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(54) **NON-CONTACT ULTRASONIC TONOMETER**

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A61B 3/10 (2006.01)
A61B 3/16 (2006.01)

(52) **U.S. Cl.**
USPC **351/211**; 351/214; 351/205; 600/399; 600/402

(58) **Field of Classification Search**
USPC 351/205, 212; 600/398–402
See application file for complete search history.

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(57) **ABSTRACT**

A non-contact ultrasonic tonometer for measuring intraocular pressure of an examinee's eye, in non-contact manner by use of an ultrasonic wave comprises: a probe including a vibrator for making the ultrasonic wave incident on the examinee's eye and a sensor for detecting the ultrasonic wave reflected from the examinee's eye; and an observation optical system for observing an anterior segment of the eye, wherein the probe is placed in an optical path of the observation optical system, and the observation optical system forms an image of the anterior segment through a surrounding region of the probe.

15 Claims, 7 Drawing Sheets

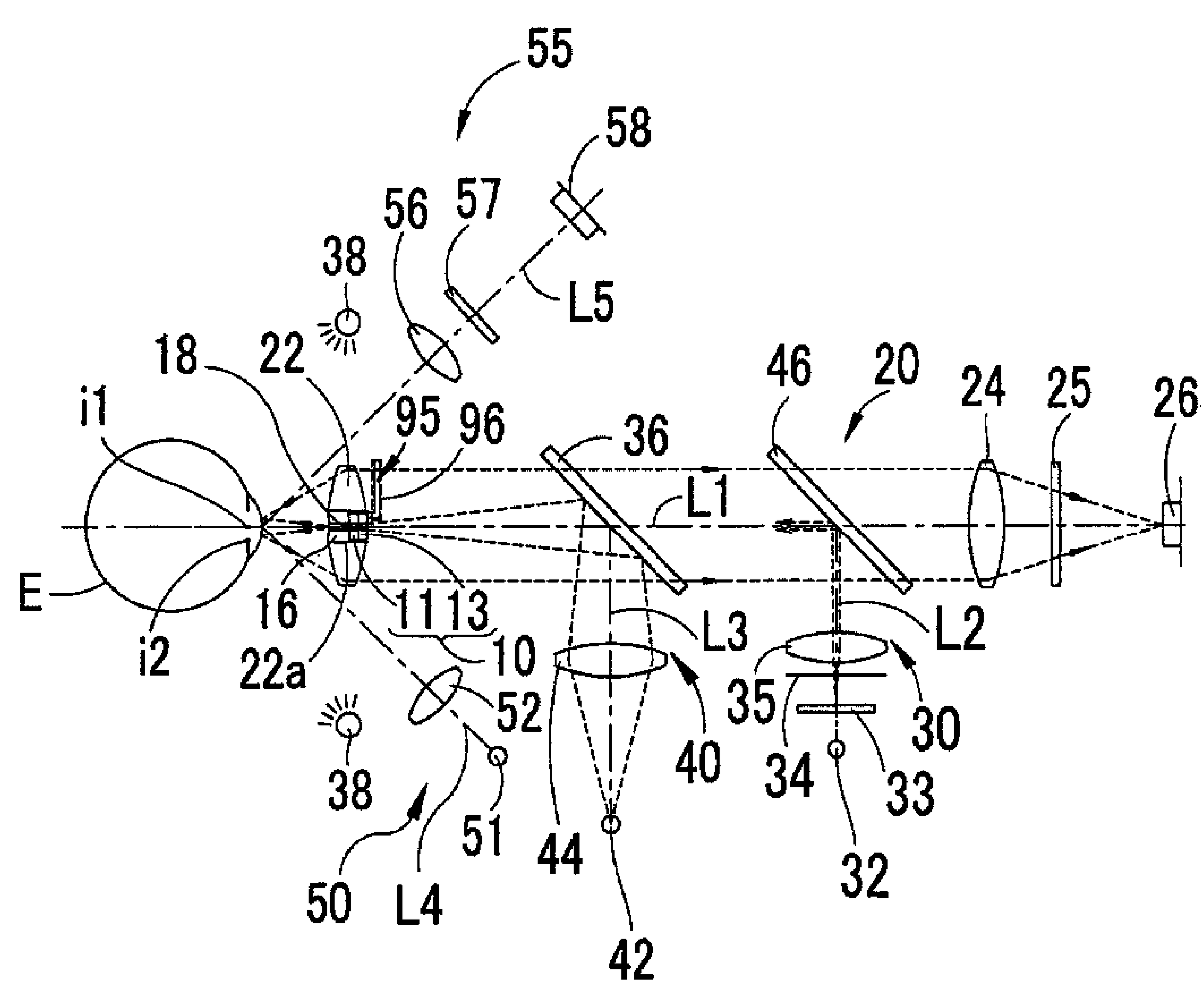

FIG. 1

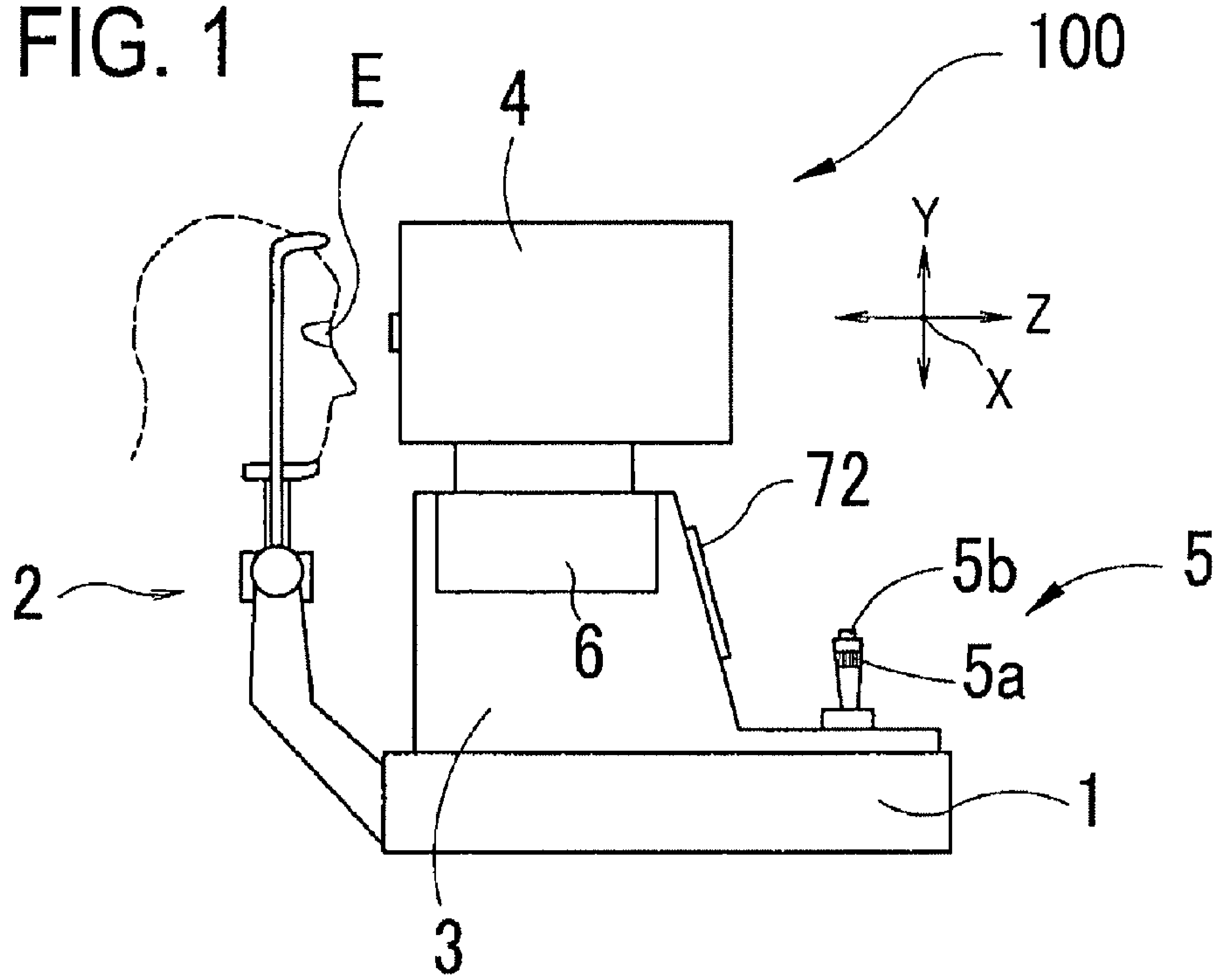

FIG. 2

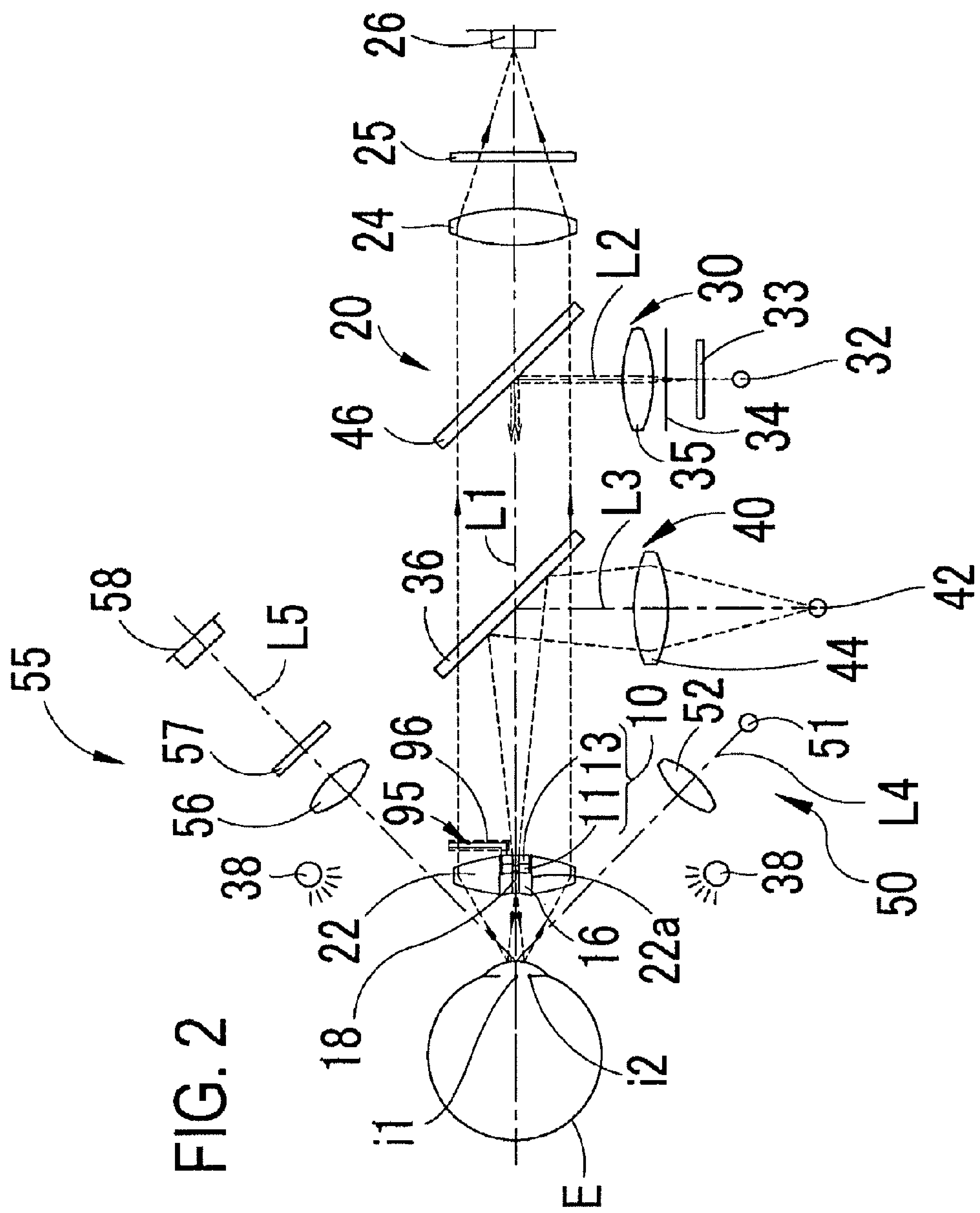
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FIG. 3

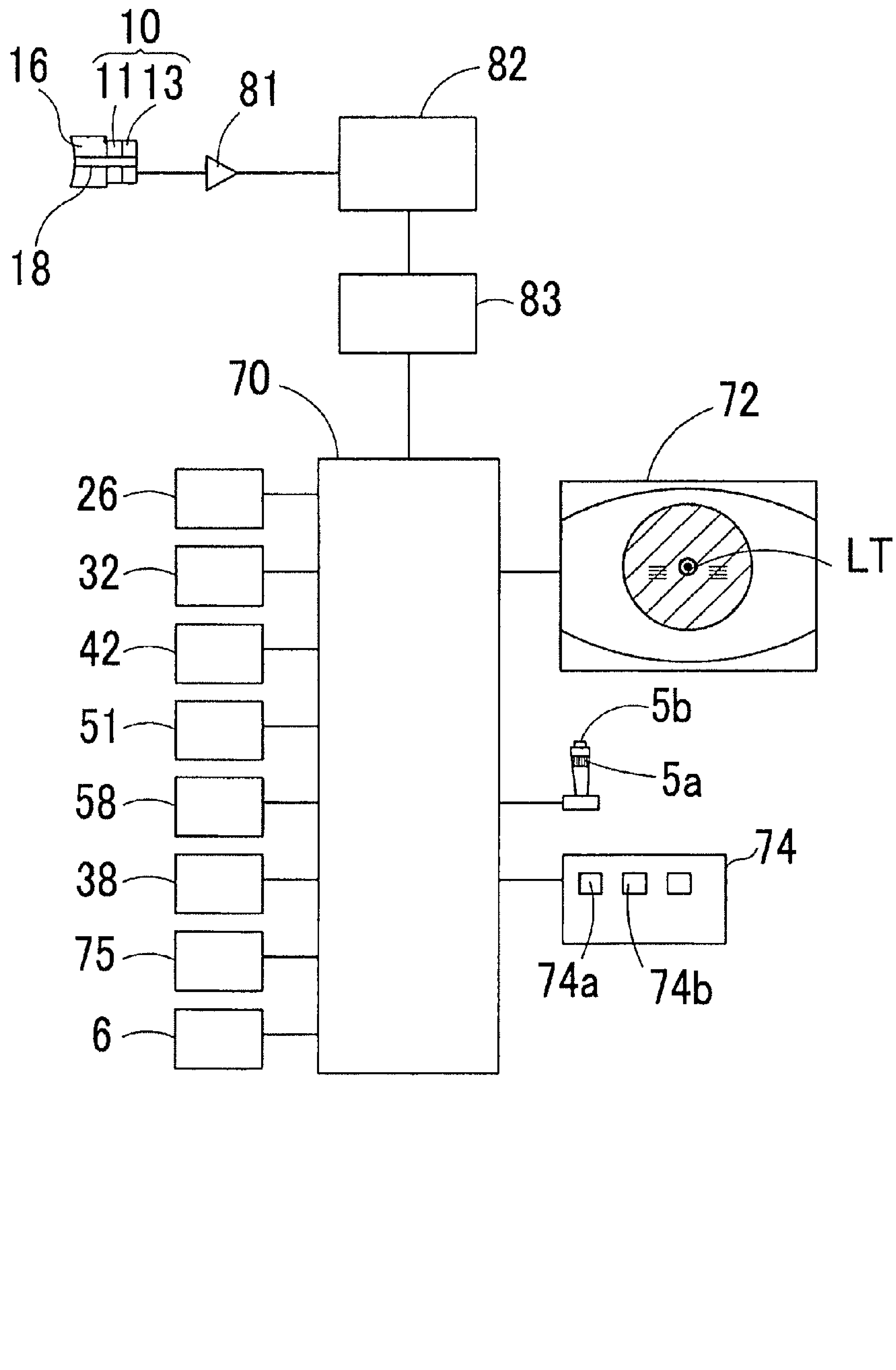


FIG. 4A

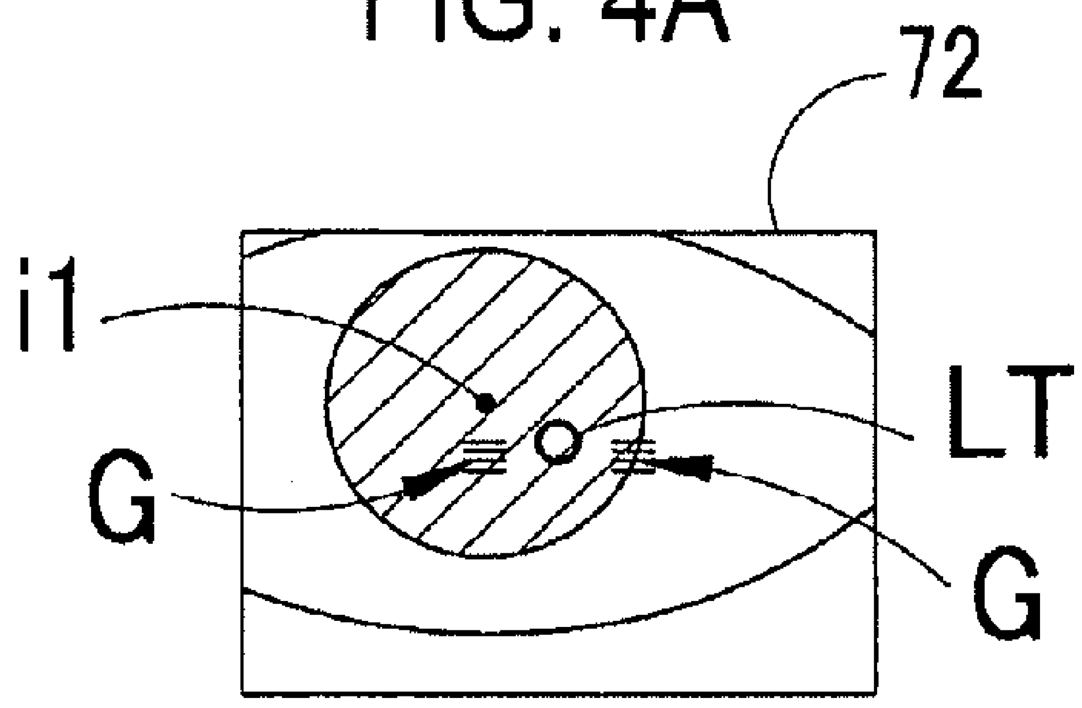


FIG. 4B

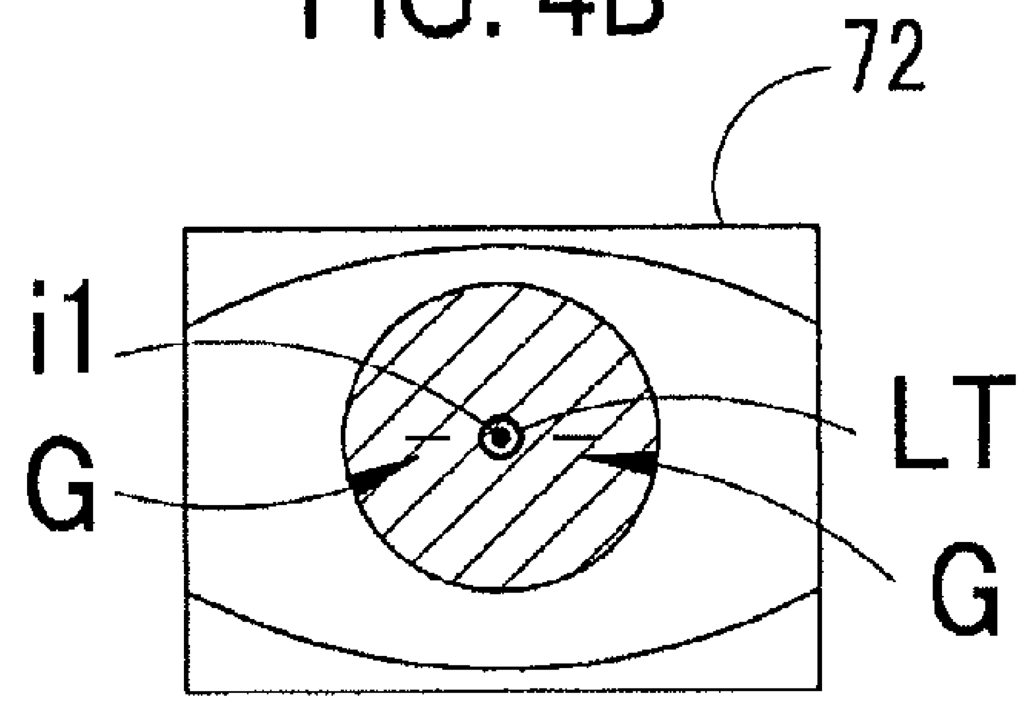


FIG. 5

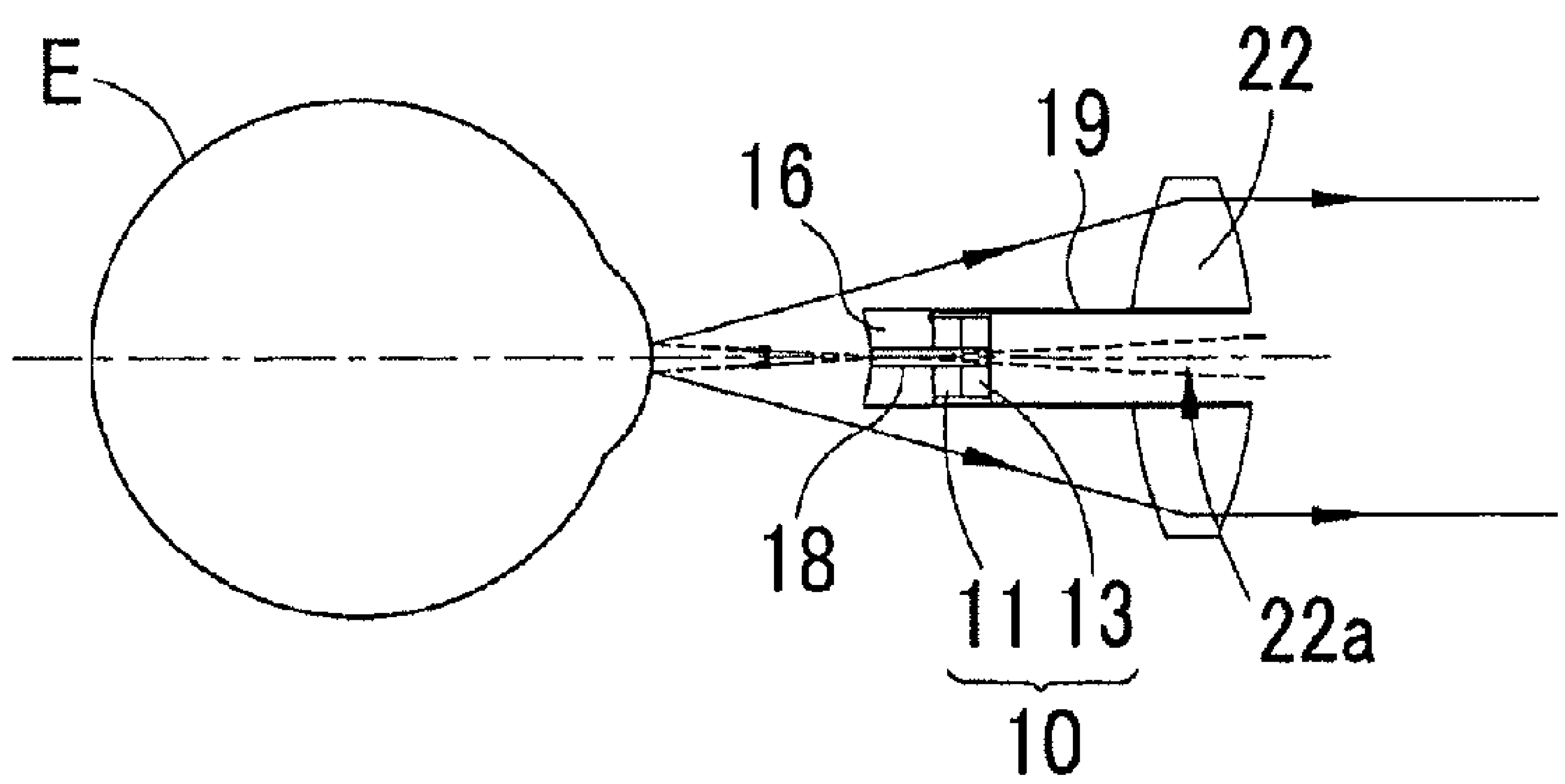


FIG. 6

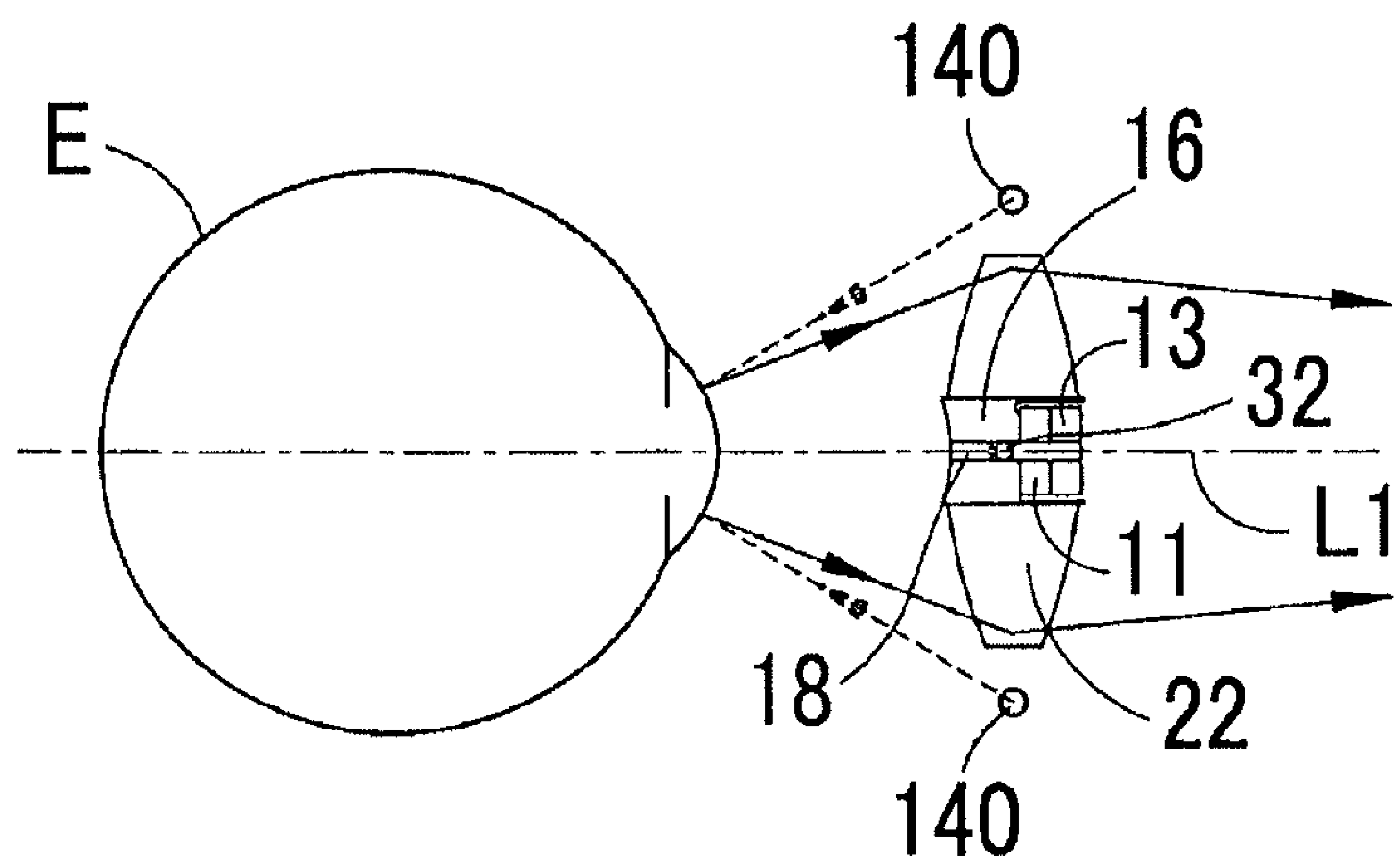
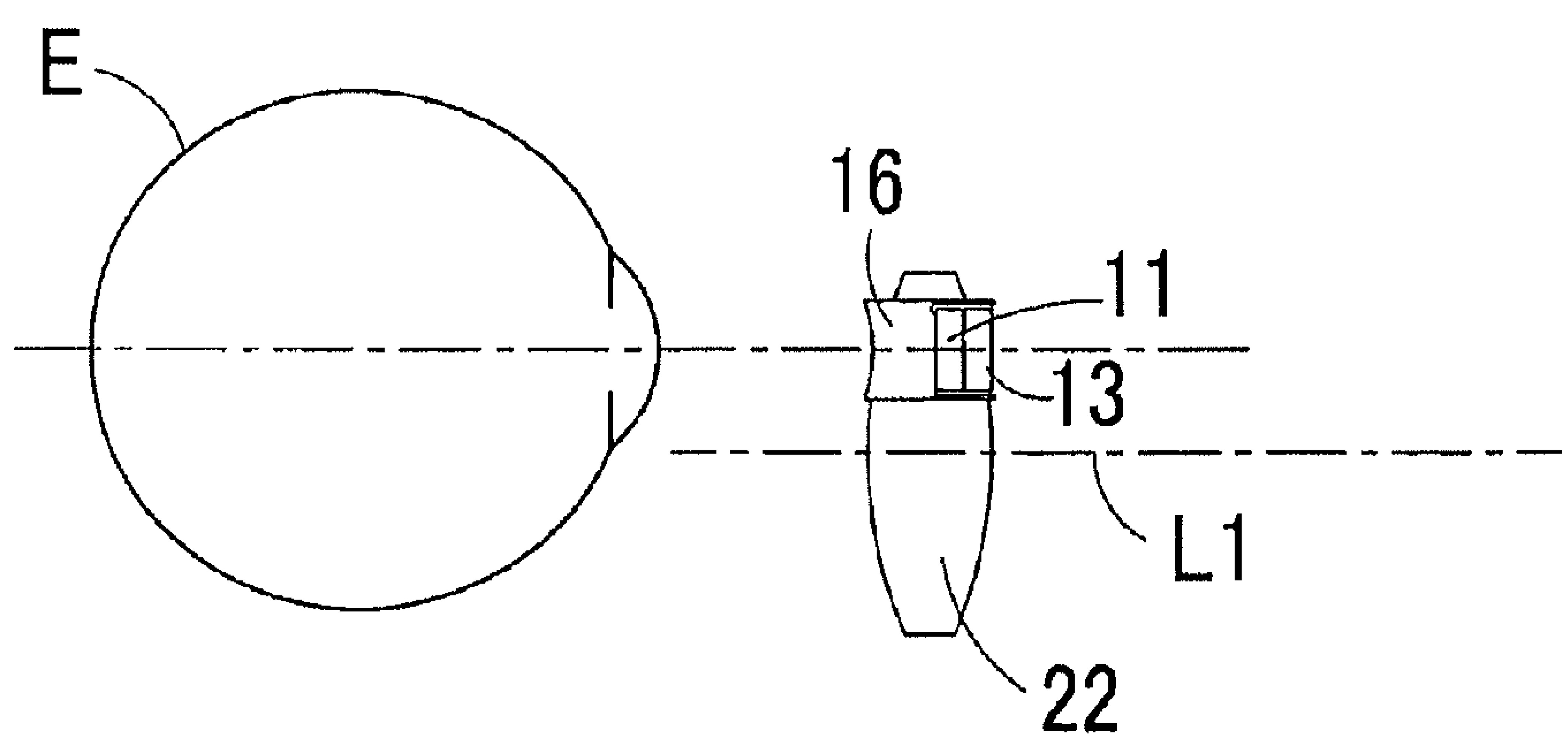


FIG. 7



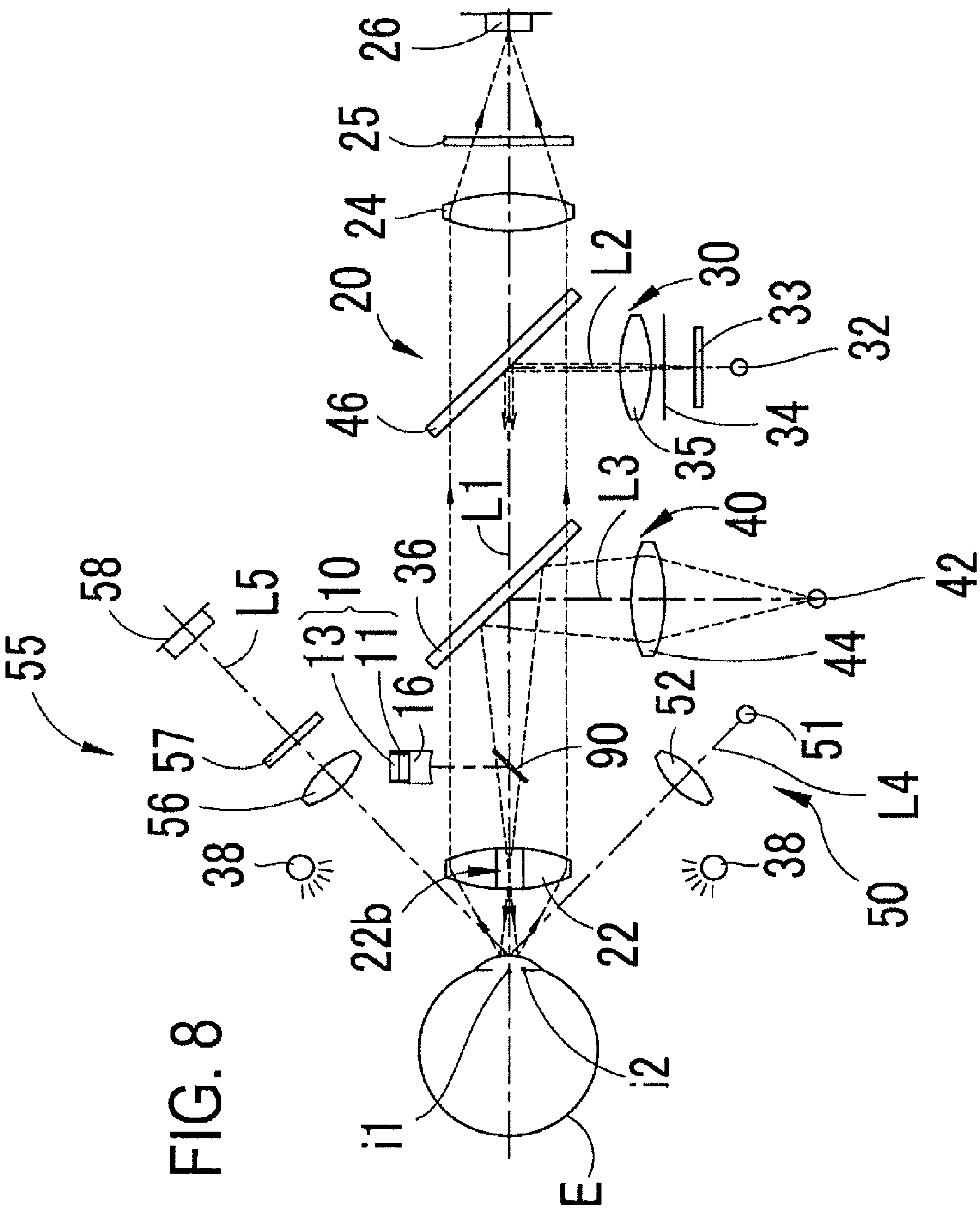

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FIG. 8

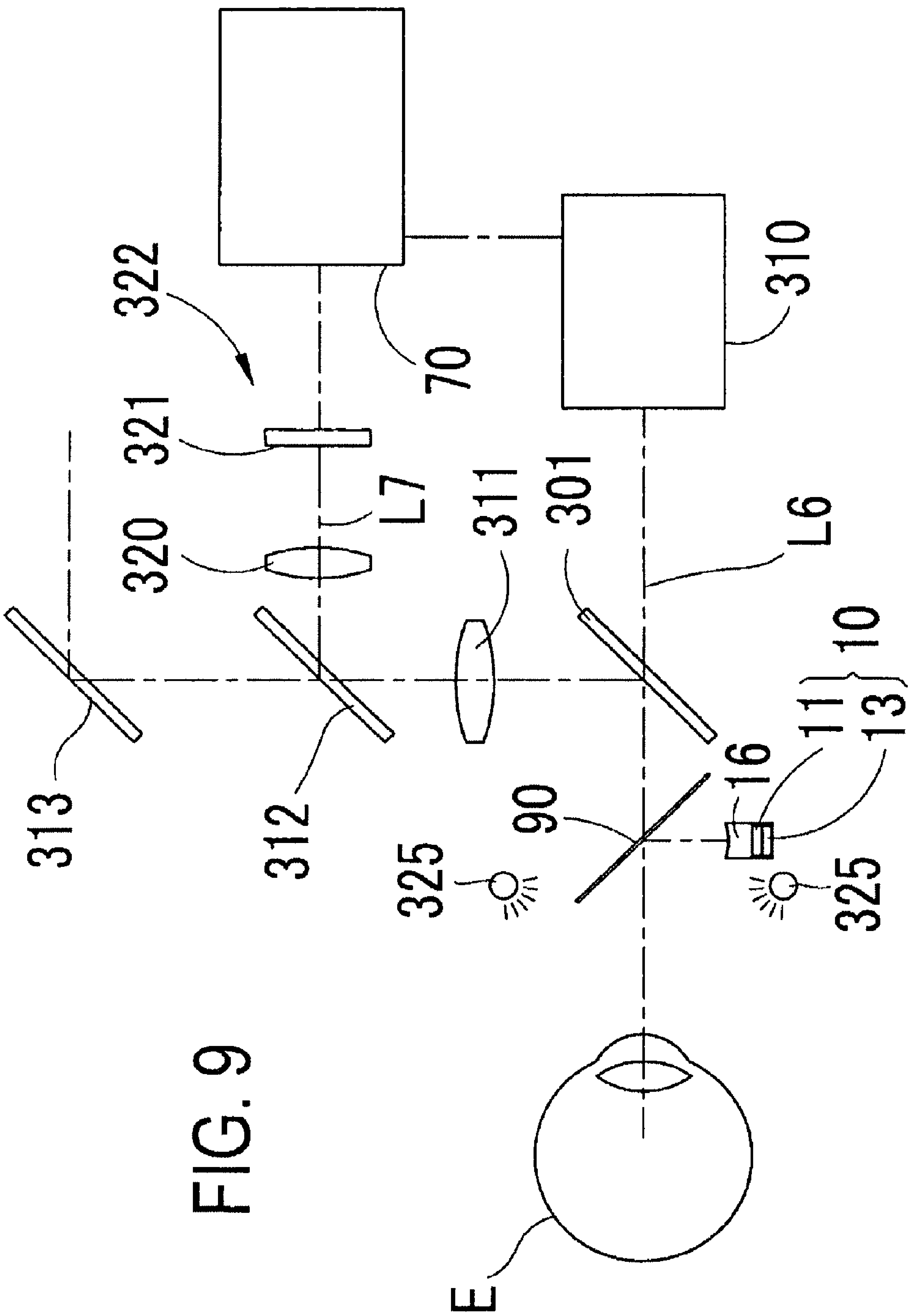

FIG. 9

NON-CONTACT ULTRASONIC TONOMETER

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

TECHNICAL FIELD

The non-contact ultrasonic tonometer for measuring intraocular pressure of an examinee's eye in non-contact manner by ultrasound.

BACKGROUND ART

There is proposed a contact intraocular pressure examination apparatus for measuring intraocular pressure by pressing a distal end of a probe pen against an eye, the probe pen holding a probe device including a vibrator for introducing vibration into the eye and a vibration detecting sensor for detecting the vibration reflected by the eye (see Patent Literature 1: JP2004-267299A).

Also proposed is a non-contact intraocular pressure measurement system for measuring intraocular pressure by making an ultrasonic wave enter in an eye (actually, an eyeball model) and detecting the ultrasonic wave reflected from the eye by use of a sensor (see Non-patent Literature 1: "Development of a new non-contact intraocular pressure measurement system using a phase shift method", Masayuki JINDE and other three persons, Conference of Institute of Electrical Engineers, Sensors and Micromachines Division, Document p. 93-96, 2007). This system is arranged to measure a phase shift of a reflected wave with respect to a transmission wave as a frequency change, and determine a correlation between an amount of the frequency change and hardness of the eye model.

In the case of the apparatus configuration of Patent Literature 1, however, the probe pen is brought into contact with the eye to measure intraocular pressure and thus a large burden would be given to the eye. The apparatus configuration of Non-patent Literature 1 is merely intended to measure the eyeball model, which is insufficient to measure human eyes. In the case of measuring human eyes, which exhibit involuntary eye movement and visual line movement, the ultrasonic wave characteristics (e.g., frequency and phase) detected by the sensor are likely to vary due to misalignment of the apparatus with the eye, leading to variations in measurement results.

SUMMARY OF INVENTION

Technical Problem

The present invention has a purpose to provide a non-contact ultrasonic tonometer capable of easily making alignment of the tonometer with respect to an examinee's eye.

Solution to Problem

To achieve the above purpose, the present invention provides a non-contact ultrasonic tonometer for measuring intraocular pressure of an examinee's eye in non-contact manner by use of an ultrasonic wave, the tonometer comprising: a probe including a vibrator for making the nultrasonic wave incident on the examinee's eye and a sensor for detecting the ultrasonic wave reflected from the examinee's eye; and an observation optical system for observing an anterior segment of the eye, wherein the probe is placed in an optical path of the observation optical system, and the observation optical system forms an image of the anterior segment through a surrounding region of the probe.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a perspective external view of a non-contact ultrasonic tonometer of a preferred embodiment of the present invention;

FIG. **2** is a perspective configuration view of a measurement system and an optical system of the tonometer;

FIG. **3** is a perspective configuration view (partly a block diagram) of a control system of the tonometer;

FIGS. **4**A and **4**B are views showing examples of an observation screen displayed on a monitor;

FIG. **5** is a view showing a case where an objective lens is placed behind a probe;

FIG. **6** is a view showing a modified example of a fixation target projection optical system and a first alignment mark projection optical system;

FIG. **7** is a view showing a case where the probe is displaced in a direction perpendicular to an optical axis of an observation optical system;

FIG. **8** is a view showing a case where the probe is placed out of an optical path of the observation optical system; and

FIG. **9** is a view showing a case where the tonometer is provided with an eye refractive power measurement optical system.

DESCRIPTION OF EMBODIMENTS

A preferred embodiment of the present invention will be described below with reference to accompanying drawings. FIG. **1** is a perspective external view of a non-contact ultrasonic tonometer **100** of this embodiment.

The tonometer **100** is a so-called stationary apparatus including a base **1**, a head support unit **2** attached to the base **1**, a movable unit **3** movably placed on the base **1**, and a measurement part **4** that is movably provided on the movable base **3** and contains a measurement system and optical systems mentioned later. The measurement part **4** is moved in a right-and-left direction (an X-direction), an up-and-down direction (a Y-direction), and a back-and-force direction (a working distance direction; a Z-direction) relative to an examinee's eye E by a movement part **6** provided in the movable unit **3**. The movable unit **3** is moved in the X- and Z-directions on the base **1** by inclining operation of a joystick **5**. The measurement part **4** is moved in the Y-direction by the movement part **6** by a rotating operation of a knob **5**a. The joystick **5** is provided, at its top, with a measurement start switch **5**b. On the movable base **3**, a monitor **72** is provided.

FIG. **2** is a perspective configuration view of the measurement system and optical systems of the tonometer **100**, showing a case where a probe is placed in an optical path of an observation optical system. FIG. **3** is a perspective configuration view (partly a block diagram) of a control system of the tonometer **100**.

A probe (a transducer) **10** placed in front of the examinee's eye E has a vibrator (an ultrasonic wave transmitting section) **11** for making an ultrasonic wave (an incident wave, a transmission wave) incident on the eye E and a sensor (an ultrasonic wave receiving section) **13** for detecting an ultrasonic wave (a reflected wave, a received wave) reflected by the eye E. The probe **10** is constituted of for example two piezoelectric elements arranged one on another. One of the piezoelectric elements is used as the vibrator **11** and the other is used as the sensor **13**. In this embodiment, a pulse wave is used as the ultrasonic wave made incident on the eye E but a continuous wave may be used instead.

On the side of the probe **10** closer to the eye E, an acoustic lens **16** is placed to converge the ultrasonic wave from the vibrator **11**. This lens **16** comes into focus on the eye E when the probe **10** is placed in proper alignment with the eye E.

The probe **10** is connected sequentially to an amplifier **81**, a frequency component analysis section **82**, a frequency phase difference specifying section **83**, and an arithmetic and control section **70**. An electric signal corresponding to an incident wave and a reflected wave is amplified to an appropriate signal level by the amplifier **81** and subjected to frequency component analysis by the analysis section **82** to obtain a spectral distribution of the phase difference with respect to the frequency. The specifying section **83** compares the spectral distribution of the incident wave and the spectral distribution of the reflected wave to specify a phase difference θx which is a difference in phase between the incident wave and the reflected wave at respective frequencies fx. The phase difference θx at the frequency fx will vary according to intraocular pressure (strictly speaking, changes in hardness of a cornea of the examinee's eye E resulting from changes in the intraocular pressure). Accordingly, the arithmetic and control section **70** detects the phase difference θx based on an output signal of the specifying section **83** and obtains the intraocular pressure of the eye E based on the detection result. This method is referred to U.S. Pat. No. 6,854,331 (JP2002-272743A).

The probe **10** and the lens **16** are formed, at respective centers, with an aperture **18** (e.g., a circular hole having a diameter of about 1 mm) through which fixation target projecting light (hereinafter, referred to as "fixation target light") from a light source **32** and alignment mark projecting light (hereinafter, referred to as "alignment mark light") from a light source **42** are allowed to pass.

The vibrator **11** and the sensor **13** are electrically connected to a circuit system (the amplifier **81**, the analysis section **82**, the specifying section **83**, the arithmetic and control section **70**, and others) disposed out of an optical path of the observation optical system **20** (hereinafter, referred to as an "observation optical path") with a wiring cable **95**. This cable **95** is covered with a cover **96** applied with a coating for absorbing reflected light (e.g., infrared light) from an anterior segment of the eye E. This makes it possible to prevent the reflected light by the anterior segment from diffusing on the surface of the cable **95** to be detected as noise light by a two-dimensional image pickup device **26**.

Provided as the optical systems of the tonometer **100** are the observation optical system **20** for observing the anterior segment of the eye E, a fixation target projection optical system **30** for causing the eye E to hold fixation, a first alignment mark projection optical system **40** for projecting an alignment mark in the X- and Y-directions to the eye E, a second alignment mark projection optical system **50** for projecting an alignment mark in the Z-direction to the eye E, and an alignment mark detection optical system **55** for detecting the Z-direction alignment mark projected onto the eye E.

The observation optical system **20**, having the optical path in which the probe **10** is placed, forms an image of the anterior segment through a region surrounding the probe **10**. Specifically, the observation optical system **20** includes, an objective lens **22**, an imaging lens **24**, a filter **25**, and the image pickup device **26** and provides an optical axis (hereinafter, an "observation optical axis") L**1** in which the probe **10** is placed. Thus, when the observation optical axis L**1** is aligned to a predetermined portion (for example, a corneal center or a pupil center of the eye E), the probe **10** is placed in front of the eye E. Furthermore, in the configuration of FIG. **2**, the probe **10** is arranged so that the central axis (an extension of the central axis) of the probe **10** is coaxial with the observation optical axis L**1**. Accordingly, when the observation optical axis L**1** is aligned with the predetermined portion of the eye E, the central axis of the probe **10** comes to coincide with the predetermined portion of the eye E and therefore an ultrasonic wave reflected by the eye E can be efficiently detected.

Light sources **38** which emit infrared light to illuminate the anterior segment of the eye E are disposed diagonally to the front of the eye E. The filter **25** has a property of transmitting the light from each light source **38** and the light from the light source **42** and blocking light from a the light source **51**.

The light from each light source **38** is projected onto the anterior segment of the eye E and then the light reflected by the anterior segment travels toward the lens **22**. The light reaching the surrounding region of the probe **10** passes through the lens **22**, further passes a half mirror **36** and a dichroic mirror **46**, and forms an image on the image pickup device **26** by the lens **24**. Specifically, the anterior segment image by the light source **38** is formed on the image pickup device **26** through the surrounding region of the probe **10**. The dichroic mirror **46** has a property of transmitting the light from each light source **38** and the light from the light source **42** and reflecting the light from the light source **32**.

A signal output from the image pickup device **26** is input to the arithmetic and control section **70**. The picked-up anterior segment image is displayed on the monitor **72**. In the configuration of FIG. **2**, an imaging optical system (a lens system constituted of a plurality of lenses) including the lenses **22** and **24** is used as a light delivery member for delivering the anterior segment image to the image pickup device **26**. Alternatively, a single lens may be used to deliver the anterior segment image to the image pickup device **26**.

For a positional relationship between the probe **10** and the lens **22** in the direction of the observation optical axis L**1** (the Z-direction), the lens **22** is placed behind the probe **10** (closer to the image pickup device **26**) or in the same position as the probe **10** and hence wider space can be provided between the eye E and a housing of the apparatus (see FIGS. **2** and **5**). In this case, the reflected light from the anterior segment may be interrupted by the probe **10** and the lens **16**. In order to allow clear observation of the anterior segment image, the probe **10** and the lens **22** are preferably placed close to each other on the observation optical axis L**1** and more preferably placed in substantially the same position on the observation optical axis L**1**.

FIG. **2** shows one example of the configuration in which the probe **10** and the lens **22** are placed in the same position. That is, the lens **22** is formed, in almost the center thereof, with an aperture **22**a in which the probe **10** is inserted. In this aperture **22**a, the probe **10** and the lens **16** are set.

FIG. **5** shows one example of the configuration in which the lens **22** is placed behind the probe **10**. Specifically, the lens **22** is formed, in almost the center thereof, with the aperture **22**a in which a support member **19** is inserted. The probe **10** and the lens **16** are set in a forward position in the support member **19** inserted in the aperture **22**a.

Alternatively, the lens **22** may be placed before the probe **10**. In this case, the lens **22** is preferably formed with an aperture in a position corresponding to an ultrasonic wave propagation path in order to prevent the lens **22** from reflecting and attenuating the ultrasonic wave from the probe **10**. Thus, the incident wave from the vibrator **11** is allowed to enter the eye E through the aperture and the reflected wave from the eye E is detected by the sensor **13** through the aperture.

The fixation target projection optical system **30** includes at least a fixation target projection light source to project a fixation target onto the eye E to cause the eye E to view the fixation target. Specifically, the projection optical system **30** includes the light source **32**, a fixation target **33**, a diaphragm **34**, a projection lens **35**, and the dichroic mirror **46** to project the fixation target onto the eye E through the aperture **18**. An optical axis L**2** of the projection optical system **30** is made coaxial with the observation optical axis L**1** by the dichroic mirror **46** located in the observation optical path.

Light of the fixation target **33** illuminated by visible light from the light source **32** is reduced in light diameter by the diaphragm **34**, passes through the lens **35**, is reflected by the dichroic mirror **46**, passes through the half mirror **36**, and then is projected onto the fundus of the eye E through the aperture **18**. Thus, the eye E holds fixation.

The first alignment mark projection optical system **40** includes at least an alignment mark projecting light source to project an alignment mark in the X- and Y-directions onto the eye E from front. Specifically, the projection optical system **40** includes the light source **42**, a projection lens **44**, and the half mirror **36** to project the alignment marks (the alignment mark light) onto the eye E through the aperture **18**. An optical axis L**3** of the projection optical system **40** is made coaxial with the observation optical axis L**1** by the half mirror **36** located in the observation optical path.

Infrared light from the light source **42** passes through the lens **44**, is reflected by the half mirror **36**, and then is projected onto the cornea of the eye E through the aperture **18**. Light mirror-reflected by the cornea forms an image (an alignment mark image) i**1** which is a virtual image (a corneal reflection image) of the light source **42**.

The light of the mark image i**1** travels toward the lens **22**. The light reaching the surrounding region of the probe **10** passes through the lens **22**, the half mirror **36**, and the dichroic mirror **46**, and forms an image on the image pickup device **26** by the lens **24**. In other word, the mark image i**1** by the light source **42** is formed on the image pickup device **26** through the surrounding region of the probe **10**. When the eye E moves in the X- and Y-directions, an image forming position of the mark image i**1** also moves on the image pickup device **26**. Based on a detection signal of the image pickup device **26**, the arithmetic and control section **70** can detect an alignment state of the apparatus (the probe **10**) in the X- and Y-directions with respect to the eye E.

In the case of projecting the alignment mark light through the aperture **18** formed in the probe **10** and the lens **16** and receiving the reflected light from the eye E through the surrounding region of the probe **10**, part of the reflected light may be interrupted by the lens **16**. To avoid such defect, as shown in FIG. **2**, the projection optical system **40** is preferably configured as an optical system whereby the alignment mark light is converged once before reaching the eye E and then is projected as dispersion light onto the cornea.

The second alignment mark projection optical system **50** includes at least an alignment mark projecting light source to project an alignment mark in the Z-direction onto the eye E from an oblique direction. Specifically, the projection optical system **50** includes the light source **51** and a projection lens **52** to project the alignment mark (the alignment mark light) onto the eye E. An optical axis L**4** of the projection optical system **50** intersects with the observation optical axis L**1** at a predetermined angle.

Infrared light from the light source **51** passes through the lens **52**, is substantially collimated, and then is projected onto the cornea of the eye E. The light mirror-reflected by the cornea forms an image (an alignment mark image) i**2** which is a virtual image (a corneal reflection image) of the light source **51**.

The alignment mark detection optical system **55** includes a photo-receiving lens **56**, a filter **57**, and a position sensitive device **58** (e.g., a line CCD) to detect the alignment mark image formed by the projection optical system **50**. The filter **57** has a property of transmitting the light from the light source **51** and blocking the light from the light source **38** and the light from the light source **42**. An optical axis L**5** of the detection optical system **55** is symmetrical to the optical axis L**4** of the projection optical system **50** with respect to the observation optical axis L**1**. The optical axis L**5** intersects with the optical axis L**4** at a point on the optical axis L**1**.

The mark image i**2** by the light source **51** is formed on the position sensitive device **58** by the lens **56**. When the eye E moves in the Z-direction, an image forming position of the mark image i**2** moves on the position sensitive device **58**. Based on a detection signal of the position sensitive device **58**, the arithmetic and control section **70** can detect an alignment state of the apparatus (the probe **10**) in the Z-direction with respect to the eye.

The arithmetic and control section **70** is coupled to the knob **5**a, the switch **5**b, the movement part **6**, the monitor **72**, the specifying section **83**, the light sources **32**, **38**, **42**, and **51**, the image pickup device **26**, the position sensitive device **58**, an operation section (an input section) **74** provided with various switches, a memory **75** serving as a storage section, and others. The arithmetic and control section **70** performs control of the entire apparatus, calculation of measured values, and so on.

The memory **75** stores a table showing a correlation between the phase difference θx at the frequency fx and an intraocular pressure value. The arithmetic and control section **70** retrieves an intraocular pressure value corresponding to the detected phase difference θx from the memory **75** based on the output signal of the specifying section **83** and displays the retrieved intraocular pressure value on the monitor **72**.

The correlation between the phase difference θx and the intraocular pressure value can be set by experimentally determining in advance a correlation between phase differences θx obtained by the present apparatus and intraocular pressure values measured by a Goldmann tonometer. The memory **75** stores a program for measuring intraocular pressure by use of the probe **10**, a program for controlling the entire apparatus, and so on.

On the operation part **74**, there are arranged a selection switch **74**a for selecting either an automatic alignment mode of automatically aligning the measurement part **4** with respect to the eye E or a manual alignment mode of manually aligning the measurement part **4** with respect to the eye E, a selection switch **74**b for selecting either an automatic shot mode of automatically generating a trigger signal to start measurement upon completion of alignment or a manual shot mode of generating a trigger signal to start measurement based on an operation signal of the switch **5**b, and others. When the automatic shot mode is selected, the arithmetic and control section **70** determines whether the alignment state is proper or not based on each detection signal of the image pickup device **26** and the position sensitive device **58**. Based on the determination result, the arithmetic and control section **70** generates a measurement-start trigger signal and, based on the generation of the trigger signal, causes the probe **10** to emit an ultrasonic wave to the eye E.

Operations of the apparatus having the above configuration are explained below. Firstly, the face (head) of an examinee is fixed on the head support unit **2**. An examiner makes alignment of the apparatus with the examinee's eye E by manipulating the joystick **5** while viewing the monitor **72**. At that time, the arithmetic and control section **70** displays the anterior segment image picked up by the image pickup device **26** and a reticle LT and an indicator G for alignment on the monitor **72** as shown in FIGS. **4**A and **4**B.

When the mark image **i1** starts to appear on the monitor **72** (when the image pickup device **26** starts to detect the mark image **i1**), the automatic alignment in the X- and Y-directions is enabled. Furthermore, when the position sensitive device **58** starts to detect the mark image **i2**, the automatic alignment in the Z-direction is enabled. The arithmetic and control section **70** controls display of the indicator G based on information about the alignment state in the Z-direction obtained from the detection signal of the position sensitive device **58**.

The case of selecting the automatic alignment mode and the automatic shot mode is explained below. The arithmetic and control section **70** obtains misalignment amounts of the apparatus in the X-, Y-, and Z-directions relative to the eye E located in a proper position, and controls driving of the movement part **6** to bring each misalignment amount into a predetermined permissible range. When each misalignment amount falls within the permissible range, the arithmetic and control section **70** stops the driving of the movement part **6** and automatically generates the measurement-start trigger signal to start intraocular pressure measurement.

The case of selecting the manual alignment mode and the manual shot mode is explained below. In this case, the examiner manipulates the joystick **5** (the knob **6**a) so that the mark image **i1** displayed on the monitor **72** enters in the reticle LT and the indicator G appears in the form representing alignment completion (see FIG. **4**B). When the alignment is completed in each direction and the switch **5**b is pressed by the examiner, the arithmetic and control section **70** generates the measurement-start trigger signal to start the intraocular pressure measurement.

Upon generation of the measurement-start trigger signal, the arithmetic and control section **70** causes the vibrator **11** to emit the ultrasonic wave to the eye E and detects the ultrasonic wave reflected from the eye E by the sensor **13**. The arithmetic and control section **70** calculates an intraocular pressure value of the eye E based on the output signal of the specifying section **83** and displays a result thereof on the monitor **82**.

With the above configuration, the alignment between the eye E and the probe **10** can be easily performed.

In the above explanation, the fixation target light is projected onto the eye. E through the aperture **18** formed in the center of the probe **10**. It is not limited thereto but may be arranged to project the fixation target light through the surrounding region of the probe **10** in the lens **22**. A conceivable configuration in this case is, for instance, to use a diaphragm having an annular aperture centered on the optical axis L**2** instead of the diaphragm **34** having a spot aperture on the optical axis L**2**.

In the above embodiment, the alignment mark light is projected onto the eye E through the aperture **18** formed in the center of the probe **10**. It is not limited thereto but may be arranged to project the alignment mark light through the surrounding region of the probe **10** in the lens **22**, and allow the image pickup device **26** to detect the reflected light passing through the surrounding region of the probe **10** in the lens **22**. A conceivable configuration in this case is, for instance, to use an annular light source instead of the spot light source **42**.

FIG. **6** is a view showing a modified example of the fixation target projection optical system and the first alignment mark projection optical system. In this case, the light source **32** (e.g., an LED) is placed in the center of the probe **10**.

A first alignment mark projection optical system **140** for projecting alignment mark light at a predetermined angle to the observation optical axis L**1** is placed outside the lens **22**. Reflected light thereof is allowed to pass through the surrounding region of the probe **10** in the lens **22**. In this case, the angle of the optical axis of the projection optical system **140** to the observation optical axis L**1** is determined to prevent part of the reflected light from becoming interrupted by the lens **16**.

In the case where the light source **32** is placed in the center of the probe **10** as shown in FIG. **6**, a light source that emits visible light and infrared light may be used as the light source **32** to serve both as the fixation target projecting light source and the alignment mark projecting light source.

In the above explanation, the probe **10** is placed on the observation optical axis L**1** but not limited thereto. The probe **10** may be displaced from the observation optical axis L**1** in a direction (the X- and Y-directions) perpendicular to the optical axis L**1** as shown in FIG. **7**. In this case, a detection position of the mark image **i1** on the image pickup device **26** when the central axis (the extension of the central axis) of the probe **10** comes into alignment with the predetermined portion (e.g., the corneal center or the pupil center) of the eye E is set as an alignment reference position, and a display position of the reticle LT, an alignment completion position, and others are set.

FIG. **8** is a schematic configuration view of the measurement system and the optical system of the tonometer **100**, showing the case where the probe is placed out of the optical path of the observation optical system.

An ultrasonic wave reflecting member (an acoustic mirror) **90** reflects an incident wave from the vibrator **11** toward the eye E while reflecting a reflected wave from the eye E toward the sensor **13**. The observation optical system **20** is arranged so that the probe **10** is placed out of the optical path thereof and the observation optical axis L**1** is positioned on an ultrasonic wave propagation path between the reflecting member **90** and the eye E. The lens **22** is formed with an aperture **22**b through which an ultrasonic wave from the probe **10** is allowed to pass. The incident wave from the vibrator **11** is reflected by the reflecting member **90** to enter the eye E after passing through the aperture **22**b. The reflected wave from the eye E passes through the aperture **22**b, is reflected by the reflecting member **90**, and then is detected by the sensor **13**.

In the case where the lens **22** is placed between the reflecting member **90** and the eye E, the lens **22** formed with the aperture **22**b in a portion corresponding to the ultrasonic wave propagation path can avoid attenuation of the ultrasonic wave which is likely to be caused in passing through the lens **22**. In this case, the reflecting member **90** applied with a coating having a property of blocking the reflection light from the anterior segment by the light source **38** may be used to prevent the anterior segment reflection light from entering the image pickup device **26** through the aperture **22**b, thereby preventing resultant noise light.

As the reflecting member **90**, a member having a property of reflecting the ultrasonic wave and transmitting light (for example, a transparent and colorless, hard plastic plate) may be used. This can prevent the fixation target light and the alignment mark light from becoming interrupted even when the reflecting member **90** is placed in each optical path of the projection optical system **30** and the projection optical system **40**. In the case of using the reflecting member **90** having a light transmission property, taking into consideration that the optical length is changed by passage of light through the reflecting member **90**, a member having the area almost equal to an optical path splitting member such as the half mirror **36** and the dichroic mirror **46** may be used.

The present invention is not limited to the above configuration and may be arranged such that the reflecting member **90** is partly provided with an aperture through which the fixation target light and the alignment mark light are allowed to pass to be projected onto the eye E. The above configuration shows the case in which the reflecting member **90** is placed in a common optical path of the projection optical systems **30** and **40**. The above configuration can be applied to the case where the reflecting member **90** is placed in the optical path of at least one of the projection optical systems **30** and **40**.

The configuration in which the probe **10** is placed out of the observation optical path is not limited to one shown in FIG. **8** and may be arranged so that the reflecting member **90** is placed between the lens **22** and the eye E. In this case, the incident wave from the vibrator **11** is reflected by the reflecting member **90** to enter the eye F, while the reflected wave from the eye E is reflected by the reflecting member **90** and detected by the sensor **13**.

The tonometer may be additionally provided with a measurement optical system for measuring eye characteristics different from the intraocular pressure. FIG. **9** is a view showing the case where an eye refractive power measurement optical system is added to the tonometer.

An eye refractive power measurement optical system **310** is arranged so that the probe **10** is placed out of an optical path of the measurement optical system **310** (a measurement optical path), and an optical axis L**6** of the measurement optical system **310** (hereinafter, referred to as a "measurement optical axis") is located on the ultrasonic wave propagation path between the reflecting member **90** and the eye E. The reflecting member **90** is placed in front of the eye E. The incident wave from the vibrator **11** is reflected by the reflecting member **90** to enter the eye E and the reflected wave from the eye E is reflected by the reflecting member **90** and detected by the sensor **13**. Thus, the intraocular pressure of the eye E is measured.

The measurement optical system **310** is placed on the transmission side of a dichroic mirror **301** located at the rear of the reflecting member **90**. The measurement optical system **310** is an optical system for projecting measurement light to the fundus of the eye E and receiving reflected light from the fundus by a photo-receiving device. Based on an output signal of the photo-receiving device, the eye refractive power is measured. The measurement optical system **310** and a measurement principle of eye refractive power are well known and thus their details are omitted herein.

On the reflection side of the dichroic mirror **301**, an objective lens **311**, a dichroic mirror **312**, and a total reflection mirror **313** are placed. On the reflection side of the mirror **313**, a fixation target projection optical system not shown is arranged to cause the eye E to view the fixation target.

On the reflection side of the dichroic mirror **312**, arranged is an observation optical system **322** including an imaging lens **320** and a two-dimensional image pickup device **321** placed in a substantially conjugate relationship with the vicinity of the anterior segment of the eye E. The image pickup device **321** picks up the anterior segment image formed by a light source **325** and a mark image formed by the alignment mark projection optical system not shown.

The measurement optical axis L**6** and an optical axis L**7** of the observation optical system **322** are made coaxial by the dichroic mirror **301**. The dichroic mirror **301** has a property of transmitting light from a light source of the measurement optical system **310** and reflecting the light from the light source **325**, light from a light source of the alignment mark projection optical system, and light from a light source of the fixation target projection optical system. The dichroic mirror **312** also has a property of transmitting the light from the light source of the fixation target projection optical system and reflecting the light from the light source **325** and the light from the light source of the alignment mark projection optical system. Used as the reflecting member **90** is a member having a property of reflecting an ultrasonic wave and transmitting light (e.g., a transparent and colorless, hard plastic plate). This member transmits the measurement light by the measurement optical system **310**, the anterior segment reflected light by the light source **325**, the fixation target light by the fixation target projection optical system, the alignment mark light by the alignment mark projection optical system, and others.

In the configuration of FIG. **9**, the reflecting member **90** is placed in a common optical path of the measurement optical system **310**, the observation optical system **322**, and the fixation target projection optical system but it is not limited thereto. The configuration has only to reflect the ultrasonic wave from the probe **10** by the reflecting member **90** to enter the eye E from front. For instance, the reflecting member **90** may be placed between the dichroic mirror **301** and the lens **311**.

Although the above explanation exemplifies the eye refractive power measurement optical system, the present invention is not limited thereto and may be applied to a measurement optical system for measuring eye characteristics different from intraocular pressure by receiving reflected light resulting from measurement light projected onto the eye E. For example, a non-contact type eye axial length measurement optical system (e.g., see U.S. Pat. No. 7,434,932 (JP2007-37984A), a corneal thickness measurement optical system (e.g., see JP63-197433 (1988)A), and others may be adopted.

Furthermore, a mode of performing intraocular pressure measurement based on the measurement-start trigger signal may be selected as needed with a switch or the like between a normal measurement mode of performing one intraocular pressure measurement in response to one trigger signal and a continuous measurement mode of repeating intraocular pressure measurements several times in response to one trigger signal.

The case of selecting the continuous measurement mode is explained below. Upon generation of the measurement-start trigger signal, the arithmetic and control section **70** causes the probe **10** to continuously emit an ultrasonic wave pulse toward the eye E to obtain information on variations in intraocular pressure caused by pulsation of the eye E, and performs the arithmetic processing corresponding to each ultrasonic wave pulse continuously emitted.

Specifically, the ultrasonic wave pulse is continuously made incident on the eye E at predetermined time intervals (e.g., 0.1 seconds intervals) within a range (e.g., within 1.5 seconds) of a pulsation cycle of the eye E, and an intraocular pressure value corresponding to each ultrasonic wave pulse is calculated. In this way, many intraocular pressure values can be obtained within the range of the pulsation cycle and thus variations in intraocular pressure values in the pulsation cycle can be captured. In this case, based on each measured value obtained within the range of the pulsation cycle, it is possible to calculate a representative value (e.g., an average value of the measured values, a central value of the measured values) and calculate measured values at a peak, a bottom, and a middle of the pulsation.

In the above explanation, the ultrasonic wave pulse is emitted at the predetermined time intervals (e.g., 0.1 seconds intervals) but not limited thereto. The ultrasonic wave pulse may be emitted at a predetermined number of times previously set within the range of the pulsation cycle. The time intervals and number of emissions for continuously emitting the ultrasonic wave pulse may be made arbitrarily settable and a switch thereof may be provided in the operation part **74**.

In the above explanation, the alignment state of the apparatus with respect to the eye E in the Z-direction is optically detected (a working distance is detected) but it may be detected by the probe **10** used for intraocular pressure measurement. In this case, the control of the probe **10** has to be switched between control for measuring the intraocular pressure and control for detecting the working distance. In the case of detecting the working distance with respect to the eye E by use of the probe **10**, the arithmetic and control section **70** measures a measurement time T from emission of the incident wave from the vibrator **11** toward the eye E until the reflected wave from the eye E is detected by the sensor **13** and thereby detects the working distance of the probe **10** from the eye E. In other words, as the measurement time T from the emission of the ultrasonic wave from the vibrator **11** until the ultrasonic wave is detected by the sensor **13** is longer, the working distance is larger. As the measurement time T is shorter, the working distance is smaller. The arithmetic and control section **70** previously determines a reference measurement time Tk for which the working distance is proper with respect to the eye E and considers the alignment in the Z-direction to be completed when the measurement time T reaches the reference measurement time Tk.

In the case of the above configuration, for example, the arithmetic and control section **70** controls the probe **10** as a working distance sensor with respect to the eye E before completion of alignment and controls the probe **10** as an intraocular pressure measurement sensor with respect to the eye E after completion of alignment. This can facilitate the configuration for detecting the alignment state of the apparatus relative to the eye E in the Z-direction.

The above explanation is made to determine the intraocular pressure based on a difference in acoustic impedance resulting from the phase difference between an input phase and an output phase. The present invention is not limited thereto and may be applied to a configuration that can determine intraocular pressure by performing a comparison and arithmetic processing of the incident wave from the vibrator **11** and the reflected wave detected by the sensor **13**. For instance, it may be arranged to determine intraocular pressure by performing a comparison and arithmetic processing of the frequency of the incident wave from the vibrator **11** and the frequency of the reflected wave detected by the sensor **13**. Specifically, a phase shift circuit may be provided to shift the phase difference to zero by changing the frequency of an ultrasonic wave generated by the vibrator **11** when the phase difference occurs between the input waveform to the vibrator **11** and the output waveform from the sensor **13**. The intraocular pressure is determined by detecting a frequency change amount when the phase difference is shifted to zero.

The invention claimed is:

1. A non-contact ultrasonic tonometer for measuring intraocular pressure of an examinee's eye in a non-contact manner by use of an ultrasonic wave, the tonometer comprising:

a fixation target projection optical system provided with a light source for fixation target projection to project a fixation target onto the eye to cause the eye to view the fixation target;

a probe including a vibrator for making the ultrasonic wave incident on the examinee's eye and a sensor for detecting the ultrasonic wave reflected from the examinee's eye, the probe being configured to measure the intraocular pressure based on an output signal from the sensor; and

an observation optical system for observing an anterior segment of the eye,

wherein the probe is placed in an optical path of the observation optical system and has an aperture through which fixation target light from the light source is allowed to pass, and

the observation optical system forms an image of the anterior segment through a surrounding region of the probe.

2. The tonometer according to claim **1** further comprising an alignment mark projection optical system provided with a light source for alignment mark projection to project an alignment mark onto the eye, and

an alignment mark detection optical system provided with an image pickup device to detect a corneal reflection image formed by the light source,

wherein the observation optical system forms the corneal reflection image on the image pickup device through the surrounding region of the probe.

3. The tonometer according to claim **2**, wherein

the probe has an aperture through which alignment mark light from the light source is allowed to pass.

4. A non-contact ultrasonic tonometer for measuring intraocular pressure of an examinee's eye in a non-contact manner by use of an ultrasonic wave, the tonometer comprising:

a fixation target projection optical system provided with a light source for fixation target projection to project a fixation target onto the examinee's eye to cause the eye to view the fixation target;

a probe including a vibrator for making the ultrasonic wave incident onto the examinee's eye and a sensor for detecting the ultrasonic wave reflected from the examinee's eye, the probe being configured to measure the intraocular pressure based on an output signal from the sensor;

an observation optical system for observing an anterior segment of the eye; and

a refractive power measurement optical system configured to project measurement light onto a fundus of the examinee's eye and cause a photo-receiving device to receive reflection light from the fundus, the refractive power measurement optical system being arranged to measure refractive power of the examinee's eye based on an output from the photo-receiving device,

wherein the probe is placed out of an optical path of the fixation target projection optical system, the observation optical system, *and* the refractive power measurement optical system*; and*

wherein the tonometer is structured such that it does not contact the examinee's eye during measurement of the intraocular pressure of the examinee's eye.

5. The tonometer according to claim **1**, further comprising an acoustic lens placed on a side of the vibrator closer to the examinee's eye and for converging the ultrasonic wave from the vibrator, the acoustic lens including an aperture through which fixation target light from the light source is allowed to pass, and the observation optical system forms the anterior segment image through the surrounding region of the acoustic lens.

6. The tonometer according to claim **1**, further comprising an alignment detection unit for detecting an alignment state of the probe in a working distance direction with respect to the examinee's eye.

7. The tonometer according to claim **6**, wherein the alignment detection unit includes a projection optical system for projecting an alignment mark onto a cornea of the examinee's eye from an oblique direction and a detection optical system for detecting the alignment mark projected on the cornea from an oblique direction symmetrical to the oblique projecting direction.

8. The tonometer according to claim **1**, wherein the probe is connected to a circuit system with a cable having a surface property of absorbing reflection light from the anterior segment.

9. The tonometer according to claim **4**, further comprising an acoustic lens placed on a side of the vibrator closer to the examinee's eye and for converging the ultrasonic wave from the vibrator.

10. The tonometer according to claim **4**, further comprising an alignment detection unit for detecting an alignment state of the probe in a working distance direction with respect to the examinee's eye.

11. The tonometer according to claim **10**, wherein the alignment detection unit includes a projection optical system for projecting an alignment mark onto a cornea of the examinee's eye from an oblique direction and a detection optical system for detecting the alignment mark projected on the cornea from an oblique direction symmetrical to the oblique projecting direction.

12. A non-contact ultrasonic tonometer for measuring intraocular pressure of an examinee's eye in a non-contact manner by use of an ultrasonic wave, the tonometer comprising:

a reflecting member for reflecting the ultrasonic wave propagating through air;

an observation optical system for observing an anterior segment of the examinee's eye, the observation optical system being placed so that at least a portion of its optical axis is positioned on a path of the ultrasonic wave between the eye and the reflecting member, a refractive power measurement optical system being configured to measure the refractive power of the examinee's eye;

a fixation target projection optical system to project a fixation target onto a fundus of the examinee's eye to cause the eye to view the fixation target; and

a probe including a vibrator for making the ultrasonic wave incident onto the examinee's eye and a sensor for detecting the ultrasonic wave reflected from the examinee's eye through the ultrasonic wave reflecting member, the probe being placed out of optical paths of the observation optical system, the fixation target projection optical system, and the refractive power measurement optical system;

wherein the tonometer is structured such that it does not contact the examinee's eye during measurement of the intraocular pressure of the examinee's eye.

13. The tonometer according to claim 12, further comprising an acoustic lens placed on a side of the vibrator closer to the examinee's eye and for converging the ultrasonic wave from the vibrator.

14. The tonometer according to claim 12, further comprising an alignment detection unit for detecting an alignment state of the probe in a working distance direction with respect to the examinee's eye.

15. The tonometer according to claim 14, wherein the alignment detection unit includes a projection optical system for projecting an alignment mark onto a cornea of the examinee's eye from an oblique direction and a detection optical system for detecting the alignment mark projected on the cornea from an oblique direction symmetrical to the oblique projecting direction.

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