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(71) Applicants and
(72) Inventors: **CAMPBELL, Melanie, C. W.** [CA/CA]; 536 Clair Creek Blvd., Waterloo, Ontario N2T 1R9 (CA). **GARCIA, Juan, Manuel, Bueno** [ES/ES]; Atenas 8, Urb. La Molineta, 30500 Molina de Segura, E-30500 Murcia (ES).

(74) Agent: **HILL & SCHUMACHER**; 87 Falcon Street, Toronto, Ontario M4S 2P4 (CA).

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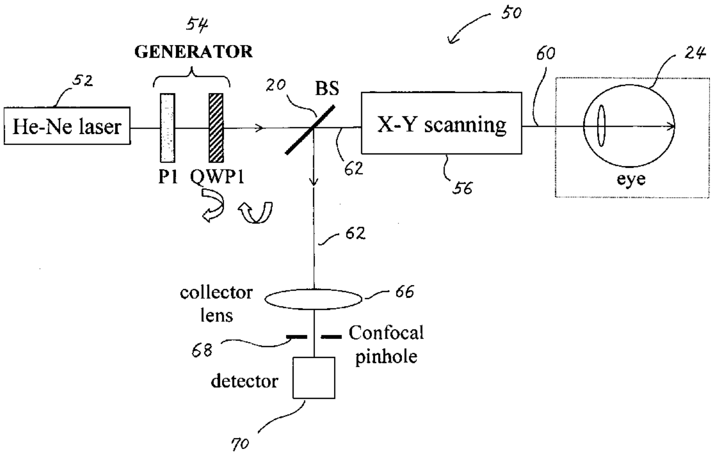
(54) Title: METHOD AND APPARATUS FOR IMPROVED FUNDUS IMAGING THROUGH CHOICE OF LIGHT POLARISATION



(57) Abstract: The present invention provides a method and device to image the fundus of the eye using polarized light which includes circular polarization. The invention is most broadly comprised of a device to generate polarization states of light, including circularly polarized light (i.e. potentially combinations of elliptically polarized light and depolarized light combined, elliptically polarized light alone, or circularly polarized light with depolarised light or circularly polarized light alone). This light can be used with any fundus imaging device including but not limited to fundus cameras, scanning laser ophthalmoscopes, confocal scanning laser ophthalmoscopes, optical coherence tomography instruments, with or without some form of wavefront correction. This is a change from common fundus imaging systems which use randomly polarized light or linearly polarized light. The simplest implementation of this is a quarter wave plate (or equivalent retarder) combined with a linear polarizer located after the light source and before the eye. The QWP can be rotated to produce differing circular and elliptical polarizations of light which are ideal for imaging differing structures at the rear of the eye for different people.

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METHOD AND APPARATUS FOR IMPROVED FUNDUS IMAGING THROUGH CHOICE OF LIGHT POLARISATION

CROSS REFERENCE TO RELATED U.S. APPLICATIONS

This patent application relates to, and claims the priority benefit from, United States Provisional Patent Application Serial No. **60/796,899** filed on May 3, 2006, in English, entitled **METHOD AND APPARATUS FOR IMPROVED FUNDUS IMAGING THROUGH CHOICE OF LIGHT POLARISATION,** *and which is incorporated herein by reference in its entirety.*

FIELD OF THE INVENTION

The present invention relates to a device to image the fundus of the eye using polarized light which includes circular polarization. The use of circularly polarized light also means that the polarization vector orientation of the input light rotates continuously in space and time which is important to image quality. More particularly the present invention relates to a device to generate polarization states of light, including elliptically polarized light alone, circularly polarized light alone, a combination of elliptically polarized light and depolarized light, and a combination of circularly polarized light and depolarised light

BACKGROUND OF THE INVENTION

Light coming from structures in fundus images is differentially polarised, leading to clinical applications such as assessment of glaucoma and foveal fixation. Using polarisation, it has been shown to be possible to obtain objective image improvement in visualisation of the retinal structures, see references 1-4 listed after the description. Nevertheless, improvements are needed to obtain better images of the fundus for visualization, diagnosis and guided therapy.

Therefore it would be very advantageous to provide a method and apparatus to provide better imaging of the fundus of the eye to improve the diagnosis of abnormalities of the optic nerve head (ONH), and of other structures which interact with polarized light, including but not limited to those that change in glaucoma. This methodology may also improve visualization of other structures at the rear of the eye, for example blood vessels important to the diagnosis of diabetic retinopathy and age related macular degeneration among others. In addition bacteria and parasites and other invading cells and organisms may also be better visualized.

SUMMARY OF THE INVENTION

Embodiments of methods and devices to image the fundus of the eye using polarized light which includes circular polarization are provided. In its broadest, the present invention provides a device to generate polarization states of light, including circularly polarized light alone, elliptically polarized light alone, combinations of elliptically polarized light and depolarized light combined, or circularly polarized light with depolarised light. This light can be used with any fundus imaging device including but not limited to fundus cameras, scanning laser ophthalmoscopes, confocal scanning laser ophthalmoscopes, optical coherence tomography instruments, with or without some form of wavefront correction. This is an improvement from common fundus imaging systems which use randomly polarized light or one linear polarization state of light or multiple linear polarization states of light.

Thus, in one aspect of the present invention, there is provided an apparatus for imaging the fundus of the eye using polarized light, comprising:

a light source for generating a beam of light;

an optical element configured to generate non-linear polarization states of light in said beam of light;

light directing and focusing means for directing the beam of light containing the non-linear polarization states onto the fundus of the eye; and

fundus imaging detector for receiving images of the fundus of the eye after illumination by the non-linearly polarized light.

In this aspect of the invention the optical element may be a quarter wave plate (or equivalent retarder) combined with a linear polarizer located after the light source and before the eye.

In another aspect of the present invention there is provided a method for imaging the fundus of the eye using polarized light, comprising:

a) generating non-linear polarization states of light in a beam of light;

b) directing and focusing the non-linearly polarized beam of light onto the fundus of the eye; and

c) directing and focusing a reflected beam of light containing information of the fundus of the eye onto a detector and producing images of the fundus.

A further understanding of the functional and advantageous aspects of the invention can be realized by reference to the following detailed description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be more fully understood from the following detailed description thereof taken in connection with the accompanying drawings, which form a part of this application, and in which:

Figure 1 shows a polarization generator comprised of a linear polarizer (P1) and a quarter wave plate (QWP) positioned in the input path;

Figure 2 shows the input and measured polarised light represented by the Stokes Vectors S and S', respectively, where the top row of the Mueller matrix, M_{0j}, represents the modulation effect of the tissue on the incoming light;

Figure 3 shows optic nerve head structures of subject 1 obtained using the method and apparatus disclosed herein;

Figure 4 shows optic nerve head structures of subject 2 obtained using the method and apparatus disclosed herein (top row) and derived by calculation from the images using the method disclosed in United States Patent No. 6,927,888, issued August 9, 2005, entitled "Method And Apparatus For Imaging Using Polarimetry And Matrix Based Image Reconstruction", which is incorporated herein by reference in its entirety, (bottom row);

Figure 5 shows the effect of focusing plane for upper row for this subject a -0.50D lens was used with the apparatus and ONH structures near the base of the ONH are imaged, for middle row for this subject a plano lens was used with the apparatus to image ONH structures anterior to the structures in the upper row, and for lower row for this subject a +0.50D lens was used to image structures anterior to the middle row and close to the Retinal Nerve Fiber Layer;

Figure 6a, **6b** and **6c** show Poincaré spheres for images with maximum and minimum values of metrics of ONH features; and

Figure 7 shows a confocal scanning laser ophthalmoscope with a generator constructed in accordance with the present invention which is capable of providing the required polarization states of light.

DETAILED DESCRIPTION OF THE INVENTION

Generally speaking, the systems described herein are directed to devices to image the fundus of the eye using polarized light. As required, embodiments of the present invention are disclosed herein. However, the disclosed embodiments are merely exemplary, and it should be understood that the invention may be embodied in many various and alternative forms. The Figures are not to scale and some features may be exaggerated or minimized to show details of particular elements while related elements may have been eliminated to prevent obscuring novel aspects. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting but merely as a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the present invention. For purposes of teaching and not limitation, the illustrated embodiments are directed to devices to image the fundus of the eye using polarized light, with more general properties than currently used.

Light coming from structures in fundus images is differentially polarised, leading to clinical applications such as assessment of glaucoma and foveal fixation. Using polarisation, it has been shown to be possible to obtain objective image improvement in visualisation of the retinal structures, see references 1-4.

The purpose of the study from which the present invention is based was to explore the subjective quality of fundus images obtained directly through polarimetry and reconstructed using Mueller matrix polarimetry (as disclosed in United States Patent No. 6,927,888, issued August 9, 2005, entitled “Method And Apparatus For Imaging Using Polarimetry And Matrix Based Image Reconstruction”, which is incorporated herein by reference in its entirety) in combination with various image quality metrics

The present invention provides a method and device to image the fundus of the eye using polarized light which includes circular polarization.

Referring to **Figure 1**, an apparatus shown generally at **10** includes a light source **12** which produces a beam of light (coherent or incoherent, of a visible or infrared wavelength, and of any polarization) **14** and optic element **16** to generate polarization states of light, including elliptically polarized light alone, combinations of elliptically polarized light and depolarized light combined, elliptically polarized light alone, circularly polarized light in combination with depolarized light, or circularly polarized light alone when the beam **14** passes through the optics **16**. The light beam 18 having the desired polarization properties produced by the light beam **14** passing through the optical element**16** is passed through a beam splitter **20** or other device separating the ingoing and outgoing paths of light after which it passes through optics **22** which directs the beam to a patient's eye **24**. The light beam reflected by the fundus returns through optics **22** and into the eye after which this reflected beam **26** carrying the image of the fundus is split and the beam **26** is directed to a detector **30** after passing through optics **28**.

The optical element **16** is configured to generate any one of circularly polarized light alone, elliptically polarized light alone, a combination of elliptically polarized light and depolarized light, and a combination of circularly polarized light with depolarised light.

The optical element **16**, in its simplest implementation, may be comprised of a quarter wave plate (QWP) **36** (or equivalent retarder) combined with a linear polarizer **38,** with the polarizer **38** and quarter wave plate **36** located after the light source **12** and before the eye **24,** with the polarizer **38** located between the quarter wave plate **36** and the light source **12**. The QWP **36** can be rotated to produce differing circular and elliptical polarizations of light which are ideal for imaging differing structures at the rear of the eye for different people. The light source **12** may be configured to produce linearly polarized light in which case the linear polarizer **38** is not required, and once again the QWP **36** can be rotated to produce differing circular and elliptical polarizations of light.

Other embodiments may include any other retarder which causes two perpendicular linear polarizations to be either 90 or 180 degrees out of phase producing circularly polarized light or causes them to be out of phase by an amount different than 0, 90 or 180 degrees, producing elliptically polarized light.

Another specific example of a retarder is a birefringent liquid crystal device of sufficient thickness and orientation to the linear polarizer to cause two perpendicular polarization states of light to be 90 or 180 degrees out of phase. If the light source **12** produces linearly polarized light, then optical element **16** need only be comprised of an optical retarder oriented properly with respect to the linear polarization. Embodiments giving elliptically polarized light are those that cause the two linear polarizations to be out of phase by amounts different from 0, 90 or 180 degrees (produced in one implementation by rotating a QWP with respect to the axis of linear polarization of entering light in any orientation other than those which produce circular or linear polarizations).

Another embodiment useful for producing elliptically polarized light is to produce two perpendicular polarizations of light with differing relative intensities incident on a retarder which causes the two polarizations to be out of phase by an amount different from 0 degrees (including retardations of 90 or 180 degrees).

Another embodiment is to combine circularly polarized light with linear polarized light oriented in any direction to produce any type of elliptically polarized light. In order to produce elliptically or circularly polarized light in combination with depolarized light, a depolarizing element should be introduced after optical element **16,** or optical element **16** should depolarize a portion of the light incident on it.

The optics **22** used to deliver light beam **18** to the eye **24** may include the input path of any fundus imaging device including but not limited to fundus cameras, scanning laser ophthalmoscopes, confocal scanning laser ophthalmoscopes, optical coherence tomography instruments, with or without some form of wavefront correction. The key is that the light with the desired polarization states is directed into the entrance pupil of the eye by any combination of lenses or mirrors or apertures or other optomechanical components without loss of circular polarization and that the light is focused onto the fundus with a fixed or variable position of focus.

The optics **28** used to deliver the refelected light beam **26** to the detector **30** may include the output arm of any fundus imaging device including but not limited to fundus cameras, scanning laser ophthalmoscopes, confocal scanning laser ophthalmoscopes, optical coherence tomography instruments, with or without some form of wavefront correction which collects and images the light coming from the pupil of the eye with minimal impact on its polarization state. This arm will use lens(es), mirror(s) or other optomechanical devices to focus the fundus plane of interest onto the detector **30**. Some of the optics **22** and **28** may be common.

The apparatus for producing circular, elliptical or both mixed with depolarized light disclosed herein may be retrofitted into existing devices for imaging the eye. It may be placed in the input arm following the light source including but not limited to fundus cameras, scanning laser ophthalmoscopes, confocal scanning laser ophthalmoscopes, optical coherence tomography instruments, with or without some form of wavefront correction. This is a change from common fundus imaging systems which use randomly polarized light or linearly polarized light. A similar device called an analyzer which can sample varying polarization states of light returning to the detector may be placed in the reflected beam path of any existing fundus imaging device including but not limited to fundus cameras, scanning laser ophthalmoscopes, confocal scanning laser ophthalmoscopes, optical coherence tomography instruments, with or without some form of wavefront correction.

An initial demonstration was with a confocal scanning laser ophthalmoscope (Example below) where images of the optic nerve head area were preferred by a clinician (with no knowledge of the polarizations) if they were formed with input light containing circular polarization, usually elliptically polarized light. This image could be formed directly by inputting the light of the polarization state which forms the preferred image.

Alternately the inventors have previously shown in United States Patent No. 6,927,888, issued August 9, 2005, entitled “Method And Apparatus For Imaging Using Polarimetry And Matrix Based Image Reconstruction”, which is incorporated herein by reference in its entirety that the image can be reconstructed from images corresponding to four different input polarizations.

When four different polarizations are used, images can be reconstructed which correspond to polarization states for each position on the Poincaré sphere. Thus images corresponding to a range of circularly, linearly and elliptically polarized light can be reconstructed. A clinician's preference for images reconstructed corresponding to polarization states which contained circularly polarized light was clear. Preferred images are marked in **Figures 3** and **4** by coded bars corresponding to the feature being observed. Such polarizations can improve the visibility and clarity of clinically important features and potentially improve the resolution of such features.

Images presented for a clinician to evaluate included those corresponding to specific polarization states of light and also those in which specific image quality metrics were maximized or minimized, using a methodology previously patented by the inventors in U.S. Patent No. 6,927,888. This patent specified the use of any image quality metric but gave specific examples of the Signal to noise (SNR) metric. In this work, the images preferred by a clinician for the optic nerve head features were images included those taken with circular and elliptical polarizations states of input light and images which corresponded to a minimization of the image quality metric, entropy, a minimization of the image quality metric acutance and a maximization of the image quality metric, entropy. This was reproducible across subjects and on two different evaluation dates. When a clinician evaluated images of blood vessels, again images formed by incident elliptical and circular polarizations were preferred. The image quality metrics of minimum acutance, maximum entropy, maximum acutance and maximum SNR were preferred. In some cases the images were directly measured and again in some cases they were formed when the reconstruction assumed that circular or elliptically polarized incident light was incident on the rear of the eye (see **Figure 6**).

This novel method is expected to improve the diagnosis of abnormalities of the optic nerve head and the retinal nerve fiber layer, including but not limited to, glaucoma. This methodology may also improve visualization of other structures at the rear of the eye, for example blood vessels important to the diagnosis of diabetic retinopathy and age related macular degeneration among others. In addition bacteria and parasites and other invading cells and organisms may also be better visualized.

Figure 7 shows a confocal scanning laser ophthalmoscope at **50** which uses a laser beam of visible or infrared wavelength (He-Ne for this experiment) **52** with a generator **54** capable of providing the required polarization states of light. Beamsplitter **20** operates the same as in apparatus **10** in **Figure 1**. An X-Y scanning stage **56** provides for displacement of the light beam **60** with respect to the fundus at the rear of the patient's eye. The reflected light beam **62** carrying the image information about the back of the eye passes through a collector lens **66** which focuses the beam through the confocal pinhole **68** and onto detector **70**.

The invention will be illustrated using the following non-limiting example.

EXAMPLE

Polarisation images were obtained using the confocal scanning laser ophthalmoscope (CSLO) shown in **Figure 7**. Four video segments of the ONH (10° and 15° fields) were recorded for differing generator polarisation states. At each polarisation state, eight frames were registered, averaged and used to calculate the top row of the Mueller matrix for each pixel, see **Figure 2**. Images evaluated corresponded to recorded images for input states of linear polarisation (00), circular polarisation (45) and elliptical polarisation (30, 60), as well as the calculated unpolarized light (M00) image. Images were reconstructed by incrementing the incident Stokes vector in degree steps on the Poincaré sphere and some of these images producing maximum or minimum values of an image quality metric were also evaluated.

When circularly polarized light is used as the input, the image produced by the reflected light is often of better quality than images produced with linearly polarized light. On other occasions, when elliptically polarized light is used as the input, the image produced by the reflected light is often of better quality than images produced with linearly polarized light.

When the step of reconstructing images from the initial four images taken (fully described in the previous patent) is included, we can predict the polarization state of incident light that would produce an image with the highest quality, defined by a metric. The polarization states for which quality can be predicted are all circular, linear and elliptical polarizations. This incident light producing the maximum or minimum metric value in general has elliptical polarization, indicating that elliptically polarized light (or light that contains circular polarization) produces higher quality images than linearly polarized incident light.

Those images evaluated in our example had minimum and maximum values of the image quality metrics: signal-to-noise ratio (SNR), entropy (ENT) and acutance (ACU). Image recordings were repeated on subsequent days (Subject 1and 2) (**Figures 3** and **4**) and at ±0.50D of defocus (Subject 1) (**Figure 5**). A clinician, masked to the process of image generation, subjectively evaluated the entire set of images and ranked them. Clinically relevant features of the optic nerve head were evaluated: optic cup (shape and size); lamina cribrosa visibility; neuroretinal rim (NRR) visibility; the retinal nerve fibre layer (RNFL) and the ONH vasculature.

The following rating scale was used:

1: Not Visible, 2: Poor Visibility, 3: Satisfactory Visibility, 4: Good Visibility

The evaluations were repeated several months later on the same image sets. Overall, the data indicates that images containing more complex polarization information were preferred for evaluation of the optic nerve head and retinal structures to images of M00 and linear polarization (00) alone.

1) Optic nerve cup & Lamina cribrosa:

Circular and elliptical polarization orientations were preferred for visualization of the cup. The preferred polarization state was different at different focus depths but preferred states, coded by hatched bars include circular and elliptical polarizations (Figure 4).

2) Neural retinal rim edge and Vessels:

Across the two individuals, images of M00 and Min ACU (vessels, corresponding to elliptically polarized light), and M00 and circularly polarized light (NRR Edge) were most highly ranked.

3) *Retinal nerve fibre layer:* Max ACU and Min ENT constructed images (with elliptically polarized light) were preferred for images taken nearer to the plane of the retinal nerve fiber layer.

M00, Min ACU and Max SNR (constructed with elliptically polarized light) were consistent across subjects for visualization of the blood vessels. Other measurements by the inventors have shown that vessels contrast is improved in images of the near periphery for constructed images which maximize entropy using elliptically polarized light.

Figure 3 shows optic nerve head structures of subject 1 obtained using the method and apparatus disclosed herein and **Figure 4** shows optic nerve head structures of subject 2. These Figures show an example, for each subject, of a complete set of the evaluated images. The line beneath the image indicates that it was selected as 'Satisfactory' or 'Good' on repeated evaluations for a particular feature. Subject 2 had little cupping so evaluations were not made for the cup or lamina cribrosa. The polarization state of the measured images are given in the lower left corners of the images in the top row. The minimum or maximum metric that gave the reconstructed images is given in the lower left corner of images in the second row. Max SNR (indicated by an asterisk) was not ranked highest across all evaluations but was ranked highly across subjects for viewing the vessels.

Figure 5 shows the effect of focusing plane, where, for the upper row for this subject, a -0.50D lens used with the apparatus which focused ONH structures near the base of the ONH, for the middle row for this subject a plano lens was used with the apparatus to image ONH structures anterior to the structures in the upper row, and for the lower row for this subject a +0.50D lens was used to image structures anterior to the middle row and close to the retinal nerve fiber layer. The polarization state of the measured image or the minimum or maximum metric that gave the constructed images that were selected in repeated evaluations for viewing features at the optic nerve head are shown in the upper left of the images. Towards the base of the cup (-0.50D) raw polarization inputs of 60 (elliptical) and 00 were preferred. With no defocus in place, Min ACU was preferred for visualization of the internal ONH structures. At the anterior position of focus (+0.50D), Max ACU and Min ENT were preferred for visualization of the RNFL. Reference images (M00 and 00) are also given for comparison.

Figure 6 shows plots of the Stokes vectors for all images evaluated corresponding to the maximum and minimum magnitudes of each of the image quality metrics (SNR, ENT & ACU) on Poincaré spheres. The value on the sphere gives the polarization state that corresponded to images that were evaluated. The vectors with large circles give the polarization states of the images that were preferred for images of specific ONH features. The metrics that were maximized or minimized are labeled. The vectors indicate that images containing circular/elliptical polarization were preferred to linear polarization alone.

As used herein, the terms "comprises" and "comprising" are to be construed as being inclusive and open ended, and not exclusive. Specifically, when used in this specification including claims, the terms "comprises" and "comprising" and variations thereof mean the specified features, steps or components are included. These terms are not to be interpreted to exclude the presence of other features, steps or components.

The foregoing description of the preferred embodiments of the invention has been presented to illustrate the principles of the invention and not to limit the invention to the particular embodiment illustrated. It is intended that the scope of the invention be defined by all of the embodiments encompassed within the following claims.

References:

1. JM Bueno & MCW Campbell (2002), Opt Let 27:830;

2. SI Guthrie et al. (2004), Invest Ophthalmol Vis Sci 45: E-Abstract 2796 ;

3. SA Burns et al. (2003) Invest Ophthalmol Vis Sci 44:4061.

4. A Weber et al. (2004), Opt Express 12:5178.

THEREFORE WHAT IS CLAIMED IS:

1. An apparatus for imaging the fundus of the eye using polarized light, comprising:

a light source for generating a beam of light;

an optical element configured to generate desired non-linear polarization states of light in said beam of light;

light directing and focusing means for directing the beam of light containing the non-linear polarization states onto the fundus of the eye; and

fundus imaging detector for receiving images of the fundus of the eye after illumination by the light having the desired non-linear polarization states.

2. The apparatus according to claim 1 wherein said fundus imaging detector is selected from the group consisting of fundus cameras, scanning laser ophthalmoscopes, confocal scanning laser ophthalmoscopes and optical coherence tomography instruments, with or without wavefront correction.

3. The apparatus according to claim 1 or 2 wherein said light source and said optical element are configured to generate any one of circularly polarized light alone, elliptically polarized light alone, a combination of elliptically polarized light and depolarized light, and a combination of circularly polarized light and depolarized light.

4. The apparatus according to claim 1 including a light depolarizing element located between the optical element and the eye for producing polarization states having a mixture of polarized light and depolarized light in said beam of light.

5. The apparatus according to claim 1 wherein said light source produces linearly polarized light, and wherein said optical element is an optical retarder plate.

6. The apparatus according to claim 1 wherein said light source produces linearly polarized light, and wherein said optical element is a quarter wave

plate, and including a rotation mechanism connected to said quarter wave plate wherein rotating said quarter wave plate to a first position with respect to an axis of linear polarization of the linearly polarized light entering said quarter wave plate generates elliptically polarized light, and wherein rotating said quarter wave plate to a second position with respect to an axis of linear polarization of the linearly polarized light entering said quarter wave plate for generates circularly polarized light.

7. The apparatus according to any one of claims 1 to 6 wherein said light directing and focusing means for directing the beam of light containing the non-linear polarization states onto the fundus of the eye includes an X-Y scanning stage configured to provide displacement of the light beam with respect to the fundus at the rear of the eye.

8 . The apparatus according to claim 7 wherein said fundus imaging detector includes a detector and a confocal pinhole and associated collection optics for focusing images of the fundus onto said detector.

9. A method for imaging the fundus of the eye using polarized light, comprising:

a) generating non-linear polarization states of light in a beam of light;

b) directing and focusing the non-linearly polarized beam of light onto the fundus of the eye; and

c) directing and focusing a reflected beam of light containing information of the fundus of the eye onto a detector and producing images of the fundus.

10. The method according to claim 9 including analyzing said images of the fundus.

11. The method according to claim 9 wherein said step of generating non-linear polarization states of light in a beam of light includes generating any one of circularly polarized light alone, elliptically polarized light alone, a combination of elliptically polarized light and depolarized light, and a

combination of circularly polarized light and depolarized light.

12. The method according to claim 9 wherein said non-linear polarization states of light includes any non-linear polarization state generated by combining circularly polarized light with linear polarized light in any direction to produce any type of elliptically polarized light.

13. The method according to claim 9 wherein said step of generating non-linear polarization states of light in a beam of light includes producing two perpendicular polarizations of light with differing relative intensities incident on a retarder which causes the two polarizations to be out of phase by an amount different from 0 degrees thereby producing elliptically polarized light.

14. The method according to claim 14 wherein said two polarizations are out of phase by an amount of 90 or 180 degrees.

15. The method according to claim 9 wherein said step of generating non-linear polarization states of light in a beam of light includes producing two oppositely rotating circular polarizations of light with differing relative intensities and combining the two oppositely rotating circular polarizations of light thereby producing elliptically polarized light.

16. The method according to claim 10 including repeating steps a), b) and c) for four different states of polarization of the input light beam including circularly and elliptically polarized states of light, and wherein said step of analyzing said images of the fundus includes producing images corresponding to input light with circularly and elliptically polarized states other than those states used to record original images.

17. The method according to claim 9 wherein said step of generating non-linear polarization states of light includes generating elliptically or circularly polarized light in combination with depolarized light.

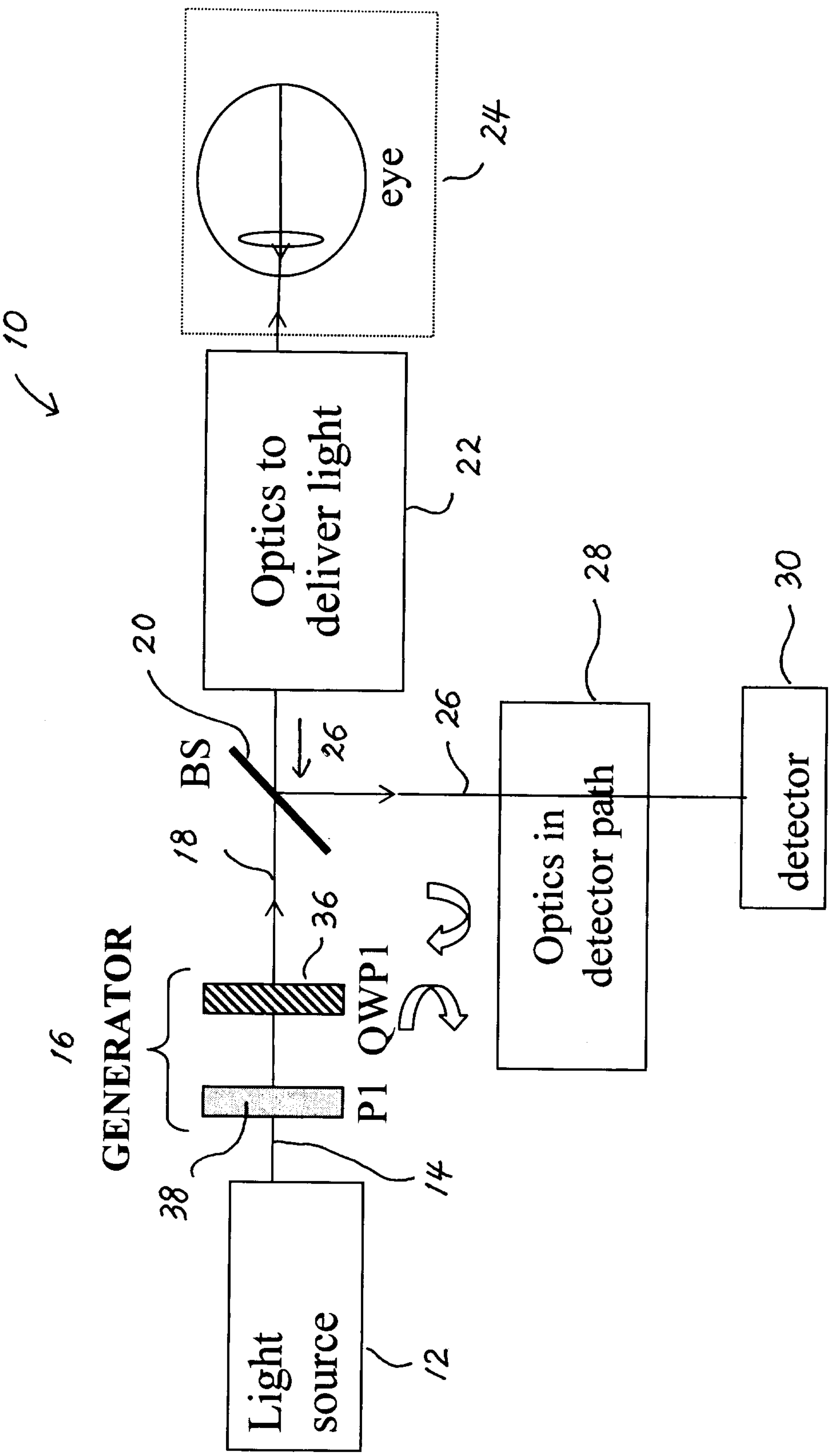
10
eye
24
Optics to deliver light
22
BS
20
26
26
28
Optics in detector path
30
detector
18
36
QWP1
GENERATOR
16
P1
38
14
Light source
12

Figure 1

$$\begin{pmatrix} S_0' \\ S_1' \\ S_2' \\ S_3' \end{pmatrix} = \begin{pmatrix} m_0 & m_0 & m_0 & m_0 \\ m_{10} & m_{11} & m_1 & m_{13} \\ m_2 & m_2 & m_2 & m_2 \\ m_{30} & m_{31} & m_3 & m_{33} \end{pmatrix} \cdot \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix}$$

Figure 2

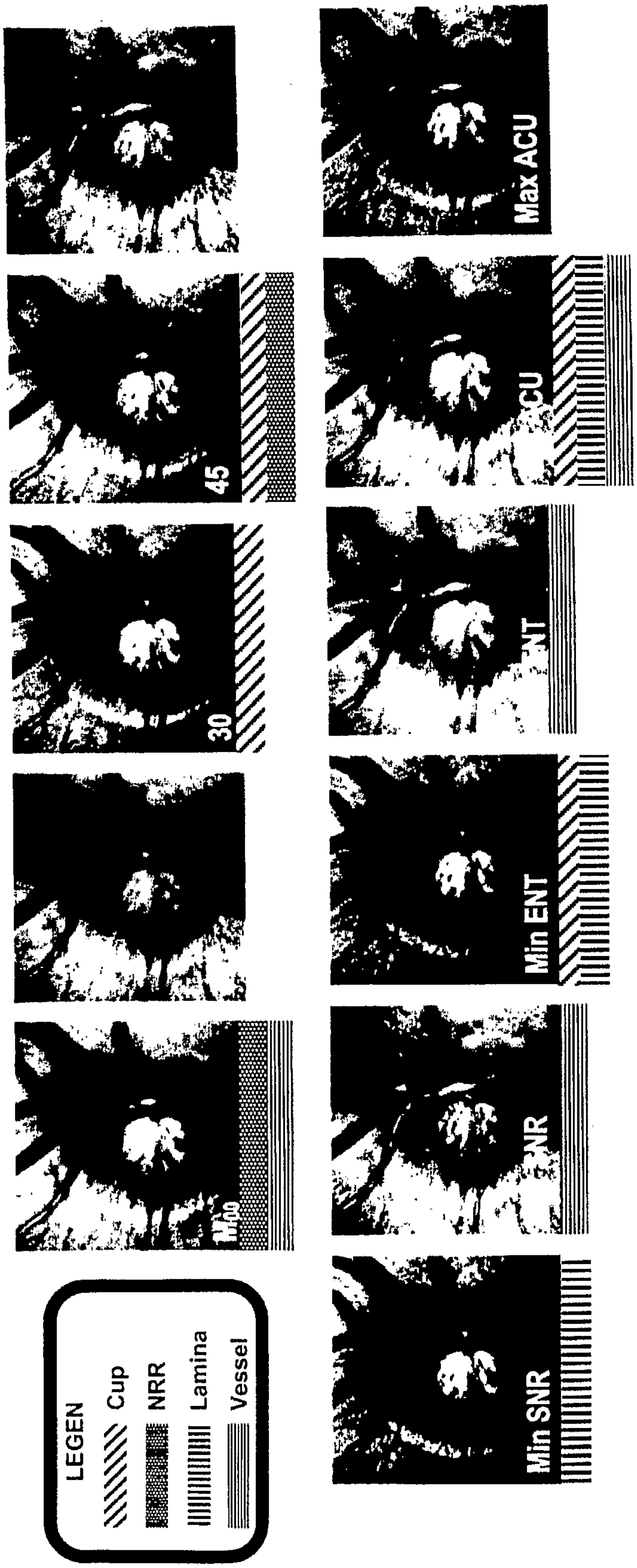

Figure 3

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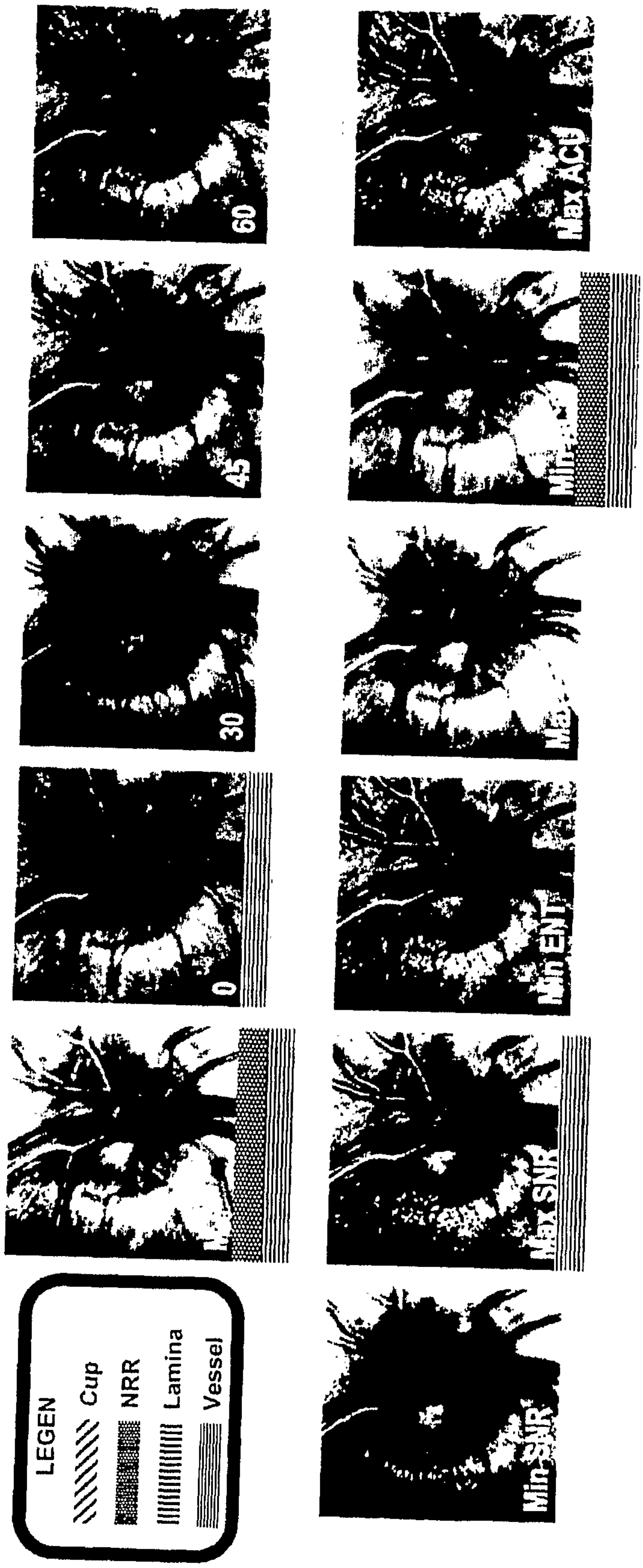
60
45
30
0
Max ACU
Min ENT
Max SNR
Min SNR
LEGEN
Cup
NRR
Lamina
Vessel

Figure 4

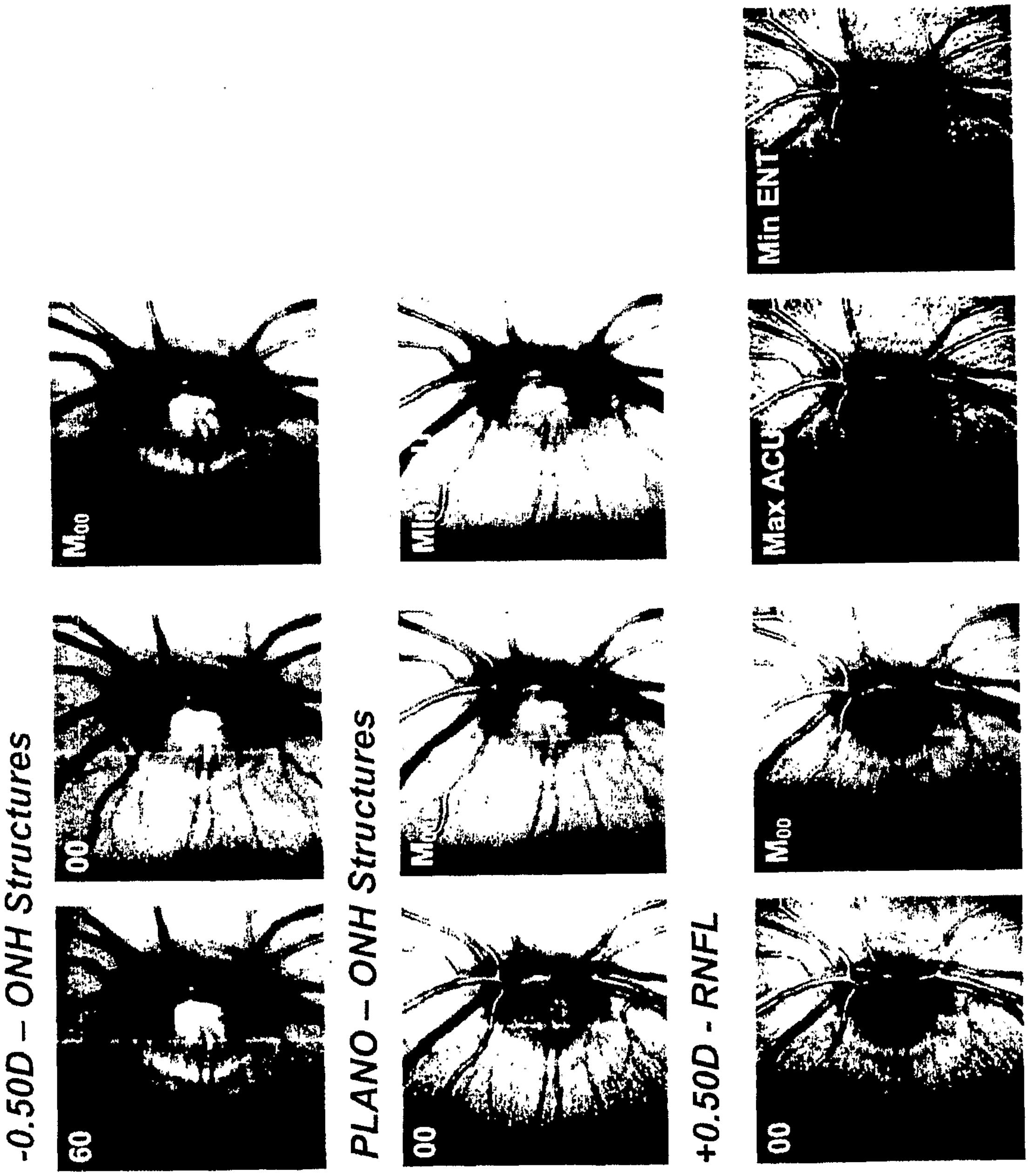
-0.50D – ONH Structures
PLANO – ONH Structures
+0.50D - RNFL
Min ENT
Max ACU

Figure 5

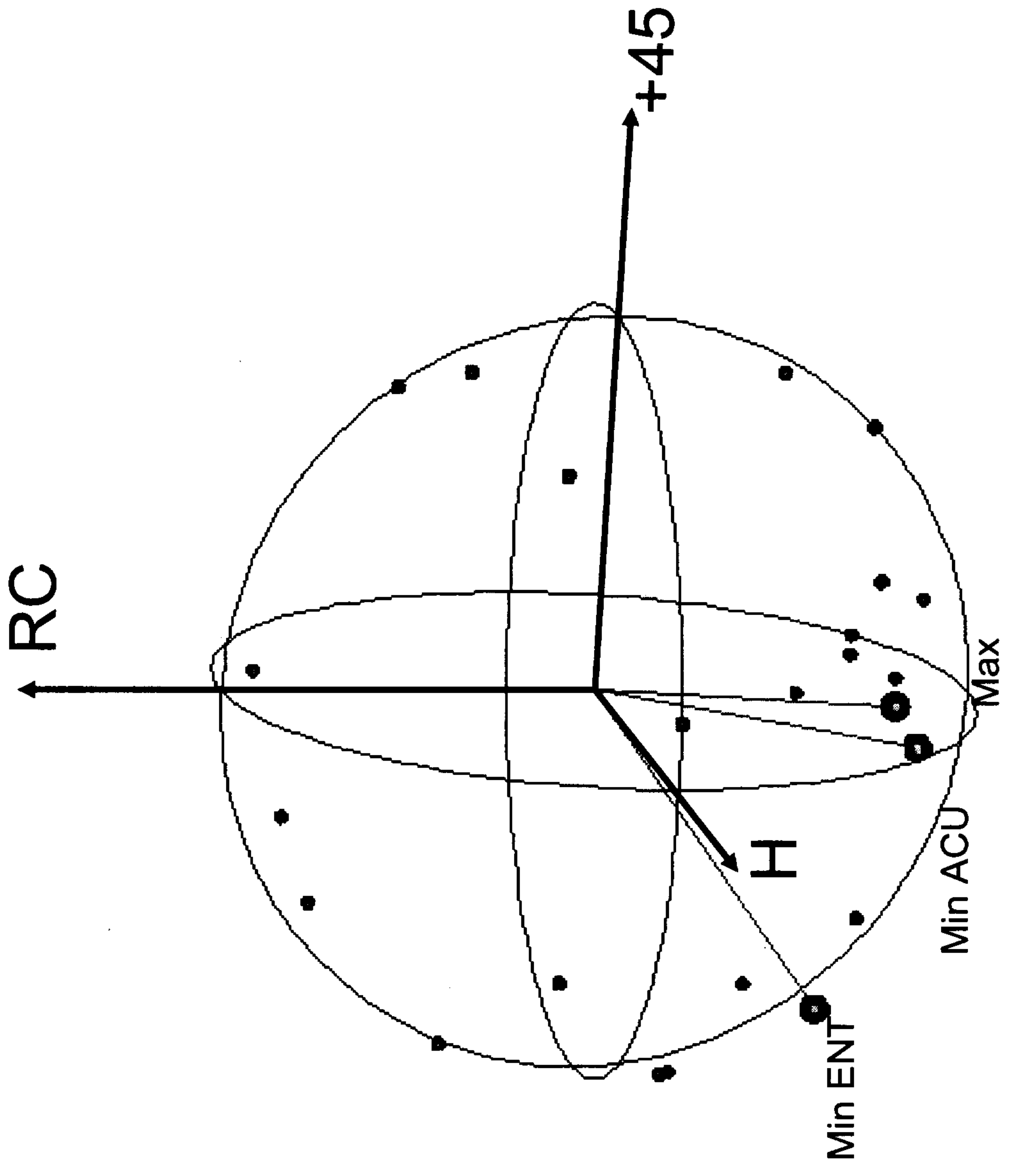

Figure 6a

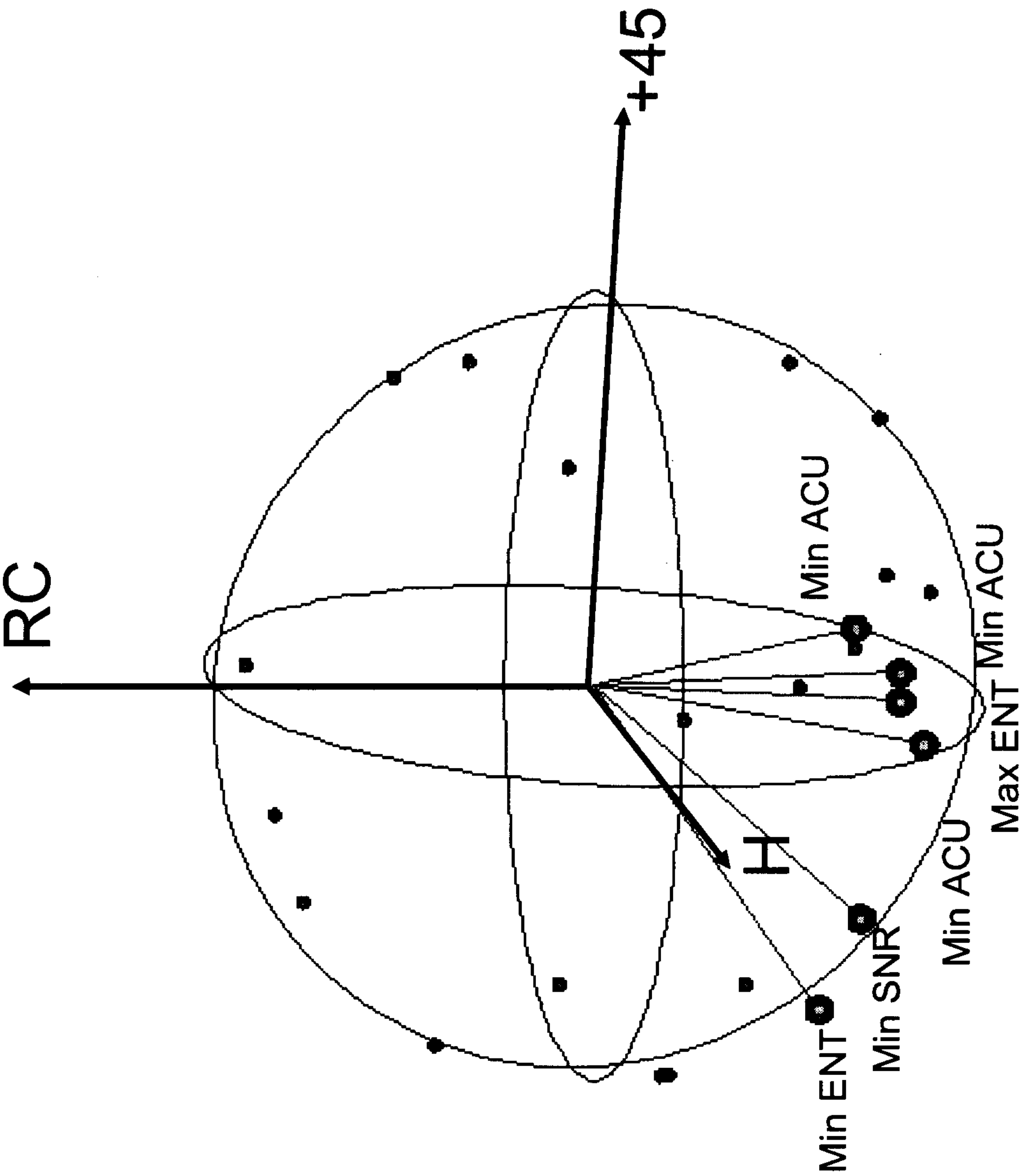

Figure 6b

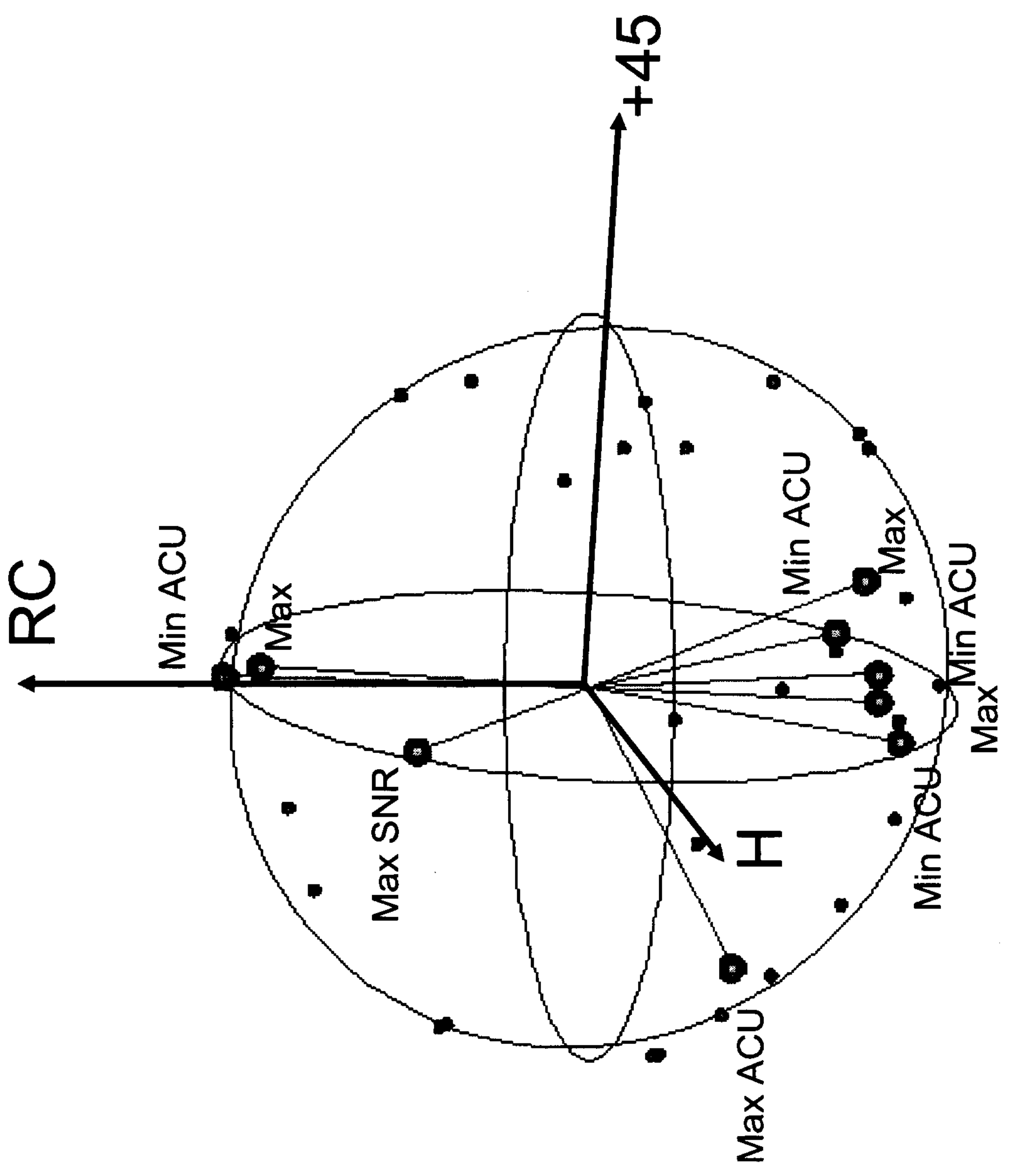
+45
RC
H
Min ACU
Max
Min ACU
Max
Min ACU
Max
Min ACU
Max SNR
Max ACU

Figure 6c

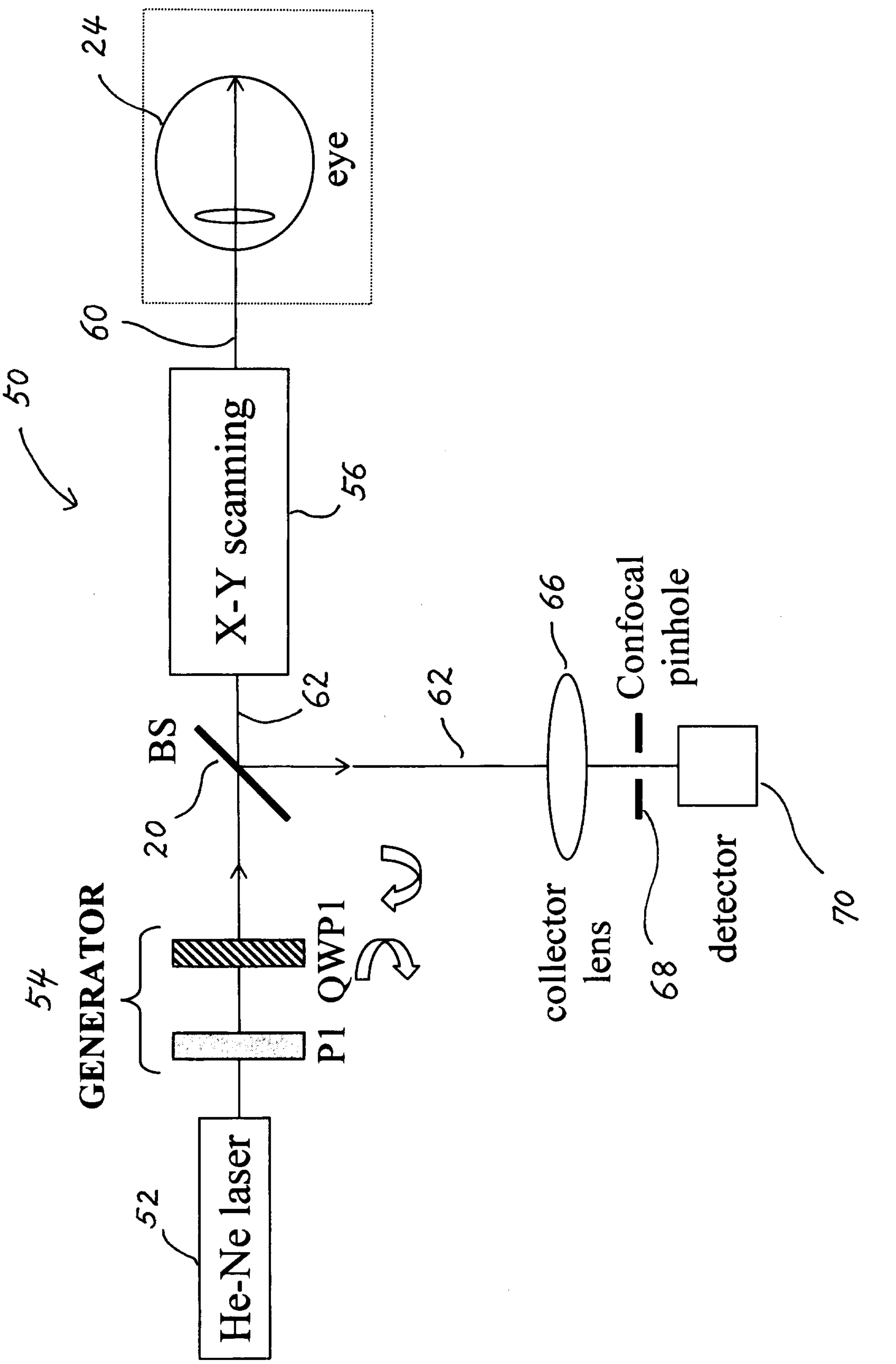
24
eye
60
50
X-Y scanning
56
62
BS
20
62
66
Confocal pinhole
collector lens
68
detector
70
54
GENERATOR
P1
QWP1
52
He-Ne laser

Figure 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2007/000750

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***A61B 3/12*** (2006.01)
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)
IPC: A61B-3/12; US classification: 351/—;

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Canadian Patent Database, Derwent, West, Delphion, Qpat, Espacenet, Internet search. Keywords: polariz*, circular*, elliptical*, fundus, retina, eye, retarder, quarter wave, imaging, photography.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X, Y	US 6,540,357 B1 (Ohnuma et al.), 1 April 2003 (01-04-2003), entire document.	1 to 4 and 6 to 17, 5
X, P Y, P	JP 200604517 A2 (Kikuta et al.), 10 August 2006 (10-08-2006), abstract.	1 to 4 and 6 to 17, 5
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A	GB 440,735 (Keeler), 6 January 1936 (06-01-1936), entire document.	1, 4 to 17
A	US 6,027,216 (Guyton et al.), 22 February 2000 (22-02-2000), entire document.	1 to 17

[ ] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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- "P" document published prior to the international filing date but later than the priority date claimed
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- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
2 August 2007 (02-08-2007)	28 September 2007 (28-09-2007)

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Raouf Ali Ahmed 819- 934-7572

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2007/000750

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