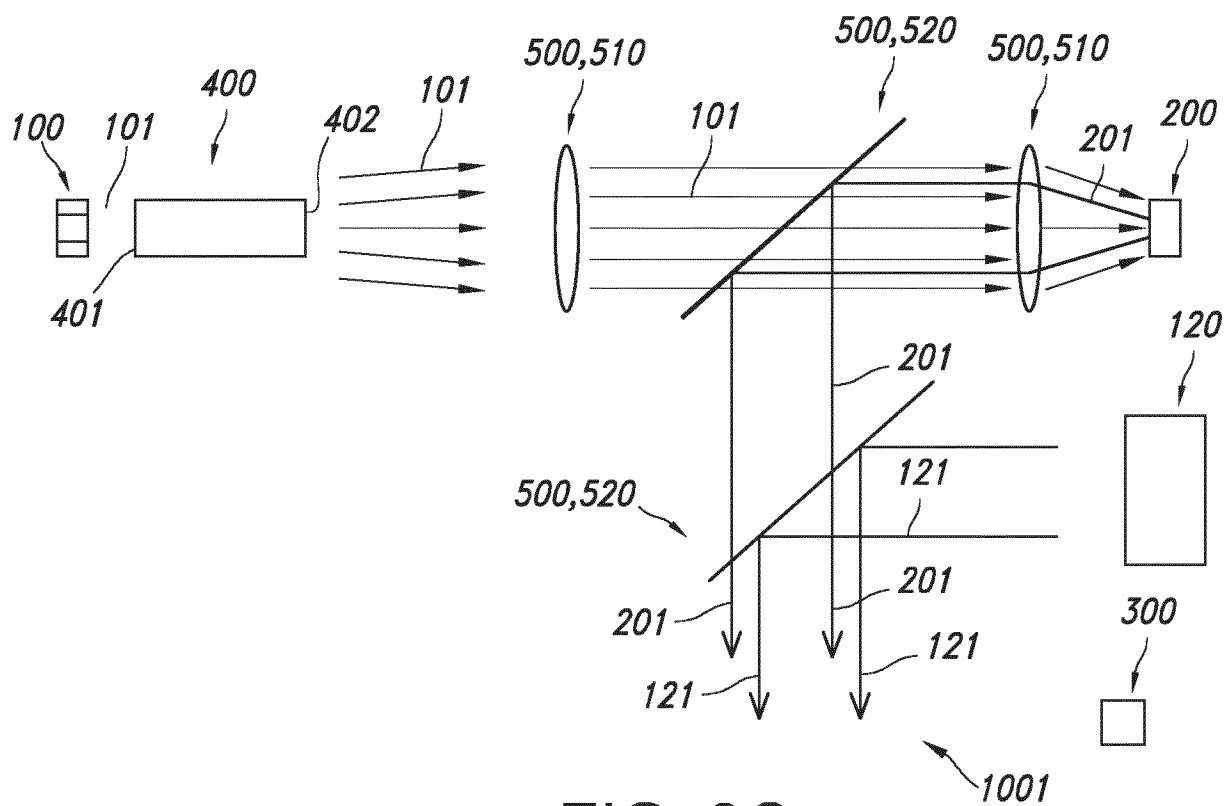


FIG. 3C

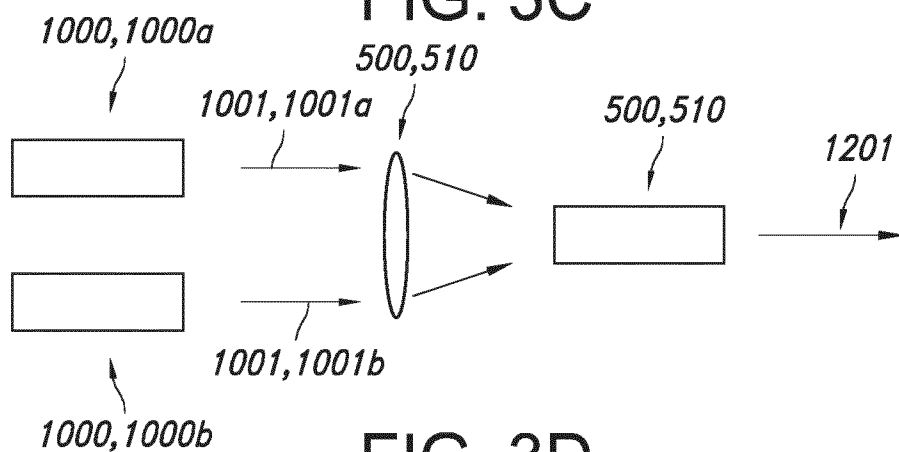


FIG. 3D

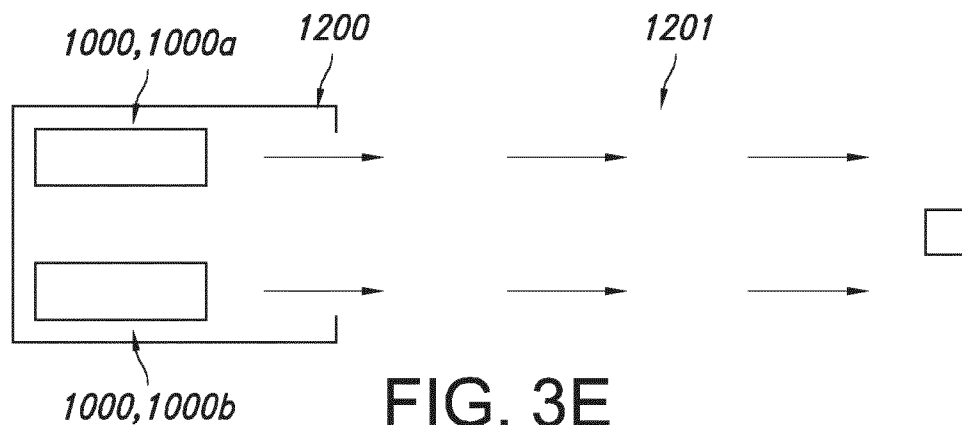


FIG. 3E

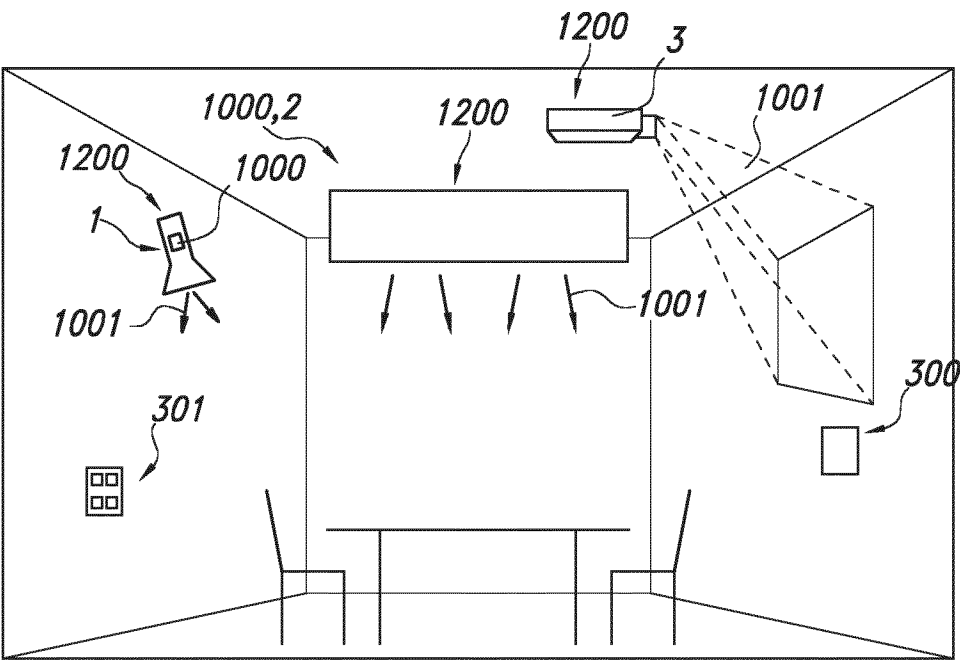


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2021/079113

A. CLASSIFICATION OF SUBJECT MATTER
INV. F21V8/00 G02B6/02
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

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	US 2020/326044 A1 (HAENEN LUDOVICUS JOHANNES LAMBERTUS [NL] ET AL) 15 October 2020 (2020-10-15) paragraphs [0052], [0173], [0178], [0235] - [0236], [0267], [0271] - [0272], [0280] paragraphs [0159], [0192] - [0195], [0256], [0257], [0260], [0264] - [0265], [0283], [0312] - [0317] figures 1-4, 6-8 -----	1-15
Y	US 2019/032886 A1 (DAICHO HISAYOSHI [JP] ET AL) 31 January 2019 (2019-01-31) paragraphs [0112], [0118], [0119], [0152] - [0156], [0182] - [0188] figures 3, 9, 11, 14, 16 ----- -/-	1-15

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

☒ See patent family annex.

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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

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"&" document member of the same patent family

Date of the actual completion of the international search

17 January 2022

Date of mailing of the international search report

02/02/2022

Name and mailing address of the ISA/
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Moroz, Alexander

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2021/079113

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2010/053970 A1 (SATO TAKAHIRO [JP] ET AL) 4 March 2010 (2010-03-04) paragraphs [0149] - [0156], [0175] - [0182] figures 11,13,14,18-20,23 -----	1-15
A	WO 2020/114817 A1 (SIGNIFY HOLDING BV [NL]) 11 June 2020 (2020-06-11) page 12, line 28 - page 13, line 15 page 16, lines 7-22 page 24, line 27 - page 26, line 28 page 41, line 8 - page 43, line 2 page 52, line 23 - page 56, line 17 figures 1,3,5,6 -----	1-15
A	US 2020/216356 A1 (LOGUNOV STEPHAN LVOVICH [US] ET AL) 9 July 2020 (2020-07-09) abstract paragraphs [0022], [0056] figures 1,2,5 -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2021/079113

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