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Ophthalmologic apparatus

Abstract

An ophthalmologic apparatus includes an objective lens that faces a subject's eye, an illumination optical system that irradiates a cornea of the subject's eye with illumination light through the objective lens, and a corneal measurement optical system including an interference image capturing camera that takes an image of a corneal reflection light. The corneal reflection light is a reflection of the illumination light reflected from the cornea, through the objective lens. A numerical aperture G of the illumination optical system is larger than a numerical aperture g of the corneal measurement optical system.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a national stage of International Patent Application Serial No. PCT/JP2020/017834 filed Apr. 24, 2020, which claims priority to U.S. Provisional Patent Application No. 62/844,794 filed May 8, 2019, the disclosures of both are incorporated herein by reference in their entirety.

TECHNICAL FIELD

(1) The present disclosure relates to an ophthalmologic apparatus, and more particularly, to an ophthalmologic apparatus that examines states of an anterior segment and tear fluid film of a subject's eye.

BACKGROUND ART

(2) There has been known an ophthalmologic apparatus that irradiates a cornea of a subject's eye with illumination light, and observes a state of an anterior segment and an interference image formed by a tear fluid film of the cornea of the subject's eye to make a diagnosis of dry eye, for example.

(3) For example, it has been known that the anterior segment is successfully observed or photographed when a light beam is allowed to enter the cornea through a light projection system (illumination optical system) in a direction perpendicular to a corneal surface so that the reflection from the cornea is efficiently condensed (Patent Document 1).

CITATION LIST

Patent Document

(4) Patent Document 1: Japanese Patent No. 3586039

SUMMARY OF THE INVENTION

Technical Problem

(5) However, Patent Document 1 does not specify numerical apertures of the light projection system and a corneal measurement system for the interference image formed by the tear fluid film, and thus, has not been a technique that permits variation in eye shape for each subject and incomplete alignment, while improving the capability of interference image observation.

(6) It is an object of the present disclosure to provide an ophthalmologic apparatus that attempts to optimize a numerical aperture (NA) of an illumination optical system and a numerical aperture of a corneal measurement optical system, and improves a measurement accuracy while permitting variation in subject's eye shape and incomplete alignment.

Solution to the Problem

(7) An ophthalmologic apparatus of the present disclosure is an ophthalmologic apparatus including: an objective lens that faces a subject's eye; an illumination optical system that irradiates a cornea of the subject's eye with illumination light through the objective lens; and a corneal measurement optical system that takes an image of a corneal reflection light, which is a reflection of the illumination light reflected from the cornea, through the objective lens. A numerical aperture G of the illumination optical system is larger than a numerical aperture g of the corneal measurement optical system.

Advantages of the Invention

(8) The present disclosure can provide an ophthalmologic apparatus that attempts to optimize a numerical aperture of an illumination optical system and a numerical aperture of a corneal measurement optical system, and improves a measurement accuracy while permitting variation in subject's eye shape and incomplete alignment.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. **1** is a schematic view illustrating an optical system of an ophthalmologic apparatus according to an embodiment of the present disclosure.

(2) FIG. **2** is a schematic view illustrating a relationship among a cornea, illumination light, and corneal reflection light according to the embodiment of the present disclosure.

(3) FIG. **3** is a schematic view illustrating a relationship among a cornea, illumination light, and corneal reflection light according to the embodiment of the present disclosure.

DESCRIPTION OF EMBODIMENTS

(4) FIG. **1** is a schematic view illustrating an optical system of an ophthalmologic apparatus **1** according to an embodiment of the present disclosure. The optical system of the ophthalmologic apparatus **1** includes an anterior segment observation optical system **1***a*, a corneal measurement optical system **1***b*, and an illumination optical system **1***c*.

(5) The anterior segment observation optical system **1***a* includes a first lens group **18** of the present disclosure. The anterior segment observation optical system **1***a* includes a third half mirror **17**, an anterior segment lens **19**, and an anterior segment camera **20** that are arranged along the direction of an optical axis of the first lens group **18**.

(6) The first lens group **18** is a so-called objective lens. In the present embodiment, the objective lens (first lens group **18**) includes a plurality of lenses (**18***a*, **18***b*), but the objective lens may include a single lens only. The first lens group **18** is capable of causing the illumination light incident from the illumination optical system **1***c* to irradiate the corneal surface of the cornea Ea of the subject's eye E via the third half mirror **17**. Corneal reflection light, which is the reflection of the illumination light from the corneal surface, enters the first lens group **18**. This corneal reflection light enters the third half mirror **17** from the first lens group **18**.

(7) The third half mirror **17** allows part of the corneal reflection light incident from the first lens group **18** to pass therethrough and exit therefrom toward the anterior segment lens **19**, and reflects the rest of the corneal reflection light toward a second lens group **16**, which will be described later.

(8) The anterior segment lens **19** allows the corneal reflection light incident from the first half mirror **17** to pass therethrough and exit therefrom toward the anterior segment camera **20**. The anterior segment camera **20** includes a complementary metal oxide semiconductor (CMOS) or charge coupled device (CCD) imaging element, and takes an image of the corneal reflection light incident from the anterior segment lens **19** to output an imaging signal of an observation image of an anterior segment of the subject's eye E (will be hereinafter referred to as an "anterior segment observation image") to a control unit **9**.

(9) The illumination optical system **1***c* forms an optical path branching from the anterior segment observation optical system **1***a* via the third half mirror **17**.

(10) The illumination optical system **1***c* includes an illumination light source **10**. The illumination optical system **1***c* further includes an illumination system lens **11**, a filter **12**, an illumination system diaphragm **13**, a first half mirror **14**, a second half mirror **15**, and a second lens group **16** which are arranged on an optical path of illumination light emitted from the illumination light source **10**. The illumination optical system **1***c* shares the first half mirror **17** and the first lens group **18** with the anterior segment observation optical system **1***a*.

(11) The illumination light source **10** is a light source that emits light. The illumination light source **10** may be, for example, a light emitting diode (LED) light source or halogen lamp which emits white light, and emits white light as illumination light L**1** toward the lens **11**. Alternatively, an LED having a different wavelength, a laser light source, or a combination of them may also be used. The illumination system lens **11** allows the illumination light L**1** incident from the illumination light source **10** to exit therefrom toward the filter **12**. The filter **12** adjusts the light intensity and/or wavelength distribution of the illumination light entered from the illumination system lens **11**, and allows the adjusted illumination light L**1** to exit therefrom toward the illumination system diaphragm **13**. The illumination system diaphragm **13** emits the illumination light L**1** entered from the filter **12** toward the first half mirror **14**.

(12) The first half mirror **14** reflects part of the corneal reflection light (R**2**) incident from the second lens group **16**, which will be described later, toward the corneal measurement optical system **1***b*. The first half mirror **14** is capable of allowing part of the illumination light L**1** incident from the filter **12** to pass therethrough and exit therefrom toward the second half mirror **15**.

(13) The second half mirror **15** and the second lens group **16** allow the illumination light L**1** incident from the first half mirror **14** to exit therefrom toward the third half mirror **17** described

above, and allow the corneal reflection light R**2** incident from the third half mirror **17** to exit therefrom toward the first half mirror **14**.

(14) The illumination light L**1** emitted from the illumination light source **10** irradiates the corneal surface of the cornea Ea through the first lens group **18** after passing through the illumination system lens **11** and the third half mirror **17**. As a result, the corneal reflection light R**1**, which is the reflection of the illumination light L**1** reflected from the corneal surface, can enter the first lens group **18**.

(15) It will be described below a numerical aperture G of the illumination optical system **1***c*. As described above, the illumination optical system **1***c* of the present disclosure includes the following optical elements, namely, the illumination light source **10**, the illumination system lens **11**, the filter **12**, the illumination system diaphragm **13**, the first half mirror **14**, the second half mirror **15**, the second lens group **16**, the third half mirror **17**, and the first lens group **18**. These optical elements are configured such that the illumination optical system **1***c* has a numerical aperture G of approximately 0.10. The illumination optical system **1***c* shares the optical elements from the third half mirror to the first lens group **18** with the corneal measurement optical system **1***b*. Thus, the numerical aperture G can be set through appropriate selection of the optical characteristics, such as an aperture, of the illumination system lens **11** and the illumination light source **10**, in particular. The numerical aperture G can be set through adjustment of an aperture of the illumination system diaphragm **13**.

(16) The corneal measurement optical system **1***b* forms an optical path branching from the illumination optical system **1***c* via the first half mirror **14**. The corneal measurement optical system **1***b* shares the optical elements from the first lens group **18** to the first half mirror **14** with the illumination optical system **1***c*, and also includes a corneal measurement system diaphragm **21**, a corneal measurement system lens **22**, and an interference image capturing camera **23**.

(17) The corneal measurement system diaphragm **21** and the corneal measurement system lens **22** allow the corneal reflection light R**2** incident from the first half mirror **14** to exit therefrom toward the interference image capturing camera **23**.

(18) The interference image capturing camera **23** includes a CMOS or CCD imaging element, and takes an image of the corneal reflection light R**2** incident from the lens **22** to output an imaging signal of a corneal reflection image to the control unit **9**.

(19) It will be described below a numerical aperture g of the corneal measurement optical system **1***b*. As described above, the corneal measurement optical system **1***b* of the present disclosure includes the following optical elements, namely, the interference image capturing camera **23**, the corneal measurement system lens **22**, the corneal measurement system diaphragm **21**, the first half mirror **14**, the second half mirror **15**, the second lens group **16**, the third half mirror **17**, and the first lens group **18**. These optical elements are configured such that the corneal measurement optical system **1***b* has a central value of the numerical aperture g of approximately 0.03. The corneal measurement optical system **1***b* shares the optical elements from the first half mirror **14** to the first lens group **18** with the illumination optical system **1***c*. Thus, the numerical aperture g is set through appropriate selection of the optical characteristics of the corneal measurement system lens **22** and the interference image capturing camera **23**, in particular. Further, the numerical aperture g can be set through adjustment of an aperture of the corneal measurement system diaphragm **21**. Note that the numerical aperture g can be set to 0.01 to 0.06 for a reason described later. From the viewpoint of the accuracy of detection of a tear fluid film based on a focal depth and wavelength characteristics of the interference image, the numerical aperture g is desirably 0.02 to 0.05.

(20) A fixation lamp **24** is a light source that fixes the position of the subject's eye E by guiding the subject's gaze for accurate observation and photographing of the state of the subject's eye E. A light emitting diode (LED) light source, or a halogen lamp can be used as the fixation lamp **24**. Fixation light L**2** emitted from the fixation lamp **24** passes through the second half mirror **15** and the second lens group **16**, is reflected from the third half mirror **17**, and enters the subject's eye E through the

first lens group **18**.

(21) The control unit **9** is electrically connected to the illumination light source **10**, the anterior segment camera **20**, the interference image capturing camera **23**, and the fixation lamp **24**.

(22) The control unit **9** includes a computing unit **9***a*. The computing unit **9***a* detects wavelength characteristics of the interference image at each position of the corneal reflection image based on the inputted image data of the corneal reflection light R**2** (corneal reflection image). Accordingly, the thickness of the tear fluid film at each position on the corneal surface can be detected. The tear fluid film herein refers to an oil layer (lipid layer), an aqueous layer, and a mucinous layer, or a combination of these layers.

(23) Referring to FIGS. **2** and **3**, it will be described below a relationship among the cornea, the illumination light, and the corneal reflection light according to the embodiment of the present disclosure. FIG. **2** illustrates a state where the ophthalmologic apparatus **1** and the subject's eye E are in an ideal positional relationship, i.e., they are in proper alignment. FIG. **3** illustrates a state where the ophthalmologic apparatus **1** and the subject's eye E are shifted in position from each other, i.e., they are in misalignment.

(24) Referring to FIG. **2**, it will be described below the state where the ophthalmologic apparatus **1** and the subject's eye E are in the ideal positional relationship, i.e., they are in proper alignment. FIG. **2** assumes that the cornea Ea of the subject's eye E is a sphere having a radius R_0. The radius R_0 of the cornea Ea is approximately 7.7 mm. In FIG. **2**, a front direction of the subject's eye E is defined as a Z-axis, and an axis orthogonal to the Z-axis as an X-axis. Of the illumination light L**1** entering the surface of the cornea Ea from the first lens group **18**, part that contributes to corneal observation is denoted by L**1**′ and of the corneal reflection light R**1** reflected from the cornea Ea, part of the corneal reflection light reaching the interference image capturing camera **23** of the corneal measurement optical system **1***b* is referred to as the corneal reflection light R**2**.

(25) In FIG. **2**, the cornea Ea is assumed to be a sphere, and the alignment is appropriate. Thus, the center of light flux of the illumination light L**1** focusing on the first lens group **18** passes through the center the center of the sphere formed by the cornea Ea. Thus, in FIG. **2**, the illumination light L**1** has an optical axis passing through the radial center P of the cornea Ea, and the corneal reflection light R**2** is reflected in a normal direction of a tangent line of the cornea E**1** with respect to a point Q at which the illumination light L**1** enters the cornea E**1**, i.e., in a direction that is 180-degree opposite to the illumination light L**1**. Since L**1**′ is present at the center of the aperture of the illumination light L**1**, the corneal reflection light R**2** reflected from the cornea can exist within the aperture.

(26) In FIG. **2**, the illumination light incident from the Z-axis direction is aligned to be focused on a vertex portion of the cornea Ea, thereby forming a focal plane (focusing plane) fp at the vertex portion of the cornea Ea. Since the illumination light L**1** expands to some extent, the illumination light L**1**′ that enters from a position shifted from the Z-axis in the X-axis direction by a distance H has an incident angle θ, and a defocus amount dZ between the surface of the cornea Ea and the focal plane fp is represented by the following formula:

$dZ = -R_0(1 - \cos\theta).$

(27) Hence, the numerical aperture g of the corneal measurement optical system **1***b* is desirably set to be somewhat small so that the interference image capturing camera **23** can capture an image even if the corneal reflection light R**2**(R**1**) is reflected with the above-mentioned defocus amount dZ.

(28) Next, referring to FIG. **3**, it will be described below a state where the ophthalmologic apparatus **1** and the subject's eye E are shifted in position from each other, i.e., a state in which they are in misalignment, or the alignment is incomplete. The shape of the subject's eye E, i.e., an eyeball of a human (human eye), is different for each person, and the curvature of the cornea Ea also varies for each person. In addition, vertical and horizontal curvatures of the same subject are

generally different, and the shape of the eye is not always a perfect sphere. This results directly or indirectly in incomplete alignment. Further, the ophthalmologic apparatus **1** and the subject's eye E may be shifted in position during measurement, for example, due to involuntary movement of the eyeball, because the target of the measurement is a human who is a living body. In this way, there are also some limits to the ideal improvement of the position of the ophthalmologic apparatus **1** and the subject's Eye. Therefore, in the observation and measurement of the human eye, the ophthalmologic apparatus **1** and the subject's eye E may fall into incomplete alignment.

(29) FIG. **3** illustrates a state in which the positional relationship between the ophthalmologic apparatus **1** and the subject's Eye is sifted by a distance Δz in the Z direction and a distance Δx in the X direction as compared to the state shown in FIG. **2**. Here, if the numerical aperture g of the corneal measurement optical system **1**b is made large, the focal depth decreases, and the image is more significantly deteriorated (more significant blurring occurs) relative to a defocus amount. Therefore, the numerical aperture g is desirably selected to be a somewhat small value. In the state of FIG. **3**, the alignment is inappropriate, and the illumination light L**1** enters the surface of the cornea E**1** at an angle β with respect to a normal line orthogonal to a tangent line at a point S where the illumination light L**1** enters the surface of the cornea E**1**. Hence, the corneal reflection light R**2** reflected at the point P is reflected at the angle β with respect to the normal line. Accordingly, the illumination light L**1** and the corneal reflection light R**2** form an angle of 2β. As shown in FIG. **3**, if the numerical aperture g of the corneal measurement optical system **1**b is sufficiently smaller than the numerical aperture G of the illumination optical system **1**c, and the angle 2β is sufficiently smaller than the numerical aperture G of the illumination optical system **1**c, the part L**1** of the illumination light (part L**1**-NA of the numerical aperture of the illumination optical system **1**c) can contribute to the corneal reflection light R**2**. This enables the corneal measurement. On the other hand, if the numerical aperture g of the corneal measurement optical system **1**b is not smaller than the numerical aperture G of the illumination optical system **1**c, and the angle 2β is approximately equal to or larger than the numerical aperture G of the illumination optical system **1**c, part L**1** of the illumination light contributes only partially, or is completely unable to contribute, to the corneal reflection light R**2**. In such a case, the corneal measurement is hardly performed with a sufficient light intensity. Note that the angle 2β cannot be reduced below a certain value because the angle 2β is caused by the incomplete alignment determined by the characteristics of the human eye. Therefore, setting the numerical aperture g of the corneal measurement optical system **1**b and the numerical aperture G of the illumination optical system **1**c in a predetermined relationship makes it possible to provide an ophthalmologic apparatus that improves the measurement accuracy, while permitting variation in subject's eye shape and incomplete alignment.

(30) Here, the numerical aperture G of the illumination optical system **1**c is assumed to be approximately 0.10, and the numerical aperture g of the corneal measurement optical system **1**b approximately 0.03. In this case, the numerical aperture g of the corneal measurement optical system **1**b is sufficiently smaller than the numerical aperture G of the illumination optical system **1**c. Therefore, the corneal measurement optical system **1**b can efficiently take an image of the corneal reflection light R**2** with respect to the illumination light L**1**, and the wavelength characteristics of the interference image can be detected with high accuracy. From the viewpoint of the accuracy of detection of the wavelength characteristics of the interference image, the numerical aperture G of the illumination optical system **1**c is desirably 0.10 to 0.20, and the numerical aperture g of the corneal measurement optical system **1**b is 0.01 to 0.06, more specifically, 0.02 to 0.05.

(31) The above-described configuration can provide an ophthalmologic apparatus that optimizes the numerical apertures of the illumination optical system **1**c and the corneal measurement optical system **1**b, thereby improving the measurement accuracy, while permitting variation in subject's eye shape.

DESCRIPTION OF REFERENCE CHARACTERS

(32) **1**: Ophthalmologic Apparatus **1***a*: Anterior Segment Observation Optical System **1***b*: Corneal Measurement Optical System **1***c*: Illumination Optical System **9**: Control Unit **9***a*: Computing Unit **10**: Illumination Light Source **11**: Illumination System Lens **12**: Filter **13**: Illumination system Diaphragm **14**: First Half Mirror **15**: Second Half Mirror **16**: Second Lens Group **17**: Third Half Mirror **18**: First Lens Group **19**: Anterior Segment Lens **20**: Anterior Segment Camera **21**: Corneal Measurement System Diaphragm **22**: Corneal Measurement System Lens **23**: Interference Image Capturing Camera **24**: Fixation Lamp

Claims

1. An ophthalmologic apparatus, comprising: an objective lens that faces a subject's eye; an illumination optical system that irradiates a cornea of the subject's eye with illumination light through the objective lens; and a corneal measurement optical system including an interference image capturing camera that takes an image of a corneal reflection light, which is a reflection of the illumination light reflected from the cornea, through the objective lens, wherein a numerical aperture G of the illumination optical system is larger than a numerical aperture g of the corneal measurement optical system.

2. The ophthalmologic apparatus of claim 1, wherein the numerical aperture G of the illumination optical system and the numerical aperture g of the corneal measurement optical system establish the following relationship:
$0.01/0.2 < g/G < 0.06/0.1$.

3. The ophthalmologic apparatus of claim 1, wherein the numerical aperture G of the illumination optical system and the numerical aperture g of the corneal measurement optical system establish the following relationship:
$0.02/0.15 < g/G < 0.05/0.1$.

4. The ophthalmologic apparatus of claim 1, further comprising a computing unit that detects, based on a corneal reflection image of the corneal reflection light taken by the interference image capturing camera, wavelength characteristics of an interference image at each position of the corneal reflection image, thereby calculating a thickness of a tear fluid film at each position on a corneal surface.