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2K103BC50
2K103BC51
2K103CA26
2K103CA29
2K103CA45
2K103CA76
3K243AA01
3K243AB01
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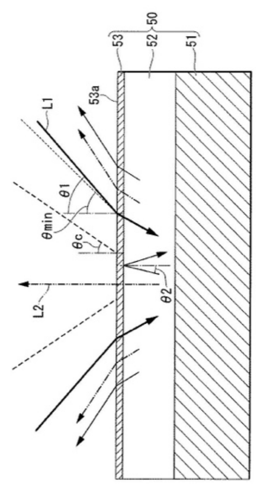
(57) [Summary]
[Problem] To provide a light source device and projector capable of improving the luminous efficiency of a phosphor.
[Solution Means] Comprises an excitation light source emitting an excitation light L1; a phosphor layer 52 receiving excitation light L1 and radiating a fluorescence L2 at a wavelength different from excitation light L1; a reflector 51 disposed on the opposite side of the phosphor layer 52 from the side on which excitation light L1 is incident, reflecting both the excitation light L1 and the fluorescence L2; and a wavelength-selecting reflective layer 53 disposed on the optical path between the excitation light source and the phosphor layer 52, for transmitting fluorescence L2;

whereby wavelength-selecting reflective layer 53 is constituted to transmit the excitation light L1 incident on the wavelength-selecting reflective layer 53 at an incident angle within a predetermined incident angle range and reflect excitation light L1 incident on wavelength-selecting reflective layer 53 at an incident angle outside the predetermined incident angle range; and to cause excitation light L1 to be made incident on wavelength-selecting reflective layer 53 at an incident angle within the predetermined incident angle range.

[Selected Figure] FIG. 5



Patent Claims

[Claim 1]

A light source comprising: an excitation light source emitting excitation light,

a phosphor layer that receives the excitation light and radiates fluorescence at a wavelength different from the excitation light,

a reflector disposed on the opposite side to the side on which the phosphor layer excitation light is incident, reflecting both the excitation light and the fluorescence,

and a wavelength-selecting reflective layer disposed on the optical path between the excitation light source and the phosphor layer, transmitting the fluorescence,

whereby the wavelength-selecting reflective layer is constituted to transmit excitation light incident on the wavelength-selecting reflective layer at an incident angle within a predetermined incident angle range and to reflect excitation light incident on the wavelength-selecting reflective layer at an incident angle outside the predetermined incident angle, and the excitation light source causes excitation light to be made incident on the wavelength-selecting reflective layer at an incident angle within the predetermined incident angle range.

[Claim 2]

The light source device of Claim 1, wherein the wavelength-selecting reflective layer is constituted to transmit excitation light incident on the wavelength-selecting reflective layer at an incident angle θ such that θ min ≤ θ, and to reflect excitation light incident on the wavelength-selecting reflective layer at an incident angle θ such that $\theta < \theta min$;

and wherein the excitation light source causes excitation light to be made incident on the wavelength-selecting reflective layer at an incident angle of θ such that $\theta min \leq \theta$.

[Claim 3]

The light source device of Claim 1, constituted so that the wavelength-selecting reflective layer is configured to transmit excitation light incident on the wavelength-selecting reflective layer at an incident angle θ such that $\theta \leq \theta max$, reflecting excitation light incident on the wavelength-selecting reflective layer at an incident angle θ such that $\theta > \theta max$;

wherein excitation light source causes excitation light to be made incident on the wavelength-selecting reflective layer at an incident angle θ such that $\theta \leq \theta max$.

[Claim 4]

The light source device of Claim 2, wherein the excitation light source is a laser light source array in which multiple laser light sources are disposed;

whereby the laser light source array causes light from the multiple laser beams to be made incident on the outer perimeter portion of a condensing lens as the excitation light;

and the condensing lens bends the optical path of multiple laser beams incident on the outer perimeter of said condensing lens to make the laser light incident on the wavelength-selecting reflective layer.

[Claim 5]

The light source device of Claim 4, wherein the multiple laser light sources are disposed in a ring shape on the laser light source array.

[Claim 6]

The light source device of Claim 4, wherein the laser light sources disposed at the center portion of the laser light source array emit laser light in a direction diagonal to the normal of the plane in which the multiple laser light sources are disposed.

[Claim 7]

The light source device of any of Claims 4-6, wherein the laser light source array comprises:

a laser light source emitting a relatively short wavelength laser light as excitation light;

and a laser light source emitting a relatively long wavelength laser light as excitation light;

and wherein the laser light source array causes the short wavelength laser light to be made incident on the wavelength-selecting reflective layer at an incident angle greater than the long wavelength laser light.

[Claim 8]

The light source device of Claim 4, comprising a condensing lens for focusing excitation light onto the phosphor layer,

wherein the excitation light source is a laser light source array in which multiple laser light sources are disposed;

the laser light source array causes multiple laser light sources to be made incident as excitation light on the center of the condensing lens;

and the condensing lens causes multiple laser lights incident on the center portion of said condensing lens to be made incident on the wavelength-selecting reflective layer.

[Claim 9]

The light source device of Claim 8, wherein the laser light source disposed on the peripheral portion of the laser light source array emits laser light in a diagonal direction relative to the normal of the plane in which said multiple laser light sources are disposed.

[Claim 10]

The light source device of Claim 9, wherein the laser light source array comprises:

a laser light source emitting relatively short wavelength laser light as the excitation light;

whereby the laser light source array causes the short wavelength laser light to be made incident on the wavelength-selecting reflective layer at a smaller incident angle than the long wavelength laser light.

[Claim 11]

The light source device of any of Claims 4-10, wherein the multiple laser light sources cause P-polarized light to be incident on the wavelength-selecting reflective layer.

[Claim 12]

The light source device of any of Claims 1 to 11, wherein the wavelength-selecting reflective layer is disposed on the opposite side of the phosphor layer from the reflector.

[Claim 13]

The light source device of any of Claims 1 to 12, wherein the excitation light is blue light and the fluorescence is red light.

[Claim 14]

A projector comprising: the light source device of any of Claims 1 to 13,

a light modulation device for modulating light emitted from the light source device in response to image information;

and projection optics for projecting modulated light from the light modulation device as a projected image.

Detailed Description of the Invention
[Technical Field]
[0001]
The present invention pertains to a light source device and a projector.

[Background Technology]
[0002]
Light source devices furnished with a light source emitting excitation light and a phosphor layer emitting fluorescence excited by an excitation light emitted from a light source have become known in recent years. For example, the light source device set forth in Patent Document 1 is constituted so as to irradiate a phosphor layer formed on the surface of a reflective body with excitation light to extract fluorescence from the excitation light-irradiated surface.

[Prior Art References]
[Patent References]
[0003]
[Patent Document 1] Patent Publication No. 2004-327361

[Summary of the Invention]
[Problem the Invention Seeks to Solve]
[0004]
Excitation light incident on the phosphor layer, in addition to a component which is converted into fluorescence by excitation of the phosphor layer, also has a component which scatters without being converted into fluorescence. In the light source device set forth in Patent Document 1, excitation light scattered without being converted into fluorescence by the phosphor layer may leak away from the surface of the phosphor layer. Since it is difficult to make effective use of leaked excitation light, the decrease the phosphor's luminous efficiency becomes a problem.

[0005]
The present invention was undertaken in light of these circumstances, and has the object of providing a light source device and projector capable of improving the luminous efficiency of the phosphor.

[Means for Solving the Problem]
[0006]

To resolve the aforementioned problems, the light source device of the present invention comprises: an excitation light source emitting excitation light, a phosphor layer that receives the excitation light and radiates fluorescence at a wavelength different from the excitation light, a reflector disposed on the opposite side to the side on which the phosphor layer excitation light is incident, reflecting both the excitation light and the fluorescence, and a wavelength-selecting reflective layer disposed on the optical path between the excitation light source and the phosphor layer, transmitting the fluorescence, whereby the wavelength-selecting reflective layer is constituted to transmit excitation light incident on the wavelength-selecting reflective layer at an incident angle within a predetermined incident angle range and to reflect excitation light incident on the wavelength-selecting reflective layer at an incident angle outside the predetermined incident angle range, and the excitation light source causes excitation light to be made incident on the wavelength-selecting reflective layer at an incident angle within the predetermined incident angle range.

[0007]

Using this light source device, excitation light scattered without being converted to fluorescence by the phosphor layer (excitation light reflected by a reflector) is incident on the wavelength-selecting reflective layer. Excitation light incident from the phosphor layer on the wavelength-selecting reflective layer at an incident angle outside the predetermined incident angle range is reflected by the wavelength-selecting reflective layer and used to excite fluorescence inside the phosphor layer. I.e., at least part of the excitation light that travels from the phosphor layer back toward the wavelength-selecting reflective layer can be effectively used for excitation of fluorescence. The luminous efficiency of the phosphor can thus be improved.

[0008]

In the light source device, the wavelength-selecting reflective layer is constituted to transmit excitation light incident on the wavelength-selecting reflective layer at an incident angle θ such that θ min ≤ θ, and to reflect excitation light incident on the wavelength-selecting reflective layer at an incident angle θ such that $\theta < \theta min$; whereby the excitation light source may be made incident on the wavelength-selecting reflective layer at an incident angle of θ such that $\theta min \leq \theta$.

[0009]

Using this light source device, excitation light from the phosphor layer incident at an incident angle $\theta < \theta min$ on the wavelength-selecting reflective layer is reflected by the wavelength-selecting reflective layer and used to excite fluorescence inside the phosphor layer. The luminous efficiency of the phosphor can thus be improved.

[0010]

In the light source device, the wavelength-selecting reflective layer may be constituted to transmit excitation light incident on the wavelength-selecting reflective layer at an incident angle θ such that $\theta \leq \theta max$, and to reflect excitation light incident on the wavelength-selecting reflective layer at an incident angle θ such that $\theta > \theta max$.

[0011]

Using this light source device, excitation light from the phosphor layer incident on the wavelength-selecting reflective layer at an incident angle such that $\theta > \theta max$ is reflected by the wavelength-selecting reflective layer and used to excite fluorescence inside the phosphor layer. Luminous efficiency of the phosphor can thus be improved.

[0012]

The light source device comprises a condensing lens for focusing the excitation light onto the phosphor layer; the excitation light source may be a laser light source array in which multiple laser light sources are disposed, whereby the laser light source array causes multiple laser beams to be incident on the peripheral portion of the condensing lens as excitation light, and the condensing lens bends the optical path of the multiple laser beams incident on the condensing lens periphery, causing the laser light to be incident on the wavelength-selecting reflective layer.

[0013]

Using this light source device, a highly efficient light source can be realized because multiple laser beams are focused and irradiated onto the phosphor layer. Also, because the optical path of the multiple laser beams incident on the periphery of the condensing lens are bent, [the device] is suitable for use with a wavelength-selecting reflective layer that transmits excitation light incident at a wide angle.

[0014]

In the light source device, the multiple laser light sources in the laser light source array may be arranged in a ring shape.

[0015]

Using this light source device, multiple laser beams are incident on only the periphery of the condensing lens, thereby satisfying the incident angle condition that the excitation light transmits through the wavelength-selecting reflective layer.

[0016]

In the light source device, the laser light source disposed at the center of the laser light source array may emit laser light in a diagonal direction relative to the normal of the plane on which the multiple laser light sources are arranged.

[0017]

Using this light source device, almost all of the laser light emitted from the multiple laser light sources disposed in the laser light source array can be made incident on only the periphery of the condensing lens. A high efficiency light source can thus be achieved while making effective use of multiple laser light to excite fluorescence.

[0018]

In the light source device, the laser light source array may comprise a laser light source emitting a relatively short wavelength laser light as the excitation light, and a laser light source emitting a relatively long wavelength laser light as the excitation light, whereby the laser light source array causes the short wavelength laser light to be incident on the wavelength-selecting reflective layer at an incident angle greater than that of the long wavelength laser light.

[0019]

The wavelength-selecting reflective layer has the wavelength characteristic that it transmits more long wavelength light than short wavelength light. Although the component which approaches light incident on the wavelength-selecting reflective layer at an incident angle such that $\theta < \theta min$ has difficulty satisfying the incident angle condition for transmission [through] the wavelength-selecting reflective layer, it is relatively longer wavelength light, and therefore more easily incident on the phosphor layer. Multiple laser beams can thus be effectively used to excite fluorescence.

[0020]

The light source device comprises a condensing lens for focusing the excitation light onto the phosphor layer; the excitation light source may be a laser light source array in which multiple laser light sources are disposed, whereby the laser light source array causes multiple laser beams to be incident on the center portion of the condensing lens as excitation light, and the condensing lens causes the multiple laser beams incident on the center portion of said condensing lens to be incident on the wavelength-selecting reflective layer.

[0021]

Using this light source device, multiple laser beams are focused and irradiated onto a phosphor layer, thus enabling a high efficiency light source to be achieved. Also, the multiple laser beams incident on the center of the condensing lens are made incident on the wavelength-selecting reflective layer, making this suitable for use as a wavelength-selecting reflective layer for transmitting excitation light incident at an angle close to perpendicular.

[0022]

In the light source device, the laser light source disposed on the peripheral portion of the laser light source array may emit laser light in a diagonal direction relative to the normal of the plane in which the multiple laser light sources are disposed.

[0023]

Using this light source device, almost all of the laser light emitted from the multiple laser light sources disposed in the laser light source array can be made incident on only the center of the condensing lens. A high efficiency light source can thus be achieved while making effective use of multiple laser beams to excite fluorescence.

[0024]

In the light source device, the laser light source array may comprise a laser light source emitting a relatively short wavelength laser light as the excitation light, and a laser light source emitting a relatively long wavelength laser light as the excitation light, whereby the laser light source array causes the short wavelength laser light to be incident on the wavelength-selecting reflective layer at an incident angle smaller than that of the long wavelength laser light.

[0025]

The wavelength-selecting reflective layer has the wavelength characteristic of transmitting more long wavelength light than short wavelength light. Although the component which approaches light incident on the wavelength-selecting reflective layer at an incident angle such that $\theta < \theta min$ has difficulty satisfying the incident angle condition for transmission [through] the wavelength-selecting reflective layer, it is relatively longer wavelength light, and therefore more easily incident on the phosphor layer. Multiple laser light can thus be effectively used to excite fluorescence.

[0026]

In the above light source device, the multiple laser light sources may cause P-polarized light to be incident on the wavelength-selecting reflective layer.

[0027]

The wavelength-selecting reflective layer [is such that] P-polarized light generally has a longer cutoff wavelength than S-polarized light. Therefore making P-polarized light incident on the wavelength-selecting reflective layer as the excitation light facilitates the transmission of excitation light [through] the wavelength-selecting reflective layer at a wide incident angle. On the other hand, S-polarized light generated by scattering inside the phosphor layer has a shorter cutoff wavelength than P-polarized light, so it is more easily reflected by the wavelength-selecting reflective layer than P-polarized light. Therefore excitation light scattering inside the phosphor layer and transmission through the wavelength-selecting reflective layer can be reduced. Luminous efficiency of the phosphor can be thus improved.

[0028]

In the light source device, the wavelength-selecting reflective layer may be disposed on the opposite side of the phosphor layer from the reflector.

[0029]

Using this light source device, the spread of excitation light reflected by the wavelength-selecting reflective layer and returned to the phosphor layer can be suppressed compared to a constitution in which the wavelength-selecting reflective layer is disposed at a distance from the phosphor layer. Excitation light traveling in a direction returning to the phosphor layer can therefore be made incident on the phosphor layer, and the luminous efficiency of the phosphor improved.

[0030]

In the light source device, excitation light may be blue light and the fluorescence red light.

[0031]

Using this light source device, the difference between the excitation light peak wavelength and the fluorescence peak wavelength is larger than when the fluorescence is a green light. This enables a wavelength-selecting reflective layer to be constituted so that fluorescence at a wavelength different from the excitation light passes [through it], and excitation light incident at an incident angle outside a predetermined incident angle range is reflected [by it].

[0032]

The projector of the invention comprises the above-described light source device, a light modulation device for modulating light emitted from the light source device in response to image information, and projection optics for projecting modulated light from the light modulation device as a projected image.

[0033]

Because this projector comprises the light source device described above, a high-quality projector capable of efficiently obtaining bright images can be obtained.

[Brief Description of Drawings]

[0034]

[Fig. 1] A schematic diagram of a light source device and projector according to a first embodiment of the invention.

[Fig. 2] A front view of an excitation light source incorporated by the light source device in same.

[Fig. 3] A side view of a light source device in same.

[Fig. 4] A graph showing luminescence characteristics of an excitation light source and phosphor layer in same.

[Fig. 5] A schematic diagram showing excitation light incident on a phosphor layer, and fluorescence and excitation light scattered by the phosphor layer in same.

[Fig. 6] An example of the relationship between incident light wavelength and transmittance when incident angles are varied in same.

[Fig. 7] A diagram explaining cutoff wavelength in same.

[Fig. 8] A front view of a first variation of the excitation light source provided in a light source device in same.

[Fig. 9] A side view of a first variation of the light source device in same.

[Fig. 10] A front view of an excitation light source provided in a light source device according to a second embodiment of the invention.

[Fig. 11] A side view of a light source device in same.

[Fig. 12] A graph showing emission characteristics of a phosphor layer in same.

[Fig. 13] A schematic diagram showing excitation light incident on the phosphor layer, and fluorescence and excitation light scattered by the phosphor layer in same.

[Fig. 14] An example of the relationship between incident light wavelength and transmittance when incident angles are varied in same.
[Fig. 15] A front view showing a first variation of an excitation light source provided in a light source device in same.
[Fig. 16] A side view showing a first variation of the light source device in same.
[Fig. 17] A front view of an excitation light source provided in a light source device according to a third embodiment of the invention.
[Fig. 18] A diagram showing an example of the relationship between incident light wavelength and transmittance for P-polarized light and S-polarized light.

[Embodiments of the Invention]
[0035]
Below we explain embodiments of the invention with reference to figures. These embodiments depict one form of the invention; they do not limit the invention, and may be varied within the scope of the technical concept of the invention. Also, for ease of understanding, the scale and numbers, etc. of each of the structures differ from the actual structure.

[0036]
(First Embodiment)
Fig. 1 is a schematic diagram showing a light source device 100A and projector PJ of the present embodiment.
Projector PJ shown in Fig. 1 includes a first light source device 100A, a second light source device 100B, a dichroic mirror 200, a liquid crystal light valve (optical modulator) 300R, a liquid crystal light valve 300G, a liquid crystal light valve 300B, a color synthesizing element 400, and projection optics 500. The constitution incorporated in the first light source device 100A corresponds to the light source device of the present invention.

[0037]
Projector PJ essentially operates as follows. Light emitted from first light source device 100A is separated into red light R and green light G by dichroic mirror 200. Blue light B is emitted from second light source device 100B. This red light R, green light G, and blue light B are respectively incident on and modulated by corresponding liquid crystal light valves 300R, 300G, and 300B. Each colored light modulated by liquid crystal light valve 300R, liquid crystal light valve 300G, and liquid crystal light valve 300B is made incident on color synthesizing element 400 and synthesized. Light synthesized by color synthesizing element 400 is magnified and projected onto a projection surface 600 such as a wall or

screen by projection optics 500 to display a full-color projection image. Each constituent element of projector PJ is described below.

[0038]

Light source device 100A consists of a light source unit (excitation light source) 10A, collimating optics 20, a dichroic mirror 30, pickup optics 40, a light emitting element 50, focusing optics 60, a polarized light conversion element 70, a rod integrator 80, and a collimating lens 90, arranged in that order on the optical path. In light source device 100A, by irradiating excitation light emitted from light source portion 10A onto light emitting element 50, fluorescence used as liquid crystal light valve illumination light is made to emit from fluorescent layer 52 provided in light emitting element 50. Note that wavelength-selecting reflective layer 53 is formed on the surface (incident surface) of phosphor layer 52.

[0039]

As shown in Fig. 2, light source portion 10A is a laser light source array in which multiple laser light sources 12 (24 total) are arranged on a base 11. Light source portion 10A makes multiple laser beams incident on the periphery of condensing lens 23. Multiple laser light sources 12 are disposed in a ring shape on light source portion 10A (on the periphery, excluding the center portion of base 11).

[0040]

Fig. 3 shows a side view of light source device 100A. Note than in Fig. 3, condensing optics 60, polarized light conversion element 70, rod integrator 80, and collimating lens 90 are omitted for convenience.

[0041]

As shown in Fig. 3, excitation light emitted from light source portion 10A is collimated by the collimator lens array 21 included in light source portion 10A, focused by condensing lens 23, then transmitted through collimating lens 25 to narrow the overall excitation light beam. Condensing lens 23 bends the optical path of the multiple laser light incident on the periphery of said condensing lens 23 to cause the excitation light to enter wavelength-selecting reflective layer 53. Excitation light is focused onto the wavelength-selecting reflective layer 53 at a relatively large incident angle.

[0042]

The light source portion 10A emits blue laser light (emission intensity peak: approx. 450 nm, see Fig. 4(a)) as excitation light to excite the phosphor provided by light emitting element 50. In Fig. 4(a), the color light component emitted by light source portion 10A as excitation light is indicated by reference symbol LB.

[0043]

Note that light source portion 10A may use only one laser light source instead of the laser light source array shown in Figs. 2 and 3. A light source emitting colored light with a peak wavelength other than 450 nm is also acceptable, so long as the light has a wavelength capable of exciting a phosphor substance as described below. In Fig. 1, the excitation light emitted from light source portion 10A is indicated by the symbol LB.

[0044]

Excitation light transmitted through collimating optics 20 is reflected by dichroic mirror 30. Dichroic mirror 30 is a dielectric multilayer film laminated on a glass surface. Dichroic mirror 30 has wavelength selectivity that selectively reflects colored light in the wavelength band of the excitation light and transmits colored light in other wavelength bands. Specifically, dichroic mirror 30 reflects blue light and transmits light of longer wavelengths than blue light (e.g., longer than 490 nm). Excitation light is then incident on pickup optics 40.

[0045]

Pickup optics 40 comprises a first lens 41, which is a convex lens, and a second lens 42, which is a single convex lens into which excitation light enters through the first lens 41. Pickup optics 40 is disposed on the beam axis of excitation light LB reflected by dichroic mirror 30, and focuses excitation light LB on light emitting element 50.

[0046]

The focusing angle of pickup optics 40 is, for example, a minimum of 45 degrees. On light emitting element 50, the individual spots of the laser light sources 12 incorporated in light source portion 10A are set so that their focusing positions do not completely overlap; for example, each laser light source 12 spot is configured to delineate an approximately square shape of 1 mm square. In the following description, the excitation light “spot” or “beam spot” indicates the entire spot of the laser light sources 12 included in light source portion 10A (in the example above, the entirety of the approximately square-shaped spot).

[0047]

Pickup optics 40 also has the function of focusing and collimating fluorescence emitted isotropically by light emitting element 50.

[0048]

Light emitting element 50 has: a flat reflector 51, a phosphor layer 52 formed on the excitation light incident side of reflector 51, and a wavelength-selecting reflective layer 53 disposed on the opposite side of the phosphor layer 52 from reflector 51. Phosphor layer 52 has fluorescent particles that emit fluorescence, and has the function of absorbing excitation light (blue light) and converting it into yellow fluorescence (peak emission intensity: approximately 550 nm, see Fig. 4(b)). The component indicated by symbol R in Fig. 4(b) is the colored light component usable as red light within the yellow light emitted by phosphor layer 52, and the component indicated by the symbol G is the colored light component similarly usable as green light. In Fig. 1, red light is indicated by the symbol R and green light by the symbol G, and fluorescence including red light R and green light G is indicated by the symbol RG.

[0049]

After collimation by pickup optics 40, fluorescence RG emitted from light emitting element 50 passes through dichroic mirror 30 and is incident on focusing optics 60. Focusing optics 60 collects the fluorescence and directs it to polarized light conversion element 70.

[0050]

Polarized light conversion element 70 has the function of separating incoming fluorescence into P and S polarization, aligning the polarization direction of one of the incident P and S polarizations with that of the other for emission.

[0051]

Fluorescence RG, in which the polarization direction is aligned by polarized light conversion element 70, is incident on one end of rod integrator 80. Rod integrator 80 is a prism-shaped optical member extending in the optical path direction which blends light emitted from polarized light conversion element 70 by causing reflections of the light transmitted through the interior, thereby homogenizing the luminance distribution. The cross-sectional shape of rod integrator 80 in the direction perpendicular to the optical path is similar to the external shape of the image forming area of liquid crystal light valve 300R, liquid crystal light valve 300G, and liquid crystal light valve 300B.

[0052]

Fluorescence RG emitted from the other end of rod integrator 80 is collimated by collimating lens 90 and emitted from the light source device 100A.

[0053]

On the other hand, second light source device 100B is constituted so that a light source 10B, which is an LED (Light Emitting Diode) light source emitting blue light B, a collimator optics 20B having a first lens 27 on which blue light B is incident and a second lens 29 for collimating laser light passing through said first lens 27, focusing optics 60 similar to light source device 100A, rod collimator 80, and collimating lens 90 are disposed in that order on the optical path. I.e., light source device 100B is constituted to emit the blue light used as illumination light for liquid crystal light valve 300B.

[0054]

Fluorescence RG emitted from light source device 100A is incident on dichroic mirror 200. Similar to the dichroic mirror 30 described above, in dichroic mirror 200 a dielectric multilayer film is laminated on a glass surface. Dichroic mirror 200 has a wavelength selectivity that reflects green light G and transmits red light R.

[0055]

Red light R contained in fluorescence RG passes through dichroic mirror 200, is reflected at mirror 210, and is incident on liquid crystal light valve 300R. Green light G contained in fluorescence RG is reflected by dichroic mirror 200, reflected at mirror 220, and incident on liquid crystal light valve 300G.

[0056]

Blue light B emitted from light source device 100B is reflected at mirror 230 and incident on liquid crystal light valve 300B.

[0057]

Normally known light modulation devices may be used for liquid crystal light valve 300R, liquid crystal light valve 300G, and liquid crystal light valve 300B; e.g., they may be constituted by as a transmissive type liquid crystal light valve having a liquid crystal element 310 and polarizing elements 320 and 330 that sandwich the liquid crystal element 310. Polarizing elements 320 and 330, for example, are constituted so that their transmission axes are orthogonal to one other (a crossed-nicol arrangement).

[0058]

Liquid crystal light valves 300R, 300G, and 300B are electrically connected to a signal source (not shown) such as a PC supplying image signals containing image information. Liquid crystal light valve 300R, liquid crystal light valve 300G, and liquid crystal light valve 300B form images by spatially modulating incident light for each pixel based on supplied image signals. LCD light valve 300R, LCD light valve 300G, and LCD light valve 300B form red, green, and blue images, respectively. Light modulated by liquid crystal light valve 300R, liquid crystal light valve 300G, and liquid crystal light valve 300B (the formed image) is incident on color synthesizing element 400.

[0059]

Color synthesizing element 400 is constituted by dichroic prisms or the like. The dichroic prism has a structure in which four triangular prisms are adhered together. The mutually adhered surfaces of the triangular prisms are the inner surfaces of the dichroic prisms. A mirror surface that reflects red light R and transmits green light G and a mirror surface that reflects blue light B and transmits green light G are formed orthogonally to one other on the inner surface of the dichroic prism. Green light G incident on the dichroic prism is emitted as is through the mirror surface. Red light R and blue light B incident on the dichroic prism are selectively reflected or transmitted by the mirror surface and emitted in the same direction as green light G is emitted. The three colored lights ([of the] image) are thus superimposed and synthesized, and the synthesized colored light magnified and projected onto the projection surface 600 by projection optics 500.

Images are thus displayed by the projector PJ of the present embodiment.

[0060]

Fig. 5 is a schematic diagram showing the excitation light incident on phosphor layer 52 and the fluorescence and excitation light scattered by phosphor layer 52. In Fig. 5, symbol L1 is the excitation light and symbol L2 is the fluorescence.

[0061]

As shown in Fig. 5, light emitting element 50 has a flat reflector 51, a phosphor layer 52 formed on the surface of reflector 51 on the excitation light incident side, and a wavelength-selecting reflective layer 53 disposed on the opposite side of phosphor layer 52 from reflector 51.

[0062]

Reflector 51 has a surface that reflects light (blue light as excitation light and yellow light as fluorescence); a reflective metal material sheet such as an aluminum substrate, or a light transmissive sheet of forming material such as quartz glass, crystal, sapphire (single crystal corundum), or transparent resin, on the surface of which a reflective film is formed, may be used for the forming material. The reflector 51 in the present embodiment should be formed using an aluminum substrate.

[0063]

Phosphor layer 52 is a sintered body of glass powder and phosphor powder. Phosphor layer 52 is attached to the top surface of the reflector 51. A YAG (yttrium aluminum garnet) phosphor may be used, for example, as the phosphor to constitute phosphor layer 52.

[0064]

The phosphor radiates fluorescence in the wavelength region of approximately 490 nm to 750 nm, centered on 570 nm (see solid line in Fig. 4(b)). This fluorescence includes G light in the wavelength region centered around 530 nm (see the single-dotted line in Fig. 4(b)) and R light in the wavelength region centered around 630 nm (see the wavy line in Fig. 4(b)). Light source device 100A emits fluorescence L2 including G light and R light.

[0065]

Wavelength-selecting reflective layer 53 is, for example, a dielectric multilayer film. Wavelength-selecting reflective layer 53 has a layer structure of between 40 to 50 layers using, for example, TiO2 as a high refractive index material, SiO2 as a low refractive index material, and optical glass such as BK7 as a substrate.

[0066]

Wavelength-selecting reflective layer 53 transmits fluorescence L2 emitted from phosphor layer 52. Wavelength-selecting reflective layer 53 also transmits light incident on wavelength-selecting reflective layer 53 at a predetermined incident angle out of the excitation light L1 emitted from light source portion 10A.

[0067]

The angle between the normal to light incident surface 53a on the opposite side from phosphor layer 52 of wavelength-selecting reflecting layer 53 and the primary beam of the excitation light flux incident on light-incident surface 53a should be the smallest incident angle θmin among incident angles θ1 and θ1 [*note: possible typo in original?*]. Here, “main beam of the excitation light flux” is a beam passing through the center of a predetermined excitation light flux. The “minimum incident angle” is the incident angle of the excitation light incident closest to the normal of light incident surface 53a among the multiple excitation lights incident on light incident surface 53a (the incident angle of the beam incident closest to the normal of the light incident surface 53a among the multiple beams constituting the excitation light flux incident on the light incident surface 53a).

[0068]

Wavelength-selecting reflective layer 53 transmits excitation light incident on wavelength-selecting reflective layer 53 at an incident angle θ1 such that θmin ≤ θ1. Of the excitation light incident inside the phosphor layer 52, scattered by the phosphor layer 52 and incident on the opposite side of the light incident surface 53a, wavelength-selecting reflective layer 53 reflects the excitation light incident from phosphor layer 52 on wavelength-selecting reflective layer 53 at an incident angle θ2 such that θ2 < θmin.

[0069]

Wavelength-selecting reflective layer 53 has the function of reflecting excitation light incident on wavelength-selecting reflective layer 53 at an incident angle θ1 such that θ1 < θmin. In the present embodiment, a constitution is adopted in which excitation light is made incident on wavelength-selecting reflective layer 53 at an incident angle θ1 such that θmin ≤ θ1. Therefore almost no excitation light incident on wavelength-selecting reflective layer 53 light-incident surface 53a is reflected by light-incident surface 53a, but it is transmitted through wavelength-selecting reflective layer 53 and incident inside phosphor layer 52.

[0070]

The minimum incident angle θmin of excitation light incident on wavelength-selecting reflective layer 53 through pickup optics 40 is, for example, 45 degrees. For light with a wavelength of around 450 nm, for example, wavelength-selecting reflective layer 53 is designed to transmit the component traveling at an incident angle greater than the minimum incident angle θmin and reflect the component traveling at an incident angle less than minimum incident angle θmin.

[0071]

Fig. 6 shows an example of the relationship between wavelength and transmittance of incident light when the incident angle is varied. Fig. 7 illustrates cutoff wavelengths.

[0072]

When wavelength characteristics and the incident angle of the wavelength-selecting reflective layer 53 have been determined, the cutoff wavelength is the wavelength at which the transmittance of light incident on wavelength-selecting reflective layer 53 begins to diminish relative to changes in the wavelength of said light. In the present embodiment, it is the wavelength at which the transmittance of light incident on wavelength-selecting reflective layer 53 begins to decrease relative to a reduction in the wavelength of said light, in the vicinity of 450 nm. As shown in Fig. 7, when the relationship between wavelength and transmittance is represented for light incident on the wavelength-selecting reflective layer 53 at a particular incident angle, the cutoff wavelength λc is the wavelength at which, when the part S1, where transmittance decreases at a predetermined slope relative to a decrease in wavelength along said slope, is stretched along said slope, transmittance reaches virtually 100%. For light incident at such an incident angle, a transmittance close to 100%, e.g., 95%, is obtained when the wavelength is longer than the cutoff wavelength λc. As the wavelength becomes shorter than the cutoff wavelength λc, on the other hand, transmittance decreases and reflectance increases.

[0073]

Wavelength-selecting reflective layer 53 has wavelength characteristics such that the cutoff wavelength λc shortens as incident angle increases. For wavelength-selecting reflective layer 53, the cutoff wavelength λc for light incident at a minimum incident angle θmin is set to the vicinity of 450 nm, which is the wavelength of the excitation light. For this condition, the cutoff wavelength λc for light incident on wavelength-selecting reflective layer 53 at an incident angle greater than the minimum incident angle θmin is shorter than the wavelength of the excitation light. For example, the wavelength-selecting reflective layer 53 cutoff wavelength λc is set to 490 nm for an incident angle of 0 degrees (vertical incidence), 460 nm for an incident angle of 30 degrees, and 450 nm for an incident angle of 45 degrees.

[0074]

For a 450 nm excitation light , wavelength-selecting reflective layer 53 is set so that the cutoff angle θc is slightly smaller than the minimum incident angle of θmin. "Cutoff angle θc" here is the incident angle at which transmittance begins to diminish relative to a decrease in incident angle when wavelength characteristics and the incident light wavelength are determined for wavelength-selecting reflective layer 53. I.e., cutoff angle θc is the incident angle that serves as the boundary between transmission and reflection of excitation light incident on wavelength-selecting reflective layer 53. For example, if the minimum incident angle θmin is 45 degrees, the cutoff angle is set to around 40 degrees. Of the excitation light incident at an incident angle greater than cutoff angle θc, wavelength-selecting reflection layer 53 transmits the component of excitation light incident at an incident angle greater than the cutoff angle θc. Note that wavelength-selecting reflective layer 53 is designed to reflect at wide incident angles relative to fluorescence wavelengths of 490 nm.

[0075]

Almost of all of the approx. 450 nm wavelength excitation light L1 incident on wavelength-selecting reflective layer 53 through pickup optics 40 passes through wavelength-selecting reflective layer 53 when incident on wavelength-selecting reflective layer 53 at an incident angle greater than 45 degrees, which is the minimum incident angle θmin. A part of excitation light L1 transmitted through wavelength-selecting reflective layer 53 and incident on phosphor layer 52 is converted to fluorescence L2. Fluorescence L2 generated by phosphor layer 52 is scattered around the emission position.

[0076]

Of the fluorescence L2, the component scattered by phosphor layer 52 and traveling toward wavelength-selecting reflective layer 53 is transmitted through wavelength-selecting reflective layer 53 and emitted to the outside. The component traveling toward reflector 51 is reflected by the surface of reflector 51. Fluorescence L2, reflected by the surface of reflector 51, travels toward wavelength-selecting reflective layer 53 and is emitted to the outside.

[0077]

The component of excitation light L1 incident on phosphor layer 52 that is not converted into fluorescence L2 is scattered by phosphor layer 52. Of the excitation light L1, the component which is scattered by phosphor layer 52 which travels toward wavelength-selecting reflective layer 53 and is incident on wavelength-selecting reflective layer 53 at an incident angle θ2 such that θ2 < θmin, is reflected by wavelength-selecting reflective layer 53. Excitation light L1 reflected by wavelength-selecting reflective layer 53 travels through the interior of phosphor layer 52 toward reflector 51. A portion of excitation light L1 traveling through the interior of phosphor layer 52 is converted to fluorescence L2. The component converted into fluorescence L2 and the component remaining as excitation light L1 are respectively scattered by phosphor layer 52.

[0078]

Of the scattered fluorescence L2, the component that travels toward wavelength-selecting reflective layer 53 is emitted to the outside. The component that travels toward reflector 51 is reflected by the surface of reflector 51, travels toward wavelength-selecting reflective layer 53, and is emitted to the outside. On the other hand, the component of scattered excitation light L1 that travels toward wavelength-selecting reflective layer 53 and is incident on wavelength-selecting reflective layer 53 at an incident angle θ2 such that θ2 < θmin is reflected by wavelength-selecting reflective layer 53 and travels through the interior of phosphor layer 52 toward reflector 51.

[0079]

Of the excitation light L1, the component scattered by phosphor layer 52 which travels toward wavelength-selecting reflective layer 53 and is incident on wavelength-selecting reflective layer 53 at an incident angle θ2 such that θ min ≤ θ2 transmits through wavelength-selecting reflective layer 53. Almost all of the excitation light L1 transmitted through wavelength-selecting reflective layer 53 is emitted to the outside without being captured by pickup optics 40.

[0080]

Using the light source device 100A of the present embodiment, excitation light L1 scattered without being converted into fluorescence in phosphor layer 52 (excitation light L1 reflected by reflector 51) is incident on wavelength-selecting reflective layer 53. Excitation light L1 incident from phosphor layer 52 on wavelength-selecting reflective layer 53 at an incident angle outside a predetermined range of incident angles (such that θ2 < θmin) is reflected by wavelength-selecting reflective layer 53 and used to excite fluorescence L2 inside phosphor layer 52. I.e., at least a portion of the excitation light L1 that travels from phosphor layer 52 back to wavelength-selecting reflection layer 53 can be effectively used to excite fluorescence L2. The luminous efficiency of the phosphor can thus be improved.

[0081]

A highly efficient light source can be achieved with this constitution, since multiple laser beams are focused and irradiated onto phosphor layer 52. Also, because the optical path of the multiple laser beams incident on the periphery of condensing lens 23 is bent, [this arrangement] is suitable when using a wavelength-selecting reflective layer 53 that transmits excitation light incident at a wide angle.

[0082]

Also, with this configuration multiple laser light sources 12 are disposed in a ring shape in a laser light source array, therefore multiple laser beams are incident on only the periphery of condensing lens 23. This therefore further satisfies of the incident angle condition for excitation light L1 to pass through wavelength-selecting reflective layer 53.

[0083]

Also, with this constitution the spreading of excitation light L1 reflected by wavelength-selecting reflection layer 53 and returning to phosphor layer 52 can be suppressed compared to a constitution in which wavelength-selecting reflection layer 53 is disposed at a distance from phosphor layer 52. Therefore excitation light L1 traveling in a direction returning to the phosphor layer 52 can be made incident on phosphor layer 52, thereby improving the luminous efficiency of the phosphor.

[0084]

The projector PJ of the present embodiment comprises the light source device 100A described above, therefore a projector P capable of efficiently obtaining bright images with high quality can be obtained.

[0085]

Note also that in the present embodiment, wavelength-selecting reflection layer 53 is formed on the surface of phosphor layer 52 (the side of the phosphor layer 52 opposite reflector 51), but is not limited thereto. For example, wavelength-selecting reflection layer 53 may be disposed on the optical path between light source portion 10A and phosphor layer 52 (specifically, on the optical path between pickup optics 40 and phosphor layer 52).

[0086]

(First Variation of the First Embodiment)

Fig. 8 is a front view of a first variation of the excitation light source provided by the light source device of the first embodiment. Fig. 9 is a side view of a first variation of the light source device of the first embodiment.

[0087]

Light source device 100A1 of this variation differs from the light source device 100A of the first embodiment described above in that it has a light source portion 10A1 instead of the above-described light source portion 10A. Other points are the same as in the above-described constitution, therefore the same symbols are applied to the same elements as those in Figs. 1 to 3, and a detailed description thereof is omitted.

[0088]

As shown in Fig. 8, light source portion 10A1 is a laser light source array in which laser light sources 12 are arranged in a two-dimensional array of 6 x 6 squares (36 total) on a base 11.

[0089]

As shown in Fig. 9, of the multiple laser light sources 12 in light source portion 10A1, the laser light sources 12 disposed at the center of the base 11 emit excitation light in a direction diagonal to the normal of the plane in which the multiple laser light sources 12 are disposed. For example, of the 36 laser light sources 12 arranged on base 11, the 12 laser light sources 12 disposed at the center of base 11 are tilted relative to the top surface of base 11 so that the main beam of laser light flux emitted from said laser light sources 12 passes through the periphery of condensing lens 23. On the other hand, the 24 laser light sources 12 disposed at the center of base 11 are in the same arrangement as in the first embodiment described above. Excitation light emitted from light source portion 10A1 is collimated by collimator lens array 21 incorporated in light source portion 10A1, focused by condensing lens 23, then transmitted through collimating lens 25 to narrow the overall beam flux of the excitation light.

[0090]

Using this variation of light source device 100A1, almost all of the laser light emitted from the multiple laser light sources 12 disposed in the laser light source array can be made incident on only the periphery of condensing lens 23. A highly efficient light source can thus be achieved while effectively utilizing multiple laser beams to excite fluorescence.

[0091]

(Second Variation of the First Embodiment)

In the light source device of the present variation, the above-described light source portion 10A comprises a laser light source 12 emitting a laser light of a relatively short wavelength as excitation light and a laser light source 12 emitting a laser light of a relatively long wavelength as an excitation light. The light source portion in the present variation makes the short wavelength laser light incident on wavelength-selecting reflective layer 53 at a greater incident angle than the long wavelength light. For example, the laser light sources 12 disposed relatively to the outside on base 11 (e.g., the laser light sources 12 disposed at the four corners) emit a laser beam of a shorter wavelength (e.g., 445 nm) than the reference wavelength light (e.g., 450 nm) as an excitation light. On the other hand, the laser light source 12 disposed relatively toward the inside of base 11 emit a longer wavelength light (e.g., 455 nm) than the reference wavelength light as the excitation light.

[0092]

In the region where the switch between transmissivity and reflectivity occurs, wavelength-selecting reflective layer 53 has wavelength characteristics such that longer light wavelengths transmits through [it] more easily than shorter light wavelengths for light incident at the same incident angle. It also has the characteristic that for light of the same wavelength, light with a large incident angle is more easily transmitted than light with a small incident angle. I.e, in some cases light with a wavelength not transmitted at a certain incident angle may be transmitted if the incident angle is increased. Therefore if short wavelength-emitting laser light sources 12 are disposed outside base 11 and long wavelength-emitting laser light sources 12 are disposed inside base 11, both laser lights can be transmitted through wavelength-selecting reflection layer 53 and made incident on phosphor layer 52. Multiple laser light can thus be effectively used to excite fluorescence.

[0093]

(Second Embodiment)

Fig. 10 is a front view showing an excitation light source portion 10A2 provided in a light source device 100A2 according to a second embodiment.

Fig. 11 is a side view of light source device 100A2 according to a second embodiment.

[0094]

Light source device 100A2 of the present embodiment differs from the light source device 100A of the first embodiment described above in that it is equipped with a light source portion 10A2 instead of the light source portion 10A described above, and a light emitting element 50A emitting red light instead of the light emitting element 50 described above. Other points are the same as in the above-described constitution, therefore the same symbols are applied to the same elements as those in Figs. 1 to 7, and a detailed description thereof is omitted. Although not shown in the figure, the light emitting element having a phosphor layer which emits green light fluorescence is disposed separately from light emitting device 50A which emits red light fluorescence. The light emitting element emitting green light fluorescence illuminates the liquid crystal light valve 300G.

[0095]

As shown in Fig. 10, the light source portion 10A2 is a laser light source array in which multiple laser light sources 12 (12 total) are disposed on a base 11. In light source portion 10A2, the multiple laser light sources 12 are arranged in the center of base 11, excluding the four corners.

[0096]

Fig. 11 is a side view of light source unit 100A2. In Fig. 11, the focusing optics 60, polarized light conversion element 70, rod integrator 80, and collimating lens 90 are omitted from the figure for convenience.

[0097]

As shown in Fig. 11, excitation light emitted from light source portion 10A2 is collimated by a collimator lens array 21 incorporated in light source portion 10A2, focused by condensing lens 23, then transmitted through collimating lens 25 to narrow the overall light beam flux of the excitation light. Condensing lens 23 causes the multiple laser beams incident on the center of said condensing lens 23 to be incident on wavelength-selecting reflective layer 53. Excitation light is focused onto wavelength-selecting reflective layer 53 at a relatively small incident angle.

[0098]

Fig. 13 is a schematic diagram showing excitation light incident on phosphor layer 52A, and scattering of fluorescence and excitation light by phosphor layer 52A.

[0099]

As shown in Fig. 13, light emitting element 50A has a flat reflector 51, a phosphor layer 52A formed on the excitation light incident side surface of reflector 51, and a wavelength-selecting reflective layer 53A disposed on the opposite side of phosphor layer 52A from reflector 51.

[0100]

Phosphor layer 52A is a sintered body of glass powder and phosphor powder. Phosphor layer 52A is attached to the top surface of reflector 51. A YAG (yttrium aluminum garnet) phosphor may be used, for example, as the phosphor constituting phosphor layer 52A.

[0101]

Phosphor emits fluorescence in the wavelength region of approximately 550 nm to 750 nm, centered around 620 nm (see Fig. 12). This fluorescence includes R light in the wavelength region centered around 630 nm. Light source device 100A2 emits fluorescence L2 including R light.

[0102]

Wavelength-selecting reflective layer 53A is, for example, a dielectric multilayer film. Wavelength-selecting reflective layer 53A has a layer structure of 40 to 50 layers with, for example, TiO_2 as a high refractive index material, SiO_2 as a low refractive index material, and optical glass such as BK7 as a substrate.

[0103]

Wavelength-selecting reflective layer 53A transmits fluorescence L2 emitted from phosphor layer 52. Of the excitation light L1 emitted from the light source portion 10A, wavelength-selecting reflective layer 53A transmits light incident at a predetermined incident angle on wavelength-selecting reflective layer 53A.

[0104]

The angle between the normal of the light incident surface 53Aa on the opposite side of the wavelength-selecting reflective layer 53A from phosphor layer 52 and the main beam of the excitation light flux incident on light incident surface 53Aa is the incident angle θ1, and the maximum incident angle among the incident angles θ1 is θmax. "Maximum incident angle" here is the incident angle of excitation light incident on light-incident surface 53Aa which, among the multiple excitation light rays entering light-incident surface 53Aa, is furthest apart from the normal of light-incident surface 53Aa (the incident angle of the beam incident on light-entering surface 53Aa which, among the multiple beams constituting the light flux of excitation light incident on light-entering surface 53Aa, is furthest apart from the normal of the light-entering surface 53Aa).

[0105]

Wavelength-selecting reflection layer 53A transmits excitation light incident on wavelength-selecting reflection layer 53A at an incident angle θ1 whereby θ1 ≤ θmax. Wavelength-selecting reflective layer 53A reflects excitation light incident on wavelength-selecting reflective layer 53A from phosphor layer 52A at an incident angle θ2 such that θ2 > θmax, from among the excitation light incident inside phosphor layer 52A, scattered by phosphor layer 52A, and incident on the side opposite light input surface 53Aa.

[0106]

Note that wavelength-selecting reflective layer 53A has the function of reflecting the excitation light incident on wavelength-selecting reflective layer 53A at an incident angle θ1 where θ1 > θmax. In the present embodiment a constitution is adopted in which excitation light is incident on wavelength-selecting reflective layer 53A at an incident angle θ1 where θ1≤θmax. Therefore almost no excitation light incident on light-incident surface 53Aa of wavelength-selecting reflecting layer 53A is reflected by light-incident surface 53Aa, [rather] it is transmitted through wavelength-selecting reflecting layer 53A and made incident inside fluorescent material layer 52A.

[0107]

The maximum incident angle θmax of excitation light passing through pickup optics 40 and incident on wavelength-selecting reflective layer 53A is, for example, 10 degrees. For light with a wavelength near 450 nm, for example, wavelength-selecting reflective layer 53A is designed, for example, to transmit the component traveling at an incident angle smaller than the maximum incident angle θmax and reflect the component traveling at an incident angle larger than the maximum incident angle θmax.

[0108]

Fig. 14 shows an example of the relationship between the wavelength and transmittance of incident light when the incident angle is varied.

[0109]

Wavelength-selecting reflective layer 53A has a wavelength characteristic such that cutoff wavelength λc increases as incident angle decreases. The cutoff wavelength in the present embodiment is around 450 nm, which is the wavelength at which the transmittance of light incident on wavelength-selecting reflective layer 53A begins to decrease with an increase in the wavelength of said light. In wavelength-selecting reflective layer 53A, the cutoff wavelength λc for light incident at the maximum incident angle θmax is set around 450 nm, which is the excitation light wavelength. Under this condition, the cutoff wavelength λc for light incident on wavelength-selecting reflective layer 53A at an incident angle smaller than the maximum incident angle θmax is longer than the excitation light wavelength. For example, the cutoff wavelength λc of wavelength-selecting reflective layer 53A is set to 470 nm when the incident angle is 0 degrees (vertical incidence), 450 nm when the incident angle is 13 degrees, and 425 nm when the incident angle is 45 degrees.

[0110]

Wavelength-selecting reflective layer 53A is set so that cutoff angle θc is slightly larger than the maximum incident angle θmax for excitation light at 450 nm. "Cutoff angle θc" here means the incident angle at which, when wavelength-selecting reflective layer 53A wavelength characteristics and the wavelength of incident light have been determined, transmittance begins to decrease with increasing incident angle. I.e., cutoff angle θc is the incident angle that serves as the boundary between transmission and reflection of excitation light incident on wavelength-selecting reflective layer 53A. For example, if the maximum incident angle θmax is 10 degrees, the cutoff angle θc is set to around 13 degrees. Of the excitation light incident at an incident angle smaller than the cutoff angle θc, wavelength-selecting reflection layer 53A transmits the component incident at an incident angle θ1 smaller than the maximum incident angle θmax. At wavelengths above the fluorescence wavelength of 550 nm, wavelength-selecting reflective layer 53A is designed to reflect at a wide incident angle.

[0111]

After passing through pickup optics 40 and becoming incident on wavelength-selecting reflective layer 53A, excitation light at a wavelength of around 450nm, by being incident on wavelength-selecting reflective layer 53A at an incident angle smaller than 10 degrees, which is the maximum incident angle θmax, is almost completely transmitted through wavelength-selecting reflective layer 53A. Part of excitation light L1 transmitted through wavelength-selecting reflective layer 53A and incident on phosphor layer 52A is converted to fluorescence L2. Fluorescence L2 generated by phosphor layer 52A is scattered around the emission position.

[0112]

The component of fluorescence L2 which is scattered by phosphor layer 52A and travels toward wavelength-selecting reflective layer 53A is transmitted through wavelength-selecting reflective layer 53A and emitted to the outside. The component which travels toward reflector 51 is reflected by the surface of reflector 51. Fluorescence L2 reflected on the surface of the reflector 51 travels toward wavelength-selecting reflective layer 53A and is emitted to the outside.

[0113]

The component of excitation light L1 incident on phosphor layer 52A not converted into fluorescence L2 is scattered by phosphor layer 52A. The component of excitation light L1 scattered by phosphor layer 52A directed toward wavelength-selecting reflective layer 53A and incident on wavelength-selecting reflective layer 53A at an incident angle θ2 such that θ2 > θmax is reflected by wavelength-selecting reflective layer 53A. Excitation light L1 reflected by wavelength-selecting reflective layer 53A travels inside [through] phosphor layer 52A toward reflector 51. A portion of excitation light L1 traveling inside phosphor layer 52A is converted into fluorescence L2. The component converted into fluorescence L2 and the component remaining as excitation light L1 are respectively scattered by phosphor layer 52A.

[0114]

Of the scattered fluorescence L2, the component that has traveled toward wavelength-selecting reflective layer 53A is emitted to the outside. The component that travels toward reflector 51 is reflected by the surface of reflector 51 and travels toward wavelength-selecting reflective layer 53A to be emitted to the outside. On the other hand, the component of the scattered excitation light L1 that travels toward wavelength-selecting reflective layer 53A and is incident on wavelength-selecting reflective layer 53A at the incident angle θ2 such that θ2 > θmax is reflected by wavelength-selecting reflective layer 53A and travels inside phosphor layer 52A toward reflector 51.

[0115]

Using the light source device 100A2 of the present embodiment, excitation light L1 which is scattered without being converted into fluorescence by phosphor layer 52A (excitation light L1 reflected by reflector 51), is incident on wavelength-selecting reflection layer 53A . Excitation light L1 incident on wavelength-selecting reflection layer 53A from phosphor layer 52A at an incident angle outside a predetermined incident angle range (an incident angle such that $\theta2 > \theta max$) is reflected by wavelength-selecting reflection layer 53A and used to excite fluorescence L2 inside phosphor layer 52A. I.e., at least a portion of the excitation light L1 that travels from phosphor layer 52A back to wavelength-selecting reflection layer 53A can be effectively used to excite fluorescence L2. The luminous efficiency of the phosphor can thus be improved.

[0116]

Also, using this constitution multiple laser beams are focused and irradiated on phosphor layer 52A, enabling the achievement of a highly efficient light source. Since the multiple laser beams incident on the central portion of condensing lens 23 are made incident on wavelength-selecting reflection layer 53A, this [constitution] is suitable for use with a wavelength-selecting reflection layer 53A that transmits excitation light incident at an angle close to perpendicular.

[0117]

Also, using this constitution, because the excitation light is blue light and the fluorescence is red light, there is a large difference between excitation light peak wavelength and fluorescence excitation light compared to the case when the fluorescence is green light. Wavelength-selecting reflective layer 53A can therefore be constituted so that fluorescence at a wavelength different from excitation light is transmitted, and excitation light incident at an incident angle outside a predetermined incident angle range (such that $\theta2 > \theta max$) is reflected.

[0118]

Also, using this constitution the laser light sources 12 can be concentrated at the center of the laser light source array so that light source portion 10A2 can be reduced in size.

[0119]

(First Variation of the Second Embodiment)

Fig. 15 is a front view showing a first variation of an excitation light source provided in a light source device pertaining to a second embodiment.

Fig. 16 is a side view showing a first variation of a light source device pertaining to a second embodiment.

[0120]

Light source device 100A3 in this variation differs from light source device 100A2 of the second embodiment described above in that it is equipped with a light source unit 10A3 instead of the light source unit 10A2 described above. Other points are the same as in the above-described constitution, therefore the same symbols are applied to the same elements as those in Figs. 10 and 11, and a detailed description thereof is omitted.

[0121]

As shown in Fig. 15, the light source unit 10A3 is a laser light source array in which six laser light sources 12 are arranged in a two-dimensional array (total 36) in a square shape on base 11.

[0122]

As shown in Fig. 16, of the multiple laser light sources 12 in light source portion 10A3, laser light sources 12 disposed on the outer circumference of base 11 emit excitation light in a direction diagonal to the normal of the plane on which the multiple laser light sources 12 are arranged. For example, of the 36 laser light sources 12 arranged on base 11, the 24 laser light sources 12 disposed on the outer circumference of base 11 are inclined relative to the top surface of base 11 so that the main beam of the laser light emitted from said laser light sources 12 passes through the center of condensing lens 23. At the same time, the 12 laser light sources 12 disposed at the center of base 11 are in the same arrangement as described above for the second embodiment. Excitation light emitted from light source portion 10A3 is collimated by collimator lens array 21 incorporated in light source portion 10A3, then passes through collimating lens 25, so that the excitation light flux as a whole is narrowed.

[0123]

Using this variation of light source device 100A3, it is possible to make almost all of the laser light emitted from the multiple laser light sources 12 arranged in the laser light source array incident on the center portion of condensing lens 23. A high-efficiency light source can thus be achieved while effectively using multiple laser beams to excite fluorescence.

[0124]

(Second Variation of the Second Embodiment)

In the above-described light source portion 10A2, the light source device of the present variation comprises laser light sources 12 that emit a relatively short wavelength laser light as an excitation light, and laser light sources 12 that emit a relatively long wavelength laser light as an excitation light. In the light source portion of this variant, the laser light sources 12 disposed on the outside base 11 emit a shorter wavelength light (e.g. 445 nm) than the reference wavelength (e.g. 450 nm) as excitation light. At the same time, laser light sources 12 disposed relatively to the inside of base 11(e.g., four laser light sources arranged in the center) emit longer wavelength laser light (e.g., 455 nm) than the reference wavelength as the excitation light.

[0125]

Wavelength-selecting reflective layer 53A has wavelength characteristics such that in the region where the characteristics of transmission and reflection switch, for light incident at the same incident angle, shorter wavelengths transmit more readily than longer wavelengths. It also has wavelength characteristics such that for the same wavelength of light, light at a smaller incident angle transmits more readily than light at a larger incident angle. I.e., even if a [particular] wavelength of light does not transmit at a certain incident angle, it may transmit if the incident angle is reduced. Thus by disposing laser light sources 12 which emit short-wavelength light toward the outside of base 11, and disposing laser light sources 12 that emit long-wavelength light toward the inside of base 11, beams from both lasers can be transmitted through the wavelength-selecting reflective layer 53A and made incident on phosphor layer 52A. Multiple laser light can thus be effectively used to excite fluorescence.

[0126]

(Third Embodiment)

Fig. 17 is a front view of an excitation light source provided in a light source device of a third embodiment.

[0127]

The light source device of the present embodiment differs from the light source device 100A of the above-described first embodiment in that it comprises a light source unit 10A4 instead of the light source unit 10A described above. Other points are the same as in the above-described constitution, therefore the same symbols are applied to the same elements as those in Fig. 2, and a detailed description thereof is omitted.

[0128]

As shown in Fig. 17, light source unit 10A4 is a laser light source array in which multiple (24 total) laser light sources 12A4 are disposed on a base 11. For each laser light source 12A4, the polarization plane is radially aligned with the top surface of base 11. Each laser light source 12A4 emits light that enters the incident surface of the wavelength-selecting reflection layer with P polarization. Note that two-headed arrows in Fig. 17 represent the polarization directions of light emitted from light source portion 10A4.

[0129]

Fig. 18 shows an example of the relationship between transmittance and wavelength of incident light for P-polarized and S-polarized light. Shown here are P-polarized light Lp and S-polarized light Ls incident on the incident surface of a wavelength-selecting reflection layer at a predetermined incident angle (e.g. 45 degrees).

[0130]

The wavelength-selecting reflection layer has the property that S-polarized light is more easily reflected than P-polarized light. The cutoff wavelength θc of the wavelength-selecting reflection layer is longer for P-polarized light than for S-polarized light. The wavelength-selecting reflection layer in this variation is designed with wavelength characteristics that are specialized for P-polarized light.

[0131]

Using the light source device of the present embodiment, making P-polarized light incident on the wavelength-selecting reflection layer as the excitation light facilitates the transmission of excitation light through the wavelength-selecting reflection layer at a wide incident angle. S-polarized light, on the other hand, which is generated by scattering within the phosphor layer, has a shorter cutoff wavelength than P-polarized light, and so is more easily reflected by the wavelength-selecting reflective layer than P-polarized light. The amount of excitation light that scatters within the phosphor layer and passes through the wavelength-selecting reflective layer can thus be reduced. As a result, luminous efficiency of the phosphor can be improved.

[0132]

Note also that light source unit 10A4 is not limited to the case where all of the multiple laser light sources emit P-polarized light. Some light sources emitting non-P-polarized light may be mixed in among the multiple laser light sources.

[0133]

Also, light source portion 10A4 may be applied to constitutions similar to the second embodiment (in which multiple laser light sources are disposed at the center portion of a base), without limitation to constitutions similar to the first embodiment (in which multiple laser light sources are disposed on the outer circumference of a base).

[0134]

The projector is not limited to one using a transmissive liquid crystal light valve as the optical modulation device. A reflective LCOS (Liquid Crystal on Silicon) or DMD (Digital Micro-Mirror Device) device may also be applied for the projector. In addition, scanning optics which scan light modulated in response to an image signal onto the irradiated surface, such as a MEMS mirror, etc., may be applied to the projector.

[0135]

The present invention may be applied to front projection projectors that project images from the observed side, and to rear projection type projectors that project images from the side opposite the observed side.

[0136]

In the above embodiments we have described examples in which the light source device of the present invention is applied to projectors, but [the invention] is not limited thereto. For example, the light source device of the present invention may also be applied to other optical equipment (e.g., optical disk devices, automobile headlamps, lighting equipment, etc.).

[Explanation of Symbols]
[0137]
10A, 10A1, 10A2, 10A3, 10A4: light source portions (excitation light sources)
12, 12A4: laser light sources
23: condensing lens (condensing means)
51: reflector
52, 52A: phosphor layers
53, 53A: wavelength-selecting reflection layers
10 0A, 100A1, 100A2, 100A3: light source devices
400R, 400G, 400B: liquid crystal light valves (light modulation devices)
600: projection optics
L1: excitation light
L2: fluorescence
PJ: projector

θ1, θ2: incident angle

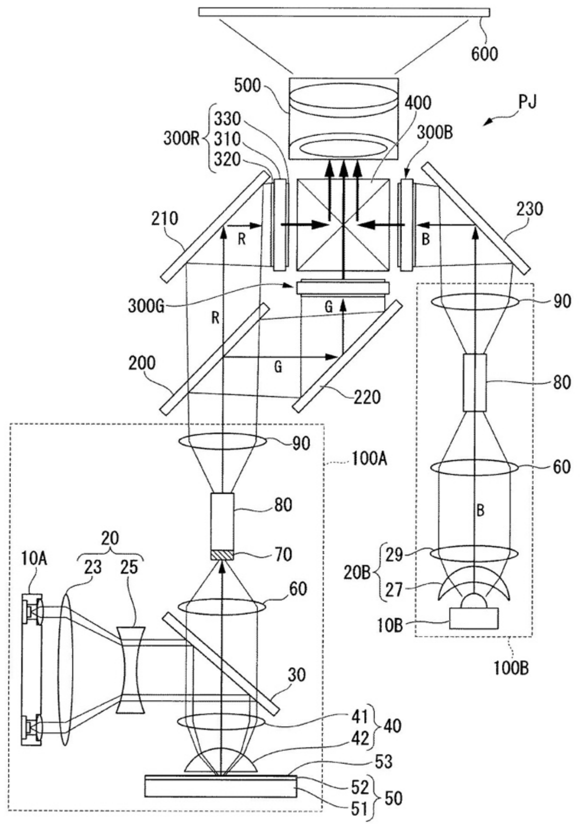


FIG. 1

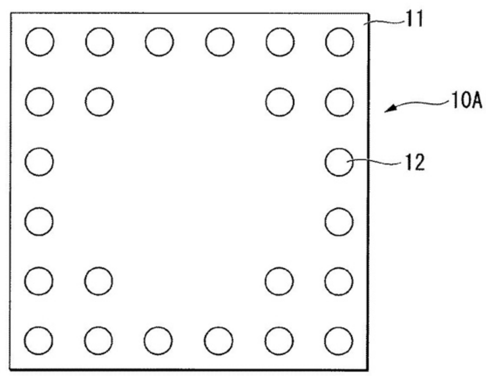


FIG. 2

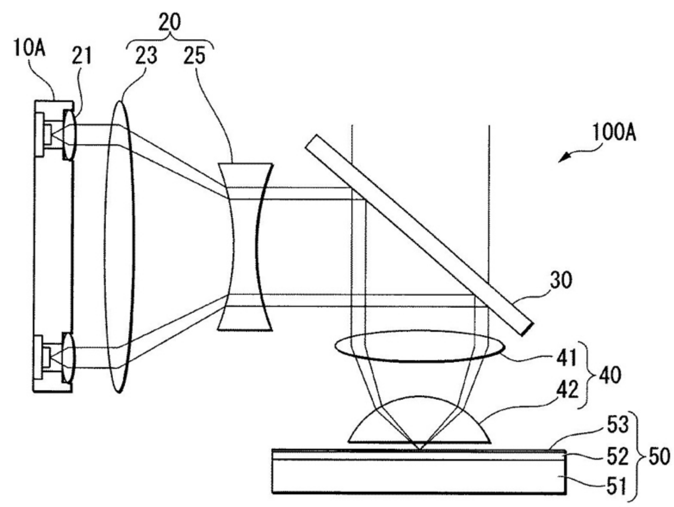


FIG. 3

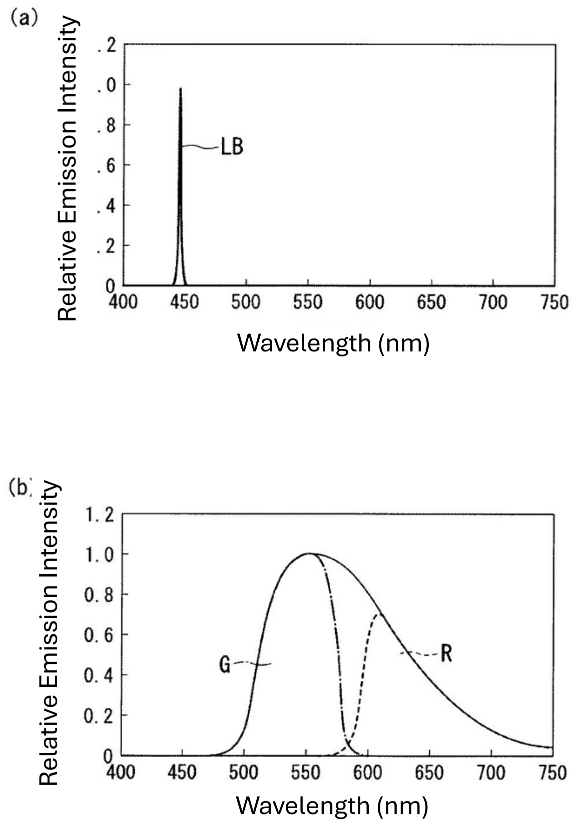

(a)
Relative Emission Intensity
.2
.0
.8
.6
.4
.2
0
400
450
500
550
600
650
700
750
LB
Wavelength (nm)
(b)
Relative Emission Intensity
1.2
1.0
0.8
0.6
0.4
0.2
0
400
450
500
550
600
650
700
750
G
R
Wavelength (nm)

FIG. 4

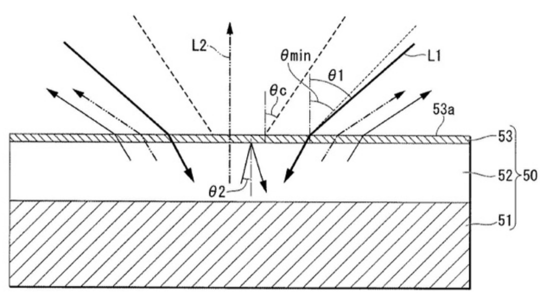
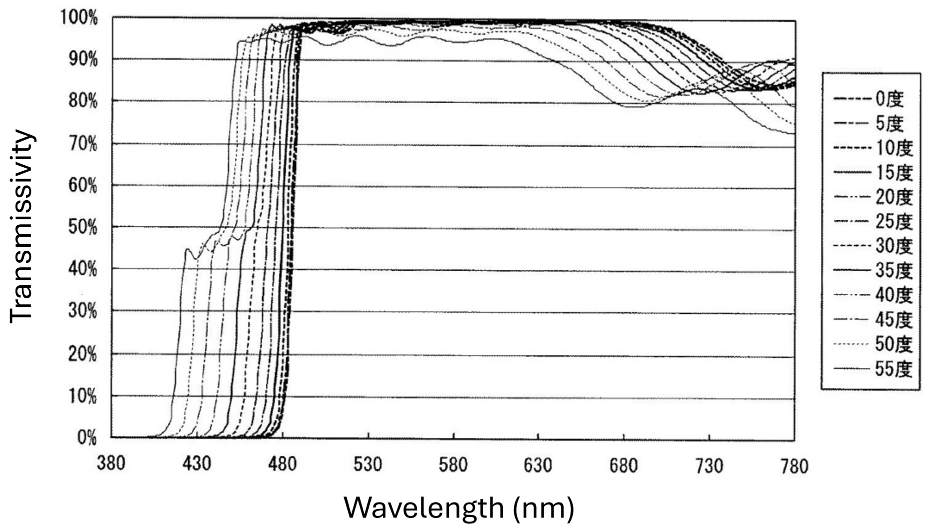
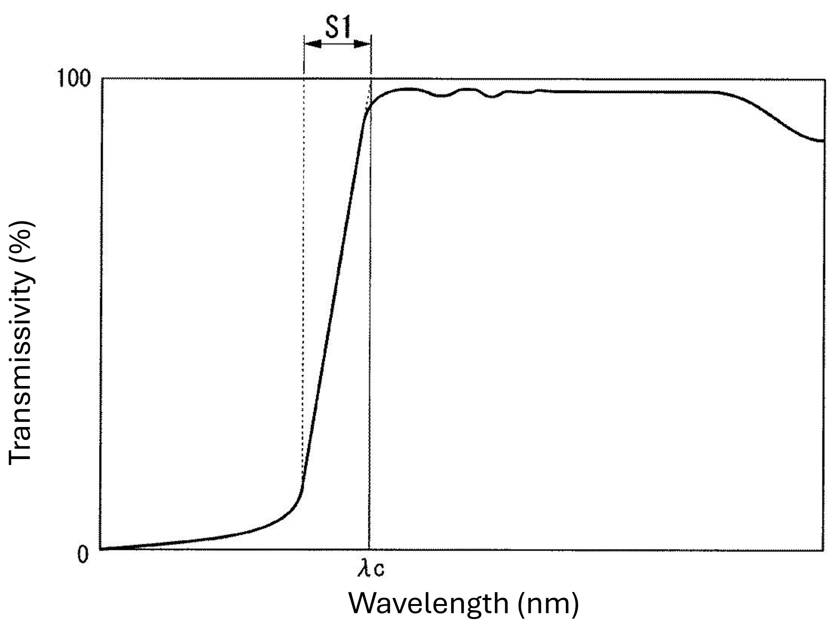

L2
θmin
θ1
L1
θc
53a
53
52
50
51
θ2

FIG. 5



100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Transmissivity
380
430
480
530
580
630
680
730
780
Wavelength (nm)
0度
5度
10度
15度
20度
25度
30度
35度
40度
45度
50度
55度

FIG. 6



S1
100
0
Transmissivity (%)
λc
Wavelength (nm)

FIG. 7

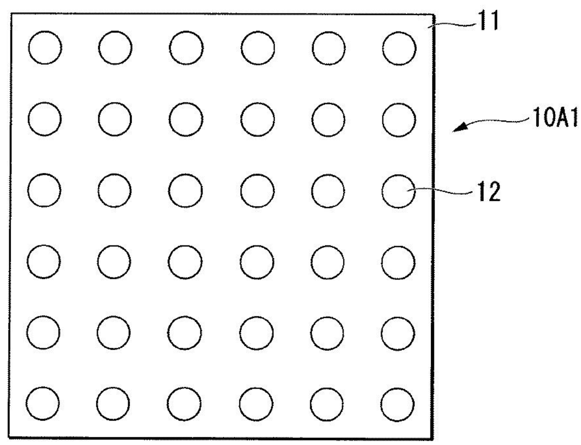


FIG. 8

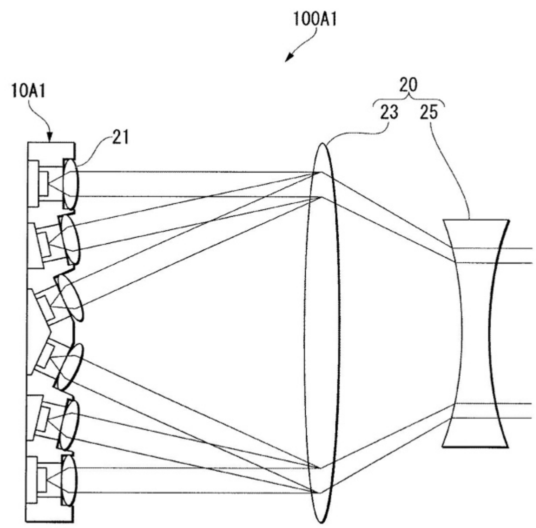


FIG. 9

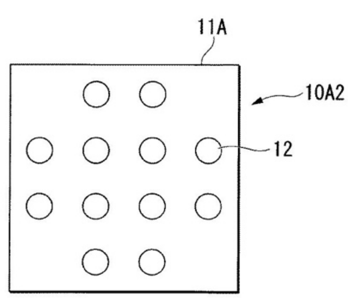


FIG. 10

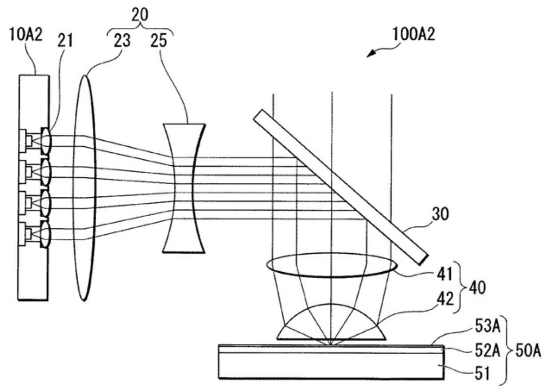


FIG. 11

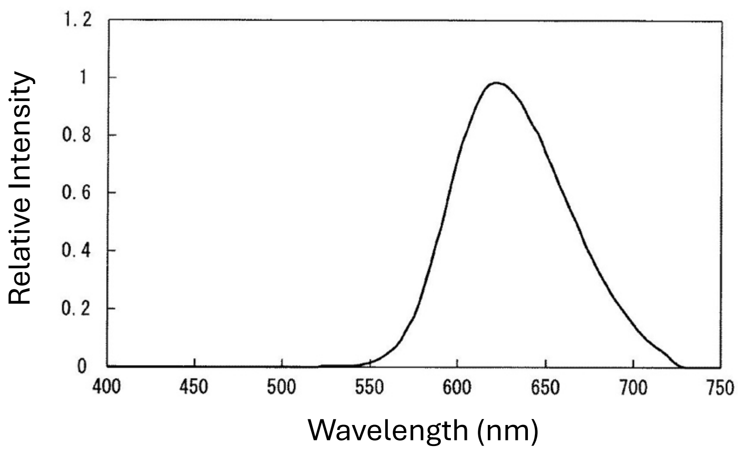


FIG. 12

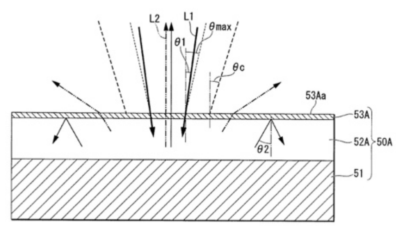


FIG. 13

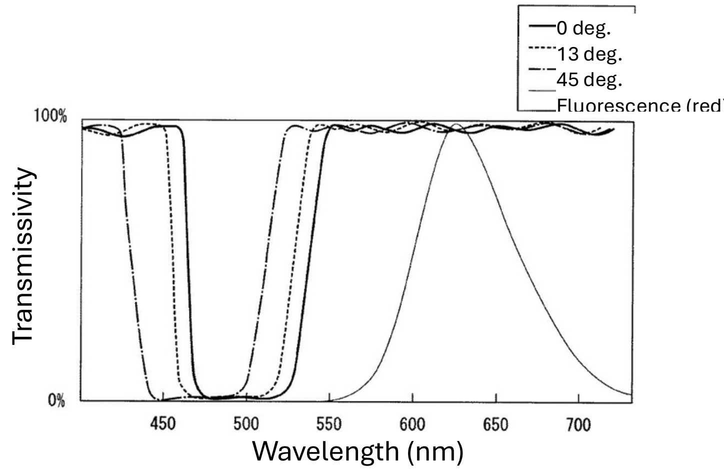


FIG. 14

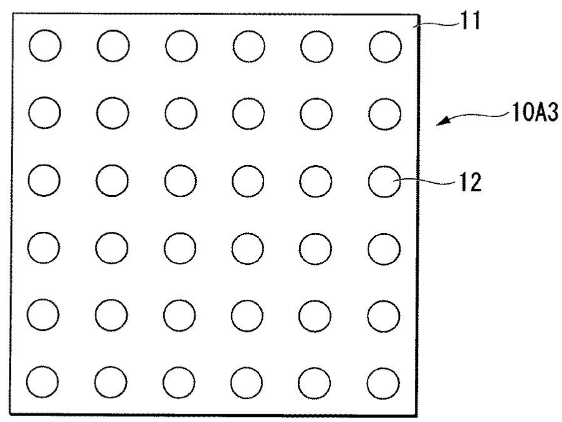


FIG. 15

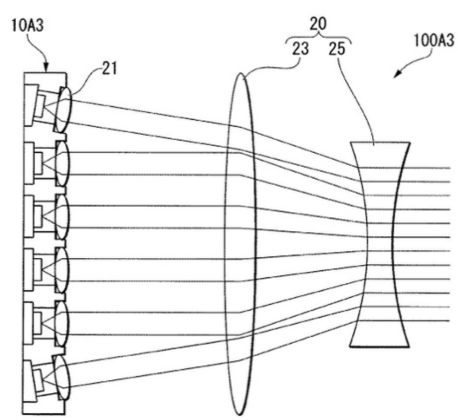


FIG. 16

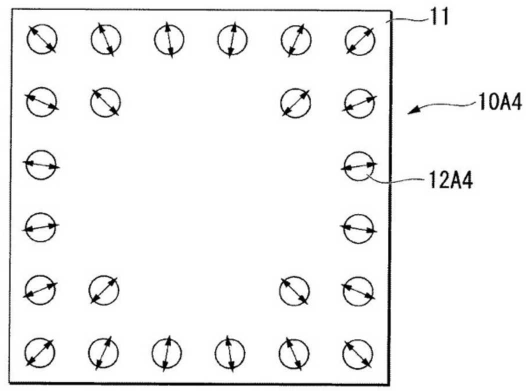


FIG. 17