



(51) International Patent Classification:

F21V 5/00 (2018.01) *F21V 13/02* (2006.01)
F21V 9/35 (2018.01) *F21Y 115/30* (2016.01)

(21) International Application Number:

PCT/EP2022/083759

(22) International Filing Date:

30 November 2022 (30.11.2022)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

21214235.0 14 December 2021 (14.12.2021) EP

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(81) Designated States (*unless otherwise indicated, for every
kind of national protection available*): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE,
KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU,
LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG,
NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS,
RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH,
TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS,
ZA, ZM, ZW.

(54) Title: HIGH BRIGHTNESS LIGHT SOURCE

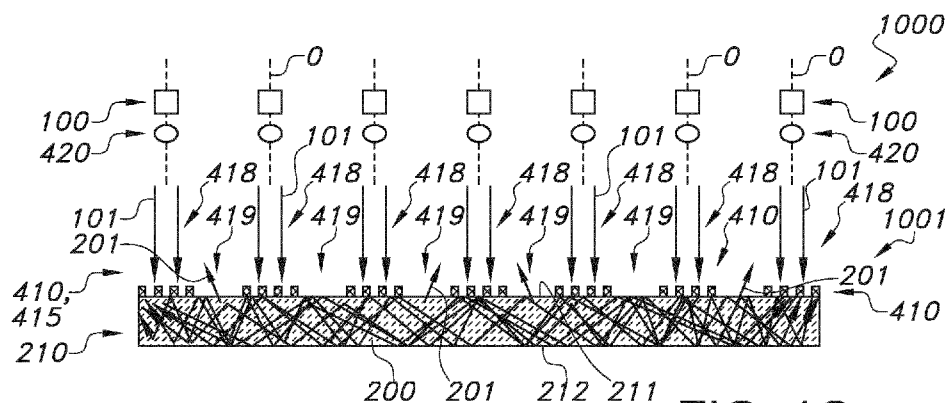


FIG. 1C

(57) **Abstract:** The invention provides a light generating system (1000) comprising a light generating device (100), a converter body (210), a first optical element (410), and a thermally conductive body (500); wherein the light generating system (1000) is configured to generate system light (1001); wherein: (A) the light generating device (100) is configured to generate n beams of device light (101), wherein the light generating device (100) comprises one or more solid state material lasers; wherein $n \geq 1$; (B) the converter body (210) comprises a first face (211) and a second face (212), wherein a distance between the first face (211) and the second face (212) defines a converter body height ($H1$), wherein the converter body (210) has one or more converter body dimensions (D) defined perpendicular to the converter body height ($H1$); wherein the converter body height ($H1$) is selected from the range of at maximum $80 \mu\text{m}$; wherein $H1/D1 \leq 0.5$; wherein the converter body (210) is configured in a light-receiving relationship with the light generating device (100), wherein the converter body (210) comprises a luminescent material (200) configured to convert at least part of the device light (101) into luminescent material light (201); wherein the converter body (210) is light transmissive for the device light (101); (C) the first optical element (410) is configured downstream of the light generating device (100) and is configured to increase an angle of refraction ($\theta1$) of at least part of the device light (101) entering the converter body (210) via the first optical element (410); wherein the first optical element (410) comprises a transmissive diffractive optical element; wherein one or more of the following applies: (i) the first optical element (410) is comprised by the first face (211) and (ii) the first optical element (410) is configured on the first face (211); and (D) the thermally conductive body (500) is configured in thermal contact with the second face (212).

(84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

- *with international search report (Art. 21(3))*
 - *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*
-

High brightness light source

FIELD OF THE INVENTION

The invention relates to a light generating system and to a lighting device comprising such light generating system.

5 BACKGROUND OF THE INVENTION

Laser-based lighting devices are known in the art. US2017/0074466, for instance, describes a system and method of generating perceived white light by laser. The system comprises a laser, a phosphoric substrate, and optionally a diffraction grating. In one embodiment, a blue laser beam from the laser penetrates the phosphoric substrate to create
10 perceived white light in a Gaussian distribution appropriate for emergency lighting. In another embodiment, the blue laser beam is split into multiple beams by the diffraction grating. The multiple beams penetrate the phosphoric substrate to create perceived white light in a Gaussian distribution appropriate for emergency lighting.

15 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
20 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 embodiments realize almost full conversion of blue light, leading to emission of converted
25 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, 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 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.

Hence, it is an aspect of the invention to provide an alternative luminescent element, 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.

According to a first aspect, the invention provides a light generating system comprising a light generating device, a converter body, and a first optical element. Further, the light generating system may comprise a thermally conductive body. Especially, the light generating device may be configured to generate n beams of device light. Especially, $n \geq 1$. Further, in embodiments the light generating device may comprise one or more solid state material lasers. In embodiments, the converter body may comprise a first face and a second face. Further, a distance between the first face and the second face may define a converter body height ($H1$). Further, the converter body may have one or more converter body dimensions (D) defined perpendicular to the converter body height ($H1$). In specific embodiments, the converter body height ($H1$) may be selected from the range of at maximum $80 \mu\text{m}$. Further, in specific embodiments $H1/D \leq 0.5$. Especially, the converter body may be configured in a light-receiving relationship with the light generating device. In embodiments, the converter body comprises a luminescent material configured to convert at least part of the device light into luminescent material light. Further, in embodiments the converter body may be light transmissive for the device light. In embodiments, the first optical element may be configured downstream of the light generating device. Further, in embodiments the first optical element may be configured to increase an angle of refraction (θ_1) of at least part of the device light entering the converter body via the first optical element. Yet, especially the first optical element may be comprised by the first face and/or may be configured on the first face. In specific embodiments, the first optical element may comprise a transmissive diffractive optical element. In specific embodiments, wherein the system comprises a thermally conductive body, the thermally conductive body is configured in thermal contact with the second face. Hence, the invention provides in specific embodiments a light generating system comprising a light generating device, a converter body, a first optical

element, and a thermally conductive body; wherein: (A) the light generating device is configured to generate n beams of device light, wherein the light generating device comprises one or more solid state material lasers; wherein $n \geq 1$; (B) the converter body comprises a first face and a second face, wherein a distance between the first face and the second face defines a converter body height ($H1$), wherein the converter body has one or more converter body dimensions (D) defined perpendicular to the converter body height ($H1$); wherein the converter body height ($H1$) is selected from the range of at maximum $80 \mu\text{m}$; wherein $H1/D1 \leq 0.5$; wherein the converter body is configured in a light-receiving relationship with the light generating device, wherein the converter body comprises a luminescent material configured to convert at least part of the device light into luminescent material light; wherein the converter body is light transmissive for the device light; (C) the first optical element is configured downstream of the light generating device and is configured to increase an angle of refraction ($\theta 1$) of at least part of the device light entering the converter body via the first optical element; wherein the first optical element is comprised by the first face or is configured on the first face; wherein the first optical element comprises a transmissive diffractive optical element; and (D) the thermally conductive body is configured in thermal contact with the second face.

With such system, efficiency may be relatively high as a large area of the luminescent body may be in thermal contact with a thermally conductive material, such as a heatsink. A thinner converter body may be beneficial in term of cooling and thus also beneficial for intensity. Further, a relatively small device may be provided which may be able to provide light with a relatively high intensity. The present invention may provide a compact effectively reflective configuration, with improved heat removal from the phosphor. The good cooling that may be possible, may also allow to use luminescent materials that may be less efficient (and generate more heat). For instance, higher concentration cerium garnets and/or higher concentration gadolinium garnets may be applied which show a red shift (which may lead to a higher $R9$).

As indicated above, the light generating system may comprise a light generating device, a converter body, and a first optical element.

Especially, the light generating device is configured to generate n beams of device light. As indicated above, the light generating device may be configured to generate device light. The light generating device may comprise a light source, especially a solid state light source.

The term “light source” may in principle relate to any light source known in the art. It may be a conventional (tungsten) light bulb, a low-pressure mercury lamp, a high pressure mercury lamp, a fluorescent lamp, a LED (light emissive diode). In a specific embodiment, the light source comprises a solid state LED light source (such as a LED or laser diode (or “diode laser”)). 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 terms “light source” or “solid state light source” may also refer to a superluminescent diode (SLED).

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).

In embodiments, the light source may be configured to provide primary radiation, which is used as such, such as e.g. a blue light source, like a blue LED, or a green light source, such as a green LED, and a red light source, such as a red LED. Such LEDs, which may not comprise a luminescent material (“phosphor”) may be indicated as direct color LEDs.

In other embodiments, however, the light source may be configured to provide primary radiation and part of the primary radiation is converted into secondary radiation. Secondary radiation may be based on conversion by a luminescent material. The secondary radiation may therefore also be indicated as luminescent material radiation. The luminescent material may in embodiments be comprised by the light source, such as a LED with a luminescent material layer or dome comprising luminescent material. Such LEDs may be indicated as phosphor converted LEDs or PC LEDs (phosphor converted LEDs). In other embodiments, the luminescent material may be configured at some distance (“remote”) from the light source, such as a LED with a luminescent material layer not in physical contact with a die of the LED. Hence, in specific embodiments the light source may be a light source that during operation emits at least light at wavelength selected from the range of 380-470 nm. However, other wavelengths may also be possible. This light may partially be used by the luminescent material.

In embodiments, the light generating device may comprise a luminescent material. In embodiments, the light generating device may comprise a PC LED. In other embodiments, the light generating device may comprise a direct LED (i.e. no phosphor). In embodiments, the light generating device may comprise a laser device, like a laser diode. In embodiments, the light generating device may comprise a superluminescent diode.

The light source may especially be 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.

The term “light source” may (thus) refer to a light generating element as such, like e.g. a solid state light source, or e.g. to a package of the light generating element, such as a solid state light source, and one or more of a luminescent material comprising element and (other) optics, like a lens, a collimator. A light converter element (“converter element” or “converter”) may comprise a luminescent material comprising element. For instance, a solid state light as such, like a blue LED, is a light source. A combination of a solid state light source (as light generating element) and a light converter element, such as a blue LED and a light converter element, optically coupled to the solid state light source, may also be a light source. Hence, a white LED is a light source.

The term “light source” herein may also refer to a light source comprising a solid state light source, such as an LED or a laser diode or a superluminescent diode. The “term light source” may (thus) in embodiments also refer to a light source that is (also) based on conversion of light, such as a light source in combination with a luminescent converter material. Hence, the term “light source” may also refer to a combination of a LED with a luminescent material configured to convert at least part of the LED radiation, or to a combination of a (diode) laser with a luminescent material configured to convert at least part of the (diode) laser radiation.

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 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” or “solid state material 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; Al₂O₃:Ti³⁺) laser, trivalent uranium doped calcium fluoride (U:CaF₂) solid-state laser, Ytterbium doped glass laser (rod, plate/chip, and fiber), Ytterbium YAG (Yb:YAG) laser, Yb₂O₃ (glass or ceramics) laser, etc.

For instance, including second and third harmonic generation embodiments, the light source may comprise one or more of an F center laser, an yttrium orthovanadate (Nd:YVO₄) laser, a promethium 147 doped phosphate glass (147Pm³⁺:glass), and a titanium sapphire (Ti:sapphire; Al₂O₃:Ti³⁺) laser. For instance, considering second and third harmonic generation, such light sources may be used to generated blue light.

In embodiments, the terms “laser” or “solid state laser” or “solid state material laser” may refer to one or more of a semiconductor laser diodes, 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 heat sinking and/or optics e.g. a lens to collimate the laser light.

The laser light source may be 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 laser 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. 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).

The term “solid state material laser”, and similar terms, may refer to a solid state laser like based on a crystalline or glass body doped with ions, like transition metal ions

and/or lanthanide ions, to a fiber laser, to a photonic crystal laser, to a semiconductor laser, such as e.g. a vertical cavity surface-emitting laser (VCSEL), etc.

The term “solid state light source”, and similar terms, may especially refer to semiconductor light sources, such as a light emitting diode (LED), a diode laser, or a superluminescent diode. Hence, in embodiments the light generating device may comprise one or more of a light emitting diode (LED), a diode laser, or a superluminescent diode. Especially, in embodiments the light generating device may comprise a diode laser. In embodiments, the light generating device may comprise a VCSEL.

A vertical-cavity surface-emitting laser, or VCSEL, is known in the art and may especially be a type of semiconductor laser diode with laser beam emission perpendicular from the top surface, contrary to edge-emitting semiconductor lasers (also in-plane lasers) which emit from surfaces formed by cleaving the individual chip out of a wafer. VCSELs may be tunable in emission wavelength, as known in the art. For instance, Dupont et al., Applied Physics Letters 98(16):161105 - 161105-3, DOI:10.1063/1.3569591, or Wendi Chang et al., Applied Physics Letters 105(7):073303, DOI:10.1063/1.4893758, or Thor Ansbaek, IEEE Journal of Selected Topics in Quantum Electronics 19(4):1702306-1702306, DOI:10.1109/JSTQE.2013.2257164, or C.J. Chang-Hasnain, IEEE Journal of Selected Topics in Quantum Electronics (Volume: 6, Issue: 6, Nov.-Dec. 2000), DOI: 10.1109/2944.902146, or Kögel et al., IEEE Sensors Journal, December 2007, volume 7, no. 11, pages 1483-1489, or Jayaraman, et al., Electron Lett. 2012 Jul 5; 48(14): 867–869, doi: 10.1049/el.2012.1552, all document herein incorporated by reference, describe emission wavelength tunable VCSELs. Especially, with varying electrical voltage, the spectral power distribution of the VCSEL may vary. Hence, the term “VCSEL” may thus especially refer herein to a tunable VCSEL, as known in the art. Such tunable VCSELs may be based on MEMS technology. Such (tunable) VCSEL may also be indicated as “MEMS VCSEL”. Therefore, in embodiments the laser diode may comprise a vertical-cavity surface-emitting laser (VCSEL) that has single-mode light emission and a long coherence length. The wavelength sweep may be implemented using a micro-electro-mechanical system (MEMS) to change the length of the laser cavity by which a stable and rapid wavelength sweep results.

Hence, with a VCSEL different spectral power distributions may be generated. Especially, the VCSEL may be configured to generate (during operation of the VCSEL) laser light. Therefore, the (VCSEL) laser light may have a controllable spectral power distribution. To control the spectral power distribution the (VCSEL) laser light, a control system may be

applied. The control system may be configured to control the spectral power distribution of the (VCSEL) laser light.

Especially, the light generating device may be configured to generate n beams of device light. The number of beams may be 1; however, the number of beams may also be larger than 1, like in the range of up to 10.000. Such as in the range of 4-4096. Other numbers, however, may also be possible, like 1-16. Different beams may be made with multi-mirrors. Different beams may be generated simultaneously. In embodiments, (other) optics may be used to generate a plurality of beams and/or to provide a substantially collimated beam (see further also below). Alternatively or additionally, different beams may be generated consecutively. In embodiments the light generating device comprises one or more solid state material lasers; wherein $n \geq 1$. A plurality of beams may be generated with a single light generating device and optics, like a grating, or a multi-mirror and/or a plurality of beams may be generated with a plurality of light generating devices. Hence, in embodiments n is at least 2. In other embodiments, however, $n=1$.

As indicated above, the system may comprise a converter body. The luminescent material may be configured to convert at least part of the device light into luminescent material light.

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. Hence, the term “luminescent material” may in specific embodiments also refer to a luminescent material composition. In embodiments, luminescent material(s) 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 $A_3B_5O_{12}:\text{Ce}$, 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 $A_3B_5O_{12}$ 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 $(Y_{1-x}\text{Lu}_x)_3B_5O_{12}:\text{Ce}$, 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.

Especially, herein, the cerium concentration may be relatively low. In embodiments, a dopant concentration of cerium relative to A may be selected from the range of 0.001-2 at.%, such as especially 0.005-1.5 at.%, even more especially 0.01-1 at.%. For instance, the luminescent material may comprise $(Lu_{0.99}Ce_{0.01})_3Al_5O_{12}$, which is 1 at.% or 1% Ce^{3+} , or e.g. $(Y_{0.9999}Ce_{0.0001})_3Al_5O_{12}$, which is 0.01 at.% or 0.01% Ce^{3+} . Here, by way of example aluminates are chosen. Further, by way of example a lutetium garnet with 1% Ce is provided as example and an yttrium garnet with 0.01% Ce is provided as example. Of course, other examples may also be possible. The low concentration may allow a substantial pathlength via total internal reflection, and thus a high conversion over a substantial part of the converter body. In specific embodiments, a dopant concentration of cerium relative to A may be selected from the range of 0.01-0.5 at.%. In other specific embodiments, a dopant concentration of cerium relative to A may be selected from the range of 0.5-1 at.%.

As will be clear from the above, in embodiments the luminescent material may comprise $(A_{(1-x)}Ce_x)_3Al_5O_{12}$. Especially, x may be selected from the range of 0.0001-0.01 (i.e. 0.01-1% of A). A may comprise one or more of Y, La, Gd, Tb and Lu, especially (at least) one or more of Y, Gd, Tb and Lu. In specific embodiments, the luminescent material may comprise $(A_{(1-x-y)}Gd_yCe_x)_3Al_5O_{12}$. Especially, x may be as indicated above and y may be selected from the range of 0.002-0.2. Therefore, in embodiments (a) a dopant concentration of cerium relative to A may be selected from the range of 0.01-1 at.%, like at least about 0.02 at.%, such as up to about 0.9 at.%; and/or (b) a concentration of Gd relative to A may be selected from the range of 2-20 at.%, such as 5-20 at.%, like at maximum 15 at.%, more especially at maximum 10 at.%. The phrase “relative to A”, and similar phrases, especially refer to all atoms (or ions) of the type A. Hence, 5 at.% cerium relative to A may in fact also be indicated as “ $(A_{(1-0.05)}Ce_{0.05})$ ”.

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, especially 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.

Alternatively or additionally, wherein the luminescent material may comprises a luminescent material of the type $A_3Si_6N_{11}:Ce^{3+}$, wherein A comprises one or more of Y, La, Gd, Tb and Lu, such as in embodiments one or more of La and Y.

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. Hence, 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 $Ba_{1.5}Sr_{0.5}Si_5N_8:Eu$ (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 $(Ba,Sr,Ca)AlSiN_3:Eu$ can also be indicated as $MAISiN_3:Eu$, 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.

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 (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 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 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 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 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, 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.

5 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..

10 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)
15 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
20 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.

25 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.

30 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.

In embodiments the luminescent body may be a crystalline body, or a ceramic body, or a luminescent material dispersed in another material, like e.g. a polymeric body (see further also below).

In specific embodiments, at least one of the one or more luminescent bodies comprises a ceramic body. Further, in embodiments at least one of the one or more luminescent bodies comprises (a) 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, and/or (b) a luminescent material of the type $A_3Si_6N_{11}:Ce^{3+}$, wherein A comprises one or more of Y, La, Gd, Tb and Lu. especially wherein A comprises one or more of La and Y.

In embodiments, the converter body ("body") may have lateral dimensions, like width or length (W1 or L1) or diameter (D1), and a thickness or height (H1). The length or width or the diameter are indicated as converter body dimensions. Though the thickness or height may also be considered a converter body dimension, the term converter body dimension is especially used in relation to width or length (W1 or L1) or diameter (D1). These converter body dimensions may substantially be larger than the thickness or height (H1). Hence, the converter body may have one or more converter body dimensions (D) defined perpendicular to the converter body height (H1).

In embodiments, (i) $D1 \geq H1$ or (ii) and $W1 \geq H1$ and/or $L1 \geq H1$. In specific embodiments, $L1 \leq 100$ mm, such as especially $L1 \leq 60$ mm, more especially $L1 \leq 50$ mm, most especially $L1 \leq 40$ mm. In specific embodiments, $W1 \leq 100$ mm, such as especially $W1 \leq 60$ mm, more especially $W1 \leq 50$ mm, most especially $W1 \leq 40$ mm. In specific embodiments, $H1 \leq 1$ mm, such as especially $H1 \leq 0.2$ mm, more especially $H1 \leq 0.1$ mm, most especially $H1 \leq 0.05$ mm (i.e. 50 μ m or smaller). In specific embodiments, $D1 \leq 100$ mm, such as especially $D1 \leq 60$ mm, more especially $D1 \leq 50$ mm, most especially $D1 \leq 40$ mm. In specific embodiments, the body may have in embodiments a thickness in the range 5-50 μ m. Further, the body may have lateral dimensions (width/diameter) in the range 500 μ m – 100 mm, like

0.1-40 mm. In yet further specific embodiments, (i) $D1 > H1$ or (ii) $W1 > H1$ and $W1 > H1$.

Especially, the lateral dimensions like length, width, and diameter are at least 2 times, like at least 5 times, larger than the height. In specific embodiments, the converter body has a first length $L1$, a first height $H1$, and a first width $W1$, wherein $H1 \leq 0.5 * L1$ and $H1 \leq 0.5 * W1$.

- 5 Hence, the converter body may have a tile shape. The converter body may have a rectangular cross-section or a circular cross-section, though other cross-sections may also be possible. In embodiments, the converter body height may be selected from the range of 3-60 μm , such as e.g. 5-50 μm , like in specific embodiments selected from the range of 8-40 μm . In specific embodiments, the converter body height ($H1$) may be selected from the range of 5-50 μm .
- 10 Further, in specific embodiments the one or more converter body dimensions (D) may be selected from the range of 0.1-40 mm. In specific embodiments, the converter body height ($H1$) is selected from the range of at maximum 80 μm ; wherein $H1/D1 \leq 0.5$. Yet, in embodiments the one or more converter body dimensions (D) may be selected from the range of 0.1-30 mm, such as 0.1-20 mm, like in specific embodiments 0.1-10 mm, like at least 0.2
- 15 mm, such as at least 2 mm.

The one or more converter bodies may form a body having planar faces, with adjacent faces perpendicular configured relative to one another. In other embodiments, the one or more converter bodies may form a body with one or more curved faces and one or more planar faces, like e.g. a spherical cap-shaped body.

- 20 Therefore, the converter body may comprises a first face and a second face, wherein a distance between the first face and the second face defines a converter body height ($H1$). Especially, these faces may be configured parallel.

- Especially, the converter body is configured in a light-receiving relationship with the light generating device. Hence, the converter body may especially be configured
- 25 downstream of the light generating device.

- The terms “light-receiving relationship” or “light receiving relationship”, and similar terms, may indicate that an item may during operation of a source of light (like a light generating device or light generating element or light generating system) may receive light from that source of light. Hence, the item may be configured downstream of that source of
- 30 light. Between the source of light and the item, optics may be configured. The terms “upstream” and “downstream”, such as in the context of propagation of light, may especially relate to an arrangement of items or features relative to the propagation of the light from a light generating element (here the especially the light generating device), wherein relative to a first position within a beam of light from the light generating element, a second position in

the beam of light closer to the light generating element (than the first position) is “upstream”, and a third position within the beam of light further away from the light generating element (than the first position) is “downstream”. For instance, instead of the term “light generating element” also the term “light generating means” may be applied. The terms “radiationally coupled” or “optically coupled” or “radiatively 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. 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. In embodiments, the term “light-receiving relationship” and “downstream” may essentially be synonyms.

Especially, the converter body may be light transmissive for the device light. Hence, the converter body may comprise a light transmissive material. In embodiments, the transmissivity for the device light through the converter body in a direction parallel to the height may be at least 80%, such as at least about 85%, like in embodiments at least 90%, even more especially at least about 95%. Parallel to the height may be perpendicular to the first face (or second face).

Note that the converter body may also be light transmissive for the luminescent material light. In embodiments, the transmissivity for the luminescent material light through the converter body in a direction parallel to the height may be at least 80%, such as at least about 85%, like in embodiments at least 90%, even more especially at least about 95%. In embodiments, the converter body is transparent.

Scattering in a transparent body may be relatively low. For instance, assuming perpendicular irradiation of the first face with light having a wavelength of the device light, then less than 10% of that light entering converter body may be scattered within the body, like less than 5%. Alternatively or additionally, assuming perpendicular irradiation of the first

face with light having a wavelength of the luminescent material light, then less than 10% of that light entering converter body may be scattered within the body, like less than 5%.

Especially, in embodiments the converter body is transparent for the device light. Alternatively or additionally, in embodiments the converter body is transparent for the luminescent material light. In embodiments, the converter body is transparent for the device light and for the luminescent material light.

In embodiments, the converter body comprises transparent polycrystalline luminescent material, such as a ceramic converter body.

The converter body especially comprises a light transmissive material, like glass or light transmissive polymeric material, such as e.g. PMMA, though other materials may also be possible, like e.g. PC, ceramic material, or a single crystal. In specific embodiments, the converter body comprises a single crystal or ceramic body.

In specific embodiments, the luminescent material is provided as ceramic body or is comprised by a ceramic body. Alternatively, the luminescent material may be provided as single crystal. In such embodiments, the luminescent material may thus be provided as converter body.

The converter body may be transmissive, especially (essentially) transparent for one or more of the device light and the luminescent material light, especially for both. Hence, especially a single crystal or ceramic body may be used, as those may be provided with a relative high transmission, even more especially (essentially) transparent. In this way, device light that has entered the converter body may bounce (reflect) several times between the first face and the second face. In embodiments, at least 20% of the device light that has entered the converter body bounces at least three times (i.e. e.g. twice at the first face and once at the second face, or vice versa), such as at least 30%, more especially at least 40%, at the faces of the converter body. Even more especially, at least 50% of the device light that has entered the converter body bounces at least three times. In embodiments, at least 20% of the device light that has entered the converter body bounces at least four times (i.e. e.g. twice at the first face and twice at the second face, or vice versa), such as at least 30%, more especially at least 40%. Here, the percentages may especially refer to a percentage of the spectral power (Watts). The larger the number of bounces, the more red-shifted the luminescent material light may be (in embodiments), such as in the case of cerium comprising garnets may be.

In embodiments, after at least three bounces at least 80%, more especially at least 90% of the device light that has entered the converter body and is totally internally reflected within the converter body, may be absorbed by the luminescent material.

In addition to a high transmission for the wavelength(s) of interest, also the scattering for the wavelength(s) may especially be low. Hence, the mean free path for the wavelength of interest only taking into account scattering effects (thus not taking into account possible absorption (which should be low anyhow in view of the high transmission), may be at least 0.5 times the length of the body, such as at least the length of the body, like at least twice the length of the body.

The converter element is relatively thin. Hence, to increase the conversion by the luminescent material comprised by the converter body, it may be desirable to couple the device light in the converter body in such a way that at least part of the device light propagates through the converter body with a component perpendicular to the height. For instance, due to total internal reflection, the device light may propagate through the converter body, and thereby a substantial part of the device light may be converted by the luminescent material.

To this end, an optical element may be used, that may be configured to increase an angle with a normal to the converter body of the device light coupled into the converter body. In this way, at least a part of the device light coupled into the converter body may have an angle larger than the critical angle, thereby facilitating total internal reflection. The critical angle, in optics, may be the greatest angle at which a ray of light, travelling in one transparent medium, can strike the boundary between that medium and a second of lower refractive index without being totally reflected within the first medium.

Therefore, in embodiments a first optical element may be configured downstream of the light generating device and may be configured to increase an angle of refraction (θ_1) of at least part of the device light entering the converter body via the first optical element. The angle of refraction may be increased relative to a situation where such optical element may not be available. Especially, the first optical element may be comprised by the first face or may be configured on the first face (or in embodiments a combination thereof).

Especially, the first optical element may be transmissive for the device light. However, the first optical element may alter its pathway. Especially, in embodiments the first optical element may comprise a transmissive diffractive optical element. Further, the first optical may thus also be transmissive for the luminescent material light.

In specific embodiments, the first optical element may comprise a grating selected from the group of a holographic grating and a diffraction grating. Especially such gratings may be useful to increase the angle of diffraction. For instance, first and higher order diffractions may provide substantially larger angles.

5 Further, the light generating system may comprise a thermally conductive body. Further, especially the thermally conductive body may be configured in thermal contact with the second face. Especially, the thermally conductive body may be applied for dissipating heat from one or more of (i) the light generating device, and (ii) the converter body. More especially, the thermally conductive body may be applied for dissipating heat
10 from at least the converter body.

The thermally conductive body may comprise thermally conductive material. Especially, the thermally conductive body may consist of thermally conductive material. A thermally conductive material may especially have a thermal conductivity of at least about 20 W/(m*K), like at least about 30 W/(m*K), such as at least about 100 W/(m*K), like
15 especially at least about 200 W/(m*K). In yet further specific embodiments, a thermally conductive material may especially have a thermal conductivity of at least about 10 W/(m*K). In embodiments, the thermally conductive material may comprise of one or more of copper, aluminum, silver, gold, silicon carbide, aluminum nitride, boron nitride, aluminum silicon carbide, beryllium oxide, a silicon carbide composite, aluminum silicon carbide, a
20 copper tungsten alloy, a copper molybdenum carbide, carbon, diamond, and graphite. Alternatively, or additionally, the thermally conductive material may comprise or consist of aluminum oxide. In specific embodiments, the thermally conductive body may comprise one or more of a copper body and an aluminum body. In specific embodiments, the thermally conductive body may comprise one or more of a heat sink and a heat spreader.

25 Heatsinks are known in the art. The term “heatsink” (or heat sink) may especially be a passive heat exchanger that transfers the heat generated by device, such as an electronic device or a mechanical device, to a fluid (cooling) medium, often air or a liquid coolant. Thereby, the heat is (at least partially) dissipated away from the device. A heat sink is especially designed to maximize its surface area in contact with the fluid cooling medium
30 surrounding it. Hence, especially a heatsink may comprise a plurality of fins. For instance, the heatsink may be a body with a plurality of fins extending thereof. A heatsink especially comprises (more especially consists of) a thermally conductive material. The term “heatsink” may also refer to a plurality of (different) heatsinks.

Heat spreaders are known in the art. A heat spreader may be configured to transfer energy as heat from a first element to a second element. The second element may especially be a heatsink or heat exchanger. A heat spreader may be passive or active.

Embodiments of passive heat spreaders may comprise a plate or block of material having high thermal conductivity, such as copper, aluminum, or diamond. An active heat spreader may be configured to speed up heat transfer with expenditure of energy as work supplied by an external source. Herein, the heat spreader may especially be a passive heat spreader.

Alternatively or additionally, the heat spreader may be an active heat spreader, such as selected from the group of heat pipes and vapor chambers. A heat spreader especially

comprises (more especially consists of) a thermally conductive material. The term “heat spreader” may also refer to a plurality of (different) heat spreaders.

An element may be considered in thermal contact with another element if it can exchange energy through the process of heat. Hence, the elements may be thermally coupled. In embodiments, thermal contact can be achieved by physical contact. In

embodiments, thermal contact may be achieved via a thermally conductive material, such as a thermally conductive glue (or thermally conductive adhesive). Thermal contact may also be achieved between two elements when the two elements are arranged relative to each other at a distance of equal to or less than about 10 μm , though larger distances, such as up to 100 μm may be possible. The shorter the distance, the better the thermal contact. Especially, the

distance is 10 μm or less, such as 5 μm or less. The distance may be the distance between two respective surfaces of the respective elements. The distance may be an average distance.

For instance, the two elements may be in physical contact at one or more, such as a plurality of positions, but at one or more, especially a plurality of other positions, the elements are not in physical contact. For instance, this may be the case when one or both elements have a rough surface. Hence, in embodiments in average the distance between the two elements may be 10 μm or less (though larger average distances may be possible, such as up to 100 μm). In embodiments, the two surfaces of the two elements may be kept at a distance with one or more distance holders.

Especially, the converter body may be configured in physical contact with the thermally conductive body and/or a reflective surface thereof.

In embodiments, the thermally conductive body may comprise a first reflective face. This may e.g. be the case when the thermally conductive body comprises a metal as thermally conductive material, like Al or Cu. However, when the thermally conductive material is not reflective, or not reflective enough, a reflective coating, such as an

Al coating, a silver coating, or an Al and Ag coating, may be available on at least part of the surface of the thermally conductive material. Alternatively or additional coatings may also be possible, such as an (additional) dielectric thin film coating to enhance reflectivity. In these ways, a thermally conductive body may be provided comprising a first reflective face. The term “reflective face” may also refer to two or more reflective faces. Further, here the term “reflective” especially refers to optical reflective for one or more of the luminescent material light (see below) and the first light (see (also) below). Especially, the terms “reflective” and “reflectivity”, and similar terms, herein, may refer to a reflectivity of at least 80%, even more especially at least 90%, yet even more especially at least 95%, such as at least about 98%, under perpendicular irradiation with the radiation for which the item or face, etc., like the first reflective face, is reflective. Especially, the radiation may be one or more of the luminescent material light and the first light, more especially both.

Further, especially the reflectivity of the first face is essentially specular reflective. Hence, under perpendicular irradiation, at least 90% of the radiation may specularly be reflected. However, in other embodiments the reflectivity of the first face is essentially diffuse reflective. In specific embodiments, a silver sinter thermal interface material can be applied in between the converter and the thermally conductive material, such as a heatsink, with the interface material having both reflective and thermal transfer functions. Hence, under perpendicular irradiation, at least 90% of the radiation may diffusively be reflected (by the first reflective face). Therefore, in specific embodiments under perpendicular irradiation, at least 90% of the radiation may specularly or diffusively be reflected.

Hence, in embodiments the thermally conductive body may be reflective for the device light and/or reflective for the luminescent material light, especially reflective for both. Further, in embodiments the thermally conductive body may be selected from the group of a heat sink and a heat spreader.

The light generating device is configured to generate more than one beam, hence, $n \geq 2$. In specific embodiments, $n \geq 4$. A beam may be defined by its full width half maximum. Especially, the light generating device, optional further optics, and the converted body may be configured such that the beams do not fully overlap at the first face. In this way, the device light may be distributed over at least part of the converter body. Therefore, in embodiments the light generating device, the converter body, and optional optics, may be configured such that at least two of the n beams of device light irradiate partly overlapping or non-overlapping parts of the first face. Therefore, in embodiments wherein $n \geq 2$, the light

generating device, the converter body, and optional optics, are configured such that at least two of the n beams of device light irradiate partly overlapping or non-overlapping parts of the first face. The optional optics may include the first optical element and/or beam shaping element, like e.g. a lens or a collimator.

5 Note that “ n beams” does not necessarily imply n light generating devices. For instance, the number of light generating devices may be smaller than the number of beams, when n is at least 2. Further, note that the plurality of beams may be provided by one or more of optical elements, while using a single light generating device. Alternatively, or additionally a plurality of beams may be provided by one or more of optical elements, while
10 using a plurality of light generating device. Alternatively, or additionally a plurality of beams may be provided by a plurality of light generating device, without using optics. For instance, the plurality of beams may be generated by a plurality of lasers, with optional optics to beam shape the laser light of the lasers. In specific embodiments, the n beams of device light, defined by full width half maxima at the first face overlap less than 10%. In specific
15 embodiments, the n beams of device light, defined by full width half maxima at the first face overlap less than 5%, such as less than 2%.

As indicated above, in specific embodiments $n \geq 4$.

In specific embodiments, the plurality of beams may have optical axes which are essential parallel. In specific embodiments, they may further be parallel to a normal (N)
20 to the first face. Hence, in specific embodiments the light generating device is configured to generate n parallel beams of device light, wherein the n parallel beams of device light are parallel to a normal (N) to the first face. Especially, the optical axis may be defined as an imaginary line that defines the path along which light propagates through a system starting from the light generating element, here especially the light generating device. Especially, the
25 optical axis may coincide with the direction of the light with the highest radiant flux.

Further, it may be possible to provide a plurality of areas with grating, and not a single grating. In this way, e.g. gratings may be aligned with beams / beams may be aligned with gratings. This may lead to a plurality of parts of the first face provided with the grating and other parts of the first face not comprising such grating. Therefore, in embodiments the
30 first optical element may comprise an arrangement of (a) (n) grating parts comprising grating structures and (b) intermediate part, configured between the grating parts not comprising grating structures. Especially, the grating parts and the n beams may be aligned.

Especially good results may be obtained when $(a \cos[(H1 \cdot A)/2.78] \cdot \mu\text{m}) \leq \theta_1 \leq 80^\circ$, wherein θ_1 is the angle of refraction of first order diffracted device light, and wherein

A is selected from the range of $0.005\text{-}0.08\ \mu\text{m}^{-1}$. Therefore, in the light generating system, $(a\cos[(H1 \cdot A)/2.78] \cdot \mu\text{m}) \leq \theta_1 \leq 80^\circ$, wherein θ_1 is the angle of refraction of first order diffracted device light, and wherein A is selected from the range of $0.005\text{-}0.08\ \mu\text{m}^{-1}$, preferably A is selected from the range of $0.005\text{-}0.06\ \mu\text{m}^{-1}$, more preferably A is selected from the range of $0.005\text{-}0.05\ \mu\text{m}^{-1}$.

In specific embodiments, the angle of refraction (θ_1) of first order diffracted device light may be selected from the range of $35\text{-}80^\circ$.

In specific embodiments, the first optical element may be configured on the first face. For instance, a holographic grating may be provided on the first face. In embodiments, the first optical element may be comprised by the first face. In specific embodiments, the first optical element comprises an etched surface structure of the first face or the first optical element comprises a replicated structure on the first face. For instance, in embodiments e.g. using lithography processes locally part of the converter may be etched away, to provide an etched surface structure having e.g. the function of a grating (for the device light). Hence, in this way the converter body may comprises an etched surface structure comprised in the first face. A replicated structure may e.g. be provided with imprint technology.

Hence, the herein described gratings may in embodiments especially be gratings configured to diffract the device light and not configured to diffract luminescent material light.

The grating may be a 1D grating or a 2D grating, especially a 2D grating. For instance, the grating may be a 1D or 2D holographic grating, especially a 2D holographic grating. In embodiments, the grating may be a 1D or 2D diffractive grating, especially a 2D diffractive grating.

In embodiments, the first optical element may comprise a phase grating, a holographic grating, a ruled grating, an edged grating, a holographic volume grating, a planar phase grating, etc.

The luminescent material light may escape from the light generating system. Light escaping from the light generating system is herein especially indicated as system light. In an operational mode, the system light may comprise the luminescent material light. In embodiments, at part of the device light may not be converted and may also escape from the system. Hence, in an operational mode the system light may comprise the luminescent material light and the device light. Optionally, the system light may comprise (second) device light of a second light generating device, which may especially be different from the (first)

device light of the (first) light generating device. The second device light and the (first) device light may differ in one or more of color point and spectral power distribution. Especially, they may at least differ in color point.

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 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 embodiments, the system light may be white light (in an operational mode).

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 190-380 nm, such as 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.

In embodiments, the system light may have a CCT of at maximum 8000 K, such as at maximum 6500 K, like in embodiments at maximum 5000 K. Especially, in embodiments the system light may have a CCT of not more than about 4000 K. Further, in embodiments the system light may have a CRI of at least 70, such as at least 75, more especially at least 80, like in embodiments at least about 85. In yet further embodiments, the R9 value may be positive. Therefore, in embodiments the light generating system may be configured to generate white system light having a correlated color temperature in a range of

at maximum 4000 K and a color rendering index of at least 80, and optionally a positive R9. For instance, R9 may be at least 5, like at least 10, such as in embodiments at least 20. The R9 value may also be at least 30, such as at least 40. In embodiments, the R9 value may be up to about 100, though other values may be possible. In embodiments, the system light may have a CCT selected from the range of 1800-4000 K, such as selected from the range of 2000-4000 K. In specific embodiments, the system light may have a CCT of at maximum 3000 K, such as at maximum 2700 K.

Especially, when there are light generating devices having different spectral power distributions, the spectral power distribution of the system light may be controllable.

Hence, in embodiments the system may further comprise a control system. The control system may be configured to control the spectral power distribution of the system light. In specific embodiments, the control system may be configured to control one or more of the color rendering index (CRI), the correlated color temperature (CCT), and the color point of the system light.

In embodiments, the luminescent material light may be yellow or green. In embodiments, two or more different luminescent materials may be applied. For instance, in embodiments two different types of garnet luminescent materials may be applied.

In embodiments, the (first) light generating device may be configured to generate blue device light. In yet further embodiments, wherein an optional second light generating device is applied, the second device light may be red second device 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. The phrase “light having one or more wavelengths in a wavelength range” and similar phrases may especially indicate that the indicated light (or

radiation) has a spectral power distribution with at least intensity or intensities at these one or more wavelengths in the indicate wavelength range. For instance, a blue emitting solid state light source will have a spectral power distribution with intensities at one or more wavelengths in the 440-495 nm wavelength range.

5 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,
10 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 systems or disinfection systems.

15 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,
20 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
25 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
30 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 or 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” or “operational mode”. The term “operational mode may also be indicated as “controlling mode”. 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”. 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. Hence, in an aspect the invention also provides a lighting device selected from the group of a lamp, a luminaire, a projector device, a disinfection device, a photochemical reactor, and an optical wireless communication device, comprising the light generating system as defined herein. The lighting device may comprise a housing or a carrier, configured to house or support, one or more elements of the light generating system. For instance, in embodiments the lighting device may comprise a housing or a carrier, configured to house or support one or more of the light generating device, the converter body and/or the thermally conductive body.

Instead of the terms “lighting device” or “lighting system”, and similar terms, also the terms “light generating device” or “light generating system”, may be applied. A lighting device or a lighting system may be configured to generate device light (or “lighting device light”) or system light (“or lighting system light”). As indicated above, the terms light and radiation may interchangeably be used.

The lighting device may comprise a light source. The device light may in embodiments comprise one or more of light source light and converted light source light (such as luminescent material light). The lighting system may comprise a light source. The system light may in embodiments comprise one or more of light source light and converted light source light (such as luminescent material light). 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 visible light.

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-1e schematically depict some aspects and embodiments;

Figs. 2-5 show some data; and

Fig. 6 schematically depicts some aspects and embodiments. The schematic drawings are not necessarily to scale.

DETAILED DESCRIPTION OF THE EMBODIMENTS

5 In order to produce such high intensity source with e.g. a CCT of at maximum 4000 K, a CRI of at least 80 and a positive R9, it is possible to dope Ce:YAG with gadolinium (Gd) and/or use a Ce doped YAG. It is also possible to combine YAG with a red emitting phosphor for increasing re-emission and thus increasing the CRI and R9. However, such converters may show temperature quenching already at relatively low temperatures
10 ($T < 100\text{ }^{\circ}\text{C}$).

Therefore, it is herein especially proposed to keep the thickness of the light converting crystal very low, such as in embodiments in a range from 10 to 20 mm. However, another challenge is to achieve sufficient (laser) light conversion in a layer with such a low thickness. To overcome this problem, it is herein propose placing in embodiments a
15 holographic or diffractive grating on top of a transparent phosphor as shown below in Fig. 1a. In this configuration light, is coupled into the light guide and travels laterally and bounces one or more times.

Hence, amongst others the invention provides in specific embodiments a light generating system 1000 comprising a light generating device 100, a converter body 210, a
20 first optical element 410, and a thermally conductive body 500.

The light generating device 100 may be configured to generate n beams of device light 101. The light generating device 100 may comprise one or more solid state material lasers. Especially, $n \geq 1$.

The converter body 210 may comprise a first face 211 and a second face 212,
25 A distance between the first face 211 and the second face 212 defines a converter body height $H1$. The converter body 210 has one or more converter body dimensions D defined perpendicular to the converter body height $H1$. The converter body height ($H1$) may be selected from the range of at maximum $80\text{ }\mu\text{m}$. Especially, $H1/D1 \leq 0.5$. The converter body 210 may be configured in a light-receiving relationship with the light generating device 100,
30 The converter body 210 may comprise a luminescent material 200 configured to convert at least part of the device light 101 into luminescent material light 201. The converter body 210 may be light transmissive for the device light 101.

The first optical element 410 may be configured downstream of the light generating device 100 and may be configured to increase an angle of refraction θ_1 of at least part of the device light 101 entering the converter body 210 via the first optical element 410.

The first optical element 410 may be comprised by the first face 211 or may be configured on the first face 211. The first optical element 410 may comprise a transmissive diffractive optical element.

The thermally conductive body 500 may be configured in thermal contact with the second face 212.

In embodiments, the thermally conductive body 500 may be reflective for the device light 101 and reflective for the luminescent material light 201. The thermally conductive body 500 may be selected from the group of a heat sink and a heat spreader.

Fig. 1a also schematically depicts a top view an embodiment of the converter body 210. As can be seen, the first optical element 410, such as a grating, like a holographic (2D) grating may only be available on part of the first face 211.

Referring to Figs. 1a-1b, in embodiments, at least 20% of the device light 101 that has entered the converter body 210 may bounce at least three times at the faces 211, 212 of the converter body 210. In Fig. 1b a single bounce is indicated; in Fig. 1a about 4-6 bounces are schematically depicted.

In embodiments, $n \geq 2$. In embodiments, $n \geq 4$. The light generating device 100, the converter body 210, and optional optics, may be configured such that at least two of the n beams of device light 101 irradiate partly overlapping or non-overlapping parts of the first face 211.

The n beams of device light 101, defined by full width half maxima at the first face 211 overlap less than 10%.

In embodiments, the light generating device 100 may be configured to generate n parallel beams of device light 101. The n parallel beams of device light 101 may be parallel to a normal N to the first face 211.

The first optical element 410 may comprise a grating 415 selected from the group of a holographic grating and a diffraction grating.

In specific embodiments, $(\arccos[(H_1 * A)/2.78] * \mu\text{m}) \leq \theta_1 \leq 80^\circ$, θ_1 may be the angle of refraction of first order diffracted device light 101, and A may be selected from the range of $0.005\text{--}0.08 \mu\text{m}^{-1}$.

In embodiments, the angle of refraction θ_1 of first order diffracted device light 101 may be selected from the range of $35\text{--}80^\circ$.

In embodiments, the converter body height (H1) may be selected from the range of 5-50 μm . In embodiments, the one or more converter body dimensions (D) are selected from the range of 0.1-40 mm.

Fig. 1c schematically depicts an embodiment wherein a plurality of light generating devices 100 are applied. Optionally, optics 420 may be used to beam shape the device light 101 of the light generating devices 100. Reference O indicates the optical axis (here especially of the respective light generating devices 100).

Hence, in embodiments, the first optical element 410 may comprise an arrangement of (a) [n] grating parts 418 comprising grating structures and (b) intermediate part 419, configured between the grating parts 418 not comprising grating structures. Especially, the grating parts 418 and the n beams are aligned.

An embodiment of a top view is schematically depicted in Fig. 1d, wherein the about circles indicated beams of device light on the first face 211, substantially addressing the grating parts 418 and substantially not addressing intermediate parts 419.

Referring to Fig. 1e, it is also possible to produce multiple beams from a single laser source rather than using multiple laser sources. When optics 420, such as a beam shaping element or a grating, is placed in front of a laser beam, a 1-D or 2-D light pattern can be produced on the surface of such a phosphor. Then a patterned “grating structure” can be produced on the phosphor for coupling the laser light into the transparent phosphor. For example, a grating is placed in front of the blue laser to produce concentric laser pattern on the phosphor concentric diffraction pattern corresponding to the laser pattern is used as shown in Fig. 1e.

In the configuration shown in Fig. 1a, there may be an issue with lateral light penetration in the light absorbing material. In Fig. 2 the transmission of blue light at maximum point of absorbance in a garnet is shown as a function of Ce concentration (1, 2 and 3 % (i.e. $(\text{A}_{1-x}\text{Ce}_x)_3\text{Al}_5\text{O}_{12}$, wherein x is 0.01, 0.02, and 0.03). Here it can be seen that at a concentration of 1% within 130 mm substantially all the light may get absorbed. For example for a tile with a radius of 1 mm, this means that all the light is absorbed within the radius of 130 mm creating a hot spot in the middle of the tile. The hot spot becomes smaller when higher concentrations of Ce is used. On the x-axis a thickness (of the material, such as of the converter body), indicated with *l*, in μm is indicated. The absorption or transmission follow Lambert-Beer, as known in the art.

It may therefore be desirable to cover the total surface of the convertor with a grating and illuminate the whole surface with blue laser. In fig. 1b schematically coupling

light into a layer of transparent material is shown. Ray a is coupled into the slab using a grating to become ray b. After total internal reflection it becomes ray c. Ray c exits the slab as ray d. It is therefore desirable that after getting reflected once the blue light needs to be absorbed to a large extent. Therefore, after length $2L$ light may desirable be absorbed to a large extent. i.e. $\cos(q)=d/L$ and $L=d/\cos(q)$. Assuming 98% absorption is large enough then for Ce doped YAG having a maximum absorbance A per mm for the used material $2\%=100*10^{-(A*L)}$; $\text{Log}(0.02)=-A*L$; $2.78=A*L$; $L=2.78/A$. This means for a given thickness of $H1$, $d/\cos(q)<2.78/A$; $\cos(q)<(H1*A)/2.78$; $q>\arccos[(H1*A)/2.78]$. N indicates a normal, here relative to the first face 211.

In Fig. 3, the angular range for the in-coupling angle q is shown as a function of absorbance A at maximum absorbance for Ce doped YAG. In this figure the upper line, indicated with reference B, defines the boundary and in coupling angles above this line needs to be used in combination with a total surface coverage of the diffraction based coupling means. The lower, horizontal, line in Fig. 3, indicated with reference C, indicates the boundary below which there may be no total internal reflection.

In Fig. 4 absorbance is shown as a function of wavelength for a YAG sample. Here it can be seen that it is also possible to use a wavelength where absorption is lower enabling longer penetration lengths. This is also valid for cases where Gadolinium doped YAG is used. In those cases for example when 10% Gadolinium doping is used Ce doping should not be higher than 0.4% in order to avoid temperature quenching.

Hence, it may be desirable to look into penetration length where the material absorbance is low. In Fig. 5 absorbance is shown as a function of length at lower absorbances. In Fig. 5 the transmission of blue light at maximum point of absorbance in a garnet is shown as a function of Ce concentration (0.2, 0.05 and 0.1 % (i.e. $(A_{1-x}Ce_x)_3Al_5O_{12}$, wherein x is 0.002, 0.0005, and 0.001).

It can be seen that for example when a samples with relatively low Ce concentration showing is used then penetration depth can increase considerably. However this increase is accompanied with a very large intensity gradient as can be seen in Fig. 5. In order to solve this we suggest illuminating the transparent YAG at multiple points with the laser as shown in Fig. 1c rather than a single point.

The distance between is ideally as short possible for homogenization of the light. Ideally during the in-coupling and the travel of laser light in YAG, areas with grating are avoided.

Hence, in specific embodiments the invention provides a system comprising a laser, a luminescent body, having a thickness of not more than about 50 μm , provided with a grating structure, an operated with especially multiple excitation spots.

In embodiments, the luminescent material 200 may comprise a luminescent material of the type $\text{A}_3\text{B}_5\text{O}_{12}:\text{Ce}$, A may comprise one or more of Y, La, Gd, Tb and Lu, and B may comprise one or more of Al, Ga, In and Sc. In embodiments, a dopant concentration of cerium relative to A may be selected from the range of 0.01-1 at. %.

The converter body 210 may comprise a single crystal or ceramic body.

The first optical element 410 may be configured on the first face 211. In embodiments, the first optical element 410 may comprise an etched surface structure of the first face 211 or the first optical element 410 may comprise a replicated structure on the first face 211.

Fig. 6 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. 6 also schematically depicts an embodiment of lamp 1 comprising the light generating system 1000. Reference 3 indicates a projector 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, Fig. 6 schematically depicts embodiments of a lighting device 1200 selected from the group of a lamp 1, a luminaire 2, a projector device 3, a disinfection device, a photochemical reactor, and an optical wireless communication device, comprising the light generating system 1000 as described herein. In embodiments, such lighting device may be a lamp 1, a luminaire 2, a projector device 3, a disinfection device, or an optical wireless communication device. Lighting device light escaping from the lighting device 1200 is indicated with reference 1201. Lighting device light 1201 may essentially consist of system light 1001, and may in specific embodiments thus be system light 1001.

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 “comprises” means “consists of”.

The term “and/or” especially relates to one or more of the items mentioned before and after “and/or”. For instance, a phrase “item 1 and/or item 2” and similar phrases may relate to one or more of item 1 and item 2. The term "comprising" may in an embodiment refer to "consisting of" but may in another embodiment also refer to "containing at least the defined species and optionally one or more other species".

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

The devices, 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.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims.

In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim.

Use of the verb "to comprise" and its conjugations does not exclude the presence of elements or steps other than those stated in a claim. Unless the context clearly requires otherwise, throughout the description and the claims, the words “comprise”, “comprising”, and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense; that is to say, in the sense of “including, but not limited to”.

The article "a" or "an" preceding an element does not exclude the presence of a plurality of such elements.

The invention may be implemented by means of hardware comprising several distinct elements, and by means of a suitably programmed computer. In 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. In yet a further aspect, the invention (thus) provides a

software product, which, when running on a computer is capable of bringing about (one or more embodiments of) the method as described herein.

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
5 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.

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

The various aspects discussed in this patent can be combined in order to provide additional advantages. Further, the person skilled in the art will understand that
15 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 a light generating device (100), a converter body (210), a first optical element (410), and a thermally conductive body (500); wherein the light generating system (1000) is configured to generate system light (1001); wherein:
- 5 - the light generating device (100) is configured to generate n beams of device light (101), wherein the light generating device (100) comprises one or more solid state material lasers; wherein $n \geq 2$;
- the converter body (210) comprises a first face (211) and a second face (212), wherein a distance between the first face (211) and the second face (212) defines a converter
10 body height (H1), wherein the converter body (210) has one or more converter body dimensions (D) defined perpendicular to the converter body height (H1); wherein the converter body height (H1) is selected from the range of at maximum 80 μm ; wherein $H1/D1 \leq 0.5$; wherein the converter body (210) is configured in a light-receiving relationship with the light generating device (100), wherein the converter body (210) comprises a
15 luminescent material (200) configured to convert at least part of the device light (101) into luminescent material light (201); wherein the converter body (210) is light transmissive for the device light (101);
- the first optical element (410) is configured downstream of the light generating device (100) and is configured to increase an angle of refraction (θ_1) of at least part of the
20 device light (101) entering the converter body (210) via the first optical element (410); wherein the first optical element (410) comprises a transmissive diffractive optical element; wherein one or more of the following applies: (i) the first optical element (410) is comprised by the first face (211) and (ii) the first optical element (410) is configured on the first face (211);
- 25 - the thermally conductive body (500) is configured in thermal contact with the second face (212);
- the light generating device (100), the converter body (210), and optional optics, are configured such that at least two of the n beams of device light (101) irradiate partly overlapping or non-overlapping parts of the first face (211); and

- wherein $(a \cos[(H1 * A) / 2.78] * \mu\text{m}) \leq \theta_1 \leq 80^\circ$, wherein θ_1 is the angle of refraction of first order diffracted device light (101), and wherein A is selected from the range of $0.005\text{--}0.08 \mu\text{m}^{-1}$.

5 2. The light generating system (1000) according to claim 1, wherein the n beams of device light (101), defined by full width half maxima at the first face (211), overlap less than 10%

3. The light generating system (1000) according to claim 1 or 2, wherein $n \geq 4$,
10 and wherein the n beams of device light (101), defined by full width half maxima at the first face (211) overlap less than 10%.

4. The light generating system (1000) according to any one of the preceding claims, wherein the light generating device (100) is configured to generate n parallel beams
15 of device light (101), wherein the n parallel beams of device light (101) are parallel to a normal (N) to the first face (211).

5. The light generating system (1000) according to any one of the preceding claims, wherein the first optical element (410) comprises a grating (415) selected from the
20 group of a holographic grating and a diffraction grating.

6. The light generating system (1000) according to any one of the preceding claims 2-4 and according to claim 5, wherein the first optical element (410) comprises an arrangement of (a) grating parts (418) comprising grating structures and (b) intermediate part
25 (419), configured between the grating parts (418) not comprising grating structures; wherein the grating parts (418) and the n beams are aligned.

7. The light generating system (1000) according to any one of the preceding claims, wherein the n beams of device light (101), defined by full width half maxima at the
30 first face (211), overlap less than 5%.

8. The light generating system (1000) according to claim 7, wherein the angle of refraction (θ_1) of first order diffracted device light (101) is selected from the range of $35\text{--}80^\circ$;

and wherein at least 20% of the device light (101) that has entered the converter body (210) bounces at least three times at the faces (211,212) of the converter body (210).

9. The light generating system (1000) according to any one of the preceding claims, wherein the converter body height (H1) is selected from the range of 5-50 μm ; and wherein the one or more converter body dimensions (D) are selected from the range of 0.1-40 mm.

10. The light generating system (1000) according to any one of the preceding claims, wherein the light generating system (1000) is configured to generate white system light (1001) having a correlated color temperature in a range of at maximum 4000 K and a color rendering index of at least 80, and a positive R9.

11. The light generating system (1000) according to any one of the preceding claims, wherein the thermally conductive body (500) is reflective for the device light (101) and reflective for the luminescent material light (201); wherein the thermally conductive body (500) is selected from the group of a heat sink and a heat spreader; and wherein the light generating device (100) comprises a diode laser.

12. The light generating system (1000) according to any one of the preceding claims, wherein the luminescent material (200) comprises a luminescent material of the type $\text{A}_3\text{B}_5\text{O}_{12}:\text{Ce}$, 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;

13. The light generating system (1000) according to claim 12, wherein the converter body (210) comprises a single crystal or ceramic body; wherein a dopant concentration of cerium relative to A is selected from the range of 0.01-1 at.%; wherein a concentration of Gd relative to A is selected from the range of 2-20 at.%; and wherein the converter body (210) is transparent for the device light (101) and for the luminescent material light (201).

14. The light generating system (1000) according to any one of the preceding claims, wherein the first optical element (410) comprises an etched surface structure

comprised in the first face (211) and/or wherein the first optical element (410) comprises a replicated structure on the first face (211)

15. A lighting device (1200) selected from the group of a lamp (1), a luminaire
5 (2), a projector device (3), a disinfection device, a photochemical reactor, and an optical wireless communication device, comprising the light generating system (1000) according to any one of the preceding claims.

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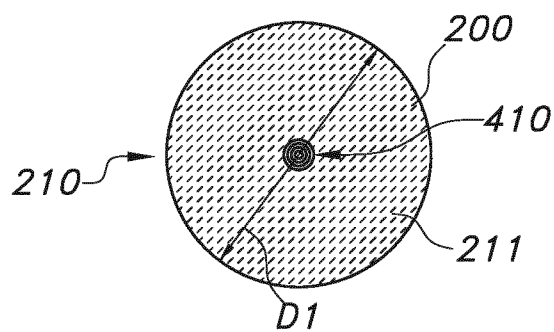
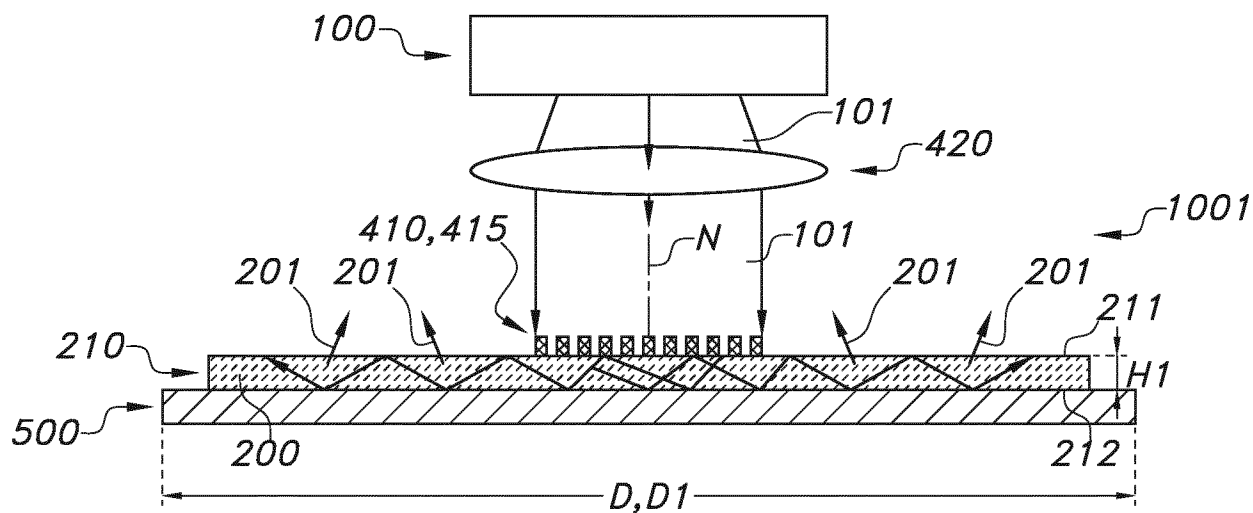


FIG. 1A

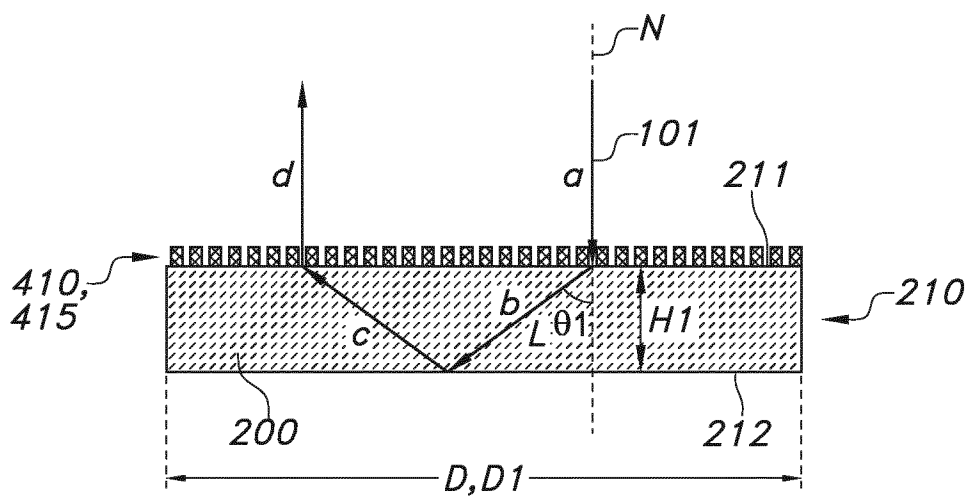
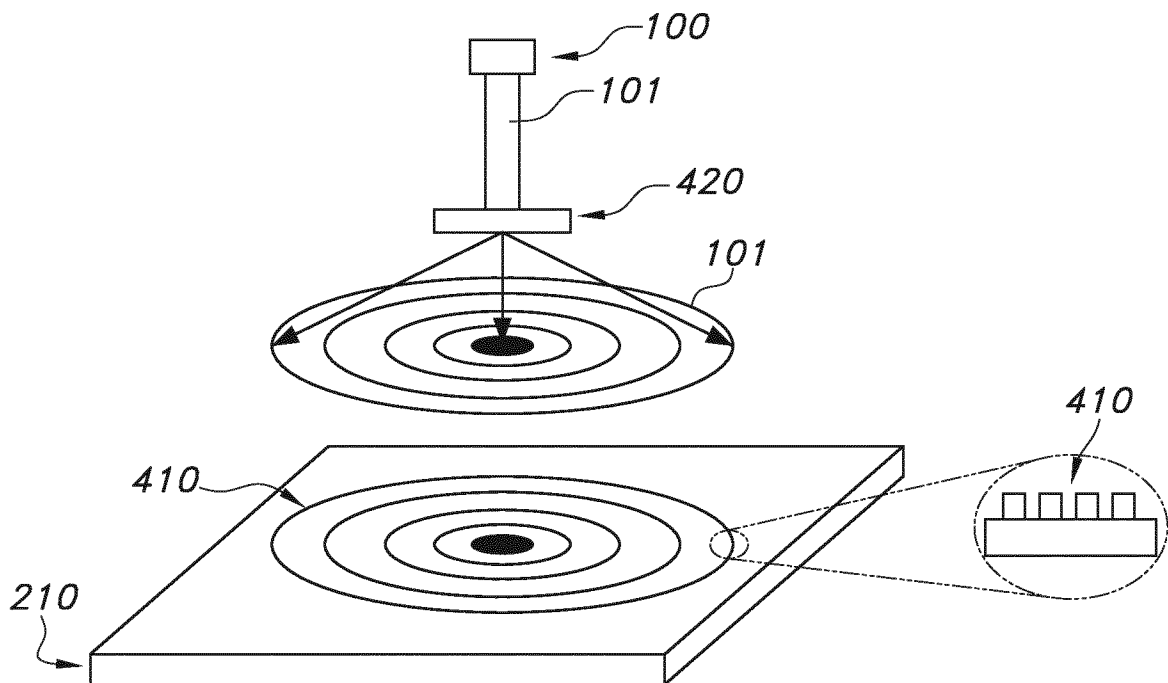
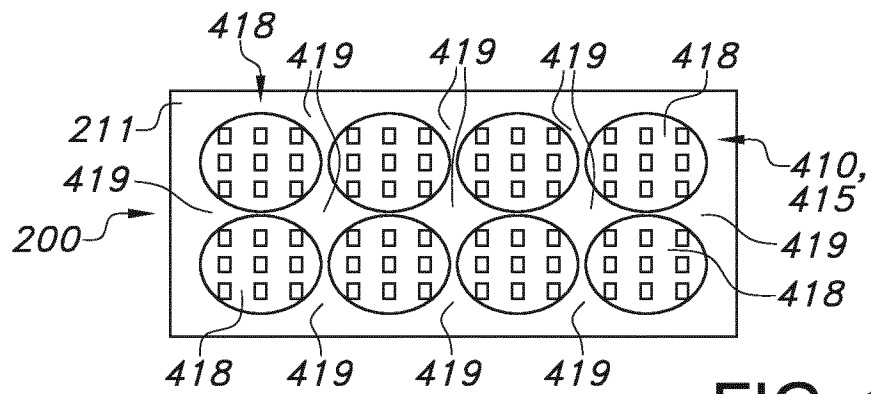
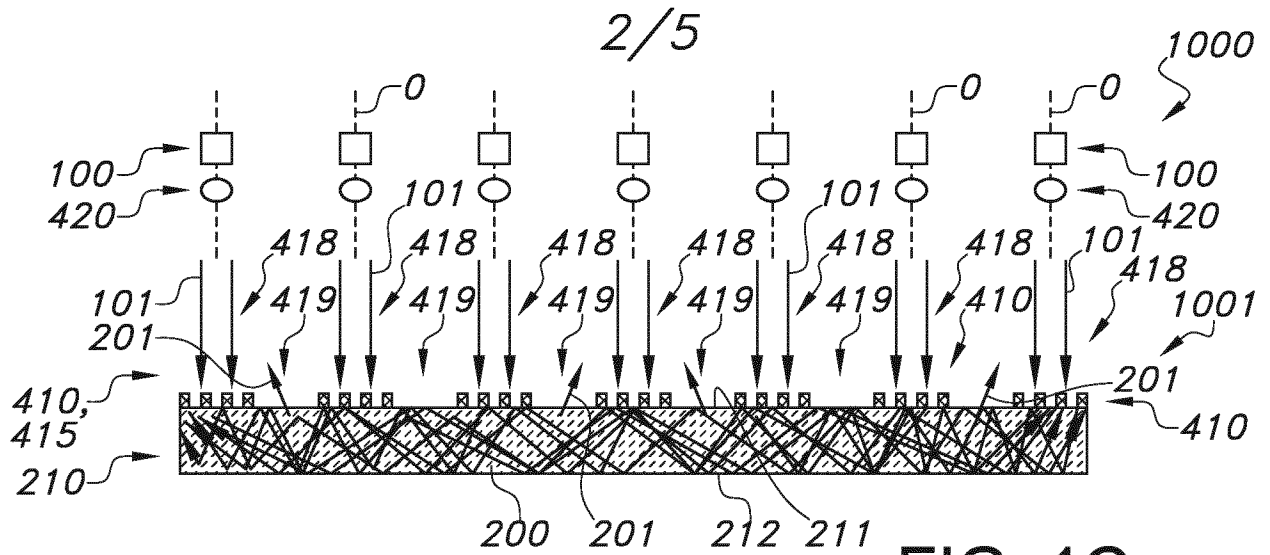


FIG. 1B



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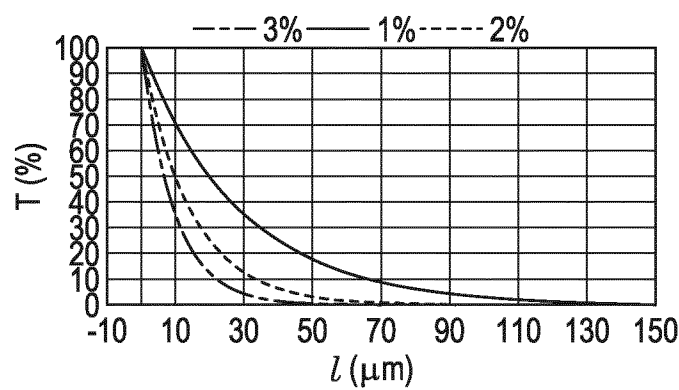


FIG. 2

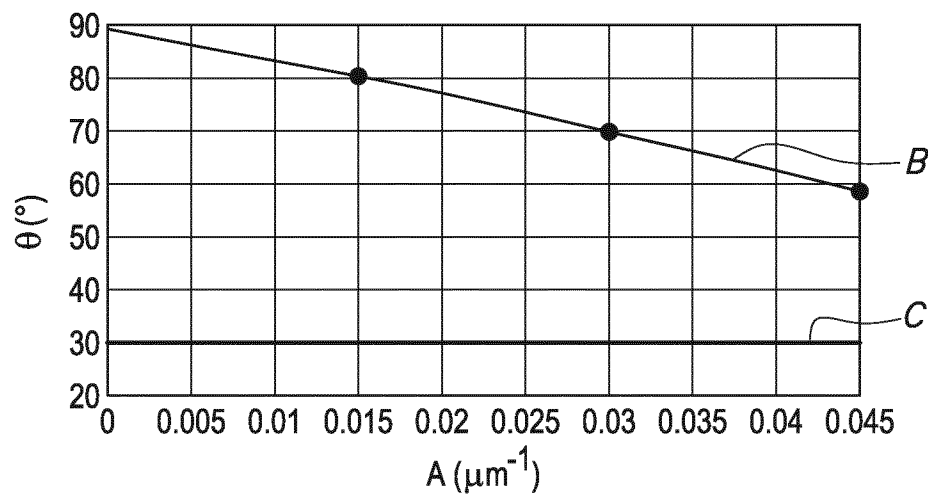


FIG. 3

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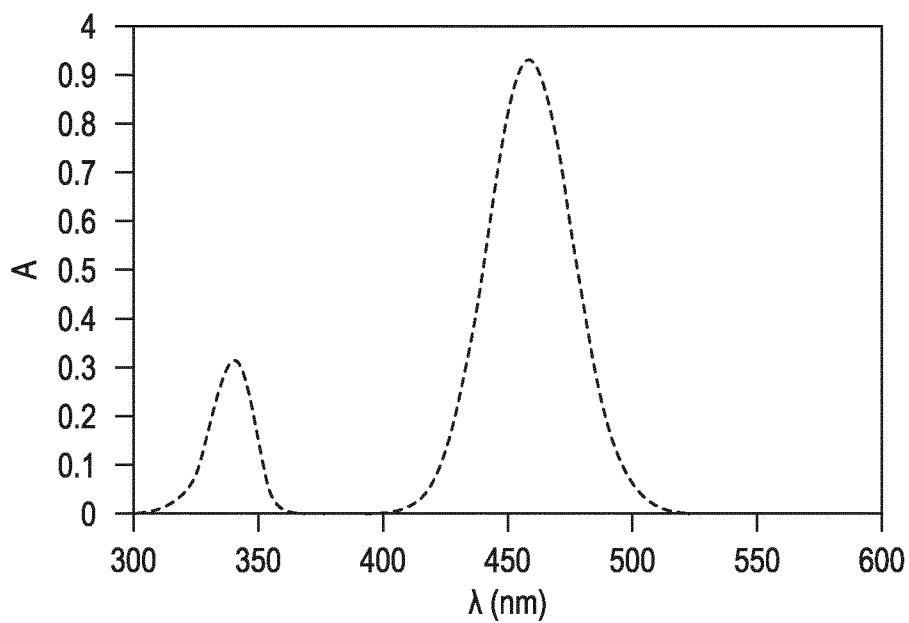


FIG. 4

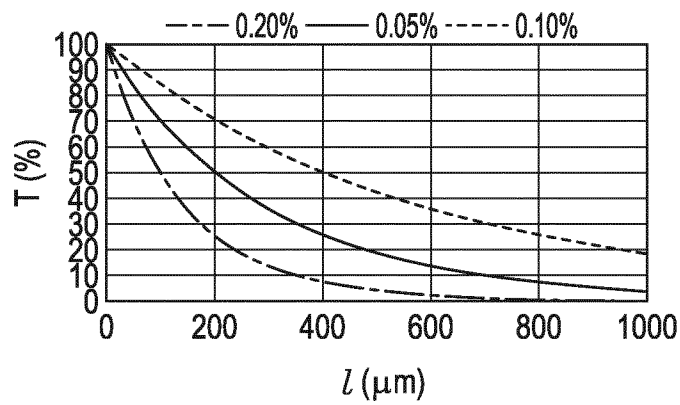


FIG. 5

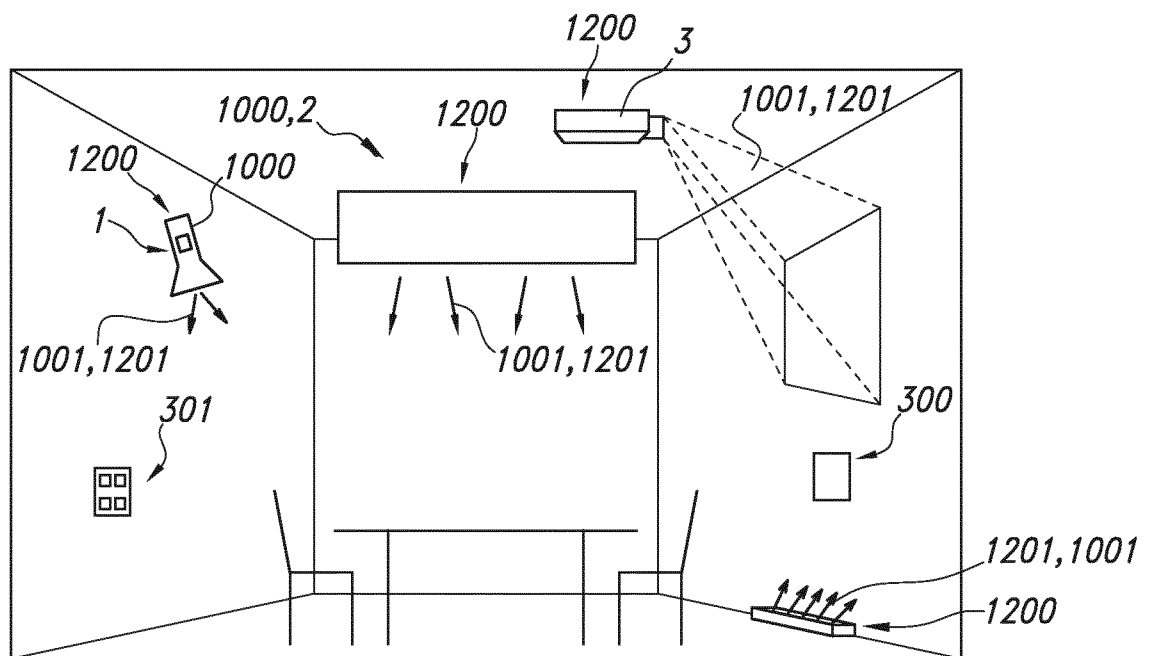


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2022/083759

A. CLASSIFICATION OF SUBJECT MATTER

INV. F21V5/00 F21V9/35 F21V13/02
 ADD. F21Y115/30

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)

F21V G02B F21Y

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.
X	US 2016/230945 A1 (INOUE MASAKI [JP] ET AL) 11 August 2016 (2016-08-11) figures 1-4, 15 paragraphs [0037], [0046], [0058], [0068], [0094] -----	1-15
X	US 2016/327717 A1 (HASHIYA AKIRA [JP] ET AL) 10 November 2016 (2016-11-10) figures 36, 48, 49, 61a paragraphs [0210], [0253], [0254], [0258], [0260], [0281], [0287], [0288], [0290], [0298], [0335], [0360] -----	1-15
X	US 2021/297641 A1 (YOTSUYA SHINICHI [JP] ET AL) 23 September 2021 (2021-09-23) figures 2, 3, 6, 7 paragraphs [0069], [0070], [0078] paragraph [0102] - paragraph [0106] -----	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

15 March 2023

Date of mailing of the international search report

27/03/2023

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Authorized officer

Dinkla, Remko

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2022/083759

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