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(54) Title: LIGHTING SYSTEM THAT MAINTAINS THE MELANOPIC DOSE DURING DIMMING OR COLOR TUNING

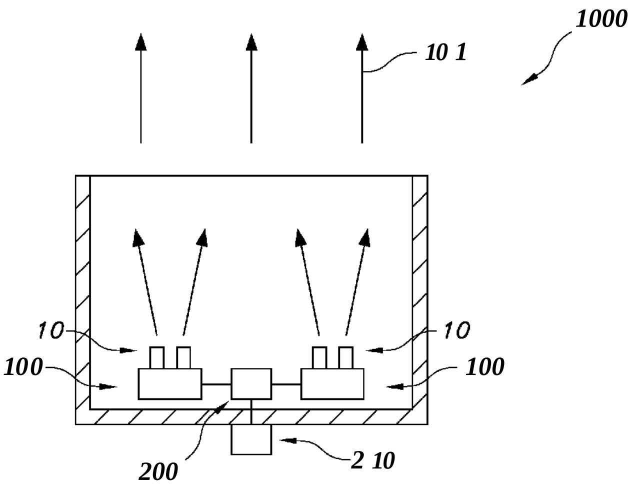

FIG. 3A

(57) Abstract: The invention provides a lighting system (1000) comprising a lighting device (100) configured to provide light (101), wherein one or more lighting properties, including the spectral power distribution, of the light are controllable, wherein the lighting system further comprises a control system (200) adapted to provide at least a controlling mode which comprises maintaining a predetermined melanopic flux value of the light (1010) while allowing another lighting property of the light (101) to be changed from a first lighting property value to a second lighting property value.

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Lighting system that maintains the melanopic dose during dimming or color tuning

FIELD OF THE INVENTION

The invention relates to a lighting system. The invention further relates to a method of controlling light, especially of such lighting system, and to a computer program product.

BACKGROUND OF THE INVENTION

Lighting systems with adjustable melatonin suppression effects are known in the art. US2015/0195885, for instance, describes a light emitting apparatus comprising a first LED component, a second LED component, and a control device, wherein the control device is arranged to operate the first LED component and the second LED component in a first operating mode in which combined emissions of the first LED component and the second LED component (i) are within six MacAdam ellipses of a target correlated color temperature, and (ii) embody a first melatonin suppression milliwatt per hundred lumens value, wherein the control device is arranged to operate the first LED component and the second LED component in a second operating mode in which combined emissions of the first LED component and the second LED component (i) are within six MacAdam ellipses of the target correlated color temperature, and (ii) embody a second melatonin suppression milliwatt per hundred lumens value that is at least about 10 percent greater than the first melatonin suppression milliwatt per hundred lumens value, and wherein the light emitting apparatus comprises at least one of the following features (a) to (c): (a) at least one of the first LED component and the second LED component comprises at least one LED arranged to stimulate emissions of at least one lumiphoric material, (b) combined emissions of the first LED component and the second LED component, when operated in the first operating mode, embody a color rendering index (CRI) value of at least about 80, (c) the light emitting apparatus comprises at least one element of a timer, a clock, a photosensor, and at least one user input element, wherein the at least one element is arranged to trigger switching between the first operating mode and the second operating mode.

SUMMARY OF THE INVENTION

Critical to our sleep/wake cycle is melatonin, a hormone that promotes sleep during night time. Melatonin is a sleep supportive hormone that we only produce around (and during) our usual bedtime. Light exposure during the evening and at night suppresses the natural production of melatonin. When the spectrum of the light is shifted towards lower CCT and intensity levels (like during dawn and dusk), this reduces melatonin suppression and makes the light less disruptive for sleep. During day time, natural daylight with high correlated color temperature (CCT, herein also indicated as "color temperature") and intensity energizes people making them awake and alert. Current high performance LED based lighting apparatus with tunable CCT are able to mimic different phases of daylight, i.e., changes in spectral power distribution and variations in CCT, to a certain extent.

Next to the commonly known cones and rods, the human eye has melanopsin containing photoreceptors, affecting circadian entrainment and melatonin secretion, which are sensitive in a specific wavelength range. The relative spectral sensitivity for the classic receptors (rods and cones) and for the melanopic receptors are provided in Fig. 1 (see also R.J. Lucas, et al., Measuring and using light in the melanopsin age, Trends in Neurosciences, Vol. 37, No. 1, January 2014, pp. 1-9; http ://www.sciencedirect. com/science/article/pii/SO 166223613001975. the report "CIE TN 003:2015 : Report on the First International Workshop on Circadian and Neurophysio logical Photometry, 2013" at http://cie.co.at/index.php?i_ca_id=978 (with a link to an excel toolbox ht1p://files.cie.co.at/784_TN003_Toolbox.xls). If the spectral power in the melanopic sensitive wavelength range is absent or low, the light exposure will be less suppressive for the melatonin hormone production thus enabling faster sleep onset and more consolidated sleep. If the spectral power in the melanopic sensitivity range is increased, a nocturnal light exposure will result in a stronger melatonin suppression. In general a light exposure can be said to be more biologically active and more alerting when the power in the melanopic sensitive wavelength range (and the ability to suppress melatonin at night) is increased. The effectiveness of a given light spectrum in suppressing melatonin production can be expressed in terms of the melanopsin effectiveness factor (MEF). This factor is calculated by multiplying the spectral power distribution of the light emitted by a lighting system (SPD(X)) with the melanopic sensitivity function ($m(\lambda)$) divided by the product of SPD(λ) and the photopic sensitivity function **($\nu(\lambda)$),** normalized by the areas under the curves of $m(\lambda)$ and **$\nu(\lambda)$,** see equation 1 (and see also Fig. 1).

$$MEF = \left(\frac{\int_\lambda V(\lambda)d\lambda}{\int_\lambda m(\lambda)d\lambda}\right) \cdot \left(\frac{\int_\lambda SPD(\lambda)m(\lambda)d\lambda}{\int_\lambda SPD(\lambda)V(\lambda)d\lambda}\right) \quad \text{(Eq. 1)}$$

This can be simplified to

$$MEF = 1.22 \left(\frac{\int_\lambda SPD(\lambda)m(\lambda)d\lambda}{\int_\lambda SPD(\lambda)V(\lambda)d\lambda}\right) \quad \text{(Eq. 2)}$$

or

$$MEF = 1.22 \frac{\sum_{\lambda=380}^{780} SPD(\lambda)m(\lambda)\Delta\lambda}{\sum_{\lambda=380}^{780} SPD(\lambda)V(\lambda)\Delta\lambda} \quad \text{(Eq. 3)}$$

Hence, the above indicated summations are over the visible wavelength range of 380-780 nm. By definition, the MEF for an equi-energy light source MEFEE equals 1. Especially, an equi-energy light source has constant radiant energy at all visible wavelengths i.e. SPD(X) is a constant (for instance 1) for all visible wavelengths.

For any kind of luminous radiation, the luminous (radiant) flux (Φ_v, expressed in lumen) is defined as:

$$\Phi_V = Km \int_\lambda SPD(\lambda)V(\lambda)d\lambda$$

or

$$\Phi_V = Km \sum_{\lambda=380}^{780} SPD(\lambda)V(\lambda)\,\Delta\lambda \quad \text{(Eq. 4)}$$

wherein Km equals 683 lm/W and ν (λ) equals the photopic sensitivity function. Km is also referred to as the maximum luminous efficacy and ν (λ) as the photopic luminous efficiency function.

By combining eqs. 3 and 4, the melanopic flux or melanopic radiant flux Φ_{mel}, defined as Σ (SPD(λ)·m(λ)·Δλ), can be calculated from the luminous flux or luminous radiant flux Φ_v according to

$$\Phi_{mel} = \sum_{\lambda=380}^{780} SPD(\lambda)m(\lambda)\,\Delta\lambda =$$

$$\frac{MEF}{1.22} \sum_{\lambda=380}^{780} SPD(\lambda)V(\lambda)\,\Delta\lambda = \frac{MEF}{1.22}\,\frac{\Phi_V}{Km} \qquad \text{(Eq. 5)}$$

The melanopic irradiance (E_{mel}) is defined as the melanopic radiant flux per unit area (A) and can be calculated according to

$$E_{mel} = \Phi_{mel} / A = (MEF/1.22)*(E_v/Km) \qquad \text{(Eq. 6)}$$

where E_v represents the illuminance (Φ_v / A) expressed in photopic lux.

Lucas et al. 2014 (Measuring and using light in the melanopsin age; Trends in Neurosciences, January 2014, vol. 37, no. 1, pages 1-9), introduced a new way to quantify light in terms of "(equivalent) melanopic illuminance" Ez, which is expressed in (equivalent) melanopic lux according to:

$$E_Z = Km\left(\frac{\sum_{\lambda=380}^{780} V(\lambda)\,\Delta\lambda}{\sum_{\lambda=380}^{780} \hat{m}(\lambda)\,\Delta\lambda}\right)\sum_{\lambda=380}^{780} SPD(\lambda)\hat{m}(\lambda)\,\Delta\lambda$$

$$= 72983.25 \sum_{\lambda=380}^{780} SPD(\lambda)\hat{m}(\lambda)\,\Delta\lambda \qquad \text{Eq. (7)}$$

wherein $m\backslash X)$ represents the melanopic sensitivity function but now normalized according to $\sum_{\lambda=380}^{780} \hat{m}(\lambda)\,\Delta\lambda=1$. See also the manual (appendix 1) of the irradiance toolbox referred to in Lucas et al 2014.

By definition, an equi-energy light source producing an (photopic) illuminance of 1 (photopic) lux, i.e. 1 (photopic) lumen on an area of 1 m^2, is said to produce a "(equivalent) melanopic illuminance" of 1 "(equivalent) melanopic lux", and therefore also has a melanopic (radiant) flux of 1 "(equivalent) melanopic lumen".

According to this definition, the E_z value (expressed in melanopic lux) of a test light condition t with a MEF value of MEFt and an illuminance of E_v can be calculated from Emei (as defined in Eq. 6) according to

$$E_z = \frac{\{\, E_{mel} \text{ of a test light condition t with } MEF_t \text{ and illuminance Ev} \}}{\{\, E_{mel} \text{ value of equi-energy light with an illuminance of 1 lux} \}}$$

$$= \frac{(MEF_t/1.22)*(Ev/Km)}{\{\,(MEF_{EE}/1.22)*(1/Km)}$$

$$= MEF_t * Ev \qquad \text{(Eq. 8)}$$

Similarly, the melanopic (radiant) flux Φ_ζ (expressed in melanopic lumen) of a test light condition t with an MEF value of MEFt and a luminous flux of Φ_v can be calculated from Φ_{mel} (as defined in Eq. 5) according to

$$\Phi_z = \frac{\{\ \Phi\text{mel of a test light condition t with } MEF_t \text{ and luminous flux } \Phi v\}}{\{\ \Phi\text{mel value of equi-energy light with an luminous flux of 1 lumen }\}}$$

$$= \frac{(MEF_t/1.22)*(\Phi v/Km)}{\{\ (MEF_{EE}/1.22)*(1/Km)}$$

$$= MEF_t * \Phi v \qquad \text{(Eq. 9)}$$

Users have personal preferences regarding color temperatures and light intensity, which preferences may be mutually dependent and do depend on the context. LED based lighting systems may allow users to adjust color temperature and light intensity according to their preferences. However, a problem is that, in general, such personalization will lead to a change (lower or higher) in melanopic stimulation, which is not always desired. Further, users may desire to adapt the melanopic (radiant) flux of light as function of e.g. desired activity or time of the day, but the light generally associated with the desired melanopic flux may not fit with the desired type of light for the activity or time of day (e.g. too cool or too warm).

Hence, the present disclosure provides an alternative lighting system, which preferably further at least partly obviates one or more of above-described drawbacks. . Further, also a method of controlling light which preferably further also at least partly obviates one or more of above-described drawbacks is provided.

In a first aspect, a lighting system ("system") comprises a lighting device ("device") configured to provide light ("lighting device light"), wherein one or more lighting properties, including the spectral power distribution, of the light are controllable, wherein the lighting system further comprises a control system ("controller") adapted to provide at least a controlling mode which comprises maintaining a predetermined melanopic flux value (and/or another non-visual parameter) of the light while allowing another (visual) lighting property of the light to be changed from a first lighting property value to a second lighting property value.

With such apparatus, it is possible to maintain a desired or required melanopic flux value while changing other lighting properties to the preference of a user. For instance, it may be possible to increase the light intensity for improved reading comfort in the evening or at night, while maintaining a constant low melanopic flux to prevent disruptive effects on subsequent sleep. Likewise, it may be possible to keep a high melanopic flux value early in the morning, allowing for effective waking up, while slowly increasing light intensity and/or color temperature to ensure optimal visual comfort just after waking up. Hence, the disclosed apparatus or method allows maintaining the melanopic flux value at a desired or preset level, while tuning one or more other lighting properties, e.g. in conformance with personal preferences or in conformance with lighting of surrounding spaces. The disclosed apparatus or method also allows lamps to be used in different regions of the world where preferred color points or color temperatures may differ between regions and wherein nonetheless essentially the same melanopic flux value may be desirable during for example working conditions or reading conditions. Whereas the prior art, such as US2015/0195885, focusses on maintaining the correlated color temperature at an essentially same level, the disclosed apparatus and method focusses on maintaining the non-visual effects of light at essentially the same level. The disclosed apparatus and method therefore addresses an essentially different problem. With the disclosed apparatus and method, lighting properties that affect the visual effects (e.g. brightness, color) of light may be adapted, without essentially (positively or negatively) influencing the non-visual effects (e.g. melatonin production or alertness) of the light.

In yet a further aspect, a lighting system is disclosed wherein the lighting system comprises a lighting device configured to provide light, wherein one or more lighting properties, including the spectral power distribution, of the light are controllable, wherein the lighting system further comprises a control system adapted to provide at least a controlling mode which comprises maintaining a predetermined value for a non-visual effect of the light, where the value of the non-visual effect may in embodiments be approximated by a melanopic flux value, while allowing another lighting property of the light to be changed from a first lighting property value to a second lighting property value.

In yet a further aspect, a lighting system is disclosed wherein the lighting system comprises a lighting device configured to provide light, wherein one or more lighting properties, including the spectral power distribution, of the light are controllable, wherein the lighting system further comprises a control system adapted to provide at least a controlling mode which comprises maintaining a predetermined melanopic illuminance (i.e. melanopic lux level) of the light at a certain position while allowing another lighting property of the light to be changed from a first lighting property value to a second lighting property value. In embodiments the position may be the location of a user's eye or the location of a visual task.

The non-visual effect may also be approximated in other ways. For instance, an approximation may be based on one of the five Alpha-opic fluxes (as defined in Lucas et al. 2014) or on a combination of at least two of the five Alpha-opic fluxes. Yet, in other embodiments the non-visual effect may be approximated by an alternative quantity such as the circadian stimulus CLa and Cs as defined in Bellia L, Pedace A, Barbato G. Indoor artificial lighting: Prediction of the circadian impact of different spectral power distributions. Lighting Research and Technology, 2013, or Rea, M. S., Figueiro, M. G., Bierman, A., & Bullough, J. D. (2010). Circadian light. Journal of Circadian Rhythms, 8(1), 2. Instead of the melanopic flux also the melanopic irradiance or the melanopic illuminance can be used.

Hence, the present disclosure also provides a lighting system comprising a lighting device configured to provide light, wherein one or more lighting properties, including the spectral power distribution, of the light are controllable, wherein the lighting system further comprises a control system adapted to provide at least a controlling mode which comprises maintaining a predetermined melanopic illuminance value of the light while allowing another lighting property of the light to be changed from a first lighting property value to a second lighting property value.

Herein, the disclosed apparatus, systems and methods are further defined in relation to the melanopic flux. However, in alternative embodiments the term "melanopic flux" may also be replaced by "melanopic irradiance" or "melanopic illuminance" or "melanopic luminance". Likewise, where applicable the term "luminous flux" may also be replaced by "luminous irradiance" or "luminous illuminance" or "melanopic luminance".

Hence, embodiments may also be formulated as a lighting system comprising a lighting device configured to provide light, wherein one or more lighting properties, including the spectral power distribution, of the light are controllable, wherein the lighting system further comprises a control system adapted to provide at least a controlling mode which comprises maintaining a predetermined non-visual effect of the light, where the non-visual effect may in embodiments relate to the melanopic flux value, while allowing another lighting property of the light to be changed from a first lighting property value to a second lighting property value. The phrase "relates to" in this context may also refer to scaling with. For instance, other parameter that scale with melanopic flux are a melanopic irradiance, a melanopic illuminance, or a melanopic luminance. By maintaining one of these parameters, also the (related) melanopic flux value may be maintained. Hence, the phrase "maintaining the melanopic flux value" may also be defined as "effectively maintaining the melanopic flux value".

As indicated above, the lighting system comprises a lighting device configured to provide light. The term "lighting device" may refer to one or more lighting devices. Further, the term "lighting device" may refer to one or more light sources. In embodiments, a "light source" may be a solid state light source, such as a laser light source, an organic or inorganic light emitting diode (LED), etc.. The terms "light source" or "lighting device" may also relate to a plurality of light sources, such as e.g. 2-200 light sources. Hence, the term LED may also refer to a plurality of LEDs. Further, the terms "light source" or "lighting device" may in embodiments also refer to a so-called chips-on-board (COB) light source. The term "COB" especially refers to LED chips in the form of a semiconductor chip that is neither encased nor connected but directly mounted onto a substrate, such as a PCB. Hence, a plurality of semiconductor light sources may be configured on the same substrate. In embodiments, a COB is a multi LED chip configured together as a single lighting module.

The light generated during use of the apparatus is indicated as light or lighting device light. The lighting device light may comprise light of one or more light sources and/or one or more lighting devices. The lighting device is adapted to provide lighting device light that has tunable lighting properties. Lighting properties that are tunable may especially be selected from the group consisting of spectral power distribution of the light, correlated color temperature (CCT), color point, relative gamut area index, and intensity of the light.

For instance, the phrase "allowing to be changed from a first lighting property value to a second lighting property value" and similar phrases may related to a change in correlated color temperature of at least 5 K, such as at least 10 K, like in the range of 5-3000 K, such as especially in the range of 10-2000 K, like in the range of 20-1500 K, like in the order of about 50-1250 K, e.g. 50-1000 K, or up to 500 K.

For instance, the phrase "allowing to be changed from a first lighting property value to a second lighting property value" and similar phrases may related to a change in x-value and/or y-value (CIE 1931) of in the range of at least 0.01, like at least 0.02, such as at least 0.04, like in the range of 0.01-0.25, such as 0.02-0.2, like in the range of 0.02-0.15, like in the range of 0.02-0. 1.

For instance, the phrase "allowing to be changed from a first lighting property value to a second lighting property value" and similar phrases may related to a change in intensity of 0.1-50% of the maximum intensity. Light intensity relates to or scales with operating power of the lighting device or light source. Changes in intensity may therefore be expressed as changes from e.g. 40 Watt (maximum power) to 30 Watt, which is 10/40*100=25%), like 0.5-40%, such as in the range of 1-25%, like in the range of 2-15%.

Dependent upon the lighting property selected, changing such lighting property may lead to a visible change of the light, whereas changing the melanopic flux not necessarily leads to a visible change of the light. For example, changing the melanopic lux of light can be done while keeping e.g. the color point constant. Likewise, the melanopic flux may be kept constant while changing the color point or color temperature, etc. of the light.

Especially, at least the spectral power distribution of the light is controllable as well as another lighting property selected from the group consisting of correlated color temperature, color point, and intensity of the light. Note that different spectral power distributions may provide the same color point or correlated color temperature.

Further, in general also the intensity of the light will be controllable. Further, in general also the color point and/or correlated color temperature of the light will be controllable.

Hence, in general the lighting device will comprise a plurality of light sources configured to provide light source light having different spectral power distributions. By individually controlling for example a light intensity of each of the plurality of light sources, the spectral power distribution of lighting device light may be controlled.

The term "controllable" in the context of the lighting properties especially refer to the possibility that a plurality of values, especially more than two, can be chosen for the respective lighting property. Hence, with reference to intensity, "controllable" may imply a plurality of different intensity values between off and maximum power. With reference to color point, "controllable" may imply the possibility of selecting a plurality of different x-values and y-values (in the CIE 1931 color space). Hence, one or more lighting properties, including the spectral power distribution, of the light are controllable.

Further, the lighting system comprises a control system ("controller") adapted to provide at least a controlling mode which comprises maintaining a predetermined melanopic flux value of the light while allowing another lighting property of the light to be changed from a first lighting property value to a second lighting property value. When maintaining the melanopic flux value also the melanopic irradiance or melanopic illuminance may indirectly effectively be kept constant, especially if assumed that other parameters, such as the distance to the user and reflectance properties of the surroundings etc. remain constant.

The control system may execute control based on the input of a sensor, such as a (day)light sensor, or may execute control based on a predefined (time) scheme. In such embodiments, the control system may essentially autonomously select the predetermined melanopic flux value. The control system may for example control the light based on the input of a (day)light sensor and adapt the light provided by the lighting system while taking into account (as much as possible) the already available (day)light. Further, the control system may be configured to control the light as function of an activity of a user such as for example reading, studying, relaxing etc.. The type (and optionally intensity of the) activity may be retrieved from a device, a sensor, or a user input.

In yet other embodiments, it may also be possible to influence the predetermined melanopic flux value determined by the control system. For instance, the control system may allow (via a user interface) input such as "low", "medium", "high", etc. to be entered. Hence, the control system may include a user interface device, such as a graphical user interface device and/or may functionally be coupled to a user interface device (such as a computer, smart phone, I-phone, etc.). The melanopic flux value may also be selected by a user, e.g. via such user interface. The selected melanopic flux value may then be defined as the predetermined melanopic flux value. The user may in embodiments also be able to select a condition or status that reflects a certain melanopic flux, or that reflects a certain melanopic flux at specific other conditions (such as early in the morning; or under specific lighting conditions). For instance, it may also be possible that the user may select options like "sleep", "wake up", "high alert", "reading", "working", etc.. This may then be translated by the control system into a predetermined melanopic flux. Hence, the user may select input associated with a predetermined melanopic flux and/or the control system may include a routine which define the predetermined melanopic flux. For instance, the predetermined melanopic flux may be dependent upon the time of the day, day of the week, etc. Instead of the term "routine" also the term "scheme" or "program" may be used.

As will be clear from the above, the predetermined melanopic flux value may in embodiments be a fixed value, but may in other embodiments be a variable value, e.g. variable based on a ((day)light) sensor, a time scheme, user interface input, etc..

As indicated above, the control system is adapted to provide at least a controlling mode which comprises maintaining a predetermined melanopic flux value of the light while allowing another lighting property of the light to be changed from a first lighting property value to a second lighting property value. This does not exclude that the control system is further adapted for providing another controlling mode, or a plurality of other controlling modes. For instance, in embodiments the control system may also be adapted to provide a controlling mode wherein essentially all lighting properties may be freely varied, or wherein another lighting property is fixed and one or more other, including the melanopic flux value, may be varied. However, the control system is adapted to provide *at least* a controlling mode which comprises maintaining a predetermined melanopic flux value of the light while allowing another lighting property of the light to be changed from a first lighting property value to a second lighting property value. 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. For instance, the control system may be in the controlling mode as defined herein from sunset to sunrise, allowing the user other lighting choices during the day, etc.. The term "controlling" and similar terms especially refer to at least determining the behavior or supervising the running of an element. Hence, herein "controlling" and similar terms may e.g. refer to imposing behavior to the element (determining the behavior or supervising the running of an element), etc., such as e.g. measuring, displaying, actuating, opening, shifting, changing temperature, etc.. Beyond that, the term "controlling" and similar terms may additionally include monitoring. Hence, the term "controlling" and similar terms may include imposing behavior on an element and also imposing behavior on an element and monitoring the element. In the context of the present disclosure, light and lighting properties can of course only be controlled within the technical boundaries that the system, such as for example the lighting device, provides (like maximum power, etc.).

The phrase "control system is adapted to provide at least a controlling mode which comprises maintaining a predetermined melanopic flux value of the light while allowing another lighting property of the light to be changed from a first lighting property value to a second lighting property value" especially indicates that the melanopic flux value is at a fixed value, while one or more other lighting properties may be varied.

With respect to the one or more other lighting properties, these may be controlled with the control system. Hence, the control system may control based on the input of a sensor, such as a (day)light sensor, or may control based on a predefined (time) scheme, etc., one or more of the other lighting properties. Alternatively or additionally, one or more other lighting properties may be selected by a user (via a user interface). Hence, controlling a lighting property may include controlling such lighting property in dependence of one or more of a sensor signal, a (time) scheme and a user input (value or instruction).

The phrase "maintaining a predetermined melanopic flux value of the light" especially indicates that the melanopic flux value is essentially the same at the first lighting property value and the second lighting property value. Here, the terms "maintaining" and "essentially the same", may especially refer to a change in value of the melanopic flux value of at maximum 20%, such as at maximum 10%. Hence, in specific embodiments the light has a first melanopic flux (Φ_{mel1}) at the first lighting property value and a second melanopic flux (Φ_{mel2}) at the second lighting property, wherein $0.8 \leq (\Phi_{mel1}/\Phi_{mel2}) \leq 1.2$, especially $0.9 \leq (\Phi_{mel1}/\Phi_{mel2}) \leq 1.1$, even more especially $0.95 \leq (\Phi_{mel1}/\Phi_{mel2}) \leq 1.05$. Here and elsewhere in the claims and description the Φ_{mel} value represents the melanopic flux value. Hence, the word "maintaining" and similar terms may also refer to "substantially maintaining", or maintaining within some tolerance, which, as indicated above, may e.g. be in the range of about +/- 20%, such as about +/- 10%>, like especially about +/- 5%.

Especially, the control system is adapted to provide a mode wherein not only the melanopic flux value can (effectively) be held at a fixed value, but wherein also the luminous flux of the light can be held at a fixed value. Hence, in embodiments the controlling mode comprises maintaining said predetermined melanopic flux value and maintaining a predetermined luminous flux value or intensity level of the light while allowing another lighting property of the light to be changed from a first lighting property value to a second lighting property value. The predetermined luminous flux value or intensity level of the light may be determined by the control system in dependence of one or more of a sensor signal, a time scheme, and a user input.

Hence, in specific embodiments the light has a first melanopic flux (Φ_{mel1}) at the first lighting property value and a second melanopic flux (Φ_{mel2}) at the second lighting property, wherein the light has a first luminous flux level (Φ_{v1}) and first melanopsin effectiveness factor MEF1 at the first lighting property value and a second luminous flux level (Φ_{v2}) and second melanopsin effectiveness factor MEF2 at the second lighting property, wherein especially $0.8 \leq (MEF1*\Phi_{v1})/(MEF2*\Phi_{v2}) \leq 1.2$, especially $0.9 \leq (MEF1*\Phi_{v1})/(MEF2*\Phi_{v2}) \leq 1.1$, even more especially $0.95 \leq (MEF1*\Phi_{v1})/(MEF2*\Phi_{v2}) \leq 1.05$.

As indicated above, instead of the melanopic flux, also the melanopic illuminance may be applied. Likewise, instead of the luminous flux, also the luminous illuminance may be applied. Hence, identical formulas may be provided wherein instead of flux the illuminance is applied, e.g. $0.8 \leq (E_{mel1})/(E_{mel2}) \leq 1.2$ (see above) or **0.8** ≤

(MEFl*Evi)/(MEF2*Ev2) ≤ 1.2 (see previous paragraph). Here, MEF refers to Eq. 3 and E refers to illuminance (in lux (lx)). Further, "mel" refers to melanopic and "v" refers to luminous (with "v" from visible).

As indicated above, the term "predetermined melanopic flux value" does not necessarily mean that the melanopic flux value is eternally fixed. The melanopic flux value may also vary according to a time scheme or in dependence of a sensor, such as a (day)light sensor. However, the control system determines the melanopic flux value in dependence of such a sensor signal of such sensor or according to such time in such time scheme and as long as the control system does not change the so determined melanopic flux value, the melanopic flux value is the predetermined melanopic flux value from which, in the herein indicated mode, substantially no deviation is allowed. Would for instance later in time the control system change the melanopic flux value, e.g. because of a changed (day)light intensity level or due to a change time, then the new melanopic flux value is the predetermined melanopic flux value, from which, in the herein indicated mode, substantially no deviation is allowed.

Therefore, in embodiments the control system may be adapted to provide at least a controlling mode which comprises controlling the melanopic flux of the light in dependence of a ((day)light) sensor signal, wherein a temporary predetermined melanopic flux value is defined by said control system, and wherein said controlling mode comprises maintaining said temporary predetermined melanopic flux value while allowing another lighting property of the light to be changed from a first lighting property value to a second lighting property value. The control system may define the temporary predetermined melanopic flux value based on a predefined scheme with relation to sensor signals and (predetermined) melanopic flux value. Other sensor signal(s) than a (day)light sensor signal may also be used as input, either additionally or alternatively, such as a presence sensor, a temperature sensor, etc..

Therefore, in yet other embodiments, which may be combined with the former embodiments related to the ((day)light) sensor, the control system may be adapted to provide at least a controlling mode which comprises controlling the melanopic flux of the light as function of a time scheme defining the melanopic flux of the light as function of one or more of time, day, week, month and season, wherein a temporary predetermined melanopic flux value is defined by said control system, and wherein said controlling mode comprises maintaining said temporary predetermined melanopic flux value while allowing another lighting property of the light to be changed from a first lighting property value to a second lighting property value. In embodiments, the time scheme may include a calendar. In embodiments, the time scheme may include information about activities and/or about rest periods. In further embodiments, the time scheme may be based on circadian rhythm data, etc.

The present disclosure also provides a lighting device suitable for use in the lighting system as a controllable lighting device (and for use in the herein described controlling mode).

The lighting system may also be part of a (larger) system, such as a (lighting) system for a hospitality area, such as restaurant, a hotel, a clinic, or a hospital, etc.. Such (lighting) system may include a single control system. Hence, in yet a further aspect the disclosure also provides a (lighting) system comprising a plurality of lighting devices as defined herein and said control system as defined herein, wherein the control system is adapted to provide at least a controlling mode which comprises maintaining a predetermined melanopic flux value of the light of one or more of said lighting devices while allowing another lighting property of the light to be changed from a first lighting property value to a second lighting property value. With such (lighting) system, it may e.g. be possible to tune the lighting properties in different areas and maintain a predetermined melanopic flux value in those areas or maintain different predetermined melanopic flux value in those areas, or maintain in one or more areas a predetermined melanopic flux value while allowing varying the melanopic flux value in other areas. For instance, in hotel rooms the user may freely choose the desired lighting properties, in the hallways the predetermined melanopic flux value may be set (but may depend on the time of the day), and at the front desk a relatively high predetermined melanopic flux value is set to keep personnel alert during night hours.

Hence, the lighting device or lighting 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, or LCD backlighting.

As indicated above, the lighting device or lighting system may be used as backlighting unit in an LCD display device. Hence, the present disclosure provides also a LCD display device comprising a lighting system as defined herein, configured as backlighting unit. The present disclosure also provides in a further aspect a liquid crystal display device comprising a backlighting unit, wherein the backlighting unit comprises one or more lighting devices as defined herein. The present disclosure also provides an electronic device comprising a backlighting unit, wherein the electronic device comprises a lighting system as defined herein and wherein said backlighting unit comprises a lighting device as defined herein. Such electronic device may also include a plurality of lighting system. In further embodiments, the electronic device comprises a lighting system as defined herein, wherein said backlighting unit comprises a plurality of a lighting devices as defined herein. The electronic device may for example be a display or a mobile device such as a smart phone, an i-Phone, a tablet, etc..

In embodiments, the lighting device comprises at least four different light sources, even more especially at least five different light sources. The different light sources may have a different spectral power distribution of its light output. Controlling the contribution of each of the different light sources to the lighting device light output, for example by varying the intensity of the light output from at least one of the different light sources, also controls the spectrum power distribution of said lighting device light and may allow varying the lighting properties of the lighting device light while maintaining the melanopic flux value essentially constant.

In yet a further aspect, the invention also provides a method of controlling light, wherein one or more lighting properties, including the spectral power distribution, of the light are controllable, the method comprising providing said light with a predetermined melanopic flux value of the light, wherein the method further comprises maintaining said predetermined melanopic flux value of the light while changing another lighting property of the light from a first lighting property value to a second lighting property value. Such method may especially be executed with the herein described apparatus or system. Further, the embodiments as described above in relation to the lighting system, lighting device(s) or electronic device(s) may also be used with the method. A few of these embodiments are described in more detail below.

In specific embodiments of the method the other lighting property is selected from the group consisting of correlated color temperature, color point, relative gamut area index, and intensity of the light, such as one or more of correlated color temperature, color point, and intensity of the light.

Further, in other specific embodiments of the method the light has a first melanopic flux (Φ_{mel1}) at the first lighting property value and a second melanopic flux (Φ_{mel2}) at the second lighting property, wherein the method further comprises maintaining a predetermined melanopic flux value of the light in the range $0.8 \leq (\Phi_{mel1}/(\Phi_{mel2}) \leq 1.2$, especially $0.9 \leq (\Phi_{mel1}/\Phi_{mel2}) \leq 1.1$, even more especially $0.95 \leq (\Phi_{mel1}/\Phi_{mel2}) \leq 1.05$, while another lighting property of the light is changed from said first lighting property value to said second lighting property value.

In further specific embodiments of the method the light has a first luminous flux level (Φ_{v1}) and first melanopsin effectiveness factor MEF1 at the first lighting property value and a second luminous flux level (Φ_{v2}) and a second melanopsin effectiveness factor MEF2 at the second lighting property, wherein the method further comprises maintaining the flux and melanopsin effectiveness factor of the light in the range of $0.8 \leq (MEF1*\Phi_{v1})/(MEF2*\Phi_{v2}) \leq 1.2$, especially $0.9 \leq (MEF1*\Phi_{v1})/(MEF2*\Phi_{v2}) \leq 1.1$, even more especially $0.95 \leq (MEF1*\Phi_{v1})/(MEF2*\Phi_{v2}) \leq 1.05$, while another lighting property of the light is changed from said first lighting property value to said second lighting property value.

As indicated above, the predetermined melanopic flux value may also be dependent upon a sensor signal or (time) scheme. Hence, in further specific embodiments of the method, the method comprises controlling the melanopic flux of the light as function of a time scheme defining the melanopic flux of the light as function of one or more of time, day, week, month and season, wherein a temporary predetermined melanopic flux value is defined by said control system based on said time scheme, and wherein the method further comprises maintaining said temporary predetermined melanopic flux value while changing another lighting property of the light to be changed from a first lighting property value to a second lighting property value.

In yet a further aspect, the present disclosure also provides a computer program product, when running on a computer which is functionally coupled to a lighting device, is capable of bringing about the method as described herein, wherein the lighting device is configured to provide light, wherein one or more lighting properties, including the spectral power distribution, of the light are controllable. In embodiments, the computer may be the processor of the system controller as described herein.

In the herein described "controlling mode", the apparatus may especially be configured to provide white light. Alternatively or additionally, when there are also one or more other modes available, one or more of the other modes may provide white light. The term white light herein, is known to the person skilled in the art. It especially relates to light having a correlated color temperature (CCT) between about 1500 and 20000 K, especially 2000-20000 K, for general lighting especially in the range of about 2000 K and 6500 K, and for backlighting purposes especially in the range of about 7000 K and 20000 K, and especially within about 15 SDCM (standard deviation of color matching) from the BBL (black body locus), especially within about 10 SDCM from the BBL, even more especially within about 5 SDCM from the BBL.

BRIEF DESCRIPTION OF THE DRAWINGS

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

Fig. 1 shows the normalized melanopic sensitivity function of the human eye (solid line m) and the normalized photopic sensitivity function of the human eye (dashed line p) (R.J. Lucas, et al., Measuring and using light in the melanopsin age, Trends in Neurosciences, Vol.37, No.l, Jan. 2014, pp 1-9; http://www.sciencedirect.com/science/article/pii/SO1662236 1300 1975) (see also the report "CIE TN 003:2015 : Report on the First International Workshop on Circadian and Neurophysiological Photometry, 2013", with a link to an excel toolbox at http://cie.co.at/index.php?i_ca_id=978 and http://files.cie.co.at/784_TN003_Toolbox.xls . respectively;

Fig. 2 shows the minimum and maximum MEF that can be obtained by tuning the spectral power distribution in order to achieve a given CCT while also fulfilling the CRI requirement as specified. Three CRI cases are plotted (a) CRI unrestricted, (b) CRI=50 for (c) CRI = 80. The reference MAX in Fig. 2 refers to the curve indicating the unrestricted maximum; the reference MIN refers to the curve indicating the unrestricted minimum. The ranges are theoretical MEF ranges with a 2° observer;

Figs. 3A-3C schematically depict some embodiments of the lighting system, lighting system, and electronic device;

Figs. 4A-4B show examples at different CCT, with Fig. 4a at a CCT = 3000 K and Fig. 4b at a CCT = 6500 K; on the x-axis the photopic lux (PL) value that results from a certain luminous flux value is indicated, the y-axis indicates the melanopic flux (MF) value (in W/m^2) that results from the melanopic (radiant) flux that corresponds to this luminous flux;

Figs. 5A-5B shows examples at different lux levels, with Fig. 5a at 300 lux and Fig. 5c at 600 lux; on the x-axis the correlate color temperature (CCT) and on the y-axis the melanopic lux (MF) are indicated;

Fig. 6A shows spectral power distribution of three settings of a lighting device wherein the melanopic (f)lux is essentially identical, but wherein one or more other lighting parameters are varied;

Fig. 6B shows spectral power distribution of light of light sources that can be used for the lighting system.

The schematic drawings are not necessarily on scale.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Fig.l shows the relative melanopic (m) and photopic (p) human eye sensitivity functions. The maximum sensitivity for the melanopic function is at 490 nm, the full width half maximum values are at 447 nm and 531 nm, as indicated in the numerical representation of the melanopic function in the table below.

lambda (nm)	sensitivity	lambda (nm)	sensitivity	lambda (nm)	sensitivity
380	9.18E-04	515	7.85E-01	650	8.66E-05
385	1.67E-03	520	7.00E-01	655	5.92E-05
390	3.09E-03	525	6.09E-01	660	4.07E-05
395	5.88E-03	530	5.19E-01	665	2.81E-05
400	1.14E-02	535	4.33E-01	670	1.96E-05
405	2.28E-02	540	3.52E-01	675	1.36E-05
410	4.62E-02	545	2.79E-01	680	9.58E-06
415	7.95E-02	550	2.16E-01	685	6.75E-06
420	1.37E-01	555	1.62E-01	690	4.79E-06
425	1.87E-01	560	1.19E-01	695	3.41E-06
430	2.54E-01	565	8.43E-02	700	2.44E-06
435	3.21E-01	570	5.87E-02	705	1.75E-06
440	4.02E-01	575	4.00E-02	710	1.27E-06
445	4.74E-01	580	2.69E-02	715	9.18E-07
450	5.54E-01	585	1.79E-02	720	6.69E-07
455	6.30E-01	590	1.18E-02	725	4.9E-07
460	7.08E-01	595	7.73E-03	730	3.6E-07
465	7.85E-01	600	5.07E-03	735	2.65E-07

lambda (nm)	sensitivity	lambda (nm)	sensitivity	lambda (nm)	sensitivity
470	8.60E-01	605	3.32E-03	740	1.97E-07
475	9.18E-01	610	2.18E-03	745	1.46E-07
480	9.66E-01	615	1.43E-03	750	1.09E-07
485	9.91E-01	620	9.47E-04	755	8.2E-08
490	1.00E+00	625	6.28E-04	760	6.17E-08
495	9.92E-01	630	4.18E-04	765	4.66E-08
500	9.66E-01	635	2.80E-04	770	3.53E-08
505	9.22E-01	640	1.88E-04	775	2.69E-08
510	8.63E-01	645	1.27E-04	780	2.05E-08

Assume a lighting system which, when increasing the colour temperature of the light produced by the lighting system, also the melanopic stimulation increases (see Fig. 2). In the evening and at night time, this means that the light system becomes more sleep disruptive. In such system, CCT and melanopic flux are linked. The disclosed system prevents this from happening by using a special controller allowing a user can change the correlated colour temperature (CCT) of the light from the lighting system without changing the melanopic stimulation. The controller automatically adjusts the emitted spectrum to reach the desired CCT without changing the melanopic or the photopic illuminance of the light.

Assuming a system, which, when decreasing the colour temperature the melanopic stimulation goes down, see Fig. 2. This is undesired in applications where for instance light is used to improve mood or even treat depression. In general, a higher melanopic stimulation is believed to be more effective in achieving these non-visual benefits of light. The disclose system allows the user to decrease colour temperature while maintaining the same melanopic illuminance, thus securing the biological effect. By using a special controller the user can lower the colour temperature of for instance a light system or light therapy device without lowering the melanopic dose. The light controller automatically changes the emitted spectrum of the system to lower the CCT without changing the melanopic or photopic illuminance.

Hence, the disclosure provides amongst others a lighting system that comprises at least one lighting device and at least one (programmed) controller ("control system"). Especially, the controller is configured to vary the spectral intensity of the light of the system, in such a way that, at least during part of the time, the melanopic flux (i.e., the amount of melanopic lumen or melanopic illuminance) generated by the system is kept virtually constant or changes less than 10% when the lighting system changes colour temperature, and/or colour, and/or dim level.

In an embodiment the execution of the various embodiments the controller also keeps lighting properties such the colour temperature and/or the CRI and/or the relative gamut area index (now denoted as Color Saturation Index) constant, or minimizes undesired changes in these parameters, while changing another lighting property. In another embodiment, the lighting system also automatically generates a dynamic lighting rhythm. For the relative gamut area index, see also Teunissen C, van der Heijden F, Poort S, de Beer E. Characterising user preference for white LED light sources with CIE colour rendering index combined with a relative gamut area index. Lighting Research and Technology 2016; 0: 1-20.

Fig. 3A schematically depicts an embodiment of a lighting system 1000 as defined herein. The lighting system 1000 comprises a lighting device 100 configured to provide light 101, wherein one or more lighting properties, including the spectral power distribution, of the light 101 are controllable, wherein the lighting system 1000 further comprises a control system 200 adapted to provide at least a controlling mode which comprises maintaining a predetermined melanopic flux value of the light 101 while allowing another lighting property of the light 101 to be changed from a first lighting property value to a second lighting property value. In operation, the lighting system 1000 may execute a method of controlling light 101, wherein one or more lighting properties, including the spectral power distribution, of the light 101 are controllable, the method comprising providing said light 101 with a predetermined melanopic flux value of the light 101, wherein the method further comprises maintaining said predetermined melanopic flux value of the light 101 while changing another lighting property of the light 101 from a first lighting property value to a second lighting property value. Hence, the lighting device 100 is especially configured to provide light 101 wherein one or more lighting properties, including the spectral power distribution, of the light 101 are controllable.

Here, by way of example two lighting devices 100, each comprising two light sources 10 are depicted. However, less or more than two lighting devices 100 may be available. Further, a lighting device 100 may comprise one or more light sources 10. The light sources 10 may all generate light with different spectral power distributions. The light generated by the device(s) is indicated with reference 101. The light may comprise the contributions of one or more of the light sources, dependent upon the mode and the light sources. Likewise, the light generated by the device may comprise the contributions of one or more of the lighting devices, dependent upon the mode and the lighting devices.

Reference 210 indicates an optional user interface, e.g. to change the mode or to change the predetermined melanopic flux value, or to change another lighting property. The user interface may be comprised by the control system or may be remote. The user interface 210 is functionally coupled with the control system 200.

Fig. 3B schematically depicts an embodiment of a lighting system 1000 comprising a plurality of lighting devices 100 and the control system 200 as defined herein. The control system 200 is adapted to provide at least a controlling mode which comprises maintaining a predetermined melanopic flux value of the light 101 of one or more of said lighting devices 100 while allowing another lighting property of the light 101 to be changed from a first lighting property value to a second lighting property value. Further, such lighting system 1000 may allow different predetermined melanopic flux value for the different lighting devices 100, if desired. Here, by way of example a hospitality area is schematically depicted with left a control room with the control system 200 and a user interface 210, such as a computer, and right e.g. a hotel room or hospital room or elderly room, etc.. Hence, the invention also provides a computer program product, when running on a computer which is functionally coupled to a lighting device 100, is capable of bringing about the method as described herein. Further, by way of examples the lighting devices 100 include sleeve control systems 200', which are subordinate to the (master) control system 200.

Fig. 3C very schematically depicts an embodiment of an electronic device 2000 comprising a backlighting unit 2100. The electronic device 2000 comprises a lighting system 1000 as described with Fig. 3A or Fig. 3B. The backlighting unit 2100 comprises said lighting device(s) 100. The electronic device 2000 can e.g. be a display or a mobile device. Reference 2200 indicates a screen.

In an embodiment the user may change CCT from setting 1 to 2, while keeping for example the light intensity constant, and the controller automatically adjusts the spectral composition of the light system so that the MEF of the system is not affected, or changes less than 10%

$$0.9 < (MEF1) / (MEF2) < 1.1 \qquad \text{(Eq. 10)}$$

Normally the MEF increases when the colour temperature is increased. This is not desirable in the evening or night time, as it makes the light more disruptive to sleep.

In a further embodiment, the illuminance Ev (expressed in photopic lux) is changed from Evl to Ev2 by for example the user or the system to secure a desired dynamic lighting rhythm and the controller automatically adjusts the spectral composition of the light (changing the MEF from MEF1 to MEF2) to keep MEF * Ev constant, or with less than 10 % change

$$0.9 < (MEF1 * Ev1) / (MEF2 * Ev2) < 1.1 \qquad \text{(Eq. 11)}$$

This example is shown schematically in Fig. 4A. Similarly, when the user adjusts the CCT without wanting to change the photopic lux, the spectrum can be changed while fulfilling Eq. (11). This is presented in Fig. 4B.

Fig. 4A shows an example with keeping melanopic flux and CCT constant while changing the photopic flux (see arrows A and B). Each line in Fig. 4A and Fig. 4B represents the change in melanopic flux during dimming when the spectrum is not adapted, using the spectrum that corresponds 3000 K and 6500 K points on the Min and Max MEF lines in Fig. 2. Fig. 4A shows the relationship between photopic and melanopic flux for a CCT of 3000 K. Fig. 4B illustrates the same for a CCT of 6500 K. Each line represents a spectrum with a combination of a given MEF value and a CRI taking the right points from Fig. 2. In case A (arrow A) in Fig. 4A, the user dims from 480 to 220 lx (lx = lux), while the controller changes spectrum from minMEF(CRI = 80 at 3000 K) light to maxMEF(CRI = 80 at 3000 K) light (see Fig. 2) in order to keep the melanopic flux constant at 200 melanopic lux. In case A (arrow A) in Fig. 4B the user dims the illuminance from 220 to 150 lx, while the controller changes the light spectrum in order to keep the (equivalent) melanopic illuminance, which is expressed in (equivalent) melanopic lux (melanopic lux), see Lucas et al. 2014), constant at 200 melanopic lux.

In case B (arrow B) in Fig. 4A, the user increases the illuminance form 50 to 150 lx while the controller adjusts the spectrum from maxMEF(CRI = 80 at 3000 K) light to minMEF(CRI = 50 at 3000 K) light to keep the melanopic illuminance constant at 50 melanopic lux. Note that here the controller sacrifices CRI (going from 80 to 50) to secure the melanopic stimulus is maintained at 50 melanopix lux when when increasing the intensity of the 3000 K light.

Lucas et al. 2014 describes that light is a potent stimulus for regulating circadian, hormonal, and behavioral systems. In addition, light therapy is effective for certain affective disorders, sleep problems, and circadian rhythm disruption. These biological and behavioral effects of light are influenced by a distinct photoreceptor in the eye, melanopsin-containing intrinsically photosensitive retinal ganglion cells (ipRGCs), in addition to conventional rods and cones.

Fig. 5 shows examples with keeping the melanopic illuminance (or flux) and photopic illuminance (or flux) constant while changing CCT (see arrows). Each line represent the change in melanopic flux when the CRI and MEF setting (either max or min from Fig. 2) are not adapted when changing the CCT while keeping the photopic illuminance constant to 300 lx (Fig. 5A) or 600 lx (Fig. 5B). When the colour temperature of the light output is adjusted, the system automatically changes the spectrum of the light (switching from one line to the other) to ensure that the melanopic flux remains constant, so that the melanopic illuminance for the user remains 60 (equivalent) melanopic lux for use case D (arrow D in Fig. 5A) and at 500 melanopic melanopic lux for use case C (arrow C in Fig. 5B). In use case C, when the CCT from the light is changed from about 6000 K to about 2500 K, the system tries to adjust the spectrum to keep its MEF while also maintaining its original CRI value. However, when the user changes CCT from about 6000K to about 2500K, i.e. towards a CCT below 2900 K, the system will also to adapt the CRI to a lower value, so that it can further minimize the MEF variation and switch the spectrum from minMEF(CRI=80) the to the maxMEF(CRI=50) light (see Fig. 2). The system will look for the spectrum that minimizes the reduction in CRI while securing the melanopic flux remains constant. The use cases are further explained in the examples of execution.

The arrows in Figs. 4A-5B indicate a change from a first lighting property value to a second lighting property value.

In an embodiment the user changes both the colour temperature and the luminous intensityof the light and the controller automatically adjusts the spectral composition of the light to keep the melanopic illuminance of the user (more precisely the melanopic flux value) constant.

In an embodiment the user changes the colour of for instance a Philips Hue light source and the controller automatically adapts the spectrum to keep the melanopic flux value constant.

In an example, a bedside light keeps the melanopic flux below a threshold level so that the melanopic illuminance does not exceed 40 melanopic lux when the user increases the (luminous) intensity of the light for bedside reading prior to sleep, thus limiting suppression of the sleep supporting hormone melatonin. This is sketched by the use case B arrow in Fig. 4A. In this example, the relevant melanopic illumance is at the location of the user (e.g. the location reading page or the eye level of the user).

In another example a user may lower the intensity or colour temperature of a light therapy device because he/she does not find it comfortable and the system will automatically adjust the MEF of the spectrum to keep the melanopic illuminance for the user constant, thus securing effectiveness of the light therapy. This corresponds to use case A in Fig. 4A or Fig. 4B, where the system secures a melanopic flux that results in a melanopic illuminance (at the eye of the user) of 200 melanopic lux.

In a further example a user may select an intensity or CCT of office lighting that normally would moves the melanopic flux outside a desired range for alert office work. The system will then automatically choose a light condition with a light spectrum having the highest possible CRI while maintaining the melanopic flux (or melanopic illuminance) in the desired range, for instance to enhance subjective alertness of users or to support their circadian rhythms. This use case is shown as C in Fig. 5B for a user that uses light with a photopic illuminance of 600 lx and wishes to switch to a warmer, more socializing, colour tone (CCT 6000 to 2300 K). In order to secure the melanopic flux/activation (with a melanopic illuminance at the eye level or task level of the user of least 500 melanopic lux) the system automatically adopts a spectrum corresponding to the solid line with the desired CCT, but with a CRI of 50 instead of the original CRI of 80 of the black dotted line.

In stil another example a bedside light keeps the melanopic illuminance (at the eye level) at a low melanopic lux level to limit suppressing the sleep supporting hormone melatonin when the user chooses a high colour temperature for bedside reading prior to sleep. This is sketched by the use case D arrow in Fig. 5A for a user switching from about 2000 K to about 2500 K at a photopic illluminance of 300 lx. At this illuminance, the system cannot switch to a spectrum that maintains both CRI and secures the low melanopic flux. Therefore it switches to the desired CCT but with a lower CRI (adopting the spectrum of the dashed line).

In an embodiment, the control system may adapt the spectral power distribution depending on the light intensity chosen by the user.

In embodiments, the control system may provide a 24 dynamic lighting rhythm to one or more lighting properties, such as the melanopic lux value.

The discloses system may be applied in backlights in displays or mobile devices that automatically adjust spectrum depending on a time and intensity chosen by the user.

The disclosed method may be applied in a lighting system that automatically adjusts the CCT and intensity range that a user can choose from depending on the time of day or the current melanopic flux or a desired melanopic flux, or a desired melanopic illuminance. The desired melanopic flux need not be constant but can also vary over time. During daytime the melanopic illuminance at the eye level of a user may exceed **400** melanopic lux to secure sufficient subjective alertness (moreover, a high daytime melanopic flux also strengthens the body clock and the circadian rhythm) while at night it is below **40** melanopic lux to prevent sleep disruption.

An example is shown in Fig. 6A. This Figure shows three different spectral power distributions, generated with a plurality of LED primaries. The following values were targeted at:

Target values	Setting A	Setting B	Setting C
target CCT	3000	4000	4000
target MEF	1	1	2
target photopic lux	500	500	250
target melanopic flux	500	500	500

The following values were obtained with the plurality of LED primaries:

Obtained values	Setting A	Setting B	Setting C
CCT	2999	4002	3995
MEF	0,99	1,01	2,00
photopic lux	500,0	499,6	249,9
melanopic lux	496,0	504,6	500,0

It appears that especially at least four different light sources, even more especially at least five different light sources may be used to be able to vary the lighting properties while maintaining the melanopic flux value essentially constant. Fig. 6B shows the spectral power distributions of an embodiment using a combination of LED light sources, wherein the spectral power distributions are normalized to 1 for convenience. The light of the different light sources can be mixed in specific combinations. For the settings A, B and C as indicated below, these spectra were used with the below indicated radiant powers (in units of W/m^2) per LED light source.

LED	Setting A	Setting B	Setting C
green	0.228	0.209	0.005
520 nm	0.009	0.123	0.143
635 nm	0.975	0.746	0.833
420 nm	0.019	0.133	0.019
475 nm	0.332	0.266	0.411

In Fig. 6B curve 1 refers to the LED with indication "green", curve 2 refers to the LED with indication "520 nm", curve 3 refers to the LED with indication "635 nm", curve 4 refers to the LED with indication "420 nm", and curve 5 refers to the LED with indication "475 nm". Good results may be achieved with a lighting device comprising a plurality of (solid state) light sources able to generate light having a spectral distribution in at least the following wavelength ranges a) 410-490 nm, especially 410-435 nm and/or 455-490 nm, b) 505-530 nm, especially 510-530 nm, c) 535-575 nm, especially 535-565 nm, and d) 610-680 nm, especially 620-650 nm. Especially, the (solid state) light sources have peak wavelengths in the indicated wavelength ranges.

The term "substantially" herein, such as in "substantially all light" or in "substantially consists", will be understood by the person skilled in the art. The term "substantially" may also include embodiments with "entirely", "completely", "all", etc. Hence, in embodiments the adjective substantially may also be removed. Where applicable, the term "substantially" 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" includes also embodiments wherein the term "comprises" means "consists of. The term "and/or" especially relates to one or more of the items mentioned before and after "and/or". For instance, a phrase "item 1 and/or item 2" and similar phrases may relate to one or more of item 1 and item 2. The term "comprising" may in an embodiment refer to "consisting of but may in another embodiment also refer to "containing at least the defined species and optionally one or more other species".

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

The devices herein are amongst others 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 in operation.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. Use of the verb "to comprise" and its conjugations does not exclude the presence of elements or steps other than those stated in a claim. Unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise", "comprising", and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense, that is to say, in the sense of "including, but not limited to". The article "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The invention may be implemented by means of hardware comprising several distinct elements, and by means of a suitably programmed computer. In the device 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.

The invention further applies to a device 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 lighting system (1000) comprising:

- a lighting device (100) configured to provide light (101), wherein one or more lighting properties, including a spectral power distribution, of the light (101) are controllable, and

- a control system (200) adapted to provide at least a controlling mode which comprises maintaining a predetermined melanopic flux value of the light (101) while allowing another lighting property of the light (101) to be changed from a first lighting property value to a second lighting property value,

wherein the control system (200) is adapted to maintain the predetermined melanopic flux value of the light (101) while allowing another lighting property of the light (101) to be changed from a first lighting property value to a second lighting property value by changing the spectral power distribution of the light (101).

2. The lighting system (1000) according to claim 1, wherein the light (101) has a first melanopic flux Φ_{mel1} at the first lighting property value and a second melanopic lux Φ_{mel2} at the second lighting property, wherein $0.9 \leq \Phi_{mel1}/\Phi_{mel2} \leq 1.1$.

3. The lighting system (1000) according to any one of the preceding claims, wherein the other lighting property is selected from the group consisting of correlated color temperature, color point and intensity of the light (101).

4. The lighting system (1000) according to any one of the preceding claims, wherein said controlling mode comprises maintaining said predetermined melanopic lux value and maintaining a predetermined intensity level of the light (101) while allowing another lighting property of the light (101) to be changed from a first lighting property value to a second lighting property value.

5. The lighting system (1000) according to any one of the preceding claims, wherein the light has a first luminous flux level Φ_{v1} and first melanopsin effectiveness factor

MEF1 at the first lighting property value and a second luminous flux level Φ_{v2} and second melanopsin effectiveness factor MEF2 at the second lighting property, wherein $0.9 \leq (MEF1*\Phi_{v1})/(MEF2*\Phi_{v2}) \leq 1.1$.

6. The lighting system (1000) according to any one of the preceding claims, wherein the control system (200) is adapted to control the melanopic flux of the light (101) in dependence of a light sensor signal or as function of a time scheme defining the melanopic flux of the light as function of one or more of time, day, week, month and season, wherein a temporary predetermined melanopic flux value is defined by said control system (200) in dependence on the light sensor signal or as a function of the time schedule respectively, and wherein said other controlling mode comprises maintaining said temporary predetermined melanopic flux value while allowing another lighting property of the light (101) to be changed from a first lighting property value to a second lighting property value.

7. The lighting system (1000) according to any one of the preceding claims, wherein the lighting device (100) comprises a plurality of solid state light configured to generate light having peak wavelengths in the wavelength ranges a) 410-490 nm, b) 505-530 nm, c) 535-575 nm, and d) 610-680 nm, respectively.

8. The lighting system (1000) according to any one of the preceding claims, comprising a plurality of lighting devices (100), wherein the control system (200) is adapted to maintain the predetermined melanopic flux value of the light (101) of one or more of said lighting devices (100) while allowing another lighting property of the light (101) of the one or more of said lighting devices (100) to be changed from a first lighting property value to a second lighting property value.

9. An electronic device (2000) comprising a backlighting unit (2100), wherein the electronic device (2000) comprises the lighting system (1000) according to any one of the claims, wherein said backlighting unit (2100) comprises said lighting device (100).

10. The electronic device (2000) according to claim 9, wherein the electronic device (2000) is selected from the group consisting of a display and a mobile device.

11. A method of controlling light (101) wherein one or more lighting properties, including a spectral power distribution, of the light (101) are controllable, the method comprising:

- providing said light (101) with a predetermined melanopic flux value of the light (101),

- maintaining said predetermined melanopic flux value of the light (101) while changing another lighting property of the light (101) from a first lighting property value to a second lighting property value by changing the spectral power distribution of the light (101).

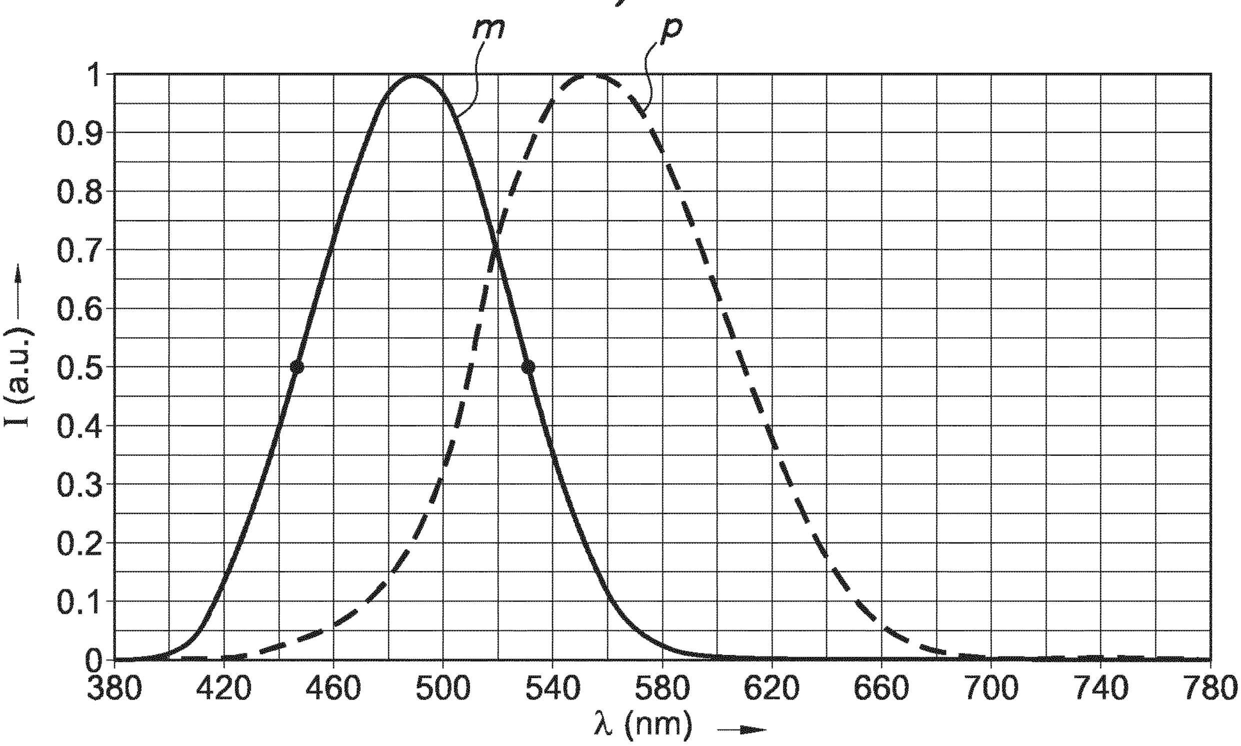
12. The method according to claim 11, wherein the other lighting property is selected from the group consisting of correlated color temperature, color point and intensity of the light (101), wherein the light (101) has a first melanopic flux Φ_{mel1} at the first lighting property value and a second melanopic flux Φ_{mel2} at the second lighting property, wherein the method further comprises maintaining said predetermined melanopic lux value of the light (101) in the range of $0.9 \leq \Phi_{mel1}/\Phi_{mel2} \leq 1.1$ while the other lighting property of the light (101) is changed from said first lighting property value to said second lighting property value.

13. The method according to any one of the preceding claims 11-12, wherein the light (101) has a first luminous flux level Φ_{v1} and first melanopsin effectiveness factor MEF1 at the first lighting property value and a second luminous flux level Φ_{v2} and second melanopsin effectiveness factor MEF2 at the second lighting property, wherein the method further comprises maintaining a melanopic flux in the range of $0.9 \leq (MEF1*\Phi_{v1})/(MEF2*\Phi_{v2}) \leq 1.1$, while changing the other lighting property of the light (101) from said first lighting property value to said second lighting property value.

14. The method according to any one of the preceding claims 11-13, wherein the method comprises controlling the melanopic flux of the light (101) as function of a time scheme defining the melanopic flux of the light as function of one or more of time, day, week, month and season, wherein a temporary predetermined melanopic flux value is defined by said control system (200) based on said time scheme, and wherein the method further comprises maintaining said predetermined melanopic flux value while changing the other

lighting property of the light (101) from said first lighting property value to said second lighting property value.

15. A computer program product, when running on a computer which is functionally coupled to a lighting device (100) for providing light (101) of which a spectral power distribution is controllable, is capable of bringing about the method as described in any one of the preceding claims 11-14.


m
p
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
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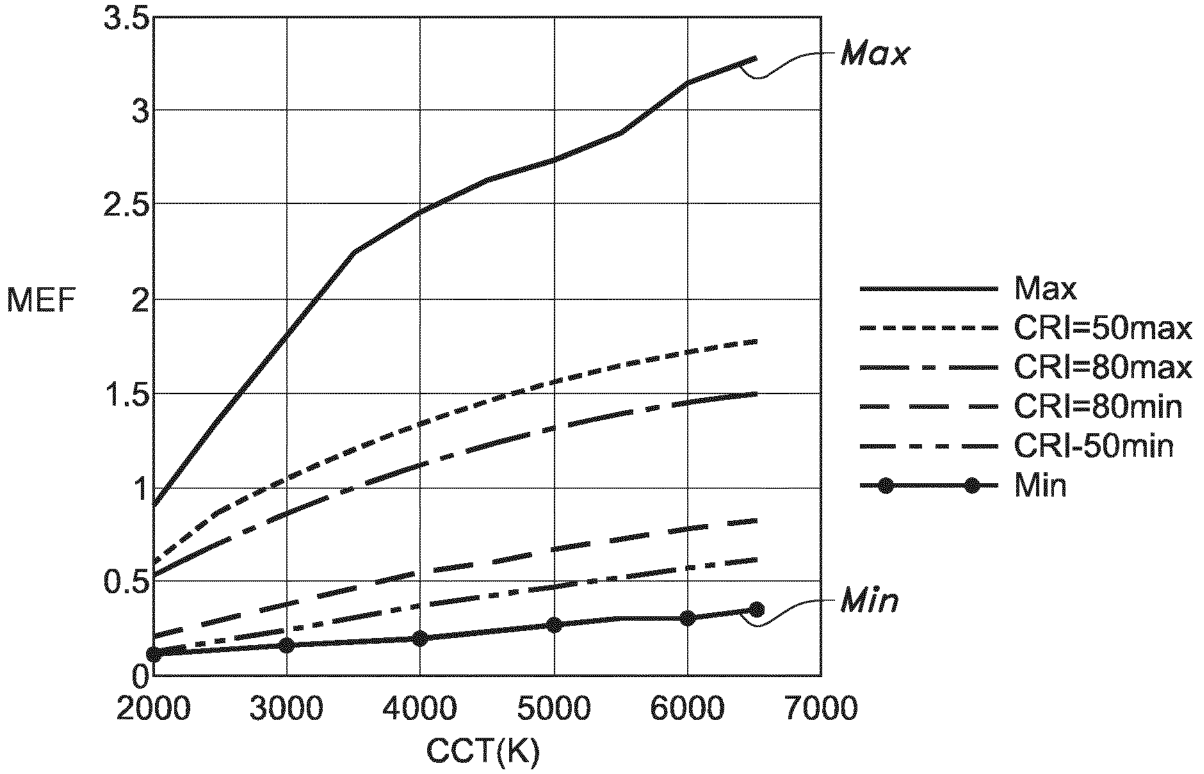
0
I (a.u.)
380
420
460
500
540
580
620
660
700
740
780
λ (nm)

FIG. 1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3
2.5
2
1.5
1
0.5
0
MEF
Max
Min
2000
3000
4000
5000
6000
7000
CCT(K)
Max
CRI=50max
CRI=80max
CRI=80min
CRI-50min
Min

FIG. 2

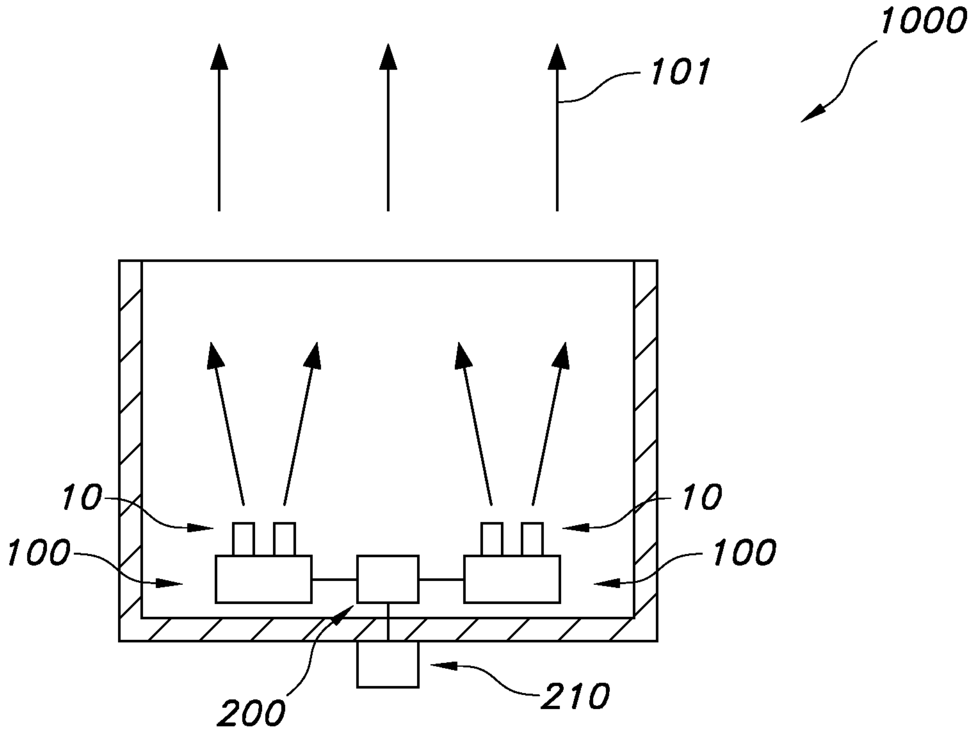

1000
101
10
10
100
100
200
210

FIG. 3A

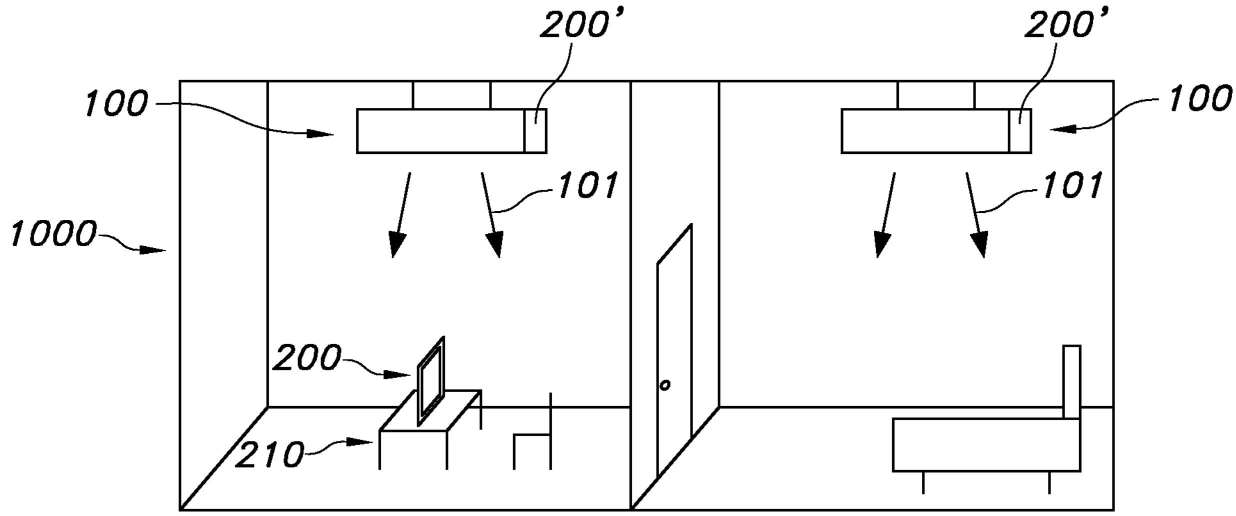

200'
200'
100
100
101
101
1000
200
210

FIG. 3B

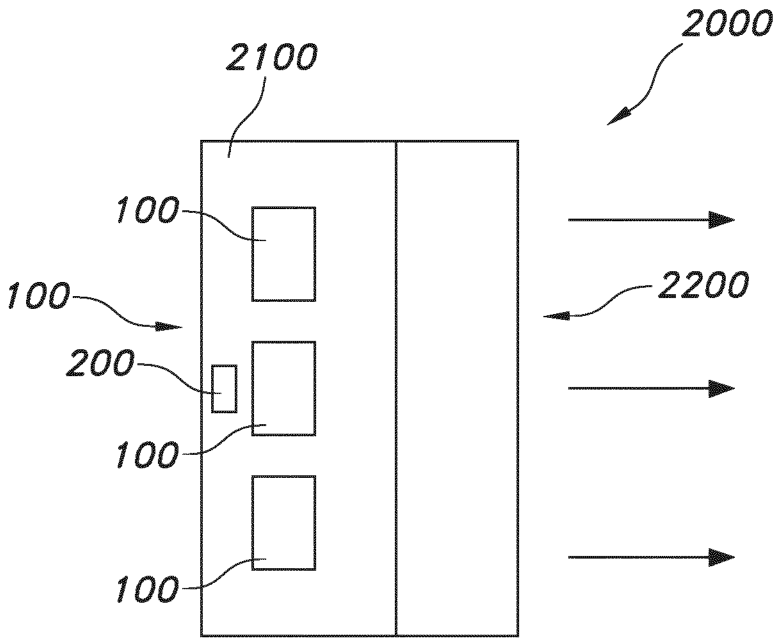
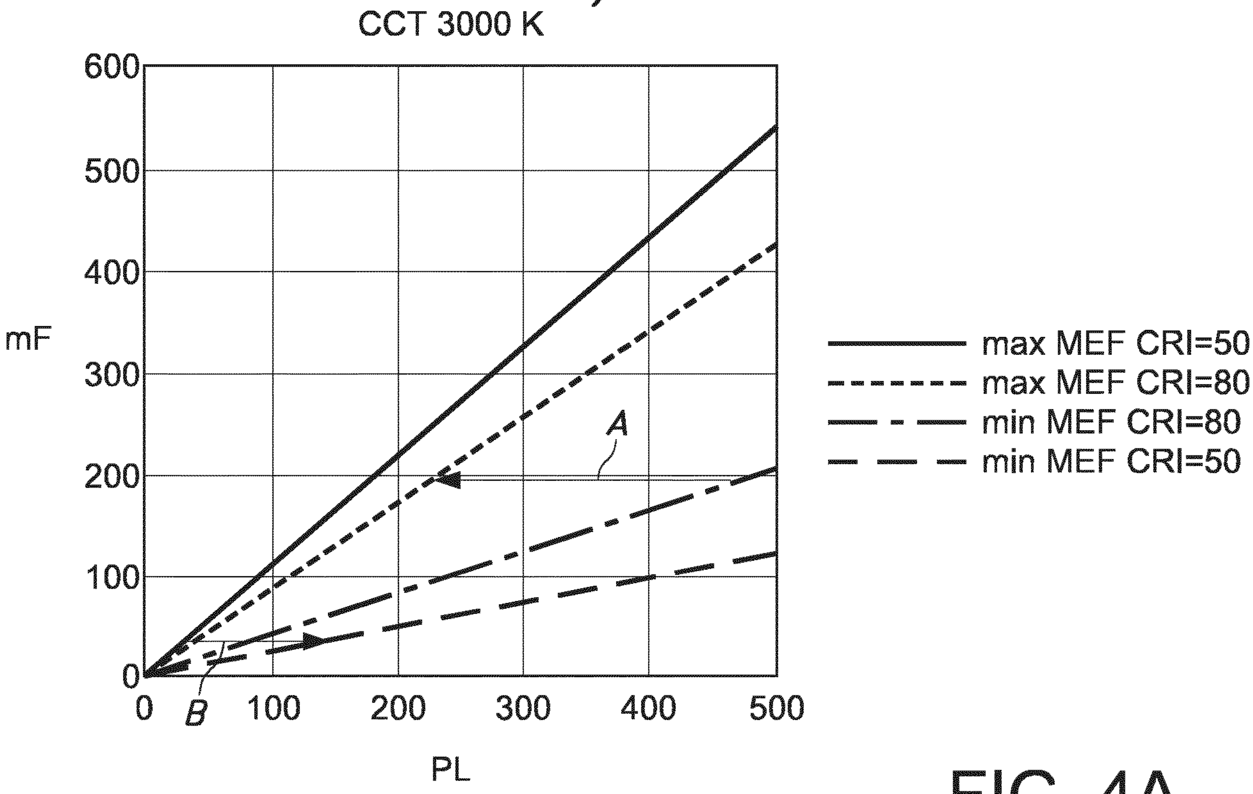


FIG. 3C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600
500
400
300
200
100
0
mF
0
100
200
300
400
500
PL
A
B
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max MEF CRI=80
min MEF CRI=80
min MEF CRI=50

FIG. 4A

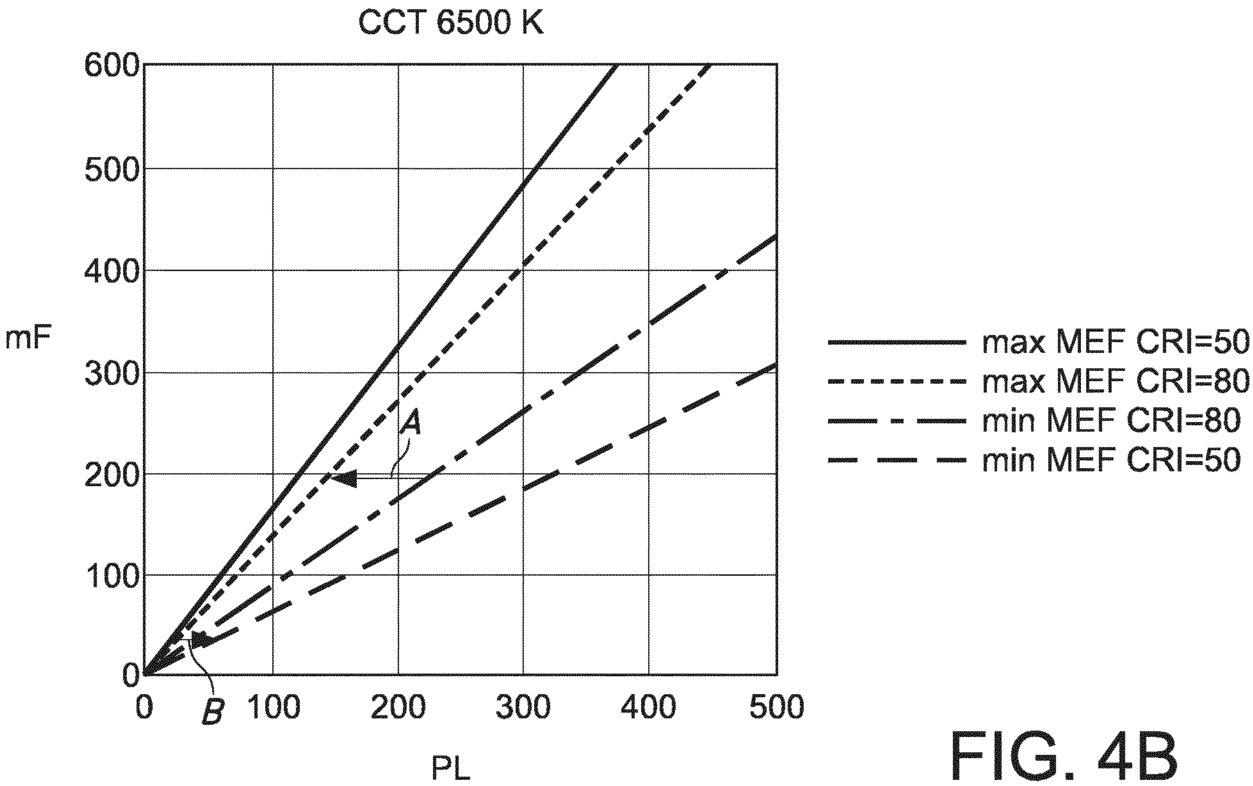

CCT 6500 K
600
500
400
300
200
100
0
mF
0
100
200
300
400
500
PL
A
B
max MEF CRI=50
max MEF CRI=80
min MEF CRI=80
min MEF CRI=50

FIG. 4B

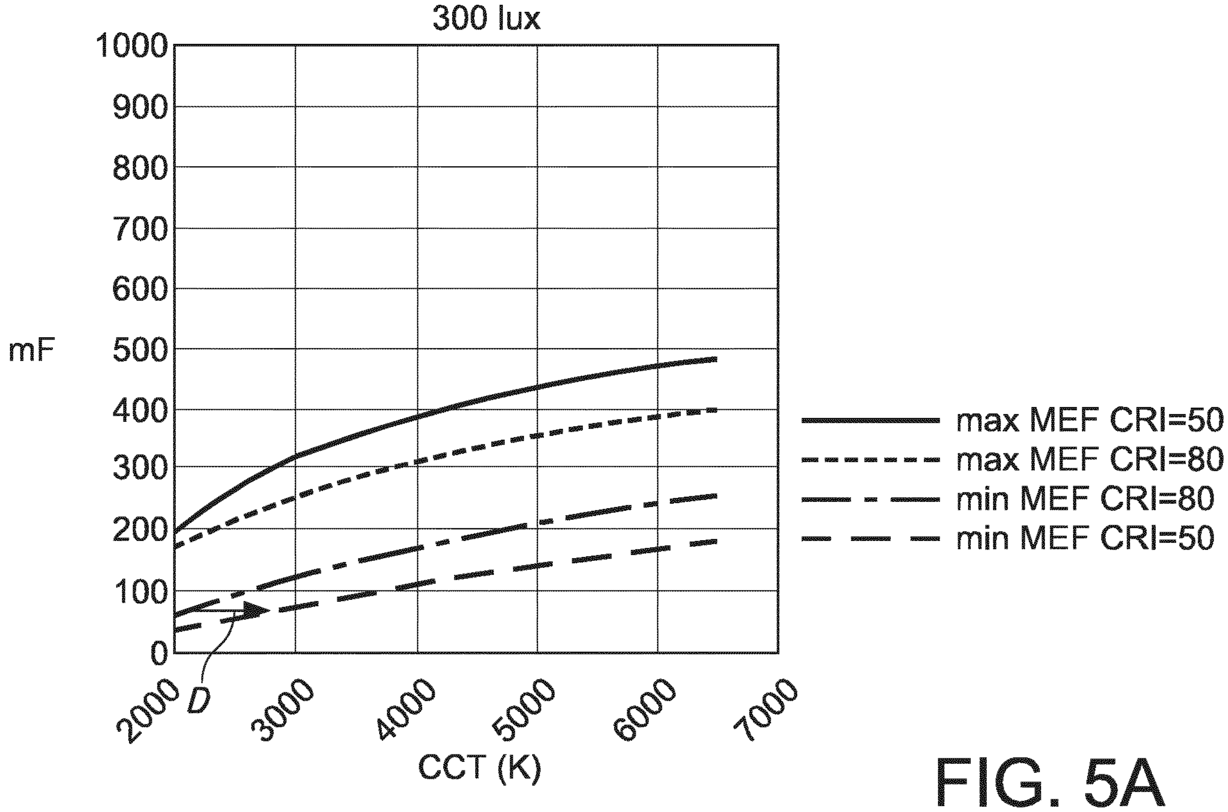

300 lux
mF
1000
900
800
700
600
500
400
300
200
100
0
2000
3000
4000
5000
6000
7000
CCT (K)
D
max MEF CRI=50
max MEF CRI=80
min MEF CRI=80
min MEF CRI=50

FIG. 5A

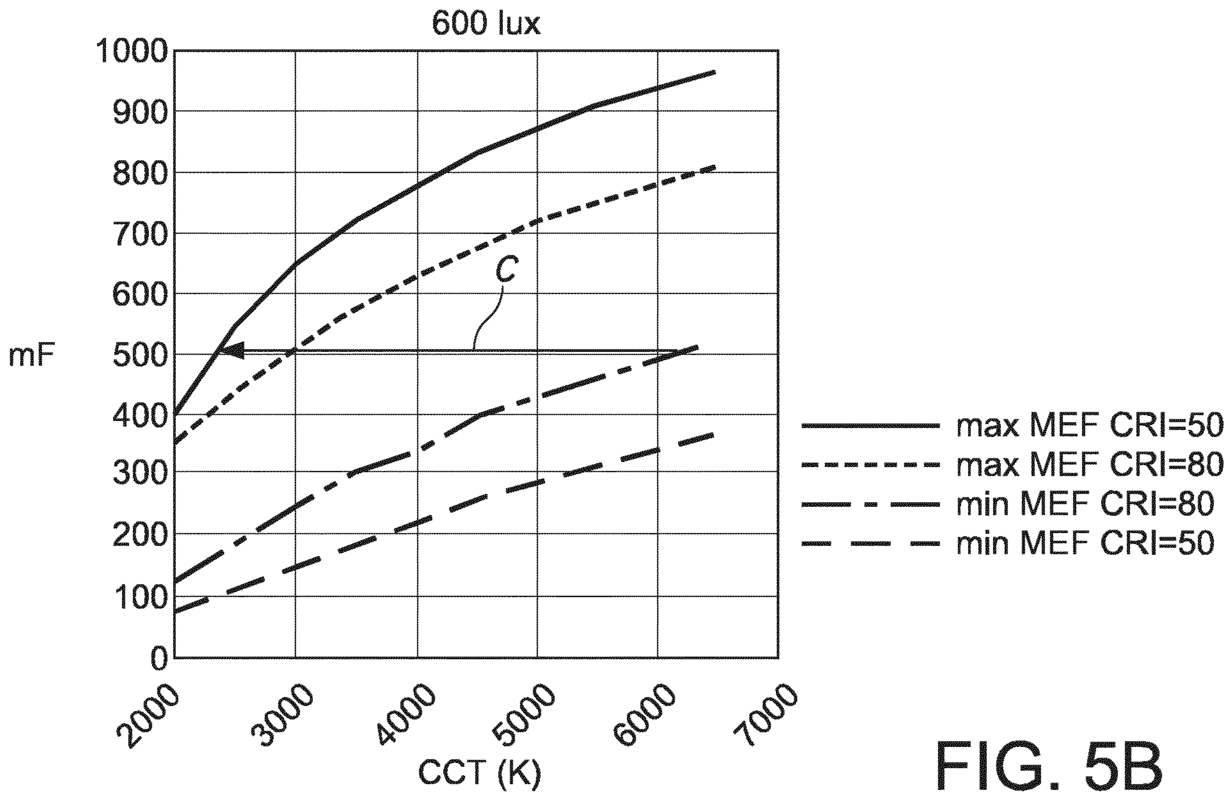
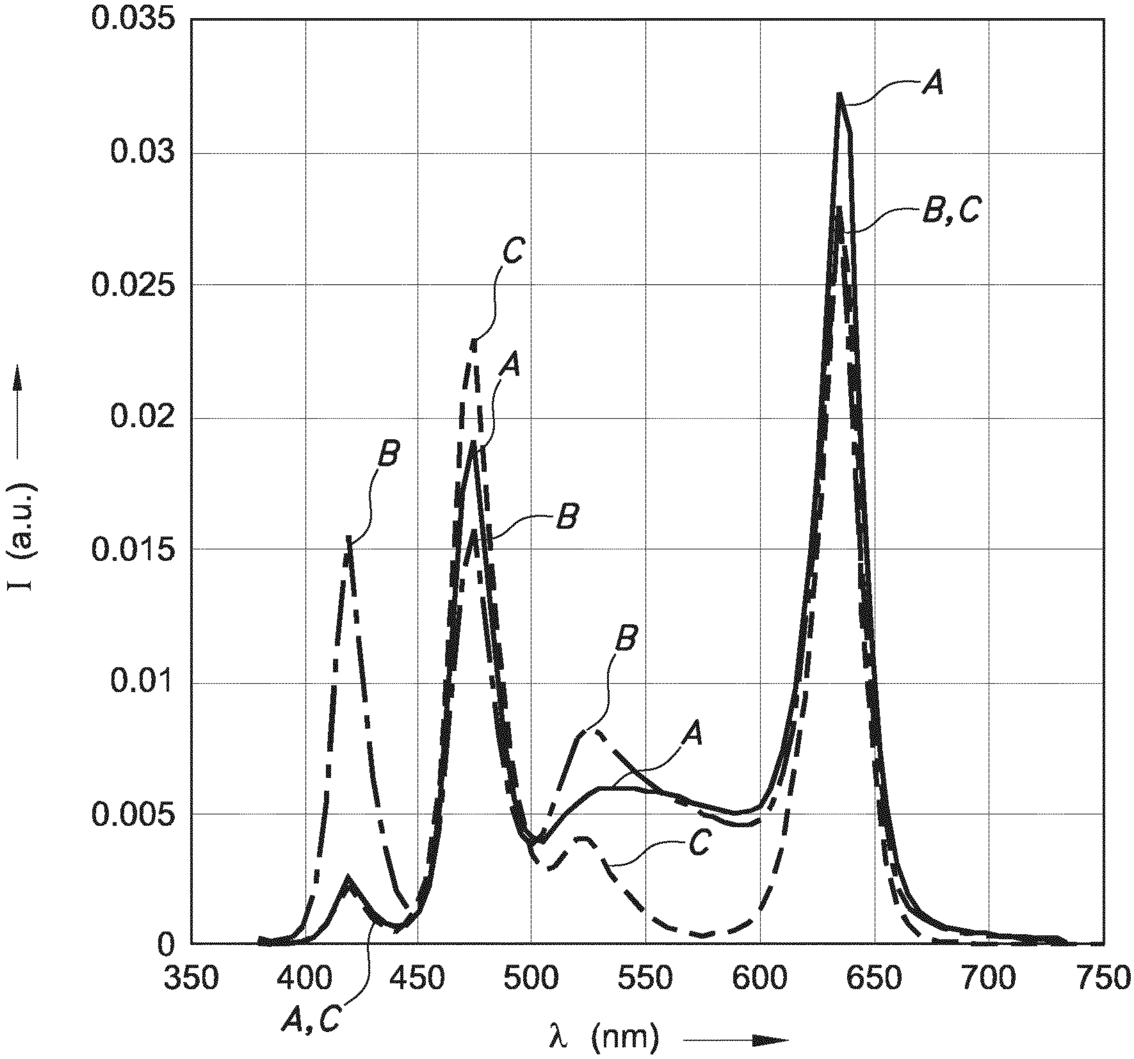

600 lux
mF
1000
900
800
700
600
500
400
300
200
100
0
2000
3000
4000
5000
6000
7000
CCT (K)
C
max MEF CRI=50
max MEF CRI=80
min MEF CRI=80
min MEF CRI=50

FIG. 5B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0.005
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I (a.u.)
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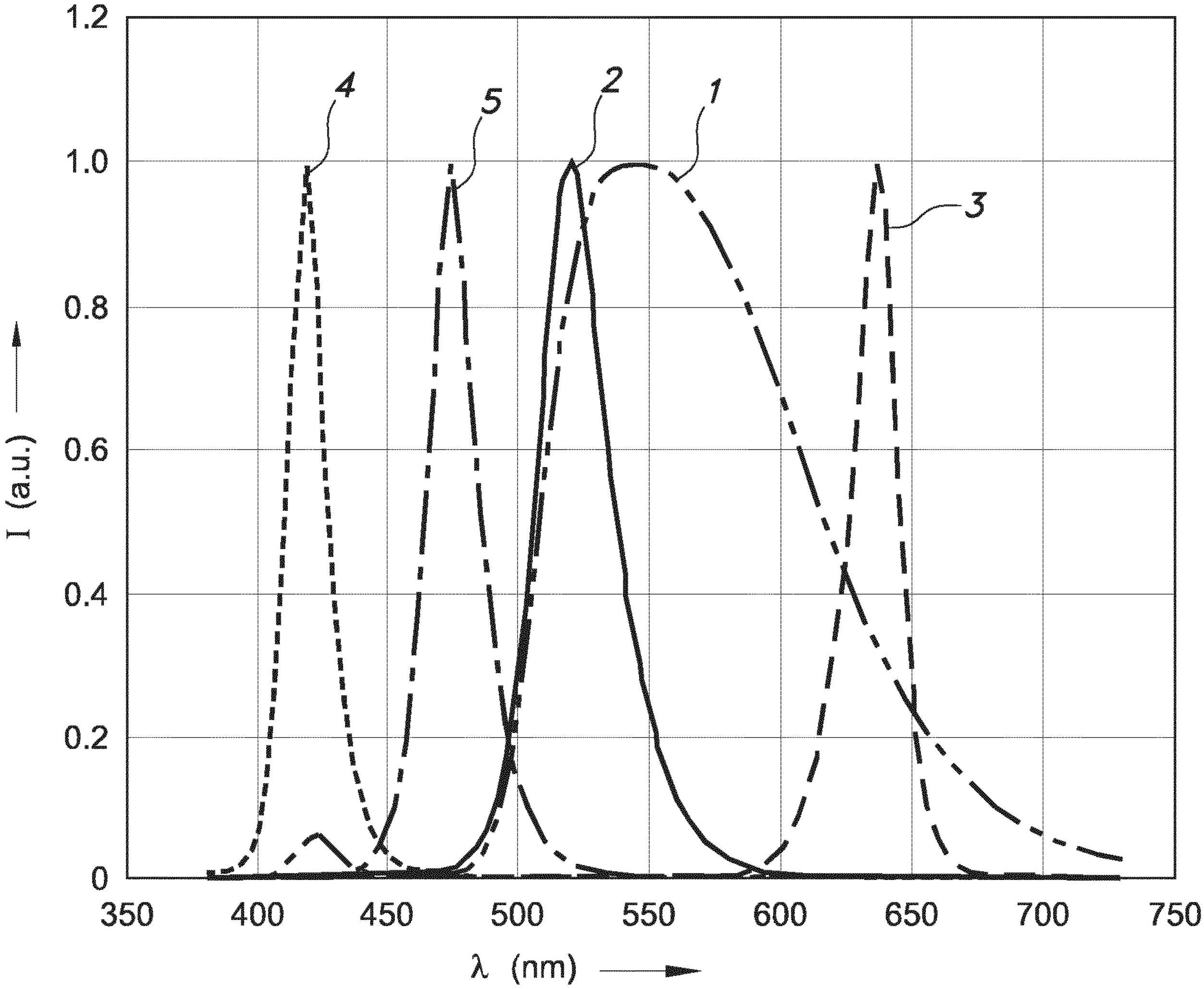
400
450
500
550
600
650
700
750
λ (nm)
A
B,C
C
A
B
B
B
A
C
A,C

FIG. 6A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0.2
0
I (a.u.)
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400
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500
550
600
650
700
750
λ (nm)
4
5
2
1
3

FIG. 6B

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/084188

A. CLASSIFICATION OF SUBJECT MATTER
INV. H05B33/08 H05B37/02
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2008/146219 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]; PHILIPS CORP [US]; ASHDOWN IAN [C) 4 December 2008 (2008-12-04) pages 6-22; figures 3, 4, 6, 7 -----	1-15
X	US 2010/063566 A1 (UCHIUMI TADASHI [JP] ET AL) 11 March 2010 (2010-03-11) pages 2-6; figures 5, 9 -----	1-15
A	US 2012/259392 A1 (FENG XIAO-FAN [US] ET AL) 11 October 2012 (2012-10-11) pages 1-3; figures 3-5 -----	1-15

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

☒ See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 February 2018	09/03/2018

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

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/084188

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		JP W02008069101 Al	18-03-2010
		US 2010063566 Al	11-03-2010
		WO 2008069101 Al	12-06-2008
US 2012259392 Al	11-10-2012	US 2012259392 Al	11-10-2012
		WO 2012137986 Al	11-10-2012