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(54) **OPTICAL ELEMENT, POLARIZATION ILLUMINATION DEVICE, AND PROJECTOR**

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(Continued)

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(21) Appl. No.: **09/985,390**

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Kunio Yoneno et al., "High Definition Front Projector Using Poly-Si TFT LCD" Conference Record of the 1991 International Display Research Conference, Oct. 15, 1991, pp. 147-150, XP000314344, Abstract, FIG. 1.\*

**Related U.S. Patent Documents**

Reissue of:

(64) Patent No.: **5,978,136**  
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Appl. No.: **08/992,012**  
Filed: **Dec. 17, 1997**

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(30) **Foreign Application Priority Data**

Dec. 18, 1996 (JP) ..... 8-354364

(57) **ABSTRACT**

(51) **Int. Cl.**  
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**G02B 27/28** (2006.01)  
**G03B 21/00** (2006.01)

Two polarization conversion element arrays are disclosed. Each polarization conversion element array is composed of a plurality of polarization conversion elements for converting light incident upon the polarization conversion element array to a linearly polarized light beam with a predetermined polarization direction. The plurality of polarization conversion elements are disposed opposite to each other with a predetermined space provided between at about the center of the light-outgoing surface of a lens array in the direction of arrangement. Of the light beams (s-polarized+p-polarized light beams) gathered by the lens array, light beam that is not incident upon the polarization conversion element and passes through the predetermined space is a light beam including a predetermined polarized light beam (s-polarized light beam) that is primarily made to leave the array 320a and an ineffective polarized light beam (p-polarized light beam). Of the light passing through and leaving the space, the required polarized light beam alone can be made to leave as an effective light beam by providing a polarization plate or the like at the light-outgoing side of the space.

(52) **U.S. Cl.** ..... **359/487**; 359/495; 359/497; 359/250; 359/253; 359/622; 359/627; 359/634; 353/20; 353/31; 353/34; 353/37; 362/19; 349/5

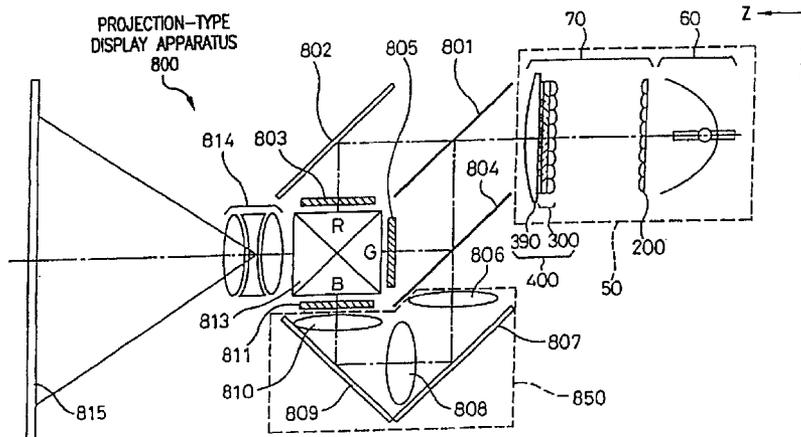
(58) **Field of Classification Search** ..... 359/250, 359/252, 253, 256, 259, 487, 495, 497, 619, 359/621, 622, 626, 627, 629, 634, 638; 362/19; 353/20, 31, 32, 33, 34, 37; 349/5  
See application file for complete search history.

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**24 Claims, 11 Drawing Sheets**



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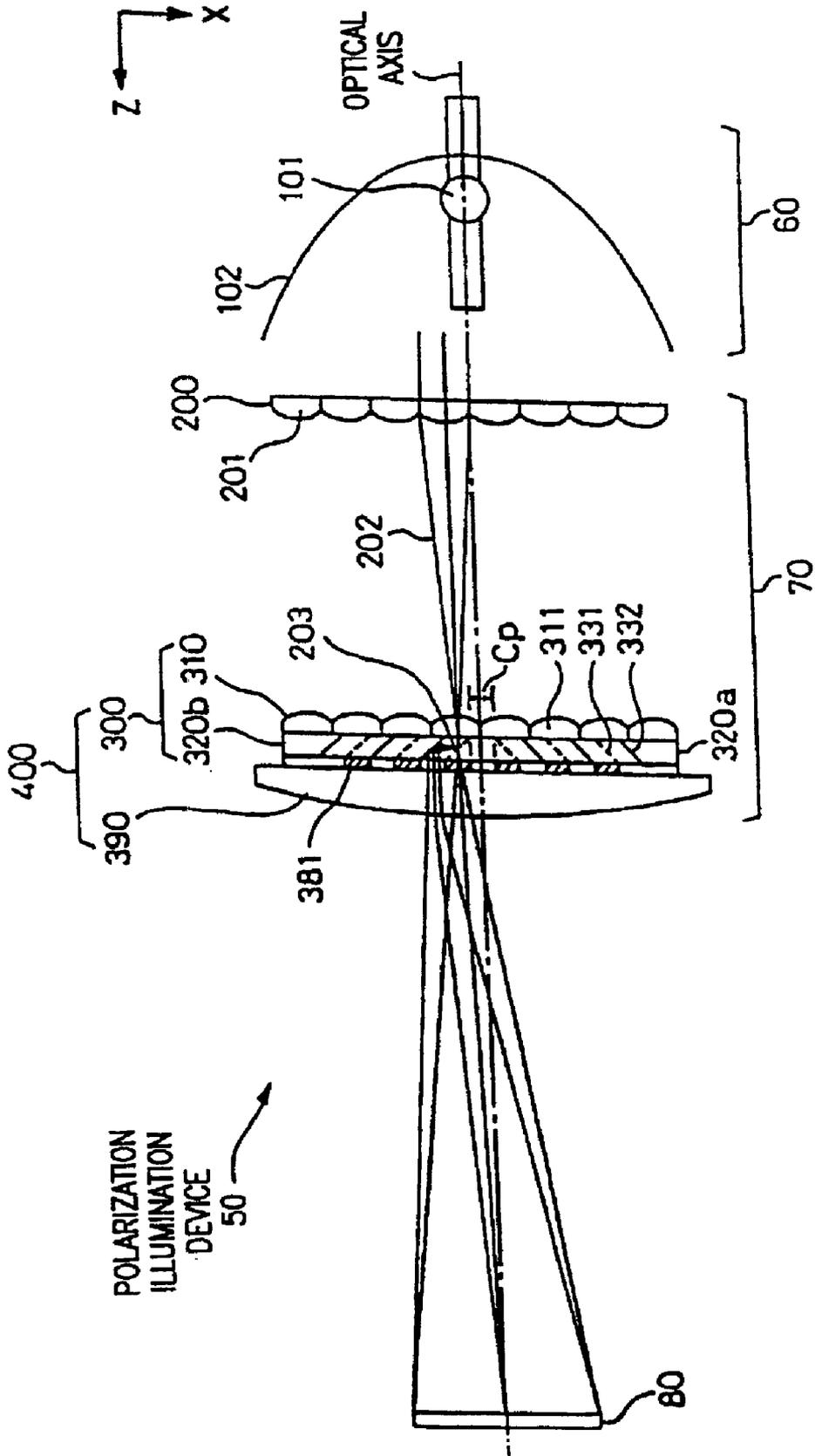


FIG. 1

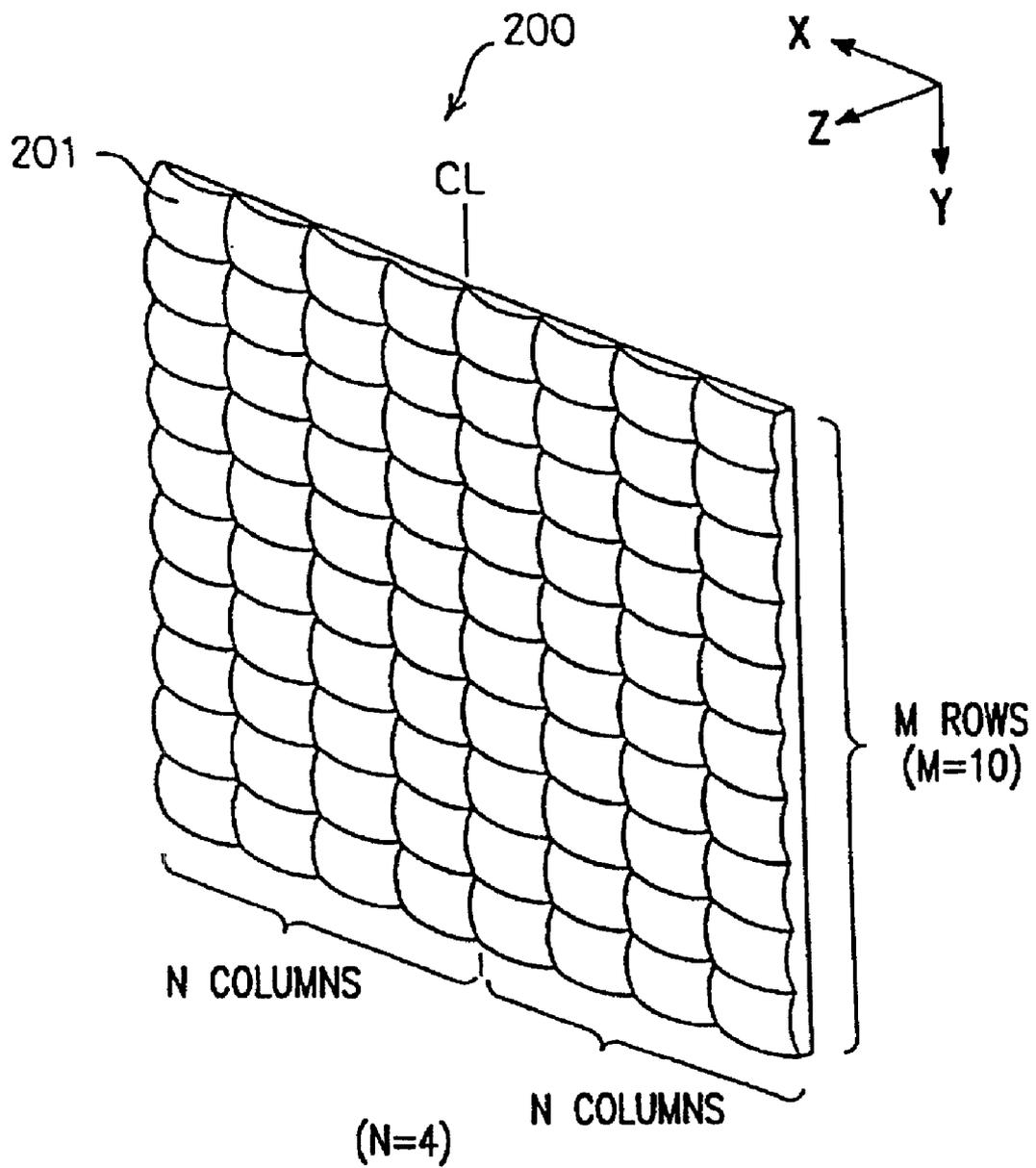


FIG.2

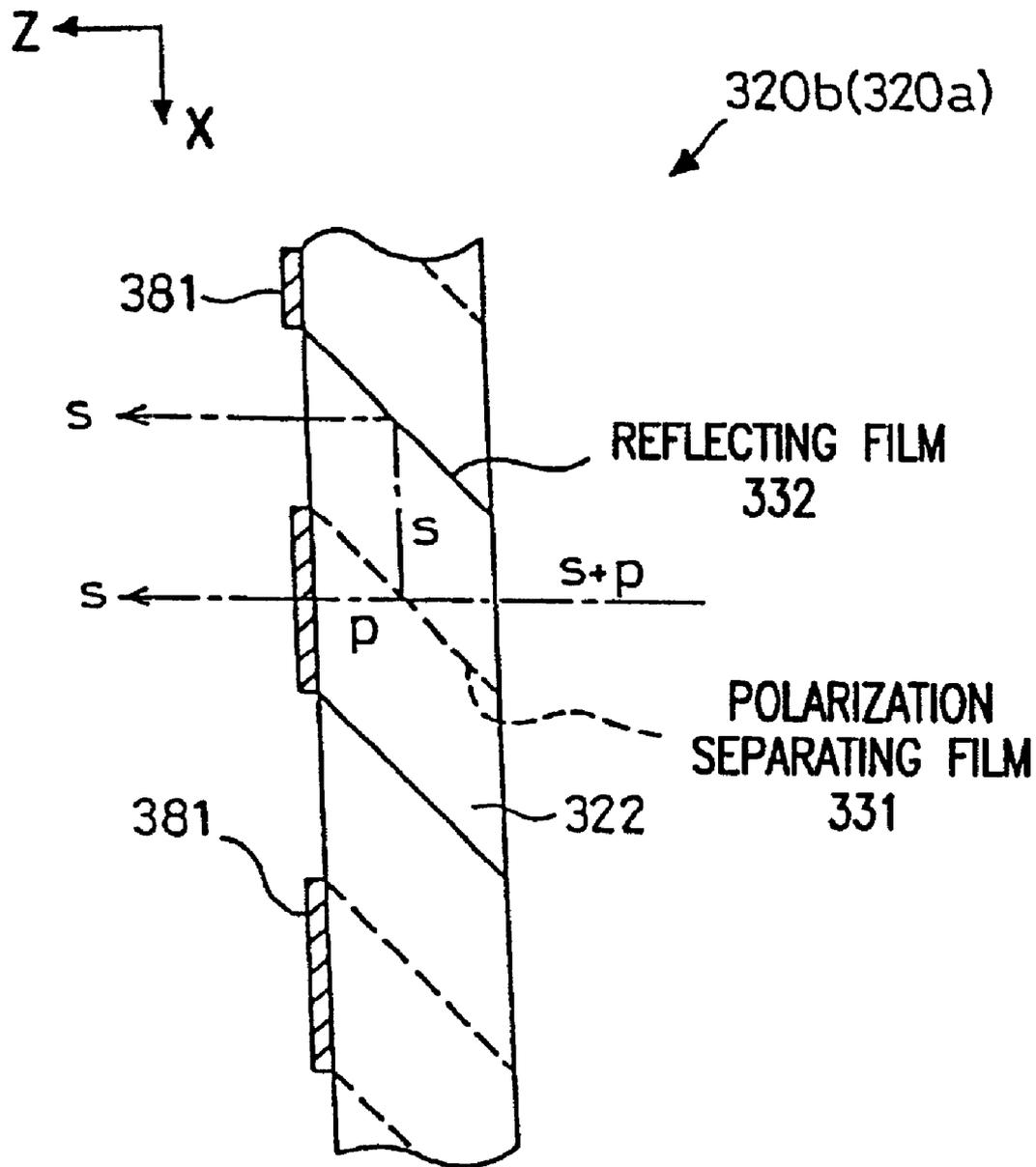
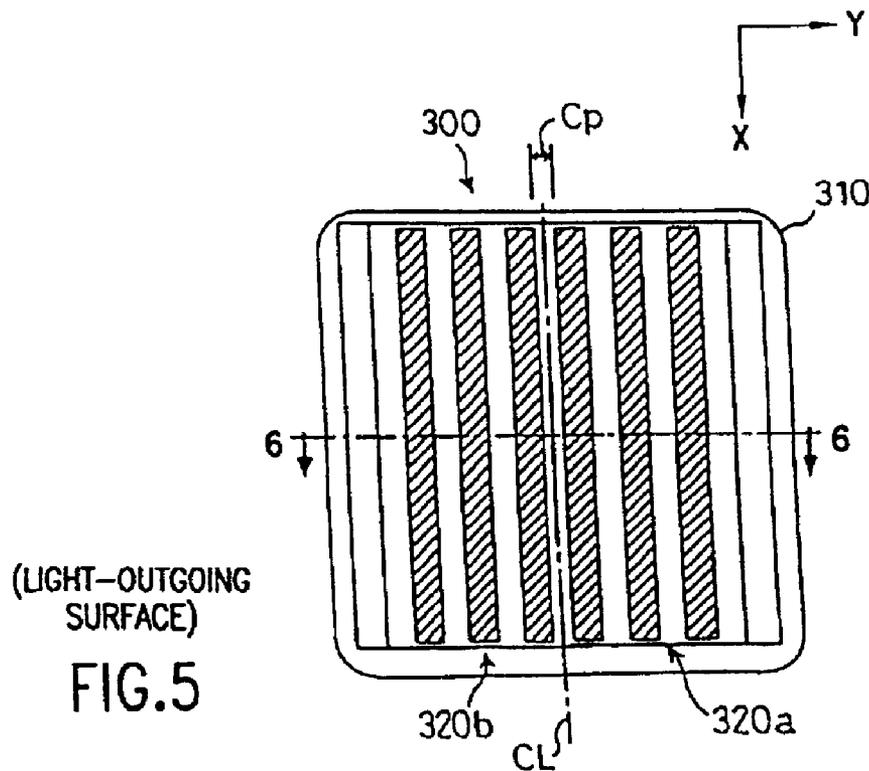
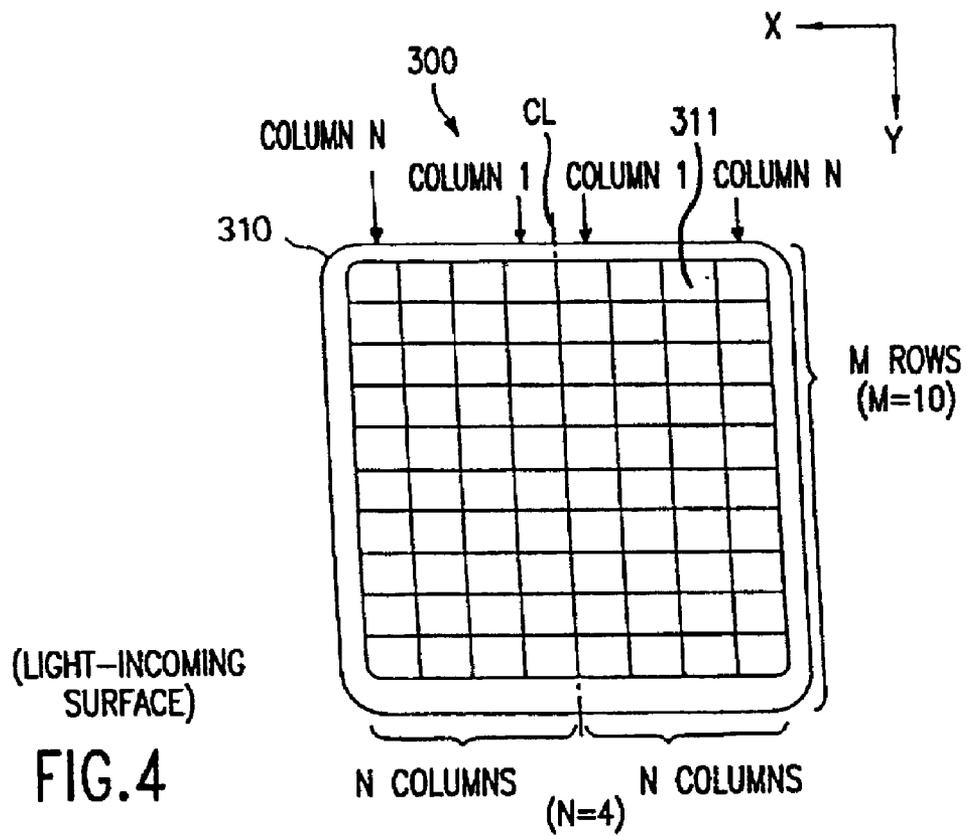


FIG.3



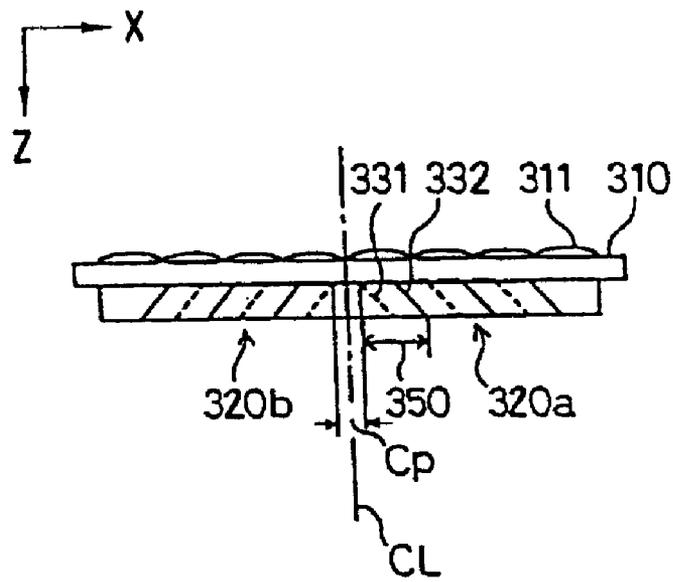


FIG. 6

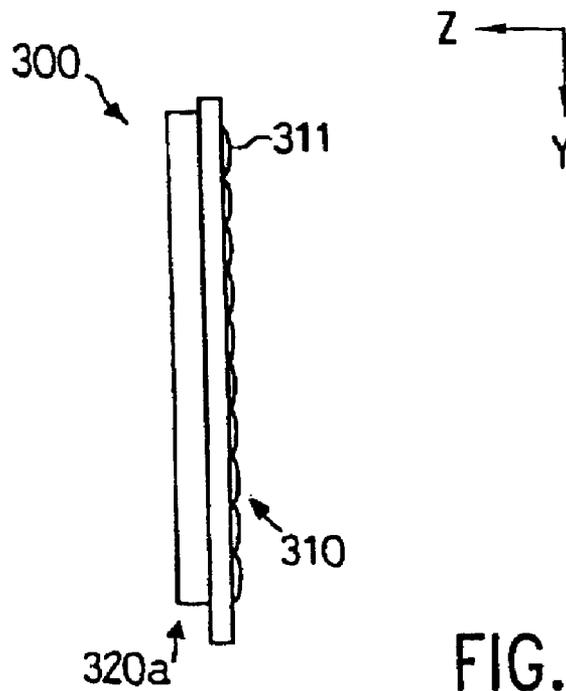


FIG. 7

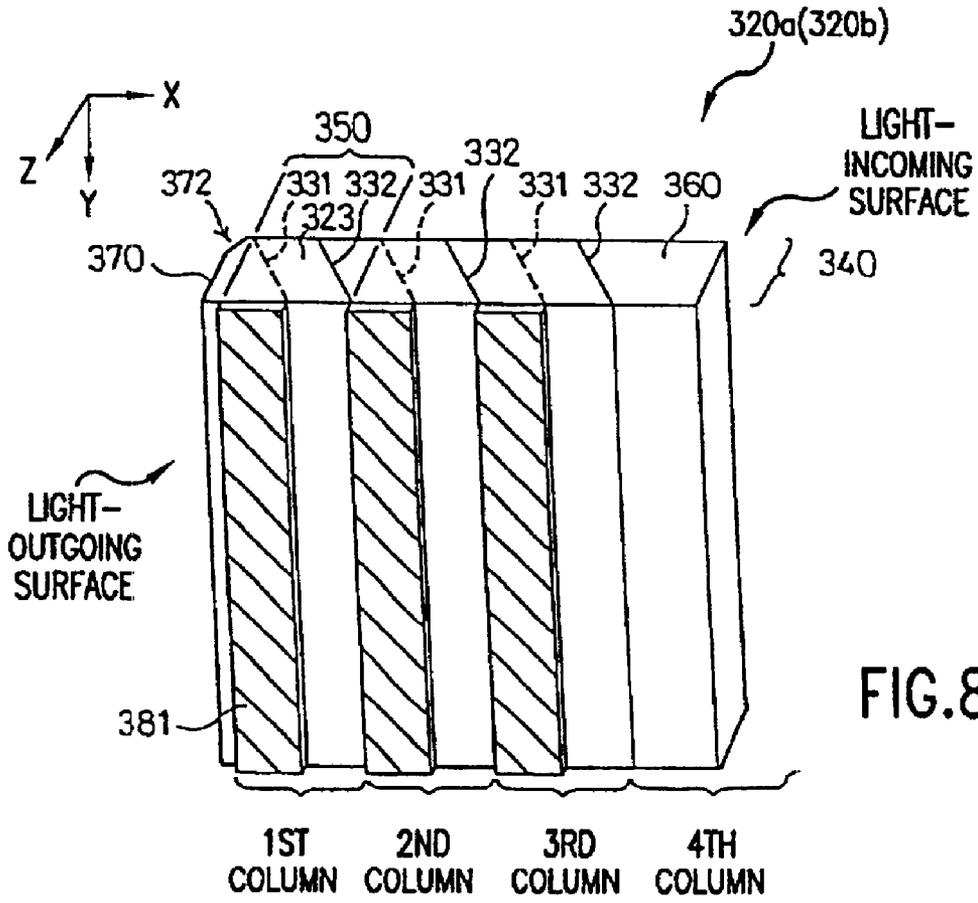


FIG. 8

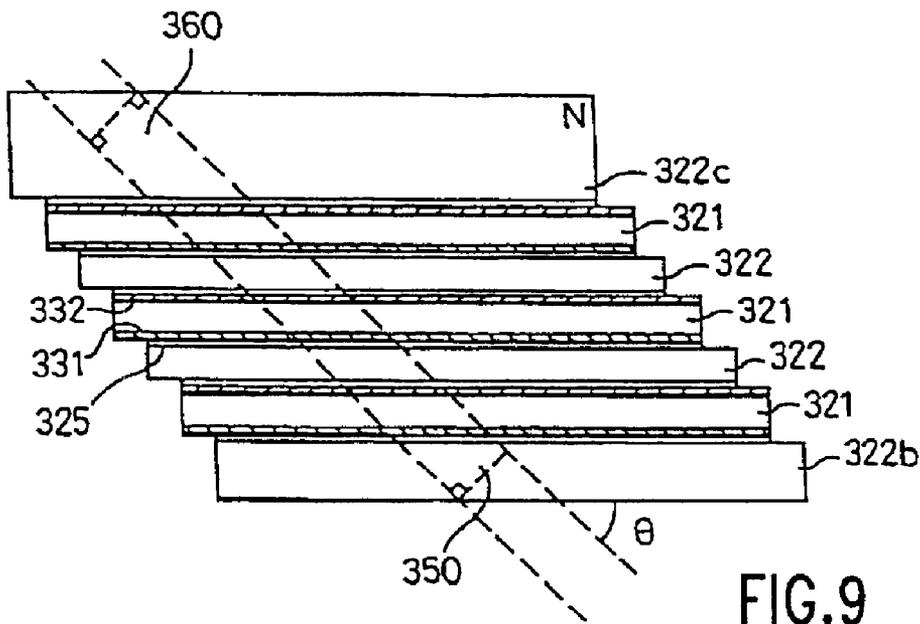


FIG. 9





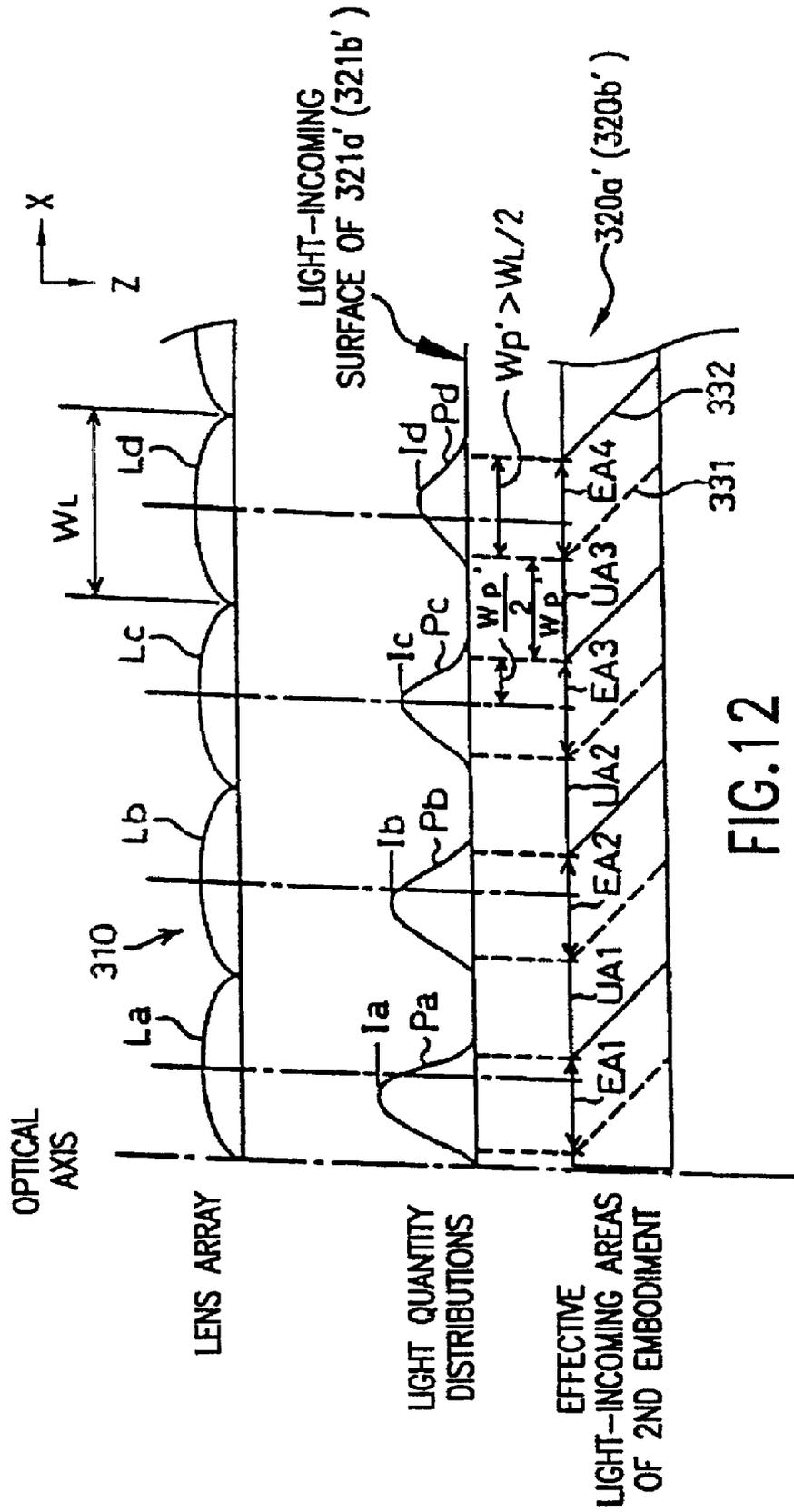


FIG.12

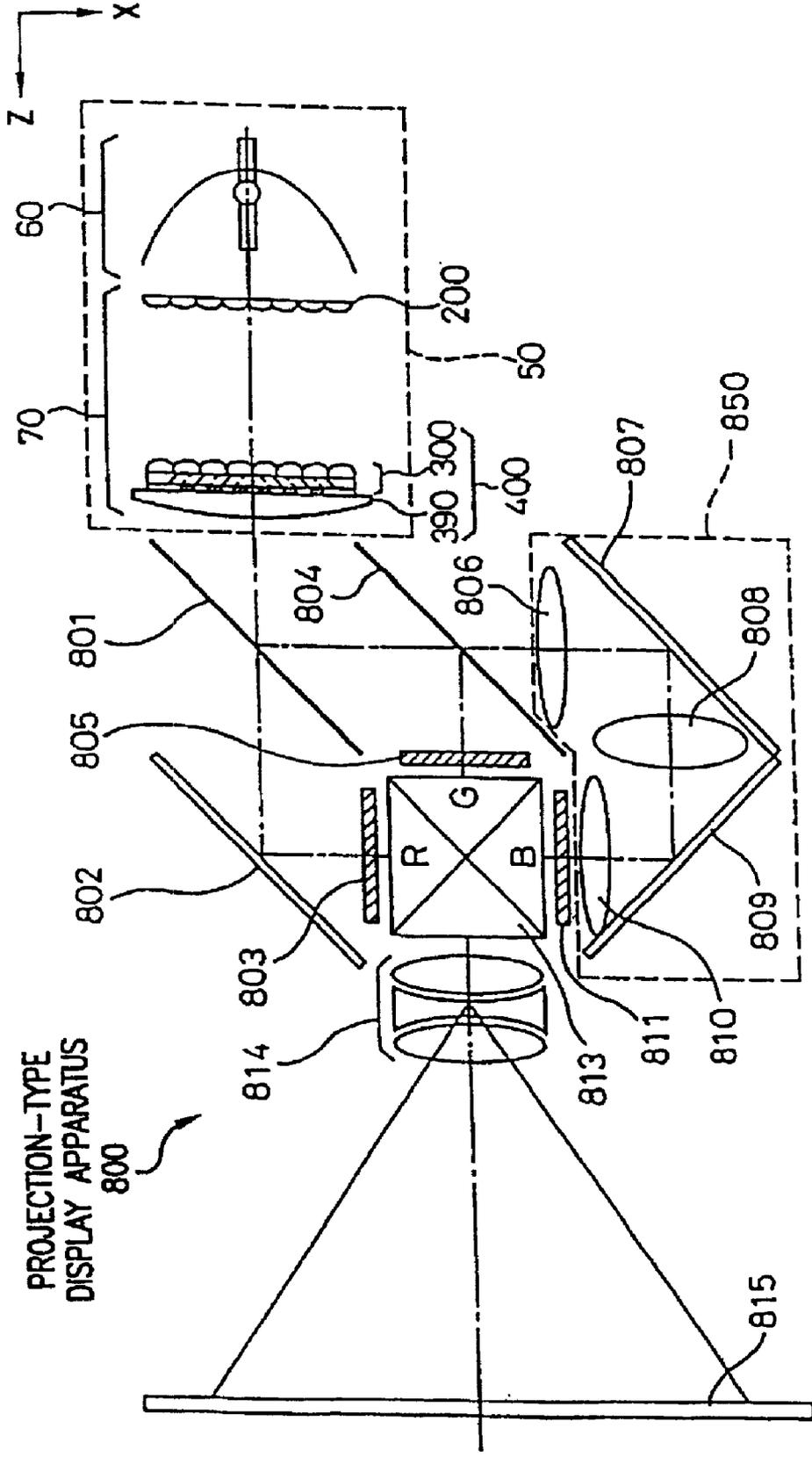


FIG.13



## OPTICAL ELEMENT, POLARIZATION ILLUMINATION DEVICE, AND PROJECTOR

**Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.**

*Notice: More than one reissue application has been filed for the reissue of U.S. Pat. No. 5,978,136. The reissue applications are application numbers 09/985/390 (the present application), Reissue Application No. 11/066,243 filed Feb. 25, 2005, and Reissue Application No. 11/403,242 filed Apr. 13, 2006, all three of which are reissue applications of Pat. No. 5,978,136.*

### BACKGROUND OF THE INVENTION

#### 1. Field of Invention

The present invention relates to an optical element for converting light incident thereto to a predetermined polarized light beam, as well as a polarization illumination device and a projection display apparatus using the same.

#### 2. Description of Related Art

In order to increase the efficiency with which light is utilized to provide a bright display, illuminating optical systems of projection display apparatuses make use of a method that converts polarized light with random polarization directions to polarized light with one polarization direction. A known optical element (polarization conversion element) for converting light with random polarization directions to light with one polarization direction is disclosed in Japanese Patent Laid-Open No. 7-294906. FIGS. 14A and 14B are plan view of such an optical element containing a polarization beam splitter array 20 formed by alternately bonding together linear polarization beam splitters 30 including polarization separating films 36 and linear prisms 40 including reflecting films 46. A lens array composed of a plurality of focus lenses is provided at the light-incoming surface of the polarization beam splitter array 20, with  $\frac{1}{2}$  phase plates 24 selectively provided at the light-outgoing surface of the splitter array 20.

As shown in FIG. 14A, light incident upon the lens array 10 is gathered and converted by the lens array 10 into a plurality of separated light beams (or intermediate light beams) that are incident upon the polarization beam splitters 30 disposed in correspondence with the lens array 10 in the form of light beams containing s-polarized components and p-polarized components. The incident light is separated into s-polarized light beams and p-polarized light beams by the polarization separating films 36. Each s-polarized light beam is reflected substantially vertically by its corresponding polarization separating film 36 formed at an angle of 45 degrees with respect to the light-incoming plane. Then, each s-polarized light beam is reflected again by its corresponding reflecting film 46 formed at an angle of 45 degrees with respect to the light-incoming plane, and leaves its associated prism 40. On the other hand, each p-polarized light beam passes through its corresponding polarization separating film 36, and is converted into an s-polarized light beam by its associated  $\frac{1}{2}$  phase plate and leaves it. Thus, this optical element is of the type that converts all of the incident light beams with random polarization directions to be converted into s-polarization light beams before leaving the optical element.

Ideally, all of the light incident upon the lens array 10 and gathered by each of the focus lenses of the lens array 10 should be incident upon the polarization beam splitters

disposed in correspondence with each of the focus lenses. As shown in FIG. 14B, however, there are actually portions of the light incident upon the lens array 10 that are not completely gathered by the array 10, causing them to be incident upon their corresponding prisms 40. The light portions incident upon the prisms 40 are totally reflected at their corresponding reflecting film 46, and strike the polarization beam splitters 30 adjacent thereto. The light incident upon the polarization beam splitter 30 is separated into s-polarized light beams and p-polarized light beams by the polarization separating films 36. The s-polarized light beams produced by the separation are reflected by their respective polarization separating film 36, and are converted into p-polarized light beams by their respective  $\frac{1}{2}$  phase plates and leave them. On the other hand, the p-polarized light beams pass through their respective polarization separating films 36, and are reflected by and leave the reflecting films 46 disposed in the direction of passage of the light beams. Thus, some of the light incident upon the optical element (polarization conversion element) leaves the optical element as s-polarized light beams, and some of the light incident upon the optical element leaves the optical element as p-polarized light beams. Here, the light-incoming surface of the polarization conversion element can be divided into effective light-incoming areas EA and ineffective light-incoming areas UA. The effective light-incoming areas EA are areas of the light-incoming surface of the polarization conversion element where the incident light beams are converted into the desired polarized light beams and leave the polarization conversion element. On the other hand, the ineffective light-incoming areas UA are areas of the light-incoming surface of the polarization conversion element where the incident light beams leave the polarization conversion element after being converted into undesired polarized light beams.

When there is a desire to use only one type of polarized light beam, it is necessary to cut off the light beams traveling toward the ineffective light-incoming areas UA using a polarization plate or the like. In this case, the aforementioned outgoing p-polarized light beams are not used, thereby reducing the efficiency with which light is used.

### SUMMARY OF THE INVENTION

Accordingly, in view of the above-described prior art problem, it is an object of the present invention to provide a technique permitting more efficient use of light of an optical element used in a polarization illumination device or a projection display apparatus.

According to a first aspect of the present invention, there is provided an optical element containing two polarization conversion element arrays for converting polarized light with random polarization directions to one type of polarized light. Each of the two polarization conversion element arrays includes polarization separating surfaces for separating the polarized light with random polarization directions into two types of linearly polarized light and reflecting surfaces for reflecting one of the two types of the linearly polarized light produced by separation by the polarization separating surfaces. The polarization separating surfaces and the reflecting surfaces are alternately arranged between light-transmissive members. The two polarization conversion element arrays are separated by a predetermined space. The polarization separating surfaces of one array are arranged opposite to the polarization separating surfaces of the other array with respect to the predetermined space.

The light-incoming surface of each polarization conversion element array is divided into a first area where light

incident thereupon directly impinges upon a polarization separating film surface and into a second area where light incident thereupon directly impinges upon a reflecting surface. Of the incident light, the portion of the light incident upon the first light-incoming area is converted into a predetermined type of polarized light beam (effective polarized light beam), while the portion of the light incident upon the second light-incoming area is converted into an ineffective polarized light beam. According to the first aspect of the present invention, light passing through a predetermined space is not incident upon the second area, so that it leaves the optical element, without being converted into an ineffective light beam, as a light beam with random polarization directions. Thus, the effective polarized component of the light beam with random polarization directions that passes through the predetermined space can be utilized, thereby increasing the efficiency with which the light of the optical element is used.

It is preferable that dummy regions not including the aforementioned polarization separating surfaces and the reflecting surfaces are formed using a transmissive material at the predetermined space side end of the two ends of each of the two polarization conversion element arrays.

This makes it possible to make the length of the path of light passing through each polarization conversion element array and the length of the path of light passing through the predetermined space to be close to each other. The light reflected by the predetermined space side end of the two ends of each of the two polarization conversion element arrays may not be effectively used, since it cannot effectively irradiate the irradiating surface depending on the direction of reflection. This problem can be mitigated using the above-described construction.

Regions not including the aforementioned polarization separating surfaces and the reflective surfaces may be formed using a transmissive material at the other one of the two ends of each of the two polarization conversion element arrays which is not disposed at the side of the predetermined space.

In general, the optical element of the first aspect of the present invention is used by setting the center thereof midway between the two conversion element arrays, that is in a predetermined space, so as to lie on the optical axis of the light source. Light leaving the light source, in general, tends to become weaker with increasing distance from the optical axis of the light source, so that even when light incident upon the end of each of the two polarization conversion element arrays which is not disposed at the side of the predetermined space is converted into a predetermined type of polarized light beam, there is almost no increase in the efficiency with which light is used. Thus, by virtue of the above-described construction, it is possible to use fewer polarization separating surfaces and reflecting surfaces, thereby reducing the cost of the optical element.

According to the second aspect of the present invention, there is provided an optical element containing a lens array composed of a plurality of lenses disposed in a matrix, and two polarization conversion element arrays, affixed to one of the surfaces of the lens array, for converting polarized light with random polarization directions to one type of polarized light.

Each of the two polarization conversion element arrays includes polarization separating surfaces for separating the polarized light with random polarization directions into two types of linearly polarized light and reflecting surfaces the reflecting one of the two types of the linearly polarized light

produced by separation by the polarization separating surfaces. The polarization separating surfaces and the reflecting surfaces are alternately arranged between light-transmissive members. The two polarization conversion element arrays are separated by a predetermined space. The polarization separating surfaces of one array are arranged opposite to the polarization separating surfaces of the other array with respect to the predetermined space.

As in the first aspect of the present invention, in the second aspect of the present invention, the light-incoming surface of each polarization conversion element array is divided into a first area where light incident thereupon directly impinges upon a polarization separating film surface and into a second area where light incident thereupon directly impinges upon a reflecting surface. It is preferable that all of the light gathered by the lens array is incident upon the first area, but there are some parts of the light that are incident upon the second area. According to the construction of the second aspect of the present invention, of the light beams leaving the lens arrays, those that are not incident upon the polarization conversion element arrays and pass through a predetermined space are not incident upon the second area, so that the light beams with random polarization directions leave the optical element unchanged. Therefore, it is possible to use the effective polarized component included in the polarized light beams with random polarization directions that pass through such a predetermined space, thereby allowing more efficient use of the light of the optical element.

It is preferable that the polarization separating surfaces and the reflecting surfaces along the light-incoming surfaces of the polarization conversion element arrays be arranged at a pitch which is greater than  $\frac{1}{2}$  the pitch with which the lens arrays are arranged along the direction of arrangement of the polarization separating surfaces and the reflecting surfaces.

According to the above-described construction, each of the two polarization conversion element arrays can be constructed to allow the light beams from the lens arrays to efficiently impinge thereupon, thereby allowing more efficient use of the light of the optical element.

According to a third aspect of the present invention, there is provided a polarization illumination device containing a light source and an optical element for converting light from the light source into one type of polarized light.

The optical element includes a lens array composed of a plurality of lenses disposed in a matrix, and two polarization conversion element arrays, affixed to one of the surfaces of the lens array, for converting polarized light with random polarization directions to one type of polarized light. Each of the two polarization conversion element arrays includes polarization separating surfaces for separating the polarized light with random polarization directions into two types of linearly polarized light and reflecting surfaces for reflecting one of the two types of the linearly polarized light produced by separation by the polarization separating surfaces. The polarization separating surfaces and the reflecting surfaces are alternatively arranged between light-transmission members. The two polarization conversion element arrays are separated by a predetermined space. The polarization separating surfaces of one array are arranged opposite to the polarization separating surfaces of the other array with respect to the predetermined space.

According to the third aspect of the present invention, an optical element allowing light to be used with high efficiency is used, so that light can be used with greater efficiency in an illumination device.

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It is preferable that the polarization separating surfaces be arranged in accordance with a distribution of light from the lens array. This allows light from the lens array to be used effectively, so that light of an illumination device can be used with even greater efficiency.

It is preferable that a polarization separating surface be disposed at a location closest to the predetermined space in each of the two polarization conversion element arrays, such that the center of this polarizing separating surface is shifted towards the predetermined space from the center axis of the lens of the lens array which is disposed closest to the polarization separating surface.

A large amount of light leaves the light source at around the optical axis of the light source. The light quantity distribution of light leaving a portion around the optical axis of the light source is shifted towards the optical axis of the light sources from the center axis of the lens disposed closest to the polarization separating surface disposed closest to the predetermined space. Thus, by virtue of such a construction it is possible to effectively use the light near the optical axis of the light source, thereby allowing even more efficient use of the light of the illumination device.

According to a fourth aspect of the present invention, there is provided a projection display apparatus containing a polarization illumination device, modulating device for modulating light from the polarization illumination device in accordance with a received image signal, and projection optical device for projecting the light beam modulated by the modulating device.

The polarization illumination device includes a light source and an optical element for converting light from the light source incident thereupon a light with a predetermined polarization direction that leaves the optical element.

The optical element includes a lens array composed of a plurality of lenses disposed in a matrix, and two polarization conversion element arrays, affixed to one of the surfaces of the lens array, for converting polarized light with random polarization directions to one type of polarized light. Each of the two polarization conversion element arrays includes polarization separating surfaces for separating the polarized light with random polarization directions into two types of linearly polarized light and reflecting surfaces for reflecting one of the two types of the linearly polarized light produced by separation by the polarization separating surfaces. The polarization separating surfaces and the reflecting surfaces are alternately arranged between light-transmissive members. The two polarization conversion element arrays are separated by a predetermined space. The polarization separating surfaces of one array are arranged opposite to the polarization separating surfaces of the other array with respect to the predetermined space.

According to the fourth aspect of the present invention, an illumination device using an optical element allowing light to be used with higher efficiency is used, thereby allowing a brighter image to be projected onto a projection surface.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic structural as viewed in a plane of the main portion of a polarization illumination device of an embodiment of the present invention.

FIG. 2 is a perspective view of the optical element 200 of FIG. 1.

FIG. 3 is a view illustrating the basic operation of the polarization conversion element array 320b (320a).

FIG. 4 is a front view showing the light-incoming surface of the optical element 300 of a first embodiment of the present invention.

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FIG. 5 is a rear view showing the light-outgoing surface of the optical element 300 of the first embodiment.

FIG. 6 is a sectional view taken along A—A' of FIG. 5.

FIG. 7 is a side view of the optical element 300 of the first embodiment.

FIG. 8 is a perspective view of the structure of the polarization conversion element arrays 320a and 320b.

FIG. 9 is a view showing an example of how the polarization beam splitter array 340 is manufactured.

FIG. 10 is an enlarged partial sectional view taken along the line A—A' in FIG. 5.

FIGS. 11A and 11B are enlarged views of the predetermined space side ends of the polarization conversion element arrays 320a and 320b, shown in FIG. 8.

FIG. 12 is a view showing an optical element 300 of the second embodiment of the present invention.

FIG. 13 is a schematic structural view of the main portion of a projection display apparatus 800 provided with the polarization illumination device 50 of FIG. 1.

FIGS. 14A and 14B are plan views of a conventional optical element.

#### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

A description will now be given of the preferred embodiments of the present invention.

##### A. Polarization Illumination Device:

FIG. 1 is a schematic structural view as viewed from a plane of the main portion of a polarization illumination device 50 of an embodiment of the present invention. The polarization illumination device 50 contains a light source 60 and a polarization portion 70. Light with random polarization directions that include an s-polarized component and a p-polarized component leave the light source 60. The light leaving the light source 60 is converted into one type of polarized light beam (such as an s-polarized light beam) in which the polarization directions are substantially the same by means of the polarization portion 70, thereby illuminating an illumination area 80.

The light source 60 includes a lamp 101 and a parabolic surface reflector 102. The light emitted from the lamp 101 is reflected unidirectionally by the parabolic surface reflector 102, and converted into substantially parallel light beams that are incident upon the polarization portion 70.

The polarization portion 70 includes a first optical main element 200 and a second optical main element 400. FIG. 2 is a perspective view of the first optical main element 200. The first optical main element 200 includes tiny and rectangular light beam separating lenses 200 arranged in a matrix arrangement with M rows and 2N columns. Thus, there is an N column of lenses on the left side of a center CL in the lens horizontal direction, and an N column of lenses on the right side of the center CL in the lens horizontal direction. In the example, M=10 and N=4. The first optical main element 200 is disposed such that the optical axis lies on the center of the first optical main element 200. As seen from the direction of arrow Z, the external shape of each of the light-beam separating lenses 201 is similar to the shape of the illumination area 80. Since, in the present embodiment, the illumination area 80 is assumed to be long in the X-direction, the external shape of each of the light beam separating lenses is also long horizontally in the X-Y plane.

The second optical main element 400 of FIG. 1 contains an optical element 300 and a light-outgoing side lens 390.

The element **300** and the lens **390** are disposed such that their centers lie on the optical axis.

The optical element **300** includes a focus lens array **310** and two polarization conversion element arrays **320a** and **320b**. The focus lens array **310** has the same structure as that of the first optical main element **200**, and opposes the first optical main element **200**. The focus lens array **310** gathers a plurality of light beams separated by each of the light beam separating lenses **201** of the first optical main element **200**. The polarization conversion element arrays **320a** and **320b** each convert the light beams incident thereupon into one type of linearly polarized light beams (such as s-polarized light beams or p-polarized light beams), so that the light beams leave the arrays **320a** and **320b** as one type of polarized light beams. FIG. 3 is a view illustrating the basic operation of the polarization conversion element array **320b** (**320a**). Light beams with random polarization directions, each including an s-polarized component and a p-polarized component, impinge upon the light-incoming surface of the polarization conversion element array. Each incident light beam is first separated into s-polarized light beams and p-polarized light beams by each polarization separating film **331**. The s-polarized light beams are reflected substantially vertically by each polarization separating film **331**. Then, they are reflected vertically by and leave the reflecting films **332**. On the other hand, the p-polarized light beams pass through the polarization separating films **331**.  $\frac{1}{2}$  phase plates **381** are disposed at the surface of the polarization separating films where the p-polarized light beams leave. The plates **381** convert the p-polarized light beams into s-polarized light beams that leave the plates **381**. Thus, almost all of the light beams that have passed through the polarization conversion elements leave them as s-polarized light beams. When one wants light to leave the polarization conversion element as p-polarized light beams, a  $\frac{1}{2}$  phase plate **381** is placed at the surface where the s-polarized light beams are reflected by the reflecting films **332** leave. The distinctive feature of the present invention is the structure of the optical element **300**, which will be described in detail below.

The light-outgoing side lens **390** of FIG. 1 is used for transmitting the plurality of separated light beams leaving the optical element **300** (that is, the separated linearly polarized light beams formed by means of the polarization conversion element arrays **320a** and **320b**) such that each of them illuminate the entire illumination area **80**.

The light leaving the light source section **60** and impinging upon the first optical main element **200** is separated into intermediate light beams **202**. The intermediate light beams **202** converge within a plane (in the XY plane in FIG. 1) perpendicular to the optical axis by means of the light beam separating lenses **201** of the first optical main element **200** and the focus lenses **311** of the focus lens array **310** that gather the light beams. Light source images are formed at the location **203** where the intermediate light beams converge, with the number of light source images being the same as the number of light beam separating lenses **201**. The light source images are formed near the polarization separating films **331** (see FIG. 3) in the polarization conversion element arrays **320a** and **320b**.

Of the light beam incident upon the optical element **300**, those that are gathered by the focus lens array **310** and irradiate the polarization separating films **331** are converted into one type of linearly polarized light beams and leave the polarization separating films **331**. The light beams that have left the optical element illuminate the illuminating area **80** by means of the light-outgoing side lens **390**. The whole illumination area **80** is uniformly illuminated by the plurality

of light beams separated by means of the plurality of light beams separating lenses **201**.

B: First Embodiment:

FIG. 4 is a front view showing the light-incoming surface of the optical element **300** of the first embodiment. FIG. 5 is a rear view of the light-outgoing surface thereof. FIG. 6 is a sectional view taken along line A—A' of FIG. 5. FIG. 7 is a side view of the optical element **300**.

In the optical element **300**, two polarization conversion element arrays **320a** and **320b** are affixed to the flat light-outgoing surface of the light-gathering focus lens array **310**, using an optical adhesive. The two polarization conversion element arrays **320a** and **320b** are arranged opposite to each other, and are disposed on the left and right sides of a center CL in the horizontal direction of the focus lens array **310** so as to be spaced apart by a predetermined space  $C_p$  which is described later. Like the first optical main element **200** (of FIG. 2), the focus lens array **310** contains substantially rectangular focus leaves **311** in a matrix arrangement with M rows and 2N columns. Thus, there are N columns on the left side of and N columns on the right side of the center CL in the lens horizontal direction. In this example, M=10 and N=4.

FIG. 8 is a perspective view of the structure of the polarization conversion element arrays **320a** and **320b**. The polarization conversion element arrays **320a** and **320b** each include a polarization beam splitter array **340** and  $\frac{1}{2}$  phase plates **381** (represented by slanted lines in the figure) selectively disposed at portions of the light outgoing surface of the polarization beam splitter array **340**. The shape of the polarization beam splitter array **340** is formed by successively adhering a plurality of light-transmissive members **323** parallelogrammic and column-like in sections. At the interfaces of the light-transmissive members **323** are alternately disposed polarization separating films **331** and reflecting films **332**.  $\frac{1}{2}$  phase plates **381** are selectively disposed at the image portions in the X-direction of the light-outgoing surfaces of the polarization separating films **331** or the reflecting films **332**. In the present embodiment,  $\frac{1}{2}$  phase plates **381** are selectively disposed at the image portions in the X-direction of the light-outgoing surfaces of the polarization separating films **331**.

As described above using FIG. 3, light incident upon the polarization separation film **331** either passes through the polarization separation film **331** and is converted into a predetermined linearly polarized light beam by the  $\frac{1}{2}$  phase plate **381** and leaves it or is reflected by the polarization separation film **331** and then by the reflecting film **332** and leaves it as a predetermined linearly polarized light beam. Accordingly, one block including one polarization separation film **331**, one reflecting film **332** adjacent thereto, and one  $\frac{1}{2}$  plate **381** can be considered as one polarization conversion element **350**. The polarization conversion element arrays **320a** and **320b** are each formed by a plurality of such polarization conversion elements **350** arranged in the x-direction. In the present embodiment, N=4 for one side of the focus lens array **310**, so that there are four columns of polarization conversion elements **350** on one side of the array **310**. It is to be noted that a portion **360** equivalent to the polarization conversion element of the 4th column is only formed by a light-transmissive material, so that it does not include a polarization separation film **331** or a reflecting film **332**. For description purposes, the portion **360** will be called light-transmissive portion that will be described later.

In FIG. 8, a dummy portion **370** composed of a light-transmissive material is provided at a side (end) surface of

the polarization conversion element **350** in the leftmost column. A corner of an edge **372** at the light-incoming surface (adhered surface) of the dummy portion **370** is rounded or removed. The reason for this will be discussed later.

FIG. **9** is a view illustrating an example of how the polarization beam splitter array **340** is manufactured. The polarization beam splitter array **340** is formed by alternately bonding together plate glasses **321**, each provided with, for example, a polarization separation film **331** and a reflecting film **332** such that they are alternately disposed, and plate glasses **332** that is not provided with anything, using an adhesive **325**. Here, a plate glass **332b** and **332c**, each of which does not have the same thickness as the plate glasses **322**, are bonded to the beginning and end of the bonded structure. This forms the dummy portion **370** and the light-transmissive portion **360** (FIG. **8**). Accordingly, light-transmissive blocks are formed by cutting out virtually parallel bonded sections (represented by broken lines in FIG. **9**) of the plurality of light-transmissive members **321**, **322**, **322b**, and **322c** at a predetermined angle  $\theta$  from the surfaces thereof. It is preferable that  $\theta$  be about 45 degrees. The protrusions at both ends are cut to a substantially rectangular shape. Grinding the cut surfaces of the light-transmissive blocks produces the polarization beam splitter array **340** (FIG. **8**). It is to be noted that in the specification, a light-transmissive member is also called "base", and that the block formed by bonding together the plurality of light-transmissive members and a block portion cut out from this block are called "base block".

FIG. **10** is a partial enlarged view taken along line A—A' of FIG. **5**. The polarization conversion element arrays **320a** and **320b** are symmetrically disposed on opposite sides of the lens center and have exactly the same functions, so that a description of only the polarization conversion element array **320a** will be given below. The light-incoming surface of the polarization conversion element array **320a** has alternately disposed effective light-incoming area EA (the light-incoming surface portions corresponding to the polarization separation films **331** in which light incident to the polarization separation films **331** is converted into effective polarized light beams and ineffective light-incoming area UA (the light-incoming surface portions corresponding to the reflecting films **332**) in which light incident upon the reflective films **332** is converted into ineffective polarized light beams. The width  $W_p$  of each effective light-incoming area EA and each ineffective light-incoming area UA in the X-direction is  $\frac{1}{2}$  the width  $W_L$  of the focus lens **311** in the X-direction. The center **311c** of the focus lenses **311** is disposed so as to match the center of each effective light-incoming area EA in the X-direction. Here, the effective polarized light beams produced by the polarization conversion element **350** are s-polarized light beams.

The light gathered by the focus lens array **310** (that is light with random polarization directions that include an s-polarized component and a p-polarized component) is incident upon the polarization conversion element array **320a**. Of the light incident thereupon, light beam L1 incident upon an effective light-incoming area EA is separated into an s-polarized component and an p-polarized component by the associated polarization separation film **331**, as described earlier using FIG. **3**. The s-polarized light beam is reflected by the associated polarization separation film **331** and then by the associated reflecting film **332** and leaves it. The p-polarized light beam passes through the associated polarization separation film **331** and is converted into an s-polarization light beam by the associated  $\frac{1}{2}$  phase plate

**381** and leaves it. Thus, almost all of the light incident upon the effective light-incoming area EA of the polarization conversion element array **320a** is converted into s-polarized light beams and leave it.

$\frac{1}{2}$  phase plates **381** are selectively provided at the light-outgoing surfaces of the reflecting films **332**, making it possible for selectively causing substantially only p-polarized light beams to leave the polarization conversion elements.

As described in the prior art section, the portions of the light incident upon the ineffective light-incoming area UA are converted into undersired polarized light beams (p-polarized light beams in the present embodiment). Ordinarily, the efficiency with which light is used is reduced, since the light is cut off by a light-shielding plate or the like provided at an ineffective light-incoming area UA. In a structure such as that of the polarization illumination device **50** of FIG. **1**, in particular, the quantity of light becomes greatest around the optical axis of the light source, so that when there is an ineffective light-incoming area UA around the optical axis, the efficiency with which light is used is considerably reduced. The present invention makes it possible to overcome such a problem in a way described below.

In the first embodiment, the polarization conversion element **350a** of the polarization conversion element array **320a** closest to the optical axis (see FIG. **10**) and the polarization conversion element **350b** of the polarization conversion element array **320b** closest to the optical axis (see FIG. **10**) are disposed on the left and right side of the space Cp so as to oppose each other. The dummy portions **370** of the two polarization conversion element arrays **320a** and **320b** as well as a gap Gp therebetween are located in the space Cp. Thus, of the light beams incident upon the focus lens array **310** around the optical axis, light beam L2 passes through the space Cp within which neither a polarization separating film **331** nor a reflecting film **332** are present and leaves the gap Cp unchanged. The light beam passing through the space Cp is a light beam consisting of an effective s-polarized component as well as an ineffective p-polarized component. Of the components of the outgoing light beam passing through the space Cp, the required polarized component (the s-polarized component in the present embodiment) alone can be made to leave the space Cp by placing a polarization plate at the light-outgoing plane side for effective use. When the polarization illumination device **50** (FIG. **1**) is applied to a projection display apparatus described later, a polarization plate is ordinarily provided at the light-incoming surface of a liquid crystal light valve being an illumination area **80**. Therefore, in this case, it is not necessary to provide a separate polarization plate.

The light-transmissive portion **360** at the outermost side of the polarization conversion element array **320a** is a portion through which light from the lens at the outermost side of the focus lens array **310** passes. The light source of the polarization illumination device **50** having the structure of the present embodiment is ordinarily disposed on a centerline extending through the center of the light-incoming surface of the focus lens array **310** and being perpendicular to the light-incoming surface (see FIG. **4**), so that the quantity of light incident upon the outer side of the lens array **310**, that is the light-transmissive portion **360**, is smallest. In such a situation, there is often not much difference between the quantities of light that can be effectively used in the entire first optical main element **300** (see FIG. **1**) when the light incident upon the outermost side of the focus lens array **310** is converted into a polarized light beam by the polarization conversion element for use compared to when

the light just passes through the array **310** unchanged. Thus, the light-transmissive portion **360** at the outmost side of the focus lens array **310** of the polarization conversion element array **320a** is formed only by a light-transmissive member, so that it does not take structure of the polarization conversion element **350** (see FIG. **8**), and is not provided with a  $\frac{1}{2}$  phase plate **381**. This causes light beam **L3** passing through the lens at the outermost side of the focus lens array **310** to pass through and leave the light-transmissive portion **360** unchanged. The light beam leaving the light-transmissive portion **360** is, like the light beam passing through and leaving the space **Cp**, a light beam containing an effective s-polarized component and an ineffective p-polarized component. Of the outgoing polarized components leaving the light-transmissive portion **360**, only the required polarized component (the s-polarized component in the present embodiment) is utilized by providing a polarization plate at the light-outgoing side of the light-transmissive portion **360**, allowing the light beam to be utilized as an effective light beam.

FIGS. **11A** and **11B** are enlarged views of the predetermined space side ends of the polarization conversion element arrays **320a** and **320b** of FIG. **8**. In FIG. **11A**, it is assumed that polarization conversion element arrays **320a** and **320b** that do not have dummy portions **370** shown in FIG. **8** are disposed in the horizontal direction of the light-outgoing surface of the focus lens array **310**, with a predetermined space **Cp** provided therebetween with respect to the center **CL**. Here, there is a difference between the light path lengths of the light beam passing through the space **Cp** and the light beam passing through the polarization conversion element arrays **320a** and **320b**. If possible, it is preferable that lengths of the light paths be as close to each other as possible. Depending on the direction of reflection, the light beam **Lex1** reflected by the ends **371** of the polarization conversion element arrays **320a** or **320b** cannot be used effectively. The focus lens array **310** and the polarization conversion element arrays **320a** and **320b** are bonded together using, for example, an adhesive **375** shown in FIG. **11A**. Here, an adhesive protruding portion **376** is produced at the predetermined space **Cp**. The light beam **Lex2** passing through such an adhesive protruding portion **376** is reflected irregularly, since the adhesive surface is not even, thereby preventing effective use of the light.

In FIG. **11B**, it is assumed that dummy portions **370** composed of the same material as the light-transmissive members **323** of the polarization conversion element arrays **320a** and **320b** are disposed in the predetermined space **Cp**. When the dummy portions are provided, as shown in FIG. **8**, it is possible to mitigate problems regarding differences in the lengths of the light paths and differences in the reflection directions of the light beam **Lex1** reflected at an end surface of the polarization conversion element arrays **320a** or **320b**. As shown in FIG. **11B**, the amount of protrusions of the adhesive is made smaller by providing dummy portions **370**, and either rounding or removing the corners of the sides of the dummy portions **370** at the light-incoming surfaces (adhered surfaces). The gap **Gp** at the center portion does not have to be formed. Taking into account the accuracy of alignment of the polarization conversion element arrays **320a** and **320b** with the light-outgoing of the focus lens array **310** when bonding them together, however, it is preferable there be a slight gap between the dummy portions **370** at the center portion, when the polarization conversion element arrays **320a** and **320b** have been bonded to the light-outgoing surface of the focus lens array **310**.

C. Second Embodiment:

FIG. **12** is a diagram illustrating an optical element of the second embodiment. The middle portion of FIG. **12** shows the distribution of the quantities of light illuminating the light-incoming surface of a polarization conversion element array **320a**, after gathering of the light by each of the lenses **La** to **Ld** of the lens array **310** in a structure such as that of the polarization illumination device **50** (FIG. **1**). In general, the intensity **Ia** of the light gathered by the lens **La** nearest the optical axis is the strongest, while the intensity of the light gathered by the lens furthest from the optical axis is weakest. In FIG. **12**, the intensity **Id** of the light gathered by the fourth lens is the weakest. The light quantity distribution shifts from its associated lens center towards or away from the optical axis starting from a certain lens position (the position of the third lens **Lc** in FIG. **12**), so that for the light quantity distributions of the lenses **La** to **Ld**, the closer the lens is to the optical axis the more the distribution is shifted towards the optical axis from its associated lens center, and the further away the lens is from the optical axis the more the distribution is shifted towards the opposite side of the optical axis from its associated lens center. In FIG. **12**, the light quantity distribution **Pc** of the third lens **Lc** is centered at about the lens center, while the light quantity distributions **Pa** and **Pb** of the lenses **La** and **Lb** that are closer to the optical axis than the lens **Lc** are shifted towards the optical axis with respect to their lens center. The light quantity distribution **Pd** of the lens **Ld** that is farther from the optical axis than the lens **Lc** is shifted away from the optical axis with respect to its lens center.

In such a case, when the centers of the effective light-incoming areas of the polarization conversion element arrays are aligned with their corresponding lens centers, without exception, light loss occurs as a result of a shift in the light quantity distribution as described above. This loss of light becomes particularly large at around the optical axis of the light source when the distribution of light from a lens array and an effective light-incoming area are not aligned. Thus, it is preferable that the centers of each of the effective light-incoming areas of the polarization conversion element array **320a'** be arranged in accordance with the distributions of light leaving the lens array **310**, that is in accordance with the peak interval of the distribution of the light from the lens array **310**. In addition, in order to utilize the light gathered by the lens array **310** more effectively, it is preferable that the light gathered by the lenses closer to the optical axis of the light source be used more effectively. In particular, it is preferable to substantially align the center of the effective light-incoming area **EA1** of the polarization conversion element array **320a'** disposed closest to the optical axis with the peak position of the light distribution **Pa** of light from the lens **La** disposed near the optical axis, when the light quantity around the optical axis of the light source is large, or when the distribution **Pa** is shifted towards the optical axis of the light source with respect to the center of the lens **La**.

According to the second embodiment, it is possible to overcome problems related to light intensities and light quantity distributions that depend on a lens position of the focus lens array. The optical element of the second embodiment has the same basic structure as that of the optical element of the first embodiment, but differs from it in that it utilizes polarization conversion element arrays **320a'** and **320b'** whose effective light-incoming areas **EA** (designated **EA1** to **EA4** in the figure) and ineffective light-incoming areas (designated **UA1** to **UA4** in the figure) each have a width **Wp'** in the X-direction that is larger than  $\frac{1}{2}$  the width **W<sub>L</sub>** in the X-direction of each of the lenses **La** to **Ld** of the

lens array **310**. FIG. **12** only shows the polarization conversion element array **320a'** side. The polarization conversion element array **320b'** side is simply symmetrical to the polarization conversion element array **320a** side with reference to the optical axis.

For instance, the polarization conversion element array **320a'** is disposed such that the center of lens **Lc** in the third column is aligned with the center of its associated effective light-incoming area **EA3**. Ordinarily, the width of each of the ineffective light-incoming areas **UA** (designated **UA1** to **UA4** in the figure) is equal to the width **Wp'** of each of the effective light-incoming area **EA**, so that the left two effective light-incoming areas **EA1** and **EA2** are shifted from the centers of their corresponding lenses **La** and **Lb** towards the optical axis. On the other hand, the rightmost effective light-incoming area **EA4** is shifted from the center of the lens **Ld** away from the optical axis. As a result, each of the effective light-incoming area **EA1** to **EA4** substantially is aligned with the location of its corresponding light quantity distribution of the lens array **310**. Since a predetermined number of lenses, such as two or three lenses, disposed close to the optical axis has a strong light intensity, it is particularly preferable to align the distribution of the quantity of light gathered by each of these lenses substantially with their respective effective light-incoming areas. By virtue of such a construction, according to the second embodiment, it is possible to use the light with greater efficiency. How much larger the width of an effective light-incoming area should be made than  $\frac{1}{2}$  width of the associated lens, or which lens should be used as a reference to place an effective light-incoming area can be experimentally determined easily from the number of lens arrays and the relationship between the light quantity distribution and its associated lens. The widths of the effective light-incoming areas and the ineffective light-incoming areas do not have to be made greater than  $\frac{1}{2}$  the widths of their corresponding lenses. The widths are determined by the actual distribution of the quantity of light irradiating the light-incoming surface of the polarization conversion array.

#### D. Projection display apparatus:

FIG. **13** is a structural schematic view of the main portion display apparatus provided with the polarization illumination device **50** of FIG. **1**. The projection display apparatus (*projector*) includes the polarization illumination device **50**, dichroic mirrors **801** and **804**, reflecting mirrors **802**, **807**, and **809**, lenses **806**, **808**, and **810**, three liquid crystal light valves **803**, **805**, and **811**, a cross dichroic prism **813**, and a projection lens assembly **814**.

The dichroic mirrors **801** and **804** each functions as a color light separating means for separating white light into three color components, red, blue, and green. The three liquid crystal light valves **803**, **805**, and **811** each functions as a light modulating means for modulating the three color components in order to form an image, in accordance with the image information or signal received. The cross dichroic prism **813** functions as a color light combining means for combining the three color components to form a color image. The projecting lens assembly **814** functions as a projection optical system for projecting the light carrying the combined color image onto a screen **815**.

The red component of white light from the polarization illumination device **50** passes through the dichroic mirror **801** reflecting a blue component and a green component, whereas the blue component and the green component are reflected thereto. The red component that has passed through is reflected by the reflecting mirror **802** and arrives

at the red component liquid crystal light valve **803**. On the other hand, of the blue component and the green component reflected by the first dichroic mirror **801**, the green component is reflected by the green component reflective dichroic mirror **804** and arrives at the green component liquid crystal light valve **805**. The blue component passes through the second dichroic mirror **804**.

In the present embodiment, the path of the component is the longest. Thus, for the blue component, following the dichroic mirror **804**, a light-guiding means **850** formed by a relay lens unit including the light-incoming lens **806**, the intermediate lens **808**, and the light-outgoing lens **810** is provided. The blue component, after passing through the green component reflective dichroic mirror **804**, passes through the light-incoming lens **806**, is reflected by the reflecting mirror **807**, and is guided to the intermediate lens **808**. Then, after being reflected by the reflecting mirror **809**, it is guided to the light-outgoing lens **810** and reaches the blue component liquid crystal light valve **811**. The three liquid crystal light valves **803**, **805**, and **811** correspond to the illumination area **80** of FIG. **1**.

In accordance with the image signal (information) provided by an external control circuit (not shown), the three liquid crystal light valves **803**, **805**, and **811** modulate their corresponding color components to generate color light beams containing image information of the light components. The modulated three color components are incident upon the cross dichroic prism **813**. A dielectric multi-layered film reflecting a red component and a dielectric multi-layered film reflecting a blue component are formed into the shape of a cross at the cross dichroic prism **813**. These dielectric multi-layered films combine the three color components, forming a light beam representing the color image. The light beam in which the light components have been combined is projected onto the screen **815** by the projecting lens assembly **814** being a projection optical system in order to enlarge the image for display.

The projection display apparatus projection display apparatus uses liquid crystal light valves **803**, **805**, and **811** serving as light modulating means of the type that modulates a light beam polarized in a particular direction (that is, an s-polarized light beam or a p-polarized light beam). Polarization plates (not shown) are ordinarily affixed onto the light-incoming side and the light-outgoing side of each of the liquid crystal light valves. Therefore, a light beam polarized in a predetermined direction, such as an s-polarized light beam, is modulated and impinges upon the cross dichroic prism **813**. Here, of the light beams incident upon the optical element **300**, those gathered by the focus lens array **310** and irradiating the polarization separating films **331**, as shown in FIG. **10**, are all converted into s-polarized light beams and leave the optical element **300**. The light beams from the optical element **300** illuminate the liquid crystal light valves **803**, **805**, and **811** through a light-outgoing side lens **390**.

Of the light beams incident upon the optical element **300**, those that could not be completely gathered by the focus lens array **310** and irradiate their respective reflecting films **332** are converted into p-polarized light beams, as described in the conventional example, and leave the optical element **300** to illuminate the liquid crystal light valves **803**, **805**, and **811**. As mentioned above, however, polarizing plates are provided at the light-incoming surfaces of the liquid crystal light valves **803**, **805**, and **811** to block p-polarized light beams, whereby only s-polarized light beams are used. On the other hand, the light beams passing through the space **Cp** in the optical element of the above-described embodiment of

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the present invention leave the space Cp and illuminate the liquid crystal light valves **803**, **805**, and **811**, without being converted into a polarized light beam. Since the illuminating light is white light including an s-polarized component usable at the liquid crystal light valves **803**, **805**, and **811**, it is possible to use only the s-polarized component of the light irradiating the liquid crystal light valves **803**, **805**, and **811**. Thus, since the projection display apparatus **800** of FIG. **13** incorporates the polarization illumination device **50** using the optical element **300** of the above-described embodiment of the present invention, it is possible to use the light more efficiently than in the conventional case.

As can be understood from the foregoing description, the optical element of the present embodiment of the present invention can allow light in the projection display apparatus to be used more efficiently than in conventional projection display apparatuses. Therefore, the image projected onto the screen **815** can be made brighter.

While the preferred embodiments of the present invention have been described, it is to be understood that various modifications may be made without departing from the spirit and scope of the appended claims, as follows.

The polarization illumination device of the present invention may be used in apparatuses other than the projection display apparatus of FIG. **13**. For example, the polarization beam splitter array in accordance with the present invention may also be applied to a projection display apparatus that does not project a color image, but projects a black-and-white image. In this case, compared to the apparatus of FIG. **13**, only one liquid crystal light valve needs to be used, and the color light separating means for separating a light beam into its three color components and a color light combining means for combining the three color components of the light beam are not required. In addition, the present invention can be applied to a projection-type color display apparatus using only one light valve. Further, the present invention can be applied to a projection display apparatus using a reflective light valve or an image display apparatus using the polarization illuminating light of a rear-type display apparatus or the like.

What is claimed is:

1. An optical element comprising:

two polarization conversion element arrays for converting polarized light with random polarization directions to one type of polarized light,

wherein each of said two polarization conversion element arrays includes polarization separating surfaces for separating the polarized light with random polarization directions into two types of linearly polarized light and reflecting surfaces for reflecting one of the two types of the linearly polarized light produced by separation by said polarization separating surfaces, said polarization separating surfaces and said reflecting surfaces being alternately arranged between light-transmissive members, and

wherein said two polarization element arrays are separated by a predetermined space with no elements disposed between the two polarization conversion element arrays, said polarization separating surfaces of one of said two polarization conversion element arrays are arranged opposite to said polarization separating surfaces of the other of said two polarization conversion element arrays with respect to the predetermined space.

2. An optical element according to claim 1, further comprising a dummy region including neither said polarization separating surfaces nor said reflecting surfaces, said

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dummy region being made of a transmissive material and disposed on an end at a predetermined side of each of said two polarization conversion element arrays.

3. An optical element according to claim 1, further comprising a region including neither said polarization separating surfaces nor said reflecting surfaces, said region being made of a transmissive material and disposed on an end opposite to a predetermined space side of each of said two polarization conversion element arrays.

4. An optical element comprising:

a lens array composed of a plurality of lenses disposed in a matrix; and

two polarization conversion element arrays, affixed to one surface of said lens array, the two polarization conversion element arrays converting polarized light with random polarization directions to one type of polarized light,

wherein each of said polarization conversion element arrays include polarization separating surfaces for separating the polarized light with random polarization directions into two types of linearly polarized light and reflecting surfaces for reflecting one of the two types of the linearly polarized light produced by separation by said polarization separating surfaces, said polarization separating surfaces and said reflecting surfaces being alternately arranged between light-transmissive members, and

wherein said two polarization conversion element arrays are separated by a predetermined space with no elements disposed between the two polarization conversion element arrays, said polarization separating surfaces of one of said two polarization conversion element arrays are arranged opposite to said polarization separating surfaces of the other of said two polarization conversion element arrays with respect to the predetermined space.

5. An optical element according to claim 4, further comprising a dummy region including neither said polarization separating surfaces nor said reflecting surfaces, said dummy region being made of a transmissive material and disposed on an end at a predetermined space side of each of said two polarization conversion element arrays.

6. An optical element according to claim 5, wherein a corner at the side of the predetermined space side of said dummy region is removed.

7. An optical element according to claim 4, further comprising a region including neither said polarization separating surfaces nor said reflecting surfaces, said region being made of a transmissive material and disposed on an end opposite to a predetermined space side of each of said two polarization conversion element arrays.

8. An optical element according to claim 4, wherein said polarization separating surfaces and said reflecting surfaces of each of said polarization conversion element arrays are arranged along a direction of arrangement at a pitch that is greater than  $\frac{1}{2}$  an arrangement pitch of said lens array disposed along the direction of arrangement of said polarization separating surfaces and said reflecting surfaces.

9. A polarization illumination device comprising:

a light source; and

an optical element for converting light from said light source into one type of polarized light, wherein said optical element includes a lens array composed of a plurality of lenses disposed in a matrix; and

two polarization conversion element arrays, affixed to one surface of said lens array, for converting polarized light

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with random polarization directions to one type of polarized light,

wherein each of said two polarization conversion element arrays includes polarization separating surfaces for separating the polarized light with random polarization directions into two types of linearly polarized light and reflecting surfaces for reflecting one of the two types of the linearly polarized light produced by separation by said polarization separating surfaces, said polarization separating surfaces and said reflecting surfaces being alternately arranged between light-transmissive members, and

wherein said two polarization conversion element arrays are separated by a predetermined space with no elements disposed between the two polarization conversion element arrays, said polarization separating surfaces of one of said two polarization conversion element arrays are arranged opposite to said polarization separating surfaces of the other of said two polarization conversion element arrays with respect to the predetermined space.

10. A polarization illumination device according to claim 9, further comprising a dummy region including neither said polarization separating surfaces nor said reflecting surfaces, said dummy region being made of a transmissive material and disposed on an end at a predetermined space side of each of said two polarization conversion element arrays.

11. A polarization illumination device according to claim 10, wherein a corner at the predetermined space side of said dummy region is removed.

12. A polarization illumination device according to claim 9, further comprising a region including neither said polarization separating surfaces nor said reflecting surfaces, said region being made of a transmissive material and disposed on an end opposite to a predetermined space side of each of said two polarization conversion element arrays.

13. A polarization illumination device according to claim 9, wherein said polarization separating surfaces are arranged in accordance with a distribution of light leaving said lens array.

14. A polarization illumination device according to claim 9, further comprising a polarization separating surface disposed at a location closest to the predetermined space between said two polarization conversion element arrays, such that a center of said closest polarization separating surface is disposed closer towards the predetermined space than a center of a lens among said plurality of lenses of said lens array which is disposed closest to said closest polarization separating surface.

15. A polarization illumination device according to claim 9, wherein said polarization separating surfaces and said reflecting surfaces of each of said polarization conversion element arrays are arranged along a direction of arrangement at a pitch that is greater than  $\frac{1}{2}$  an arrangement pitch of said lens array disposed along the direction of arrangement of said polarization separating surfaces and said reflecting surfaces.

16. A [projection display apparatus] *projector* comprising: a polarization illumination device;

a modulating [means for modulating] *device that modulates light from said polarization illumination device in accordance with a received image signal; and*

a projection [optical means for projecting] *lens that projects the light beam modulated by said modulating [means] device,*

wherein said polarization illumination device includes a light source; and an optical element for converting light

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from said light source incident thereupon to light with a predetermined polarization direction that leaves said optical element, and

wherein said optical element includes a lens array composed of a plurality of lenses disposed in a matrix; and two polarization conversion element arrays, affixed to one surface of said lens array, for converting polarized light with random polarization directions to one type of polarized light,

wherein each of said two polarization conversion element arrays includes polarization separating surfaces for separating the polarized light with random polarization directions into two types of linearly polarized light and reflecting surfaces for reflecting one of the two types of the linearly polarized light produced by separation by said polarization separating surfaces, said polarization separating surfaces and said reflecting surfaces being alternately arranged between light-transmissive members, and

wherein said two polarization conversion element arrays are separated by a predetermined space with no elements disposed between the two polarization conversion element arrays, said polarization separating surfaces of one of said two polarization conversion element arrays are arranged opposite to said polarization separating surfaces of the other of said two polarization conversion element arrays with respect to the predetermined space.

17. A [projection display apparatus] *projector* according to claim 16, further comprising a dummy region including neither said polarization separating surfaces nor said reflecting surfaces, said dummy region being made of a transmissive material and disposed on an end at a predetermined space side of each of said two polarization conversion element arrays.

18. A [projection display apparatus] *projector* according to claim 17, wherein a corner at the predetermined space side of said dummy region is removed.

19. A [projection display apparatus] *projector* according to claim 16, further comprising a region including neither said polarization separating surfaces nor said reflecting surfaces, said region being made of a transmissive material and disposed on an end opposite to a predetermined space side of each of said two polarization conversion element arrays.

20. A [projection display apparatus] *projector* according to claim 16, wherein said polarization separating surfaces are arranged in accordance with a distribution of light leaving said lens array.

21. A [projection display apparatus] *projector* according to claim 16, further comprising a polarization separating surface disposed at a location closest to the predetermined space between said two polarization conversion element arrays, such that a center of said closest polarization separating surface is disposed closer towards the predetermined space than a center axis of a lens among said plurality of lenses of said lens array which is disposed closest to said chosen polarization separating surface.

22. A [projection display apparatus] *projector* according to claim 16, wherein said polarization separating surfaces and said reflecting surfaces along the light-incoming surface of each of said polarization conversion element arrays are arranged along a direction of arrangement at a pitch that is greater than  $\frac{1}{2}$  an arrangement pitch of said lens array disposed along the direction of arrangement of said polarization separating surfaces and said reflecting surfaces.

23. *The optical element according to claim 4, wherein each of the polarization separating surfaces being arranged*

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*such that a center of each polarization separating surface is disposed closest to a peak of a distribution of light coming out of the lens array.*

*24. The optical element according to claim 4, further comprising a polarization separating surface disposed at a location closest to the predetermined space between said two polarization conversion element arrays, such that a*

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*center of said closest polarization separating surface is disposed closer towards the predetermined space than a center axis of a lens among said plurality of lenses of said lens array which is disposed closest to said closest polarization separating surface.*

\* \* \* \* \*