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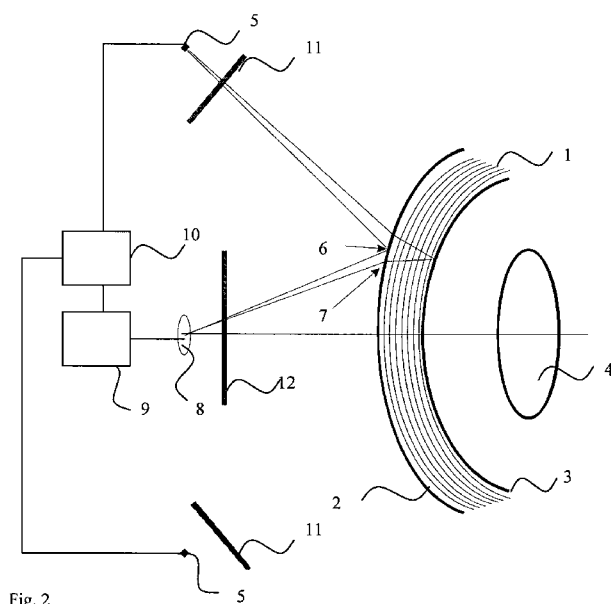
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[Continued on next page]

(54) Title: METHOD AND ARRANGEMENT FOR DETERMINING CORNEAL RADII



(57) Abstract: The invention relates to a method and arrangements for determining the posterior radius of a cornea. In this case, a pattern of known geometry is projected onto the cornea and the light reflected by the anterior side of the cornea and posterior side of the cornea is analysed.

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METHOD AND ARRANGEMENT FOR DETERMINING CORNEAL RADII

[0001] The invention relates to a method and an arrangement for optically determining the internal radius of a cornea (posterior cornea radius).

[0002] The cornea contributes about 40 % of the total refractive power of the optical apparatus of the eye. Thus, its influence must be taken into account in particular when optimally determining intraocular lenses for the treatment of cataracts, but knowledge of the geometry of the cornea is required also for planning a refractive correction of the cornea.

[0003] The anterior side of the cornea is relatively easy to access for the purposes of measurement, and thus it is also possible to determine the external radius of a cornea by means which are known as keratometers. The measuring principle is based on projecting a known pattern of light beams onto the central region of the cornea and recording and geometrically evaluating the image reflected by the curved surface using an image receiver arranged on the optical axis of the eye.

[0004] An extension of the principle is realized in Topographers which can measure the shape of whole corneas by means of a placido disc, consisting of clearly delimited concentric rings, onto the cornea. It is possible to conclude the curvature and thus the radius of the cornea from the shape of the image of the reflected rings. Solutions of this type are disclosed for example in US 6 692 126, US 6 575 573 and US 7 246 905. DD 251 497 discloses that, instead of the imaging of rings, discrete points can also be imaged onto the cornea and the curvature of these points can be determined from the evaluation of the geometric locations of the reflections thereof. In US 5 886 767 a pattern consisting of points is projected onto the cornea by a projector arranged on the optical axis of the eye and the resulting scatter image is recorded using two cameras arranged at an angle to the axis of the eye and stereoscopically evaluated.

[0005] Furthermore, solutions have been described as to how corneal thickness on the axis of the eye can be determined. As early as in 1975 D. G. Green et al. proposed in "Corneal thickness measured by interferometry", Journal of the Optical Society of America, col. 65, February 1975, p. 119 carrying out the measurement of corneal thickness by interferometry. For this purpose, the light of a laser is directed onto the centre of the cornea in such a way

that incident light and reflected light form an angle of 90°. The light reflected on the posterior side and anterior side of the cornea interferes, the resulting interference rings are evaluated to determine corneal thickness on the axis of the eye. In "Measurement of corneal thickness by low-coherence interferometry", Ch. K. Hitzenberger, Applied Optics Vol. 31, 1992, p. 6637, laser Doppler interferometry is used to measure central corneal thickness. M. Boehnke et al. ("Real-time pachymetry during photo-refractive keratectomy using optical low-coherence reflectometry", J. Biomedical Optics Vol. 6, 2001, p. 412) describe the measurement of central corneal thickness during a refractive laser treatment by means of optical low-coherence reflectometry. Optical coherence tomography (OCT) has also been used to determine central corneal thickness (J. Wang at al., "Noncontact measurement of central corneal epithelial and flap thickness after laser in situ keratomileusis", Investigative Ophthalmology & Visual Science, Vol. 45, 2004, p. 1812). US 7 154 111 describes determining central corneal thickness using a detector operating in accordance with the confocal principle. US 7 133 137 specifies an arrangement in which the respective interference of light of three wavelengths is used as the starting point for determining central corneal thickness.

[0006] These methods cannot be used to determine the internal radius of the cornea and Scheimpflug- or Purkinje-Imaging are used instead. In order to obtain information about the shape of the cornea, the slit lamp has been known as a standard apparatus since the start of the 20th century. In this case, a slit is used to generate through the eye a light section which is observed laterally. The cornea is also imaged in this light section. Developments of the slit lamp include what are known as Scheimpflug cameras such as described for example in DE 299 13 601 U1, DE 299 13 602 U1, DE 299 13 603 U1 and US 7 264 335. In principle, information about the curvature of the cornea can be obtained by evaluating the sectional images recorded. Nevertheless, this would necessitate lateral sectional images having extremely high spatial resolutions, as the changes in axial position resulting from the curvatures are marginal.

[0007] Therefore, the known OrbScan apparatus (Orbtex, Bausch & Lomb, Rochester) combines a topographer with a Placido disc and a slit lamp.

[0008] It is also known to combine a topographer with an OCT system (for example US 7 246 905 or WO 2005/077256). In this case, the OCT is used to obtain a sectional image of the anterior portion of the eye, from which information about the corneal thickness and, if the curvature of the anterior surface of the cornea is known, in principle also about the internal radius can be derived. However, an apparatus of this type is very complex, and in this case too the requirements placed on spatial resolution are immense in order to be able to measure utilisable changes in curvature.

[0009] The object of the invention is to eliminate the drawbacks of the prior art and provide a simple and precise method for determining the internal radius of a cornea.

[0010] According to the invention, this object is achieved by a method for determining the internal radius of a cornea, in which at least one pattern of known geometry is projected onto the cornea and the light respectively reflected by the posterior side of the cornea and the anterior side of the cornea is analysed.

[0011] An advantageous configuration of the invention is obtained if the light reflected by the anterior side of the cornea and the posterior side of the cornea is brought to interference and the resulting interference pattern is evaluated.

[0012] Another advantageous solution consists in geometrically evaluating the light reflected by the anterior side of the cornea and the posterior side of the cornea. In this case, according to the invention, this geometric evaluation can be carried out by adapting the intensities of the anterior side reflections and posterior side reflections using polarisation optical means. Another advantageous solution is obtained if these reflections are recorded by an image recording unit having a high dynamic range.

[0013] A first arrangement according to the invention for carrying out the method for determining the internal radius of a cornea consists of a light source having a coherence length of greater than 2 mm, preferably in the range of from 2 to 6 mm, a unit for generating a pattern of known geometry, an imaging optical system which images the test pattern onto the cornea, a recording optical system, an image recording unit and an image evaluation unit. In this case, it is advantageous if the image evaluation unit is configured for analysis of the light reflected by the anterior side of the cornea and for the analysis of the interference

pattern resulting from interference of the light reflected by the anterior side and the posterior side.

[0014] A second arrangement according to the invention for carrying out the method for determining the internal radius of a cornea consists of at least one light source, a unit for generating a pattern of known geometry, at least one imaging optical system which images the test pattern onto the cornea, a recording optical system, an image recording unit and an image evaluation unit.

[0015] In this case, it can be advantageous if the image recording unit has a high dynamic range.

[0016] Alternatively, according to the invention, at least one polariser can be arranged in the imaging beam path and an analyser can be arranged in the recording beam path.

[0017] In this case, the pattern of known geometry can consist of a structure of a plurality of rings in the form of a Placido disc or of discrete light sources in this case preferably Vertical-Cavity Surface-Emitting Laser (VCSEL) sources preferably having a wavelength of between 650 and 1,550 nm. Such sources have better beam profiles compared to edge emitters, for example with respect to symmetry and uniformity.

[0018] In the case of the method for determining the internal radius of a cornea using interference, it can be advantageous if the interference pattern is evaluated for a plurality of phase positions which are attained by varying the wavelength of the light sources during a plurality of measurements.

[0019] Another advantageous method for determining the internal radius of a cornea is obtained if the wavelength of the light sources used is varied rapidly during a measurement in order to suppress interferometric signal components which are undesirable during the geometric evaluation.

[0020] Geometrical evaluation primarily refers to determination of directions in which the spots are reflected by the cornea surfaces. In general, geometric evaluation can include absolute or relative evaluation of the recorded intensity distributions of the spots reflected or scattered by the cornea with respect to their location, sizes, shapes and divergences. This

information then can be utilized to evaluate or monitor the status of the cells of the cornea at multiple illuminated locations in parallel, while it is not necessary to optically resolve single cells. Such information is very useful to evaluate the health or estimate the potential stress resistance of a cornea, for example before treatment, surgery or contact lens application. For example endothelium cells at the posterior surface of the cornea are essential for the corneal metabolism and hydration, but can change their density, shape, spacing or size with age or due to pathologies, which then impacts the way the light is reflected or scattered from the posterior cornea surface.]

[0021] The invention will be described hereinafter in greater detail with reference to the schematic figures, in which:

[0022] Fig. 1 shows a first basic embodiment of an arrangement according to the invention;

[0023] Fig. 2 shows a second basic embodiment of an arrangement according to the invention;

[0024] Fig. 3 shows details of the second basic embodiment;

[0025] Fig. 4 a to d show variants of polariser/analyser combinations of the second basic embodiment;

[0026] Fig. 5 shows a variant of the second basic embodiment with a rotatable analyser;

[0027] Fig. 6 shows a second variant of the second basic embodiment;

[0028] Fig. 7 is a second view of the arrangement from Fig. 1 or 2;

[0029] Fig. 8 shows a third basic embodiment of an arrangement according to the invention; and

[0030] Fig. 9 a and b show camera images of the reflections of the cornea anterior side and posterior side.

[0031] Fig. 1 schematically illustrates a first exemplary embodiment of the invention showing the cornea 1 with its anterior side 2 and posterior side 3 and the eye lens 4. The light issuing from a light source 5, which is in this case shown to be a point-type source, is

reflected on the cornea anterior side 2 and the cornea posterior side 3; the resulting reflections 6 (anterior side reflection) and 7 (posterior side reflection) are recorded by a camera 8 and evaluated using an evaluation unit 9. A control unit 10 controls the arrangement and the measuring sequence.

[0032] For the sake of simplicity, an imaging optical system for imaging the light source 5 onto the cornea 1 and also a recording optical system for imaging the reflections 6, 7 onto the camera 8 have not been shown. In addition, only one light source 5 is shown by way of example. The pattern of known geometry is accordingly formed by a plurality of light sources 5.

[0033] The method according to the invention now consists in directing the light sources 5 onto the cornea and in analysing the imaging of the reflections 6, 7 on the camera.

[0034] For this purpose, use may be made, for the anterior side reflections 6, of the methods known in the art from US 6 692 126, US 6 575 573, US 7 246 905 or DD 251 497, to the content of which reference is hereby made.

[0035] The evaluation of the posterior side reflections 7 requires more extensive considerations which are not known from the prior art.

[0036] As can be seen from Fig. 1, anterior side reflection 6 and posterior side reflection 7 are close together on the camera image. As, moreover, the step in refractive index is very much higher on the cornea anterior side 2 than on the posterior side 3, the anterior side reflection 6 is approx. 100 x stronger than the posterior side reflection 7 and additional measures are necessary in order to be able geometrically to evaluate the images of the two reflections.

[0037] A first solution to this problem consists in recording the image of the reflections 6, 7 using a camera with very high dynamic range, i.e. a camera having a dynamic range of well over 120:1, i.e. 7 bits to over 12 bits, dynamics of approx. 1,000:1 or 10 bits being preferred. Examples of cameras of this type are either CCD cameras with an algorithm for dynamic extension or highly dynamic CMOS cameras. This also allows the very different brightnesses of the anterior side reflections 6 and posterior side reflections 7 to be recorded and evaluated.

In this case, the same methods can be used for the evaluation of the posterior side reflections 7 as for the anterior side reflections 6.

[0038] A second, very advantageous solution to this problem consists in attaining an adaptation of the intensities of the reflections 6, 7 using polarisation optical means. In this case, the invention utilizes the fact that the cornea has birefringent properties. This effect is described in detail in US 7 287 885, to the complete content of which reference is hereby made.

[0039] In Fig. 2 polarisers 11 for polarising the light emanating from the light sources 5 and an analyser 12 before the camera 8 are inserted into the basic embodiment according to Fig. 1.

[0040] In this case, the cornea anterior side reflection 6 is polarisation optically suppressed in order thus to achieve adaptation to the intensity of the posterior side reflection 7, leading to simpler evaluability of the images obtained by the camera 8. The basic principles for this polarisation suppression will be described in greater detail hereinafter.

[0041] In Fig. 2 a plane is spanned between the beam impinging on the cornea 1 and the beam reflected by the cornea anterior side 2: the plane of incidence. A polarisation direction perpendicular to this plane is referred to as s-polarisation and a polarisation lying in the plane is referred to as p-polarisation. The reflection of the beam emitted by the light sources 5 on the cornea 1 is described by way of the Fresnel equations. If the polarisation of the incident beam is a pure s- or p-polarisation, then the state of polarisation is not altered during the reflection.

[0042] If then the polarisation of the incident wave is rotationally symmetrically adjusted in the radial or in the azimuthal direction by a corresponding polariser 11 in such a way that the state of polarisation can be changed by the cornea, then the reflection 6 from the cornea anterior side 2 can be completely suppressed by an analyser 12 which is perpendicular to the polarisation of the incident beam, whereas reflection 7 remains detectable. The polarisers shown in Fig. 2 can consist of an annular excitation polariser 11 and a circular analyser (detection polariser) 12. The excitation polariser and the detection polariser 11, 12 can in this

case be embodied as independent constructional elements (Fig. 3) or as an assembled polariser (Fig. 4 a to 4 d).

[0043] A further possible technical configuration is shown in Fig. 4 b. If this element is used, then, in the method according to the invention, a plurality of images, each having a rotating analyser 12, are extracted and assembled to form an approximately polarisation rotationally symmetrical image which is then evaluated. If a unit for rotating the analyser 12 is omitted, it is also possible, as shown in Fig. 4 c, to use a polariser/analyser assembled from, for example, 16 linear polarisers.

[0044] In this case and in order to avoid crosstalk between adjacent polarisers as a result of image errors in the imaging optical system, the edges of the polarisers are advantageously blackened.

[0045] The polariser arrangements 11, 12 shown in Fig. 4 a to 4 c allow the polarisation of the incident light wave not to be changed during the reflection on the cornea anterior side 2 and to be suppressed almost completely using a detection polariser 12 which is perpendicular to the excitation polarisation. The light which enters the cornea 1 and is reflected on the posterior surface 3 has on the other hand, as a result of the birefringence, a changed state of polarisation and is accordingly not completely suppressed by the detection polariser 12. Thus, it is possible greatly to increase the intensity ratio of cornea posterior side reflection 7 and cornea anterior side reflection 6 in the camera image 8.

[0046] In this case, two states of optimisation are possible.

[0047] On one hand, it is possible to attempt completely to suppress the cornea anterior side reflection 6 using an arrangement according to Fig. 3, 4 a and 4 c. For this purpose, a rotationally symmetrical s- or p-polarisation is irradiated. However, this polarisation symmetry in the azimuthal direction or radial direction prevents the form birefringence of the cornea 1 from being utilised, as its coordinate system is also oriented in the azimuthal direction or radial direction. For this reason, the form birefringence cannot alter the state of polarisation and the cornea posterior side reflection 7 is greatly suppressed. However, the residual birefringence produces a minor change in polarisation on passing through the cornea 1 and the posterior side reflection 7 is not completely suppressed. However, the degree of

suppression depends on the strength and the orientation of the residual birefringence which can differ for each point of the cornea 1 and for each person. For this reason, it may be better to use the embodiment according to Fig. 4 b because, in the case of this construction, any polarisation axial position can be measured by rotating the polarisation filter combination 11, 12. On the other hand, in the second optimisation one does not attempt to completely suppress the anterior side reflection 6, but rather tries to minimize the suppression of the posterior side reflection 7. A polarisation filter combination corresponding to this optimisation is shown in Fig. 4 d. In the case of this construction, the diameter of the pattern formed by the light sources 5 is adjusted in such a way that the average phase deviation resulting from the birefringence in the cornea 1 is approximately $\lambda/2$, in the case of an average eye in the two polarisation directions on passing twice through the cornea 1, and thus the posterior side reflection 7 of the cornea can pass through the detection polariser 12 almost unattenuated. In this case, the Fresnel formulae also describe how much the polarisation at the anterior side 2 of the cornea 1 is changed due to the reflection.

[0048] As a result of the reflection at the anterior side 2 of the cornea 1, the polarisation of an incident wave is changed if irradiation is not carried out with pure s- or p-polarisation. As the reflection happens at the surface of a medium having a higher refractive index with very weak absorption, the phase difference of the reflected s component and p component is always 0 (or 180° for angles of incidence above the Brewster-angle).

[0049] Thus, although the reflected wave is linearly polarised, it has, as a result of the different reflection coefficients in s-polarisation and p-polarisation, a polarisation direction which has changed in relation to the initial polarisation. In this case, in the arrangement according to Fig. 4 b or 4 d, the orientation of the detection polarisers 12 can be adjusted in such a way that the cornea anterior side reflection 6 is completely suppressed even in the case of an s-/p- mixed polarisation.

[0050] A further preferred variant is shown in Fig. 5 which takes as its starting point six point-type light sources 5 (not shown), a linear polariser 11 being connected upstream of each light source 5 in a 45° s/p mixed direction, in combination with a linear rotatable detection polariser 12. A plurality of images is recorded at different detection polarisations and assembled to form a resulting image. In this case, the polarisation between excitation

polariser 11 and detection polariser 12 is adjusted not at 90° relative to each other, but rather at an exact angle which allows suppressing the cornea anterior side reflection 6 completely.

[0051] In the case of all the above-mentioned embodiments, in which orientations of polarisers 11 or analysers 12 are varied to measure various cornea regions, a film sequence is preferably recorded using a camera 8 (in particular a CMOS camera) and subsequently evaluated in the evaluation unit 9.

[0052] Instead of changing the orientations of analysing polarisers, use may also be made of stationary polarisers in combination with rotatable wave plates or polarisation rotators. This facilitates an arrangement in which only one polariser is used for excitation and detection.

[0053] As an alternative to rotatable polarisers, wave plates or rotators, use may also be made of sensor arrays in which adjacent pixels are provided with various microanalysers of differing orientation. Sensor arrays of this type were disclosed for a different application in the presentation [6844A-43] at Photonics West 2008 San Jose, CA, USA: A polarization measurement method for the quantification of retardation in optic nerve fiber layer, Yasufumi Fukuma, Topcon Medical Systems, Inc.; Yoshio Okazaki, Takashi Shioiri, Topcon Corp. (Japan); Yukio Iida, Komazawa Univ. (Japan); Hisao Kikuta, Osaka Prefecture Univ. (Japan); Kazuhiko Ohnuma, Chiba Univ. (Japan).

[0054] The variation of polarisation directions, including those in a locally resolved or radially symmetrical manner, can also be carried out by means of programmable liquid crystal modulators, in particular low-scatter twisted nematic LC arrays such as are known in the art (for example in T. Brixner et al. "Femtosecond polarization pulse shaping"; Optics Letters Vol. 26, 2001, p. 557).

[0055] A polariser can be omitted, if a laser is used, which generates polarised light by itself, for example as with a Fabry-Perot-laser

[0056] Fig. 6 shows a modification of the arrangement according to Fig. 2. In this case, polarisers 11 and analysers 12 are arranged in a common plane; this simplifies the integration shown in Fig. 4 a to 4 d. In addition, this arrangement has apertures 13 for the light sources 5, where the apertures serve correctly to adjust the distance between the measuring arrangement

and the eye to be measured. For exact adjustment, the arrangement is brought closer to the eye until the reflection on the cornea is just still visible.

[0057] Alternatively, this adjustment can also be attained by "focusing" the anterior side reflections 6 on the camera 8.

[0058] In order to minimise measurement errors resulting from patient movement, measuring times of less than 50 ms are preferred.

[0059] Fig. 7 shows a preferred arrangement of the light sources 5 (viewed in the axial direction of the eye) in the form of a regular hexagon. The light sources used are preferably VCSEL sources, for example ADNV-6340 from Avago Technologies, San Jose, CA, USA). In addition, radial changes in the radii of curvature, for example the asphericity of the surface, can be determined with the aid of further light sources 5' at different radial distances from the optical axis. Fig. 8 shows a third basic embodiment of an arrangement according to the invention. The light from a light source 5, which is in this case preferably a semiconductor laser having a coherence length of between 2 and 6 mm (for example HL 6711 from Hitachi), is directed, collimated via an imaging optical system 14, onto the cornea 1; the light reflected by the cornea anterior side 2 and the cornea posterior side 3 is imaged onto the camera 8 by means of a partially reflecting mirror 15 and a recording optical system 16. In this case, the coherence length of the light source 5 is selected such that the light reflected by the cornea anterior side 2 and that reflected by the posterior side 3 can interfere with each other, leading on the camera 8 to an interferogram 17. In this case, it is possible to determine information about the difference in curvature between the cornea anterior side 2 and cornea posterior side 3 from the interference fringes (also known as "Newton's rings") using known methods of optical test engineering. The amplification of the back reflection signal by the interference is in particular advantageous in this regard: The resulting interference fringes have a greatly increased contrast compared to the front reflection signal of up to 1:5, instead of the conventional intensity contrast of approx. 1:120.

[0060] The curvature of the cornea anterior side 2 can also be determined in a known manner from the brightness distribution of the envelope of the light distribution of the interferogram 17 (spatial distribution of the amount of the interference maxima).

[0061] In addition, a second light source 18 of shorter coherence length (for example a superluminescence diode SLD) can be combined with the beam path from the first light source 5 by means of a coupler 19 in order to be able to separately measure the anterior side curvature while suppressing the interference effects caused by the posterior side. The curvature of the anterior side 2 can be determined using conventional means from the brightness distribution 20, recorded by the camera 8, of the reflection of the light from the second light source 18 on the cornea anterior side 2. The radius of the cornea posterior side 3 can then easily be calculated from this curvature and the spatial deviation, which is also determined, of the curvature between the anterior side and posterior side of the cornea 1.

[0062] In a further embodiment, the curvature of the anterior cornea surface certainly can also be determined by means of one of the above described methods according to the state-of-the-art in order to combine this curvature with the interferometrically determined curvature deviations to deduce the curvature of the posterior cornea surface 3.

[0063] The coherence length of from 2 to 6 mm of the light source 5 in this exemplary embodiment is in this case determined in such a way that it is greater than or equal to twice the optical thickness of the thickest corneas ($2 \cdot 650 \mu\text{m} \cdot n_{\text{cornea}}$, wherein $n_{\text{cornea}} = 1.38$), but is less than approx. twice the optical distance from other anterior chamber structures such as for example the crystal lens ($2 \cdot 2.5 \text{ mm} \cdot n_{\text{aqueous}}$, wherein $n_{\text{aqueous}} = 1.34$). This reliably prevents interferences on deeper structures of the eye, such as for example the eye lens, from distorting the result.

[0064] Fig. 9 a and 9 b show details from camera images of the arrangement according to Fig. 1 or 2 for a respective light source 5. The large light spot 21 is the much brighter and larger anterior side reflection 6, the smaller light spot 22 is the posterior side reflection 7. In Fig. 9 a said reflections are geometrically sufficiently separated and can thus be readily evaluated. In Fig. 9 b the two reflections 6 and 7 are so close together that evaluation is possible, but difficult. It has been found in this regard that usable test results can be obtained in this case too by utilising the interference. If the coherence length of the light source 5 is, as in the case of the arrangement according to Fig. 8, in the range of from 2 to 6 mm, the anterior side reflection and posterior side reflection interfere with each other. In this case, the

optical path length of the cornea thickness at the measuring point determines whether more constructive (amplifying) or destructive (extinguishing) interference is obtained. Fig. 9 b shows destructive interference, i.e. the posterior side reflection 7 extinguishes a portion of the light spot 21 of the anterior side reflection 6. Slight variation of the wavelength of the light source 5 (this can be achieved, in the case of a VCSEL source for example, by varying the current or the temperature) allows these two states of interference to be successively adjusted and thus the position of the posterior side reflection to be determined with high precision despite spatial superposition. The curvatures or radii of the cornea anterior side 2 and cornea posterior side 3 can be calculated, as described, from the geometric locations of the anterior side reflection and posterior side reflection 6, 7.

[0065] The invention has been exemplified for a known pattern consisting of discrete light sources 5. Alternatively, annular light sources, such as the conventional Placido disc, or else other dot or line patterns can of course also be used for the method according to the invention. In this case, it is beneficial if the patterns have clearly delimited luminous surfaces in order to facilitate the separation of the anterior side reflection and posterior side reflection.

[0066] The use of a plurality of ring light sources or annularly arranged point-type light sources of this type not only allows keratometry of the cornea anterior side and posterior side to be carried out, but to determine also higher orders of deformation (asphericity, etc), ranging up to topographies of the cornea anterior side and posterior side, to be determined.

LIST OF THE REFERENCE NUMERALS

1	Cornea
2	Cornea anterior surface
3	Cornea posterior surface
4	Crystalline lens
5 and 5'	Light source
6	Cornea anterior surface reflection
7	Cornea posterior surface reflection
8	Camera (including optical system)
9	Evaluation unit
10	Control unit
11	Polariser
12	Analyser
13	Aperture
14	Imaging optical system
15	Partially reflecting mirror
16	Recording optical system
17	Interferogram
18	super luminescent diode (SLD)
19	Coupler
20	Intensity distribution
21	Light spot, anterior side reflection
22	Light spot, posterior side reflection

CLAIMS

1. Method for determining the internal radius of a cornea, in which at least one pattern of known geometry is projected onto the cornea and the light reflected by the posterior side of the cornea and preferably by the anterior side of the cornea is analysed.
2. Method for determining the internal radius of a cornea as claimed in claim 1, wherein the light reflected by the anterior side of the cornea and the posterior side of the cornea is brought to interference and the resulting interference pattern is evaluated.
3. Method for determining the internal radius of a cornea as claimed in claim 1, wherein the light reflected by the posterior side of the cornea or anterior side of the cornea is geometrically evaluated.
4. Method for determining the internal radius of a cornea as claimed in claim 3, wherein this geometric evaluation is carried out while adapting the intensities of the cornea anterior side reflections and cornea posterior side reflections using polarisation optical means.
5. Method for determining the internal radius of a cornea as claimed in claim 3, wherein the reflections are recorded by an image recording unit having a high dynamic range of from preferably 120 to above 1,000.
6. Arrangement for determining the internal radius of a cornea, in particular using the method as claimed in claim 2, consisting of a light source having a coherence length of greater than 2 mm, preferably in the range of from 2 to 6 mm, a unit for generating a pattern of known geometry, an imaging optical system which images the test pattern onto the cornea, a recording optical system, an image recording unit and an image evaluation unit.
7. Arrangement for determining the internal radius of a cornea as claimed in claim 6, wherein the image evaluation unit is configured for analysis of the light reflected by the anterior side of the cornea and for the analysis of the interference pattern resulting from interference of the light reflected by the anterior side and the posterior side.
8. Arrangement for determining the internal radius of a cornea, in particular using the method as claimed in claim 3, consisting of at least one light source, a unit for generating a pattern of known geometry, at least one imaging optical system which images the test pattern

onto the cornea, a recording optical system, an image recording unit and an image evaluation unit.

9. Arrangement for determining the internal radius of a cornea as claimed in claim 8, wherein the image recording unit has a high dynamic range of from preferably 120 to above 1,000.

10. Arrangement for determining the internal radius of a cornea as claimed in claim 8, wherein at least one polariser is arranged in the imaging beam path and an analyser is arranged in the recording beam path.

11. Arrangement for determining the internal radius of a cornea according to any one of claims 6 to 10, wherein the pattern of known geometry consists of a structure of a plurality of rings in the form of a Placido disc or of discrete light sources.

12. Arrangement for determining the internal radius of a cornea as claimed in claim 11, wherein the discrete light sources used are VCSEL sources preferably having a wavelength in the range between from 650 to 1,550 nm.

13. Arrangement for determining the internal radius of a cornea as claimed in claim 12, wherein the VCSEL sources are configured so as to be spectrally tunable.

14. Method for determining the internal radius of a cornea as claimed in claim 2, wherein the interference pattern is evaluated for a plurality of phase positions which are attained by varying the wavelength of the light sources during a plurality of measurements.

15. Method for determining the internal radius of a cornea as claimed in claim 3, wherein the wavelength of the light sources used is varied rapidly during a measurement in order to suppress interferometric signal components which are undesirable during the geometric evaluation.

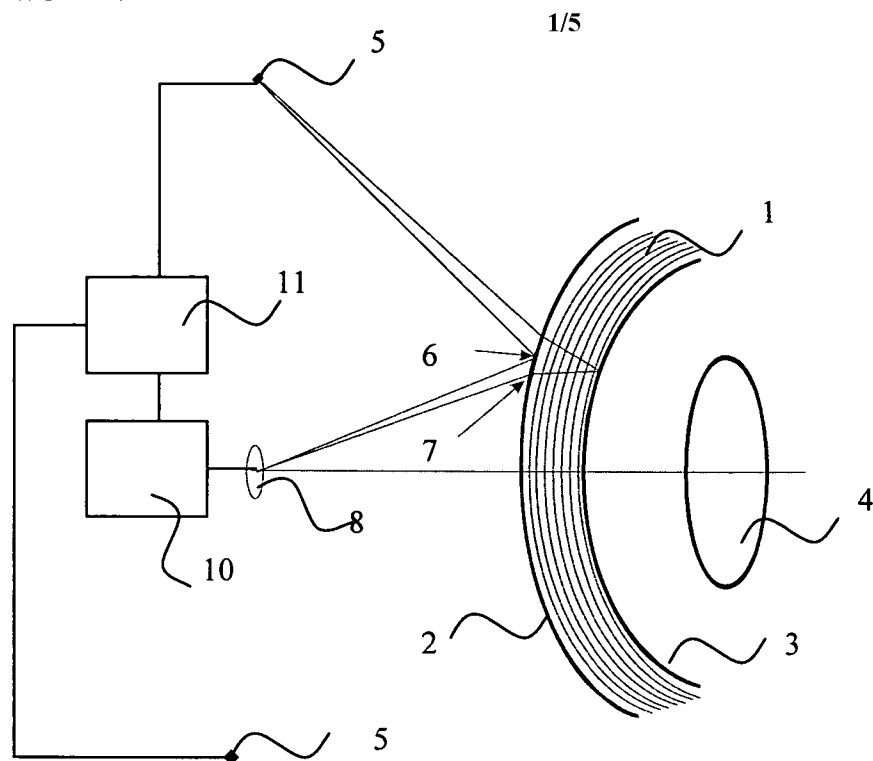


Fig. 1

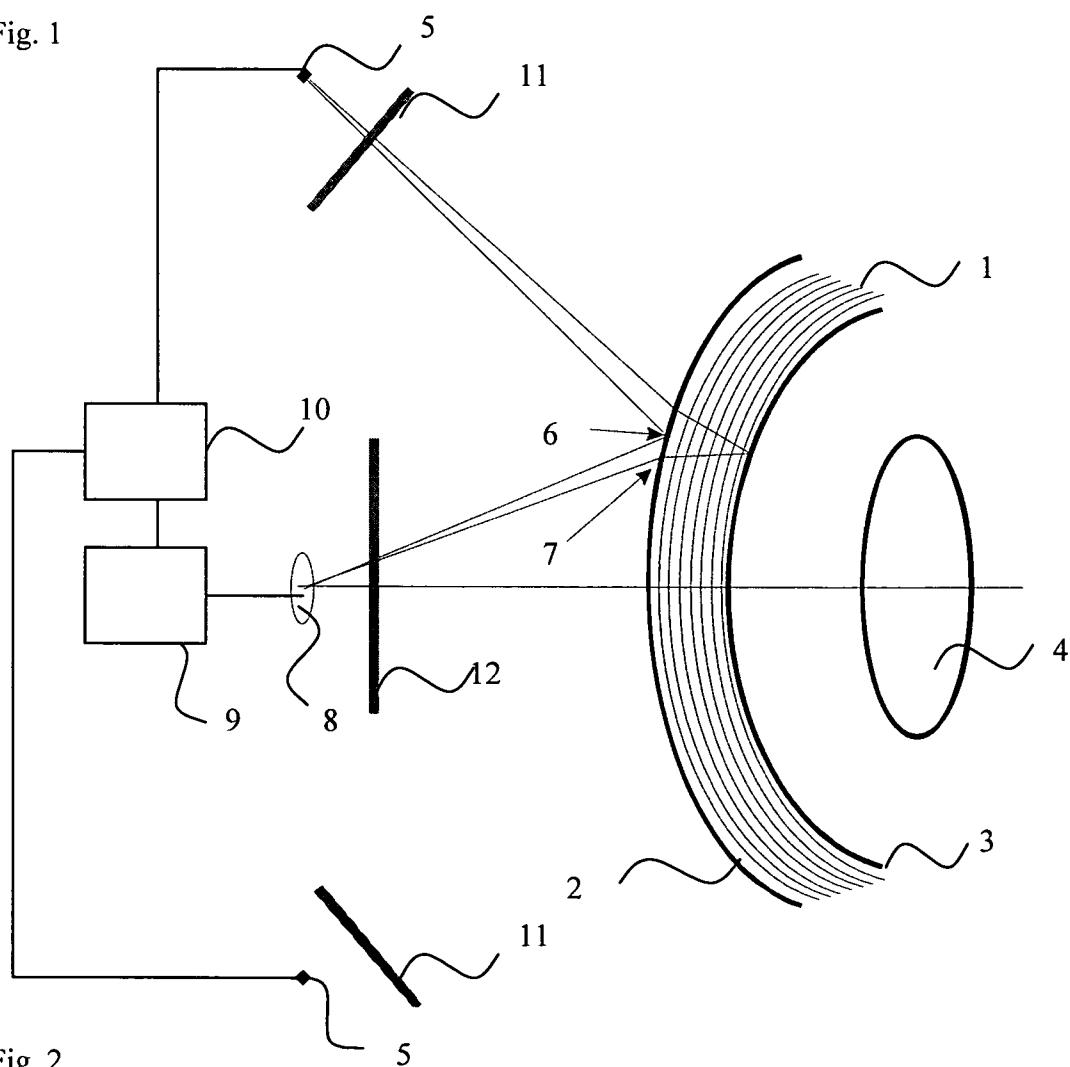


Fig. 2

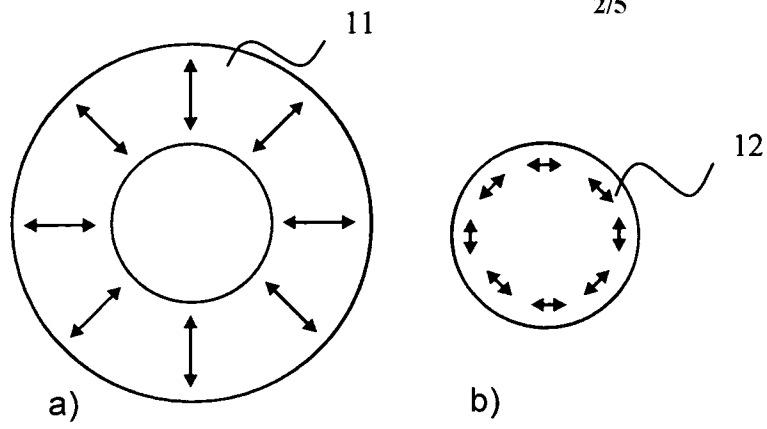


Fig. 3

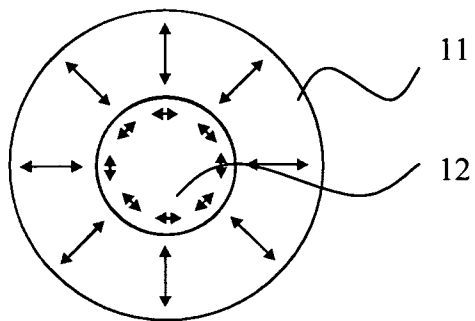


Fig. 4a

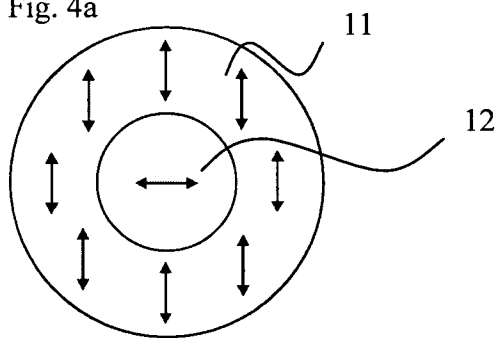


Fig. 4b

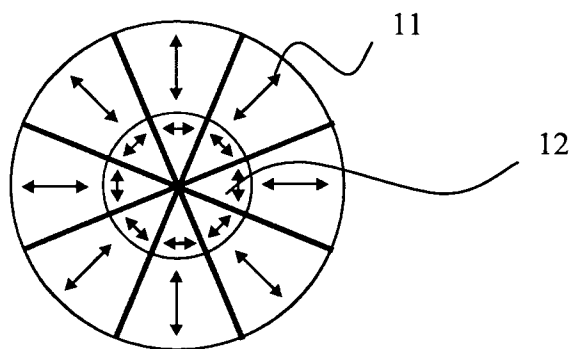


Fig. 4c

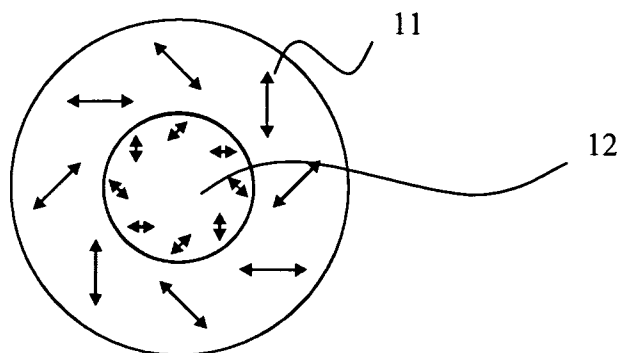


Fig. 4d

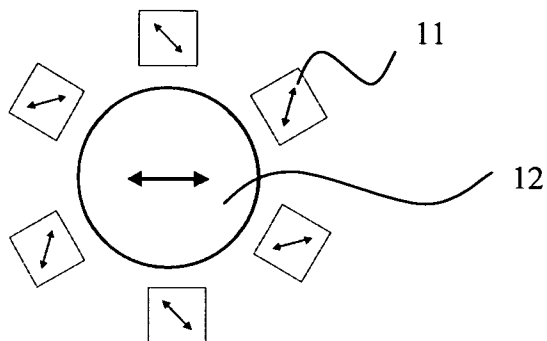


Fig. 5

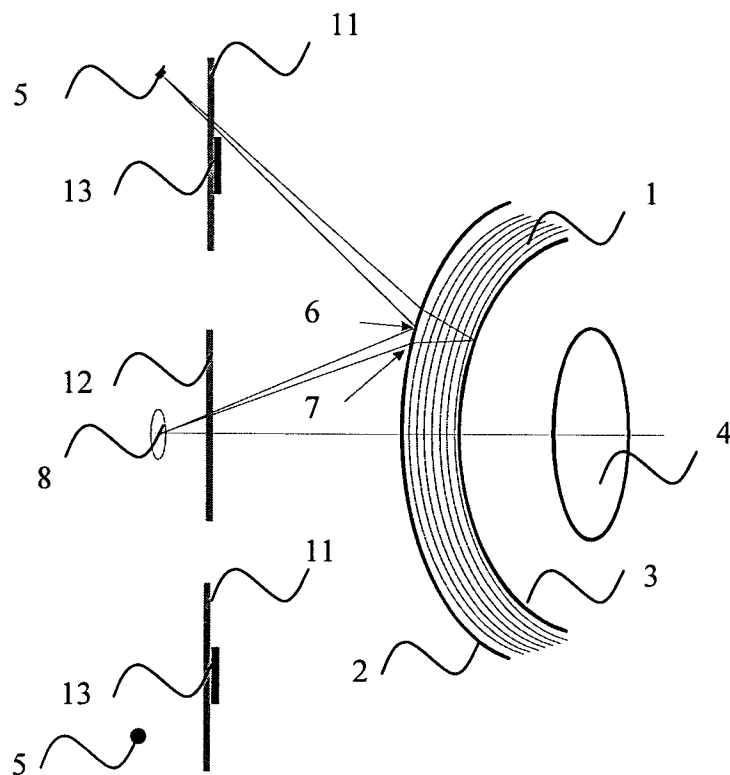


Fig. 6

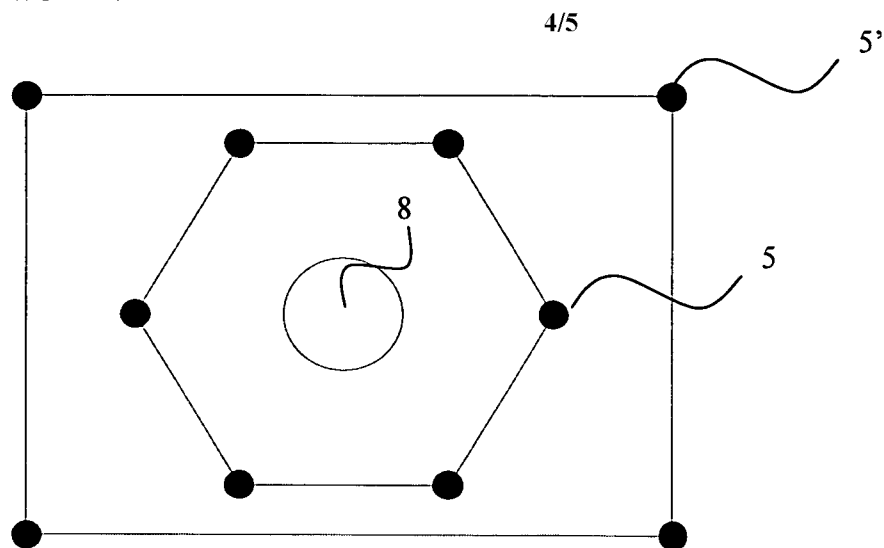


Fig. 7

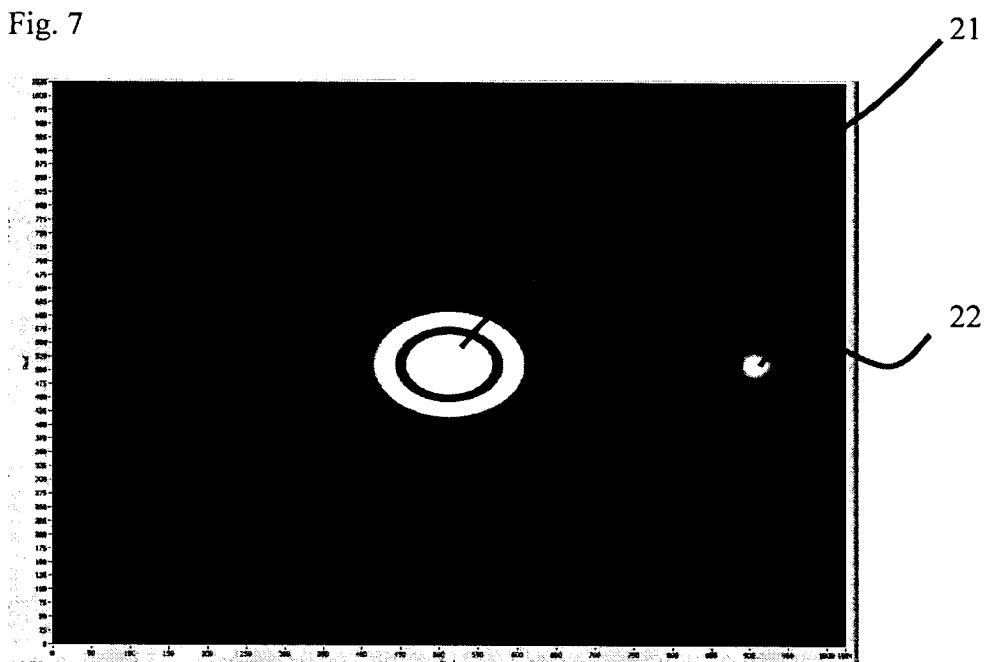


Fig. 9a

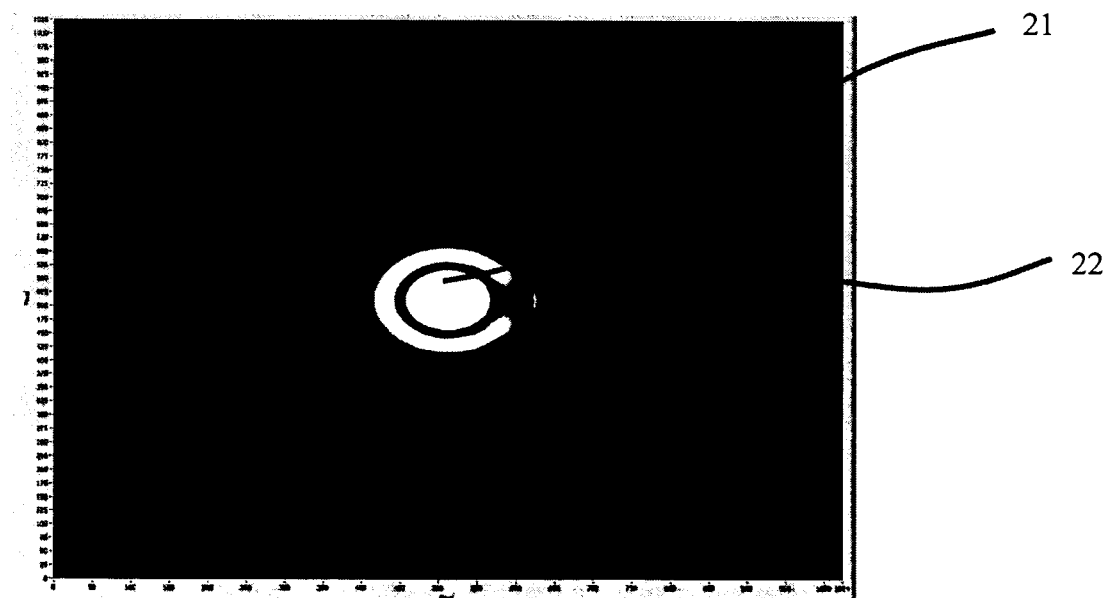


Fig. 9b

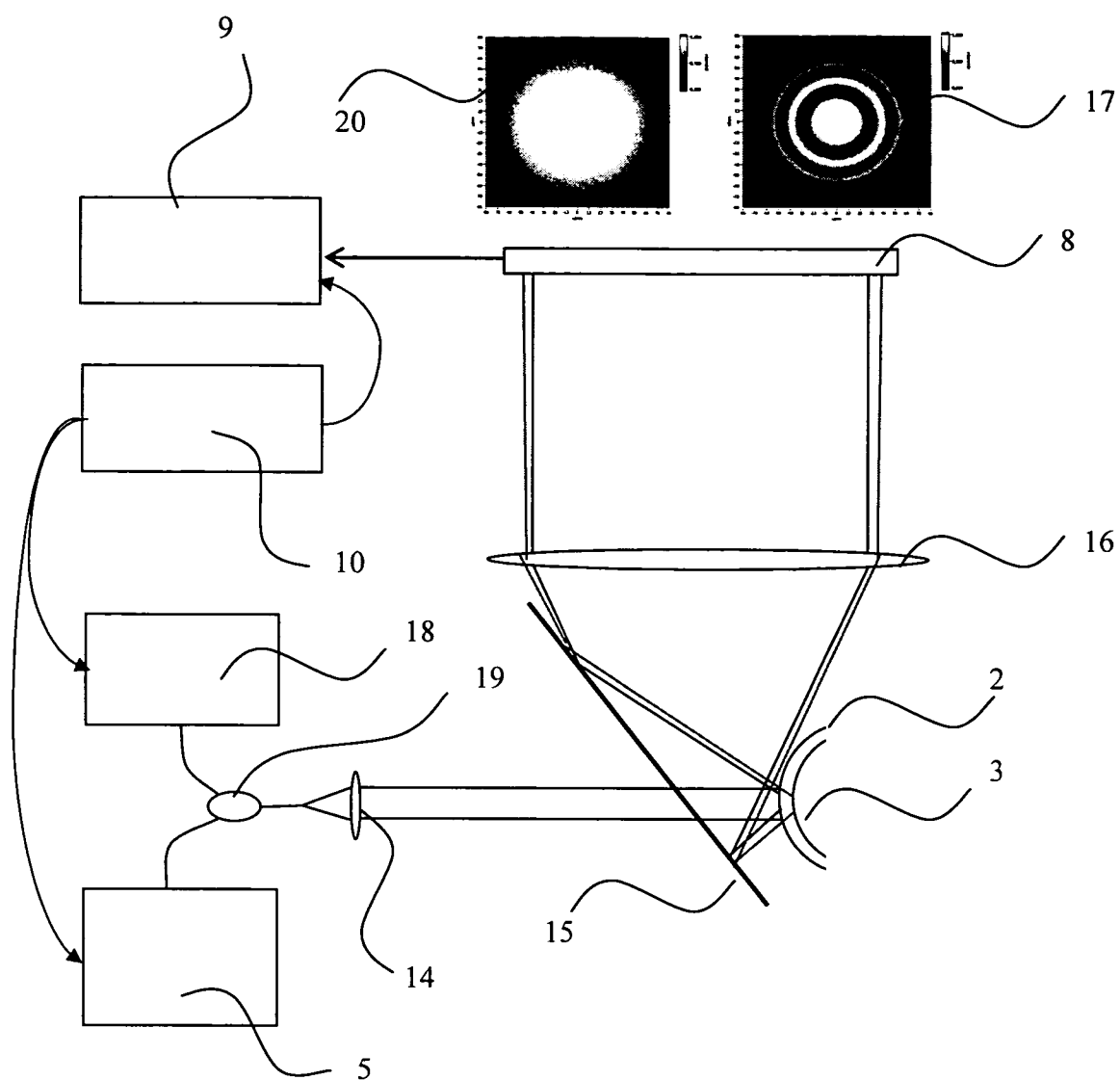


Fig. 8

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2009/000871

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B3/10 A61B3/107

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	abstract paragraph [0002] paragraphs [0021], [0025], [0026] paragraph [0029] - paragraph [0032] paragraph [0041] - paragraph [0043] paragraph [0046] - paragraph [0047] paragraph [0050] - paragraph [0051] claims 18-34 figures 3,4 ----- -/--	6, 12-15

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

A document defining the general state of the art which is not considered to be of particular relevance

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O document referring to an oral disclosure, use, exhibition or other means

P document published prior to the international filing date but later than the priority date claimed

T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

X document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

Y document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

& document member of the same patent family

Date of the actual completion of the international search

29 April 2009

Date of mailing of the international search report

13/05/2009

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Authorized officer

Tommaseo, Giovanni

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2009/000871

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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International application No

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