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Iiyama et al.

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(45) **Date of Patent: Aug. 13, 2013**

(54) **ILLUMINATING LENS, LIGHTING DEVICE, SURFACE LIGHT SOURCE, AND LIQUID-CRYSTAL DISPLAY APPARATUS**

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(73) Assignee: **Panasonic Corporation**, Osaka (JP)

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(22) Filed: **Mar. 9, 2010**

(65) **Prior Publication Data**

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Related U.S. Application Data

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(30) **Foreign Application Priority Data**

Feb. 12, 2009 (JP) 2009-029350

(51) **Int. Cl.**
G02F 1/1335 (2006.01)

(52) **U.S. Cl.**
USPC **349/61**; 349/62

(58) **Field of Classification Search**
None
See application file for complete search history.

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Primary Examiner — Thanh-Nhan P Nguyen
(74) *Attorney, Agent, or Firm* — Hamre, Schumann, Mueller & Larson, P.C.

(57) **ABSTRACT**

An illuminating lens has a light entrance surface and a light exit surface. The light exit surface has a first light exit surface recessed toward a point on an optical axis A and a second light exit surface extending outwardly from the periphery of the first light exit surface. The first light exit surface includes a transmissive region located in the center of the first light exit surface and a total reflection region located around the transmissive region. The transmissive region transmits light that has been emitted from a starting point Q, which is the position of a light source on the optical axis A, at a relatively small angle with respect to the optical axis A. The total reflection region totally reflects light that has been emitted from the starting point Q at a relatively large angle with respect to the optical axis A.

14 Claims, 21 Drawing Sheets

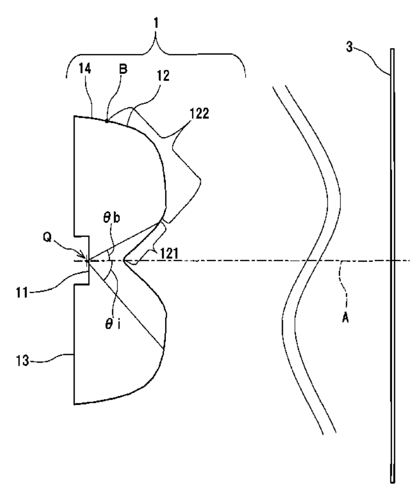

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FIG.1

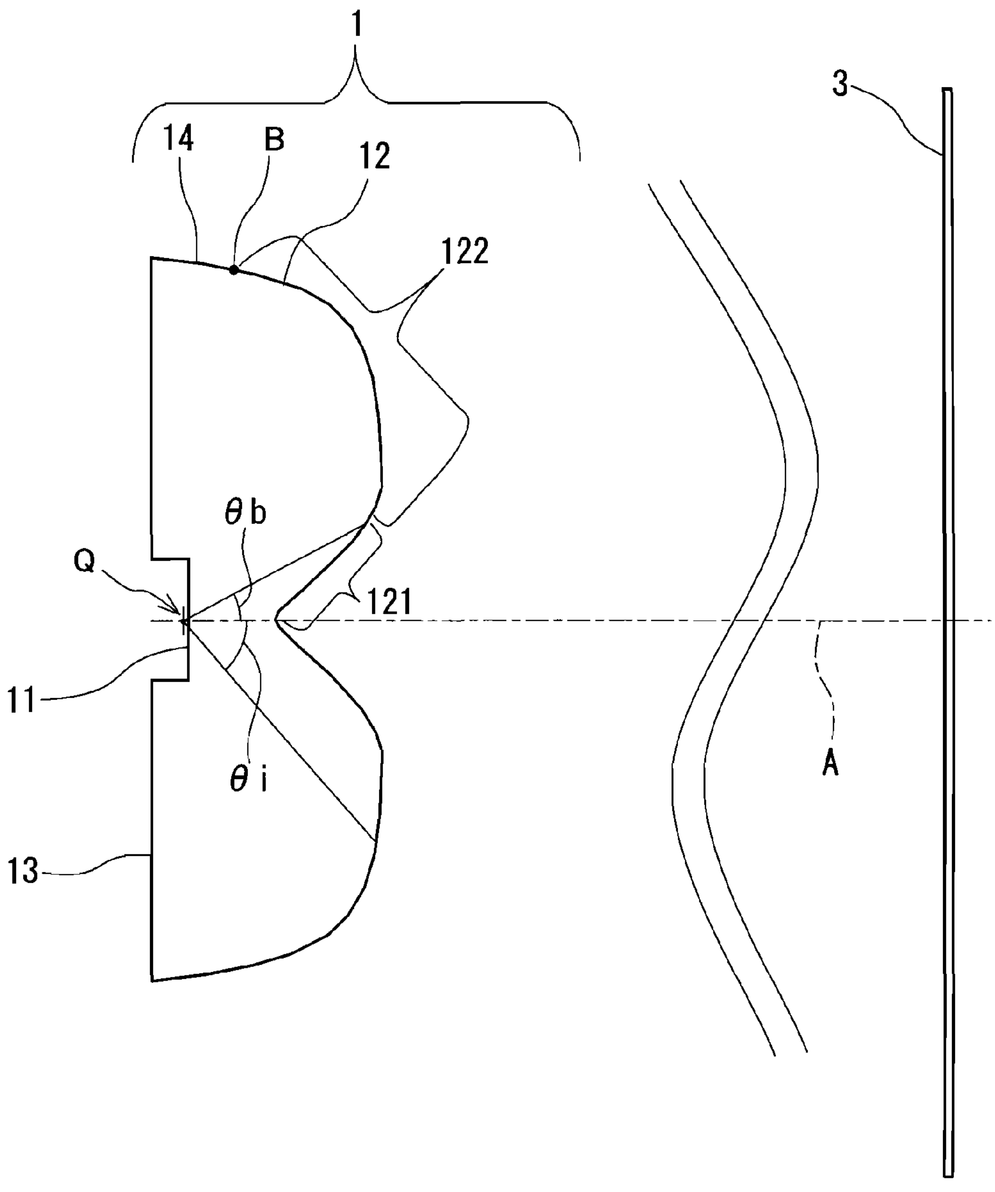


FIG.2

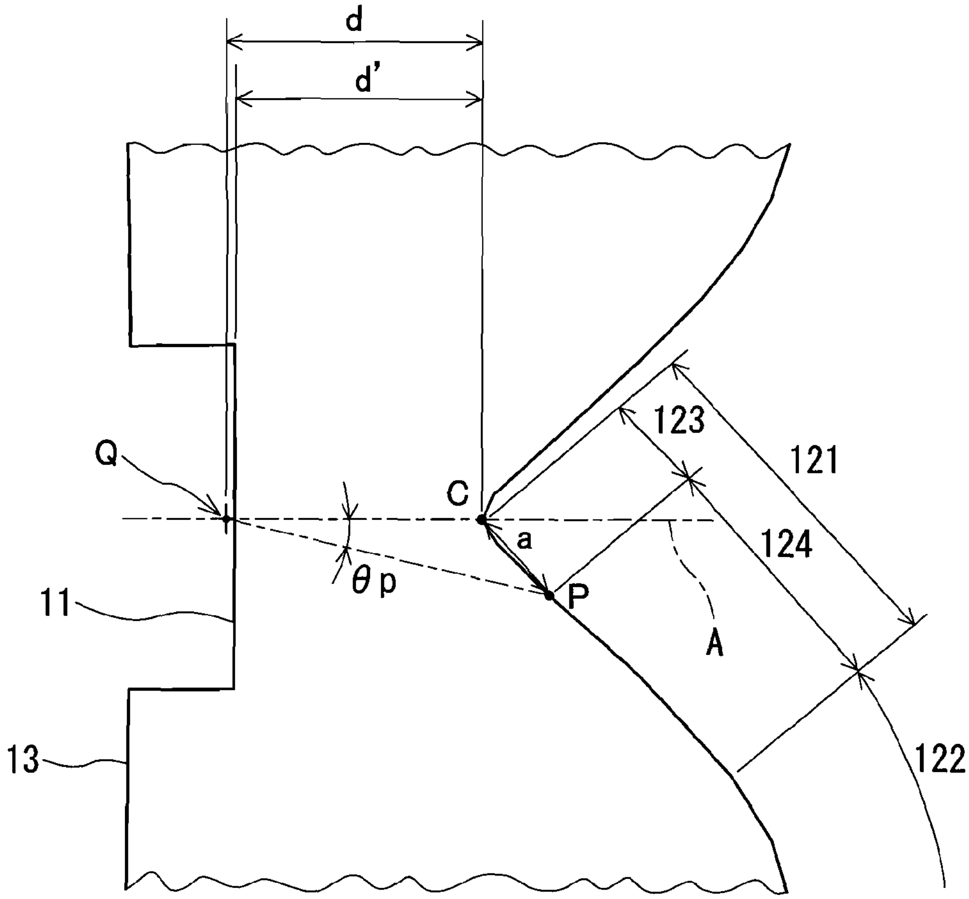


FIG.3

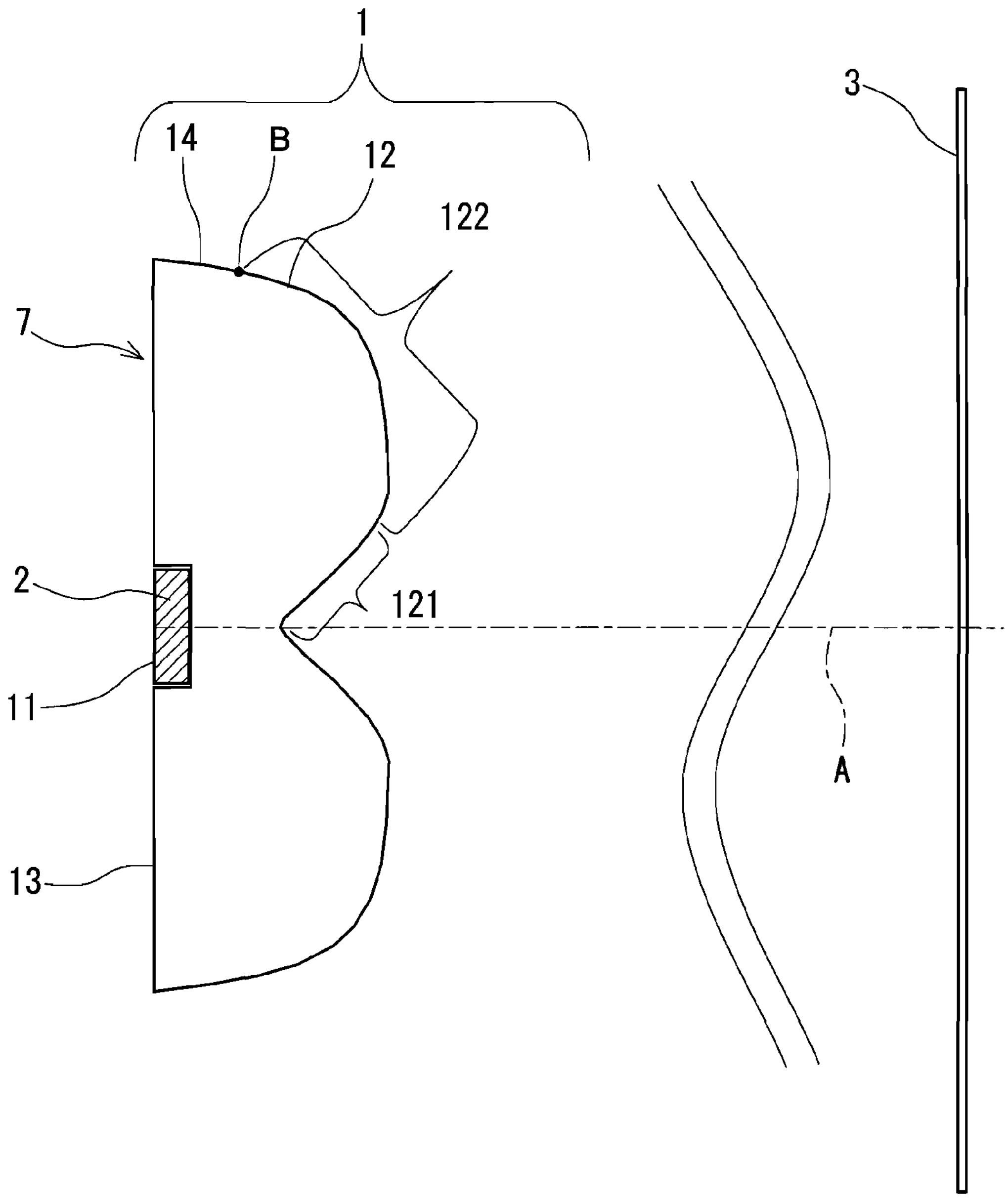


FIG.4

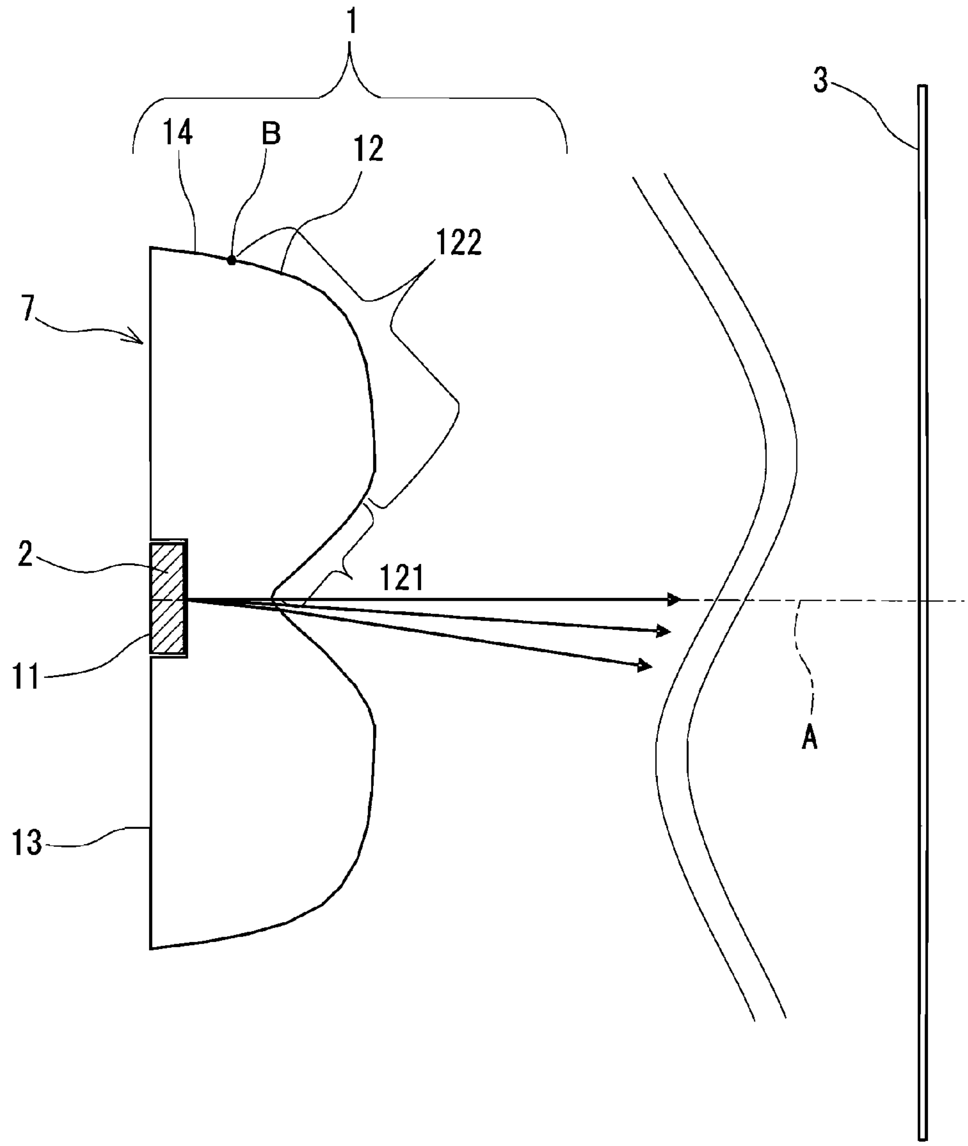


FIG.5

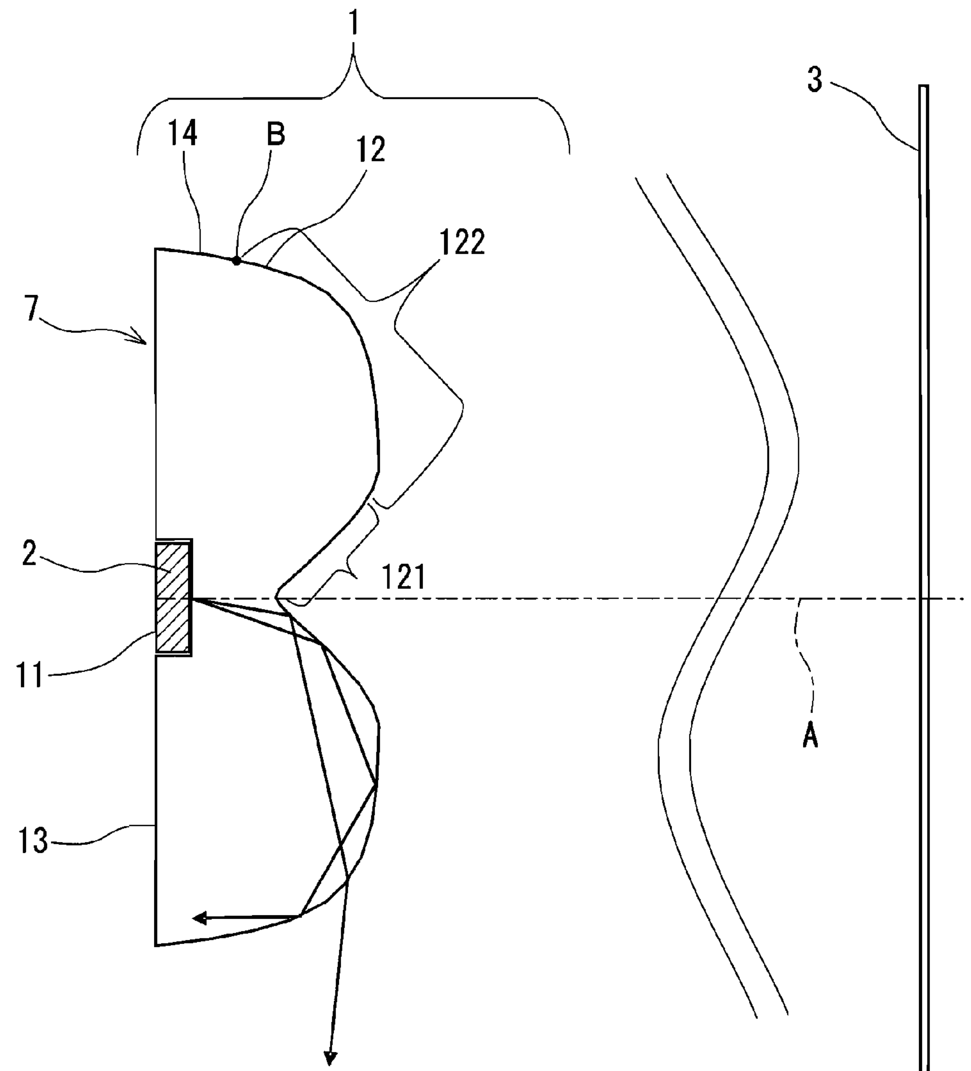


FIG.6

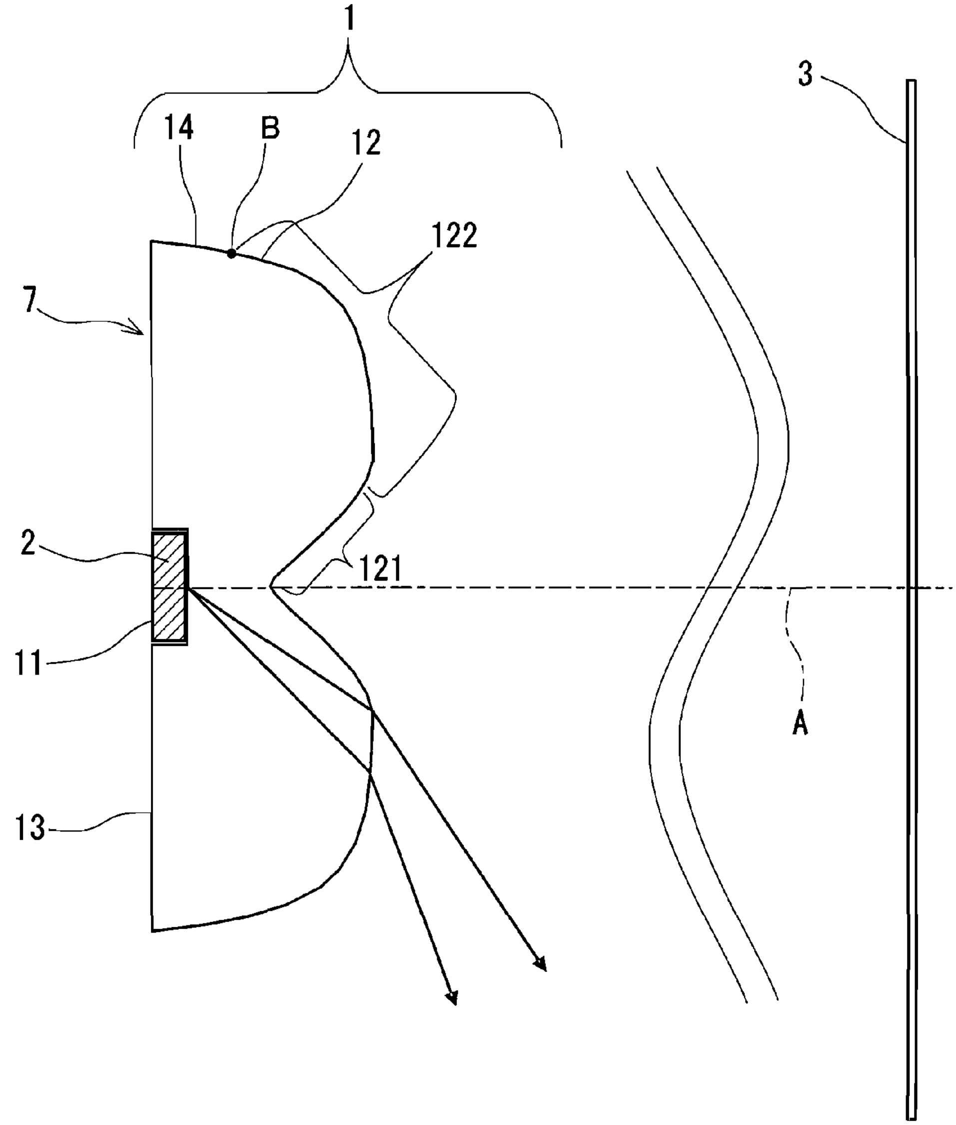


FIG.7

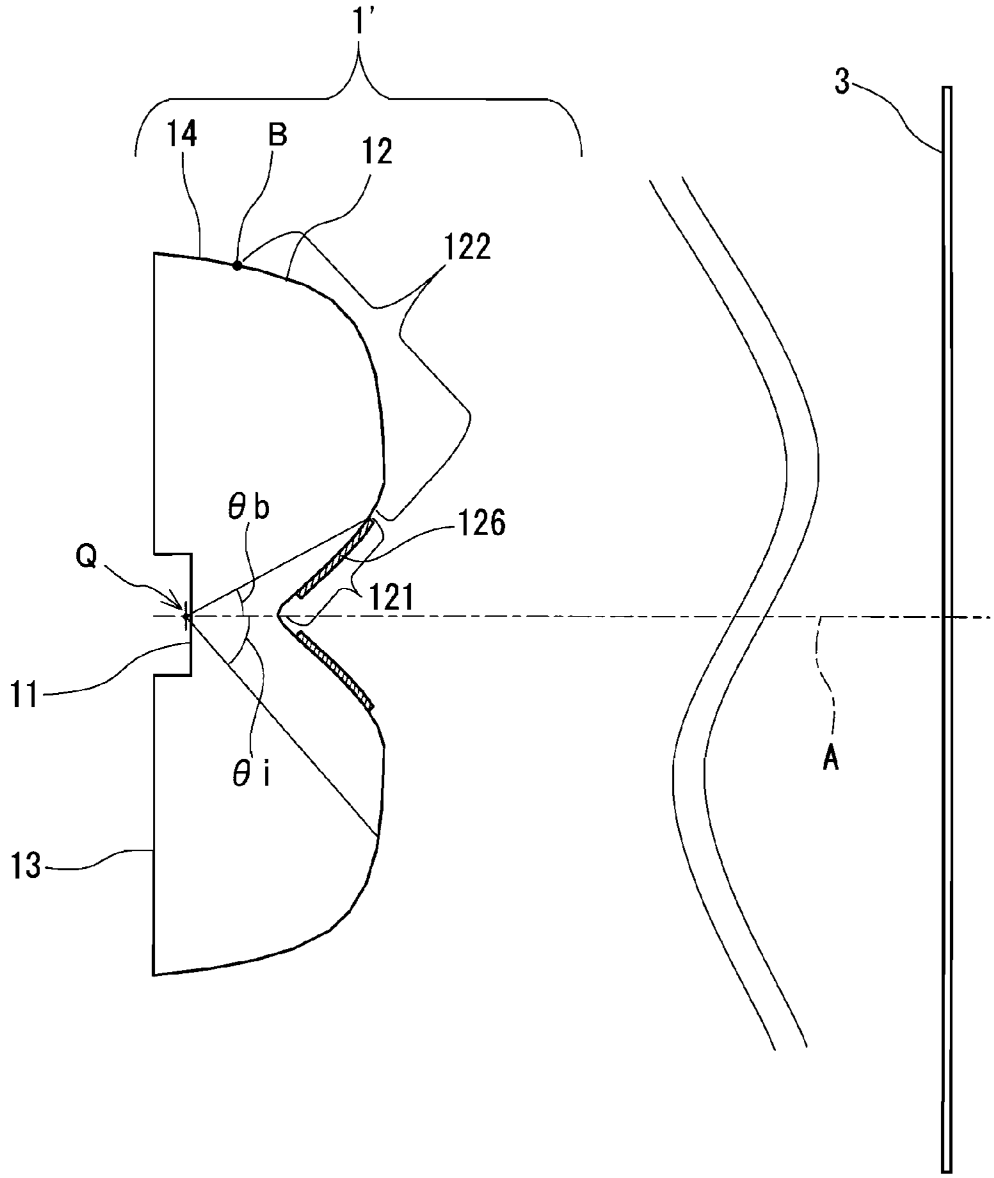


FIG.8

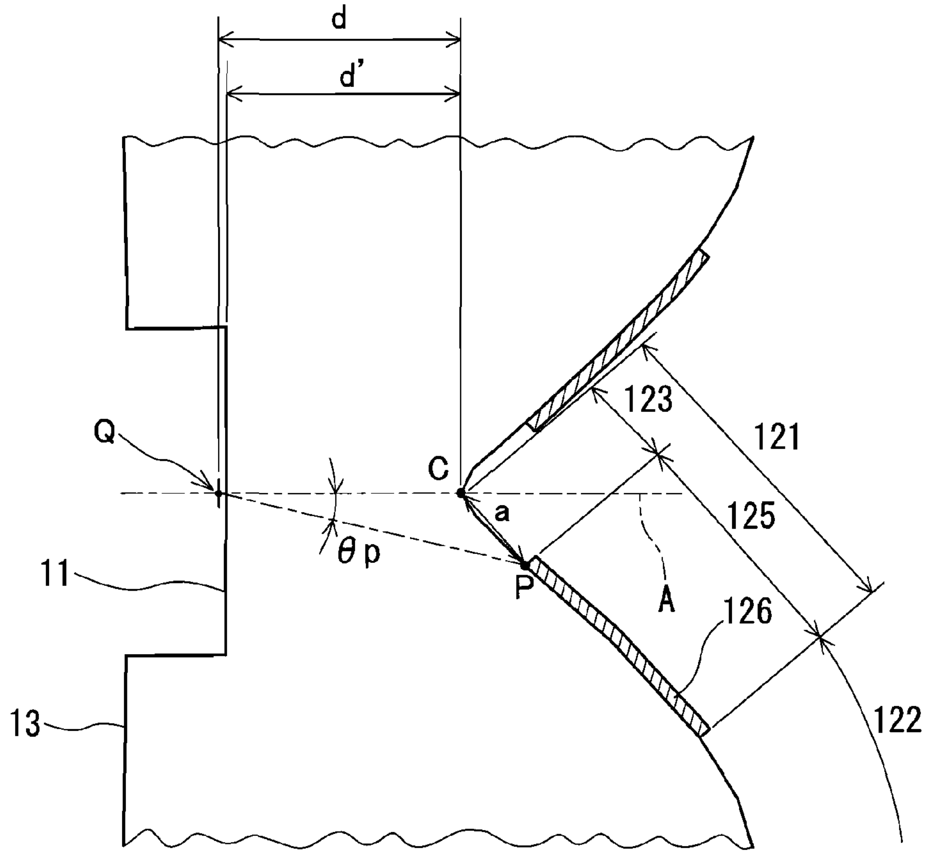


FIG.9

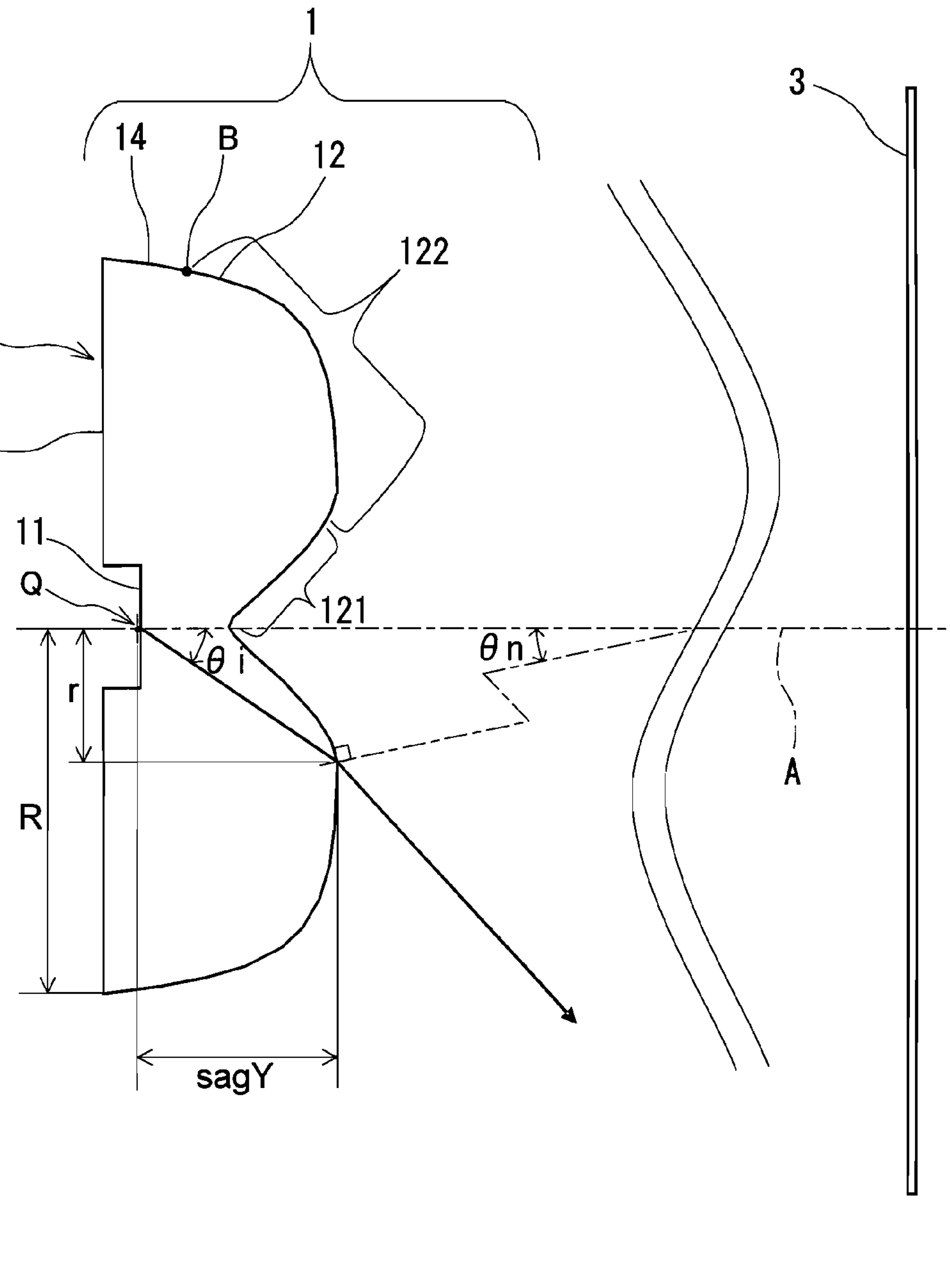


FIG.10

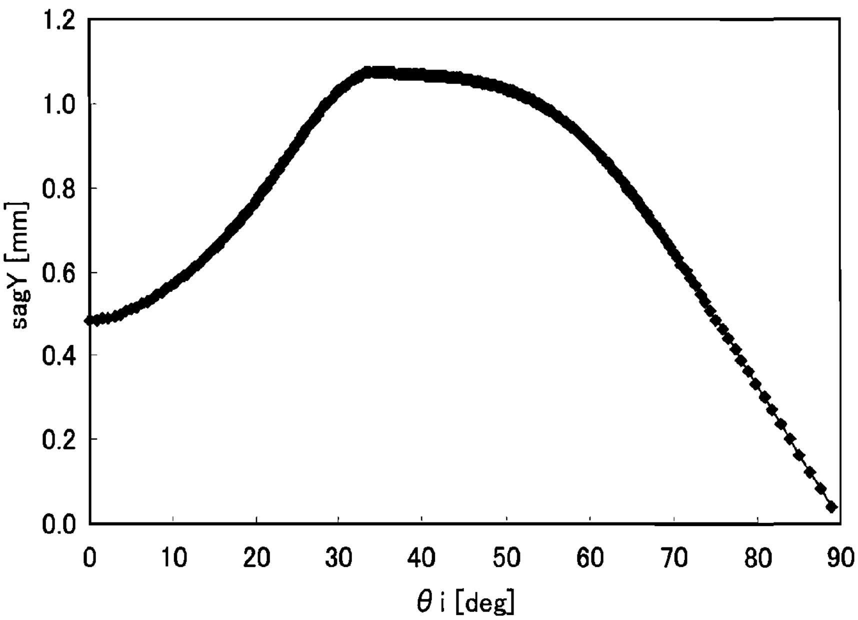
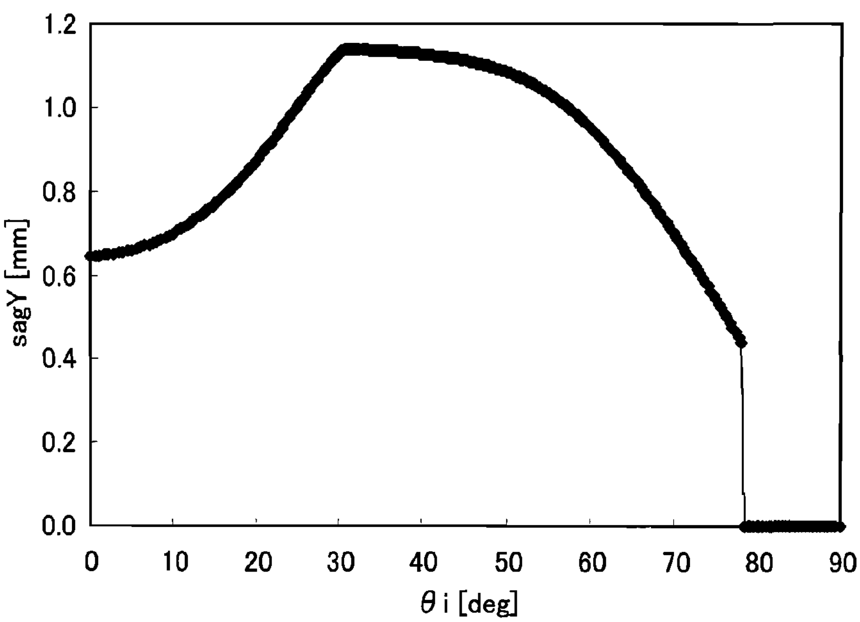

1.2
1.0
0.8
0.6
0.4
0.2
0.0
sagY [mm]
0
10
20
30
40
50
60
70
80
90
θ i [deg]

FIG.11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1.0
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0.4
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0.0
sagY [mm]
0
10
20
30
40
50
60
70
80
90
θ i [deg]

FIG.12

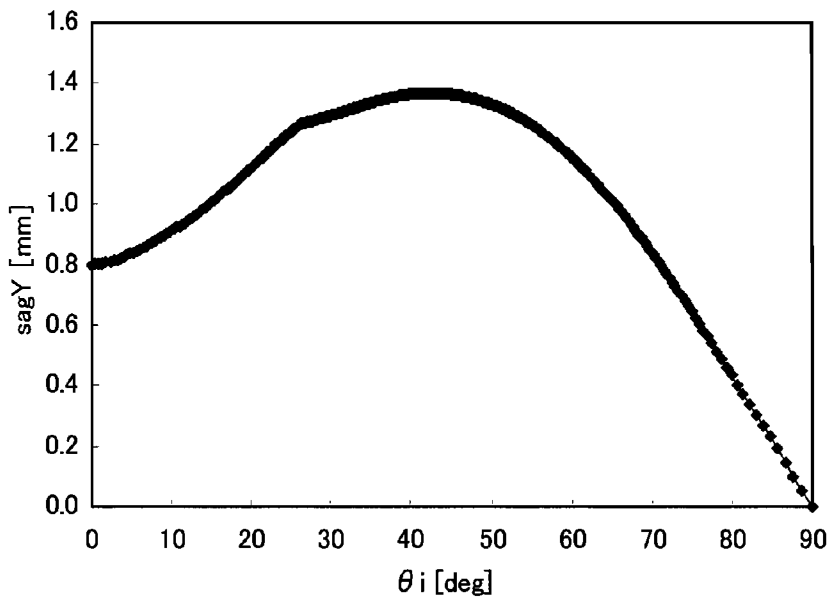

1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
sagY [mm]
0
10
20
30
40
50
60
70
80
90
θ i [deg]

FIG.13

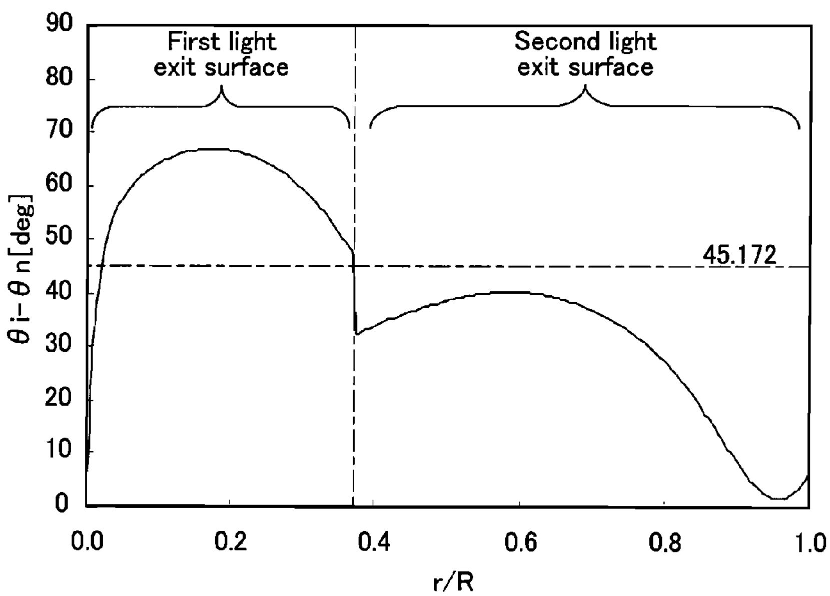
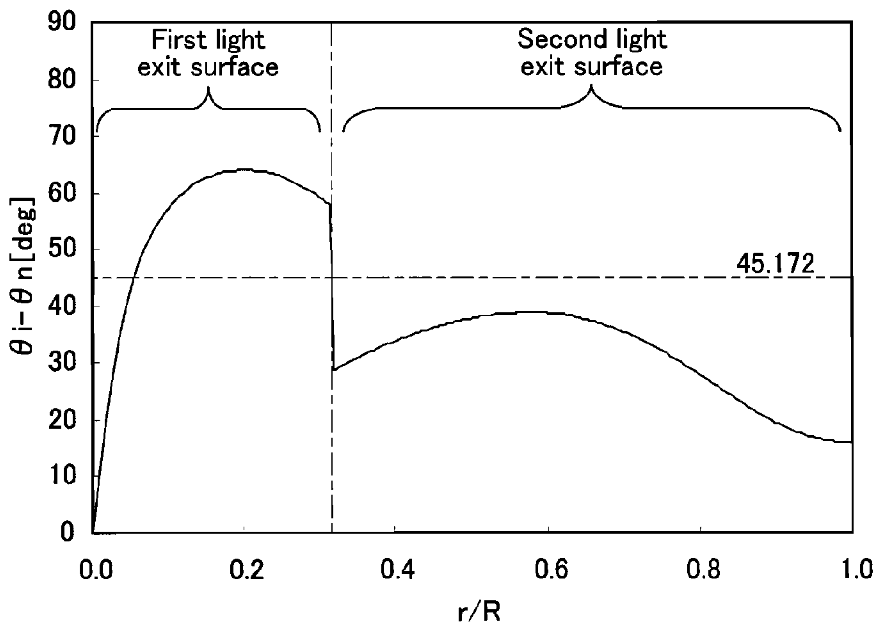
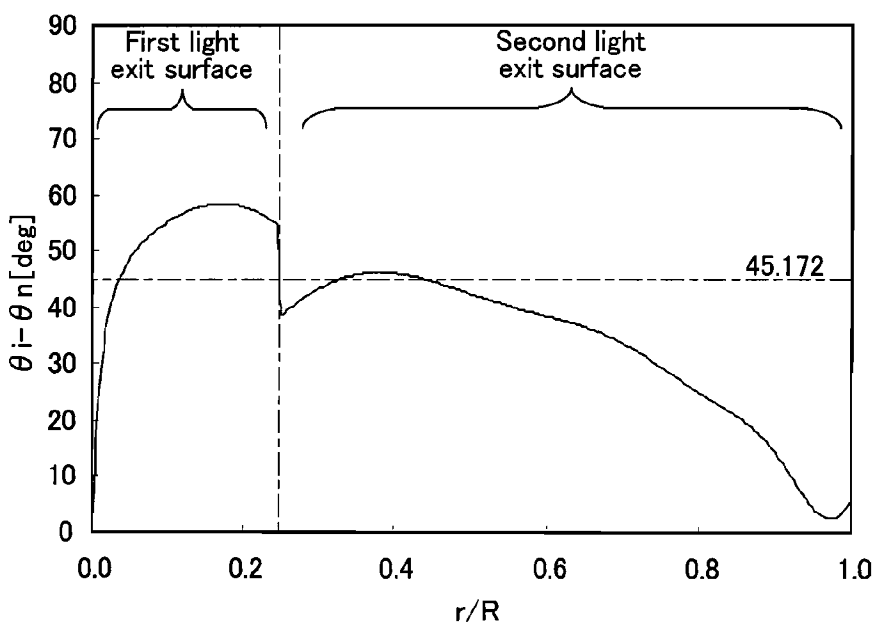

90
80
70
60
50
40
30
20
10
0
θ i- θ n[deg]
First light
exit surface
Second light
exit surface
45.172
0.0
0.2
0.4
0.6
0.8
1.0
r/R

FIG.14



First light exit surface
Second light exit surface
45.172
90
80
70
60
50
40
30
20
10
0
θi−θn[deg]
0.0
0.2
0.4
0.6
0.8
1.0
r/R

FIG.15



First light exit surface
Second light exit surface
45.172
90
80
70
60
50
40
30
20
10
0
θi−θn[deg]
0.0
0.2
0.4
0.6
0.8
1.0
r/R

FIG.16

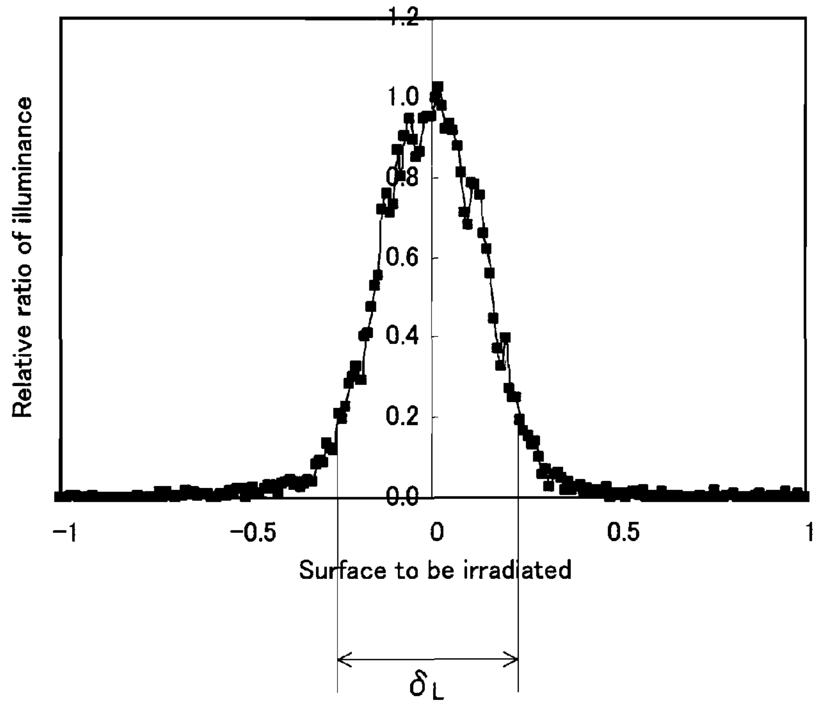

Relative ratio of illuminance
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−1
−0.5
0
0.5
1
Surface to be irradiated
δ_L

FIG.17

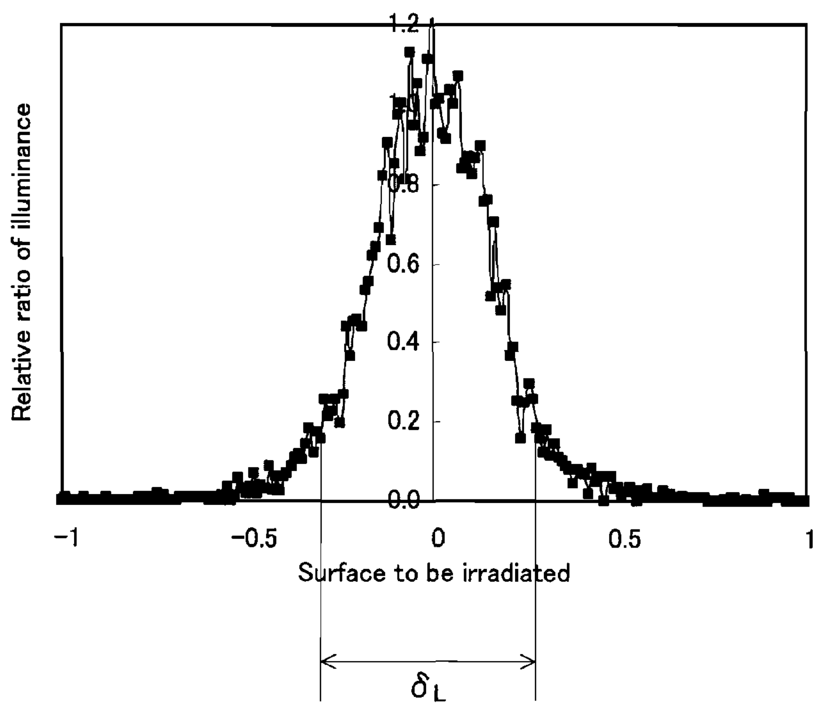

Relative ratio of illuminance
1.2
0.8
0.6
0.4
0.2
0.0
−1
−0.5
0
0.5
1
Surface to be irradiated
δ_L

FIG.18

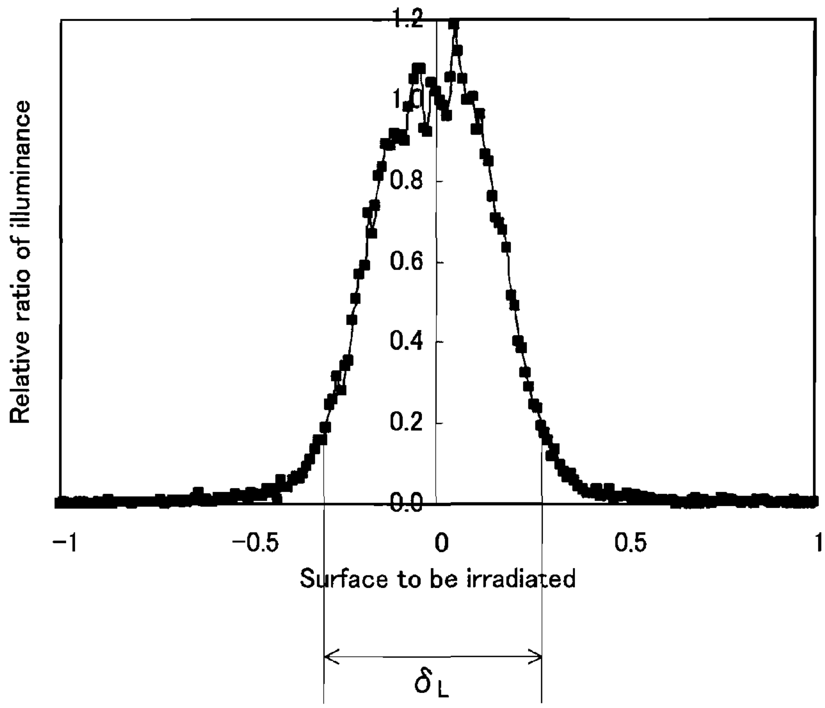
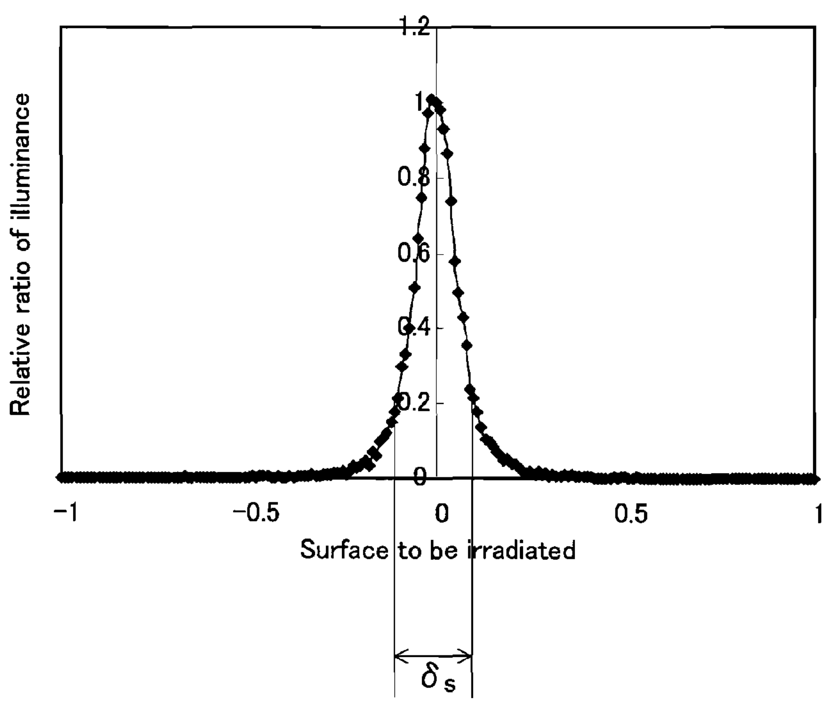

1.2
1.0
0.8
0.6
0.4
0.2
0.0
Relative ratio of illuminance
−1
−0.5
0
0.5
1
Surface to be irradiated
δL

FIG.19


1.2
1
0.8
0.6
0.4
0.2
0
Relative ratio of illuminance
−1
−0.5
0
0.5
1
Surface to be irradiated
δs

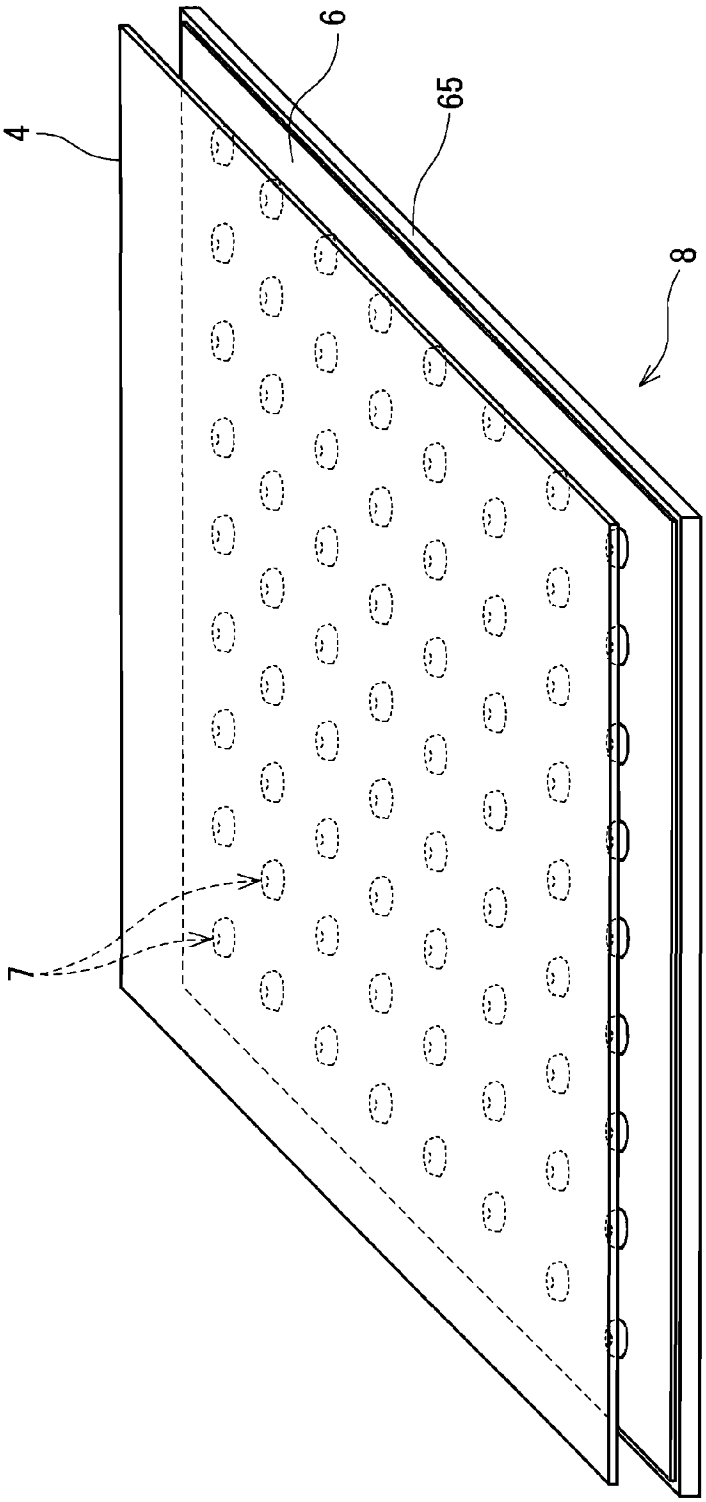


FIG.20

FIG.21

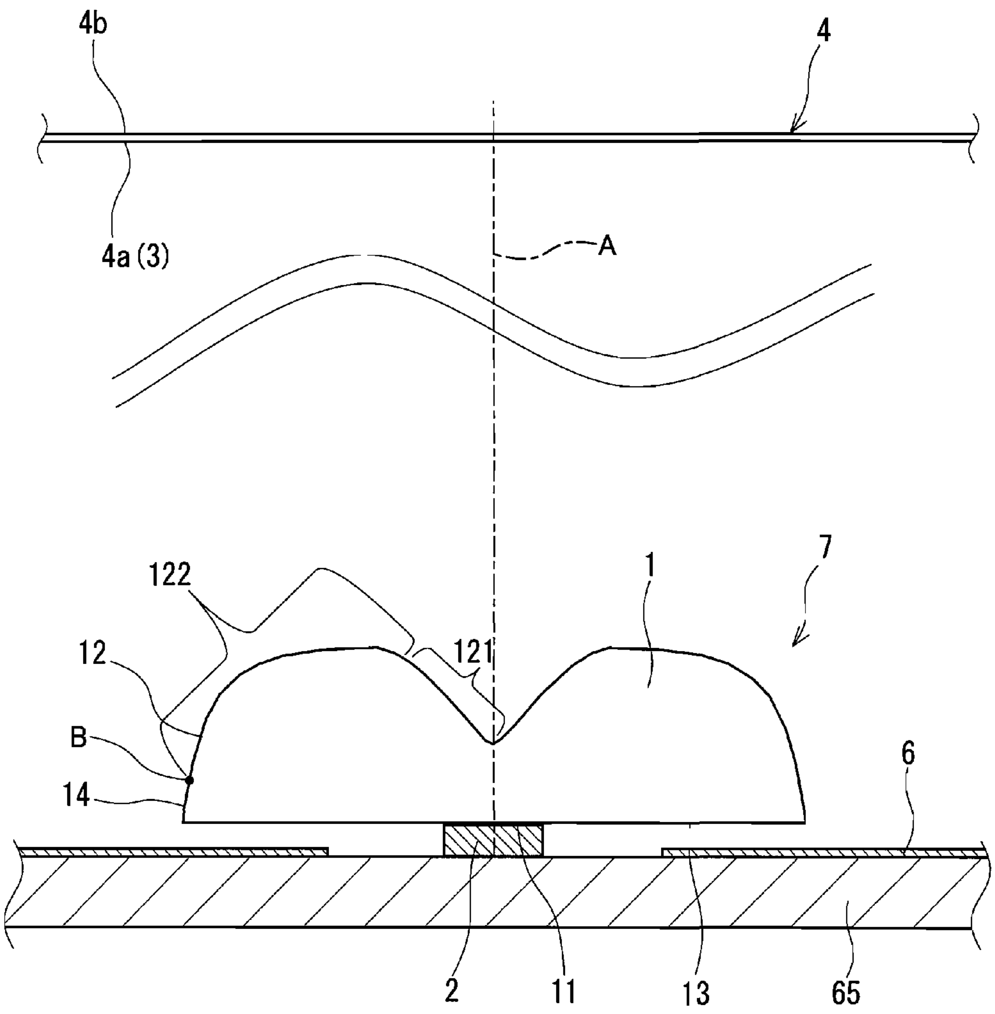


FIG.22

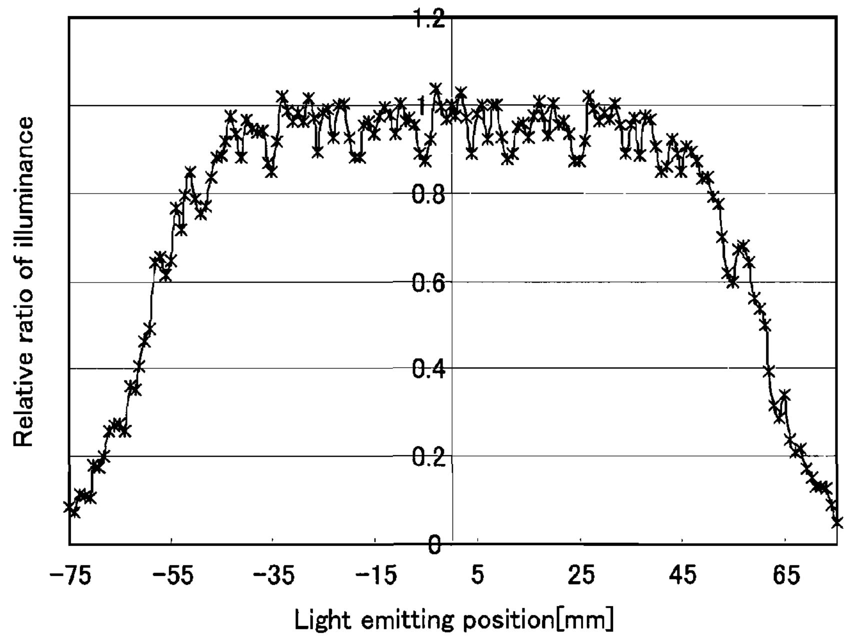

1.2
1
0.8
0.6
0.4
0.2
0
Relative ratio of illuminance
−75
−55
−35
−15
5
25
45
65
Light emitting position[mm]

FIG.23

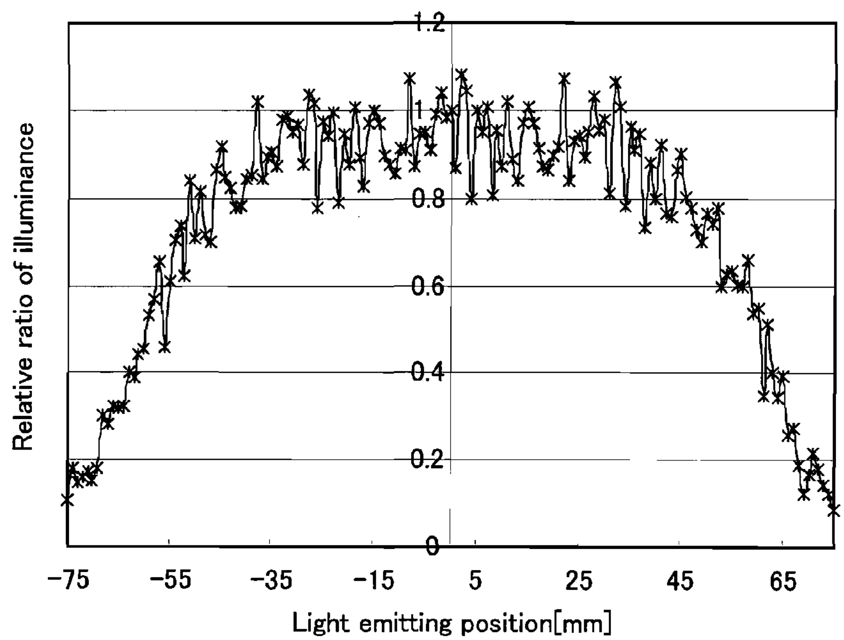
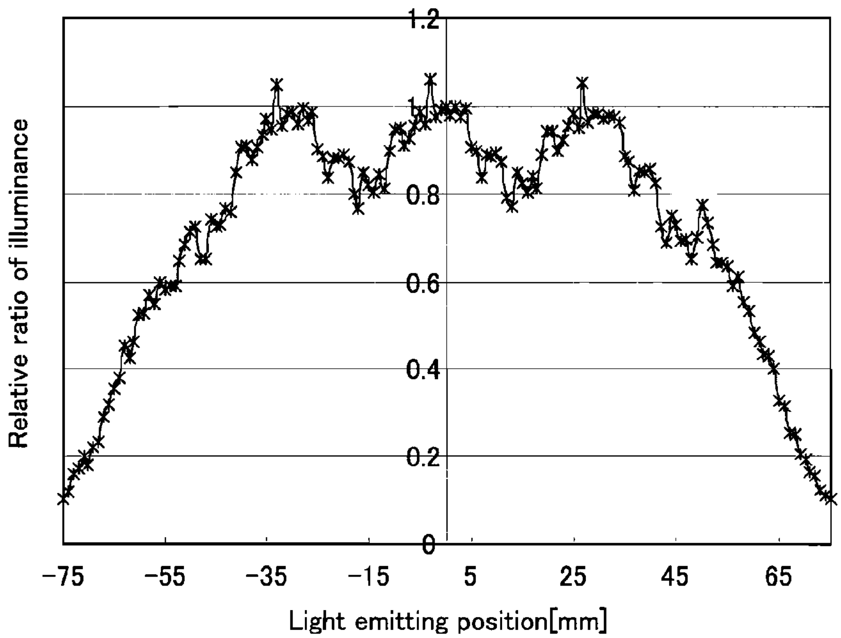
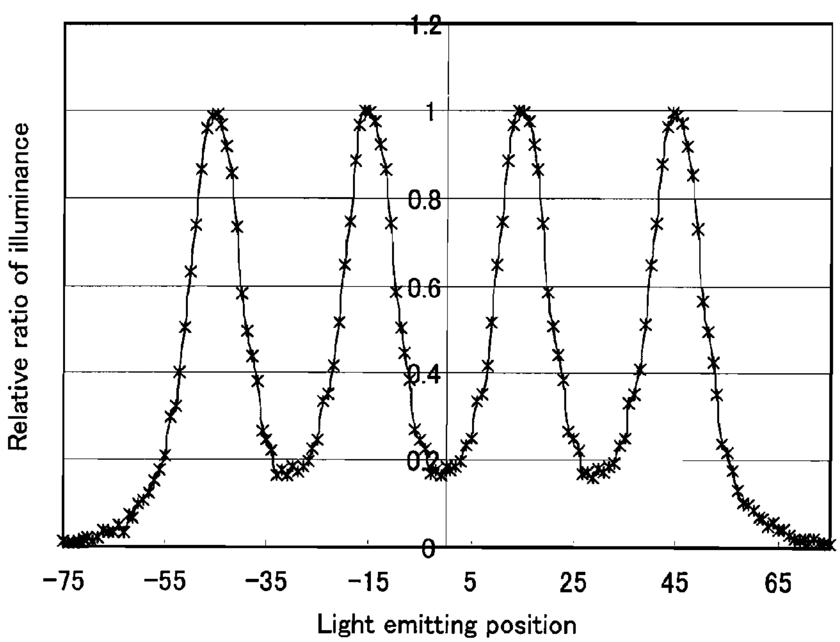

1.2
1
0.8
0.6
0.4
0.2
0
Relative ratio of illuminance
−75
−55
−35
−15
5
25
45
65
Light emitting position[mm]

FIG.24



1.2
1
0.8
0.6
0.4
0.2
0
−75
−55
−35
−15
5
25
45
65
Relative ratio of illuminance
Light emitting position[mm]

FIG.25



1.2
1
0.8
0.6
0.4
0.2
0
−75
−55
−35
−15
5
25
45
65
Relative ratio of illuminance
Light emitting position

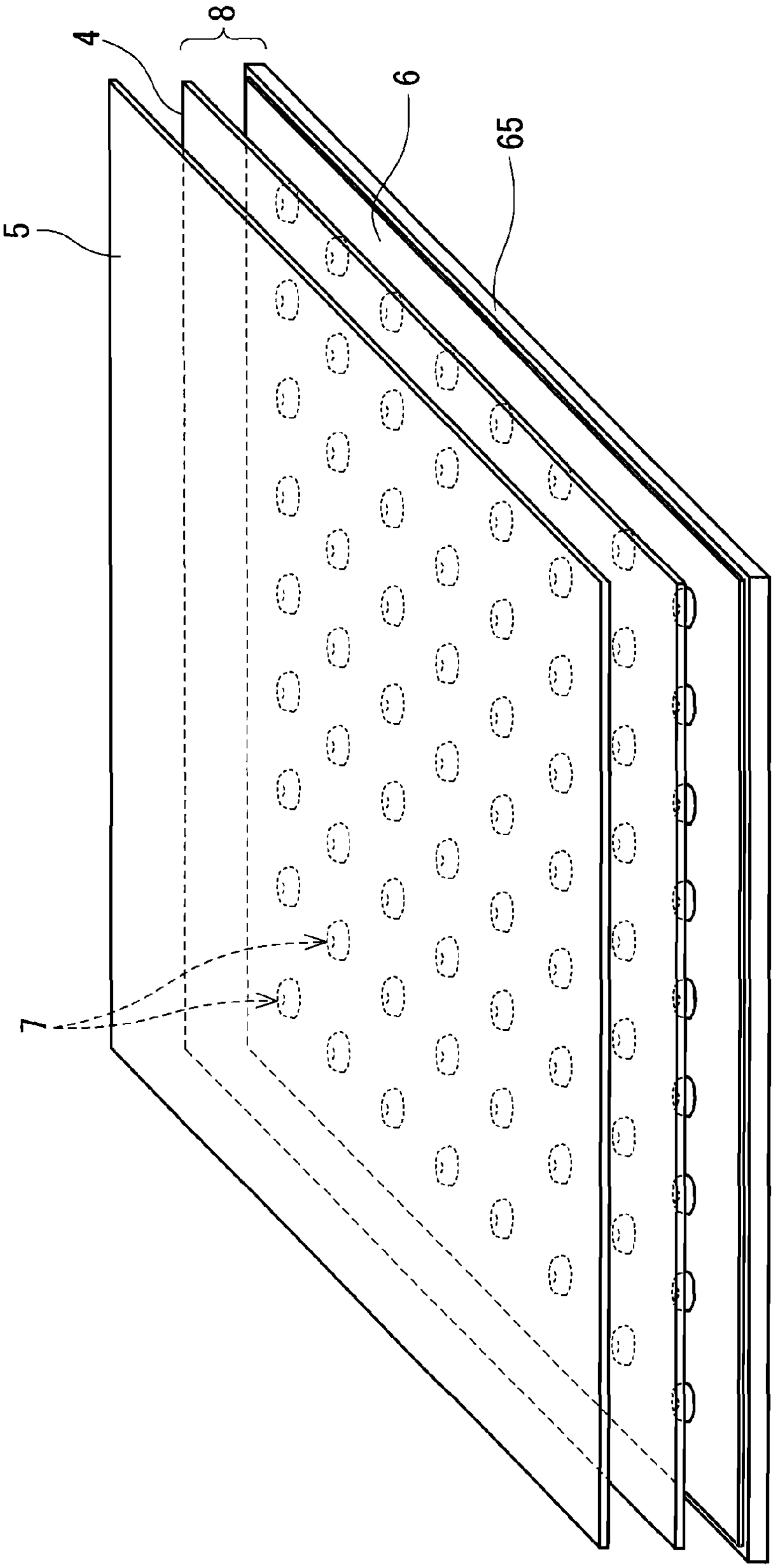


FIG.26

FIG.27

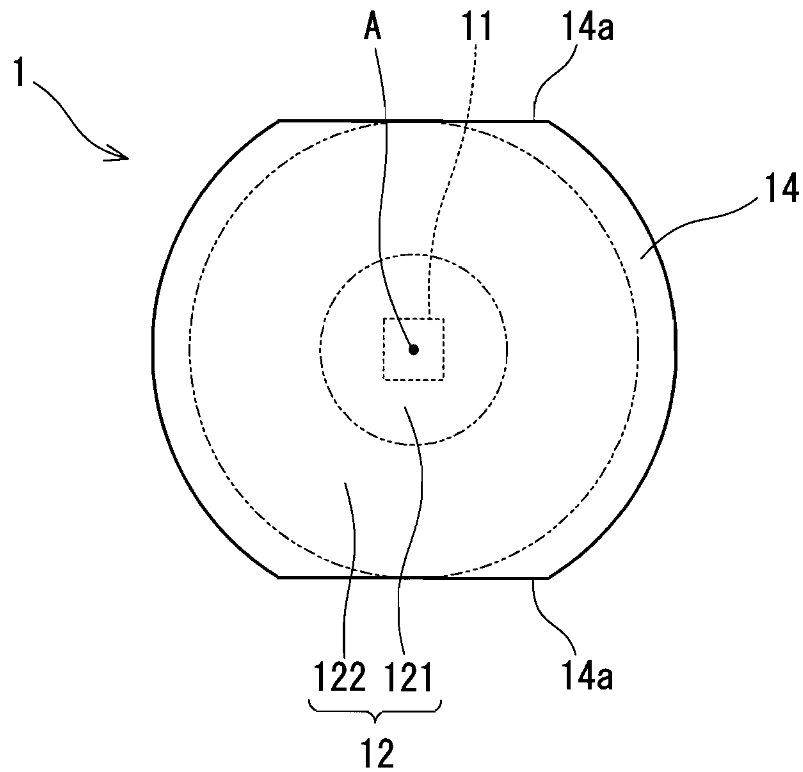


FIG.28A

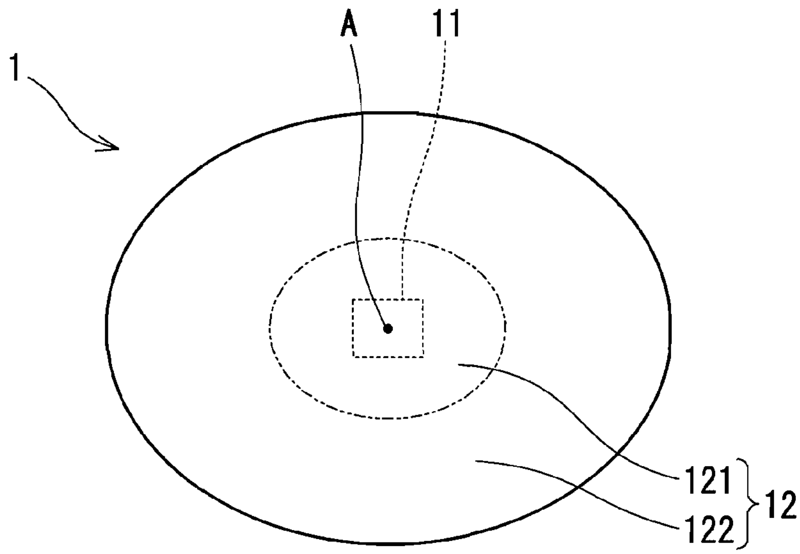
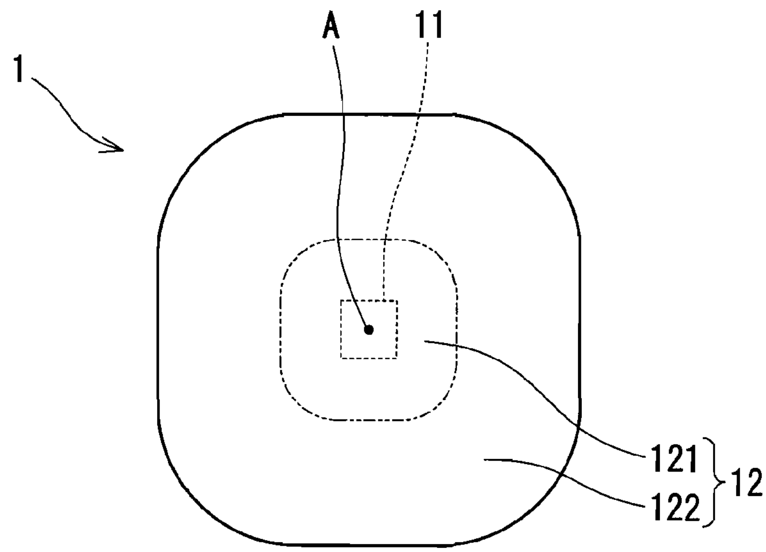


FIG.28B



ILLUMINATING LENS, LIGHTING DEVICE, SURFACE LIGHT SOURCE, AND LIQUID-CRYSTAL DISPLAY APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an illuminating lens for widening a range of transmission directions for light from a light source such as a light emitting diode, and to a lighting device using this illuminating lens. The present invention further relates to a surface light source including a plurality of lighting devices, and to a liquid-crystal display apparatus in which this surface light source is disposed behind a liquid-crystal panel to serve as a backlight.

2. Description of Related Art

In a conventional backlight of a large-sized liquid-crystal display apparatus, a number of cold cathode tubes are disposed immediately below a liquid-crystal panel, and these cold cathode tubes are used with other members such as a diffusing plate and a reflecting plate. In recent years, light emitting diodes have been used as light sources for backlights. Light emitting diodes have increased their efficiency recently, and are expected to serve as low-power light sources to replace fluorescent lamps. In the case where light emitting diodes are used as a light source in a liquid-crystal display apparatus, the power consumption of the apparatus can be reduced by controlling the light and dark states of the light emitting diodes according to an image to be displayed.

In a backlight of a liquid-crystal display apparatus using light emitting diodes as a light source, a large number of light emitting diodes are disposed therein instead of cold cathode tubes. The use of a large number of light emitting diodes allows the entire surface of the backlight to have uniform brightness, but the need for such a large number of light emitting diodes is an obstacle to cost reduction. In view of this, attempts to increase the output power of each light emitting diode to reduce the required number of light emitting diodes have been made. For example, Japanese Patent No. 3875247 has proposed a lens that is designed to provide a uniform surface light source with a reduced number of light emitting diodes.

In order to obtain a uniform surface light source with a reduced number of light emitting diodes, the area to be irradiated with the light emitted from each light emitting diode needs to be increased. That is, light emitted from each light emitting diode needs to be spread to obtain a wider range of transmission directions for light from the diode. For this purpose, in Japanese Patent No. 3875247, a lens having a circular shape in a plan view is disposed on a light emitting diode as a chip to control the directivity of the chip. The light exit surface of this lens, through which light exits the lens, has a shape such that a portion in the vicinity of the optical axis is a concave and a portion surrounding the concave is a convex extending continuously from the concave.

A light emitting diode as a chip emits light mostly in the front direction of the light emitting diode chip. In the lens disclosed in Japanese Patent No. 3875247, light that has been emitted in the front direction of the chip is refracted at the concave surface in the vicinity of the optical axis and diffused. As a result, the surface to be irradiated is illuminated to have a wide illuminance distribution with a reduced illuminance in the vicinity of the optical axis.

In the lens disclosed in Japanese Patent No. 3875247, however, the light emitted from the light source needs to be refracted, and therefore the difference in height between the concave and the convex must be reduced to a certain level.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an illuminating lens capable of further widening the range of transmission directions for light from a light source, and to provide a lighting device, a surface light source, and a liquid-crystal display apparatus each including this illuminating lens.

In order to achieve the above object, the present inventors have considered it important, in obtaining a wider range of transmission directions for light from a light source, to distribute radially the intense light that has been emitted in the front direction of the light emitting diode chip, and come up with an idea of distributing radially the light emitted in the front direction of the light emitting diode chip by utilizing intentionally the total reflection of the light. The present invention has been made in view of the above circumstances.

The present invention provides an illuminating lens for spreading light emitted from a light source so that a surface to be irradiated is irradiated with the spread light. The lens includes: a light entrance surface through which the light emitted from the light source enters the lens; and a light exit surface through which the light that has entered the lens exits the lens. In this illuminating lens, the light exit surface has a first light exit surface and a second light exit surface. The first light exit surface is recessed toward a point on an optical axis of the illuminating lens, and the second light exit surface extends outwardly from a periphery of the first light exit surface to form a convex. The first light exit surface has a transmissive region located in the center of the first light exit surface and a total reflection region located around the transmissive region. The transmissive region transmits light that has been emitted from a starting point at a relatively small angle with respect to the optical axis and then reached the first light exit surface, when a position of the light source on the optical axis is defined as the starting point. The total reflection region totally reflects light that has been emitted from the starting point at a relatively large angle with respect to the optical axis and then reached the first light exit surface. The second light exit surface has a shape capable of transmitting approximately the entire amount of light that has been emitted from the starting point and then reached the second light exit surface.

Herein, "approximately the entire amount" means at least 90% of the entire amount. It may be the entire amount, and may be an amount slightly smaller than the entire amount.

The present invention also provides a lighting device including: a light emitting diode for emitting light; and an illuminating lens for spreading light emitted from the light emitting diode so that a surface to be irradiated is irradiated with the spread light. This illuminating lens is the above-mentioned illuminating lens.

The present invention further provides a surface light source including: a plurality of lighting devices arranged in a plane; and a diffusing plate disposed to cover the plurality of lighting devices, and configured to receive on one surface thereof light emitted from the plurality of lighting devices and to emit the light from the other surface thereof in a diffused manner. Each of the plurality of lighting devices is the above-mentioned lighting device.

The present invention still further provides a liquid-crystal display apparatus including: a liquid-crystal panel; and the above-mentioned surface light source disposed behind the liquid-crystal panel.

In the illuminating lens configured as described above, the most part of the light that has been emitted from the light source and reached the transmissive region located in the center of the first light exit surface is refracted at the transmissive region, and thus the area surrounding the optical axis of the lens on the surface to be irradiated is irradiated with the refracted light. On the other hand, the most part of the light that has been emitted from the light source and reached the total reflection region located on the outer peripheral side of the first light exit surface is totally reflected at the total reflection region. For example, in the case where a reflecting plate is disposed on the light entrance surface side of the illuminating lens, the area of the surface to be irradiated located away from the optical axis of the lens is irradiated with the totally reflected light at the end. Furthermore, the most part of the light that has been emitted from the light source and reached the second light exit surface is refracted at the second light exit surface, and thus the area of the surface to be irradiated located away from the optical axis of the lens is irradiated with the refracted light. Accordingly, the present invention makes it possible to obtain a wider range of transmission directions for light from the light source. Therefore, the outer diameter of the lens of the present invention may be smaller than that of a conventional lens having a concave for only refracting light.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of an illuminating lens according to a first embodiment of the present invention.

FIG. **2** is an enlarged view of the main portions of FIG. **1**.

FIG. **3** is a schematic diagram of a lighting device according to a second embodiment of the present invention.

FIG. **4** is a diagram showing optical paths of light rays that reach a transmissive region of a first light exit surface of the lighting device according to the second embodiment of the present invention.

FIG. **5** is a diagram showing optical paths of light rays that reach a total reflection region of a first light exit surface of the lighting device according to the second embodiment of the present invention.

FIG. **6** is a diagram showing optical paths of light rays that exist the lighting device through a second light exit surface thereof according to the second embodiment of the present invention.

FIG. **7** is a schematic diagram of a modified illuminating lens.

FIG. **8** is an enlarged view of the main portions of FIG. **7**.

FIG. **9** is a diagram for explaining Examples 1 to 3 of the lighting device according to the second embodiment of the present invention.

FIG. **10** is a graph showing a relationship between θi and sagY, which represent the shape of the light exit surface in Example 1 of the lighting device according to the second embodiment of the present invention (i.e., a graph obtained by plotting the values in Table 1).

FIG. **11** is a graph showing a relationship between θi and sagY, which represent the shape of the light exit surface in Example 2 of the lighting device according to the second embodiment of the present invention (i.e., a graph obtained by plotting the values in Table 2).

FIG. **12** is a graph showing a relationship between θi and sagY, which represent the shape of the light exit surface in Example 3 of the lighting device according to the second embodiment of the present invention (i.e., a graph obtained by plotting the values in Table 3).

FIG. **13** is a graph showing a relationship between r/R and θi-θn in Example 1 of the lighting device according to the second embodiment of the present invention.

FIG. **14** is a graph showing a relationship between r/R and θi-θn in Example 2 of the lighting device according to the second embodiment of the present invention.

FIG. **15** is a graph showing a relationship between r/R and θi-θn in Example 3 of the lighting device according to the second embodiment of the present invention.

FIG. **16** shows an illuminance distribution in Example 1 of the lighting device according to the second embodiment of the present invention.

FIG. **17** shows an illuminance distribution in Example 2 of the lighting device according to the second embodiment of the present invention.

FIG. **18** shows an illuminance distribution in Example 3 of the lighting device according to the second embodiment of the present invention.

FIG. **19** shows an illuminance distribution obtained when only light emitting diodes are used to confirm the effects of Examples 1 to 3.

FIG. **20** is a schematic diagram of a surface light source according to a third embodiment of the present invention.

FIG. **21** is a partial cross-sectional view of the surface light source according to the third embodiment of the present invention.

FIG. **22** shows an illuminance distribution obtained when the lighting device of Example 1 is used in the surface light source according to the third embodiment of the present invention.

FIG. **23** shows an illuminance distribution obtained when the lighting device of Example 2 is used in the surface light source according to the third embodiment of the present invention.

FIG. **24** shows an illuminance distribution obtained when the lighting device of Example 3 is used in the surface light source according to the third embodiment of the present invention.

FIG. **25** shows an illuminance distribution obtained when a surface light source including lighting devices each composed of only a light emitting diode is used to confirm the effects of Examples 1 to 3.

FIG. **26** is a schematic diagram of a liquid-crystal display apparatus according to a fourth embodiment of the present invention.

FIG. **27** is a plan view of an illuminating lens in which a pair of flat portions are formed on its outer peripheral surface.

FIG. **28**A and FIG. **28**B are each a plan view of an illuminating lens of another embodiment.

DETAILED DESCRIPTION OF THE INVENTION

First Embodiment

An illuminating lens according to the first embodiment of the present invention will be described with reference to the accompanying drawings. FIG. **1** is a schematic diagram of an illuminating lens **1** according to the first embodiment. The illuminating lens **1**, which is disposed between a light source (not shown in FIG. **1**) having directivity and a surface to be irradiated **3**, spreads light emitted from the light source and emits the spread light to the surface to be irradiated **3**. That is, the illuminating lens **1** widens the range of transmission directions for light from the light source. In the illuminance distribution on the surface to be irradiated **3**, the illuminance is greatest on the optical axis A that is the design center line of the illuminating lens **1** and decreases almost monotonically toward the edge. The light source and the illuminating lens **1** are disposed so that their optical axes coincide with each other.

Specifically, the illuminating lens **1** has a light entrance surface **11** through which the light emitted from the light source enters the lens and a light exit surface **12** through which the light that has entered the lens exits the lens. The illuminating lens **1** has a bottom surface **13** surrounding the light entrance surface **11** and facing oppositely to the light exit surface **12**. The illuminating lens **1** further has an outer peripheral surface **14** located outwardly of the light exit surface **12** to connect the periphery of the light exit surface **12** and the outer edge of the bottom surface **13**.

The light entrance surface **11** need not be rotationally symmetric with respect to the optical axis A. In the present embodiment, the light entrance surface **11** is located closer to the light exit surface **12** than the annular bottom surface **13** surrounding the light entrance surface **11**, and the light source is fitted in the recess formed by the level difference between the surfaces **11** and **13**. The light entrance surface **11** and the bottom surface **13** may be located on the same level. In this case, the light entrance surface **11** is the area that is connected optically to the light source. The light entrance surface **11** need not necessarily be joined directly to the light source. For example, the light entrance surface **11** may be recessed in a hemispherical shape so that an air space is formed between the light entrance surface **11** and the light source.

In the present embodiment, the light exit surface **12** is rotationally symmetric with respect to the optical axis A. The light exit surface **12** is the area (area located inwardly of a point B shown in FIG. **1**) for controlling at least a specified amount (for example, 90%) of light emitted from the light source. The diameter of the light exit surface **12** is the effective diameter of the illuminating lens **1** when viewed from the optical axis direction.

The outer peripheral surface **14** forms a curved surface extending continuously from the light exit surface **12** in the present embodiment, but may be a tapered surface having a linear cross section. Alternatively, the illuminating lens **1** may be provided with a ring portion projecting from the entire periphery of the light exit surface **12** so that the end surface of the ring portion serves as the outer peripheral surface **14**, although not illustrated here. The outer peripheral surface **14** need not be rotationally symmetric with respect to the optical axis A. For example, as shown in FIG. **27**, the outer peripheral surface **14** may have a pair of flat portions **14*a*** that are parallel to each other across the optical axis A such that the illuminating lens **1** has an oval shape when viewed from the optical axis direction.

The light emitted from the light source enters the illuminating lens **1** through the light entrance surface **11**, exits the lens **1** through the light exit surface **12**, and then reaches the surface to be irradiated **3**. The light emitted from the light source is spread by the action of the light exit surface **12**, and reaches a large area of the surface to be irradiated **3**.

As the light source, for example, a light emitting diode can be used. Light emitting diodes usually are chips with a rectangular plate shape. Therefore, it is preferable that the light entrance surface **11** of the illuminating lens **1** have a shape conforming to the shape of a light emitting diode to fit in close contact with the light emitting diode. The light emitting diode is in contact with the light entrance surface **11** of the illuminating lens **1** via a bonding agent, and connected optically to the light entrance surface **11**. The light emitting diode usually is covered with a sealing resin to avoid contact with air, but the light emitting diode need not be covered with a sealing resin because the illuminating lens **1** serves as a sealing resin. As a conventional sealing resin for a light emitting diode, an epoxy resin, silicone rubber, or the like is used.

The illuminating lens **1** is made of a transparent material having a specified refractive index. The refractive index of the transparent material is, for example, about 1.4 to 1.5. Examples of such a transparent material include resins such as epoxy resin, silicone resin, acrylic resin, and polycarbonate, and rubbers such as silicone rubber. Particularly, it is preferable to use epoxy resin, silicone rubber, or the like that has been used as a sealing resin for a light emitting diode.

The light exit surface **12** includes a first light exit surface **121** that is recessed toward a point on the optical axis A, and a second light exit surface **122** extending radially outwardly from the periphery of the first light exit surface **121** to form a convex. Light enters the illuminating lens **1** through the light entrance surface **11** at a wide range of angles. Light that has entered the lens at a small angle with respect to the optical axis A reaches the first light exit surface **121**, and light that has entered the lens at a larger angle with respect to the optical axis A reaches the second light exit surface **122**.

Next, the shapes of the first light exit surface **121** and the second light exit surface **122** will be described. For that purpose, a starting point Q is defined first, and then light emitted from the starting point Q is assumed. As stated herein, the starting point Q is the position of the light source on the optical axis A. In the case where a light emitting diode is used as a light source, the starting point Q is the point of intersection of the optical axis A and the light emitting surface that is the front surface of the light emitting diode. That is, the starting point Q is spaced from the light entrance surface **11** by the thickness of the above-mentioned bonding agent. When an angle between the optical axis A and a line connecting the starting point Q and the boundary between the first light exit surface **121** and the second light exit surface **122** is θb, light that has been emitted from the starting point Q at an angle reaches the first light exit surface **121** or the second light exit surface **122** based on the angle θb as a threshold angle.

As shown in FIG. **2**, the first light exit surface **121** includes a transmissive region **123** located in the center of the first light exit surface **121** and a total reflection region **124** located around the transmissive region **123**. The transmissive region **123** transmits light that has been emitted from the starting point Q at a relatively small angle of less than a specified value of θp with respect to the optical axis A and reached the first light exit surface **121**, and the total reflection region **124** totally reflects light that has been emitted from the starting point Q at a relatively large angle of θp or more with respect to the optical axis A and reached the first light exit surface **121**. That is, θp is an angle between the optical axis A and a line connecting a point P and the starting point Q, when the point P is a point on the boundary between the transparent region **123** and the total reflection region **124**.

On the other hand, the second light exit surface **122** has a shape capable of transmitting approximately the entire amount of light that has been emitted from the starting point Q and reached the second light exit surface **122**. The angle between the optical axis A and the light emitted from the starting point Q increases toward the outer edge of the second light exit surface **122**. The angle of the light emitted from the starting point Q with respect to a normal line at the point on the second light exit surface **122** reached by the emitted light is the incident angle of the light with respect to the second light exit surface **122**. An excessively large incident angle causes total reflection. The incident angle needs to be kept small in order to prevent total reflection. Accordingly, the second light exit surface **122** has a shape such that the angle between the normal line and the optical axis A increases with increasing distance from the optical axis A. That is, the shape of the second light exit surface **122** is a convex.

The entire second light exit surface **122** need not transmit the light emitted from the starting point Q (i.e., the second light exit surface **122** need not necessarily transmit the entire amount of the light). The second light exit surface **122** may have a shape capable of totally reflecting a part of the light emitted from the starting point Q and transmitting the remaining part of the light.

In the illuminating lens **1** configured as described above, the most part of the light that has been emitted from the light source and reached the transmissive region **123** located in the center of the first light exit surface **121** is refracted at the transmissive region **123**, and thus the area surrounding the optical axis A of the lens on the surface to be irradiated **3** is irradiated with the refracted light. On the other hand, the most part of the light that has been emitted from the light source and reached the total reflection region **124** located on the peripheral side of the first light exit surface **121** is totally reflected at the total reflection region **124**. For example, in the case where a reflecting plate is disposed on the light entrance surface **11** side of the illuminating lens **1**, the area away from the optical axis A of the lens on the surface to be irradiated **3** is irradiated with the totally reflected light at the end. Furthermore, the most part of the light that has been emitted from the light source and reached the second light exit surface **122** is refracted at the second light exit surface **122**, and thus the area away from the optical axis A of the lens on the surface to be irradiated **3** is irradiated with the refracted light. Accordingly, the illuminating lens **1** of the present embodiment allows the range of transmission directions for light from the light source to be widened further. Therefore, the outer diameter of the lens of the present embodiment may be smaller than that of a conventional lens having a concave for only refracting light.

The basic configuration of the illuminating lens **1** of the present embodiment has been described so far. A preferable configuration of the illuminating lens **1** of the present embodiment will be described below.

It is preferable that the above-mentioned angle θb (see FIG. **1**) between the optical axis A and the line connecting the starting point Q and the boundary between the first light exit surface **121** and the second light exit surface **122** satisfies the following inequality (1):

$$20\text{ degrees}<\theta b<40\text{ degrees} \quad (1)$$

The inequality (1) defines the range of the first light exit surface **121**. The inequality (1) defines the range of the first light exit surface **121** with an angle based on the starting point Q (polar coordinate), and indicates the range of angles at which light to be directed to the surface to be irradiated **3** can be allocated appropriately to an area surrounding the optical axis A of the lens on the surface to be irradiated **3** (hereinafter referred to as a "near-axis area") and an area away from the optical axis A of the lens on the surface to be irradiated **3** (hereinafter referred to as an "outer peripheral area"). When θb is 40 degrees or more, the range of the first light exit surface **121** increases and the light that has been emitted from the light source toward the vicinity of the optical axis is directed excessively outwardly. As a result, the near-axis area of the surface to be irradiated **3** has a low illuminance, which causes an uneven illuminance on the surface **3**. On the other hand, when the θb is 20 degrees or less, the range of the first light exit surface **121** decreases, and thus a large amount of light is directed to the near-axis area of the surface to be irradiated **3** while sufficient light cannot be directed to the outer peripheral area. As a result, not only the surface **3** has an uneven illuminance but also the range of light transmission directions is narrowed.

When the point of intersection of the first light exit surface **122** and the optical axis A is denoted as C, the distance between the point C and the starting point Q is denoted as d, and the length of the straight line connecting the point C and the above-mentioned point P is denoted as a, as shown in FIG. **2**, it is preferable that the following inequality (2) is satisfied:

$$1.10<a/(d\times\tan\theta p)<1.30 \quad (2)$$

The inequality (2) defines the range of the transmissive region **123** of the first light exit surface **121**, and indicates the amount of light directed to the near-axis area of the surface to be irradiated **3**. When "a/(d tan θp)" in the inequality (2) is 1.30 or more, an excessive amount of light passes through the transmissive region **123**. As a result, the near-axis area of the surface to be irradiated **3** has a high illuminance, which causes an uneven illuminance on the surface **3**. On the other hand, when "a/(d tan θp)" in the inequality (2) is 1.10 or less, the amount of light that passes through the transmissive region **123** decreases excessively. As a result, the near-axis area of the surface to be irradiated **3** has a low illuminance, which causes an uneven illuminance on the surface **3**.

Furthermore, it is preferable that the following inequalities (3) and (4) are satisfied. When the thickness of the illuminating lens **1** on the optical axis A (i.e., the distance from the point C to the light entrance surface **11**) is denoted as d', and the outermost radius of the illuminating lens **1** is denoted as R, the inequality (3) is expressed as follows:

$$d'/2R<0.25 \quad (3)$$

In addition, in the case where the surface to be irradiated **3** is illuminated via the illuminating lens **1**, when the distribution width of illuminances of 0.2 or more in an illuminance distribution curve on the surface to be irradiated **3**, which is obtained by normalizing illuminances with respect to an illuminance at the center of the optical axis being 1, is denoted as δ_L, and in the case where the surface to be irradiated **3** is illuminated only by the light source, when the distribution width of illuminances of 0.2 or more in an illuminance distribution curve on the surface to be irradiated **3**, which is obtained by normalizing illuminances with respect to an illuminance at the center of the optical axis being 1, is denoted as δ_S, the inequality (4) is expressed as follows:

$$2.0<\delta_L/\delta_S<4.0 \quad (4)$$

When "d'/2R" in the inequality (3) is 0.25 or more and the inequality (3) is not satisfied, the ratio between the first light exit surface **121** and the second light exit surface **122** is out of balance in the light exit surface **12**, which causes an uneven illuminance.

In the inequality (4), "δ_L/δ_S" indicates a ratio of illuminance distribution between the case with the illuminating lens and the case without the illuminating lens. When the value of δ_L/δ_S is 4.0 or more, the range of light transmission directions is widened, but the illuminated area is excessively large, which causes an insufficient illuminance. On the other hand, when the value of δ_L/δ_S" is 2.0 or less, the lens itself is large in size. As a result, the compact property and the cost effectiveness of the lens decrease, and the range of light transmission directions is narrowed.

The illuminating lens of the present invention also is applicable to light sources (such as lasers and organic ELs) as well as light emitting diodes.

In the present embodiment, the light exit surface **12** is axisymmetric with respect to the optical axis A. The light exit surface **12**, however, need not be axisymmetric with respect to the optical axis A. For example, as shown in FIG. **28**A, the light exit surface **12** may have an elliptical shape when viewed from the optical axis direction. This illuminating lens **1** is suitable particularly for an elongated light source. Alternatively, as shown in FIG. **28**B, the light exit surface **12** may have a rounded rectangular shape when viewed from the optical axis direction.

(Modification)

Next, a Modified Illuminating Lens **1'** Will be Described with Reference to FIG. **7** and FIG. **8**. The same components as those in the above-described illuminating lens **1** are denoted by the same reference numerals.

In this illuminating lens **1'**, the first light exit surface **121** has a specular reflection region **125** covered with a reflective layer **126**, instead of the total reflection region **124** (see FIG. **2**). Therefore, the light that has been emitted from the starting point Q at an angle of θp or more with respect to the optical axis A and reached the first light exit surface **121** is specularly reflected at the reflective layer **126**. The optical path of the specularly reflected light is the same as that of the totally reflected light. The reflective layer **126** may be formed of a reflective film obtained by applying a reflective material on the specular reflection region **125** and curing the material. The reflective layer **126** also may be formed of a reflective sheet attached to the specular reflection region **125**.

In the case where specular reflection is utilized as in the present modification, the angle of inclination of the first light exit surface **121** can be reduced compared with the case where total reflection is utilized. Therefore, the flexibility in designing the lens shape can be increased. The specular reflection region **125** may have the same shape as the total reflection region **124**. That is, when the specular reflection region **125** is not covered with the reflective layer **126**, it may have a shape such that the light that has been emitted from the starting point Q at a specified angle of θp or more with respect to the optical axis A and reached the first light exit surface **121** can be totally reflected.

Second Embodiment

FIG. **3** is a schematic diagram of a lighting device **7** according to a second embodiment of the present invention. This lighting device **7** includes a light emitting diode **2** for emitting light, and an illuminating lens **1** of the first embodiment for spreading light emitted from the light emitting diode **2** so that the surface to be irradiated **3** is irradiated with the spread light.

The light emitting diode **2** is in contact with the light entrance surface **11** of the illuminating lens **1** via a bonding agent, and connected optically to the light entrance surface **11**. The light that has exited the illuminating lens **1** through the light exit surface **12** reaches the surface to be irradiated **3**, and thus the surface to be irradiated **3** is illuminated with that light.

Light generation in the light emitting diode **2** has no directivity in itself, and a light emitting region has a refractive index of at least 2.0. When light from the light emitting region enters a low refractive region, the refraction of the light at the interface causes the light to have the maximum intensity in the normal direction of the interface and to have a lower intensity as the angle of the light with respect to the normal line increases. As described above, since the light emitting diode **2** has high directivity, it is necessary to widen the range of transmission directions for light therefrom using the illuminating lens **1** to illuminate a larger area.

FIG. **4** is a diagram showing the paths of light rays in the lighting device **7**. In FIG. **4**, the paths of light rays that are emitted from the light source at small angles and reach the transmissive region **123** (see FIG. **2**) of the first light exit surface **121** are described. The light that has been emitted from the light emitting diode **2** passes through the light entrance surface **11** and reaches the transmissive region **123** of the first light exit surface **121**. The light that has reached the transmissive region **123** of the first light exit surface **121** passes through the transmissive region **123** while being refracted, and then reaches the surface to be irradiated **3**.

FIG. **5** is a diagram showing the paths of light rays in the lighting device **7**. In FIG. **5**, the paths of light rays that are emitted from the light source at small angles and reach the total reflection region **124** (see FIG. **2**) of the first light exit surface **121** are described. The light that has been emitted from the light emitting diode **2** passes through the light entrance surface **11** and reaches the total reflection region **124** of the first light exit surface **121**. The light that has reached the total reflection region **124** of the first light exit surface **121** is totally reflected at the total reflection region **124**. The light that has traveled near the optical axis A is totally reflected to reach the second light exit surface **122**, and then passes through the second light exit surface **122** while being refracted. In the case where a reflecting plate is provided on the side of the light entrance surface **11** of the illuminating lens **1**, approximately the entire amount of light that has passed through the second light exit surface **122** reaches the surface to be irradiated **3**. On the other hand, the light that has traveled away from the optical axis A is totally reflected to reach the second light exit surface **122**. Then, the totally reflected light is reflected one or more times within the illuminating lens **1**, passes through the light exit surface **12** while being refracted, and reaches the surface to be irradiated **3**.

FIG. **6** is a diagram showing the paths of light rays in the lighting device **7**. In FIG. **6**, the paths of light rays that are emitted from the light source at larger angles and reach the second light exit surface **122** are described. The light that has been emitted from the light emitting diode **2** passes through the light entrance surface **11** and reaches the second light exit surface **122**. In the case where the second light exit surface **122** does not have a shape capable of totally reflecting a part of the light, approximately the entire amount of the light that has reached the second light exit surface **122** passes through the second light exit surface **122** while being refracted, and then reaches the surface to be irradiated **3**.

Hereinafter, Examples 1 to 3 are given as specific numerical examples of the present invention.

FIG. **9** is a schematic diagram of a lighting device in Examples 1 to 3 according to the second embodiment of the present invention. Examples 1 to 3 are examples of a lighting device designed to widen the range of transmission directions for light from a 0.45 mm cubic-shaped light emitting diode as a light source. In FIG. **9**, θi is an angle between the optical axis A and a straight line connecting the position of the light source (starting point Q) on the optical axis A and an arbitrary point on the light exit surface **12**. In FIG. **9**, θn is an angle between the optical axis A and a normal line at the arbitrary point on the light exit surface **12**, that is, a normal line at a position on the light exit surface **12** reached by the light that has been emitted from the light source position (starting point Q) on the optical axis A at an angle of θi. Furthermore, in FIG. **9**, sagY is a distance along the optical axis A between the light source position (starting point Q) on the optical axis A and the arbitrary point on the light exit surface **12**.

Example 1

Table 1 below shows specific numerical values in Example 1.

TABLE 1

θi	sagY
0.00	0.485
0.76	0.485
1.52	0.487
2.26	0.490
2.99	0.494
3.70	0.499
4.38	0.505
5.05	0.511
5.70	0.517
6.33	0.523
6.94	0.530
7.53	0.537
8.10	0.544
8.65	0.551
9.19	0.558
9.71	0.565
10.22	0.572
10.71	0.580
11.19	0.587
11.65	0.594
12.10	0.602
12.54	0.609
12.97	0.616
13.38	0.624
13.79	0.631
14.18	0.638
14.56	0.645
14.94	0.653
15.30	0.660
15.66	0.667
16.01	0.675
16.35	0.682
16.68	0.689
17.00	0.696
17.32	0.703
17.63	0.710
17.93	0.717
18.23	0.724
18.52	0.731
18.81	0.738
19.09	0.745
19.37	0.752
19.64	0.759
19.90	0.766
20.17	0.773
20.42	0.779
20.68	0.786
20.92	0.793
21.17	0.799
21.41	0.806
21.65	0.813
21.88	0.819
22.11	0.825
22.34	0.832
22.57	0.838
22.79	0.844
23.01	0.850
23.23	0.857
23.44	0.863
23.66	0.869
23.87	0.875
24.08	0.881
24.28	0.886
24.49	0.892
24.69	0.898
24.89	0.904
25.09	0.909
25.29	0.915
25.49	0.920
25.68	0.925
25.88	0.931
26.07	0.936

TABLE 1-continued

θi	sagY
26.26	0.941
26.45	0.946
26.64	0.951
26.83	0.956
27.02	0.961
27.21	0.966
27.40	0.971
27.59	0.975
27.77	0.980
27.96	0.984
28.15	0.989
28.33	0.993
28.52	0.997
28.70	1.001
28.89	1.005
29.07	1.009
29.26	1.013
29.45	1.017
29.63	1.021
29.82	1.024
30.00	1.028
30.19	1.031
30.38	1.034
30.57	1.038
30.75	1.041
30.94	1.044
31.13	1.047
31.32	1.049
31.51	1.052
31.70	1.055
31.89	1.057
32.09	1.060
32.28	1.062
32.48	1.064
32.67	1.066
32.87	1.068
33.07	1.070
33.26	1.072
33.47	1.073
33.70	1.074
33.94	1.074
34.18	1.073
34.42	1.073
34.66	1.073
34.89	1.073
35.13	1.073
35.36	1.072
35.60	1.072
35.83	1.072
36.06	1.072
36.29	1.072
36.52	1.072
36.74	1.071
36.97	1.071
37.19	1.071
37.42	1.071
37.64	1.070
37.86	1.070
38.08	1.070
38.30	1.070
38.52	1.069
38.74	1.069
38.96	1.069
39.17	1.069
39.39	1.068
39.60	1.068
39.81	1.068
40.02	1.068
40.23	1.067
40.44	1.067
40.65	1.067
40.86	1.066
41.06	1.066
41.27	1.066
41.47	1.065
41.68	1.065
41.88	1.065
42.08	1.064

TABLE 1-continued

θi	sagY
42.28	1.064
42.48	1.063
42.68	1.063
42.88	1.063
43.08	1.062
43.28	1.062
43.47	1.061
43.67	1.061
43.86	1.060
44.06	1.060
44.25	1.059
44.44	1.059
44.63	1.058
44.83	1.058
45.02	1.057
45.21	1.057
45.39	1.056
45.58	1.055
45.77	1.055
45.96	1.054
46.15	1.053
46.33	1.053
46.52	1.052
46.70	1.051
46.89	1.051
47.07	1.050
47.26	1.049
47.44	1.048
47.62	1.047
47.81	1.047
47.99	1.046
48.17	1.045
48.35	1.044
48.54	1.043
48.72	1.042
48.90	1.041
49.08	1.040
49.26	1.039
49.44	1.038
49.62	1.037
49.80	1.036
49.98	1.034
50.16	1.033
50.34	1.032
50.52	1.031
50.70	1.029
50.88	1.028
51.06	1.027
51.25	1.025
51.43	1.024
51.61	1.022
51.79	1.021
51.97	1.019
52.15	1.017
52.33	1.016
52.51	1.014
52.69	1.012
52.88	1.011
53.06	1.009
53.24	1.007
53.43	1.005
53.61	1.003
53.79	1.001
53.98	0.999
54.16	0.997
54.35	0.995
54.54	0.992
54.72	0.990
54.91	0.988
55.10	0.985
55.29	0.983
55.48	0.980
55.67	0.978
55.87	0.975
56.06	0.972
56.25	0.970
56.45	0.967
56.65	0.964

TABLE 1-continued

θi	sagY
56.84	0.961
57.04	0.958
57.24	0.955
57.44	0.951
57.65	0.948
57.85	0.945
58.06	0.941
58.27	0.937
58.47	0.934
58.69	0.930
58.90	0.926
59.12	0.922
59.33	0.918
59.55	0.914
59.78	0.909
60.00	0.905
60.23	0.900
60.46	0.896
60.69	0.891
60.93	0.886
61.17	0.881
61.41	0.875
61.66	0.870
61.91	0.864
62.16	0.858
62.42	0.852
62.69	0.846
62.95	0.840
63.23	0.833
63.51	0.826
63.79	0.819
64.08	0.812
64.38	0.804
64.69	0.796
65.00	0.788
65.32	0.780
65.65	0.771
65.99	0.762
66.33	0.752
66.69	0.742
67.06	0.732
67.43	0.721
67.83	0.710
68.23	0.698
68.65	0.686
69.08	0.673
69.53	0.660
69.99	0.646
70.47	0.631
70.97	0.616
71.50	0.600
72.04	0.583
72.60	0.566
73.19	0.547
73.81	0.528
74.45	0.508
75.13	0.487
75.83	0.464
76.57	0.441
77.34	0.416
78.15	0.390
79.00	0.362
79.89	0.333
80.83	0.303
81.82	0.271
82.85	0.237
83.94	0.201
85.09	0.164
86.29	0.124
87.56	0.082
88.88	0.037

FIG. **10** is a graph obtained by plotting the values of θi and sagY in Table 1. FIG. **13** is a graph showing a relationship between r/R and θi-θn. Here, r/R is a value obtained by normalizing, with respect to the outermost radius of the lens, the distance in the direction parallel to the light entrance surface **11** from the optical axis A to the arbitrary point on the light exit surface **12**, where r is the distance in the direction parallel to the light entrance surface from the optical axis to the arbitrary point on the light exit surface, and R is the outermost radius of the lens (see FIG. **9**).

θi-θn is an angle of a light ray emitted at an angle of θi, with respect to a normal line at a point on the light exit surface **12** reached by the light ray, that is, an incident angle of the light ray on the light exit surface **12**. As a condition of the total reflection region **124** of the first light exit surface **121**, since the refractive index of the transparent material constituting the lens in Example 1 is 1.41, θi-θn is 45.172 degrees or more. Accordingly, FIG. **13** shows that in Example 1, the transmissive region **123** of the first light exit surface **121** is a narrow region in the vicinity of the optical axis and the total reflection region **124** is a wide region away from the optical axis. FIG. **13** also shows that in Example 1, the entire second light exit surface **122** totally reflects the light emitted from the starting point Q.

In Example 1, d, θp, and a shown in FIG. **2** are 0.485 mm, 4.2 degrees, and 0.042 mm, respectively. Accordingly, a/(d× tan θp) is 1.17, and this value satisfies the above inequality (2).

Furthermore, in Example 1, d' and R shown in FIG. **2** are 0.48 mm and 1.95 mm, respectively. Accordingly, d'/2R is 0.12, and this value satisfies the above inequality (3).

FIG. **16** shows the illuminance distribution on the surface to be irradiated obtained by calculation assuming that the lighting device of Example 1 (i.e., the illuminating lens in FIG. **10** and the light emitting diode) is used and the surface to be irradiated is placed at a distance of 8 mm from the light emitting diode. FIG. **19** shows the illuminance distribution on the surface to be irradiated obtained by calculation assuming that only the same light emitting diode as in FIG. **16** is used and the surface to be irradiated is placed at a distance of 8 mm from the light emitting diode. Each of FIG. **16** and FIG. **19** shows a curve indicating the distribution of illuminances on the surface to be irradiated when the illuminances are normalized with respect to the illuminance at the center of the optical axis being 1. A comparison between FIG. **16** and FIG. **19** shows that the illuminating lens is effective in increasing the illuminated area of the surface to be irradiated.

Furthermore, the distribution width δ_L of illuminances of 0.2 or more on the illuminance distribution curve in FIG. **16** is 0.48, and the distribution width δ_S of illuminances of 0.2 or more on the illuminance distribution curve in FIG. **19** is 0.2. Accordingly, δ_L/δ_S is 2.4, which satisfies the above inequality (4).

Example 2

Table 2 below shows specific numerical values in Example 2.

TABLE 2

θi	sagY
0.00	0.647
0.57	0.647
1.14	0.648
1.71	0.649
2.27	0.650
2.83	0.652
3.39	0.653
3.94	0.656
4.48	0.658
5.02	0.661
5.55	0.664
6.07	0.667
6.59	0.670
7.09	0.674
7.59	0.678
8.07	0.682
8.55	0.686
9.02	0.691
9.48	0.695
9.93	0.700
10.37	0.705
10.80	0.710
11.22	0.715
11.64	0.720
12.04	0.726
12.44	0.731
12.83	0.736
13.21	0.742
13.58	0.748
13.94	0.753
14.30	0.759
14.65	0.765
14.99	0.771
15.33	0.776
15.66	0.782
15.98	0.788
16.30	0.794
16.61	0.800
16.91	0.806
17.21	0.812
17.51	0.818
17.79	0.824
18.08	0.830
18.35	0.836
18.63	0.842
18.89	0.848
19.16	0.854
19.42	0.860
19.67	0.866
19.92	0.872
20.17	0.878
20.42	0.884
20.66	0.890
20.89	0.896
21.13	0.901
21.36	0.907
21.58	0.913
21.81	0.919
22.03	0.925
22.25	0.930
22.46	0.936
22.67	0.942
22.88	0.947
23.09	0.953
23.30	0.959
23.50	0.964
23.70	0.970
23.90	0.975
24.10	0.981
24.30	0.986
24.49	0.991
24.68	0.997
24.87	1.002
25.06	1.007
25.25	1.012
25.43	1.017
25.62	1.022
25.80	1.027
25.99	1.032
26.17	1.037
26.35	1.042
26.53	1.047
26.70	1.051
26.88	1.056
27.06	1.061
27.23	1.065
27.41	1.070
27.58	1.074

TABLE 2-continued

θi	sagY
27.75	1.079
27.93	1.083
28.10	1.087
28.27	1.091
28.44	1.096
28.61	1.100
28.78	1.104
28.95	1.108
29.12	1.111
29.29	1.115
29.46	1.119
29.63	1.123
29.80	1.126
29.97	1.130
30.14	1.133
30.31	1.136
30.49	1.139
30.73	1.139
30.98	1.139
31.22	1.139
31.46	1.139
31.70	1.138
31.94	1.138
32.18	1.138
32.41	1.138
32.65	1.137
32.88	1.137
33.12	1.137
33.35	1.137
33.58	1.137
33.81	1.136
34.04	1.136
34.27	1.136
34.50	1.136
34.73	1.135
34.95	1.135
35.18	1.135
35.40	1.135
35.62	1.134
35.84	1.134
36.06	1.134
36.28	1.133
36.50	1.133
36.72	1.133
36.94	1.132
37.15	1.132
37.37	1.132
37.58	1.131
37.79	1.131
38.01	1.131
38.22	1.130
38.43	1.130
38.64	1.130
38.85	1.129
39.05	1.129
39.26	1.128
39.47	1.128
39.67	1.128
39.88	1.127
40.08	1.127
40.28	1.126
40.48	1.126
40.69	1.125
40.89	1.125
41.09	1.124
41.28	1.124
41.48	1.123
41.68	1.123
41.88	1.122
42.07	1.122
42.27	1.121
42.46	1.121
42.65	1.120
42.85	1.120
43.04	1.119
43.23	1.118
43.42	1.118
43.61	1.117

TABLE 2-continued

θi	sagY
43.80	1.117
43.99	1.116
44.18	1.115
44.36	1.114
44.55	1.114
44.74	1.113
44.92	1.112
45.11	1.112
45.29	1.111
45.48	1.110
45.66	1.109
45.84	1.108
46.03	1.108
46.21	1.107
46.39	1.106
46.57	1.105
46.75	1.104
46.93	1.103
47.11	1.102
47.29	1.101
47.47	1.100
47.65	1.099
47.83	1.098
48.01	1.097
48.18	1.096
48.36	1.095
48.54	1.094
48.71	1.093
48.89	1.092
49.07	1.091
49.24	1.090
49.42	1.088
49.59	1.087
49.77	1.086
49.94	1.085
50.12	1.083
50.29	1.082
50.47	1.081
50.64	1.079
50.82	1.078
50.99	1.076
51.16	1.075
51.34	1.073
51.51	1.072
51.69	1.070
51.86	1.069
52.03	1.067
52.21	1.065
52.38	1.064
52.56	1.062
52.73	1.060
52.91	1.058
53.08	1.056
53.26	1.055
53.43	1.053
53.61	1.051
53.78	1.049
53.96	1.047
54.13	1.045
54.31	1.042
54.49	1.040
54.66	1.038
54.84	1.036
55.02	1.034
55.19	1.031
55.37	1.029
55.55	1.026
55.73	1.024
55.91	1.021
56.09	1.019
56.27	1.016
56.45	1.014
56.63	1.011
56.82	1.008
57.00	1.005
57.18	1.002
57.37	0.999
57.55	0.996

TABLE 2-continued

θi	sagY
57.74	0.993
57.93	0.990
58.11	0.987
58.30	0.984
58.49	0.981
58.68	0.977
58.87	0.974
59.06	0.970
59.26	0.967
59.45	0.963
59.64	0.959
59.84	0.956
60.04	0.952
60.23	0.948
60.43	0.944
60.63	0.940
60.83	0.936
61.04	0.932
61.24	0.927
61.45	0.923
61.65	0.919
61.86	0.914
62.07	0.910
62.28	0.905
62.49	0.900
62.71	0.895
62.92	0.890
63.14	0.885
63.36	0.880
63.58	0.875
63.80	0.870
64.02	0.864
64.24	0.859
64.47	0.853
64.70	0.848
64.93	0.842
65.16	0.836
65.39	0.830
65.63	0.824
65.87	0.818
66.11	0.811
66.35	0.805
66.59	0.799
66.84	0.792
67.09	0.785
67.34	0.778
67.59	0.771
67.85	0.764
68.10	0.757
68.36	0.750
68.62	0.742
68.89	0.735
69.15	0.727
69.42	0.719
69.70	0.711
69.97	0.703
70.25	0.695
70.53	0.687
70.81	0.678
71.09	0.669
71.38	0.661
71.67	0.652
71.96	0.643
72.26	0.633
72.56	0.624
72.86	0.615
73.17	0.605
73.47	0.595
73.79	0.585
74.10	0.575
74.42	0.565
74.74	0.554
75.06	0.544
75.39	0.533
75.72	0.522
76.05	0.511
76.39	0.500
76.73	0.488
77.07	0.477
77.42	0.465
77.77	0.453
78.12	0.441
78.47	0.000
78.83	0.000
79.20	0.000
79.57	0.000
79.94	0.000
80.31	0.000
80.69	0.000
81.07	0.000
81.45	0.000
81.84	0.000
82.23	0.000
82.63	0.000
83.03	0.000
83.43	0.000
83.84	0.000
84.25	0.000
84.66	0.000
85.08	0.000
85.50	0.000
85.92	0.000
86.35	0.000
86.78	0.000
87.21	0.000
87.65	0.000
88.09	0.000
88.54	0.000
88.99	0.000
89.44	0.000
89.89	0.000

FIG. **11** is a graph obtained by plotting the values of θi and sagY in Table 2. FIG. **14** is a graph showing a relationship between r/R and θi-θn. r/R and θi-θn in FIG. **14** are the same as those in FIG. **13**.

In Example 2, the lens is made of a material having a refractive index of 1.41, as in the case of Example 1 described above. Accordingly, as a condition of the total reflection region **124** of the first light exit surface **121**, θi-θn is 45.172 degrees or more, as in the case of Example 1. Accordingly, FIG. **14** shows that in Example 2, the transmissive region **123** is wider than that of Example 1, and the total reflection region **124** is narrower than that of Example 1. FIG. **14** also shows that in Example 2, the entire second light exit surface **122** totally reflects the light emitted from the starting point Q.

In Example 2, d, θp, and a shown in FIG. **2** are 0.647 mm, 9.3 degrees, and 0.123 mm, respectively. Accordingly, a/(d× tan θp) is 1.16, and this value satisfies the above inequality (2).

Furthermore, in Example 2, d' and R shown in FIG. **2** are 0.642 mm and 2.1 mm, respectively. Accordingly, d'/2R is 0.15, and this value satisfies the above inequality (3).

FIG. **17** shows the illuminance distribution on the surface to be irradiated obtained by calculation assuming that the lighting device of Example 2 (i.e., the illuminating lens in FIG. **11** and the light emitting diode) is used and the surface to be irradiated is placed at a distance of 8 mm from the light emitting diode. FIG. **17** shows a curve indicating the distribution of illuminances on the surface to be irradiated when the illuminances are normalized with respect to the illuminance at the center of the optical axis being 1, as in the case of FIG. **16**. A comparison between FIG. **17** and FIG. **19** shows that the illuminating lens is effective in increasing the illuminated area of the surface to be irradiated.

Furthermore, the distribution width δ_L of illuminances of 0.2 or more on the illuminance distribution curve in FIG. **17** is 0.5. Accordingly, δ_L/δ_S is 2.5, which satisfies the above inequality (4).

Example 3

Table 3 below shows specific numerical values in Example 3.

TABLE 3

θi	sagY
0.000	0.800
0.462	0.800
0.922	0.802
1.379	0.804
1.833	0.806
2.282	0.809
2.725	0.813
3.163	0.817
3.595	0.821
4.021	0.826
4.441	0.830
4.855	0.835
5.262	0.840
5.664	0.845
6.059	0.851
6.449	0.856
6.833	0.861
7.211	0.867
7.583	0.872
7.949	0.878
8.311	0.883
8.666	0.889
9.017	0.894
9.362	0.900
9.703	0.905
10.038	0.911
10.368	0.917
10.694	0.922
11.014	0.928
11.331	0.933
11.642	0.939
11.950	0.945
12.253	0.950
12.551	0.956
12.846	0.962
13.136	0.967
13.423	0.973
13.706	0.979
13.984	0.984
14.260	0.990
14.531	0.995
14.799	1.001
15.064	1.007
15.325	1.012
15.583	1.018
15.837	1.023
16.089	1.029
16.337	1.034
16.583	1.040
16.825	1.045
17.065	1.051
17.302	1.056
17.536	1.061
17.768	1.067
17.997	1.072
18.224	1.077
18.448	1.083
18.670	1.088
18.889	1.093
19.107	1.099
19.322	1.104
19.535	1.109
19.746	1.114
19.955	1.119
20.162	1.124

TABLE 3-continued

θi	sagY
20.367	1.129
20.571	1.134
20.772	1.139
20.972	1.144
21.171	1.149
21.368	1.154
21.563	1.159
21.757	1.164
21.949	1.168
22.140	1.173
22.330	1.178
22.518	1.182
22.705	1.187
22.892	1.191
23.076	1.196
23.260	1.200
23.443	1.205
23.625	1.209
23.806	1.213
23.986	1.218
24.165	1.222
24.344	1.226
24.522	1.230
24.699	1.234
24.875	1.238
25.051	1.242
25.226	1.246
25.401	1.250
25.575	1.253
25.749	1.257
25.922	1.261
26.095	1.264
26.290	1.266
26.499	1.268
26.706	1.269
26.913	1.271
27.117	1.272
27.321	1.274
27.523	1.275
27.724	1.276
27.923	1.278
28.122	1.279
28.318	1.281
28.514	1.282
28.709	1.284
28.902	1.285
29.094	1.287
29.284	1.288
29.474	1.290
29.662	1.291
29.849	1.293
30.035	1.294
30.220	1.296
30.404	1.297
30.586	1.299
30.768	1.300
30.949	1.302
31.128	1.303
31.306	1.305
31.484	1.306
31.660	1.307
31.836	1.309
32.010	1.310
32.184	1.312
32.356	1.313
32.528	1.315
32.699	1.316
32.869	1.318
33.038	1.319
33.206	1.320
33.374	1.322
33.541	1.323
33.706	1.325
33.872	1.326
34.036	1.327
34.200	1.329
34.363	1.330
34.525	1.331

TABLE 3-continued

θi	sagY
34.687	1.333
34.848	1.334
35.009	1.335
35.168	1.337
35.328	1.338
35.486	1.339
35.645	1.340
35.802	1.341
35.959	1.343
36.116	1.344
36.272	1.345
36.428	1.346
36.583	1.347
36.738	1.348
36.892	1.349
37.046	1.350
37.199	1.351
37.352	1.352
37.505	1.353
37.658	1.354
37.810	1.355
37.962	1.356
38.113	1.357
38.264	1.357
38.415	1.358
38.566	1.359
38.716	1.360
38.866	1.361
39.016	1.361
39.166	1.362
39.316	1.363
39.465	1.363
39.614	1.364
39.763	1.364
39.912	1.365
40.060	1.365
40.209	1.366
40.357	1.366
40.505	1.367
40.653	1.367
40.8007	1.367
40.9485	1.368
41.0961	1.368
41.2436	1.368
41.3910	1.369
41.5383	1.369
41.6856	1.369
41.8327	1.369
41.9797	1.369
42.1267	1.369
42.2736	1.369
42.4205	1.369
42.5672	1.369
42.7139	1.369
42.8606	1.369
43.0072	1.369
43.1537	1.369
43.3002	1.369
43.4466	1.369
43.5930	1.369
43.7393	1.368
43.8856	1.368
44.0318	1.368
44.1780	1.367
44.3241	1.367
44.4702	1.367
44.6163	1.366
44.7623	1.366
44.9083	1.365
45.0542	1.365
45.2001	1.364
45.3460	1.364
45.4918	1.363
45.6375	1.363
45.7833	1.362
45.9290	1.361
46.0746	1.361
46.2202	1.360

TABLE 3-continued

θi	sagY
46.3658	1.359
46.5113	1.358
46.6568	1.357
46.8023	1.357
46.9477	1.356
47.0931	1.355
47.2385	1.354
47.3838	1.353
47.5291	1.352
47.6744	1.351
47.8196	1.350
47.9648	1.349
48.1100	1.348
48.2552	1.347
48.4004	1.346
48.5455	1.345
48.6907	1.343
48.8358	1.342
48.9809	1.341
49.1261	1.340
49.2712	1.338
49.4164	1.337
49.5615	1.336
49.707	1.334
49.852	1.333
49.997	1.332
50.143	1.330
50.288	1.329
50.433	1.327
50.579	1.326
50.724	1.324
50.870	1.322
51.016	1.321
51.162	1.319
51.308	1.317
51.454	1.316
51.600	1.314
51.746	1.312
51.893	1.310
52.040	1.308
52.187	1.306
52.334	1.305
52.481	1.303
52.628	1.301
52.776	1.299
52.924	1.296
53.073	1.294
53.221	1.292
53.370	1.290
53.519	1.288
53.669	1.285
53.819	1.283
53.969	1.281
54.119	1.278
54.270	1.276
54.422	1.273
54.574	1.271
54.726	1.268
54.879	1.266
55.032	1.263
55.185	1.260
55.340	1.258
55.494	1.255
55.649	1.252
55.805	1.249
55.962	1.246
56.119	1.243
56.276	1.240
56.434	1.237
56.593	1.234
56.752	1.230
56.913	1.227
57.073	1.224
57.235	1.220
57.397	1.217
57.560	1.213
57.723	1.210
57.888	1.206

TABLE 3-continued

θi	sagY
58.053	1.203
58.219	1.199
58.386	1.195
58.553	1.191
58.721	1.187
58.891	1.183
59.060	1.179
59.231	1.175
59.403	1.171
59.575	1.167
59.749	1.162
59.923	1.158
60.098	1.154
60.274	1.149
60.451	1.144
60.629	1.140
60.808	1.135
60.988	1.130
61.169	1.126
61.350	1.121
61.533	1.116
61.717	1.111
61.902	1.105
62.088	1.100
62.275	1.095
62.463	1.090
62.652	1.084
62.842	1.079
63.033	1.073
63.226	1.067
63.420	1.062
63.615	1.056
63.812	1.050
64.010	1.044
64.209	1.038
64.410	1.032
64.612	1.025
64.816	1.019
65.022	1.013
65.230	1.006
65.439	0.999
65.651	0.992
65.865	0.985
66.080	0.978
66.299	0.971
66.520	0.964
66.743	0.956
66.970	0.949
67.199	0.941
67.432	0.933
67.668	0.925
67.909	0.916
68.153	0.908
68.401	0.899
68.654	0.890
68.912	0.880
69.176	0.871
69.445	0.861
69.720	0.851
70.002	0.840
70.291	0.829
70.588	0.818
70.892	0.807
71.206	0.795
71.528	0.782
71.861	0.769
72.205	0.756
72.560	0.742
72.927	0.727
73.308	0.712
73.703	0.696
74.113	0.679
74.539	0.662
74.983	0.644
75.445	0.625
75.927	0.605
76.430	0.584
76.957	0.562
77.507	0.539
78.083	0.515
78.686	0.489
79.319	0.462
79.983	0.434
80.680	0.404
81.412	0.373
82.181	0.340
82.990	0.305
83.841	0.269
84.735	0.230
85.676	0.189
86.666	0.146
87.707	0.101
88.801	0.053
89.952	0.002

FIG. **12** is a graph obtained by plotting the values of θi and sagY in Table 3. FIG. **15** is a graph showing a relationship between r/R and θi-θn. r/R and θi-θn in FIG. **15** are the same as those in FIG. **13**.

In Example 3, the lens is made of a material having a refractive index of 1.41, as in the case of Example 1 described above. Accordingly, as a condition of the total reflection region **124** of the first light exit surface **121**, θi-θn is 45,172 degrees or more, as in the case of Example 1. Accordingly, FIG. **15** shows that in Example 3, the transmissive region **123** is wider than that of Example 1, and the total reflection region **124** is narrower than that of Example 1. FIG. **15** also shows that in Example 3, the second light exit surface **122** totally reflects a part of the light emitted from the starting point Q and transmits the remaining part of the light.

In Example 3, d, θp, and a shown in FIG. **2** are 0.8 mm, 6.0 degrees, and 0.103 mm, respectively. Accordingly, a/(d×tan θp) is 1.22, and this value satisfies the above inequality (2).

Furthermore, in Example 3, d' and R shown in FIG. **2** are 0.795 mm and 2.55 mm, respectively. Accordingly, d'/2R is 0.16, and this value satisfies the above inequality (3).

FIG. **18** shows the illuminance distribution on the surface to be irradiated obtained by calculation assuming that the lighting device of Example 3 (i.e., the illuminating lens in FIG. **12** and the light emitting diode) is used and the surface to be irradiated is placed at a distance of 8 mm from the light emitting diode. FIG. **18** shows a curve indicating the distribution of illuminances on the surface to be irradiated when the illuminances are normalized with respect to the illuminance at the center of the optical axis being 1, as in the case of FIG. **16**. A comparison between FIG. **18** and FIG. **19** shows that the illuminating lens is effective in increasing the illuminated area of the surface to be irradiated.

Furthermore, the distribution width δ_L of illuminances of 0.2 or more on the illuminance distribution curve in FIG. **18** is 0.56. Accordingly, δ_L/δ_S is 2.8, which satisfies the above inequality (4).

Third Embodiment

FIG. **20** is a schematic diagram of a surface light source **8** according to a third embodiment of the present invention. This surface light source **8** includes a plurality of lighting devices **7** of the second embodiment arranged in a plane, and a diffusing plate **4** disposed to cover the plurality of lighting devices **7**. The lighting devices **7** may be arranged in a matrix as shown in FIG. **20**. They may be arranged in a staggered manner.

The surface light source **8** includes a substrate **65** facing the diffusing plate **4** with the lighting devices **7** being disposed therebetween. As shown in FIG. **21**, the light emitting diode **2** of each lighting device **7** is mounted on the substrate **65**. In the present embodiment, a reflecting plate **6** is disposed on the substrate **65** to cover the substrate **65** with the light emitting diodes **2** being exposed.

In the present embodiment, the light entrance surface **11** of the illuminating lens **1** and the bottom surface **13** surrounding the light entrance surface **11** are on the same level.

The lighting device **7** emits light to one surface **4***a* of the diffusing plate **4**. That is, the one surface **4***a* of the diffusing plate **4** is the surface to be irradiated **3** that has been described in the first and second embodiments. The diffusing plate **4** emits the light received on its one surface **4***a* from the other surface **4***b* in a diffused manner. The lighting devices **7** emit light individually toward a large area of the one surface **4***a* of the diffusing plate **4** so that the one surface **4***a* has a uniform illuminance, and upon receiving this light, the diffusing plate **4** emits the light diffusely. As a result, the surface light source capable of emitting light having less uneven brightness in the plane is obtained.

The light emitted from the lighting device **7** is diffused by the diffusing plate **4** so that the diffuse light returns to the lighting device side or passes through the diffusing plate **4**. The light that has returned to the lighting device side and struck the reflecting plate **6** is reflected at the reflecting plate **6** and again enters the diffusing plate **4**.

FIG. **22** shows the illuminance distribution on the light entrance surface (one surface on the side of the lighting device) of the diffusing plate obtained by calculation assuming that four lighting devices of Example 1 each including the illuminating lens in FIG. **10** and the light emitting diode are arranged in a line at a pitch of 20 mm and the diffusing plate is placed at a distance of 8 mm from the light emitting diodes. Small fluctuations in the illuminance distribution are attributed to a small number of light rays to be evaluated in calculating the illuminances. FIG. **23** and FIG. **24** show the illuminance distribution obtained in the same manner when the lighting devices of Example 2 are used and the illuminance distribution obtained when the lighting devices of Example 3 are used, respectively.

FIG. **25** shows the illuminance distribution on the light entrance surface of the diffusing plate obtained by calculation assuming that four light emitting diodes only are arranged in a line with a pitch of 20 mm and the diffusing plate is placed at a distance of 8 mm from the light emitting diodes.

A comparison between FIGS. **22** to **24** and FIG. **25** shows that the illuminating lens is effective in illuminating the light entrance surface of the diffusing plate uniformly.

Fourth Embodiment

FIG. **26** is a schematic diagram of a liquid-crystal display apparatus according to a fourth embodiment of the present invention. This liquid-crystal display apparatus includes a liquid-crystal panel **5**, and a surface light source **8** of the third embodiment disposed behind the liquid-crystal panel **5**.

A plurality of lighting devices **7** each including the light emitting diode **2** and the illuminating lens **1** are arranged in a plane, and the diffusing plate **4** is illuminated by these lighting devices **7**. The underside (one surface) of the diffusing plate **4** is irradiated with the light emitted from the lighting devices **7** to have a uniform illuminance, and then the light is diffused by the diffusing plate **4**. Thus, the liquid-crystal panel **5** is illuminated by the diffused light.

It is preferable that an optical sheet such as a diffusing sheet or a prism sheet is disposed between the liquid-crystal panel **5** and the surface light source **8**. In this case, the light that has passed through the diffusing plate **4** further is diffused by the optical sheet and illuminates the liquid-crystal panel **5**.

The invention may be embodied in other forms without departing from the spirit or essential characteristics thereof. The embodiments disclosed in this specification are to be considered in all respects as illustrative and not limiting. The scope of the invention is indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are intended to be embraced therein.

What is claimed is:

1. An illuminating lens for spreading light emitted from a light source so that a surface to be irradiated is irradiated with the spread light, the lens comprising:

a light entrance surface through which the light emitted from the light source enters the lens; and

a light exit surface through which the light that has entered the lens exits the lens,

wherein the light exit surface has a first light exit surface and a second light exit surface, the first light exit surface being recessed toward a point on an optical axis of the illuminating lens, and the second light exit surface extending outwardly from a periphery of the first light exit surface to form a convex,

the first light exit surface has a transmissive region located in the center of the first light exit surface and a total reflection region located around the transmissive region, the transmissive region being capable of transmitting light that has been emitted from a starting point at a relatively small angle with respect to the optical axis and then reached the first light exit surface, when a position of the light source on the optical axis is defined as the starting point, and the total reflection region being capable of totally reflecting light that has been emitted from the starting point at a relatively large angle with respect to the optical axis and then reached the first light exit surface, and

the second light exit surface has a shape capable of transmitting approximately the entire amount of light that has been emitted from the starting point and then reached the second light exit surface,

wherein the light exit surface is rotationally symmetric with respect to the optical axis.

2. The illuminating lens according to claim **1**, wherein the light source is a point light source and the light entrance surface has a shape conforming to the shape of the point light source.

3. The illuminating lens according to claim **1**, wherein when an angle between the optical axis and a line connecting the starting point and a boundary between the first light exit surface and the second light exit surface is defined as θb, the following inequality is satisfied:

$$20\text{ degrees}<\theta b<40\text{ degrees}.$$

4. The illuminating lens according to claim **1**, wherein the entire second light exit surface transmits the light that has been emitted from the starting point.

5. The illuminating lens ac cording to claim **1**, wherein the second light exit surface totally reflects a part of the light that has been emitted from the starting point and transmits the remaining part of the light.

6. The illuminating lens according to claim 1, wherein when a thickness of the illuminating lens on the optical axis is denoted as d', and an outermost radius of the illuminating lens is denoted as R, the following inequality is satisfied:

$d'/2R<0.25$, and

in the case where the surface to be irradiated is illuminated via the illuminating lens, when a distribution width of illuminances of 0.2 or more in an illuminance distribution curve on the surface to be irradiated is denoted as δ_L, the illuminance distribution curve being obtained by normalizing illuminances with respect to an illuminance at the center of the optical axis being 1, and in the case where the surface to be irradiated is illuminated only by the light source, when a distribution width of illuminances of 0.2 or more in an illuminance distribution curve on the surface to be irradiated is denoted as δ_S, the illuminance distribution curve being obtained by normalizing illuminances with respect to an illuminance at the center of the optical axis being 1, the following inequality is satisfied:

$2.0<\delta_L/\delta_S<4.0$.

7. A lighting device comprising:

a light emitting diode for emitting light; and

an illuminating lens for spreading light emitted from the light emitting diode so that a surface to be irradiated is irradiated with the spread light,

wherein the illuminating lens is the illuminating lens according to claim 1.

8. A surface light source comprising:

a plurality of lighting devices arranged in a plane; and

a diffusing plate disposed to cover the plurality of lighting devices, the diffusing plate being configured to receive on one surface thereof light emitted from the plurality of lighting devices and to emit the light from the other surface thereof in a diffused manner,

wherein each of the plurality of lighting devices is the lighting device according to claim 7.

9. The surface light source according to claim 8, further comprising:

a substrate on which the light emitting diode included in each of the plurality of lighting devices is mounted, the substrate facing the diffusing plate with the plurality of lighting devices being disposed therebetween; and

a reflecting plate disposed on the substrate to cover the substrate with the light emitting diodes being exposed.

10. A liquid-crystal display apparatus comprising:

a liquid-crystal panel; and

the surface light source according to claim 8 disposed behind the liquid-crystal panel.

11. An illuminating lens for spreading light emitted from a light source so that a surface to be irradiated is irradiated with the spread light, the lens comprising:

a light entrance surface through which the light emitted from the light source enters the lens; and

a light exit surface through which the light that has entered the lens exits the lens,

wherein the light exit surface has a first light exit surface and a second light exit surface, the first light exit surface being recessed toward a point on an optical axis of the illuminating lens, and the second light exit surface extending outwardly from a periphery of the first light exit surface to form a convex,

the first light exit surface has a transmissive region located in the center of the first light exit surface and a total reflection region located around the transmissive region, the transmissive region being capable of transmitting light that has been emitted from a starting point at a relatively small angle with respect to the optical axis and then reached the first light exit surface, when a position of the light source on the optical axis is defined as the starting point, and the total reflection region being capable of totally reflecting light that has been emitted from the starting point at a relatively large angle with respect to the optical axis and then reached the first light exit surface, and

the second light exit surface has a shape capable of transmitting approximately the entire amount of light that has been emitted from the starting point and then reached the second light exit surface,

wherein when a point of intersection of the first light exit surface and the optical axis is denoted as C, a point on a boundary between the transmissive region and the total reflection region is denoted as P, a distance between the point C and the starting point is denoted as d, an angle between the optical axis and a line connecting the point P and the starting point is denoted as θp, and a length of a straight line connecting the point C and the point P is denoted as a, the following inequality is satisfied:

$1.10<a/(d\times\tan\theta p)<1.30$.

12. An illuminating lens for spreading light emitted from a light source so that a surface to be irradiated is irradiated with the spread light, the lens comprising:

a light entrance surface through which the light emitted from the light source enters the lens; and

a light exit surface through which the light that has entered the lens exits the lens,

wherein the light exit surface has a first light exit surface and a second light exit surface, the first light exit surface being recessed toward a point on an optical axis of the illuminating lens, and the second light exit surface extending outwardly from a periphery of the first light exit surface to form a convex,

the first light exit surface has a transmissive region located in the center of the first light exit surface and a specular reflection region located around the transmissive region, the transmissive region being capable of transmitting light that has been emitted from a starting point at a relatively small angle with respect to the optical axis and then reached the first light exit surface, when a position of the light source on the optical axis is defined as the starting point, and the specular reflection region being covered with a reflective layer capable of specularly reflecting light that has been emitted from the starting point at a relatively large angle with respect to the optical axis and then reached the first light exit surface, and

the second light exit surface has a shape capable of transmitting approximately the entire amount of light that has been emitted from the starting point and then reached the second light exit surface.

13. The illuminating lens according to claim 12, wherein the specular reflection region has a shape capable of totally reflecting the light that has been emitted from the starting point at the relatively large angle with respect to the optical axis and then reached the first light exit surface when the specular reflection region is not covered with the reflective layer.

14. The illuminating lens according to claim 12, wherein the light exit surface is rotationally symmetric with respect to the optical axis.

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