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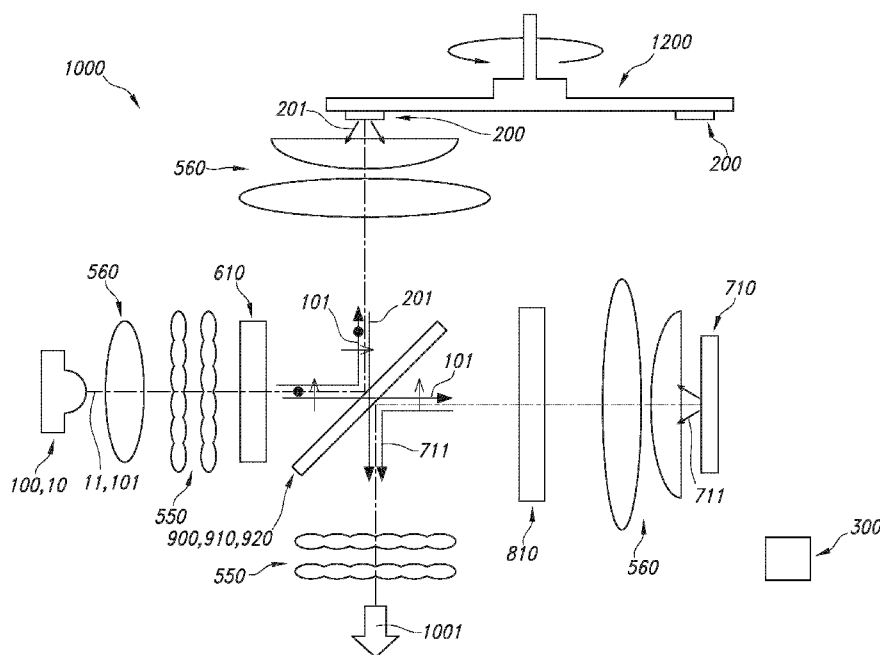


FIG. 1

(57) Abstract: The invention provides a light generating system comprising one or more light generating devices, a luminescent material, a diffuser element, a polarization changing element, central optics, and a control system, wherein: (A) the one or more light generating devices are configured to generate device light; wherein the one or more light generating devices comprise light sources selected from a laser diode and a superluminescent diode; wherein the device light received by the central optics comprises a controllable polarization; (B) the luminescent material is configured to convert at least part of the device light received by the luminescent material into luminescent material light; (C) the diffuser element is configured to diffuse at least part of the device light received by the diffuser element thereby providing diffused device light while maintaining at least part of the polarization; (D) the polarization changing element is configured in an optical path of the device light between the central optics and the diffuser element; (E) the central

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optics comprises (i) a central optics polarizing beam splitter, and (ii) a central optics dichroic beam splitter; wherein the central optics are configured to transmit and/or reflect device light, diffused device light, and luminescent material light, received by the central optics in dependence of one or more of their polarizations and their spectral power distributions; (F) the control system is configured to control the polarization of the device light received by the central optics; (G) the light generating system is configured to provide system light comprising one or more of diffused device light and luminescent material light; and wherein the light generating system is configured such that in a first operational mode of the light generating system (a) at least part of the device light irradiates the luminescent material via the central optics, and the luminescent material light escapes from the light generating system via the central optics, and (b) at least part of the device light irradiates the diffuser element via the central optics, and at least part of the diffused device light escapes from the light generating system via the central optics.

HIGH FLUX LASER PHOSPHOR ENGINE WITH PARTIAL POLARIZATION BEAM SPLITTER AND TUNABLE COLOR POINT

FIELD OF THE INVENTION

The invention relates to a light generating system. The invention further relates to a lighting device comprising the light generating system.

5 BACKGROUND OF THE INVENTION

Laser-phosphor based stage lighting engines are known in the art. For instance, WO2022143318 describes a light emitting device, comprising a first light source, a second light source, a dichroic mirror, a wavelength conversion apparatus, a first light path adjusting apparatus or a second light path adjusting apparatus, and a first scattering optical
10 system. The light mixing effect of emergent light can be improved by using the first scattering optical system. Light emitted by the first light source is all used for exciting the wavelength conversion apparatus.

SUMMARY OF THE INVENTION

15 High brightness light sources can be used in various applications including spots, stage-lighting, headlamps, home and office lighting, and automotive lighting. For this purpose, laser-phosphor technology can be used, wherein a laser provides laser light and a remote phosphor converts laser light into converted light. A relatively straightforward way to produce white light using lasers is to use laser light in combination to generate phosphor
20 converted light. Laser-phosphor systems may allow generation of high brightness light and may therefore be used in projection systems, including displays such as cinema projectors and projectors for home, school, and office applications, car front lighting, search lighting, stage lighting, architectural lighting, and special lighting applications. However, such light engine may be capable to generate only a single color point as defined by the luminescent
25 converter. Creation of a product range providing different color points may be difficult as it may require multiple unique components to be designed, qualified, produced, and kept in stock. In other cases, e.g. in RGB LCD-based projection systems, the maximum brightness may be limited by the components used, the engine volume may be large due to the many components, and the system cost may be high due to the many dedicated components. A way

to combine pump light and luminescent light may be to use a polarizing beam splitter for the pump light, by which part of the light is reflected to the luminescent material and part is transmitted to a diffuser. However, in general the diffused light may to a large degree be depolarized, which may result in relatively high losses of diffused blue light at the beam
5 combiner where it is combined with the luminescent light into white output light.

It may be possible for example to use a white light engine comprising a polarizing beam splitter configured to reflect (almost) all of s-polarized light and to transmit (almost) all of p-polarized light. In particular, such light generating systems may include a partially polarizing beam splitter with e.g. 20% transmission of the p-polarized light. Using
10 such a partially polarizing beam splitter may provide a system with limited loss of light, however, it may also have a limited luminous flux as well as a fixed color point. It may be desirable to provide a light engine that can be easily factory calibrated with respect to requested color point and/or of which the color point can be easily adjusted by the user, while providing highly efficient collection of all the spectral contributions to the output light,
15 resulting in a high efficiency high brightness white light engine.

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.

20 According to a first aspect, the invention provides a light generating system (“system”) comprising one or more light generating devices, a luminescent material, a diffuser element, a polarization changing element, central optics, and a control system. In embodiments, the one or more light generating devices may be configured to generate device light. Especially, in embodiments, the one or more light generating devices may comprise
25 light sources selected from a laser diode and a superluminescent diode. Further, in embodiments, the device light received by the central optics may comprise a controllable polarization. The luminescent material may, in embodiments, be configured to convert at least part of the device light received by the luminescent material into luminescent material light. Further, in embodiments, the diffuser element may be configured to diffuse at least part
30 of the device light received by the diffuser element. Hence, in embodiments, the diffuser element may thereby provide diffused device light. The diffuser element may especially do so while maintaining at least part of the polarization (of the device light). Yet further, in embodiments, the polarization changing element may be configured in an optical path of the device light between the central optics and the diffuser element. In embodiments, the central

optics may comprise (i) a central optics polarizing beam splitter, and (ii) a central optics dichroic beam splitter. Especially, in embodiments, the central optics may be configured to transmit and/or reflect light received by the central optics in dependence of one or more of its polarization and its spectral power distribution. More especially, in embodiments, the central optics may be configured to transmit and/or reflect (one or more of) device light, diffused device light, and luminescent material light received by the central optics in dependence of one or more of their polarizations and their spectral power distributions. Yet further, in embodiments, the control system may be configured to control the polarization of the device light received by the central optics. Furthermore, in embodiments, the light generating system may be configured to provide system light comprising one or more of diffused device light and luminescent material light. Especially, in embodiments, the light generating system may be configured such that in a first operational mode of the light generating system (a) at least part of the device light irradiates the luminescent material via the central optics, and the luminescent material light escapes from the light generating system via the central optics, and (b) at least part of the device light irradiates the diffuser element via the central optics, and at least part of the diffused device light escapes from the light generating system via the central optics. Hence, in specific embodiments, the invention provides a light generating system comprising one or more light generating devices, a luminescent material, a diffuser element, a polarization changing element, central optics, and a control system, wherein: (A) the one or more light generating devices are configured to generate device light; wherein the one or more light generating devices comprise light sources selected from a laser diode and a superluminescent diode; wherein the device light received by the central optics comprises a controllable polarization; (B) the luminescent material is configured to convert at least part of the device light received by the luminescent material into luminescent material light; (C) the diffuser element is configured to diffuse at least part of the device light received by the diffuser element thereby providing diffused device light while maintaining at least part of the polarization; (D) the polarization changing element is configured in an optical path of the device light between the central optics and the diffuser element; (E) the central optics comprises (i) a central optics polarizing beam splitter, and (ii) a central optics dichroic beam splitter; wherein the central optics are configured to transmit and/or reflect device light, diffused device light, and luminescent material light, received by the central optics in dependence of one or more of their polarizations and their spectral power distributions; (F) the control system is configured to control the polarization of the device light received by the central optics; (G) the light generating system is configured to provide system light

comprising one or more of diffused device light and luminescent material light; and wherein the light generating system is configured such that in a first operational mode of the light generating system (a) at least part of the device light irradiates the luminescent material via the central optics, and the luminescent material light escapes from the light generating system via the central optics, and (b) at least part of the device light irradiates the diffuser element via the central optics, and at least part of the diffused device light escapes from the light generating system via the central optics.

With such system, a high power light generating system may be provided. Further, such system may allow control of spectral power distribution of the system light (of a high power system). Yet, such system may in a safe way provide high power light. The system may be relatively compact, while providing (i) relatively efficient collection of various spectral contributions to the system ("output") light and (ii) relatively easy adjustability of the color point of the (white) system light. Yet, thermal management of the luminescent material may also be provided with this system. In addition to high optical power, the system may also provide high radiance (or luminance), i.e., a high optical power density of the source. The system may be more fail-safe thanks to the reflective configuration for both the luminescent light and the diffused light, by which it can be prevented that direct laser beams emit from the system in case the luminescent component or the diffusing component would fail (e.g. break, fall off, etc.). Of course the system may also function with a static luminescent converter, but in embodiments a phosphor wheel may be used here due to its good heat spreading and cooling properties. The diffuser typically dissipates far less energy and may not be in a need of such a rotatable configuration, although a rotatable configuration of the diffuser is also an embodiment herein. However, in embodiments the diffuser may also be realized in the form of a rotating wheel. For static luminescent converters in particular, liquid cooled converter configurations may also enable high optical power as well as high optical power density. Overall, a typical advantage may be that in embodiments from two (different) laser sources only part of one source may be used for diffusion and more than one source for luminescent conversion. Thereby, such embodiments may enable the most efficient use of a combination of two laser sources while also enabling maximum output light using two laser sources, e.g. when using two sources with comparable dimensions (e.g. the same number of laser diodes in convenient configurations). Therefore, amongst others in embodiments a high flux laser phosphor engine is provided having a tunable color point, wherein the laser phosphor engine may comprise central optics having at least a (partially) polarizing beam splitter function and dichroic beam splitter function.

Hence, the invention provides a light engine that can be easily factory-calibrated with respect to the requested color point and/or of which the color point can easily be adjusted by the user, while providing highly efficient collection of all the spectral contributions to the output light, resulting in a high efficiency high brightness white light engine.

As indicated above, the light generating system may in embodiments comprise one or more light generating devices, a luminescent material, a diffuser element, a polarization changing element, central optics, and a control system.

Each light generating device may comprise a (solid state) light source. Especially, in embodiments, the one or more light generating devices may comprise light sources selected from a laser diode, a stacked multi-junction light emitting diode, and a superluminescent diode. Embodiments of light generating devices and (solid state) light sources are described below in general, and may (individually) apply to the one or more light generating devices. Hence, the light generating system may comprise one or more light generating devices. A light generating device may especially be configured to generate device light. Especially, the light generating device may comprise a light source. The light source may especially configured to generate light source light. In embodiments, the device light may essentially consist of the light source light. In other embodiments, the device light may essentially consist of converted light source light. In yet other embodiments, the device light may comprise (unconverted) light source light and converted light source light. Light source light may be converted with a luminescent material into luminescent material light and/or with an upconverter into upconverted light (see also below). The term “light generating device” may also refer to a plurality of light generating devices which may provide device light having essentially the same spectral power distributions. In (other) specific embodiments, the term “light generating device” may also refer to a plurality of light generating devices which may provide device light having different spectral power distributions.

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, an LED (light emissive diode). In a specific embodiment, the light source comprises a solid state LED light source (such as an LED or laser diode (or “diode laser”)). The term “light source” may also relate to a plurality of light sources, such as 2-2000 (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 chip-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 emitting semiconductor light source may be configured on the same substrate. In embodiments, a COB is a multi
5 LED chip configured together as a single lighting module.

The term “light source” may also refer to a chip scaled package (CSP). A CSP may comprise a single solid state die with provided thereon a luminescent material comprising layer. The term “light source” may also refer to a midpower package. A midpower package may comprise one or more solid state die(s). The die(s) may be covered
10 by a luminescent material comprising layer. The die dimensions may be equal to or smaller than 2 mm, such as in the range of e.g. 0.2-2 mm. Hence, in embodiments the light source comprises a solid state light source. Further, in specific embodiments, the light source comprises a chip scale packaged LED. Herein, the term “light source” may also especially refer to a small solid state light source, such as having a mini size or micro size. For instance,
15 the light sources may comprise one or more of mini LEDs and micro LEDs. Especially, in embodiment the light sources comprise micro LEDs or “microLEDs” or “ μ LEDs”. Herein, the term mini size or mini LED especially indicates to solid state light sources having dimensions, such as die dimension, especially length and width, selected from the range of 100 μ m – 1 mm. Herein, the term μ size or micro LED especially indicates to solid state light
20 sources having dimensions, such as die dimension, especially length and width, selected from the range of 100 μ m and smaller.

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

30 Likewise, a light generating device may comprise a light escape surface, such as an end window. Further, likewise a light generating system may comprise a light escape surface, such as an end window.

A position where system light escapes from the light generating system may also be indicated as light exit. This may be a light transmissive window or an opening (in the

system). The light transmissive window may in embodiments be provided by an optical component.

The term “light source” may refer to a semiconductor light-emitting device, such as a light emitting diode (LEDs), a laser diode, a resonant cavity light emitting diode (RCLED), a vertical cavity laser diode (VCSELs), an edge emitting laser (EEL), a photonic crystal surface emitting laser (PCSEL), a vertical external cavity surface emitting laser (VECSEL), etc... The term “light source” may also refer to an organic light-emitting diode (OLED), 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 an LED or laser diode). In an embodiment, the light source comprises an LED (light emitting diode). The terms “light source” or “solid state light source” may also refer to a superluminescent diode (SLED). 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 an 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 an LED with on-chip optics. In embodiments, the light source comprises pixelated single LEDs (with or without optics) (offering in embodiments on-chip beam steering). The term LED may also refer to a plurality of LEDs.

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 an LED with a luminescent material layer or dome comprising luminescent material. Such LEDs may be indicated as phosphor converted LEDs or PC LEDs (phosphor converted LEDs). In other embodiments, the luminescent material may be configured at some distance (“remote”) from the light source, such as an 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 converted 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
5 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. Hence, in
specific embodiments, the light source may be selected from the group of laser diodes and
10 superluminescent diodes. In other embodiments, the light source may comprise an LED.

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.

15 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
20 state light source 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 (but may also be indicated as light generating device). Hence, a white LED is a light source (but may e.g. also be indicated as (white) light generating device).

25 The term “light source” herein may also refer to a light source comprising a solid state light source, such as an LED, a stacked multi-junction light emitting diode, 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
30 luminescent converter material. Hence, the term “light source” may also refer to a combination of an 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.

In embodiments, the term “light source” may also refer to a combination of a light source, like an LED, and an optical filter, which may change the spectral power distribution of the light generated by the light source. Especially, the term “light generating device” may be used to address a light source and further (optical components), like an optical filter and/or a beam shaping element, etc.

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 “solid state light source”, or “solid state material light source”, and similar terms, may especially refer to semiconductor light sources, such as a light emitting diode (LED), a laser diode, or a superluminescent diode.

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

Hence, in embodiments the light source comprises a laser light source. In embodiments, the terms “laser” or “solid state laser” or “solid state material laser” may refer to one or more of cerium doped lithium strontium (or calcium) aluminum fluoride (Ce:LiSAF, Ce:LiCAF), chromium doped chrysoberyl (alexandrite) laser, chromium ZnSe (Cr:ZnSe) laser, divalent samarium doped calcium fluoride (Sm:CaF₂) laser, Er:YAG laser, erbium doped and erbium–ytterbium codoped glass lasers, F-Center laser, holmium YAG (Ho:YAG) laser, Nd:YAG laser, NdCrYAG laser, neodymium doped yttrium calcium oxoborate Nd:YCa₄O(BO₃)₃ or Nd:YCOB, neodymium doped yttrium orthovanadate (Nd:YVO₄) laser, neodymium glass (Nd:glass) laser, neodymium YLF (Nd:YLF) solid-state laser, promethium 147 doped phosphate glass (147Pm³⁺:glass) solid-state laser, ruby laser (Al₂O₃:Cr³⁺), thulium YAG (Tm:YAG) laser, titanium sapphire (Ti:sapphire; Al₂O₃:Ti³⁺) laser, trivalent uranium doped calcium fluoride (U:CaF₂) solid-state laser, Ytterbium doped

glass laser (rod, plate/chip, and fiber), Ytterbium YAG (Yb:YAG) laser, Yb₂O₃ (glass or ceramics) laser, etc.

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

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

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

As can be derived from the below, the term “laser light source” may also refer to a plurality of (different or identical) laser light sources. In specific embodiments, the term “laser light source” may refer to a plurality N of (identical) laser light sources. In embodiments, N=2, or more. In specific embodiments, N may be at least 5, such as especially at least 8. In this way, a higher brightness may be obtained.

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

The term “solid state material laser”, and similar terms, may refer to a solid state laser like based on a crystalline or glass body doped with ions, like transition metal ions and/or lanthanide ions, to a fiber laser, to a photonic crystal laser, to a semiconductor laser, such as e.g. a vertical cavity surface-emitting laser (VCSEL), etc.

The term “solid state light source”, and similar terms, may especially refer to semiconductor light sources, such as a light emitting diode (LED), a laser diode, or a superluminescent diode.

Instead of the term “solid state light source” also the term “semiconductor-based light source” may be applied. Hence, the term “semiconductor-based light source” may e.g. refer to one or more of a light emitting diode (LED), a laser diode, and a superluminescent diode.

Hence, the light generating device may comprise one or more of a light emitting diode (LED), a laser diode, and a superluminescent diode.

A light-emitting diode (LED) is especially a semiconductor light source that emits light when current flows through it. Electrons in the semiconductor may recombine with electron holes, releasing energy in the form of photons. The color of the light

(corresponding to the energy of the photons) may be determined by the energy required for electrons to cross the band gap of the semiconductor.

A laser diode (or diode laser) may be a semiconductor device substantially similar to a light-emitting diode in which a diode pumped directly with electrical current can create lasing conditions at the diode's junction. This is known to a person skilled in the art.

Superluminescent diodes are known in the art. A superluminescent diode may be indicated as a semiconductor device which may be able to emit low-coherence light of a broad spectrum like an LED, while having a brightness in the order of a laser diode.

US2020192017 indicates for instance that “*With current technology, a single SLED is capable of emitting over a bandwidth of, for example, at most 50-70 nm in the 800-900 nm wavelength range with sufficient spectral flatness and sufficient output power. In the visible range used for display applications, i.e. in the 450-650 nm wavelength range, a single SLED is capable of emitting over bandwidth of at most 10-30 nm with current technology. Those emission bandwidths are too small for a display or projector application which requires red (640 nm), green (520 nm) and blue (450 nm), i.e. RGB, emission*”. Further, superluminescent diodes are amongst others described, in “Edge Emitting Laser Diodes and Superluminescent Diodes”, Szymon Stanczyk, Anna Kafar, Dario Schiavon, Stephen Najda, Thomas Slight, Piotr Perlin, Book Editor(s): Fabrizio Roccaforte, Mike Leszczynski, First published: 03 August 2020 <https://doi.org/10.1002/9783527825264.ch9> in chapter 9.3 superluminescent diodes. This book, and especially chapter 9.3, are herein incorporated by reference. Amongst others, it is indicated therein that the superluminescent diode (SLD) is an emitter, which combines the features of laser diodes and light-emitting diodes. SLD emitters utilize the stimulated emission, which means that these devices operate at current densities similar to those of laser diodes. The main difference between LDs and SLDs is that in the latter case, the device waveguide may be designed in a special way preventing the formation of a standing wave and lasing. Still, the presence of the waveguide ensures the emission of a high-quality light beam with high spatial coherence of the light, but the light is characterized by low time coherence at the same time” and “*Currently, the most successful designs of nitride SLD are bent, curved, or tilted waveguide geometries as well as tilted facet geometries, whereas in all cases, the front end of the waveguide meets the device facet in an inclined way, as shown in Figure 9.10. The inclined waveguide suppresses the reflection of light from the facet to the waveguide by directing it outside to the lossy unpumped area of the device chip*”. Hence, an SLD may especially be a semiconductor light source, where the spontaneous emission light is amplified by stimulated emission in the active region of the

device. Such emission is called “super luminescence”. Superluminescent diodes combine the high power and brightness of laser diodes with the low coherence of conventional light-emitting diodes. The low (temporal) coherence of the source has advantages that the speckle is significantly reduced or not visible, and the spectral distribution of emission is much broader compared to laser diodes, which can be better suited for lighting applications. Especially, with varying electrical current, the spectral power distribution of the superluminescent diode may vary. In this way the spectral power distribution can be controlled, see e.g. also Abdullah A. Alatawi, et al., Optics Express Vol. 26, Issue 20, pp. 26355-26364, <https://doi.org/10.1364/OE.26.026355>. Hence, a superluminescent diode may be indicated as a semiconductor device which may be able to emit low-coherence light of a broad spectrum like a LED, while having a brightness in the order of a laser diode. Superluminescent diodes may combine the high power and brightness of laser diodes with the low coherence of conventional light-emitting diodes. The low (temporal) coherence of the source has advantages that the speckle is significantly reduced or not visible, and the spectral distribution of emission is much broader compared to laser diodes, which can be better suited for lighting applications. Hence, in embodiments, the solid state light source may comprise a superluminescent diode. For instance, in further specific embodiments, the solid state light source may comprise a GaN-based superluminescent diode, or an InGaN-based superluminescent diode, or an AlGaN-based superluminescent diode.

Especially, in embodiments, the one or more light generating devices comprise light sources selected from a laser diode and a superluminescent diode. More especially, in embodiments, the one or more light generating devices may comprise light sources selected from photonic crystal surface emitting lasers (PCSELs), edge emitting laser diodes and vertical cavity surface emitting laser diodes, either as individual emitters or as array of emitters. In embodiments, an array of emitting may especially be configured in a laser bank. Hence, in embodiments, the light generating system may comprise a laser bank, see also further below.

In embodiments, the device light may be unpolarized light. However, in (other) embodiments the device light may comprise one or more of polarized light having a p polarization and polarized light having an s polarization. Optionally, in embodiments, the device light may be elliptically or circularly polarized. Hence, in embodiments, the one or more light generating devices may be configured to generate polarized device light. In embodiments, the light generating devices may especially be configured to generate device light having a controllable polarization. Hence, in specific embodiments, the polarization of

the device light may be controllable, such as using one or more of (i) polarization control optics, and (ii) using two or more light generating devices generating device light having different (linear, circular or elliptical) polarizations. Further, in embodiments, a degree of polarization of the polarized light may be controlled. In specific embodiments, the control system may (further) be configured to control the polarization of the device light, see also above and further below.

Especially, in embodiments the degree of polarization may be defined as a percentage of the p-polarized light or the s-polarized light relative to the total of s-polarized light and p-polarized light. For determining the percentages, the angular luminance of the device light having s polarization and the angular luminance of the device light having p polarization may be applied. For instance, the device light may have 20% s polarization and 80% p polarization. For the angular luminance, see e.g. Blom, S. et al., Towards a polarized light-emitting backlight: Micro-structured anisotropic layers, DOI- 10.1889/1.1827869, Journal of the Society for Information Display, September 2002, p. 209-213. Instead of the angular luminance, also the luminance may be applied. Yet, (in general) the term “degree of polarization” is known in the art. Especially, in embodiments the degree of polarization may be defined as a percentage of the p-polarized light and/or the s-polarized light relative to the total of p-polarized light and s-polarized light. Measurement of the degree of polarization is known in the art, and may be based on Stokes parameters.

Herein, instead of the term “s-polarized light”, and similar terms, also the term “linear s-polarized light” may be applied. Further, especially, instead of the term “p-polarized light”, and similar terms, also the term “linear p-polarized light” may be applied.

Furthermore, in specific embodiments, the device light may be blue light. The terms “blue light” or “blue emission”, and similar terms, may especially relate to light having a wavelength in the range of about 440-490 nm (including some violet and cyan hues). In specific embodiments, the blue light may have a centroid wavelength in the 440-490 nm range.

Yet further, the light generating system comprises a luminescent material. The luminescent material is, in embodiments, especially configured in a light-receiving relationship with the central optics. Furthermore, the luminescent material may be configured to convert at least part of the device light received by the luminescent material into luminescent material light. Especially, in embodiments, the luminescent material may be configured to convert at least 70%, such as at least 80%, like at least 90%, especially at least 95%, including at least 98% of the device light received by the luminescent material into

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

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

In embodiments, the term “luminescence” may refer to phosphorescence. In embodiments, the term “luminescence” may also refer to fluorescence. Instead of the term “luminescence”, also the term “emission” may be applied. Hence, the terms “first radiation” and “second radiation” may refer to excitation radiation and emission (radiation), respectively. Likewise, the term “luminescent material” may in embodiments refer to phosphorescence and/or fluorescence.

The term “luminescent material” may also refer to a plurality of different luminescent materials. Examples of possible luminescent materials are indicated below. Hence, the term “luminescent material” may in specific embodiments also refer to a luminescent material composition. Instead of the term “luminescent material” also the term “phosphor” may be applied. These terms are known to the person skilled in the art.

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. Alternatively or additionally, the

luminescent material(s) may be selected from silicates, especially doped with divalent europium.

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
 5 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.
 10 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 may comprise aluminum (Al); however, in addition to aluminum, B may also partly comprise gallium (Ga) and/or scandium (Sc) and/or
 15 indium (In), especially up to about 20% of B, more especially up to about 10 % of B (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).
 20 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
 25 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.

30 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 $(Y_{x1}A'_{x2}Ce_{x3})_3(Al_{y1}B'_{y2})_5O_{12}$, wherein $x_1+x_2+x_3=1$, wherein $x_3>0$, wherein $0<x_2+x_3\leq 0.2$, wherein $y_1+y_2=1$, wherein especially $0\leq y_2\leq 0.2$, 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, x_3 is selected from the range of 0.001-0.1. In the present invention, especially $x_1 > 0$, such as > 0.2 , like at least 0.8. Garnets with Y may provide suitable spectral power distributions.

5 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 x_3 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 (optionally in combination with
10 (the) light of other sources of light as described herein). 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 $(Y_{x_1}(Lu, Gd)_{x_2}Ce_{x_3})_3(Al_{y_1}Ga_{y_2})_5O_{12}$, wherein Lu and/or Gd may be available. Even more especially, x_3 is selected from the range of 0.001-0.1, wherein $0 < x_2 + x_3 \leq 0.1$, and wherein $0 \leq y_2 \leq 0.1$. Further, in specific embodiments, at maximum 1% of B-O may be replaced by Si-N. Here, the percentage refers to moles (as known in the art); see e.g. also EP3149108. In yet further specific embodiments, the luminescent material comprises $(Y_{x_1}Ce_{x_3})_3Al_5O_{12}$, wherein $x_1 + x_3 = 1$, and wherein $0 < x_3 \leq 0.2$, such as 0.001-0.1.

20 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 $(Y_{x_1}A'_{x_2}Ce_{x_3})_3(Al_{y_1}B'_{y_2})_5O_{12}$. 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 $(Y_{x_1}A'_{x_2}Ce_{x_3})_3(Al_{y_1}B'_{y_2})_5O_{12}$. 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 $x_1 + x_2 + x_3 = 1$, wherein $x_3 > 0$, wherein $0 < x_2 + x_3 \leq 0.2$, wherein $y_1 + y_2 = 1$, wherein
25 $0 \leq y_2 \leq 0.2$. Especially, x_3 is selected from the range of 0.001-0.1. Note that in embodiments $x_2 = 0$. Alternatively or additionally, in embodiments $y_2 = 0$.

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

Alternatively or additionally, the luminescent material may comprise 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
5 comprise one or more of $MS:Eu^{2+}$ and/or $M_2Si_5N_8:Eu^{2+}$ and/or $MAISiN_3:Eu^{2+}$ and/or $Ca_2AlSi_3O_2N_5:Eu^{2+}$, etc., wherein M comprises one or more of Ba, Sr, and Ca, especially in embodiments at least Sr. Hence, in embodiments, the luminescent may comprise one or more materials selected from the group consisting of $(Ba,Sr,Ca)S:Eu$, $(Ba,Sr,Ca)AlSiN_3:Eu$ and $(Ba,Sr,Ca)_2Si_5N_8:Eu$. In these compounds, europium (Eu) is substantially or only divalent,
10 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
15 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
20 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
25 of Eu), especially 50 to 100%, more especially 50 to 90% Ba and 50 to 0%, especially 50 to 10% Sr, such as $Ba_{1.5}Sr_{0.5}Si_5N_8:Eu$ (i.e. 75 % Ba; 25% Sr). Here, Eu is introduced and replaces at least part of M, i.e. one or more of Ba, Sr, and Ca). Likewise, the material $(Ba,Sr,Ca)AlSiN_3:Eu$ can also be indicated as $MAISiN_3:Eu$, wherein M is one or more elements selected from the group consisting of barium (Ba), strontium (Sr) and calcium (Ca);
30 especially, M comprises in this compound calcium or strontium, or calcium and strontium, more especially calcium. Here, Eu is introduced and replaces at least part of M (i.e. one or more of Ba, Sr, and Ca). Eu in the above indicated luminescent materials is substantially or only in the divalent state, as is known to the person skilled in the art.

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

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

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

Likewise, the material (Ba,Sr,Ca)AlSiN₃:Eu can also be indicated as MAlSiN₃:Eu, wherein M is one or more elements selected from the group consisting of barium (Ba), strontium (Sr) and calcium (Ca); especially, M comprises in this compound calcium or strontium, or calcium and strontium, more especially calcium. Here, Eu is introduced and replaces at least part of M (i.e. one or more of Ba, Sr, and Ca).

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

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

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

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
5 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
10 phosphide (InP), and copper indium sulfide (CuInS₂) and/or silver indium sulfide (AgInS₂) can also be used. Quantum dots show very narrow emission band and thus they show saturated colors. Furthermore the emission color can easily be tuned by adapting the size of the quantum dots. Any type of quantum dot known in the art may be used in the present invention. However, it may be preferred for reasons of environmental safety and concern to
15 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 nanowires, etcetera.

20 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.

25 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,
30 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.

Furthermore, the luminescent material may be configured in the reflective mode or in the transmissive mode. In the transmissive mode, it may be relatively easy to have
5 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 easier, 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
10 embodiments, the luminescent material may thus be configured in thermal contact with a thermally conductive material to provide improved thermal management. For instance, the luminescent material may be configured in thermal contact with a thermally conductive element.

A thermally conductive element may especially comprise thermally conductive material. A thermally conductive material may especially have a thermal
15 conductivity of at least about 20 W/(m*K), like at least about 30 W/(m*K), such as at least about 100 W/(m*K), like especially at least about 200 W/(m*K). In yet further specific embodiments, a thermally conductive material may especially have a thermal conductivity of at least about 10 W/(m*K). In embodiments, the thermally conductive material may comprise
20 one or more of copper, aluminum, silver, gold, silicon carbide, aluminum nitride, boron nitride, aluminum silicon carbide, beryllium oxide, a silicon carbide composite, aluminum silicon carbide, a copper tungsten alloy, a copper molybdenum carbide, carbon, diamond, and graphite. Alternatively, or additionally, the thermally conductive material may comprise or
consist of aluminum oxide. In embodiments, the thermally conductive element may comprise
25 one or more of a heatsink, a heat spreader, and a two-phase cooling device. In yet other embodiments, the thermally conductive element may be configured in thermal contact with one or more of a heatsink, a heat spreader, and a two-phase cooling device, and may e.g.
transfer heat to such heatsink, heat spreader, or two-phase cooling device, via another thermally conductive element. An element may be considered in “thermal contact” with
30 another element if it can exchange energy through the process of heat. Hence, the elements may be thermally coupled. In embodiments, thermal contact can be achieved by physical contact. In embodiments, thermal contact may be achieved via a thermally conductive material, such as a thermally conductive glue (or thermally conductive adhesive). Thermal contact may also be achieved between two elements when the two elements are arranged relative to each other at a distance of equal to or less than about 10 μm , though larger

distances, such as up to 100 μm may be possible. The shorter the distance, the better the thermal contact. Especially, the distance is 10 μm or less, such as 5 μm or less, such as 1 μm or less. The distance may be the distanced between two respective surfaces of the respective elements. The distance may be an average distance. For instance, the two elements may be in physical contact at one or more, such as a plurality of positions, but at one or more, especially a plurality of other positions, the elements are not in physical contact. For instance, this may be the case when one or both elements have a rough surface. Hence, in embodiments in average the distance between the two elements may be 10 μm or less (though larger average distances may be possible, such as up to 100 μm).

With high power irradiation of the luminescent material, the thermal load may become critical. Hence, in embodiments the luminescent material may be configured to extend in a circular configuration, such as on a disc, and irradiation of the luminescent material may be provided locally in a moving fashion during operation of the system. In this way, the luminescent material is only temporarily heated, and is allowed to cool during a (short) time before it is again irradiated. In some embodiments, the luminescent material may be configured in a static configuration with an additional movable optical component configured to provide a spot of device light moving in a (e.g. one of a circular, elliptical, linear, or even a curved line) trajectory over the luminescent material, thus irradiating different parts of the luminescent material over time. In other embodiments, the light generating system may comprise a rotatable element (such as e.g. a phosphor wheel) comprising the luminescent material. In specific embodiments, the light generating system may comprise a rotatable element, wherein the rotatable element comprises the luminescent material; wherein during operation of the light generating system in the first operational mode the rotatable element may rotates, such that over time different parts of the luminescent material are irradiated by the device light.

In embodiments, the rotatable element may comprise one of a phosphor wheel, a rotating phosphor disc, and a rotating rod comprising the luminescent material as a cylindrical track.

Hence, as described above, in embodiments, at least part of the device light is incident on the luminescent material, such that the luminescent material may be configured to convert at least part of the device light received by (or incident on) the luminescent material into luminescent material light.

Similarly, in embodiments, at least part of the device light is incident on the diffuser element, such that the diffuser element may be configured to convert at least part of

the device light received by (or incident on) the diffuser element into diffused device light. Hence, in embodiments, the light generating system may be configured to direct, in an operational mode of the light generating system, part of the device light to the luminescent material and part of the device light to the diffuser element.

5 In embodiments, the light generating system may (thus) comprise one or more operational modes. In some embodiments, there may only be a first operational mode, and in other embodiments there may be a first operational mode, a second operational mode, etc. etc. Especially, herein the term “a first operational mode” and similar terms may also refer to one or more, such as a plurality of first operational modes. Hence, in embodiments, there
10 may be a plurality of (first) operational modes.

 The diffuser element may, in embodiments, be configured to diffuse at least part of the device light received by the diffuser element. In particular, in embodiments, the diffuser element may be configured to diffuse at least 60% of the device light incident on the diffuser element, such as at least 70%, like at least 80%, especially at least 90% of the device
15 light incident on the diffuser element. Herein, the term “diffuser element” may refer to an element that diffuses or scatters light, such that soft light may be transmitted and/or reflected. In embodiments, such a diffuser element may comprise a diffusing material, such as one or more selected from the group comprising a glass, a polymeric material, a fabric, and a gel. An example of a reflective diffuser element may be a metallic coated glass diffuser showing
20 95-98% reflectance. Hence, in embodiments the diffuser element may especially be configured to diffuse by reflection (and/or transmission) at least part of the device light received by the diffuser element thereby providing diffused device light. The diffuser element may especially, in embodiments, be operated in the reflective mode. Herein, when an element is indicated to be operated in a transmissive mode this may, in embodiments, imply
25 that at one or more wavelengths the part of the radiation that is transmitted may be larger than the part of the radiation that is reflected or absorbed. Conversely, when an element is indicated to be operated in a reflective mode this may in embodiments imply that at one or more wavelengths the part of the radiation that is reflected may be larger than the part of the radiation that is transmitted or absorbed. For example, the diffuser element may consist of a
30 diffusive material which may be e.g. for 80% transmissive. Thus in such embodiments, the diffuser element may be configured in the transmissive mode. However, in other embodiments, the diffuser element may comprise the diffusive material configured in combination with a highly reflective mirror. Hence, in such embodiments, the diffuser element may be configured in the reflective mode.

The diffuser element may further, in embodiments, be configured to diffuse at least part of the device light received by the diffuser element while especially maintaining at least part of the polarization of the device light. Hence, the diffused device light generated by (and propagating from) the diffuser element may have substantially the same, such as exactly
5 the same, polarization as the device light incident on the diffuser element.

As indicated above, a polarization changing element may be configured in an optical path between the central optics and the diffuser element. Especially, the polarization changing element may be configured to change s-polarized light or p-polarized light to elliptically (especially circularly) polarized light having a first handedness (e.g. right-handed
10 or left-handed polarization). The diffuser element may subsequently, in embodiments, change the direction of the circularly polarized light, but the elliptically (especially circularly) polarized light may essentially stay circularly polarized light, but now having a second handedness (e.g. left-handed or right-handed polarization). At least part of the diffused light, having circular polarization, will subsequently propagate from the diffuser element (back) to
15 the polarization changing element, where it will be converted to (diffused) p-polarized light and/or (diffused) s-polarized light, respectively. Therefore, in some embodiments, the polarization changing element may comprise a $\lambda/4$ waveplate; wherein the polarization changing element is especially configured in an optical path of the device light between the central optics and the diffuser element. In this way, p-polarized light can be converted in
20 diffused s-polarized light, and s-polarized light can be converted in diffused p-polarized light. Hence, in specific embodiments, the polarization changing element comprises a $\lambda/4$ waveplate.

Especially, the polarization changing element may be an element that induces a 90° phase shift between the two orthogonal linear polarization components (s and p) of the
25 light. The most common way is to use birefringent material (birefringent rotators), such as a quarter-wave plate. An alternative may be to use the Faraday effect, in which case the phase shift is caused by an applied magnetic field (Faraday rotators). Another alternative may be to use any component or set of components resulting in an up to 180° relative phase shift of one polarization versus the other polarization. In embodiments, such phase shift may be the result
30 of any one of birefringent, electro-optical, thermo-optical, magneto-optical or any other principle known in the art.

As indicated above, the system may (also) comprise central optics. The term “central optics” is applied as essentially all light, i.e. the device light, the diffused device light, and the luminescent material light may, in embodiments, only escape from the system

via the central optics. Further, the device light may only reach the diffuser element or the luminescent material via the central optics. In embodiments, the central optics comprises (i) a central optics polarizing beam splitter, and (ii) a central optics dichroic beam splitter. Hence, the term “central optics polarizing beam splitter” refers to a polarizing beam splitter
5 comprised by the central optics. Likewise, the term “central optics dichroic beam splitter” refers to a dichroic beam splitter comprised by the central optics.

The central optics may, in embodiments, be configured in a light receiving relationship with the one or more light generating devices (via the polarization changing element and optionally additional optics, see also further below). In embodiments, the central
10 optics may be configured to transmit and/or reflect device light. Additionally or alternatively, in embodiments, the central optics may be configured to transmit and/or reflect diffused device light. Additionally or alternatively, in embodiments, the central optics may be configured to transmit and/or reflect luminescent material light. In specific embodiments, the device light received by the central optics may comprise a controllable polarization.
15 Therefore, whether the central optics transmits and/or reflects one or more of the device light, diffused device light, and luminescent material light may especially depend on one or more of the polarizations and the spectral power distributions of the respective types of light. Especially, in embodiments, the central optics polarizing beam splitter may be configured to transmit and/or reflect light in dependence of its polarization. Conversely, in embodiments,
20 the central optics dichroic beam splitter may be configured to transmit and/or reflect light in dependence of its spectral power distribution.

Especially, in embodiments, device light reaching the central optics may be reflected and/or transmitted by the central optics polarizing beam splitter. Especially, (a) the polarization of the device light and (b) the central optics polarizing beam splitter may be
25 configured such that (i) at least part of the device light propagates to the diffuser element (and is diffused at the diffuser element), and (ii) at least part of the diffused device light may escape from the system via the central optics. This may e.g. imply that the central optics polarizing beam splitter is at least partially transmissive for a first polarization and at least partially reflective for a second polarization, or, the other way around, this may e.g. imply
30 that the central optics polarizing beam splitter is at least partially transmissive for a second polarization and at least partially reflective for a first polarization.

The central optics polarizing beam splitter (comprised by the central optics) may be configured to transmit at least part of the s-polarized light and reflect at least part of the s-polarized light. Likewise, it may be configured to reflect at least part of the p-polarized

light and transmit at least part of the p-polarized light. The percentage of transmission and reflection for the respective polarization may be defined by the central optics polarizing beam splitter. An example of such partially polarizing beam splitter is e.g. a broadband partially polarizing beam splitter that at 450 nm transmits about 77% of p-polarized light and
5 substantially no s-polarized light, while it reflects ca. 10% of p-polarized light and 86% of s-polarized light. Another example of such partially polarizing beam splitter is e.g. a broadband partially polarizing beam splitter that at 450 nm transmits about 90% of p-polarized light and substantially no s-polarized light, while it reflects ca. 10% of p-polarized light and >95% of s-polarized light.

10 Especially, the central optics polarizing beam splitter may be configured such that for one polarization the transmittance is not complete, and thus may be partly reflected, whereas for the other polarization, the reflectance may be relatively high, and thus may have a small transmission or essentially no transmission. However, this may also be the other way around. Hence, in embodiments the central optics polarizing beam splitter may be configured
15 to transmit a larger part of the p-polarized light than a part of the s-polarized that is reflected. In other embodiments, the central optics polarizing beam splitter may be configured to transmit a larger part of the s-polarized light than a part of the p-polarized that is reflected. In yet other embodiments, the central optics polarizing beam splitter may be configured to reflect a larger part of the s-polarized light than a part of the p-polarized that is transmitted. In
20 yet other embodiments, the central optics polarizing beam splitter may be configured to reflect a larger part of the p-polarized light than a part of the s-polarized that is transmitted.

Hence, the central optics polarizing beam splitter may especially be a partially polarizing beam splitter.

Therefore, in embodiments, the central optics polarizing beam splitter may be
25 configured to transmit and/or reflect at least part of the device light, and to transmit and/or reflect at least part of the diffused device light in dependence of their polarizations. For example, in embodiments, the central optics polarizing beam splitter may be configured to transmit at least part of device light having a p-polarization and to reflect another (e.g., smaller) part of device light having a p-polarization. In such embodiments, the central optics
30 polarizing beam splitter may further be configured to reflect (at least part of, or even all of) the diffused device light. The higher the reflection of p-polarized device light, the more efficient the light generating system may become for the blue contribution in the white output system light. However, the higher the reflection of p-polarized device light, the smaller a tuning range for the color tunability becomes. Further, in other embodiments, the central

optics polarizing beam splitter may be configured to reflect at least part of device light having a s-polarization and to transmit another (e.g. smaller) part of device light having a s-polarization. In such embodiments, the central optics polarizing beam splitter may further be configured to transmit (at least part of, or even all of) the diffused device light.

5 In embodiments, luminescent material light reaching the central optics may be reflected or transmitted at the central optics dichroic beam splitter. The central optics dichroic beam splitter may be configured such that (a) diffused device light may be reflected at the central optics dichroic beam splitter when the central optics dichroic beam splitter is configured to transmit the luminescent material light, or (b) diffused device light may be transmitted at the central optics dichroic beam splitter when the central optics dichroic beam splitter is configured to reflect the luminescent material light. Examples of such dichroic beam splitter are e.g. a short-pass cut-off dichroic plate, or a long-pass cut-off dichroic plate. In specific embodiments, the central optics dichroic beam splitter may be designed for a 45° angle of incidence (of the device light).

15 In general, in embodiments, the central optics polarizing beam splitter and the dichroic beam splitter (and the optional first polarizing beam splitter and first dichroic beam splitter, see also further below) may be designed for an about 45° angle of incidence of light. Therefore, the herein indicated transmission and reflection percentages for the beam splitters may correspond to a configuration such that the beam splitters and the incident light have an average angle of incidence of 45(±5)°. Note, in embodiments where the beam splitters and the incident light have an average angle different from 45(±5)°, the herein indicated transmission and reflection percentages may still apply. However, in such embodiments, alternative design of the beam splitters (e.g. of PBS/DBS thin film stacks) may be required to provide the indicated transmission and reflection percentages under an average angle
20 different from 45(±5)°. Therefore, in embodiments, the system may be configured such that the central optics polarizing beam splitter and the dichroic beam splitter (and the optional first polarizing beam splitter and first dichroic beam splitter, see also further below) receive the respective light with its respective optical axis having an angle of incidence of 45(±5)°.

 Especially, a peak wavelength of the device light and the luminescent material
30 may be selected such that the peak wavelength of the device light and the centroid wavelength of the luminescent material light are spectrally positioned at two opposite sides of a cut-on / cut-off wavelength of a dichroic filter comprised by the central optics. Hence, the peak wavelength of the device light and the centroid wavelength of the luminescent

material, may be selected such, that the central optics dichroic beam splitter may spectrally substantially separate them, and essentially transmit one and essentially reflect the other.

Therefore, in embodiments, the central optics dichroic beam splitter may be configured to transmit or reflect at least part of the device light, to transmit or reflect at least
5 part of the diffused device light, and to transmit or reflect at least part of the luminescent material light in dependence of their spectral power distributions. For example, in embodiments, the central optics dichroic beam splitter may be configured to transmit at least part of (such as e.g. a p-polarized part of) blue device light and to transmit at least part of (e.g. green-red or yellow) luminescent material light. In such embodiments, the central optics
10 polarizing beam splitter may further be configured to reflect (at least part of, or even all of) the diffused blue device light. However, in other embodiments, the central optics dichroic beam splitter may be configured to reflect at least part of (such as e.g. a s-polarized part of) blue device light and to reflect part of (e.g. green-red or yellow) luminescent material light. In such embodiments, the central optics dichroic beam splitter may further be configured to
15 transmit (at least part of, or even all of) the diffused device light. Hence, in specific embodiments, the central optics polarizing beam splitter is configured (a1) to transmit and/or reflect at least part of the device light and (a2) to transmit and/or reflect at least part of the diffused device light; and the central optics dichroic beam splitter is configured (b1) to transmit or reflect at least part of the device light, (b2) to transmit or reflect at least part of the
20 diffused device light, and (b3) to reflect or transmit at least part of the luminescent material light.

In embodiments, the light generating system may be configured to provide system light. Especially, in embodiments, the system light may comprise one or more of diffused device light and luminescent material light. Therefore, the light generating system
25 may be configured such that in a first operational mode of the light generating system at least part of the device light may propagate from the light generating device via the central optics to the luminescent material and another part of the device light may propagate from the light generating device via the central optics to the diffuser element. The device light irradiating the luminescent material may, in embodiments, be converted into luminescent material light.
30 The (generated) luminescent material light may then escape from the light generating system (again) via the central optics. The device light irradiating the diffuser element may, in embodiments, be converted into diffused device light. The (generated) diffused device light may then escape from the light generating system (again) via the central optics. Therefore, the central optics polarizing beam splitter, and the central optics dichroic beam splitter are

configured such that at least part of the diffused device light reaching the central optics, and at least part of the luminescent material light reaching the central optics may escape from the system in essentially the same directions. Especially, this may imply that one of the diffused device light and the luminescent material light is transmitted by the central optics and the other one of the diffused second device light and the luminescent material light is reflected by the central optics. Hence, the system may especially be configured such that diffused device light propagating to the central optics and luminescent material light propagating to the central optics have a mutual angle of (about) 90° . Hence, the light generating system may be configured such that diffused device light and luminescent material light propagating orthogonal to the central optics may escape (in the same direction) from the system via the central optics to provide system light comprising the diffused device light and luminescent material light. The system light may especially escape from a light exit of the system (see also above).

As described above, in embodiments, the device light may be blue device light. Hence, in embodiments, the device light has a wavelength selected from the blue wavelength range. Furthermore, in embodiments, the luminescent material light may have a wavelength selected from the green-red wavelength range. Through the combination of the (blue diffused) device light and the (green-red) luminescent material light in the first operational mode, the system light may thus, in embodiments, be white light. Especially, in such embodiments, in the first operational mode the system light may comprise for at least 85%, such as at least 90%, like at least 95%, especially at least 98%, including 100% diffused device light and luminescent material light. In embodiments where, in the first operational mode the system light may comprise for less than 100% (but at least 85%) diffused device light and luminescent material light, the system light may further comprise, e.g., undiffused device light or (device) light from a different source. Hence, in specific embodiments, the device light has a wavelength selected from the blue wavelength range; the luminescent material light has a wavelength selected from the green-red wavelength range; the system light in the first operational mode is white light; and in the first operational mode the system light comprises for at least 90% diffused device light and luminescent material light.

Such embodiments may be beneficial as collection of the different types of light as described above may result in the highly efficiently combination of all spectral contributions into white system output light. The light generating system may thus provide high efficiency high brightness white system light.

Characteristics of the white system light, such as its correlated color temperature and its color rendering index, may be tunable through controlling the polarization of the device light as described above. In order to provide further control of the polarization of the device light the light generating system may further, in embodiments, comprise a polarization control element. Thus, in embodiments, the polarization control element may especially be configured to control polarization of the device light. Therefore, in embodiments, the polarization control element may comprise a rotatable birefringent rotator. Especially, in embodiments, the birefringent rotator may comprise a $\lambda/2$ waveplate. In embodiments, the control system may be configured to control the polarization control element. Especially, the control system may be configured to control the polarization control element through controlling a rotation of the polarization control element. Hence, in specific embodiments, the light generating system further comprises a polarization control element configured to control polarization of the device light; wherein the polarization control element may comprise a rotatable birefringent rotator; wherein the birefringent rotator may comprise a $\lambda/2$ waveplate; wherein the control system is configured to control the polarization control element.

Such embodiments may provide the benefit of controllability of one or more of the spectral power distribution and the radiant flux of the system light, through manipulation of the polarization control element.

Downstream of the one or more light generating devices, the polarization control element may be configured. Especially, the polarization control element may be configured in an optical path of the device light between the one or more light generating devices and the central optics. With the polarization control element, the polarization of the device light may be controlled. For instance, with a (rotatable) $\lambda/2$ retarder (or “half wave plate”, see also below), in embodiments, polarizations between fully s polarization and fully p polarization may be chosen. In this way, the ratio between the device light that is directed via the central optics to the diffuser element and device light that is directed via the central optics to the luminescent material may be controlled. Note that in embodiments in some operational modes, essentially all device light may be directed via the central optics to the diffuser element. In embodiments, in some other operational modes, essentially all device light may be directed via the central optics to luminescent material. Yet, in embodiments in other operational modes, part of the device light may be directed via the central optics to diffuser element and part of the device light may be directed via the central optics to the luminescent material. Hence, (a) the polarization control element may be used to control the

ratio of the polarizations of the device light, and (downstream thereof) the central optics routes, dependent upon the polarization of the device light, the further propagation of the device light.

In embodiments, by rotating the polarization control element the polarization of the device light may be controlled. As indicated herein, especially the device light, upstream of the polarization control element, may be linearly polarized, like s-polarized or p-polarized. Optionally, the device light may be a combination of s-polarized light and p-polarized light. For instance, the combination of polarization control element and light source may provide device light, downstream of the polarization control element, having at least two polarizations selected from: essentially p-polarized, essentially s-polarized, and a combination of p-polarized and s-polarized. Note that in embodiments by rotating the polarization control element, a ratio between p-polarized and s-polarized may be controlled. For instance, would the device light be p-polarized light, by rotating the polarization control element, the contribution of p-polarized light may be reduced and the contribution of s-polarized may be increased, until essentially s-polarized light is obtained. Hence, in dependence of the rotational angle, the polarization of the device light may be controlled. In embodiments, a degree of polarization of the device light may be controlled by the polarization control element. In embodiments, the system may comprise an actuator configured to control the polarization control element. The control system may control the actuator for controlling the polarization control element. In embodiments, the aforementioned angle may be fixed during operation (i.e. not controllable during operation), and in other embodiments, this angle may be controlled (by the control system). Especially, herein the polarization of the device light propagating to the central optics is controllable (with the polarization control element).

In embodiments, the polarization control element may comprise a rotatable birefringent rotator. More especially, the (rotatable) birefringent rotator comprises a $\lambda/2$ waveplate (with reference to a device light center wavelength, i.e., wavelength at the center of the full width half maximum). However, other phase-shift inducing components for the two linear orthogonal polarization components which can change the ratio of transmitted versus reflected light may also be applied. For example, an alternative may be to use any component or set of components resulting in an (arbitrary) phase shift up to 360° of one polarization versus the other polarization. In embodiments, such phase shift may be the result of any one of birefringent, electro-optical, thermos-optical, magneto-optical or any other principle known in the art. With a half-wavelength plate, s-polarized light can be transformed

for 0-100% into p-polarized light. With a quarter-wavelength plate that may be only 0-50%. With a 3/8th-wavelength plate 0-75%, and with a 1/8th-wavelength plate 0-25%. So, a half-wavelength plate may give full flexibility (and independence of the actual polarization direction of the source), while the other options may give more limitations, both in terms of the fraction of light that can be transformed into required polarized components and in terms of the orientation of the polarization direction of the source.

In specific embodiments, the polarization control element may be configured fixed. In such embodiments, essentially only a (single) first operational mode may be available, unless other parameters are variable (like the radiant flux of the device light). In other embodiments, the polarization control element may be configured controllable, especially rotatable. In such embodiments, by rotating the polarization control element, the spectral power distribution of the system light may be controlled. In such embodiments, a plurality of first operational modes may be available, with different spectral power distributions.

In order to further increase input power and/or to provide a further control option, more than one type of light generating device may be applied, wherein at least two types differ in the polarized light they generate. For instance, in embodiments one of the types may e.g. have primarily s-polarized light, and another one of the types may e.g. have primarily p-polarized light. In embodiments, a first polarizing beam splitter may be used to combine the beams of the two types of light generating devices. Especially, the first polarizing beam splitter may be configured downstream of the two different types of light generating devices and upstream of the central optics. In embodiments, the first polarizing beam splitter may be configured to transmit s-polarized light or p-polarized light, and to reflect p-polarized light or s-polarized light. Especially, in embodiments, the first polarizing beam splitter may be configured to transmit p-polarized light, and to reflect s-polarized light. Therefore, in embodiments, the control system may (also) be configured to control (the polarization of the device light by controlling) radiant fluxes of the device light of the two different types of light generating devices. Hence, in specific embodiments, the one or more light generating devices comprise two different types of light generating devices, differing in the type of polarization of the device light they generate; wherein the light generating system further comprises a first polarizing beam splitter, wherein the first polarizing beam splitter may be configured downstream of the two different types of light generating devices and upstream of the central optics; wherein the first polarizing beam splitter may be configured to transmit or reflect at least part of the p-polarized light, and to reflect or transmit at least part

of the s-polarized light; and wherein the control system is configured to control radiant fluxes of the device light of the two different types of light generating devices.

Hence, the term “light generating devices” may also refer to one or more primary (first) light generating devices and one or more secondary (first) light generating
5 devices. Therefore, in embodiments the system may comprise a primary light generating device and a secondary light generating device both configured to generate device light. In specific embodiments, the system may comprise a primary first light generating device and a secondary first light generating device both configured to generate first device light. In such
10 embodiments, the device light of one of the primary first light generating device and the secondary first light generating device, is more s-polarized or more p-polarized than the other one of the primary first light generating device and the secondary first light generating device.

In embodiments, the light generating devices may especially comprise laser light sources. Laser light sources may, in embodiments, be arranged in a laser bank. In
15 embodiments, laser banks (or “laser blocks”) may (thus) be applied. Laser banks may also be used to boost the input power. Therefore, in embodiments the system may comprise a plurality of light generating devices configured to generate the device light, wherein two or more of the light generating devices may comprise laser light sources configured in a laser bank. The laser bank may in embodiments comprise heat sinking and/or optics e.g. a lens to
20 collimate the laser light. Hence, in embodiments lasers in a laser bank (or “laser array bank”) may share the same optics. Especially, in embodiments, the one or more primary light generating devices, especially a plurality of primary light generating devices, may be configured in a laser bank (or “a laser block”), i.e., the primary light generating devices comprise laser diodes. Alternatively or additionally, one or more secondary light generating
25 devices, especially a plurality of secondary light generating devices may be configured in a laser bank (or “a laser block”), i.e., the secondary light generating devices comprise laser diodes. The laser banks may be different laser banks, though a configuration in the same laser bank may also be possible.

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

In embodiments, if the two different types of light generating devices (having different (linear) polarizations) have the same maximum output power, then variation in color point of the system light may be realized via adaptation of the relative powers of the different types of light generating devices. However, in other embodiments, if the potential outputs are not equal (e.g. due to a different number of laser diodes in separate laser banks for the two different types of light generating devices) then there is a net polarization in the combined light when both types of devices are operated at maximum (or optimal) power. Therefore, especially in such embodiments, a polarization control element may be introduced in the light generating system (configured downstream of the light generating devices and upstream of the central optics) such that variation in color point of the system light may be realized.

Additionally or alternatively, in embodiments, the one or more light generating devices of the light generating system may comprise two different types of light generating devices, differing in a spectral power distribution of the device light they generate. In such embodiments, the light generating system may comprise a first dichroic beam splitter. Especially, the first dichroic beam splitter may be configured downstream of the two different types of light generating devices and upstream of the central optics. The first dichroic beam splitter may especially be configured (a) to transmit or reflect at least part of the device light of a first type (of the light generating devices), and (b) to reflect or transmit at least part of the device light of a second type (of the light generating devices). Further, in such embodiments, the control system may (also) be configured to control the two different types of light generating devices. Hence, in specific embodiments, the one or more light generating devices may comprise two different types of light generating devices, differing in a spectral power distribution of the device light they generate; wherein the light generating system may further comprise a first dichroic beam splitter, wherein the first dichroic beam splitter may be configured downstream of the two different types of light generating devices and upstream of the central optics; wherein the first dichroic beam splitter may be configured (a) to transmit or reflect at least part of the device light of a first type, and (b) to reflect or transmit at least part of the device light of a second type; wherein the control system may be configured to control the two different types of light generating devices.

Hence, in order to further increase input power and/or to provide a further control options, more than one type of light generating device may be applied. Especially at least two types of light generating devices may differ in the spectral power distribution they provide. One of the types may have a different wavelength than the other one, such as a

different peak wavelength, and a dichroic beam splitter may be used to combine the beams of the two types of light generating devices.

In embodiments, the light generating system may thus comprise two different types of light generating devices, especially comprising a first light generating device and a second light generating device. The first light generating device may, in such embodiments, be configured to generate first device light having a first peak wavelength λ_1 . Similarly, the second light generating device may, in such embodiments, be configured to generate second device light having a second peak wavelength λ_2 . Hence, the device light of the first type and device light of the second type may have different spectral power distributions and/or different color points. Especially, in embodiments, the first peak wavelength λ_1 and the second peak wavelength λ_2 are different. In specific embodiments, colors or color points of a first type of light and a second type of light may be different when the respective color points of the first type of light and the second type of light differ with at least 0.01 for u' and/or with at least 0.01 for v' , even more especially at least 0.02 for u' and/or with at least 0.02 for v' . In yet more specific embodiments, the respective color points of first type of light and the second type of light may differ with at least 0.03 for u' and/or with at least 0.03 for v' . Here, u' and v' are color coordinates of the light in the CIE 1976 UCS (uniform chromaticity scale) diagram. Spectral power distributions of different sources of light having peak wavelengths differing at least 10 nm, such as at least 20 nm, or even at least 30 nm may be considered different spectral power distributions, e.g. different colors. In general, the differences in peak wavelengths will not be larger than about 400 nm, such as not more than 350 nm. Note that for the first type of device light and the second type of device light, the differences in centroid wavelengths may be relatively small, such as selected from the range of 3-50 nm, such as selected from the range of 5-50 nm, like selected from the range of 5-40 nm. Hence, in embodiments the difference in peak wavelength of the first type of device light and second type of device light herein may in embodiments be no larger than about 50 nm.

In embodiments, the device light of the first type and the device light of the second type may have a wavelength selected from the blue wavelength range (see also above), more especially have peak wavelengths selected from the blue wavelength range.

In embodiments, a first dichroic beam splitter may be used to combine the beams of the two types of light generating devices. Especially, the first dichroic beam splitter may be configured downstream of the two different types of light generating devices and upstream of the central optics. Note that, in some embodiments, the light generating system may comprise both a first polarizing beam splitter and a first dichroic beam splitter. In such

embodiments, one of the following may apply: (i) the first polarizing beam splitter may be configured downstream of the first dichroic beam splitter, or (ii) the first polarizing beam splitter may be configured upstream of the first dichroic beam splitter. In embodiments where the light generating system also comprises the polarization control element, the polarization control element may be configured either upstream or downstream of the first dichroic beam splitter.

In embodiments, the first dichroic beam splitter may be configured to transmit or reflect at least part of the device light of the first type (of light generating devices). Especially, in embodiments, the first dichroic beam splitter may be configured to transmit or reflect at least 70%, such as at least 80%, like at least 90%, including 100% of the device light of the first type (of light generating devices). Further, in embodiments, the first dichroic beam splitter may be configured to reflect or transmit at least part of the device light of the second type (of light generating devices). Especially, in embodiments, the first dichroic beam splitter may be configured to reflect or transmit at least 70%, such as at least 80%, like at least 90%, including 100% of the device light of the second type (of light generating devices). For example, in embodiments, the first dichroic beam splitter may be configured to transmit at least 90% of device light of the first type and to reflect at least 90% of device light of the second type. Therefore, in embodiments, the control system may (also) be configured to control (the spectral power distribution of the device light by controlling) radiant fluxes of the device light of the two different types of light generating devices.

Further, in embodiments, the first device light having the first peak wavelength λ_1 , and the second device light, having the second peak wavelength λ_2 , may both be (linearly or elliptically) polarized device light. In some embodiments, both the first device light and the second device light, may be used for (i) exciting the luminescent material to provide luminescent material light, and (ii) irradiating the diffuser element to provide diffused device light. However, in other embodiments, one of the first device light and the second device light may be s-polarized device light (when incident on the central optics polarizing beam splitter), whereas the other one of the first device light and the second device light may be device light having any polarization direction (e.g. p or s polarized light). In such embodiments, the s-polarized device light may be used specifically for (only) one of (i) exciting the luminescent material to provide luminescent material light, and (ii) irradiating the diffuser element to provide diffused device light.

In embodiments, the light generating system may thus function through beam splitting of light based on its spectral power distribution. Therefore, in embodiments, the

central optics dichroic beam splitter may especially be configured to transmit or reflect at least 70%, such as at least 80%, especially at least 90%, like at least 95% of the device light received by the central optics dichroic beam splitter. Additionally or alternatively, in embodiments, the central optics dichroic beam splitter may be configured to reflect or transmit at least 70%, such as at least 80%, especially at least 90%, like at least 95% of the luminescent material light received by the central optics dichroic beam splitter. Yet additionally or alternatively, in embodiments, the central optics dichroic beam splitter may be configured to transmit or reflect at least 70%, such as at least 80%, especially at least 90%, like at least 95% of the diffused device light received by the central optics dichroic beam splitter. For example, in specific embodiments, the central optics dichroic beam splitter is configured to (i) reflect at least 80% of the (s-polarized) device light, (ii) transmit at least 80% of the luminescent material light, and (iii) reflect at least 80% of the diffused device light, received by the central optics dichroic beam splitter. Hence, in such embodiments, the light generating device may provide blue device light having both p-polarization and s-polarization. The device light may be routed through the light generating system with two different paths, of which an exemplary working principle may be as follows: (1) The polarizing beam splitter may be configured to transmit p-polarized blue device light, such that the p-polarized blue device light may propagate further through the system to be diffused by the diffuser element into blue diffused device light. The blue diffused device light may then propagate from the diffuser element via the polarization changing element, where (substantially) s-polarized blue diffused device light is generated, to the central optics. At the central optics, the polarizing beam splitter is then configured to reflect the s-polarized blue diffused device light. (2) The polarizing beam splitter and dichroic beam splitter may be configured to reflect s-polarized device light, such that the (non-diffused) s-polarized blue may propagate further through the system to be converted by the luminescent material into luminescent material light. The luminescent material light may then propagate from the luminescent material to the central optics. At the central optics, the dichroic beam splitter is then configured to transmit the luminescent material light.

In embodiments, the central optics dichroic beam splitter may be configured (a) to transmit at least 80% of the device light received by the central optics dichroic beam splitter, (b) to reflect at least 80% of the luminescent material light received by the central optics dichroic beam splitter; and (c) to transmit at least 80% of the diffused device light, received by the central optics dichroic beam splitter.

In embodiments, the central optics dichroic beam splitter may be configured (a) to reflect at least 80% of the device light received by the central optics dichroic beam splitter, (b) to transmit at least 80% of the luminescent material light received by the central optics dichroic beam splitter; and (c) to reflect at least 80% of the diffused device light, received by the central optics dichroic beam splitter.

The polarizing beam splitter and the dichroic beam splitter may thus together, and in dependence of polarization and spectral power distribution of the light, guide light through the light generating system. The light generating system may have a variety of different configurations of the different optical components relative to one another. In embodiments, one configuration of the light generating system may result in the transmission of luminescent material light through the central optics to the output system light (see also figures 1 and 2). In such embodiments, especially, the central optics polarizing beam splitter may be configured to (a) reflect x% of light having s polarization, (b) reflect y% of light having p polarization, and (c) transmit z% of light having p polarization. More especially, in embodiments, x may be selected from the range of at least 75%, such as at least 85%, like at least 90%, including at least 95%. Additionally or alternatively, in such embodiments, y may be selected from the range of 15-90%, such as from the range of 25-85%, like from the range of 50-85%. Additionally or alternatively, in such embodiments, z may be selected from the range of 15-75%, such as from the range of 15-60%, like from the range of 30-60%.

In other embodiments, the central optics polarizing beam splitter may be configured to transmit x% of light having p polarization, and to reflect y% of light having s polarization. Especially, in such embodiments, one of x% and y% may be selected from the range of 10-85%, such as from the range of 15-80%, like from the range of 30-60%, whereas the other one of x% and y% may be selected from the range of 75-100%, such as from the range of 85-100%, like from the range of 85-95%. For example, in embodiments, the central optics polarizing beam splitter may be configured to transmit x% of light having p polarization, wherein x% is selected from the range of 15-80%, and to reflect y% of light having s polarization, wherein y% is selected from the range of 85-100%.

In embodiments, the central optics polarizing beam splitter may be configured to (a) reflect x% of device light having s polarization, (b) reflect y% of device light having p polarization, and (c) transmit z% of device light having p polarization, wherein x is selected from the range of at least 85%, wherein y is selected from the range of 25-85%, and wherein z is selected from the range of 15-75%.

In embodiments, the central optics polarizing beam splitter may be configured to (a) reflect x% of device light having s polarization, (b) reflect y% of device light having p polarization, and (c) transmit z% of device light having p polarization, wherein x is selected from the range of 15-75%, wherein y is selected from the range of at most 15%, and wherein
5 z is selected from the range of at least 85%.

The obtained effect is an improved correlated color temperature tunability. The reason is that the correlated color temperature of the system light is accurately tunable through controlling the polarization of the device light and partial splitting of the polarizations of the device light in the light generating system.

10 For example, the obtained effect may be to enable setting of a maximum correlated color temperature (CCT) of the system output light by a partial splitting of one of the polarizations of the device light, such that a first part of the device light is directed to the diffuser element and a second part of the device light is directed to the luminescent material. By setting the fraction of device light that can be directed to the diffuser element, the
15 accuracy of selecting a desired/targeted CCT by adjusting the polarization of the device light is maximized (in dependence of the range of CCTs that can be selected). The indicated range enables a relative large CCT range to be selected for general lighting applications. A more narrow range may be applicable for higher or lower CCTs, e.g. as desired for indoor lighting e.g. retail lighting and office lighting.

20 In embodiments, the central optics polarizing beam splitter may be configured to (a) reflect x% of device light having s polarization, (b) reflect y% of device light having p polarization, and (c) transmit z% of device light having p polarization, wherein x is selected from the range of at least 95%, wherein y is selected from the range of 50-85%, and wherein z is selected from the range of 15-50%.

25 In embodiments, the central optics polarizing beam splitter may be configured to (a) reflect x% of device light having s polarization, (b) reflect y% of device light having p polarization, and (c) transmit z% of device light having p polarization, wherein x is selected from the range of 15-50%, wherein y is selected from the range of at most 5%, and wherein z is selected from the range of at least 95%.

30 The latter two embodiments may be especially suited for (relatively) low correlated color lighting applications e.g. indoor lighting applications such as office lighting and retail lighting.

In embodiments, the central optics polarizing beam splitter may be configured to (a) reflect x% of device light having s polarization, (b) reflect y% of device light having p

polarization, and (c) transmit $z\%$ of device light having p polarization, wherein x is selected from the range of at least 95%, wherein y is selected from the range of 25-50%, and wherein z is selected from the range of 50-75%.

In embodiments, the central optics polarizing beam splitter may be configured to (a) reflect $x\%$ of device light having s polarization, (b) reflect $y\%$ of device light having p polarization, and (c) transmit $z\%$ of device light having p polarization, wherein x is selected from the range of 50-75%, wherein y is selected from the range of at most 5%, and wherein z is selected from the range of at least 95%.

The latter two embodiments may be especially suited for (relatively) high correlated color temperature applications e.g. outdoor lighting applications such as search lighting and entertainment/stage lighting.

An alternative configuration of the light generating system may, in embodiments, result in the reflection of luminescent material light by the central optics to the output system light (see also figure 3). In such embodiments, especially, the central optics polarizing beam splitter may be configured to (a) reflect $x\%$ of device light having s polarization, (b) reflect $y\%$ of device light having p polarization, and (c) transmit $z\%$ of device light having a p polarization. More especially, in embodiments, x may be selected from the range of 15-100%, such as from the range of 15-75%, like from the range of 30-70%. Additionally or alternatively, in such embodiments, y may be selected from the range of at most 30%, such as at most 15%, like at most 5%. Additionally or alternatively, in such embodiments, z may be selected from the range of at least 60%, such as at least 85%, like at least 95%. Selecting a relatively high reflection of device light having s -polarization (i.e. a relatively high x) may be beneficial as it may provide an increased range in color point tunability of the system. Hence, the higher the reflection of device light having s -polarization is selected, the higher the color point tunability of the system light may be. However, the efficiency of the light generating system may be optimized by selecting x as low as possible, as then any potentially present depolarized diffuse-reflected device light (from the diffuser) may still be partly used in the output system light.

In embodiments, the central optics may thus comprise a polarizing beam splitting functionality and a dichroic beam splitting functionality. Especially, in embodiments, the central optics may comprise a single optical component having polarizing beam splitting functionality and dichroic beam splitting functionality. In other embodiments, the central optics may comprise two (separate) optical components, one having polarizing beam splitting functionality and one having dichroic beam splitting functionality. Hence, in

specific embodiments, the central optics may comprise (i) a single optical component having polarizing beam splitting functionality and dichroic beam splitting functionality, or (ii) two optical components, one having polarizing beam splitting functionality and one having dichroic beam splitting functionality.

5 Especially, in embodiments where the central optics are configured to transmit the luminescent material light, the central optics comprise a single component having both above described functionalities. Conversely, in embodiments where the central optics are configured to reflect the luminescent material light, the central optics may comprise either a single component or two separate components having the above described functionalities. In
10 embodiments, the at least two different functionalities of the central optics may thus be realized in a single optical component, especially, it may be realized by using a single optical component with two different functional layers (or sets of layers)(e.g. surface configurations or coatings / dichroic layer stacks; or by integration of both functions in a single surface layer or coating (stack of dichroic layers)).

15 Further, the system may in embodiments comprise further optics than described above. The term “optics” may especially refer to (one or more) optical elements. Hence, the terms “optics” and “optical elements” and “optical component” may refer to the same items. The optics may include one or more of mirrors, reflectors, collimators, lenses, prisms, diffusers, phase plates, polarizers, diffractive elements, gratings, dichroics, arrays of
20 one or more of the afore-mentioned, etc. Alternatively or additionally, the term “optics” may refer to a holographic element or a mixing rod. In embodiments, the optics may include one or more of beam expander optics and zoom lens optics. See further above for examples of optics. In embodiments, the optics may comprise an integrator, like a “Koehler integrator” (or “Köhler integrator”). In specific embodiments, the system may further comprise one or more
25 of integrating optics, collimation optics, and homogenization optics. One or more of them are also depicted in the accompanying drawings. For example, in embodiments, the optics may comprise integrators, such as fly-eye lens array pairs or diffuser plates. Further, in embodiments, the optics may comprise such integrators in combination with further condensing and/or collimating optical components, e.g., integrating rods with a polygonal
30 cross sectional shape such as reflective hollow integrator rods or transmissive solid integrator rods (based on total internal reflection for lateral confinement of a longitudinal propagation of the light).

 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.

As described above, the light generating system may comprise a control system. In embodiments, the control system may especially be configured to control a spectral power distribution of the system light. Especially, in such embodiments, the control system may be configured to control the spectral power distribution of the system light by controlling the polarization of the device light.

It may be desired to provide a light generating system with a controllable color point and/or correlated color temperature (CCT). Through controlling the polarization of the device light, the control system may impact the ratio of blue diffused device light to (e.g. green-red) luminescent material light. Thus, in embodiments, the control system may be configured to control the ratio of blue diffused device light to (e.g. green-red) luminescent material light, and as such controlling the color point (and/or correlated color temperature) of the system light. Hence, controllability of parameters such as color point and CCT may be easily provided by the light generating system as described here, through controlling of the polarization of the device light using the control system. Such a control system may be used to set the above mentioned parameters in a factory setting, or may be used in combination with a user interface by an end user, see also further below.

The term “controlling”, and similar terms especially refer at least to determining the behavior or supervising the running of an element. Hence, herein “controlling” and similar terms may e.g. refer to imposing behavior to the element (determining the behavior or supervising the running of an element), etc., such as e.g. measuring, displaying, actuating, opening, shifting, changing temperature, etc.. Beyond that, the term “controlling”, and similar terms may additionally include monitoring. Hence, the term “controlling”, and similar terms may include imposing behavior on an element and also imposing behavior on an element and monitoring the element. The controlling of the element can be done with a control system, which may also be indicated as “controller”. The control system and the element may thus at least temporarily, or permanently, functionally be

coupled. The element may comprise the control system. In embodiments, the control system and element may not be physically coupled. Control can be done via wired and/or wireless control. The term “control system” may also refer to a plurality of different control systems, which especially are functionally coupled, and of which e.g. one control system may be a master control system and one or more others may be slave control systems. A control system may comprise or may be functionally coupled to a user interface.

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

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

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

However, in embodiments a control system may be available, that is adapted to provide at least the controlling mode. Would other modes be available, the choice of such modes may especially be executed via a user interface, though other options, like executing a mode in dependence of a sensor signal or a (time) scheme, may also be possible. The

operation mode may in embodiments also refer to a system, or apparatus, or device, that can only operate in a single operation mode (i.e. “on”, without further tunability).

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

Further, in embodiments, the control system may especially be configured to control a correlated color temperature of the (white) system light. Especially, in such embodiments, the control system may (thus) be configured to control the correlated color temperature of the system light in dependence of one or more of a user interface, a sensor
10 signal, and a timer. More especially, in embodiments, the control system may be configured to control in the first operational mode (see also above) the correlated color temperature of the system light between the range of 1800-20000 K, such as between the range of 1800-8000 K, like between the range of 2700-6500 K.

The term “white light”, and similar terms, herein, is known to the person
15 skilled in the art. It may especially relate 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 2000-7000 K, such as in the range of 2700 K and 6500 K. In embodiments, e.g. for backlighting purposes, or for other purposes, the correlated color temperature (CCT) may especially be in the range of about
20 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.

In specific embodiments, the correlated color temperature (CCT) may be
25 selected from the range of 6000-12000 K, like selected from the range of 7000-12000 K, like at least 8000 K. Yet further, in embodiments the correlated color temperature (CCT) may be selected from the range of 6000-12000 K, like selected from the range of 7000-12000 K, in combination with a CRI of at least 70.

In an embodiment, the light source may also provide light source light having
30 a correlated color temperature (CCT) between about 5000 and 20000 K, e.g. direct phosphor converted LEDs (blue light emitting diode with thin layer of phosphor for e.g. obtaining of 10000 K). Hence, in a specific embodiment the light source is configured to provide light source light with a correlated color temperature in the range of 5000-20000 K, even more especially in the range of 6000-20000 K, such as 8000-20000 K. An advantage of the relative

high color temperature may be that there may be a relatively high blue component in the light source light.

Alternatively or additionally, the control system may be configured to control a color point and/or color rendering index of the system light. Hence, the control system may be configured to control one or more of a color point, a color rendering index, and a correlated color temperature of the system light. This may be done in dependence of one or more of an input signal of a user interface, a sensor signal (of a sensor), and a timer (see also above).

In yet a further aspect, the invention also provides a lamp or a luminaire comprising the light generating system as defined herein. The luminaire may further comprise a housing, optical elements, louvres, etc. etc... The lamp or luminaire may further comprise a housing enclosing the light generating system. The lamp or luminaire may comprise a light window in the housing or a housing opening, through which the system light may escape from the housing. In yet a further aspect, the invention also provides a projection device comprising the light generating system as defined herein. Especially, a projection device or “projector” or “image projector” may be an optical device that projects an image (or moving images) onto a surface, such as e.g. a projection screen. The projection device may include one or more light generating systems such as described herein. Hence, in an aspect the invention also provides a lighting device selected from the group of a lamp, a luminaire, a projector device, a headlamp, and an optical wireless communication device, comprising the light generating system as defined herein. The lighting device may comprise a housing or a carrier, configured to house or support, one or more elements of the light generating system. For instance, in embodiments the lighting device may comprise a housing or a carrier, configured to house or support one or more of the one or more light generating devices, the diffuser element, the central optics, and the luminescent material (e.g. configured on a phosphor wheel).

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

The terms “light” and “radiation” are herein interchangeably used, unless clear from the context that the term “light” only refers to visible light. The terms “light” and “radiation” may thus refer to UV radiation, visible light, and IR radiation. In specific

embodiments, especially for lighting applications, the terms “light” and “radiation” refer to (at least) visible light. The terms “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. The terms “violet light” or “violet emission” especially relates to light having a wavelength in the range of about 380-440 nm. The terms “blue light” or “blue emission” especially relates to light having a wavelength in the range of about 440-495 nm (including some violet and cyan hues). The terms “green light” or “green emission” especially relate to light having a wavelength in the range of about 495-570 nm. The terms “yellow light” or “yellow emission” especially relate to light having a wavelength in the range of about 570-590 nm. The terms “orange light” or “orange emission” especially relate to light having a wavelength in the range of about 590-620 nm. The terms “red light” or “red emission” especially relate to light having a wavelength in the range of about 620-780 nm. The term “pink light” or “pink emission” refers to light having a blue and a red component. The term “cyan” may refer to one or more wavelengths selected from the range of about 490-520 nm. The term “amber” may refer to one or more wavelengths selected from the range of about 585-605 nm, such as about 590-600 nm. The phrase “light having one or more wavelengths in a wavelength range” and similar phrases may especially indicate that the indicated light (or radiation) has a spectral power distribution with at least intensity or intensities at these one or more wavelengths in the indicate wavelength range. For instance, a blue emitting solid state light source will have a spectral power distribution with intensities at one or more wavelengths in the 440-495 nm wavelength range.

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

30

BRIEF DESCRIPTION OF THE DRAWINGS

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

Fig. 1-4 schematically depict some embodiments of the invention.

Fig. 5 schematically depicts some application embodiments.

The schematic drawings are not necessarily to scale.

5 DETAILED DESCRIPTION OF THE EMBODIMENTS

The invention provides a light generating system 1000 comprising one or more light generating devices 100, a luminescent material 200, a diffuser element 710, a polarization changing element 810, central optics 900, and a control system 300. In embodiments, the one or more light generating devices 100 may be configured to generate device light 101. Especially, in embodiments, the one or more light generating devices 100 may comprise light sources 10 selected from a laser diode and a superluminescent diode. Further, in embodiments, the device light 101 received by the central optics 900 may comprise a controllable polarization. The luminescent material 200 may, in embodiments, be configured to convert at least part of the device light 101 received by the luminescent material 200 into luminescent material light 201. Further, in embodiments, the diffuser element 710 may be configured to diffuse at least part of the device light 101 received by the diffuser element 710. Hence, in embodiments, the diffuser element 710 may thereby provide diffused device light 711. The diffuser element 710 may especially do so while maintaining at least part of the polarization (of the device light 101). Yet further, in embodiments, the polarization changing element 810 may be configured in an optical path of the device light 101 between the central optics 900 and the diffuser element 710. In embodiments, the central optics 900 may comprise (i) a central optics polarizing beam splitter 910, and (ii) a central optics dichroic beam splitter 920. Especially, in embodiments, the central optics 900 may be configured to transmit and/or reflect light received by the central optics 900 in dependence of one or more of its polarization and its spectral power distribution. More especially, in embodiments, the central optics 900 may be configured to transmit and/or reflect (one or more of) device light 101, diffused device light 711, and luminescent material light 201 received by the central optics 900 in dependence of one or more of their polarizations and their spectral power distributions. Yet further, in embodiments, the control system 300 may be configured to control the polarization of the device light 101 received by the central optics 900. Furthermore, in embodiments, the light generating system 1000 may be configured to provide system light 1001 comprising one or more of diffused device light 711 and luminescent material light 201. Especially, in embodiments, the light generating system 1000 may be configured such that in a first operational mode of the light generating system 1000

(a) at least part of the device light 101 irradiates the luminescent material 200 via the central optics 900, and the luminescent material light 201 escapes from the light generating system 1000 via the central optics 900, and (b) at least part of the device light 101 irradiates the diffuser element 710 via the central optics 900, and at least part of the diffused device light
5 711 escapes from the light generating system 1000 via the central optics 900.

The light generating system may further comprise one or more of integrating optics, collimation optics, and homogenization optics. For instance, reference 560 refers to lenses, especially used for collimation of light. Reference 550 refers to integrators, which may especially be used to beam shape and homogenize light. However, further optics than
10 schematically depicted may be available.

Figure 1 schematically depicts a basic configuration of the light generating system 1000. In this basic configuration the light generating system 1000 consists of a light generating device 100, lenses 560, integrators 550, a polarization control element 610, central optics 900 comprising a polarizing beam splitter 910 and a dichroic beam splitter 920, the
15 luminescent material 200 configured on a rotatable element 1200 (here especially a phosphor wheel), the polarization changing element 810, the diffuser element 710, and the control system 300.

In embodiments as depicted in Fig. 1, the light generating device 100 may especially be configured to generate blue device light 101. Hence, especially, in
20 embodiments, the device light 101 has a wavelength selected from the blue wavelength range. The blue device light 101 may propagate via the lenses 560 to the polarization control element 610. The polarization control element 610 may be configured to control the polarization of the device light 101. Therefore, in embodiments, the polarization control element may comprise a rotatable birefringent rotator. Especially, in embodiments, the
25 rotatable birefringent rotator may comprise a $\lambda/2$ waveplate. Here, for example, the polarization control element 610 may be configured to provide device light 101 having a ratio of both p-polarized device light 101 and s-polarized device light 101. Hence, through the polarization control element 610 the device light 101 has a controllable polarization. The device light 101 may subsequently propagate from the polarization control element 610 to the
30 central optics 900. In embodiments, the central optics 900 may comprise (i) a single optical component having polarizing beam splitting functionality and dichroic beam splitting functionality (e.g. in the configuration as depicted in Fig. 1), or (ii) two optical components, one having polarizing beam splitting functionality and one having dichroic beam splitting functionality (e.g. in the configuration as depicted in Fig. 3, see further below). The device

light 101 may especially be incident on the central optics polarizing beam splitter 910. The central optics polarizing beam splitter 910 may be configured (a1) to transmit and/or reflect at least part of (a1) the device light (101) and (a2) to transmit and/or reflect at least part of the diffused device light (711) (in dependence of their polarizations). Device light 101

5 transmitted by the central optics polarizing beam splitter 910 may be incident on the central optics dichroic beam splitter 920. The central optics dichroic beam splitter 920 may be configured (b1) to transmit or reflect at least part of the device light 101, (b2) to transmit or reflect at least part of the diffused device light 711, and (b3) to reflect or transmit at least part of the luminescent material light 201 (in dependence of their spectral power distributions). If

10 the central optics PBS 910 transmitted essentially all of the device light 101, the central optics DBS 920 may especially be configured to reflect at least part of the device light 101.

Here, device light 101 reflected by the central optics 900 may propagate to the luminescent material 200. At the luminescent material 200 the device light 101 incident on the luminescent material 200 may be converted into luminescent material light 201. In

15 embodiments, the luminescent material light 201 may have a wavelength selected from the green-red wavelength range. Therefore, in embodiments, the luminescent material 200 may at least comprise 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. The generated luminescent material light 201 may then propagate from the luminescent

20 material 200 back to the central optics 900. The central optics DBS 920 may especially be configured to transmit the luminescent material light 201, such that it may be collected at the integrator 550 to provide a (green-red) contribution to the system light 1001.

Device light 101 (having a first linear polarization) transmitted by the central optics 900 may propagate to the polarization changing element 810. At the polarization

25 changing element 810 the polarization of the device light 101 (having a first linear polarization) may be changed to a first circular polarization. Therefore, in embodiments, the polarization changing element 810 may comprise a $\lambda/4$ waveplate. The device light 101 (having the first circular polarization) may propagate from the polarization changing element 810 to the diffuser element 710. At the diffuser element 710 the device light 101 may be

30 diffused such that blue diffused device light 711 (having a second circular polarization) may be provided. The blue diffused device light 711 (having the second circular polarization) may propagate from the diffuser element 710 back to the polarization changing element 810, where the polarization is again changed, such that blue diffused device light 711 (having a second linear polarization) is provided. The blue diffused device light 711 (having a second

linear polarization) may propagate from the polarization changing element 810 to the central optics 900. The central optics PBS 910 may especially be configured to reflect the blue diffused device light 711 (having a second linear polarization), such that it may be collected at the integrator 550 to provide a (blue) contribution to the system light 1001. The integrator
5 550 may especially function to homogenize the (green-red) contribution and the (blue) contribution to provide white system light 1001. Therefore, the system light 1001 may in the first operational mode be white light, and may in the first operational mode comprise for at least 90% diffused device light 711 and luminescent material light 201.

As depicted in Fig. 1, the light generating system may thus comprise a
10 rotatable element 1200. For example, as depicted here, the rotatable element 1200 may be a phosphor wheel. Especially, in embodiments, the rotatable element 1200 may comprise the luminescent material 200. In embodiments, during operation of the light generating system 1000 in the first operational mode the rotatable element 1200 may rotate, such that over time different parts of the luminescent material 200 may be irradiated by the device light 101.
15 Hence, in embodiments, the luminescent material 200 may be comprised by the rotatable element 1200. Additionally or alternatively, in embodiments, the luminescent material 200 may be configured in thermal contact with a thermally conductive material (not depicted).

As an example, a light generating system 1000 such as depicted in Fig. 1 may be configured such, that the central optics PBS 910 reflects >90% of s-polarized blue device
20 light 101 and 50-85% of p-polarized blue device light 101, while transmitting 15-50% of the p-polarized blue device light 101. In such an example, the central optics DBS 920 may further be configured to provide >90% transmittance of the luminescent material light 201.

In embodiments as depicted in Fig. 2, the one or more light generating devices
100 of the light generating system 1000 comprise two different types of light generating
25 devices 100,110,110',110''. In Fig. 2A, a light generating system 1000 is schematically depicted with one or more light generating devices 100 comprising two different types of light generating devices 100,110,110', 110'' differing in the type of polarization of the device light 101 they generate. Therefore, the light generating system 1000 further comprises a first polarizing beam splitter 525. In embodiments, the first polarizing beam splitter 525 may
30 especially be configured downstream of the two different types of light generating devices 100,110,110',110'' and upstream of the central optics 900. For example, in embodiments, the one or more light generating devices 100 may comprise a light generating device 110' configured to provide device light 101 having a first polarization (of p- or s-polarization) and a light generating device 110'' configured to provide device light 101 having a second

polarization (of p- or s-polarization). Therefore, the first polarizing beam splitter 525 may be configured to transmit or reflect at least part of the p-polarized light, and to reflect or transmit at least part of the s-polarized light. If the light generating device 110' is configured to generate device light 101 having the first polarization is p-polarized device light 101 and the light generating device 110'' is configured to generate device light 101 having the second polarization is s-polarized light, then as depicted in Fig. 2A, the first polarizing beam splitter 525 is configured to transmit at least part of the device light 101 (having the p-polarization) generated by the light generating device 110', and to reflect at least part of the device light 101 (having the s-polarization) generated by the light generating device 110''. Further propagation of the light through the light generating system 1000 may occur through the same principles as described above with Fig. 1 (especially after the device light 101 has passed the polarization control element 610).

As an example, a light generating system 1000 such as depicted in Fig. 2A may be configured such, that the first polarizing beam splitter 525 reflects >90% of s-polarized blue device light 101 and transmits >90% of p-polarized blue device light 101. Furthermore, in such an example, the central optics PBS 910 may reflect >90% of s-polarized blue device light 101 and 40-70% of p-polarized blue device light 101, while transmitting 30-60% of the p-polarized blue device light 101. Yet further, in such an example, the central optics DBS 920 may be configured to provide >90% transmittance of the luminescent material light 201.

In Fig. 2B, a light generating system 1000 is schematically depicted with one or more light generating devices 100 comprising two different types of light generating devices 100,110,120, differing in the spectral power distribution of the device light 101,111,121 they generate. Therefore, the light generating system 1000 further comprises a first dichroic beam splitter 515. In embodiments, the first dichroic beam splitter 515 may especially be configured downstream of the two different types of light generating devices 100,110,120 and upstream of the central optics 900. For example, in embodiments, the one or more light generating devices 100 may comprise a first light generating device 110 configured to provide first device light 111 having a first peak wavelength λ_1 and a second light generating device 120 configured to provide second device light 121 having a second peak wavelength λ_2 . Especially, in such embodiments, the first light generating device 110 and the second light generating device 120 may be configured such that one of the first light generating device 110 and the second light generating device 120 provides s-polarized device light 101 relative to the central optics PBS 910 (whereas the other one may have any

polarization direction). Furthermore, the first dichroic beam splitter 515 may be configured to transmit or reflect at least part of the device light of a first type (of the light generating devices), and to reflect or transmit at least part of the device light of a second type (of the light generating devices). For example, as depicted in Fig. 2B, the first dichroic beam splitter 515 is configured to transmit at least part of the second device light 121 generated by the second light generating device 120, and to reflect at least part of the first device light 111 generated by the first light generating device 110. Further propagation of the light through the light generating system 1000 may occur through the same principles as described above with Fig. 1.

As an example, a light generating system 1000 such as depicted in Fig. 2B may be configured such, that the first dichroic beam splitter 515 reflects >90% of first device light 111 (e.g. short wavelength blue device light 101) and transmits >90% of second device light 121 (e.g. long wavelength blue device light 101). Furthermore, in such an example, the central optics PBS 910 may reflect >90% of s-polarized blue device light 101 and 50-85% of p-polarized blue device light 101, while transmitting 15-50% of the p-polarized blue device light 101. Yet further, in such an example, the central optics DBS 920 may be configured to provide >90% transmittance of the luminescent material light 201.

The main aspect here is that two different wavelengths blue light sources 10,20 are used, which enables to not only increase the maximum output white system light 1001 flux, but also an increase of the color quality. The CRI of the output system light 1001 is enhanced by using the longer wavelength blue as the blue component in the output beam, while predominantly using the shorter wavelength blue for the luminescent conversion. Color point adjustment is enabled by the variable relative contribution of the longer wavelength blue to the luminescent conversion.

In embodiments, the central optics dichroic beam splitter 920 may be configured (a) to transmit or reflect at least 80% of the device light 101 received by the central optics dichroic beam splitter 920, (b) to reflect or transmit at least 80% of the luminescent material light 201 received by the central optics dichroic beam splitter 920, and (c) to transmit or reflect at least 80% of the diffused device light 711 received by the central optics dichroic beam splitter 920.

Additionally or alternatively, in embodiments as described above, the central optics polarizing beam splitter 910 may be configured to (a) reflect x% of device light 101 having s polarization, (b) reflect y% of device light 101 having p polarization, and (c) transmit z% of device light 101 having p polarization. Especially, in such embodiments, x

may selected from the range of at least 85%, y may be selected from the range of 25-85%, and z may be selected from the range of 15-75%.

Fig. 3 schematically depicts an embodiment of the light generating system 1000, wherein in contrast to Fig. 1 and Fig. 2 the luminescent material light 201 is reflected by the central optics 900. Such a configuration especially enables the possibility to implement the central optics 900 as two separate functional components. Hence, in embodiments such as depicted in Fig. 3, the central optics 900 may comprise the central optics PBS 910 and the central optics DBS 920 either integrated into a combined component or as two physically separated components. Working principles of most components of the light generating system 1000 remain the same as described above. However, the central optics polarizing beam splitter 910 may especially be configured to (a) reflect x% of device light 101 having s polarization, (b) reflect y% of device light 101 having p polarization, and (c) transmit z% of device light 101 having a p polarization. Especially, in such embodiments, x may be selected from the range of 15-75%, y may be selected from the range of at most 15%, and z may be selected from the range of at least 85%.

Furthermore, the light generating system 1000 may also comprise both a first dichroic beam splitter 515 and a first polarizing beam splitter 525, such as depicted in Fig. 4. Hence, in such embodiments, the one or more light generating devices 100 may comprise at least three different types of light generating devices 110', 110'', 120. With such a configuration of the light generating system 1000 both the system light 1001 output flux and the tunability of the color point/correlated color temperature may be further improved through the use of three (laser) light sources tailored to the desired wavelengths and polarizations. Note that the polarizations of the light sources 10,20 may be chosen differently as long as a first light source (e.g. laser) (emitting at λ_1) and a second light source (e.g. laser) (emitting at λ_2) have the same polarization that is complementary to the polarization of a third light source (e.g. laser) (emitting at λ_2 or λ_3), because the s/p polarization ratio of the combined device light 101, when incident on the central optics 900, is set via the polarization control element 610. Working principles of the light generating system 1000 as depicted in Fig. 4 may be as follows: (1) The light beams of two blue light generating devices 110', 120 (e.g. lasers or laser arrays) with different wavelengths (peak wavelengths at least 5 nm different (such as at least about 10 nm difference in peak wavelengths)) and with the same polarization are combined via a first DBS 515. (2) The light beam of a third light generating device 110'' emitting at either one of the other wavelengths or at a third wavelength is polarized complementary (orthogonal) to that of the combined beam of the first two light

generating devices. (3) Via a first PBS 525 the output beam of the first DBS 515 is combined with the output beam of the third light generating device 110". (4) The required ratio of p-polarized and s-polarized device light 101 in the combined blue device light 101 incident on the combined central optics 900 PBS 910 and DBS 920 is set via adjustment of the

5 orientation of the optical axis of the polarization control element 610 (e.g. birefringent rotator), and/or via the ratio of powers to the light generating devices 100. (5) Preferably the s-polarized device light 101 incident on the combined central optics 900 PBS 910 and DBS 920 in absence of the polarization control element 610 has the shortest wavelength blue device light 101, while in that case the longest wavelength blue device light 101 is p-

10 polarized, by which the longest wavelength blue device light 101 in combination with shorter wavelength blue device light 101 will be used as blue contribution to the system light 1001, which is preferred for both an increased color quality (CRI) and for a color point variation, upon changing the s/p polarization ratio of the blue device light 101, that is more parallel to the BBL in the targeted color temperature range of primary interest. (6) An integrator 550 is

15 applied to remove the hot spots and to homogenize the blue device light 101. (7) The PBS 910 in the combined central optics 900 PBS 910 and DBS 920 reflects (almost) all s-polarized blue device light 101 and transmits (almost) all p-polarized blue device light 101, or transmits a substantial part of p-polarized blue device light 101 and also reflects a substantial part of p-polarized blue device light 101. Thanks to the partial reflection of p-

20 polarized device blue light 101 in addition to the (almost) complete reflection of s-polarized blue device light 101, a larger fraction of blue device light 101 can be used to excite luminescent material 200 and a smaller fraction of blue device light 101 can be used as blue contribution to the white system light 1001 as generally required for the color points of interest (e.g. 4000 – 7000 K) while using three light generating devices 100 with comparable

25 output powers, and the reflectance of diffused blue device light 711 by the combined central optics 900 PBS 910 and DBS 920 is further improved, in particular when a non- or less polarization maintaining reflective diffuser element 710 is applied. (8) The transmitted p-pol. blue device light 101 is converted into circular polarized light by a polarization changing element 810 (e.g. a $\lambda/4$ plate). (9) A substantially polarization maintaining diffuser element

30 710 reflects the transmitted blue device light 101. (10) The reflected blue diffused device light 711 is converted into substantially linear (s-) polarized light by the polarization changing element 810. (11) The blue diffused device light 711 is substantially reflected by the combined central optics 900 PBS 910 and DBS 920 element. (12) The non-diffused reflected s-polarized blue device light 101 as well as the (non-diffused) reflected p-polarized

blue device light 101 if present are converted by the luminescent material 200 into luminescent material light 201. (13) The luminescent material light 201 is transmitted by the combined PBS 910 and DBS 920 and with that combined with the blue diffused device light 711 into white output system light 1001. (14) An optional integrator 550 is used to further
5 homogenize the white output system light 1001.

In embodiments, the light generating system 1000 may thus comprise a plurality of light generating devices 100 configured to generate device light 101. In embodiments, two or more of the light generating devices 100 may especially comprise laser light sources configured in a laser bank.

10 In embodiments, herein, the control system 300 may especially be configured to (individually) control one or more of the polarization control element 610 (by controlling a rotation of the polarization control element 610). Additionally or alternatively, the control system 300 may be configured to control (the polarization of the device light 101 by controlling) radiant fluxes of the device light 101 of two different types of light generating
15 devices 100. Additionally or alternatively, the control system 300 may be configured to control (the spectral power of the device light 101 by controlling) radiant fluxes of the device light 101 of two different types of light generating devices 100. Additionally or alternatively, in embodiments, the control system 300 may be configured to control a spectral power distribution of the system light 1001 by controlling the polarization of the device light 101.
20 Additionally or alternatively, the control system 300 may be configured to control a correlated color temperature of the system light 1001 in dependence of one or more of a user interface 301, a sensor signal, and a timer. Additionally or alternatively, in embodiments, the control system 300 may be configured to control in the first operational mode the correlated color temperature of the system light 1001 between 1800-8000 K.

25 In comparison to white light engines from the prior art, the light generating system as described here may thus provide improved color point tunability.

Here below the relationship between correlated color temperature and S/P polarization ratio in pump light is compared for a reference light generating system (having a fixed p polarization transmission of 20% by the central optics polarizing beam splitter) and
30 the light generating system of the present invention. Table 1 provides an overview of the impact of variation of the S/P polarization ratio on the color point of the output light for a fixed p polarization transmission of 20% by the central optics polarizing beam splitter as may be the case in such light engine. Table 1:

S/P power level	T_P [0..1]	Power Yellow in W	Average blue/yellow ("CCT")	Average Power loss in W
$P = 100, S = 0$	0.2	56	0.27	2.93
$P = 90, S = 10$	0.2	57.05	0.25	2.67
$P = 80, S = 20$	0.2	58.1	0.22	2.42
$P = 75, S = 25$	0.2	58.625	0.21	2.29
$P = 70, S = 30$	0.2	59.15	0.20	2.17
$P = 60, S = 40$	0.2	60.2	0.18	1.91
$P = 50, S = 50$	0.2	61.25	0.16	1.66
$P = 40, S = 60$	0.2	62.3	0.14	1.41
$P = 30, S = 70$	0.2	63.35	0.12	1.15
$P = 25, S = 75$	0.2	63.875	0.11	1.03
$P = 20, S = 80$	0.2	64.4	0.10	0.90
$P = 10, S = 90$	0.2	65.45	0.08	0.65
$P = 0, S = 100$	0.2	66.5	0.06	0.39

From the data in table 1 can be concluded that in the such light engine using a $T_P=0.20$ central optics polarizing beam splitter, the correlated color temperature of the output light can be changed by changing the S/P polarization ratio. Furthermore, table 1 shows that adding s polarized light to the p polarized light results in relatively more luminescent light and less blue light in the output light.

Table 2 provides an overview of the impact of the S/P polarization ratio on the p polarization transmission of the central optics polarizing beam splitter required to achieve the same CCT as when only pumping p polarization. Table 2:

S/P power level	T_P [0..1]	Power Yellow in W	Average blue/yellow ("CCT")
$P = 100, S = 0$	0.2	56	0.27
$P = 75, S = 25$	0.26	55.475	0.27
$P = 50, S = 50$	0.41	53.9	0.27

Hence from the data in table 2 can be concluded that if a system is desired where equal S and P power is provided, while reaching the same CCT as with only P then for the central optics polarizing beam splitter a $T_P=0.41$ may be required rather than $T_P=0.20$.

Hence it can be seen that, when using input blue light comprising both p- and s-polarized light in equal optical power contributions, a preferred p-polarized transmittance of 41% results. This is, however, also a function of the desired color temperature around which one would want to vary the color temperature. Nevertheless, it shows that this is fundamentally different from using only a p-polarized input as the above reference system does.

Table 3 provides an overview of the impact of variation of the S/P polarization ratio on the color point of the output light for a fixed p polarization transmission of 41% by the central optics polarizing beam splitter. Table 3:

S/P power level	T_P [0..1]	Power Yellow in W	Average blue/yellow ("CCT")	Average Power loss in W
P = 100, S = 0	0.41	41.3	0.61	11.81
P = 90, S = 10	0.41	43.82	0.52	10.69
P = 80, S = 20	0.41	46.34	0.45	9.57
P = 75, S = 25	0.41	47.6	0.42	9.01
P = 70, S = 30	0.41	48.86	0.38	8.45
P = 60, S = 40	0.41	51.38	0.32	7.34
P = 50, S = 50	0.41	53.9	0.27	6.22
P = 40, S = 60	0.41	56.42	0.22	5.10
P = 30, S = 70	0.41	58.94	0.17	3.98
P = 25, S = 75	0.41	60.2	0.15	3.42
P = 20, S = 80	0.41	61.46	0.13	2.87
P = 10, S = 90	0.41	63.98	0.09	1.75
P = 0, S = 100	0.41	66.5	0.06	0.63

10

Hence from the data in table 3 can be concluded that if a system is desired where equal S and P power is provided, while reaching the same CCT as with only P (i.e. CCT=0.27) then for the central optics polarizing beam splitter a $T_P=0.41$ may be required rather than $T_P=0.20$. Such a p-polarization transmittance for the central optics polarizing beam splitter further enables a relatively large range of selectable CCT values (i.e., a range of 0.06-0.61 around the target, here CCT=0.27).

15

Using a central optics polarizing beam splitter with a higher p polarization transmission and providing device light to the central optics that comprises a combination of

- p polarized and s polarized light may thus provide a light generating system with a tunable color point and up to 2x higher brightness than with the above indicated reference system. However, with increasing T_P values, there may also be a risk of increased power losses in the light generating system. Therefore, also a light generating system with $T_P=0.33$ was
- 5 evaluated. Table 4 provides an overview of the impact of variation of the S/P polarization ratio on the color point of the output light for a fixed p polarization transmission of 33% by the central optics polarizing beam splitter. Table 4:

S/P power level	T_P [0..1]	Power Yellow in W	Average blue/yellow ("CCT")	Average Power loss in W
P = 100, S = 0	0.33	46.9	0.47	7.72
P = 90, S = 10	0.33	48.86	0.41	7.00
P = 80, S = 20	0.33	50.82	0.36	6.29
P = 70, S = 30	0.33	52.78	0.31	5.57
P = 60, S = 40	0.33	54.74	0.27	4.85
P = 50, S = 50	0.33	56.7	0.23	4.13
P = 40, S = 60	0.33	58.66	0.19	3.41
P = 30, S = 70	0.33	60.62	0.15	2.69
P = 20, S = 80	0.33	62.58	0.12	1.98
P = 10, S = 90	0.33	64.54	0.09	1.26
P = 0, S = 100	0.33	66.5	0.06	0.54

- 10 As can be concluded from the data in table 4, the loss of power in the light generating system may be lowered when using a central optics polarizing beam splitter with a $T_P=0.33$. With such a T_P the light generating system may still provide the same CCT as before (0.27) while providing device light to the central optics that comprises an almost equal amount of p-polarization to s-polarization (60:40), thereby thus still enabling an almost
- 15 symmetric CCT tuning range (0.06-0.47) around the target ratio (here CCT=0.27) of blue to yellow optical power in the output light.

It may be obvious that multiple other permutations of building blocks / subsystems as presented so far are covered as further embodiments according to the principles of this invention as well. For example, in embodiments, the two optical branches

comprising the luminescent material and the diffuser material may be combined on the same rotatable element (e.g. a phosphor wheel, a rotating rod, or a rotating disc).

Fig. 5 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. 5 also schematically depicts an embodiment of lamp 1 comprising the light generating system 1000. Reference 3 indicates a projector device or projector system, which may be used to project images, such as at a wall, which may also comprise the light generating system 1000. Hence, Fig. 5 schematically depicts embodiments of a lighting device 1200 selected from the group of a lamp 1, a luminaire 2, a projector device 3, a disinfection device, a photochemical reactor, and an optical wireless communication device, comprising the light generating system 1000 as described herein. In embodiments, such lighting device may be a lamp 1, a luminaire 2, a projector device 3, a disinfection device, or an optical wireless communication device. Lighting device light escaping from the lighting device 1200 is indicated with reference 1201. Lighting device light 1201 may essentially consist of system light 1001, and may in specific embodiments thus be system light 1001. Reference 1300 refers to a space, such as a room. Reference 1305 refers to a floor and reference 1310 to a ceiling; reference 1307 refers to a wall.

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.

5 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
10 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
15 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.

20 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
25 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
30 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.

5 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 one or more light generating devices (100), a luminescent material (200), a diffuser element (710), a polarization changing element (810), central optics (900), and a control system (300), wherein:
- the one or more light generating devices (100) are configured to generate
5 device light (101); wherein the one or more light generating devices (100) comprise light sources (10) selected from a laser diode and a superluminescent diode; wherein the device light (101) received by the central optics (900) comprises a controllable polarization;
 - the luminescent material (200) is configured to convert at least part of the device light (101) received by the luminescent material (200) into luminescent material light
10 (201);
 - the diffuser element (710) is configured to diffuse at least part of the device light (101) received by the diffuser element (710) thereby providing diffused device light (711) while maintaining at least part of the polarization;
 - the polarization changing element (810) is configured in an optical path of the
15 device light (101) between the central optics (900) and the diffuser element (710);
 - the central optics (900) comprises (i) a central optics polarizing beam splitter (910), and (ii) a central optics dichroic beam splitter (920); wherein the central optics (900) are configured to transmit and/or reflect device light (101), diffused device light (711), and luminescent material light (201), received by the central optics (900) in dependence of one or
20 more of their polarizations and their spectral power distributions;
 - the control system (300) is configured to control the polarization of the device light (101) received by the central optics (900);
 - the light generating system (1000) is configured to provide system light (1001) comprising one or more of diffused device light (711) and luminescent material light (201);
- 25 and wherein the light generating system (1000) is configured such that in a first operational mode of the light generating system (1000) (a) at least part of the device light (101) irradiates the luminescent material (200) via the central optics (900), and the luminescent material light (201) escapes from the light generating system (1000) via the central optics (900), and (b) at least part of the device light (101) irradiates the diffuser element (710) via the central optics

(900), and at least part of the diffused device light (711) escapes from the light generating system (1000) via the central optics (900); and wherein one of the following applies:

- (i) the central optics polarizing beam splitter (910) is configured to (a) reflect x% of device light (101) having s polarization, (b) reflect y% of device light (101) having p polarization, and (c) transmit z% of device light (101) having p polarization, wherein x is selected from the range of at least 85%, wherein y is selected from the range of 25-85%, and wherein z is selected from the range of 15-75%;
- (ii) the central optics polarizing beam splitter (910) is configured to (a) reflect x% of device light (101) having s polarization, (b) reflect y% of device light (101) having p polarization, and (c) transmit z% of device light (101) having p polarization, wherein x is selected from the range of 15-75%, wherein y is selected from the range of at most 15%, and wherein z is selected from the range of at least 85%.

2. The light generating system (1000) according to claim 1, wherein the central optics polarizing beam splitter (910) is configured (a1) to transmit and/or reflect at least part of the device light (101) and (a2) to transmit and/or reflect at least part of the diffused device light (711); and wherein the central optics dichroic beam splitter (920) is configured (b1) to transmit or reflect at least part of the device light (101), (b2) to transmit or reflect at least part of the diffused device light (711), and (b3) to reflect or transmit at least part of the luminescent material light (201); and wherein the polarization changing element (810) comprises a $\lambda/4$ waveplate.

3. The light generating system (1000) according to any one of the preceding claims, wherein the device light (101) has a wavelength selected from the blue wavelength range; wherein the luminescent material light (201) has a wavelength selected from the green-red wavelength range; wherein the system light (1001) in the first operational mode is white light; and wherein in the first operational mode the system light (1001) comprises for at least 90% diffused device light (711) and luminescent material light (201).

4. The light generating system (1000) according to any one of the preceding claims, further comprising a polarization control element (610) configured to control polarization of the device light (101); wherein the polarization control element (610) comprises a rotatable birefringent rotator; wherein the birefringent rotator comprises a $\lambda/2$

waveplate; wherein the control system (300) is configured to control the polarization control element (610).

5. The light generating system (1000) according to any one of the preceding claims, wherein the one or more light generating devices comprise two different types of light generating devices (100), differing in the type of polarization of the device light (101) they generate; wherein the light generating system (1000) further comprises a first polarizing beam splitter (525), wherein the first polarizing beam splitter (525) is configured downstream of the two different types of light generating devices (100) and upstream of the central optics (900); and wherein the first polarizing beam splitter (525) is configured to transmit or reflect at least part of the p-polarized light, and to reflect or transmit at least part of the s-polarized light; and wherein the control system (300) is configured to control radiant fluxes of the device light (101) of the two different types of light generating devices (100).

6. The light generating system (1000) according to any one of the preceding claims, wherein the one or more light generating devices comprise two different types of light generating devices (100), differing in a spectral power distribution of the device light (101) they generate; wherein the light generating system (1000) further comprises a first dichroic beam splitter (515), wherein the first dichroic beam splitter (515) is configured downstream of the two different types of light generating devices (100) and upstream of the central optics (900); wherein the first dichroic beam splitter (515) is configured (a) to transmit or reflect at least part of the device light (101) of a first type, and (b) to reflect or transmit at least part of the device light (101) of a second type; wherein the control system (300) is configured to control radiant fluxes of the device light (101) of the two different types of light generating devices (100).

7. The light generating system (1000) according to any one of the preceding claims, wherein one of the following applies:

(i) the central optics dichroic beam splitter (920) is configured (a) to transmit at least 80% of the device light (101) received by the central optics dichroic beam splitter (920), (b) to reflect at least 80% of the luminescent material light (201) received by the central optics dichroic beam splitter (920); and (c) to transmit at least 80% of the diffused device light (711), received by the central optics dichroic beam splitter (920);

(ii) the central optics dichroic beam splitter (920) is configured (a) to reflect at least 80% of the device light (101) received by the central optics dichroic beam splitter (920), (b) to transmit at least 80% of the luminescent material light (201) received by the central optics dichroic beam splitter (920); and (c) to reflect at least 80% of the diffused device light (711), received by the central optics dichroic beam splitter (920).

8. The light generating system (1000) according to any one of the preceding claims, wherein the central optics polarizing beam splitter (910) is configured to (a) reflect x% of device light (101) having s polarization, (b) reflect y% of device light (101) having p polarization, and (c) transmit z% of device light (101) having p polarization, wherein x is selected from the range of at least 95%, wherein y is selected from the range of 50-85%, and wherein z is selected from the range of 15-50%.

9. The light generating system (1000) according to any one of the preceding claims, wherein the central optics polarizing beam splitter (910) is configured to (a) reflect x% of device light (101) having s polarization, (b) reflect y% of device light (101) having p polarization, and (c) transmit z% of device light (101) having p polarization, wherein x is selected from the range of 15-50%, wherein y is selected from the range of at most 5%, and wherein z is selected from the range of at least 95%.

10. The light generating system (1000) according to any one of the preceding claims, wherein the luminescent material (200) is configured in thermal contact with a thermally conductive material; wherein the light generating system (1000) comprises a plurality of light generating devices (100) configured to generate the device light (101), wherein two or more of the light generating devices (100) comprise laser light sources configured in a laser bank; wherein the light generating system (1000) further comprises one or more of integrating optics, collimation optics, and homogenization optics; wherein the luminescent material (200) at least comprises a luminescent material of the type $A_3B_5O_{12}:Ce$, wherein A comprises one or more of Y, La, Gd, Tb and Lu, and wherein B comprises one or more of Al, Ga, In and Sc; and wherein the device light (101) comprises blue device light (101).

11. The light generating system (1000) according to any one of the preceding claims, wherein the central optics (900) comprises (i) a single optical component having

polarizing beam splitting functionality and dichroic beam splitting functionality, or (ii) two optical components, one having polarizing beam splitting functionality and one having dichroic beam splitting functionality.

5 12. The light generating system (1000) according to any one of the preceding claims, comprising a rotatable element (1200), wherein the rotatable element (1200) comprises the luminescent material (200); wherein during operation of the light generating system (1000) in the first operational mode the rotatable element (1200) rotates, such that over time different parts of the luminescent material (200) are irradiated by the device light
10 (101).

13. The light generating system (1000) according to any one of the preceding claims, wherein the control system (300) is configured to control a spectral power distribution of the system light (1001) by controlling the polarization of the device light
15 (101).

14. The light generating system (1000) according to claim 13, wherein the control system (300) is configured to control a correlated color temperature of the system light (1001) in dependence of one or more of a user interface, a sensor signal, and a timer; and
20 wherein the control system (300) is configured to control in the first operational mode the correlated color temperature of the system light (1001) between 1800-8000 K.

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

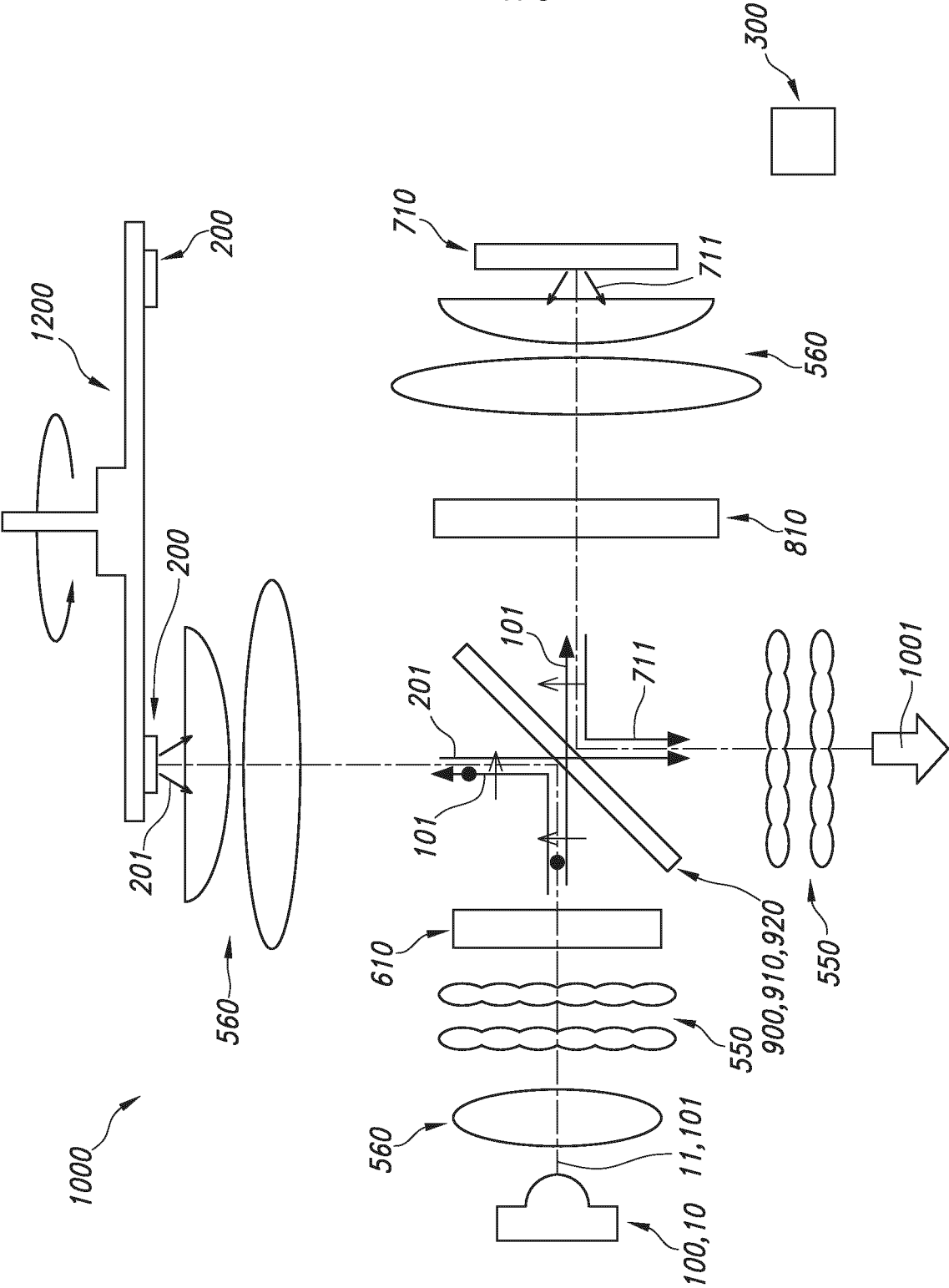


FIG. 1

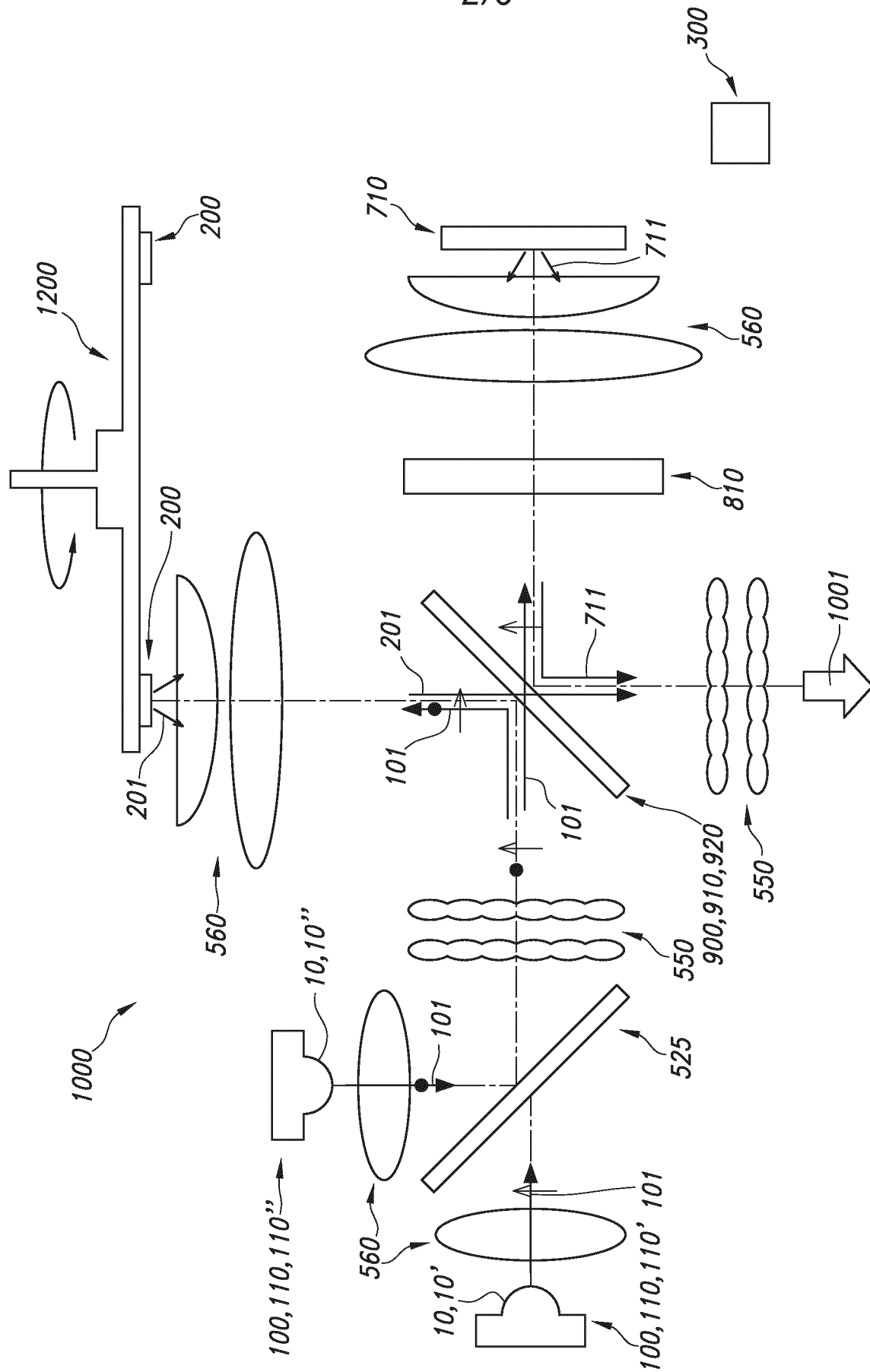


FIG. 2A

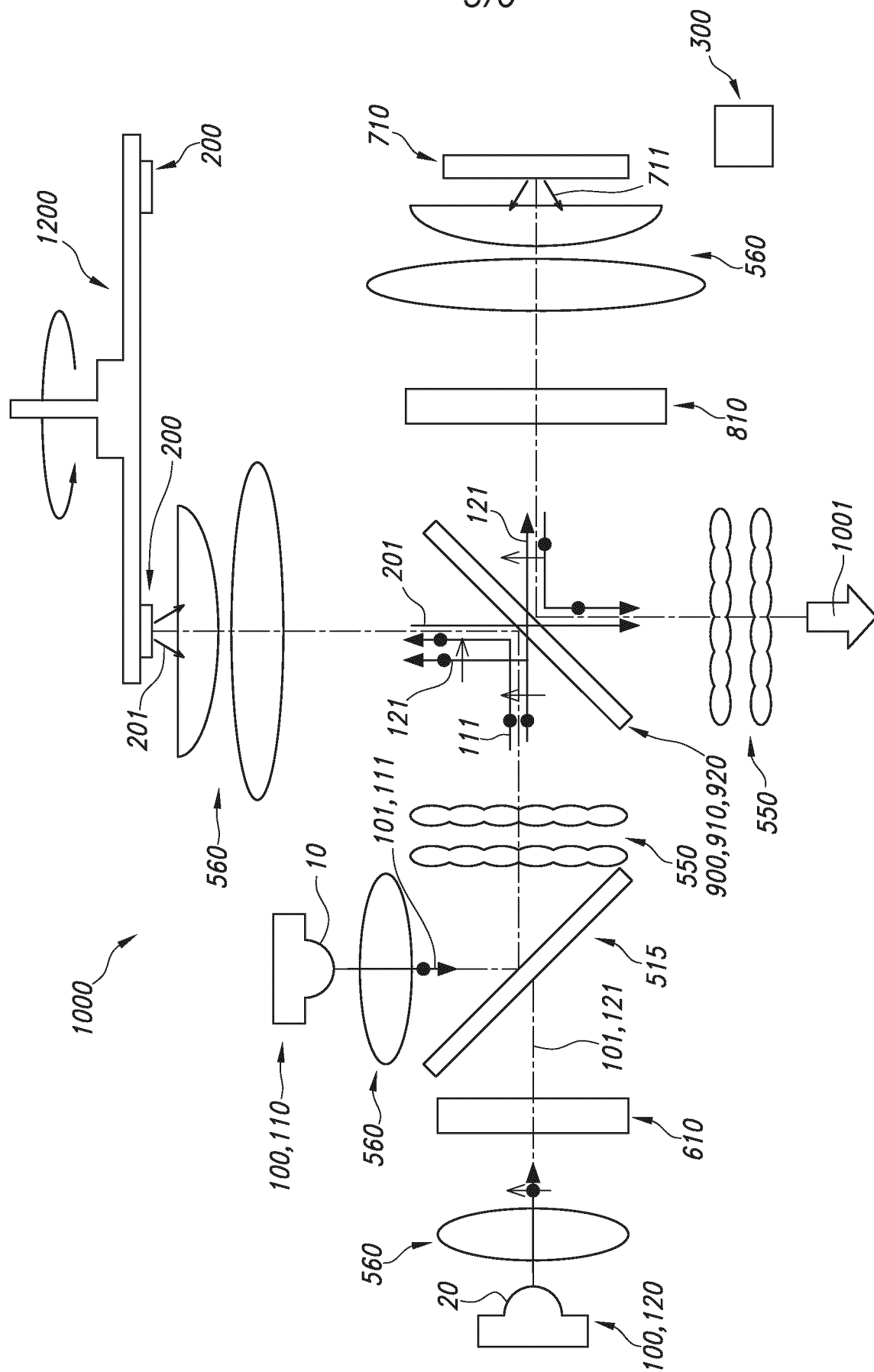


FIG. 2B

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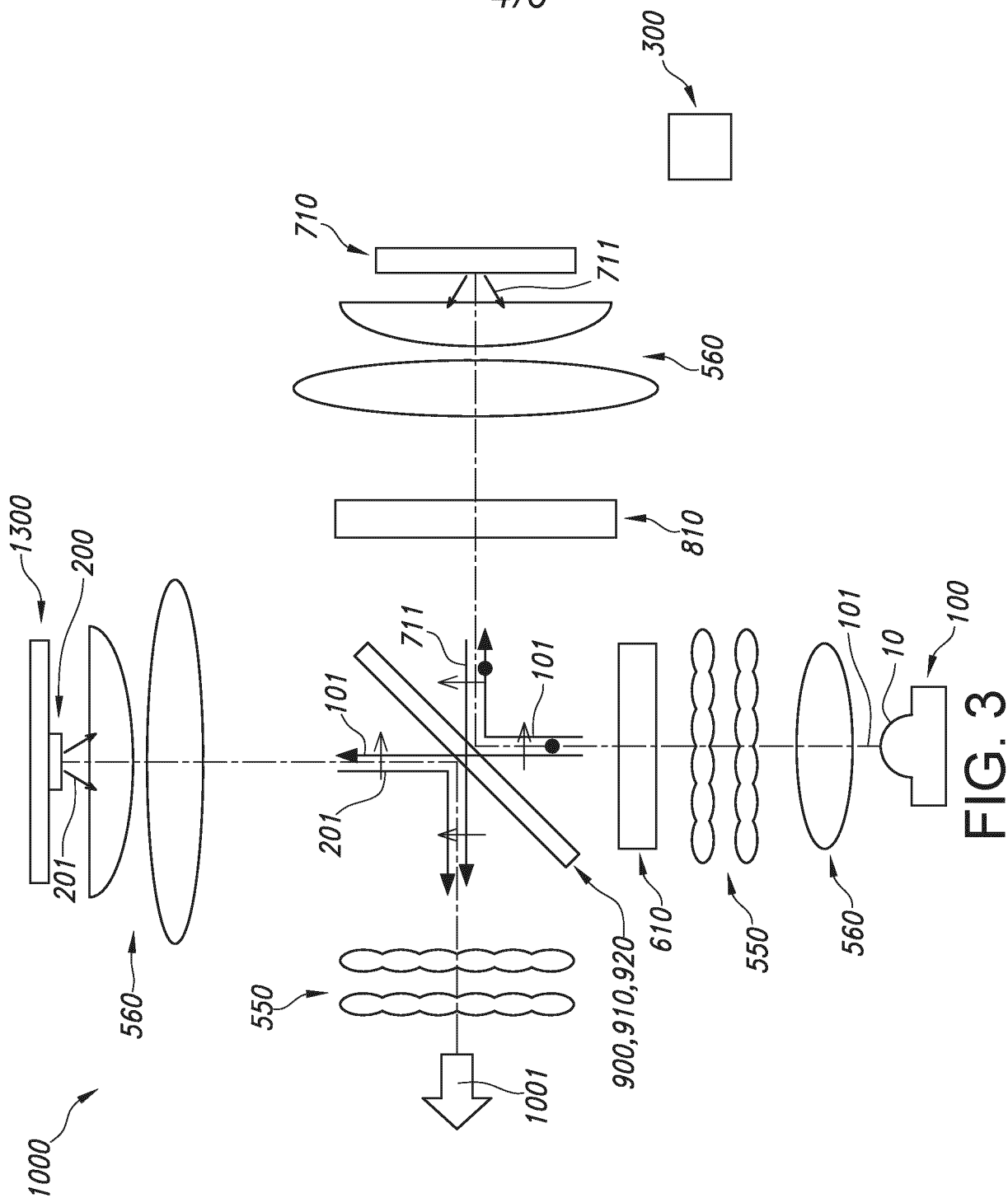


FIG. 3

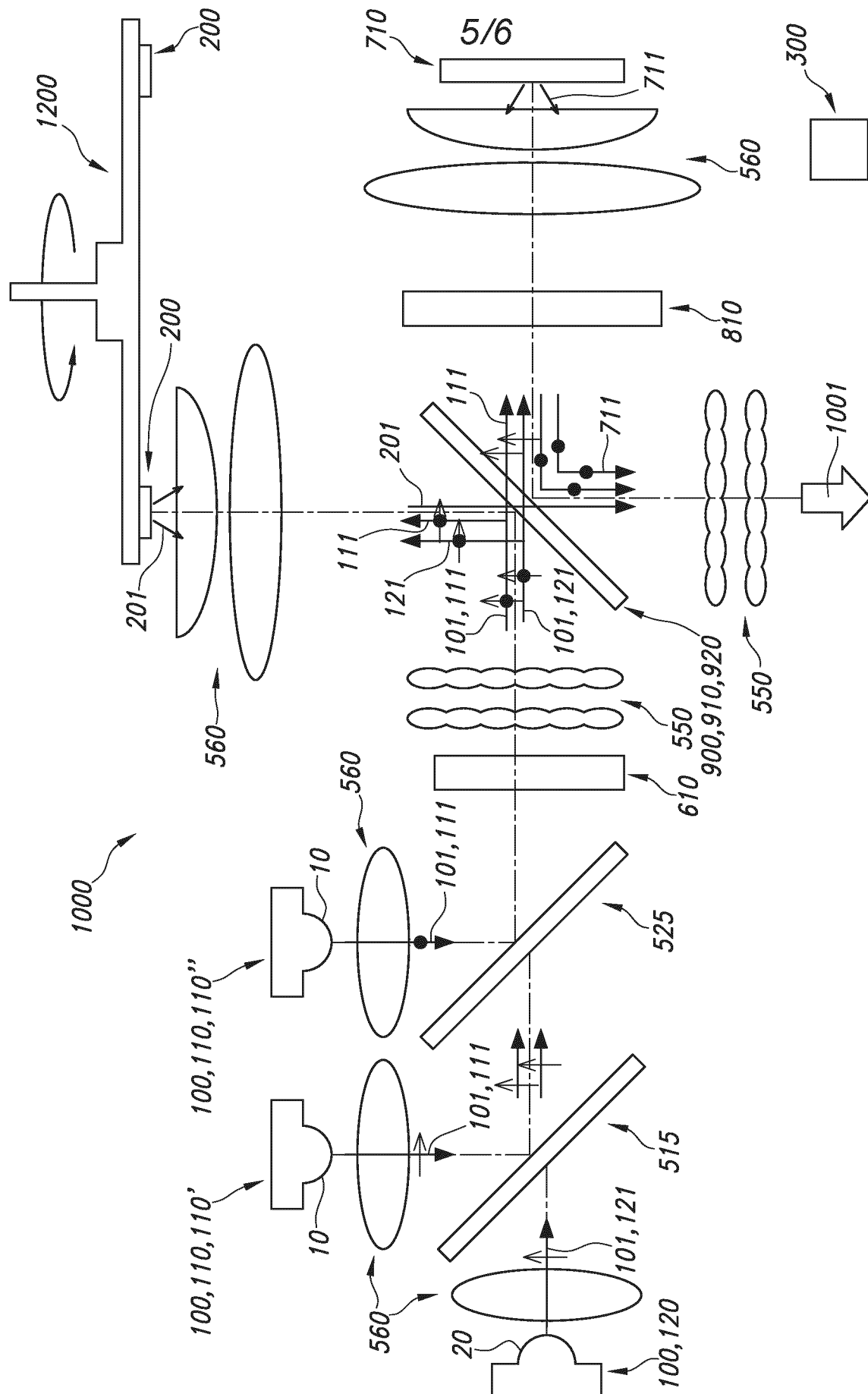
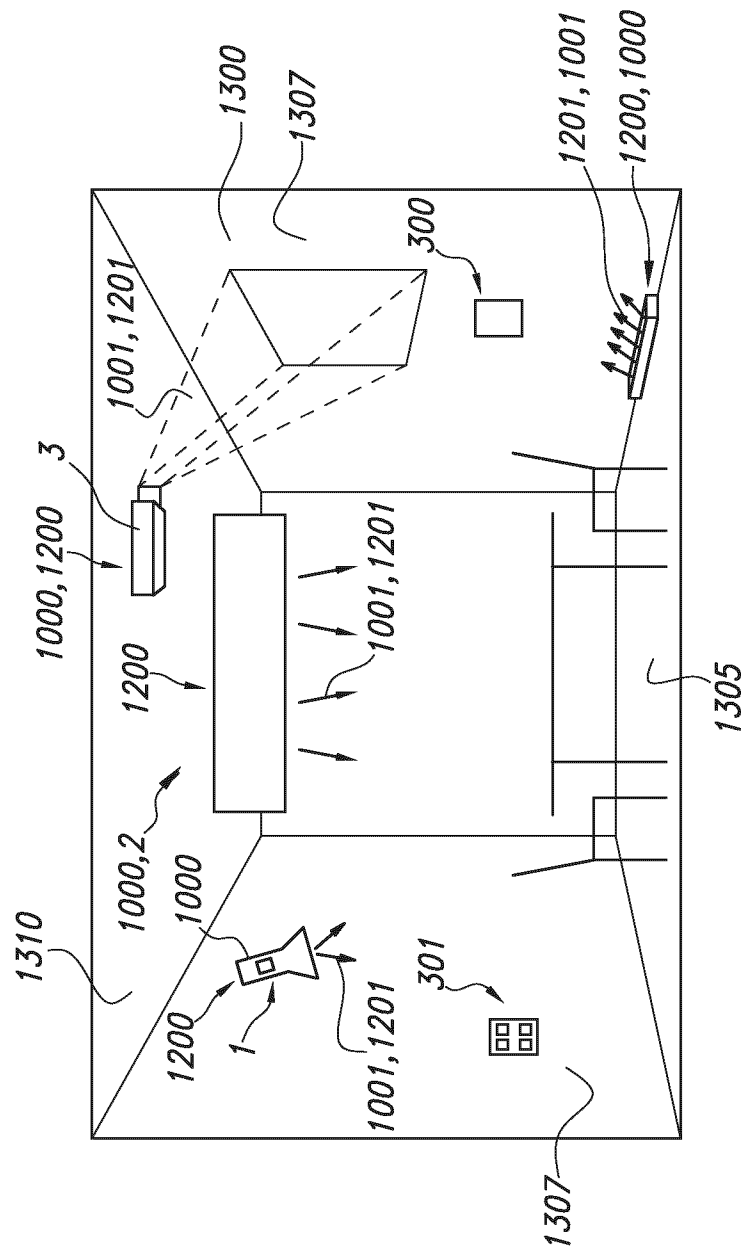


Fig. 4



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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/067274

A. CLASSIFICATION OF SUBJECT MATTER					
INV.	F21K9/64	F21K9/65	F21V9/14	F21V9/30	G03B21/20
	G03B33/00	G03B21/16			
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)					
F21V F21K G03B					
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					
C. DOCUMENTS CONSIDERED TO BE RELEVANT					
Category*	Citation of document, with indication, where appropriate, of the relevant passages				Relevant to claim No.
A	CN 113 820 914 A (SHENZHEN COLORWIN PHOTOELECTRIC TECH CO LTD) 21 December 2021 (2021-12-21) paragraphs [0042] - [0080]; claims 1-3; figure 5				1 - 15

L	WO 2024/160723 A1 (SIGNIFY HOLDING BV [NL]) 8 August 2024 (2024-08-08) page 44 - page 47; figure 1 page 36, line 30 - page 37, line 3				1 - 15

A	EP 3 290 992 A1 (SEIKO EPSON CORP [JP]) 7 March 2018 (2018-03-07) paragraphs [0001], [0034] - [0097]; figure 2				1 - 15

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☒ Further documents are listed in the continuation of Box C.					
☒ See patent family annex.					
* Special categories of cited documents :					
"A" document defining the general state of the art which is not considered to be of particular relevance			"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		
"E" earlier application or patent but published on or after the international filing date			"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone		
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Date of the actual completion of the international search			Date of mailing of the international search report		
20 September 2024			26/09/2024		
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016			Authorized officer Rückerl, Ralph		

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2024/067274

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 2022/091493 A1 (TANAKA TAKAAKI [JP]) 24 March 2022 (2022-03-24) paragraphs [0014] - [0038]; figure 1 -----	1 - 15
A	US 2015/153020 A1 (AKIYAMA KOICHI [JP]) 4 June 2015 (2015-06-04) paragraphs [0048] - [0090]; figure 2 -----	1 - 15
A	US 2020/319541 A1 (TANAKA TAKAAKI [JP]) 8 October 2020 (2020-10-08) paragraphs [0020] - [0075]; figure 1 -----	1 - 15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2024/067274

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