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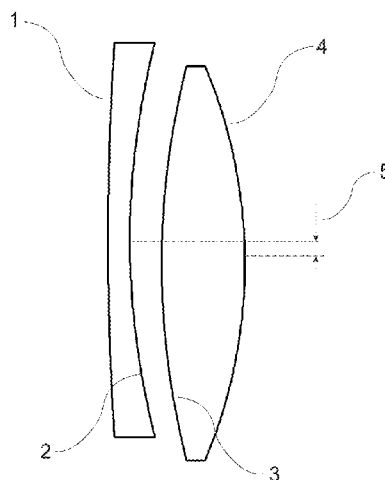
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

— *with international search report (Art. 21(3))*

(54) Title: INTRAOCULAR LENS WITH VARIABLE SHIFT

Figure 1



(57) Abstract: A novel IOL includes variable tilt of which the degree can be affected by the wearer by moving the optical elements with the natural accommodative apparatus of the eye. The wearer of the VS-IOL can tilt the optical axis, and shift the image, to a healthy sector of the macula for improved vision. Modern diagnostic equipment can now identify the healthy and blind sectors of the macula and the VS-IOL can be designed accordingly by, for example, adjusting the range of shift the initial angle of shift.

Intraocular lens with variable shift

The invention is a specific intraocular lens (henceforth: “ IOLs”) with variable optical aberrations according to WO2008,071,760 which document is incorporated in full in
5 the present document by reference.

The IOLs have two optical elements of which at least one is movable relative to the other in a direction perpendicular to the optical axis and wherein the elements have such a shape that their combination results in a lens providing at least one variable
10 optical aberration of which the degree of variation depends on the degree of movement of the optical elements. The IOL described in this document includes variable tilt, resulting in a shift of the image, of which the degree of tilt can be affected by the wearer by moving the optical elements with the natural accommodative apparatus of the eye. Note that “tilt” is the optical term referring to the direction of light and “shift”
15 of the image referring to the position of the image on the retina; the IOL is referred to henceforth as “VS-IOL”, Variable-Shift-IOL. The man skilled in the art will conclude that any aberration, including tilt, can be designed according to formulas and method described in WO2008,071,760. Such variable tilt is of benefit for treatment of Age-related Macula Degeneration (henceforth: “AMD”), which is an common ailment
20 which afflicts the retina, including the macula and fovea (retina, macula and fovea referred to henceforth as “macula”). Generally AMD affects a limited number of spots or sectors on the macula, especially at the onset of the ailment.

The wearer of the VS-IOL can affect tilt voluntarily by the natural accommodation
25 apparatus of the eye, and thus shift the image to a healthy sector of the macula for improved vision. Modern diagnostic equipment can now identify the healthy and blind sectors of the macula and the VS-IOL can be designed accordingly by, for example, adjusting the range of shift the initial angle of shift to maximize the effect. The sulcus is the preferred position of the VS-IOL, a position described in detail in WO2009,051,477
30 for accommodating IOLs of similar mechanical design. The VS-IOL and the concept of variable tilt is novel. Note that an VS-IOL with a fixed tilt can be designed by limiting

said range of tilt in, optionally, a combination with a preferred initial angle of permanent tilt.

It should be noted that a VS-IOL can include additional variable optical functions. For example, parabolic terms for tilt and shift of the image can be combined with, for example, cubic terms for a accommodative function.

The VS-IOL has, at least two, optical elements of which, at least one, is movable relative to the other in a direction perpendicular to the optical axis. The optical elements are fitted in a construction (similar to the construction described in US2009,062,912) which allows for such movement and which is coupled to the natural accommodative apparatus of the eye. At least one of the optical elements has, at least one, optical surface adapted to provide for a variable tilt, shift of the image, of which the degree of tilt depends on the degree of movement of the optical elements.

The application such IOLs is for accommodating IOLs of which the defocus aberration of the lens can be adjusted by the wearer with the natural accommodation apparatus of the eye as described in, for example, US2008,046,076 (basic optics), WO2009,051,477 (positioning in the eye) and US2009,062,912 and NL1028496 (construction and optics). The VS-IOL is largely similar to these IOL designs except that the optical surfaces of the VS-IOL are adapted to pre-dominantly provide variable tilt which can be combined with other variable optical functions such as accommodation. .

Prior to manufacturing of the individual VS-IOL its specifications are defined, including, but not restricted to: - size of the VS-IOL construction (for proper mechanical functioning in the individual eye), - required fixed optical power (for proper correction of the refraction of the eye, a common procedure for all IOLs) - range of required tilt (based on the pattern of AMD of the individual eye; range expressed as, for example, degrees of shift of the image per unit of movement of the optical elements), - initial starting point of the variable shift (for example, a fixed tilt can direct the focal beam to a required starting position for the range). Such customization maximizes the improvement of vision.

Figure 1. Cross section of the two-element intraocular lens for variable tilt. The anterior surface of the anterior optical element, 1, has a limited optical function, the posterior surface of the anterior element, 2, has an optical surface for variable tilt, in this example
 5 a parabolic surface, the anterior surface of the posterior element, 3, has the complementary surface for variable tilt, in this example, a parabolic surface, the posterior of the posterior element, 4, has a spherical surface for correction of the refraction of the eye. The range of movement of the optical elements is indicated by 5.

10 Figure 2. Graph showing the shift of the focal spot which depends on movement of the optical elements. Note that this is an example. The effects can differ based on the individual VS-IOL.

The lens has two optical surfaces to produce primarily a variable tilt of the transmitted
 15 light beam resulting in a shift of the image which effect can be combined with, optionally, other variable higher-order Zernike aberrations. The shift of the image and Zernike aberrations depend linearly on the relative displacement of the optical surfaces. Assuming that the direction of displacement coincides with the X-axis, the sag function of the optical surface can be written as

20

$$z = S(x, y) = \frac{P}{4}(x^2 + y^2) + \frac{1}{2} \int \sum_q C_q Z_q(x, y) dx, \quad (1)$$

where P is the tilt amplitude and C_q is the modal coefficient corresponding to the q -th Zernike aberration term. If two optical elements with surfaces according to Eq. (1) are
 25 shifted by Δx (movement for each surface) in opposite directions, the resulting Optical Path Difference (OPD) becomes:

$$OPD = (n-1)Px \Delta x + (n-1)\Delta x \sum_q C_q Z_q(x, y) + (n-1)R(x, y, \Delta x), \quad (2)$$

30 With n the refractive index of the material. As follows from Eq. (2), the resulting OPD includes:

1. First term, $(n-1)Px \Delta x$, variable tilt which changes linearly with Δx ;
2. Second term, $(n-1)\Delta x \sum_q C_q Z_q(x, y)$, all Zernike terms, Z_q , including defocus.

The amplitudes of these terms linearly vary with Δx .

3. The residual term, $(n-1)R(x, y, \Delta x)$, originates from higher-order shift-
- 5 dependent contributions Δx^3 , Δx^5 , *etc.* When $\Delta x \ll 1$, these contributions are negligibly small.

Claims

1. Intraocular lens comprising at least two optical elements, at least one of which is movable relative to the other in a direction perpendicular to the optical axis, which lens is coupled to the natural accommodative apparatus of the eye **characterized in that** at least one of the optical elements includes at least one optical surface adapted to provide for a variable tilt of which the degree of tilt depends on the degree of movement of the optical elements.
2. Intraocular lens according to claim 1 **characterized in that** the lens has at least one additional optical surface which is adapted to simultaneously provide for variable defocus.
3. Intraocular lens according to foregoing claims **characterized in that** the sag function of the optical surfaces is according to

$$z = S(x, y) = \frac{P}{4}(x^2 + y^2) + \frac{1}{2} \int \sum_q C_q Z_q(x, y) dx$$

1/1

Figure 1

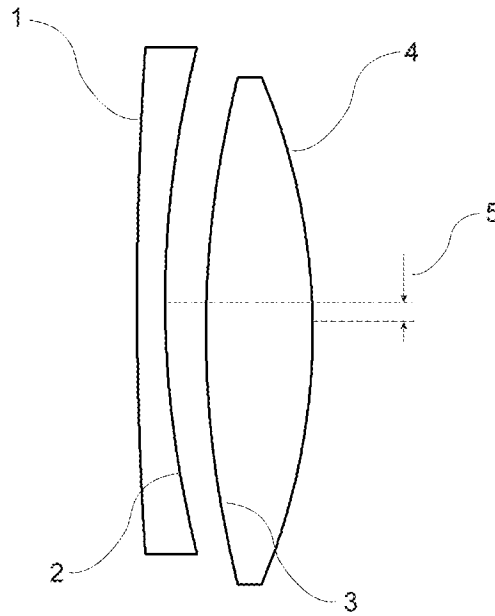
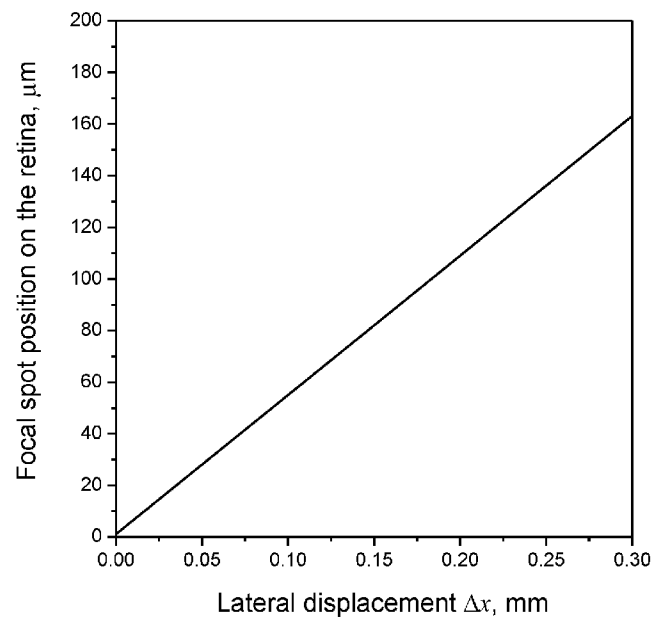


Figure 2



INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2010/050270

A. CLASSIFICATION OF SUBJECT MATTER

INV. A61F2/16
ADD.

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)
A61F

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

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2008/071760 A2 (AKKOLENS INTERNAT B V [NL]; ROMBACH MICHIEL CHRISTIAAN [NL]; SIMONOV A) 19 June 2008 (2008-06-19) cited in the application	1,2
Y	page 3, line 24 - page 19, line 24; claim 15; figures 2-6	3
X	WO 2007/015640 A1 (AKKOLENS INTERNAT B V [NL]; ROMBACH MICHIEL CHRISTIAAN [NL]) 8 February 2007 (2007-02-08)	1
Y	page 6, line 11 - page 11, line 12; claim 1 claims 1,9; figures 1,2	3

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

☒ See patent family annex.

* Special categories of cited documents :

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

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2008071760 A2	19-06-2008	CN 101568312 A	28-10-2009
		EP 1932492 A1	18-06-2008
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		US 2009024214 A1	22-01-2009