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(54) Title: A LIGHT GENERATING SYSTEM WITH B(A1)-B(A2)-G(A3) LEDS COVERED BY A KSIF TYPE PHOSPHOR

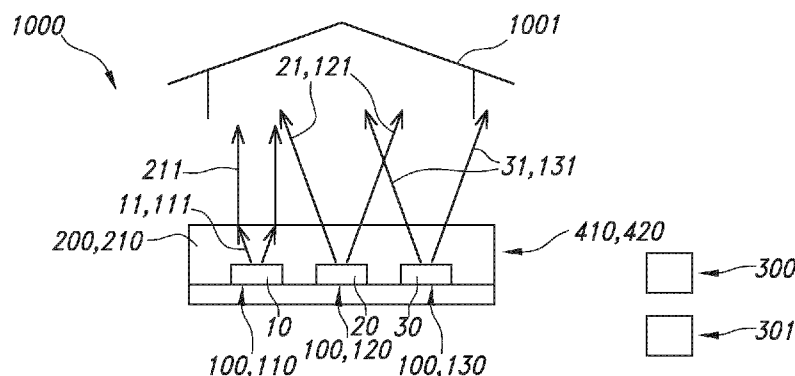


FIG. 1A

(57) **Abstract:** The invention provides a light generating system (1000) configured to provide system light (1001), wherein the light generating system (1000) comprises a first light generating device (110), a second light generating device (120), a third light generating device (130), and a luminescent element (200); wherein: (A) the first light generating device (110) comprises a first solid state light source (10), and wherein the first light generating device (110) is configured to generate first device light (111) having a first centroid wavelength (λ_{c1}), wherein the first centroid wavelength (λ_{c1}) is selected from the range of 440-460 nm; (B) the second light generating device (120) comprises a second solid state light source (20), and wherein the second light generating device (120) is configured to generate second device light (121) having a second centroid wavelength (λ_{c2}), wherein the second centroid wavelength (λ_{c2}) is selected from the range of 485-505 nm; (C) the third light generating device (130) comprises a third solid state light source (30), and wherein the third light generating device (130) is configured to generate third device light (131) having a third centroid wavelength (λ_{c3}), wherein the third centroid wavelength (λ_{c3}) is selected from the range of 520-570 nm; (D) the luminescent element (200) comprises a first luminescent material (210) configured to convert at least part of the first device light (111) received by the first luminescent material (210) into first luminescent material light (211); wherein the first luminescent material (210) comprises a luminescent material of the type $M'_xM_2-2xAX_6$ doped with tetravalent manganese, wherein M' comprises an alkaline earth cation, wherein M comprises an alkaline cation, and x is in the range of 0-1, wherein A comprises a tetravalent cation, wherein X comprises a monovalent anion,

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at least comprising fluorine; and (E) the light generating system (1000) is configured such that (a) the luminescent element (200) is configured in the transmissive mode, wherein less than 5% of the first device light (111) is transmitted through the luminescent element (200), (b) the second device light (121) and the third device light (131) are transmitted by the luminescent element (200); and (c) in an operational mode the system light (1001) is white light having a correlated color temperature selected from the range of 1500-6500 K and a color rendering index of at least 80.

A LIGHT GENERATING SYSTEM WITH B(λ_1)-B(λ_2)-G(λ_3) LEDS COVERED BY A KSiF TYPE PHOSPHOR

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

Light generating systems are known in the art. WO2009063915A1, for instance, describes a lighting system with a semiconductor light emitting device using a semiconductor light emitting element. The lighting system has a light emitting part where a plurality of types of semiconductor light emitting devices different in luminescent colors, which have the semiconductor light emitting elements and fluorescent substances and emit
10 light to an external part by light emission from the semiconductor light emitting elements, and that from the fluorescent substances which are excited and which fluoresce by emitted light from the semiconductor light emitting element or light emission from the fluorescent substances which are excited and fluoresce by emitted light from the semiconductor light
15 emitting element, are integrated and arranged.

SUMMARY OF THE INVENTION

There appears to be a desire to provide light with improved efficiency and/or white light quality. However, prior art solutions may have problems to achieve high quantum
20 efficiency (QE) and/or performance in terms of e.g. color rendering index (CRI) and/or R9 of the system light. 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.

25 According to a first aspect, the invention provides a light generating system configured to provide system light. In embodiments, the light generating system may comprise a first light generating device, a second light generating device, a third light generating device, and a luminescent element. The first light generating device may, in

embodiments, comprise a first (solid state) light source. Especially, in embodiments, the first light generating device may be configured to generate first device light having a first centroid wavelength (λ_{c1}). Especially, in embodiments, the first centroid wavelength (λ_{c1}) may be selected from the range of 440-460 nm. The second light generating device may, in

embodiments, comprise a second (solid state) light source. Especially, in embodiments, the second light generating device may be configured to generate second device light having a second centroid wavelength (λ_{c2}). Especially, in embodiments, the second centroid wavelength (λ_{c2}) may be selected from the range of 485-505 nm, more especially from the range of 488-500 nm. The third light generating device may, in embodiments, comprise a

third (solid state) light source. Especially, in embodiments, the third light generating device may be configured to generate third device light having a third centroid wavelength (λ_{c3}). Especially, in embodiments, the third centroid wavelength (λ_{c3}) may be selected from the range of 520-570 nm. Furthermore, in embodiments, the luminescent element may comprise a first luminescent material configured to convert at least part of the first device light

received by the first luminescent material into first luminescent material light. Especially, the first luminescent material may be configured to convert at least part of the first device light received by the first luminescent material into first luminescent material light having a spectral power distribution at one or more wavelengths in the orange-red wavelength range.

In embodiments, the first luminescent material may comprise a luminescent material of the

type $M'_xM_{2-2x}AX_6$ doped with tetravalent manganese. In such embodiments M' may comprise an alkaline earth cation. Further, in such embodiments, M may comprise an alkaline cation. Yet further, in such embodiments, x may be in the range of 0-1. Yet further, in such embodiments, A may comprise a tetravalent cation. Yet further, in such embodiments, X may comprise a monovalent anion, at least comprising fluorine. The light generating system may

especially be configured such that, in embodiments, the luminescent element may be configured in the transmissive mode. In embodiments, less than 5% of the first device light may be transmitted by the luminescent element. Additionally or alternatively, in

embodiments, the light generating system may especially be configured such that the second device light and the third device light may be (at least partly) transmitted by the luminescent

element. Additionally or alternatively, in embodiments, the light generating system may especially be configured such that in an operational mode the system light may be white light. Especially, the system light may be white light having a correlated color temperature selected from the range of 1500-6500 K and a color rendering index of at least 80. Hence, in embodiments, the invention may provide a light generating system configured to provide

system light, wherein the light generating system comprises a first light generating device, a second light generating device, a third light generating device, and a luminescent element; wherein: (A) the first light generating device may comprise a first light source, and wherein the first light generating device may be configured to generate first device light having a first centroid wavelength (λ_{c1}), wherein the first centroid wavelength (λ_{c1}) may be selected from the range of 440-460 nm; (B) the second light generating device may comprise a second light source, and wherein the second light generating device may be configured to generate second device light having a second centroid wavelength (λ_{c2}), wherein the second centroid wavelength (λ_{c2}) may be selected from the range of 485-505 nm; (C) the third light generating device may comprise a third light source, and wherein the third light generating device may be configured to generate third device light having a third centroid wavelength (λ_{c3}), wherein the third centroid wavelength (λ_{c3}) may be selected from the range of 520-570 nm; (D) the luminescent element may comprise a first luminescent material configured to convert at least part of the first device light received by the first luminescent material into first luminescent material light; wherein the first luminescent material may comprise a luminescent material of the type $M'_xM_{2-2x}AX_6$ doped with tetravalent manganese, wherein M' may comprise an alkaline earth cation, wherein M may comprise an alkaline cation, and x may be in the range of 0-1, wherein A may comprise a tetravalent cation, wherein X may comprise a monovalent anion, at least comprising fluorine; and (E) the light generating system may be configured such that (a) the luminescent element may be configured in the transmissive mode, wherein less than 5% of the first device light may be transmitted through the luminescent element, (b) the second device light and the third device light may be transmitted by the luminescent element; and (c) in an operational mode the system light may be white light having a correlated color temperature selected from the range of 1500-6500 K and a color rendering index of at least 80.

Such a light generating system may comprise a luminescent material in order to facilitate, in combination with a (blue) light source, the generation of white light. The first luminescent material may especially have the unique property of being excited by light having the first centroid wavelength (λ_{c1}), while essentially not being excited by light having the second and/or third centroid wavelengths (λ_{c2} and/or λ_{c3}). Hence, with three different types of light sources (having different centroid wavelengths) and the first luminescent material, the intensity of blue light in the system light (i.e., the saturation) may be controlled. Hence, with such a light generating system control of the correlated color temperature may be facilitated. Furthermore, such a light generating system may provide the benefit of high

CRI and/or high R9, through the combination of the different types of device light and luminescent material light having improved full width at half maximum (FWHM) and peak (wavelength) position.

The light generating system may thus comprise a first light generating device, a second light generating device, a third light generating device, and a luminescent element. Especially, in embodiments, the light generating devices may be covered by the luminescent element. More especially, in embodiments, (one or more of) the first light generating device, the second light generating device, and the third light generating device may be covered by the luminescent element. However, remote configurations may also be possible. Here below, embodiments of the light generating devices and the luminescent element will be described in further detail.

The first light generating device may, in embodiments, comprise a first light source. Especially, the first light source may comprise a first solid state light source, such as e.g. a light emitting diode (LED), a laser diode, or a superluminescent diode (see also further below). The first light generating device may, in embodiments, be configured to generate first device light having a first centroid wavelength (λ_{c1}). In embodiments, the first centroid wavelength (λ_{c1}) may be selected from the range of 430-470 nm, such as from the range of 435-465 nm, like from the range of 440-460 nm, especially from the range of 445-455 nm.

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 $\lambda_c = \Sigma \lambda * I(\lambda) / (\Sigma I(\lambda))$, 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.

Further, the second light generating device may, in embodiments, comprise a second light source. Especially, the second light source may comprise a second solid state light source, such as e.g. a light emitting diode (LED), a laser diode, or a superluminescent diode (see also further below). The second light generating device may, in embodiments, be configured to generate second device light having a second centroid wavelength (λ_{c2}). In embodiments, the second centroid wavelength (λ_{c2}) may be selected from the range of 480-510 nm, such as from the range of 485-505 nm, like from the range of 488-503 nm, especially from the range of 488-500 nm. In specific embodiments, the second centroid

wavelength (λ_{c2}) may be selected from the range of 487-495 nm, such as from the range of 490-495 nm, like from the range of 490-493 nm. Such embodiments may provide an increased color gamut and blue (λ_{c2}) light quality for the light generating system. In other specific embodiments, the second centroid wavelength (λ_{c2}) may be selected from the range of 495-503 nm, such as from the range of 495-500 nm. Such embodiments may result in low blue (λ_{c2}) light absorption by the luminescent element, and thus relatively more transmittance of blue (or cyan) light, thereby providing (output) system light having a color point more towards the cyan hues (and away from the red) (see further also below).

Yet further, the third light generating device may, in embodiments, comprise a third light source. Especially, the third light source may comprise a third solid state light source, such as e.g. a light emitting diode (LED), a laser diode, or a superluminescent diode (see also further below). The third light generating device may, in embodiments, be configured to generate third device light having a third centroid wavelength (λ_{c3}). In embodiments, the third centroid wavelength (λ_{c3}) may be selected from the range of 510-580 nm, such as from the range of 515-575 nm, like from the range of 520-570 nm, especially from the range of 520-560 nm, such as from the range of 530-560 nm.

In embodiments, one or more of the first device light, the second device light, and optionally the third device light may have a spectral (power) distribution with a relatively small full width half maximum (FWHM), especially $\text{FWHM} \leq 40$ nm. Especially, in embodiments, the one or more of the first device light and the second device light (and optionally the third device light) may have a spectral distribution with a $\text{FWHM} \leq 40$ nm, such as $\text{FWHM} \leq 35$ nm, like $\text{FWHM} \leq 30$ nm, especially $\text{FWHM} \leq 28$ nm. Such embodiments may be beneficial as the narrow-band emissions may prevent overlap of the emission spectrum with the excitation spectrum of (one or more elements of) the light generating system, i.e., the luminescent element. Especially, with narrow FWHM values, the light generating system may be configured such that the first device light may be substantially (absorbed and/or) converted by the luminescent element, whereas the second device light may be substantially transmitted by the luminescent element. In other words, the luminescent element (especially the first luminescent material) may substantially be excited by the first device light, but essentially not by the second (and/or third) device light.

Hence, in embodiments, the system also comprises a luminescent element, such as e.g. a layer, a body, or an encapsulant. The luminescent element may especially, in embodiments, comprise a first luminescent material. The term “first luminescent material” may also refer to a plurality of first luminescent materials (see also below). In embodiments,

the first luminescent material may be comprised by the luminescent element. Especially, in embodiments, the luminescent element may comprise one of a layer, a body, or an encapsulant comprising the first luminescent material. In embodiments, the luminescent element may especially be configured downstream of the light generating devices.

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

Referring back to the luminescent element, the luminescent element may thus be a layer, like a self-supporting layer. The luminescent element may also be a coating. The luminescent element may also comprise a luminescent coating on a support (especially a light transmissive support in the transmissive mode, or a reflective support in the reflective mode).

15 The luminescent element may also be an (elongated) encapsulant. Especially, the encapsulant may be configured covering the light generating devices and optionally a support or carrier. Especially, the luminescent element may essentially be self-supporting. In embodiments, the luminescent element may comprise a light transmissive body, wherein the luminescent material is embedded. For instance, the luminescent element may comprise a glass body, with
20 luminescent material embedded therein. Or, the glass as such may be luminescent. In other embodiments, the luminescent element may comprise a polymeric body, with luminescent material embedded therein. Further, in other embodiments, the luminescent element 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. Especially, in
25 embodiments, the luminescent element may be provided at a first distance (d_1) from the one or more light generating devices. In some embodiments, the first distance (d_1) may be essentially zero, i.e. the luminescent element may be in physical contact with the one or more light generating devices. In other embodiments, the first distance (d_1) may be at least 50 μm , such as at least 100 μm , especially at least 500 μm . For example, in embodiments, the first
30 distance (d_1) may be selected from the range of 1-50 mm, such as from the range of 1-20 mm, like from the range of 5-10 mm. Herein, the first distance may especially be defined as a shortest distance between top surfaces of the light generating devices and a first surface of the luminescent element. Especially, however the luminescent element may be configured in

physical contact with the light sources, such as in the case of a COB or LED filament (see also below).

The luminescent body may have any shape. In general, however, the luminescent body may comprise two essentially parallel faces, defining a height (of the luminescent body). Further, the luminescent body may comprise a third side (or “edge face”), bridging the first side and second side. The edge face may be curved in one or two dimensions. The edge face may be planar. The luminescent body may have a rectangular or circular cross-section, though other cross-sections may also be possible, like e.g. hexagonal, octagonal, etc. Hence, the luminescent body may have a circular cross-section, an oval cross-section, square, or non-square rectangular. In embodiments, the luminescent body may have an n-gonal cross-section, wherein n is at least 3, like 4 (square or rectangular cross-section), 5 (pentagonal cross-section), 6 (hexagonal cross-section), 8 (octagonal cross-section) or higher. The first side and second side may also be indicated as “main faces”, as they may especially provide the largest external area of the luminescent body. Perpendicular to the afore-

mentioned cross-section, may be another cross-section, which may in embodiments be rectangular. Hence, the luminescent body may e.g. have a cubic shape, a (non-cubic) cuboid shape, an n-gonal prism shape with n being at least 5 (such as pentagonal prism, hexagonal prism), and a cylindrical shape. Other shapes, however, may also be possible. Especially, the luminescent body may have a cuboid shape, a cylindrical shape, or an n-gonal prism shape wherein n is 6 or 8. In embodiments, the luminescent body (or “body”) has lateral dimensions width or length (W_B or L_B) or diameter (D_B) and a thickness or height (H_B). In embodiments, (i) $D_B \geq H_B$ or (ii) $W_B \geq H_B$ and/or $L_B \geq H_B$. The luminescent body may be transparent or light scattering. In embodiments, the luminescent body may comprise a ceramic luminescent material. In specific embodiments, $L_B \leq 10$ mm, such as especially $L_B \leq 5$ mm, more

especially $L_B \leq 3$ mm, most especially $L_B \leq 2$ mm. In specific embodiments, $W_B \leq 10$ mm, such as especially $W_B \leq 5$ mm, more especially $W_B \leq 3$ mm, most especially $W_B \leq 2$ mm. In specific embodiments, $H_B \leq 10$ mm, such as especially $H_B \leq 5$ mm, more especially $H_B \leq 3$ mm, most especially $H_B \leq 2$ mm. In specific embodiments, $D_B \leq 10$ mm, such as especially $D_B \leq 5$ mm, more especially $D_B \leq 3$ mm, most especially $D_B \leq 2$ mm. In specific embodiments, the luminescent body may have a height (H_B) in the range $50 \mu\text{m} - 1$ mm. Further, the luminescent body may have lateral dimensions (width/diameter) in the range $100 \mu\text{m} - 10$ mm. In yet further specific embodiments, (i) $D_B > H_B$ or (ii) $W_B > H_B$ and $L_B > H_B$.

Especially, the lateral dimensions like length, width, and diameter are at least 2 times, like at least 5 times, larger than the height. In specific embodiments, the luminescent body has a first

length L_B , a first height H_B , and a first width W_B , wherein $H_B \leq 0.5 * L_B$ and $H_B \leq 0.5 * W_B$. In embodiments, the luminescent body may be a (small) tile.

The first luminescent material, comprised by the luminescent element (e.g. a luminescent body) may be configured to, in embodiments, convert at least part of the first device light received by the first luminescent material into first luminescent material light. The phrase "... light received by ...", and similar phrases, such as "device light received by the first luminescent material" may especially indicate that when the light is actually received by an item, an action may take place. The action may in embodiments be one or more of conversion, reflection, and transmission. Further, the action may also include refraction. The phrase "to convert at least part of the device light received by the first luminescent material into first luminescent material light", and similar phrases, may thus indicate that when at least part of device light indeed irradiates the first luminescent material (in an operational mode of the light generating system), then at least part of that device light may be converted into first luminescent material light. Hence, in embodiments, the luminescent element, especially the first luminescent material, may be configured in a light-receiving relationship with the first light generating device. For example, in embodiments, the first luminescent material may be configured covering the first (, second, and third) light generating device as an encapsulant. As such, the first luminescent material may be configured to convert at least part of the first device light (incident on the first luminescent material) into first luminescent material light, especially having a spectral power distribution at one or more wavelengths in the orange-red wavelength range (see also further below). In embodiments, the first luminescent material may be configured to convert at least 70% of the first device light into first luminescent material light, such as at least 80% of the first device light, especially at least 90% of the first device light, like at least 95% of the first device light, especially at least 98% of the first device light.

The term "luminescent material" may especially refer 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 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 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 may emit radiation. In general, the luminescent material will be a down converter, i.e. radiation with 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 with 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 “luminescent material light” or “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 may be 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 embodiments, the first luminescent material may especially comprise a luminescent material of the type $M'_x M_{2-2x} A X_6$ doped with tetravalent manganese, wherein M' comprises an alkaline earth cation, M comprises an alkaline cation, and x may be selected from the range of 0-1, wherein A comprises a tetravalent cation, for instance comprising one or more of silicon and titanium, wherein X comprises a monovalent anion, at least comprising fluorine. Such luminescent materials may herein also be indicated as “KSiF” or “KSF”, whether or not M comprises K or one or more other alkaline cations. A luminescent material of the type $M'_x M_{2-2x} A X_6$ doped with tetravalent manganese is amongst others described in WO2013121355A1, which is herein incorporated by reference. Passages from WO2013121355A1 are also copied herein. Herein, $M'_x M_{2-2x} A X_6$ doped with tetravalent

manganese, may further also shortly be indicated as “phosphor”, i.e. the phrase “phosphor comprising $M'_xM_{2-2x}AX_6$ doped with tetravalent manganese” may in an embodiment also be read as $M'_xM_{2-2x}AX_6$ doped with tetravalent manganese phosphor, or (tetravalent) Mn-doped $M'_xM_{2-2x}AX_6$ phosphor, or shortly “phosphor”. Relevant alkaline earth cations (M') are magnesium (Mg), strontium (Sr), calcium (Ca) and barium (Ba), especially one or more of Sr and Ba. Relevant alkaline cations (M) are sodium (Na), potassium (K) and rubidium (Rb). Optionally, also lithium (Li) and/or cesium (Cs) may be applied. In a preferred embodiment, M comprises at least potassium. In yet another embodiment, M comprises at least rubidium. The phrase “wherein M comprises at least potassium” indicates for instance that of all M cations in a mole $M'_xM_{2-2x}AX_6$, a fraction comprises K^+ and an optionally remaining fraction comprises one or more other monovalent (alkaline) cations (see also below). In another preferred embodiment, M comprises at least potassium and rubidium. Optionally, the $M'_xM_{2-2x}AX_6$ luminescent material has the hexagonal phase. In yet another embodiment, the $M'_xM_{2-2x}AX_6$ luminescent material has the cubic phase. In an embodiment, a combination of different alkaline cations may be applied. In yet another embodiment, a combination of different alkaline earth cations may be applied. In yet another embodiment, a combination of one or more alkaline cations and one or more alkaline earth cations may be applied. For instance, $KRb_{0.5}Sr_{0.25}AX_6$ might be applied. As indicated above, x may be selected from the range of 0-1, especially $x \leq 1$. In specific embodiments, $x = 0$.

The term “tetravalent manganese” refers to Mn^{4+} . This is a well-known luminescent ion. In the formula as indicated above, part of the tetravalent cation A (such as Si) is being replaced by manganese. Hence, $M'_xM_{2-2x}AX_6$ doped with tetravalent manganese may also be indicated as $M'_xM_{2-2x}A_{1-m}Mn_mX_6$. The mole percentage of manganese, i.e. the percentage it replaces the tetravalent cation A will in general be in the range of 0.1-15 %, especially 1-12 %, i.e. m is in the range of 0.001-0.15, especially in the range of 0.01-0.12.

A comprises a tetravalent cation, and preferably at least comprises silicon. A may optionally (further) comprise one or more of titanium (Ti), germanium (Ge), stannum (Sn) and zinc (Zn). Preferably, at least 80%, even more preferably at least 90%, such as at least 95% of M consists of silicon. Hence, in a specific embodiment, $M'_xM_{2-2x}AX_6$ may also be described as $M'_xM_{2-2x}A_{1-m-t-g-s-zr}Mn_mTi_tGe_gSn_sZr_{zr}X_6$, wherein m and x are as indicated above, and wherein t,g,s,zr are each individually preferably in the range of 0-0.2, especially 0-0.1, even more especially 0-0.05, wherein $t+g+s+zr$ is smaller than 1, especially equal to or smaller than 0.2, preferably in the range of 0-0.2, especially 0-0.1, even more especially 0-0.05, and wherein A is especially Si. X is preferably fluorine (F).

As indicated above, M relates to monovalent cations, but preferably at least comprises potassium and/or rubidium. Other monovalent cations that may further be comprised by M can be selected from the group consisting of lithium (Li), sodium (Na), cesium (Cs) and ammonium (NH_4^+). In an embodiment, preferably at least 80% (i.e. 80% of all moles of the type M), even more preferably at least 90%, such as 95% of M consists of potassium and/or rubidium. Especially, in these embodiments, x is thus zero.

Hence, in a specific embodiment, $\text{M}'_x\text{M}_{2-2x}\text{AX}_6$ can also be described as $(\text{K}_{1-r-l-n-c-nh}\text{Rb}_r\text{Li}_l\text{Na}_n\text{Cs}_c(\text{NH}_4)_{nh})_2\text{AX}_6$, wherein r is in the range of 0-1, wherein l, n, c, nh are each individually preferably in the range of 0-1, preferably 0-0.2, especially 0-0.1, even more especially 0-0.05, and wherein $r+l+n+c+nh$ is in the range of 0-1, especially $l+n+c+nh$ is smaller than 1, especially equal to or smaller than 0.2, preferably in the range of 0-0.2, especially 0-0.1, even more especially 0-0.05. X is preferably fluorine (F).

As indicated above, instead of or in addition to the alkaline cation(s), also one or more alkaline earth cations may be present. Hence, in a specific embodiment, $\text{M}'_x\text{M}_{2-2x}\text{AX}_6$ can also be described as $\text{Mg}_{mg}\text{Ca}_{ca}\text{Sr}_{sr}\text{Ba}_{ba}(\text{K}_k\text{Rb}_r\text{Li}_l\text{Na}_n\text{Cs}_c(\text{NH}_4)_{nh})_2\text{AX}_6$, with k, r, l, n, c, nh each individually being in the range of 0-1, wherein mg, ca, sr, ba are each individually in the range of 0-1, and wherein $mg+ca+sr+ba+k+r+l+n+c+nh=1$. In embodiments, $k=1$, and the others (mg, ca, sr, ba, r, l, n, c, nh) are zero.

As indicated above, X relates to a monovalent anion, but at least comprises fluorine. Other monovalent anions that may optionally be present may be selected from the group consisting of chlorine (Cl), bromine (Br), and iodine (I). Preferably, at least 80%, even more preferably at least 90%, such as 95% of X consists of fluorine. Hence, in a specific embodiment, $\text{M}'_x\text{M}_{2-2x}\text{AX}_6$ can also be described as $\text{M}'_x\text{M}_{2-2x}\text{A}(\text{F}_{1-cl-b-i}\text{Cl}_{cl}\text{Br}_b\text{I}_i)_6$, wherein cl, b, i are each individually preferably in the range of 0-0.2, especially 0-0.1, even more especially 0-0.05, and wherein $cl+b+i$ is smaller than 1, especially equal to or smaller than 0.2, preferably in the range of 0-0.2, especially 0-0.1, even more especially 0-0.05. Especially, X essentially consists of F (fluorine).

Hence, $\text{M}'_x\text{M}_{2-2x}\text{AX}_6$ can also be described as $(\text{K}_{1-r-l-n-c-nh}\text{Rb}_r\text{Li}_l\text{Na}_n\text{Cs}_c(\text{NH}_4)_{nh})_2\text{Si}_{1-m-t-g-s-zr}\text{Mn}_m\text{Ti}_t\text{Ge}_g\text{Sn}_s\text{Zr}_{zr}(\text{F}_{1-cl-b-i}\text{Cl}_{cl}\text{Br}_b\text{I}_i)_6$, with the values for r, l, n, c, nh, m, t, g, s, zr, cl, b, i as indicated above. X is preferably fluorine (F).

Even more especially, $\text{M}'_x\text{M}_{2-2x}\text{AX}_6$ can also be described as $\text{Mg}_{mg}\text{Ca}_{ca}\text{Sr}_{sr}\text{Ba}_{ba}(\text{K}_k\text{Rb}_r\text{Li}_l\text{Na}_n\text{Cs}_c(\text{NH}_4)_{nh})_2\text{Si}_{1-m-t-g-s-zr}\text{Mn}_m\text{Ti}_t\text{Ge}_g\text{Sn}_s\text{Zr}_{zr}(\text{F}_{1-cl-b-i}\text{Cl}_{cl}\text{Br}_b\text{I}_i)_6$, with k, r, l, n, c, nh each individually being in the range of 0-1, wherein mg, ca, sr, ba are

each individually in the range of 0-1, wherein $mg+ca+sr+ba+k+r+l+n+c+nh=1$, and with the values for m,t,g,s,zr,cl,b,i as indicated above. X is preferably fluorine (F).

In an embodiment, $M'_xM_{2-2x}AX_6$ comprises K_2SiF_6 (indicated herein also as KSiF system). As indicated above, in another preferred embodiment, $M'_xM_{2-2x}AX_6$ comprises KRbSiF₆ (i.e. $r=0.5$ and l,n,c,nh,t,g,s,zr,cl,b,i are 0) (herein also indicated as K,Rb system). As indicated above, part of silicon is replaced by manganese (i.e. the formula may also be described as $K_2Si_{1-m}Mn_mF_6$ or $KRbSi_{1-m}Mn_mF_6$, with m as indicated above, or as $KRbSiF_6:Mn$ and $K_2SiF_6:Mn$, respectively). As manganese replaces part of a host lattice ion and has a specific function, it is also indicated as “dopant” or “activator”. Hence, the hexafluorosilicate is doped or activated with manganese (Mn^{4+}). Here below, $M'_xM_{2-2x}AX_6$ is also indicated as $M'_xM'^{'}_{2-2x}AX_6$. In specific embodiments, the indication $M'_xM_{2-2x}AX_6$ may refer to one or more of $(K,Rb)_2SiF_6:Mn^{4+}$, $(K,Rb)_2TiF_6:Mn^{4+}$, $K_2(Si,Ti)F_6:Mn^{4+}$, and $Rb_2(Si,Ti)F_6:Mn^{4+}$, such as one or more of $K_2TiF_6:Mn^{4+}$, of $K_2SiF_6:Mn^{4+}$, and of $Rb_2SiF_6:Mn^{4+}$. The luminescent material may also be coated, as also described in WO2013121355A1.

Hence, in embodiments, the first luminescent material may comprise a luminescent material of the type $M'_xM_{2-2x}AX_6$ doped with tetravalent manganese. In embodiments, the luminescent element may also comprise a type of luminescent material different from the first luminescent material, such as one or more of the types of luminescent materials described further below. However, in embodiments, at least 70 vol.% of the luminescent material in the luminescent element may be of the type $M'_xM_{2-2x}AX_6$ doped with tetravalent manganese, such as at least 80 vol.%, like at least 90 vol.%, especially at least 95 vol.%, more especially at least 98 vol.%, including 100 vol.%. Hence, in specific embodiments, at least 95 vol.% of the luminescent material in the luminescent element may be first luminescent material. Such embodiments may be beneficial as so-called “KSiF” type luminescent materials may have the unique property of converting (royal) blue light, but not green and (extreme) long wavelength blue light. As such, the first luminescent material may provide the benefit of low selectivity for excitation of the first luminescent material by (cyan/green) light having the second and/or third centroid wavelength (λ_{c2} and/or λ_{c3}), and high selectivity for excitation of the first luminescent material by (violet/blue) light having the first and/or fourth centroid wavelength (λ_{c1} and/or λ_{c4} , see also further below). Hence, with such embodiments, the intensity of blue light in the system light (i.e. the saturation) may be controlled. The system may therefore provide (white) system light having a controllable correlated color temperature. Furthermore, the system may provide (non-white) system light

having an improved performance in terms of CRI and/or R9. Thus, such a light generating system may provide high tunability, e.g. by varying the intensities of the different light generating devices.

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

In the reflective mode, a dichroic reflector may be used, to promote the luminescent material light over the first device light. The latter may be transmitted with a higher transmission than the former and the former may be reflected with a higher reflection than the latter.

Herein, when an element is indicated to be operated in a transmissive mode this may, in embodiments, imply 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. Herein, 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.

Further, in embodiments, the light generating system may be configured such that the luminescent element may be configured downstream of, especially covering the first, second and third light generating devices. In such embodiments, the light generating system may be configured such that less than 10%, such as less than 8%, like less than 5%, especially less than 3% of the first device light may be transmitted by the luminescent element. Especially, in embodiments, the luminescent element may be configured to transmit less than 10%, such as less than 8%, like less than 5%, especially less than 3%, more especially less than 2% of the first device light. In other words, in embodiments, at least 90%, such as at least 95%, like at least 98%, especially at least 99% of the first device light may be absorbed by the (luminescent material comprised by the) luminescent element. Especially, in

embodiments, at least part of the first device light may be converted into first luminescent material light by the luminescent element, see also above. Herein, these percentages may refer to percentages of the radiant flux (within the 380-780 nm wavelength range).

Here, absorption of light may refer to the absorption of photons of radiation incident on a luminescent species (e.g. the luminescent element) by the luminescent material. The term excitation, known to the person skilled in the art, refers to absorption of light and conversion thereof into emission. In contrast, transmission may refer to radiation passing through the luminescent element without being absorbed and/or converted by the luminescent material. The transmission, absorption, and/or conversion of radiation may depend on the thickness of the luminescent element, especially one or more luminescent material layers in the luminescent element, and/or a concentration of the absorbing species (see also Lambert Beer's Law). Especially, in embodiments, in case of transmission, thicker luminescent material layers have lower light-outcoupling efficiency due to higher light trapping efficiency of the luminescent material layer. Further, in embodiments, in case of conversion, too thin luminescent material layers may result in lower light-conversion efficiency, whereas too thick (or too many) luminescent material layers may result in reabsorption of the incident light, thus leading to higher loss of light (and hence also lower light-conversion efficiency). Hence, in embodiments, a thickness of the luminescent material layer (comprised by the luminescent element) may be selected such that substantially all of the first device light (having λ_{c1}) is absorbed.

Yet further, in embodiments, the light generating system may be configured such that the second device light and the third device light may be (at least partially) transmitted by the luminescent element. Especially, in embodiments, the light generating system may be configured such that more than 60%, such as more than 70%, like more than 80%, especially more than 90%, more especially more than 95%, including 100%, of the second and/or third device light may be transmitted by the luminescent element. In specific embodiments, the luminescent element may be configured to transmit more than 90%, such as more than 95%, like more than 98%, especially more than 99% of the (green) third device light. Hence, in embodiments, the third device light may not be converted into first luminescent material light by the luminescent element. However, in other embodiments, a small percentage of the third device light may yet be converted into first luminescent material light by the luminescent element, such as at most 10%, like at most 8%, especially at most 5%, like at most 2% of the third device light.

Similarly, in specific embodiments, the luminescent element may be configured to transmit more than 85%, like more than 90%, such as more than 95%, like more than 98%, especially more than 99% of the (blue) second device light. Hence, in embodiments, the second device light may not be converted into first luminescent material light by the luminescent element. However, in other embodiments, a small percentage of the second device light may yet be converted into first luminescent material light by the luminescent element, such as at most 20%, like at most 15%, especially at most 10%, like at most 5% of the second device light.

The light generating system may thus, in embodiments, be configured to provide one or more of first device light, second device light, third device light, and first luminescent material light. As described above, the first device light may be substantially converted by the first luminescent material into the first luminescent material light. Thus, in embodiments, the system light may comprise one or more of second device light, third device light, and first luminescent material light. Especially, in embodiments, in an operational mode of the light generating system, the system light may be white light. The term “white light”, and similar terms, herein, is known to the person skilled in the art. In general, if a light source is indicated to generate white light, it may especially relate to light having a correlated color temperature (CCT) between about 1500 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. More especially, in embodiments, in an operational mode (i.e. a first and/or second operational mode) the system light may be white light having a correlated color temperature selected from the range of 1500-10000K, such as selected from the range of 1500-6500K, like selected from the range of 2500-5500K. Additionally or alternatively, in such embodiments, the system light may be white light having a color rendering index of at least 70, especially at least 80, such as at least 90.

As described above, the first, second, and third light generating devices may comprise first, second, and third solid state light sources, respectively. 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.

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.

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 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, 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 sources having dimensions, such as die dimension, especially length and width, selected from the range of 100 μ m and smaller. For example, in embodiments, one or more of the first light generating device, the second light generating device, and the third light generating device may comprise micro LEDs having a size smaller than 100 μ m. Hence, in embodiments, the light generating system may comprise micro LEDs having a size smaller than 100 μ m. In embodiments, the micro LEDs may further have a size larger than 3 μ m, such as larger than 5 μ m, like larger than 15 μ m, especially larger than 20 μ m.

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 may be applied to the LED die, the outer surface of the resin. In principle, it may also be the terminal

end of a fiber. The term escape surface especially relates to that part of the light source, where the light actually leaves or escapes from the light source. The light source is configured to provide a beam of light. This beam of light (thus) escapes from the light exit surface of the light source.

5 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
10 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
15 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
20 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-
25 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).

 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
30 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”) and may be indicated as direct color LEDs. Such a light emitting diode configured to provide primary radiation may also be referred to as “direct emitting” light emitting diode. In embodiments, one or more of the light generating devices may comprise a direct-emitting light emitting diode. Especially, in

embodiments, the third light generating device may comprise a green direct-emitting light emitting diode. Such embodiments may be beneficial as direct-emitting LEDs may provide a relatively narrow FWHM, thus reducing overlap of its emission spectrum with the excitation spectrum of (one or more elements of) the light generating system, i.e., the luminescent element. In other words, with a direct-emitting LED for the third (green) light generating device, the third device light may essentially not excite the first luminescent material, but may substantially be transmitted by the luminescent element (see also above). Similarly, in embodiments, the second light generating device may comprise a (blue) direct-emitting light emitting diode.

In other embodiments, however, the light source may be configured to provide primary radiation and part of the primary radiation may be 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 (thus) comprise a luminescent material. In embodiments, the light generating device may comprise a PC LED. In embodiments, one or more of the light generating devices may comprise a phosphor converted light emitting diode. Especially, in embodiments, the third light generating device may comprise a phosphor converted light emitting diode. Such embodiments may be beneficial as phosphor converted LEDs may provide a relatively high efficiency. The third light generating device may for example, in embodiments, comprise a blue LED comprising a green-yellow phosphor. In such embodiments, the green-yellow phosphor may especially comprise a narrow-band green-yellow phosphor. Furthermore, in such embodiments, the PC-LED of the third light generating device may comprise yellow (and especially red-shifted) YAG or LuAG (see below). Such embodiments may be beneficial as by using such a PC-LED for the third (green) light generating device, the third

device light may result in reduced conversion of the third device light into first luminescent material light by the first luminescent material.

In specific embodiments the third light generating device comprises a second luminescent material of the type $A_3B_5O_{12}:Ce$, wherein A in embodiments comprises one or more of Y, La, Gd, Tb and Lu, especially (at least) one or more of Y, Gd, Tb and Lu, and wherein B in embodiments comprises one or more of Al, Ga, In and Sc. Especially, A may comprise one or more of Y, Gd and Lu, such as especially one or more of Y and Lu. Especially, B may comprise one or more of Al and Ga, more especially at least Al, such as essentially entirely Al. Hence, especially suitable luminescent materials are cerium comprising garnet materials. Embodiments of garnets especially include $A_3B_5O_{12}$ garnets, wherein A comprises at least yttrium or lutetium and wherein B comprises at least aluminum. Such garnets may be doped with cerium (Ce), with praseodymium (Pr) or a combination of cerium and praseodymium; especially however with Ce. Especially, B may comprise aluminum (Al); however, in addition to aluminum, B may also partly comprise gallium (Ga) and/or scandium (Sc) and/or 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). Further, Gd and/or Tb are especially only present up to an amount of about 20% of A. In a specific embodiment, the garnet luminescent material comprises $(Y_{1-x}Lu_x)_3B_5O_{12}:Ce$, wherein x is equal to or larger than 0 and equal to or smaller than 1. The term “:Ce”, indicates that part of the metal ions (i.e. in the garnets: part of the “A” ions) in the luminescent material is replaced by Ce. For instance, in the case of $(Y_{1-x}Lu_x)_3Al_5O_{12}:Ce$, part of Y and/or Lu is replaced by Ce. This is known to the person skilled in the art. Ce will replace A in general for not more than 10%; in general, the Ce concentration will be in the range of 0.1 to 4%, especially 0.1 to 2% (relative to A). Assuming 1% Ce and 10% Y, the full correct formula could be $(Y_{0.1}Lu_{0.89}Ce_{0.01})_3Al_5O_{12}$. Ce in garnets is substantially or only in the trivalent state, as is known to the person skilled in the art.

In embodiments, the second 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 second 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,
 10 have a relatively high thermal stability, and allow a high CRI (optionally in combination with (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
 15 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 third light generating device may only include second luminescent materials selected from the type of cerium comprising garnets. In even further specific embodiments, the third light generating device includes a single type of second 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 third light generating device comprises second luminescent material,
 25 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 second luminescent material comprises $(Y_{x_1}A'_{x_2}Ce_{x_3})_3(Al_{y_1}B'_{y_2})_5O_{12}$ as defined above. 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.

30 Hence, in embodiments, the third light generating device may comprise the second luminescent material, wherein the second luminescent material may be a luminescent material of the type $A_3B_5O_{12}:Ce^{3+}$, 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.

Further, in embodiments, the second luminescent material may include a luminescent material such as $(Y_{x1}Lu_{x2}A'_{x3}Ce_{x4})_3B_5O_{12}$, wherein $x1' + x2' + x3' + x4' = 1$, wherein $x4'$ may be selected from the range of 0.001-0.1. Further, in embodiments, the

second luminescent material may comprise at least two luminescent materials of the type

5 $A_3B_5O_{12}:Ce^{3+}$, such as at least $(Y_{x1}Lu_{x2}A'_{x3}Ce_{x4})_3B_5O_{12}$ and $(Y_{x1}Lu_{x2}A'_{x3}Ce_{x4'})_3B_5O_{12}$.

In such embodiments, the second luminescent material may comprise a primary second

luminescent material such as $(Y_{x1}Lu_{x2}A'_{x3}Ce_{x4})_3B_5O_{12}$, wherein $x1' \geq x2'$, wherein $0.001 \leq x4' \leq 0.1$, wherein A' comprises one or more of La, Gd, and Tb, and wherein B comprises

one or more of Al, Ga, In, and Sc. Further, in such embodiments, the second luminescent

10 material may comprise a secondary second luminescent material such as

$(Y_{x1}Lu_{x2}A'_{x3}Ce_{x4'})_3B_5O_{12}$, wherein $x1'' + x2'' + x3'' + x4'' = 1$, wherein $x2'' > x2'$, wherein

$0.001 \leq x4'' \leq 0.1$, wherein A' comprises one or more of La, Gd, and Tb, and wherein B

comprises one or more of Al, Ga, In, and Sc. In embodiments, the secondary second

luminescent material may thus comprise on a molar basis more Lu than the primary second

15 luminescent material. Further, in embodiments, the primary second luminescent material may

comprise on a molar basis more Y than the secondary second luminescent material, $x1' >$

$x1''$. In embodiments, $x2'$ may be equal to zero. Further, in embodiments, one or more of $x2'$,

$x3'$, and $x3''$ may be equal to zero. In embodiments, $x4'$ may be equal to $x4''$. Yet, in

embodiments, $x4'$ may be different from $x4''$, wherein (both) $x4'$ and $x4''$ may be

20 individually selected from the range of 0.001-0.1. Hence, in embodiments, the second

luminescent material may comprise a primary second luminescent material such as

$(Y_{x1}Lu_{x2}Ce_{x4})_3B_5O_{12}$ (wherein $x1' + x2' + x4' = 1$) and a secondary second luminescent

material such as $(Y_{x1}Lu_{x2}Ce_{x4'})_3B_5O_{12}$ (wherein $x1'' + x2'' + x4'' = 1$), wherein $x2'' > x2'$, and

wherein in specific embodiments $x2' = 0$.

25 Further, in embodiments, the second luminescent material may include a

luminescent material such as $(Lu_{x1}A'_{x2}Ce_{x3})(Al_{y1}B'_{y2})_5O_{12}$, where $x1$, $x2$, $x3$, $y1$, and $y2$ are

as defined above. Especially, in embodiments, $x1 + x2 + x3 = 1$, wherein $x1 \geq 0.5$. Further, in

embodiments, the second luminescent material may comprise at least two luminescent

materials of the type $A_3B_5O_{12}:Ce^{3+}$, such as at least $(Y_{x1}A'_{x2}Ce_{x3})(Al_{y1}B'_{y2})_5O_{12}$ and

30 $(Lu_{x1}A'_{x2}Ce_{x3})(Al_{y1}B'_{y2})_5O_{12}$. In such embodiments, the second luminescent material may

comprise (i) a primary second luminescent material such as $(Y_{x1}A'_{x2}Ce_{x3})(Al_{y1}B'_{y2})_5O_{12}$,

wherein A' comprises one or more of La, Gd, Tb, and Lu, and (ii) a secondary second

luminescent material such as $(Lu_{x1}A'_{x2}Ce_{x3})(Al_{y1}B'_{y2})_5O_{12}$, wherein A' comprises one or

more of Y, La, Gd, and Tb. In such embodiments, for the primary second luminescent

material and the secondary second luminescent material may individually apply that $x_1+x_2+x_3=1$, that $x_1 \geq 0.5$, and that B' comprises one or more of Ga, In, and Sc. In embodiments, the primary second luminescent material may thus comprise on a molar basis more Y than Lu. Conversely, the secondary second luminescent material may comprise on a molar basis more Lu than Y. Note that in embodiments, $x_2 = 0$, and the primary second luminescent material may (essentially) consist of $(Y_{x_1}Ce_{x_3})_3(Al_{y_1}B'_{y_2})_5O_{12}$, wherein $x_1+x_3 = 1$. Similarly, the secondary second luminescent material may (essentially) consist of $(Lu_{x_1}Ce_{x_3})_3(Al_{y_1}B'_{y_2})_5O_{12}$, wherein $x_1+x_3 = 1$. Such a composition of second luminescent material may provide a broader spectral power distribution of the second luminescent material light. For instance, the primary second luminescent material may be configured to provide primary second luminescent material light, and the secondary second luminescent material may be configured to provide secondary second luminescent material light, wherein a centroid wavelength of the primary second luminescent material light may be larger than a centroid wavelength of the secondary second luminescent material light.

In embodiments, the second luminescent material may comprise at least 10 wt.%, such as at least 25 wt.%, especially at least 40 wt.% primary second luminescent material. Conversely, the second luminescent material may comprise at least 10 wt.%, such as at least 25 wt.%, especially at least 40 wt.% secondary second luminescent material. Further, in embodiments, the second luminescent material may comprise at most 90 wt.%, such as at most 75 wt.%, especially at most 60 wt.% primary second luminescent material. Additionally or alternatively, in embodiments, the second luminescent material may comprise at most 90 wt.%, such as at most 75 wt.%, especially at most 60 wt.% secondary second luminescent material.

Alternatively or additionally, the second 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 specific embodiments, the second luminescent material may comprise at least two different luminescent materials configured to provide luminescent material light having different spectral power distributions (see also above). As can be derived from the above, the term "different luminescent materials" may refer to luminescent materials that are different, or to two compositions, each including at least one luminescent material in common, but wherein the compositions differ. For instance, a primary second luminescent material comprising luminescent materials A and B, and a secondary second luminescent material comprising only A or only B, or comprising both A and B, but in a different weight

ratio. Such primary second luminescent material and secondary second luminescent material may have different spectral power distributions of their respective luminescent material light.

Referring back to the (solid-state) light generating devices, in embodiments, the light generating device may thus comprise a luminescent material. In embodiments, the light generating device may comprise a PC LED. In other embodiments, the light generating device may comprise a direct LED (i.e. no phosphor). In embodiments, the light generating device may comprise a laser device, like a laser diode. In embodiments, the light generating device may comprise a superluminescent diode. Hence, in specific embodiments, the light source may be selected from the group of laser diodes and superluminescent diodes. In other embodiments, the light source may comprise an LED.

The 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, e.g. having band widths as known for lasers.

The term “light source” may (thus) refer to a light generating element as such, like e.g. a solid state light source, or e.g. to a package of the light generating element, such as a solid state light source, and one or more of a luminescent material comprising element and (other) optics, like a lens, a collimator. For instance, a solid 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 luminescent material comprising 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).

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 diode laser, or a superluminescent diode.

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).

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

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

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.

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. A superluminescent diode 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". 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 AlGaIn-based superluminescent diode.

Hence, the first light generating device, the second light generating device, and the third light generating device may comprise solid-state light sources. Further, in embodiments, the light generating system may comprise a fourth light generating device. The fourth light generating device may, in embodiments, comprise a fourth light source.

Especially, the fourth light source may comprise a fourth solid state light source, such as e.g. a light emitting diode (LED), a laser diode, or a superluminescent diode (see also above). The fourth light generating device may, in embodiments, be configured to generate fourth device light having a fourth centroid wavelength (λ_{c4}). In embodiments, the fourth centroid wavelength (λ_{c4}) may be selected from the range of 390-440 nm, such as from the range of 395-425 nm, like from the range of 400-420 nm, especially from the range of 405-415 nm. Such embodiments may be beneficial as the addition of a violet light generating light source may help improve uniform light distribution in the white (output) system light, and improve the color rendering index of the white (output) system light. Therefore, in specific embodiments, the fourth light generating device may only be operational, i.e., may only be configured to generate fourth device light, in an operational mode where the system is configured to provide white system light. However, this may not necessarily be the case. The fourth light generating device may also, in embodiments, be operated in a non-white light providing operational mode, such as e.g. in an operational mode to provide (royal or short wavelength) blue or violet system light. In line with such reasoning, in embodiments, the

light generating system may comprise further light generating devices, such as e.g. a fifth light generating device configured to provide fifth device light having a fifth centroid wavelength (λ_{c5}) selected from the yellow or orange wavelength range. Hence, in embodiments, the light generating system may comprise at least the first, second, and third light generating devices, and optionally further fourth, fifth, etc. light generating devices.

Further, in embodiments, the first luminescent material may be configured in a light-receiving relationship with the fourth light generating device. For example, in embodiments, the (luminescent element, especially the) first luminescent material may be configured covering the first, second, third, and fourth light generating devices as an encapsulant. Hence, in such embodiments, the luminescent element may be configured in a transmissive mode. As such, the first luminescent material may be configured to convert at least part of the (first and) fourth device light (incident on the first luminescent material) into first luminescent material light, especially having a spectral power distribution at one or more wavelengths in the orange-red wavelength range. In embodiments, the first luminescent material may be configured to convert at least 70% of the fourth device light into first luminescent material light, such as at least 80% of the fourth device light, especially at least 90% of the fourth device light, like at least 95% of the fourth device light, especially at least 98% of the fourth device light.

In other embodiments, the luminescent element may be configured in a reflective mode. In such embodiments, the light generating system may further comprise one or more dichroic reflectors, such as e.g. a dichroic mirror, and optionally one or more further optics, such as a reflector or mirror. As such, in embodiments, the one or more dichroic mirrors may be configured to reflect unconverted first device light (and optionally unconverted fourth device light) and to transmit the first luminescent material light, the second device light, and the third device light (and optionally fifth device light). In such embodiments, the one or more further optics may be configured to combine the different types of light into (white) system light. Alternatively, in embodiments, the one or more dichroic mirrors may be configured to transmit unconverted first devices light (and optionally unconverted fourth device light) and to reflect the first luminescent material light, the second device light, and the third device light (and optionally fifth device light).

The light generating system may further comprise a control system. The control system may, in embodiments, be configured to control the spectral power distribution (and radiant flux) of the system light. Especially, the control system may do so by controlling one or more of the light generating devices comprised by the light generating system. For

example, in specific embodiments, wherein the light generating system also comprises the fourth light generating device, the control system may be configured to control a spectral power of the first device light in dependence of a conversion of the fourth device light by the luminescent element. In other words, the control system may be configured to change the spectral power of the first device light when conversion of the fourth device light by the luminescent element increases or decreases. As such, the control system may be configured to balance the (output) system light by e.g. lowering (royal, or short wavelength) blue first device light emission from the first light generating device to compensate for the conversion of the violet light provided by the fourth light generating device. Therefore, in embodiments, the light generating system may e.g. comprise a sensor. In such embodiments, the sensor may be configured to (i) sense or detect the level of fourth device light being converted by the luminescent element, e.g. by measuring the amount of (remaining) fourth device light in the system light, and (ii) provide a sensor signal to the control system based on its detection. Hence, in embodiments, the sensor may be configured functionally (such as communicatively) coupled with the control system. As a result, the control system may be configured to control a spectral power of the first device light in dependence of a sensor signal related to conversion of the fourth device light by the luminescent element.

Additionally or alternatively, in embodiments, the control system may be configured to control one or more of the first light generating device, the second light generating device, and the third light generating device (and optionally the fourth light generating device). Especially, in embodiments, the control system may be configured to individually control two or more of the first light generating device, the second light generating device, and the third light generating device. More especially, in embodiments, the control system may be configured to control one or more of the first light generating device, the second light generating device, and the third light generating device (and the fourth, and optional further, light generating devices) such that in a first operational mode the system light may have a first correlated color temperature (CCT1). Additionally or alternatively, in embodiments, the control system may be configured to control one or more of the first light generating device, the second light generating device, and the third light generating device such that in a second operational mode the system light may have a second correlated color temperature (CCT2). Especially, in embodiment, the control system may be configured to individually control the light generating devices, such that the CCT may be altered from CCT1 in the first operational mode to CCT2 in the second operational mode, and vice versa. Further, in embodiments, $CCT2 - CCT1 \geq 250 \text{ K}$, like $CCT2 - CCT1 \geq 500 \text{ K}$,

such as $CCT2-CCT1 \geq 750$ K, like, $CCT2-CCT1 \geq 1000$ K, especially $CCT2-CCT1 \geq 1500$ K. In embodiments, $CCT2-CCT1$ may be at most 5000K, such as at most 3000K, like at most 2500K. Hence, in embodiments, the light generating system may comprise a control system, wherein the control system may be configured to individually control one or more of the first
5 light generating device, the second light generating device, and the third light generating device, such that: (i) in a first operational mode the system light may have a first correlated color temperature (CCT1), and (ii) in a second operational mode the system light may have a second correlated color temperature (CCT2); and wherein $CCT2-CCT1 \geq 500$ K.

The term “controlling” and similar terms especially refer at least to
10 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
15 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
20 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.

25 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.

30 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
5 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
10 “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
15 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 the spectral power
20 distribution (, especially e.g. the color point) of the system light in dependence of one or more of an input signal of a user interface, a sensor signal (of a sensor), and a timer. The term “timer” may refer to a clock and/or a predetermined time scheme.

The control system may further, in embodiments, be configured to control one
25 or more of the first light generating device, the second light generating device, and the third light generating device (and optionally the fourth light generating device), such that in a third operational mode the system light may comprise red light. In specific embodiments, in the third operational mode, the system light may be red light. Additionally or alternatively, in embodiments, the control system may be configured to control one or more of the first light
30 generating device, the second light generating device, and the third light generating device (and optionally the fourth light generating device), such that in a fourth operational mode the system light may comprise green light. In specific embodiments, in the fourth operational mode, the system light may be green light. Additionally or alternatively, in embodiments, the control system may be configured to control one or more of the first light generating device,

the second light generating device, and the third light generating device (and optionally the fourth light generating device), such that in a fifth operational mode the system light may comprise blue (or cyan) light, especially blue light including some violet and cyan hues. In specific embodiments, in the fifth operational mode, the system light may be blue (or cyan) light.

The light generating system may thus, in embodiments, be operated in different operational modes by controlling the different light generating devices in the light generating system. Alternatively, in embodiments, the light generating system (especially the different light generating devices) may not be controllable, i.e., the light generating system may be configured to operate in only one operational mode (i.e. in such embodiments a spectral power distribution of the system light generated in the first operational mode is not controllable). In embodiments, the different light generating devices may be configured spatially separated (but electrically coupled). However, in embodiments, one or more of the (first, second, third, and optionally fourth) light generating devices may also be configured together, e.g., as a Chip-on-Board or a LED filament. Hence, in embodiments, the light generating system may comprise one or more of a Chip-on-Board and a LED filament.

In embodiments, the light generating system may comprise a Chip-on-Board (CoB). The term “Chip-on-Board” (or “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 printed circuit board (PCB), wherein a single luminescent body is configured in a light-receiving relationship with (all of) said LED chips. Hence, a plurality of light emitting semiconductor light sources may be configured on the same substrate. In embodiments, a COB is a multi LED chip configured together as a single lighting module. In embodiments, the Chip-on-Board may thus comprise one or more of the first, second, third, and optionally fourth light generating devices. Further, the Chip-on-Board may comprise the luminescent element. Especially, the luminescent element may be configured on top of the first, second, third, and optionally fourth light generating devices. Such a CoB system may provide relatively high intensity system light from a relatively small surface area. Further, such a CoB system may reduce the appearance of areas with higher and lower intensity within a lighting device (such as a LED strip), thereby providing a more homogeneous illumination by the lighting device.

Further, in embodiments, the light generating system may comprise a LED filament. LED filaments as such are known, and are e.g. described in US 8,400,051 B2, WO2020016058, WO2019197394, etc., which are herein incorporated by reference. In

general, a LED filament may in embodiments comprise (i) a plurality of light emitting diodes (LEDs), arranged on (at least a first major surface of) an elongated carrier, and (ii) an elongated encapsulant covering the plurality of LEDs and at least part of the elongated carrier. The LED filament may in embodiments be defined by a filament length L_F , a filament width W_F , and a filament thickness T_F . The LED filament may further comprise a filament axis of elongation A_F . The filament axis of elongation A_F may especially be a straight axis centered on the direction along which the LED filament is elongated. The filament axis of elongation A_F may define an axis length L_A , wherein the axis length L_A may be the length of the LED filament along the filament axis of elongation A_F . In some embodiments, the LED filament may be straight. In straight embodiments, the filament length L_F may (essentially) be equivalent to the axis length L_A . In other embodiments, the LED filament may be curved. For instance, the filament may have a (2D or 3D) spiraling shape, (like) a helical shape, or another curved shape. In curved embodiments, the axis length L_A may be smaller than the filament length L_F , such as $L_A/L_F \leq 0.95$, especially $L_A/L_F \leq 0.75$, more especially $L_A/L_F \leq 0.55$. Further, the LED filament may have relatively high aspect ratios (L_F/W_F or L_F/T_F), such as at least 10, especially at least 15, such as at least 20, more especially at least 50. Large aspect ratios may better mimic a filament. Yet, in embodiments, the aspect ratio (L_F/W_F and/or L_F/T_F) may be at most 200, such as at most 150, especially at most 100. Hence, in specific embodiments, $10 \cdot W_F \leq L_F \leq 200 \cdot W_F$, and $10 \cdot T_F \leq L_F \leq 200 \cdot T_F$.

Further, as indicated, the LED filament may comprise an elongated carrier, solid state light sources, and an encapsulant. Especially, the elongated carrier may support the solid state light sources. The elongated carrier may e.g. comprise glass, quartz, metal, or sapphire. In other embodiments, the elongated carrier may e.g. comprise a polymeric material or (flexible) metal, e.g., a film or foil. The elongated carrier may be rigid (self-supporting), but may (in polymeric embodiments) also be flexible. In embodiments, the elongated carrier may be light transmissive, translucent, or transparent for light, especially visible light. Alternatively, in embodiments, the carrier may be light reflective, especially reflective for one or more of the light source light and the LED filament light (see below), such as reflective for at least the light source light and the LED filament light. In specific embodiments, the carrier may be diffuse reflective. The elongated carrier may have (essentially) similar dimensions to the LED filament. Especially, the elongated carrier may (essentially) define the filament length L_F and axis length L_A of the LED filament. The width W_F and thickness T_F of the LED filament may be defined by the elongated carrier as well as other components of the LED filament, e.g., the solid state light sources and an encapsulant.

In embodiments, the (elongated) carrier may comprise a first major surface at a first side of the carrier and a second major surface at a second side of the carrier, opposite to the first side. In embodiments, the solid state light sources may be arranged on at least one of these surfaces. Hence, in embodiments, at least part of, such as all of, the solid state light sources may be mounted onto the first major surface. Additionally or alternatively, at least part of the solid state light sources may be mounted onto the second major surface. Hence, in embodiments, the solid state light sources may be arranged, mounted and/or mechanically coupled on/to the carrier, wherein the carrier may especially be configured to mechanically and/or electrically support the LEDs.

In embodiments, the solid state light sources may comprise LEDs. Alternatively or additionally, in embodiments, the solid state light sources may comprise diode lasers. Further, the LED filament may comprise one or more of LEDs, laser diodes, and superluminescent diodes. Especially, the LED filament comprises a plurality of light emitting diodes (LEDs). The (plurality of) solid state light sources may be arranged in an array (on the elongated carrier), especially over (at least part of) the filament length L_F . The number of solid state light sources in the array may be at least 4, such as at least 8, even more especially at least 12, and may e.g. be up to 100, or yet even larger. Especially, in embodiments the number of solid state light sources in the array may be selected from the range of 10-1000, such as 10-200. In embodiments, the solid state light sources may be configured in a 1D (linear) array over at least part of the filament length L_F . A first and a last solid state light source may, when measured along the LED filament, have a mutual distance of at least $0.5 \cdot L_F$, even more especially at least $0.7 \cdot L_F$. Further, in embodiments, the solid state light sources may be configured in two 1D arrays, one on the first major surface of the elongated carrier and one on the second major surface. A 2D array of solid state light sources of $n \cdot m$ LEDs may also be possible. In embodiments, n may be selected from the range of 1-4, such as 1-3, like 1-2, such as in embodiments 1 or in embodiments 2, and m may be selected from the range of larger than n , such as especially selected from the range of at least 4 (when $n < 4$), like at least 6, such as at least 8. Hence, a 2D array of solid state light sources may especially have a (much) smaller number of rows (n) than the number of solid state light sources in those respective rows (m), such as $n/m \leq 0.5$, especially $n/m \leq 0.2$, like $n/m \leq 0.1$, especially $n/m \leq 0.05$.

In embodiments, the LED filament may comprise an encapsulant. The encapsulant may especially (at least partly) cover the plurality of solid state light sources. Further, the encapsulant may (at least partly) cover at least part of the elongated carrier, such

as at least (part of) one of the first major and second major surface. In general, the encapsulant may be in contact with the elongated carrier and may cover all of the solid state light sources. Hence, in embodiments the encapsulant may be configured over a substantial part of the filament length L_F of the LED filament (such as over more than 70% of the filament length L_F). The encapsulant may be a continuous coating along the filament length L_F , at one or both of the first major and the second major surface. Further, the encapsulant may at least partly cover the solid state light sources, such as in embodiments at least 50% of the total number of solid state light sources in the array, such as at least 75%, especially at least 95%, up to 100%.

In embodiments, the encapsulant may comprise one or more of a luminescent material and a light scattering material, especially at least a luminescent material. Especially, in embodiments, the encapsulant may comprise at least the first luminescent material. Hence, the encapsulant comprising at least the first luminescent material may essentially be an embodiment of the luminescent element as defined for the light generating system. The one or more of the luminescent material and the light scattering material may especially be configured embedded in an encapsulant material, e.g. a (flexible) polymer material (such as a silicone). In embodiments, the luminescent material may be configured to convert at least part, such as all, of the light source light (generated by the solid state light sources) into luminescent material light. In specific embodiments, the luminescent material may comprise a phosphor such as an inorganic phosphor and/or quantum dots or rods. Further, in embodiments, the light scattering material may be configured to scatter (or “diffuse”) the light source light, especially in a direction transverse to a normal of the (first and/or second) major surface. In specific embodiments, the light scattering material may comprise light scattering particles, such as e.g. at least one of BaSO_4 , Al_2O_3 and TiO_2 particles.

In embodiments, the LED filament may be configured to generate filament light, which may comprise one or more of (scattered) light source light and luminescent material light. The term “LED filament light” may refer to the light emitted by the LED filament during operation of the LED filament. Further, the solid state light sources, comprised by the LED filament, may be configured to generate light source light. In embodiments, at least two, such as all, of the solid state light sources may be configured to emit light source light having different spectral power distributions. In other embodiments, at least two, such as all, of the solid state light sources may be configured to provide light source light having essentially the same spectral power distribution. In embodiments, the filament light may comprise the light source light, or may even essentially consist of

(scattered) light source light. However, in embodiments wherein the encapsulant may comprise a luminescent material, the filament light may comprise luminescent material light, or may even essentially consist of luminescent material light. Further, in embodiments, the filament light may comprise luminescent material light and at least part of the (non-converted and/or scattered) light source light. In embodiments, the LED filament may provide filament light with a desired spectral light distribution, e.g., white light having a correlated color temperature selected from the range of 1500-3000 K. In such embodiments, the filament light may comprise luminescent material light and optionally transmitted light source light. Further, the filament light may at least comprise light at a wavelength selected from the range of 380-780 nm, i.e., visible light. In embodiments, the filament light may at least comprise white light. Especially, the filament light may be relatively warm (white) light, such as selected from the range of 1500 – 3000 K, especially selected from 1500 – 2700 K, most especially selected from the range of 1800-2700 K. In embodiments, the LED filament may comprise multiple sub-filaments.

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.

The terms “visible”, “visible light” or “visible emission” and similar terms refer to light having one or more wavelengths in the range of about 380-780 nm. Herein, UV may especially refer to a wavelength selected from the range of 190-380 nm, such as 200-380 nm. The terms “light” and “radiation” are herein interchangeably used, unless clear from the context that the term “light” only refers to visible light. The terms “light” and “radiation” may thus refer to UV radiation, visible light, and IR radiation. In specific embodiments, especially for lighting applications, the terms “light” and “radiation” refer to (at least) visible light. 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.

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 may also provide 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, an automotive lighting device, 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 first light generating device, the second light generating devices, the third light generating device (and optionally the fourth light generating device), and the luminescent element.

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”).

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

BRIEF DESCRIPTION OF THE DRAWINGS

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

Figs. 1 and 2 schematically depict some embodiments of the light generating system.

15 Fig. 3 depicts emission and excitation spectra of the light generating system.

Fig. 4 schematically depicts some applications of the light generating system in lighting devices.

The schematic drawings are not necessarily to scale.

20 DETAILED DESCRIPTION

Fig. 1 schematically depicts a light generating system 1000 configured to provide system light 1001. In embodiments, the light generating system 1000 may comprise light generating devices 100. In specific embodiments, the light generating system 1000 (especially one or more of the light generating devices 100) may comprise micro LEDs
25 having a size smaller than 100 μm . Especially, the light generating system 1000 may comprise a first light generating device 110, a second light generating device 120, and a third light generating device 130.

The first light generating device 110 may, in embodiments, comprise a first (solid state) light source 10 configured to provide first light source light 11. Especially, in
30 embodiments, the first light generating device 110 may be configured to generate first device light 111 having a first centroid wavelength (λ_{c1}). Especially, in embodiments, first centroid wavelength (λ_{c1}) may be selected from the range of 440-460 nm.

The second light generating device 120 may, in embodiments, comprise a second (solid state) light source 20 configured to provide second light source light 21.

Especially, in embodiments, the second light generating device 120 may be configured to generate second device light 121 having a second centroid wavelength (λ_{c2}). Especially, in embodiments, the second centroid wavelength (λ_{c2}) may be selected from the range of 488-500 nm. In specific embodiments, the second centroid wavelength (λ_{c2}) may be selected from the range of 487-495 nm. In other specific embodiments, the second centroid wavelength (λ_{c2}) may be selected from the range of 495-503 nm.

The third light generating device 130 may, in embodiments, comprise a third (solid state) light source 30 configured to provide third light source light 31. Especially, in embodiments, the third light generating device 130 may be configured to generate third device light 131 having a third centroid wavelength (λ_{c3}). Especially, in embodiments, the third centroid wavelength (λ_{c3}) may be selected from the range of 520-570 nm. In embodiments, the third light generating device 130 may comprise a green direct-emitting light-emitting diode. However, in other embodiments, the third light generating device 130 may comprise a phosphor-converted light-emitting diode (i.e. a blue LED comprising a green-yellow phosphor). In such embodiments, the third light generating device 130 may comprise a second luminescent material 220 of the type $A_3B_5O_{12}:Ce^{3+}$ (see Fig. 2a). In embodiments, A may comprise one or more of Y, La, Gd, Tb and Lu. In embodiments, B may comprise one or more of Al, Ga, In and Sc.

Furthermore, in embodiments, the light generating system 1000 may also comprise a luminescent element 200. The luminescent element 200 may for example comprise one or more of a layer, a body, and an encapsulant (as depicted here). In embodiments, the luminescent element 200 may comprise a first luminescent material 210 configured to convert at least part of the first device light 111 received by the first luminescent material 210 into first luminescent material light 211. Especially, the first luminescent material 210 may be configured to convert at least part of the first device light 111 received by the first luminescent material 210 into first luminescent material light 211 having a spectral power distribution at one or more wavelengths in the orange-red wavelength range. In specific embodiments, the luminescent element 200 may be configured to transmit less than 2% of the first device light 111. Hence, in embodiments, most of the first device light 111 may be absorbed and/or converted by the first luminescent material 210. In contrast, in embodiments, the luminescent element 200 may be configured to transmit more than 95% of the third device light 131. Hence, in embodiments, most of the third device light 131 may not be absorbed and/or converted by the first luminescent material 210. Similarly, in embodiments, the luminescent element 200 may be configured to transmit more than 85% of

the second device light 121. Hence, in embodiments, most of the second device light 121 may not be absorbed and/or converted by the first luminescent material 210.

Therefore, in embodiments, the first luminescent material 210 may comprise a luminescent material of the type $M'_xM_{2-2x}AX_6$ doped with tetravalent manganese. In such
5 embodiments M' may comprise an alkaline earth cation. Further, in such embodiments, M may comprise an alkaline cation. Yet further, in such embodiments, x may be in the range of 0-1. Yet further, in such embodiments, A may comprise a tetravalent cation. Yet further, in such embodiments, X may comprise a monovalent anion, at least comprising fluorine. The luminescent material may comprise one or more (different) types of luminescent materials.
10 However, in embodiments, at least 95 vol.% of the luminescent material in the luminescent element may be first luminescent material 210.

The light generating system 1000 may especially be configured such that, in embodiments, the luminescent element 200 may be configured in the transmissive mode. Especially, in embodiments, less than 5% of the first device light 111 may be transmitted
15 through the luminescent element 200. Additionally or alternatively, in embodiments, the light generating system 1000 may especially be configured such that the second device light 121 and the third device light 131 may be (at least partly) transmitted by the luminescent element 200. Additionally or alternatively, in embodiments, the light generating system 1000 may especially be configured such that in an operational mode the system light 1001 may be white
20 light. Especially, the system light 1001 may be white light having a correlated color temperature selected from the range of 1500-6500 K and a color rendering index of at least 80. In specific embodiments, the system light 1001 may have a color rendering index of at least 90.

In embodiments, the system light 1001 may comprise one or more of the
25 second device light 121, the third device light 131, and the first luminescent material light 211. Hence, in embodiments such as depicted in Fig. 1A, the first device light 111 may be converted in first luminescent material light 211, such that the system light 1001 may comprise second device light 121, third device light 131, and first luminescent material light 211.

30 Reference 410 may herein refer to a Chip-on-Board (COB), see also below. Reference 420 may herein refer to a LED filament, see also below.

Further, in embodiments such as depicted in Fig. 1B, the light generating system may comprise a fourth light generating device 140. In embodiments, the fourth light generating device 140 may comprise a fourth (solid state) light source 40 configured to

provide fourth light source light 41. In embodiments, the fourth light generating device 140 may be configured to generate fourth device light 141 having a fourth centroid wavelength (λ_{c4}). In embodiments, the fourth centroid wavelength (λ_{c4}) may be selected from the range of 400-420 nm. As depicted in Fig. 1B, in embodiments, the luminescent element 200 may be configured over the fourth light generating device 140. In such embodiments, the first luminescent material 210 may be configured to convert at least part of the fourth device light 140 into first luminescent material light 211. Hence, in such embodiments, the system light 1001 may comprise at least second device light 121, third device light 131, and first luminescent material light 211, and optionally some transmitted first and/or fourth device light 111, 141.

Yet further, in embodiments, the light generating system 1000 may comprise a control system 300. In embodiments, the control system 300 may be configured to control one or more of the first light generating device 110, the second light generating device 120, and the third light generating device 130. Especially, in embodiments, the control system may be configured to control one or more of the light generating devices 100, such that in a first operational mode the system light 1001 may have a first correlated color temperature (CCT1). Similarly, in embodiments, the control system may be configured to control one or more of the light generating devices 100, such that in a second operational mode the system light 1001 may have a second correlated color temperature (CCT2). In embodiments, CCT2-CCT1 $\geq$ 500K.

Further, in embodiments, the control system 300 may be configured to control one or more of the first light generating device 110, the second light generating device 120, and the third light generating device 130, (and optionally the fourth light generating device 140,) such that in a third operational mode the system light 1001 may comprise red light. Additionally or alternatively, in embodiments, the control system 300 may be configured to control one or more of the first light generating device 110, the second light generating device 120, and the third light generating device 130, (and optionally the fourth light generating device 140,) such that in a fourth operational mode the system light 1001 may comprise green light. Additionally or alternatively, in embodiments, the control system 300 may be configured to control one or more of the first light generating device 110, the second light generating device 120, and the third light generating device 130, (and optionally the fourth light generating device 140,) such that in a fifth operational mode the system light 1001 may comprise blue (including some violet hues) or cyan light.

Yet further, in embodiments, the control system 300 may be configured to control the spectral power distribution (, especially e.g. the color point) of the system light 1001 in dependence of one or more of an input signal of a user interface 301, a sensor signal (of a sensor), and a timer.

Yet further, in embodiments, the control system 300 may be configured to control a spectral power of the first device light 111 in dependence of a conversion of the fourth device light 141 by the luminescent element 200. For example, in embodiments, the sensor may be configured to provide a sensor signal in dependence of the conversion of the fourth device light 141 by the luminescent element 200 to the control system 300.

Subsequently, the control system 300 may be configured to control a spectral power of the first device light 111 in dependence of the sensor signal.

Fig. 2 schematically depicts some further embodiments of the light generating system 1000. Especially, Fig. 2A schematically depicts a Chip-on-Board 410 comprising the first light generating device 110, the second light generating device 120, the third light generating device 130, the fourth light generating device 140, and the luminescent element 200 as described above. Here, reference 500 may refer to a housing. Especially, in embodiments, the Chip-on-Board 410 may be configured in the housing 500. However, this may not necessarily be the case. Reference 510 may herein refer to a light exit window.

Further, in embodiments, as depicted in Fig. 2B, the luminescent element 200 may be configured remote from one or more of (here especially all of) the first light generating device 110, the second light generating device 120, the third light generating device 130, and the fourth light generating device 140. Especially, in embodiments, the light generating devices may each have a top surface 115, 125, 135, 145, respectively. In embodiments, the luminescent element 200 may be configured remote from the light generating devices at a first distance d_1 . Especially, in embodiments, the first distance d_1 may be at least 100 μm , such as selected from the range of 1-50 mm. However, the first distance d_1 may, in embodiments, also be essentially zero, see e.g. Figs. 1A, 1B, and 2A. Herein, the first distance d_1 may especially be defined as a shortest distance between the top surfaces 115, 125, 135, 145 of the light generating devices and a first surface 205 of the luminescent element 200.

Further, Fig. 2C schematically depicts a LED filament 420 comprising the first light generating device 110, the second light generating device 120, the third light generating device 130, the fourth light generating device 140, and (an encapsulant comprising) the luminescent element 200 as described above. Hence, in embodiments, the light generating

system may comprise one or more of a Chip-on-Board 410 and a LED filament 420. The Chip-on-board 410 may especially be configured to provide Chip-on-Board light 411. Similarly, in embodiments, the LED filament may be configured to provide LED filament light 421.

5 Fig. 3 schematically depicts some spectral power distributions of elements in the light generating system 1000. Especially, Fig. 3 depicts embodiments of the centroid wavelength ranges of the first device light 111, the second device light 121, and the third device light 131, respectively, and the excitation spectrum of the first luminescent material light 211. As can be derived from the spectra, the different types of device light have
10 differing centroid wavelengths, thus resulting in different interactions with the luminescent element 200. Especially, in embodiments, the first device light 111 having the first centroid wavelength (λ_{c1}) may especially be substantially converted by the first luminescent material 210 into first luminescent material light 211. In contrast, the second device light 121 having the second centroid wavelength (λ_{c2}) and the third device light 131 having the third centroid
15 wavelength (λ_{c3}) may be substantially transmitted by the luminescent element 200, and may thus not (or barely) contribute to the excitation of the first luminescent material 210.

Especially, in embodiments, one or more of the first device light 111 and the second device light 121 (and optionally the third device light 131) may have a spectral distribution with a FWHM $\leq 40\text{nm}$.

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

5 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
10 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
15 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
20 than described or illustrated herein.

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

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

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

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

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

The invention may be implemented by means of hardware comprising several distinct elements, and by means of a suitably programmed computer. In a device claim, or an apparatus claim, or a system claim, enumerating several means, several of these means may be embodied by one and the same item of hardware. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. In yet a further aspect, the invention (thus) provides a software product, which, when running on a computer is capable of bringing about (one or more embodiments of) the method as described herein.

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

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

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

CLAIMS:

1. A light generating system (1000) configured to provide system light (1001), wherein the light generating system (1000) comprises a first light generating device (110), a second light generating device (120), a third light generating device (130), and a luminescent element (200); wherein:

- 5 - the first light generating device (110) comprises a first solid state light source (10), and wherein the first light generating device (110) is configured to generate first device light (111) having a first centroid wavelength (λ_{c1}), wherein the first centroid wavelength (λ_{c1}) is selected from the range of 440-460 nm;
- the second light generating device (120) comprises a second solid state light
10 source (20), and wherein the second light generating device (120) is configured to generate second device light (121) having a second centroid wavelength (λ_{c2}), wherein the second centroid wavelength (λ_{c2}) is selected from the range of 485-505 nm;
- the third light generating device (130) comprises a third solid state light source
15 device light (131) having a third centroid wavelength (λ_{c3}), wherein the third centroid wavelength (λ_{c3}) is selected from the range of 520-570 nm;
- the luminescent element (200) comprises a first luminescent material (210) configured to convert at least part of the first device light (111) received by the first luminescent material (210) into first luminescent material light (211); wherein the first
20 luminescent material (210) comprises a luminescent material of the type $M'_xM_{2-2x}AX_6$ doped with tetravalent manganese, wherein M' comprises an alkaline earth cation, wherein M comprises an alkaline cation, and x is in the range of 0-1, wherein A comprises a tetravalent cation, wherein X comprises a monovalent anion, at least comprising fluorine; and
- the light generating system (1000) is configured such that (a) the luminescent
25 element (200) is configured in the transmissive mode, wherein less than 5% of the first device light (111) is transmitted through the luminescent element (200), (b) the second device light (121) and the third device light (131) are transmitted by the luminescent element (200); and (c) in an operational mode the system light (1001) is white light having a correlated color

temperature selected from the range of 1500-6500 K and a color rendering index of at least 80.

2 The light generating system (1000) according to claim 1, wherein the second
5 centroid wavelength (λ_{c2}) is selected from the range of 487-495 nm.

3. The light generating system (1000) according to claim 1, wherein the second
centroid wavelength (λ_{c2}) is selected from the range of 495-503 nm.

10 4. The light generating system (1000) according to any one of the preceding
claims, wherein the luminescent element (200) is configured to (i) transmit less than 2% of
the first device light (111), and (ii) transmit more than 95% of the third device light (131).

5. The light generating system (1000) according to any one of the preceding
15 claims, wherein the luminescent element (200) is configured to transmit more than 85% of
the second device light (121).

6. The light generating system (1000) according to any one of the preceding
claims, wherein the third light generating device (130) comprises a green direct-emitting
20 light-emitting diode.

7. The light generating system (1000) according to any one of the preceding
claims, wherein at least 95 vol.% of the luminescent material in the luminescent element
(200) is first luminescent material (210).

25 8. The light generating system (1000) according to any one of the preceding
claims, wherein one or more of the first device light (111) and the second device light (121)
have a spectral distribution with a FWHM ≤ 40 nm.

30 9. The light generating system (1000) according to any one of the preceding
claims, wherein the third light generating device (130) comprises a phosphor-converted light-
emitting diode.

10. The light generating system (1000) according to claim 6, wherein the third light generating device (130) comprises a second luminescent material (220) of the type $A_3B_5O_{12}:Ce^{3+}$, 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.

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11. The light generating system (1000) according to any one of the preceding claims, wherein the light generating system (1000) comprises a control system (300), wherein the control system (300) is configured to control one or more of the first light generating device (110), the second light generating device (120), and the third light generating device (130), such that: (i) in a first operational mode the system light (1001) has a first correlated color temperature (CCT1), and (ii) in a second operational mode the system light (1001) has a second correlated color temperature (CCT2); and wherein $CCT2 - CCT1 \geq 500K$.

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12. The light generating system (1000) according to claim 8, wherein the control system (300) is configured to control one or more of the first light generating device (110), the second light generating device (120), and the third light generating device (130), such that: (i) in a third operational mode the system light (1001) comprises red light, (ii) in a fourth operational mode the system light (1001) comprises green light, and (iii) in a fifth operational mode the system light (1001) comprises blue or cyan light.

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13. The light generating system (1000) according to any one of the preceding claims 11-12, wherein the control system (300) is configured to control the spectral power distribution of the system light (1001) in dependence of one or more of an input signal of a user interface, a sensor signal (of a sensor), and a timer.

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14. The light generating system (1000) according to any one of the preceding claims, wherein the light generating system (1000) comprises one or more of a Chip-on-Board (410) and a LED filament (420).

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

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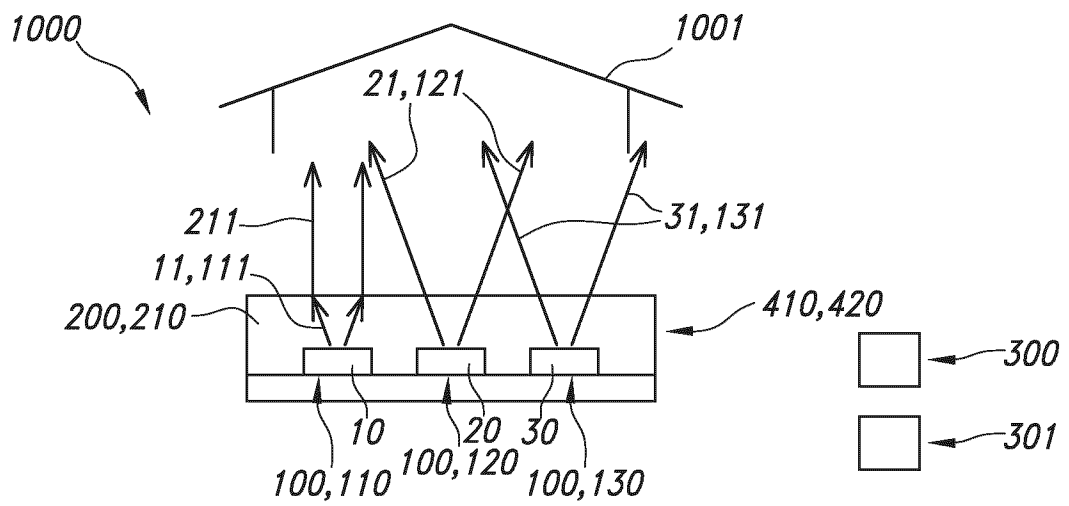


FIG. 1A

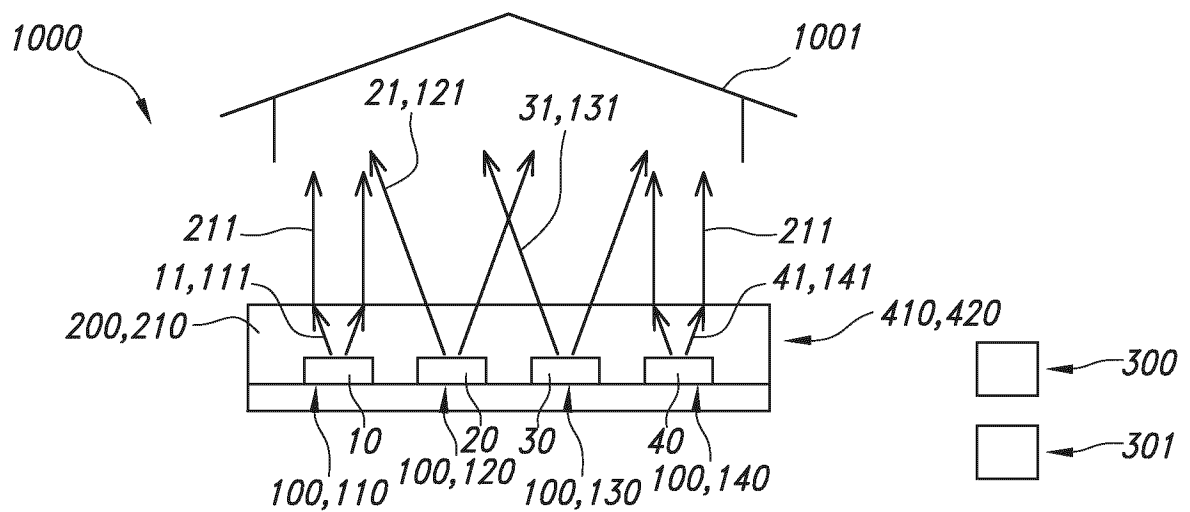


FIG. 1B

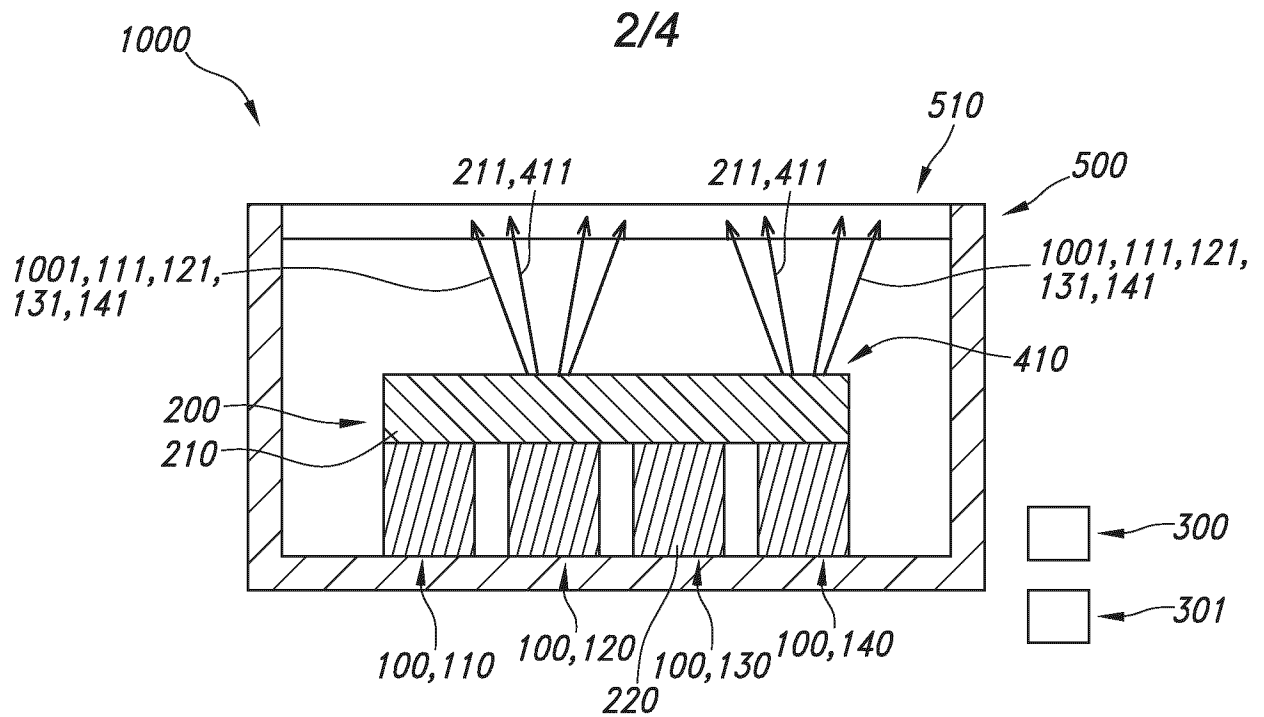


FIG. 2A

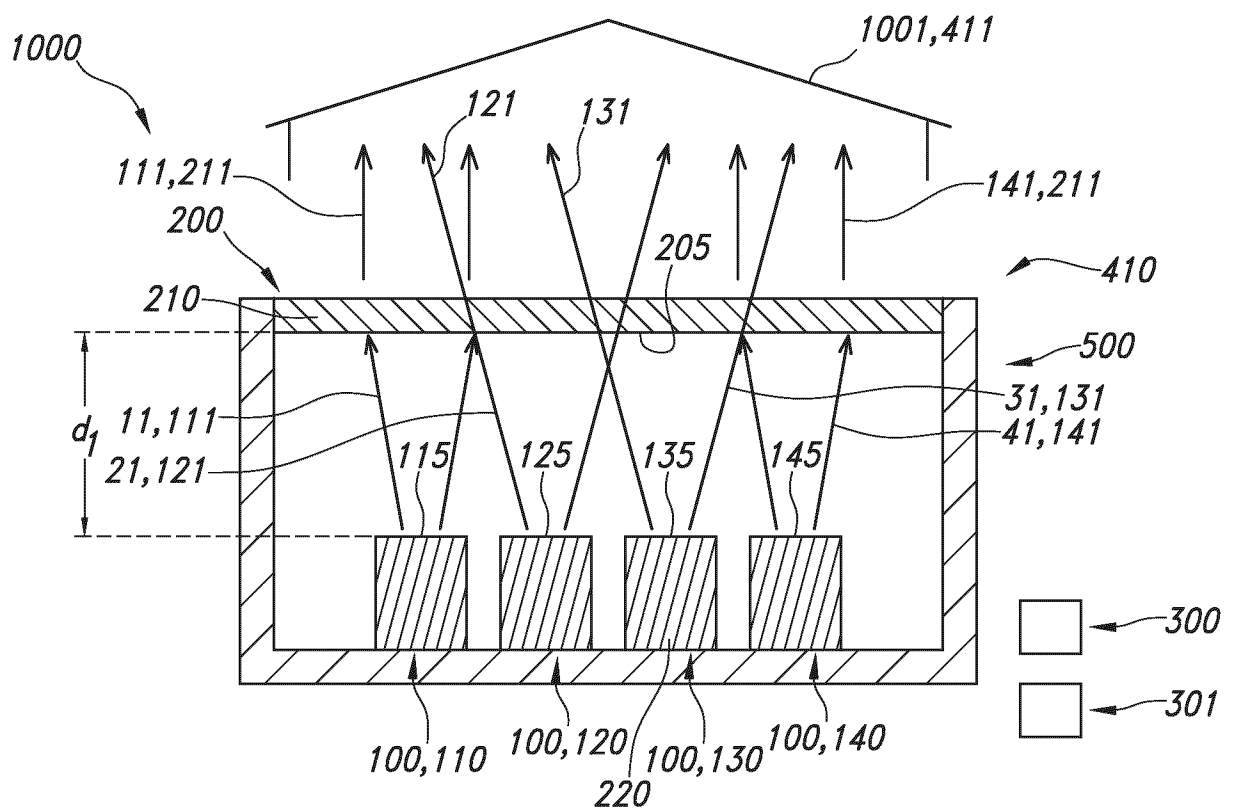


FIG. 2B

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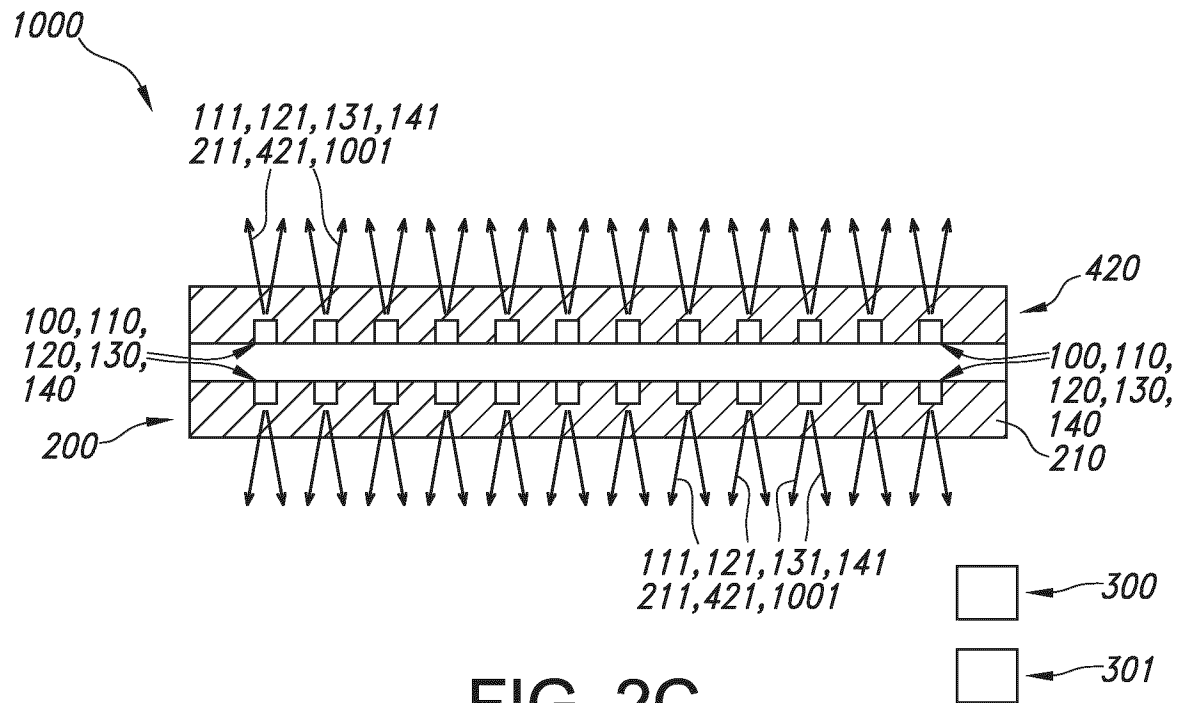


FIG. 2C

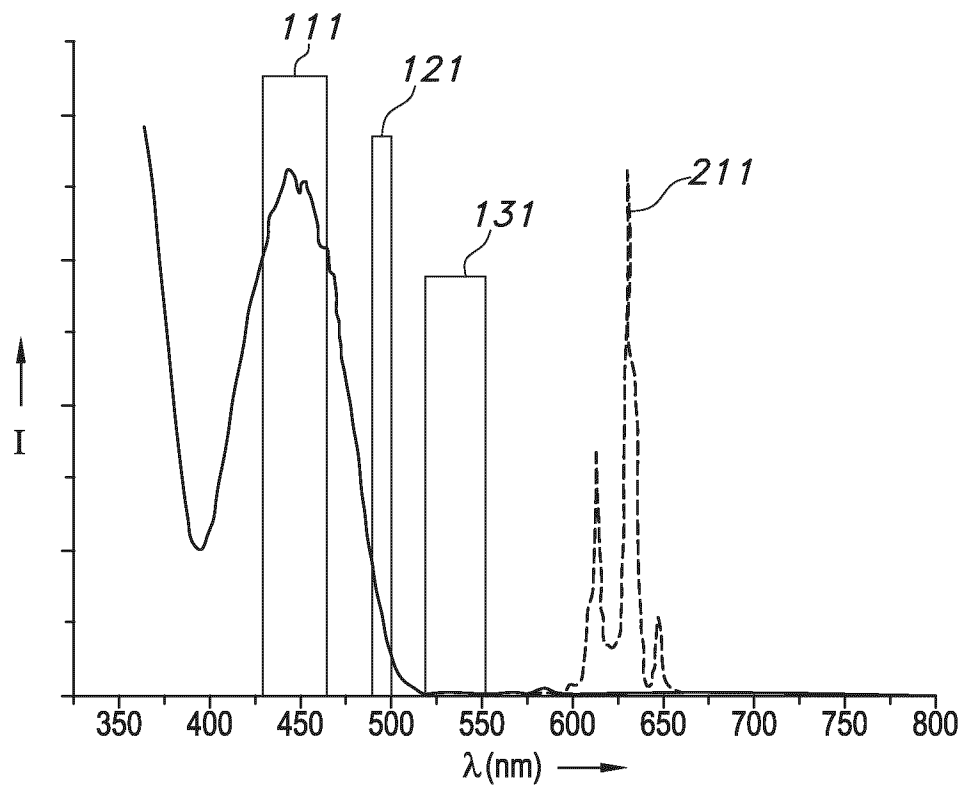


FIG. 3

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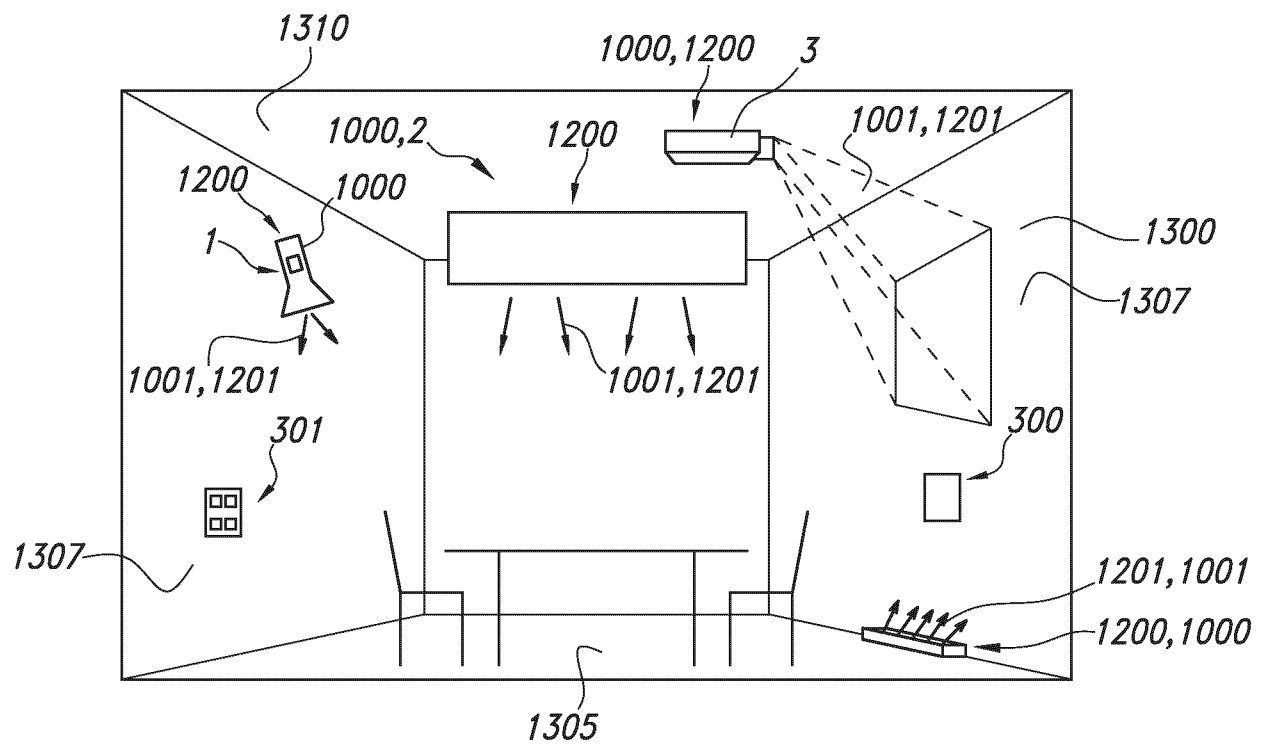


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2024/072379

A. CLASSIFICATION OF SUBJECT MATTER		
INV.	F21K9/64	C09K11/61
		C09K11/77
		H05B45/20
ADD.	F21Y113/13	F21Y115/10
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)		
F21K H05B C09K F21Y		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2013/121355 A1 (KONINKL PHILIPS NV [NL]; PHILIPS INTELLECTUAL PROPERTY [DE]) 22 August 2013 (2013-08-22) cited in the application page 3, lines 5-16 page 11, lines 9-26 -----	1 - 15
A	WO 2023/006550 A1 (SIGNIFY HOLDING BV [NL]) 2 February 2023 (2023-02-02) page 6, line 21 - page 7, line 34 -----	1 - 15
A	WO 2016/037773 A2 (PHILIPS LIGHTING HOLDING BV [NL]) 17 March 2016 (2016-03-17) page 19, lines 12-23 -----	1 - 15
A	US 2020/313048 A1 (YAO SHUGUANG [CN] ET AL) 1 October 2020 (2020-10-01) paragraphs [0037] - [0041] -----	1 - 15
☐ Further documents are listed in the continuation of Box C.		
☒ See patent family annex.		
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"P" document published prior to the international filing date but later than the priority date claimed		
Date of the actual completion of the international search	Date of mailing of the international search report	
9 October 2024	23/10/2024	
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 Allen, Katie	

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2024/072379

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