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(54) **OPTICAL IMAGING APPARATUS AND METHOD FOR IMAGING AN OPTICAL IMAGE**

OPTISCHES BILDGEBUNGSGERÄT UND VERFAHREN ZUR DARSTELLUNG EINES OPTISCHEN BILDES

APPAREIL D’IMAGERIE OPTIQUE ET PROCÉDÉ D’IMAGERIE D’UNE IMAGE OPTIQUE

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Description

TECHNICAL FIELD

[0001] The present invention relates to an optical imaging apparatus and a method for imaging an optical image, and particularly to an optical imaging apparatus and a method for imaging an optical image used for ophthalmologic diagnosis and treatment.

BACKGROUND ART

[0002] Optical Coherent Tomography (OCT) using an interference phenomenon of multi-wavelength light is a method for acquiring a tomographic image of a sample (particularly the fundus) with a high resolution. An apparatus for imaging a tomographic image by using such OCT is hereinafter called "an OCT apparatus". Recently, by enlarging the beam diameter of a measuring beam in an OCT apparatus of the Fourier Domain system, a tomographic image of the retina can be provided with an improved lateral the resolution. However, as the beam diameter of the measuring beam has been enlarged, there is, at acquisition of a tomographic image of the retina, presented a problem of decrease in the S/N ratio and resolution of the tomographic image due to an aberration in an eye to be inspected. To resolve the problem, an adaptive optics OCT apparatus having adaptive optics has been developed in which an aberration in an eye to be inspected is measured by a wavefront sensor in real time, the aberration, generated in the eye to be inspected, of a measuring beam or a return beam are corrected by a wavefront correcting device, and thereby the apparatus enables a tomographic image being provided with a high lateral resolution.

[0003] Regarding an apparatus using such adaptive optics, Japanese Patent Application Laid-Open No. 2007-14569 proposes an ophthalmologic imaging apparatus capable of acquiring an image of the fundus by using adaptive optics, a polygon mirror, a galvano-mirror, etc. in a scanning laser ophthalmoscope (SLO apparatus). This ophthalmologic imaging apparatus is adapted so that an aberration in an eye to be inspected is detected and an aberration of a return beam formed of a measuring beam irradiated to a retina is corrected by using the adaptive optics, and allows a lateral resolution to be prevented from being degraded. Also, "Ultrahigh-resolution optical coherence tomography with monochromatic and chromatic aberration correction", Opt. Express 16, 8126 (2008) describes an OCT apparatus of the Fourier Domain system in which both of a high lateral resolution and a high longitudinal resolution are intended to be coexistent by using the adaptive optics and a chromatic aberration correction lens. Here, it is tried to reduce speckles and improve the contrast of a tomographic image by measuring and correcting an aberration of a measuring beam and a return beam generated in an eye to be inspected using the adaptive optics, and further averaging obtained tomographic images of the retina.

[0004] Further relevant prior art comprises the US 2008/225228 A1, US 2008/158508 A1, US 2007/171366 A1 and US 2007/252951. For example, the claims are delimited against the disclosure of US 2008/225228 A1.

DISCLOSURE OF THE INVENTION

[0005] An ophthalmic apparatus having the conventional adaptive optics described above is, as described above, adapted so that it can provide an image with a high lateral resolution by measuring and correcting an aberration of a measuring beam and a return beam generated in an eye to be inspected using the adaptive optics. However, enlarging the beam diameter of a measuring beam decreases the depth of focus, but an adverse effect caused due to the enlarging cannot be excluded in these conventional examples, and the enlargement of the beam diameter cannot necessarily provide a satisfactory advantage for acquiring an image with a high resolution. Further, prior to imaging, optical adjustment is necessary to be suitable for each of eyes to be inspected as objects, which forms restriction to imaging.

[0006] An object of the present invention is, in view of the problems described above, to provide an optical imaging apparatus capable of providing a high lateral resolution in a wide region and easily adjusting prior to imaging for imaging an eye to be inspected as an object, and a method for imaging an optical image. The present invention provides an optical imaging apparatus and a method for imaging an optical image as defined in the appended claims.

[0007] The present invention can realize an optical imaging apparatus capable of providing a high lateral resolution in a wide region and easily adjusting prior to imaging for imaging an eye to be inspected as an object, and a method for imaging an optical image.

[0008] Further features of the present invention will become apparent from the following description of exemplary embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009]

FIG. 1 illustrates a whole configuration of an OCT apparatus in a first exemplary embodiment of the present invention.

FIGS. 2A, 2B and 2C illustrate a method for acquiring an image of the OCT apparatus in the first exemplary embodiment of the present invention.

FIGS. 3A, 3B, 3C, 3D and 3E illustrate a method for acquiring a tomographic image of the OCT apparatus in the first exemplary embodiment of the present invention.

FIG. 4 is a flow chart for illustrating a procedure for acquiring a tomographic image of the OCT apparatus in the first exemplary embodiment of the present invention.

FIG. 5 illustrates a whole configuration of an OCT apparatus in a second exemplary embodiment of the present invention.

FIGS. 6A, 6B, 6C, 6D and 6E illustrate a method for acquiring a tomographic image of the OCT apparatus in the second exemplary embodiment of the present invention.

FIG. 7 is a flow chart for illustrating a procedure for acquiring a tomographic image of the OCT apparatus in the second exemplary embodiment of the present invention.

FIG. 8 illustrates a whole configuration of an OCT apparatus in a third exemplary embodiment of the present invention.

BEST MODES FOR CARRYING OUT THE INVENTION

[0010] Embodiments of the present invention will be described with reference to exemplary embodiments below.

Embodiments

Exemplary embodiment 1

[0011] A first exemplary embodiment describes an OCT apparatus to which the present invention is applied. Particularly, here, there is given a description of an OCT apparatus with a high lateral resolution and capable of imaging both of a planar image (SLO image) and a tomographic image (OCT image) of an eye to be inspected. In this exemplary embodiment, an optical imaging apparatus is adapted so that a measuring beam from a light source is irradiated to an object, and a planar image and a tomographic image of the object are imaged based on light intensity of a return beam formed of the measuring beam irradiated to the object. Particularly, the beam from the light source is split into a measuring beam and a reference beam, and a return beam formed of the measuring beam irradiated to the object and the reference beam traveling through a reference light path are combined to interfere with each other, and then a tomographic image of the object is provided based on intensity of an interference signal formed from the interference. At this time, an OCT apparatus of the Fourier Domain system is adapted so that a plurality of tomographic images having a different focus position are composited to form a single tomographic image, and thereby a good tomographic image can be provided regardless of a diopter scale of an eye to be inspected.

[0012] Referring to FIG. 1, first, a whole, schematic configuration of an optical system of an OCT apparatus in the present exemplary embodiment is specifically described. An OCT apparatus 100 of the exemplary embodiment is, as illustrated in FIG. 1, a Michelson interference system as a whole. In FIG. 1, a beam emitted from a light source 101 is split into a reference beam 105 and a measuring beam 106 by a beam splitter 103. The measuring beam 106 is reflected or scattered by an eye 107 to be inspected as an object to be observed, forming a return beam 108, which comes back and is combined with the reference beam 105 by the beam splitter 103. The reference beam 105 and the return beam 108, after being combined, are dispersed into their wavelength components by a transmission grating 141 and projected on a line camera 139. The line camera 139 converts light intensities into a voltage for each of positions (wavelengths), and these signals are used to form a tomographic image of the eye 107 to be inspected. Also, a part of the return beam 108 is projected to a detector 138 by a beam splitter 158-3. The detector 138 converts light intensities into voltages, and these signals are used to form a planar image of the eye 107 to be inspected. In the exemplary embodiment, the whole optical system is adapted mainly using a refractive optical system using lenses, but may be also adapted using a reflective optical system using spherical mirrors instead of the lenses. Further, a part of the optical system may be adapted using an optical fiber.

[0013] Next, details of the light source 101 are described. The light source 101 is a Super Luminescent Diode (SLD), which is a representative low-coherence light source. The wavelength is 830 nm, and the bandwidth is 50 nm. Here, the bandwidth is an important parameter because it has an effect on a resolution of the obtained tomographic image in a direction of the optical axis. Also, the type of light source selected here is a SLD, but it may be any type which can emit low-coherence light, and Amplified Spontaneous Emission (ASE), etc. may be used. Further, near-infrared light is, with consideration for a measurement of the eye, suitable for the wavelength. Further, the wavelength is desirably as short as possible because it has an effect on a resolution of the obtained tomographic image in a lateral direction, and here 830 nm has been selected as the wavelength. Another wavelength may be selected dependent on a position to be measured of an object. The beam emitted from the light source 101 passes through a single-mode fiber 110, and is directed to a lens 111 and adjusted to be a collimated beam having the beam diameter of 2 mm.

[0014] Next, a light path of the reference beam 105 is described. The reference beam 105 split by the beam splitter 103 is projected on a mirror 114-2 to turn its direction, projected on a mirror 114-1, and reflected therefrom, and then goes back toward the beam splitter 103. Next, the reference beam 105 passes through the beam splitter 103 and is directed to the line camera 139. Here, a dispersion compensation glass compensates the reference beam 105 for dispersion produced when the measuring beam 106 goes to and comes back from the eye 107 to be inspected. It is, here, supposed that a representative value of the average diameter of Japanese eyeballs, L1 = 23 mm, is set. Further, an electrical stage 117-1 can move in the directions shown by the arrow, and adjust and control the light path length of the reference beam 105. Also, the electrical stage 117-1 can be controlled by a personal computer 125 at a high speed.

[0015] Next, a light path of the measuring beam 106 is described. The measuring beam 106 split by the beam splitter 103 passes through beam splitters 158-3 and 158-1, and lenses 120-3 and 120-4 and is projected on a mirror of an XY scanner 119. Here, for the simplicity, the XY scanner 119 is illustrated as one mirror, but actually the XY scanner 119 has two mirrors, a mirror for X scanning and a mirror for Y scanning, disposed close to each other therein, and scans the retina 127 in the direction perpendicular to the optical axis in the raster scan mode. Also, the center of the measuring beam 106 is adjusted to coincide with the rotation center of the mirror of the XY scanner 119. Lenses 120-1 and 120-2 form an optical system for scanning the retina 127 and play a role in scanning the retina 127 with the measuring beam 106 using the vicinity of the cornea 126 as a pupil of the optical system. Here, the focus distances of the lenses 120-1 and 120-2 are 50 mm and 40 mm, respectively. Here, the measuring beam 106 has the beam diameter of 2 mm, and the depth of focus of about 250 μm in the eye 107 to be inspected. The beam diameter may be more enlarged to acquire a tomographic image with a higher resolution. However, because the depth of focus is inversely proportional to the square of the beam diameter, optical adjustment becomes difficult. Further, an electrical stage 117-2 can move in the directions shown by the arrow, and adjust and control a position of the lens 120-2 which is a focus lens attached thereto. By adjusting the position of the lens 120-2, the measuring beam 106 can be focused on a predetermined layer in the retina 127 of the eye 107 to be inspected, and observing can be performed. Further, the case of the eye 107 to be inspected having a refractive error can be addressed. When the measuring beam 106 is projected in the eye 107 to be inspected, it is reflected or scattered by the retina 127 to form the return beam 108, which is reflected by the beam splitter 103 and directed to the line camera 139. Also, a part of the return beam 108 is reflected by the beam splitter 158-3 and directed to the detector 138 through a lens 120-5. Here, a shield plate 172 has a pin hole and plays a role in blocking an unnecessary beam, i.e. the beam not focused on the retina 127, in the return beam 108. Also, the pin hole of the shield plate 172 is disposed to become conjugate with a focus position of the lens 120-5. Also, the diameter of the pin hole is, for example, 50 μm. The detector 138 used is, for example, an Avalanche Photo Diode (APD) which is a high-speed, high-sensitivity optical sensor. Here, the electrical stage 117-2 can be controlled by the personal computer 125, which characterizes the present embodiment.

[0016] Also, a part of the return beam 108 split by the beam splitter 158-1 is projected on a wavefront sensor 155 (as an aberration detecting device of the present embodiment), and an aberration of the return beam 108 is measured. The wavefront sensor 155 is electrically connected to the personal computer 125. The lenses 120-1, 120-2, 120-3 and 120-4 are disposed so that the cornea 126, the XY scanner 119 and the wavefront sensor 155 become approximately optically conjugate with each other, and an aberration in the eye 107 to be inspected can be measured by the wavefront sensor 155. Further, the position of the lens 120-2 is adjusted and controlled based on the obtained aberration so that the measuring beam 106 can be focused on a predetermined layer in the retina 127. Here, the lens 120-2 used is a spherical lens, but a cylindrical lens may be used for the lens 120-2 dependent on an aberration (refractive error) in the eye 107 to be inspected. Also, another lens may be added to the light path of the measuring beam 106. A cylindrical lens can effectively correct the astigmatism in a Zernike polynomial, and also is effective in the case where the eye 107 to be inspected is astigmatic.

[0017] Next, a configuration of a measuring system in the OCT apparatus of the exemplary embodiment is described. The OCT apparatus 100 can provide a tomographic image (OCT image) formed of intensities of an interference signal generated by a Mickelson interference system. This measuring system is described. A part of the return beam 108 formed of a beam reflected or scattered by the retina 127 is reflected by the beam splitter 103. Here, the reference beam 105 and the return beam 108 are adjusted to be combined with each other at the back of the beam splitter 103. Then, the combined beam 142 is dispersed into its wavelength components by the transmission grating 141, which are condensed by a lens 135, and light intensities are converted into a voltage for each of positions (wavelengths) by the line camera 139. Specifically, an interference pattern in a spectral region in the wavelength axis will be observed on the line camera 139.

[0018] The obtained group of voltage signals are converted into digital values by a frame grabber 140, which are data processed by the personal computer 125 to form a tomographic image. In the exemplary embodiment, the line camera 139 has 1024 pixels and can provide intensities of the combined beam 142 for each of wavelengths (1024 division). Also, the OCT apparatus 100 can provide a planar image (SLO image) formed of intensities of the return beam 108. Then, a measuring system for the purpose is described. A part of the return beam 108 which is a beam reflected or scattered by the retina 127 is reflected by the beam splitter 158-3. The reflected beam, after an unnecessary beam therein is blocked by the shield plate 172, arrives at the detector 138, and light intensities are converted into electrical signals. The obtained electrical signals are data processed in synchronization with a scan signal by the personal computer 125 to form a planar image. Also, a part of the return beam 108 split by the beam splitter 158-1 is projected on the wavefront sensor 155, and an aberration of the return beam 108 is measured. The wavefront sensor 155 is of the Shack-Hartmann system. The obtained aberration is expressed in a Zernike polynomial, which expresses an aberration of the eye 107 to be inspected. The Zernike polynomial includes terms of tilt, defocus, astigmatism, coma, trefoil, etc.

[0019] Next, a method for acquiring a tomographic image using an OCT apparatus is described. The OCT apparatus 100 controls the XY scanner 119 so that the line camera 139 acquires an interference pattern, and thereby a tomographic image of the retina 127 can be provided (see FIG. 1). Here, with reference to FIGS. 2A, 2B and 2C, a method for acquiring a tomographic image of the retina 127 (plane parallel to the optical axis) is described. FIG. 2A is a schematic view of an eye 107 to be inspected, and illustrates a situation in which the eye 107 to be inspected is observed by the OCT apparatus 100. As illustrated in FIG. 2A, when the measuring beam 106 is projected through the cornea 126 on the retina 127, it is reflected or scattered at various positions to form the return beam 108, which arrives at the line camera 139 with a time delay at each of positions. Here, if the light source 101 has a wide bandwidth and a short coherence length, and accordingly the light path length of the reference light path is approximately equal to that of the measuring light path, then the line camera 139 can detect an interference pattern. As described above, what is acquired by the line camera 139 is an interference pattern in a spectral region in the wavelength axis. Next, the interference pattern which is information in the wavelength axis is converted into an interference pattern in the light frequency axis with consideration for characteristics of the line camera 139 and the transmission grating 141. Further, the converted interference pattern in the light frequency axis is inversely Fourier transformed, and thereby information in the depth direction can be provided.

[0020] Further, as illustrated in FIG. 2B, by detecting an interference pattern while driving X axes of the XY scanner 119, an interference pattern can be provided for each position of each X axis, that is, information for each position of each X axis in the depth direction can be provided. As the result, a two-dimensional distribution of intensities of the return beam 108 in the XZ plane can be provided, which is namely a tomographic image 132 (see FIG. 2C). Originally, the tomographic image 132 is, as described above, an array in which intensities of the return beam 108 are arranged, and, for example, the intensities are displayed in a gray scale. In Fig. 2C, only the boundaries of the obtained tomographic image are displayed to make an emphasis. The retinal pigment epithelium is shown by the number 146, and the optic nerve fiber layer is shown by the number 147. Next, a method for acquiring a planar image using an OCT apparatus is described. The OCT apparatus 100 controls the XY scanner 119 so that the detector 138 detects intensities of the return beam 108, and thereby a planar image of the retina 127 can be provided (see FIG. 1). Here, with reference to FIGS. 2A and 2B, a method for acquiring a planar image of the retina 127 (plane perpendicular to the optical axis) is described. FIG. 2A is a schematic view of an eye 107 to be inspected, and illustrates a situation in which the eye 107 to be inspected is observed by the OCT apparatus 100. As illustrated in FIG. 2A, when the measuring beam 106 is projected through the cornea 126 on the retina 127, it is reflected or scattered at various positions to form the return beam 108, which arrives at the detector 138. Further, as illustrated in FIG. 2B, by detecting intensities of the return beam 108 while driving X axes of the XY scanner 119, information for each position of each X axis can be provided. Further, by detecting intensities of the return beam 108 while driving Y axes of the XY scanner 119, a two-dimensional distribution of intensities of the return beam 108 in the XY plane can be provided, which is namely a planar image.

[0021] Next, there is given a description of a procedure which characterizes the present embodiment for acquiring a tomographic image using an OCT apparatus with reference to FIGS. 1, 3A, 3B, 3C, 3D, 3E, and 4. Here, a procedure for acquiring a tomographic image is described, but a similar procedure can be also applied to acquiring a planar image. Here, as illustrated in FIG. 1, the OCT apparatus 100 controls the position of the lens 120-2 using the electrical stage 117-2, based on an aberration of the eye 107 to be inspected obtained by the wavefront sensor 155. According to this, a plurality of tomographic images are acquired, and these tomographic images are composited with each other, and thereby a tomographic image can be provided. Here, the case where two tomographic images are acquired is described, but the number of tomographic images to be acquired may be any number. Particularly, if the beam diameter of the measuring beam 106 is large, the depth of focus of the measuring beam 106 becomes short, and accordingly acquiring and compositing many tomographic images are effective.

[0022] FIGS. 3A, 3B, 3C, 3D and 3E illustrate procedures of the OCT apparatus 100 for acquiring a tomographic image. Here, as illustrated in FIGS. 3A, 3B, 3C, 3D and 3E, a device for acquiring a tomographic image of the retina 127 in a myopic eye 107 to be inspected is adapted. Of course, if the eye 107 to be inspected is hyperopic or astigmatic, a similar device may be applied. The method for acquiring a tomographic image is such that the following steps (1) to (6) are, for example, successively executed in this order. Alternatively, the steps may return suitably. FIG. 4 is a flow diagram for illustrating a procedure for acquiring a tomographic image described above.

(1) At step 1 (S11 in FIG. 4), while an eye 107 to be inspected is fixed to a fixation lamp 156 (fixation target), the measuring beam 106 is irradiated to the eye 107 to be inspected. Here, the position of the lens 120-2 is adjusted so that the measuring beam 106 is irradiated to the eye 107 to be inspected while being kept in a collimated beam (see FIG. 3A). Then, at step 2 (S12 in FIG. 4), the return beam 108 is measured by the wavefront sensor 155, and thereby an aberration of the return beam 108 is obtained (first

step).

(2) At step 3 (S13 in FIG. 4), the obtained aberration is converted into a Zernike polynomial by the personal computer 125, and a defocus component thereof is recorded in memory (second step). This expresses a diopter scale of the eye 107 to be inspected.

(3) At step 4 (S14 in FIG. 4), the position of the lens 120-2 is adjusted using the electrical stage 117-2 so that the defocus component is minimized (third step). Here, the measuring beam 106 is kept focused on the vicinity of the retinal pigment epithelium 127 (not shown) (see FIG. 3B). For example, if the diopter scale of the eye 107 to be inspected is - 5D, the position of the lens 120-2 is moved to the side of the lens 120-1 by 8 mm.

(4) At step 5 (S15 in FIG. 4), by detecting an interference pattern by the line sensor 139 while driving X axes of the XY scanner 119, a first tomographic image 157-1 (XZ plane) is obtained (see FIG. 3C). Here, dashed lines in the tomographic image 157 schematically illustrate that a lateral resolution and a contrast are low. That is, it is illustrated that the tomographic image 157-1 is well imaged at the vicinity of the retinal pigment epithelium 146.

(5) At step 6 (S16 in FIG. 4), the electrical stage 117-2 is controlled using the personal computer 125 to adjust the position of the lens 120-2 so that the measuring beam 106 is focused on the vicinity of the optic nerve fiber layer 147 (fifth step). Here, a displacement magnitude of the lens 120-2 is determined based on a diopter scale of the eye 107 to be inspected detected in the step (2). Then, at step 7 (S17 in FIG. 4), similar to the step (4) described above, a second tomographic image 157-2 is obtained (see FIG. 3D).

(6) At step 8 (S18 in FIG. 4), the first tomographic image 157-1 and the second tomographic image 157-2 are composited with each other to obtain a tomographic image 132 (see FIG. 3E). Here, the tomographic image 132 shows a good resolution and a good contrast in the whole measured region.

[0023] As described above, by adapting a focus adjusting device for adjusting a focus lens based on an aberration, the focus lens can be adjusted so that an aberration contained in the object itself is measured, and the aberration can be corrected. As the result, a planar image and a tomographic image can be provided with a high lateral resolution and a high measurement sensitivity. Also, a focused state can be quantified, and thereby the focus lens can be easily adjusted, and accordingly an adjustment prior to imaging can be easily performed. Also, the focus lens can be adjusted based on a defocus component. Note that the case based on the defocus component has been described in the procedures described above, but it can be adapted so that the focus lens is adjusted based on at least any one of the defocus component and the astigmatic component. It is particularly effective when a cylindrical lens is used for the focus lens. As a result, the focus lens can be properly adjusted even when the eye to be inspected is myopic, hyperopic or astigmatic. Also, there can be provided the fixation target to which the eye to be inspected as an object is fixed, and thereby a tomographic image can be provided without a blur. Also, there can be provided a construction in which a single tomographic image is obtained by compositing a plural of tomographic images with different focus positions, and thereby the tomographic image can be provided with a high lateral resolution in a wide region in a direction of the optical axis.

Exemplary embodiment 2

[0024] A second exemplary embodiment describes an OCT apparatus to which the present invention is applied. Here, particularly, there is given a description of an OCT apparatus with a high lateral resolution for imaging a tomographic image (OCT image) of an eye to be inspected. The present exemplary embodiment provides an OCT apparatus of the Fourier Domain system for acquiring a tomographic image by correcting an aberration, generated in the eye to be inspected, of a measuring beam or a return beam are inspected using a deformable mirror (as an aberration correcting device of the present embodiment), and the OCT apparatus is adapted so that a good tomographic image can be provided regardless of a diopter scale and/or an aberration of the eye to be inspected. Referring to FIG. 5, first, there is given a description of a whole, schematic configuration of an optical system of an OCT apparatus in the exemplary embodiment. In FIG. 5, a similar component to that of the first exemplary embodiment in FIG. 1 is designated by an identical symbol, and a description of a common part is omitted. In FIG. 5, an optical coupler is designated by the number 131, and lenses are designated by the numbers 135-1, 135-2, 135-3, 135-4, 135-5, 135-6, 135-7, 135-8, 135-9 and 135-10. Single-mode fibers are designated by the numbers 130-1, 130-2, 130-3 and 130-4, and polarization controllers are designated by the numbers 153-1, 153-2, 153-3 and 153-4. A deformable mirror is designated by the number 159.

[0025] An OCT apparatus 100 of the exemplary embodiment is, as illustrated in FIG. 5, a Michelson interference system as a whole. In FIG. 5, a beam emitted from a light source 101 passes through the optical fiber 130-1 and is split into a reference beam 105 and a measuring beam 106 with the ratio of 90:10 by the optical coupler 131. The measuring beam 106 is directed through the optical fiber 130-4, the deformable mirror 159, an XY scanner 119, etc. to an eye 107 to be inspected as an object to be observed. Further, the measuring beam 106 is reflected or scattered at the eye 107 to be inspected to form a return beam 108, which comes back and is combined with the reference beam 105 by the optical coupler 131. The reference beam 105 and the return beam 108, after being combined, are projected on the line camera 139, and the obtained light intensities are used to form a tomographic image of the eye 107 to be inspected.

[0026] Next, details of the light source 101 are described. The light source 101 is a Super Luminescent Diode (SLD) which is a representative, low-coherence light source, and similar to the light source 101 of the first exemplary embodiment, and accordingly a description thereof is omitted. The beam emitted from the light source 101 passes through the single-mode fiber 130-1, and is directed to the optical coupler 131 and split into beams with the ratio of 90:10, which are the reference beam 105 and the measuring beam 106, respectively.

[0027] Next, a light path of the reference beam 105 is described. The reference beam 105 split by the optical coupler 131 passes through the single-mode fiber 130-2 and is directed to the lens 135-1 and adjusted to be a collimated beam having the beam diameter of 2 mm. Next, the reference beam 105 is directed through the mirrors 114-2 and 114-3 to the mirror 114-1 which is a reference mirror. Next, the reference beam 105 is reflected by the mirror 114-1 and directed back to the optical coupler 131. Here, a dispersion compensation glass 115 through which the reference beam 105 passed compensates the reference beam 105 for dispersion produced when the measuring beam 106 goes to and comes back from the eye 107 to be inspected through the lenses 135-4, 135-5, 135-6, 135-7, 135-8, 135-9 and 135-10. The dispersion compensation glass 115 has the length of L2, and here, it is set to L2 = 50 mm. Further, an electrical stage 117-1 can move in the directions shown by the arrow, and adjust and control the light path length of the reference beam 105. Also, the electrical stage 117-1 is controlled by a personal computer 125.

[0028] Next, a light path of the measuring beam 106 is described. The measuring beam 106 split by the optical coupler 131 passes through the single-mode fiber 130-4 and is directed to the lens 135-4 and adjusted to be a collimated beam having the beam diameter of 2 mm. The measuring beam 106 passes through the beam splitter 158-2 and the lenses 135-5 and 135-6, and is projected on the deformable mirror 159. Here, the deformable mirror 159 is a mirror device for correcting an aberration of the measuring beam 106 and the return beam 108 by changing the mirror form thereof as desired, based on an aberration detected by the wavefront sensor 155. In this embodiment the deformable mirror has been used as a device for correcting an aberration, but the device may be any device capable of correcting an aberration, and a spatial light modulator using liquid crystal, etc. may be used. Next, the measuring beam 106 passes through the lenses 135-7 and 135-8, and is projected on a mirror of the XY scanner 119. In this embodiment, the XY scanner 119 is, for the simplicity, illustrated as one mirror, but actually the XY scanner 119 has two mirrors, a mirror for X scanning and a mirror for Y scanning, disposed close to each other therein, and scans the retina 127 in the direction perpendicular to the optical axis in the raster scan mode. Also, the center of the measuring beam 106 is adjusted to coincide with the rotation center of the mirror of the XY scanner 119. The lenses 135-9 and 135-10 form an optical system for scanning the retina 127, and play a role in scanning the retina 127 with the measuring beam 106 using the vicinity of the cornea 126 as a pupil of the optical system. In this embodiment, the focus distances of the lenses 135-9 and 135-10 are 50 mm and 40 mm, respectively. Also, an electrical stage 117-2 can move in the directions shown by the arrow, and adjust and control a position of the attached lens 135-10. By adjusting the position of the lens 135-10, the measuring beam 106 can be focused on a predetermined layer in the retina 127 in the eye 107 to be inspected, and thereby observation can be performed. Also, the case of the eye 107 to be inspected having a refractive error can be addressed. When the measuring beam 106 is projected in the eye 107 to be inspected, it is reflected or scattered by the retina 127 to form the return beam 108, which is directed by the optical coupler 131 again to arrive at the line camera 139. The electrical stage 117-2 can be controlled by the personal computer 125, which characterizes the present exemplary embodiment.

[0029] Also, a part of the return beam 108 split by the beam splitter 158-2 is projected on the wavefront sensor 155, and an aberration of the return beam 108 is measured. The wavefront sensor 155 is electrically connected to the personal computer 125. The obtained aberration is expressed by using the personal computer 125 in a Zernike polynomial, which shows an aberration contained in the eye 107 to be inspected. The obtained aberration is expressed in the Zernike polynomial. Further, the position of the lens 135-10 is controlled by using the electrical stage 117-2 so that a defocus component in the Zernike polynomial can be corrected. A component except the defocus component can be corrected by controlling the form of the surface of the deformable mirror 159, which characterizes the exemplary embodiment. Here, the lenses 135-5, 135-6, 135-7, 135-8, 135-9 and 135-10 are disposed so that the cornea 126, the XY scanner 119, the wavefront sensor 155 and the deformable mirror 159 become optically conjugate with each other, and thereby the wavefront sensor 155 can measure an aberration contained in the eye 107 to be inspected. Here, the lens 135-10 used is a spherical lens, but a cylindrical lens may be used for the lens 135-10 dependent on an aberration (refractive error) in the eye 107 to be inspected. Also, another lens may be added to the light path of the measuring beam 106. A cylindrical lens can effectively correct the astigmatism in the Zernike polynomial, and also is effective in the case where an eye 107 to be inspected is astigmatic. Further, the position of the lens 135-10 is adjusted and controlled based on the obtained aberration, and the measuring beam 106 is kept focused on a predetermined layer in the retina 127, and then the form of the surface of the deformable mirror 159 is controlled. Thus, an aberration produced in the eye 107 to be inspected is corrected, and thereby a tomographic image can be provided with a higher lateral resolution.

[0030] Next, a configuration of a measuring system in the OCT apparatus of the exemplary embodiment is described. The OCT apparatus 100 can provide a tomographic image (OCT image) formed of intensities of an interference signal generated by a Mickelson interference system. This measuring system is described. The return beam 108 which is a beam reflected or scattered by the retina 127 is combined with the reference beam 105 by the optical coupler 131. Then, the combined beam 142 passes through the optical fiber 130-3 and the lens 135-2 and is projected on the transmission grating 141. Also, the combined beam 142 is dispersed into its wavelength components by the transmission grating 141, which are condensed by the lens 135-2, and light intensities are converted into a voltage for each of positions (wavelengths) by the line camera 139. Specifically, an interference pattern in a spectral region in the wavelength axis will be observed on the line camera 139.

[0031] The obtained group of voltage signals are converted into digital values by the frame grabber 140, which are data processed by the personal computer 125 to form a tomographic image. Here, the line camera 139 has 1024 pixels, and can provide intensities of the combined beam 142 for each of wavelengths (1024 division). Also, a part of the return beam 108 split by the beam splitter 158-2 is projected on the wavefront sensor 155, and an aberration of the return beam 108 is measured. The wavefront sensor 155 is of the Shack-Hartmann system. The obtained aberration is expressed in a Zernike polynomial, which expresses an aberration of the eye 107 to be inspected. The Zernike polynomial includes terms of tilt, defocus, astigmatism, coma, trefoil, etc. Note that the method for acquiring a tomographic image using an OCT apparatus is identical to that of the first exemplary embodiment, and a description thereof is omitted. The OCT apparatus 100 can provide a tomographic image of the retina 127 by controlling the XY scanner 119 and acquiring an interference pattern using the line camera 139.

[0032] Next, there is given a description of a procedure which characterizes the present embodiment for acquiring a tomographic image using an OCT apparatus with reference to FIGS. 5, 6A, 6B, 6C, 6D, 6E, and 7. Here, in the OCT apparatus 100, an aberration, generated in the eye to be inspected, of a measuring beam or a return beam is corrected by controlling the form of the surface of the deformable mirror 159 based on an aberration in the eye 107 to be inspected detected by the wavefront sensor 155, and thereby a tomographic image can be provided with a higher lateral resolution. Further, the aberration is kept corrected using the deformable mirror 159, and the position of the lens 135-10 is controlled using the electrical stage 117-2, and thus two tomographic images are acquired and composited with each other, and thereby a tomographic image can be provided with a high lateral resolution (see FIG. 5). In this embodiment the two tomographic images are acquired, but the number of tomographic images to be acquired may be any number. Particularly, if the beam diameter of the measuring beam is large, the depth of focus of the measuring beam 106 becomes short, and accordingly acquiring and compositing many tomographic images are effective.

[0033] FIGS. 6A, 6B, 6C, 6D and 6E illustrate procedures of the OCT apparatus 100 for acquiring a tomographic image. Here, a device for acquiring a tomographic image of the retina 127 in a myopic eye 107 to be inspected is described. The method for acquiring a tomographic image is such that the following steps (1) to (7) are, for example, successively executed in this order. Alternatively, the steps may return suitably. Also, the method may be configured so that the following steps are automatically executed using a computer, etc. FIG. 7 is a flow diagram for illustrating a procedure for acquiring a tomographic image described above.

(1) At step 1 (S21 in FIG. 7), while an eye 107 to be inspected is fixed to a fixation lamp 156, the measuring beam 106 is irradiated to the eye 107 to be inspected. In this embodiment, the position of the lens 135-10 is adjusted so that the measuring beam 106 is irradiated to the eye 107 to be inspected while being kept in a collimated beam (see FIG. 6A). The beam diameter of the measuring beam 106 is 2 mm, and the depth of focus is about 250 μm in the eye 107 to be inspected. Then, at step 2 (S22 in FIG. 7), the return beam 108 is measured by the wavefront sensor 155, and at step 3 (S23 in FIG. 7), an aberration of the return beam 108 is obtained (first step).

(2) The obtained aberration is converted into a Zernike polynomial by the personal computer 125, and a defocus component thereof is recorded in memory (second step). This expresses a diopter scale of the eye 107 to be inspected.

(3) At step 4 (S24 in FIG. 7), the position of the lens 135-10 is adjusted using the electrical stage 117-2 so that the defocus component is minimized (third step). Here, the measuring beam 106 is kept focused on the vicinity of the retinal pigment epithelium 127 (not shown) (see FIG. 6B).

(4) At step 5 (S25 in FIG. 7), the return beam 108 is measured by the wavefront sensor 155 to obtain an aberration of the eye 107 to be inspected. At step 6 (S26 in FIG. 7), the form of the surface of the deformable mirror 159 is controlled so that the obtained aberration is minimized (fourth step). In this embodiment, in order that the aberration is minimized, the form of the surface of the deformable mirror 159 is controlled in real time by means of feedback control using the wavefront sensor 155, the deformable mirror 159 and the personal computer 125. Here, the feedback control may be conducted without regard for one of the defocus component and an astigmatic component of the aberration, so that the high speed

of the controlling is realized.

(5) At step 7 (S27 in FIG. 7), by detecting an interference pattern by the line sensor 139 while driving X axis of the XY scanner 119, a first tomographic image 157-1 (XZ plane) is obtained (see FIG. 6C). Here, dashed lines in the tomographic image 157 schematically illustrate that a lateral resolution and a contrast are low. That is, it is illustrated that the tomographic image 157-1 is imaged well at the vicinity of the retinal pigment epithelium 146.

(6) At step 8 (S28 in FIG. 7), the electrical stage 117-2 is controlled using the personal computer 125 to adjust the position of the lens 135-10 so that the measuring beam 106 is focused on the vicinity of the optic nerve fiber layer 147 (fifth step). Here, a displacement magnitude of the lens 135-10 is determined based on the diopter scale of the eye 107 to be inspected measured in the step (2). Then, at step 9 (S29 in FIG. 7), similar to the step (4) described above, a second tomographic image 157-2 is obtained (see FIG. 6D).

(7) At step 10 (S30 in FIG. 7), the first tomographic image 157-1 and the second tomographic image 157-2 are composited with each other to obtain a tomographic image 132 (see FIG. 6E). In this embodiment, the tomographic image 132 shows a good resolution and a good contrast in the whole measured region. Further, in the exemplary embodiment, because the aberration in the eye 107 to be inspected is corrected, a tomographic image can be provided with a high resolution and a high contrast, compared to the first exemplary embodiment.

Exemplary embodiment 3

[0034] A third exemplary embodiment describes an OCT apparatus to which the present invention is applied. In this embodiment, particularly, there is given a description of an OCT apparatus with a high lateral resolution for imaging a tomographic image (OCT image) of an eye to be inspected. The present exemplary embodiment provides an OCT apparatus of the Fourier Domain system for acquiring a tomographic image by correcting an aberration in an eye to be inspected using a deformable mirror (as an aberration correcting device of the present embodiment), and the OCT apparatus is adapted so that a good tomographic image can be provided regardless of a diopter scale and/or an aberration in the eye to be inspected. In the exemplary embodiment, a whole optical system includes a reflective optical system mainly using spherical mirrors. Referring to FIG. 8, first, there is given a description of a whole, schematic configuration of an optical system of an OCT apparatus in the exemplary embodiment. In FIG. 8, a similar component to that of the second exemplary embodiment in FIG. 5 is designated by an identical symbol, and a description of a common part is omitted. In FIG. 8, mirrors are designated by the numbers 114-2, 114-3, 114-4, and 114-5, and spherical mirrors are designated by the numbers 160-1, 160-2, 160-3, 160-4, 160-5, 160-6, 160-7, 160-8 and 160-9.

[0035] An OCT apparatus 100 of the exemplary embodiment is, as illustrated in FIG. 8, a Michelson interference system as a whole. In FIG. 8, a beam emitted from a light source 101 passes through an optical fiber 130-1 and is split into a reference beam 105 and a measuring beam 106 with the ratio of 90:10 by an optical coupler 131. The measuring beam 106 is directed through an optical fiber 130-4, the spherical mirror 160-1, 160-2, 160-3, 160-4, 160-5, 160-6, 160-7, 160-8 and 160-9, a deformable mirror 159, an XY scanner 119, etc. to an eye 107 to be inspected as an object to be observed. Further, the measuring beam 106 is reflected or scattered at the eye 107 to be inspected to form a return beam 108, which comes back and is combined with the reference beam 105 by the optical coupler 131. The reference beam 105 and the return beam 108, after being combined, are projected on a line camera 139, and the obtained light intensities are used to form a tomographic image of the eye 107 to be inspected.

[0036] Next, details of the light source 101 are described. The light source 101 is a Super Luminescent Diode (SLD) which is a representative, low-coherence light source, and similar to the light source 101 of the first exemplary embodiment, and accordingly a description thereof is omitted. The beam emitted from the light source 101 passes through the single-mode fiber 130-1, and is directed to the optical coupler 131 and split into beams with the ratio of 90:10, which are the reference beam 105 and the measuring beam 106, respectively.

[0037] Next, a light path of the reference beam 105 is described. The reference beam 105 split by the optical coupler 131 passes through a single-mode fiber 130-2, and is directed to a lens 135-1 and adjusted to be a collimated beam having the beam diameter of 2 mm. Next, the reference beam 105 is directed through the mirrors 114-2, 114-3, 114-4 and 114-5 to a mirror 114-1 which is a reference mirror. Next, the reference beam 105 is reflected by the mirror 114-1 and directed back to the optical coupler 131. A dispersion compensation glass 115 through which the reference beam 105 passed compensates the reference beam 105 for dispersion produced when the measuring beam 106 goes to and comes back from the eye 107 to be inspected. The dispersion compensation glass 115 has the length of L3, and in this embodiment, it is set to L3 = 40 mm. Further, an electrical stage 117-1 can move in the directions shown by the arrow, and adjust and control the light path length of the reference beam 105. Also, the electrical stage 117-1 is controlled by a personal computer 125. Also, the light path length of the reference beam 105 is approximately equal to the light path length of the measuring beam 106 described below. Therefore, the light path length of the reference beam 105 is longer, compared to the second exemplary embodiment.

[0038] Next, a light path of the measuring beam 106 is described. The measuring beam 106 split by the optical coupler 131 passes through the single-mode fiber 130-4, and is directed to a lens 135-4 and adjusted to be a collimated beam having the beam diameter of 2 mm. The measuring beam 106 is projected through a beam splitter 158-1 and the spherical mirrors 160-1 and 160-2 on the deformable mirror 159. Here, the deformable mirror 159 is a mirror device for correcting an aberration of the measuring beam 106 and the return beam 108 by changing the mirror form thereof as desired, based on an aberration detected by a wavefront sensor 155. Here the deformable mirror has been used as a device for correcting an aberration, but the device may be any device capable of correcting an aberration, and a spatial light modulator using liquid crystal, etc. may be also used. Next, the measuring beam 106 passes through the lenses 160-3, 160-4, 160-5 and 160-6 and is projected on a mirror of the XY scanner 119. In this embodiment, for the simplicity, the XY scanner 119 is illustrated as one mirror, but actually the XY scanner 119 has two mirrors, a mirror for X scanning and a mirror for Y scanning, disposed close to each other therein, and scans the retina 127 in the direction perpendicular to the optical axis in the raster scan mode. Also, the center of the measuring beam 106 is adjusted to coincide with the rotation center of the mirror of the XY scanner 119. The spherical mirrors 160-7, 160-8 and 160-9 form an optical system for scanning the retina 127, and play a role in scanning the retina 127 with the measuring beam 106 using the vicinity of the cornea 126 as a pupil of the optical system. An electrical stage 117-2 can move in the directions shown by the arrow, and adjust and control a position of the attached spherical mirror 160-8. By adjusting the position of the spherical mirror 160-8, the measuring beam 106 can be focused on a predetermined layer in the retina 127 in the eye 107 to be inspected, and thereby observation of it can be performed. Also, the case of the eye 107 to be inspected having a refractive error can be addressed. When the measuring beam 106 is projected in the eye 107 to be inspected, it is reflected or scattered by the retina 127 to form the return beam 108, which is directed by the optical coupler 131 again to arrive at the line camera 139. The electrical stage 117-2 can be controlled by the personal computer 125, which characterizes the present embodiment.

[0039] Also, a part of the return beam 108 split by the beam splitter 158-1 is projected on the wavefront sensor 155, and an aberration of the return beam 108 is measured. The wavefront sensor 155 is electrically connected to the personal computer 125. The obtained aberration is expressed by using the personal computer 125 in a Zernike polynomial, which shows an aberration contained in the eye 107 to be inspected. The obtained aberration is expressed in the Zernike polynomial, which characterizes the present embodiment. Further, a defocus component in the Zernike polynomial can be corrected by controlling the position of the spherical mirror 160-8 using the electrical stage 117-2. A component except the defocus component can be corrected by controlling the form of the surface of the deformable mirror 159, which characterizes the present embodiment. In this embodiment, the spherical mirrors 160-1, 160-2, 160-3, 160-4, 160-5, 160-6, 160-7, 160-8 and 160-9 are disposed so that the cornea 126, the XY scanner 119, the wavefront sensor 155 and the deformable mirror 159 become optically conjugate with each other, and thereby the wavefront sensor 155 can measure an aberration contained in the eye 107 to be inspected. Further, the position of the spherical mirror 160-8 is adjusted and controlled based on the obtained aberration, and the measuring beam 106 is kept focused on a predetermined layer in the retina 127, and then the form of the surface of the deformable mirror 159 is controlled. Thus, an aberration produced in the eye 107 to be inspected is corrected, and thereby a tomographic image can be provided with a higher lateral resolution.

[0040] The reference beam 105 and the return beam 108 described above are combined with each other by the optical coupler 131, and further the combined beam 142 is split with the ratio of 90:10. Then, the combined beam 142 is dispersed into its wavelength components by a transmission grating 141, which are condensed by a lens 135-3, and light intensities are converted into a voltage for each of positions (wavelengths) by the line camera 139. Specifically, an interference pattern in a spectral region in the wavelength axis will be observed on the line camera 139. The obtained group of voltage signals are converted into digital values by a frame grabber 140, which are data processed by the personal computer 125 to form a tomographic image. In this embodiment, the line camera 139 has 1024 pixels, and the intensities of the combined beam 142 can be provided for each of wavelengths (1024 division).

[0041] Next, a configuration of a measuring system in the OCT apparatus of the exemplary embodiment is described. The OCT apparatus 100 can provide a tomographic image (OCT image) formed of intensities of an interference signal generated by a Mickelson interference system. This measuring system is similar to the second exemplary embodiment, and a description thereof is omitted.

[0042] Next, there is given a description of a method which characterizes the present embodiment for acquiring a tomographic image using an OCT apparatus. The method for measuring the tomographic image is similar to the second exemplary embodiment, and a description thereof is omitted. However, here, the spherical mirror 160-8 instead of the lens 135-10 in the second exemplary embodiment is used to adjust the focus position of the measuring beam 106.

Other Embodiments

[0043] Aspects of the present invention can also be realized by a computer of a system or apparatus (or devices such as a CPU or MPU) that reads out and executes a program recorded on a memory device to perform the functions of the above-described embodiment(s), and by a method, the steps of which are performed by a computer of a system or apparatus by, for example, reading out and executing a program recorded on a memory device to perform the functions of the above-described embodiment(s). For this purpose, the program is provided to the computer for example via a network or from a recording medium of various types serving as the memory device (e.g., computer-readable medium).

[0044] While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

[0045] This application claims the benefit of Japanese Patent Application Nos. 2009-113818, filed May 8, 2009, and 2010-047052, filed on March 3, 2010, which is hereby incorporated by reference herein in its entirety.

Claims

1. An optical imaging apparatus (100) for acquiring a tomographic image of an object (107) using a device for detecting intensities of an interference signal generated from the interference of a combined beam in which a return beam (108) and a reference beam (105) are combined to interfere with each other, wherein the reference beam (105) is formed by splitting a beam from a light source into a measuring beam (106) and the reference beam (105), and the return beam (108) is formed of the measuring beam (106) irradiated to the object, the apparatus comprising:

an optical means for focusing the measuring beam on the object,
an aberration measuring means (155) for measuring an aberration of the return beam, and
a focus adjusting means for adjusting the optical means to adjust focus positions of the optical means at different depth positions based on the measured aberration,

characterized in that the apparatus further comprises:

an acquiring means for acquiring a plurality of tomographic images corresponding to the focus positions at different depth positions; and
a generating means for generating a planar tomographic image by compositing the plurality of tomographic images having a different focus position in a depth direction from each other.

2. The optical imaging apparatus according to claim further comprising: a recording device for recording at least any one of a defocus component and an astigmatic component in a Zernike polynomial into which the aberration is converted, wherein the focus adjusting means is a device for adjusting the optical device based on the component recorded in the recording device, and the focus adjusting device adjusts the optical device so that the measuring beam is focused on a predetermined region of the object.

3. The optical imaging apparatus according to claim 2, wherein the optical means includes a first spherical lens and the optical imaging cylindrical apparatus further includes a second cylindrical lens, and the focus adjusting means is adapted to adjust the first lens based on the defocus component and adjust the second lens based on the astigmatic component after the adjustment of the first lens.

4. The optical imaging apparatus according to claim 2 or 3, comprising:

an aberration correcting means (159) for correcting an aberration of at least any one of the measuring beam and the return beam, based on an aberration excluding at least any one of the defocus component and the astigmatic component, after the focus adjusting means has adjusted the optical means.

5. The optical imaging apparatus according to any one of claims 1 to 4 in which the object is an eye to be inspected, comprising:

a fixation target to which the eye to be inspected is fixed.

6. The optical imaging apparatus according to any one of claims 1 to 5, further comprising:

a means for splitting a beam from a light source into a measuring beam and a reference beam,
a means for combining a return beam formed of the measuring beam irradiated to the object and the reference beam traveling a reference light path to interfere with each other, and
a means for detecting intensities of an interference signal generated from the interference.

7. The optical imaging apparatus according to any one of claims 2 to 6, further comprising:

a cylindrical lens,

wherein the adjusting means is adapted to adjust the cylindrical lens based on the astigmatic component.

8. The optical imaging apparatus according to claim 1, wherein the optical means is a lens (120-2), and the focus adjusting means is configured to adjust the lens (120-2) to adjust focus positions of the lens (120-2) at different depth positions based on the measured aberration.

9. A method of acquiring a tomographic image of an object using a device for detecting intensities of an interference signal generated from the interference of a combined beam in which a return beam (108) and a reference beam (105) are combined to interfere with each other, wherein the reference beam (105) is formed by splitting a beam from a light source into a measuring beam (106) and the reference beam (105), and the return beam (108) is formed of the measuring beam (106) irradiated to the object, the method comprising:

measuring an aberration of the return beam; and
adjusting an optical means, to adjust focus positions of the optical means at different depth positions based on the measured aberration, wherein the optical means focuses the measuring beam on the object,

characterized by:

acquiring a plurality of tomographic images corresponding to the focus positions at different depth positions; and
generating a planar tomographic image by compositing the plurality of tomographic images having a different focus position in a depth direction from each other.

10. The method according to claim 9, wherein:

the adjustment of the optical means is based on at least any one of a defocus component and an astigmatic component in a Zernike polynomial that expresses the aberration,
, the component of the aberration expressed in the polynomial is recorded, and the focus adjusting device is adjusted based on the component of the recorded aberration.

11. The method according to claim 10, wherein:

the optical means includes a first spherical lens, and
the adjustment of the first lens is based on the defocus component, the method further comprising adjusting a second cylindrical lens based on the astigmatic component after the adjustment of the first lens.

12. The method according to claim 10, comprising:

after adjusting the optical means,
correcting the aberration of one of the measuring beam and the return beam, based on one of the defocus component and the astigmatic component.

13. The method according to any one of claims 9 to 12, comprising:

adjusting a position of the optical means in a direction of an optical axis, and
acquiring one of the plurality of tomographic images at the position.

14. The method according to claim 9, wherein the optical means is a lens (120-2), and the lens (120-2) is adjusted to adjust focus positions of the lens (120-2) at different depth positions based on the measured aberration.

15. A program for an optical imaging apparatus for acquiring a tomographic image of an object based on a combined beam in which a return beam (108) and a reference beam (105) are combined to interfere with each other, wherein the reference beam (105) is formed by splitting a beam from a light source into a measuring beam (106) and the reference beam (105), and the return beam (108) is formed of the measuring beam (106) irradiated to the object, the apparatus comprising an optical means for focusing the measuring beam on the object, and an aberration measuring means for measuring an aberration of the return beam, wherein the program carries out the steps of the method of any one of claims 9 to 14 when the program is run on a computer of said optical imaging apparatus.

Patentansprüche

1. Optische Bildgebungsvorrichtung (100) zum Beschaffen eines Tomografiebildes eines Objekts (107) unter Verwendung einer Einrichtung zur Erfassung von Intensitäten eines Interferenzsignals, das aus der Interferenz eines kombinierten Strahls erzeugt wird, bei dem ein Rückstrahl (108) und ein Referenzstrahl (105) zum Interferieren miteinander kombiniert sind, wobei der Referenzstrahl (105) durch Teilen eines Strahls von einer Lichtquelle in einen Messstrahl (106) und den Referenzstrahl (105) gebildet wird, und der Rückstrahl (108) aus dem Messstrahl (106) erzeugt wird, der das Objekt bestrahlt, mit
einer optischen Einrichtung zum Fokussieren des Messstrahls auf das Objekt,
einer Aberrationsmesseinrichtung (155) zum Messen einer Aberration des Rückstrahls und
einer Brennpunktanpassungseinrichtung zum An-

passen der optischen Einrichtung zum Anpassen von Brennpunktpositionen der optischen Einrichtung an verschiedenen Tiefenpositionen beruhend auf der gemessenen Aberration,
dadurch gekennzeichnet, dass die Vorrichtung ferner umfasst
eine Beschaffungseinrichtung zur Beschaffung einer Vielzahl von Tomografiebildern, die den Brennpunktpositionen an verschiedenen Tiefenpositionen entsprechen, und
eine Erzeugungseinrichtung zur Erzeugung eines planaren Tomografiebildes durch Zusammensetzen der Vielzahl der Tomografiebilder, die jeweils eine andere Brennpunktposition in einer Tiefenrichtung aufweisen.

2. Optische Bildgebungsvorrichtung nach Anspruch 1, ferner mit
einer Aufzeichnungseinrichtung zur Aufzeichnung einer Defokussierkomponente und/oder einer astigmatischen Komponente in einem Zernike-Polynom, in die die Aberration umgewandelt wird, wobei die Brennpunktanpassungseinrichtung eine Einrichtung zur Anpassung der optischen Einrichtung beruhend auf der in der Aufzeichnungseinrichtung aufgezeichneten Komponente ist, und die Brennpunktanpassungseinrichtung die optische Einrichtung derart anpasst, dass der Messstrahl auf eine vorbestimmte Region des Objekts fokussiert ist.

3. Optische Bildgebungsvorrichtung nach Anspruch 2, wobei

die optische Einrichtung eine erste sphärische Linse enthält, und die optische Bildgebungsvorrichtung ferner eine zweite zylindrische Linse enthält, und
die Brennpunktanpassungseinrichtung zur Anpassung der ersten Linse beruhend auf der Defokussierkomponente und zur Anpassung der zweiten Linse beruhend auf der astigmatischen Komponente nach der Anpassung der ersten Linse eingerichtet ist.

4. Optische Bildgebungsvorrichtung nach Anspruch 2 oder 3, mit
einer Aberrationskorrektureinrichtung (159) zur Korrektur einer Aberration des Messstrahls und/oder des Rückstrahls beruhend auf einer Aberration, die die Defokussierkomponente und/oder die astigmatische Komponente ausschließt, nachdem die Brennpunktanpassungseinrichtung die optische Einrichtung angepasst hat.

5. Optische Bildgebungsvorrichtung nach einem der Ansprüche 1 bis 4, wobei das Objekt ein zu untersuchendes Auge ist, mit
einem Fixiertarget, an dem das zu untersuchende Auge fixiert wird.

6. Optische Bildgebungsvorrichtung nach einem der Ansprüche 1 bis 5, ferner mit

einer Einrichtung zum Teilen eines Strahls von einer Lichtquelle in einen Messstrahl und einen Referenzstrahl,
einer Einrichtung zum Kombinieren eines Rückstrahls, der aus dem Messstrahl, der das Objekt bestrahlt, und dem Referenzstrahl erzeugt wird, der auf einem Referenzstrahlengang läuft, sodass sie miteinander interferieren, und
einer Einrichtung zur Erfassung von Intensitäten eines aus der Interferenz erzeugten Interferenzsignals.

7. Optische Bildgebungsvorrichtung nach einem der Ansprüche 2 bis 6, ferner mit

einer zylindrischen Linse,

wobei die Anpassungseinrichtung zur Anpassung der zylindrischen Linse beruhend auf der astigmatischen Komponente eingerichtet ist.

8. Optische Bildgebungsvorrichtung nach Anspruch 1, wobei die optische Einrichtung eine Linse (120-2) ist, und die Brennpunktanpassungseinrichtung zur Anpassung der Linse (120-2) zur Anpassung von Brennpunktpositionen der Linse (120-2) an verschiedenen Tiefenpositionen beruhend auf der gemessenen Aberration eingerichtet ist.

9. Verfahren zur Beschaffung eines Tomografiebildes eines Objekts unter Verwendung einer Einrichtung zur Erfassung von Intensitäten eines aus der Interferenz eines kombinierten Strahls erzeugten Interferenzsignals, in dem ein Rückstrahl (108) und ein Referenzstrahl (105) zum miteinander Interferieren kombiniert werden, wobei der Referenzstrahl (105) durch Teilen eines Strahls von einer Lichtquelle in einen Messstrahl (106) und den Referenzstrahl (105) erzeugt wird, und der Rückstrahl (108) aus dem Messstrahl (106) erzeugt wird, der das Objekt bestrahlt, mit

Messen einer Aberration des Rückstrahls und
Anpassen einer optischen Einrichtung zur Anpassung von Brennpunktpositionen der optischen Einrichtung an verschiedenen Tiefenpositionen beruhend auf der gemessenen Aberration, wobei die optische Einrichtung den Messstrahl auf das Objekt fokussiert,
gekennzeichnet durch
Beschaffen einer Vielzahl von Tomografiebildern, die den Brennpunktpositionen an verschiedenen Tiefenpositionen entsprechen, und

Erzeugen eines planaren Tomografiebildes **durch** Zusammensetzen der Vielzahl der Tomografiebilder, die jeweils eine andere Brennpunktposition in einer Tiefenrichtung aufweisen.

10. Verfahren nach Anspruch 9, wobei
die Anpassung der optischen Einrichtung auf einer Defokussierkomponente und/oder einer astigmatischen Komponente in einem Zernike-Polynom beruht, das die Aberration ausdrückt, die Komponente der in dem Polynom ausgedrückten Aberration aufgezeichnet wird, und die Brennpunktanpassungseinrichtung beruhend auf der Komponente der aufgezeichneten Aberration angepasst wird.

11. Verfahren nach Anspruch 10, wobei

die optische Einrichtung eine erste sphärische Linse enthält, und
die Anpassung der ersten Linse auf der Defokussierkomponente beruht, wobei das Verfahren ferner umfasst
Anpassen einer zweiten zylindrischen Linse beruhend auf der astigmatischen Komponente nach Anpassung der ersten Linse.

12. Verfahren nach Anspruch 10, mit

nach Anpassen der optischen Einrichtung,
Korrigieren der Aberration des Messstrahls oder des Rückstrahls beruhend auf der Defokussierkomponente oder der astigmatische Komponente.

13. Verfahren einem der Ansprüche 9 bis 12, mit

Anpassen einer Position der optischen Einrichtung in einer Richtung einer optischen Achse, und
Beschaffen eines der Vielzahl der Tomografiebilder an der Position.

14. Verfahren nach Anspruch 9, wobei die optische Einrichtung eine Linse (120-2) ist, und die Linse (120-2) zur Anpassung von Brennpunktpositionen der Linse (120-2) an verschiedenen Tiefenpositionen beruhend auf der gemessenen Aberration angepasst wird.

15. Programm für eine optische Bildgebungsvorrichtung zur Beschaffung eines Tomografiebildes eines Objekts beruhend auf einem kombinierten Strahl, in dem ein Rückstrahl (108) und ein Referenzstrahl (104) zum miteinander Interferieren kombiniert sind, wobei der Referenzstrahl (105) durch Teilen eines Strahls von einer Lichtquelle in einen Messstrahl (106) und den Referenzstrahl (105) erzeugt wird, und der Rückstrahl (108) aus dem der Messstrahl (106) erzeugt wird, der das Objekt bestrahlt, wobei die Vorrichtung eine optische Einrichtung zum Fokussieren des Messstrahls auf das Objekt und eine Aberrationsmesseinrichtung zum Messen einer Aberration des Rückstrahls umfasst, wobei das Programm die Schritte des Verfahrens nach einem der Ansprüche 9 bis 14 ausführt, wenn das Programm auf einem Computer der optischen Bildgebungsvorrichtung läuft.

Revendications

1. Appareil d'imagerie optique (100) pour l'acquisition d'une image tomographique d'un objet (107) utilisant un dispositif permettant de détecter les intensités d'un signal d'interférence généré à partir de l'interférence d'un faisceau combiné dans lequel un faisceau de retour (108) et un faisceau de référence (105) sont combinés pour interférer l'un avec l'autre, dans lequel le faisceau de référence (105) est formé en divisant un faisceau provenant d'une source lumineuse en un faisceau de mesure (106) et le faisceau de référence (105), et le faisceau de retour (108) est constitué du faisceau de mesure (106) irradié vers l'objet, l'appareil comprenant :

un moyen optique permettant de focaliser le faisceau de mesure sur l'objet,
un moyen de mesure d'aberration (155) permettant de mesurer une aberration du faisceau de retour, et
un moyen d'ajustement de focalisation permettant d'ajuster le moyen optique afin d'ajuster les positions de focalisation du moyen optique à différentes positions de profondeur sur la base de l'aberration mesurée,

l'appareil étant **caractérisé en ce qu'**il comprend en outre :

un moyen d'acquisition permettant d'acquérir une pluralité d'images tomographiques correspondant aux positions de focalisation à différentes positions de profondeur ; et
un moyen de génération permettant de générer une image tomographique planaire en combinant la pluralité d'images tomographiques ayant une position de focalisation dans une direction de profondeur différente l'une de l'autre.

2. Appareil d'imagerie optique selon la revendication 1, comprenant en outre :

un dispositif d'enregistrement permettant d'enregistrer au moins l'une quelconque d'une composante de défocalisation et d'une composante d'astigmatisme dans un polynôme de Zernike en lequel l'aberration est convertie, le moyen d'ajustement de focalisation étant un dispositif permettant d'ajuster le dispositif optique sur la base de la composante enregistrée dans le dispositif d'enregistrement, et le dispositif d'ajustement de focalisation ajustant le dispositif optique de sorte que le faisceau de mesure soit focalisé sur une région prédéterminée de l'objet.

3. Appareil d'imagerie optique selon la revendication 2, dans lequel :

le moyen optique comprend une première lentille sphérique et l'appareil d'imagerie optique comprend en outre une seconde lentille cylindrique, et
le moyen d'ajustement de focalisation est adapté pour ajuster la première lentille sur la base de la composante de défocalisation et ajuster la seconde lentille sur la base de la composante d'astigmatisme après l'ajustement de la première lentille.

4. Appareil d'imagerie optique selon la revendication 2 ou 3, comprenant :

un moyen de correction d'aberration (159) permettant de corriger une aberration d'au moins l'un quelconque du faisceau de mesure et du faisceau de retour, sur la base d'une aberration excluant au moins l'une quelconque de la composante de défocalisation et de la composante d'astigmatisme, après que le moyen d'ajustement de focalisation a ajusté le moyen optique.

5. Appareil d'imagerie optique selon l'une quelconque des revendications 1 à 4, dans lequel l'objet est un oeil à examiner, comprenant :

une cible de fixation à laquelle l'oeil à examiner est fixé.

6. Appareil d'imagerie optique selon l'une quelconque des revendications 1 à 5, comprenant en outre :

un moyen permettant de diviser un faisceau provenant d'une source lumineuse en un faisceau de mesure et un faisceau de référence,
un moyen permettant de combiner un faisceau de retour constitué du faisceau de mesure irradié vers l'objet et le faisceau de référence effectuant un trajet lumineux de référence de façon à interférer l'un avec l'autre, et
un moyen permettant de détecter les intensités d'un signal d'interférence généré à partir de l'interférence.

7. Appareil d'imagerie optique selon l'une quelconque des revendications 2 à 6, comprenant en outre :

une lentille cylindrique,

dans lequel le moyen d'ajustement est adapté pour ajuster la lentille cylindrique sur la base de la composante d'astigmatisme.

8. Appareil d'imagerie optique selon la revendication 1, dans lequel le moyen optique est une lentille (120-2), et le moyen d'ajustement de focalisation est configuré pour ajuster la lentille (120-2) afin d'ajuster les positions de focalisation de la lentille (120-2) à différentes positions de profondeur sur la base de l'aberration mesurée.

9. Procédé d'acquisition d'une image tomographique d'un objet utilisant un dispositif permettant de détecter les intensités d'un signal d'interférence généré à partir de l'interférence d'un faisceau combiné dans lequel un faisceau de retour (108) et un faisceau de référence (105) sont combinés pour interférer l'un avec l'autre, dans lequel le faisceau de référence (105) est formé en divisant un faisceau provenant d'une source lumineuse en un faisceau de mesure (106) et le faisceau de référence (105), et le faisceau de retour (108) est constitué du faisceau de mesure (106) irradié vers l'objet, le procédé comprenant :

la mesure d'une aberration du faisceau de retour ; et
l'ajustement d'un moyen optique, afin d'ajuster les positions de focalisation du moyen optique à différentes positions de profondeur sur la base de l'aberration mesurée, le moyen optique focalisant le faisceau de mesure sur l'objet,

caractérisé par :

l'acquisition d'une pluralité d'images tomographiques correspondant aux positions de focalisation à différentes positions de profondeur ; et
la génération d'une image tomographique planaire en combinant la pluralité d'images tomographiques ayant une position de focalisation dans une direction de profondeur différente l'une de l'autre.

10. Procédé selon la revendication 9, dans lequel :

l'ajustement du moyen optique est basé sur au moins l'une quelconque d'une composante de défocalisation et d'une composante d'astigmatisme dans un polynôme de Zernike qui exprime l'aberration, la composante de l'aberration exprimée dans le polynôme est enregistrée, et le dispositif d'ajustement de focalisation est ajusté sur la base de la composante de l'aberration enregistrée.

11. Procédé selon la revendication 10, dans lequel :

le moyen optique comprend une première lentille sphérique, et
l'ajustement de la première lentille est basé sur la composante de défocalisation,

le procédé comprenant en outre :

l'ajustement d'une seconde lentille cylindrique sur la base de la composante d'astigmatisme après l'ajustement de la première lentille.

12. Procédé selon la revendication 10, comprenant :

après l'ajustement du moyen optique,
la correction de l'aberration de l'un du faisceau de mesure et du faisceau de retour, sur la base de l'une de la composante de défocalisation et de la composante d'astigmatisme.

13. Procédé selon l'une quelconque des revendications 9 à 12, comprenant :

l'ajustement d'une position du moyen optique dans une direction d'un axe optique, et
l'acquisition d'une de la pluralité d'images tomographiques à cette position.

14. Procédé selon la revendication 9, dans lequel le moyen optique est une lentille (120-2), et la lentille (120-2) est ajustée afin d'ajuster les positions de focalisation de la lentille (120-2) à différentes positions de profondeur sur la base de l'aberration mesurée.

15. Programme destiné à un appareil d'imagerie optique pour l'acquisition d'une image tomographique d'un objet sur la base d'un faisceau combiné dans lequel un faisceau de retour (108) et un faisceau de référence (105) sont combinés pour interférer l'un avec l'autre, dans lequel le faisceau de référence (105) est formé en divisant un faisceau provenant d'une source lumineuse en un faisceau de mesure (106) et le faisceau de référence (105), et le faisceau de retour (108) est constitué du faisceau de mesure (106) irradié vers l'objet, l'appareil comprenant un moyen optique permettant de focaliser le faisceau de mesure sur l'objet, et un moyen de mesure d'aberration permettant de mesurer une aberration du faisceau de retour, le programme réalisant les étapes du procédé selon l'une quelconque des revendications 9 à 14 lorsque le programme est exécuté sur un ordinateur dudit appareil d'imagerie optique.

FIG. 1

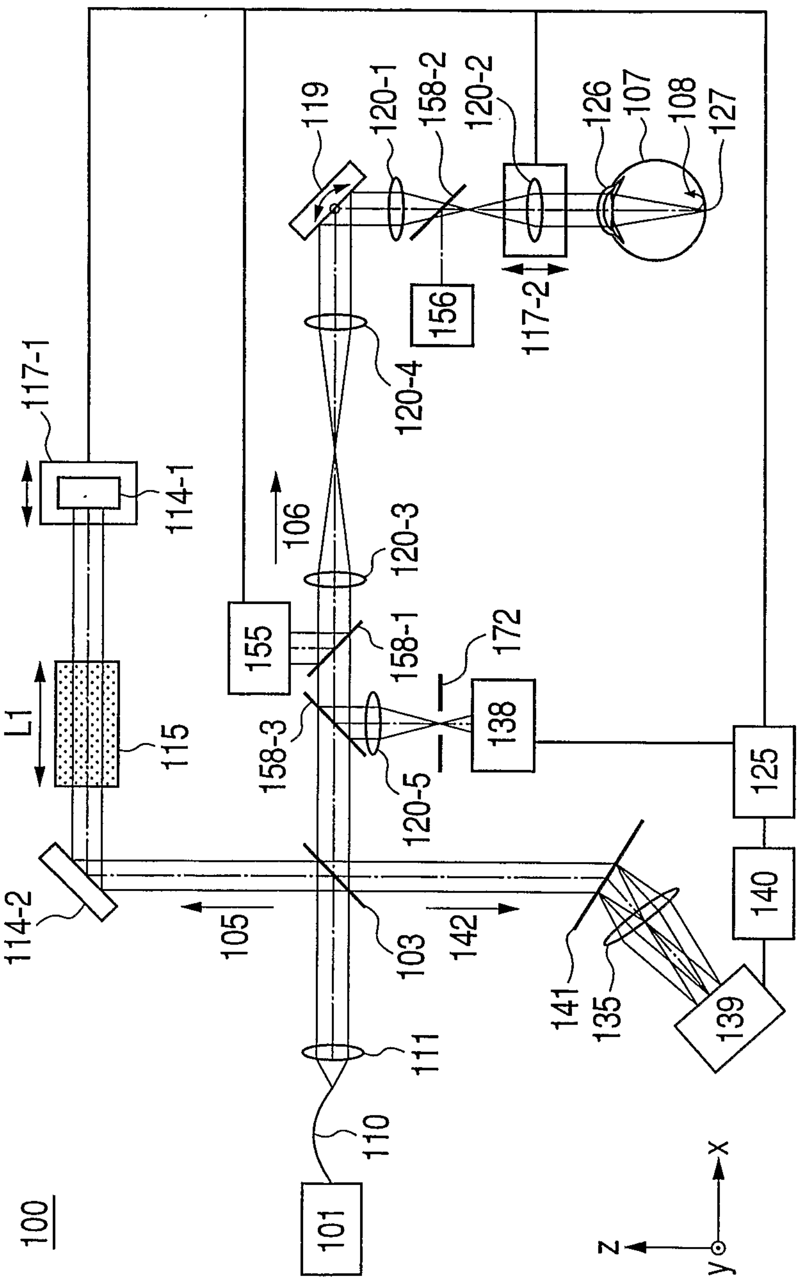
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FIG. 2A

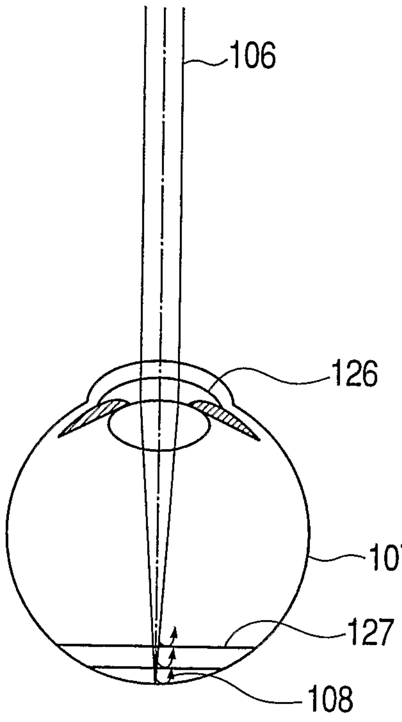

FIG. 2B

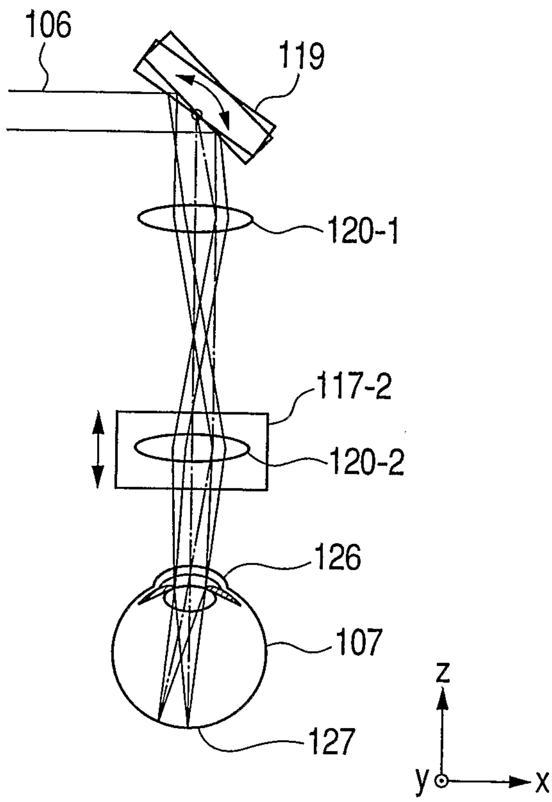

FIG. 2C

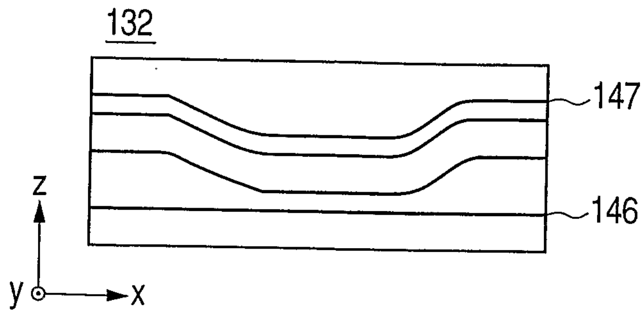

FIG. 3A

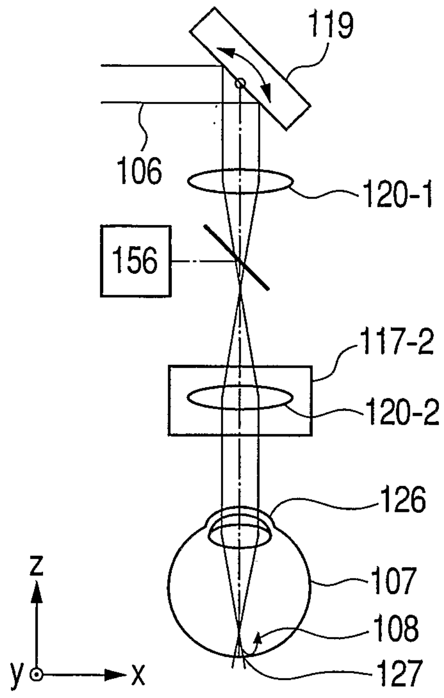

FIG. 3B

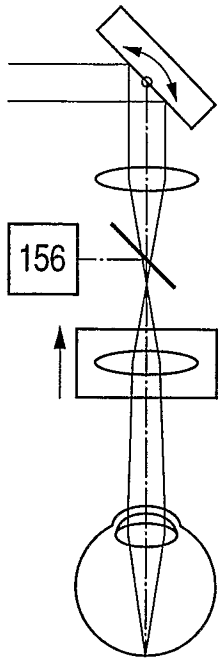

FIG. 3C

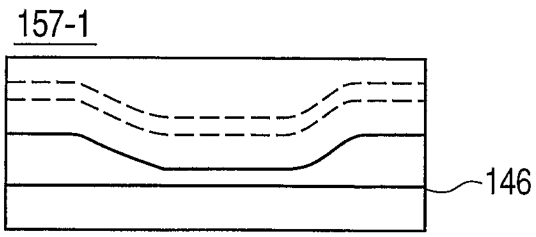

FIG. 3D

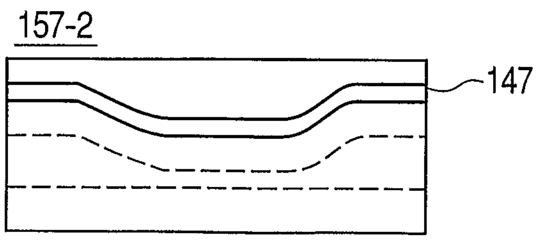

FIG. 3E

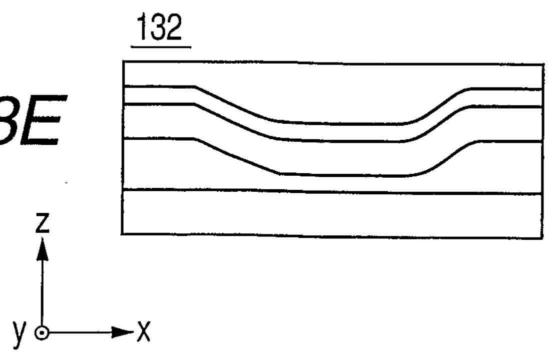

FIG. 4

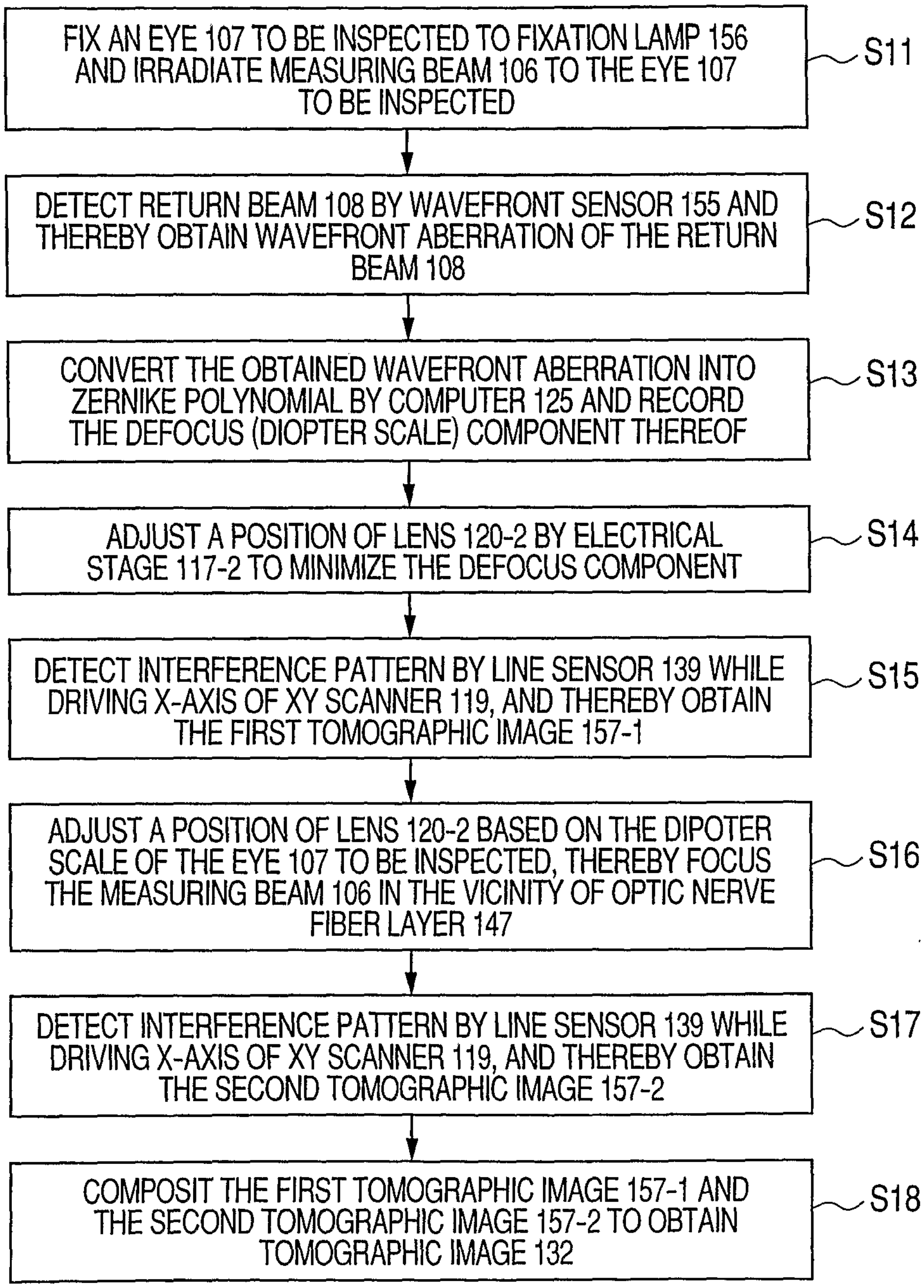
FIX AN EYE 107 TO BE INSPECTED TO FIXATION LAMP 156 AND IRRADIATE MEASURING BEAM 106 TO THE EYE 107 TO BE INSPECTED
S11
DETECT RETURN BEAM 108 BY WAVEFRONT SENSOR 155 AND THEREBY OBTAIN WAVEFRONT ABERRATION OF THE RETURN BEAM 108
S12
CONVERT THE OBTAINED WAVEFRONT ABERRATION INTO ZERNIKE POLYNOMIAL BY COMPUTER 125 AND RECORD THE DEFOCUS (DIOPTER SCALE) COMPONENT THEREOF
S13
ADJUST A POSITION OF LENS 120-2 BY ELECTRICAL STAGE 117-2 TO MINIMIZE THE DEFOCUS COMPONENT
S14
DETECT INTERFERENCE PATTERN BY LINE SENSOR 139 WHILE DRIVING X-AXIS OF XY SCANNER 119, AND THEREBY OBTAIN THE FIRST TOMOGRAPHIC IMAGE 157-1
S15
ADJUST A POSITION OF LENS 120-2 BASED ON THE DIPOTER SCALE OF THE EYE 107 TO BE INSPECTED, THEREBY FOCUS THE MEASURING BEAM 106 IN THE VICINITY OF OPTIC NERVE FIBER LAYER 147
S16
DETECT INTERFERENCE PATTERN BY LINE SENSOR 139 WHILE DRIVING X-AXIS OF XY SCANNER 119, AND THEREBY OBTAIN THE SECOND TOMOGRAPHIC IMAGE 157-2
S17
COMPOSIT THE FIRST TOMOGRAPHIC IMAGE 157-1 AND THE SECOND TOMOGRAPHIC IMAGE 157-2 TO OBTAIN TOMOGRAPHIC IMAGE 132
S18

FIG. 5

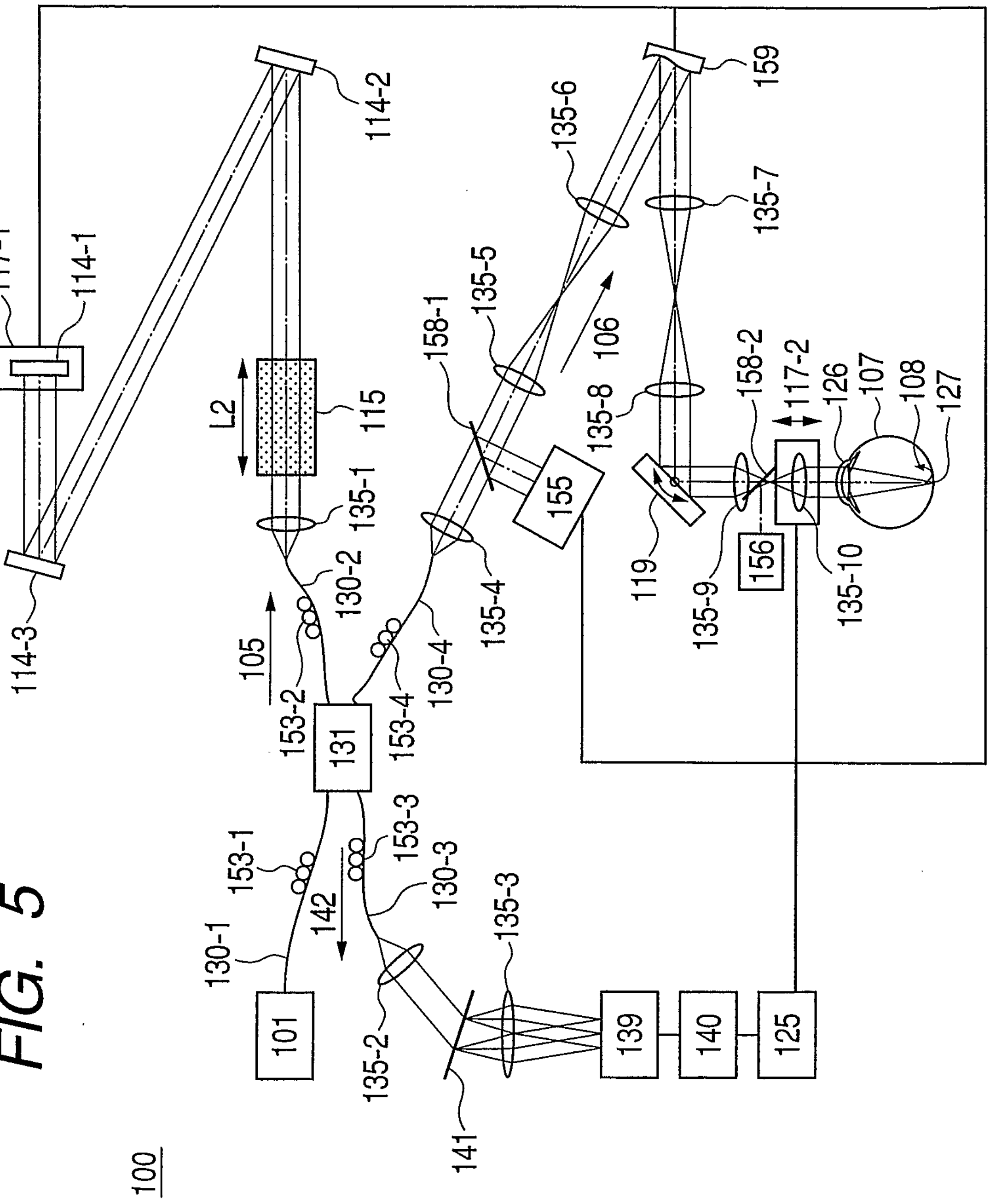
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FIG. 6A

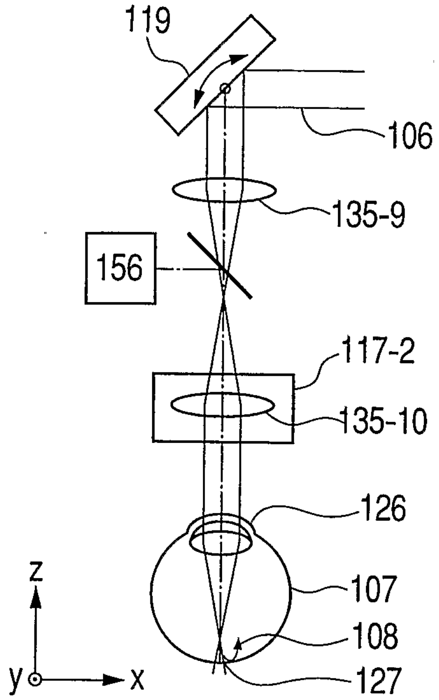


FIG. 6B

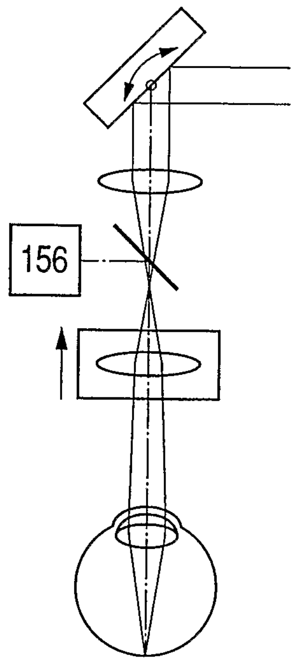


FIG. 6C

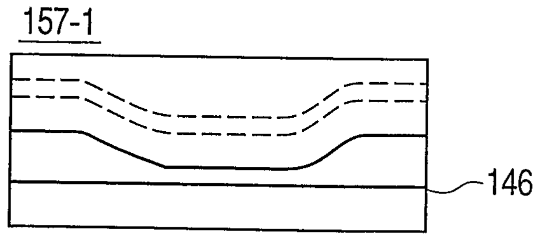


FIG. 6D

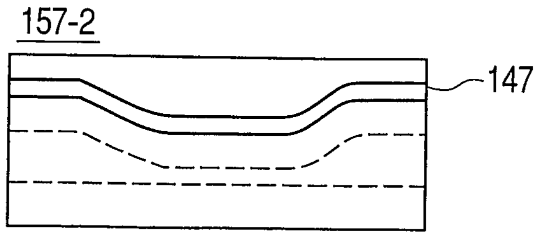


FIG. 6E

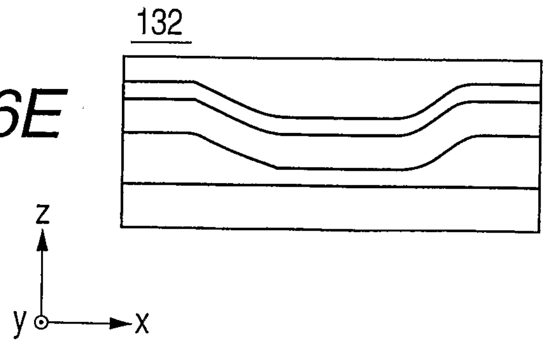
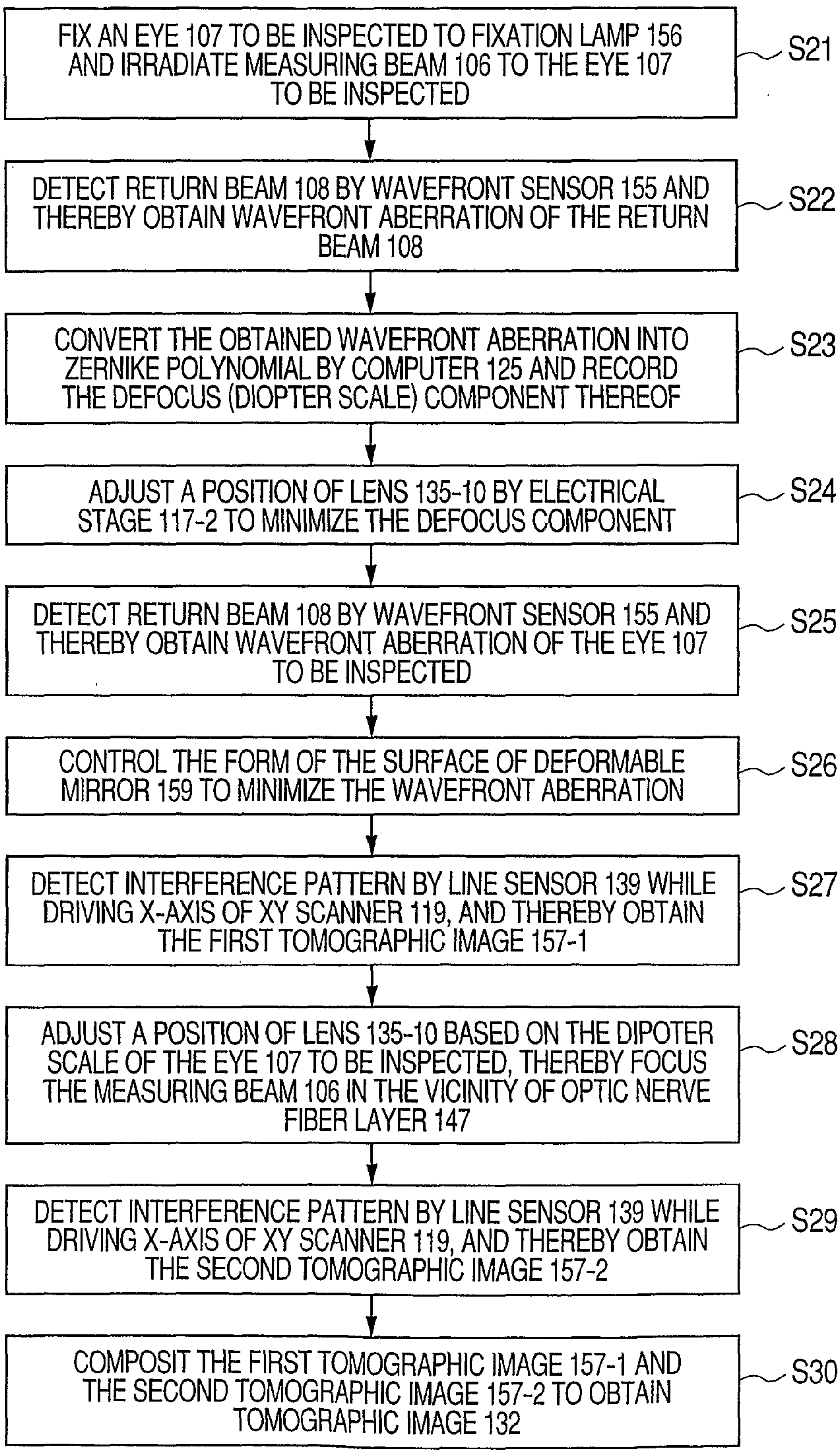


FIG. 7


FIX AN EYE 107 TO BE INSPECTED TO FIXATION LAMP 156 AND IRRADIATE MEASURING BEAM 106 TO THE EYE 107 TO BE INSPECTED
S21
DETECT RETURN BEAM 108 BY WAVEFRONT SENSOR 155 AND THEREBY OBTAIN WAVEFRONT ABERRATION OF THE RETURN BEAM 108
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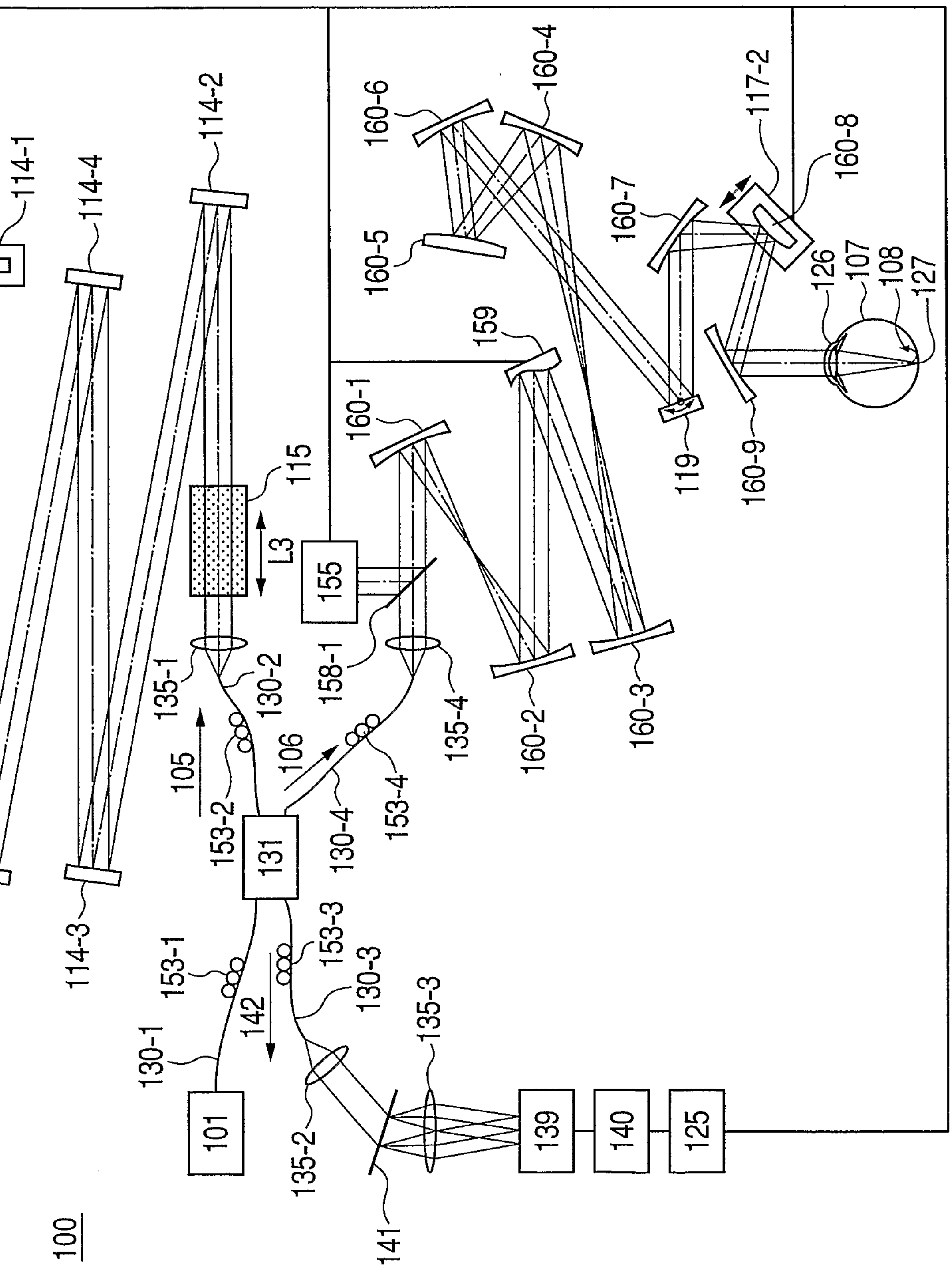
S23
ADJUST A POSITION OF LENS 135-10 BY ELECTRICAL STAGE 117-2 TO MINIMIZE THE DEFOCUS COMPONENT
S24
DETECT RETURN BEAM 108 BY WAVEFRONT SENSOR 155 AND THEREBY OBTAIN WAVEFRONT ABERRATION OF THE EYE 107 TO BE INSPECTED
S25
CONTROL THE FORM OF THE SURFACE OF DEFORMABLE MIRROR 159 TO MINIMIZE THE WAVEFRONT ABERRATION
S26
DETECT INTERFERENCE PATTERN BY LINE SENSOR 139 WHILE DRIVING X-AXIS OF XY SCANNER 119, AND THEREBY OBTAIN THE FIRST TOMOGRAPHIC IMAGE 157-1
S27
ADJUST A POSITION OF LENS 135-10 BASED ON THE DIPOTER SCALE OF THE EYE 107 TO BE INSPECTED, THEREBY FOCUS THE MEASURING BEAM 106 IN THE VICINITY OF OPTIC NERVE FIBER LAYER 147
S28
DETECT INTERFERENCE PATTERN BY LINE SENSOR 139 WHILE DRIVING X-AXIS OF XY SCANNER 119, AND THEREBY OBTAIN THE SECOND TOMOGRAPHIC IMAGE 157-2
S29
COMPOSIT THE FIRST TOMOGRAPHIC IMAGE 157-1 AND THE SECOND TOMOGRAPHIC IMAGE 157-2 TO OBTAIN TOMOGRAPHIC IMAGE 132
S30

FIG. 8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REFERENCES CITED IN THE DESCRIPTION

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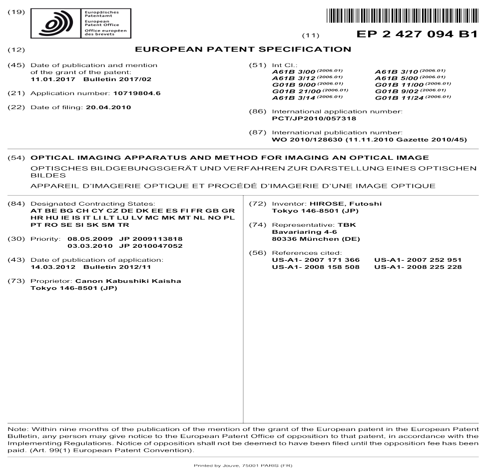
patsnap

专利名称(译)	光学成像设备和用于对光学图像成像的方法		
公开(公告)号	EP2427094B1	公开(公告)日	2017-01-11
申请号	EP2010719804	申请日	2010-04-20
[标]申请(专利权)人(译)	佳能株式会社		
申请(专利权)人(译)	佳能株式会社		
当前申请(专利权)人(译)	佳能株式会社		
[标]发明人	HIROSE FUTOSHI		
发明人	HIROSE, FUTOSHI		
IPC分类号	A61B3/00 A61B3/10 A61B3/12 A61B5/00 G01B9/00 G01B11/00 G01B21/00 G01B9/02 A61B3/14 G01B11/24		
CPC分类号	G01B9/02063 A61B3/14 G01B9/0203 G01B9/02044 G01B9/02058 G01B9/02068 G01B9/02083 G01B9/02091 G01B11/2441		
代理机构(译)	TBK		
优先权	2010047052 2010-03-03 JP 2009113818 2009-05-08 JP		
其他公开文献	EP2427094A1		
外部链接	Espacenet		

摘要(译)

本发明提供一种光学成像装置，其能够在宽区域内提供高横向分辨率，并且在成像之前容易地调整以对作为对象的被检眼的光学图像进行成像，以及用于对光学图像进行成像的方法。将来自光源的光束用作测量光束，并且基于由照射到物体的测量光束形成的返回光束的强度对物体的图像进行成像的光学成像设备具有以下特征：用于将测量光束聚焦在物体上的光学装置;接下来，用于测量返回光束的像差的像差检测装置;和焦点调节装置，用于根据像差检测装置检测到的像差调节光学装置。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(54) OPTICAL IMAGING APPARATUS AND METHOD FOR IMAGING AN OPTICAL IMAGE

OPTISCHES BILDGEBUNGSGERÄT UND VERFAHREN ZUR DARSTELLUNG EINES OPTISCHEN BILDES

APPAREIL D'IMAGERIE OPTIQUE ET PROCÉDÉ D'IMAGERIE D'UNE IMAGE OPTIQUE

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(56) References cited: US-A1- 2007 171 366, US-A1- 2007 252 951, US-A1- 2008 158 508, US-A1- 2008 225 228

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