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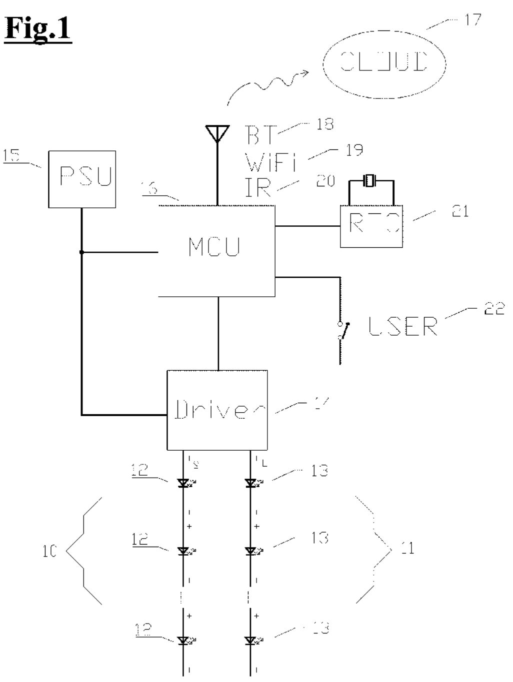
(54) **Title:** LIGHTING DEVICES, LIGHTING SYSTEMS, METHODS AND COMPONENTS

Fig.1



(57) Abstract: A lighting device comprising first and second groups of solid state light emitters. Each first group emitter comprises at least one light source having a peak wavelength in a range of from about 400 nm to about 459 nm and at least one first group luminescent material. Each second group emitter comprises at least one light source having a peak wavelength in a range of from about 460 nm to about 510 nm and at least one second group luminescent material. Upon supplying electricity to the first group of solid state light emitters and to the second group of solid state light emitters, at least some light emitted from the first group of solid state light emitters mixes with at least some light emitted from the second group of solid state light emitters.

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LIGHTING DEVICES, LIGHTING SYSTEMS, METHODS AND COMPONENTS

Field of the Invention

The present invention relates to lighting devices that comprise solid state light emitters, systems that comprise such lighting devices, methods that comprise supplying electricity to solid state light emitters in a lighting device, and components for such lighting devices and lighting systems.

Background

As ASHRAE guidelines stated (ASHRAE, 2010), since people spend about 80 to 90 percent of their time indoors, and studies have indicated that a range of comfort and health related effects are linked to characteristics of buildings, there has been a growth in interest in both academic and practitioner literature on occupant health and building design.

Research indicates that the relationship between indoor environmental quality (IEQ) and well-being is complicated. A range of indoor factors such as thermal, visual, acoustic, and chemical can impact the well-being of the occupants (Apte et al., 2000, Jantunen et al., 1998, WHO, 2002).

Brief Summary of the Invention

This section (i.e., "Brief Summary of the Invention") presents a simplified summary of the invention in order to provide a basic understanding of some aspects of the invention. This summary is not an extensive overview of the invention. It is not intended to identify key/critical elements of the invention or to delineate the scope of the invention. Its purpose is to present some concepts of the invention in a simplified form as a prelude to the more detailed description that is presented later.

Visual comfort is very important for the well-being and productivity of occupants inside buildings (Leech et al., 2002, Serghides et al., 2015). Several past studies have analyzed the effects of visual comfort on occupant work performance, productivity, comfort and satisfaction (Veitch, 2001). Visual comfort defines lighting conditions and the views from one's workspace.

Insufficient light and especially daylight or glare reduces the ability of occupants to see objects or details clearly (Leech et al., 2002). Architectural design has a direct impact on office lighting and office lighting has a direct impact on well-being and productivity. The access to natural lighting as well as artificial lighting is essential in order to ensure the well-being of occupants in areas where natural lighting is missing or during evening when the natural lighting fades (Aries et al., 2010).

Visual comfort at work has an impact on comfort after work as well (Chang and Chen, 2005). There are studies that have looked at the impact of visual comfort on sleep quality at home after work. These studies have documented differences in impacts by gender, age, and seasons on the overall discomfort levels and impacts on health (Serghides et al., 2015). Several visual comfort criteria such as view type, view quality and social density have an impact on the physical and psychological health of the occupants (Chang and Chen, 2005).

Visual comfort plays such a vital role in the overall productivity, comfort and well-being of occupants that buildings need to avoid excessive use of artificial lighting yet still maintain some level of optimality (Yun et al., 2012). Studying daylight, artificial lighting, glare and visual comfort together provides a more holistic picture (Van Den Wymelenberg and Inanici, 2014, Huang et al., 2012).

The light spectrum of indoor artificial lighting differs significantly from natural sunlight. Sunlight contains some important wavelengths that affect the human body significantly. In addition, the sunlight spectrum is constantly varying from sunrise to sunset, and this variety affects human moods significantly.

Melanopsin is one of a group of light-sensitive retinal proteins found in mammals. In humans, melanopsin is found in intrinsically photosensitive retinal ganglion cells (ipRGCs). ipRGCs are photoreceptor cells that are particularly sensitive to the absorption of light within a particular wavelength range of blue visible light, and they communicate information directly to the brain, in particular, to the suprachiasmatic nucleus (SCN) of the brain, also known as the central "body clock", in mammals. At different times of the day, clock genes in the SCN send signals to regulate activity throughout the body.

Melanopsin-containing ganglion cells, like rods and cones, exhibit both light and dark adaptation; they adjust their sensitivity according to the recent history of light exposure. While rods and cones are responsible for the reception of images (as well as patterns, motion, and color), melanopsin-containing ipRGCs contribute to various reflexive responses of the brain and body to the presence of light.

Upon sunlight entering a human eye, some of the light (i.e., light of wavelengths for which absorption by melanopsin is high) activates the melanopsin contained in intrinsically photosensitive retinal ganglion cells (ipRGCs), triggering an action potential. These neuronal electrical signals travel through neuronal axons to specific brain targets. Stimulation by light of melanopsin in ipRGCs mediates behavioral and physiological responses, including inhibition of melatonin release from the pineal gland (as well as other responses, e.g., pupil constriction). Melanopsin thus plays an important non-image-forming role in the setting of circadian rhythms as well as other functions.

The expression “melanopsin activation” (or “activating” or “activate”) relates to suppression of melatonin (i.e., a greater extent of melanopsin activation results in greater suppression of melatonin, and thus a greater degree of alertness).

A representative example of a daily schedule for a human comprises deepest sleep at 2 am, lowest body temperature at 4:30 am, sharpest blood pressure rise at 6:45 am, melatonin secretion stops at 7:30 am, bowel movement at 8:30 am, highest testosterone secretion at 9 am, highest alertness at 10 am, best coordination at 2:30 pm, fastest reaction time at 3:30 pm, greatest cardiovascular efficiency and muscle strength at 5 pm, highest blood pressure at 6:30 pm, highest body temperature at 7 pm, melatonin secretion starts at 9 pm, and bowel movements suppressed at 10:30 pm.

Maintaining the human circadian cycle is important for health. The human circadian cycle is modulated by the amount of light and spectral content of the light incident on the melanopsin sensitive receptors in the eye. The peak wavelength of the melanoptic sensitivity range is around 500nm and sufficient amounts of these wavelengths suppress melatonin and keep humans awake and alert.

In an aspect of the present invention, there is provided a lighting device that comprises two blue light emitters whose peak wavelengths differ, the first blue emission being substantially outside the melanoptic range, and the second being within the melanoptic range.

For example, some embodiments in accordance with the present invention comprise blue LEDs (i.e., LEDs that emit blue light), in which the emitters are both coated with lumiphores, typically phosphors excitable by blue light, well known in the field. The phosphors are excited by the blue lights, substantially similar to well known white PC LEDs. The phosphor are chosen to emit longer wavelengths of light then blue, including a combinations of all or some of red, yellow and green wavelengths. Some blue light passes through the lumiphore, and the resultant output light is a mixture of the leaked blue excitation light and the phosphor's light emissions, and is generally whiteish and unsaturated in color; generally acceptable for general illumination or backlighting.

The present invention, in some aspects, allows for selection and control of the spectral content of the mixed light. In some embodiments, the device's light sources excite a phosphor (or phosphors) with a variable amount of at least one of two types of light, namely, a shorter wavelength (outside the melanoptic range, i.e., shorter than the melanoptic range) light source (e.g., a shorter wavelength blue light source, such as about 450 nm) and a longer wavelength light source (in the melanoptic range)(e.g., a longer wavelength blue light source, such as about 480 nm), and produce substantially white light suitable for illumination. White light produced and emitted by the emitter with the longer wavelength blue light source will suppress melatonin and keep humans alert, and white light emitted by the emitter with the shorter wavelength blue light source will not activate the melatonin suppression and will allow humans to sleep (and/or be less alert). In some aspects, the present invention provides lighting devices with which selection and control of melatonin suppression can be achieved, while also achieving surprisingly high CRI Ra and/or wall plug efficiency.

The different blue light sources can be used individually or in combination. The intensity of the emitters can be controlled and varied by many well known means including PWM, current and/or voltage regulation; and with well known electronic systems can be user-controlled locally or under remote control; or even automatically with the use of a timer. The lighting device can be powered by any electrical power source of sufficient capacity and appropriate voltages such as battery or power supply.

In accordance with some aspects of the present invention, there is provided a comprehensive true circadian lighting system that simulates specific aspects of sunlight with multiple wavelengths of visible light.

The lighting devices and methods in accordance with the present invention can deliver the right melanopic to photopic ratio (i.e., the "M/P ratio") at the right time of day, to help avoid circadian disruption, thereby avoiding (or ameliorating) poor sleep and risk of serious illnesses such as cancer, heart disease and delirium.

In accordance with a first aspect of the present invention, there is provided a lighting device comprising:

a first group of solid state light emitters; and

a second group of solid state light emitters,

wherein:

the first group of solid state light emitters comprises at least one first group solid state light emitter,

each first group solid state light emitter comprises at least one first group solid state light source and at least one first group luminescent material,

each first group solid state light source, when supplied with electricity, emits light having a peak wavelength in a range of from about 400 nm to about 459 nm,

the second group of solid state light emitters comprises at least one second group solid state light emitter,

each second group solid state light emitter comprises at least one second group solid state light source and at least one second group luminescent material,

each second group solid state light source, when supplied with electricity, emits light having a peak wavelength in a range of from about 460 nm to about 510 nm, and

upon supplying electricity to the first group of solid state light emitters and to the second group of solid state light emitters, at least some light emitted from the first group of solid state light emitters mixes with at least some light emitted from the second group of solid state light emitters.

In some embodiments in accordance with the present invention, which can include or not include, as suitable, any of the other features described herein:

upon supplying electricity to the first group of solid state light emitters, the first group of solid state light emitters emits light of a first correlated color temperature (CCT),

upon supplying electricity to the second group of solid state light emitters, the second group of solid state light emitters emits light of a second CCT,

the first CCT is less than the second CCT. In such embodiments, by adjusting the current and/or voltage supplied to the respective first and second groups of solid state light emitters, the M/P and the CCT can be adjusted (lower CCT (warm white) with low M/P; and higher CCT (cool white) with higher M/P). Calculation of M/P values is well known in the art, e.g., as described in the WELL Building Standard v2 Q2 (2019), the disclosure of M/P value calculation hereby being incorporated herein by reference.

In some embodiments in accordance with the present invention, which can include or not include, as suitable, any of the other features described herein:

upon supplying electricity to the first group of solid state light emitters, the first group of solid state light emitters emits light of a CCT in a range of from about 2500K to about 3000K; and

upon supplying electricity to the second group of solid state light emitters, the second group of solid state light emitters emits light of a CCT in a range of from about 4000K to about 7500K.

In some embodiments in accordance with the present invention, which can include or not include, as suitable, any of the other features described herein:

upon supplying electricity to the first group of solid state light emitters, the first group of solid state light emitters emits light of a CCT of about 2700K; and

upon supplying electricity to the second group of solid state light emitters, the second group of solid state light emitters emits light of a CCT of about 5000K.

In some embodiments in accordance with the present invention, which can include or not include, as suitable, any of the other features described herein:

upon supplying electricity to the first group of solid state light emitters, the first group of solid state light emitters emits light of a first CCT, upon supplying electricity to the second group of solid state light emitters, the second group of solid state light emitters emits light of a second CCT, and

the first CCT is substantially the same as the second CCT, e.g., an absolute value of the first CCT minus the second CCT is less than 4 percent of the first CCT (in some embodiments, less than 1 percent of the first CCT).

In such embodiments, by adjusting the current and/or voltage supplied to the respective first and second groups of solid state light emitters, the M/P can be adjusted while the CCT is kept substantially constant.

In some embodiments in accordance with the present invention, which can include or not include, as suitable, any of the other features described herein:

upon supplying electricity to the first group of solid state light emitters, the first group of solid state light emitters emits light of a CCT in a range of from about 3500K to about 4500K (in some embodiments, about 4000K), and

upon supplying electricity to the second group of solid state light emitters, the second group of solid state light emitters emits light of a CCT in the range of from about 3500K to about 4500K (in some embodiments, about 4000K).

In some of such embodiments, the first CCT is substantially the same as the second CCT, e.g., an absolute value of the first CCT minus the second CCT is less than 4 percent of the first CCT (in some embodiments, less than 1 percent of the first CCT).

In some embodiments in accordance with the present invention, which can include or not include, as suitable, any of the other features described herein:

the at least one first group luminescent material comprises a first luminescent material, and

the at least one second group luminescent material comprises said first luminescent material, e.g., the first group luminescent material is the same as the second group luminescent material (or the first group luminescent material is a particular mixture of luminescent materials and the second group luminescent material is the same mixture of luminescent materials).

In some of such embodiments:

-[1] the at least one first group luminescent material consists essentially of the first luminescent material, and the at least one second group luminescent material consists essentially of the first luminescent material, or [2] the at least one first group luminescent material consists essentially of a first mixture of luminescent materials, and the at least one second group luminescent material consists essentially of said first mixture of luminescent materials, and/or

-upon supplying electricity to the first group of solid state light emitters, the first group of solid state light emitters emits light of a CCT in a range of from about 2500K to about 3000K (in some embodiments, about 2750K), and upon supplying electricity to the second group of solid state light emitters, the second group of solid state light emitters emits light of a CCT in a range of from about 3500K to about 4500K (in some embodiments, about 4100K).

In embodiments in which the first group luminescent material is the same as the second group luminescent material (or the first group luminescent material is a particular mixture of luminescent materials and the second group luminescent material is the same mixture of luminescent materials), by adjusting the current and/or voltage supplied to the respective first and second groups of solid state light emitters, the M/P and the CCT can be adjusted (lower CCT (warm white) with low M/P; and higher CCT (cool white) with higher M/P).

In some embodiments in accordance with the present invention, which can include or not include, as suitable, any of the other features described herein:

the first group of solid state light emitters is on a first string of solid state light emitters connected in series,

the second group of solid state light emitters is on a second string of solid state light emitters connected in series, and

the first string of solid state light emitters and the second string of solid state light emitters are electrically connected in parallel.

In some embodiments in accordance with the present invention, which can include or not include, as suitable, any of the other features described herein:

the lighting device comprises an encapsulant, and

at least one of the first group of light solid state emitters and the second group of solid state light emitters is embedded in the encapsulant.

In some embodiments, using only two channels, two types of blue light allow illumination with different circadian characteristics, simple control with two channels, and a substantially continuous range of melatonin suppression at similar CCT or variable CCT if desired.

In some embodiments, the lighting device can further comprise at least a third group of solid state light emitters, whereby CCT and M/P can each be adjusted to some degree independently. For example, an embodiment can comprise:

a first group of solid state light emitters that emit light having a CCT of 2700K and a M/P of 0.8;

a second group of solid state light emitters that emit light having a CCT of 2700K and a M/P of 0.4;

a third group of solid state light emitters that emit light having a CCT of 4000K and a M/P of 1.3; and

a fourth group of solid state light emitters that emit light having a CCT of 2700K and a M/P of 0.8. By adjusting ratios of luminous flux from the four groups of solid state light emitters, the CCT and M/P can be adjusted to some degree independently.

In some embodiments of methods in accordance with the present invention:

the lighting device comprises a plurality of lighting device settings,

the method further comprises adjusting current and/or voltage supplied to at least one solid state light emitter in the lighting device, and

said adjusting current and/or voltage supplied to at least one solid state light emitter selected from among the first group of solid state light emitters and the second group of solid state light emitters is performed automatically by the lighting device in response to changes selected from among changes in lighting device settings, and changes in a local time of day.
In some of such embodiments, at least some of the lighting device settings are intended degrees of melanopsin activation.

The invention may be more fully understood with reference to the accompanying drawings and the following detailed description of the invention.

Brief Description of the Drawing Figures

Fig. 1 schematically depicts an arrangement that comprises first and second strings of solid state light emitters, a driver, a power supply unit, and a microprocessor configured to receive signals from the cloud, from bluetooth® devices, from wifi, from infrared transmitters, from a clock and/or from a user-actuated controller.

Fig. 2 schematically depicts a lighting device 20 in accordance with the present invention.

Fig. 3 schematically depicts a lighting device 30 in accordance with the present invention.

Fig 4 schematically depicts a lighting device 40 in accordance with the present invention.

Fig 5 schematically depicts a lighting device 50 in accordance with the present invention.

Fig 6 schematically depicts a lighting device 60 in accordance with the present invention.

Fig. 7 is a schematic diagram showing a plurality of first group light emitters 71 electrically arranged in series, and a plurality of second group light emitters 72 arranged in series, with the series of first group light emitters 71 electrically arranged parallel with the series of second group light emitters 72.

Figs. 8-13 schematically depict representative examples in accordance with the present invention, of combinations of electronic components that are configured to enable the current and/or voltage supplied to respective individual strings to be controlled.

Fig. 14 shows an SPD plot (power vs. wavelength) for a first group solid state light emitters, a second group solid state light emitters, and a 60:40 mixture of light from the first and second groups of solid state light emitters.

Fig. 15 shows an SPD plot (power vs. wavelength) for a first group solid state light emitters, a second group solid state light emitters, and a 67:33 mixture of light from the first and second groups of solid state light emitters.

Fig. 16 shows an SPD plot (power vs. wavelength) for a first group solid state light emitters, a second group solid state light emitters, and a mixture of light from the first and second groups of solid state light emitters.

Fig. 17 is a plot of the excitation spectrum of a red phosphor material (CaAlSiN3:Eu), and Fig. 18 is a plot of the emission spectrum of that red phosphor material.

Fig. 19 is a plot of the excitation spectrum of a yellow phosphor material (YAG (cerium-doped yttrium aluminum garnet, also known as YAG:Ce), and Fig. 20 is a plot of the emission spectrum of that yellow phosphor material.

Fig. 21 is a plot of the excitation spectrum of a green phosphor material (LuAG (lutetium aluminum, also known as LuAG:Ce), and Fig. 22 is a plot of the emission spectrum of that green phosphor material.

Detailed Description of the Invention

The expression "comprises" or "comprising," as used herein, is used in accordance with its well known usage, and means that the item that "comprises" the recited elements (or that is "comprising" the recited elements) includes at least the recited elements, and can optionally include any additional elements. For example, an item that "comprises a power line" includes at least one power line, i.e., it can include a single power line or a plurality of power lines (and it can additionally include any other components).

Where an expression is defined herein in terms of the meaning of the expression in the singular, the definition applies also to the plural (and vice-versa, i.e., for an expression defined herein in the plural, the definition applies also to the singular). Definitions of one form of an expression apply to the same expression in a different form of the word or words.

The term "plurality," as used herein, means two or more, i.e., it encompasses two, three, four, five, etc.

The present invention encompasses many combinations of elements and features. The expression "In some embodiments in accordance with the present invention, which can include or not include, as suitable, any of the other features described herein," or the like, is used in the present specification to introduce elements and/or features of the present invention that can be included or not included in any particular embodiment, i.e., elements and/or features that are not mutually exclusive can be combined in any suitable way. In other words, the present invention encompasses any and all combinations of elements and/or features that are introduced with the expression "In some embodiments in accordance with the present invention, which can include or not include, as suitable, any of the other features described herein," or the like (and that are not mutually exclusive).

The expression "light" is used herein in accordance with common usage to refer to electromagnetic radiation of any wavelength or any combination of wavelengths, and to refer to one or more photon. Accordingly, the expression "light," as used herein, can refer to visible light or to non-visible light (e.g., visible light, UV light and/or infrared light). The expression "light," as used herein, can refer to a single photon of a single wavelength, or it can refer to a plurality of photons that may be of the same wavelength, or one or more photons of each of two or more wavelengths.

The expression "accounts for," as used herein (e.g., in the expression "a sum of light emitted from the first and second groups of solid state light emitters accounts for at least 80% of light emitted from the lighting device") means that the light emitted from the lighting device comprises at least the specified percentage of the specified light among the entirety of light emitted from the device.

The term "ratio", as used herein (e.g., in the expression "a first ratio equal to a quantity of first group solid state light emitters on the first string divided by a quantity of second group solid state light emitters on the first string") does not require that both of the quantities are necessarily non-zero, i.e., the expression encompasses situations in which the ratio is zero (e.g., where the quantity of first group solid state light emitters on the first string is zero) and in which the ratio is infinity (e.g., where the quantity of second group solid state light emitters on the first string is zero).

The expression "shorter wavelength light source" is used herein to refer to a light source that emits light outside the melanoptic range (i.e., of wavelength lower than the melanoptic range).

The expression "longer wavelength light source" is used herein to refer to a light source that emits light within the melanoptic range.

The expression "substantially white light" is used herein to refer to light that is perceived by the human eye as being white or near-white.

General illumination devices are typically rated in terms of their color reproduction. Color reproduction is typically measured using the Color Rendering Index (CRI Ra). CRI Ra is a modified average of the relative measurements of how the color rendition of an illumination system compares to that of a reference radiator when illuminating eight reference colors, i.e., it is a relative measure of the shift in surface color of an object when lit by a particular lamp. The CRI Ra equals 100 if the color coordinates of a set of test colors being illuminated by the illumination system are the same as the coordinates of the same test colors being irradiated by the reference radiator.

Daylight has a high CRI (Ra of approximately 100), with incandescent bulbs also being relatively close (Ra greater than 95), and fluorescent lighting being less accurate (typical Ra of 70-80). Certain types of specialized lighting have very low CRI (e.g., mercury vapor or sodium lamps have Ra as low as about 40 or even lower). Sodium lights are used, e.g., to light highways – driver response time, however, significantly decreases with lower CRI Ra values (for any given brightness, legibility decreases with lower CRI Ra).

The expression "correlated color temperature" (also, "CCT") is used according to its well-known meaning to refer to the temperature of a blackbody that is, in a well-defined sense (i.e., can be readily and precisely determined by those skilled in the art), nearest in color.

The expression "receive, generate and/or communicate commands or signals" refers to a single transmission or any number of transmissions. For example, a command can be sent in a single transmission, or it can be broken into pieces (e.g., packets) and sent in a plurality of transmissions to convey the entire item of information. A component can receive a signal from another component via a third component (e.g., where a first component sends a signal to a second component, and the second component sends the signal to a third component, the signal received by the third component can be characterized as an incoming signal from the first component, and/or as an incoming signal from the second component. Similarly, a component can send a signal to another component via a third component (e.g., where a first component sends a signal to a second component, and the second component sends the signal to a third component, the signal sent by the first component can be characterized as an outgoing signal from the first component (or an outgoing signal from the first component to the second component, or an outgoing signal from the first component to the third component).

The expression "wall plug efficiency", as used herein, is measured in lumens per watt (LPW), and means the lumens exiting a lighting device (resulting from supplying energy to the lighting device, i.e., not including light generated from any other source of energy, e.g., it would not include any electromagnetic radiation generated from the presence of any radioactive material, any phosphorescence resulting from previously supplied energy, etc.), divided by the quantity of energy supplied to the lighting device to create the light, as opposed to values for individual components and/or assemblies of components. Accordingly, wall plug efficiency, as used herein, accounts for all losses, including, among others, any quantum losses, i.e., losses generated in converting line voltage into electricity supplied to light emitters, the ratio of the number of photons emitted by luminescent material(s) divided by the number of photons absorbed by the luminescent material(s), any Stokes losses, i.e., losses due to the change in frequency involved in the absorption of light and the re-emission of visible light (e.g., by luminescent material(s)), and any optical losses involved in the light emitted by a component of the lighting device actually exiting the lighting device. In some embodiments, the lighting devices in accordance with the present invention provide the wall plug efficiencies specified herein when they are supplied with AC power (i.e., where the AC power is converted to DC power before being supplied to some or all components, the lighting device also experiences losses from such conversion), e.g., AC line voltage. The expression "line voltage" is used in accordance with its well known usage to refer to electricity supplied by an energy source, e.g., electricity supplied from a grid (e.g., to a wall plug), including AC and DC.

The expression "peak wavelength" (peak λ), is used herein according to its well-known and accepted meaning to refer to the spectral line with the greatest power in the spectral power distribution of a light emitter (or light emitters). Because the human eye does not perceive all wavelengths equally (it perceives yellow and green better than red and blue), and because the light emitted by many solid state light emitters (e.g., LEDs) is actually a range of wavelengths, the color perceived (i.e., the dominant wavelength) is not necessarily equal to (and often differs from) the wavelength with the highest spectral power (peak wavelength).

The expression "dominant wavelength" (dominant λ), is used herein according to its well-known and accepted meaning to refer to the perceived color of a spectrum, i.e., the single wavelength of light which produces a color sensation most similar to the color sensation perceived from viewing light emitted by the light emitter(s) (i.e., it is roughly akin to "hue").

The expression "electrically connected in series" is used herein in accordance with its well known meaning, i.e., to mean that electrons pass sequentially through the components that are electrically connected in series.

The expression "electrically connected in parallel" is used herein in accordance with its well known meaning, i.e., to mean that each electron passes through only one of the paths that are electrically connected in parallel.

A truly monochromatic light – such as a laser – has a dominant wavelength which is the same as its peak wavelength.

The term "string", as used herein, means that at least two solid state light emitters are electrically connected in series

As noted above, in some aspects of the present invention, there are provided lighting devices that comprise a first group of solid state light emitters and a second group of solid state light emitters, wherein:

each first group solid state light emitter comprises at least one first group solid state light source and at least one first group luminescent material, and

each second group solid state light emitter comprises at least one second group solid state light source and at least one second group luminescent material.

People of skill in the art are familiar with, and have ready access to, a wide variety of solid state light sources, and any suitable solid state light source (or solid state light sources) can be employed in the lighting devices according to the present invention. Representative examples of solid state light sources include light emitting diodes (inorganic or organic, including polymer light emitting diodes (PLEDs)), as well as combinations (e.g., comprising two or more light emitting diodes).

Representative specific examples of light emitting diodes that can be used in lighting devices in accordance with the present invention include InGaN (blue light emitters and green light emitters), and AlInGaP (red light emitters).

The solid state light sources in any lighting device according to the present invention can be of any suitable size (or sizes), e.g., and any quantity (or respective quantities) of solid state light sources of one or more sizes can be employed. In some instances, for example, a greater quantity of smaller light emitting diodes can be substituted for a smaller quantity of larger light emitting diodes, or vice-versa.

People of skill in the art are also familiar with, and have ready access to, a wide variety of luminescent materials, and any suitable luminescent material (or luminescent materials) can be employed in the lighting devices according to the present invention. Luminescent materials are materials that emit visible light under excitation by, e.g., electromagnetic radiation, e.g., visible light. Representative types of luminescent materials include phosphors, nano particles, quantum dots, scintillators, day glow tapes and inks that glow in the visible spectrum upon illumination with ultraviolet light. Representative specific examples of luminescent materials that can be used in lighting devices in accordance with the present invention include YAG (cerium-doped yttrium aluminum garnet, also known as YAG:Ce, available, e.g., from https://www.samaterials.com/phosphor-materials/1891-yttrium-aluminum-garnet-yag-phosphor-powder.html), CaAlSiN3:Eu (red, available, e.g., from https://www.samaterials.com/phosphor-materials/1894-red-nitride-phosphors.html) and LuAG (green, available, e.g., from https://www.samaterials.com/phpsphor-materials/1893-green-luag-phosphor.html)(lutetium aluminum, also known as LuAG:Ce). A wide variety of luminescent materials are readily available, e.g., as marketed by Intematix Corporation (www.intematix.com).

People of skill in the art are familiar with, and have ready access to, a variety of luminescent materials that emit light having a desired peak emission wavelength and/or dominant emission wavelength, or a desired hue, and any of such luminescent materials, or any combinations of such luminescent materials, can be employed, if desired.

As noted above, in some embodiments, the at least one first group luminescent material consists essentially of a first luminescent material, and the at least one second group luminescent material consists essentially of the first luminescent material, i.e., the first group luminescent material is the same as (or substantially the same as) the second group luminescent material.

As noted above, in some embodiments, the at least one first group luminescent material consists essentially of a first mixture of luminescent materials, and the at least one second group luminescent material consists essentially of said first mixture of luminescent materials, i.e., the luminescent material in the first group of solid state light emitters consists essentially of a first mixture of luminescent materials, and the luminescent material in the second group of solid state light emitters consists essentially of the same mixture of luminescent materials.

In embodiments in accordance with the present invention, a luminescent material (or luminescent materials) are provided in the form of the luminescent material (or materials) by itself (or themselves) (or substantially by itself or themselves), e.g., fused or pressed, or as a sintered layer, and/or mixed with or dispersed in one or more other materials, e.g., mixed with a binder and coated on an LED or LEDs, or applied on an LED or LEDs as a drop.

The statement above that "the first group of solid state light emitters comprises at least one first group solid state light emitter," means that the first group of solid state light emitters can consist of a single solid state light emitter or it can consist of two or more solid state light emitters. Similarly, the statement above that "the second group of solid state light emitters comprises at least one second group solid state light emitter," means that the second group of solid state light emitters can consist of a single solid state light emitter or it can consist of two or more solid state light emitters.

The expression "upon supplying electricity to the first group of solid state light emitters" (and the like) refers to what occurs upon supplying electricity to the solid state light source(s) in the first group of solid state light emitters, such that the solid state light source(s) emit light (i.e., the magnitudes of the current and voltage are such that the light source(s) emit light).

In some embodiments according to the present invention, which can include or not include, as suitable, any of the other features described herein, the lighting device is substantially devoid of any light emitters other than the first group of solid state light emitters and the second group of solid state light emitters.

In some embodiments according to the present invention, which can include or not include, as suitable, any of the other features described herein, upon electricity being supplied to the lighting device (e.g., by being supplied to a power line of the lighting device), a sum of light emitted from the first and second groups of solid state light emitters accounts for at least 80% of light emitted from the lighting device.

In some of such embodiments, the lighting device further comprises a power line, and the lighting device is configured such that upon line voltage being supplied to the power line, the lighting device emits light, and a sum of light emitted from the first, second and third groups of solid state light emitters accounts for at least 80% of the light emitted from the lighting device.

Some embodiments of lighting devices in accordance with the present invention can further comprise a wide variety of electrical components and/or circuitry to provide electricity to each of the light sources, and to control the electricity supplied to each light source in terms of respective desired currents and voltages in respective desired time sequences.

For example, lighting devices in accordance with the present invention can further comprise (or can be used in combination with) power supply units to supply electricity, and drivers to regulate the voltage and current supplied to light sources (e.g., to respective strings that comprise light sources, e.g., a string that comprises light sources consisting of shorter wavelength blue light sources, a string that comprises light sources consisting of longer wavelength blue light sources, a string that comprises shorter wavelength blue light sources and longer wavelength blue light sources in one or more ratios (i.e., the number of shorter wavelength blue light sources on the string divided by the number of longer wavelength blue light sources on the string), and/or strings that comprise one or more other types of light sources.

Some embodiments of lighting devices in accordance with the present invention can further comprise electronic components that are configured to control the current and/or voltage supplied to respective individual strings. Such electronic components include, for example, rheostats, variable resistors, switches, shunts, etc., individually and/or in a variety of combinations and layouts.

Some embodiments of lighting devices in accordance with the present invention can be used in combination with (or can further comprise) any suitable components that can receive, generate (e.g., in response to data received from sensors) and/or communicate commands or signals that control or alter electricity supplied to light emitters and/or strings, to control or alter characteristics of light emitted from the device, characteristics of light emitted from any one or more solid state light emitter, and/or characteristics of light emitted from any one or more light source, such characteristics including luminous flux, color point, CCT, at any particular time and/or in accordance with any particular time sequence or time-sequence pattern. Representative components that can receive, generate and/or communicate commands that control (or alter) such characteristics of light include user inputs, processors (e.g., a microprocessor) radio transmitters, receivers and transceivers (e.g., bluetooth® transmitters, receivers and transceivers), wifi transmitters, receivers and transceivers, infrared transmitters, receivers and transceivers (e.g., remote controls), the cloud (e.g., an AI central control platform, learning management software (LMS), a smart home via the Internet of Things), and/or any suitable clock (e.g., an RTC or a radio data system (RDS)).

In some aspects in accordance with the present invention, there are provided devices and systems that comprise one or more communication elements so that the device or the system can connect and interrogate or be controlled by remote devices, e.g., bt, wifi, lifi, 3g, 4g, 5g, iot, the cloud, ai devices, and MI devices.

As an example, Fig. 1 (described in more detail later) schematically depicts an arrangement that comprises a first string 10 of solid state light emitters, a second string 11 of solid state light emitters, a driver 14, a power supply unit 15, and a microprocessor 16 configured to receive signals from the cloud 17, from bluetooth® devices 18, from wifi 19, from infrared transmitters 20, from a clock 21 (e.g., RTC) and/or from a user-actuated controller 22. The driver 14 can comprise any desired circuitry, e.g., sub-circuits as disclosed in Figs. 8-13, discussed later.

In some embodiments in accordance with the present invention, light emitters that comprise light sources that emit light of differing peak wavelengths (e.g., some of the light emitters comprise shorter wavelength light sources and other emitters comprise longer wavelength light sources) can be separated into different strings, e.g., [1] for at least a first string (or for plural strings), each of the light emitters comprises one or more light sources that emit light in a first wavelength range, and [2] for at least a second string (or for plural other strings), each of the light emitters comprises one or more light sources that emit light in a second wavelength range.

In some embodiments in accordance with the present invention, light emitters that comprise light sources that emit light of differing peak wavelengths can be included in the same string or strings.

In some embodiments in accordance with the present invention, there are plural strings of light emitters, and only in some of the strings (or only in one of the strings) does every light source in the light emitters on the string emit light in the same wavelength range.

In some embodiments in accordance with the present invention, there are one or more strings of light emitters, and in none of the strings does every light source in the light emitters on the string emit light in the same wavelength range.

For example, some embodiments comprise [1] at least a first string (or plural strings), in which each of the light emitters comprises one or more light sources that emit light in a first wavelength range, and [2] at least a second string (or plural other strings), in which each of the light emitters comprises one or more light sources that emit light in a second wavelength range, attached to drivers such that the power applied to each type of emitter can be independently controlled by varying the current flow and/or voltage in the string in any suitable way, e.g., by PWM.

Some embodiments in accordance with the present invention are devices and systems that comprise light emitters arranged in strings, a power modulation circuit connected to each string, and a power supply to provide power at appropriate levels and amounts for the emitters. The modulation circuits can be connected and controlled by a logic circuit, typically an MCU, which can vary the amount of power applied to the strings of emitters. In some embodiments, the power supplied to any of the emitters can be changed automatically in response to preprogrammed conditions (such as time of day), motion sensing, and/or alarm conditions, and/or can be changed by a user locally or remotely.

In some embodiments according to the present invention, which can include or not include, as suitable, any of the other features described herein, there is provided a lighting device that comprises one or more first emitter strings and one or more second emitter strings, each of the first group solid state light emitters in the device is on one of the first emitter strings, and each of the second group solid state light emitters in the device is on one of the second strings (and/or only first group solid state light emitters are on the first emitter string(s), and only second group solid state light emitters are on the second emitter string(s)).

In some embodiments according to the present invention, which can include or not include, as suitable, any of the other features described herein, there is provided a lighting device that comprises at least a first string and a second string, and

a first ratio equal to a quantity of first group solid state light emitters on the first string divided by a quantity of second group solid state light emitters on the first string, differs from a second ratio equal to a quantity of first group solid state light emitters on the second string divided by a quantity of second group solid state light emitters on the second string. In some of such embodiments, two or more strings are provided that have respective ratios (i.e., the quantity of one group of emitters on the string divided by the quantity of another group of emitters on the string) that differ from each other by any selected extent, e.g., to provide much greater control within a smaller color tie line or gamut (for example, a first embodiment that comprises 11 first group emitters and 4 second group emitters on a first string and 9 first group emitters and 6 second group emitters on a second string, vs. a second embodiment that comprises 20 first group emitters on a first string and 10 second group emitters on a second string.

In any device or system in accordance with the present invention, a database and/or a processor can be built into the device (which also includes at least the first and second groups of solid state light emitters), or either or both of a database and/or a processor can be anywhere else, e.g., remote from the device and connected to the device so as to be able to communicate with the device wirelessly and/or through wire (with some or all of such communication being through the internet, or none of such communication being through the internet). Instead of a single processor, two or more processors can be employed, e.g., tasks (such as calculations) can be delegated (i.e., one or more tasks on one processor, one or more tasks on another processor, etc.). In any case, communication can be provided such that processors and/or databases can be local, remote or any combination of local and remote.

In some aspects in accordance with the present invention, there are provided devices and systems in which, with the device connected to a cloud, a processor in the cloud calculates currents and/or voltages that, if applied on respective strings, will provide a desired effect or regimen, and/or will create a desired modification, and/or will adapt for changes in other factors (e.g., reduced luminous flux from one or more light sources and/or luminescent materials), and those calculated currents and/or voltages are communicated to the device, so that the device executes the instructions received from the cloud.

Some embodiments of lighting devices in accordance with the present invention can be used in combination with (or can further comprise) one or more databases, e.g., a light prescription database (different wavelength combinations for different sunlight simulations, daily activities, and special purposes/treatments).

Some embodiments of lighting devices in accordance with the present invention comprise such a database, e.g., a light prescription database that contains data that is used in calculating current and/or voltage adjustments needed in response to user requests, or in response to changes that are expected to occur or that are known to occur in some instances.

Some embodiments of lighting devices in accordance with the present invention are configured to access data from a remote database (e.g., via the internet), e.g., comprising light prescription data and/or data that is capable of being used in calculating current and/or voltage adjustments needed in response to user requests, or in response to changes that are expected to occur or that are known to occur in some instances.

Some embodiments of lighting devices in accordance with the present invention comprise a processor that comprises a database that contains data (e.g., light prescription data and/or data that is used in calculating adjustments to current and/or voltage supplied to at least one solid state light emitter in the lighting device needed in order to satisfy at least one user request).

In accordance with the present invention, for example, a light prescription database can comprise combinations of luminous flux from different groups of light emitters for different sunlight simulations, daily activities, special purposes, and/or treatments). In some aspects, the present invention provides hardware and/or software components that are connected, e.g., to a central cloud, and that can be easily adjusted or controlled by an AI central control platform automatically and/or by a user.

In some embodiments, lighting cycles to which people are exposed during the day is provided, to avoid disruption of their circadian rhythm, and to avoid negative effects of detraction from the duration and quality of sleep, along with the resulting potential repercussions on health and productivity. In some instances, circadian stimulus values (CS values), which range from zero (the threshold for circadian system activation) to 0.7 (response saturation), and which are directly proportional to nocturnal melatonin suppression after one hour of light exposure, are recommended for specific parts of the day (e.g., high CS of greater than 0.3 for early morning, reducing to less than 0.1 in the evening.

In some embodiments, light prescriptions take into account the users' ages, e.g., for elderly and/or visually impaired people, light prescriptions are provided that are tailored to such individuals' particular needs (indeed, lighting for the elderly and the visually impaired involves requirements higher than that for normal-sighted people); for normal-sighted people, light prescriptions that are tailored to those individuals may be provided; for infants, babies, toddlers, children, youths, adults etc., light prescriptions that are tailored to each may be provided.

The present invention also provides databases including data regarding a plurality of respective different light wavelength and spectral flux combinations (and sequences of such light outputs, e.g., a sequence in which each member of the sequence can be represented by a spectral flux vs. wavelength plot). Data stored in such databases can include: combinations of lighting controls (e.g., respective currents and/or voltages supplied to different strings of light emitters) resulting from user selections; and/or combinations of lighting controls received from outside sources (e.g., recommendations or spectra "recipes" for providing light treatments, for use with specific activities, and/or for providing (or tending to facilitate) specific moods. For example, a user might have a light session in which the user adjusts respective currents and/or voltages supplied to different strings of light emitters, and the user can store the combination such that the overall light output can be substantially identically repeated at a later time. Some of such databases contain a web interface to make it possible (and/or easy) to add new combinations (or sequences of combinations), and/or update already-stored combinations, e.g., continuously. Any of such combinations in a database according to the present invention can be used in the devices and systems of the present invention, e.g., through the cloud. In some embodiments, the most updated spectrum combinations can be matched for different times, schedules, applications, activities, and treatments. Some databases according to the present invention can have an open API to facilitate other LED lighting manufacturers licensing and using the databases. In some instances, calculations are made (e.g., on processors) to account for different specific color outputs of light-emitting components and/or different specific ratios of light-emitting components in terms of their color output in strings in the device.

In some embodiments in accordance with the present invention, the quantity and characteristics of the spectral power distribution (SPD) of light can be adjusted or controlled, to influence people's ability to maintain attention and good cognitive performance during the day (and/or at night for persons who do night work).

In some embodiments in accordance with the present invention, quantifications of circadian effects of light are performed using the level of light that arrives – on average – to the user's eyes, rather the level of light that arrives on a work surface;

In some embodiments in accordance with the present invention, influences of the internal environment are factored into lighting selections, e.g., effects on the real CCT of the light that reaches the eyes (such CCT is generally lower than that of the light emitted from the light emitters in the lighting device.

In some embodiments in accordance with the present invention, influences of lighting settings on people's assessment of lighting and interior spaces where they are located are factored into lighting selections – in many cases, light settings preferred by individuals show substantial individual-to-individual variations.

In some embodiments in accordance with the present invention, an interface is provided that makes it possible (and in some cases, easy) to customize the lighting.

In some aspects, the present invention provides devices and systems that comprise LED components of different sizes and shapes. In some embodiments, vertical chip, eutectic bonding technology, and/or phosphor sheet attachment are employed, and by using such features or combinations of such features, compact multi-color LED components of a variety of sizes and shapes, and with sufficient spectral flux, are obtained.

In some aspects, the present invention provides devices and systems that comprise LED components with optical lenses with a variety of respective different output angles and sizes of optical lens. In some embodiments, microstructure on lens surfaces is provided to enhance extraction efficiency and color mixing effect. In some embodiments, such optical lenses are coupled with specific lighting fixtures to provide unexpectedly favorable color mixing effects while also guaranteeing the final output quality.

In embodiments in accordance with the present inventive subject matter that include one or more lenses and/or diffusers and/or light control elements, the one or more lenses and/or diffusers and/or light control elements can be positioned in any suitable location and orientation.

In some aspects, the present invention provides a series of LED multi-channel drivers with dimming technology (e.g., Bluetooth 5.0 Mesh and 16 bits dimming technology), for driving multi-channel lighting fixtures. Among this series of drivers provided by the present invention are drivers that are of small size, include many channels, provide high frequency, provide short responding time, and/or provide capability for data exchange.

In some aspects, the present invention provides artificial lighting that is more similar (in at least some ways) to sunlight in any of a number of parameters (and especially combinations of parameters), and to thereby provide important benefits in maintaining human health. In some aspects, the present invention provides specific light wavelengths and/or spectra for specific activities and/or treatments that enhance persons' performances, keep (or improve) their mood, and maintain their health.

The present invention comprises devices and systems that comprise any of the features of the present invention as described herein, and may be selected from among any of a wide variety of types of devices, e.g., devices for general illumination, general lighting devices, down lights, panel lights, linear lights, strip lights, spot lights, flood lights, etc., and/or can be employed in any desired fixtures.

The devices and systems in accordance with the present invention can be employed in any of a wide range of settings, e.g., in offices, gyms, schools, elder caring centers, hospitals, shopping areas, casinos, restaurants, homes, factories, garages, caravans, etc. For example, in a casino, there might be a desire to keep people alert; in a hospital, there might be a desire to manage alertness levels of patients to coincide with the time of day and/or with each other. Exposure to light for night workers can reduce melatonin production and influence sleep quality, with long-term health effects, and in some aspects of the present invention, devices and/or systems are used to ameliorate or eliminate the adverse effects of such shift work.

In some aspects of the present invention, there is provided a lighting device that can be part of a group of devices that adjust the degree of melanopsin activation in an illuminated area so as to keep persons viewing the illuminated area directly alert (or that influence the alertness levels of persons viewing the illuminated area according to a desired schedule, e.g., a 24-hour routine).

As noted herein, the devices and systems in accordance with the present invention can be used in any suitable location (e.g., type of building or region within a building), to provide light that provides any desired effect, and/or for any suitable purpose.

For example, in some embodiments, within a hospital, a diagnosis room comprises lighting for diagnosing and/or lighting for general working; a ward comprises daytime color changing lighting, noon break lighting, evening time lighting and sleeping mode lighting; a waiting area / reception area comprises calm down mode lighting, working hours lighting, off-hours lighting, and emergency mode lighting; and/or an operation room comprises lighting for performing medical procedures. Providing an environment that promotes alertness during the day and restfulness during the night can be especially important in hospitals, where schedules are erratic, and where support of circadian health can improve overall health and well-being, as well as improving sleep quality, reducing agitation, reducing depression, and reducing fatigue for patients, caregivers and families in hospital environments. These positive effects can last beyond a patient's discharge or after a night shift nurse leaves to go home.

Lighting devices in accordance with the present invention can be used in any suitable systems, e.g., for back lighting and side lighting in TVs, in PCs, handheld devices, telephones, electronic tablets, wearable electronic devices, VR and AR headsets, indicator displays in appliances, medical displays, medical equipment, clocks, electric lanterns, "torches", motor vehicles, etc.

In some embodiments, within an elder caring center, a reception area comprises working hours lighting and off-hours lighting; a residential room / area comprises daytime color changing lighting, noon break lighting, evening time lighting, sleeping mode lighting, exercising mode lighting, reading mode lighting and movie / television mode lighting; an activity area comprises relax mode lighting and energized mode lighting; and/or a restaurant area comprises dining mode lighting and vivid light color for food lighting.

In some embodiments, within an office, a general office space comprises working hours lighting, noon break lighting and off-hours lighting; a meeting room comprises official meeting lighting, speech mode lighting and power point mode lighting; a reception area comprises working hours lighting and off-hours lighting; a recreation area comprises relax mode lighting and energize mode lighting; a brainstorm area comprises rational mode lighting and emotional mode lighting; and a lab area comprises focusing mode lighting and importance mode lighting. Color temperatures as high as 6,500 K are generally not favored for office settings and the like (the light is typically considered to contain more blue light than is desirable). Light at lower color temperatures tends to have lower melanopsin activation (i.e., lower $a_{mel,v}$ values).

Embodiments in accordance with the present invention are described herein in detail in order to provide exact features of representative embodiments that are within the overall scope of the present invention. The present invention is not limited to such detail.

Fig. 1 schematically depicts an arrangement in accordance with the present invention that comprises a first string 10 of solid state light emitters and a second string 11 of solid state light emitters, the first string 10 comprising a plurality of first group light emitters 12 that each comprise a shorter wavelength light source (that emits light at wavelength of about 2700 K) and the second string 11 comprising a plurality of second group light emitters 13 that each comprise a longer wavelength light source (that emits light at wavelength of about 5000 K). The arrangement depicted in Fig. 1 further comprises a driver 14, a power supply unit 15, and a microprocessor 16 configured to receive signals from the cloud 17, from bluetooth® devices 18, from wifi 19, from infrared transmitters 20, from a clock 21 (e.g., RTC) and/or from a user-actuated controller 22.

Fig. 2 schematically depicts a lighting device 23 in accordance with the present invention, that comprises a shorter wavelength light source 24, a longer wavelength light source 25, a light mixing space 26, and optics 27, and Fig. 2 schematically depicts output light exiting the lighting device 23 from above (in the orientation depicted in Fig. 2) the optics 27.

Fig. 3 schematically depicts a lighting device 30 in accordance with the present invention, that comprises a shorter wavelength light source 31, a longer wavelength light source 32, a lumiphore 33 (which comprises luminescent material dispersed in a binder), positioned in a cup reflector 34 (which functions as one of the electrodes for the light sources 31 and 32, as well as making more light travel within a beam of light exiting from the cup reflector 34), electrodes 35 and 36 (which respectively function as the other electrode for the respective light sources 31 and 32), and wire bonds 37 and 38, which electrically connect the light sources 31 and 32 to the electrodes 35 and 36, respectively, and a dome-shaped encapsulant 39. The lead frame (which comprises the cup reflector 34 and the electrodes 35 and 36 (and in some embodiments, also other cup reflectors and/or electrodes) is preferably made of metal and may be stamped and optionally post-plated. The lead frame may also undergo optional ultrasonic or other cleaning. The reflective elements may be polished or plated to increase their reflectivity. If desired, the lumiphore 33 can be a glob-top deposited on the solid state light sources.

Fig 4 schematically depicts a lighting device 40 in accordance with the present invention, that comprises a substrate 41, a shorter wavelength light source 42, a longer wavelength light source 43, and a phosphor coating 44 (which comprises luminescent material).

Fig 5 schematically depicts a lighting device 50 in accordance with the present invention, that comprises a substrate 51, a shorter wavelength light source 52, a longer wavelength light source 53, a first group phosphor coating 54 (which comprises luminescent material).on the shorter wavelength light source 52 and a second group phosphor coating 55 (which comprises luminescent material).on the longer wavelength light source 53.

Fig 6 schematically depicts a lighting device 60 in accordance with the present invention, that comprises a substrate 61, a pair of first group light emitters 62, a pair of second group light emitters 63, and pads 64 to which electrical connections can be attached. Each of the first group light emitters 62 comprises a shorter wavelength light source and a first group phosphor coating, and each of the second group light emitters 63 comprises a longer wavelength light source and a second group phosphor coating. A dome-shaped encapsulant 65 covers the first group light emitters 62 and the second group light emitters 63.

Fig. 7 is a schematic diagram showing a plurality of first group light emitters 71 electrically arranged in series, and a plurality of second group light emitters 72 arranged in series, with the series of first group light emitters 71 electrically arranged parallel with the series of second group light emitters 72. Each of the first group light emitters 71 comprises a shorter wavelength light source, and each of the second group light emitters 72 comprises a longer wavelength light source.

Figs. 8-13 schematically depict representative examples in accordance with the present invention, of combinations of electronic components that are configured to enable the current and/or voltage supplied to respective individual strings to be controlled.

Fig. 8 depicts a sub-circuit that comprises a rheostat 80 and first and second strings 81 and 82 of light emitters, in which by adjusting the rheostat 80, the ratio of current being supplied to the first string 81 of light emitters relative to current being supplied to the second string 82 of light emitters is altered.

Fig. 9 depicts a sub-circuit that comprises a variable resistor 90 and first and second strings 91 and 92 of light emitters, in which by adjusting the variable resistor 90, the ratio of current being supplied to the first string 91 of light emitters relative to current being supplied to the second string 92 of light emitters is altered.

Fig. 10 depicts a sub-circuit that comprises a switch 100 and first and second strings 101 nd 102 of light emitters, in which by changing the position of the switch 100, electricity can be selectively supplied to the first string 101 of light emitters or to the second string 102 of light emitters (i.e., in a first position of the switch 100, electricity is supplied to the first string 101 of light emitters and not to the second string 102 of light emitters; and in a second position of the switch 100, electricity is supplied to the second string 102 of light emitters and not to the first string 101 of light emitters.

Fig. 11 depicts a sub-circuit that comprises a first switch 110, a second switch 111, a first string 112 of light emitters, and a second string of light emitters 113, in which:

with the first switch 110 in a closed position and the second switch 111 in a closed position, electricity is supplied to the first string 112 of light emitters and to the second string 113 of light emitters,

with the first switch 110 in a closed position and the second switch 111 in an open position, electricity is supplied to the first string 112 of light emitters and not to the second string 113 of light emitters,

with the first switch 110 in an open position and the second switch 111 in a closed position, electricity is supplied to the second string 113 of light emitters and not to the first string 113 of light emitters, and with the first switch 110 in an open position and the second switch 111 in an open position, electricity is not supplied to the first string 112 of light emitters or to the second string 113 of light emitters.

Fig. 12 depicts a sub-circuit that comprises a switch 120 and first and second strings 121 and 122 of light emitters, in which:

with the first switch 120 in an open position, electricity is supplied to the second string 122 of light emitters and not to the first string 121 of light emitters, and

with the first switch 120 in a closed position, electricity is supplied to the first string 121 of light emitters and to the second string 122 of light emitters.

Fig. 13 depicts a sub-circuit that comprises a switch 130 and first and second strings 131 and 132 of light emitters, in which:

with the first switch 130 in an open position, electricity is supplied to the first string 131 of light emitters and to the second string 131 of light emitters, and

with the first switch 130 in a closed position, electricity is shunted around the second string 131 of light emitters, such that electricity is supplied to the first string 131 of light emitters and not to the second string 132 of light emitters, i.e., the first switch provides a shunt sub-circuit by which electricity can be selectively shunted from the second string 132 of light emitters.

In a way that is similar to the way electricity can be selectively shunted from the second string 132 of light emitters in Fig. 13, in other embodiments, one or more shunt sub-circuits can be provided in which some or all of the light emitters in one or more strings (e.g., a first string of light emitters and a second string of light emitters) can be selectively shunted (e.g., a shunt sub-circuit including a switch can be provided across some of the the light emitters in one of the strings. In some embodiments in which light emitters can be selectively shunted, the light emitters that can be selectively shunted are those that are closest to the ground in the string.

In another representative embodiment in accordance with the present invention, there is provided a lighting device that comprises a first string of one or more first group solid state light emitters (each of which has one or more shorter wavelength blue light sources and no other light sources) and a second string of one or more second group solid state light emitters (each of which has one or more longer wavelength blue light sources and no other light sources). In this embodiment:

> each first group solid state light emitter comprises a first group solid state light source that emits light at about 450 nm and a first group luminescent material that comprises a first mixture of red light-emitting phosphor (1.0 parts), green light-emitting phosphor (1.9 parts) and yellow light-emitting phosphor (0.7 parts), with a peak excitor wavelength of 444 nm;
>
> each first group solid state light emitter emits light having CCT of about 2700K, M/P (Amel.v*1.218) of 0.4, and Ra (CRI) of 88;
>
> each second group solid state light emitter comprises a second group solid state light source that emits light at about 475 nm and a second group luminescent material that comprises a second mixture of red light-emitting phosphor (0.6 parts), green light-emitting phosphor (1.0 parts) and yellow light-emitting phosphor (0.2 parts), with a peak excitor wavelength of 475 nm;
>
> each second group solid state light emitter emits light having CCT of about 5000K, M/P (Amel.v*1.218) of 1.4, and Ra (CRI) of 57; and
>
> a 60:40 mixture of light from the first and second groups of solid state light emitters (i.e., 60 percent of the light is emitted from the first group of solid state light emitters and 40 percent of the light is emitted from the first group of solid state light emitters) has a CCT of about 3800K, M/P (Amel.v*1.218) of 1.0, and Ra (CRI) of 75 (and with peak excitor wavelengths of 444 nm and 475 nm).

In this embodiment, by adjusting the amount of light emitted from the first group of solid state light emitters relative to the amount of light emitted from the second group of solid state light emitters, the CCT and the M/P can be varied. Fig. 14 shows an SPD plot (power vs. wavelength) for the first group solid state light emitters, the second group solid state light emitters, and a 60:40 mixture of light from the first and second groups of solid state light emitters.

In another representative embodiment in accordance with the present invention, there is provided a lighting device that comprises a first string of one or more first group solid state light emitters (each of which has one or more shorter wavelength blue light sources and no other light sources) and a second string of one or more second group solid state light emitters (each of which has one or more longer wavelength blue light sources and no other light sources). In this embodiment:

each first group solid state light emitter comprises a first group solid state light source that emits light at about 450 nm and a first group luminescent material that comprises a first mixture of red light-emitting phosphor (0.3 parts), and yellow light-emitting phosphor (2.5 parts), with a peak excitor wavelength of 445 nm;

each first group solid state light emitter emits light having CCT of about 4000K, M/P (Amel.v*1.218) of 0.55, and Ra (CRI) of 75;

each second group solid state light emitter comprises a second group solid state light source that emits light at about 475 nm and a second group luminescent material that comprises a second mixture of red light-emitting phosphor (0.9 parts), and green light-emitting phosphor (2.1 parts), with a peak excitor wavelength of 475 nm;

each second group solid state light emitter emits light having CCT of about 4000K, M/P (Amel.v*1.218) of 1.3, and Ra (CRI) of 52; and

a 67:33 mixture of light from the first and second groups of solid state light emitters (i.e., 67 percent of the light is emitted from the first group of solid state light emitters and 33 percent of the light is emitted from the first group of solid state light emitters) has a CCT of about 4000K, M/P (Amel.v*1.218) of 0.8, and Ra (CRI) of 98 (and with peak excitor wavelengths of 445 nm and 475 nm).

In this embodiment, by adjusting the amount of light emitted from the first group of solid state light emitters relative to the amount of light emitted from the second group of solid state light emitters, the M/P can be varied while the CCT is maintained constant. Fig. 15 shows an SPD plot (power vs. wavelength) for the first group solid state light emitters, the second group solid state light emitters, and a 67:33 mixture of light from the first and second groups of solid state light emitters.

In another representative embodiment in accordance with the present invention, there is provided a lighting device that comprises a first string of one or more first group solid state light emitters (each of which has one or more shorter wavelength blue light sources and no other light sources) and a second string of one or more second group solid state light emitters (each of which has one or more longer wavelength blue light sources and no other light sources). In this embodiment:

each first group solid state light emitter comprises a first group solid state light source that emits light at about 450 nm and a first group luminescent material that comprises a first mixture of red light-emitting phosphor (1.3 parts), green light-emitting phosphor (3.0 parts) and yellow light-emitting phosphor (2.9 parts), with a peak excitor wavelength of 445 nm;

each first group solid state light emitter emits light having CCT of about 2725K, M/P (Amel.v*1.218) of 0.4, and Ra (CRI) of 85;

each second group solid state light emitter comprises a second group solid state light source that emits light at about 480 nm and a second group luminescent material that comprises the same first mixture of red light-emitting phosphor (1.3

parts), green light-emitting phosphor (3.0 parts), and yellow light-emitting phosphor (2.9 parts) with a peak excitor wavelength of 480 nm;

each second group solid state light emitter emits light having CCT of about 4100K, M/P (Amel.v*1.218) of 1.2, and Ra (CRI) of 60; and

a mixture of light from the first and second groups of solid state light emitters has a CCT of about 3000K, M/P (Amel.v*1.218) of 0.6, and Ra (CRI) of 96 (and with peak excitor wavelengths of 445 nm and 480 nm).

In this embodiment, by adjusting the amount of light emitted from the first group of solid state light emitters relative to the amount of light emitted from the second group of solid state light emitters, the CCT and the M/P can be varied. As noted above, in this embodiment, the same phosphor mix is used in the first and second groups of solid state light emitters; the amount of light that is converted by the phosphor in the respective groups can be caused to differ by altering the thicknesses of the phosphor layers. Fig. 16 shows an SPD plot (power vs. wavelength) for the first group solid state light emitters, the second group solid state light emitters, and a mixture of light from the first and second groups of solid state light emitters.

Fig. 17 is a plot of the excitation spectrum of a red phosphor material (CaAlSiN3:Eu, from https://www.samaterials.com/phosphor-materials/1894-red-nitride-phosphors.html), and Fig. 18 is a plot of the emission spectrum of that red phosphor material.

Fig. 19 is a plot of the excitation spectrum of a yellow phosphor material (YAG (cerium-doped yttrium aluminum garnet, also known as YAG:Ce, from https://www.samaterials.com/phosphor-materials/1891-yttrium-aluminum-garnet-yag-phosphor-powder.html), and Fig. 20 is a plot of the emission spectrum of that yellow phosphor material.

Fig. 21 is a plot of the excitation spectrum of a green phosphor material (LuAG (lutetium aluminum, also known as LuAG:Ce), from https://www.samaterials.com/phpsphor-materials/1893-green-luag-phosphor.html), and Fig. 22 is a plot of the emission spectrum of that green phosphor material.

Any two or more structural parts of the lighting devices described herein can be integrated. Any structural part of the devices and systems described herein can be provided in two or more parts (which are held together, if necessary). Similarly, any two or more functions can be conducted simultaneously, and/or any function can be conducted in a series of steps.

Each component described herein can be a unitary one-piece structure. In some cases, if suitable, two or more structural parts of the devices described herein can be integrated, and/or a component can be provided in two or more parts (which are held together, if necessary). Similarly, any two or more functions can be conducted simultaneously, and/or any function can be conducted in a series of steps.

Many alterations and modifications may be made by those having ordinary skill in the art, given the benefit of the present disclosure, without departing from the spirit and scope of the invention.

Claims

1. A lighting device comprising:

a first group of solid state light emitters; and

a second group of solid state light emitters,

wherein:

the first group of solid state light emitters comprises at least one first group solid state light emitter,

each first group solid state light emitter comprises at least one first group solid state light source and at least one first group luminescent material,

each first group solid state light source, when supplied with electricity, emits light having a peak wavelength in a range of from about 400 nm to about 459 nm,

the second group of solid state light emitters comprises at least one second group solid state light emitter,

each second group solid state light emitter comprises at least one second group solid state light source and at least one second group luminescent material,

each second group solid state light source, when supplied with electricity, emits light having a peak wavelength in a range of from about 460 nm to about 510 nm, and

upon supplying electricity to the first group of solid state light emitters and to the second group of solid state light emitters, at least some light emitted from the first group of solid state light emitters mixes with at least some light emitted from the second group of solid state light emitters.

2. A lighting device as recited in claim 1, wherein:

upon supplying electricity to the first group of solid state light emitters, the first group of solid state light emitters emits light of a first CCT,

upon supplying electricity to the second group of solid state light emitters, the second group of solid state light emitters emits light of a second CCT, and

the first CCT is less than the second CCT.

3. A lighting device as recited in claim 2, wherein:

upon supplying electricity to the first group of solid state light emitters, the first group of solid state light emitters emits light of a CCT in a range of from about 2500K to about 3000K; and

upon supplying electricity to the second group of solid state light emitters, the second group of solid state light emitters emits light of a CCT in a range of from about 4000K to about 7500K.

4. A lighting device as recited in claim 2, wherein:

upon supplying electricity to the first group of solid state light emitters, the first group of solid state light emitters emits light of a CCT of about 2700K; and

upon supplying electricity to the second group of solid state light emitters, the second group of solid state light emitters emits light of a CCT of about 5000K.

5. A lighting device as recited in claim 1, wherein:

upon supplying electricity to the first group of solid state light emitters, the first group of solid state light emitters emits light of a first CCT,

upon supplying electricity to the second group of solid state light emitters, the second group of solid state light emitters emits light of a second CCT, and

an absolute value of the first CCT minus the second CCT is less than 4 percent of the first CCT.

6. A lighting device as recited in claim 5, wherein an absolute value of the first CCT minus the second CCT is less than 1 percent of the first CCT.

7. A lighting device as recited in claim 5, wherein:

upon supplying electricity to the first group of solid state light emitters, the first group of solid state light emitters emits light of a CCT in a range of from about 3500K to about 4500K, and upon supplying electricity to the second group of solid state light emitters, the second group of solid state light emitters emits light of a CCT in the range of from about 3500K to about 4500K.

8. A lighting device as recited in claim 5, wherein:

upon supplying electricity to the first group of solid state light emitters, the first group of solid state light emitters emits light of a CCT of about 4000K, and

upon supplying electricity to the second group of solid state light emitters, the second group of solid state light emitters emits light of a CCT of about 4000K.

9. A lighting device as recited in claim 1, wherein:

the at least one first group luminescent material comprises a first luminescent material, and

the at least one second group luminescent material comprises said first luminescent material.

10. A lighting device as recited in claim 9, wherein:

the at least one first group luminescent material consists essentially of the first luminescent material, and

the at least one second group luminescent material consists essentially of the first luminescent material.

11. A lighting device as recited in claim 9, wherein:

the at least one first group luminescent material consists essentially of a first mixture of luminescent materials, and

the at least one second group luminescent material consists essentially of said first mixture of luminescent materials.

12. A lighting device as recited in claim 9, wherein:

upon supplying electricity to the first group of solid state light emitters, the first group of solid state light emitters emits light of a CCT in a range of from about 2500K to about 3000K, and

upon supplying electricity to the second group of solid state light emitters, the second group of solid state light emitters emits light of a CCT in a range of from about 3500K to about 4500K.

13. A lighting device as recited in claim 9, wherein:

upon supplying electricity to the first group of solid state light emitters, the first group of solid state light emitters emits light of a CCT of about 2750K, and

upon supplying electricity to the second group of solid state light emitters, the second group of solid state light emitters emits light of a CCT of about 4100K.

14. A lighting device as recited in claim 1, wherein:

the first group of solid state light emitters is on a first string of solid state light emitters connected in series,

the second group of solid state light emitters is on a second string of solid state light emitters connected in series, and

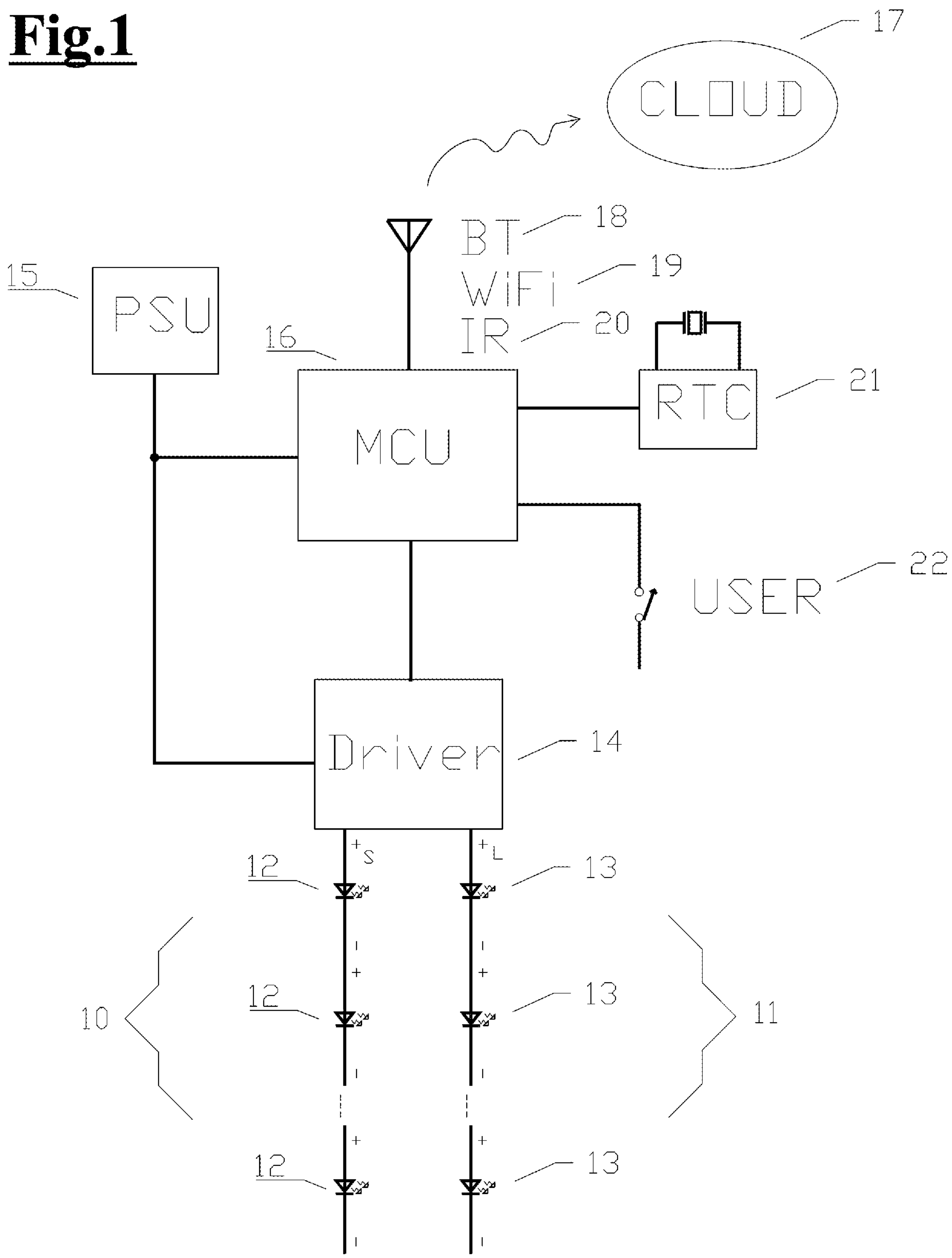
the first string of solid state light emitters and the second string of solid state light emitters are electrically connected in parallel.

15. A lighting device as recited in claim 1, wherein:

the lighting device comprises an encapsulant, and

at least one of the first group of light solid state emitters and the second group of solid state light emitters is embedded in the encapsulant.

Fig.1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CLOUD
18
BT
19
WiFi
20
IR
15
PSU
16
MCU
RTC
21
USER
22
Driver
14
+S
+L
12
13
10
11

Fig.2

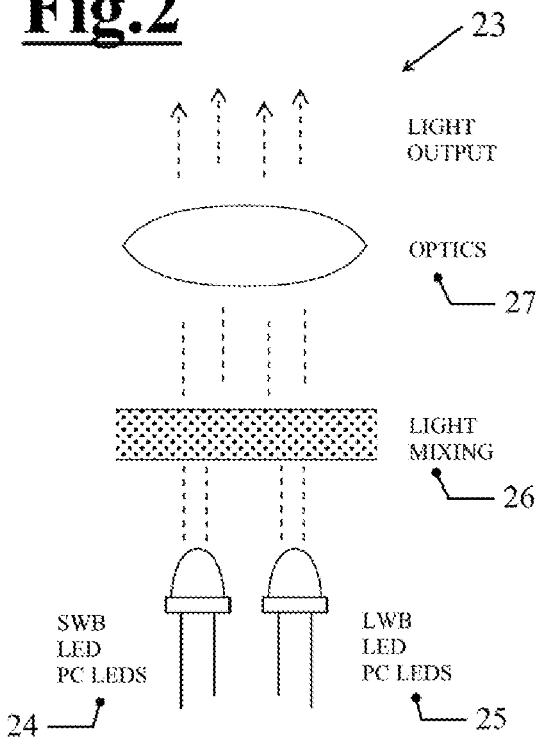


Fig.3

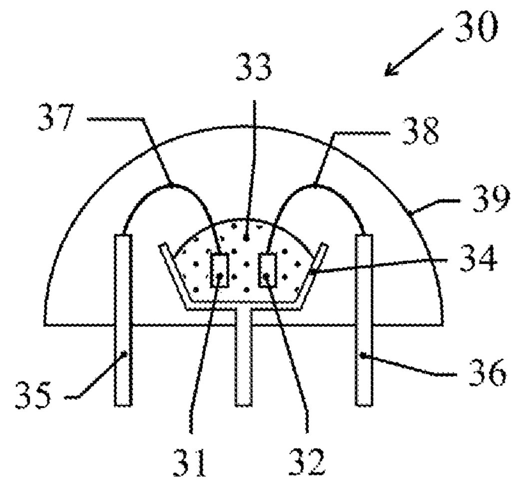


Fig.4

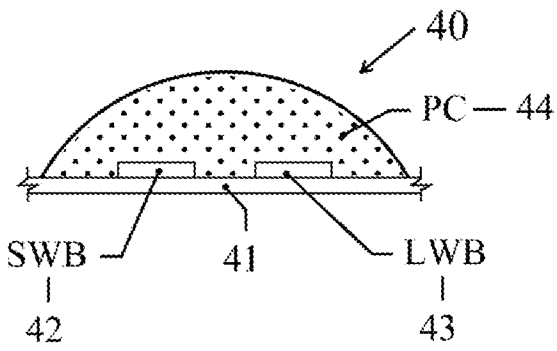


Fig.5

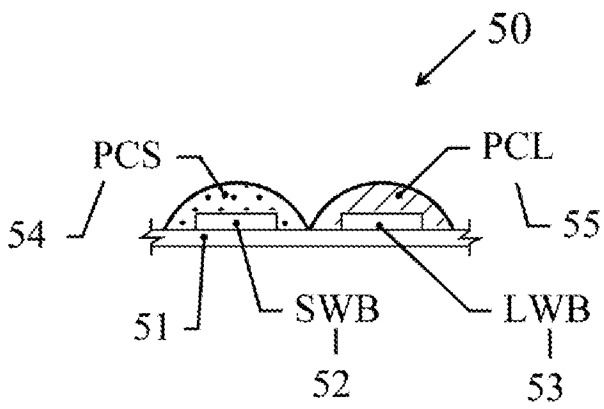


Fig.6

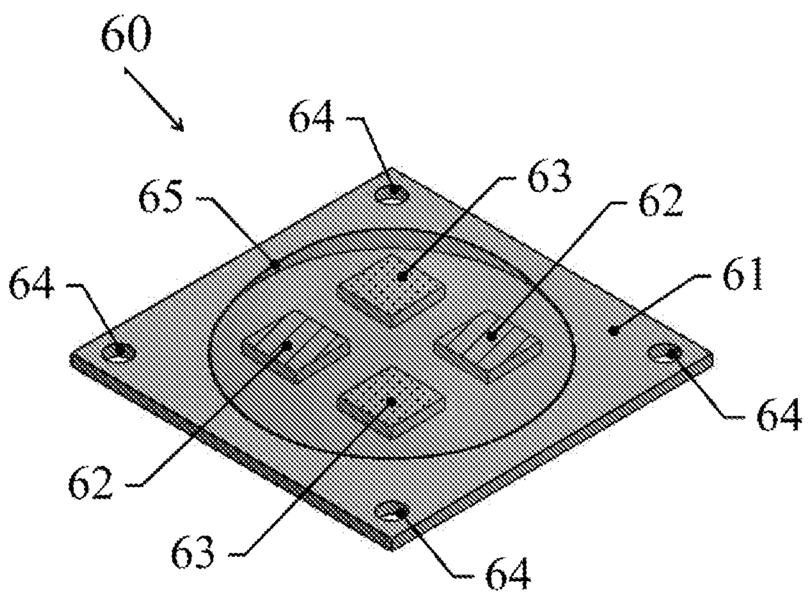


Fig.7

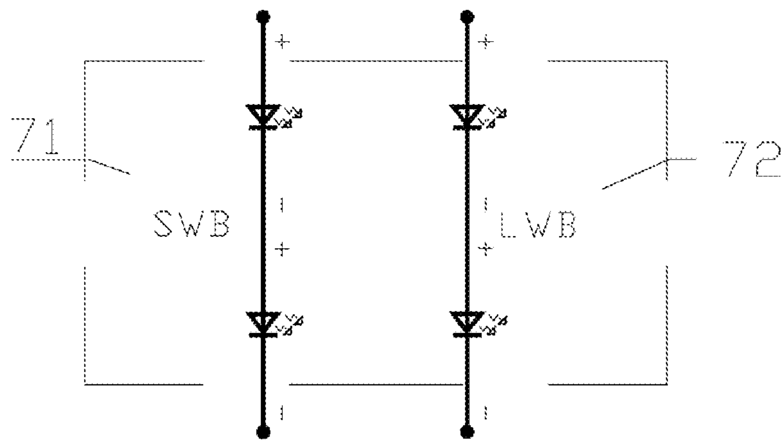


Fig.8

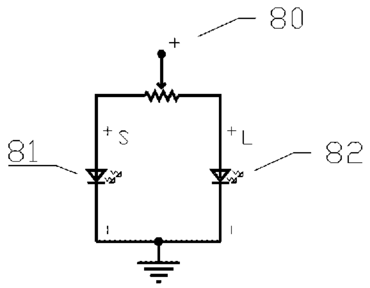


Fig.9

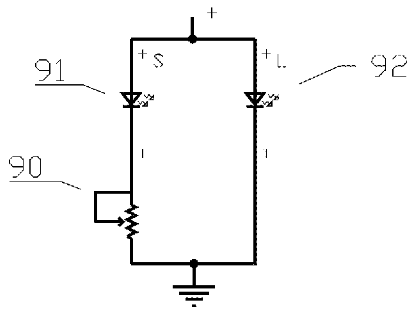


Fig.10

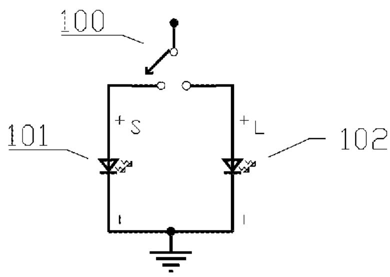


Fig.11

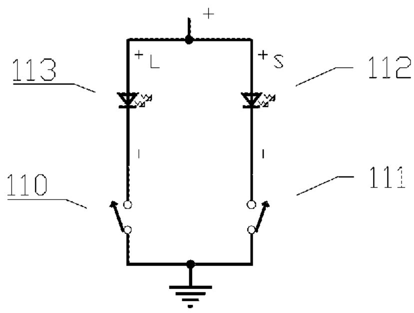


Fig.12

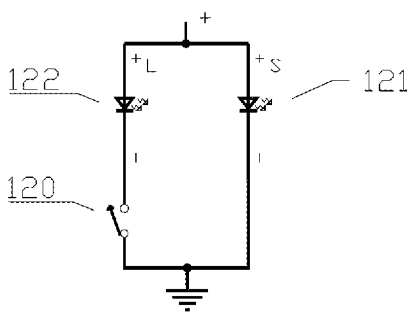


Fig.13

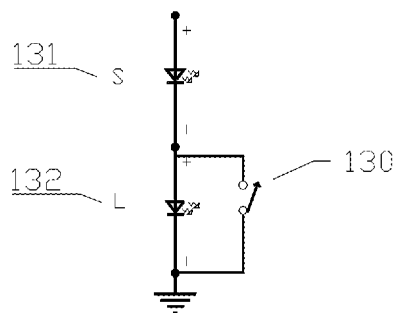
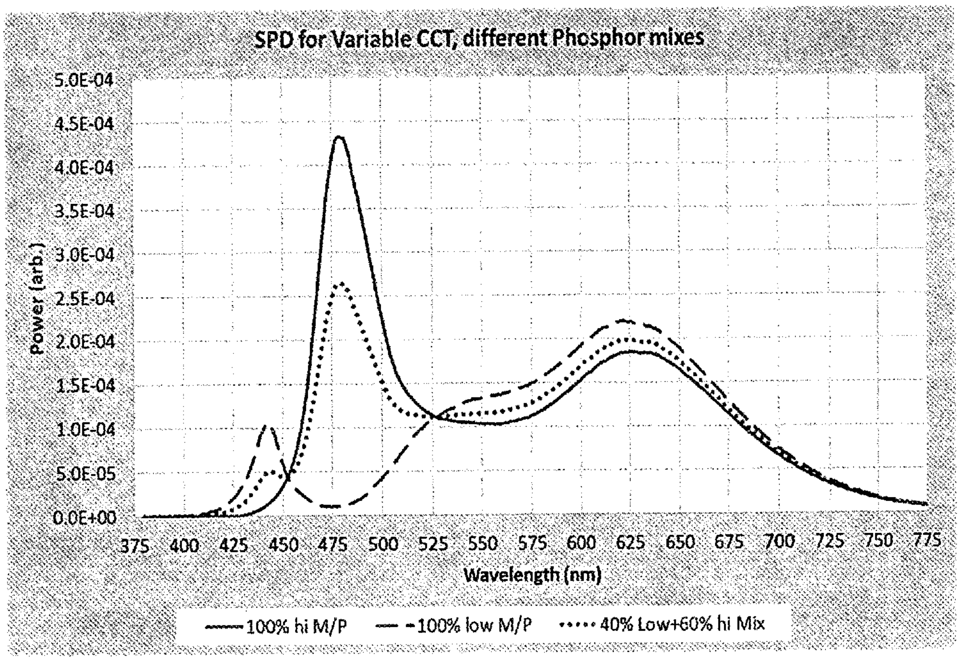


Fig. 14


SPD for Variable CCT, different Phosphor mixes
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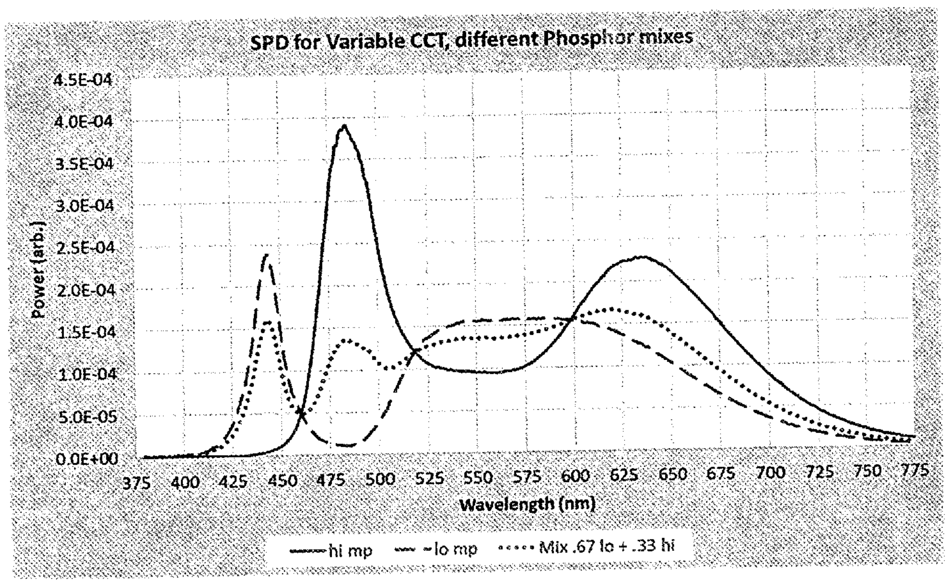
4.5E-04
4.0E-04
3.5E-04
3.0E-04
2.5E-04
2.0E-04
1.5E-04
1.0E-04
5.0E-05
0.0E+00
Power (arb.)
375 400 425 450 475 500 525 550 575 600 625 650 675 700 725 750 775
Wavelength (nm)
100% hi M/P
100% low M/P
40% Low+60% hi Mix

Fig. 15


SPD for Variable CCT, different Phosphor mixes
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4.0E-04
3.5E-04
3.0E-04
2.5E-04
2.0E-04
1.5E-04
1.0E-04
5.0E-05
0.0E+00
Power (arb.)
375 400 425 450 475 500 525 550 575 600 625 650 675 700 725 750 775
Wavelength (nm)
hi mp
lo mp
Mix .67 lo + .33 hi

Fig. 16

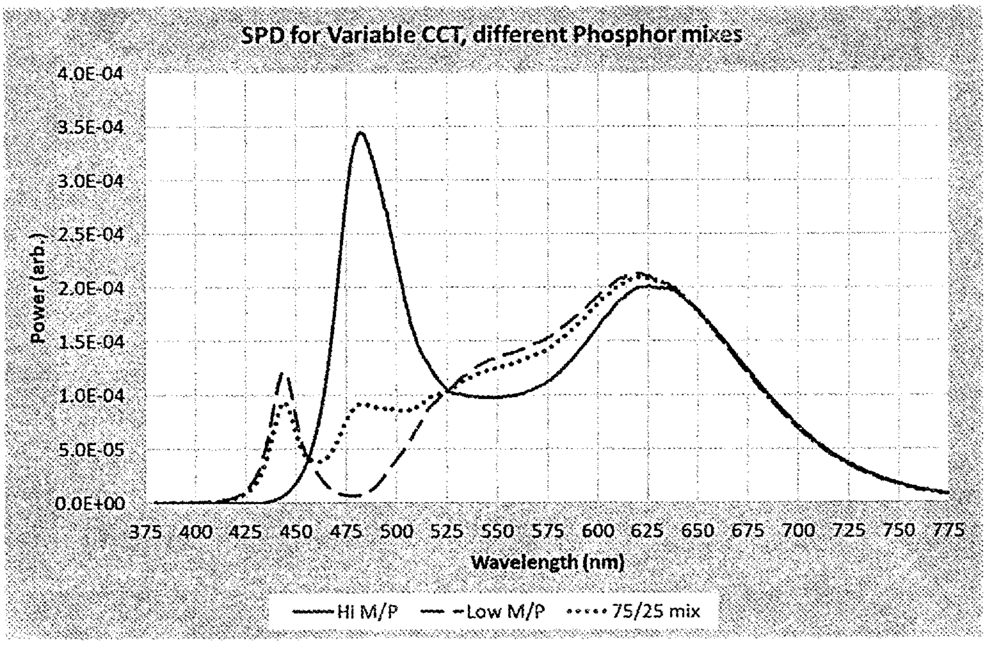


Fig. 17

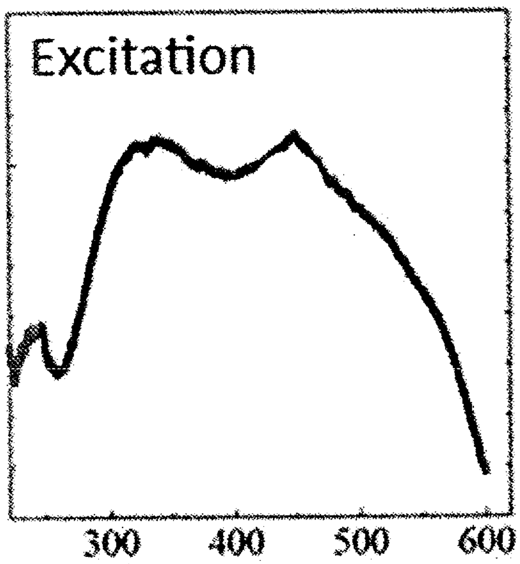


Fig. 18

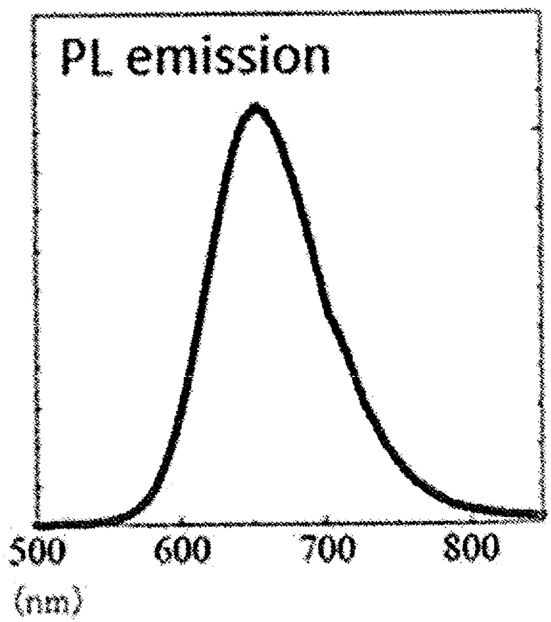
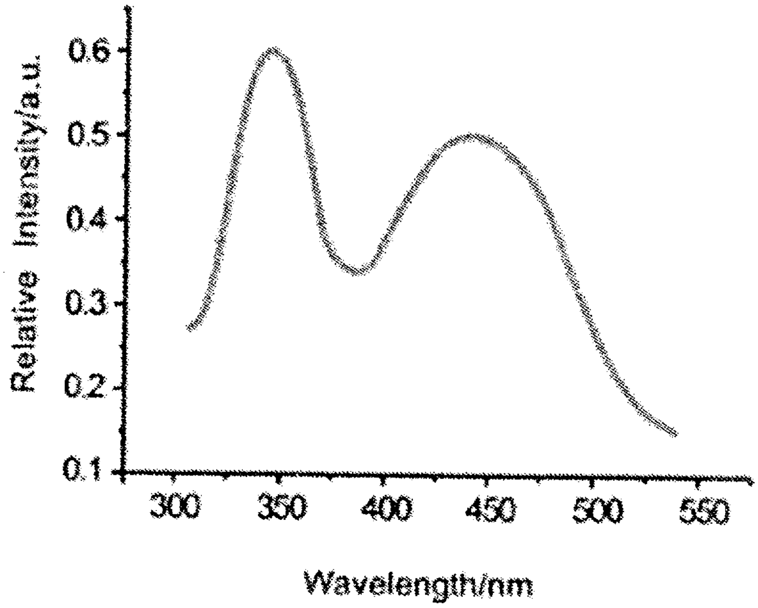


Fig. 19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0.5
0.4
0.3
0.2
0.1
Relative Intensity/a.u.
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350
400
450
500
550
Wavelength/nm

Fig. 20

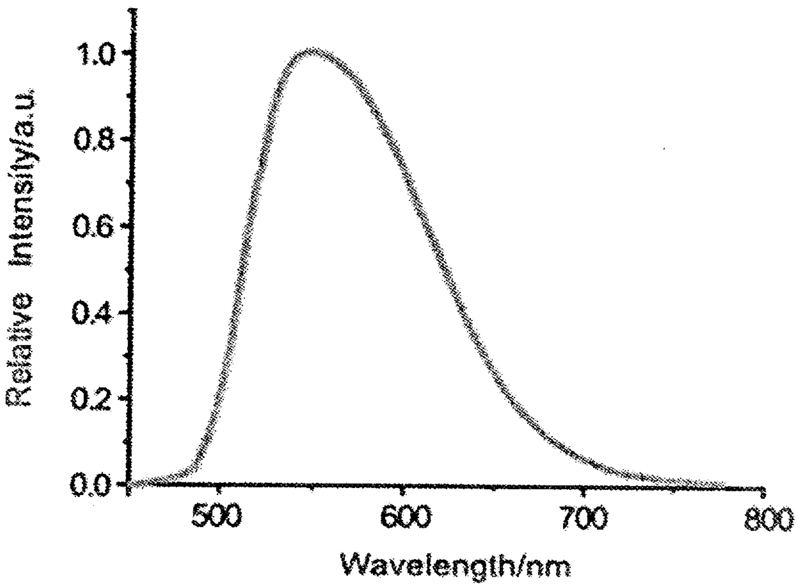

1.0
0.8
0.6
0.4
0.2
0.0
Relative Intensity/a.u.
500
600
700
800
Wavelength/nm

Fig. 21

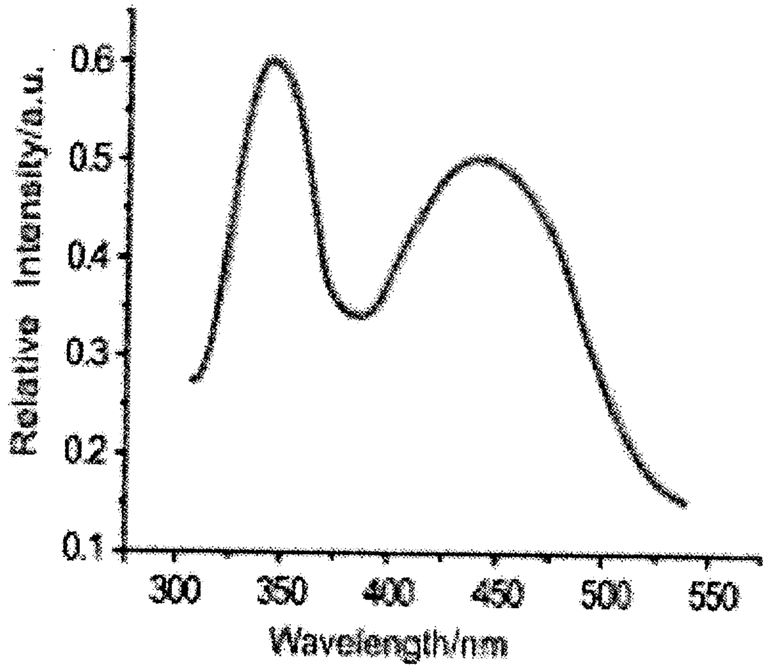
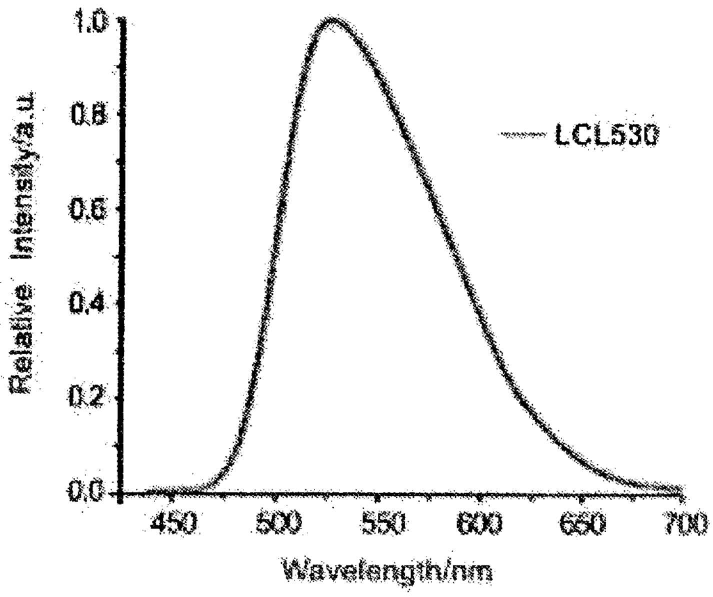

0.6
0.5
0.4
0.3
0.2
0.1
Relative Intensity/a.u.
300
350
400
450
500
550
Wavelength/nm

Fig. 22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0.6
0.4
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Relative Intensity/a.u.
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450
500
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600
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700
Wavelength/nm

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2022/143083

A. CLASSIFICATION OF SUBJECT MATTER

H01L25/075(2006.01)i

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)

IPC: H01L, F21S

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)

CNPAT;EPODOC;WPI;CNKI: illuminate, lighting, daylight, sunlight, melanopsin, melatonin, circadian, phosphor, fluorescent , white, blue

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 112543995 A (IDEAL INDUSTRIES LIGHTING L.L.C.) 23 March 2021 (2021-03-23) description, paragraphs [0108]-[0144] and figures 8-22	1-4,9-15
X	CN 107002957 A (PHILIPS LIGHTING HOLDING B.V.) 01 August 2017 (2017-08-01) description, paragraphs [0032]-[0039] and figures 1-4	1,5-8,14-15
A	CN 101678209 A (KONINKL PHILIPS ELECTRONICS N.V.) 24 March 2010 (2010-03-24) the whole document	1-15
A	CN 102893365 A (CREE INC.) 23 January 2013 (2013-01-23) the whole document	1-15
A	CN 112424962 A (IDEAL INDUSTRIES LIGHTING L.L.C.) 26 February 2021 (2021-02-26) the whole document	1-15
A	US 2019069355 A1 (ECOSENSE LIGHTING INC.) 28 February 2019 (2019-02-28) the whole document	1-15
A	US 2020357958 A1 (LUMILEDS L.L.C.) 12 November 2020 (2020-11-12) the whole document	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
- "D" document cited by the applicant in the international application
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 February 2023	**08 March 2023**

Name and mailing address of the ISA/CN	Authorized officer
CHINA NATIONAL INTELLECTUAL PROPERTY ADMINISTRATION **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088, China**	**CHEN,XiJie**
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2022/143083

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
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				WO	2019231711	A1	05 December 2019
				CA	3101735	A1	05 December 2019
				CA	3101735	C	18 October 2022
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				WO	2016096367	A1	23 June 2016
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				EP	3408586	A1	05 December 2018
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