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(54) Title: WHITE LIGHT SOURCE WITHOUT RED SOLID STATE LIGHT SOURCE

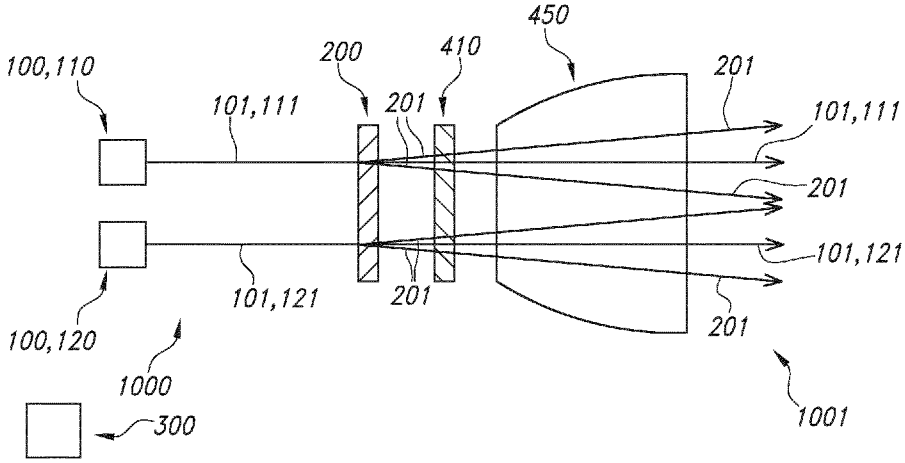

FIG. 1A

(57) Abstract: The invention provides a light generating system (1000) comprising (a) two or more solid state light sources (100), (b) one or more luminescent materials (200), and an optical filter (410), wherein: (A) the two or more solid state light sources (100) are configured to generate (i) first light (111), having a first peak wavelength (λ_{pw1}), and (ii) second light (121), having a second peak wavelength (λ_{pw2}); wherein the first peak wavelength ($\lambda pw1$) and the second peak wavelength ($\lambda pw2$) are selected from the range of 430-495 nm; and wherein | λ_{pw1}- λ_{pw2}|≥ 10 nm; (B) the one or more luminescent materials (200) are configured to convert part of the one or more of the first light (111) and the second light (121) into luminescent material light (201); wherein the luminescent material light (201) has one or more emission bands with: (C) (i) a first intensity (I1) at one or more first wavelengths selected from a first wavelength range of λ_{11}-λ_{12}; (ii) a second intensity (I2) at one or more second wavelengths selected from a second wavelength range of λ^{21}-λ_{22}; and (iii) a third intensity (I3)

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at one or more third wavelengths selected from a third wavelength range of λ_{31}-λ_{32}; wherein: λ11 is selected from the range of 485-505 nm; $\lambda_{12} \leq \lambda_{21}$; λ_{12} and λ_{21} are selected from the range of 520-580 nm; $\lambda_{22}=\lambda_{21}+\lambda_f$; $\lambda_f \geq 5$ nm; $\lambda_{22} \leq \lambda_{31}$; λ_{22} and λ_{31} are selected from the range of 570-620 nm; λ_{32} is selected from the range of 650-780 nm; the optical filter (410) is configured downstream of the one or more luminescent materials (200), wherein the optical filter is configured to reduce the second intensity (I2) relative to the first intensity (I1) and relative to the third intensity (I_3); (D) in an operational mode of the light generating system (1000) the light generating system is configured to generate white system light (1001) comprising the first light (111), the second light (121), and the luminescent material light (201).

White light source without red solid state light source

FIELD OF THE INVENTION

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

BACKGROUND OF THE INVENTION

Conversion devices are known in the art. US2017/0219171, for instance, describes a conversion device, comprising: a phosphor element made of a phosphor element material for converting pump radiation into conversion radiation; and a scattering element embodied as a volume scatterer; wherein the scattering element is arranged in direct optical contact with the phosphor element in order to be transilluminated by the conversion radiation; and wherein the phosphor element material is present in monocrystalline form in the phosphor element over a volume of at least 1×10^{-2} mm^3. The scattering element is provided to be made of a scattering element material which has a refractive index deviating by no more than 20% from a refractive index of the phosphor element material.

US2020/088359A discloses a lamp having blue-pumped solid state light emitters (SSLEs) and violet-pumped SSLEs. Each blue-pumped SSLE has a blue excitation source configured to output blue light, and blue-pumped phosphors for converting a portion of the blue light to non-blue visible light, for the blue-pumped SSLEs to output blue-pumped white light. Each violet-pumped SSLE has a violet excitation source configured to output violet light, and violet-pumped phosphors for converting a portion of the violet light to non-violet visible light, for the one or more violet-pumped SSLEs to output violet-pumped white light. A support structure fixedly supports the blue-pumped SSLEs and the violet-pumped SSLEs in an orientation such that the blue-pumped white light and the violet-pumped white light will propagate in a common direction and intermix with each other through beam-spreading to yield a combined white light.

SUMMARY OF THE INVENTION

While white LED sources can give an intensity of e.g. up to about 300 lm/mm^2; static phosphor converted laser white sources can give an intensity even up to about

20.000 lm/mm^2. Ce doped garnets (e.g. YAG, LuAG) may be the most suitable luminescent convertors which can be used for pumping with blue laser light as the garnet matrix has a very high chemical stability. Further, at low Ce concentrations (e.g. below 0.5%) temperature quenching may only occur above about 200 °C. Furthermore, emission from Ce has a very short 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 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, which may not always be relatively easy. Further, there appears to be a desire to provide high intensity light sources, able to provide (high-intensity) white light. Yet further, there appears to be a desire to provide a (high-intensity) white light having a neutral to warm correlated color temperature (CCT) and/or having an acceptable color rendering across the visible spectral range, defined e.g. by CRI index.

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

Neutral/Warm-white laser light with acceptable color rendering properties appear difficult to realize. A blue laser in combination with a Ce-doped yellow/green phosphor may generate cool white light with a CRI of ~ 70. By red shifting the garnet emission spectrum, lower CCTs can be made (~neutral white), but then CRI may be unacceptably low for general lighting applications. To go to lower CCTs with acceptable color rendering index (CRI), some red light may need to be added. Using a red phosphor, as typically done for LEDs, may introduce problems of photo-saturation when applying laser pump light with high power densities. Alternatively or additionally, red lasers can be used, but more complex dual channel driving schemes may be necessary. Moreover, red lasers may be more susceptible to operating temperatures, which imposes other challenges in thermal management. In addition, the wavelength of the commercially available watt-class red lasers may often be too long, leading to low R9 values (due to red oversaturation). Using a red laser may also introduce color mixing problems. Amongst others, it is herein proposed to make in embodiments neutral/warm-white laser-based light essentially without the (necessarily) use of red phosphor (photo-saturation) and/or a red laser, which may at least partly alleviate one or more of the above mentioned problems.

In a first aspect, the invention provides a light generating system according to claim 1.

The light generation system comprises (a) two or more solid state light sources, (b) a single luminescent material, and an optical filter. The two or more solid state light sources are configured to generate (i) first light, having a first peak wavelength (λ_{pw1}), and (ii) second light, having a second peak wavelength (λ_{pw2}). The first peak wavelength (λ_{pw1}) and the second peak wavelength (λ_{pw2}) are selected from the range of 430-495 nm. Further, $|\lambda_{pw1}- \lambda_{pw2}|\geq 10$ nm, even more especially $| \lambda_{pw1}- \lambda_{pw2}|\geq 5$ nm. Further, especially the luminescent material is configured to convert part of the one or more of the first light and the second light into luminescent material light. In embodiments, the luminescent material light may have one or more emission bands. Especially, the one or more emission bands provide intensity (especially in terms of spectral power (such as radiant flux per unit frequency or wavelength), especially W/nm) in at least three wavelength ranges. The luminescent material light has one or more emission bands with: (i) a first intensity (I_1) at one or more first wavelengths selected from a first wavelength range of λ_{11}-λ_{12}, (ii) a second intensity (I_2) at one or more second wavelengths selected from a second wavelength range of λ_{21}-λ_{22}, and (iii) a third intensity (I_3) at one or more third wavelengths selected from a third wavelength range of λ_{31}- λ_{32}. The following applies: λ_{11} is selected from the range of 485-505 nm; $\lambda_{12}\leq\lambda_{21}$; λ_{12} and λ_{21} are selected from the range of 520-580 nm; $\lambda_{22}=\lambda_{21}+\lambda_f$; $\lambda_f \geq 5$ nm; $\lambda_{22}\leq\lambda_{31}$; λ_{22} and λ_{31} are selected from the range of 570-620 nm; λ_{32} is selected from the range of 650-780 nm. Hence, in embodiments $\lambda_{11}<\lambda_{12}$. The optical filter is configured downstream of the one or more luminescent materials. The optical filter is configured to reduce the second intensity (I_2) relative to the first intensity (I_1) and relative to the third intensity (I_3). In an operational mode of the light generating system the light generating system is configured to generate white system light comprising the first light, the second light, and the luminescent material light (downstream of the optical filter), having a color rendering index (CRI) of at least 80. Hence, in specific embodiments the invention provides a light generating system comprising (a) two or more solid state light sources, (b) one or more luminescent materials, and an optical filter, wherein: (A) the two or more solid state light sources are configured to generate (i) first light, having a first peak wavelength (λ_{pw1}), and (ii) second light, having a second peak wavelength (λ_{pw2}); wherein the first peak wavelength (λ_{pw1}) and the second peak wavelength (λ_{pw2}) are selected from the range of 430-495 nm; and wherein $| \lambda_{pw1} - \lambda_{pw2}| \geq 10$ nm; (B) the one or more luminescent materials are configured to convert part of the one or more of the first light and the second light into luminescent material light; wherein the luminescent material light has one or more emission bands with: (i) a first intensity (I_1) at one or more first wavelengths selected from a first wavelength range of λ_{11}-λ_{12}, (ii) a second intensity (I_2) at one or more second wavelengths selected from a second wavelength range of λ_{21}-λ_{22}, and (iii) a third intensity (I_3) at one or more third wavelengths selected from a third wavelength range of λ_{31}-λ_{32}; wherein: λ_{11} is selected from the range of 485-505 nm; $\lambda_{11}<\lambda_{12}$; $\lambda_{12}\leq\lambda_{21}$; λ_{12} and λ_{21} are selected from the range of 520-580 nm; $\lambda_{22}=\lambda_{21}+\lambda_f$; $\lambda_f \geq 5$ nm; $\lambda_{22}\leq\lambda_{31}$; λ_{22} and λ_{31} are selected from the range of 570-620 nm; λ_{32} is selected from the range of 650-780 nm; (C) the optical filter is configured downstream of the one or more luminescent materials, wherein the optical filter is configured to reduce the second intensity (I_2) relative to the first intensity (I_1) and relative to the third intensity (I_3); (D) in an operational mode of the light generating system the light generating system is configured to generate white system light comprising the first light, the second light, and the luminescent material light (downstream of the optical filter).

With such system, it is possible to provide in a relative simple way a light source, especially a high intensity light source, having an acceptable CRI and having a neutral to warm white CCT. Basically, with a single luminescent material, two (laser) light sources, and a single optical filter, the desired white light may already be obtained. Further, the optical properties of the white light may be controllable. Further, the invention allows a simplified architecture without the need of additional red laser or red luminescent material, though these are not excluded herein in embodiments.

As indicated above, the light generating system may comprise (a) two or more (solid state) light sources, (b) one or more luminescent materials, and an optical filter. In specific embodiments, the light generating system may comprise only two different types of (solid state) light sources (though of each type there may be one or more of such (solid state) light sources).

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 form 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 (i.e. a non-zero) 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” 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 ($Sm:CaF_2$) 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 $Nd:YCa_4O(BO_3)_3$ or Nd:YCOB, neodymium doped yttrium orthovanadate ($Nd:YVO_4$) laser, neodymium glass (Nd:glass) laser, neodymium YLF (Nd:YLF) solid-state laser, promethium 147 doped phosphate glass ($147Pm^{3+}$:glass) solid-state laser, ruby laser ($Al_2O_3:Cr^{3+}$), thulium YAG (Tm:YAG) laser, titanium sapphire (Ti:sapphire; $Al_2O_3:Ti^{3+}$) laser, trivalent uranium doped calcium fluoride ($U:CaF_2$) solid-state laser, Ytterbium doped glass laser (rod, plate/chip, and fiber), Ytterbium YAG (Yb:YAG) laser, Yb_2O_3 (glass or ceramics) laser, etc.

For instance, including second and third harmonic generation embodiments, the light source may comprise one or more of an F center laser, a yttrium orthovanadate ($Nd:YVO_4$) laser, a promethium 147 doped phosphate glass ($147Pm^{3+}$:glass), and a titanium sapphire (Ti:sapphire; $Al_2O_3:Ti^{3+}$) laser.

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

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

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

The laser light source is configured to generate laser light source light (or “laser light”). The light source light may essentially consist of the laser light source light. The light source light may also comprise laser light source light of two or more (different or identical) laser light sources. For instance, the laser light source light of two or more (different or identical) laser light sources may be coupled into a light guide, to provide a single beam of light comprising the laser light source light of the two or more (different or identical) laser light sources. In specific embodiments, the light source light is thus especially collimated light source light. In yet further embodiments, the light source light is especially (collimated) laser light source light.

The 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 $\leq 2°$ (FWHM), more especially $\leq 1°$ (FWHM), most especially $\leq 0.5°$ (FWHM). Hence, $\leq 2°$ (FWHM) may be considered (highly) collimated light source light. Optics may be used to provide (high) collimation (see also above).

In embodiments, the light generating device comprises a solid state light source. In specific embodiments, the light source may be selected from the group of laser diodes and superluminescent diodes. In other embodiments, the light source may comprise an LED.

The invention may further be explained with reference to (the embodiments of) solid state light sources (as light sources).

Especially, the two or more solid state light sources may be configured to generate (i) first light, having a first peak wavelength (λ_{pw1}), and (ii) second light, having a second peak wavelength (λ_{pw2}). Especially, both types of solid state light sources are selected from the blue-cyan wavelength range. Herein, the terms “blue light” or “blue emission” especially relates to light having a wavelength in the range of about 430-495 nm (including some violet and cyan hues). Hence, in specific embodiments the first peak wavelength (λ_{pw1}) and the second peak wavelength (λ_{pw2}) may be selected from the range of 430-495 nm.

Further, the two types of solid state light sources may especially have different emission wavelengths. Especially, in this way the CCT and color point of the system light may be controllable. Further, it appears that with the choices of the different light sources, in combination with the luminescent material(s) and the optical filter, the desired optical properties of the (white) system light may be obtained.

Hence, in specific embodiments the two or more solid state light sources may comprise two (different) types of solid state light sources, especially in embodiments from (two) different bins. In specific embodiments, the light generating system may (thus) comprise a first solid state light source configured to generate the first light and a second solid state light source configured to generate the second light. In further specific embodiments, the first solid state light source and the second solid state light source may be selected from the group of laser diodes and superluminescent diodes.

In specific embodiments, one of the first peak wavelength (λ_{pw1}) and the second peak wavelength (λ_{pw2}) may be at least 465 nm, and (another) one of the first peak wavelength (λ_{pw1}) and the second peak wavelength (λ_{pw2}) may be at maximum 465 nm. Especially, the peak wavelengths may differ at least 5 nm, such as at least 10 nm. Hence, in embodiments $|\lambda_{pw1}-\lambda_{pw2}|\geq 10$ nm. Especially, in embodiments 5 nm $\leq|\lambda_{pw1}-\lambda_{pw2}|\leq 50$ nm.

In specific embodiments, one of the first peak wavelength (λ_{pw1}) and the second peak wavelength (λ_{pw2}) may be at least 470 nm, and (another) one of the first peak wavelength (λ_{pw1}) and the second peak wavelength (λ_{pw2}) may be at maximum 460 nm.

Further, the light generating system comprises a single luminescent material. In embodiments, the light generating system may also comprise two or more luminescent materials. The single luminescent material converts at least part of one or more of the first light and the second light into luminescent material light.

The luminescent material light may especially comprise one or more broad bands. When there is more than one broad band, in embodiments adjacent broad bands may spectrally overlap. In embodiments, the luminescent material light may especially comprise one or more emissions bands, especially each having a width (full width half maximum (FWHM)) of at least about 40 nm, even more specially at least about 50 nm. Further, the one or more luminescent materials may emit (at least) in the wavelength range of about 485-780 nm. Hence, in this wavelength range the luminescent material light may comprise one or more emission bands of each at least 40 nm width (FWHM).

Especially in embodiments there may be emission intensity in at least three wavelength range (within this about 485-780 nm). Hence, the luminescent material light may have one or more emission bands with: (i) a first intensity (I_1) at one or more first wavelengths selected from a first wavelength range of λ_{11}-λ_{12}, (ii) a second intensity (I_2) at one or more second wavelengths selected from a second wavelength range of λ_{21}-λ_{22}, and (iii) a third intensity (I_3) at one or more third wavelengths selected from a third wavelength range of λ_{31}- λ_{32}. For instance, the luminescent material light of the one or more luminescent materials may e.g. have intensity in the wavelength ranges of 495-570 nm, 570-620 nm, and 620-780 nm. The phrase “having intensity in the wavelength range”, and similar phrases, may indicated that at least part of an emission band may be in that wavelength range. More especially, in embodiments the luminescent material light may have an emission band (comprising a single emission band or two or more emissions band with at least two adjacent bands spectrally overlapping) having intensity in the entire wavelength range of 570-620 nm and also intensity in at least part of the wavelength range of 495-570 nm, and also intensity in at least part of the wavelength range of 620-780 nm.

In specific embodiments, one or more of the following may apply: (a) λ_{11} is selected from the range of 485-505 nm, (b) λ_{12} and λ_{21} are selected from the range of 520-580 nm, (c) λ_{22} and λ_{31} are selected from the range of 570-620 nm, and (d) λ_{32} is selected from the range of 650-780 nm. Further, especially one or more of the following may apply (a) $\lambda_{11}<\lambda_{12}$, $\lambda_{12}\leq\lambda_{21}$; (b) $\lambda_{22}=\lambda_{21}+\lambda_f$, and especially also $\lambda_f \geq 5$ nm, and (c) $\lambda_{22}\leq\lambda_{31}$. Especially, in embodiments all of the following may apply: (a) λ_{11} is selected from the range of 485-505 nm, (b) $\lambda_{12}\leq\lambda_{21}$, (c) λ_{12} and λ_{21} are selected from the range of 520-580 nm, (d) $\lambda_{22}=\lambda_{21}+\lambda_f$, (e) $\lambda_f \geq 5$ nm, (f) $\lambda_{22}\leq\lambda_{31}$, (g) λ_{22} and λ_{31} are selected from the range of 570-620 nm, and (h) λ_{32} is selected from the range of 650-780 nm. Hence, thereby also the following may apply: $\lambda_{11}<\lambda_{12}$.

Hence, the one or more luminescent materials may provide luminescent material light having intensity in the green wavelength range, the yellow wavelength range, and the orange-red wavelength range. Especially, the one or more luminescent materials may provide luminescent material light comprising green light, yellow light, and light being orange or red. 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 terms “violet light” or “violet emission” especially relates to light having a wavelength in the range of about 380-440 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.

In embodiments, a single luminescent material may be applied having luminescent material emission with a full width half maximum of at least about 100 nm. Alternatively or additionally, two or more luminescent materials may be applied, having a continuous emission band based on two or more emission bands, and extending over at least 100 nm.

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 ($\lambda_{ex}<\lambda_{em}$), 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 ($\lambda_{ex}>\lambda_{em}$).

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

In specific embodiments the luminescent material comprises a luminescent material of the type $A_3B_5O_{12}$: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 $(Y_{1-x}Lu_x)_3B_5O_{12}$:Ce, wherein x is equal to or larger than 0 and equal to or smaller than 1. The term ":Ce", indicates that part of the metal ions (i.e. in the garnets: part of the "A" ions) in the luminescent material is replaced by Ce. For instance, in the case of $(Y_{1-x}Lu_x)_3Al_5O_{12}$:Ce, part of Y and/or Lu is replaced by Ce. This is known to the person skilled in the art. Ce will replace A in general for not more than 10%; in general, the Ce concentration will be in the range of 0.1 to 4%, especially 0.1 to 2% (relative to A). Assuming 1% Ce and 10% Y, the full correct formula could be $(Y_{0.1}Lu_{0.89}Ce_{0.01})_3Al_5O_{12}$. Ce in garnets is substantially or only in the trivalent state, as is known to the person skilled in the art.

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

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

In specific embodiments at maximum 10% of B-O may be replaced by Si-N. Here, B in B-O refers to one or more of Al, Ga, In and Sc (and O refers to oxygen); in specific embodiments B-O may refer to Al-O. As indicated above, in specific embodiments x3 may be selected from the range of 0.001-0.04. Especially, such luminescent materials may have a suitable spectral distribution (see however below), have a relatively high efficiency, have a relatively high thermal stability, and allow a high CRI (in combination with the first light source light and the second light source light (and the optical filter)). Hence, in specific embodiments A may be selected from the group consisting of Lu and Gd. Alternatively or additionally, B may comprise Ga. Hence, in embodiments the luminescent material comprises $(Y_{x1-x2-x3}(Lu,Gd)_{x2}Ce_{x3})_3(Al_{y1-y2}Ga_{y2})_5O_{12}$, wherein Lu and/or Gd may be available. Even more especially, x3 is selected from the range of 0.001-0.1, wherein $0<x2+x3\leq0.1$, and wherein $0\leq y2\leq0.1$. 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 $0<x3\leq0.2$, 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 $0<x2+x3\leq0.2$, wherein $y1+y2=1$, wherein $0\leq y2\leq0.2$. 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 $MAlSiN_3:Eu^{2+}$ 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 $MAlSiN_3$: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, $(Ba,Sr,Ca)AlSiN_3$: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 $MAlSiN_3$: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.

Blue luminescent materials may comprise YSO ($Y_2SiO_5:Ce^{3+}$), or similar compounds, or BAM ($BaMgAl_{10}O_{17}:Eu^{2+}$), or similar compounds.

The term “luminescent material” herein especially relates to inorganic luminescent materials.

Instead of the term “luminescent material” also the term “phosphor”. These terms are known to the person skilled in the art.

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

Quantum dots are small crystals of semiconducting material generally having a width or diameter of only a few nanometers. When excited by incident light, a quantum dot emits light of a color determined by the size and material of the crystal. Light of a particular color can therefore be produced by adapting the size of the dots. Most known quantum dots with emission in the visible range are based on cadmium selenide (CdSe) with a shell such as cadmium sulfide (CdS) and zinc sulfide (ZnS). Cadmium free quantum dots such as indium phosphide (InP), and copper indium sulfide ($CuInS_2$) and/or silver indium sulfide ($AgInS_2$) can also be used. Quantum dots show very narrow emission band and thus they show saturated colors. Furthermore the emission color can easily be tuned by adapting the size of the quantum dots. Any type of quantum dot known in the art may be used in the present invention. However, it may be preferred for reasons of environmental safety and concern to use cadmium-free quantum dots or at least quantum dots having a very low cadmium content.

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

Organic phosphors can be used as well. Examples of suitable organic phosphor materials are organic luminescent materials based on perylene derivatives, for example compounds sold under the name Lumogen® by BASF. Examples of suitable compounds include, but are not limited to, Lumogen® Red F305, Lumogen® Orange F240, Lumogen® Yellow F083, and Lumogen® F170.

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

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

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, the one or more luminescent materials may 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, A may comprise one or more of La and Y.

In specific embodiments, the system comprises a single luminescent material.

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

Whichever mode may be applied, in embodiments it is desirable that part of the first light and the second light end up in the system light, especially when the system light should be white light. Hence, part of the first light and the second light may bypass the one or more luminescent materials, and not be reflected or transmitted by the one or more luminescent materials. For instance, in embodiments one or more light sources may be used to generate the first light and second light, and are configured upstream of the one or more luminescent materials, and one or more light sources may be used to generate the first light and/or the second light but are not configured upstream of the one or more luminescent materials. Alternatively or additionally, part of the first light and part of the second light is not absorbed (and thus not converted) by the one or more luminescent materials and is reflected or transmitted by the one or more luminescent materials. At least part of the non-absorbed first light and at least part of the non-absorbed second light may propagate together with converted light and end up as system light.

It surprisingly appears that the optical properties of the light provided by the first light, the second light, and the luminescent material light may be improved by attenuating a part thereof in a wavelength range (later also indicated as “second wavelength range”; see below) which wavelength range may be within about the wavelength range of 520-580 nm. This wavelength range may also be indicated as attenuation wavelength range. This attenuation wavelength range may be relatively narrow, such as between about 5-50 nm, like about 5-40 nm, such as even only about 5-30 nm width.

Hence, an optical filter may be configured downstream of the one or more luminescent materials. Especially, the optical filter may be configured to reduce the second intensity (I_2) relative to the first intensity (I_1) and relative to the third intensity (I_3).

The term “optical filter” may refer to one or more optical filters. The phrase “configured to reduce”, and similar phrases, may indicate that the optical filter may be used in a reflective or in a transmissive mode. However, whatever mode is applied, by reflection or transmission, the second intensity (I_2) may be reduced relative to the first intensity (I_1) and relative to the third intensity (I_3).

Hence, in embodiments in an operational mode of the light generating system the light generating system is configured to generate system light, especially white system light, comprising the first light, the second light, and the luminescent material light. Here, especially the term “system light” may thus refer to the light downstream of the optical filter. The light upstream of the optical filter may thus be relatively more rich in second intensity relative to the first intensity or relative to the third intensity when compared to the system light downstream of the optical filter.

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

The term “white light” herein, is known to the person skilled in the art. It especially relates to light having a correlated color temperature (CCT) between about 1800 K and 20000 K, such as between 2000 and 20000 K, especially 2700-20000 K, for general lighting especially in the range of about 2700 K and 6500 K. In embodiments, for backlighting purposes the correlated color temperature (CCT) may especially be in the range of about 7000 K and 20000 K. Yet further, in embodiments the correlated color temperature (CCT) is especially within about 15 SDCM (standard deviation of color matching) from the BBL (black body locus), especially within about 10 SDCM from the BBL, even more especially within about 5 SDCM from the BBL.

The terms “visible”, “visible light” or “visible emission” and similar terms refer to light having one or more wavelengths in the range of about 380-780 nm. Herein, UV may especially refer to a wavelength selected from the range of 200-380 nm. The terms “light” and “radiation” are herein interchangeably used, unless clear from the context that the term “light” only refers to visible light. The terms “light” and “radiation” may thus refer to UV radiation, visible light, and IR radiation. In specific embodiments, especially for lighting applications, the terms “light” and “radiation” refer to (at least) visible light.

In embodiments, the white system light may have a correlated color temperature selected from the range of 2000-6500 K, especially in the range of about 2700-6500 K, such as 2700-5000 K, like in specific embodiments 2700-4500 K, such as in embodiments at least 3000 K, like in embodiments up to about 4000 K. Further, the white system light may have a color rendering index of at least about 75, even more especially at least about 80. Further, the white system light may have a R_9 value of equal to or larger than 0. Especially, in embodiments CRI≥80 and $R_9 \geq 0$. Hence, in the operational mode of the light generating system the light generating system may be configured to generate white system light having a correlate color temperature selected from the range of 2700-4500 K and a color rendering index of at least 80. For instance, in embodiments, in the operational mode of the light generating system the light generating system may be configured to generate white system light having a correlate color temperature selected from the range of 2700-6500 K, such as at least 3000 K, like in embodiments in the range of 3000-4500 K, and a color rendering index of at least 80.

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 embodiments, the optical filter may comprise a neodymium doped glass filter. Neodymium doped glass filters are known in the art. They are known to have a relatively strong absorption around about 580 nm.

Alternatively or additionally, the optical filter may comprise a dichroic filter. Dichroic filters are known in the art. An advantage over the neodymium doped filter is that the spectral properties, especially the position of the attenuation band (such as an absorption band), may be easier tuned than for neodymium doped filter, of which the tunability may essentially be limited to the absorption strength, and of which the position of the absorption bands may be much less tunable than of dichroic filters. Other names of dichroic filters may be notch filter, multi-layer dielectric mirror, thin film interference mirror/filter.

In specific embodiments, the optical filter may have a first average transmission T_{1a} over the first wavelength range of λ_{11}-λ_{12}, a second average transmission T_{2a} over the second wavelength range of λ_{21}-λ_{22}, and a third average transmission T_{3a} over the third wavelength range of λ_{31}-λ_{32}. Here, the term “average transmission” may refer to an average over the wavelength. Hence, the term “average transmission” may refer to a wavelength averaged transmission, which may especially be averaged over the indicated wavelength range. Further, note that “transmission” may refer to the transmission of the light in case of an optical filter that may be designed to be used in transmission, or may refer to the effective transmission of the light in case of an optical filter that may be designed for reflection. In the former embodiments, the transmission may be defined as the ratio of the transmitted light relative to the incident light, and in the latter embodiments the transmission may be defined as the ratio of the reflected light relative to the incident light. In the latter embodiments, the transmission may be angle dependent.

Especially, in embodiments $T_{2a}<T_{1a}$ and $T_{2a}<T_{3a}$. In specific embodiments, λ_{21} and λ_{22} may be selected from the range of 540-620 nm, wherein λ_{21} and λ_{22} (also) define 50% transmission values for the optical filter. The 50% transmission values, more precisely the half minimum transmission values, for the optical filter may be defined as 100-0.5*(100-T_{min}), wherein T_{min} is the transmission value at the lowest transmission (or minimum transmission) of an attenuation band in a transmission spectrum. These half minimum transmission values are found at the half minimum transmission wavelengths (λ_{T50_1},λ_{T50_2}), see also below.

Further, in specific embodiments 5 nm $\leq \lambda_f \leq$ 30 nm. For instance, the transmission may e.g. be 50% or less in a wavelength range of 570-600 nm (i.e. λ_f = 30 nm). In embodiments, $T_{2a}/T_{1a}\leq 0.95$ and $T_{2a}/T_{3a}\leq 0.95$, such as $T_{2a}/T_{1a}\leq 0.9$ and $T_{2a}/T_{3a}\leq 0.9$. In specific embodiments, $T_{2a}/T_{1a}\leq 0.8$ and $T_{2a}/T_{3a}\leq 0.8$.

Here, the term “attenuation band” is used, which may in e.g. Nd filter embodiments refer an absorption band, and in the case of e.g. a dichroic filter may refer to a suppression of a spectra region due to reflection.

In embodiments, the optical filter may have a spectral filter width (λ_W) selected from the range of 5-40 nm, such as selected from the range of 5-30 nm. This filter width may define an attenuation band in the transmission spectrum, leading to a transmission minimum. The filter width (or "spectral filter width") may also be indicated as attenuation wavelength range. Especially, the spectral filter width (λ_W) may be defined by the half minimum transmission wavelengths (λ_{T50_1}, λ_{T50_2}) at both sides of a transmission minimum, with the transmission minimum having a transmission minimum wavelength (λ_{Tmin}) and a minimum transmission value (T_{min}), wherein for the half minimum transmission wavelengths (λ_{T50_1}, λ_{T50_2}) apply that the transmission is 100-0.5*(100-T_{min}). The filter wavelength (λ_{TP}) may be defined by the wavelength middle between the half minimum transmission wavelengths (λ_{T50_1}, λ_{T50_2}). Hence, in the case of a symmetric absorption band (on a wavelength scale), the absorption minimum and the filter wavelength will coincide. The filter wavelength is herein also indicated as true filter wavelength. Especially, the filter wavelength (λ_{TP}) is selected from range of 560-590 nm.

With the formula 100-0.5*(100-T_{min}) it may be basically assumed that the maximum transmission is at 100%. In practice, this may be a bit lower. However, in general the transmission in those wavelengths where the light is not to be attenuated, the transmission may in average (over the wavelengths) be at least about 90%, such as even about 95%; hence this formula is used as approximation to determine the half minimum transmission values of the attenuation band.

Note that the (wavelength dependent) transmission may in embodiments, such as e.g. dielectric thin films, be angle dependent. Hence, the above conditions may apply to a specific angle or a specific angle range (of the incident light relative to the optical filter). In other embodiments, the (wavelength dependent) transmission can be calculated as integral value for all angles of light propagation.

Further, in embodiments the filter strength may be at least 0.05, even more especially at least 1. In specific embodiment, the filter strength may be up to about 2. Absorbance (Abs) and filter strength (FS) may be related according to Abs=e^{-FS}. Likewise, transmittance and filter strength (FS) may be related according to transmittance=e^{-FS}.

In specific embodiments, in the operational mode the white system light may have a first system light intensity (I_{S1}) in a first wavelength range of 495-570 nm, (ii) a second system light intensity (I_{S2}) in a second wavelength range of 570-620 nm, and (iii) a third system light intensity (I_{S3}) in a third wavelength range of 620-780 nm. In specific embodiments, $0.2 \leq I_{S2}/I_{S1} \leq 1.8$ and $0.4 \leq I_{S2}/I_{S3} \leq 2.0$. Here the term "intensity" refers to the integrated intensity over the indicated wavelength range with the intensity especially on an energy scale (especially radiometric flux). Therefore, I_{S1} may refer to the integrated intensity over the 495-570 nm wavelength range, I_{S2} may refer to the integrated intensity over the 570-620 nm wavelength range, and I_{S3} may refer to the integrated intensity over the 620-780 nm wavelength range.

In specific embodiments, especially in the range of 2700-6500 K, the value of I_{S2}/I_{S1} may be selected from the range of $(-0.000133*T_{CCT} + 1.1) \leq I_{S2}/I_{S1} \leq (-0.000167*T_{CCT} + 2.2)$, and/or the value of I_{S2}/I_{S3} may be selected from the range of $(0.000117*T_{CCT} + 0.15) \leq I_{S2}/I_{S3} \leq (0.000167*T_{CCT} + 0.9)$, wherein is the T_{CCT} correlated color temperature of the (white) system light. As indicated above, blue and/or cyan may be provided by the (solid state) light sources.

Especially (spectral) intensities in relation to the system light may refer to a radiometric flux, e.g. in Watts. Note that these intensities refer to intensities of spectral ranges in the system light downstream of the optical filter.

Further, the radiant flux or radiometric flux per unit frequency or wavelength. Radiant flux is generally indicate per unit frequency or wavelength, and measured in W/nm. This may especially apply to spectral intensities I_1, I_2, and I_3.

Further, in specific embodiments, the optical filter may have the first average transmission T_{1a} over a first wavelength range of *430*-570 nm, the second average transmission T_{2a} over a second wavelength range of 570-620 nm, and the third average transmission T_{3a} over a third wavelength range of 620-*680* nm. Especially, in embodiments $T_{2a}/T_{1a} \leq 0.8$ and $T_{2a}/T_{3a} \leq 0.8$.

As indicated above, in specific embodiments the light generating system may comprise a single luminescent material. In other embodiments, the light generating system comprises more than one luminescent material. Especially, in such embodiments the system may comprise two luminescent materials, of which in further specific embodiments one may essentially comply with all conditions of the one or more luminescent materials in relation to spectral power distribution (in the three wavelength ranges), and (the other) one may be configured to provide luminescent material light in the orange-red wavelength range.

Therefore, in embodiments the system may comprise a second luminescent material configured to convert part of the one or more of the first light and the second light into second luminescent material light having at least 80% of the total spectral power in the visible wavelength range in the wavelength range of 600-780 nm.

Further, as indicated above the system may in specific embodiments comprise (a) one or more luminescent materials selected from (a1) a luminescent material of the type $A_3B_5O_{12}:Ce^{3+}$ (see also above), and/or (a2) a luminescent material of the type $A_3Si_6N_{11}:Ce^{3+}$

(see also above), and (b) a second luminescent material configured to convert part of the one or more of the first light and the second light into second luminescent material light having at least 80% of the total spectral power in the visible wavelength range in the wavelength range of 600-780 nm.

In yet other embodiments, the system may comprise two or more luminescent materials selected from (a) a luminescent material of the type $A_3B_5O_{12}:Ce^{3+}$ and (b) a luminescent material of the type $A_3Si_6N_{11}:Ce^{3+}$. Yet, in specific embodiments, the system may comprise two or more luminescent materials, especially two, selected from luminescent materials of the type $A_3B_5O_{12}:Ce^{3+}$. For instance one of the luminescent materials may be chosen to have a dominant wavelength below 570 nm, such as below about 568 nm, and one of the luminescent materials may be chosen to have a dominant wavelength above 570 nm, such as above about 573 nm.

When two or more luminescent materials, especially two luminescent materials are applied, the luminescent materials may be configured stacked, or may be configured next to each other (laterally positioned), or may be provided as luminescent material mixture.

In specific embodiments, a compact package may e.g. be provided. For instance, in embodiments the system may comprise an integrated light source package, wherein the integrated light source package comprises a common support member configured to support the two or more solid state light sources and the one or more luminescent materials, wherein common support member comprises a thermally conductive support. The thermally conductive support may comprise one or more of a heatsink, a heat spreader, and a vapor chamber.

As indicated above, the system may comprise a control system or may be functionally coupled to a control system. The control system may especially control the two or more (solid state) light sources.

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

The control system may also be configured to receive and execute instructions form a remote control. In embodiments, the control system may be controlled via an App on a device, such as a portable device, like a Smartphone or I-phone, a tablet, etc.. The device is thus not necessarily coupled to the lighting system, but may be (temporarily) functionally coupled to the lighting system.

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

The 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, 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.

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 light generating device selected from the group of a lamp, a luminaire, a projector device, a disinfection device, and an optical wireless communication device, comprising the light generating system as defined herein. The light generating 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 light generating device may comprise a housing or a carrier, configured to house or support one or more of the two or more (solid state) light sources and the one or more luminescent materials.

BRIEF DESCRIPTION OF THE DRAWINGS

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

Figs. 1a-1d schematically depict some embodiments and aspects;

Figs. 2a-2c schematically depict some embodiments and variants;

Fig. 3 schematically depict some possible (application) embodiments;

Figs. 4a-4d depict some further aspects; and

Figs. 5a-5c depict yet some further aspects.

The schematic drawings are not necessarily to scale.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Fig. 1a schematically depicts an embodiment of a light generating system 1000. The light generating system 1000 may comprise (a) two or more solid state light sources 100, (b) one or more luminescent materials 200, and an optical filter 410.

The two or more solid state light sources 100 may be configured to generate (i) first light 111, having a first peak wavelength λ_{pw1}, and (ii) second light 121, having a second peak wavelength λ_{pw2}. Especially, the first peak wavelength λ_{pw1} and the second peak wavelength λ_{pw2} may be selected from the range of 430-495 nm. In embodiments, $|\lambda_{pw1}-\lambda_{pw2}|\geq 10$ nm.

The one or more luminescent materials 200 may be configured to convert part of the one or more of the first light 111 and the second light 121 into luminescent material light 201. Especially, the luminescent material light 201 may have one or more emission bands with: (i) a first intensity I_1 at one or more first wavelengths selected from a first wavelength range of λ_{11}-λ_{12}, (ii) a second intensity I_2 at one or more second wavelengths selected from a second wavelength range of λ_{21}-λ_{22}, and (iii) a third intensity I_3 at one or more third wavelengths selected from a third wavelength range of λ_{31}- λ_{32}.

In embodiments, λ_{11} may be selected from the range of 485-505 nm; $\lambda_{11}<\lambda_{12};\lambda_{12}\leq\lambda_{21}$, λ_{12} and λ_{21} may be selected from the range of 520-580 nm, $\lambda_{22}=\lambda_{21}+\lambda_f$, $\lambda_f \geq 5$ nm, $\lambda_{22}\leq\lambda_{31}$, λ_{22} and λ_{31} may be selected from the range of 570-620 nm, and λ_{32} may be selected from the range of 650-780 nm. For instance, there may be three optical ranges with intensity at one or more wavelengths: 495-570 nm, 570-620 nm, and 620-780 nm.

In embodiments, the optical filter 410 may be configured downstream of the one or more luminescent materials 200. Especially, the optical filter may be configured to reduce the second intensity I_2 relative to the first intensity I_1 and relative to the third intensity I_3.

In an operational mode of the light generating system 1000, the light generating system may be configured to generate white system light 1001 comprising the first light 111, the second light 121, and the luminescent material light 201 (downstream of the optical filter 410).

In Fig. 1a, element 450 is an optical element which may be used to beam shape the system light 1001. For instance, the optical element 450 may be a hollow or massive compound parabolic concentrator.

Reference 300 refers to a control system. The control system 300 may be configured to control the spectral power distribution of the system light 1001. The control system 300 may control the spectral power distribution of the system light 1001 by controlling the two or more solid state light sources 100.

In embodiments, the light generating system 1000 may comprise a first solid state light source 110 configured to generate the first light 111 and a second solid state light source 120 configured to generate the second light 121. In specific embodiments, the first solid state light source 110 and the second solid state light source 120 may be selected from the group of laser diodes and superluminescent diodes.

The one or more luminescent materials 200 may comprise one or more of (a) a luminescent material of the type $A_3B_5O_{12}$:Ce, wherein A may comprise one or more of Y, La, Gd, Tb and Lu, and wherein B may comprise one or more of Al, Ga, In and Sc, and (b) a luminescent material of the type $A_3Si_6N_{11}:Ce^{3+}$, wherein A may comprise one or more of Y, La, Gd, Tb and Lu (especially wherein A may comprise one or more of La and Y).

In specific embodiments, the light generating system 1000 may comprise a single luminescent material 200. In other embodiments, the system may comprise (a) the one or more luminescent materials 200 as defined in the previous paragraph, and (b) a second luminescent material 220 configured to convert part of the one or more of the first light 111 and the second light 121 into second luminescent material light 221 having at least 80% of the total spectral power in the visible wavelength range in the wavelength range of 600-780 nm.

Referring to Fig. 1b, an embodiment of a spectral power distribution of the system light 1001 is depicted. The system light 1001 comprises the first light 111, the second light 121, and the luminescent material light 201. The three different spectral regions are indicated in the spectrum.

As shown in Fig. 1b, one of the first peak wavelength λ_{pw1} and the second peak wavelength λ_{pw2} may be at least 465 nm, and one of the first peak wavelength λ_{pw1} and the second peak wavelength λ_{pw2} is at maximum 465 nm. Here, the first peak wavelength λ_{pw1} is at least 465 nm and the second peak wavelength λ_{pw2} is at maximum 465 nm. More especially, one of the first peak wavelength λ_{pw1} and the second peak wavelength λ_{pw2} may be at least 470 nm, and one of the first peak wavelength λ_{pw1} and the second peak wavelength λ_{pw2} may be at maximum 460 nm. The two or more solid state light sources 100 may comprise two types of solid state light sources (from two different bins).

Referring to Figs. 1a and 1c, it may be possible that part of first light 111 and/or second light 121 is not absorbed by the one or more luminescent materials 200 and end up in the system light 1001. Alternatively or additionally, part of the first light 111 and/or second light 121 may be rerouted, and may not interact with the one or more luminescent materials 200. This may in embodiments be achieved by allowing at least part of the first light and/or second light bypass the one or more luminescent materials 200. Alternatively, one or more separate solid state light sources may be applied, which is in Fig. 1c schematically indicated with reference 130. Note that this light source may in embodiments be a light source different from the first solid state light source 110 and second solid state light source 120, but may in other embodiments be a light source essentially identical to the first solid state light source 110 or second solid state light source 120.

Referring to Fig. 1d, the optical filter 410 may be also integrated with a phosphor (see embodiment I). In case of dichroic mirror as the optical filter 410, the optical filter 410 can be deposited directly on the surface of the phosphor 200. The optical filter 410 can be also applied as a last element, after a collimating optical element 450, at the light exit window, see embodiment II. Alternatively, the optical filter 410 can be applied in close vicinity to a converter or further downstream of the converter, see e.g. Fig. 1a. In this case, an additional collimating optics may be configured in between the phosphor and the filter to collect and collimate the light from the phosphor, see embodiment III. The luminescent material 200 in these embodiments is applied in the transmissive mode.

Fig. 2a schematically depict two embodiments, with embodiment I schematically depicting the transmissive mode of the optical filter 410, and embodiment II schematically depicting the reflective mode of the optical filter 410. References I_{111a} and I_{111b} indicate the intensity of the first light 111 upstream of the optical filter 410 and downstream of the optical filter 410, respectively. Likewise, references I_{121a} and I_{121b} indicate the intensity of the second light 121 upstream of the optical filter 410 and downstream of the optical filter 410. Likewise, references I_{201a} and I_{201b} indicate the intensity of the luminescent material light 201 upstream of the optical filter 410 and downstream of the optical filter 410.

The ratio of $(I_{111b}/I_{111a})*100\%$ indicates the transmission of the optical filter 410 for the first light 111. The ratio of $(I_{121b}/I_{121a})*100\%$ indicates the transmission of the optical filter 410 for the second light 111. The ratio of $(I_{201b}/I_{201a})*100\%$ indicates the transmission of the optical filter 410 for the luminescent material light 201. Especially, the former two may be relatively high. The latter transmission may especially be wavelength dependent, with a smaller transmission for luminescent material light 201 in the second wavelength range, than for the luminescent material light 201 in the first wavelength range and third wavelength range.

Very schematically, the transmission of an embodiment of the optical filter 410 is shown in Fig. 2b, with on the x-axis the wavelength and on the y-axis the transmission of the optical filter 410. Note that in embodiments the optical filter may be used in a reflective mode; then also the effective transmission may be used (at a specific angle in case of collimated light beam, or an integral value for transmission may be used for all angles of possible light propagation). Further, this is a very schematically transmission curve, with a single minimum. There may also be more than one minimum.

References F1, F2, and F3 indicate filter regions, with the filter region F2 having an in average (over the wavelength) lower transmission that the filter regions F1 and F3.

In embodiments, the optical filter 410 may comprise a neodymium doped glass filter. Alternatively or additionally, the optical filter 410 may comprise a dichroic filter (or notch filter, multi-layer dielectric mirror, or thin film interference mirror/filter).

In specific embodiments, the optical filter 410 may have a first average transmission T_{1a} over the first wavelength range of λ_{11}-λ_{12}, a second average transmission T_{2a} over the second wavelength range of λ_{21}-λ_{22}, and a third average transmission T_{3a} over the third wavelength range of λ_{31}-λ_{32}, wherein λ_{21} and λ_{22} may be selected from the range of 540-620 nm, wherein λ_{21} and λ_{22} define half minimum transmission values (see also below) for the optical filter 410, wherein 5 nm $\leq \lambda_f \leq$ 30 nm, and wherein $T_{2a}<T_{1a}$ and $T_{2a}<T_{3a}$. Especially, in embodiments the optical filter 410 may have the first average transmission T_{1a} over a first wavelength range of 430-570 nm, the second average transmission T_{2a} over a second wavelength range of 570-620 nm, and the third average transmission T_{3a} over a third wavelength range of 620-680 nm, wherein $T_{2a}/T_{1a}\leq 0.95$ and $T_{2a}/T_{3a}\leq 0.95$.

The half minimum transmission values for the optical filter may be defined as 100-0.5*(100-T_{min}), wherein T_{min} is the transmission value at the lowest transmission of an attenuation band (due to absorption in absorption filters or reflection in dichroic filters) in a transmission spectrum. For instance, in Fig. 2b the transmission at the minimum may be about 10%. Hence, the 50% transmission values are 45%. The transmission minimum is indicated with λ_{TP}, which is herein also indicated as “true filter position”.

In embodiments, the optical filter 410 may have a spectral filter width λ_W selected from the range of about 1-40 nm, such as especially about 5-40 nm. The spectral filter width λ_W may be defined by the half minimum transmission wavelengths λ_{T50_1},λ_{T50_2} at both sides of a transmission minimum at λ_{Tmin} having a minimum transmission T_{min} for which apply that the transmission is 100-0.5*100-T_{min}. The filter wavelength λ_{TP} may be defined by the wavelength middle between the half minimum transmission wavelengths λ_{T50_1},λ_{T50_2}. Especially, in embodiments the filter wavelength λ_{TP} is selected from range of 560-590 nm.

Referring to Fig. 2c, the light generating system 1000 may comprise an integrated light source package 600, wherein the integrated light source package 600 may comprise a common support member 610 configured to support the two or more solid state light sources 100 and the one or more luminescent materials 200, wherein common support member 610 may comprise a thermally conductive support 500. Embodiments I and II schematically depict reflective modes of the luminescent material. In embodiment I, the optical filter 410 is remote from the luminescent material(s) 200 and in embodiment II, the optical filter 410 may be on top of or integrated with the luminescent material(s) 200.

In embodiments, in the operational mode of the light generating system 1000 the light generating system 1000 may be configured to generate white system light 1001 having a correlate color temperature selected from the range of 3000-4500 K and a color rendering index of at least 80.

In embodiments, in the operational mode the white system light 1001 may have a first system light intensity I_{S1} in a first wavelength range of 495-570 nm, (ii) a second system light intensity I_{S2} in a second wavelength range of 570-620 nm, and (iii) a third system light intensity I3 in a third wavelength range of 620-780 nm; wherein $0.2 \leq I_{S2}/I_{S1} \leq 1.8$ and wherein $0.4 \leq I_{S2}/I_{S3} \leq 2.0$. In specific embodiments, $0.5 \leq I_{S2}/I_{S1} \leq 1.6$. Alternatively or additionally, in specific embodiments $0.6 \leq I_{S2}/I_{S3} \leq 1.8$.

In specific embodiments, the value of I_{S2}/I_{S1} may be selected from the range of $(-0.000133*T_{CCT} + 1.1) \leq I_{S2}/I_{S1} \leq (-0.000167* T_{CCT} + 2.2)$, and the value of I_{S2}/I_{S3} may be selected from the range of $(0.000117*T_{CCT} + 0.15) \leq I_{S2}/I_{S3} \leq (0.000167*T_{CCT} + 0.9)$, wherein is the T_{CCT} correlated color temperature. This may especially apply in the range of 2700-6500 K.

Fig. 3 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. 3 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.

A number of simulations were executed. The invention is not limited to these simulations. Amongst others, in simulations the following was varied:

Laser 1: 440, 450 and 460 nm, FWHM=3 nm (“blue wavelength lasers”)
Laser 2: 470, 480 and 490 nm, FWHM=3 nm (“cyan wavelength lasers”)
Fraction of power of laser 2: 0-0.5 in 0.1 steps
Strength of filter: 0.2, 0.4, 0.6, 0.8 and 1.0
Filter position: 530-580 nm in 5 nm steps (short wavelength edge of the filter)

True Filter Position: Center of transmission minimum

Filter width: 10, 20, 30 nm (slope: 3 nm)

Figs. 4a-4c show the impact of the filters on the spectral power distribution of the luminescent material light. A curve of the transmission minimum (T_{min}) as function of the filter strength is shown in Fig. 4d. In Figs. 4a-4c, FW indicates the filter width (above also indicated as λ_W). In Figs 4a-4d, FS indicates the filter strength. In Fig. 4d, on the y-axis the value of the minimal filter transmission in the attenuation band is indicated, wherein 1 on the (linear) y-axis indicates 100%, and wherein 0.1 indicates 10% transmission (e.g. Fig. 2b, wherein the transmission minimum is at about 10%, the filter strength of that filter would be about 2.3; especially, $FS = -\ln(T_{min}) = -\ln(0.1) = 2.3$).

Based on the simulations, amongst others the following was found:

A CRI of at least 80 is possible with all three blue wavelength pump lasers (at least with a CCT of 4000 K);

The shorter the peak wavelength of the blue laser, the stronger the cyan laser contribution should be;

A CRI of at least 80 is possible with all three ‘cyan’ wavelength lasers (at least with a CCT of 4000 K);

A higher CRI is obtained for longer wavelength ‘cyan’ lasers (at comparable contribution to the spectrum);

For CRI of at least 80, an R9 of at least 0, and a CE of at least 230 lumen/Watt (i.e. the lumen of the generated system light relative to watts of the pump laser), true filter positions can be selected from the range of 555-590 nm, such as 560-585 nm, at e.g. 4000 K CCT. Especially, the true filter position may be selected from the range of 560-575 nm for highest CRI values;

For instance at a CCT of at least 4000 K, the filter width can be between 10-30 nm, though with values of at least 20 nm, CRI values may be higher, such as at least 85, or even at least 90;

Especially, true filter positions can be selected from the range of 555-590 nm, e.g. at CCT 4000 K, and with filter widths in the range of about 10-30 nm;

With a filter width of 10 nm, the true filter position may desirably be in the range of 560-585 nm, e.g. with a CCT of 4000 K;

With a filter width of 20 nm, the true filter position may desirably be in the range of 555-590 nm, e.g. with a CCT of 4000 K;

With a filter width of 30 nm, the true filter position may desirably be in the range of 555-590 nm, e.g. with a CCT of 4000 K;

For CCT of about 4000 K, and CRI of at least 80, it appears that the higher the fraction cyan, the weaker the filter can be;

For CCT of about 4000 K, and CRI of at least 80, it appears that the first laser at about 440 nm peak wavelength, the filter strength should be at least 0.3 and/or the filer width should be at least 30. With higher filter strength, the filter width can (but is not necessarily) more narrow;

For CCT of about 4000 K, and CRI of at least 80, it appears that the first laser at about 450 nm peak wavelength, the filter strength should be at least 0.2 and/or the filer width should be at least 30. With higher filter strength, the filter width can (but is not necessarily) more narrow;

For CCT of about 4000 K, and CRI of at least 80, it appears that the first laser at about 460 nm peak wavelength, the filter strength should be at least 0.05 and/or the filter width should be at least 30. With higher filter strength, the filter width can (but is not necessarily) be more narrow;

Some of the above date are summarized in Fig. 5a-5c, with on the y-axis the average filter transmission (T_a; %) and on the x-axis the true filter position (λ_{TM}; nm) . The dashed rectangle indicates optimal conditions for the respective filter characteristics;

Based on a number of simulations, it appears desirable to choose a filter width of at maximum about 25 nm, such as maximum about 20 nm, like especially at maximum about 15 nm. It appears that narrower filters may in general result in a higher efficiency (CE);

Further, it appears that a shorter wavelength filter may lead to a lower R9 and to a higher efficiency (CE), whereas a longer wavelength filter may lead to a higher R9 but a lower efficiency (CE);

About the same simulations were executed to provide system light having a CCT of 3000 K:

Laser 1:	440, 450 and 460 nm, FWHM=3 nm
Laser 2:	470, 480 and 490 nm, FWHM=3 nm
Fraction of laser 2:	0-0.5 in 0.1 steps
Strength of filter:	0.6-1.65 in 0.15 steps
Filter position:	530-580 nm in 5 nm steps (short wavelength edge of the filter)
TrueFilterPosition:	Center of transmission minimum
Filter width:	10, 20, 30 nm (slope: 3 nm)

For 3000 K, and with a CRI of at least 80, all three blue wavelength pump lasers can be used;

For 3000 K, and with a CRI of at least 80, all three cyan wavelength pump lasers can be used;

For 3000 K, a filter strength in the range of about 0.6-1.65 may be desirable to get CRI's of at least 80, such as a filter strength of at least 0.75;

For CRI of at least 80, an R9 of at least 0, and a CE of at least 200 lumen/Watt, true filter positions can be selected from the range of 565-575 nm, at e.g. 3000 K CCT;

For 3000 K, the filter width should especially be larger than 10 nm, such as selected from the range of 15-30 nm.

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

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

CLAIMS:

1. A light generating system (1000) comprising (a) two or more solid state light sources (100), (b) a single luminescent material (200), and an optical filter (410), wherein:

- the two or more solid state light sources (100) are configured to generate (i) first light (111), having a first peak wavelength (λ_{pw1}), and (ii) second light (121), having a second peak wavelength (λ_{pw2}); wherein the first peak wavelength (λ_{pw1}) and the second peak wavelength (λ_{pw2}) are selected from the range of 430-495 nm; and wherein $| \lambda_{pw1} - \lambda_{pw2}| \geq 10$ nm, wherein the two or more solid state light sources (100) comprise a first solid state light source (110) configured to generate the first light (111) and a second solid state light source (120) configured to generate the second light (121), and wherein the first solid state light source (110) and the second solid state light source (120) are selected from the group of laser diodes and superluminescent diodes;

- the single luminescent materials (200) is configured to convert part of the one or more of the first light (111) and the second light (121) into luminescent material light (201); wherein the luminescent material light (201) has one or more emission bands with:

(i) a first intensity (I_1) at one or more first wavelengths selected from a first wavelength range of λ_{11}-λ_{12},

(ii) a second intensity (I_2) at one or more second wavelengths selected from a second wavelength range of λ_{21}-λ_{22}, and

(iii) a third intensity (I_3) at one or more third wavelengths selected from a third wavelength range of λ_{31}- λ_{32}; wherein:

- λ_{11} is selected from the range of 485-505 nm;
- $\lambda_{12} \leq \lambda_{21}$;
- λ_{12} and λ_{21} are selected from the range of 520-580 nm;
- $\lambda_{22} = \lambda_{21}+\lambda_f$;
- $\lambda_f \geq 5$ nm
- $\lambda_{22} \leq \lambda_{31}$;
- λ_{22} and λ_{31} are selected from the range of 570-620 nm;
- λ_{32} is selected from the range of 650-780 nm;

- the optical filter (410) is configured downstream of the one or more luminescent materials (200), wherein the optical filter is configured to reduce the second intensity (I_2) relative to the first intensity (I_1) and relative to the third intensity (I_3);
- in an operational mode of the light generating system (1000) the light generating system is configured to generate white system light (1001) comprising the first light (111), the second light (121), and the luminescent material light (201) and wherein the white system light (1001) has a color rendering index (CRI) of at least 80.

2. The light generating system (1000) according to claim 1, wherein the first solid state light source (110) and the second solid state light source (120) are laser diodes.

3. The light generating system (1000) according to any one of the preceding claims, wherein one of the first peak wavelength (λ_{pw1}) and the second peak wavelength (λ_{pw2}) is at least 470 nm, and wherein one of the first peak wavelength (λ_{pw1}) and the second peak wavelength (λ_{pw2}) is at maximum 460 nm.

4. The light generating system (1000) according to any one of the preceding claims, wherein the two or more solid state light sources (100) comprise two types of solid state light sources.

5. The light generating system (1000) according to any one of the preceding claims, wherein the optical filter (410) comprises a neodymium doped glass filter.

6. The light generating system (1000) according to any one of the preceding claims, wherein the optical filter (410) comprises a dichroic filter.

7. The light generating system (1000) according to any one of the preceding claims, wherein the optical filter (410) has the first average transmission T_{1a} over a first wavelength range of 430-570 nm, the second average transmission T_{2a} over a second wavelength range of 570-620 nm, and the third average transmission T_{3a} over a third wavelength range of 620-680 nm, wherein $T_{2a}/T_{1a} \leq 0.95$ and $T_{2a}/T_{3a} \leq 0.95$.

8. The light generating system (1000) according to any one of the preceding claims, wherein the optical filter (410) has a spectral filter width (λ_W) selected from the range

of 5-40 nm, wherein the spectral filter width (λ_W) is defined by the half minimum transmission wavelengths (λ_{T50_1},λ_{T50_2}) at both sides of a transmission minimum, the transmission minimum having a transmission minimum wavelength (λ_{Tmin}) and a minimum transmission value (T_{min}), wherein for the half minimum transmission wavelengths (λ_{T50_1},λ_{T50_2}) apply that the transmission is 100-0.5*(100-T_{min}), and wherein the filter wavelength (λ_{TP}) is defined by the wavelength middle between the half minimum transmission wavelengths (λ_{T50_1},λ_{T50_2}), wherein the filter wavelength (λ_{TP}) is selected from range of 560-590 nm.

9. The light generating system (1000) according to any one of the preceding claims, wherein the single luminescent material (200) 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, 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.

10. The light generating system (1000) according to any one of the preceding claims 2-9, wherein the two or more solid state light sources (100) further comprise a red laser diode.

11. The light generating system (1000) according to any one of the preceding claims 1-9, wherein the single luminescent material (200) is configured remote from the two or more solid state light sources (100).

12. The light generating system (1000) according to any one of the preceding claims, comprising an integrated light source package (600), wherein the integrated light source package (600) comprises a common support member (610) configured to support the two or more solid state light sources (100) and the one or more luminescent materials (200), wherein common support member (610) comprises a thermally conductive support (500).

13. The light generating system (1000) according to any one of the preceding claims, wherein in the operational mode of the light generating system (1000) the light generating system (1000) is configured to generate white system light (1001) having a correlate color temperature selected from the range of 2700-6500 K and an R_9 value of equal to or larger than 0.

14. The light generating system (1000) according to any one of the preceding claims, wherein in the operational mode the white system light (1001) has a first system light intensity (I_{S1}) in a first wavelength range of 495-570 nm, (ii) a second system light intensity (I_{S2}) in a second wavelength range of 570-620 nm, and (iii) a third system light intensity (I3) in a third wavelength range of 620-780 nm; wherein $0.2 \leq I_{S2}/I_{S1} \leq 1.8$ and wherein $0.4 \leq I_{S2}/I_{S3} \leq 2$.

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

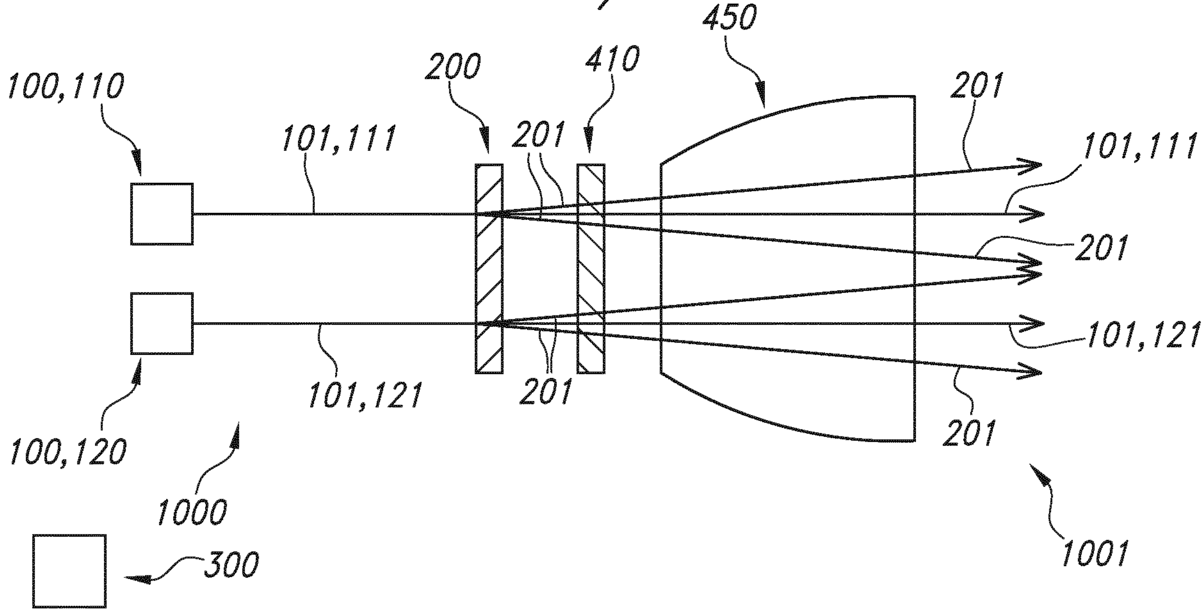

100,110
101,111
200
201
410
450
201
101,111
201
101,121
100,120
101,121
201
201
1000
300
1001

FIG. 1A

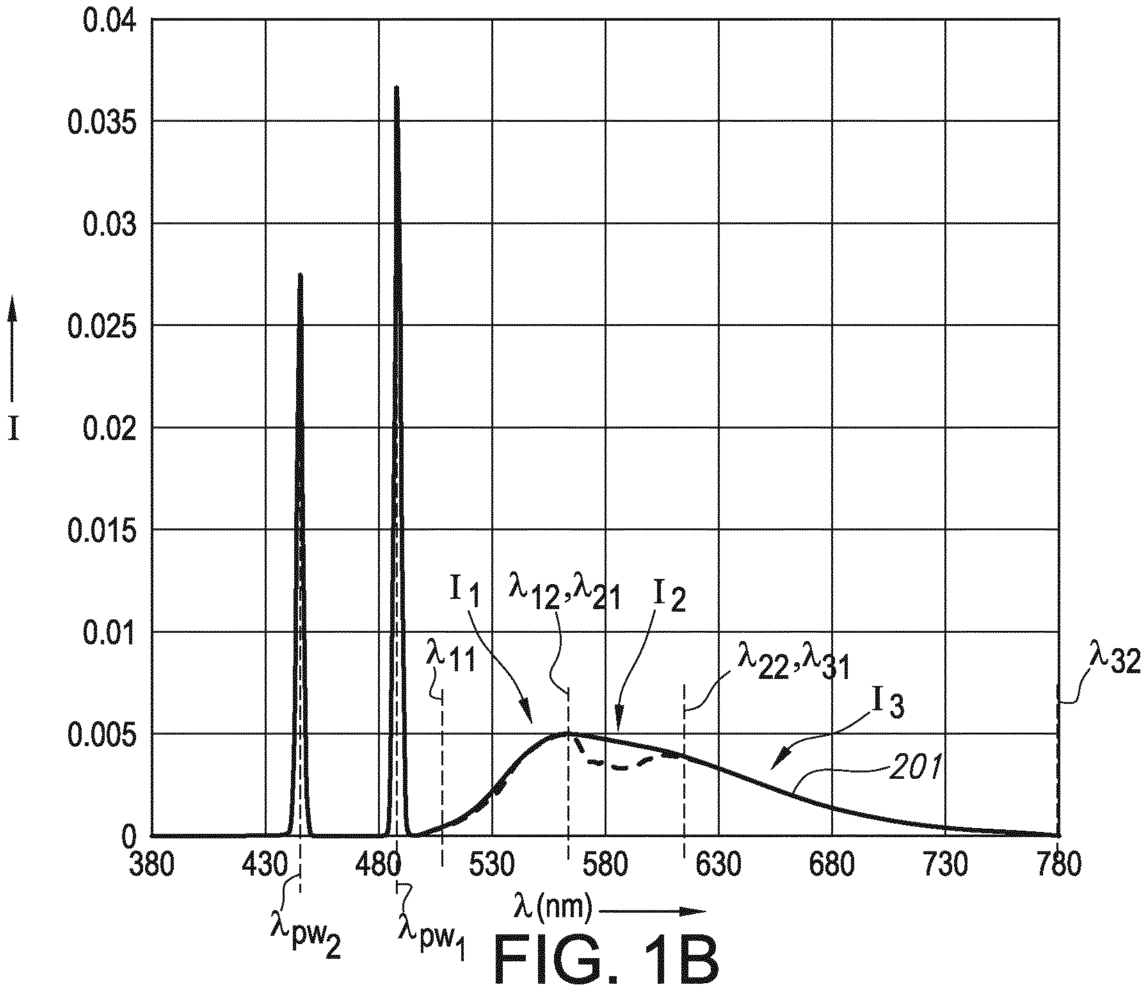

0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
I
380
430
480
530
580
630
680
730
780
λ(nm)
λ_{pw_2}
λ_{pw_1}
I_1
$\lambda_{12},\lambda_{21}$
I_2
λ_{11}
$\lambda_{22},\lambda_{31}$
I_3
λ_{32}
201

FIG. 1B

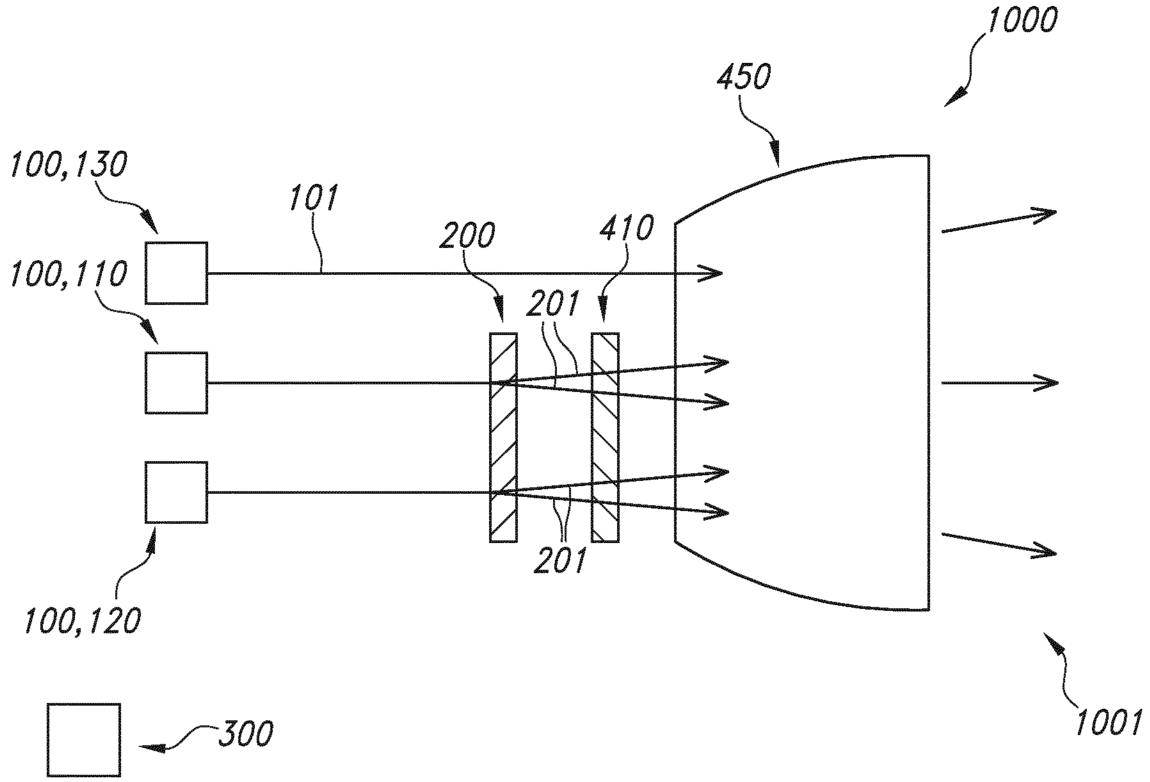
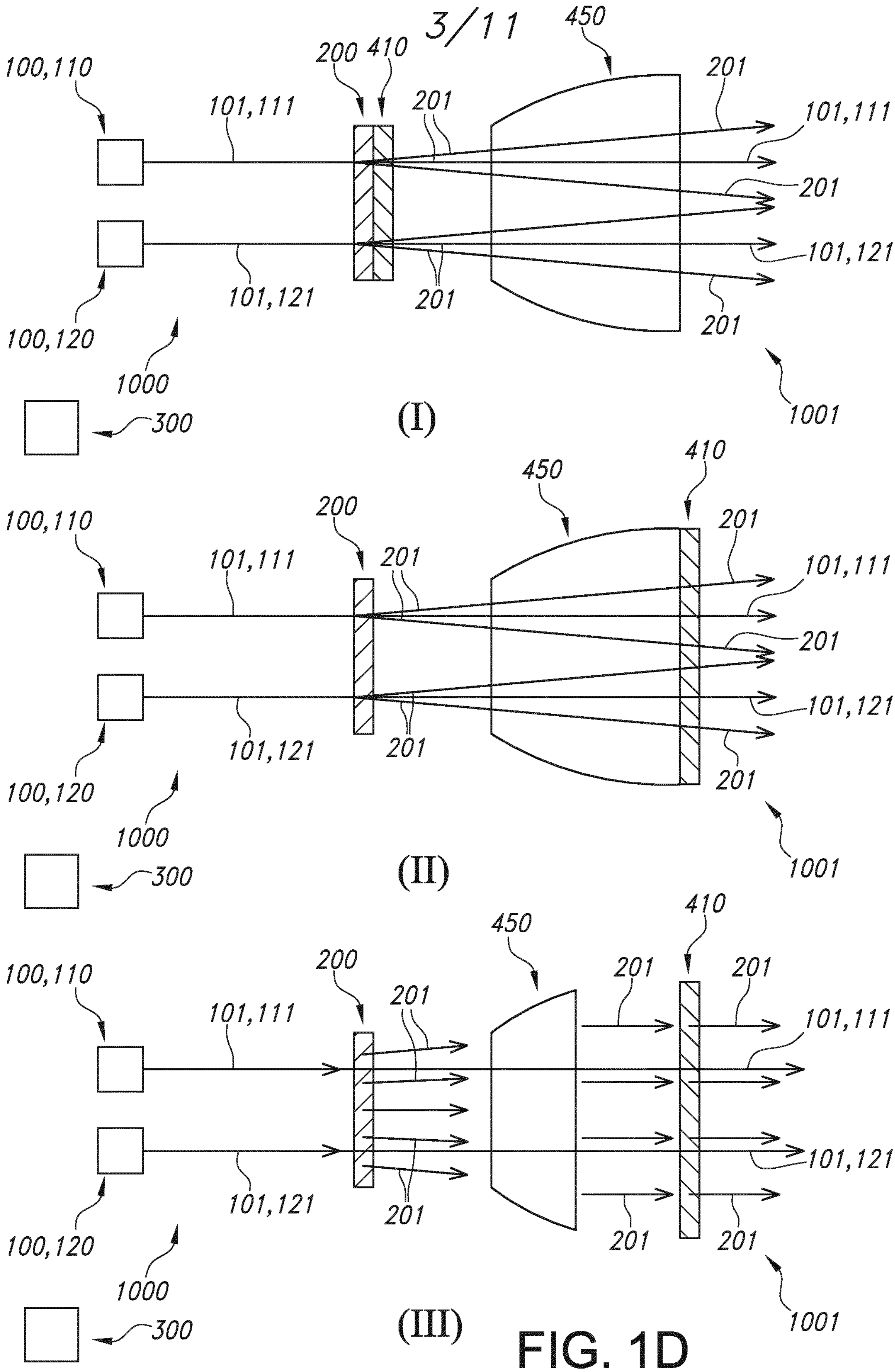
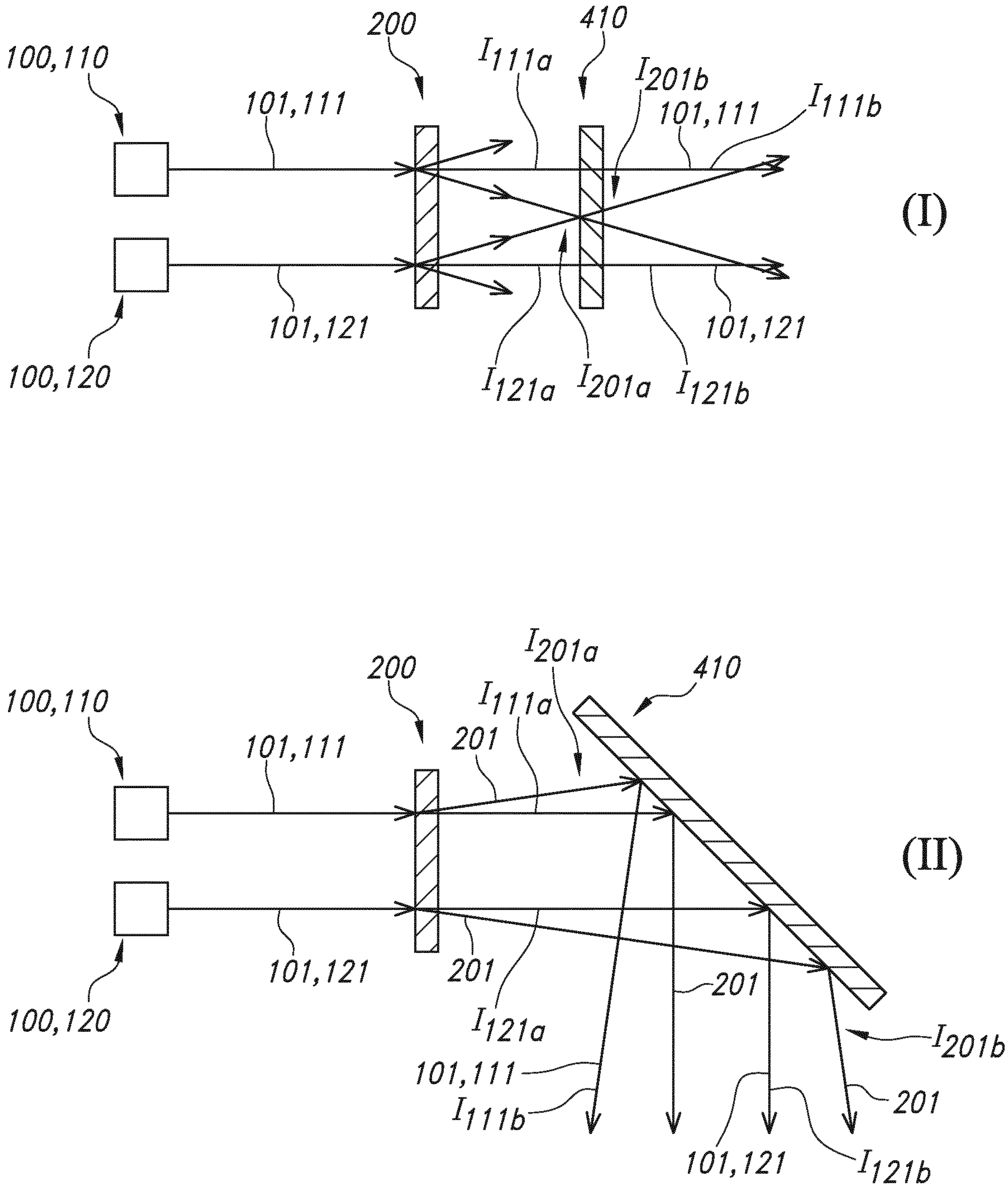


FIG. 1C



450
100,110
200
410
201
101,111
201
101,111
201
101,121
101,121
201
201
100,120
1000
1001
300
(I)
100,110
450
410
200
201
201
101,111
101,111
201
101,121
101,121
201
201
100,120
1000
1001
300
(II)
100,110
450
410
200
201
201
201
101,111
101,111
101,121
101,121
201
201
201
100,120
1000
1001
300
(III)

FIG. 1D



100,110
101,111
200
410
I_{111a}
I_{201b}
101,111
I_{111b}
(I)
100,120
101,121
I_{121a}
I_{201a}
I_{121b}
101,121
100,110
101,111
200
I_{201a}
I_{111a}
410
201
(II)
100,120
101,121
201
I_{121a}
201
I_{201b}
101,111
I_{111b}
201
101,121
I_{121b}

FIG. 2A

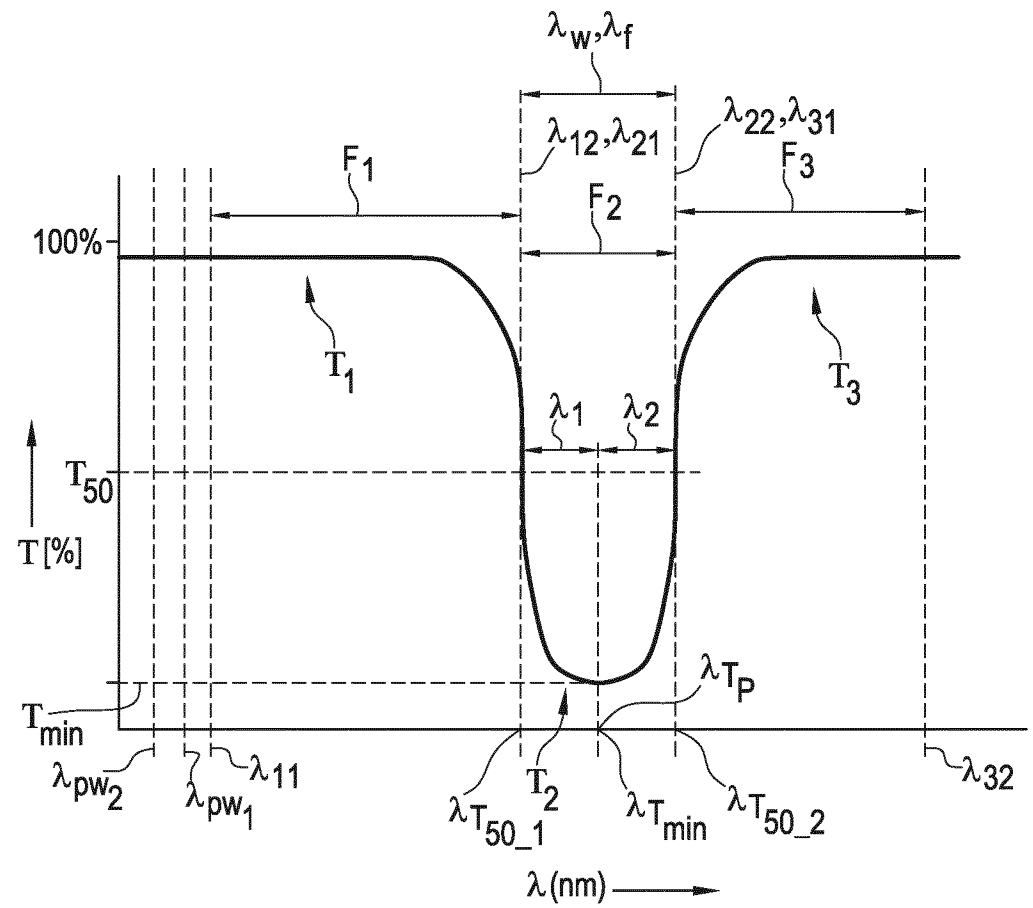
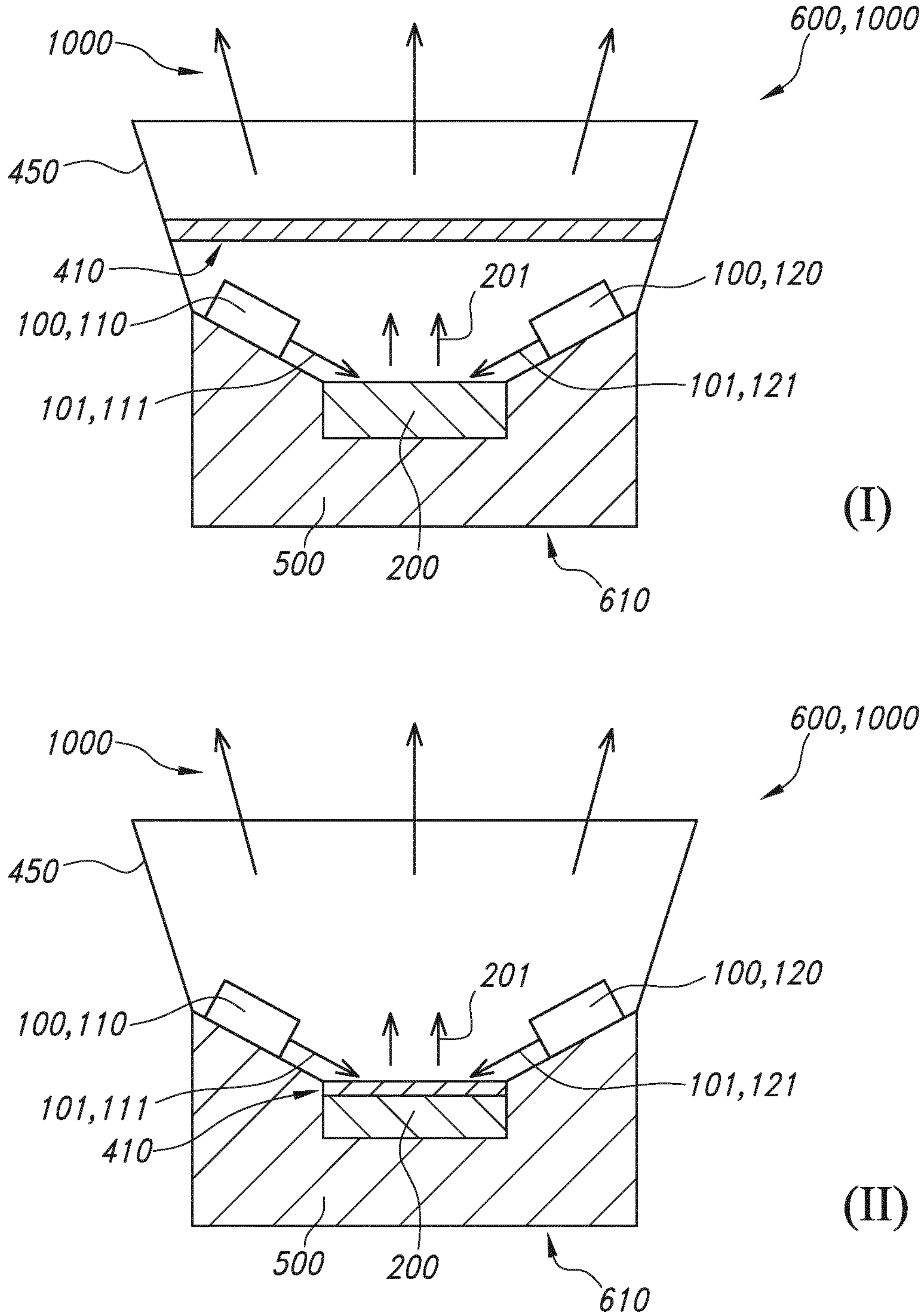

λ_w, λ_f
$\lambda_{12}, \lambda_{21}$
$\lambda_{22}, \lambda_{31}$
F_1
F_2
F_3
100%
T_1
T_3
λ_1
λ_2
T_{50}
T [%]
T_{min}
λ_{T_P}
λ_{pw_2}
λ_{pw_1}
λ_{11}
T_2
$\lambda_{T_{50\_1}}$
$\lambda_{T_{min}}$
$\lambda_{T_{50\_2}}$
λ_{32}
λ (nm)

FIG. 2B



1000
600,1000
450
410
201
100,120
100,110
101,111
101,121
(I)
500
200
610
1000
600,1000
450
201
100,120
100,110
101,121
101,111
410
(II)
500
200
610

FIG. 2C

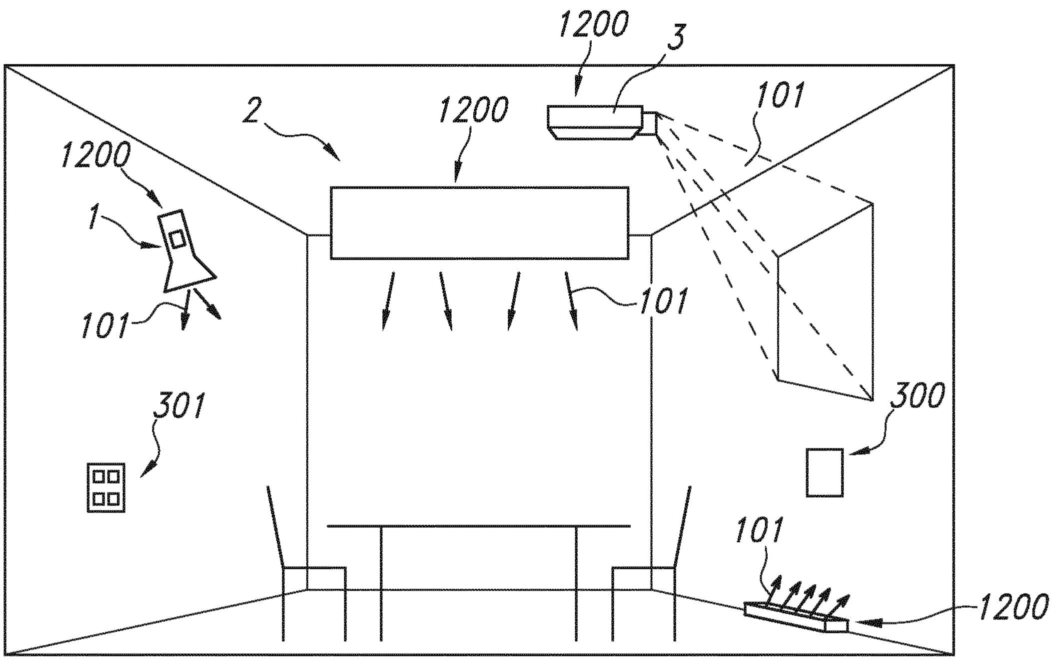


FIG. 3

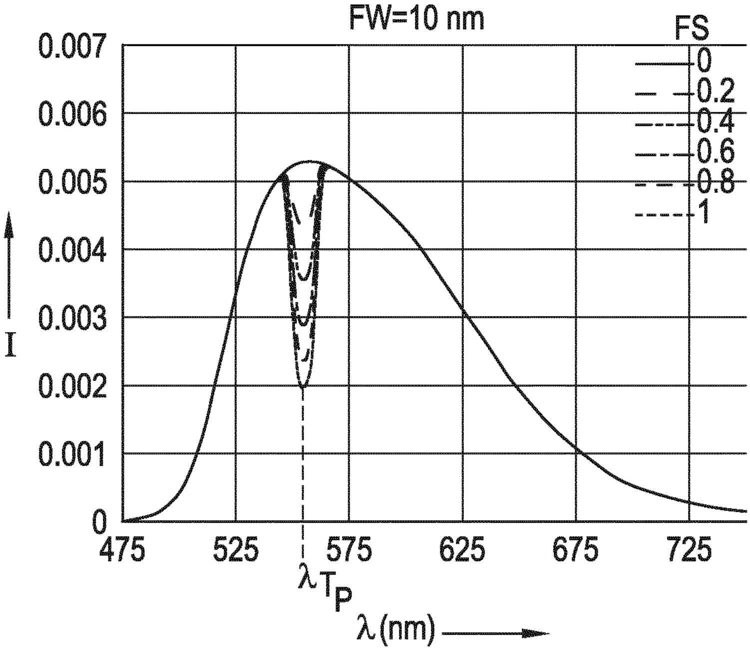

FW=10 nm
FS
0
0.2
0.4
0.6
0.8
1
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
I
475
525
575
625
675
725
λ_{T_P}
λ (nm)

FIG. 4A

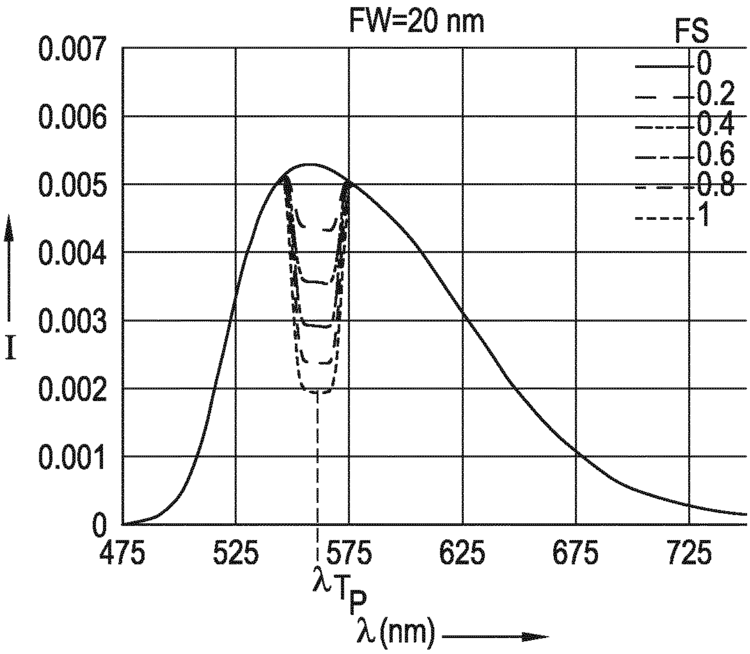

FW=20 nm
FS
0
0.2
0.4
0.6
0.8
1
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
I
475
525
575
625
675
725
λ_{T_P}
λ (nm)

FIG. 4B

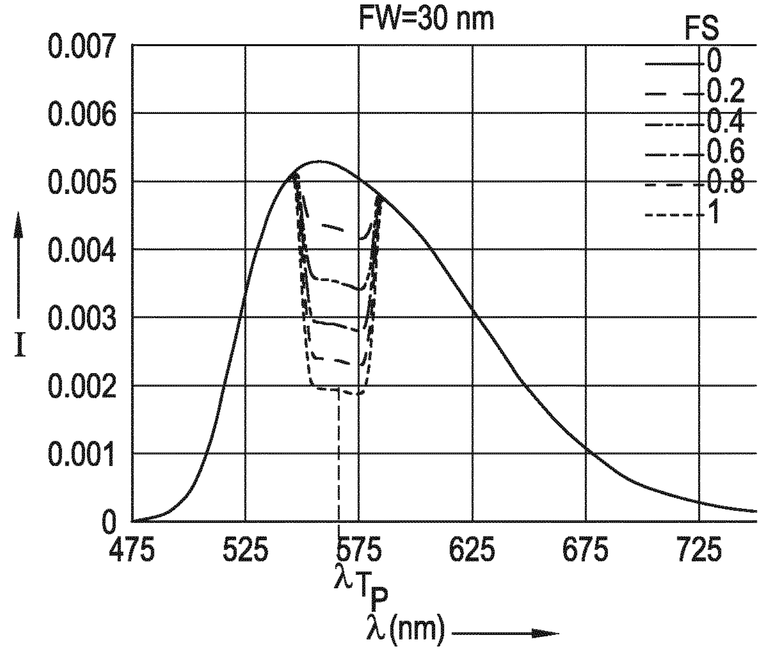

FW=30 nm
FS
0
0.2
0.4
0.6
0.8
1
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
I
475
525
575
625
675
725
λ_{T_P}
λ(nm)

FIG. 4C

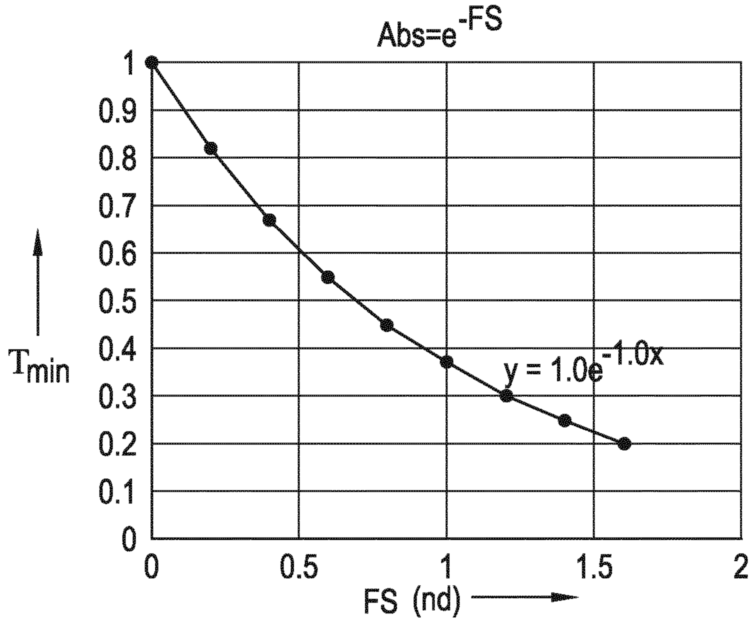

Abs=e^{-FS}
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
T_{min}
y = 1.0e$^{-1.0x}$
0
0.5
1
1.5
2
FS (nd)

FIG. 4D

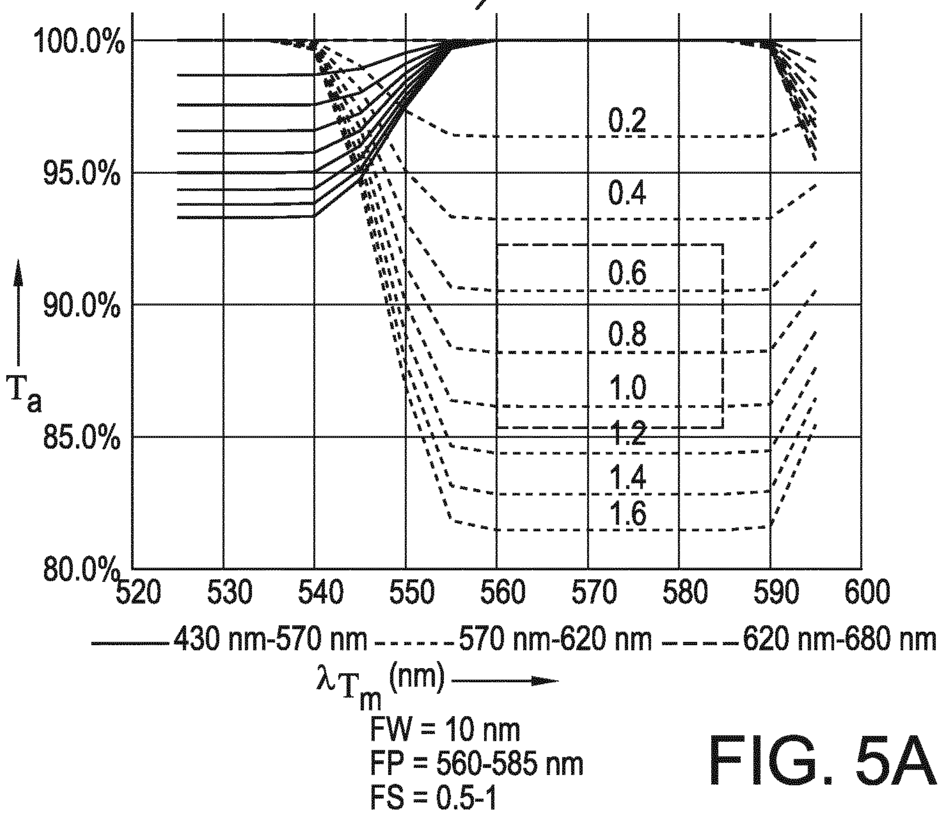

100.0%
95.0%
90.0%
85.0%
80.0%
T_a
520 530 540 550 560 570 580 590 600
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
430 nm-570 nm
570 nm-620 nm
620 nm-680 nm
λ_{T_m} (nm)
FW = 10 nm
FP = 560-585 nm
FS = 0.5-1

FIG. 5A

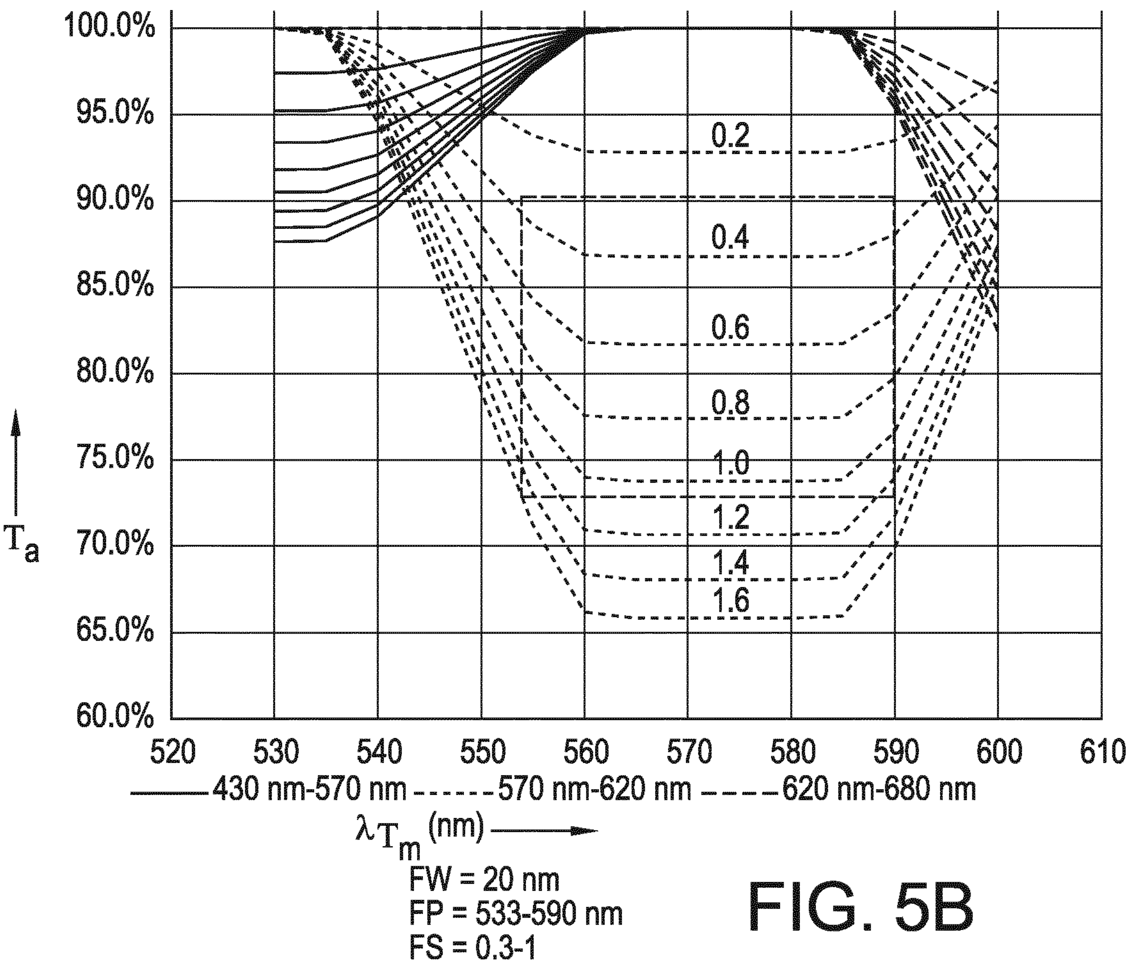

100.0%
95.0%
90.0%
85.0%
80.0%
75.0%
70.0%
65.0%
60.0%
T_a
520 530 540 550 560 570 580 590 600 610
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
430 nm-570 nm
570 nm-620 nm
620 nm-680 nm
λ_{T_m} (nm)
FW = 20 nm
FP = 533-590 nm
FS = 0.3-1

FIG. 5B

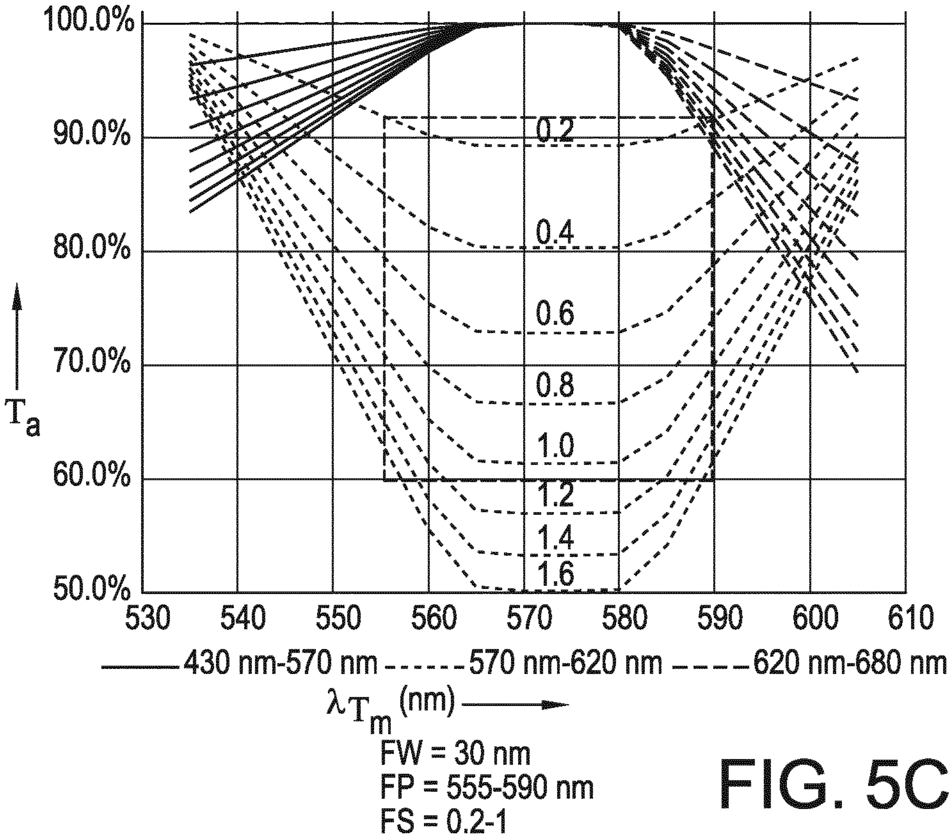

100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
T_a
530 540 550 560 570 580 590 600 610
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
430 nm-570 nm
570 nm-620 nm
620 nm-680 nm
λ_{T_m} (nm)
FW = 30 nm
FP = 555-590 nm
FS = 0.2-1

FIG. 5C

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2022/065354

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L25/075 H01L33/50
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01L

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 2020/088359 A1 (WANG TIEJUN [CN] ET AL) 19 March 2020 (2020-03-19) the whole document -----	1-15
A	US 2015/311402 A1 (VAN DE VEN ANTONY PAUL [CN]) 29 October 2015 (2015-10-29) paragraph [0099] paragraph [0146] figure 20 -----	1-15
A	US 2014/055982 A1 (TAO DEJIE [US] ET AL) 27 February 2014 (2014-02-27) paragraph [0063] figure 8 -----	1-15

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 August 2022	07/09/2022

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	But, Gabriela-Ileana

1

Form PCT/ISA/210 (second sheet) (April 2005)

International application No
PCT/EP2022/065354

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013/100639 A1 (LI YI [US] ET AL) 25 April 2013 (2013-04-25) paragraph [0050] paragraph [0063] figure 10 -----	1-15
A	WO 2017/141415 A1 (HOYA CORP [JP]) 24 August 2017 (2017-08-24) figure 9 -----	1-15

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2022/065354

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2020088359 A1	19-03-2020	CA 3027287 A1	18-03-2020
		US 2020088359 A1	19-03-2020
US 2015311402 A1	29-10-2015	NONE	
US 2014055982 A1	27-02-2014	US 2014055982 A1	27-02-2014
		US 2015022998 A1	22-01-2015
US 2013100639 A1	25-04-2013	CN 102520571 A	27-06-2012
		EP 2778505 A1	17-09-2014
		US 2013100639 A1	25-04-2013
		WO 2013063976 A1	10-05-2013
WO 2017141415 A1	24-08-2017	CN 209091322 U	12-07-2019
		JP 6686127 B2	22-04-2020
		JP WO2017142095 A1	20-12-2018
		WO 2017141415 A1	24-08-2017
		WO 2017142095 A1	24-08-2017