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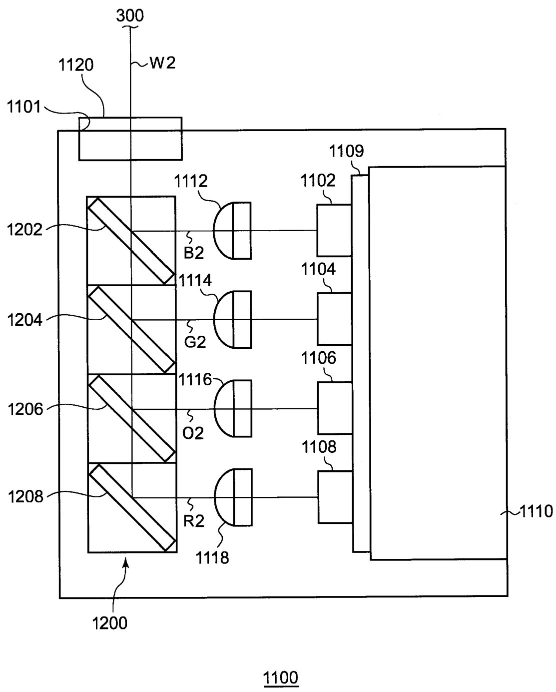
(54) AUTOMOTIVE LAMP

(57) An automotive lamp (1) comprising: a first light source (1102) that emits a blue first laser light (B2); a second light source (1104) that emits a green second laser light (G2); a third light source (1106) that emits a yellow or orange third laser light (02); a fourth light source (1108) that emits a red fourth laser light (R2); and a light condensing unit (1200) that collects each of the first to fourth laser lights so as to generate a white laser light (W2).

FIG.14



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Description

[0001] The present invention relates to an automotive lamp, and more particularly to an automotive lamp used for a vehicle such as an automobile.

[0002] Patent Document 1 discloses an automotive lamp comprised of a semiconductor light source, a mirror, which reflects the light, emitted from the semiconductor light source, around a vehicle, and a scanning actuator for turnably reciprocating the mirror. In this automotive lamp, the scanning actuator drives the mirror at high speed and scans the light reflected by the mirror in a predetermined illumination range around the vehicle, thereby forming a predetermined light distribution pattern in a frontward direction of the vehicle. Hereafter, such an optical system as this will be appropriately referred to as a "scanning optical system" also. Also, in this automotive lamp, a red LED, a green LED and a blue LED are combined and used as the light source.

[0003] [Patent Document 1] Japanese Unexamined Patent Application Publication No. 2010-36835.

[0004] The laser light source can emit light excellent in directivity and convergence in comparison with the LED. Accordingly, the laser light source can help improve the light availability in the automotive light more than the LED. Since the light availability of the automotive lamp can be improved, the laser light can be preferably employed for an automotive lamp equipped with the above-described scanning optical system whose light availability is more likely to be reduced. In the light of this, through diligent research activities on the automotive lamp using the laser light source, the inventors of the present invention have found out that there is room for improvement in the performance of the conventional automotive lamp when the laser light source is used for the conventional automotive lamp.

[0005] Also, the inventors have found out that when the LED is replaced by the laser light source in the above-described conventional automotive lamp, namely when white light is formed by combining the red, green and blue laser lights, an improvement in the color rendering properties is desired.

[0006] The present invention has been made in view of the foregoing circumstances, and one of purposes thereof is to provide a technology that helps improve the performance of an automotive lamp equipped with a laser light source.

[0007] Another purpose thereof is to provide a technology that helps improve the color rendering properties of the automotive lamp equipped with the laser light source.

[0008] In order to resolve the above-described problems, one embodiment of the present embodiment relates to an automotive lamp. The automotive lamp includes: a first light source that emits a first laser light having a peak wavelength in a wavelength region of 450 nm to 475 nm (both inclusive); a second light source that emits a second laser light having a peak wavelength in a wavelength region of 525 nm to 555 nm (both inclusive), wherein an interval between the peak wavelength of the first laser light and the peak wavelength of the second laser light is greater than or equal to 65 nm and less than or equal to 95 nm; a third light source that emits a third laser light having a peak wavelength in a wavelength region of 605 nm to 620 nm (both inclusive), wherein an interval between the peak wavelength of the second laser light and the peak wavelength of the third laser light is greater than or equal to 60 nm and less than 80 nm, and an interval between the peak wavelength of the first laser light and the peak wavelength of the third laser light is less than 170 nm; and a light condensing unit that collects the first to third laser lights so as to generate a white laser light. By employing this embodiment, the performance of the automotive lamp equipped with the laser light sources can be improved.

[0009] In the above-described embodiment, the third laser light may have a peak wavelength in a wavelength region of 610 nm to 620 nm (both inclusive). In any of the above-described embodiments, the first laser light may have a peak wavelength in a wavelength region of 450 nm to 470 nm (both inclusive). By employing these embodiments, the performance of the automotive lamp equipped with the laser light sources can be further improved. Optional combinations of the aforementioned constituting elements, and implementations of the invention in the form of methods, apparatuses, systems and so forth may also be practiced as additional modes of the present invention.

[0010] Another embodiment of the present embodiment relates also to an automotive lamp. The automotive lamp includes: a first light source that emits a blue first laser light; a second light source that emits a green second laser light; a third light source that emits a yellow or orange third laser light; a fourth light source that emits a red fourth laser light; and a light condensing unit that collects each of the first to fourth laser lights so as to generate a white laser light. This embodiment can help improve the color rendering properties of the automotive lamp equipped with the laser light sources.

[0011] In the above-described embodiment, the first laser light may have a peak wavelength in a wavelength region of 450 nm to 470 nm (both inclusive), the second laser light may have a peak wavelength in a wavelength region of 510 nm to 550 nm (both inclusive), the third laser light may have a peak wavelength in a wavelength region of 570 nm to 612 nm (both inclusive), and the fourth laser light may have a peak wavelength in a wavelength region of 630 nm to 650 nm (both inclusive). In the above-described embodiment, the third laser light may have a peak wavelength in a wavelength region of 580 nm to 600 nm (both inclusive). This embodiment facilitates the improvement of the performance of the automotive lamp. It is appreciated here that optional combinations of the aforementioned constituting elements, and implementations of the invention in the form of methods, apparatuses, systems and so forth may also be practiced as additional modes of the present invention.

[0012] Embodiments will now be described, by way of example only, with reference to the accompanying drawings which are meant to be exemplary, not limiting, and wherein like elements are numbered alike in several Figures, in which:

FIG. 1 is a vertical cross-sectional view schematically showing a structure of an automotive lamp according to a first embodiment;
FIG. 2 is a side view schematically showing a structure of a light source unit;
FIG. 3 is a schematic perspective view of a scanning unit as observed from a front side of a lamp;
FIG. 4 shows an exemplary light distribution pattern formed by an automotive lamp according to an embodiment;
FIG. 5A is a graph showing the spectral distribution of the conventional white LED;
FIG. 5B is a graph showing the spectral distribution of the RGB laser light source;
FIG. 5C is a table showing the color rendering indexes Ra and R9 and the theoretical efficiency of each of RGB laser light source and white LED;
FIG. 6 is a table showing calculation results of average color rendering indexes Ra;
FIG. 7 is a table showing calculation results of average color rendering indexes Ra;
FIG. 8 is a table showing calculation results of average color rendering indexes Ra;
FIG. 9 is a table showing calculation results of special color rendering indexes R9;
FIG. 10 is a table showing calculation results of special color rendering indexes R9;
FIG. 11 is a table showing calculation results of theoretical efficiencies;
FIG. 12 is a table showing calculation results of theoretical efficiencies;
FIG. 13 is a vertical cross-sectional view schematically showing a structure of an automotive lamp according to a second embodiment;
FIG. 14 is a side view schematically showing a structure of a light source unit;
FIG. 15A is a graph showing the spectral distribution of the conventional white LED;
FIG. 15B is a graph showing the spectral distribution of the RGB laser light source;
FIG. 15C is a table showing the color rendering indexes Ra and R9 and the theoretical efficiency of each of RGB laser light source and white LED;
FIG. 16A is a table showing calculation results of chromaticity, average color rendering index Ra, special color rendering index R9 and theoretical efficiency;
FIG. 16B is a graph showing a relationship between the calculation results of chromaticities and a white region;
FIG. 17A is a table showing calculation results of chromaticity, average color rendering index Ra, special color rendering index R9 and theoretical efficiency;
FIG. 17B is a graph showing a relationship between calculation results of chromaticities and a white region;
FIG. 18A is a table showing calculation results of chromaticity, average color rendering index Ra, special color rendering index R9 and theoretical efficiency;
FIG. 18B is a graph showing a relationship between calculation results of chromaticities and a white region;
FIG. 19A is a table showing calculation results of chromaticity, average color rendering index Ra, special color rendering index R9 and theoretical efficiency;
FIG. 19B is a graph showing a relationship between calculation results of chromaticities and a white region;
FIG. 20A is a table showing calculation results of chromaticity, average color rendering index Ra, special color rendering index R9 and theoretical efficiency;
FIG. 20B is a graph showing a relationship between calculation results of chromaticities and a white region;
FIG. 21A is a table showing calculation results of chromaticity, average color rendering index Ra, special color rendering index R9 and theoretical efficiency; and
FIG. 21B is a graph showing a relationship between calculation results of chromaticities and a white region.

[0013] Hereinafter, the present invention will be described based on preferred embodiments with reference to the accompanying drawings.

[0014] The same or equivalent constituents, members, or processes illustrated in each drawing will be denoted with the same reference numerals, and the repeated description thereof will be omitted as appropriate.

[0015] The preferred embodiments do not intend to limit the scope of the invention but exemplify the invention. All of the features and the combinations thereof described in the embodiments are not necessarily essential to the invention.

(First Embodiment)

[0016] FIG. 1 is a vertical cross-sectional view schematically showing a structure of an automotive lamp according to a first embodiment. In FIG. 1, a light source unit 100 is shown in a state where the interior thereof is seen through. Also, permanent magnets 312 and 314 of a scanning unit 300 are omitted in FIG. 1. The automotive lamp according to the present embodiment is, for instance, an automotive headlamp apparatus that has a pair of headlamp units placed in left- and right-side front parts of a vehicle. Since the pair of headlamp units are of practically identical structure to each other, FIG. 1 shows the structure of either one of the left and right headlamp units, as an automotive lamp 1. Note that the structure of the automotive lamp 1 described below is exemplary and is not limited to the structure shown and explained below.

[0017] The automotive lamp 1 includes a lamp body 2, having an opening on a frontward side of a vehicle, and a transparent cover 4, which covers the opening of the lamp body 2. The transparent cover 4 is formed of resin or glass, having translucency, for instance. A lamp chamber 3, which is formed by the lamp body 2 and the transparent cover 4, contains a supporting plate 6, a light source unit 100, a scanning unit 300, and a control unit 400.

[0018] The light source unit 100 and the scanning unit 300 are supported by the supporting plate 6 at predetermined positions in the lamp chamber 3. The supporting plate 6 is connected to the lamp body 2 by aiming screws 8 at corners of the supporting plate 6. The light source unit 100 has a first light source 102, a second light source 104, a third light source 106, a heatsink 110, a light condensing unit 200, and so forth. The light source unit 100 is fixed on a front surface of the supporting plate 6 such that the heatsink 110 is in contact with the supporting plate 6. A detailed description will be given later of the internal structure of the light source unit 100.

[0019] The scanning unit 300 has a reflector 318. The structure of the scanning unit 300 will be discussed later in detail. The scanning unit 300 is positioned relative to the light source unit 100 in a predetermined manner such that laser light emitted from the light source unit 100 is reflected in a frontward direction of the lamp. And the scanning unit 300 is secured to a protrusion 10 that protrudes on a frontward side of the lamp from the front surface of the supporting plate 6. The protrusion 10 has a pivot mechanism 10a, and the scanning unit 300 is supported by the protrusion 10 via the pivot mechanism 10a. Also, the protrusion 10 has a supporting actuator 10b, having a rod and a motor by which to elongate and contract this rod in the longitudinal directions of the lamp. The tip of the rod is connected to the scanning unit 300. The protrusion 10 enables the scanning unit 300 to make a swing motion by having the rod elongate and contract with the pivot mechanism 10a functioning as a shaft. This can adjust the inclination angle (pitch angle) of the scanning unit 300 in the vertical direction (initial aiming adjustment and the like). The supporting actuator 10b is connected to the control unit 400.

[0020] The control unit 400 includes a lamp ECU, a ROM, a RAM and so forth. Here, the lamp ECU appropriately and selectively executes a control program and generates various control signals. The ROM stores various control programs. The RAM is used for data storage and used as a work area for the programs executed by the lamp ECU. The control unit 400 controls the drive of the supporting actuator 10b, the drive of a scanning actuator described later, the turning on and off of the first light source 102 to the third light source 106, and so forth. The control unit 400 is secured to the lamp body 2 such that the control unit 400 is located behind the supporting plate 6 toward the rear end of the lamp. The position where the control unit 400 is provided is not particular limited to this position.

[0021] The automotive lamp 1 is configured such that the light axis of the automotive lamp 1 is adjustable in the horizontal and vertical directions. More specifically, adjusting the position (posture) of the supporting plate 6 by rotating the aiming screws 8 allows the light axis thereof to be adjusted in the horizontal and vertical directions. An extension member 12, having an opening that allows the light reflected by the scanning unit 300 to travel toward a front area of the lamp, is provided in a frontward side of the light source unit 100 and the scanning unit 300 in the lamp chamber 3. A detailed description is given hereunder of the structures of the light source unit and the scanning unit that constitute the automotive lamp 1.

(Light source unit)

[0022] FIG. 2 is a side view schematically showing a structure of the light source unit. Note that FIG. 2 is a transparent view showing the interior of the light source unit 100. The light source unit 100 has a first light source 102, a second light source 104, a third light source 106, a heatsink 110, a first lens 112, a second lens 114, a third lens 116, a light transmission part 120, a light condensing unit 200, and other components.

[0023] The first light source 102 emits a first laser light B having a peak wavelength in an approximate wavelength region of blue light. The second light source 104 emits a second laser light G having a peak wavelength in an approximate wavelength region of green light. The third light source 106 emits a third laser light O having a peak wavelength in an approximate wavelength region of orange light. A detailed description will be given later of the peak wavelengths of the first laser light B to the third laser light O. The first light source 102 to the third light source 106 are each constituted by a laser diode, for instance, and are mounted on a common substrate 109. Each light source may be constituted by a laser device other than the laser diode.

[0024] The first light source 102, the second light source 104 and the third light source 106 are arranged such that their respective laser light emission surfaces face a front area of the lamp and such that the substrate 109 faces a rear area of the lamp. Also, the first to third light sources 102, 104 and 106 are mounted on a surface of the heatsink 110 that faces a front area of the lamp. The heatsink 110 is formed of a material, having a high thermal conductivity, such as aluminum, for the purpose of efficiently recovering the heat produced by each light source. A rear-side surface of the heatsink 110 is in contact with the supporting plate 6 (see FIG. 1). The heat produced by each light source is radiated through the substrate 109, the heatsink 110 and the supporting plate 6.

[0025] The first lens 112, the second lens 114 and the third lens 116 are each a collimator lens, for instance. The first lens 112 is provided on a light path of the first laser light B between the first light source 102 and the light condensing unit 200, and converts the first laser light B, emitted from the first light source 102 toward the light condensing unit 200, into parallel light. The second lens 114 is provided on a light path of the second laser light G between the second light source 104 and the light condensing unit 200, and converts the second laser light G, emitted from the second light source 104 toward the light condensing unit 200, into parallel light. The third lens 116 is provided on a light path of the third laser light O between the third light source 106 and the light condensing unit 200, and converts the third laser light O, emitted from the third light source 106 toward the light condensing unit 200, into parallel light.

[0026] The light transmission part 120 is fitted to an opening 101 formed in a housing of the light source unit 100. A white laser light W described later passes through the light transmission part 120 from the light condensing unit 200 and travels toward the scanning unit 300.

[0027] The light condensing unit 200 (polarizing unit) collects the first laser light B, the second laser light G and the third laser light O so as to generate the white laser light W. The light condensing unit 200 has a first dichroic mirror 202, a second dichroic mirror 204 and a third dichroic mirror 206.

[0028] The first dichroic mirror 202 is a mirror that reflects at least the first laser light B, and is arranged such it reflects the first laser light B, which has passed through the first lens 112, toward the light transmission part 120. The second dichroic mirror 204 is a mirror that reflects at least the second laser light G and transmits the first laser light B, and is arranged such it reflects the second laser light G, which has passed through the second lens 114, toward the light transmission part 120. The third dichroic mirror 206 is a mirror that reflects at least the third laser light O and transmits the first laser light B and the second laser light G, and is arranged such it reflects the third laser light O, which has passed through the third lens 116, toward the light transmission part 120.

[0029] A mutual positional relation among the dichroic mirrors 202 to 206 is determined such that the light paths of the laser lights reflected by the dichroic mirrors 202 to 206 are parallel to each other and such that their respective laser lights are collected and the thus collected light transmits the light transmission part 120. In the present embodiment, the first dichroic mirror 202 to the third dichroic mirror 206 are arranged such that the areas where the laser lights strike on the respective dichroic mirrors, namely the reflecting points of laser lights, are aligned on a same line.

[0030] The first laser light B emitted from the first light source 102 is reflected by the first dichroic mirror 202 toward the second dichroic mirror 204. The second laser light G emitted from the second light source 104 is reflected by the second dichroic mirror 204 toward the third dichroic mirror 206, and the thus reflected light is simultaneously superposed on the first laser light B that has transmitted the second dichroic mirror 204. The third laser light O emitted from the third light source 106 is reflected by the third dichroic mirror 206 toward the light transmission part 120, and the thus reflected light is superposed on the first laser light B and the second laser light G that have transmitted the third dichroic mirror 206. As a result, the white laser light W is formed. The white laser light W passes through the light transmission part 120 and travels toward the scanning unit 300.

(Scanning unit)

[0031] FIG. 3 is a schematic perspective view of a scanning unit as observed from a front side of the lamp. The scanning unit 300 is a mechanism used to scan the laser lights, emitted from the first light source 102 to the third light source 106, and form a predetermined light distribution pattern (see FIG. 4). The scanning unit 300 includes a base 302, a first rotating body 304, a second rotating body 306, first torsion bars 308, second torsion bars 310, permanent magnets 312 and 314, a terminal part 316, a reflector 318, and so forth. The base 302 is a frame body having an opening 302a in the center, and is secured to the tip of the protrusion 10 (see FIG. 1) such that the base 302 is tilted in the longitudinal directions of the lamp. The terminal part 316 is provided in a predetermined position of the base 302. The first rotating body 304 is arranged in the opening 302a. The first rotating body 304 is a frame body having an opening 304a in the center, and is turnably supported by the first torsion bars 308, which extend, from a rear lower side to a frontal upper side of the lamp, laterally (in the vehicle width direction) in relation to the base 302.

[0032] The second rotating body 306 is arranged in the opening 304a of the first rotating body 304. The second rotating body 306 is a rectangular plate, and is turnably supported by the second torsion bars 310, which extend in the vehicle width direction, vertically in relation to the first rotating body 304. When the first rotating body 304 is turned laterally with the first torsion bars 308 as a turning shaft, the second rotating body 306 is turned laterally together with the first rotating body 304. The reflector 318 is provided on the surface of the second rotating body 306 by use of a plating, vapor deposition or like method.

[0033] A pair of permanent magnets 312 are provided on the base 302 in a position orthogonal to the direction along which the first torsion bars 308 extend. The permanent magnets 312 form a magnetic field running orthogonal to the first torsion bars 308. A first coil (not shown) is wired in the first rotating body 304, and the first coil is connected to the control unit 400 via the terminal part 316 (see FIG. 1). Also, a pair of permanent magnets 314 are provided on the base

302 in a position orthogonal to the direction along which the second torsion bars 310 extend. The permanent magnets 314 form a magnetic field running orthogonal to the second torsion bars 310. A second coil (not shown) is wired in the second rotating body 306, and the second coil is connected to the control unit 400 via the terminal part 316.

[0034] The first coil and the permanent magnets 312, and the second coil and the permanent magnets 314 constitute a scanning actuator. The drive of the scanning actuator is controlled by the control unit 400. The control unit 400 controls the amount and the direction of electric current flowing through the first coil and the second coil. Controlling the amount and the direction of electric current flowing therethrough enables the first rotating body 304 and the second rotating body 306 to turnably reciprocate from side to side (laterally) and enables the second rotating body 306 to turnably reciprocate vertically independently. As a result, the reflector 318 makes turnably reciprocating movements in vertical and lateral directions.

[0035] The white laser light W emitted from the light source unit 100 is reflected, by the reflector 318, in a frontward direction of the lamp. Then the scanning unit 300 scans a front area of the vehicle using the white laser light W by turnably reciprocating the reflector 318. For example, the scanning unit 300 turns the reflector 318 over a scanning range that is wider than a region where the light distribution pattern is formed. Then the control unit 400 turns on the first light source 102 to the third light source 106 when the turning position of the reflector 318 is in a position corresponding to the region where the light distribution pattern is formed. Thereby, the white laser light W is distributed over the region where the light distribution pattern is formed and, as a result, a predetermined light distribution pattern is formed in the front area of the vehicle.

(Shape of light distribution pattern)

[0036] FIG. 4 shows an exemplary light distribution pattern formed by the automotive lamp according to the first embodiment. FIG. 4 shows a visible light distribution pattern formed on a vertical screen placed at a predetermined position in front of the lamp, for example, at a point 25 meters ahead of the lamp. The scan tracks of the laser light are shown schematically using broken lines and solid line.

[0037] The scanning unit 300 can scan a rectangular scan area SA, which extends in the vehicle width direction, with the laser light. When a scanning position of laser light by the scanning unit 300 is within a low beam distribution pattern Lo, the control unit 400 has each of the first light source 102 to the third light source 106 emit the laser light. When the scanning position thereof is outside the low beam distribution pattern Lo, the control unit 400 stops the emission of the laser light from each of the first light source 102 to the third light source 106. This forms the low beam distribution pattern Lo having a cutoff line CL1 on the side of an oncoming traffic lane, a cutoff line CL2 on the side of a driver’s own lane and a sloping cutoff line CL3. Note that the automotive lamp 1 can also form other light distribution patterns such as a high beam distribution pattern.

(The peak wavelength of each light source)

[0038] A detailed description is now given of the peak wavelength of laser light emitted from each of the first light source 102 to the third light source 106. FIG. 5A is a graph showing the spectral distribution of the conventional white LED. FIG. 5B is a graph showing the spectral distribution of the RGB laser light source. FIG. 5C is a table showing the color rendering indexes Ra and R9 and the theoretical efficiency of each of RGB laser light source and white LED. FIGS. 5A and 5B are graphs where the horizontal axis indicates the wavelength (nm) and the vertical axis indicates the relative irradiance. For example, the RGB laser light source is a light source emitting the white laser light such that a red laser light, whose peak wavelength is 639 nm, a green laser light, whose peak wavelength is 532 nm, and a blue laser light, whose peak wavelength is 465 nm, are combined together.

[0039] As shown in FIG. 5A, the white light emitted from the white LED indicates a high irradiance in a wavelength region wider than that of the RGB laser light source. On the other hand, as shown in FIG. 5B, the white light emitted from the RGB laser light source has peak wavelengths, each having an extremely narrow bandwidth (half bandwidth), in a wavelength region of the blue light, in a wavelength region of the green light and in a wavelength region of the red light, respectively.

[0040] An average color rendering index Ra, a special color rendering index R9 and a theoretical efficiency (lm/W) of light irradiated from each of the white LED and the RGB laser light source having such spectral distribution characteristics are those indicated in FIG. 5C. The values indicated in FIG. 5C are values derived such that the chromaticity (x, y) of the respective irradiation lights and the color temperatures thereof are adjusted to the chromaticities and the color temperatures generally required of the automotive lamp. The aforementioned "theoretical efficiency" as meant here indicates the luminous efficacy when all of the energy inputted to the light source is outputted as visible light. As shown in FIG. 5C, the RGB light source indicates values lower than those of the white LED in terms of all of Ra, R9 and the theoretical efficiency.

[0041] In contrast to this, the automotive lamp 1 according to the present embodiment has the following features regarding the peak wavelengths of the first laser light B to the third laser light O, respectively. Specifically, the first laser light B emitted by the first light source 102 has a peak wavelength in the wavelength region of 450 nm to 475 nm (both inclusive). Also, the second laser light G emitted by the second light source 104 has a peak wavelength in the wavelength region of 525 nm to 555 nm (both inclusive). Also, the third laser light O emitted by the third light source 106 has a peak wavelength in the wavelength region of 605 nm to 620 nm (both inclusive).

[0042] The interval between the peak wavelength of the first laser light B and the peak wavelength of the second laser light G is greater than or equal to 65 nm and less than or equal to 95 nm. Also, the interval between the peak wavelength of the second laser light G and the peak wavelength of the third laser light O is greater than or equal to 60 nm and less than 80 nm. Also, the interval between the peak wavelength of the first laser light B and the peak wavelength of the third laser light O is less than 170 nm.

[0043] If the first laser light B to the third laser light O satisfy the above-described conditions for the peak wavelengths, the automotive lamp 1 can irradiate the light that satisfies the Ra (e.g., Ra=60) generally required of the automotive lamp. As a result, the preferred laser light source can be provided as the light source of the automotive lamp.

[0044] It is preferable that the third laser light O has a peak wavelength in the wavelength region of 610 nm to 620 nm (both inclusive). Setting the peak wavelength of the third laser light O in the wavelength region of 610 nm to 620 nm (both inclusive) allows the R9 of the irradiation light to be improved. R9 is used for evaluation of red color. It is required of the automotive lamp that the red color of tail lamps and the like of other vehicles be more accurately expressed. For this purpose, R9 is just as important characteristic as Ra for the automotive lamp. Thus, improving the R9 of the irradiation light enables the performance of the automotive lamp to be further raised.

[0045] Also, it is preferable that the first laser light B has a peak wavelength in the wavelength region of 450 nm to 470 nm (both inclusive). Setting the peak wavelength of the first laser light B in the wavelength region of 450 nm to 470 nm (both inclusive) allows an excellent theoretical efficiency to be given more reliably to the automotive lamp. This can, for example, improve the luminance of the irradiation light and reduce the power consumed by the automotive lamp. Thus, the performance of the automotive can be further improved.

(Calculation of average color rendering index Ra)

[0046] Ra was calculated for irradiation light of the automotive lamp. In the course of calculating the Ra, the irradiation light of the automotive lamp 1 was adjusted such that the chromaticity (x, y) lies in a range where $0.34 \leq x \leq 0.36$ and $0.34 \leq y \leq 0.36$ and such that the color temperature (K) ranges from 4500 to 5500 (both inclusive). Ra can be calculated by following a method defined in the Japanese Industrial Standards JIS Z 8726. In the present embodiment, Ra=60, which is generally required of the automotive lamp, is set as a threshold value. When Ra is greater than or equal to 60, the evaluation was made as "A"; when Ra is less than 60, the evaluation was made as "B". The results are shown in FIG. 6 to FIG. 8.

[0047] FIGS. 6, 7 and 8 are tables showing the calculation results of average color rendering indexes Ra. In the tables shown in FIGS. 6, 7 and 8, "2nd-1st" means the interval between the peak wavelengths of the second laser light G and the first laser light B. Similarly, "3rd-2nd" means the interval between the peak wavelengths of the third laser light O and the second laser light G; "3rd-1 st" means the interval between the peak wavelengths of the third laser light O and the first laser light B. Also, the hatched cells under "2nd-1st", "3rd-2nd" and "3rd-1st" of each of FIGS. 6, 7 and 8 indicate that the intervals therebetween regarding "2nd-1st", "3rd-2nd", "3rd-1st" do not meet the above-described conditions. Similarly, the hatched cells under "Ra" of each of FIGS. 6, 7 and 8 regarding "Ra" indicate that the average color rendering indexes Ra are less than 60; the hatched cells under "determination (evaluation)" indicate that the evaluations are "B".

[0048] As shown in FIGS. 6, 7 and 8, it was verified that Ra of the irradiation light of the automotive lamp is greater than or equal to 60 and therefore an excellent Ra is obtained under the following conditions. That is, Ra is greater than or equal to 60 when the first laser light B has a peak wavelength ranging from 450 nm to 475 nm (both inclusive), the second laser light G has a peak wavelength ranging from 525 nm to 555 nm (both inclusive), the third laser light O has a peak wavelength ranging from 605 nm to 620 nm (both inclusive), and when the interval between the peak wavelengths of the first laser light B and the second laser light G is greater than or equal to 65 nm and less than or equal to 95 nm, the interval between the peak wavelengths of the second laser light G and the third laser light O is greater than or equal to 60 nm and less than 80 nm, and the interval between the peak wavelengths of the first laser light B and the third laser light O is less than 170 nm.

(Calculation of special color rendering index R9)

[0049] R9 was calculated for irradiation light, of the automotive lamp, whose determination was "A" in the above-described calculation of Ra. The chromaticity and the color temperature were set similarly to the calculation of Ra. R9 can be calculated by following the method defined in the Japanese Industrial Standards JIS Z 8726. In the present embodiment, R9=-37.4 of white LED (see FIG. 5C) is set as a threshold value. When R9 is greater than or equal to

-37.4, the evaluation was made as "AA"; when R9 is less than -37.4, the evaluation was made as "A". The results are shown in FIGS. 9 and 10.

[0050] FIGS. 9 and 10 are tables showing the calculation results of special color rendering indexes R9. In the tables shown in FIGS. 9 and 10, "2nd-1st", "3rd-2nd" and "3rd-1st" mean ones similar to FIG. 6 to FIG. 8, respectively. In FIGS. 9 and 10, the irradiation lights whose evaluatins of R9 are "A" are indicated as hatched cells under the columns of "third light source", "R9" and "evaluation", respectively.

[0051] As shown in FIGS. 9 and 10, it was verified that R9 of the irradiation light of the automotive vehicle is greater than or equal to -37.4 and therefore an excellent R9 is obtained when the third laser light O has a peak wavelength ranging from 610 nm to 620 nm (both inclusive).

(Calculation of theoretical efficiency)

[0052] Then, the theoretical efficiency (lm/W) was calculated for irradiation light, of the automotive lamp, whose determination was "AA" in the above-described calculation of R9. The chromaticity and the color temperature were set similarly to the calculation of Ra. The theoretical efficiency η_{theo} can be calculated based on the following Equation. In the present embodiment, [theoretical efficiency]=330, which is equal to the theoretical efficiency of white LED, is set as a threshold value. When the theoretical efficiency is greater than or equal to 330, the evaluation was made as "AAA"; when the theoretical efficiency is less than 330, the evaluation was made as "AA". The results are shown in FIGS. 11 and 12.

$$\textit{Theoretical efficiency } \eta_{theo} = \frac{k_m \times \int_{\lambda=380nm}^{780nm} E_e(\lambda) \times V(\lambda) \times d\lambda}{\int_{\lambda=380nm}^{780nm} E_e(\lambda) \times d\lambda}$$

$E_e(\lambda)$: Spectral distribution of radiant flux
$V(\lambda)$: Spectral luminous efficacy
K_m(=683 [lm/W]): luminous efficacy.

[0053] FIGS. 11 and 12 are tables showing the calculation results of theoretical efficiencies. In the tables shown in FIGS. 11 and 12, "2nd-1st", "3rd-2nd" and "3rd-1st" mean ones similar to FIG. 6 to FIG. 8, respectively. In FIGS. 11 and 12, the irradiation lights whose evaluations of theoretical efficiency are "AA" are indicated as hatched cells under the columns of "first light source", "theoretical efficiency" and "evaluation", respectively.

[0054] As shown in FIGS. 11 and 12, it was verified that the theoretical efficiency of the irradiation light of the automotive lamp is greater than or equal to 330 and therefore an excellent theoretical efficiency is obtained when the first laser light B has a peak wavelength ranging from 450 nm to 470 nm (both inclusive).

[0055] As described above, the automotive lamp 1 according to the present embodiment includes the first light source 102 that emits the first laser light B having a peak wavelength in the wavelength region of 450 nm to 475 nm (both inclusive), the second light source 104 that emits the second laser light G having a peak wavelength in the wavelength region of 525 nm to 555 nm (both inclusive), the interval between the peak wavelength of the first laser light B and the peak wavelength of the second laser light G being greater than or equal to 65 nm and less than or equal to 95 nm, the third light source 106 that emits the third laser light O having a peak wavelength in the wavelength region of 605 nm to 620 nm (both inclusive), the interval between the peak wavelength of the second laser light G and the peak wavelength of the third laser light O being greater than or equal to 60 nm and less than 80 nm, and the interval between the peak wavelength of the first laser light B and the peak wavelength of the third laser light O being less than 170 nm, and the light condensing unit 200 that collects the first to third laser lights so as to generate a white laser light. As result, the color rendering properties of the automotive lamp equipped with the laser light sources can be improved. Thus, the performance of the automotive lamp 1 can be improved. Also, installing the automotive lamp equipped with such laser light sources in the vehicle can improve the light availability of the automotive lamp while the drop in the visibility of the driver is being suppressed or the visibility thereof is being improved.

[Second Embodiment]

[0056] FIG. 13 is a vertical cross-sectional view schematically showing a structure of an automotive lamp according to a second embodiment. In FIG. 13, a light source unit 1100 is shown in a state where the interior thereof is seen through. Also, permanent magnets 312 and 314 of a scanning unit 300 are omitted in FIG. 13. The automotive lamp according to the present embodiment is, for instance, an automotive headlamp apparatus that has a pair of headlamp units placed in left- and right-side front parts of a vehicle. Since the pair of headlamp units are of practically identical structure to each other, FIG. 13 shows the structure of either one of the left and right headlamp units, as an automotive lamp 1. Note that the structure of the automotive lamp 1 described below is exemplary and is not limited to the structure shown and explained below.

[0057] The automotive lamp 1 includes a lamp body 2, having an opening on a frontward side of a vehicle, and a transparent cover 4, which covers the opening of the lamp body 2. The transparent cover 4 is formed of resin or glass, having translucency, for instance. A lamp chamber 3, which is formed by the lamp body 2 and the transparent cover 4, contains a supporting plate 6, a light source unit 1100, a scanning unit 300, and a control unit 400.

[0058] The light source unit 1100 and the scanning unit 300 are supported by the supporting plate 6 at predetermined positions in the lamp chamber 3. The supporting plate 6 is connected to the lamp body 2 by aiming screws 8 at corners of the supporting plate 6. The light source unit 1100 has a first light source 1102, a second light source 1104, a third light source 1106, a fourth light source 1108, a heatsink 1110, a light condensing unit 1200, and so forth. The light source unit 1100 is fixed on a front surface of the supporting plate 6 such that the heatsink 1110 is in contact with the supporting plate 6. A detailed description will be given later of the internal structure of the light source unit 1100.

[0059] The scanning unit 300 has a similar structure to that of the first embodiment. The control unit 400 has a similar structure to that of the first embodiment. The control unit 400 controls the drive of the supporting actuator 10b, the drive of a scanning actuator described later, the turning on and off of the first light source 1102 to the fourth light source 1108, and so forth. The control unit 400 is secured to the lamp body 2 such that the control unit 400 is located behind the supporting plate 6 toward the rear end of the lamp. The position where the control unit 400 is provided is not particular limited to this position.

[0060] Similar to the first embodiment, the automotive lamp 1 can adjust the light axis. An extension member 12, having an opening that allows the light reflected by the scanning unit 300 to travel toward a front area of the lamp, is provided in a frontward side of the light source unit 1100 and the scanning unit 300 in the lamp chamber 3. A detailed description is given hereunder of the structure of the light source unit that constitutes the automotive lamp 1.

(Light source unit)

[0061] FIG. 14 is a side view schematically showing a structure of the light source unit. Note that FIG. 14 is a transparent view showing the interior of the light source unit 1100. The light source unit 1100 has a first light source 1102, a second light source 1104, a third light source 1106, a fourth light source 1108, a heatsink 1110, a first lens 1112, a second lens 1114, a third lens 1116, a fourth lens 1118, a light transmission part 1120, a light condensing unit 1200, and other components.

[0062] The first light source 1102 emits a blue first laser light B2. The second light source 1104 emits a green second laser light G2. The third light source 1106 emits a yellow or orange third laser light 02. The fourth light source 1108 emits a red fourth laser light R2. A detailed description will be given later of the peak wavelengths of the first laser light B2 to the fourth laser light R2. The first light source 1102 to the fourth light source 1108 are each constituted by a laser diode, for instance, and are mounted on a common substrate 1109. Each light source may be constituted by a laser device other than the laser diode.

[0063] The first light source 1102, the second light source 1104, the third light source 1106 and the fourth light source 1108 are arranged such that their respective laser light emission surfaces face a front area of the lamp and such that the substrate 1109 faces a rear area of the lamp. Also, the first to fourth light sources 1102, 1104, 1106 and 1108 are mounted on a surface of the heatsink 1110 that faces a front area of the lamp. The heatsink 1110 is formed of a material, having a high thermal conductivity, such as aluminum, for the purpose of efficiently recovering the heat produced by each light source. A rear-side surface of the heatsink 1110 is in contact with the supporting plate 6 (see FIG. 13). The heat produced by each light source is radiated through the substrate 1109, the heatsink 1110 and the supporting plate 6.

[0064] The first lens 1112, the second lens 1114, the third lens 1116 and the fourth lens 1118 are each a collimator lens, for instance. The first lens 1112 is provided on a light path of the first laser light B2 between the first light source 1102 and the light condensing unit 1200, and converts the first laser light B2, emitted from the first light source 1102 toward the light condensing unit 1200, into parallel light. The second lens 1114 is provided on a light path of the second laser light G2 between the second light source 1104 and the light condensing unit 1200, and converts the second laser light G2, emitted from the second light source 1104 toward the light condensing unit 1200, into parallel light. The third lens 1116 is provided on a light path of the third laser light 02 between the third light source 1106 and the light condensing unit 1200, and converts the third laser light 02, emitted from the third light source 1106 toward the light condensing unit 1200, into parallel light. The fourth lens 1118 is provided on a light path of the fourth laser light R2 between the fourth light source 1108 and the light condensing unit 1200, and converts the fourth laser light R2, emitted from the fourth light source 1108 toward the light condensing unit 1200, into parallel light.

[0065] The light transmission part 1120 is fitted to an opening 1101 formed in a housing of the light source unit 1100. A white laser light W2 described later passes through the light transmission part 1120 from the light condensing unit

1200 and travels toward the scanning unit 300.

[0066] The light condensing unit 1200 (polarizing unit) collects the first laser light B2, the second laser light G2, the third laser light 02 and the fourth laser light R2 so as to generate the white laser light W2. The light condensing unit 1200 has a first dichroic mirror 1202, a second dichroic mirror 1204, a third dichroic mirror 1206 and a fourth dichroic mirror 1208.

[0067] The first dichroic mirror 1202 is a mirror that reflects at least the first laser light B2 and transmits the second laser light G2, the third laser light 02 and the fourth laser light R2, and is arranged such it reflects the first laser light B2, which has passed through the first lens 1112, toward the light transmission part 1120. The second dichroic mirror 1204 is a mirror that reflects at least the second laser light G2 and transmits the third laser light 02 and the fourth laser light R2, and is arranged such it reflects the second laser light G2, which has passed through the second lens 1114, toward the light transmission part 1120. The third dichroic mirror 1206 is a mirror that reflects at least the third laser light 02 and transmits the fourth laser light R2, and is arranged such it reflects the third laser light 02, which has passed through the third lens 1116, toward the light transmission part 1120. The fourth dichroic mirror 1208 is a mirror that reflects at least the fourth laser light R2, and is arranged such it reflects the fourth laser light R2, which has passed through the fourth lens 1118, toward the light transmission part 1120.

[0068] A mutual positional relation among the dichroic mirrors 1202 to 1208 is determined such that the light paths of the laser lights reflected by the dichroic mirrors 1202 to 1208 are parallel to each other and such that their respective laser lights are collected and the thus collected light transmits the light transmission part 1120. In the present embodiment, the first dichroic mirror 1202 to the fourth dichroic mirror 1208 are arranged such that the areas where the laser lights strike on the respective dichroic mirrors, namely the reflecting points of laser lights, are aligned on a same line.

[0069] The fourth laser light R2 emitted from the fourth light source 1108 is reflected by the fourth dichroic mirror 1208 toward the third dichroic mirror 1206. The third laser light 02 emitted from the third light source 1106 is reflected by the third dichroic mirror 1206 toward the second dichroic mirror 1204, and the thus reflected light is simultaneously superposed on the fourth laser light R2 that has transmitted the third dichroic mirror 1206. The second laser light G2 emitted from the second light source 1104 is reflected by the second dichroic mirror 1204 toward the first dichroic mirror 1202, and the thus reflected light is simultaneously superposed on the fourth laser light R2 and the third laser light 02 that have transmitted the second dichroic mirror 1204. The first laser light B2 emitted from the first light source 1102 is reflected by the first dichroic mirror 1202 toward the light transmission part 1120, and the thus reflected light is simultaneously superposed on the fourth laser light R2, the third laser light 02 and the second laser light G2 that have transmitted the first dichroic mirror 1202. As a result, the white laser light W2 is formed. The white laser light W2 passes through the light transmission part 1120 and travels toward the scanning unit 300.

(Scanning unit)

[0070] As shown in FIG. 3, the scanning unit 300 is a mechanism used to scan the laser lights, emitted from the first light source 1102 to the fourth light source 1108, and form a predetermined light distribution pattern (see FIG. 4). Since the scanning unit 300 according to the second embodiment has a similar structure to that of the first embodiment, the detailed description thereof is omitted here.

[0071] The white laser light W2 emitted from the light source unit 1100 is reflected, by the reflector 318, in a frontward direction of the lamp. Then the scanning unit 300 scans a front area of the vehicle using the white laser light W2 by turnably reciprocating the reflector 318. For example, the scanning unit 300 turns the reflector 318 over a scanning range that is wider than a region where the light distribution pattern is formed. Then the control unit 400 turns on the first light source 1102 to the fourth light source 1108 when the turning position of the reflector 318 is in a position corresponding to the region where the light distribution pattern is formed. Thereby, the white laser light W2 is distributed over the region where the light distribution pattern is formed and, as a result, a predetermined light distribution pattern is formed in the front area of the vehicle.

(Shape of light distribution pattern)

[0072] The light distribution pattern formed by the automotive lamp according to the present embodiment is similar to that according to the first embodiment. The scanning unit 300 can scan a rectangular scan area SA, which extends in the vehicle width direction, with the laser light. When a scanning position of laser light by the scanning unit 300 is within a low beam distribution pattern Lo, the control unit 400 has each of the first light source 1102 to the fourth light source 1108 emit the laser light. When the scanning position thereof is outside the low beam distribution pattern Lo, the control unit 400 stops the emission of the laser light from each of the first light source 1102 to the fourth light source 1108. This forms the low beam distribution pattern Lo having a cutoff line CL1 on the side of an oncoming traffic lane, a cutoff line CL2 on the side of a driver's own lane and a sloping cutoff line CL3. Note that the automotive lamp 1 can also form other light distribution patterns such as a high beam distribution pattern.

(Color rendering properties of automotive lamp)

[0073] A detailed description is now given of the color rendering properties of the automotive lamp 1. FIG. 15A is a graph showing the spectral distribution of the conventional white LED. FIG. 15B is a graph showing the spectral distribution of the RGB laser light source. FIG. 15C is a table showing the color rendering indexes Ra and R9 and the theoretical efficiency of each of RGB laser light source and white LED. FIGS. 15A and 15B are graphs where the horizontal axis indicates the wavelength (nm) and the vertical axis indicates the relative irradiance. For example, the RGB laser light source is a light source emitting the white laser light such that a red laser light, whose peak wavelength is 639 nm, a green laser light, whose peak wavelength is 532 nm, and a blue laser light, whose peak wavelength is 465 nm, are combined together.

[0074] As shown in FIG. 15A, the white light emitted from the white LED indicates a high irradiance in a wavelength region wider than that of the RGB laser light source. On the other hand, as shown in FIG. 15B, the white light emitted from the RGB laser light source has peak wavelengths, each having an extremely narrow bandwidth (half bandwidth), in a wavelength region of the blue light, in a wavelength region of the green light and in a wavelength region of the red light, respectively.

[0075] The average color rendering index Ra, the special color rendering index R9 and the theoretical efficiency (Im/W) of light irradiated from each of the white LED and the RGB laser light source having such spectral distribution characteristics are those indicated in FIG. 15C. The values indicated in FIG. 15C are values derived such that the chromaticity (x, y) of the respective irradiation lights and the color temperatures thereof are adjusted to the chromaticities and the color temperatures generally required of the automotive lamp. The aforementioned "theoretical efficiency" as meant here indicates the luminous efficacy when all of the energy inputted to the light source is outputted as visible light. As shown in FIG. 15C, the RGB light source indicates values lower than those of the white LED in terms of all of Ra, R9 and the theoretical efficiency.

[0076] In contrast to this, the automotive lamp 1 according to the present embodiment forms the white laser light W2 by combining together the blue first laser light B2, the green second laser light G2, the yellow or orange third laser light 02 and the red fourth laser light R2. This can raise the average color rendering index Ra further as compared with a case when the white laser light is formed by combining together the blue laser light, the green laser light and the red laser light. If the white laser light W2 is formed by combining together the first laser light B2 to the fourth laser light R2, an automotive lamp, having excellent color rendering properties, where the average color rendering index Ra is 60 or above, can be designed. This can help improve the performance of the automotive lamp equipped with the laser light source.

[0077] Also, this not only improves Ra but also can contribute to giving a higher theoretical efficiency to the automotive lamp than the RGB laser source. Thus, for example, the luminance of the irradiation light can be improved and the power consumed by the automotive lamp can be reduced and thereby the performance of the automotive can be further improved.

[0078] Also, it is preferable that the first laser light B2 has a peak wavelength in the wavelength region of 450 nm to 470 nm (both inclusive), that the second laser light G2 has a peak wavelength in the wavelength region of 510 nm to 550 nm (both inclusive), that the third laser light 02 has a peak wavelength in the wavelength region of 570 nm to 612 nm (both inclusive), and that the fourth laser light R2 has a peak wavelength in the wavelength region of 630 nm to 650 nm (both inclusive). This can help achieve both the chromaticity (x, y) required for the automotive lamp and the improvement in the color rendering properties of the automotive lamp.

[0079] It is more preferable that the third laser light 02 has a peak wavelength in the wavelength region less than or equal to 610 nm. As a result, not only Ra can be improved but also the special color rendering index R9 of the irradiation light can be improved more reliably.

[0080] Also, it is more preferable that the third laser light 02 has a peak wavelength in the wavelength region of 580 nm to 600 nm (both inclusive), and it is further preferable that the third laser light 02 has a peak wavelength in the wavelength region of 590 nm to 600 nm (both inclusive). Setting the peak wavelength of the third laser light 02 in the range of 580 nm to 600 nm (both inclusive) allows the conditions, such as the output intensity ratio of each laser light, to be relaxed. Here, the conditions such as the output intensity ratio thereof are, for example, those required for designing the lamp in order to achieve both excellent chromaticity and excellent color rendering properties. As a result, the performance of the automotive lamp can be more likely to be improved.

(Evaluation regarding the relationships among the chromaticity, Ra, R9, and the theoretical efficiency)

(Evaluation test I)

[0081] For the irradiation lights of the automotive lamp, the relationships among the chromaticity (x, y), Ra, R9, and the theoretical efficiency thereof were evaluated. The peak wavelengths of the first laser light B2, the second laser light

G2 and the fourth laser light R2 were first set to 465 nm, 532 nm and 639 nm, respectively, similarly to the above-described RGB laser light sources. Then the peak wavelengths of the third laser light 02 were set to 570 nm, 580 nm, 585 nm, 590 nm, 600 nm and 610 nm, and the chromaticity (x, y), Ra, R9, and the theoretical efficiency thereof at each of the peak wavelengths were calculated. It was assumed that the output intensity ratio of each laser light is B2:G2:O2:R2 = 1.00:1.00:0.90:1.00.

[0082] The chromaticity (x) can be calculated based on Equation (1), which is x=X/(X+Y+Z), and the chromaticity (y) can be calculated based on Equation (2), which is y=Y/(X+Y+Z). Here, X, Y and Z in Equation (1) and Equation (2) are tri-stimulus values in the colorimetric system. The tri-stimulus values X, Y and Z can be obtained by using a known spectrophotometer or colorimeter, for instance. The chromaticity was evaluated based on whether or not the chromaticity is contained in a white region defined by the European standards ECE No. 98; specifically, the chromaticity is more satisfactory when it is contained in the white region than when it is not contained therein. Here, the white region defined by the European standards ECE No. 98 is a region **A** in FIGS. 16B, 17B, 18B, 19B, 20B and 21B. More specifically, the region **A** is the region surrounded by straight lines that are y=0.150+0.540x, y=0.440, x=0.500, y=0.382, y=0.050+0.750x, and x=0.310.

[0083] Ra and R9 can be calculated by following the methods defined in the Japanese Industrial Standards JIS Z 8726. For the evaluation of the average color rendering indexes Ra, Ra=60 is set as a threshold value, and Ra was evaluated as being more satisfactory when Ra is greater than or equal to 60 than when it is less than 60. For the evaluation of the special color rendering indexes R9, [R9 of white LED]=-37.4 is set as a threshold value (see FIG. 15C), and R9 was evaluated as being more satisfactory when R9 is greater than or equal to -37.4 than when it is less than -37.4.

[0084] The theoretical efficiency η_{theo} (lm/W) can be calculated by following the above Equation used in the first embodiment. For the evaluation of the theoretical efficiencies, [theoretical efficiency]=295 is set as a threshold value, and the theoretical efficiency was evaluated as being more satisfactory when the theoretical efficiency is greater than or equal to 295 than when it is less than 295.

[0085] The results are shown in FIGS. 16A and 16B. FIG. 16A is a table showing the calculation results of chromaticity, average color rendering index Ra, special color rendering index R9 and theoretical efficiency. FIG. 16B is a graph showing a relationship between the calculation results of chromaticities and the white region. In FIG. 16A, when the "chromaticity (x)" or the "chromaticity (y)" of a peak wavelength of the third laser light 02 is not contained in the white region, a cell corresponding thereto is hatched in the table. Similarly, when the average color rendering index Ra thereof is less than 60, a cell corresponding thereto is also hatched in the table of FIG. 16A. When the special color rendering index R9 thereof is less than -37.4, a cell corresponding thereto is also hatched in the table of FIG. 16A. When the theoretical efficiency thereof is less than 295, a cell corresponding thereto is also hatched in the table of FIG. 16A.

(Evaluation test II)

[0086] Similar to the evaluation test I, the calculations and the evaluations of the chromaticity, Ra, R9, and the theoretical efficiency were conducted excepting that the output intensity ratio of each laser light is B2:G2:O2:R2 = 1.00:1.20:0.90:1.00. The results are shown in FIGS. 17A and 17B. FIG. 17A is a table showing the calculation results of chromaticity, average color rendering index Ra, special color rendering index R9 and theoretical efficiency. FIG. 17B is a graph showing a relationship between the calculation results of chromaticities and the white region. In FIG. 17A, the hatched cells are those under the same conditions as in the evaluation test I.

(Evaluation test III)

[0087] Similar to the evaluation test I, the calculations and the evaluations of the chromaticity, Ra, R9, and the theoretical efficiency were conducted excepting that the output intensity ratio of each laser light is B2:G2:O2:R2 = 0.80:0.50:0.90:1.00. The results are shown in FIGS. 18A and 18B. FIG. 18A is a table showing the calculation results of chromaticity, average color rendering index Ra, special color rendering index R9 and theoretical efficiency. FIG. 18B is a graph showing a relationship between the calculation results of chromaticities and the white region. In FIG. 18A, the hatched cells are those under the same conditions as in the evaluation test I.

(Evaluation test IV)

[0088] Similar to the evaluation test I, the calculations and the evaluations of the chromaticity, Ra, R9, and the theoretical efficiency were conducted excepting that the peak wavelength of the second laser light G2 is 545 nm and the output intensity ratio of the third laser light O2 is 0.80. The results are shown in FIGS. 19A and 19B. FIG. 19A is a table showing the calculation results of chromaticity, average color rendering index Ra, special color rendering index R9 and theoretical efficiency. FIG. 19B is a graph showing a relationship between the calculation results of chromaticities and the white region. In FIG. 19A, the hatched cells are those under the same conditions as in the evaluation test I.

(Evaluation test V)

[0089] Similar to the evaluation test II, the calculations and the evaluations of the chromaticity, Ra, R9, and the theoretical efficiency were conducted excepting that the peak wavelength of the second laser light G2 is 545 nm, that the output intensity ratio of the third laser light 02 is 0.80, and that the wavelengths of 612 nm and 613 nm are added to the setting of the peak wavelength of the third laser light 02. The results are shown in FIGS. 20A and 20B. FIG. 20A is a table showing the calculation results of chromaticity, average color rendering index Ra, special color rendering index R9 and theoretical efficiency. FIG. 20B is a graph showing a relationship between the calculation results of chromaticities and the white region. In FIG. 20A, the hatched cells are those under the same conditions as in the evaluation test I.

(Evaluation test VI)

[0090] Similar to the evaluation test III, the calculations and the evaluations of the chromaticity, Ra, R9, and the theoretical efficiency were conducted excepting that the peak wavelength of the second laser light G2 is 545 nm, that the output intensity ratio of the third laser light 02 is 0.80, and that the wavelengths of 572 nm and 573 nm are added to the setting of the peak wavelength of the third laser light 02. The results are shown in FIGS. 21A and 21B. FIG. 21A is a table showing the calculation results of chromaticity, average color rendering index Ra, special color rendering index R9 and theoretical efficiency. FIG. 21B is a graph showing a relationship between the calculation results of chromaticities and the white region. In FIG. 21A, the hatched cells are those under the same conditions as in the evaluation test I.

[0091] As shown in FIGS. 16A and 16B, it was verified in the evaluation test I that, when the first laser light B2 to the fourth laser light R2 are combined, Ra is improved over the case where the third laser light O2 is not included. Also, it was verified that an excellent chromaticity and an excellent Ra are obtained when the peak wavelength of the third laser light O2 lies in the range of 585 nm to 600 nm. Also, it was verified that, at the same time, an excellent R9 and an excellent theoretical efficiency are obtained. Also, it was verified that a higher theoretical efficiency, which is 301 m/w or above, is obtained when the peak wavelength of the third laser light O2 is less than 600 nm.

[0092] As shown in FIGS. 17A and 17B, it was verified in the evaluation test II that, when the first laser light B2 to the fourth laser light R2 are combined, Ra is improved over the case where the third laser light O2 is not included. Also, it was verified that an excellent chromaticity and an excellent Ra are obtained and, at the same time, an excellent R9 and an excellent theoretical efficiency are obtained when the peak wavelength of the third laser light O2 lies in the range of 590 nm to 600 nm.

[0093] As shown in FIGS. 18A and 18B, it was verified in the evaluation test III that, when the first laser light B2 to the fourth laser light R2 are combined, Ra is improved over the case where the third laser light O2 is not included. Also, it was verified that an excellent chromaticity and an excellent Ra are obtained and, at the same time, an excellent R9 and an excellent theoretical efficiency are obtained when the peak wavelength of the third laser light O2 lies in the range of 570 nm to 580 nm.

[0094] As shown in FIGS. 19A and 19B, it was verified in the evaluation test IV that, when the first laser light B2 to the fourth laser light R2 are combined, Ra is improved over the case where the third laser light O2 is not included. Also, it was verified that an excellent chromaticity and an excellent Ra are obtained and, at the same time, an excellent R9 and an excellent theoretical efficiency are obtained when the peak wavelength of the third laser light O2 lies in the range of 580 nm to 600 nm.

[0095] As shown in FIGS. 20A and 20B, it was verified in the evaluation test V that, when the first laser light B2 to the fourth laser light R2 are combined, Ra is improved over the case where the third laser light O2 is not included. Also, it was verified that an excellent chromaticity and an excellent Ra are obtained when the peak wavelength of the third laser light O2 lies in the range of 590 nm to 612 nm. Also, it was verified that, at the same time, an excellent theoretical efficiency is obtained. Also, it was verified that not only an excellent chromaticity, an excellent Ra and an excellent theoretical efficiency but also an excellent R9 are obtained when the peak wavelength of the third laser light O2 lies in the range of 590 nm to 610 nm.

[0096] As shown in FIGS. 21A and 21B, it was verified in the evaluation test VI that, when the first laser light B2 to the fourth laser light R2 are combined, Ra is improved over the case where the third laser light O2 is not included. Also, it was verified that an excellent chromaticity and an excellent Ra are obtained and, at the same time, an excellent R9 and an excellent theoretical efficiency are obtained when the peak wavelength of the third laser light O2 lies in the range of 573 nm to 580 nm.

[0097] Since, as described above, the four laser lights, including the third laser light O2, are combined together, it was verified that Ra is more improved than when no third laser light O2 is included. Also, it was verified that an automotive lamp, having excellent color rendering properties, where Ra is 60 or above can be designed. Also, it was verified that, when the peak wavelength of the third laser light O2 is in the range of 570 nm to 612 nm (both inclusive), a white laser light W2 having not only a desired chromaticity but also Ra of 60 or above can be formed. Thus, it was verified that both the chromaticity required for the automotive lamp and the improvement in the color rendering properties of the automotive lamp can be achieved.

[0098] It was verified from the results of the evaluation test V that setting the peak wavelength of the third laser light O2 at 610 nm or below allows R9 to be more reliably improved under the conditions where an excellent chromaticity and an excellent Ra are realizable. Further, it was verified from the results of all evaluation tests I to VI that, when the peak wavelength of the third laser light O2 is in a wavelength region of 580 nm to 600 (both inclusive), a more satisfactory chromaticity and a more satisfactory Ra are obtained than when the peak wavelength thereof is in the other wavelength region, under wider conditions different from the peak wavelengths of the first laser light B2, the second laser light G2 and the fourth laser light R2 and different from the output intensity ratio of each laser light. Also, it was verified that, when the peak wavelength of the third laser light O2 is in a wavelength region of 590 nm to 600 (both inclusive), an excellent chromaticity and an excellent Ra are obtained under much wider conditions. Hence, it was verified that setting the peak wavelength of the third laser light O2 in a wavelength region of 580 nm to 600 nm (both inclusive) and more preferably in a wavelength region of 590 nm to 600 nm (both inclusive) facilitates the improvement of the performance of the automotive lamp.

[0099] As described above, the automotive lamp 1 according to the present embodiment includes the first light source 1102 that emits the blue first laser light B, the second light source 1104 that emits the green second laser light G, the third light source 1106 that emits the yellow or orange third laser light O2, the fourth light source 1108 that emits the red fourth laser light R2, and the light condensing unit 1200 that collects each of the laser lights so as to generate the white laser light W2. As result, the color rendering properties of the automotive lamp can be improved over the RGB laser light source. Also, the automotive lamp having excellent color rendering properties can be designed. This can contribute to improving the performance of the automotive lamp equipped with the laser light sources. Also, installing the automotive lamp equipped with such laser light sources in the vehicle can improve the light availability of the automotive lamp while the drop in the visibility of the driver is being suppressed or the visibility thereof is being improved.

[0100] The present invention is not limited to the above-described embodiments only, and those resulting from any appropriate combination of and/or replacement with a component or components of any of the embodiments are included in the present embodiment. Also, it is understood by those skilled in the art that various modifications such as changes in design may be added to each of the embodiments based on their knowledge and newly combined embodiments or embodiments added with such modifications are also within the scope of the present invention.

[0101] In the above-described embodiments, the scanning unit 300 can be configured by a galvanometer mirror, an MEMS mirror type, a polygon mirror type and so forth. Also, the automotive lamp 1 may be a projector-type lamp having a projection lens, for instance.

Claims

1. An automotive lamp (1) comprising:

a first light source (1102) that emits a blue first laser light (B2);
a second light source (1104) that emits a green second laser light (G2);
a third light source (1106) that emits a yellow or orange third laser light (02);
a fourth light source (1108) that emits a red fourth laser light (R2); and
a light condensing unit (1200) that collects each of the first to fourth laser lights so as to generate a white laser light (W2).

2. The automotive lamp (1) according to claim 1, wherein the first laser light (B2) has a peak wavelength in a wavelength region of 450 nm to 470 nm (both inclusive),
wherein the second laser light (G2) has a peak wavelength in a wavelength region of 510 nm to 550 nm (both inclusive),
wherein the third laser light (O2) has a peak wavelength in a wavelength region of 570 nm to 612 nm (both inclusive), and
wherein the fourth laser light (R2) has a peak wavelength in a wavelength region of 630 nm to 650 nm (both inclusive).

3. The automotive lamp (1) according to claim 2, wherein the third laser light (O2) has a peak wavelength in a wavelength region of 580 nm to 600 nm (both inclusive).

4. The automotive lamp according to one of claims 1 through 3, wherein the first through fourth light sources (1102, 1104, 1106, 1108) are each constituted by a laser diode and are mounted on a common substrate.

5. The automotive lamp according to one of claims 1 through 4, wherein
the light condensing unit (1200) includes:

a first dichroic mirror (1202) that reflects the first laser light (B2);
a second dichroic mirror (1204) that reflects the second laser light (G2); a third dichroic mirror (1206) that reflects the third laser light (O2); and
a fourth dichroic mirror (1208) that reflects the fourth laser light (R2).

6. The automotive lamp according to one of claims 1 through 5, further comprising:

a first lens (1112) provided on a light path of the first laser light (B2) between the first light source (1102) and the light condensing unit (1200) and is constituted by a collimator lens;
a second lens (1114) provided on a light path of the second laser light (G2) between the second light source (1104) and the light condensing unit (1200) and is constituted by a collimator lens;
a third lens (1116) provided on a light path of the third laser light (O2) between the third light source (1106) and the light condensing unit (1200) and is constituted by a collimator lens; and
a fourth lens (1118) provided on a light path of the fourth laser light (R2) between the fourth light source (1108) and the light condensing unit (1200) and is constituted by a collimator lens.

7. The automotive lamp according to one of claims 1 through 6, further comprising:

a scanning unit (300) that scans the laser lights emitted from the first through fourth light sources (1102, 1104, 1106, 1108) and forms a predetermined light distribution pattern.

FIG.1

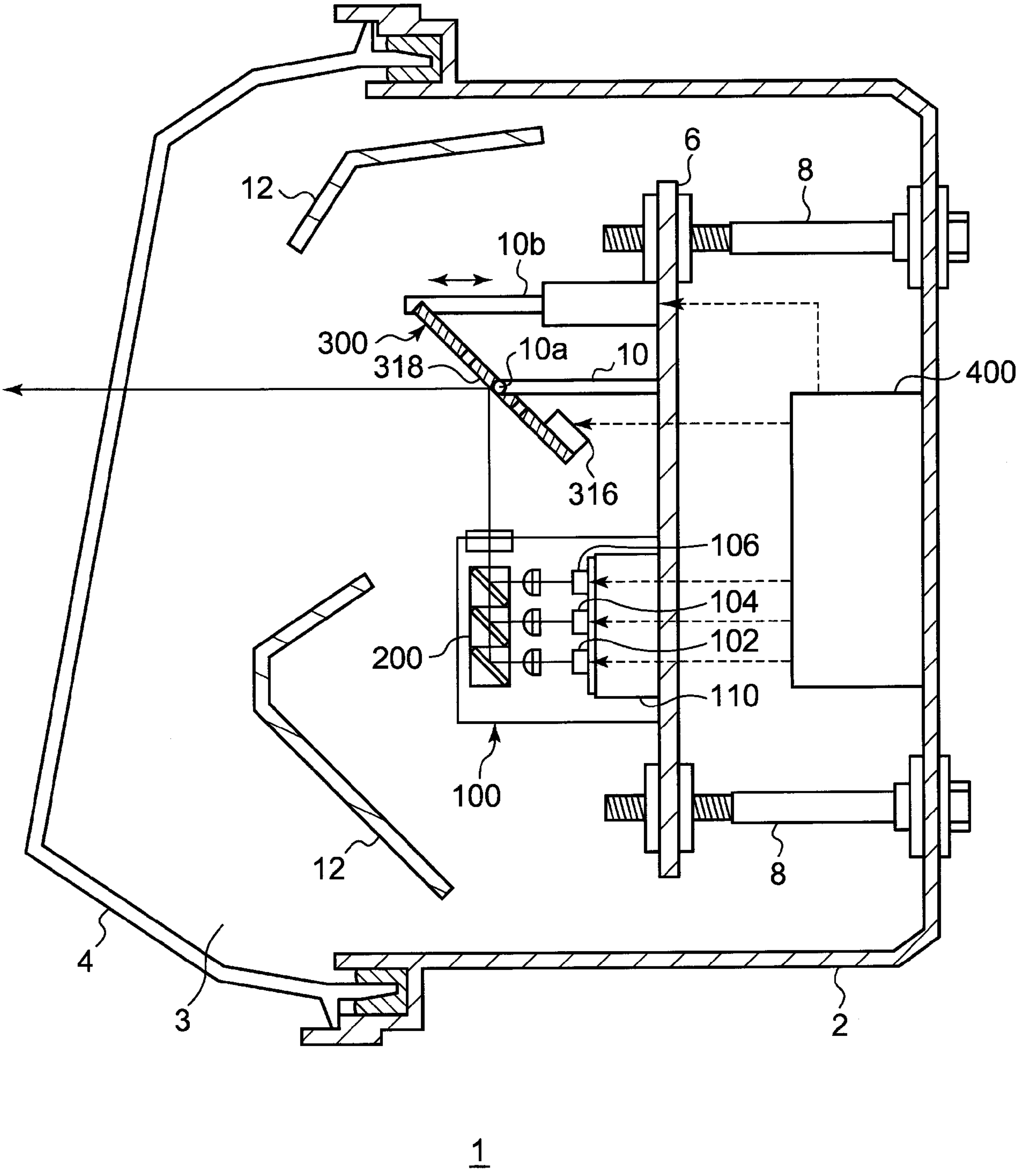


FIG.2

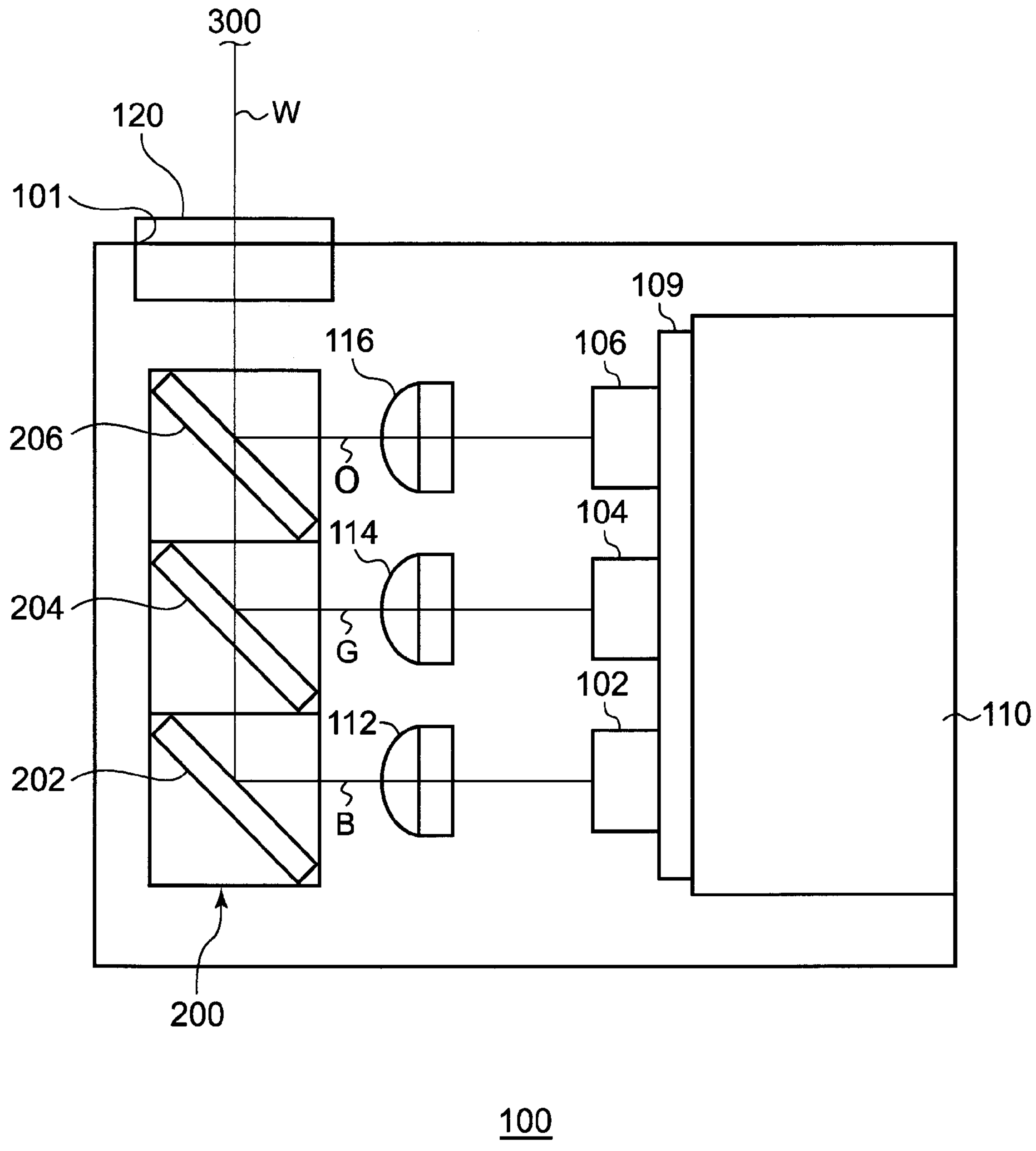
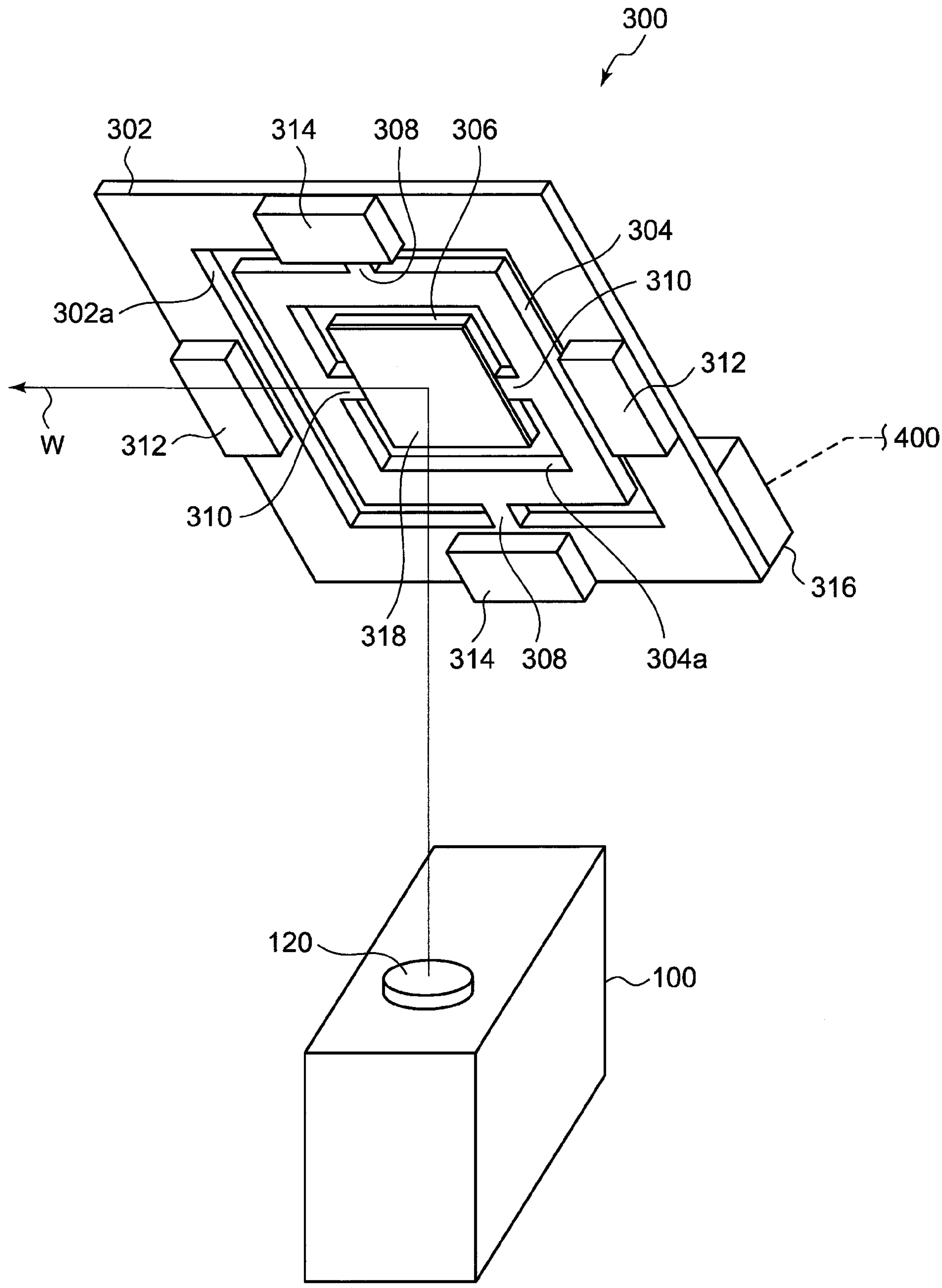

300
W
120
101
109
116
106
206
O
114
104
204
G
102
112
110
202
B
200
100

FIG.3


300
302
314
308
306
304
310
302a
312
W
312
400
310
318
314
308
304a
316
120
100

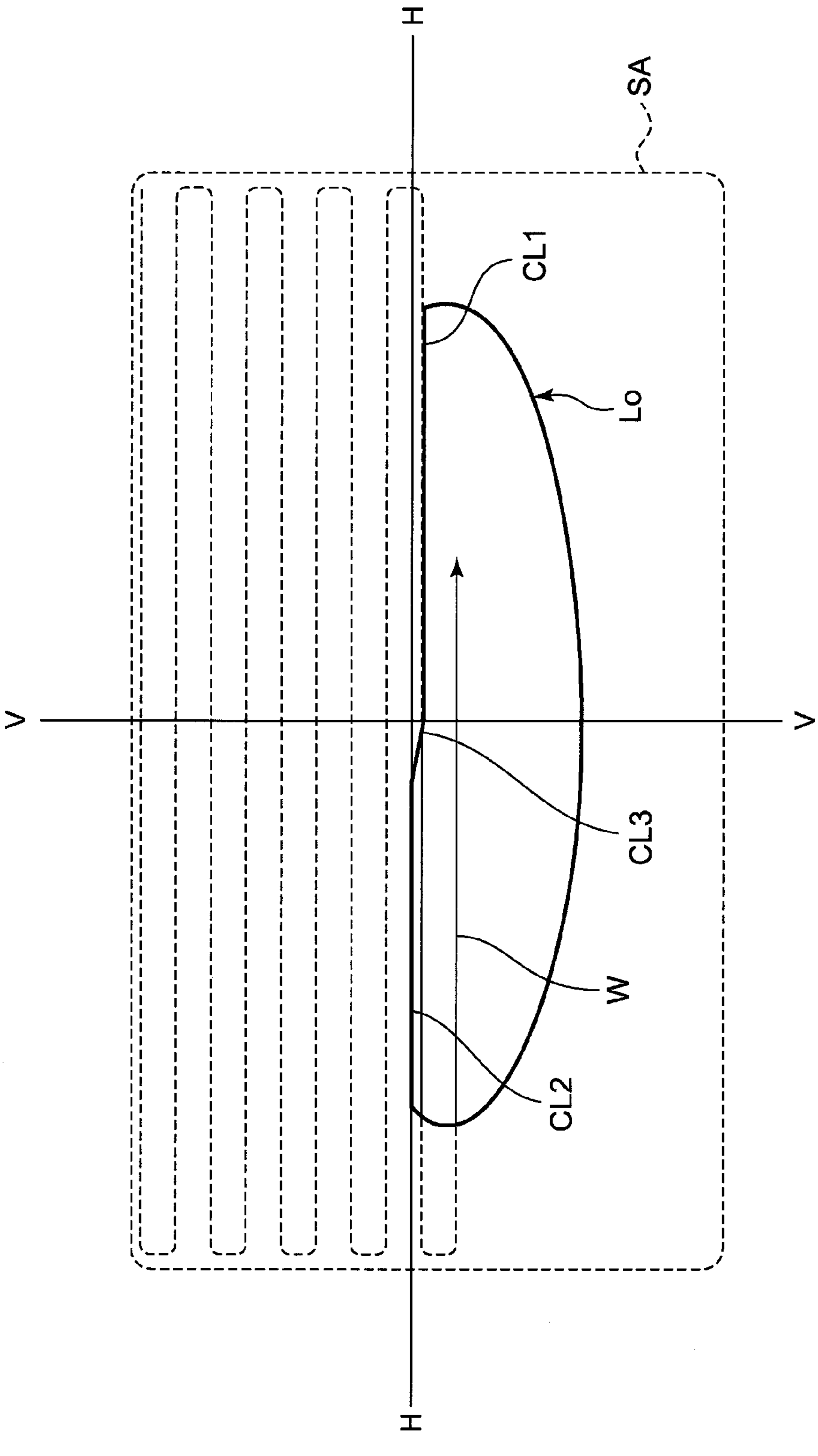


FIG.4

FIG.5A

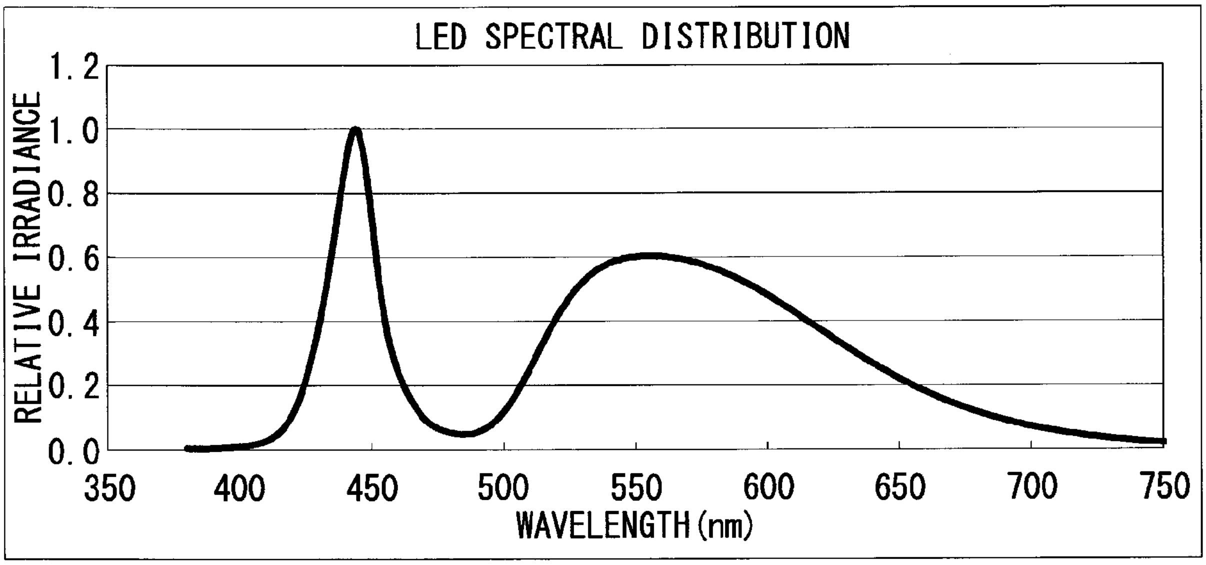


FIG.5B

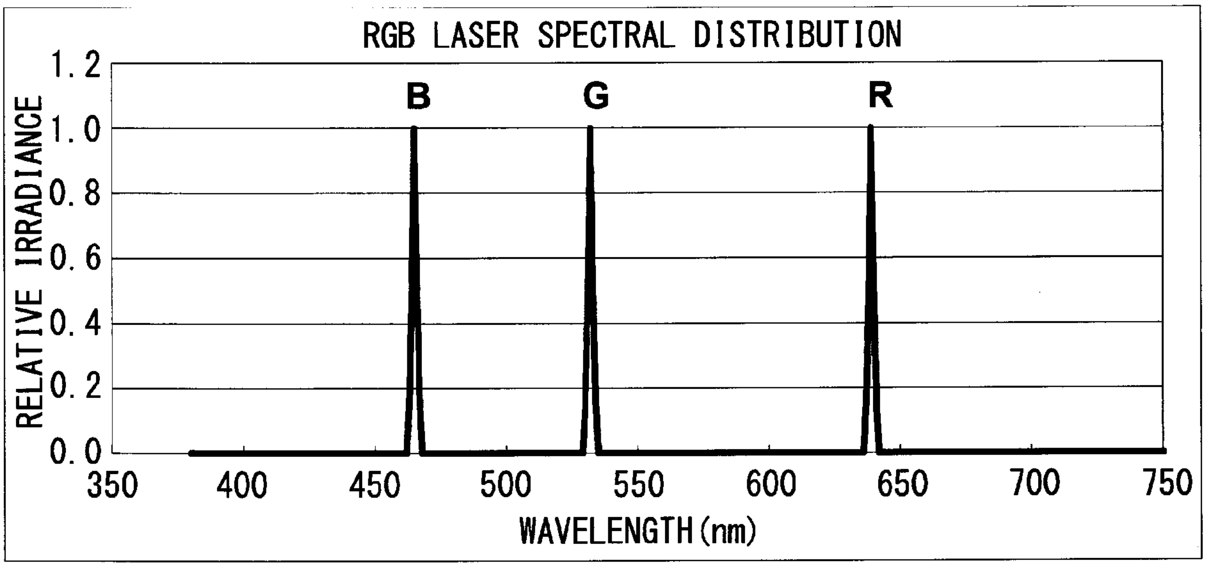


FIG.5C

	CHROMATICITY		COLOR TEMPERATURE (K)	COLOR RENDERING INDICES		THEORETICAL EFFICIENCY (lm/W)
	x	y		Ra	R9	
RGB LASER LIGHT SOURCE	0.346	0.354	4975	3.6	-361.6	243
WHITE LED	0.346	0.357	5001	65.1	-37.4	335

FIG.6

1ST LIGHT SOURCE	2ND LIGHT SOURCE	3RD LIGHT SOURCE	2ND-1ST	3RD-2ND	3RD-1ST	Ra	EVALUATION
450	525	605	65	80	145	63.0	A
450	525	610	75	85	160	58.0	B
450	525	615	75	90	165	41.6	B
450	525	620	75	95	170	24.2	B
450	530	605	80	75	155	67.4	A
450	530	610	80	80	160	62.9	A
450	530	615	80	85	165	48.0	B
450	530	620	80	90	170	33.1	B
450	535	605	85	70	155	68.2	A
450	535	610	85	75	160	66.0	A
450	535	615	85	80	165	53.8	B
450	535	620	85	85	170	40.8	B
450	540	605	90	65	155	67.7	A
450	540	610	90	70	160	67.4	A
450	540	615	90	75	165	60.4	A
450	540	620	90	80	170	46.5	B
450	545	605	95	60	155	62.3	A
450	545	610	95	65	160	66.0	A
450	545	615	95	70	165	63.3	A
450	545	620	95	75	170	55.9	B
455	525	605	70	80	150	63.9	A
455	525	610	70	85	155	58.4	B
455	525	615	70	90	160	42.1	B
455	525	620	70	95	165	26.5	B
455	530	605	75	75	150	69.9	A
455	530	610	75	80	155	64.6	A
455	530	615	75	85	160	48.5	B
455	530	620	75	90	165	34.2	B
455	535	605	80	70	150	72.2	A
455	535	610	80	75	155	69.8	A
455	535	615	80	80	160	56.4	B
455	535	620	80	85	165	51.4	B
455	540	605	85	65	150	71.8	A
455	540	610	85	70	155	72.8	A
455	540	615	85	75	160	62.5	A
455	540	620	85	80	165	50.9	B
455	545	605	90	60	150	66.7	A
455	545	610	90	65	155	71.6	A
455	545	615	90	70	160	68.0	A
455	545	620	90	75	165	60.0	A
455	550	605	95	55	150	60.6	A
455	550	610	95	60	155	61.9	A
455	550	615	95	65	160	65.3	A
455	550	620	95	70	165	61.2	A
460	525	605	65	80	145	63.1	A
460	525	610	65	85	150	57.5	B
460	525	615	65	90	155	41.6	B
460	525	620	65	95	160	27.3	B
460	530	605	70	75	145	70.5	A
460	530	610	70	80	150	64.4	A
460	530	615	70	85	155	48.6	B
460	530	620	70	90	160	33.8	B
460	535	605	75	70	145	74.4	A
460	535	610	75	75	150	72.1	A

FIG.7

1ST LIGHT SOURCE	2ND LIGHT SOURCE	3RD LIGHT SOURCE	2ND-1ST	3RD-2ND	3RD-1ST	Ra	EVALUATION
460	535	615	75	80	155	57.5	B
460	535	620	75	85	160	43.6	B
460	540	605	80	65	145	76.0	A
460	540	610	80	70	150	77.3	A
460	540	615	80	75	155	66.2	A
460	540	620	80	80	160	53.3	B
460	545	605	85	60	145	71.5	A
460	545	610	85	65	150	76.8	A
460	545	615	85	70	155	73.0	A
460	545	620	85	75	160	64.3	A
460	550	605	90	55	145	60.2	A
460	550	610	90	60	150	67.3	A
460	550	615	90	65	155	72.5	A
460	550	620	90	70	160	67.3	A
460	555	605	95	50	145	46.4	B
460	555	610	95	55	150	62.5	A
460	555	615	95	60	155	60.1	A
460	555	620	95	65	160	61.6	A
465	525	605	60	80	140	58.0	B
465	525	610	60	85	145	53.9	B
465	525	615	60	90	150	39.9	B
465	525	620	60	95	155	23.6	B
465	530	605	65	75	140	66.4	A
465	530	610	65	80	145	62.3	A
465	530	615	65	85	150	47.8	B
465	530	620	65	90	155	32.1	B
465	535	605	70	70	140	73.2	A
465	535	610	70	75	145	70.0	A
465	535	615	70	80	150	56.0	B
465	535	620	70	85	155	42.0	B
465	540	605	75	65	140	76.5	A
465	540	610	75	70	145	77.7	A
465	540	615	75	75	150	67.0	A
465	540	620	75	80	155	54.8	B
465	545	605	80	60	140	73.4	A
465	545	610	80	65	145	79.6	A
465	545	615	80	70	150	76.4	A
465	545	620	80	75	155	66.1	A
465	550	605	85	55	140	61.5	A
465	550	610	85	60	145	71.5	A
465	550	615	85	65	150	76.1	A
465	550	620	85	70	155	70.8	A
465	555	605	90	50	140	50.6	B
465	555	610	90	55	145	62.8	A
465	555	615	90	60	150	64.3	A
465	555	620	90	65	155	67.3	A
470	525	610	55	85	140	46.4	B
470	525	615	55	90	145	34.5	B
470	525	620	55	95	150	21.7	B
470	530	605	60	75	135	61.3	A
470	530	610	60	80	140	58.0	B
470	530	615	60	85	145	45.0	B
470	530	620	60	90	150	32.3	B
470	535	605	65	70	135	66.8	A

FIG.8

1ST LIGHT SOURCE	2ND LIGHT SOURCE	3RD LIGHT SOURCE	2ND-1ST	3RD-2ND	3RD-1ST	Ra	EVALUATION
470	535	610	65	75	140	65.1	A
470	535	615	65	80	145	52.7	B
470	535	620	65	85	150	38.9	B
470	540	605	70	65	135	71.1	A
470	540	610	70	70	140	73.1	A
470	540	615	70	75	145	63.7	A
470	540	620	70	80	150	51.5	B
470	545	605	75	60	135	72.1	A
470	545	610	75	65	140	77.1	A
470	545	615	75	70	145	74.3	A
470	545	620	75	75	150	66.5	A
470	550	605	80	55	135	67.1	A
470	550	610	80	60	140	74.3	A
470	550	615	80	65	145	77.1	A
470	550	620	80	70	150	73.1	A
470	555	605	85	50	135	67.6	A
470	555	610	85	55	140	63.7	A
470	555	615	85	60	145	69.9	A
470	555	620	85	65	150	72.0	A
475	525	610	50	85	135	34.1	B
475	525	615	50	90	140	24.0	B
475	525	620	50	95	145	11.9	B
475	530	605	55	75	130	49.4	B
475	530	610	55	80	135	48.2	B
475	530	615	55	85	140	37.8	B
475	530	620	55	90	145	24.7	B
475	535	605	60	70	130	59.0	B
475	535	610	60	75	135	56.9	B
475	535	615	60	80	140	46.6	B
475	535	620	60	85	145	32.7	B
475	540	605	65	65	130	62.5	A
475	540	610	65	70	135	63.4	A
475	540	615	65	75	140	60.7	A
475	540	620	65	80	145	45.0	B
475	545	605	70	60	130	66.7	A
475	545	610	70	65	135	69.9	A
475	545	615	70	70	140	66.5	A
475	545	620	70	75	145	64.7	A
475	550	605	75	55	130	66.9	A
475	550	610	75	60	135	72.5	A
475	550	615	75	65	140	73.4	A
475	550	620	75	70	145	67.6	A
475	555	605	80	50	130	74.3	A
475	555	610	80	55	135	68.2	A
475	555	615	80	60	140	74.2	A
475	555	620	80	65	145	74.4	A

FIG.9

1ST LIGHT SOURCE	2ND LIGHT SOURCE	3RD LIGHT SOURCE	2ND-1ST	3RD-2ND	3RD-1ST	R9	EVALUATION
450	530	605	80	75	155	-37.8	A
450	535	605	85	70	155	-54.2	A
450	535	610	85	75	160	51.0	AA
450	540	605	90	65	155	-76.1	A
450	540	610	90	70	160	27.9	AA
450	540	615	90	75	165	65.7	AA
450	545	605	95	60	155	-98.0	A
450	545	610	95	65	160	-0.2	AA
450	545	615	95	70	165	92.5	AA
455	530	605	75	75	150	-35.8	AA
455	535	605	80	70	150	-52.1	A
455	535	610	80	75	155	54.4	AA
455	540	605	85	65	150	-74.1	A
455	540	610	85	70	155	32.3	AA
455	540	615	85	75	160	59.8	AA
455	545	605	90	60	150	-94.9	A
455	545	610	90	65	155	4.6	AA
455	545	615	90	70	160	90.5	AA
455	545	620	90	75	165	0.5	AA
455	550	605	95	55	150	-120.2	A
455	550	610	95	60	155	-29.7	AA
455	550	615	95	65	160	60.2	AA
455	550	620	95	70	165	53.1	AA
460	530	605	70	75	145	-38.5	A
460	535	605	75	70	145	-53.7	A
460	535	610	75	75	150	58.6	AA
460	540	605	80	65	145	-70.8	A
460	540	610	80	70	150	38.1	AA
460	540	615	80	75	155	53.2	AA
460	545	605	85	60	145	-87.4	A
460	545	610	85	65	150	11.7	AA
460	545	615	85	70	155	83.4	AA
460	545	620	85	75	160	-17.1	AA
460	550	605	90	55	145	-111.4	A
460	550	610	90	60	150	-20.7	AA
460	550	615	90	65	155	73.2	AA
460	550	620	90	70	160	34.6	AA
460	555	610	95	55	150	-32.8	AA
460	555	615	95	60	155	19.1	AA
460	555	620	95	65	160	97.2	AA
465	530	605	65	75	140	-34.1	AA
465	535	605	70	70	140	-47.0	A
465	535	610	70	75	145	63.4	AA
465	540	605	75	65	140	-63.4	A
465	540	610	75	70	145	44.5	AA
465	540	615	75	75	150	42.8	AA
465	545	605	80	60	140	-82.4	A
465	545	610	80	65	145	20.5	AA
465	545	615	80	70	150	73.3	AA
465	545	620	80	75	155	-29.0	AA
465	550	605	85	55	140	-111.2	A
465	550	610	85	60	145	-9.5	AA
465	550	615	85	65	150	82.0	AA
465	550	620	85	70	155	19.8	AA

FIG.10

1ST LIGHT SOURCE	2ND LIGHT SOURCE	3RD LIGHT SOURCE	2ND-1ST	3RD-2ND	3RD-1ST	R9	EVALUATION
465	555	610	90	55	145	-37.0	AA
465	555	615	90	60	150	32.6	AA
465	555	620	90	65	155	73.4	AA
470	535	605	65	70	135	-41.7	A
470	535	610	65	75	140	68.8	AA
470	540	605	70	65	135	-54.5	A
470	540	610	70	70	140	52.7	AA
470	540	615	70	75	145	31.0	AA
470	545	605	75	60	135	-75.2	A
470	545	610	75	65	140	31.2	AA
470	545	615	75	70	145	59.7	AA
470	545	620	75	75	150	-35.1	AA
470	550	605	80	55	135	-97.8	A
470	550	610	80	60	140	2.1	AA
470	550	615	80	65	145	85.8	AA
470	550	620	80	70	150	-1.1	AA
470	555	610	85	55	140	-35.2	AA
470	555	615	85	60	145	51.9	AA
470	555	620	85	65	150	55.1	AA
475	540	605	65	65	130	-43.4	A
475	540	610	65	70	135	62.9	AA
475	540	615	65	75	140	15.0	AA
475	545	605	70	60	130	-61.3	A
475	545	610	70	65	135	44.7	AA
475	545	615	70	70	140	41.9	AA
475	545	620	70	75	145	-36.9	AA
475	550	605	75	55	130	-82.1	A
475	550	610	75	60	135	20.4	AA
475	550	615	75	65	140	70.4	AA
475	550	620	75	70	145	-28.7	AA
475	555	610	80	55	135	-13.5	AA
475	555	615	80	60	140	74.7	AA
475	555	620	80	65	145	23.2	AA

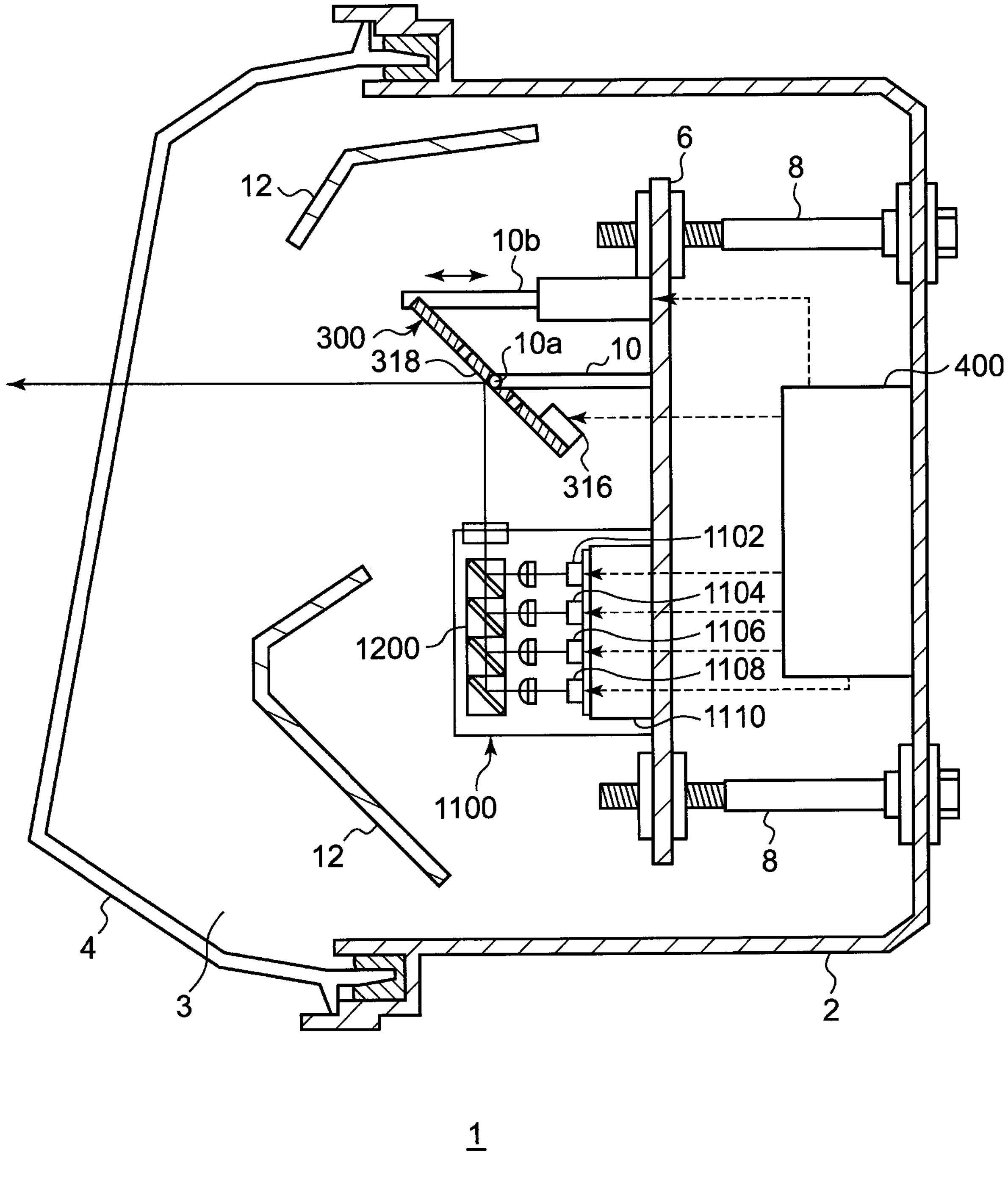
FIG.11

1ST LIGHT SOURCE	2ND LIGHT SOURCE	3RD LIGHT SOURCE	2ND-1ST	3RD-2ND	3RD-1ST	THEORETICAL EFFICIENCY	EVALUATION
450	535	610	85	75	160	374.1	AAA
450	540	610	90	70	160	384.1	AAA
450	540	615	90	75	165	371.8	AAA
450	545	610	95	65	160	391.2	AAA
450	545	615	95	70	165	381.3	AAA
455	530	605	75	75	150	363.8	AAA
455	535	610	80	75	155	372.7	AAA
455	540	610	85	70	155	382.2	AAA
455	540	615	85	75	160	369.3	AAA
455	545	610	90	65	155	392.1	AAA
455	545	615	90	70	160	380.0	AAA
455	545	620	90	75	165	365.8	AAA
455	550	610	95	60	155	398.9	AAA
455	550	615	95	65	160	389.7	AAA
455	550	620	95	70	165	379.5	AAA
460	535	610	75	75	150	369.6	AAA
460	540	610	80	70	150	378.3	AAA
460	540	615	80	75	155	366.6	AAA
460	545	610	85	65	150	387.4	AAA
460	545	615	85	70	155	376.1	AAA
460	545	620	85	75	160	357.2	AAA
460	550	610	90	60	150	395.9	AAA
460	550	615	90	65	155	384.3	AAA
460	550	620	90	70	160	368.9	AAA
460	555	610	95	55	150	374.8	AAA
460	555	615	95	60	155	393.6	AAA
460	555	620	95	65	160	383.6	AAA
465	530	605	65	75	140	359.1	AAA
465	535	610	70	75	145	361.7	AAA
465	540	610	75	70	145	370.4	AAA
465	540	615	75	75	150	357.9	AAA
465	545	610	80	65	145	377.9	AAA
465	545	615	80	70	150	367.2	AAA
465	545	620	80	75	155	348.7	AAA
465	550	610	85	60	145	385.2	AAA
465	550	615	85	65	150	375.5	AAA
465	550	620	85	70	155	361.6	AAA
465	555	610	90	55	145	377.7	AAA
465	555	615	90	60	150	385.8	AAA
465	555	620	90	65	155	369.7	AAA
470	535	610	65	75	140	345.5	AAA
470	540	610	70	70	140	353.3	AAA
470	540	615	70	75	145	341.5	AAA
470	545	610	75	65	140	359.6	AAA
470	545	615	75	70	145	349.5	AAA
470	545	620	75	75	150	338.7	AAA
470	550	610	80	60	140	367.3	AAA
470	550	615	80	65	145	357.2	AAA
470	550	620	80	70	150	340.6	AAA
470	555	610	85	55	140	373.1	AAA
470	555	615	85	60	145	365.8	AAA
470	555	620	85	65	150	353.5	AAA
475	540	610	65	70	135	330.5	AAA
475	540	615	65	75	140	320.2	AA

FIG.12

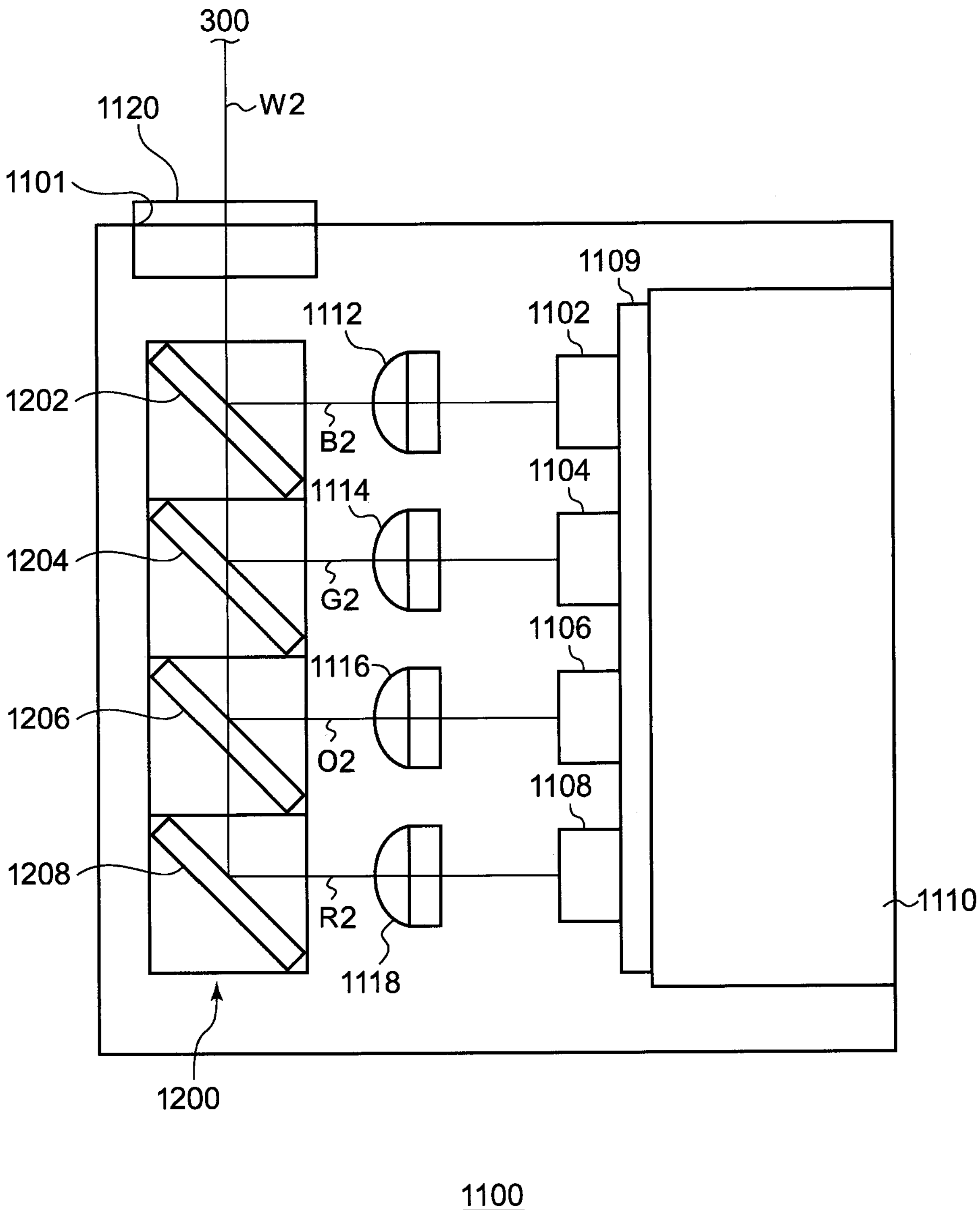
1ST LIGHT SOURCE	2ND LIGHT SOURCE	3RD LIGHT SOURCE	2ND-1ST	3RD-2ND	3RD-1ST	THEORETICAL EFFICIENCY	EVALUA-TION
475	545	610	70	65	135	336.7	AAA
475	545	615	70	70	140	327.1	AA
475	545	620	70	75	145	330.4	AAA
475	550	610	75	60	135	342.0	AAA
475	550	615	75	65	140	332.2	AAA
475	550	620	75	70	145	316.8	AA
475	555	610	80	55	135	347.4	AAA
475	555	615	80	60	140	339.5	AAA
475	555	620	80	65	145	326.4	AA

FIG.13



12
6
8
10b
300
318
10a
10
400
316
1102
1104
1106
1108
1110
1200
1100
12
8
4
3
2
1

FIG.14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B2
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1206
O2
1108
1208
R2
1110
1118
1200
1100

FIG.15A

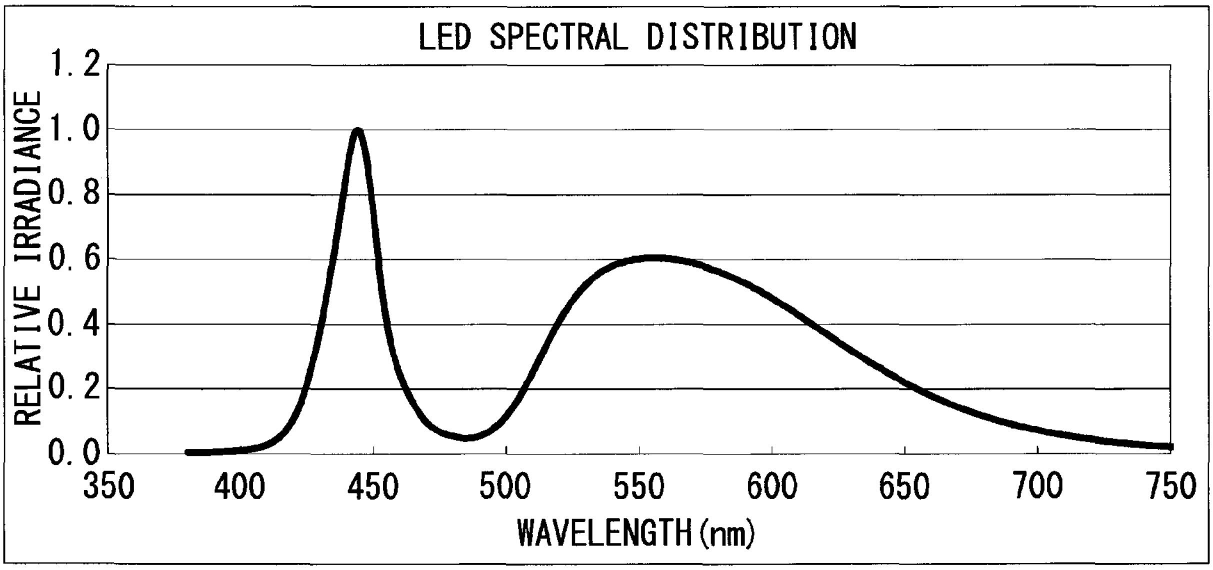


FIG.15B

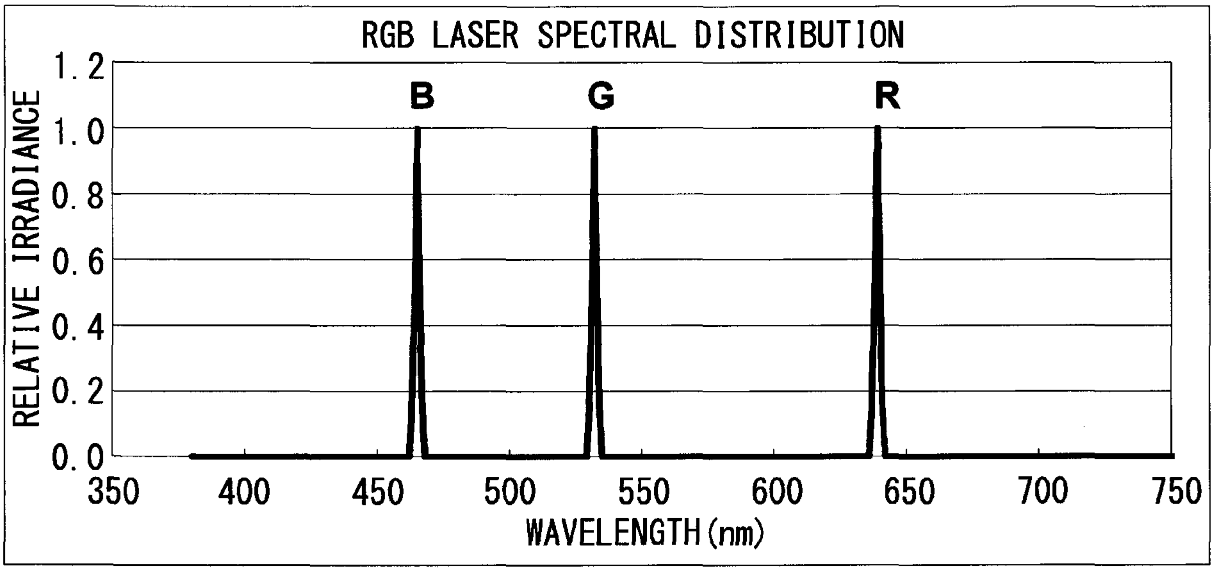


FIG.15C

	CHROMATICITY		COLOR TEMPER-ATURE (K)	COLOR RENDERING INDICES		THEORETICAL EFFICIENCY (lm/W)
	x	y		Ra	R9	
RGB LASER LIGHT SOURCE	0.346	0.354	4975	3.6	-361.6	243
WHITE LED	0.346	0.352	5001	65.1	-37.4	335

FIG.16A

	PEAK WAVELENGTH OF 3RD LASER LIGHT					
	570nm	580nm	585nm	590nm	600nm	610nm
CHROMATICITY (x)	0.309	0.332	0.342	0.351	0.363	0.364
CHROMATICITY (y)	0.388	0.369	0.359	0.350	0.333	0.321
Ra	65.7	80.0	88.4	89.3	62.0	29.8
R9	76.0	86.8	92.1	90.4	34.9	-88.1
THEORETICAL EFFICIENCY (lm/W)	350.0	337.0	328.6	319.3	299.4	279.2

FIG.16B

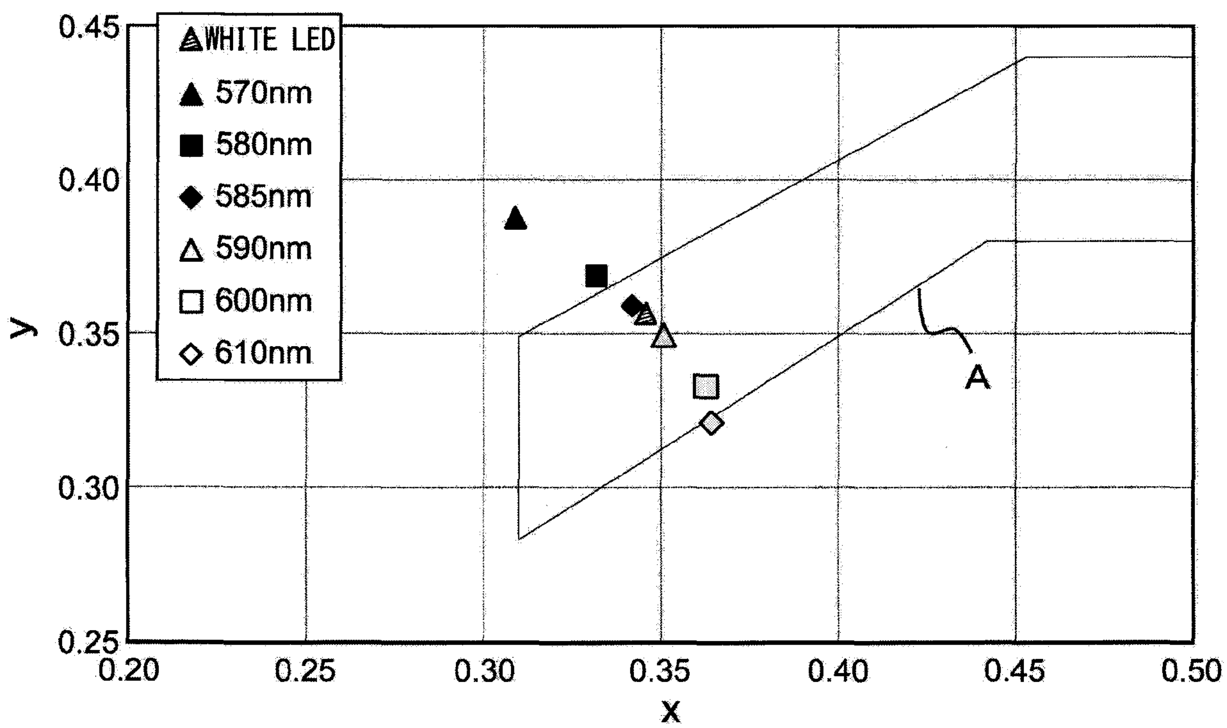


FIG.17A

	PEAK WAVELENGTH OF 3RD LASER LIGHT					
	570nm	580nm	585nm	590nm	600nm	610nm
CHROMATICITY (x)	0.303	0.325	0.335	0.343	0.355	0.356
CHROMATICITY (y)	0.405	0.386	0.377	0.368	0.352	0.341
Ra	64.0	77.3	85.6	91.5	67.2	37.6
R9	81.8	81.3	84.4	93.7	43.5	-82.7
THEORETICAL EFFICIENCY (lm/W)	362.4	350.1	342.0	333.2	314.3	295.1

FIG.17B

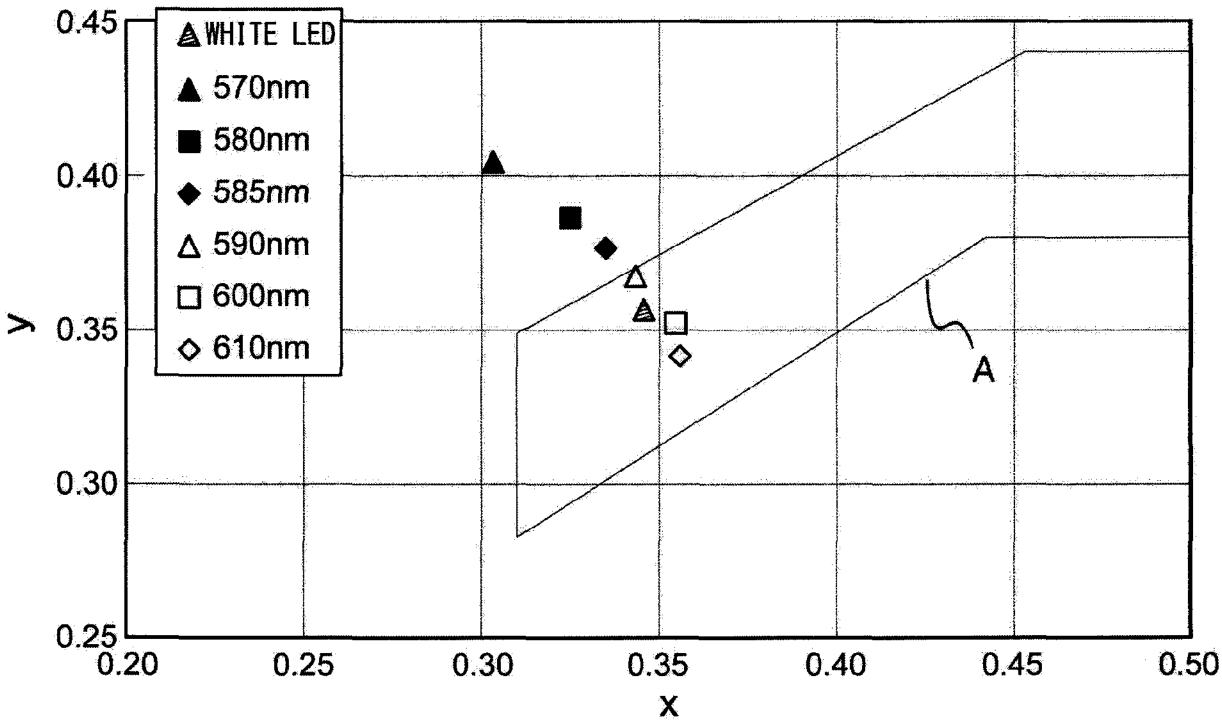


FIG.18A

	PEAK WAVELENGTH OF 3RD LASER LIGHT					
	570nm	580nm	585nm	590nm	600nm	610nm
CHROMATICITY (x)	0.342	0.369	0.382	0.393	0.408	0.412
CHROMATICITY (y)	0.364	0.342	0.330	0.318	0.298	0.282
Ra	66.9	79.5	81.2	76.9	51.4	23.9
R9	35.3	72.4	95.5	82.3	85.0	7.9
THEORETICAL EFFICIENCY (lm/W)	328.9	313.2	302.9	291.5	267.3	242.7

FIG.18B

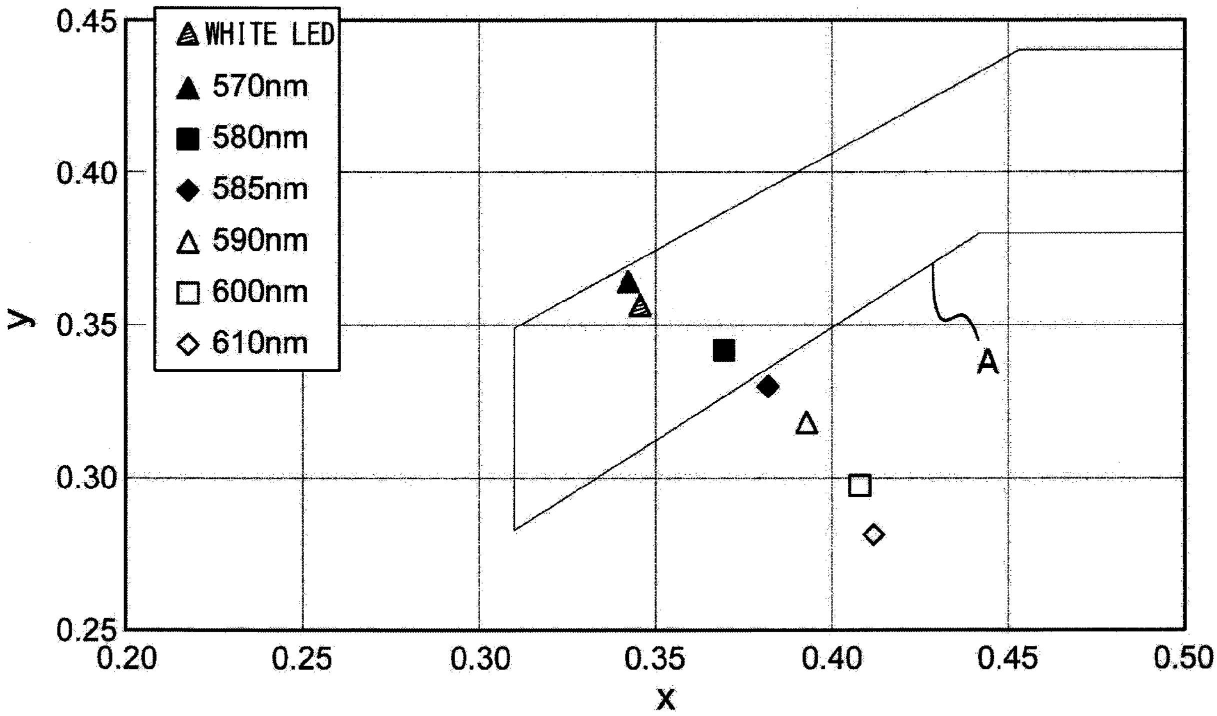


FIG.19A

	PEAK WAVELENGTH OF 3RD LASER LIGHT					
	570nm	580nm	585nm	590nm	600nm	610nm
CHROMATICITY (x)	0.323	0.343	0.352	0.359	0.370	0.371
CHROMATICITY (y)	0.382	0.366	0.357	0.349	0.334	0.324
Ra	53.1	62.2	68.3	76.0	81.5	58.5
R9	85.0	79.2	78.0	82.1	72.3	−36.9
THEORETICAL EFFICIENCY (lm/W)	359.2	347.4	339.7	331.2	313.1	294.7

FIG.19B

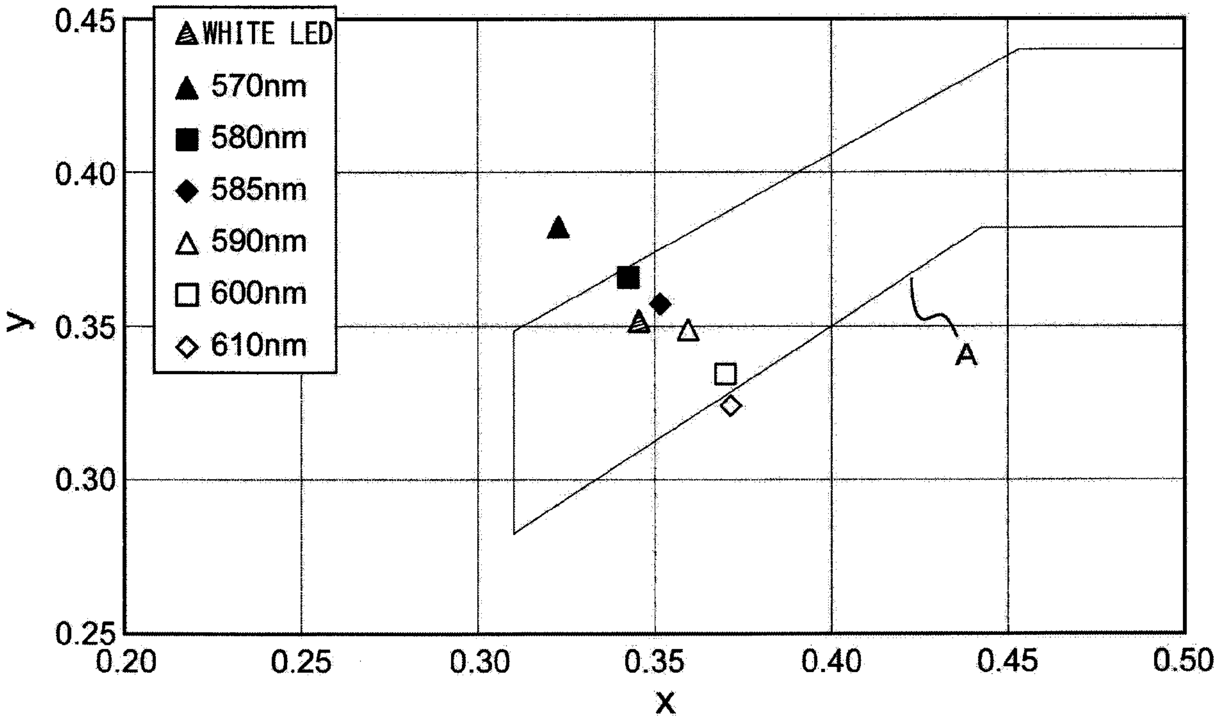


FIG.20A

	PEAK WAVELENGTH OF 3RD LASER LIGHT							
	570nm	580nm	585nm	590nm	600nm	610nm	612nm	613nm
CHROMATICITY (x)	0.320	0.339	0.347	0.355	0.365	0.366	0.365	0.365
CHROMATICITY (y)	0.399	0.383	0.375	0.367	0.354	0.345	0.343	0.343
Ra	49.4	57.7	63.5	70.9	81.5	64.3	61.7	58.0
R9	64.4	56.5	56.6	63.7	85.1	-23.2	-41.2	-68.0
THEORETICAL EFFICIENCY (lm/W)	374.7	363.5	356.2	348.1	330.9	313.4	310.0	308.3

FIG.20B

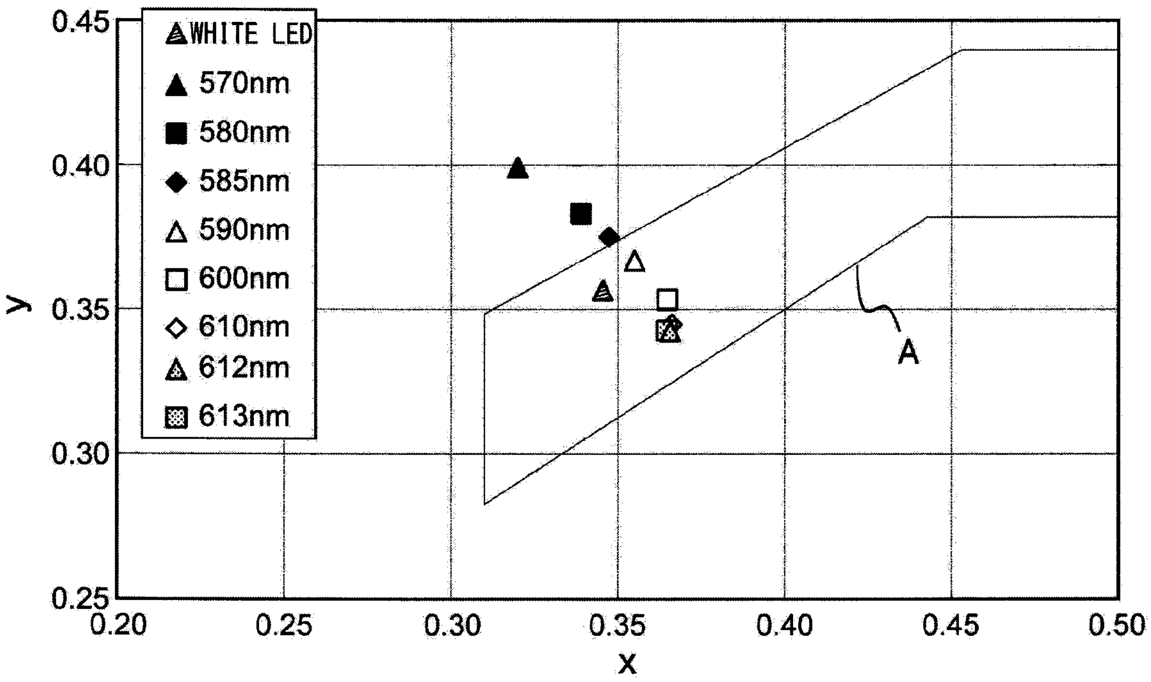
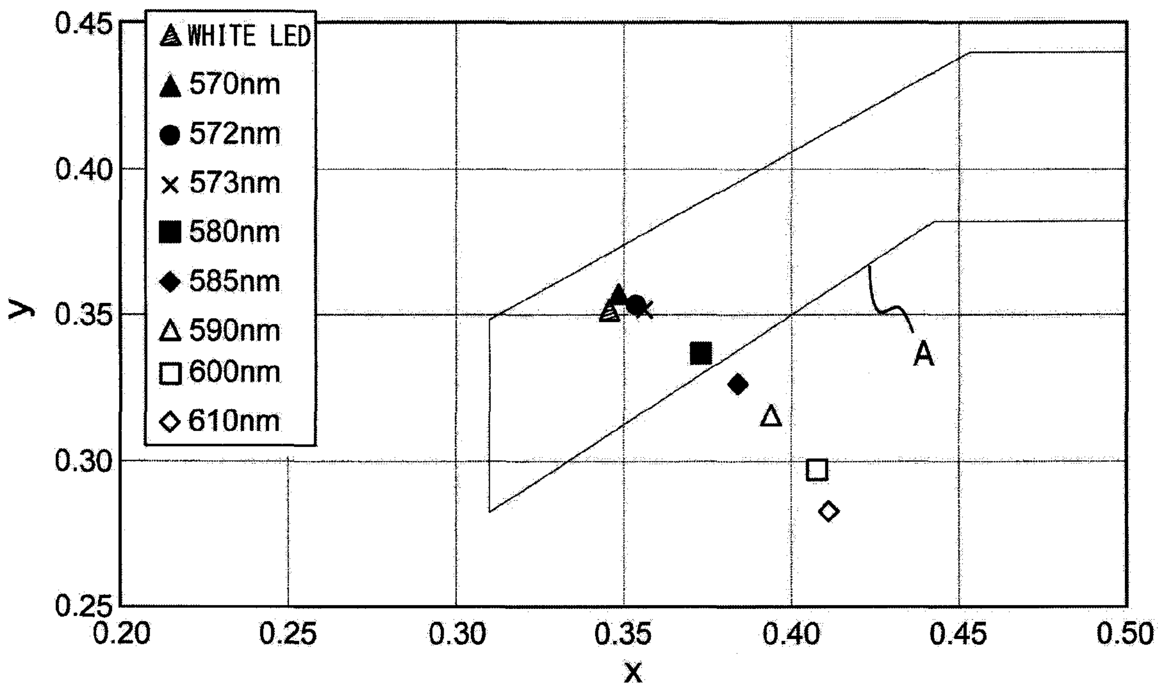


FIG.21A

	PEAK WAVELENGTH OF 3RD LASER LIGHT							
	570nm	572nm	573nm	580nm	585nm	590nm	600nm	610nm
CHROMATICITY (x)	0.349	0.353	0.356	0.373	0.384	0.394	0.408	0.411
CHROMATICITY (y)	0.357	0.354	0.352	0.337	0.326	0.316	0.297	0.283
Ra	57.5	59.5	61.7	69.9	75.1	78.0	71.6	48.2
R9	36.6	43.1	46.0	74.8	95.2	80.8	85.6	17.8
THEORETICAL EFFICIENCY (lm/W)	329.1	326.7	325.4	314.7	305.2	294.8	272.6	250.0

FIG.21B



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EUROPEAN SEARCH REPORT

Application Number
EP 17 18 2349

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	DE 10 2008 022795 A1 (OSRAM OPTO SEMICONDUCTORS GMBH [DE]) 12 November 2009 (2009-11-12) * paragraph [0041] - paragraph [0042] * * figure 1 * -----	1,4,6,7	INV. F21S8/10 F21S8/12 ADD. F21Y115/30 F21Y113/10 F21Y113/13
Y	US 2007/297171 A1 (BERBEN DIRK [DE] ET AL) 27 December 2007 (2007-12-27) * paragraph [0031] - paragraph [0032] * * paragraph [0036] * * figures * -----	1,4,7	
Y	JP 2012 169375 A (SHARP KK) 6 September 2012 (2012-09-06) * abstract; figure 4d * -----	6	
A	US 2011/044070 A1 (TAKAHASHI KOJI [JP]) 24 February 2011 (2011-02-24) * paragraph [0101] - paragraph [0103] * * figure 2 * -----	1	TECHNICAL FIELDS SEARCHED (IPC)
A	KR 2012 0009527 A (SEOUL SEMICONDUCTOR CO LTD [KR]) 31 January 2012 (2012-01-31) * abstract * -----	1	F21Y F21S
A	US 2012/299476 A1 (ROBERTS BRUCE R [US] ET AL) 29 November 2012 (2012-11-29) * paragraph [0064] * * figure 6 * -----	1	
A,D	JP 2010 036835 A (KOITO MFG CO LTD) 18 February 2010 (2010-02-18) -----	1	

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
The Hague	1 December 2017	Prévot, Eric

CATEGORY OF CITED DOCUMENTS

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01-12-2017

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 102008022795 A1	12-11-2009	NONE	
US 2007297171 A1	27-12-2007	NONE	
JP 2012169375 A	06-09-2012	JP 5722068 B2	20-05-2015
		JP 2012169375 A	06-09-2012
US 2011044070 A1	24-02-2011	CN 101997265 A	30-03-2011
		JP 2011065979 A	31-03-2011
		US 2011044070 A1	24-02-2011
KR 20120009527 A	31-01-2012	NONE	
US 2012299476 A1	29-11-2012	DE 112012002240 T5	03-04-2014
		JP 2014519160 A	07-08-2014
		TW 201313515 A	01-04-2013
		US 2012299476 A1	29-11-2012
		WO 2012162203 A2	29-11-2012
JP 2010036835 A	18-02-2010	JP 5271002 B2	21-08-2013
		JP 2010036835 A	18-02-2010

EPO FORM P0459

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Patent documents cited in the description

- JP 2010036835 A **[0003]**