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Inventor(s)	Mitobe; Fumitake et al.

Optical element and image display apparatus

Abstract

An optical element includes a light guide plate, an incidence portion, and an emission portion, in which the incidence/emission portion includes an $\Lambda 1$ diffraction element having a diffraction period $\Lambda 1$, an $\Lambda 2$ diffraction element having a diffraction period $\Lambda 2$, and an $\Lambda 3$ diffraction element having a diffraction period $\Lambda 3$, “ $\Lambda 1:\Lambda 2:\Lambda 3=1:1\sqrt{2}\pm 0.015:1/2\pm 0.015$ ” is satisfied, an angle between periodic directions of the $\Lambda 1$ diffraction element and the $\Lambda 2$ diffraction element and an angle between periodic directions of the $\Lambda 2$ diffraction element and the $\Lambda 3$ diffraction element is 45° or $135^\circ (\pm 0.5^\circ)$, and an angle between the periodic directions of the $\Lambda 2$ diffraction elements in the incidence portion and the emission portion is any one of 0° , 90° , 180° , or $270^\circ (\pm 0.5^\circ)$.

Inventors: Mitobe; Fumitake (Minamiashigara, JP), Sasata; Katsumi (Minamiashigara, JP), Sato; Hiroshi (Minamiashigara, JP), Watano; Akiko (Minamiashigara, JP), Saitoh; Yukito (Minamiashigara, JP)

Applicant: FUJIFILM Corporation (Tokyo, JP)

Family ID: 1000008763796

Assignee: FUJIFILM Corporation (Tokyo, JP)

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Primary Examiner: Briggs; Nathanael R

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a Continuation of PCT International Application No. PCT/JP2021/022616 filed on Jun. 15, 2021, which claims priority under 35 U.S.C § 119(a) to Japanese Patent Application No. 2020-106014 filed on Jun. 19, 2020. Each of the above application(s) is hereby expressly incorporated by reference, in its entirety, into the present application.

BACKGROUND OF THE INVENTION

1. Field of the Invention

(1) The present invention relates to an optical element in which light is incident, propagates, and is emitted and an image display apparatus including the optical element.

2. Description of the Related Art

(2) Recently, as described in Bernard C. Kress et al., Towards the Ultimate Mixed Reality Experience: HoloLens Display Architecture Choices, SID 2017 DIGEST, pp. 127-131, augmented reality (AR) glasses that display a virtual image and various information or the like to be superimposed on a scene that is actually being seen have been put into practice. The AR glasses are also called, for example, smart glasses or a head mounted display (HMD).

(3) As described in Bernard C. Kress et al., Towards the Ultimate Mixed Reality Experience: HoloLens Display Architecture Choices, SID 2017 DIGEST, pp. 127-131, in AR glasses, for example, an image displayed by a display (optical engine) is incident into one end of a light guide plate, propagates in the light guide plate, and is emitted from another end of the light guide plate such that a virtual image is displayed to be superimposed on a scene that a user is actually seeing.

(4) In AR glasses, light (projection light) projected from a display is diffracted (refracted) using a diffraction element to be incident into one end part of a light guide plate. As a result, the light is introduced into the light guide plate at an angle such that the light is totally reflected and propagates in the light guide plate. The light propagating in the light guide plate is also diffracted by the diffraction element in the other end part of the light guide plate and is emitted from the light guide plate to an observation position by the user.

(5) Here, in the AR glasses disclosed in Bernard C. Kress et al., Towards the Ultimate Mixed Reality Experience: HoloLens Display Architecture Choices, SID 2017 DIGEST, pp. 127-131, in a case where a full color image consisting of light components of three colors including red, green, and blue is displayed, three light guide plates including a light guide plate for a blue image, a light guide plate for a green image, and a light guide plate for a red image are used.

(6) However, in a case where the number of the light guide plates increases, the size of AR glasses increases, and the weight thereof also increases. Therefore, it is preferable that the number of light guide plates used in AR glasses is small, and AR glasses including one light guide plate is desired.

(7) On the other hand, WO2017/180403A describes AR glasses where an image consisting of light components of three colors including red, green, and blue is emitted from a display, and each of the light components is diffracted by an incidence diffraction element to be incident into one light guide plate, propagates in the light guide plate, and is emitted from the light guide plate to an observation position of a user by an emission diffraction element such that the images of the three light components are superimposed on each other and are displayed. As a result, a color image can be displayed.

SUMMARY OF THE INVENTION

(8) For the AR glasses, it is required that an image in a wide region of a display screen of a display can be observed without a user changing a visual line, that is, a field of view (FOV) is wide.

- (9) Accordingly, in the AR glasses described in WO2017/180403A, light that is incident from the incidence diffraction element and propagates in the light guide plate is further diffracted by an intermediate diffraction element, propagates in the light guide plate, and is emitted by the emission diffraction element.
- (10) In the AR glasses described in WO2017/180403A, an emission region of light from the emission diffraction element is expanded to expand the FOV.
- (11) In addition, for AR glasses, it is required that the FOV is wide and an appropriate image can be observed without occurrence of blurring, double images, color shift, and the like in the image, that is, an appropriate image can be observed without occurrence of so-called crosstalk.
- (12) However, in AR glasses including one light guide plate, crosstalk is likely to occur. In addition, as the FOV is wider, crosstalk is more likely to occur. Therefore, AR glasses where a wide FOV is realized using one light guide plate while suppressing crosstalk are desired to appear.
- (13) An object of the present invention is to solve the above-described problem of the related art and to provide an optical element that is used for AR glasses or the like and where a wider FOV can be realized using one light guide plate while suppressing crosstalk, and an image display apparatus including the optical element.
- (14) In order to achieve the object, the present invention has the following configurations.
- (15) [1] An optical element comprising: a light guide plate; an incidence portion that causes light to be incident into the light guide plate; and an emission portion that emits light from the light guide plate, wherein the incidence portion includes 6 or more diffraction elements, the emission portion includes 8 or more diffraction elements, each of the incidence portion and the emission portion includes, as the diffraction elements, a $\Lambda 1$ diffraction element where a period in a diffraction structure is $\Lambda 1$, a $\Lambda 2$ diffraction element where a period in a diffraction structure is $\Lambda 2$, and a $\Lambda 3$ diffraction element where a period in a diffraction structure is $\Lambda 3$, the diffraction period $\Lambda 1$, the diffraction period $\Lambda 2$, and the diffraction period $\Lambda 3$ satisfy a relationship of " $\Lambda 1:\Lambda 2:\Lambda 3=1:1/\sqrt{2}\pm 0.015:1/2\pm 0.015$ ", an angle between a periodic direction of the diffraction structure of the $\Lambda 1$ diffraction element and a periodic direction of the diffraction structure of the $\Lambda 2$ diffraction element and an angle between a periodic direction of the diffraction structure of the $\Lambda 2$ diffraction element and a periodic direction of the diffraction structure of the $\Lambda 3$ diffraction element are $45^\circ \pm 0.5^\circ$ or $135^\circ \pm 0.5^\circ$, and an angle between the periodic direction in the diffraction structure of the $\Lambda 2$ diffraction element provided in the incidence portion and the periodic direction in the diffraction structure of the $\Lambda 2$ diffraction element provided in the emission portion is any one of 0° , 0.5° , $90^\circ \pm 0.5^\circ$, $180^\circ \pm 0.5^\circ$, or $270^\circ \pm 0.5^\circ$.
- (16) [2] The optical element according to [1], in which the diffraction element includes a liquid crystal diffraction layer that is formed of a composition including a liquid crystal compound, the liquid crystal diffraction layer has a liquid crystal alignment pattern where a direction in which a direction of an optical axis derived from the liquid crystal compound changes while continuously rotating is in at least one in-plane direction, in the liquid crystal alignment pattern, the direction in which the direction of the optical axis derived from the liquid crystal compound changes while continuously rotating in the at least one in-plane direction is the periodic direction in the diffraction structure of the diffraction element, and a length over which the direction of the optical axis derived from the liquid crystal compound rotates by 180° in the periodic direction of the diffraction structure is the period in the diffraction structure of the diffraction element.
- (17) [3] The optical element according to [2], in which the liquid crystal diffraction layer is a cholesteric liquid crystal layer obtained by immobilizing a cholesteric liquid crystalline phase.
- (18) [4] The optical element according to any one of [1] to [3], in which the optical element includes a plurality of the $\Lambda 1$ diffraction elements, and the incidence portion and the emission portion include a combination of the $\Lambda 1$ diffraction elements where an angle between the periodic directions in the diffraction structures is $180^\circ \pm 0.5^\circ$.
- (19) [5] The optical element according to any one of [1] to [4], in which the incidence portion and

the emission portion include a plurality of the $\Lambda 3$ diffraction elements, and the incidence portion and the emission portion include a combination of the $\Lambda 3$ diffraction elements where an angle between the periodic directions in the diffraction structures is $180^\circ \pm 0.5^\circ$.

(20) [6] The optical element according to any one of [1] to [5], in which the incidence portion and the emission portion include a plurality of the $\Lambda 2$ diffraction elements, and the incidence portion and the emission portion include a combination of the $\Lambda 2$ diffraction elements where an angle between the periodic directions in the diffraction structures is $90^\circ \pm 0.5^\circ$.

(21) [7] The optical element according to [6], in which in a case where the periodic direction in the diffraction structure of one of the $\Lambda 2$ diffraction elements is 0° , the emission portion includes, in addition to the $\Lambda 2$ diffraction element where the periodic direction in the diffraction structure is 0° , the $\Lambda 2$ diffraction element where the periodic direction in the diffraction structure is $90^\circ \pm 0.5^\circ$, the $\Lambda 2$ diffraction element where the periodic direction in the diffraction structure is $180^\circ \pm 0.5^\circ$, and the $\Lambda 2$ diffraction element where the periodic direction in the diffraction structure is $270^\circ \pm 0.5^\circ$.

(22) [8] An image display apparatus comprising: the optical element according to any one of [1] to [7]; and a display element that emits an image to the incidence portion of the optical element.

(23) According to an aspect of the present invention, for example, in AR glasses or the like, crosstalk can be prevented and an image having a wide FOV can be displayed using one light guide plate.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. 1 is a diagram conceptually showing an example of an image display apparatus according to the present invention including an optical element according to the present invention.

(2) FIG. 2 is a diagram conceptually showing a plane of the optical element shown in FIG. 1.

(3) FIG. 3 is a diagram conceptually showing an example of a liquid crystal diffraction element.

(4) FIG. 4 is a plan view conceptually showing a liquid crystal layer of the liquid crystal diffraction element shown in FIG. 3.

(5) FIG. 5 is a diagram conceptually showing a cross-sectional scanning electron microscopic (SEM) image of the liquid crystal layer shown in FIG. 4.

(6) FIG. 6 is a conceptual diagram showing an action of the liquid crystal layer shown in FIG. 4.

(7) FIG. 7 is a diagram conceptually showing another example of the liquid crystal layer used in the liquid crystal diffraction element.

(8) FIG. 8 is a diagram conceptually showing another example of the liquid crystal layer used in the liquid crystal diffraction element.

(9) FIG. 9 is a conceptual diagram showing an example of an exposure device that exposes an alignment film.

(10) FIG. 10 is a diagram conceptually showing another example of the liquid crystal diffraction element.

(11) FIG. 11 is a plan view conceptually showing the liquid crystal layer of the liquid crystal diffraction element shown in FIG. 10.

(12) FIG. 12 is a conceptual diagram showing an action of the liquid crystal layer shown in FIG. 10.

(13) FIG. 13 is a conceptual diagram showing the action of the liquid crystal layer shown in FIG. 10.

(14) FIG. 14 is a conceptual diagram showing an incidence portion of the optical element shown in FIG. 1.

(15) FIG. 15 is a conceptual diagram showing an emission portion of the optical element shown in FIG. 1.

(16) FIG. **16** is a conceptual diagram showing Example 2.

(17) FIG. **17** is a conceptual diagram showing Example 2.

(18) FIG. **18** is a conceptual diagram showing a method of measuring a FOV in Examples.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

(19) Hereinafter, an optical element and an image display apparatus according to an embodiment of the present invention will be described in detail based on a preferable embodiment shown in the accompanying drawings.

(20) In the present specification, numerical ranges represented by “to” include numerical values before and after “to” as lower limit values and upper limit values.

(21) In the present specification, “(meth)acrylate” represents “either or both of acrylate and methacrylate”.

(22) In the present specification, the meaning of “the same” includes a case where an error range is generally allowable in the technical field. In addition, in the present specification, the meaning of “all”, “entire”, or “entire surface” includes not only 100% but also a case where an error range is generally allowable in the technical field, for example, 99% or more, 95% or more, or 90% or more.

(23) In the present specification, visible light refers to light having a wavelength which can be observed by human eyes among electromagnetic waves and refers to light in a wavelength range of 380 to 780 nm. Invisible light refers to light in a wavelength range of shorter than 380 nm or longer than 780 nm.

(24) In addition, although not limited thereto, in visible light, light in a wavelength range of 420 to 490 nm refers to blue light, light in a wavelength range of 495 to 570 nm refers to green light, and light in a wavelength range of 620 to 750 nm refers to red light.

(25) FIG. **1** conceptually shows an example of the optical element and the image display apparatus according to the embodiment of the present invention.

(26) FIG. **2** conceptually shows a plan view of the image display apparatus shown in FIG. **1**. FIG. **2** is a diagram showing the image display apparatus (optical element) shown in FIG. **1** in a case where the optical element is seen from an observation direction of an image by a user U shown in FIG. **1**.

(27) As shown in FIGS. **1** and **2**, an image display apparatus **10** includes an optical element **12** and a display **14**. The optical element **12** includes: a light guide plate **18**; an incidence portion **20** that includes incidence elements as diffraction elements; and an emission portion **24** that includes emission elements as diffraction elements.

(28) In the optical element **12** in the example shown in the drawing, the incidence portion **20** has a rectangular planar shape and is provided in the vicinity of one corner portion of a main surface of the rectangular light guide plate **18**. The emission portion **24** is provided on another main surface of the light guide plate **18** to cover the entire surface of a region of the light guide plate **18** other than the incidence portion **20** in a plane direction. That is, the emission portion **24** has a rectangular planar shape where one corner portion is cut out in a rectangular shape.

(29) The main surface is the maximum surface of a sheet-shaped material (a plate-shaped material, a film, or a layer).

(30) The planar shape is a shape in a case where each of the members is seen from the observation direction of the user U, and is a shape of main surfaces of the light guide plate **18**, the incidence portion **20** (incidence element), and the emission portion **24** (emission elements) in the optical element **12**.

(31) As shown in FIG. **1**, in the image display apparatus **10** shown in the example shown in the drawing, light that carries and supports an image displayed (emitted) by a display **14** is diffracted and reflected by the incidence portion **20** to be incident into the light guide plate **18** at an angle where total reflection can occur. The light incident into the light guide plate **18** propagates in the light guide plate **18** while repeating total reflection and is incident into the emission portion **24**. The

emission portion **24** diffracts and reflects the incident light to emit the light from the light guide plate **18** to an observation position by the user U.

(32) In the optical element **12** in the example shown in the drawing, the incidence portion **20** includes an incidence element **26Λ1-1**, an incidence element **26Λ1-2**, an incidence element **28Λ2-1**, an incidence element **28Λ2-2**, an incidence element **30Λ3-1**, and an incidence element **30Λ3-2** in this order from the light guide plate **18** side.

(33) The incidence element **26Λ1-1** and the incidence element **26Λ1-2** are the $\Lambda 1$ diffraction elements according to the embodiment of the present invention, in which a period in a diffraction structure (periodic structure of the diffraction element) is $\Lambda 1$. The incidence element **28Λ2-1** and the incidence element **28Λ2-2** are the $\Lambda 2$ diffraction elements according to the embodiment of the present invention, in which a period in a diffraction structure is $\Lambda 2$. Further, the incidence element **30Λ3-1** and the incidence element **30Λ3-2** are the $\Lambda 3$ diffraction elements according to the embodiment of the present invention, in which a period in a diffraction structure is $\Lambda 3$.

(34) In the optical element according to the embodiment of the present invention, the lamination order of the $\Lambda 1$ diffraction elements, the $\Lambda 2$ diffraction elements, and the $\Lambda 3$ diffraction elements are not particularly limited, and various lamination orders other than that shown in the drawing can be used. That is, in the optical element according to the embodiment of the present invention, for example, the lamination order of the diffraction elements may be the order of the $\Lambda 3$ diffraction elements, the $\Lambda 2$ diffraction elements, and the $\Lambda 1$ diffraction elements from the light guide plate **18** side or may be the order of the $\Lambda 2$ diffraction elements, the $\Lambda 3$ diffraction elements, and the $\Lambda 1$ diffraction elements from the light guide plate **18** side.

(35) In the optical element **12** in the example shown in the drawing, the emission portion **24** includes an emission element **34Λ1-1**, an emission element **34Λ1-2**, an emission element **36Λ2-1**, an emission element **36Λ2-2**, an emission element **36Λ2-3**, an emission element **36Λ2-4**, an emission element **38Λ3-1**, and an emission element **38Λ3-2** in this order from the light guide plate **18**.

(36) The emission element **34Λ1-1** and the emission element **34Λ1-2** are the $\Lambda 1$ diffraction elements according to the embodiment of the present invention, in which a period in a diffraction structure is $\Lambda 1$. The emission element **36Λ2-1**, the emission element **36Λ2-2**, the emission element **36Λ2-3**, and the emission element **36Λ2-4** are the $\Lambda 2$ diffraction elements according to the embodiment of the present invention, in which a period in a diffraction structure is $\Lambda 2$. Further, the emission element **38Λ3-1** and the emission element **38Λ3-2** are the $\Lambda 3$ diffraction elements according to the embodiment of the present invention, in which a period in a diffraction structure is $\Lambda 3$.

(37) Although described below, in the optical element **12** according to the embodiment of the present invention, the period $\Lambda 1$, the period $\Lambda 2$, and the period $\Lambda 3$ in the diffraction structures of the diffraction elements satisfy a relationship of " $\Lambda 1:\Lambda 2:\Lambda 3=1:1/\sqrt{2}\pm 0.015:1/2\pm 0.015$ ".

(38) In the example shown in the drawing, in a preferable aspect, the incidence element and the emission element include a liquid crystal diffraction layer and are reflective liquid crystal diffraction elements including a cholesteric liquid crystal layer as the liquid crystal diffraction layer.

(39) Here, the image display apparatus including the optical element **12** according to the embodiment of the present invention may display a color image or a monochrome image.

(40) In a case where the image display apparatus including the optical element **12** displays a monochrome image, each of the incidence element and the emission element includes a liquid crystal diffraction layer that selectively reflects light in a wavelength range of the corresponding color.

(41) On the other hand, in a case where the image display apparatus including the optical element **12** displays a color image, each of the incidence portion **20** and the emission portion **24** may reflect blue light, green light, and red light using one liquid crystal diffraction layer (diffraction element),

may include a liquid crystal diffraction layer corresponding to each of blue light, green light, and red light, and may include a liquid crystal diffraction layer corresponding to two colors of blue light, green light, and red light and a liquid crystal diffraction layer corresponding to the remaining color.

(42) Alternatively, in a case where the image display apparatus including the optical element **12** displays a color image, the image display apparatus may include an incidence portion and an emission portion for blue light, an incidence portion and an emission portion for green light, and an incidence portion and an emission portion for red light, or may include an incidence portion and an emission portion corresponding to two colors of blue light, green light, and red light and an incidence portion and an emission portion corresponding to the remaining color. In a case where the optical element **12** includes a plurality of incidence portions and a plurality of emission portions, the incidence portions and the emission portions may be disposed and laminated or may be disposed at different positions in a plane direction of the light guide plate **18**.

(43) In the optical element **12**, the members that are laminated are optionally bonded to each other using an adhesive layer.

(44) As long as it has a sufficient light-transmitting property, the adhesive layer may be a layer formed of an adhesive that has fluidity during bonding and becomes a solid after bonding, a layer formed of a pressure sensitive adhesive that is a gel-like (rubber-like) flexible solid during bonding and of which the gel state does not change after bonding, or a layer formed of a material having characteristics of both the adhesive and the pressure sensitive adhesive. Accordingly, the adhesive layer may be any well-known layer that is used for bonding a sheet-shaped material in an optical device or an optical element, for example, an optical clear adhesive (OCA), an optically transparent double-sided tape, or an ultraviolet curable resin.

(45) Alternatively, instead of bonding the members using the adhesive layer, the members may be held using a frame, a jig, or the like to form the optical element according to the embodiment of the present invention.

(46) The image display apparatus including the optical element **12** according to the embodiment of the present invention may display a color image or a monochrome image.

(47) In a case where a color image is displayed, the diffraction elements in the incidence portion **20** and the emission portion **24** reflect blue light, green light, and red light.

(48) Hereinafter, the components forming the optical element and the image display apparatus according to the embodiment of the present invention will be described.

(49) [Display (Display Element)]

(50) In the image display apparatus according to the embodiment of the present invention, the display **14** is not particularly limited. For example, various well-known displays used in AR glasses or the like can be used.

(51) Examples of the display include a liquid crystal display, an organic electroluminescent display, and a scanning type display employing a digital light processing (DLP) type projector or Micro Electro Mechanical Systems (MEMS) mirror. Examples of the liquid crystal display include a liquid crystal on silicon (LCOS).

(52) The display may display a color image or may display a monochrome image. In addition, in a case where the display device displays a color image, the display device may include three displays corresponding to a blue image, a green image, and a red image, respectively.

(53) In the image display apparatus according to the embodiment of the present invention, optionally, a well-known projection lens used in AR glasses or the like may be provided between the display **14** and the light guide plate (incidence portion).

(54) Here, in the image display apparatus according to the embodiment of the present invention, light to be emitted from the display **14** is not limited and is preferably unpolarized light (natural light) or circularly polarized light.

(55) Optionally, depending on the polarization of light to be emitted from the display, a circularly

polarizing plate consisting of a linear polarizer and a $\lambda/4$ plate, a $\lambda/4$ plate, or the like may be provided between the display **14** and the light guide plate **18**.

(56) [Light Guide Plate]

(57) The light guide plate **18** is a well-known light guide plate that reflects light incident thereinto and propagates (guides) the reflected light. In the example shown in the drawing, the light guide plate **18** has a rectangular planar shape.

(58) As the light guide plate **18**, various well-known light guide plates used for a backlight unit or the like of AR glasses or a liquid crystal display can be used without any particular limitation.

(59) The refractive index of the light guide plate **18** is not particularly limited and is preferably high. Specifically, the refractive index of the light guide plate **18** is preferably 1.7 to 2.0 and more preferably 1.8 to 2.0. By adjusting the refractive index of the light guide plate **18** to be 1.7 to 2.0, an angle range where light can be totally reflected and propagate in the light guide plate **18** can be widened.

(60) [Incidence Portion and Emission Portion]

(61) In the optical element **12** (image display apparatus **10**) in the example shown in the drawing, the incidence portion **20** has a rectangular planar shape and is provided in the vicinity of one corner portion of one main surface of the rectangular light guide plate **18**. On the other hand, the emission portion **24** is provided on another main surface of the light guide plate **18** to cover the entire surface of a region of the light guide plate **18** other than the incidence portion **20** in a plane direction. That is, the emission portion **24** has a rectangular planar shape where one corner portion is cut out in a rectangular shape.

(62) As described above, the incidence portion **20** includes the incidence element **26Λ1-1**, the incidence element **26Λ1-2**, the incidence element **28Λ2-1**, the incidence element **28Λ2-2**, the incidence element **30Λ3-1**, and the incidence element **30Λ3-2**. In addition, the emission portion **24** includes the emission element **34Λ1-1**, the emission element **34Λ1-2**, the emission element **36Λ2-1**, the emission element **36Λ2-2**, the emission element **36Λ2-3**, the emission element **36Λ2-4**, the emission element **38Λ3-1**, and the emission element **38Λ3-2**.

(63) Both of the incidence element and the emission element are reflective polarization diffraction elements. Specifically, both of the incidence element and the emission element are liquid crystal diffraction elements, include a cholesteric liquid crystal layer as a liquid crystal diffraction layer that acts as a diffraction element, and selectively reflect right circularly polarized light or left circularly polarized light.

(64) Here, the incidence element **26Λ1-1**, the incidence element **26Λ1-2**, the incidence element **28Λ2-1**, the incidence element **28Λ2-2**, the incidence element **30Λ3-1**, and the incidence element **30Λ3-2** of the incidence portion **20** and the emission element **34Λ1-1**, the emission element **34Λ1-2**, the emission element **36Λ2-1**, the emission element **36Λ2-2**, the emission element **36Λ2-3**, the emission element **36Λ2-4**, the emission element **38Λ3-1**, and the emission element **38Λ3-2** of the emission portion **24** basically have the same configuration, except that the incidence portion **20** and the emission portion **24** are different, the periods of the diffraction structures in the diffraction elements described below are different, and/or periodic directions of the diffraction structures in the diffraction elements described below are different.

(65) Accordingly, in the following description, in a case where each of the incidence elements and each of the emission elements do not need to be distinguished from each other, these diffraction elements will also be collectively referred to as “liquid crystal diffraction element”.

(66) (Liquid Crystal Diffraction Element)

(67) The liquid crystal diffraction element will be described using FIGS. 3 to 5.

(68) FIG. 3 is a diagram conceptually showing a layer configuration of the liquid crystal diffraction element. As conceptually shown in FIG. 3, the liquid crystal diffraction element includes a support **50**, an alignment film **52**, and a cholesteric liquid crystal layer **54** as a liquid crystal diffraction layer that exhibits an action as a diffraction element.

(69) FIG. 4 is a schematic diagram showing an alignment state of a liquid crystal compound in a plane of a main surface of the cholesteric liquid crystal layer 54.

(70) In the following description, it is assumed that a main surface of the cholesteric liquid crystal layer 54 is an X-Y plane and a cross-section perpendicular to the X-Y plane is an X-Z plane. That is, FIG. 3 corresponds to a schematic diagram of the X-Z plane of the cholesteric liquid crystal layer 54, and FIG. 4 corresponds to a schematic diagram of the X-Y plane of the cholesteric liquid crystal layer 54.

(71) As shown in FIG. 3, the cholesteric liquid crystal layer 54 is a layer obtained by cholesteric alignment of a liquid crystal compound. In addition, FIGS. 3 to 5 show an example in which the liquid crystal compound forming the cholesteric liquid crystal layer is a rod-like liquid crystal compound.

(72) In the following description, the cholesteric liquid crystal layer will also be referred to as “liquid crystal layer”.

(73) The liquid crystal diffraction element shown in FIG. 3 includes the support 50, the alignment film 52, and the liquid crystal layer 54. However, the present invention is not limited to this configuration. The liquid crystal diffraction element may include only the alignment film 52 and the liquid crystal layer 54 by peeling off the support 50 after bonding the laminate to the light guide plate 18 and the like. Alternatively, the liquid crystal diffraction element may include only the liquid crystal layer 54 by peeling off the support 50 and the alignment film 52 after bonding the laminate to the light guide plate 18 and the like.

(74) Support>

(75) The support 50 supports the alignment film 52 and the liquid crystal layer 54.

(76) As the support 50, various sheet-shaped materials (films or plate-shaped materials) can be used as long as they can support the alignment film 52 and the liquid crystal layer 54.

(77) A transmittance of the support 50 with respect to corresponding light is preferably 50% or higher, more preferably 70% or higher, and still more preferably 85% or higher.

(78) The thickness of the support 50 is not particularly limited and may be appropriately set depending on the use of the liquid crystal diffraction element, a material for forming the support 50, and the like in a range where the alignment film 52 and the liquid crystal layer 54 can be supported.

(79) The thickness of the support 50 is preferably 1 to 2000 μm , more preferably 3 to 500 μm , and still more preferably 5 to 250 μm .

(80) The support 50 may have a monolayer structure or a multi-layer structure.

(81) In a case where the support 50 has a monolayer structure, examples thereof include supports formed of glass, triacetyl cellulose (TAC), polyethylene terephthalate (PET), polycarbonates, polyvinyl chloride, acryl, polyolefin, and the like. In a case where the support 50 has a multi-layer structure, examples thereof include a support including: one of the above-described supports having a monolayer structure that is provided as a substrate; and another layer that is provided on a surface of the substrate.

(82) <Alignment Film>

(83) In the liquid crystal diffraction element, the alignment film 52 is formed on a surface of the support 50.

(84) The alignment film 52 is an alignment film for aligning the liquid crystal compound 40 to a predetermined liquid crystal alignment pattern during the formation of the liquid crystal layer 54.

(85) Although described below, in the present invention, the liquid crystal layer 54 has a liquid crystal alignment pattern in which a direction of an optical axis 40A (refer to FIG. 4) derived from the liquid crystal compound 40 changes while continuously rotating in one in-plane direction. Accordingly, the alignment film 52 is formed such that the liquid crystal layer 54 can form the liquid crystal alignment pattern.

(86) In the following description, “the direction of the optical axis 40A rotates” will also be simply

referred to as “the optical axis **40A** rotates”.

(87) As the alignment film **52**, various well-known films can be used.

(88) Examples of the alignment film include a rubbed film formed of an organic compound such as a polymer, an obliquely deposited film formed of an inorganic compound, a film having a microgroove, and a film formed by lamination of Langmuir-Blodgett (LB) films formed with a Langmuir-Blodgett's method using an organic compound such as w-tricosanoic acid, dioctadecylmethylammonium chloride, or methyl stearate.

(89) The alignment film **52** formed by a rubbing treatment can be formed by rubbing a surface of a polymer layer with paper or fabric in a given direction multiple times.

(90) As the material used for the alignment film **52**, for example, a material for forming polyimide, polyvinyl alcohol, a polymer having a polymerizable group described in JP1997-152509A (JP-H9-152509A), or an alignment film **52** such as JP2005-97377A, JP2005-99228A, and JP2005-128503A is preferable.

(91) In the liquid crystal diffraction element, for example, the alignment film **52** can be suitably used as a so-called photo-alignment film obtained by irradiating a photo-alignment material with polarized light or non-polarized light. That is, in the liquid crystal diffraction element, a photo-alignment film that is formed by applying a photo-alignment material to the support **50** is suitably used as the alignment film **52**.

(92) The irradiation of polarized light can be performed in a direction perpendicular or oblique to the photo-alignment film, and the irradiation of non-polarized light can be performed in a direction oblique to the photo-alignment film.

(93) Preferable examples of the photo-alignment material used in the alignment film that can be used in the present invention include: an azo compound described in JP2006-285197A, JP2007-076839A, JP2007-138138A, JP2007-094071A, JP2007-121721A, JP2007-140465A, JP2007-156439A, JP2007-133184A, JP2009-109831A, JP3883848B, and JP4151746B; an aromatic ester compound described in JP2002-229039A; a maleimide- and/or alkenyl-substituted nadiimide compound having a photo-alignable unit described in JP2002-265541A and JP2002-317013A; a photocrosslinking silane derivative described in JP4205195B and JP4205198B, a photocrosslinking polyimide, a photocrosslinking polyamide, or a photocrosslinking polyester described in JP2003-520878A, JP2004-529220A, and JP4162850B; and a photodimerizable compound, in particular, a cinnamate compound, a chalcone compound, or a coumarin compound described in JP1997-118717A (JP-H9-118717A), JP1998-506420A (JP-H10-506420A), JP2003-505561A, WO2010/150748A, JP2013-177561A, and JP2014-012823A.

(94) Among these, an azo compound, a photocrosslinking polyimide, a photocrosslinking polyamide, a photocrosslinking polyester, a cinnamate compound, or a chalcone compound is suitably used.

(95) The thickness of the alignment film **52** is not particularly limited. The thickness with which a required alignment function can be obtained may be appropriately set depending on the material for forming the alignment film **52**.

(96) The thickness of the alignment film **52** is preferably 0.01 to 5 μm and more preferably 0.05 to 2 μm .

(97) A method of forming the alignment film **52** is not limited. Any one of various well-known methods corresponding to a material for forming the alignment film **52** can be used. For example, a method including: applying the alignment film **52** including a photo-alignment material to a surface of the support **50**; drying the applied alignment film **52**; and exposing the alignment film **52** to laser light to form an alignment pattern can be used.

(98) FIG. **9** conceptually shows an example of an exposure device that exposes the alignment film **52** to form an alignment pattern.

(99) An exposure device **60** shown in FIG. **9** includes: a light source **64** including a laser **62**; a $\lambda/2$ plate **65** that changes a polarization direction of laser light M emitted from the laser **62**; a

polarization beam splitter **68** that splits the laser light **M** emitted from the laser **62** into two beams **MA** and **MB**; mirrors **70A** and **70B** that are disposed on optical paths of the split two beams **MA** and **MB**; and $\lambda/4$ plates **72A** and **72B**.

(100) The light source **64** emits linearly polarized light $P_{\text{sub.0}}$. The $\lambda/4$ plate **72A** converts the linearly polarized light $P_{\text{sub.0}}$ (beam **MA**) into right circularly polarized light $P_{\text{sub.R}}$, and the $\lambda/4$ plate **72B** converts the linearly polarized light $P_{\text{sub.0}}$ (beam **MB**) into left circularly polarized light $P_{\text{sub.L}}$.

(101) The support **50** including the alignment film **52** on which the alignment pattern is not yet formed is disposed at an exposed portion, the two beams **MA** and **MB** intersect and interfere with each other on the alignment film **52**, and the alignment film **52** is irradiated with and exposed to the interference light.

(102) Due to the interference in this case, the polarization state of light with which the alignment film **52** is irradiated periodically changes according to interference fringes. As a result, an alignment film having an alignment pattern in which the alignment state periodically changes can be obtained. In the following description, this alignment film having the alignment pattern will also be referred to as “patterned alignment film”.

(103) In the exposure device **60**, by changing an intersecting angle α between the two beams **MA** and **MB**, the period of the alignment pattern can be adjusted. That is, by adjusting the intersecting angle α in the exposure device **60**, in the alignment pattern in which the optical axis **40A** derived from the liquid crystal compound **40** continuously rotates in the one in-plane direction, the length (period **A** in the diffraction structure) of the single period over which the optical axis **40A** rotates by 180° in the one in-plane direction in which the optical axis **40A** rotates can be adjusted.

(104) By forming the cholesteric liquid crystal layer on the alignment film **52** having the alignment pattern in which the alignment state periodically changes, as described below, the liquid crystal layer **54** having the liquid crystal alignment pattern in which the optical axis **40A** derived from the liquid crystal compound **40** continuously rotates in the one in-plane direction can be formed.

(105) In addition, by rotating the optical axes of the $\lambda/4$ plates **72A** and **72B** by 90° , respectively, the rotation direction of the optical axis **40A** can be reversed.

(106) As described above, the patterned alignment film has a liquid crystal alignment pattern in which the liquid crystal compound is aligned such that the direction of the optical axis of the liquid crystal compound in the liquid crystal layer formed on the patterned alignment film changes while continuously rotating in at least one in-plane direction.

(107) In a case where an axis in the direction in which the liquid crystal compound is aligned is an alignment axis, it can be said that the patterned alignment film has an alignment pattern in which the direction of the alignment axis changes while continuously rotating in at least one in-plane direction. The alignment axis of the patterned alignment film can be detected by measuring absorption anisotropy. For example, in a case where the amount of light transmitted through the patterned alignment film is measured by irradiating the patterned alignment film with linearly polarized light while rotating the patterned alignment film, it is observed that a direction in which the light amount is the maximum or the minimum gradually changes in the one in-plane direction.

(108) In the present invention, the alignment film **52** is provided as a preferable aspect and is not an essential component.

(109) For example, the following configuration can also be adopted, in which, by forming the alignment pattern on the support **50** using a method of rubbing the support **50**, a method of processing the support **50** with laser light or the like, the liquid crystal layer has the liquid crystal alignment pattern in which the direction of the optical axis **40A** derived from the liquid crystal compound **40** changes while continuously rotating in at least one in-plane direction. That is, in the present invention, the support **50** may be made to function as the alignment film.

(110) <Liquid Crystal Layer (Cholesteric Liquid Crystal Layer)>

(111) In the liquid crystal diffraction element, the liquid crystal layer **54** is formed on a surface of

the alignment film **52**.

(112) The liquid crystal layer **54** is a cholesteric liquid crystal layer that is obtained by immobilizing a cholesteric liquid crystalline phase and has a liquid crystal alignment pattern in which a direction of an optical axis derived from a liquid crystal compound changes while continuously rotating in at least one in-plane direction.

(113) As conceptually shown in FIG. **3**, the liquid crystal layer **54** has a helical structure in which the liquid crystal compound **40** is helically turned and laminated as in a cholesteric liquid crystal layer obtained by immobilizing a typical cholesteric liquid crystalline phase. In the helical structure, a configuration in which the liquid crystal compound **40** is helically rotated once (rotated by 360°) and laminated is set as one helical pitch (helical pitch P), and plural pitches of the helically turned liquid crystal compound **40** are laminated.

(114) As is well known, the cholesteric liquid crystalline phase exhibits selective reflectivity with respect to left or circularly polarized light at a specific wavelength. Whether or not the reflected light is right circularly polarized light or left circularly polarized light is determined depending on a helical twisted direction (sense) of the cholesteric liquid crystalline phase. Regarding the selective reflection of the circularly polarized light by the cholesteric liquid crystalline phase, in a case where the helical twisted direction of the cholesteric liquid crystalline phase is right, right circularly polarized light is reflected, and in a case where the helical twisted direction of the cholesteric liquid crystalline phase is left, left circularly polarized light is reflected.

(115) For example, in the liquid crystal layer **54** that selectively reflects right circularly polarized light, the helical twisted direction of the cholesteric liquid crystalline phase is the right direction.

(116) The turning direction of the cholesteric liquid crystalline phase can be adjusted by adjusting the kind of the liquid crystal compound that forms the cholesteric liquid crystal layer and/or the kind of the chiral agent to be added.

(117) In addition, a half-width $\Delta\lambda$ (nm) of a selective reflection wavelength range (circularly polarized light reflection wavelength range) where selective reflection is exhibited depends on Δn of the cholesteric liquid crystalline phase and the helical pitch P and satisfies a relationship of $\Delta\lambda = \Delta n \times P$. Therefore, the width of the selective reflection wavelength range can be controlled by adjusting Δn . Δn can be adjusted by adjusting a kind of a liquid crystal compound for forming the cholesteric liquid crystal layer and a mixing ratio thereof, and a temperature during alignment immobilization.

(118) Accordingly, regarding the wavelength of light that is reflected (diffracted) by the liquid crystal diffraction element, the selective reflection wavelength range of the liquid crystal layer **54** may be set, for example, by adjusting the helical pitch P of the liquid crystal layer **54** according to each of the liquid crystal diffraction elements.

(119) The half-width of the reflection wavelength range is appropriately adjusted depending on the use of the optical element **12** and the wavelength range corresponding to the diffraction element where the liquid crystal layer **54** is provided. For example, the half-width of the reflection wavelength range may be 10 to 500 nm and is preferably 20 to 300 nm and more preferably 30 to 100 nm.

(120) As shown in FIG. **4**, in the X-Y plane of the liquid crystal layer **54**, the liquid crystal compounds **40** are arranged along a plurality of arrangement axes D parallel to the X-Y plane. On each of the arrangement axes D, the direction of the optical axis **40A** of the liquid crystal compound **40** changes while continuously rotating in the one in-plane direction along the arrangement axis D. In the example shown in the drawing, the optical axis **40A** rotates clockwise in the arrangement axis D.

(121) In the example shown in the drawing, for example, it is assumed that the arrangement axis D is directed to the X direction. In addition, in the Y direction, the liquid crystal compounds **40** in which the directions of the optical axes **40A** are the same are arranged at regular intervals.

(122) Specifically, “the direction of the optical axis **40A** of the liquid crystal compound **40** changes

while continuously rotating in the one in-plane direction along the arrangement axis D” represents that angles between the optical axes **40A** of the liquid crystal compounds **40** and the arrangement axes D vary depending on positions in the arrangement axis D direction and gradually change from θ to $\theta+180^\circ$ or $\theta-180^\circ$ along the arrangement axis D. That is, in each of the plurality of liquid crystal compounds **40** arranged along the arrangement axis D, as shown in FIG. **4**, the optical axis **40A** changes along the arrangement axis D while rotating on a given angle basis.

(123) A difference between the angles of the optical axes **40A** of the liquid crystal compounds **40** adjacent to each other in the arrangement axis D direction is preferably 45° or less, more preferably 15° or less, and still more preferably less than 15° . In the present specification, represents “degree”.

(124) In addition, in the present specification, in a case where the liquid crystal compound **40** is a rod-like liquid crystal compound, the optical axis **40A** of the liquid crystal compound **40** refers to a molecular major axis of the rod-like liquid crystal compound. On the other hand, in a case where the liquid crystal compound **40** is a disk-like liquid crystal compound, the optical axis **40A** of the liquid crystal compound **40** refers to an axis parallel to the normal direction with respect to a disc plane of the disk-like liquid crystal compound.

(125) In the diffraction element (liquid crystal diffraction element) including the liquid crystal layer **54** (liquid crystal diffraction layer), the arrangement axis D direction (X direction), that is, the direction (in-plane rotation direction) in which the optical axis **40A** of the liquid crystal compound **40** rotates in a plane of the liquid crystal layer **54** is the periodic direction in the diffraction structure of the diffraction element. In the example shown in the drawing, for example, as described above, the direction in which the optical axis **40A** rotates clockwise is the periodic direction in the diffraction structure of the diffraction element.

(126) In the following description, “the periodic direction in the diffraction structure of the diffraction element” will also be referred to as “periodic direction”.

(127) In the diffraction element (liquid crystal diffraction element) including the liquid crystal layer **54** (liquid crystal diffraction layer), in the liquid crystal alignment pattern of the liquid crystal compound **40**, the length (distance) over which the optical axis **40A** rotates by 180° in the arrangement axis D direction in which the optical axis **40A** changes while continuously rotating in a plane is the period A (in-plane rotation period A) in the diffraction structure of the diffraction element. That is, in the diffraction element including the liquid crystal layer **54** having the liquid crystal alignment pattern, The length (distance) over which the optical axis **40A** of the liquid crystal compound **40** rotates by 180° in the periodic direction is the period A in the diffraction structure of the diffraction element.

(128) In the following description, “the period A in the diffraction structure of the diffraction element” will also be referred to as “diffraction period Λ ”.

(129) That is, a distance between centers of two liquid crystal compounds **40** in the arrangement axis D direction (periodic direction) is the diffraction period Λ , the two liquid crystal compounds having the same angle in the arrangement axis D direction (periodic direction). Specifically, as shown in FIG. **4**, a distance between centers in the arrangement axis D direction of two liquid crystal compounds **40** in which the arrangement axis D direction and the direction of the optical axis **40A** match each other is the diffraction period Λ .

(130) In the liquid crystal alignment pattern of the liquid crystal layer **54**, the diffraction period A is repeated in the arrangement axis D direction, that is, in the one in-plane direction in which the direction of the optical axis **40A** changes while continuously rotating.

(131) As described above, in the optical element **12** according to the embodiment of the present invention, the incidence portion **20** and the emission portion **24** include, as the incidence element and the emission element, the $\Lambda 1$ diffraction element including the liquid crystal layer **54** where the diffraction period is $\Lambda 1$, the $\Lambda 2$ diffraction element including the liquid crystal layer **54** where the diffraction period is $\Lambda 2$, and the $\Lambda 3$ diffraction element including the liquid crystal layer **54** where the diffraction period is $\Lambda 3$.

(132) On the other hand, in the liquid crystal compound **40** forming the liquid crystal layer **54**, the directions of the optical axes **40A** are the same in the direction (in FIG. **4**, the Y direction) perpendicular to the arrangement axis D direction as the periodic direction, that is, the Y direction perpendicular to the one in-plane direction in which the optical axis **40A** continuously rotates.

(133) In other words, in the liquid crystal compound **40** forming the liquid crystal layer **54**, angles between the optical axes **40A** of the liquid crystal compound **40** and the arrangement axis D (X direction) are the same in the Y direction.

(134) In a case where a cross-section of the cholesteric liquid crystal layer in a thickness direction is observed with a scanning electron microscope (SEM), a stripe pattern in which bright portions and dark portions derived from a cholesteric liquid crystalline phase are alternately provided is observed.

(135) Here, in a case where an X-Z plane of the liquid crystal layer **54** shown in FIG. **3**, that is, a cross-section in the thickness direction is observed with an SEM, a stripe pattern in which bright portions **42** and dark portions **44** are tilted at a predetermined tilt angle θ with respect to the main surface (X-Y plane) as shown in FIG. **5** is observed.

(136) This tilt angle θ is not particularly limited and is preferably 10° or more and more preferably 20° or more. It is preferable that the tilt angle θ is 10° or more from the viewpoint of obtaining a high diffraction efficiency at a large diffraction angle.

(137) In this SEM cross-section, an interval between the bright portions **42** adjacent to each other or between the dark portions **44** adjacent to each other in a normal direction of lines formed by the bright portions **42** or the dark portions **44** corresponds to a $\frac{1}{2}$ pitch. That is, as indicated by P in FIG. **5**, two bright portions **42** and two dark portions **44** correspond to one helical pitch (one helical turn), that is, the helical pitch P.

(138) Hereinafter, an action of diffraction of the liquid crystal layer will be described.

(139) In a cholesteric liquid crystal layer of the related art, a helical axis derived from a cholesteric liquid crystalline phase is perpendicular to the main surface (X-Y plane), and a reflecting surface thereof is parallel to the main surface (X-Y plane). In addition, the optical axis of the liquid crystal compound is not tilted with respect to the main surface (X-Y plane). In other words, the optical axis is parallel to the main surface (X-Y plane). Accordingly, in a case where the X-Z plane of the cholesteric liquid crystal layer in the related art is observed with an SEM, an arrangement direction in which bright portions and dark portions are alternately arranged is perpendicular to the main surface (X-Y plane).

(140) The cholesteric liquid crystalline phase has specular reflectivity. Therefore, in a case where light is incident from the normal direction into the cholesteric liquid crystal layer, the light is reflected in the normal direction.

(141) On the other hand, the liquid crystal layer **54** reflects incident light in a state where it is tilted in the arrangement axis D direction as the periodic direction with respect to the specular reflection.

(142) Hereinafter, the description will be made with reference to FIG. **6**.

(143) For example, it is assumed that the liquid crystal layer **54** is a cholesteric liquid crystal layer that selectively reflects right circularly polarized light R.sub.R of red light. Accordingly, in a case where light is incident into the liquid crystal layer **54**, the liquid crystal layer **54** reflects only right circularly polarized light R.sub.R of red light and allows transmission of the other light.

(144) The liquid crystal layer **54** has the liquid crystal alignment pattern in which the optical axis **40A** of the liquid crystal compound **40** changes while continuously rotating in the arrangement axis D direction as the periodic direction.

(145) The liquid crystal alignment pattern in the liquid crystal layer **54** is a pattern that is periodic in the arrangement axis D direction. Therefore, as conceptually shown in FIG. **6**, the right circularly polarized light R.sub.R of red light incident into the liquid crystal layer **54** is reflected (diffracted) in a direction corresponding to the period of the liquid crystal alignment pattern, and the reflected right circularly polarized light R.sub.R of red light is reflected (diffracted) in a

direction tilted with respect to the XY plane (the main surface of the cholesteric liquid crystal layer) in the arrangement axis D direction.

(146) As a result, in a case where the liquid crystal layer **54** is applied to the optical element, the liquid crystal layer **54** can be used as a diffraction element in which light incident from a direction perpendicular to the main surface of the light guide plate can be reflected (diffracted) at an angle at which total reflection occurs in the light guide plate and the light guided in the light guide plate by total reflection can be reflected (diffracted) in a direction perpendicular to the main surface of the light guide plate.

(147) In the liquid crystal layer **54**, by appropriately setting the arrangement axis D direction as the one in-plane direction in which the optical axis **40A** rotates, the reflection direction (diffraction angle) of light can be adjusted.

(148) For example, in a case where circularly polarized light having the same wavelength and the same turning direction is reflected, by reversing the arrangement axis D direction as the periodic direction, a reflection direction of the circularly polarized light can be reversed. In other words, by setting the rotation direction of the optical axis **40A** of the liquid crystal compound **40** toward the arrangement axis D direction, that is, the periodic direction to be counterclockwise, the reflection direction of circularly polarized light can be reversed.

(149) Further, in the liquid crystal layer having the same liquid crystal alignment pattern, the reflection direction is reversed by adjusting the helical turning direction of the liquid crystal compound **40**, that is, the turning direction of circularly polarized light to be reflected.

(150) For example, in a case where the helical turning direction is right-twisted, the liquid crystal layer selectively reflects right circularly polarized light, and has the liquid crystal alignment pattern in which the optical axis **40A** rotates clockwise in the arrangement axis D direction. As a result, the right circularly polarized light is reflected in a state where it is tilted in the arrangement axis D direction.

(151) In addition, for example, in a case where the helical turning direction is left-twisted, the liquid crystal layer selectively reflects left circularly polarized light, and has the liquid crystal alignment pattern in which the optical axis **40A** rotates clockwise in the arrangement axis D direction. As a result, the left circularly polarized light is reflected in a state where it is tilted in a direction opposite to the arrangement axis D direction.

(152) That is, in the liquid crystal layers where the helical turning directions are opposite to each other, the arrangement axis D directions are adjusted to be opposite to each other, that is, to be different by 180° , light can be tilted and diffracted (reflected) in the same direction. In other words, in the liquid crystal layer having an opposite helical turning direction, by setting the rotation direction of the optical axis **40A** of the liquid crystal compound **40** toward the arrangement axis D direction, that is, the periodic direction to be counterclockwise, light can be tilted and diffracted in the same direction.

(153) As described above, in the liquid crystal diffraction element, in the liquid crystal alignment pattern of the liquid crystal compound in the liquid crystal layer, the in-plane period Λ as the length over which the optical axis of the liquid crystal compound rotates by 180° is the single period in the diffraction structure (the periodic structure of the diffraction element), that is, the diffraction period Λ . In addition, in the liquid crystal layer, the one in-plane direction (arrangement axis D direction) in which the optical axis of the liquid crystal compound changes while rotating is the periodic direction in the diffraction structure (the periodic structure of the diffraction element).

(154) In the optical element **12** according to the embodiment of the present invention, the length of the diffraction period Λ of the liquid crystal diffraction element is not particularly limited, and may be appropriately adjusted depending on the incidence angle into the light guide plate **18**, the size of diffraction of light for emitting the light from the light guide plate **18**, and the like.

(155) In the liquid crystal layer having the liquid crystal alignment pattern, as the diffraction period Λ decreases, the diffraction increases. That is, as the diffraction period Λ decreases, reflected light

can be reflected in a state where it is largely tilted with respect to the specular reflection direction of incidence light. In other words, as the diffraction period Λ decreases, an angle between the specular reflection direction and the reflected light increases.

(156) As described above, in the optical element **12** according to the embodiment of the present invention, the incidence portion **20** and the emission portion **24** include, as the incidence element and the emission element, three kinds of diffraction elements including the $\Lambda1$ diffraction element where the diffraction period is $\Lambda1$, the $\Lambda2$ diffraction element where the diffraction period is $\Lambda2$, and the $\Lambda3$ diffraction element where the diffraction period is $\Lambda3$. In addition, the diffraction period $\Lambda1$, the diffraction period $\Lambda2$, and the diffraction period $\Lambda3$ satisfy a relationship of “ $\Lambda1:\Lambda2:\Lambda3=1:1/\sqrt{2}\pm0.015:1/2\pm0.015$ ”.

(157) In addition, in the liquid crystal layer having the liquid crystal alignment pattern, the reflection angle (diffraction angle) of light varies depending on the wavelength of light to be reflected. Specifically, as the wavelength of light increases, the angle of reflected light with respect to incidence light increases.

(158) In the example shown in FIG. 3, a configuration in which, on the X-Z plane of the liquid crystal layer **54**, the optical axes **40A** of the liquid crystal compound **40** is aligned to be parallel with respect to the main surface (X-Y plane) is adopted.

(159) However, the present invention is not limited to this configuration. For example, as conceptually shown in FIG. 7, a configuration in which, on the X-Z plane of the liquid crystal layer **54**, the optical axes **40A** of the liquid crystal compound **40** is aligned to be tilted with respect to the main surface (X-Y plane) may be adopted.

(160) In addition, the example shown in FIG. 7 shows the configuration in which, on the X-Z plane of the liquid crystal layer **54**, the tilt angle of the liquid crystal compound **40** with respect to the main surface (X-Y plane) is uniform in the thickness direction (Z direction). However, the present invention is not limited to this configuration. In the liquid crystal layer **54**, a region where the tilt angle of the liquid crystal compound **40** varies in the thickness direction may be provided.

(161) For example, in an example shown in FIG. 8, the optical axis **40A** of the liquid crystal compound **40** at an interface of the liquid crystal layer on the alignment film **52** side is parallel to the main surface (the pretilt angle is 0°), the tilt angle of the liquid crystal compound **40** increases in a direction away from the interface on the alignment film **52** side to the thickness direction, and the liquid crystal compound is aligned at a given tilt angle on another interface (air interface).

(162) In the cross-section of the liquid crystal layer **54** shown in FIG. 8 observed with an SEM, as the angle of the bright portions and the dark portions derived from the cholesteric liquid crystalline phase with respect to the main surface, that is, the tilt angle θ (refer to FIG. 5) gradually increases as the distance from the interface on the alignment film **52** side increases in the thickness direction.

(163) In this liquid crystal layer **54**, the helical pitch P of the cholesteric liquid crystalline phase changes in the thickness direction. That is, in the liquid crystal layer **54**, the helical pitch P gradually increases as the distance from the interface on the alignment film **52** side increases in the thickness direction.

(164) As described above, the wavelength of light to be selectively reflected by the liquid crystal layer **54** (cholesteric liquid crystalline phase) varies depending on the helical pitch, and as the helical pitch P increases, the wavelength of light to be selectively reflected increases. Accordingly, in the liquid crystal layer **54** shown in FIG. 8 where the tilt angle θ gradually increases as the distance from the interface on the alignment film **52** side increases in the thickness direction, light in a wide wavelength range can be reflected.

(165) In the liquid crystal layer **54** shown in FIG. 8 where the tilt angle θ gradually increases as the distance from the interface on the alignment film **52** side increases in the thickness direction, it is preferable that the tilt angle θ has a region of 10° or more.

(166) In the liquid crystal layer **54**, it is preferable that the tilt angle θ has a region of 10° or more from the viewpoint of obtaining a large diffraction angle with a high diffraction efficiency.

(167) In this liquid crystal layer **54**, it is more preferable that the tilt angle θ has a region of 20° or more, and it is still more preferable that the tilt angle θ has a region of 30° or more.

(168) In addition, in the liquid crystal layer **54** where the tilt angle θ gradually increases as the distance from the interface on the alignment film **52** side increases in the thickness direction, it is also preferable that a difference between a maximum value and a minimum value of the tilt angle θ is 10° or more.

(169) It is preferable that the difference between the maximum value and the minimum value of the tilt angle θ is 10° or more from the viewpoints that the diffraction angle of light can increase and the wavelength range of light to be selectively reflected from the liquid crystal layer **54** can be widened.

(170) In the liquid crystal layer **54**, the difference between the maximum value and the minimum value of the tilt angle θ is more preferably 15° or more and still more preferably 20° or more.

(171) This way, the liquid crystal layer **54** may have a configuration in which the optical axis of the liquid crystal compound has a pretilt angle at one interface among the upper and lower interfaces or may have a pretilt angle at both of the interfaces. In addition, the pretilt angles at both of the interfaces may be different from each other.

(172) The liquid crystal compound has the tilt angle (is tilted). As a result, in a case where light is diffracted, the effective birefringence index of the liquid crystal compound increases, and the diffraction efficiency can be improved.

(173) The average angle (average tilt angle) between the optical axis **40A** of the liquid crystal compound **40** and the main surface (X-Y plane) is preferably 5° to 80° and more preferably 10° to 50° . The average tilt angle can be measured by observing the X-Z plane of the liquid crystal layer **54** with a polarization microscope. In particular, it is preferable that, on the X-Z plane of the liquid crystal layer **54**, the optical axis **40A** of the liquid crystal compound **40** is aligned to be tilted with respect to the main surface (X-Y plane) in the same direction.

(174) In a case where the cross-section of the cholesteric liquid crystal layer is observed with a polarization microscope, the tilt angle is a value obtained by measuring the angle between the optical axis **40A** of the liquid crystal compound **40** and the main surface at any five or more positions and obtaining the average value thereof.

(175) Light that is vertically incident into the liquid crystal diffraction element (liquid crystal layer **54**) travels obliquely in an oblique direction in the liquid crystal layer along with a bending force. In a case where light travels in the liquid crystal layer, diffraction loss is generated due to a deviation from conditions such as a diffraction period that are set to obtain a desired diffraction angle with respect to the vertically incident light.

(176) In a case where the liquid crystal compound is tilted, an orientation in which a higher birefringence index is generated than that in an orientation in which light is diffracted as compared to a case where the liquid crystal compound is not tilted is present. In this direction, the effective extraordinary light refractive index increases, and thus the birefringence index as a difference between the extraordinary light refractive index and the ordinary light refractive index increases.

(177) By setting the orientation of the tilt angle according to the desired diffraction orientation, a deviation from the original diffraction conditions in the orientation can be suppressed. As a result, it is presumed that, in a case where the liquid crystal compound having a tilt angle is used, a higher diffraction efficiency can be obtained.

(178) In addition, it is preferable that the tilt angle is controlled by treating the interface of the liquid crystal layer **54**.

(179) By pretilting the alignment film on the support side interface, the tilt angle of the liquid crystal compound can be controlled. For example, by exposing the alignment film to ultraviolet light from the front and subsequently obliquely exposing the alignment film during the formation of the alignment film, the liquid crystal compound in the liquid crystal layer formed on the alignment film can be made to have a pretilt angle. In this case, the liquid crystal compound is

pretilted in a direction in which the single axis side of the liquid crystal compound can be seen with respect to the second irradiation direction. Since the liquid crystal compound having an orientation in a direction perpendicular to the second irradiation direction is not pretilted, a region where the liquid crystal compound is pretilted and a region where the liquid crystal compound is not pretilted are present in a plane. This configuration is suitable for improving the diffraction efficiency because it contributes to the most improvement of birefringence in the desired direction in a case where light is diffracted in the direction.

(180) Further, an additive for promoting the pretilt angle can also be added to the liquid crystal layer or to the alignment film. In this case, the additive can be used as a factor for further improving the diffraction efficiency.

(181) This additive can also be used for controlling the pretilt angle on the air side interface.

(182) Here, in a cross-section of the liquid crystal layer **54** observed with an SEM, the bright portions and the dark portions derived from a cholesteric liquid crystalline phase are tilted with respect to the main surface. In the liquid crystal layer **54**, it is preferable that, in a case where an in-plane retardation R_e is measured from a normal direction and a direction tilted with respect to a normal line, a direction in which the in-plane retardation R_e is minimum in any one of a slow axis plane or a fast axis plane is tilted from the normal direction. Specifically, it is preferable that an absolute value of the measured angle between the direction in which the in-plane retardation R_e is minimum and the normal line is 5° or more. In other words, it is preferable that the liquid crystal compound of the liquid crystal layer **54** is tilted with respect to the main surface and the tilt direction substantially matches the bright portions and the dark portions of the liquid crystal layer **54**. The normal direction is a direction perpendicular to the main surface.

(183) By the liquid crystal layer **54** having the above-described configuration, circularly polarized light can be diffracted with a higher diffraction efficiency than the liquid crystal layer in which the liquid crystal compound **40** is parallel to the main surface.

(184) In the configuration in which the liquid crystal compound **40** of the liquid crystal layer **54** is tilted with respect to the main surface and the tilt direction substantially matches with the bright portions and the dark portions, bright portions and dark portions corresponding to a reflecting surface matches with the optical axis **40A** of the liquid crystal compound **40**. Therefore, the action of the liquid crystal compound **40** on light reflection (diffraction) increases, the diffraction efficiency can be improved. As a result, the amount of reflected light with respect to incidence light can be further improved.

(185) In the fast axis plane or the slow axis plane of the liquid crystal layer **54**, the absolute value of the tilt angle of the optical axis of the liquid crystal layer **54** is preferably 5° or more, more preferably 15° or more, and still more preferably 20° or more.

(186) It is preferable that the absolute value of the tilt angle of the optical axis is 15° or more from the viewpoint that the direction of the liquid crystal compound **40** matches with the bright portions and the dark portions more suitably such that the diffraction efficiency can be improved.

(187) Further, the liquid crystal layer **54** may be a layer where, even in a case where the tilt angle θ of the bright portions and the dark portions does not gradually increase, the helical pitch of the cholesteric liquid crystalline phase gradually changes in the thickness direction. For example, the liquid crystal layer **54** may be a cholesteric liquid crystal layer where the helical pitch P gradually increases as the distance from the interface on the alignment film **52** side increases in the thickness direction.

(188) As described above, the wavelength of light to be selectively reflected by the liquid crystal layer **54** (cholesteric liquid crystalline phase) varies depending on the helical pitch, and as the helical pitch P increases, the wavelength of light to be selectively reflected increases. Accordingly, in the liquid crystal layer **54** where the helical pitch P gradually increases in the thickness direction, light in a wide wavelength range can be reflected.

(189) <<Method of Forming Liquid Crystal Layer>>

(190) The liquid crystal layer **54** can be formed by immobilizing a liquid crystal phase in a layer shape, the liquid crystal phase obtained by aligning a liquid crystal compound in a predetermined alignment state. For example, the cholesteric liquid crystal layer can be formed by immobilizing a cholesteric liquid crystalline phase in a layer shape.

(191) The structure in which a cholesteric liquid crystalline phase is immobilized may be a structure in which the alignment of the liquid crystal compound as a liquid crystal phase is immobilized. Typically, the structure in which a liquid crystal phase is immobilized is preferably a structure which is obtained by making the polymerizable liquid crystal compound to be in a state where a predetermined liquid crystalline phase is aligned, polymerizing and curing the polymerizable liquid crystal compound with ultraviolet irradiation, heating, or the like to form a layer having no fluidity, and concurrently changing the state of the polymerizable liquid crystal compound into a state where the alignment state is not changed by an external field or an external force.

(192) The structure in which a liquid crystal phase is immobilized is not particularly limited as long as the optical characteristics of the liquid crystal phase are maintained, and the liquid crystal compound **40** in the liquid crystal layer does not necessarily exhibit liquid crystallinity. For example, the molecular weight of the polymerizable liquid crystal compound may be increased by a curing reaction such that the liquid crystallinity thereof is lost.

(193) Examples of a material used for forming the liquid crystal layer include a liquid crystal composition including a liquid crystal compound. It is preferable that the liquid crystal compound is a polymerizable liquid crystal compound.

(194) In addition, the liquid crystal composition used for forming the liquid crystal layer may further include a surfactant and a chiral agent.

(195) —Polymerizable Liquid Crystal Compound—

(196) The polymerizable liquid crystal compound may be a rod-like liquid crystal compound or a disk-like liquid crystal compound.

(197) Examples of the rod-like polymerizable liquid crystal compound include a rod-like nematic liquid crystal compound. As the rod-like nematic liquid crystal compound, an azomethine compound, an azoxy compound, a cyanobiphenyl compound, a cyanophenyl ester compound, a benzoate compound, a phenyl cyclohexanecarboxylate compound, a cyanophenylcyclohexane compound, a cyano-substituted phenylpyrimidine compound, an alkoxy-substituted phenylpyrimidine compound, a phenyldioxane compound, a tolan compound, or an alkenylcyclohexylbenzonitrile compound is preferably used. Not only a low-molecular-weight liquid crystal compound but also a polymer liquid crystal compound can be used.

(198) The polymerizable liquid crystal compound can be obtained by introducing a polymerizable group into the liquid crystal compound. Examples of the polymerizable group include an unsaturated polymerizable group, an epoxy group, and an aziridinyl group. Among these, an unsaturated polymerizable group is preferable, and an ethylenically unsaturated polymerizable group is more preferable. The polymerizable group can be introduced into the molecules of the liquid crystal compound using various methods. The number of polymerizable groups in the polymerizable liquid crystal compound is preferably 1 to 6 and more preferably 1 to 3.

(199) Examples of the polymerizable liquid crystal compound include compounds described in Makromol. Chem. (1989), Vol. 190, p. 2255, Advanced Materials (1993), Vol. 5, p. 107, U.S. Pat. Nos. 4,683,327A, 5,622,648A, 5,770,107A, WO95/022586A, WO95/024455A, WO97/000600A, WO98/023580A, WO98/052905A, JP1989-272551A (JP-H1-272551A), JP1994-016616A (JP-H6-016616A), JP1995-110469A (JP-H7-110469A), JP1999-080081A (JP-H11-080081A), and JP2001-328973A. Two or more polymerizable liquid crystal compounds may be used in combination. In a case where two or more polymerizable liquid crystal compounds are used in combination, the alignment temperature can be decreased.

(200) In addition, as a polymerizable liquid crystal compound other than the above-described

examples, for example, a cyclic organopolysiloxane compound having a cholesteric phase described in JP1982-165480A (JP-S57-165480A) can be used. Further, as the above-described polymer liquid crystal compound, for example, a polymer in which a liquid crystal mesogenic group is introduced into a main chain, a side chain, or both a main chain and a side chain, a polymer cholesteric liquid crystal in which a cholesteryl group is introduced into a side chain, a liquid crystal polymer described in JP1997-133810A (JP-H9-133810A), and a liquid crystal polymer described in JP1999-293252A (JP-H11-293252A) can be used.

(201) —Disk-Like Liquid Crystal Compound—

(202) As the disk-like liquid crystal compound, for example, compounds described in JP2007-108732A and JP2010-244038A can be preferably used.

(203) In addition, the addition amount of the polymerizable liquid crystal compound in the liquid crystal composition is preferably 75% to 99.9 mass %, more preferably 80% to 99 mass %, and still more preferably 85% to 90 mass % with respect to the solid content mass (mass excluding a solvent) of the liquid crystal composition.

(204) —Surfactant—

(205) The liquid crystal composition used for forming the liquid crystal layer may include a surfactant.

(206) It is preferable that the surfactant is a compound that can function as an alignment control agent contributing to the stable or rapid alignment of a cholesteric liquid crystalline phase.

Examples of the surfactant include a silicone-based surfactant and a fluorine-based surfactant. Among these, a fluorine-based surfactant is preferable.

(207) Specific examples of the surfactant include compounds described in paragraphs “0082” to “0090” of JP2014-119605A, compounds described in paragraphs “0031” to “0034” of JP2012-203237A, exemplary compounds described in paragraphs “0092” and “0093” of JP2005-99248A, exemplary compounds described in paragraphs “0076” to “0078” and paragraphs “0082” to “0085” of JP2002-129162A, and fluorine (meth)acrylate polymers described in paragraphs “0018” to “0043” of JP2007-272185A.

(208) As the surfactant, one kind may be used alone, or two or more kinds may be used in combination.

(209) As the fluorine-based surfactant, a compound described in paragraphs “0082” to “0090” of JP2014-119605A is preferable.

(210) The addition amount of the surfactant in the liquid crystal composition is preferably 0.01 to 10 mass %, more preferably 0.01 to 5 mass %, and still more preferably 0.02 to 1 mass % with respect to the total mass of the liquid crystal compound.

(211) —Chiral Agent (Optically Active Compound)—

(212) The chiral agent has a function of causing a helical structure of a cholesteric liquid crystalline phase to be formed. The chiral agent may be selected depending on the purpose because a helical twisted direction or a helical pitch derived from the compound varies.

(213) The chiral agent is not particularly limited, and a well-known compound (for example, Liquid Crystal Device Handbook (No. 142 Committee of Japan Society for the Promotion of Science, 1989), Chapter 3, Article 4-3, chiral agent for twisted nematic (TN) or super twisted nematic (STN), p. 199), isosorbide (chiral agent having an isosorbide structure), or an isomannide derivative can be used.

(214) In addition, the chiral agent in which back isomerization, dimerization, isomerization, dimerization or the like occurs due to light irradiation such that the helical twisting power (HTP) decreases can also be suitably used.

(215) In general, the chiral agent includes an asymmetric carbon atom. However, an axially asymmetric compound or a planar asymmetric compound not having an asymmetric carbon atom can also be used as the chiral agent. Examples of the axially asymmetric compound or the planar asymmetric compound include binaphthyl, helicene, paracyclophane, and derivatives thereof. The

chiral agent may include a polymerizable group. In a case where both the chiral agent and the liquid crystal compound have a polymerizable group, a polymer which includes a repeating unit derived from the polymerizable liquid crystal compound and a repeating unit derived from the chiral agent can be formed due to a polymerization reaction of a polymerizable chiral agent and the polymerizable liquid crystal compound. In this aspect, it is preferable that the polymerizable group in the polymerizable chiral agent is the same as the polymerizable group in the polymerizable liquid crystal compound. Accordingly, the polymerizable group of the chiral agent is preferably an unsaturated polymerizable group, an epoxy group, or an aziridiny group, more preferably an unsaturated polymerizable group, and still more preferably an ethylenically unsaturated polymerizable group.

(216) In addition, the chiral agent may be a liquid crystal compound.

(217) In a case where the chiral agent includes a photoisomerization group, a pattern having a desired reflection wavelength corresponding to a luminescence wavelength can be formed by irradiation of an actinic ray or the like through a photomask after coating and alignment, which is preferable. As the photoisomerization group, an isomerization portion of a photochromic compound, an azo group, an azoxy group, or a cinnamoyl group is preferable. Specific examples of the compound include compounds described in JP2002-080478A, JP2002-080851A, JP2002-179668A, JP2002-179669A, JP2002-179670A, JP2002-179681A, JP2002-179682A, JP2002-338575A, JP2002-338668A, JP2003-313189A, and JP2003-313292A.

(218) The content of the chiral agent in the liquid crystal composition is preferably 0.01% to 200 mol % and more preferably 1% to 30 mol % with respect to the content molar amount of the liquid crystal compound.

(219) —Polymerization Initiator—

(220) In a case where the liquid crystal composition includes a polymerizable compound, it is preferable that the liquid crystal composition includes a polymerization initiator. In an aspect where a polymerization reaction progresses with ultraviolet irradiation, it is preferable that the polymerization initiator is a photopolymerization initiator which initiates a polymerization reaction with ultraviolet irradiation.

(221) Examples of the photopolymerization initiator include an α -carbonyl compound (described in U.S. Pat. Nos. 2,367,661A and 2,367,670A), an acyloin ether (described in U.S. Pat. No. 2,448,828A), an α -hydrocarbon-substituted aromatic acyloin compound (described in U.S. Pat. No. 2,722,512A), a polynuclear quinone compound (described in U.S. Pat. Nos. 3,046,127A and 2,951,758A), a combination of a triarylimidazole dimer and p-aminophenyl ketone (described in U.S. Pat. No. 3,549,367A), an acridine compound and a phenazine compound (described in JP1985-105667A (JP-S60-105667A) and U.S. Pat. No. 4,239,850A), and an oxadiazole compound (described in U.S. Pat. No. 4,212,970A).

(222) The content of the photopolymerization initiator in the liquid crystal composition is preferably 0.1 to 20 mass % and more preferably 0.5 to 12 mass % with respect to the content of the liquid crystal compound.

(223) —Crosslinking Agent—

(224) In order to improve the film hardness after curing and to improve durability, the liquid crystal composition may optionally include a crosslinking agent. As the crosslinking agent, a curing agent which can perform curing with ultraviolet light, heat, moisture, or the like can be suitably used.

(225) The crosslinking agent is not particularly limited and can be appropriately selected depending on the purpose. Examples of the crosslinking agent include: a polyfunctional acrylate compound such as trimethylol propane tri(meth)acrylate or pentaerythritol tri(meth)acrylate; an epoxy compound such as glycidyl (meth)acrylate or ethylene glycol diglycidyl ether; an aziridine compound such as 2,2-bis(hydroxymethyl)butanol-tris[3-(1-aziridinyl)propionate] or 4,4-bis(ethyleneiminocarbonylamino)diphenylmethane; an isocyanate compound such as hexamethylene diisocyanate or a biuret type isocyanate; a polyoxazoline compound having an

oxazoline group at a side chain thereof; and an alkoxy silane compound such as vinyl trimethoxysilane or N-(2-aminoethyl)-3-aminopropyltrimethoxysilane. In addition, depending on the reactivity of the crosslinking agent, a well-known catalyst can be used, and not only film hardness and durability but also productivity can be improved. Among these crosslinking agents, one kind may be used alone, or two or more kinds may be used in combination.

(226) The content of the crosslinking agent is preferably 3% to 20 mass % and more preferably 5% to 15 mass % with respect to the solid content mass of the liquid crystal composition. In a case where the content of the crosslinking agent is in the above-described range, an effect of improving a crosslinking density can be easily obtained, and the stability of a liquid crystal phase is further improved.

(227) —Other Additives—

(228) Optionally, a polymerization inhibitor, an antioxidant, an ultraviolet absorber, a light stabilizer, a coloring material, metal oxide fine particles, or the like can be added to the liquid crystal composition in a range where optical performance and the like do not deteriorate.

(229) In a case where the liquid crystal layer is formed, it is preferable that the liquid crystal composition is used as liquid.

(230) The liquid crystal composition may include a solvent. The solvent is not particularly limited and can be appropriately selected depending on the purpose. An organic solvent is preferable.

(231) The organic solvent is not particularly limited and can be appropriately selected depending on the purpose. Examples of the organic solvent include a ketone, an alkyl halide, an amide, a sulfoxide, a heterocyclic compound, a hydrocarbon, an ester, and an ether. Among these crosslinking agents, one kind may be used alone, or two or more kinds may be used in combination. Among these, a ketone is preferable in consideration of an environmental burden.

(232) In a case where the liquid crystal layer is formed, it is preferable that the liquid crystal layer is formed by applying the liquid crystal composition to a surface where the liquid crystal layer is to be formed, aligning the liquid crystal compound to a state of a desired liquid crystalline phase, and curing the liquid crystal compound.

(233) That is, in a case where the cholesteric liquid crystal layer is formed on the alignment film 52, it is preferable that the liquid crystal layer obtained by immobilizing a cholesteric liquid crystalline phase is formed by applying the liquid crystal composition to the alignment film 52, aligning the liquid crystal compound to a state of a cholesteric liquid crystalline phase, and curing the liquid crystal compound.

(234) For the application of the liquid crystal composition, a printing method such as ink jet or scroll printing or a well-known method such as spin coating, bar coating, or spray coating capable of uniformly applying liquid to a sheet-shaped material can be used.

(235) The applied liquid crystal composition is optionally dried and/or heated and then is cured to form the liquid crystal layer. In the drying and/or heating step, the liquid crystal compound in the liquid crystal composition may be aligned to a cholesteric liquid crystalline phase. In the case of heating, the heating temperature is preferably 200° C. or lower and more preferably 130° C. or lower.

(236) The aligned liquid crystal compound is optionally further polymerized. Regarding the polymerization, thermal polymerization or photopolymerization using light irradiation may be performed, and photopolymerization is preferable. Regarding the light irradiation, ultraviolet light is preferably used. The irradiation energy is preferably 20 mJ/cm.² to 50 J/cm.² and more preferably 50 to 1500 mJ/cm.². In order to promote a photopolymerization reaction, light irradiation may be performed under heating conditions or in a nitrogen atmosphere. The wavelength of irradiated ultraviolet light is preferably 250 to 430 nm.

(237) In a case where a chiral agent where the HTP changes depending on the polarization of light is used as the chiral agent added to the liquid crystal composition, light irradiation (first exposure step) for changing the HTP of the chiral agent may be performed before light irradiation (second

exposure step) for the polymerization of the liquid crystal compound. Alternatively, light irradiation by the photopolymerization of the liquid crystal compound may also be light irradiation for changing the HTP of the chiral agent. As a result, the above-described liquid crystal layer where the helical pitch P of the cholesteric liquid crystalline phase gradually changes can be obtained.

(238) The thickness of the liquid crystal layer **54** is not particularly limited, and the thickness with which a required light reflectivity can be obtained may be appropriately set depending on the use of the optical element, the light reflectivity required for the liquid crystal layer, the material for forming the liquid crystal layer **54**, and the like.

(239) <Other Liquid Crystal Layers (Liquid Crystal Diffraction Elements)>

(240) In the optical element in the example shown in the drawing, as the incidence element and the emission element, a reflective liquid crystal diffraction element including the liquid crystal layer **54** as a cholesteric liquid crystal layer is used. However, in the present invention, the liquid crystal diffraction layer including the liquid crystal diffraction element is not limited to this example.

(241) For example, likewise, a liquid crystal diffraction element that has the liquid crystal alignment pattern where the optical axis continuously rotates in at least one in-plane direction and in which the liquid crystal compound does not form a cholesteric liquid crystalline phase in the thickness direction can also be used. The liquid crystal diffraction element may have a configuration in which the liquid crystal compound is helically twisted and rotates in the thickness direction to some extent that a cholesteric liquid crystalline phase is not formed.

(242) FIGS. **10** and **11** show an example of another liquid crystal diffraction element.

(243) A liquid crystal diffraction element shown in FIGS. **10** and **11** includes the support **50**, the alignment film **52**, and a liquid crystal layer **56**. As the support **50** and the alignment film **52**, those described above can be used.

(244) As in the (cholesteric) liquid crystal layer **54** described above, the liquid crystal layer **56** of the liquid crystal diffraction element shown in FIG. **11** also has the liquid crystal alignment pattern in which the optical axis **40A** of the liquid crystal compound **40** continuously rotates along the arrangement axis D . FIG. **11** also shows only the liquid crystal compound of the surface of the alignment film **52** as in FIG. **4**.

(245) As shown in FIG. **10**, in the liquid crystal diffraction element, the liquid crystal compound **40** forming the liquid crystal layer **56** is not helically twisted and does not rotate in the thickness direction, and the optical axis **40A** is positioned at the same position in the plane direction. The liquid crystal layer can be formed by adding a chiral agent to a liquid crystal composition during the formation of the liquid crystal layer.

(246) As described above, the liquid crystal layer **56** has the liquid crystal alignment pattern in which the direction of the optical axis **40A** derived from the liquid crystal compound **40** changes while continuously rotating in the arrangement axis D direction in a plane, that is, in the X direction. That is, in the liquid crystal layer **56** (liquid crystal diffraction element), the periodic direction is the arrangement axis D direction, that is, the X direction. In addition, even in the liquid crystal layer **56**, as shown in FIG. **11**, the diffraction period Λ (the single period of the diffraction structure) is the length over which the optical axis **40A** rotates by 180° in the arrangement axis D direction, that is, the periodic direction.

(247) On the other hand, regarding the liquid crystal compound **40** forming the liquid crystal layer **56**, the liquid crystal compounds **40** having the same direction of the optical axes **40A** are arranged at regular intervals in the Y direction perpendicular to the X direction, that is, the Y direction perpendicular to the arrangement axis D (periodic direction) as the one in-plane direction in which the optical axis **40A** continuously rotates.

(248) In other words, regarding the liquid crystal compound **40** forming the liquid crystal layer **56**, in the liquid crystal compounds **40** arranged in the Y direction, angles between the directions of the optical axes **40A** and the arrangement axis D direction are the same.

(249) In the liquid crystal compounds arranged in the Y direction in the liquid crystal layer **56**, the

angles between the optical axes **40A** and the X direction (the one in-plane direction in which the direction of the optical axis **40A** of the liquid crystal compound **40** rotates) are the same. Regions where the liquid crystal compounds **40** in which the angles between the optical axes **40A** and the arrangement axis D are the same are disposed in the Y direction will be referred to as “regions R”.

(250) In this case, it is preferable that an in-plane retardation (Re) value of each of the regions R is a half wavelength, that is, $\lambda/2$. The in-plane retardation is calculated from the product of a difference Δn in refractive index generated by refractive index anisotropy of the region R and the thickness of the optically-anisotropic layer. Here, the difference in refractive index generated by refractive index anisotropy of the region R in the optically-anisotropic layer is defined by a difference between a refractive index of a direction of an in-plane slow axis of the region R and a refractive index of a direction perpendicular to the direction of the slow axis. That is, the difference Δn in refractive index generated by refractive index anisotropy of the region R is the same as a difference between a refractive index of the liquid crystal compound **40** in the direction of the optical axis **40A** and a refractive index of the liquid crystal compound **40** in a direction perpendicular to the optical axis **40A** in a plane of the region R. That is, the difference Δn in refractive index is the same as the difference in refractive index of the liquid crystal compound **40**.

(251) In a case where circularly polarized light is incident into the above-described liquid crystal layer **56**, the light is refracted such that the direction of the circularly polarized light is converted.

(252) This action is conceptually shown in FIGS. **12** and **13**. In the liquid crystal layer **56**, the value of the product of the difference in refractive index of the liquid crystal compound and the thickness of the optically-anisotropic layer is $\lambda/2$.

(253) As shown in FIG. **12**, in a case where the value of the product of the difference in refractive index of the liquid crystal compound **40** in the liquid crystal layer **56** and the thickness of the optically-anisotropic layer is $\lambda/2$ and incidence light L.sub.1 as left circularly polarized light is incident into the liquid crystal layer **56**, the incidence light L.sub.1 transmits through the liquid crystal layer **56** to be imparted with a retardation of 180° , and the transmitted light L.sub.2 is converted into right circularly polarized light.

(254) In addition, the liquid crystal alignment pattern formed in the liquid crystal layer **56** is a pattern that is periodic in the arrangement axis D direction. Therefore, the transmitted light L.sub.2 travels in a direction different from a traveling direction of the incidence light L.sub.1. This way, the incidence light L.sub.1 of the left circularly polarized light is converted into the transmitted light L.sub.2 of right circularly polarized light that is tilted by a predetermined angle in the arrangement axis D direction with respect to an incidence direction.

(255) On the other hand, as shown in FIG. **13**, in a case where the value of the product of the difference in refractive index of the liquid crystal compound **40** in the liquid crystal layer **56** and the thickness of the optically-anisotropic layer is $\lambda/2$ and incidence light L.sub.4 of right circularly polarized light is incident into the liquid crystal layer **56**, the incidence light L.sub.4 transmits through the liquid crystal layer **56** to be imparted with a retardation of 180° , and the transmitted light L.sub.4 is converted into transmitted light L.sub.5 of left circularly polarized light.

(256) In addition, the liquid crystal alignment pattern formed in the liquid crystal layer **56** is a pattern that is periodic in the arrangement axis D direction. Therefore, the transmitted light L.sub.5 travels in a direction different from a traveling direction of the incidence light L.sub.4. In this case, the transmitted Light L.sub.5 travels in a direction different from the transmitted light L.sub.2, that is, in a direction opposite to the arrangement axis D direction with respect to the incidence direction. This way, the incidence light L.sub.4 is converted into the transmitted light L.sub.5 of left circularly polarized light that is tilted by a predetermined angle in a direction opposite to the arrangement axis D direction with respect to an incidence direction.

(257) Here, the liquid crystal diffraction element including the liquid crystal layer **56** is a transmissive liquid crystal diffraction element.

(258) As in the liquid crystal layer **54**, by changing the diffraction period Λ of the liquid crystal

alignment pattern formed in the liquid crystal layer **56**, refraction angles of the transmitted light L.sub.2 and the transmitted light L.sub.5 can be adjusted. Specifically, even in the liquid crystal layer **56**, as the diffraction period Λ of the liquid crystal alignment pattern decreases, light components transmitted through the liquid crystal compounds **40** adjacent to each other more strongly interfere with each other. Therefore, the transmitted light components L.sub.2 and L.sub.5 can be more largely refracted. As described above, the diffraction periods Λ of the incidence element and the emission element are the diffraction period Λ_1 , the diffraction period Λ_2 , and the diffraction period Λ_3 that satisfy the predetermined relationship.

(259) In addition, by reversing the rotation direction of the optical axis **40A** of the liquid crystal compound **40** that rotates in the arrangement axis D direction, that is, the periodic direction, the refraction direction of transmitted light can be reversed. That is, in the example FIGS. **10** to **13**, the rotation direction of the optical axis **40A** toward the arrangement axis D direction, that is, the periodic direction is clockwise. By setting this rotation direction to be counterclockwise, the refraction direction of transmitted light can be reversed.

(260) From the viewpoint of diffraction efficiency, even in a case where the liquid crystal diffraction element that allows transmission of incidence light and diffracts incidence light is used, it is preferable to use a liquid crystal diffraction element having a region where the liquid crystal compound is twisted and rotates (the twisted angle is less than 360°). In particular, in a case where light is diffracted at an angle where the light is reflected in the light guide plate, from the viewpoint of diffraction efficiency, a liquid crystal diffraction element including a region in which a liquid crystal compound is twisted and rotates can be suitably used. In addition, from the viewpoint of diffraction efficiency, it is preferable to use a laminate in which liquid crystal diffraction elements having different angles at which the liquid crystal compound is twisted and rotates is laminated, or it is preferable to use a laminate in which liquid crystal diffraction elements having different directions in which the liquid crystal compound is twisted and rotates are laminated.

(261) In the image display apparatus according to the embodiment of the present invention, in a case where a transmissive incidence element and a transmissive emission element are used, a positional relationship between the incidence portion, the emission portion, the display **14**, and the user U is opposite to that in a case where the reflective incidence element and the reflective emission element shown in FIGS. **1** and **2** are used.

(262) That is, in the image display apparatus (optical element) according to the embodiment of the present invention, in a case where a transmissive incidence element and a transmissive emission element are used, the incidence portion is positioned between the display **14** and the light guide plate **18**, and the emission portion is positioned between the observation position by the user U and the light guide plate **18**. Accordingly, the display image (emitted light) of the display **14** transmits through the incidence portion (incidence element), is refracted, and is incident into the light guide plate **18**. The light that is incident into the light guide plate **18** and propagates in the light guide plate **18** while repeating total reflection is incident into the emission portion from the light guide plate **18**, transmits through the emission portion, is refracted, and is emitted to the observation position by the user U.

(263) In the optical element according to the embodiment of the present invention, the incidence portion and the emission portion may use different liquid crystal diffraction elements.

(264) For example, a transmissive liquid crystal diffraction element including the liquid crystal layer **56** may be used as the incidence element in the incidence portion **20**, and a reflective liquid crystal diffraction element including the liquid crystal layer **54** may be used as the emission element in the emission portion **24**.

(265) In the optical element **12** in the example shown in the drawing, the incidence portion **20** includes the incidence element, and the emission portion **24** includes the emission element. As described above, in the optical element **12** in the example shown in the drawing, the incidence element and the emission element are reflective liquid crystal diffraction elements including the

liquid crystal layer **54** a cholesteric liquid crystal layer as the liquid crystal diffraction layer.

(266) The incidence portion **20** includes the incidence element **26Λ1-1**, the incidence element **26Λ1-2**, the incidence element **28Λ2-1**, the incidence element **28Λ2-2**, the incidence element **30Λ3-1**, and the incidence element **30Λ3-2** in this order from the light guide plate **18** side.

(267) On the other hand, the emission portion **24** includes the emission element **34Λ1-1**, the emission element **34Λ1-2**, the emission element **36Λ2-1**, the emission element **36Λ2-2**, the emission element **36Λ2-3**, the emission element **36Λ2-4**, the emission element **38Λ3-1**, and the emission element **38Λ3-2** in this order from the light guide plate **18**.

(268) Here, in the optical element **12** according to the embodiment of the present invention, both of the incidence portion **20** and the emission portion **24** include three kinds of diffraction elements having different diffraction periods Λ that include the $\Lambda1$ diffraction element where the diffraction period is $\Lambda1$, the $\Lambda2$ diffraction element where the diffraction period is $\Lambda2$, and the $\Lambda3$ diffraction element where the diffraction period is $\Lambda3$.

(269) In the incidence portion **20**, the incidence element **26Λ1-1** and the incidence element **26Λ1-2** are the $\Lambda1$ diffraction elements where the diffraction period is $\Lambda1$, the incidence element **28Λ2-1** and the incidence element **28Λ2-2** are the $\Lambda2$ diffraction elements where the diffraction period is $\Lambda2$, and the incidence element **30Λ3-1** and the incidence element **30Λ3-2** are the $\Lambda3$ diffraction element where the diffraction period is $\Lambda3$.

(270) In the emission portion **24**, the emission element **34Λ1-1** and the emission element **34Λ1-2** are the $\Lambda1$ diffraction elements where the diffraction period is $\Lambda1$, the emission element **36Λ2-1**, the emission element **36Λ2-2**, the emission element **36Λ2-3**, and the emission element **36Λ2-4** are the $\Lambda2$ diffraction elements where the diffraction period is $\Lambda2$, and the emission element **38Λ3-1** and the emission element **38Λ3-2** are the $\Lambda3$ diffraction elements where the diffraction period is $\Lambda3$.

(271) Here, in the optical element **12** according to the embodiment of the present invention, the diffraction period $\Lambda1$, the diffraction period $\Lambda2$, and the diffraction period $\Lambda3$ satisfy a relationship of " $\Lambda1:\Lambda2:\Lambda3=1:1/\sqrt{2}\pm0.015:1/2\pm0.015$ ". That is, in the optical element **12** according to the embodiment of the present invention, a value obtained by normalizing the diffraction period $\Lambda2$ with the diffraction period $\Lambda1$ is " $1/\sqrt{2}\pm0.015$ ", and a value obtained by normalizing the diffraction period $\Lambda3$ with the diffraction period $\Lambda1$ is " $1/\sqrt{2}\pm0.015$ (that is, 0.5 ± 0.015)".

(272) In the example shown in the drawing, for example, the diffraction period $\Lambda1$ is 580 nm, the diffraction period $\Lambda2$ is 410 nm ($580/\sqrt{2}$), and the diffraction period $\Lambda3$ is 290 nm ($580/\sqrt{2}$)

(273) In addition, in the optical element **12** according to the embodiment of the present invention, in the incidence portion **20** and the emission portion **24**, an angle between the periodic direction of the $\Lambda1$ diffraction element and the periodic direction of the $\Lambda2$ diffraction element and an angle between the periodic direction of the $\Lambda2$ diffraction element and the periodic direction of the $\Lambda3$ diffraction element are $45^\circ\pm0.5^\circ$ or $135^\circ\pm0.5^\circ$.

(274) Accordingly, in the incidence portion **20**, an angle between the periodic direction of the incidence element **26Λ1-1** and the incidence element **26Λ1-2** as the $\Lambda1$ diffraction elements and the periodic direction of the incidence element **28Λ2-1** and the incidence element **28Λ2-2** as the $\Lambda2$ diffraction elements is $45^\circ\pm0.5^\circ$ or $135^\circ\pm0.5^\circ$. Further, in the incidence portion **20**, an angle between the periodic direction of the incidence element **28Λ2-1** and the incidence element **28Λ2-2** as the $\Lambda2$ diffraction elements and the periodic direction of the incidence element **30Λ3-1** and the incidence element **30Λ3-2** as the $\Lambda3$ diffraction elements is $45^\circ\pm0.5^\circ$ or $135^\circ\pm0.5^\circ$.

(275) On the other hand, in the emission portion **24**, an angle between the periodic direction of the emission element **34Λ1-1** and the emission element **34Λ1-2** as the $\Lambda1$ diffraction elements and the periodic direction of the emission element **36Λ2-1**, the emission element **36Λ2-2**, the emission element **36Λ2-3**, and the emission element **36Λ2-4** as the $\Lambda2$ diffraction elements is $45^\circ\pm0.5^\circ$ or $135^\circ\pm0.5^\circ$. Further, in the emission portion **24**, an angle between the periodic direction of the emission element **36Λ2-1**, the emission element **36Λ2-2**, the emission element **36Λ2-3**, and the

emission element **36Λ2-4** as the $\Lambda 2$ diffraction elements and a periodic direction of the emission element **38Λ3-1** and the emission element **38Λ3-2** as the $\Lambda 3$ diffraction elements is $45^\circ \pm 0.5^\circ$ or $135^\circ \pm 0.5^\circ$.

(276) Further, in the optical element **12** according to the embodiment of the present invention, an angle between the periodic direction of the $\Lambda 2$ diffraction element provided in the incidence portion **20** and the periodic direction of the $\Lambda 2$ diffraction element provided in the emission portion **24** is any one of $0^\circ \pm 0.5^\circ$, $90^\circ \pm 0.5^\circ$, $180^\circ \pm 0.5^\circ$, or $270^\circ \pm 0.5^\circ$. That is, in the optical element **12** according to the embodiment of the present invention, the periodic direction of the $\Lambda 2$ diffraction element provided in the incidence portion **20** and the periodic direction of the $\Lambda 2$ diffraction element provided in the emission portion are parallel (substantially parallel) or perpendicular (substantially perpendicular) to each other.

(277) Accordingly, in the optical element **12**, an angle between the periodic direction of the incidence element **28Λ2-1** and the incidence element **28Λ2-2** in the incidence portion **20** and the periodic direction of the emission element **36Λ2-1**, the emission element **36Λ2-2**, the emission element **36Λ2-3**, and the emission element **36Λ2-4** in the emission portion **24** is any one of $0^\circ \pm 0.5^\circ$, $90^\circ \pm 0.5^\circ$, $180^\circ \pm 0.5^\circ$, or $270^\circ \pm 0.5^\circ$.

(278) For example, the right direction on the plane of FIG. 2 is 0° , and the upper direction on the plane of FIG. 2 is 90° . FIG. 2 is a plan view in a case where the optical element **12** is seen from the observation direction of the user U.

(279) In FIG. 2, the periodic direction of the $\Lambda 1$ diffraction element is indicated by a solid line arrow, the periodic direction of the $\Lambda 2$ diffraction element is indicated by a broken line arrow, and the periodic direction of the $\Lambda 3$ diffraction element is indicated by a fine broken line arrow.

(280) Further, in FIG. 2, the diffraction period $\Lambda 1$ (580 nm), the diffraction period $\Lambda 2$ (410 nm), and the diffraction period $\Lambda 3$ (280 nm) are inverted and represented by the lengths of the arrows. That is, the arrow of the $\Lambda 1$ diffraction element indicated by the solid line is the shortest, and the arrow of the $\Lambda 3$ diffraction element indicated by the fine broken line is the longest.

(281) As conceptually shown in FIGS. 2 and 14, in the incidence portion **20** of the optical element **12** in the example shown in the drawing, the periodic direction of the incidence element **26Λ1-1** as the $\Lambda 1$ diffraction element (solid line) is 45° , and the periodic direction of the incidence element **26Λ1-2** is 225° . In addition, the periodic direction of the incidence element **28Λ2-1** as the $\Lambda 2$ diffraction element (broken line) is 0° , and the periodic direction of the incidence element **28Λ2-2** is 270° . Further, the periodic direction of the incidence element **30Λ3-1** as the $\Lambda 3$ diffraction element (fine broken line) is 45° , and the periodic direction of the incidence element **30Λ3-2** is 225° . In FIG. 1, the arrow indicating the periodic direction of each of the incidence elements is represented by the reference numeral of the corresponding incidence element. Regarding this point, the same can also be applied to the emission element.

(282) On the other hand, as conceptually shown in FIGS. 2 and 15, in the emission portion **24** of the optical element **12** in the example shown in the drawing, the periodic direction of the emission element **34Λ1-1** as the $\Lambda 1$ diffraction element (solid line) is 45° , and the periodic direction of the emission element **34Λ1-2** is 225° . In addition, the periodic direction of the emission element **36Λ2-1** as the $\Lambda 2$ diffraction element (broken line) is 0° , the periodic direction of the emission element **36Λ2-2** is 90° , the periodic direction of the emission element **36Λ2-3** is 180° , and the periodic direction of the emission element **36Λ2-4** is 270° . Further, the periodic direction of the emission element **38Λ3-1** as the $\Lambda 3$ diffraction element (fine broken line) is 45° , and the periodic direction of the emission element **38Λ3-2** is 225° .

(283) With the above-described configuration, in a case where the optical element **12** and the image display apparatus according to the embodiment of the present invention is used, for example, for AR glasses, the FOV can be widened by one light guide plate without occurrence of crosstalk.

(284) In AR glasses or the like, in order to widen the FOV, it is necessary that light that carries and supports an image displayed (emitted) by the display **14** is incident into the light guide plate **18**, is

totally reflected, and propagates in the light guide plate **18** according to the entire surface of the display screen of the display **14**.

(285) However, the image that is displayed by the display **14** and incident into the incidence portion is incident from various angles depending on the positions of the display screen of the display. It is difficult to allow the light incident from various angles to be incident into the light guide plate at an angle where total reflection occurs according to the entire display screen of the display.

(286) In addition, in AR glasses or the like, in order to widen the FOV, in the emission portion **24**, it is necessary that the light propagating in the light guide plate **18** is emitted from the entire surface at various angles.

(287) However, it is also difficult that all of the light components that are totally reflected and propagate are diffracted at angles where they can be emitted and emitted at various directions.

(288) Accordingly, in the optical element **12** according to the embodiment of the present invention, both of the incidence portion **20** and the emission portion **24** include, as the incidence elements and the emission elements, three kinds of diffraction elements having different diffraction periods Λ that include the $\Lambda1$ diffraction element where the diffraction period is $\Lambda1$, the $\Lambda2$ diffraction element where the diffraction period is $\Lambda2$, and the $\Lambda3$ diffraction element where the diffraction period is $\Lambda3$.

(289) As described above, the liquid crystal layer **54** (cholesteric liquid crystal layer) having the liquid crystal alignment pattern where the direction of the optical axis **40A** of the liquid crystal compound **40** changes while continuously changing in the one in-plane direction (periodic direction) acts as the liquid crystal diffraction element and diffracts and reflects incidence light in a direction different from specular reflection. Regarding the diffraction of the light, as the diffraction period Λ decreases, the light is largely diffracted and reflected.

(290) Therefore, in the optical element **12** according to the embodiment of the present invention, even in a case where light is incident from the display **14** into the incidence portion **20** at various angles, any incidence element of the incidence element **26 $\Lambda1$ -1** and the incidence element **26 $\Lambda1$ -2** as the $\Lambda1$ diffraction elements, the incidence element **28 $\Lambda2$ -1** and the incidence element **28 $\Lambda2$ -2** as the $\Lambda2$ diffraction elements, and the incidence element **30 $\Lambda3$ -1** and the incidence element **30 $\Lambda3$ -2** as the $\Lambda3$ diffraction elements can cause light to be incident into the light guide plate **18** at an angle where the light can be totally reflected and propagate.

(291) Accordingly, in the optical element **12** according to the embodiment of the present invention, the light that is displayed by the display **14** and incident into the incidence portion **20** can be incident into the light guide plate **18** at angle where the light can be totally reflected and propagate according to the entire surface of the display screen of the display **14**.

(292) In addition, the incidence portion **20** includes the three diffraction elements having different diffraction periods Λ . Therefore, light is totally reflected and propagates in the light guide plate **18** at various angles in various directions.

(293) Further, as in the incidence portion **20**, the emission portion **24** also includes the three kinds of diffraction elements including the $\Lambda1$ diffraction element, the $\Lambda2$ diffraction element, and the $\Lambda3$ diffraction element having different diffraction periods Λ as the emission elements. Further, the diffraction periods of the diffraction elements are the same as those of the incidence portion **20**. Therefore, the light that propagates at various angles in various directions and is incident into the emission portion **24** can be emitted from light guide plate **18** to various directions using the entire surface of the emission portion **24** without leaking.

(294) That is, in the optical element **12** and the image display apparatus **10** according to the embodiment of the present invention, light from the entire surface of the display screen of the display **14** can be incident into the light guide plate **18** and propagate in the light guide plate **18** by the incidence portion **20**, and light from the entire surface of the display screen of the display **14** can be emitted from the light guide plate **18** at various angles by the emission portion **24**.

(295) Therefore, in the present invention, the FOV can be widened in AR glasses or the like.

(296) Here, as described above, in AR glasses having a wide FOV and AR glasses including one light guide plate **18**, crosstalk is likely to occur.

(297) On the other hand, in the optical element **12** according to the embodiment of the present invention, the diffraction period $\Lambda 1$, the diffraction period $\Lambda 2$, and the diffraction period $\Lambda 3$ in the diffraction elements forming the incidence elements and the emission elements satisfy a relationship of " $\Lambda 1:\Lambda 2:\Lambda 3=1:1/\sqrt{2}\pm 0.015:1/2\pm 0.015$ ".

(298) The optical element **12** according to the embodiment of the present invention satisfies this relationship such that the occurrence of crosstalk can be suppressed.

(299) Specifically, in the optical element **12** in the example shown in the drawing, the light that is diffracted by the incidence element **26** $\Lambda 1$ -1 and the incidence element **26** $\Lambda 1$ -2 as the $\Lambda 1$ diffraction elements, is incident into the light guide plate **18**, and propagates in the light guide plate **18** is diffracted by the emission element **34** $\Lambda 1$ -1 and the emission element **34** $\Lambda 1$ -2 as the $\Lambda 1$ diffraction elements, and is emitted from the light guide plate **18**. the light that is diffracted by the incidence element **28** $\Lambda 2$ -1 and the incidence element **28** $\Lambda 2$ -2 as the $\Lambda 2$ diffraction elements, is incident into the light guide plate **18**, and propagates in the light guide plate **18** is diffracted by the emission element **36** $\Lambda 2$ -1, the emission element **36** $\Lambda 2$ -2, the emission element **36** $\Lambda 2$ -3, and the emission element **36** $\Lambda 2$ -4 as the $\Lambda 2$ diffraction elements, and is emitted from the light guide plate **18**.

(300) Further, the light that is diffracted by the incidence element **30** $\Lambda 3$ -1 and the incidence element **30** $\Lambda 3$ -2 as the $\Lambda 3$ diffraction elements, is incident into the light guide plate **18**, and propagates in the light guide plate **18** is diffracted by the emission element **38** $\Lambda 3$ -1 and the emission element **38** $\Lambda 3$ -2 as the $\Lambda 3$ diffraction elements, and is emitted from the light guide plate **18**.

(301) Further, in the optical element **12** according to the embodiment of the present invention, in the incidence portion **20** and the emission portion **24**, an angle between the periodic direction of the $\Lambda 1$ diffraction element and the periodic direction of the $\Lambda 2$ diffraction element and an angle between the periodic direction of the $\Lambda 2$ diffraction element and the periodic direction of the $\Lambda 3$ diffraction element are $45^\circ\pm 0.5^\circ$ or $135^\circ\pm 0.5^\circ$.

(302) Further, in the optical element **12** according to the embodiment of the present invention, an angle between the periodic direction of the $\Lambda 2$ diffraction element among the incidence elements provided in the incidence portion **20** and the periodic direction of the $\Lambda 2$ diffraction element among the emission elements provided in the emission portion **24** is any one of $0^\circ\pm 0.5^\circ$, $90^\circ\pm 0.5^\circ$, $180^\circ\pm 0.5^\circ$, or $270^\circ\pm 0.5^\circ$.

(303) In the optical element **12** according to the embodiment of the present invention, with the above-described configuration, the relationship of the incidence directions in which the incidence elements having the diffraction periods in the incidence portion **20** cause light to be incident into the light guide plate **18**, the relationship of the emission directions where the emission elements having the diffraction periods in the emission portion **24** emit light from the light guide plate **18**, and the relationship between the incidence direction in which the incidence portion **20** causes light to be incident into the light guide plate **18** and the emission direction in which the emission portion **24** emits light from the light guide plate can be appropriately maintained.

(304) By satisfying both of the conditions, even in a case where the FOV is widened by one light guide plate **18**, crosstalk can be prevented.

(305) That is, in the optical element **12** according to the embodiment of the present invention and the image display apparatus according to the embodiment of the present invention including the optical element **12** according to the embodiment of the present invention, for example, in AR glasses or the like, the FOV can be widened, crosstalk can be prevented, and an appropriate image can be displayed using one light guide plate.

(306) In the optical element **12** according to the embodiment of the present invention, in a case where the diffraction periods Λ of the incidence elements provided in the incidence portion **20** and

the emission elements provided in the emission portion **24** are two or more kinds, the FOV cannot be sufficiently widened.

(307) In addition, in the optical element **12** according to the embodiment of the present invention, in a case where the diffraction periods Λ of the diffraction elements forming the incidence portion **20** and the emission portion **24** did not satisfy a relationship of " $\Lambda1:\Lambda2:\Lambda3=1:1/\sqrt{2}\pm0.015:1/2\pm0.015$ ", the relationship of the combination of the incidence elements and the emission elements is collapsed, crosstalk occurs, and an appropriate image can be displayed.

(308) In the optical element **12** according to the embodiment of the present invention, it is preferable that the diffraction periods Λ of the incidence elements of the incidence portion **20** and the emission elements of the emission portion **24** satisfy " $\Lambda1:\Lambda2:\Lambda3=1:1/\sqrt{2}\pm0.005:1/\sqrt{2}\pm0.005$ ", it is more preferable that the diffraction periods Λ satisfy " $\Lambda1:\Lambda2:\Lambda3=1:1/\sqrt{2}\pm0.001:1/\sqrt{2}\pm0.001$ ", and it is still more preferable that the diffraction periods Λ satisfy " $\Lambda1:\Lambda2:\Lambda3=1:1/\sqrt{2}:1/2$ ".

(309) Optionally, in the optical element **12** according to the embodiment of the present invention, both of the incidence portion **20** and the emission portion **24** may include incidence elements and emission elements (diffraction elements) having diffraction periods other than $\Lambda1$, $\Lambda2$, and $\Lambda3$. Here, in this case, it is necessary that diffraction periods of the incidence elements and the emission elements having diffraction periods other than $\Lambda1$, $\Lambda2$, and $\Lambda3$ are integer multiples of the diffraction period $\Lambda2$ or the diffraction period $\Lambda3$, for example, " $1:2/\sqrt{2}$ " where the diffraction period $\Lambda1$ is 1.

(310) In the optical element **12** according to the embodiment of the present invention, the diffraction period $\Lambda1$ is not limited. That is, the diffraction period $\Lambda1$ may be appropriately set depending on the color of the image displayed by the image display apparatus according to the embodiment of the present invention, whether or not the display image of the image display apparatus according to the embodiment of the present invention is a monochrome image, a two-color image, or a full-color image, the aspect ratio of the FOV, and the like.

(311) The diffraction period $\Lambda1$ is preferably 300 to 700 nm, more preferably 400 to 600 nm, still more preferably 450 to 500 nm, and still more preferably 460 to 490 nm.

(312) It is preferable that the diffraction period $\Lambda1$ to be 300 to 700 nm from the viewpoints that, for example, any one of red light, green light, or blue light can be caused to be appropriately incident into the light guide plate **18** and to be emitted from the light guide plate **18** and the range of the incidence angle can be widened.

(313) Further, in the optical element **12** according to the embodiment of the present invention, in the incidence elements of the incidence portion **20** and the emission elements of the emission portion **24**, an angle between the periodic direction of the $\Lambda1$ diffraction element and the periodic direction of the $\Lambda2$ diffraction element and an angle between the periodic direction of the $\Lambda2$ diffraction element and the periodic direction of the $\Lambda3$ diffraction element are $45^\circ\pm0.5^\circ$ or $135^\circ\pm0.5^\circ$.

(314) In a case where the angle between the periodic directions of the $\Lambda1$ diffraction element and the $\Lambda2$ diffraction element and the angle between the periodic directions of the $\Lambda2$ diffraction element and the $\Lambda3$ diffraction element exceed $45^\circ\pm0.5^\circ$ or $135^\circ\pm0.5^\circ$, crosstalk occurs.

(315) The angle between the periodic directions of the $\Lambda1$ diffraction element and the $\Lambda2$ diffraction element and the angle between the periodic directions of the $\Lambda2$ diffraction element and the $\Lambda3$ diffraction element are preferably $45^\circ\pm0.2^\circ$ or $135^\circ\pm0.2^\circ$, more preferably 45° or 135° , and most preferably 45° or 135° .

(316) Further, in the optical element **12** according to the embodiment of the present invention, an angle between the periodic direction of the $\Lambda2$ diffraction element among the incidence elements provided in the incidence portion **20** and the periodic direction of the $\Lambda2$ diffraction element among the emission elements provided in the emission portion **24** is any one of $0^\circ\pm0.5^\circ$, $90^\circ\pm0.5^\circ$, $180^\circ\pm0.5^\circ$, or $270^\circ\pm0.5^\circ$. That is, in the incidence portion **20** and the emission portion **24**, the periodic directions of the $\Lambda2$ diffraction elements are parallel (substantially parallel) or perpendicular

(substantially perpendicular) to each other.

(317) In the incidence portion **20** and the emission portion **24**, in a case where the angle between the periodic directions of the $\Lambda 2$ diffraction elements exceed $0^\circ \pm 0.5^\circ$, $90^\circ \pm 0.5^\circ$, $180^\circ \pm 0.5^\circ$, or $270^\circ \pm 0.5^\circ$, crosstalk occurs.

(318) The angle between the periodic directions of the $\Lambda 2$ diffraction elements of the incidence portion **20** and the emission portion **24** is preferably any one of $0^\circ \pm 0.2^\circ$, $90^\circ \pm 0.2^\circ$, $180^\circ \pm 0.2^\circ$, or $270^\circ \pm 0.2^\circ$, more preferably any one of $0^\circ \pm 0.1^\circ$, $90^\circ \pm 0.1^\circ$, $180^\circ \pm 0.1^\circ$, or $270^\circ \pm 0.1^\circ$, and still more preferably any one of 0° , 90° , 180° , or 270° .

(319) In the optical element **12** according to the embodiment of the present invention, the incidence portion **20** includes 6 or more incidence elements, and the emission portion **24** includes 8 or more emission elements.

(320) In a case where the incidence portion **20** includes 6 or more incidence elements, incidence elements having the same diffraction period Λ and different periodic directions can be disposed as all of the incidence elements of the incidence portion **20** including the $\Lambda 1$ diffraction element, the $\Lambda 2$ diffraction element, and the $\Lambda 3$ diffraction element.

(321) Likewise, in a case where the emission portion **24** includes 8 or more emission elements, emission elements having different periodic directions can be disposed as all of the emission elements of the emission portion **24** including the $\Lambda 1$ diffraction element, the $\Lambda 2$ diffraction element, and the $\Lambda 3$ diffraction element. In addition, in the emission portion **24**, emission elements having different periodic directions can be disposed as all of the three kinds of emission elements having different diffraction periods, and four incidence elements having the same diffraction period and different periodic directions can be disposed as one kind among diffraction elements having different diffraction periods. Alternatively, in the emission portion **24**, emission elements having different periodic directions can be disposed as all of the three kinds of emission elements having different diffraction periods, and three incidence elements having the same diffraction period and different periodic directions can be disposed as two kinds among diffraction elements having different diffraction periods.

(322) As described above, the liquid crystal layer **54** (liquid crystal diffraction element) having the liquid crystal alignment pattern where the optical axis **40A** of the liquid crystal compound **40** rotates in the one in-plane direction refracts light in the direction in which the optical axis **40A** rotates, that is, the periodic direction (arrangement axis D direction).

(323) Accordingly, the incidence portion **20** includes one or more incidence elements as the $\Lambda 1$ diffraction element, the $\Lambda 2$ diffraction element, and the $\Lambda 3$ diffraction element, the emission portion **24** includes a plurality of emission elements as all of the $\Lambda 1$ diffraction element, the $\Lambda 2$ diffraction element, and the $\Lambda 3$ diffraction element, and the periodic directions of the diffraction elements having the diffraction periods are changed such that the diffraction directions of light by the diffraction elements having the diffraction periods A can be made to be two different directions.

(324) As a result, in the incidence portion **20**, light can be refracted in a wider direction to be incident into the light guide plate **18** and to two-dimensionally propagate more widely. In addition, in the emission portion **24**, light can be refracted in a wider direction to be emitted from the light guide plate **18** and to be two-dimensionally emitted more widely.

(325) Therefore, in the image display apparatus **10** according to the embodiment of the present invention including the optical element **12** according to the embodiment of the present invention, using one light guide plate **18**, crosstalk can be prevented, the FOV can be widened, and an excellent eye box (viewing zone) can also be secured.

(326) In the optical element **12** according to the embodiment of the present invention, the number of the incidence elements provided in the incidence portion **20** may be 6 or more and is preferably 8 or more. It is preferable that the number of the incidence elements provided in the incidence portion **20** is 8 or more from the viewpoints, for example, in a case where a plurality of diffraction elements are provided as all of the $\Lambda 1$ diffraction element, the $\Lambda 2$ diffraction element, and the $\Lambda 3$

diffraction element, the number of the diffraction elements can be made to be 3 or more, the FOV can be further widened, and the eye box can be widened.

(327) In addition, the number of the incidence elements provided in the incidence portion **20** is not limited and is preferably 12 or less.

(328) On the other hand, the number of the emission elements provided in the emission portion **24** may be 8 or more and is preferably 10 or more and more preferably 12 or more. It is preferable that the number of the emission elements provided in the emission portion **24** is 10 or more from the viewpoints that, for example, the FOV can be widened and the eye box can be widened.

(329) In addition, the number of the emission elements provided in the emission portion **24** is not limited and is preferably 15 or less.

(330) In the incidence portion **20** and the emission portion **24**, in a case where a plurality of diffraction elements are provided as one or more of the $\Lambda 1$ diffraction element, the $\Lambda 2$ diffraction element, and the $\Lambda 3$ diffraction element, in the incidence portion **20** and the emission portion **24**, an angle between the periodic directions of the $\Lambda 1$ diffraction elements, an angle between the periodic directions of the $\Lambda 2$ diffraction elements, and an angle between the periodic directions of the $\Lambda 3$ diffraction elements are not limited.

(331) In a case where the incidence portion **20** and the emission portion **24** include a plurality of diffraction elements as the $\Lambda 1$ diffraction element and/or the $\Lambda 3$ diffraction element, it is preferable that a combination of diffraction elements are provided such that an angle between the periodic directions of the $\Lambda 1$ diffraction elements and an angle between the periodic directions of the $\Lambda 3$ diffraction elements are $180^\circ \pm 0.5^\circ$.

(332) That is, it is preferable that the incidence portion **20** and the emission portion **24** include a combination of the $\Lambda 1$ diffraction elements and/or the $\Lambda 3$ diffraction elements having opposite periodic directions. In a case where turning directions of circularly polarized light to be selectively reflected by the diffraction elements are opposite to each other, it is preferable that the incidence portion **20** and the emission portion **24** include a combination of the $\Lambda 1$ diffraction elements and/or the $\Lambda 3$ diffraction elements having the same periodic direction.

(333) As a result, the FOV can be further widened.

(334) In a case where the incidence portion **20** and the emission portion **24** include three or more diffraction elements as the $\Lambda 1$ diffraction element and/or the $\Lambda 3$ diffraction element, it is preferable that in addition to the above-described combination, a combination of diffraction elements are provided such that an angle between the periodic directions of the $\Lambda 1$ diffraction elements and an angle between the periodic directions of the $\Lambda 3$ diffraction elements are $90^\circ \pm 0.5^\circ$. That is, it is preferable that the incidence portion **20** and the emission portion **24** include a combination of the $\Lambda 1$ diffraction elements and/or the $\Lambda 3$ diffraction elements having periodic directions perpendicular to each other.

(335) In addition, due to the same reason, in a case where the incidence portion **20** and the emission portion **24** include a plurality of $\Lambda 2$ diffraction elements, it is preferable that the incidence portion **20** and the emission portion **24** include a combination of $\Lambda 2$ diffraction elements such that an angle between the periodic directions of the $\Lambda 2$ diffraction elements is $90^\circ \pm 0.5^\circ$. It is preferable that the incidence portion **20** and the emission portion **24** include a combination of $\Lambda 2$ diffraction elements such that the periodic directions of the $\Lambda 2$ diffraction elements are perpendicular to each other.

(336) In particular, in a case where the periodic direction of one $\Lambda 2$ diffraction element is 0° , the emission portion **24** includes, in addition to the $\Lambda 2$ diffraction element where the periodic direction is 0° , the $\Lambda 2$ diffraction element where the periodic direction is $90^\circ \pm 0.5^\circ$, the $\Lambda 2$ diffraction element where the periodic direction is $180^\circ \pm 0.5^\circ$, and the $\Lambda 2$ diffraction element where the periodic direction is $270^\circ \pm 0.5^\circ$.

(337) In the optical element according to the embodiment of the present invention, in a case where any one of the incidence portion **20** or the emission portion **24** includes a plurality of diffraction elements having the same diffraction period Λ , it is preferable that the periodic directions of the

diffraction elements having the same diffraction period Λ are different from each other.

(338) However, in the incidence portion **20** and the emission portion **24**, optionally, the diffraction elements having the same diffraction period where the periodic directions match each other may be present, for example, in order to improve the reflectivity.

(339) In the optical element **12** in the example shown in the drawing, both of the incidence elements of the incidence portion **20** and the emission elements of the emission portion **24** are reflective liquid crystal diffraction elements including the liquid crystal layer **54** (cholesteric liquid crystal layer (liquid crystal diffraction layer)).

(340) In the $\Lambda 1$ diffraction element, the $\Lambda 2$ diffraction element, and the $\Lambda 3$ diffraction element of the incidence portion **20** and the emission portion **24**, the wavelength ranges (helical pitches P) where the liquid crystal layers **54** selectively reflect light may be all the same, may be all different, or may be partially the same and partially different.

(341) In addition, for example, in a case where the incidence portion **20** includes two incidence elements where the diffraction periods are $\Lambda 1$ and the selective reflection wavelength ranges are different, the incidence portion **20** and/or the emission portion **24** may include the diffraction elements where the selective reflection wavelength ranges may be different between the $\Lambda 1$ diffraction elements, between $\Lambda 2$ diffraction elements, and between the $\Lambda 3$ diffraction elements.

(342) In this case, between the $\Lambda 1$ diffraction elements, between $\Lambda 2$ diffraction elements, and between the $\Lambda 3$ diffraction elements in the incidence portion **20** and the emission portion **24**, the wavelength ranges where the liquid crystal layers **54** selectively reflect light overlap each other by preferably 100 nm or more, more preferably 150 nm or more, and still more preferably in the entire range.

(343) In addition, as described above, the liquid crystal layer **54** as the cholesteric liquid crystal layer selectively reflects right circularly polarized light or left circularly polarized light.

(344) The diffraction elements provided in the incidence portion **20** and the emission portion **24** may all selectively reflect circularly polarized light having the same turning direction or may selectively reflect circularly polarized light components having different turning directions.

(345) In addition, in a case where the incidence portion **20** and/or the emission portion **24** includes diffraction elements having different turning directions of circularly polarized light components to be selectively reflected, for example, the incidence portion **20** and/or the emission portion **24** may include diffraction elements having the same diffraction period and different turning directions of circularly polarized light components to be selectively reflected. Alternatively, the diffraction elements having the same diffraction period may selectively reflect circularly polarized light components having the same turning direction, and the turning directions of circularly polarized light components to be selectively reflected may be different between the diffraction elements having different diffraction periods.

(346) In the above-described example, the liquid crystal diffraction element is used as the diffraction element used in the incidence portion and the emission portion. In the optical element according to the embodiment of the present invention, the diffraction element is not limited to the liquid crystal diffraction element, and all of the well-known diffraction elements used in AR glasses or the like can be used.

(347) Examples of the diffraction element that can be used include a hologram diffraction element, a surface relief diffraction element, and a holographic polymer dispersed liquid crystal (HPDLC).

(348) The periodic directions and the diffraction periods (diffraction grating periods) in the diffraction elements may be set using a well-known method depending on the diffraction elements (diffraction gratings).

(349) In the optical element **12** shown in FIGS. **1** and **2**, the incidence portion **20** is provided in the vicinity of one corner portion of the rectangular light guide plate **18**, and the emission portion **24** may be provided to cover the remaining region of the light guide plate **18**. However, the optical element according to the embodiment of the present invention is not limited to this configuration.

(350) The optical element according to the embodiment of the present invention may adopt a well-known configuration used in AR glasses or the like, for example, a configuration where the incidence portion is provided at the center in the vicinity of an end part of one side of the rectangular light guide plate and the emission portion is provided to cover the remaining region of the light guide plate or a configuration where the incidence portion is provided in the vicinity of one end part of the elongated light guide plate and the emission portion is provided in the vicinity of another end part of the light guide plate.

(351) In the optical element **12** shown in FIGS. **1** and **2**, in a preferable aspect, all of the diffraction elements (the incidence elements and the emission elements) are laminated in both of the incidence portion **20** and the emission portion **24**. That is, the incidence elements of the incidence portion **20** are disposed at the same position of the light guide plate **18** in the plane direction, and the emission elements of the emission portion **24** are disposed at the same position of the light guide plate **18** in the plane direction.

(352) However, the present invention is not limited to this configuration. In the incidence portion **20** and/or the emission portion **24**, the diffraction elements forming the incidence portion **20** and/or the emission portion may be disposed at different positions of the light guide plate **18** in the plane direction (in a plane) without being laminated. In addition, in this case, the diffraction elements that are laminated and the diffraction elements that are disposed at different positions in the plane direction without being laminated may be mixed.

(353) In this case, the disposition of the diffraction elements is not limited and may be appropriately set to display an appropriate image depending on the size of the screen of the display **14**, the position of the display **14** relative to the light guide plate **18**, the size of AR glasses, and the like.

(354) Further, in the present invention, the incidence portion **20** and the emission portion **24** are not limited to the configuration where they are disposed on different main surfaces of the light guide plate **18**. The incidence portion **20** and the emission portion **24** may be disposed at different positions on the same main surface of the light guide plate **18** in the plane direction.

(355) Hereinabove, the optical element and the image display apparatus according to the embodiment of the present invention have been described in detail. However, the present invention is not limited to the above-described examples, and various improvements and modifications can be made within a range not departing from the scope of the present invention.

EXAMPLES

(356) Hereinafter, the characteristics of the present invention will be described in detail using examples. Materials, chemicals, used amounts, material amounts, ratios, treatment details, treatment procedures, and the like shown in the following examples can be appropriately changed within a range not departing from the scope of the present invention. Accordingly, the scope of the present invention is not limited to the following specific examples.

(357) <Preparation of Liquid Crystal Diffraction Element **1**>

(358) (Formation of Alignment Film)

(359) A glass substrate was used as the support.

(360) The following coating liquid for forming an alignment film was applied to the support using a spin coater at 2500 rpm for 30 seconds. The support on which the coating film of the coating liquid for forming an alignment film was formed was dried using a hot plate at 60° C. for 60 seconds. As a result, an alignment film was formed.

(361) Coating Liquid for Forming Alignment Film

(362) TABLE-US-00001 The following material 1.00 part by mass for photo-alignment Water 16.00 parts by mass Butoxyethanol 42.00 parts by mass Propylene glycol 42.00 parts by mass monomethyl ether

—Material for Photo-Alignment—

(363) ##STR00001##

(Exposure of Alignment Film)

(364) The alignment film was exposed using the exposure device shown in FIG. 9 to form an alignment film P-1 having an alignment pattern.

(365) In the exposure device, a laser that emits laser light having a wavelength (355 nm) was used as the laser. The exposure amount of the interference light was 3000 mJ/cm.². An intersecting angle (intersecting angle α) between the two laser beams was adjusted such that the diffraction period Λ (the length over which the optical axis rotates by 180°) of an alignment pattern formed by interference of two laser beams was 0.490 μ m.

(366) (Formation of Cholesteric Liquid Crystal Layer)

(367) As the liquid crystal composition forming the cholesteric liquid crystal layer, the following liquid crystal composition LC-1 was prepared.

(368) Liquid Crystal Composition LC-1

(369) TABLE-US-00002 Liquid crystal compound L-1 100.00 parts by mass Polymerization initiator (KAYACURE DETX-S, 1.00 part by mass manufactured by Nippon Kayaku Co., Ltd.) Chiral agent Ch-1 4.00 parts by mass Methyl ethyl ketone 142.06 parts by mass

Liquid Crystal Compound L-1

(370) ##STR00002##

(371) This chiral agent Ch-1 is a chiral agent that forms a right-handed helix (dextrorotation).

(372) The above-described liquid crystal composition LC-1 was applied to the alignment film P-1 using a spin coater. Here, the thickness of the formed film was adjusted to 10 μ m.

(373) The coating film of the liquid crystal composition LC-1 was heated on a hot plate at 80° C. for 3 minutes (180 sec).

(374) Next, the coating film was irradiated with ultraviolet light having a wavelength of 365 nm at 80° C. at an irradiation dose of 300 mJ/cm.² using a high-pressure mercury lamp in a nitrogen atmosphere. As a result, the liquid crystal composition LC-1 was cured, the alignment of the liquid crystal compound was immobilized, and a cholesteric liquid crystal layer was formed (first exposure step).

(375) Thus, a liquid crystal diffraction element including the support, the alignment film, and the cholesteric liquid crystal layer shown in FIG. 3 was prepared.

(376) The liquid crystal diffraction element was cut in a direction along the rotation direction of the optical axis of the liquid crystal compound, that is the periodic direction, and a cross-section in the thickness direction was observed with an SEM. By analyzing the SEM image, the thickness of the cholesteric liquid crystal layer, the diffraction period Λ (the single period A of the liquid crystal alignment pattern), and the length (helical pitch P) of one helical pitch in the cholesteric liquid crystalline phase were measured.

(377) <Preparation of Liquid Crystal Diffraction Elements 2 to 24>

(378) Liquid crystal diffraction elements were prepared and the same measurement was performed using the same method as that of Example 1, except that the intersecting angle α (diffraction period Λ) during the exposure of the alignment film P-1, the composition of the liquid crystal composition, the coating film thickness of the liquid crystal composition, and the exposure conditions of the liquid crystal composition were changed as shown in Table 1.

(379) Regarding the exposure of the liquid crystal composition, only the first exposure step was performed in some examples, and the second exposure step was also performed after the first exposure step in some examples. In a case where the exposure was performed twice, the HTP of the chiral agent was changed to adjust the helical pitch of the cholesteric liquid crystalline phase mainly in the first exposure step, and the liquid crystal composition was cured mainly in the second exposure step.

(380) Next, the liquid crystal composition was exposed to light having a wavelength of 315 nm using a high-pressure mercury lamp through a long pass filter of 300 nm and a short pass filter of 350 nm.

(381) In addition, in a case where a shape where the helical pitch P continuously increased in the thickness direction was seen during the SEM observation of the cross-section of the liquid crystal diffraction element, the helical pitch P was measured at two positions including a position in the vicinity of the interface side with the alignment film and a position on the air interface side with the liquid crystal diffraction element to obtain a range of the helical pitch P.

(382) TABLE-US-00003 TABLE 1 Liquid Crystal Diffraction Element #1 #2 #3 #4 #5 #6 #7 #8
 Alignment Exposure Intersecting Angle α 17.81 25.69 37.78 17.81 25.69 37.78 17.67 25.37 Film
 Step [deg.] Diffraction Period Λ [nm] 580 410 290 580 410 290 585 414 Liquid Composition
 Chiral Agent 3.3 4 5 3.3 4 5 3.3 4 Crystal [Part(s) by Mass] Layer Concentration of Solid 42.5 42.5
 42.5 10 10 10 42.5 42.5 Contents [mass %] First Exposure Wavelength 365 315 315 365 315 315
 365 315 Exposure [nm] Step Temperature [$^{\circ}$ C.] / 80/300 100/100 80/200 80/300 100/100 80/200
 80/300 100/100 Irradiation Dose [mJ/cm.sup.2] Second Exposure Wavelength — 365 365 — 365
 365 — 365 Exposure [nm] Step Temperature [$^{\circ}$ C.] / — 100/1000 80/1000 — 100/1000 80/1000
 — 100/1000 Irradiation Dose [mJ/cm.sup.2] Film Thickness [μ m] 10 10 10 1 1 1 10 10 Helical
 Pitch P [nm] 560 290-440 280-490 560 290-440 280-490 560 290-440 Liquid Crystal Diffraction
 Element #9 #10 #11 #12 #13 #14 #15 #16 Alignment Exposure Intersecting Angle α 37.27 17.67
 25.37 37.27 17.51 25.22 36.96 17.51 Film Step [deg.] Diffraction Period Λ [nm] 293 585 414 293
 590 417 295 590 Liquid Composition Chiral Agent 5 3.3 4 5 3.3 4 5 3.3 Crystal [Part(s) by Mass]
 Layer Concentration of Solid 42.5 10 10 10 42.5 42.5 42.5 10 Contents [mass %] First Exposure
 Wavelength 315 365 315 315 365 315 315 365 Exposure [nm] Step Temperature [$^{\circ}$ C.] / 80/200
 80/300 100/100 80/200 80/300 100/100 80/200 80/300 Irradiation Dose [mJ/cm.sup.2] Second
 Exposure Wavelength 365 — 365 365 — 365 365 — Exposure [nm] Step Temperature [$^{\circ}$ C.] /
 80/1000 — 100/1000 80/1000 — 100/1000 80/1000 — Irradiation Dose [mJ/cm.sup.2] Film
 Thickness [μ m] 10 1 1 1 10 10 10 1 Helical Pitch P [nm] 280-495 560 290-440 280-495 560 290-
 440 285-495 560 Liquid Crystal Diffraction Element #17 #18 #19 #20 #21 #22 #23 #24 Alignment
 Exposure Intersecting Angle α 25.22 36.96 21.69 31.58 21.69 31.58 36.34 36.34 Film Step [deg.]
 Diffraction Period Λ [nm] 417 295 480 339 480 339 300 300 Liquid Composition Chiral Agent 4 5
 4 5 4 5 5 5 Crystal [Part(s) by Mass] Layer Concentration of Solid 10 10 42.5 42.5 10 10 42.5 10
 Contents [mass %] First Exposure Wavelength 315 315 315 315 315 315 315 315 Exposure [nm]
 Step Temperature [$^{\circ}$ C.] / 100/100 80/200 80/200 80/200 80/200 80/200 80/200 80/200 Irradiation
 Dose [mJ/cm.sup.2] Second Exposure Wavelength 365 365 365 365 365 365 365 365 Exposure
 [nm] Step Temperature [$^{\circ}$ C.] / 100/1000 80/1000 80/1000 80/1000 80/1000 80/1000 80/1000
 80/1000 80/1000 Irradiation Dose [mJ/cm.sup.2] Film Thickness [μ m] 1 1 10 10 1 1 10 1 Helical
 Pitch P [nm] 290-440 285-495 330-515 290-545 330-515 290-545 285-500 285-500

Example 1

(383) (Application to AR Glasses)

(384) The support and the alignment film were peeled off from each of the liquid crystal diffraction elements #1 to #6 prepared as described above, and the cholesteric liquid crystal layer was transferred to the light guide plate to obtain the configuration shown in Table 2. As a result, optical elements were prepared as shown in FIGS. 1 and 2.

(385) The cholesteric liquid crystal layers in the incidence portion and the emission portion were laminated, for example, through the following procedure. (1) A temporary support was bonded to the cholesteric liquid crystal layer side of the liquid crystal diffraction element including the support, the alignment film, and the cholesteric liquid crystal layer to be laminated. In this example, as the temporary support, MASTACK AS3-304 manufactured by Fujimori Kogyo Co., Ltd. was used. (2) The support and the alignment film present from the step of preparing the cholesteric liquid crystal layer were peeled off to expose the interface of the cholesteric liquid crystal layer on the alignment film side. (3) A silicon oxide layer (SiOx layer) was formed on both of the interface of the cholesteric liquid crystal layer on the alignment film side and the interface of the cholesteric liquid crystal layer on the air side as the lamination side. A method of forming the

silicon oxide layer is not limited and, for example, vacuum deposition is preferably used. In this example, the formation of the silicon oxide layer was performed using a vapor deposition device (model number: ULEYES) manufactured by ULVAC, Inc. As a vapor deposition source, SiO.sub.2 powder was used. The thickness of the silicon oxide layer is not limited and is preferably 50 nm or less. In this example, the thickness of the silicon oxide layer was 50 nm or less. (4) Next, after bonding the formed silicon oxide layers at 120° C., the temporary support was peeled off.

(386) Through the steps (1) to (4), a diffraction element where the two cholesteric liquid crystal layers are laminated can be prepared. In addition, by repeating the steps (1) to (4), a diffraction element where three or four or more cholesteric liquid crystal layers are laminated can be prepared.

(387) The periodic direction in the diffraction structure of each of the cholesteric liquid crystal layers (diffraction elements) may be set, for example, by putting a mark representing the periodic direction on the support on the lamination side and the temporary support on the lamination side in advance and using the marks during the lamination. The mark representing the periodic direction can also be put on the cholesteric liquid crystal layer in addition to the support and the temporary support.

(388) In the optical element (the optical element according to Example 1) shown in FIGS. 1 and 2, the incidence portion includes six incidence elements (six layers), and the emission portion includes eight emission elements (eight layers). The angles between the diffraction elements (the incidence elements and the emission elements) shown in Table 1 are based on the directions of 0° and 90° shown in FIG. 2.

(389) As the light guide plate, a glass plate (refractive index: 1.70, thickness: 0.50 mm) was used.

(390) Table 3 shows the diffraction period of the diffraction element used in the prepared optical elements, the diffraction period (normalized with $\Lambda 1$) of each of the diffraction elements normalized with the diffraction element having the longest diffraction period, and the relationship between the periodic directions of the diffraction elements. The diffraction periods of the diffraction elements used in each of the optical elements were $\Lambda 1$, $\Lambda 2$, and $\Lambda 3$ in order from the longest.

(391) Further, as a display of AR glasses, a DLP type projector was used, and AR glasses shown in FIGS. 1 and 2 were prepared.

[Example 2], [Example 3], and [Comparative Example 1] to [Comparative Example 3]

(392) Optical elements were prepared using the same method as that of Example 1, except that the kind and the number of the liquid crystal diffraction elements bonded to the light guide plate and the periodic direction in the cholesteric liquid crystal layer of the liquid crystal diffraction element were changed in various ways as shown in Tables 2 and 3. Using the optical elements, AR glasses were prepared.

(393) FIGS. 16 and 17 conceptually show the configuration of Example 2 by simulating FIGS. 1 and 2.

(394) TABLE-US-00004

TABLE 2	Example 1	Example 2	Example 3	Comparative Example 1	Comparative Example 2	Comparative Example 3
Incidence Portion	580	585	590	480	580	580
First Diffraction Element #1	#7	#13	#19	#1	#1	#1
Second Diffraction Element #1	#1	#1	#1	#1	#1	#1
Third Diffraction Element #1	#1	#1	#1	#1	#1	#1
Fourth Diffraction Element #2	#8	#13	#19	#2	#2	#2
Fifth Diffraction Element #2	#8	#14	#20	#2	#2	#2
Sixth Diffraction Element #3	#9	#14	#20	#23	#3	#3
Seventh Diffraction Element #3	#9	#15	#23	—	—	—

Periodic Direction [deg.] 45 45 45 45 45 45 45
 Periodic Direction [deg.] 225 225 225 225 225 225 225
 Periodic Direction [deg.] 0 0 0 0 0 0 0
 Periodic Direction [deg.] 270 270 0 0 270 270 270
 Periodic Direction [deg.] 45 45 270 270 45 45 45
 Periodic Direction [deg.] 225 225 225 225 225 225 225
 Periodic Direction [deg.] — 315 225 — — — —

Element — #9 #15 — — — Eighth Diffraction Period [nm] — — 295 — — — Layer Periodic Direction [deg.] — — 315 — — — Liquid Diffraction Element — — #15 — — — Emission First Diffraction Period [nm] 580 585 590 480 580 580 Portion Layer Periodic Direction [deg.] 45 45 45 45 45 45 Liquid Diffraction Element #4 #10 #16 #21 #4 #4 Second Diffraction Period [nm] 580 585 590 480 580 580 Layer Periodic Direction [deg.] 225 225 135 135 225 225 Liquid Diffraction Element #4 #10 #16 #21 #4 #4 Third Diffraction Period [nm] 410 414 590 480 410 410 Layer Periodic Direction [deg.] 0 0 225 225 0 0 Liquid Diffraction Element #5 #11 #16 #21 #5 #5 Fourth Diffraction Period [nm] 410 414 590 480 410 410 Layer Periodic Direction [deg.] 90 90 315 315 90 90 Liquid Diffraction Element #5 #11 #16 #21 #5 #5 Fifth Diffraction Period [nm] 410 414 417 339 410 410 Layer Periodic Direction [deg.] 180 180 0 0 180 180 Liquid Diffraction Element #5 #11 #17 #22 #5 #5 Sixth Diffraction Period [nm] 410 414 417 339 410 410 Layer Periodic Direction [deg.] 270 270 90 90 270 270 Liquid Diffraction Element #5 #11 #17 #22 #5 #5 Seventh Diffraction Period [nm] 290 293 417 339 300 290 Layer Periodic Direction [deg.] 45 45 180 180 45 43 Liquid Diffraction Element #6 #12 #17 #22 #24 #6 Eighth Diffraction Period [nm] 290 293 417 339 300 290 Layer Periodic Direction [deg.] 225 135 270 270 225 225 Liquid Diffraction Element #6 #12 #17 #22 #24 #6 Ninth Diffraction Period [nm] — 293 295 — — — Layer Periodic Direction [deg.] — 225 45 — — — Liquid Diffraction Element — #12 #18 — — — Tenth Diffraction Period [nm] — 293 295 — — — Layer Periodic Direction [deg.] — 315 135 — — — Liquid Diffraction Element — #12 #18 — — — Eleventh Diffraction Period [nm] — 295 — — — Layer Periodic Direction [deg.] — 225 — — — Liquid Diffraction Element — #18 — — — Twelfth Diffraction Period [nm] — 295 — — — Layer Periodic Direction [deg.] — 315 — — — Liquid Diffraction Element — #18 — — —

[Evaluation]

(395) Regarding the AR glasses, crosstalk and FOV were evaluated.

(396) (Evaluation of Crosstalk)

(397) The display of the prepared AR glasses was driven to display an image. The display image was a square pattern.

(398) The crosstalk of the displayed image was evaluated based on the following standards. A: the occurrence of crosstalk cannot be observed by visual inspection B: the occurrence of crosstalk can be observed by visual inspection

(399) The results are shown in Table 3.

(400) (Evaluation of FOV)

(401) As conceptually shown in FIG. 18 simulating FIG. 1, Laser beams having a wavelength of 450 nm, a wavelength of 520 nm, and a wavelength of 635 nm were caused to be incident into the prepared optical element while changing the angle θ , an angle $\Delta\theta$ at which the laser beam was output was measured at an observation position by the user, and the $\Delta\theta$ was set as the FOV.

(402) The FOV was evaluated using the laser beam having a wavelength where the output angle $\Delta\theta$ was the smallest.

(403) The evaluation standards are as follows. AA+: the FOV is 70° or more AA: the FOV is 65° or more and less than 70° A: the FOV is 50° or more and less than 65° B: the FOV is less than 50°

(404) The results are shown in Table 3.

(405) TABLE-US-00005 TABLE 3 Example Example Example Comparative Comparative Comparative 1 2 3 Example 1 Example 2 Example 3 Diffraction Λ_1 [nm] 580 585 590 480 580 580 Period Λ_2 [nm] 410 414 417 339 410 410 Λ_3 [nm] 290 293 295 — 300 290 Λ_1 Normalized 1 1 1 1 1 1 Λ_2 with Λ_1 $1/\sqrt{2}$ $1/\sqrt{2}$ $1/\sqrt{2}$ $1/\sqrt{2}$ $1/\sqrt{2}$ $1/\sqrt{2}$ Λ_3 1/2 1/2 1/2 — 0.52 1/2 Relationship Angle between Periodic Directions 45 or 135 45 or 135 45 or 135 45 or 135 45 or 135 45 or 135 of Periodic of Λ_1 and Λ_2 [deg.] Directions of Angle between Periodic Directions 45 or 135 45 or 135 45 or 135 — 45 or 135 43 or 47 or Diffraction of Λ_2 and Λ_3 [deg.] 133 or 137 Elements Relationship between Periodic 0 or 90 or 0 or 90 or 0 or 90 or 0 or 90 or 0 or 90 or 0 or 90 or Directions of Λ_2 of Incidence 180 or 270 180 or 270 180 or 270 180 or 270 180 or 270 180 or 270

Portion and Emission Portion [deg.] Layer Incidence $\Lambda 1$ 2 layers 2 layers 3 layers 3 layers 2 layers 2 layers Number of Portion $\Lambda 2$ 2 layers 2 layers 2 layers 2 layers 2 layers 2 layers Diffraction $\Lambda 3$ 2 layers 3 layers 3 layers — 2 layers 2 layers Elements Emission $\Lambda 1$ 2 layers 2 layers 4 layers 4 layers 2 layers 2 layers Portion $\Lambda 2$ 4 layers 4 layers 4 layers 4 layers 4 layers 4 layers $\Lambda 3$ 2 layers 4 layers 4 layers — 2 layers 2 layers Evaluation Crosstalk A A A A B B FOV A A A A+ B A A (406) As shown in Table 3, in the optical element and the AR glasses (image display apparatus) according to the embodiment of the present invention, the incidence portion includes 6 or more layers, the emission portion includes 8 or more layers, each of the incidence portion and the emission portion includes three kinds of diffraction elements having different diffraction periods of $\Lambda 1$, $\Lambda 2$, and $\Lambda 3$, a relationship of “ $\Lambda 1:\Lambda 2:\Lambda 3=1:1:\sqrt{2}\pm 0.015:1/2\pm 0.015$ ” is satisfied, an angle between the periodic directions of the diffraction element having the diffraction period $\Lambda 1$ and the diffraction element having the diffraction period $\Lambda 2$ and an angle between the periodic directions of the diffraction element having the diffraction period $\Lambda 2$ and the diffraction element having the diffraction period $\Lambda 3$ are $45^\circ\pm 0.5^\circ$ or $135^\circ\pm 0.5^\circ$, and an angle between the diffraction elements having the diffraction period $\Lambda 2$ of the incidence portion and the emission portion is any one of $00^\circ\pm 0.5^\circ$, $90^\circ\pm 0.5^\circ$, $180^\circ\pm 0.5^\circ$, or $270^\circ\pm 0.5^\circ$. With this configuration, crosstalk can be prevented and a wide FOV can be obtained using one light guide plate.

(407) In addition, as shown in Examples 2 and 3, a wider FOV can be obtained by increasing the number of the diffraction elements in the incidence portion and the emission portion.

(408) On the other hand, in Comparative Example 1 where the incidence portion and the emission portion include only two kinds of diffraction elements having the diffraction periods of $\Lambda 1$ and $\Lambda 2$, a sufficient FOV cannot be obtained.

(409) In addition, in Comparative Example 2 where the diffraction period of the diffraction period $\Lambda 3$ normalized with the diffraction period $\Lambda 1$ exceeds $1/2\pm 0.15$ and Comparative Example 3 where the angle between the periodic directions of the diffraction element having the diffraction period $\Lambda 2$ and the diffraction element having the diffraction period $\Lambda 3$ exceeds the range of $45^\circ\pm 0.5^\circ$ and $135^\circ\pm 0.5^\circ$, crosstalk occurs, and an appropriate image cannot be displayed.

(410) As can be seen from the above results, the effects of the present invention are obvious.

(411) The present invention is suitably applicable to an image display apparatus such as AR glasses.

EXPLANATION OF REFERENCES

(412) **10**: image display apparatus **12**: optical element **14**: display **18**: light guide plate **20**: incidence portion **24**: emission portion **26** $\Lambda 1$ -1, **26** $\Lambda 1$ -2, **28** $\Lambda 2$ -1, **28** $\Lambda 2$ -2, **30** $\Lambda 3$ -1, **30** $\Lambda 3$ -2: incidence element **34** $\Lambda 1$ -1, **34** $\Lambda 1$ -2, **36** $\Lambda 2$ -1, **36** $\Lambda 2$ -2, **36** $\Lambda 2$ -3, **36** $\Lambda 2$ -4, **38** $\Lambda 3$ -1, **38** $\Lambda 3$ -2: emission element **40**: liquid crystal compound **40A**: optical axis **42**: bright portion **44**: dark portion **50**: support **52**: alignment film **54**: (cholesteric) liquid crystal layer **56**: liquid crystal layer **60**: exposure device **62**: laser **64**: light source **65**: $\lambda/2$ plate **68**: polarization beam splitter **70A**, **70B**: mirror **72A**, **72B**: $\lambda/4$ plate R.sub.R: right circularly polarized light of red light M: laser light MA, MB: beam P.sub.O: linearly polarized light P.sub.R: right circularly polarized light P.sub.L: left circularly polarized light L.sub.1, L.sub.4: incidence light L.sub.2, L.sub.5: transmitted light U: user D: arrangement axis A: diffraction period P: helical pitch

Claims

1. An optical element comprising: a light guide plate; an incidence portion that causes light to be incident into the light guide plate; and an emission portion that emits light from the light guide plate, wherein the incidence portion includes 6 or more diffraction elements, the emission portion includes 8 or more diffraction elements, each of the incidence portion and the emission portion includes, as the diffraction elements, a $\Lambda 1$ diffraction element where a period in a diffraction structure is $\Lambda 1$, a $\Lambda 2$ diffraction element where a period in a diffraction structure is $\Lambda 2$, and a $\Lambda 3$

diffraction element where a period in a diffraction structure is $\Lambda 3$, the period $\Lambda 1$, the period $\Lambda 2$, and the period $\Lambda 3$ satisfy a relationship of " $\Lambda 1:\Lambda 2:\Lambda 3=1:1/\sqrt{2}\pm 0.015:1/2\pm 0.015$ ", an angle between a periodic direction of the diffraction structure of the $\Lambda 1$ diffraction element and a periodic direction of the diffraction structure of the $\Lambda 2$ diffraction element and an angle between a periodic direction of the diffraction structure of the $\Lambda 2$ diffraction element and a periodic direction of the diffraction structure of the $\Lambda 3$ diffraction element are $45^\circ\pm 0.5^\circ$ or $135^\circ\pm 0.5^\circ$, and an angle between the periodic direction in the diffraction structure of the $\Lambda 2$ diffraction element provided in the incidence portion and the periodic direction in the diffraction structure of the $\Lambda 2$ diffraction element provided in the emission portion is any one of $0^\circ\pm 0.5^\circ$, $90^\circ\pm 0.5^\circ$, $180^\circ\pm 0.5^\circ$, or $270^\circ\pm 0.5^\circ$.

2. The optical element according to claim 1, wherein the diffraction element includes a liquid crystal diffraction layer that is formed of a composition including a liquid crystal compound, the liquid crystal diffraction layer has a liquid crystal alignment pattern where a direction in which a direction of an optical axis derived from the liquid crystal compound changes while continuously rotating is in at least one in-plane direction, in the liquid crystal alignment pattern, the direction in which the direction of the optical axis derived from the liquid crystal compound changes while continuously rotating in the at least one in-plane direction is the periodic direction in the diffraction structure of the diffraction element, and a length over which the direction of the optical axis derived from the liquid crystal compound rotates by 180° in the periodic direction of the diffraction structure is the period in the diffraction structure of the diffraction element.

3. The optical element according to claim 2, wherein the liquid crystal diffraction layer is a cholesteric liquid crystal layer obtained by immobilizing a cholesteric liquid crystalline phase.

4. The optical element according to claim 1, wherein the optical element includes a plurality of the $\Lambda 1$ diffraction elements, and the incidence portion and the emission portion include a combination of the $\Lambda 1$ diffraction elements where an angle between the periodic directions in the diffraction structures is $180^\circ\pm 0.5^\circ$.

5. The optical element according to claim 1, wherein the incidence portion and the emission portion include a plurality of the $\Lambda 3$ diffraction elements, and the incidence portion and the emission portion include a combination of the $\Lambda 3$ diffraction elements where an angle between the periodic directions in the diffraction structures is $180^\circ\pm 0.5^\circ$.

6. The optical element according to claim 1, wherein the incidence portion and the emission portion include a plurality of the $\Lambda 2$ diffraction elements, and the incidence portion and the emission portion include a combination of the $\Lambda 2$ diffraction elements where an angle between the periodic directions in the diffraction structures is $90^\circ\pm 0.5^\circ$.

7. The optical element according to claim 6, wherein in a case where the periodic direction in the diffraction structure of one of the $\Lambda 2$ diffraction elements is 0° , the emission portion includes, in addition to the $\Lambda 2$ diffraction element where the periodic direction in the diffraction structure is 0° , the $\Lambda 2$ diffraction element where the periodic direction in the diffraction structure is $90^\circ\pm 0.5^\circ$, the $\Lambda 2$ diffraction element where the periodic direction in the diffraction structure is $180^\circ\pm 0.5^\circ$, and the $\Lambda 2$ diffraction element where the periodic direction in the diffraction structure is $270^\circ\pm 0.5^\circ$.

8. An image display apparatus comprising: the optical element according to claim 1; and a display element that emits an image to the incidence portion of the optical element.
