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Torii

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(54) **OCULAR OPTICAL SYSTEM AND IMAGE DISPLAY APPARATUS**

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G02B 5/30	(2006.01)
G02B 25/00	(2006.01)
G06F 1/16	(2006.01)
G02B 13/18	(2006.01)

(52) **U.S. Cl.**

CPC ***G02B 25/001*** (2013.01); ***G02B 5/3083*** (2013.01); ***G02B 27/28*** (2013.01); ***G06F 1/163*** (2013.01); *G02B 13/18* (2013.01)

(58) **Field of Classification Search**

CPC G02B 5/3083; G02B 27/28; G02B 27/017; G02B 27/0172; G02B 3/001; G02B 3/18; G02B 17/0856; G02B 2027/0178

See application file for complete search history.

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(57) **ABSTRACT**

An ocular optical system that guides light from a display element to an eye of an observer includes a first phase plate, a second phase plate, one or more lenses, and a polarization separation element configured to reflect first linearly polarized light and allow second linearly polarized light to pass therethrough in a polarization direction orthogonal to a polarization direction of the first linearly polarized light. The second phase plate is in contact with and held by a predetermined lens among the one or more lenses. The first phase plate has a shape that determines a phase. An outer shape of the predetermined lens is a rotationally symmetric shape. The second phase plate has a rotationally symmetric shaped portion and a non-rotationally symmetric shaped portion.

13 Claims, 7 Drawing Sheets

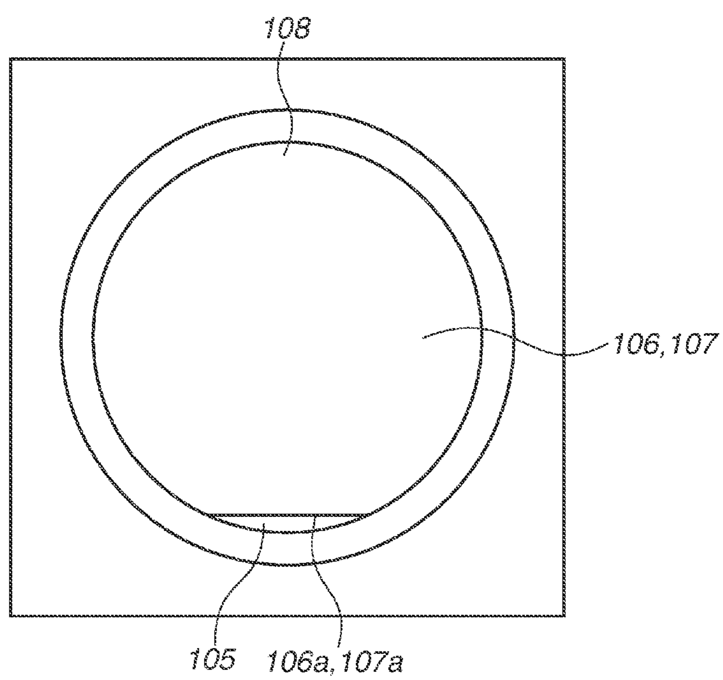


FIG.1

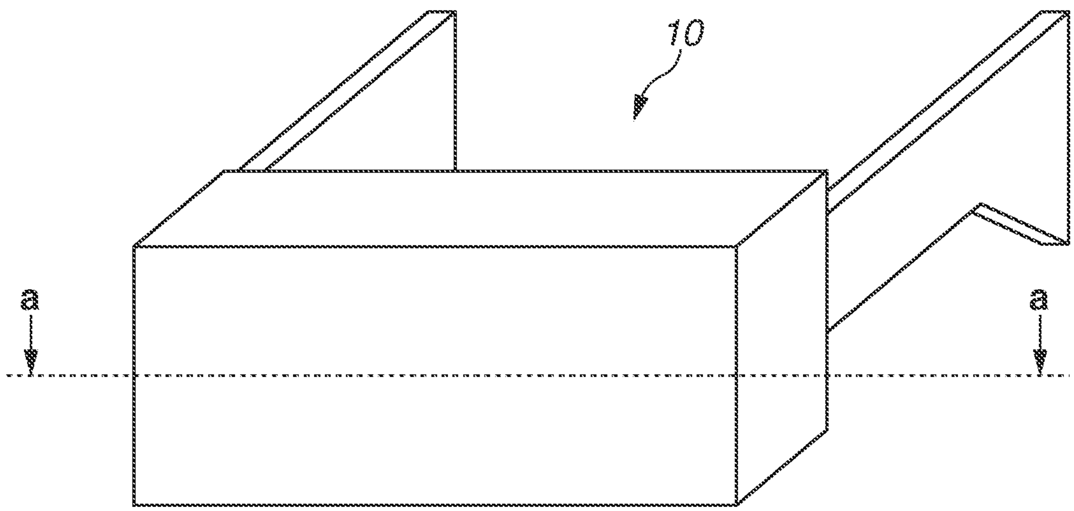


FIG.2

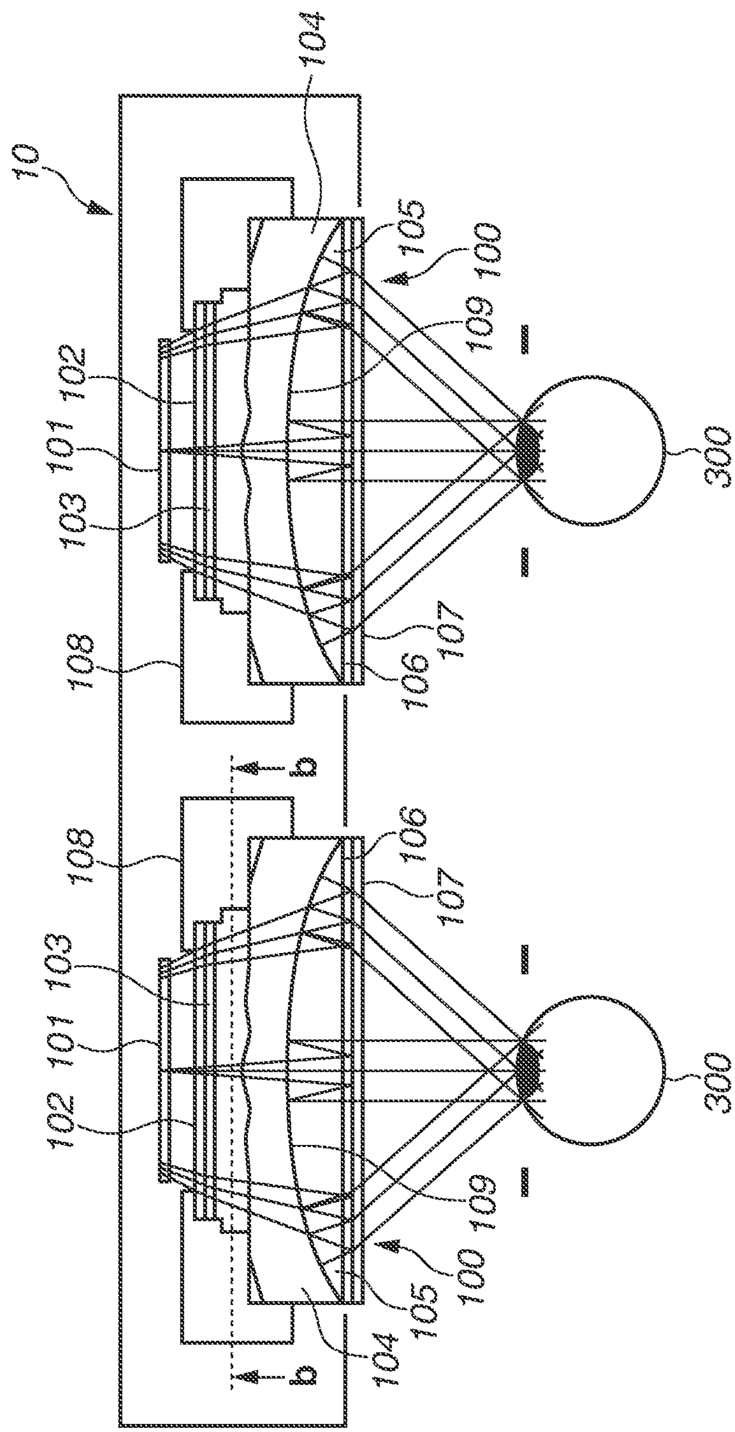


FIG.3

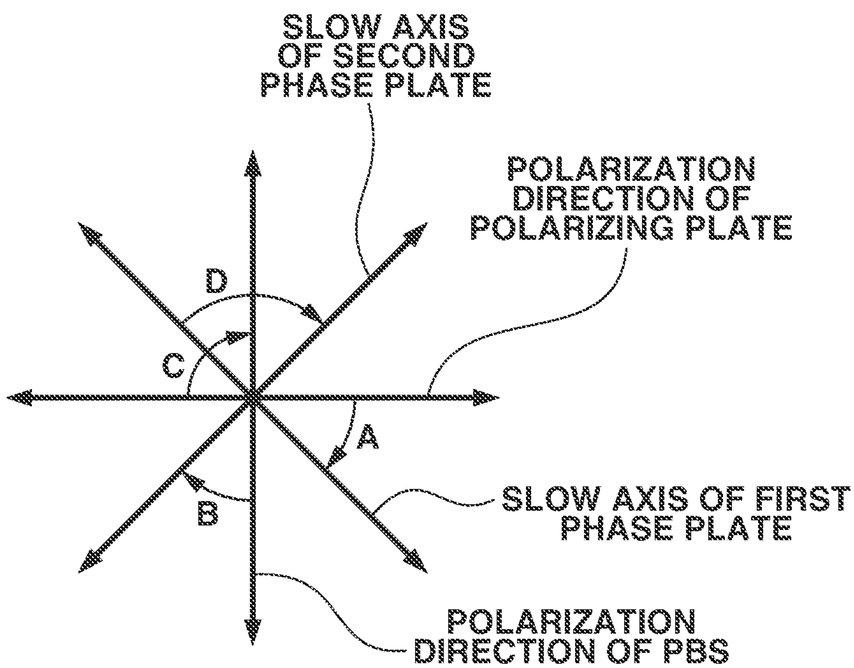

SLOW AXIS
OF SECOND
PHASE PLATE
POLARIZATION
DIRECTION OF
POLARIZING PLATE
D
C
A
B
SLOW AXIS OF FIRST
PHASE PLATE
POLARIZATION
DIRECTION OF PBS

FIG.4

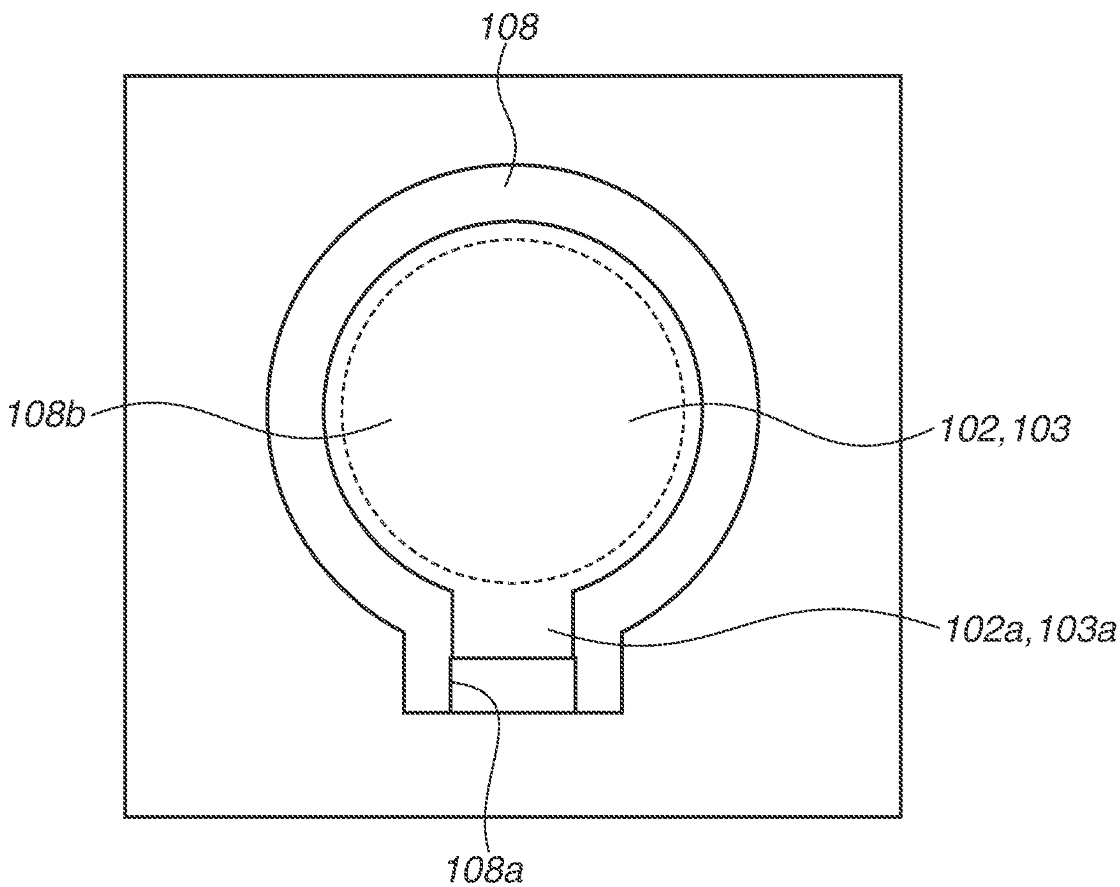


FIG.5

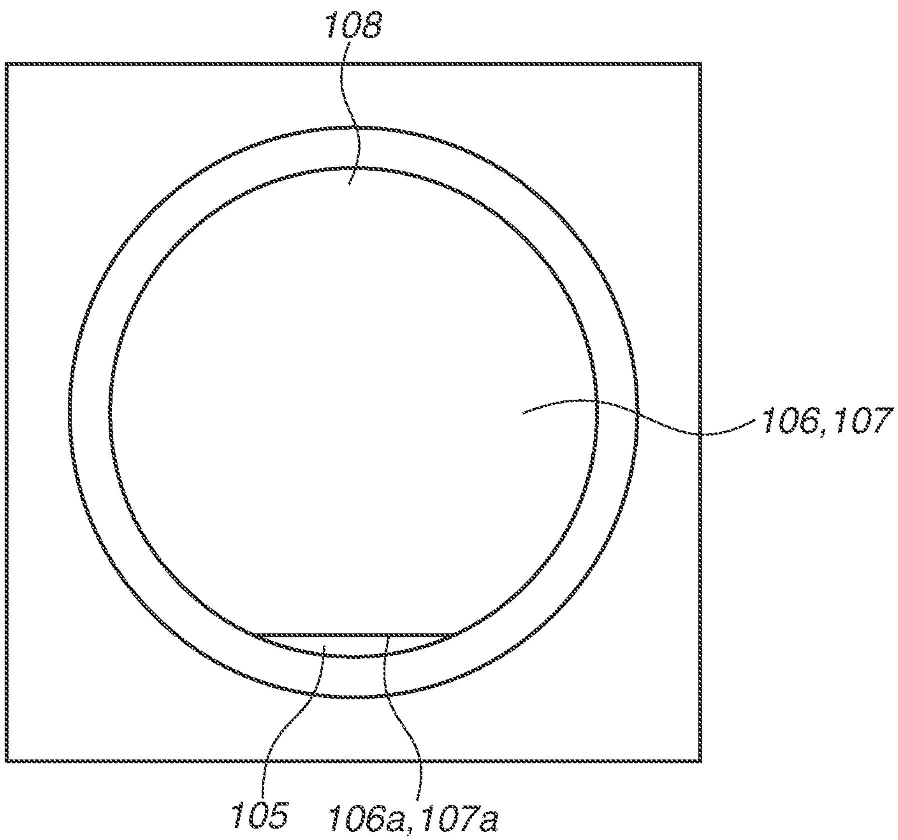
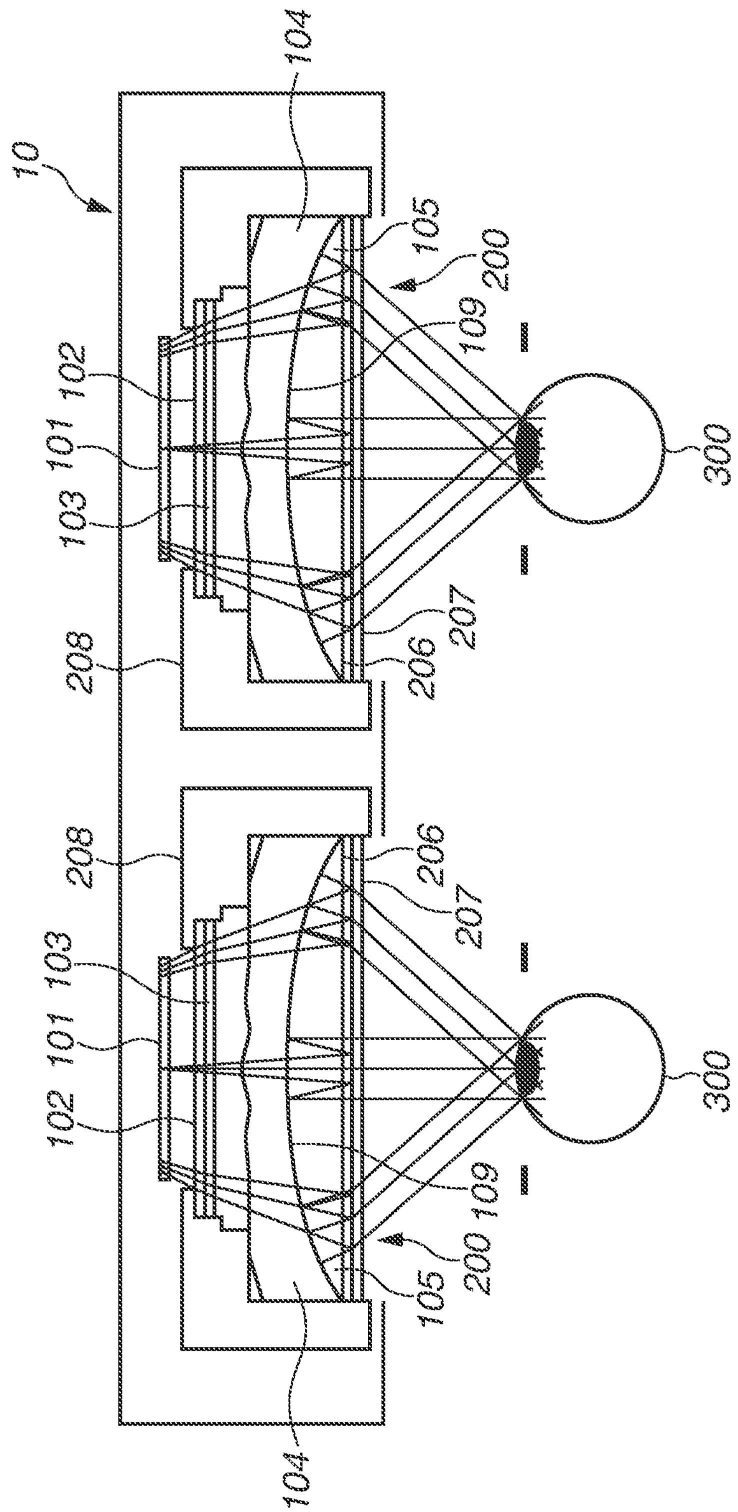


FIG.6


10
104
105
200
109
102
101
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208
207
206
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200
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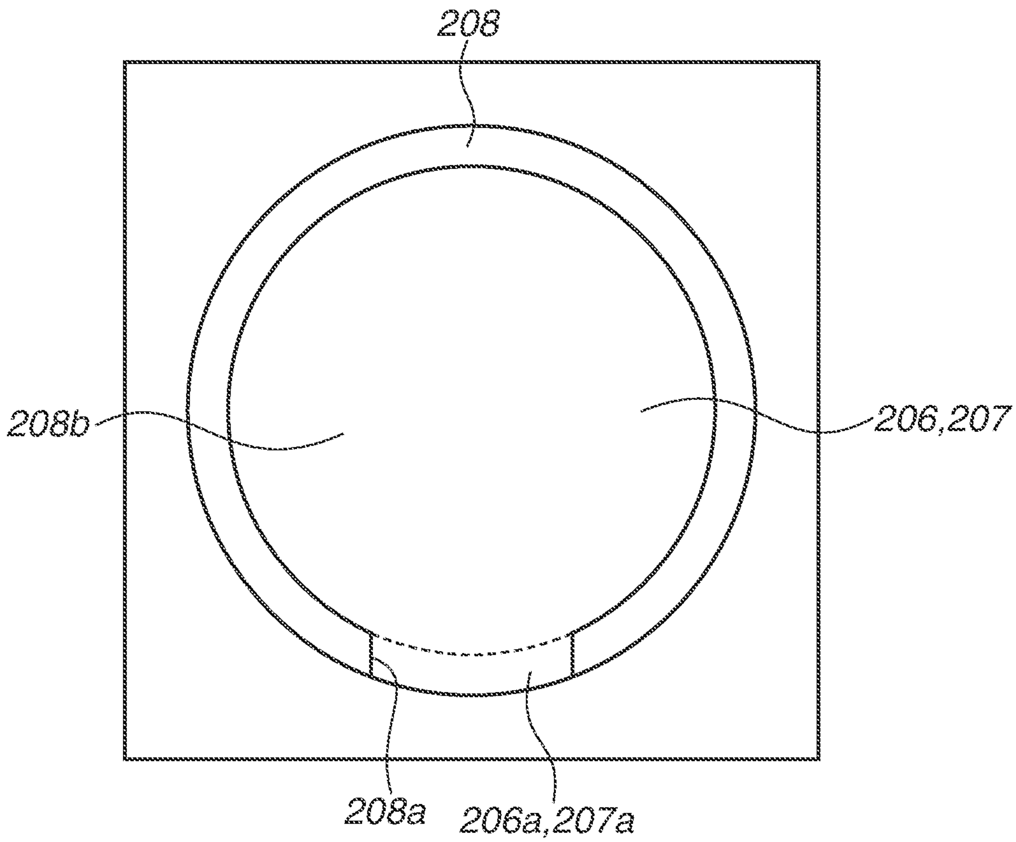
300
104

FIG.7



OCULAR OPTICAL SYSTEM AND IMAGE DISPLAY APPARATUS

BACKGROUND

Field of the Disclosure

The present disclosure relates to an ocular optical system and an image display apparatus using the same.

Description of the Related Art

A polarizing optical system that realizes reduction in size and weight thereof with a folded optical path using polarized light is known as a configuration of an optical system, as discussed in Japanese Patent Application Laid-Open No. 2020-85956. The polarizing optical system is configured with two phase plates and lenses and is also used in a head mounted display (HMD) that is required to reduce size and weight of the product. In a case where two phase plates are thus installed, a phase shift between the phase plates is to be reduced from a viewpoint of optical performance.

SUMMARY

According to an aspect of the present disclosure, an ocular optical system that guides light from a display element to an eye of an observer includes a first phase plate, a second phase plate, one or more lenses, and a polarization separation element configured to reflect first linearly polarized light and allow second linearly polarized light to pass therethrough in a polarization direction orthogonal to a polarization direction of the first linearly polarized light. The second phase plate is in contact with and held by a predetermined lens among the one or more lenses. The first phase plate has a shape that determines a phase. An outer shape of the predetermined lens is a rotationally symmetric shape. The second phase plate has a rotationally symmetric shaped portion and a non-rotationally symmetric shaped portion.

Further features of the present disclosure will become apparent from the following description of exemplary embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates an image display apparatus according to a first exemplary embodiment.

FIG. **2** is a sectional view of an ocular optical system according to the first exemplary embodiment.

FIG. **3** illustrates relationship of slow axes of phase plates, a polarization direction of a polarizing plate, and a polarization direction of a polarization separation element in the ocular optical system according to the first exemplary embodiment.

FIG. **4** illustrates a configuration for holding the polarizing plate and a first phase plate of the ocular optical system according to the first exemplary embodiment.

FIG. **5** illustrates a configuration for holding a second phase plate and a polarizing beam splitter (PBS) of the ocular optical system according to the first exemplary embodiment.

FIG. **6** is a sectional view of an ocular optical system according to a second exemplary embodiment.

FIG. **7** illustrates a configuration for holding a second phase plate and a PBS of the ocular optical system according to the second exemplary embodiment.

DESCRIPTION OF THE EMBODIMENTS

In a polarizing optical system, in order to make the size thereof more compact, for example, a phase plate which is arranged on an observer side (arranged adjacent to the observer) may be sometimes bonded to a lens.

However, in a case where an outer shape of the lens is a rotationally symmetric shape, it is difficult to determine a phase of the phase plate to be bonded to the lens, and optical performance may decrease due to degradation in a phase shift between the phase plates.

Exemplary embodiments of the present disclosure are made in consideration of the above-described issues.

The exemplary embodiments of the present disclosure will be described below with reference to the accompanying drawings.

A first exemplary embodiment of the present disclosure will be described. FIG. **1** illustrates an image display apparatus **10** according to the present exemplary embodiment. FIG. **2** is a cross-sectional view of the image display apparatus **10** taken along line a-a in FIG. **1**. The image display apparatus **10** includes left and right ocular optical systems **100** and is suitable for use in a head mounted display (HMD) and a hand held display (HHD) as illustrated in FIG. **1**.

The ocular optical systems **100** guide light from display elements **101** to the eyes **300** of a user who is an observer. The ocular optical system **100** magnifies and projects an original image displayed on the display element **101** as a virtual image and guides the virtual image to the eye **300** of the user. According to the present exemplary embodiment, the ocular optical systems **100** are configured as common components each having a common configuration so that it can be used for either the right or left eye, and are described below without distinction of right or left.

The respective ocular optical system **100** is a polarizing optical system in which an optical path is folded using polarized light. The optical path will now be described. As illustrated in FIG. **2**, a polarizing plate **102**, a first phase plate **103**, lenses **104** and **105**, a second phase plate **106**, and a polarizing beam splitter (PBS) **107** which is a polarization separation element are arranged in this order from a display element **101** side in the ocular optical system **100**. A lens barrel **108** holds the polarizing plate **102**, the first phase plate **103**, and the lens **104**.

Outer shapes of the lenses **104** and **105** are circular shapes having rotationally symmetric shapes. The lens **104** and the lens **105** are cemented, and a semitransparent mirror **109** is deposited on a surface of the lens **104** facing a lens **105**. The surface on which the semitransparent mirror **109** is deposited acts as a semi-transmissive reflective surface.

The first phase plate **103** and the second phase plate **106** are wavelength plates having a phase difference of $\lambda/4$. The polarizing plate **102** and the first phase plate **103** are bonded together. The second phase plate **106** and the PBS **107** are bonded together. The second phase plate **106** is held in contact with a user-side surface of the lens **105** in order to realize thinning of the ocular optical system **100**. According to the present exemplary embodiment, the lens **105** corresponds to a predetermined lens according to the present disclosure.

A polarization direction of light that is allowed to pass through the polarizing plate **102** (hereinafter, referred to as "polarization direction of the polarizing plate") is inclined at 45 degrees with respect to a slow axis of the first phase plate **103**. A polarization direction of light that is allowed to pass through the PBS **107** (hereinafter, referred to as "polarization direction of the PBS") is inclined at 45 degrees with respect to a slow axis of the second phase plate **106**. The polarization direction of the polarizing plate **102** and the polarization direction of the PBS **107** are orthogonal to each other.

In this case, light emitted from the display element **101** passes through the polarizing plate **102** and becomes linearly polarized light. The linearly polarized light then passes through the first phase plate **103** and becomes circular polarized light. The circular polarized light having passed through the first phase plate **103** passes through the semi-transparent mirror **109** and then the second phase plate **106**, and becomes linearly polarized light (referred to as first linearly polarized light). The polarization direction of the first linearly polarized light is orthogonal to the polarization direction of the PBS **107**, and the first linearly polarized light is reflected by the PBS **107**, passes through the second phase plate **106**, and becomes the circular polarized light. The circular polarized light passed through the second phase plate **106** is reflected by the semitransparent mirror **109**, passes through the second phase plate **106**, and becomes linearly polarized light (referred to as second linearly polarized light). Unlike the first linearly polarized light, the polarization direction of the second linearly polarized light coincides with the polarization direction of the PBS **107**, and the second linearly polarized light passes through the PBS **107** and is guided to the eye **300** of the user. The eye **300** of the user substantially coincides with an exit pupil of the ocular optical system **100**.

Thus, the polarizing optical system that folds an optical path using polarized light as described above can be thinned, shorten a focal length, thus realizing image observation with a wide angle of view.

As described above, ideally, as illustrated in FIG. **3**, (A) it is desirable that the slow axis of the first phase plate **103** is inclined at 45 degrees with respect to the polarization direction of the polarizing plate **102**. (B) It is also desirable that the slow axis of the second phase plate **106** is inclined at 45 degrees with respect to the polarization direction of the PBS **107**. (C) It is also desirable that the polarization direction of the PBS **107** is inclined at 90 degrees with respect to the polarization direction of the polarizing plate **102**. (D) It is also desirable that the slow axis of the second phase plate **106** is inclined at 90 degrees with respect to the slow axis of the first phase plate **103**. However, in reality, a phase shift occurs, resulting in a degradation in the optical performance from an ideal state.

Regarding the description (A), if the polarizing plate **102** and the first phase plate **103** each have a flat plate shape and are bonded together with an adhesive layer, the phase shift can be stably reduced to bonding accuracy of each component. Similarly, regarding the description (B), if the second phase plate **106** and the PBS **107** each have a flat plate shape and are bonded together with an adhesive layer, the phase shift can be stably reduced to bonding accuracy of each component.

By contrast, regarding the description (C), the polarizing plate **102** and the PBS **107** are components separate from each other, so that it is difficult to stably reduce the phase shift and that the respective phases are to be clarified. Similarly, regarding the description (D), the first phase plate **103** and the second phase plate **106** are components separated from each other, so that it is difficult to stably reduce the phase shift and that the respective phases are to be clarified. The phase shift in the state (C) has an effect of increasing a ratio of ghost light to normal light. The phase shift in the state (D) has an effect of color shift.

A configuration for reducing the phase shift in the states (C) and (D) will be described below.

A configuration for holding the polarizing plate **102** and the first phase plate **103** with the lens barrel **108** will now be described with reference to FIG. **4**. FIG. **4** is a sectional view taken along line b-b in FIG. **2**.

The polarizing plate **102** and the first phase plate **103** have the same flat plate shape and are bonded together by the adhesive layer to form an integrated component. The flat plate shape partially has a non-rotationally symmetric shape that determines the phase, based on a circular shape that is rotationally symmetric. More specifically, a partially thickened tab portion **102***a*, which is a projection portion that projects laterally, is provided on a side portion of the polarizing plate **102**. A partially thickened tab portion **103***a*, which is a projection portion that projects laterally, is provided on a side portion of the first phase plate **103**. The angle between the polarization direction of the polarizing plate **102** and the slow axis of the first phase plate **103** is specified based on the tab portions **102***a* and **103***a*.

The lens barrel **108** corresponds to the rotationally symmetric shape of the polarizing plate **102** and the first phase plate **103** and has a hole **108***b* that does not block the light from the display element **101** and a groove **108***a* into which the tab portions **102***a* and **103***a* are fitted. Thus, the phase of the polarizing plate **102** and the phase of the first phase plate **103** can be specified with respect to the lens barrel **108**. The polarizing plate **102** and the first phase plate **103**, which are formed as the integrated component, may be bonded to the lens barrel **108** with an adhesive layer, and a holding structure is not limited.

Next, a configuration for holding the second phase plate **106** and the PBS **107**, which are held in contact with the lens **105**, will be described with reference to FIG. **5**. FIG. **5** illustrates the ocular optical system **100** viewed from a side of the eyes **300** of the user.

The second phase plate **106** and the PBS **107** have the same flat plate shape and are bonded together with the adhesive layer to form an integrated component. The flat plate shape partially has a non-rotationally symmetric shape that determines the phase, based on a circular shape that is a rotationally symmetric shape. More specifically, a partially thinned D-cut portion **106***a* is formed by a part of a side portion of the second phase plate **106** being cut out. A partially thinned D-cut portion **107***a* is formed by a part of a side portion of the PBS **107** being cut out. The slow axis of the second phase plate **106** and the polarization direction of the PBS **107** are specified based on the D-cut portions **106***a* and **107***a*.

The second phase plate **106** is held in contact with the lens **105** so that the D-cut portions **106***a* and **107***a* are horizontal. Thus, the phase of the second phase plate **106** and the phase of the PBS **107** is specifiable with respect to the lens barrel **108**. The second phase plate **106** may be bonded to the lens **105** with an adhesive layer, and a contact holding structure thereof is not limited. After the second phase plate **106** integrated with the PBS **107** is bonded to the lens **105**, the phase shifts of the second phase plate **106** and the PBS **107** with respect to the lens barrel **108** can be detected based on degrees of respective inclinations of the D-cut portion **106***a* of the second phase plate **106** and the D-cut portion **107***a* of the PBS **107**, thus clarifying the phase shifts.

The configuration as described above enables clarification of the phase shifts regarding descriptions (C) and (D).

Thus, an angle formed by the polarization direction of the polarizing plate **102** and the polarization direction of the PBS **107** can be made substantially orthogonal (e.g., in a range of 90±5 degrees). An angle formed by the slow axis of the first phase plate **103** and the slow axis of the second phase plate **106** can be made substantially orthogonal (e.g., in a range of 90±5 degrees). The phase shifts in the descriptions (C) and (D) are reduced in this way, and thus the ocular optical system **100** that prevents degradation in the optical performance can be provided.

In the present exemplary embodiment, the display element **101** emits unpolarized light as an organic electroluminescent (EL) display, but may emit linearly polarized light as a liquid crystal display. In a case of the display element that emits the linearly polarized light, the polarizing plate **102** becomes unnecessary, and the thickness and cost can be reduced. However, it is desirable that the phase of the display element **101** is adjusted so as to reduce the phase shifts regarding the descriptions (A) and (C)

It is desirable that the lenses **104** and **105** are made from resin from the viewpoint of weight reduction, but may be made of glass. In the case of glass, birefringence of the lenses **104** and **105** becomes very small, so that high definition image observation becomes practicable. Further, the use of a plano-convex shape aspheric lens as the lens **105**, a double-sided aspheric lens as the lens **104** enhances an aberration correction effect. Since the outer shapes of the lenses **104** and **105** are rotationally symmetric, it is not necessary to determine the phase, but the optical performance may be degraded due to a gate. Thus, it is desirable that the gate is arranged in a smaller one of a horizontal angle of view and a vertical angle of view that are determined based on the ocular optical system **100** and the display element **101**. The lens **105** may be in contact with the lens barrel **108**. Ultraviolet (UV) adhesive and the like may be used for a structure of the lens barrel **108** holding the lens **104** or the lens **105**, and this holding structure is not limited.

There is concern about vignetting with respect to an optical effective diameter due to the D-cut portions **106*a*** and **107*a***. The D-cut portions **106*a*** and **107*a*** are arranged in the smaller one of the horizontal angle of view and the vertical angle of view that are determined based on the ocular optical system **100** and the display element **101**, and thus the influence of vignetting can be reduced or eliminated. Since the rotationally symmetric shape of the second phase plate **106** is the same as the rotationally symmetric shape of the lens **105**, it is easy to determine positions thereof. Further, there is no step between the second phase plate **106** and the lens **105**, and thus the definition can be improved. The ocular optical system **100** is the common component for the right and left eyes, so that the D-cut portions **106*a*** and **107*a*** in the ocular optical system **100** for the left eye and the D-cut portions **106*a*** and **107*a*** in the ocular optical system **100** for the right eye are placed at substantially the same positions.

The non-rotationally symmetric shape partially included in the first phase plate **103** is the tab portion **103*a***, but may be a D-cut portion. In this case, it is desirable that the D-cut portion is arranged in the smaller one of the horizontal angle of view and the vertical angle of view determined based on the ocular optical system **100** and the display element **101** as described above. The first phase plate **103** may not necessarily be based on the rotationally symmetric shape, and only needs to have a shape that determines the phase. The polarizing plate **102** and the first phase plate **103** which are the integrated component only need to be present between the lens **104** and the display element **101** and may not necessarily be held by the lens barrel **108**, but are to be able to detect the degree of inclination of the shape that determines the phase.

The non-rotationally symmetric shapes partially included in the second phase plate **106** and the PBS **107** are the D-cut portions, so that the lens barrel **108** does not necessarily need to come into contact with the second phase plate **106** or the PBS **107** to determine the phase. Thus, the size and weight of the lens barrel **108** can be further reduced, but the shape may be extended in an optical axis direction in order to block external light incident on the inside from an outer diameter of the lens **104**. The lens barrel **108** is placed away from the eyes **300** of the user across the PBS **107** in the optical axis direction, so that a surface closest to the eyes **300** of the user can be set to the PBS **107** that is a final optical surface. Thus, in a case where an eye relief of the ocular optical system **100** is a long eye relief in consideration of a user with glasses, the components of the image display apparatus **10** do not substantially shorten the eye relief. The components of the image display apparatus **10** may be set slightly closer to the eyes **300** of the user than the PBS **107** to the eyes **300** so that, when the image display apparatus **10** falls, the ocular optical system **100** does not hit first, while influence on the user with glasses are kept minimized.

The rotationally symmetric shape of the lens **105** and the second phase plate **106** that is held in contact with the lens **105** has been described to be the circular shape, but the shape is not limited to this example. In an n-fold rotationally symmetric shape, it becomes difficult to determine the phase of the second phase plate **106** to be bonded to the lens **105** particularly in a case where "n" is three or more, in such a case, it is desirable to apply the present disclosure.

A second exemplary embodiment of the present disclosure will be described below. Next, an ocular optical system **200** according to the present exemplary embodiment will be described with reference to FIGS. **6** and **7**. Configurations similar to those according to the first exemplary embodiment are denoted by the same reference numerals, and the descriptions thereof are omitted.

FIG. **6** is a sectional view of the ocular optical system **200** and corresponds to FIG. **2** according to the first exemplary embodiment. As illustrated in FIG. **6**, the polarizing plate **102**, the first phase plate **103**, the lenses **104** and **105**, a second phase plate **206**, and a PBS **207** are arranged in this order from the display element **101** side in the ocular optical system **200**. A lens barrel **208** holds the polarizing plate **102**, the first phase plate **103**, the lens **104**, the second phase plate **206**, and the PBS **207**.

Inclinations of the polarization direction of the polarizing plate **102**, the slow axis of the first phase plate **103**, the slow axis of the second phase plate **206**, and the polarization direction of the PBS **207** are the same as those according to the first exemplary embodiment.

A configuration for holding the polarizing plate **102** and the first phase plate **103** by the lens barrel **208** is similar to that of the first exemplary embodiment.

Next, a configuration for holding the second phase plate **206** and the PBS **207** which are held in contact with the lens **105** will be described with reference to FIG. **7**. FIG. **7** illustrates the ocular optical system **200** viewed from the eye **300** of the user.

The second phase plate **206** and the PBS **207** have the same flat plate shape and are bonded together with an adhesive layer to form an integrated component. The flat plate shape partially has a non-rotationally symmetric shape that determines the phase, based on a circular shape that is rotationally symmetric. More specifically, a partially thickened tab portion **206*a*** which is a projection portion that projects laterally is provided on a side portion of the second phase plate **206**. A partially thickened tab portion **207***a* which is a projection portion that projects laterally is provided on a side portion of the PBS **207**. The slow axis of the second phase plate **206** and the polarization direction of the light are specified based on the tab portions **206***a* and **207***a*.

The lens barrel **208** corresponds to the rotationally symmetric shapes of the second phase plate **206** and the PBS **207** and has a hole **208***b* that does not block the light from the display element **101** and a groove **208***a* into which the tab portions **206***a* and **207***a* are fitted. Thus, the phase of the second phase plate **206** and the phase of the PBS **207** can be specified with respect to the lens barrel **208**. The second phase plate **206** may be bonded to the lens **105** with an adhesive layer, and the contact holding structure thereof is not limited.

According to the second exemplary embodiment, the lens barrel **208** has a shape that determines the phases of the polarizing plate **102**, the first phase plate **103**, the second phase plate **206**, and the PBS **207** in a single component, so that the phase shifts in the descriptions (C) and (D) can be more easily reduced than the first exemplary embodiment.

While the present disclosure has been described with reference to exemplary embodiments, it is to be understood that the disclosure is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

This application claims the benefit of priority from Japanese Patent Application No. 2021-160937, filed Sep. 30, 2021, which is hereby incorporated by reference herein in its entirety.

What is claimed is:

1. An image display apparatus comprising:

a display element; and

an ocular optical system configured to guide light from the display element to an eye of an observer, the ocular optical system including:

a first phase plate;

a second phase plate;

one or more lenses; and

a polarization separation element configured to reflect first linearly polarized light and allow second linearly polarized light to pass therethrough in a polarization direction orthogonal to a polarization direction of the first linearly polarized light,

wherein the second phase plate is in contact with and held by a predetermined lens among the one or more lenses,

wherein an outer shape of the predetermined lens is a shape based on a rotationally symmetric shape,

wherein the second phase plate has a shape based on a rotationally symmetric shape and includes a D-cut portion, and

wherein the D-cut portion is arranged in a smaller one of a horizontal angle of view and a vertical angle of view that are determined by the ocular optical system and the display element.

2. The image display apparatus according to claim **1**, wherein the second phase plate and the polarization separation element have a same shape and are bonded together.

3. The image display apparatus according to claim **1**, wherein the rotationally symmetric shape of the second phase plate is the same as the rotationally symmetric shape of the predetermined lens.

4. The image display apparatus according to claim **1**, wherein an angle formed by a slow axis of the first phase plate and a slow axis of the second phase plate is 90±5 degrees.

5. The image display apparatus according to claim **1**, further comprising a polarizing plate configured to allow light from the display element to pass therethrough.

6. The image display apparatus according to claim **5**, wherein the polarizing plate and the first phase plate have a same shape and are bonded together.

7. The image display apparatus according to claim **5**, wherein an angle formed by a polarization direction of the polarizing plate and a polarization direction of the polarization separation element is 90±5 degrees.

8. The image display apparatus according to claim **1**, wherein the first phase plate is arranged adjacent to the display element, and the second phase plate is arranged adjacent to the observer.

9. The image display apparatus according to claim **1**, further comprising a semi-transmissive reflective surface that allows light from the first phase plate to pass therethrough and reflects light from the second phase plate.

10. The image display apparatus according to claim **1**, wherein the display element emits unpolarized light.

11. The image display apparatus according to claim **1**, wherein a gate of the lens is arranged in a smaller one of a horizontal angle of view and a vertical angle of view that are determined by the ocular optical system and the display element.

12. The image display apparatus according to claim **1**, wherein the ocular optical system for a left eye and the ocular optical system for a right eye are configured as a common component.

13. The image display apparatus according to claim **1**, wherein the first phase plate has a shape that defines an arrangement of a slow axis of the first phase plate.

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