



(51) International Patent Classification:
H01L 25/16 (2006.01)

(21) International Application Number:
PCT/EP2017/069065

(22) International Filing Date:
27 July 2017 (27.07.2017)

(25) Filing Language: English

(26) Publication Language: English

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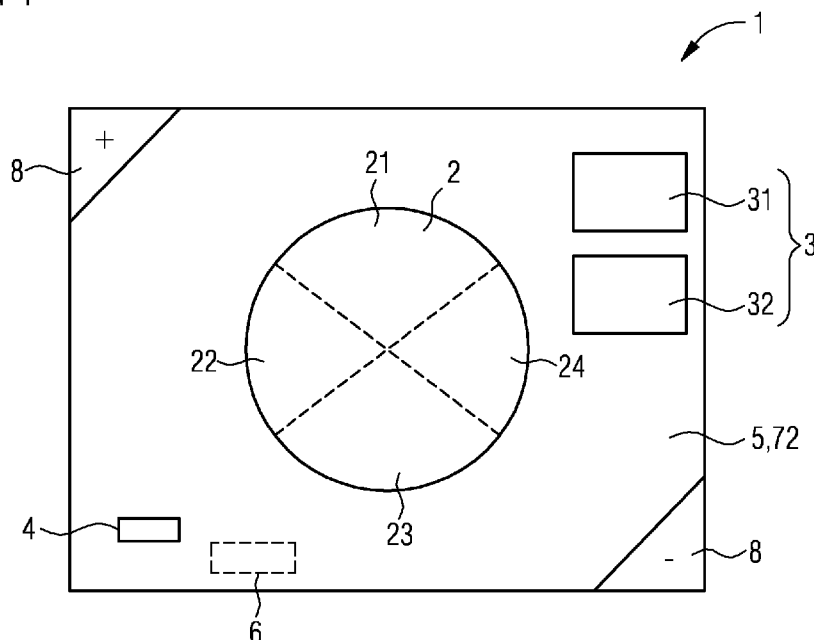
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(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,
DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP,
KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME,
MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,
TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,
EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
KM, ML, MR, NE, SN, TD, TG).

(54) Title: OPTOELECTRONIC SEMICONDUCTOR DEVICE AND METHOD FOR OPERATING AN OPTOELECTRONIC SEMICONDUCTOR DEVICE

FIG 1



(57) Abstract: In one embodiment the optoelectronic semiconductor device (1) comprises a light source (2) having a plurality of optoelectronic semiconductor chips (21, 22, 23, 24) to produce light of different colors. Further, the semiconductor device (1) comprises a control unit (3) to control and to drive the optoelectronic semiconductor chips (21, 22, 23, 24) and also comprises a multi-channel micro-spectrometer (4) and a common housing (5). The light source (2), the control unit (3) and the multi-channel micro-spectrometer (4) are firmly connected with each other and mechanically permanently integrated in the common housing (5). An emission spectrum of the light source (2) is controlled by means of optical measurements of the multi-channel micro-spectrometer (4).



Published:

— *with international search report (Art. 21(3))*

Description

Optoelectronic Semiconductor Device and Method for Operating an Optoelectronic Semiconductor Device

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An optoelectronic semiconductor device is provided. Moreover, a method for operating an optoelectronic semiconductor device is provided.

10 An object to be achieved is to provide an optoelectronic semiconductor device that can accurately emit radiation with defined chromaticity coordinates and correlated color temperature.

15 This object is achieved inter alia by an optoelectronic semiconductor device and by a method having the features of the independent claims. Preferred developments are described in the dependent claims.

20 According to at least one embodiment, the semiconductor device comprises a light source. The light source has a plurality of optoelectronic semiconductor chips. The semiconductor chips are designed to produce radiation or light of different colors. It is possible that there is one
25 semiconductor chip to produce each color. Otherwise, the semiconductor chips can be grouped so that each group of semiconductor chips produces the light of a specific color. In particular, the optoelectronic semiconductor chips are configured as light-emitting diode chips, LED chips for
30 short.

According to at least one embodiment, the optoelectronic semiconductor device comprises a control unit. The control

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unit is designed to control and to drive the optoelectronic semiconductor chips or the groups of optoelectronic semiconductor chips. For example, the control unit is or comprises an integrated circuit, IC for short, in particular an application specific integrated circuit, ASIC for short. Moreover, the control unit can comprise components like constant current sources or memory devices.

According to at least one embodiment, the semiconductor device comprises a multi-channel micro-spectrometer. That is, the micro-spectrometer has a plurality of channels wherein each channel can be configured to measure the intensity of light at a specific color and/or at a specific wavelength range. In particular, the multi-channel micro-spectrometer is not just an RGB sensor that can roughly estimate the intensity at the three basic colors, red, blue and green, but the multi-channel micro-spectrometer has significantly more than three channels for different colors, in particular more than one channel for green light as well as more than one channel for blue light and red light.

According to at least one embodiment, the semiconductor device comprises a common housing. The common housing can be the component of the semiconductor device that mechanically stabilizes and carries all other components of the semiconductor device, in particular the light source, the control unit and the multi-channel micro-spectrometer. The housing can be composed of several sub-components.

According to at least one embodiment, the light source, the control unit and the multi-channel micro-spectrometer are firmly connected with each other and mechanically permanently integrated in the common housing. That is, for example, in

the intended use of the light source the mentioned components cannot be purposefully separated from one another. Hence, the semiconductor device can preferably be handled as one single component and as a mechanical unit.

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According to at least one embodiment, an emission spectrum of the light source is controlled by means of optical measurements of the multi-channel micro-spectrometer. In other words, by the measurement of the emission spectrum the light source, in particular the optoelectronic semiconductor chips, are driven in such a way that a desired light spectrum is emitted and/or so that a deviation from the desired light spectrum is minimized.

15 In at least one embodiment the optoelectronic semiconductor device comprises a light source having a plurality of optoelectronic semiconductor chips to produce light of different colors. Further, the semiconductor device comprises a control unit to control and to drive the optoelectronic semiconductor chips as well as a multi-channel micro-spectrometer and a common housing. The light source, the control unit and the multi-channel micro-spectrometer are firmly connected with each other and mechanically permanently integrated in the common housing. An emission spectrum of the light source is controlled by means of optical measurements of the multi-channel micro-spectrometer.

There is growing demand for lighting integration with the so-called Internet of Things, IoT for short. Moreover, there is a demand for adjustable light output that can easily be handled. Thus, microcontrollers, optics, drivers and LEDs can be integrated on a board to enable easy handling. Moreover, adjustable photometric parameters like brightness, color

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saturation and/or color hue are desired. These demands can be achieved by means of the optoelectronic semiconductor device described herein.

5 Controllable semiconductor luminaires are normally based on an open-loop control system. Only certain high-end lighting systems employ closed-loop control schemes. However, these systems currently face several problems. In particular, correlated color temperature, CCT for short, chromaticity
10 coordinates and spectral power distribution, SPD for short, of the generated light changes as a function of age as well as a function of operating conditions like temperature or dimming level. Thus, periodic re-calibration is needed or luminaires of different ages will have a significant
15 difference in chromaticity. Further, such systems are typically designed only for bi-color or red-green-blue-systems, RGB-systems for short.

To enable full control of chromaticity and correlated color
20 temperature, for example, a spectrometer is required to characterize the whole light output spectrum. This is enabled by the semiconductor device described herein with the integrated multi-channel micro-spectrometer. That is, the semiconductor device described herein comprises a built-in
25 photometric control system, PCS for short.

Normal closed-loop lighting control systems typically just employ RGB sensors, lookup tables or iterative methods. However, these models break down when the chromaticity shifts
30 due to heat or dimming. Furthermore, these luminaires typically focus just on CCT control with bi-color or RGB color systems. The method and the device described herein instead allow for full control of the spectral

characteristics, in particular the spectral power distribution, and thus for full control of the CCT and the chromaticity with any relevant number of primary light emitters for general illumination, for example.

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That is, in the present device an integrated micro-spectrometer provides feedback about the instantaneous light spectral power distribution to an on-board micro-controller which then preferably calculates in particular the pulse-width modulation values, PWM for short, and sends them to the integrated LED driver according to an photometric control system algorithm. All relevant photometric data can be directly calculated from the feedback data obtained from the spectrometer.

15

The device and the method described herein show the following advantages, in particular: A feedback data can be obtained that comprises all photometric data that can be calculated from the spectral power distribution. Desired target spectra can be replicated. A chromaticity and CCT shift can be minimized over time. The method described herein practically works for any relevant number of LED channels and wavelengths. Due to the controllable output spectral power distribution a precise control of the light output is enabled. The device described herein can potentially bridge the gap between lighting research and real-world application.

25

The device and the method described here can be used for example in the following applications: In the area of research the device can ensure that results can be replicated easily and accurately, in particular in different laboratories and/or by electronic data transfer so that collaboration can be simplified. In retail, chromaticity and

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CCT shifts over time can be dealt with to enhance color uniformity. Also tunable light sources to suit different applications, for example for clothing or foods like vegetables or meat, can be achieved, in particular in retail applications. In home lighting, light recipes created by experts can be applied with adjustable circadian action factors, CAF for short, defined color rendering indexes, CRI for short, CCT and so on.

According to at least one embodiment, at least the control unit and the multi-channel micro-spectrometer are operated in a closed-loop mode. That is, a feedback loop is established. The light output of the light source is then preferably controlled and adjusted by the periodic measurement of the light output.

According to at least one embodiment, the optoelectronic semiconductor chips are powered by means of pulse width modulation, PWM for short, or bit angle modulation, BAM for short. That is, the optoelectronic semiconductor chips are driven by a constant current source and a brightness of the semiconductor chips is adjusted by the proportion of time the semiconductor chips are driven by this constant current. Otherwise, the brightness of the semiconductor chips can be adjusted by varying the current strength instead of the proportion of time the semiconductor chips are driven.

According to at least one embodiment, a spectral resolution of the multi-channel micro-spectrometer is 20 nm or less or 15 nm or less or 10 nm or less. To reduce data acquisition and calculations, the spectral resolution can be 5 nm or more or 10 nm or more. That is, the spectral resolution of the

multi-channel micro-spectrometer can be comparably low relative to a high-end spectrometer.

According to at least one embodiment, the multi-channel
5 micro-spectrometer is sensitive at least above 420 nm or 380 nm and/or up to at least 650 nm or 700 nm or 780 nm. In particular, the spectrometer is thus sensitive in the whole or nearly the whole visible spectral range.

10 According to at least one embodiment, the light source comprises at least 4 or 5 or 6 different kinds of optoelectronic semiconductor chips or of groups of semiconductor chips. Each kind of semiconductor chip or each group of such semiconductor chips is provided for producing
15 light of a different color. Preferably, the different kinds of semiconductor chip or the different groups are separately electrically addressable. Hence, the light output spectrum of the semiconductor device can be changed by differently controlling the semiconductor chips and/or the groups.

20

According to at least one embodiment, there is at least one optoelectronic semiconductor chip that has a peak wavelength of at least 435 nm or 440 nm and/or of at most 459 nm or 450 nm inclusive. Such a semiconductor chip in particular emits
25 deep blue light. A full width at half maximum, FWHM for short, of the emission spectrum of this semiconductor chip can be at least 10 nm and/or at most 25 nm.

According to at least one embodiment, there is at least one
30 optoelectronic semiconductor chip that has a peak wavelength of at least 460 nm or 465 nm and/or of at most 470 nm or 480 nm or 490 nm inclusive. Such a semiconductor chip in particular emits blue light. A full width at half maximum,

FHWM for short, of the emission spectrum of this semiconductor chip can be at least 10 nm and/or at most 25 nm.

5 According to at least one embodiment, there is at least one optoelectronic semiconductor chip that has a peak wavelength of at least 490 nm or 500 nm and/or of at most 520 nm or 515 nm inclusive. Such a semiconductor chip in particular emits blueish green light. A full width at half maximum, FHWM
10 for short, of the emission spectrum of this semiconductor chip can be at least 15 nm and/or at most 40 nm.

According to at least one embodiment, there is at least one optoelectronic semiconductor chip that has a peak wavelength
15 of at least 525 nm or 540 nm and/or of at most 560 nm or 550 nm inclusive. Such a semiconductor chip in particular emits green light. A full width at half maximum, FHWM for short, of the emission spectrum of this semiconductor chip can be at least 30 nm or 50 nm and/or at most 150 nm or
20 100 nm. It is possible that the green light stems from a phosphor that it optically pumped by blue light or deep blue light, compare above.

According to at least one embodiment, there is at least one
25 optoelectronic semiconductor chip that has a peak wavelength of at least 570 nm or 590 nm and/or of at most 610 nm or 605 nm inclusive. Such a semiconductor chip in particular emits orange light. A full width at half maximum, FHWM for short, of the emission spectrum of this semiconductor chip
30 can be at least 10 nm and/or at most 25 nm.

According to at least one embodiment, there is at least one optoelectronic semiconductor chip that has a peak wavelength

of at least 615 nm or 620 nm and/or of at most 650 nm or 635 nm inclusive. Such a semiconductor chip in particular emits red light. A full width at half maximum, FWHM for short, of the emission spectrum of this semiconductor chip
5 can be at least 10 nm and/or at most 25 nm.

According to at least one embodiment, an output data of the multi-channel micro-spectrometer allows a calculation of the correlated color temperature and/or the chromaticity of an
10 incident light and/or of a light of the light source itself with an accuracy of at most 50 K or 30 K or 10 K and/or of at most 0.04 or 0.02 or 0.01 units in the CIE chromaticity diagram, in particular the $u'v'$ chromaticity diagram. This high accuracy is enabled due to the relatively high spectral
15 resolution of the spectrometer.

According to at least one embodiment, the multi-channel micro-spectrometer has at least 60 or 120 or 240 color channels. As an alternative or in addition, the spectrometer
20 has at most 1100 or 520 or 260 color channels. The color channels are realized, for example, by the pixels of a CCD linear detector.

According to at least one embodiment, a light spectrum
25 emitted by the light source has at least temporarily two or three or more than three local minima in the visible spectral range. The visible spectral range is in particular between 400 nm and 700 nm. Thus, the light spectrum emitted by the light source can have a comparably complex shape.

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According to at least one embodiment, the multi-channel micro-spectrometer temporarily measures an ambient light and/or temporarily measures a radiation emitted by the light

source. That is, the light incident on the spectrometer can be ambient light only, radiation emitted by the light source only or a mixture of ambient light and the radiation of the light source. The radiation emitted by the light source can
5 be calculated as a difference of the intensities when the light source is turned on and when it is turned off. That is, the intensity of ambient light can be subtracted.

According to at least one embodiment, the semiconductor
10 device further comprises at least one data port. The data port is designed for wire-based and/or wire-less communication, preferably with an external computer and/or mobile communication device. Hence, due to the data port it is preferably enabled that the semiconductor device can be
15 controlled by a computer or a mobile communication device. For example, control data or desired spectral emission data is submitted to the semiconductor device through the data port.

20 According to at least one embodiment, the control unit is applied on a back side of the light source. That is, the light source can function as a carrier of the control unit. Hence, the light source itself, for example a printed circuit board of the light source, can be a part of the common
25 housing of the semiconductor device.

According to at least one embodiment, the light source and the multi-channel micro-spectrometer are completely covered by a cover sheet. The cover sheet preferably comprises an
30 optical diffusor so that the cover sheet can appear milky and/or white.

According to at least one embodiment, the cover sheet forms a front face of the common housing and/or of the semiconductor device. In particular, the complete front face can be formed by the cover sheet.

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According to at least one embodiment, the light source, the control unit and the multi-channel micro-spectrometer are arranged in a common plane. For example, these components are embedded in a casting body, for example in a direct manner so that the casting body directly and completely surrounds every one of the mentioned components when seen in top view.

10

According to at least one embodiment, the casting body is diffusive reflective for visible light. In particular, the casting body appears white.

15

According to at least one embodiment, the casting body forms part of the front face of the common housing. Other parts of the front face are then formed, for example, by a light entrance face of the spectrometer and/or by a light output face of the light source. That is, the casting body is preferably a part of the common housing and can be the mechanically stabilizing and carrying part of the common housing.

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According to at least one embodiment, a semiconductor device comprises a plurality of light sources. In this case, there is preferably only one multi-channel micro-spectrometer and/or no more light sensors in the semiconductor device.

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According to at least one embodiment, each one of the light sources is optically coupled to the multi-channel micro-spectrometer. This is done, for example, by means of at least

one optical waveguide. Hence, it is possible to control more than one light source with the spectrometer. This allows for reduced costs.

5 Also provided is a method for operating at least one semiconductor device, as described in conjunction with one or more of the aforementioned embodiments. Features of the semiconductor device are therefore also disclosed for the method and vice versa.

10

In at least one embodiment, the method comprises the step of measuring at least temporarily an ambient light spectrum and/or a light source output spectrum by the multi-channel micro-spectrometer. It is possible for these spectra to be
15 measured continuously.

In at least one embodiment, the method comprises the step of calculating a deviation to a target spectrum. In particular, the deviation is the difference between the light source
20 output spectrum and the target spectrum. As an alternative, the deviation can be a difference between a target spectrum and the mixture of ambient light and light source output light.

25 In at least one embodiment, the method comprises the step of controlling the light source to minimize the deviation to the target spectrum. To do this, the target spectrum is preferably iteratively compared with the spectrum measured by the spectrometer.

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According to at least one embodiment of the method, the ambient light spectrum, the light source output spectrum and the deviation to the target spectrum are expressed as vectors

or matrices. For example, components of the vectors or the matrices are the intensities at specific wavelengths and/or the chromaticity coordinates and/or the correlated color temperature.

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According to at least one embodiment of the method, the target spectrum is fixedly programmed and/or scribed into the control unit. Hence, the target spectrum need not be adjusted or changed during the use of the semiconductor device. As an
10 alternative, the target spectrum is set by an external control port. That is, the target spectrum and, thus, the light source output spectrum can be controlled and adjusted by means of the external control port. For example, the external control port is a computer or a mobile unit like a
15 smartphone.

An optoelectronic semiconductor device and the method described herein will be described in greater detail hereinafter with reference to the drawings with the aid of
20 exemplified embodiments. Like reference numerals designate like elements in the individual figures. However, none of the references are illustrated to scale. Rather, individual elements can be illustrated excessively large for ease of understanding.

25

In the drawings:

Figures 1 to 3 show exemplary embodiments of optoelectronic semiconductor devices described herein;

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Figures 4 to 6 show a method to operate an optoelectronic semiconductor device described herein; and

Figures 7 to 13 schematically show optical properties and applications to be achieved by the method described herein.

5 Figure 1 shows a top view of an exemplary embodiment of an optoelectronic semiconductor device 1. The semiconductor device 1 comprises a light source 2. The light source 2 is composed of optoelectronic semiconductor chips 21, 22, 23, 24 which are realized as light-emitting diode chips. The
10 semiconductor chips 21, 22, 23, 24 emit in different colors. The semiconductor chips 21, 22, 23, 24 which are illustrated only schematically can be electrically independent of each other so that the light source can emit light with an adjustable color. For example, the semiconductor device 1 can
15 emit white light or colored light by means of the light source 2.

Further, the semiconductor device 1 comprises a control unit 3. For example, the control unit is composed of a driver 31
20 like a constant current source and a microcontroller 32. By means of the control unit 3, the semiconductor chips 21, 22, 23, 24 can be driven in a controlled manner, in particular by means of pulse width modulation.

25 Further, the semiconductor device 1 comprises a multi-channel micro-spectrometer 4. The spectrometer 4 is sensitive in particular in the visible spectral range and is designed to record a complete spectrum in the visible range. Thus, the spectrometer 4 is not just an RGB sensor. Electrical
30 connections and data lines between the spectrometer 4, the control unit 3 and the light source 2 are not shown to simplify the illustration in Figure 1.

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Moreover, there are electric contacts 8, for example in corner regions of the semiconductor device 1. By means of the electrical contacts 8, the semiconductor device can be externally electrically connected, in particular to a power source like a current source.

As an option, as in all other exemplary embodiments, there is a data port. By means of the data port 6, information about a spectrum to be emitted by the semiconductor device 1 can be sent to it. The data port 6 can be designed for wireless communication or can also be a plug to enable a wire-based data connection. It is possible that the function of the data port 6 can be integrated in the electrical contact areas 8 so that a data line is led to the semiconductor device 1 by means of the electric contact areas 8.

All the components 2, 3, 4 and optionally 6 are integrated in a casting body 72 that forms a common housing 5 of the semiconductor device 1. For example, the casting body 72 appears white to an observer. It is possible that the control unit 3 is covered by the casting body 72 so that the control unit 3 is not visible from an exterior of the semiconductor device 1, when seen on the front side.

The housing 5 is, for example, based on the device Soleriq S19 from Osram Opto Semiconductors. The disclosure content of the Soleriq S19 is hereby incorporated by reference concerning the package. That is, a chip-on-board package can be used.

The spectrometer 4 is, for example, a micro-spectrometer, type C2666MA from Hamamatsu. The disclosure content

concerning said micro-spectrometer is incorporated by reference.

In the exemplary embodiment as shown in the sectional view in Figure 2, the light source 2 itself forms part of the housing 5. For this purpose, the light source 2 can comprise a printed circuit board or a ceramic board. The control unit 3 and optionally the data port 6 are mounted on a rear side of the light source 2. A front side of the light source 2 is completely covered with a cover sheet 71 that also covers the spectrometer 4. A wiring 81 connects the spectrometer 4 with the control unit 3 and, thus, indirectly also with the light source 2. Thus, the common housing 5 includes the board of the light source 2 or consists thereof.

Another exemplary embodiment is shown in the sectional view in Figure 3. The semiconductor device 1 comprises a plurality of the light sources 2. Each one of the light sources 2 is optically connected by means of an optical waveguide 9 with the spectrometer 4. Thus, the light emitted by the different light sources 2 can be detected independently of each other in the spectrometer 4 as well as ambient light.

The common housing 5 comprises a circuit board 73 that can include the control unit 3, for example. The light sources 2 are mounted on this circuit board 73 that can optionally be covered with a casting body, not shown.

Moreover, in Figure 3 it is illustrated that an external control port 10 is present, for example a smartphone or a computer. By means of the external control port 10 together with the data port 6 and the control unit 3, the

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semiconductor device 1 can be controlled so that the light output can be adjusted by a user.

In Figure 4A, a control scheme for a photometric control system implemented in the semiconductor device 1 is illustrated. In a step D, the light spectrum from the micro-spectrometer 4 is instantaneous read. Thus, an input for the step D is an ambient light spectrum, see box A, and a luminaire light output, see box I, for example.

In a step E, light spectrum vectors or matrices are normalized and then a deviation, called delta vector, is calculated, see step F. In step F, a further input can be the user-defined target spectrum, in particular in the form of a target spectrum vector, see box B.

Then, see step G, the delta vectors are read preferably channel-wise, wherein as a further input there can be dominant wavelengths and full width at half maximum values of the channels of the spectrometer 4, compare box J.

Then, new channel duty cycles for the PWM are calculated, see step H. Concerning this step H, as a further input acceptable error margins can be introduced, see box C.

Then, in step K, pulse width modulation values are written to all color channels of the light source 2 so that the new luminaire light output, box I, is produced that serves as the next input data set for the next iterative round starting with step D again.

Thus, by means of this exemplary scheme, the semiconductor device 1 can iteratively be driven and the desired light

output can be achieved, compare the schematic representation of the power against the time in Figure 4B. Over a relatively short period of time of about 1 minute, the desired steady state is reached. Due to the closed loop control scheme, an overshoot can be corrected. The gain can be adjusted to reach the desired steady state comparably fast and to avoid instabilities in the iterative scheme, in particular to avoid large overshoots.

10 In Figure 5, a different representation of the control scheme is illustrated. A target matrix is provided that is compared with the read matrix from the spectrometer 4 to calculate a delta matrix. By means of a control algorithm, in the control unit 3 the data is processed, also taking into account
15 possible disturbances. In particular, the ambient light spectrum is considered, for example subtracted. The incident light on a light detection surface is led to the spectrometer 4 that provides the matrix to be read and to be compared with the target matrix and the closed loop control scheme starts
20 again. Input to the algorithm are e_z , size and/or K_z , for example.

In Figure 6, the CIE diagram in uv coordinates is shown. Coming from starting point I, a variation of the light output
25 is made. For example a comparably bad point II is reached. From this point II, a better point III is reached. By iteration, as a target the desired point IV is achieved. The iterative steps are illustrated by the line and by the crosses in Figure 6.

30

The color control and the correlated color temperature control are enabled, for example, by means of lookup tables and/or by means of iterative methods like hill climbing.

In Figure 7, a possible application is illustrated. From the different optoelectronic semiconductor devices 1, light L1, L2 is emitted. Near window 11, sunlight L3 is also applied to a work plane 12. That is, the device 1 near the window 11 does not need to be fully powered but a light output of just 20% might be sufficient to come to the desired illumination strength at the work plane 12.

Corresponding adjustment of the devices 1 can be achieved by means of the spectrometer. That is, energy-saving by daylight harvesting or occupancy sensing can be realized. Thus, sensors like pyroelectric infrared sensors or passive infrared sensors, PIR for short, additional ambient light sensors, ultrasonic sensors, acoustic sensors and/or pressure sensors can also be present in the semiconductor device 1 or as external sensors as is also possible in all the other exemplary embodiments. By a combination of daylight harvesting and/or occupancy sensing, for example an energy-saving rate of around 15% to 60% is possible.

Figure 8 illustrates a spectrum of a semiconductor device 1 described here having eight different optoelectronic semiconductor chips that emit at the peak wavelengths as given in Figure 8. That is, a quite complex spectral emission pattern can be achieved by the individual semiconductor chips together. A correction or adjustment of this complex spectrum composed of the light of the different semiconductor chips cannot be efficiently realized by just an RGB sensor but the multi-channel micro-spectrometer is required. Thus, the feedback data of the spectrometer includes all photometric data that can be calculated from the spectral power distribution so that a larger number of color channels and

LED channels with different emission wavelengths can be precisely controlled. Zero user calibration is needed.

In Figure 9 it is illustrated that an increasing deviation
5 from a starting value occurs along a life time or readout time. With just an RGB sensor, user recalibration is needed or light sources of different ages will have a noticeable difference in chromaticity. By means of the multi-channel micro-spectrometer, the emission of different colors due to
10 the aging of the semiconductor chips can be corrected.

Figure 10 shows that, depending on the temperature, the emission characteristics of red, green and blue emitting semiconductor chips significantly change. Without the multi-
15 channel micro-spectrometer, these temperature shifts can only be minimally corrected or not be corrected at all.

Figures 11 to 13 show examples of the control effect in the semiconductor devices 1 described herein. Figure parts A
20 provide the target spectrum and the tuned spectrum, Figure parts B show the essential photometric parameters, in particular the $u'v'$ -coordinates in the CIE chromaticity diagram, the correlated color temperatures, the color rendering indexes and the deviations in the chromaticity
25 coordinates and in the correlated color temperatures achieved due to controlling of the light source by means of the spectrometer.

From Figure 11 it can be seen that the control scheme works
30 very well for comparably simple spectra with only negligible differences between the target spectrum and the output spectrum.

According to Figure 12, the target spectrum has a comparably high intensity proportion in the red spectral range. For this reason, the tuned spectrum resembles the target spectrum with increased deviation. However, the deviation in chromaticity
5 and in correlated color temperature is still small.

According to Figure 13, a relatively high correlated color temperature is desired. Also in this case, comparably small deviations in the chromaticity coordinates and in the
10 correlated color temperature can be reached.

With the semiconductor device 1 and the method described here, chromaticity coordinate and CCT shifts over time are minimized. Chromaticity uniformity between different
15 luminaires can be enhanced. The light output can be tuned remotely to suit applications without user calibration. Download and application of high quality light spectra is enabled. Thus, light recipes created by experts with adjustable CAF, with high feeling of contrast index FCI
20 and/or high color rendering index CRI can be used without user calibration. Brand recognition can be enhanced by such a device 1.

The invention is not limited by the description using the
25 exemplified embodiments. Rather, the invention includes any new feature and any combination of features included in particular in any combination of features in the claims, even if this feature or this combination itself is not explicitly stated in the claims or exemplified embodiments.

Reference Signs

	1	optoelectronic semiconductor device
	2	light source
5	21	optoelectronic semiconductor chip
	22	optoelectronic semiconductor chip
	23	optoelectronic semiconductor chip
	24	optoelectronic semiconductor chip
	3	control unit
10	31	driver
	32	micro-controller
	4	multi-channel micro-spectrometer
	5	housing
	6	data port
15	71	cover sheet
	72	casting body
	73	circuit board
	8	electric contact area for external electric contact
	81	wiring
20	9	optical waveguide
	10	external control port
	11	window
	12	work plane
	L	light
25		

Claims

1. Optoelectronic semiconductor device (1) comprising
- a light source (2) having a plurality of optoelectronic
5 semiconductor chips (21, 22, 23, 24) to produce light of
different colors,
- a control unit (3) to control and to drive the
optoelectronic semiconductor chips (21, 22, 23, 24),
- a multi-channel micro-spectrometer (4), and
10 - a common housing (5)
wherein
- the light source (2), the control unit (3) and the multi-
channel micro-spectrometer (4) are firmly connected with each
other and mechanically permanently integrated in the common
15 housing (5), and
- an emission spectrum of the light source (2) is controlled
by means of optical measurements of the multi-channel micro-
spectrometer (4).
2. Optoelectronic semiconductor device (1) according to the
20 preceding claim,
wherein at least the control unit (3) and the multi-channel
micro-spectrometer (4) are operated in a closed-loop mode,
and
wherein the optoelectronic semiconductor chips (21, 22, 23,
25 24) are powered by means of pulse width modulation or bit
angle modulation.
3. Optoelectronic semiconductor device (1) according to any
one of the preceding claims,
wherein a spectral resolution of the multi-channel micro-
30 spectrometer (4) is 20 nm or less,

wherein the multi-channel micro-spectrometer (4) is sensitive at least above 420 nm up to at least 680 nm.

4. Optoelectronic semiconductor device (1) according to anyone of the preceding claims,

5 wherein the light source (2) comprises at least five different kinds of optoelectronic semiconductor chips (21, 22, 23, 24) for producing light of different colors and which are separately electrically addressable.

5. Optoelectronic semiconductor device (1) according to any
10 one of the preceding claims,
wherein

- at least one of the optoelectronic semiconductor chips (21, 22, 23, 24) has a peak wavelength of between 435 nm and 459 nm inclusive,

15 - at least one of the optoelectronic semiconductor chips (21, 22, 23, 24) has a peak wavelength of between 460 nm and 480 nm inclusive,

- at least one of the optoelectronic semiconductor chips (21, 22, 23, 24) has a peak wavelength of between 490 nm and
20 520 nm inclusive,

- at least one of the optoelectronic semiconductor chips (21, 22, 23, 24) has a peak wavelength of between 525 nm and 560 nm inclusive,

- at least one of the optoelectronic semiconductor chips (21,
25 22, 23, 24) has a peak wavelength of between 570 nm and 610 nm inclusive, and

- at least one of the optoelectronic semiconductor chips (21, 22, 23, 24) has a peak wavelength of between 615 nm and 650 nm inclusive.

30 6. Optoelectronic semiconductor device (1) according to anyone of the preceding claims,

- 25 -

wherein an output data of the multi-channel micro-spectrometer (4) allows a calculation of a correlated color temperature and chromaticity coordinates $u'v'$ of an incident light with an accuracy of at most 30 K and 0.02,

5 respectively, as well as of an intensity of the incident light,

wherein the multi-channel micro-spectrometer (4) has at least 120 color channels.

7. Optoelectronic semiconductor device (1) according to
10 anyone of the preceding claims,
wherein a light spectrum emitted by the light source (2) when in use has at least temporarily three or more than three local minima in the visible spectral range.

8. Optoelectronic semiconductor device (1) according to
15 anyone of the preceding claims,
wherein the multi-channel micro-spectrometer (4) when in use temporarily measures an ambient light and temporarily measures a radiation emitted by the light source (2).

9. Optoelectronic semiconductor device (1) according to
20 anyone of the preceding claims,
further comprising a data port (6) which is designed for wire-based and/or wire-less communication with an external computer and/or mobile communication device.

10. Optoelectronic semiconductor device (1) according to
25 anyone of the preceding claims,
wherein the control unit (3) is applied on a back side of the light source (2), and
wherein the light source (2) and the multi-channel micro-spectrometer (4) are completely covered by a cover sheet (71)

which comprises an optical diffuser, the cover sheet (71) forms a front face of the common housing (5).

11. Optoelectronic semiconductor device (1) according to anyone of the preceding claims 1 to 9,

5 wherein the light source (2), the control unit (3) and the multi-channel micro-spectrometer (4) are arranged in a common plane and are embedded in a casting body (72) which is diffusive reflective and which forms part of a front face of the common housing (5).

10 12. Optoelectronic semiconductor device (1) according to anyone of the preceding claims, comprising a plurality of the light sources (2) and only one multi-channel micro-spectrometer (4),
wherein each one of the light sources (2) is optically
15 coupled to the multi-channel micro-spectrometer (4) by means of an optical waveguide (9).

13. Method for operating at least one optoelectronic semiconductor device (1) according to anyone of the preceding claims,

20 wherein an ambient light spectrum and a light source output spectrum are at least temporarily measured by the multi-channel micro-spectrometer (4),
wherein a deviation to a target spectrum is calculated, and
wherein the light source (2) is controlled to minimize the
25 deviation to the target spectrum.

14. Method according to the preceding claim,
wherein the ambient light spectrum, the light source output spectrum and the deviation to the target spectrum are expressed as vectors or matrices,

- 27 -

the target spectrum is fixedly programmed into the control unit (3) or is set by an external control port (10).

FIG 1

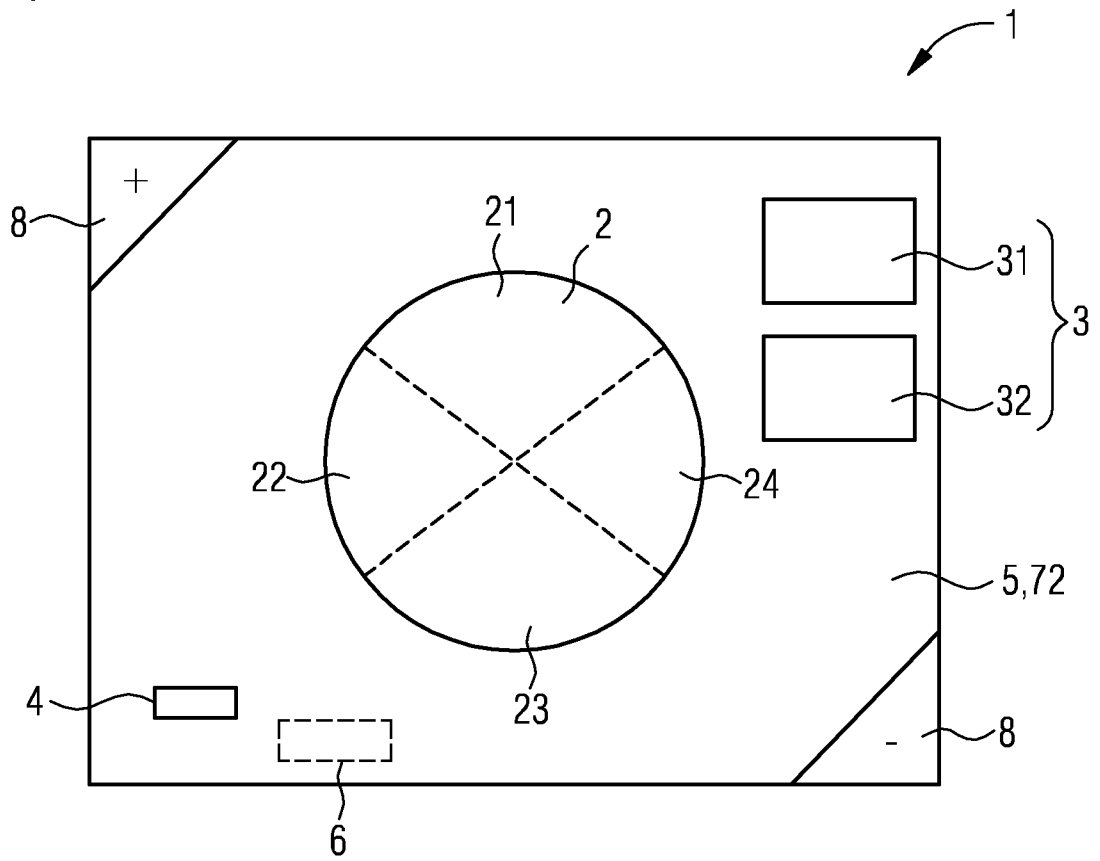


FIG 2

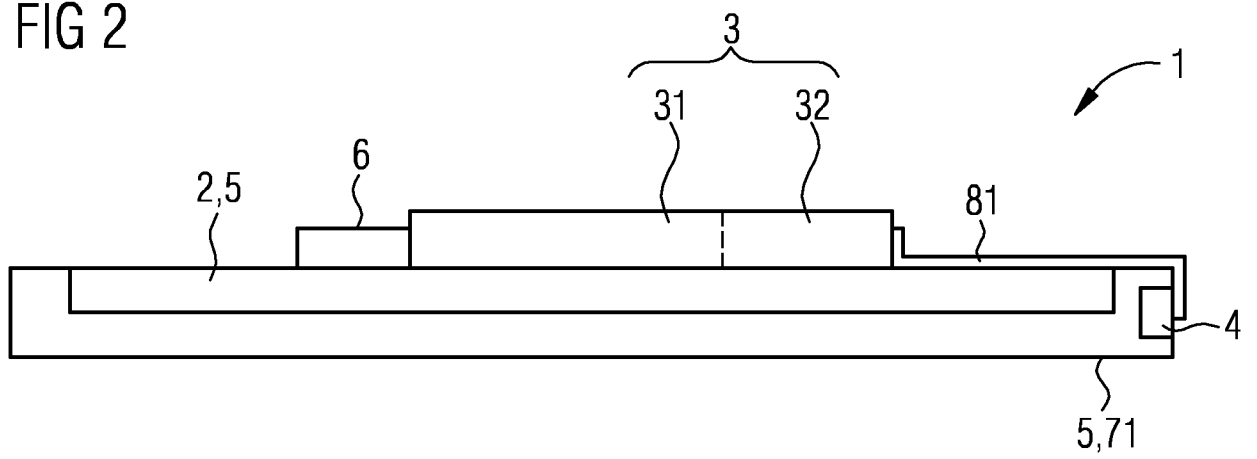


FIG 3

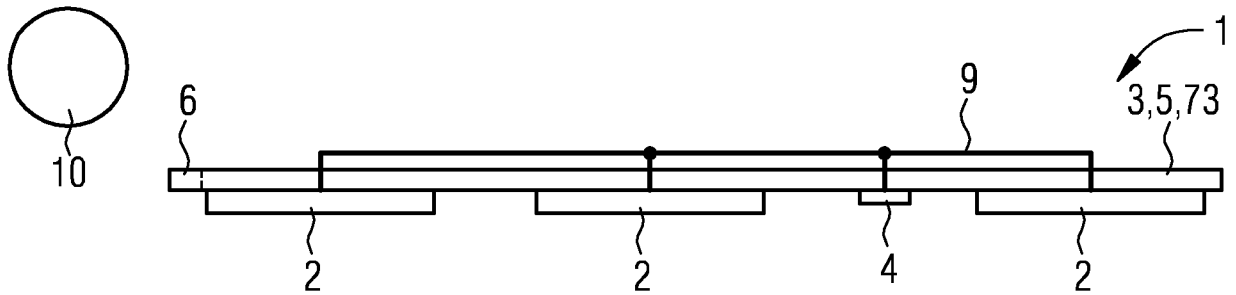


FIG 4

A)

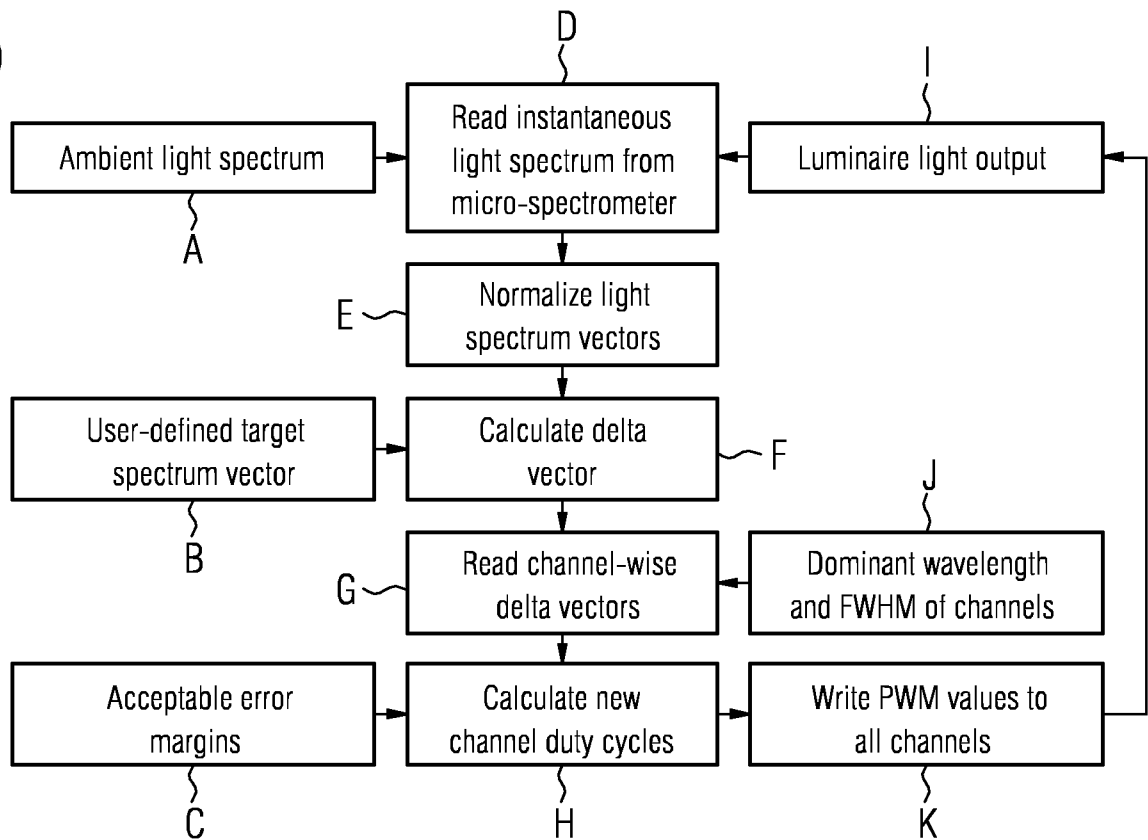


FIG 4

B)

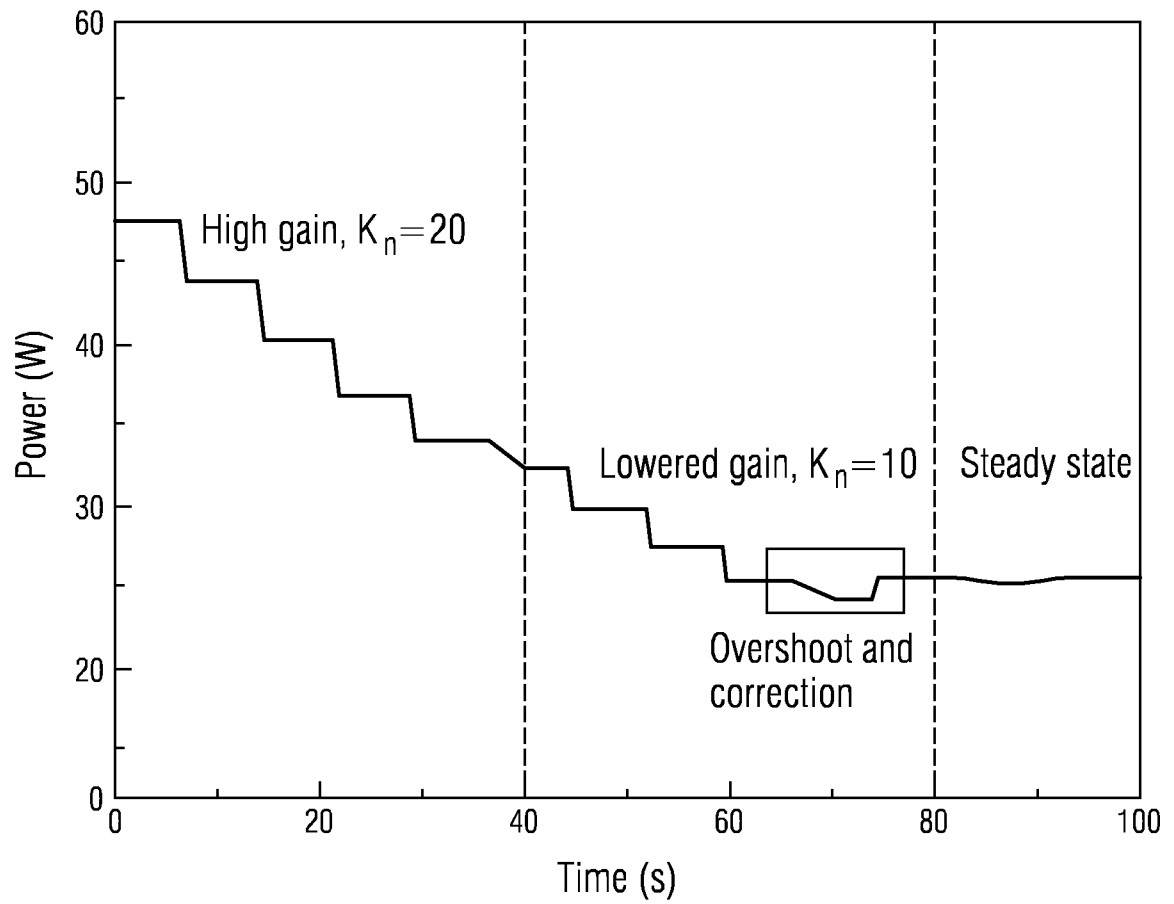


FIG 5

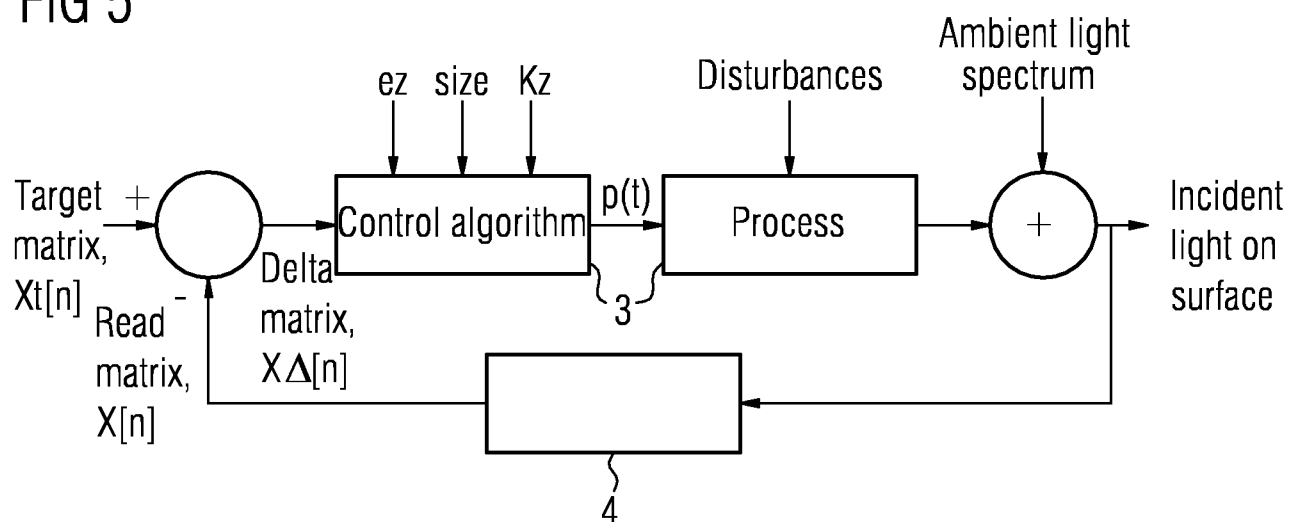


FIG 6

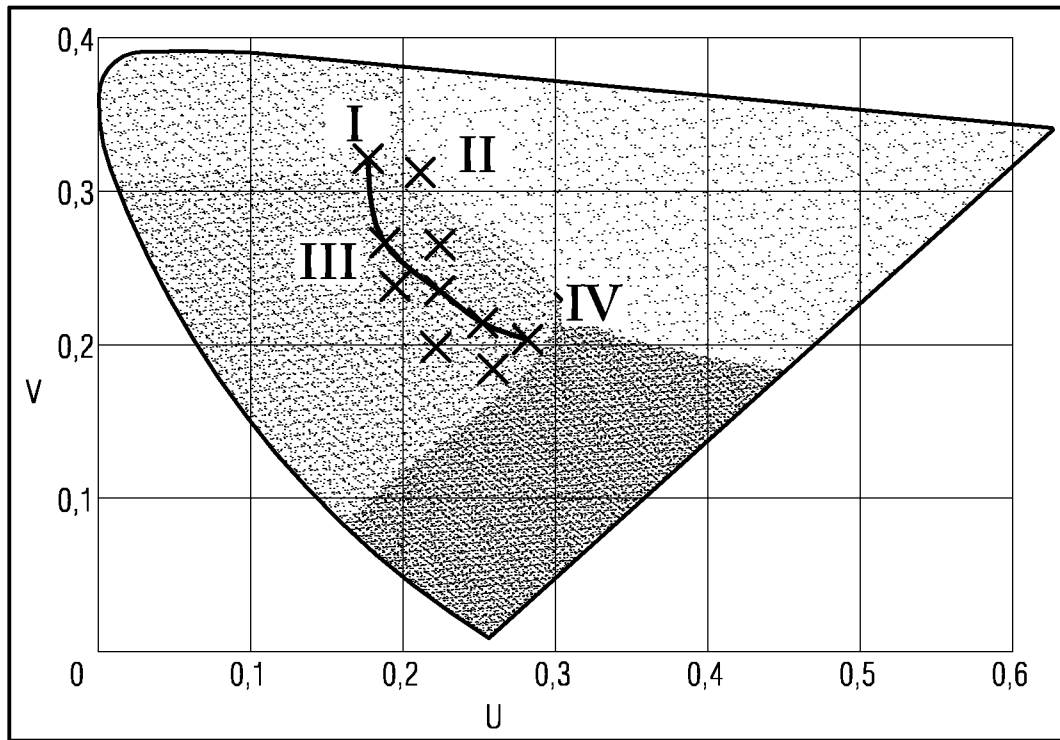


FIG 7

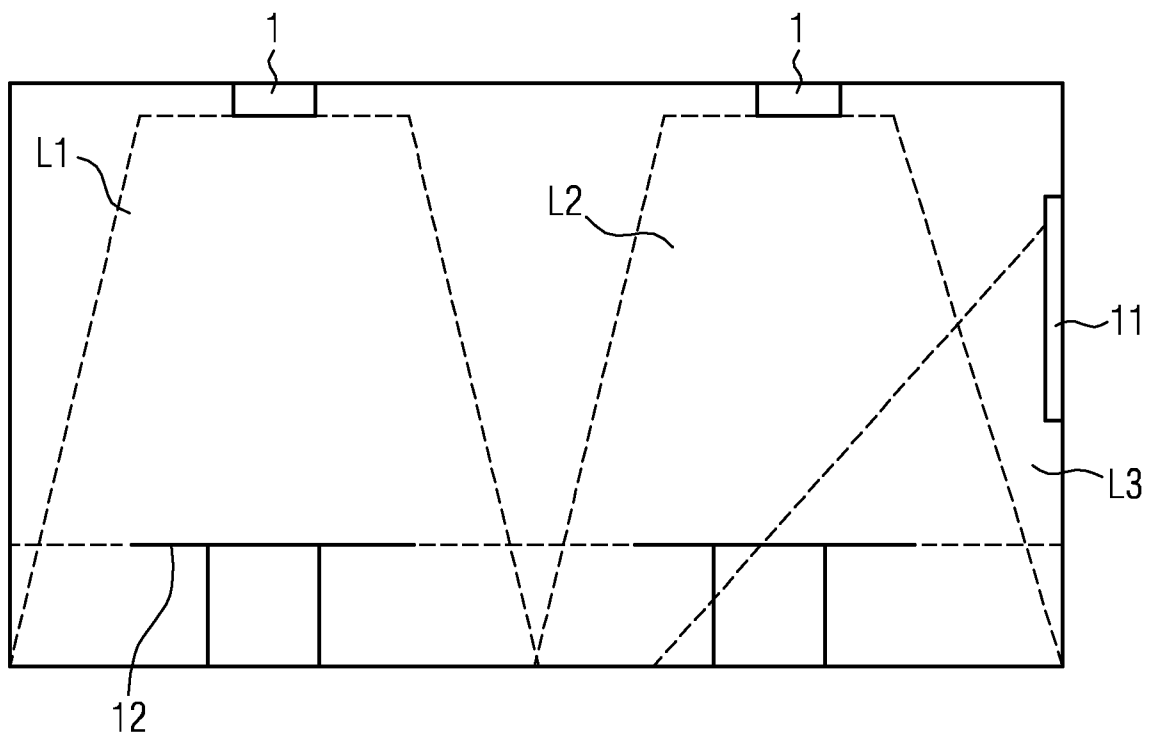


FIG 8

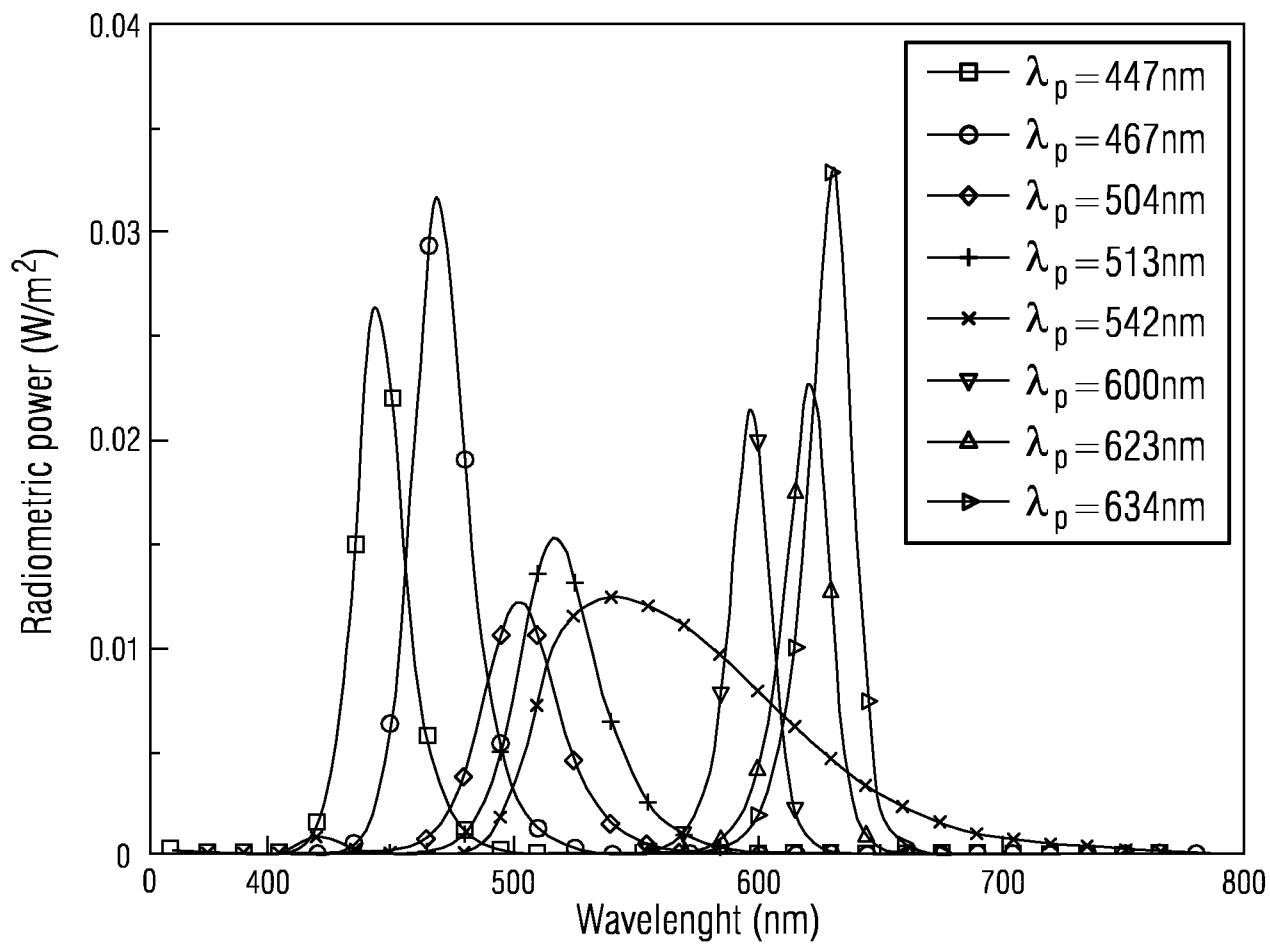


FIG 9

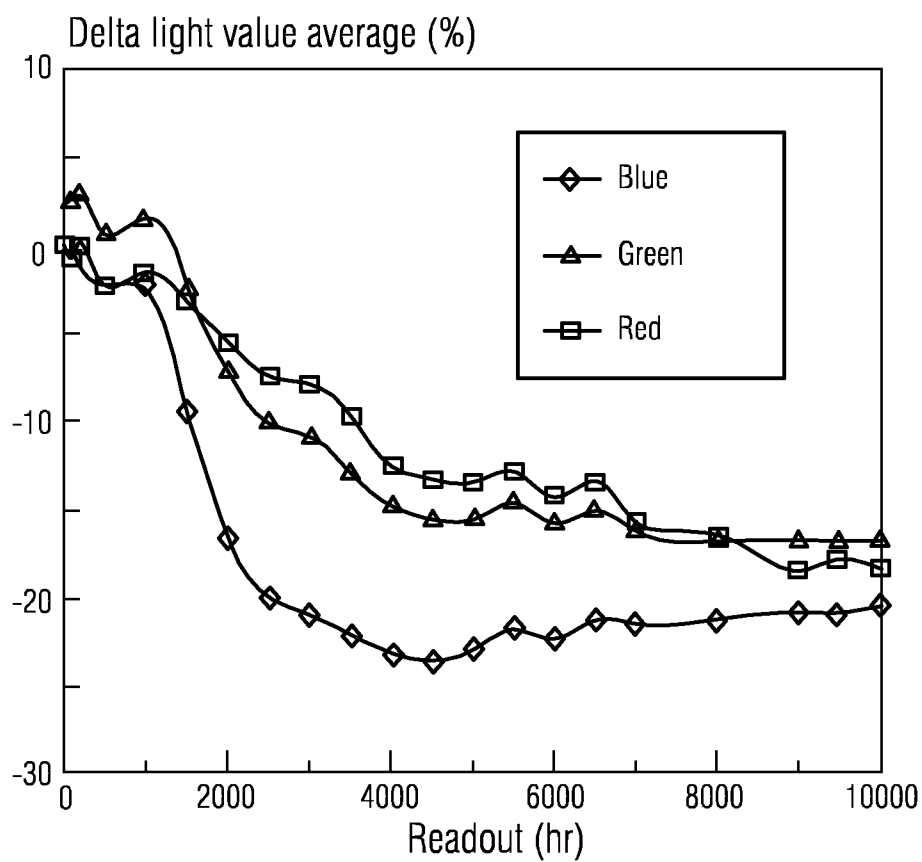


FIG 10

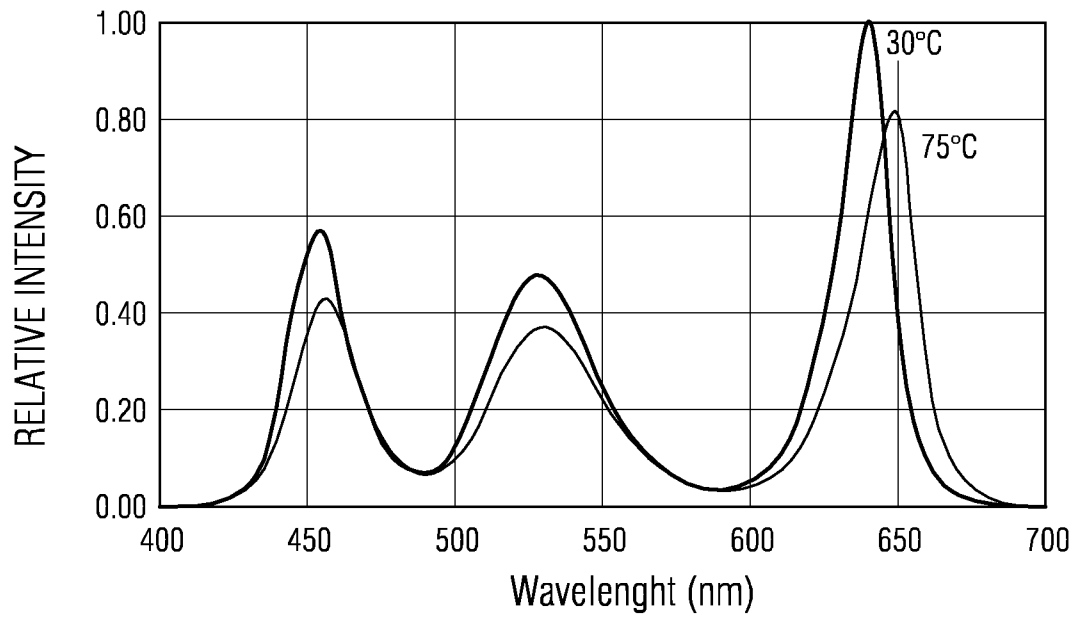


FIG 11

A)

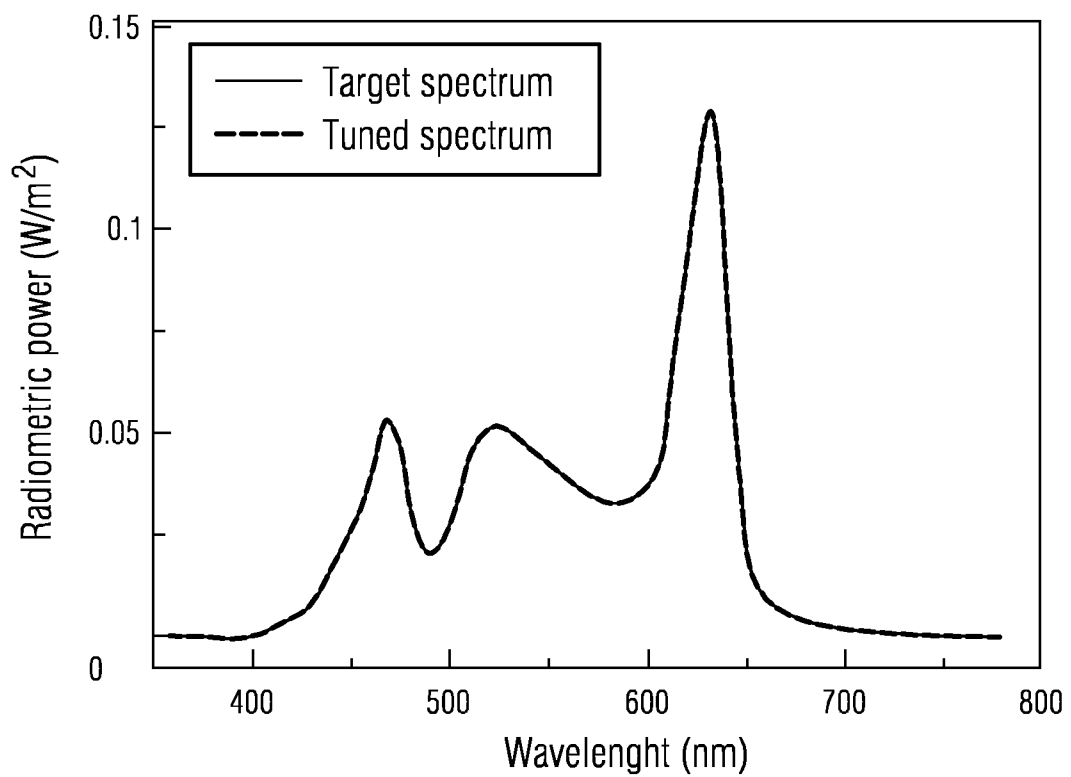


FIG 11

B)

Parameter	Target Spectrum	Output Spectrum
u'	0.2368	0.2371
v'	0.5039	0.5044
CCT (K)	3547	3532
CRI	78	78
$\Delta u' v'$	0.00058	
ΔCCT	0.42%	

FIG 12

A)

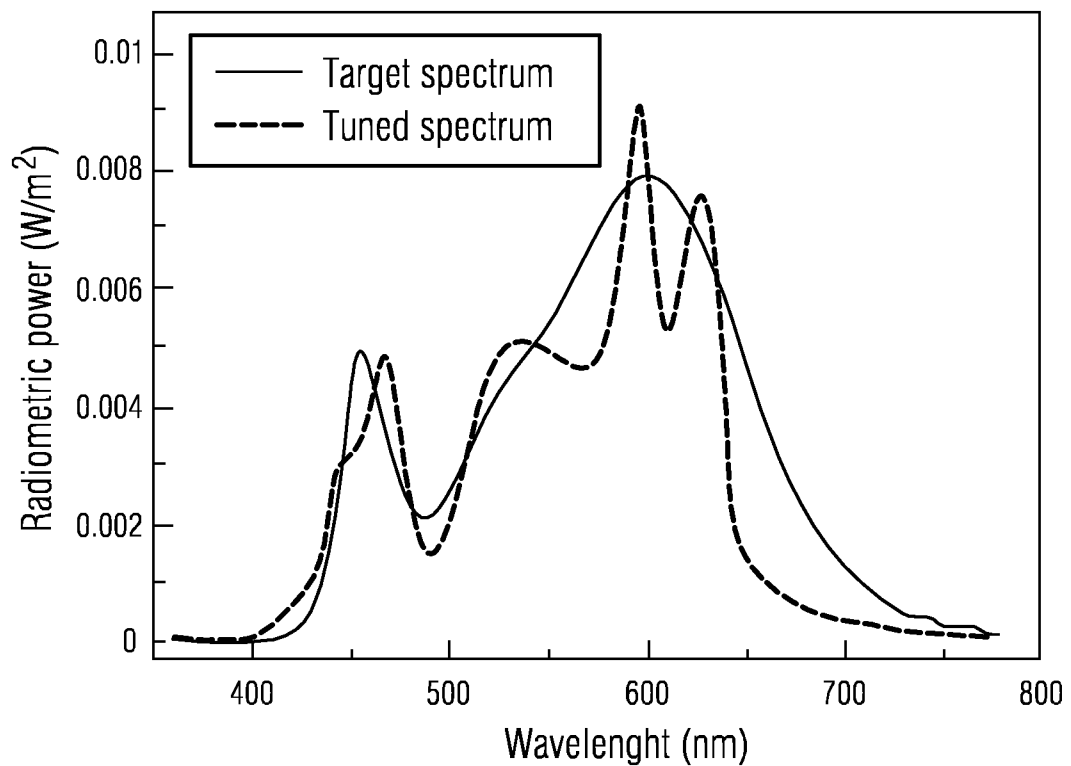


FIG 12

B)

Parameter	Target Spectrum	Output Spectrum
u'	0.2445	0.2458
v'	0.5157	0.5179
CCT (K)	3198	3151
CRI	83	80
$\Delta u' v'$	0.0025	
ΔCCT	1.47%	

FIG 13

A)

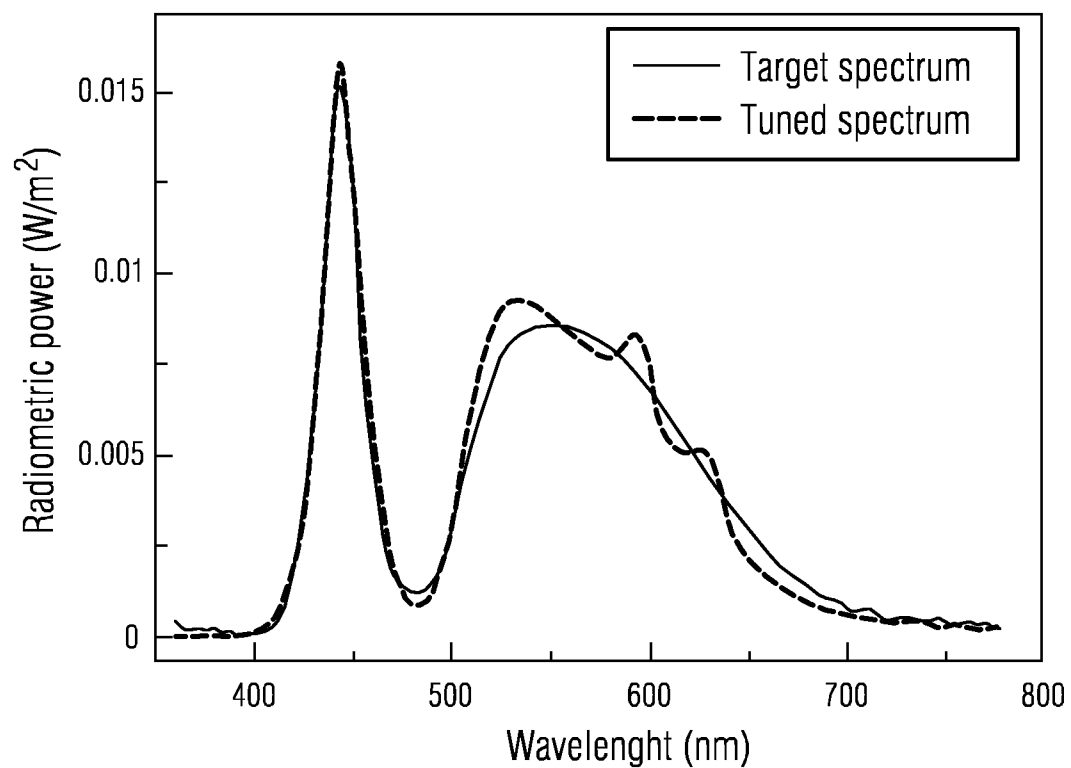


FIG 13

B)

Parameter	Target Spectrum	Output Spectrum
u'	0.2040	0.1987
v'	0.4794	0.4793
CCT (K)	5587	5895
CRI	70	70
$\Delta u' v'$		0.0053
ΔCCT		5.22%

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/069065

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L25/16
ADD.

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

B. FIELDS SEARCHED

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

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

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

EPO-Internal, INSPEC, IBM-TDB, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	DE 10 2013 223069 A1 (OSRAM OPTO SEMICONDUCTORS GMBH [DE]) 13 May 2015 (2015-05-13) paragraphs [0045] - [0050] figures 1-3	1-14
Y	----- US 2010/301777 A1 (KRAEMER REGINE [DE]) 2 December 2010 (2010-12-02) paragraph [0179]	1-14
A	----- WO 03/010830 A2 (KONINKL PHILIPS ELECTRONICS NV [NL]) 6 February 2003 (2003-02-06) page 3, lines 22-29 figure 1 -----	1-14



Further documents are listed in the continuation of Box C.



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Date of the actual completion of the international search

19 March 2018

Date of mailing of the international search report

23/03/2018

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Authorized officer

Adams, Richard

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2017/069065

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