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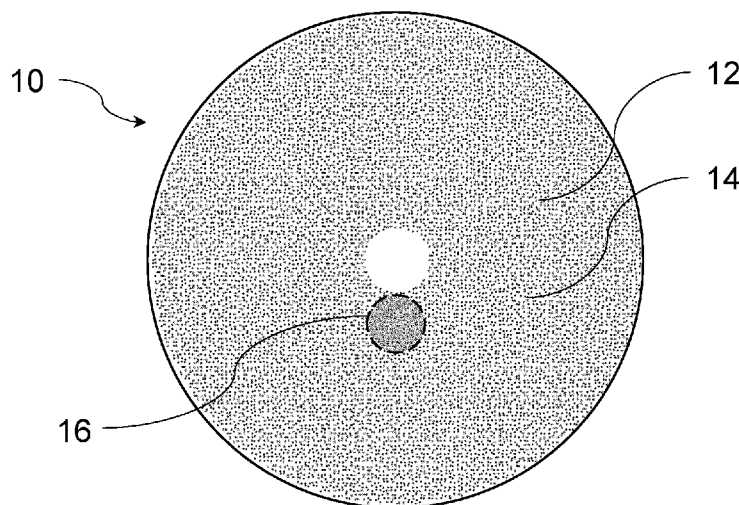


Fig. 1

(57) Abstract: An optical lens intended to be worn in front of an eye of a wearer to correct a vision impairment and to slow down the progression of said vision impairment, the optical lens comprising a pattern of microstructures, wherein over a pupil area having a diameter equal to or greater than 4.0 mm and including at least part of the microstructures, the optical lens produces a first optical path difference map (OPD1), wherein over said pupil area, the pattern of microstructures produces constant phase shifting so that the differential optical path map (DOP), being the difference between said first optical path difference map (OPD1) and a second smooth optical path difference map (OPD2), is a piecewise constant of at least two levels, characterized in that over said pupil area, an image quality (Q1) measured at a first wavelength (λ_1) is at least 10% lower than a retinal image quality (Q2) measured at a second wavelength (λ_2).



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CHROMATIC OPTIMIZARTION OF PHASE-SHIFT DESIGNS FOR MYOPIA
CONTROL

TECHNICAL FIELD

5 [0001] The disclosure relates to an optical lens, and in particular to an optical lens comprising a pattern of microstructures.

BACKGROUND

10 [0002] In recent years, there has been a rise in the development of solutions aimed at controlling the progression of abnormal refraction in the eye, such as myopia. One of the most promising solutions proposes to create a defocus in front of the retina that generates a myopia stop signal controlling the elongation of the eye and slowing down the progression of myopia. These new myopia control lenses consist of lenses comprising microlenses that refract part of the light in front and/or behind of the retina of the eye of the wearer.

15 [0003] A recent study published in 2022 by Swiatczak and Schaeffel, "*Myopia: why the retina stops inhibiting eye growth*" has demonstrated that "focus in red" images have a beneficial impact on eye elongation, while "focus in blue" images have a bad impact. Another similar study "Chromatically simulated myopic blur counteracts a myopiagenic environment" published in 2022 by Gawne et al, has shown the advantage to blur the blue channel. Thus, it appears that Longitudinal Chromatic Aberrations (LCA) create signals that can have an important role on the
20 abnormal refraction progression.

[0004] While the existing myopia control solutions have demonstrated high efficacy, they often come with a trade-off, as they may diminish the wearer's visual acuity and make the ophthalmic lenses less comfortable, particularly for the intended demographic of young individuals. Indeed, generating a defocus in front and/or behind the retina often leads to the
25 generation of visual artifacts and decrease in contrast.

[0005] Therefore, there is a need for a solution that can effectively stop, or at least decelerate the progression of abnormal refraction in the eye while preserving the wearer's optimal visual acuity.

[0006] The present disclosure aims to solve the above-mentioned problems of the prior art by providing a lens that correct a vision impairment of the wearer and reduce the contrast for specific range of wavelengths to reduce the impact on the visual acuity.

SUMMARY

[0007] To this end, the disclosure proposes an optical lens intended to be worn in front of an eye of a wearer to correct a vision impairment and to slow down the progression of said vision impairment of the eye of the wearer, the optical lens comprising a pattern of microstructures, wherein over a pupil area having a diameter equal to or greater than 4.0 mm and including at least part of the microstructures, the optical lens produces a first optical path difference map (OPD1), wherein over said pupil area, the pattern of microstructures produces constant phase shifting so that the differential optical path map (DOP), being the difference between said first optical path difference map (OPD1) and a second smooth optical path difference map (OPD2), is a piecewise constant of at least two levels, characterized in that over said pupil area, an image quality (Q1) measured at a first wavelength (λ_1) is at least 10% lower than a retinal image quality (Q2) measured at a second wavelength (λ_2).

[0008] Advantageously, the optical lens allows reducing the image contrast for part of the visual spectrum, while maintaining a good visual acuity for the rest of visual spectrum. In other words, the optical lens provides an optimized balance between the effect of correcting a visual impairment of the eye of the wearer and the effect of slowing down the progression of said visual impairment.

[0009] According to further embodiments which can be considered alone or in combination:

[0010] – the image quality is based on a Strehl ratio, and/or a Modulation Transfer Function (MTF), and/or a power error, and/or an astigmatism error, and/or a fraction of encircled energy radius, and/or, a spot diagram radius, and/or a point spread function (PSF), and/or an optical

transfer function (OTF), and/or a visual Strehl ratio (VSX, VSOTF, VSMTF), and/or a wavefront aberrations; and/or

[0011] – the value of the modulation transfer function (MTF) measured over the pupil area for wavelength (λ_1) over a range of spatial frequencies comprised from 1 to 5, for example 1 to 10, cycles per degree is smaller than the value of the modulation transfer function (MTF) measured over the same pupil area for wavelength (λ_2) over the same range of spatial frequencies; and/or

[0012] – at least part, for example all, of the microstructures are diffractive microstructures; and/or

[0013] – at least part, for example all, of the microstructures are diffusive microstructures; and/or

[0014] – the microstructures have a pillar shape; and/or

[0015] – the pillar shaped microstructures have a lateral resolution greater than or equal to 250 nm, preferably 1.0 μm , more preferably 3.0 μm , for example 10 μm , and smaller than or equal to 100 μm , for example 2.0 mm.; and/or

[0016] – the pillar shaped microstructures have a height greater than or equal to 0.1 μm , and smaller than or equal to 10 μm .; and/or

[0017] – the pillar shaped microstructures further comprises a plurality of at least two subsets of pillar shaped microstructures having different height; and/or

[0018] – at least part, for example all, of the microstructures are located on a front surface of the optical lens, and/or on a back surface of the optical lens, and/or in between a front surface and a back surface of the optical lens; and/or

[0019] – the density of microstructures over the pupil area is greater than or equal to 10 % and smaller than or equal to 80 % of the surface of the pupil area; and/or

[0020] – the microstructures are homogeneously distributed on the optical lens; and/or

- [0021] – the microstructures are organized in a plurality of concentric rings; and/or
- [0022] – the microstructures are randomly distributed on the optical lens; and/or
- [0023] – the first wavelength (λ_1) is comprised between 400 nm and 500 nm, and the second wavelength (λ_2) is comprised between 500 nm and 750 nm.

5 BRIEF DESCRIPTION OF THE DRAWINGS

[0024] Embodiments of the disclosure will now be described, by way of example only, and with reference to the following drawings in which:

- Figure 1 illustrates a schematic front view of an optical lens according to an embodiment of the disclosure;
- 10 - Figure 2 illustrates a close up view of the schematic front view of an optical lens according to an embodiment of the disclosure;
- Figure 3 illustrates a schematic profile view of a lens element according to an embodiment of the disclosure;
- Figure 4 illustrates a perspective close up view of an optical lens according to an
15 embodiment of the disclosure;
- Figures 5 illustrates a graph of the differential optical path of the pattern of microstructures according to an embodiment of the disclosure; and
- Figures 6 illustrates a graph of MTF curves of an optical lens according to an embodiment of the disclosure.

20 [0025] Elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figure may be exaggerated relative to other elements to help to improve the understanding of the embodiments of the present disclosure.

DETAILED DESCRIPTION

[0026] In the reminder of the description, terms like « up », « bottom », « horizontal », « vertical », « above », « below », « front », « rear » or other words indicating relative position may be used. These terms are to be understood in the wearing conditions of the optical lens.

5 [0027] The disclosure relates to an optical lens 10 intended to be worn in front of an eye of a wearer in specific wearing conditions, for example in standard viewing conditions.

[0028] In the context of the present disclosure, the term "optical lens" can refer to a contact lens or an optical lens or a spectacle optical lens edged to fit a specific spectacle frame or an ophthalmic lens or a progressive multifocal addition lens, or an optical device adapted to be
10 positioned on the ophthalmic lens. The optical device may be positioned on the front or back surface of the ophthalmic lens. The optical device may be an optical patch or film. The optical device may be adapted to be removably positioned on the ophthalmic lens for example a clip configured to be clipped on a spectacle frame comprising the ophthalmic lens.

[0029] The wearing conditions are to be understood as the position of the optical lens with
15 relation to the eye of a wearer, for example defined by a pantoscopic angle, a wrap angle, a Cornea to lens distance, and eventually any of a Pupil-cornea distance, a center of rotation of the eye (CRE) to pupil distance, a CRE to lens distance and.

[0030] The Cornea to lens distance is the distance along the visual axis of the eye in the primary position (usually taken to be the horizontal) between the cornea and the back surface of
20 the lens; for example comprised between 8 and 16 mm, preferably 10 and 14 mm, more preferably equal to 12mm.

[0031] The Pupil-cornea distance is the distance along the visual axis of the eye between its pupil and cornea; usually comprised between 1 and 4 mm, for example equal to 2mm.

[0032] The CRE to pupil distance is the distance along the visual axis of the eye between its
25 center of rotation (CRE) and cornea; for example comprised between 10 and 15 mm, preferably 11 and 12 mm, more preferably equal to 11.5mm.

[0033] The CRE to lens Q'O distance is the distance along the visual axis of the eye in the primary position (usually taken to be the horizontal) between the CRE of the eye and the back surface of the lens, for example comprised between 20 and 30 mm, preferably 22.5 and 28 mm, more preferably equal to 25.5mm.

5 [0034] The pantoscopic angle is the angle in the vertical plane, at the intersection between the back surface of the lens and the visual axis of the eye in the primary position (usually taken to be the horizontal), between the normal to the back surface of the lens and the visual axis of the eye in the primary position; for example comprised between -25° and $+5^{\circ}$, preferably -12° and 0° , more preferably between -10° and -6° , for example equal to -8° , preferably equal to 0° .

10 [0035] The wrap angle is the angle in the horizontal plane, at the intersection between the back surface of the lens and the visual axis of the eye in the primary position (usually taken to be the horizontal), between the normal to the back surface of the lens and the visual axis of the eye in the primary position for example comprised between -10° and $+25^{\circ}$, preferably 0° and 10° , more preferably between 0° and $+5^{\circ}$, for example equal to 0° .

15 [0036] An example of standard wearing condition may be defined by a pantoscopic angle of -8° , a Cornea to lens distance of 12 mm, a Pupil-cornea distance of 2 mm, a CRE to pupil distance of 11.5 mm, a CRE to lens distance of 25.5 mm and a wrap angle of 0° .

[0037] Another example of standard wearing condition more adapted for younger wearers may be defined by a pantoscopic angle of 0° , a Cornea to lens distance of 12 mm, a Pupil-cornea
20 distance of 2 mm, a CRE to pupil distance of 11.5 mm, a CRE to lens distance of 25.5 mm and a wrap angle of 0° .

[0038] The optical lens may be adapted for a wearer, to correct a vision impairment and to slow down the progression of said vision impairment of the eye of the wearer. In the following disclosure, the vision impairment will be considered to be a myopia of an eye of the wearer.
25 However, the present disclosure is not limited to myopia. In particular, the person skilled in the art will be able to adapt the present disclosure to other kind of vision impairment such as hyperopia, astigmatism among others.

[0039] The optical lens is adapted for a wearer according to a prescription to restore a presbyope's ability to see clearly at all distances, but also to optimally respect all physiological visual functions such as foveal vision, extra-foveal vision, binocular vision and to minimize unwanted astigmatisms.

5 [0040] The term "prescription" is to be understood to mean a set of optical characteristics of optical power, of astigmatism, of prismatic deviation, determined by an ophthalmologist or optometrist in order to correct the vision defects of the eye, for example by means of a lens positioned in front of his eye. For example, the prescription for a myopic eye comprises the values of optical power and of astigmatism with an axis for the distance vision. The prescription may
10 comprise an indication that the eye of the wearer has no defect and that no refractive power is to be provided to the wearer.

[0041] The prescription in ophthalmic field may comprise, in addition to the power prescription, an astigmatism prescription. Such a prescription is composed of an axis value (in degrees) and a module value (in diopters). The module value represents the difference between the
15 maximal and minimal power in a given direction allowing to correct the visual default of a wearer. Following the convention, the axis represents the orientation of one of the two powers versus a reference axis and following a given rotation direction. TABO convention may be used. In this convention the reference axis is horizontal and the rotation direction is counterclockwise when looking at the wearer. A 45° axis corresponds to an axis orientated obliquely linking, when looking
20 at the wearer, the upper right quadrant to the lower left quadrant. Such an astigmatism prescription is measured for the wearer in far vision. The term 'astigmatism' is used to refer to the couple (module, axis). That term is sometimes used to simply designate the module. The skilled person easily understands what it refers to depending on the context. The skilled person is also aware that the power/astigmatism prescription for a wearer is commonly described with the terms sphere,
25 cylinder and axis.

[0042] As represented in figures 3, the optical lens 10 comprises a substrate 12. The substrate 12 comprises at least a first surface and a second surface opposed to the first surface. For example, the first surface may comprise an object side surface F1 formed as a convex curved surface toward an object side and the second surface may comprise an eye side surface F2 formed as a concave

surface. Alternatively, the object side surface F1 and/or the eye side surface F2 may be any one of a plano surface, a convex surface, or a concave surface.

[0043] The optical lens 10 may be made of any suitable material such as organic material, for example polycarbonate, plastic, resin, or mineral material such as glass.

5 [0044] The eye side surface F1 and/or the object side surface F2 of the substrate 12 may have any suitable shape, such as spherical or non-spherical. The term "spherical shape" refers to the curvature of the lens surface, which closely follows the shape of a perfect or almost perfect sphere. A spherical surface has a substantially uniform curvature over the entire surface of the lens element, which remains substantially the same in all meridians. A non-spherical surface should be
10 understood as not being uniform over the entire surface of the lens element, with different curvatures in different meridians.

[0045] The eye side surface F1 and/or the object side surface F2 of the substrate 12 may have a toric shape. A toric surface has two principal meridians that are perpendicular to each other, often referred to as the "steep" and "flat" meridians. The curvature of the surface in these meridians is
15 different.

[0046] The eye side surface F1 and/or the object side surface F2 of the substrate 12 may have an aspherical shape. An aspherical surface has a curvature that progressively varies over the surface of the lens element. The curvature along different meridians varies from the geometrical center of the lens element towards the periphery, for example, the curvature of the surface increases
20 or decreases towards the peripheral part of the surface. The shape of an aspherical surface is typically described using a mathematical equation, such as a conic section or a polynomial equation.

[0047] The eye side surface F1 and/or the object side surface F2 of the substrate 12 may have progressive addition lens profile. In the sense of the disclosure, a "progressive addition lens profile
25 surface" should be understood as a surface comprising two areas having different spherical surface, and a third areas joining the two first areas, along which the curvature value of the surface transitions from the first the second curvature values of the corresponding two areas.

[0048] Alternatively, the eye side surface F1 and/or the object side surface F2 of the substrate 12 may have a plano shape. A plano surface has no curvature over the entire surface of the lens element.

[0049] At least one part, preferably all, of a surface of the optical lens 10 may be covered by at least one layer of coating element. The at least one layer of coating element may comprise features selected from the group consisting of anti-scratch, anti-reflection, anti-smudge, anti-dust, UV30 filtration, blue light-filtration, anti-abrasion features.

[0050] As illustrated in figures 1 to 3, the optical lens 10 comprises a pattern of microstructures 14.

[0051] As illustrated in figure 3A, the pattern of microstructures 14 is superimposed on the optical lens 10. In the sense of the disclosure, the expression “superimposed” should be understood as located on the front surface F1 of the substrate 12 of the optical lens 10 and/or on the back surface F2 of the substrate 12 of the optical lens 10, and/or in between the front and back surfaces of the optical lens.

[0052] As illustrated in figure 3B, the microstructures 14 may be encapsulated between the front and back surfaces of the substrate 12 of the optical lens 10. For example, the optical lens 10 may be formed by at least two sub-lens elements having complementary surfaces designed to fit precisely into the other to ensure a tight and secure fit when the two sub-lens element are brought and bonded together. The microstructures 14 may be disposed on any of the two complementary surfaces so that when the sub-lens are bonded together, the microstructures are encapsulated between them. The at least two sub-lens element are made of material having different indices of refraction.

[0053] Advantageously, having the microstructures encapsulated within the optical lens allows having an optical lens having a smooth back or eye side surface F1 and/or a front or object side surface F2.

[0054] In the sense of present disclosure, the term “smooth” refers to a state of surface of an optical lens in which the unevenness of said surface is smaller than or equal to 0.5 μm , for example

smaller than or equal to $0.4\ \mu\text{m}$. The term “unevenness of a surface” refers to the difference between a maximum value and a minimum value of the deviation distance from the most approximate sphere. The term “most approximate sphere” is a spherical shape calculated from a measured value (height distribution) of the surface using the least squares method. From the
5 viewpoint of the average surface power, the term “smooth” may be defined as follows. The term “smooth” refers to the state of a surface whose rate of change in the average surface power (unit: D) at a given position of the surface in a given direction is smaller than or equal to $0.5\ \text{D/mm}$, for example smaller than or equal to $0.4\ \text{D/mm}$.

[0055] As illustrated in figure 4, the microstructures 14 may preferably have a pillar shape.
10 The microstructures of the pattern may have a geometrical structure taking the form of slender pillars standing substantially perpendicular to the surface of the optical lens.

[0056] The pillar shaped microstructures may have a height greater than or equal to $0.01\ \mu\text{m}$, and smaller than or equal to $100\ \mu\text{m}$, for example greater than or equal to $0.1\ \mu\text{m}$, and smaller than or equal to $10\ \mu\text{m}$.

15 [0057] The pillar shaped microstructures may have a width greater than $0.1\ \mu\text{m}$ and smaller than or equal to $1.0\ \text{mm}$, for example, greater than $1.0\ \mu\text{m}$ and smaller than or equal to $100\ \mu\text{m}$. The pillars may have a substantially uniform cross-sectional shape, which may be circular, square, hexagonal, or any another geometric configuration.

[0058] The pillar shaped microstructures have a lateral resolution greater than or equal to $250\ \text{nm}$, preferably $1.0\ \mu\text{m}$, more preferably $3.0\ \mu\text{m}$, for example $10\ \mu\text{m}$, and smaller than or equal to $100\ \mu\text{m}$, for example $50\ \mu\text{m}$.
20

[0059] The pattern of microstructures 14 may have a diffractive optical function that diffracts, bends or spread incident light in specific ways. For example, the diffractive optical function may control the phase and amplitude of the diffracted light, using interference of light waves to modify
25 the shape of the incident light beam into a single focused point. Alternatively, the diffractive optical function can split a single incident beam of light into multiple beams, redirecting them along different paths.

[0060] Alternatively, the pattern of microstructures 14 may have a diffusive optical function that diffuses or scatters incident light in various directions.

[0061] Taken independently, a microstructure forming the pattern of microstructures has no geometrical power, and thus does not create a defocus in front and/or behind the retina of the
5 wearer.

[0062] The pattern of microstructures 14 is designed to provide a constant phase shift of light which reduces the contrast of images formed at the retina level, at least for specific ranges of wavelengths. Advantageously, the image contrast reduction allows slowing down the progression of the visual impairment of the eye of the wearer.

10 [0063] As illustrated in figure 1, the microstructures forming the pattern of microstructures 14 may be homogeneously, or regularly, distributed over the optical lens 10. For example, the microstructures may be distributed over the entire surface of the optical lens.

[0064] The microstructures forming the pattern of microstructures 14 may be organized along a plurality of concentric rings.

15 [0065] Alternatively, the microstructures may be organized along a triangular mesh, a square mesh, a hexagonal mesh, or any other suitable arrangement. For example, the microstructures may be randomly distributed over the optical lens.

[0066] As illustrated in figure 1, the optical lens 10 may comprise a central zone free of microstructures. The central zone is preferably centered on an optical center and/or a geometrical
20 center of the optical lens. The central zone free of microstructures may have a diameter greater than or equal to 2.5 mm, for example greater than or equal to 5.0 mm, more preferably greater than or equal to 7.5 mm.

[0067] According to an embodiment of the disclosure, the pattern of microstructures 14 of the optical lens 10 may comprise a plurality of subsets, for example at least two subsets, of
25 microstructures having different heights.

[0068] Advantageously, it allows obtaining different phase shift effects on incident light, allowing a finer tuning of the contract reduction effect and thus on the vision impairment progression slow down.

[0069] For example, the pattern of microstructures 14 may comprise a fist subset of microstructures having a first height disposed in a first annular area close to the geometrical center of the lens element and a second subset of microstructures having a second height, for example greater than the first height, and organized in a second annular area closer to the periphery of the optical lens.

[0070] Advantageously, such configuration allows improving the image contrast reduction for peripheral vision, thereby improving the effect of slowing down the progression of the vision impairment of the eye, while maintaining a good visual acuity for central vision.

[0071] As illustrated in figures 1 and 2, one can define a pupil area 16 having a diameter equal to or greater than 4.0 mm. It should be understood that the pupil area 16 does not correspond to a physical structure of the optical lens but serves as a tool for defining a zone of the optical lens over which measurements can be performed.

[0072] When measured over the pupil area 16 having a diameter equal to or greater than 4.0 mm, the density of microstructures over the pupil area, defined as the ratio of the sum of the areas covered by the microstructures and the total area of the pupil, is greater than or equal to 10 % and smaller than or equal to 90%, for example smaller than or equal to 80 %, of the total surface of the pupil area.

[0073] The optical lens 10 produces a first optical path difference map (OPD1) over a pupil area 16 including at least part of the microstructures and having a diameter equal to or greater than 4.0 mm.

[0074] The optical path difference (OPD) is a well-known feature describing the optical performances of an optical system. The optical path difference (OPD) refers to the discrepancy in optical path length experienced by light rays passing through different points on the optical lens surface. The optical path difference map provides a spatial distribution of the optical path

difference values across the optical lens. It essentially corresponds to a two-dimensional representation illustrating how the optical path length varies across the lens surface.

[0075] A second smooth optical path difference map (OPD2) may be defined over the same pupil area 16. In the context of the disclosure, a smooth optical path difference map should be understood as the optical path difference map of a theoretical lens having a spherical surface and a constant thickness. In other words, the smooth optical path difference map (OPD2) corresponds to a spatial distribution of the same optical path difference values over the optical lens. For example, the second smooth optical path difference map (OPD2) may correspond to the optical path difference map of the spherical lens that best fit the prescription adapted for the wearer or the average mean spherical power of the lens optical lens.

[0076] As illustrated in figure 5, the pattern of microstructures 14, when measured over the pupil area 16, produces constant phase shifting so that the differential optical path map (DOP), being the difference between the first optical path difference map (OPD1) and the second smooth optical path difference map (OPD2) is a piecewise constant of at least two levels.

[0077] To demonstrate the presence of at least two discrete levels within a DOP, a method involving the construction of a histogram can be employed. This histogram is created using the range of values obtained from the measurement, spanning from the minimum observed value to the maximum observed value. Each bin in the histogram represents a range of values, determined by a specified width Δ , Δ being the tolerance around a specific level. The presence of only two discrete levels in the measurement is confirmed if, and only if, exactly two bins within the histogram contain values. In other words, there should be two distinct peaks or populated bins, each representing a discrete level, and the remaining bins should be empty or contain negligible counts. This approach assumes that the variation within each discrete level k is bounded by the tolerance Δ_k of $\pm 20\%$, preferably $\pm 10\%$, more preferably $\pm 5\%$, allowing for a clear distinction between the different levels present in the measurement. The Δ value retained for the histogram would be the maximum of Δ_k values.

[0078] When measured over the pupil area 16, the image quality (Q1) measured at a first wavelength (λ_1) is at least 10% lower than a image quality (Q2) measured at a second wavelength (λ_2).

[0079] For example, the first wavelength (λ_1) is comprised between 400 nm and 500 nm, and
5 the second wavelength (λ_2) is comprised between 500 nm and 750 nm.

[0080] The inventors have observed that the optical lens comprising a pattern of microstructures allows reducing the image contrast for specific wavelengths without impacting the image contrast for the other wavelengths. In other words, the optical lens allows slowing down the progression of the visual impairment of the eye while maintaining a better visual acuity.

10 [0081] The image quality (Q) evaluates the quality of an image formed by the optical lens for an object, for example for central vision. Typically, the image quality may be determined using any well-known eye model and an optical lens model placed in front of the eye model in standard wearing conditions.

[0082] The eye model corresponds to a set of data defining at least specifications regarding
15 the geometry and/or optical properties of the optical elements of the eye. In other words, the eye model corresponds to an optical system having similar properties to the eye. The eye model comprises at least geometrical data relative to at least one structure defining the eye model, a center of rotation of the eye model (ERC), and at least one visual axis passing through said eye model rotation center (ERC). In the sense of the disclosure, the visual axis corresponds to the axis passing
20 through the center of rotation of the eye and the center of the pupil of the eye model.

[0083] Advantageously, the eye model according to the disclosure accurately simulates the optical properties of an eye, including central and off-axis aberrations, thereby improving the accuracy of the evaluation of the image quality (Q).

[0084] The eye model may comprise data relating to the cornea of the eye. The anterior corneal
25 surface of the eye model may be defined by at least the shape or topography of the corneal front surface of the eye model. For example, the anterior cornea can be described as an aspheric surface with a central radius of 7.77 mm (or more generally within the range of 6.5 mm to 8.5 mm) and an

asphericity coefficient of -0.15 (or more generally within the range of -0.5 to 0.5). Similarly, the posterior corneal surface of the eye model may be defined by at least the shape or topography of the corneal back surface of the eye model. For example, the posterior cornea can be described as an aspheric surface with a central radius of 6.4 mm (or more generally within the range of 5.5 mm to 7.5 mm) and an asphericity coefficient of -0.275 (or more generally within the range of -0.5 to 0.5). The shape or topography of the front and back corneal surface allows defining a refraction and/or asphericity of the cornea. The cornea of the eye model may further be defined by a refractive index and/or a distance or thickness between the front and back corneal surfaces. For instance, the refractive index and thickness of the cornea may respectively be selected as 1.376 and 0.55 mm (or more generally in respective ranges $[1.30; 1.45]$ and $[0.3\text{mm}; 0.8\text{mm}]$).

[0085] The eye model may comprise data relating to the anterior chamber, the posterior chamber, and the aqueous humor of the eye. The aqueous humor may be defined by a refractive index and/or a distance or thickness between the corneal back surface and the front surface of the pupil, which for instance, may respectively be selected as 1.3374 and 3.15 mm (or more generally in respective ranges $[1.30; 1.45]$ and $[2.5\text{mm}; 4.0\text{mm}]$ mm).

[0086] The eye model may comprise data relating to the pupil of the eye. The pupil of the eye model may be defined by a stop placed in a vertical plane passing through the anterior vertex of the crystalline lens. A typical diameter for the pupil is 4 mm, but may more generally be in range $[2.0\text{ mm}; 8.0\text{ mm}]$.

[0087] The eye model may comprise data relating to the crystalline lens of the eye. The anterior surface of the crystalline lens of the eye model may be defined by at least the shape or topography of the anterior surface of the crystalline lens of the eye model. For example, the anterior crystalline lens can be described as an aspheric surface with a central radius of 11.48 mm (or more generally within the range of 10 mm to 13 mm) and an asphericity coefficient of -5 (or more generally within the range of -10 to 0). Similarly, the posterior surface of the crystalline lens of the eye model may be defined by at least the shape or topography of the back surface of the crystalline lens of the eye model. For example, the posterior lens can be described as an aspheric surface with a central radius of -5.9 mm (or more generally within the range of -8 mm to -4 mm) and an asphericity coefficient of -2 (or more generally within the range of -4 to 0). The shape or topography of the anterior and

posterior crystalline lens surfaces allow defining a refraction and/or asphericity of the crystalline lens. The crystalline lens of the eye model may further be defined by a uniform or gradient refractive index and/or a distance or thickness between the front and back crystalline lens surfaces. For instance, the refractive index and thickness of the crystalline lens may respectively be selected
5 as 1.42 and 3.6 mm (or more generally in respective ranges [1.35; 1.45] and [2.5 mm; 4.0 mm]).

[0088] The eye model may comprise data relating to the vitreous chamber comprising the vitreous humor of the eye. The vitreous humor may be defined by a refractive index and/or a distance or thickness between the crystalline lens posterior surface and the retina of the eye model. For instance, the refractive index and thickness of the vitreous humor may respectively be selected
10 as 1.336 and 16.28 mm (or more generally in respective ranges [1.30; 1.40] and [15 mm; 20 mm]).

[0089] The eye model may comprise data relating to the retina of the eye. The retina of the eye model may be defined by at least the shape or topography of the retinal surface. The retina of the eye model may further be defined by a decentration in the horizontal direction and/or in the vertical direction. For instance, the retina may be a spherical surface of radius -12 mm (or more generally
15 in range [-14 mm; -12 mm]). Decentrations along x and y axis may generally lie in the range [-5.0mm; 5.0mm].

[0090] In the sense of the disclosure, the refractive index of each structure of the eye model may be constant. Alternatively, the distribution of refractive index may be variable along the structure of the eye model. Furthermore, the refractive indices may include dispersion coefficients
20 accounting for the chromatic aberrations. For instance, the refractive indices may be defined as a function of the wavelength with functions $n(\lambda) = (A + B)/\lambda^2$. Assuming that refractive indices at the central wavelength are known (e.g. at 550nm : 1.376 for the cornea, 1.3374 for the aqueous, 1.42 for the lens, and 1.336 for the vitreous), then dispersion coefficients A and B may be computed so that total longitudinal chromatic aberration of the eye is around 1.3D between 450nm
25 and 650nm.

[0091] The surfaces of each element defining the eye model may further be defined by a tilt angle about a vertical axis y and/or a tilt angle about a horizontal axis x. Finally, the surface of each element defining the eye model may further be defined by a decentration with the line of sight

of the eye model. For instance, rotation angles may be in ranges $[-15; 15^\circ]$ around x and y axis, and translations may be in ranges $[-5.0 \text{ mm}; 5.0 \text{ mm}]$ along x and y axis.

[0092] The eye model further includes an eye model rotation center (ERC). The position of the eye rotation center can be measured precisely on the wearer using known methods and apparatus

[0093] The eye model further includes at least an optical axis passing through the eye model rotation center. For example, the optical axis may pass through the center of rotation and the center of the pupil of the eye model.

[0094] The eye model may account for the accommodation process of the eye by accurately varying geometry and/or refractive indices of the different structures of the eye model with object proximity. The eye model may reproduce the variation of optical aberrations with accommodation. An example of integrating an accommodative response function in an eye model can be found in the literature, for instance “Adaptive model of the aging emmetropic eye and its changes with accommodation”, Rafael Navarro; Journal of Vision 2014;14(13):21. doi: <https://doi.org/10.1167/14.13.21>.

[0095] The eye model can be an average eye model representative of a general human being, or a segmented eye model representative of a given population. For example, the population may be defined based on a profile of the wearer, for example based on its age, and/or a prescription adapted for the wearer, and/or on central and/or peripheral wavefront aberrations, and/or central and/or peripheral refraction and astigmatism, and/or keratometry, and/or axial lengths, and/or retinal shape measurements. Eye models based on population averages of eye data measurements commonly used for simulations are described in detail in “Off-axis aberrations of a wide-angle schematic eye model, Navarro 1999” and “Optical models for human myopic eyes, Atchison 2006”.

[0096] Alternatively, the eye model may be an individual eye model representative of a unique person, based on the person profile and/or based on measurements performed on said person. Advantageously, using an eye model developed for a specific person or as close as possible to a target population allows improving the accuracy of the method according to the disclosure.

[0097] Mathematical optimization algorithms may be used to modify a general eye model to fit as best as possible data measured on the wearer. Advantageously, it allows having a more accurate model while requiring less resources.

[0098] The image quality (Q) may be based on a Strehl ratio, and/or a Modulation Transfer Function (MTF), and/or a power error, and/or an astigmatism error, and/or a fraction of encircled energy radius, and/or a spot diagram radius, and/or a point spread function (PSF), and/or an optical transfer function (OTF), and/or a visual Strehl ratio (VSX, VSOTF, VSMTF), and/or a wavefront aberrations.

[0099] The Strehl ratio corresponds to the ratio between the peak value of the actual point spread function (PSF) divided by the peak value of the diffraction-limited point spread function (PSF) for the same pupil size. The image quality (Q) may also be based on the visual Strehl ratio VSX, VSOTF and VSMTF of the optical system composed of the eye model and the optical lens.

[00100] The image quality (Q) may be based on the modulation transfer function (MTF). The modulation transfer function is a well-known quantitative measurement that describes the imaging performance of an optical system. It measures the contrast transfer as a function of the spatial frequency of the object being imaged and provides information about the optical system's resolving power and the amount of contrast degradation for different spatial frequencies. The modulation transfer function value may be determined by measuring the 3D surface of the optical lens, determining a 2D representation of optical path differences of a light beam arriving normal to the lens element, determining the point spread function over a pupil aperture, and determining the modulation transfer function over said pupil by a Fourier transform operation. For example, the area under the modulation transfer function curve between two specific limiting frequencies is measured and compared to the area under the diffraction-limited modulation transfer function curve for the same pupil size.

[00101] Typically, the modulation transfer function is calculated in the image plane. The image plane may be defined as a plane at a distance from a reference point of the optical lens corresponding to the inverse of the refractive power based on the prescription of the wearer, or

based the best fitting sphere of the optical lens. The image plane may be defined as the plane for which the maximal MTF value can be measured.

[00102] In more details, for a given gaze direction a ray is propagated to the object space from the eye rotation center (ERC). An object point ProxO is then calculated using the ergorama, which associates gaze directions to proximities. Assuming the target wearer power is Pui, then the image plane should be positioned at a proximity ProxIm = Pui-ProxO from the vertex sphere, calculated along the ERC-Pupil axis. Once the object proximity ProxO and the Image proximity ProxI are defined, then the point spread function and the modulation transfer function can be computed as for any optical system. For instance: a beam of rays is propagated from the object point to the eye entrance pupil, so as to perform a regular sampling of the pupil. The optical path lengths should be stored during this step; the optical path lengths are used to compute the pupil function; a diffraction integral is applied to the pupil function in order to obtain the point spread function; and the modulation transfer function is computed from the point spread function using a Fourier Transform.

[00103] The value of the modulation transfer function (MTF) may be measured over the pupil area for wavelength (λ_1) over a range of spatial frequencies comprised from 1 to 5, for example 1 to 10, cycles per degree is smaller than the value of the modulation transfer function (MTF) measured over the same pupil area for wavelength (λ_2) over the same range of spatial frequencies.

[00104] The image quality (Q) may be based on the power error. The focal planes of an object point of the visual environment passing through the optical lens may be distant from the retinal surface of the eye model. These distances may be converted into power errors expressed in diopters.

[00105] The image quality (Q) may be based on the astigmatism error. The tangential and sagittal focal planes of an object point of the visual environment passing through the optical lens may be distant. The distance between these two focal planes may be converted into an astigmatism error expressed in diopter.

[00106] The image quality (Q) may be based on the fraction of encircled energy radius. The encircled energy refers to the concentration of energy on the fovea or central part of the retina evaluated from the image at the retina of an object point of the visual environment passing through the optical lens model and the eye model. The radius of the point spread function (PSF) containing a predefined amount of energy, for example 50% or 80% is measured. The lower the measured radius is, the higher the quality of the image is.

[00107] The image quality (Q) may be based on the spot diagram radius which is defined as the root mean square (RMS) distance of the rays' intersections from the intersection of a chief ray. The spot diagram radius may be obtained by tracing rays from an object point of the visual environment that cover the pupil, and by computing their intersections with the retina of the eye model.

[00108] The image quality (Q) may be based on the point spread function (PSF). The point spread function is a well-known quantitative measurement that describes the blurring or spreading of light from a single point object, for example located at infinity in the visual environment. Typically, the point spread function value is determined by measuring the size of the image spot of light emitted from a point object and passing through the optical lens, for example using an eye-lens system model.

[00109] The image quality (Q) may be based on the optical transfer function (OTF) defining how different spatial frequencies are processed by the optical lens.

[00110] According to a non-limiting example of the disclosure, the optical lens is made of a first material and comprises a pattern of microstructures having a pillar shape. The optical path difference is given by the following formula: $OPD = \Delta n * z$, where Δn corresponds to the refractive index difference between the two materials on each side of the microstructures, and z corresponds to the height of the microstructures.

[00111] For an optical lens made of polycarbonate and comprising microstructures disposed on its front and/or back surface, the difference of refractive index between the two material, *i.e.*, between air and polycarbonate, is: $\Delta n = n(\text{polycarbonate}) - n(\text{air}) = 0.591$. For polycarbonate

pillar-shaped microstructures interfaced with air having a height (z) equal to 1.1 μm , the optical path difference OPD is equal to 650 nm.

[00112] For an optical lens comprising microstructures encapsulated between a first sub-lens element made of a first material having a first refractive index n_1 and a second sub-lens element made of a second material having a second refractive index n_2 (n_1 and n_2 being different), the difference of refractive index between the two material is: $\Delta n = n_1 - n_2$.

[00113] Figure 6 illustrates the difference of image quality measured for the above-described example optical lens. In this non-limiting example of the disclosure, the image quality (Q) is based on the modulation transfer function value measured over the pupil area having a diameter greater than or equal to 4.0 mm for wavelength (λ_1) equal to 450 nm, a wavelength (λ_2) equal to 650 nm, and a wavelength (λ_3) equal to 550 nm, over a range of spatial frequencies comprised from 1 to 30 cycle per degree, along the x and y plans.

[00114] It can be seen that the MTF value for a wavelength (λ_1) equal to 450 nm is lower than the MTF value for wavelength (λ_3) equal to 550 nm and even lower than for wavelength (λ_2) equal to 650 nm. In this example, the image quality, and thus the contrast is reduced for blue light and maintained for red. In other words, the optical lens produces a chromatic phase-shift that will not blur the red light will, but will blur the lower wavelengths, meaning green but especially blue.

[00115] Unless specifically stated otherwise, as apparent from the following discussions, it is appreciated that throughout the specification discussions utilizing terms such as "computing", "calculating", "generating", or the like, refer to the action and/or processes of a computer or computing system, or similar electronic computing device, that manipulate and/or transform data represented as physical, such as electronic, quantities within the computing system's registers and/or memories into other data similarly represented as physical quantities within the computing system's memories, registers or other such information storage, transmission or display devices.

[00116] Embodiments of the present disclosure may include apparatuses for performing the operations herein. This apparatus may be specially constructed for the desired purposes, or it may comprise a general purpose computer or Digital Signal Processor ("DSP") selectively activated or

reconfigured by a computer program stored in the computer. Such a computer program may be stored in a computer readable storage medium, such as, but is not limited to, any type of disk including floppy disks, optical disks, CD-ROMs, magnetic-optical disks, read-only memories (ROMs), random access memories (RAMs) electrically programmable read-only memories (EPROMs), electrically erasable and programmable read only memories (EEPROMs), magnetic or optical cards, or any other type of media suitable for storing electronic instructions, and capable of being coupled to a computer system bus.

[00117] The processes and displays presented herein are not inherently related to any particular computer or other apparatus. Various general purpose systems may be used with programs in accordance with the teachings herein, or it may prove convenient to construct a more specialized apparatus to perform the desired method. The desired structure for a variety of these systems will appear from the description below. In addition, embodiments of the present disclosure are not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings of the disclosure as described herein.

[00118] Many further modifications and variations will be apparent to those skilled in the art upon making reference to the foregoing illustrative embodiments, which are given by way of example only and which are not intended to limit the scope of the disclosure, that being determined solely by the appended claims.

[00119] In the claims, the word “comprising” does not exclude other elements or steps, and the indefinite article “a” or “an” does not exclude a plurality. The mere fact that different features are recited in mutually different dependent claims does not indicate that a combination of these features cannot be advantageously used. Any reference signs in the claims should not be construed as limiting the scope of the disclosure.

CLAIMS

1. An optical lens intended to be worn in front of an eye of a wearer to correct a vision impairment and to slow down the progression of said vision impairment of the eye of the wearer,
5 the optical lens comprising a pattern of microstructures,
wherein over a pupil area having a diameter equal to or greater than 4.0 mm and including at least part of the microstructures, the optical lens produces a first optical path difference map (OPD1),
wherein over said pupil area, the pattern of microstructures produces constant phase shifting so
that the differential optical path map (DOP), being the difference between said first optical path
10 difference map (OPD1) and a second smooth optical path difference map (OPD2), is a piecewise
constant of at least two levels,
characterized in that over said pupil area, an image quality (Q1) measured at a first wavelength (λ_1) is at least 10% lower than a retinal image quality (Q2) measured at a second wavelength (λ_2).
- 15 2. The optical lens according to claim 1, wherein the image quality is based on a Strehl ratio, and/or a Modulation Transfer Function (MTF), and/or a power error, and/or an astigmatism error, and/or a fraction of encircled energy radius, and/or, a spot diagram radius, and/or a point spread function (PSF), and/or an optical transfer function (OTF), and/or a visual Strehl ratio (VSX, VSOTF, VSMTF), and/or a wavefront aberrations.
- 20 3. The optical lens according to any of claims 1 or 2, wherein the value of the modulation transfer function (MTF) measured over the pupil area for wavelength (λ_1) over a range of spatial frequencies comprised from 1 to 5, for example 1 to 10, cycles per degree is smaller than the value of the modulation transfer function (MTF) measured over the same pupil area for wavelength (λ_2)
25 over the same range of spatial frequencies.
4. The optical lens according to any of claims 1 to 3, wherein at least part of the microstructures are diffractive microstructures.

5. The optical lens according to any of claims 1 to 4, wherein at least part of the microstructures are diffusive microstructures.

6. The optical lens according to any of claims 1 to 5, wherein the microstructures have a pillar shape.

7. The optical lens according to claim 6, wherein the pillar shaped microstructures have a lateral resolution greater than or equal to 250 nm, preferably 1.0 μm , more preferably 3.0 μm , for example 10 μm , and smaller than or equal to 100 μm .

8. The optical lens according to any of claims 6 or 7, wherein the pillar shaped microstructures have a height greater than or equal to 0.1 μm , and smaller than or equal to 10 μm .

9. The optical lens according to any of claims 6 to 8, wherein the pillar shaped microstructures further comprise a plurality of at least two subsets of pillar shaped microstructures having different heights.

10. The optical lens according to any of claims 1 to 9, wherein at least part, for example all, of the microstructures are located on a front surface of the optical lens, and/or on a back surface of the optical lens, and/or in between a front surface and a back surface of the optical lens.

11. The optical lens according to any of claims 1 to 10, wherein the density of microstructures over the pupil area is greater than or equal to 10% and smaller than or equal to 80% of the surface of the pupil area.

12. The optical lens according to any of claims 1 to 11, wherein the microstructures are homogeneously distributed on the optical lens.

13. The optical lens according to claim 12, wherein the microstructures are organized in a plurality of concentric rings.

14. The optical lens according to any of claims 1 to 11, wherein microstructures are randomly distributed on the optical lens.

- 5 15. The optical lens according to any of claims 1 to 14, wherein the first wavelength (λ_1) is comprised between 400 nm and 500 nm, and the second wavelength (λ_2) is comprised between 500 nm and 750 nm.

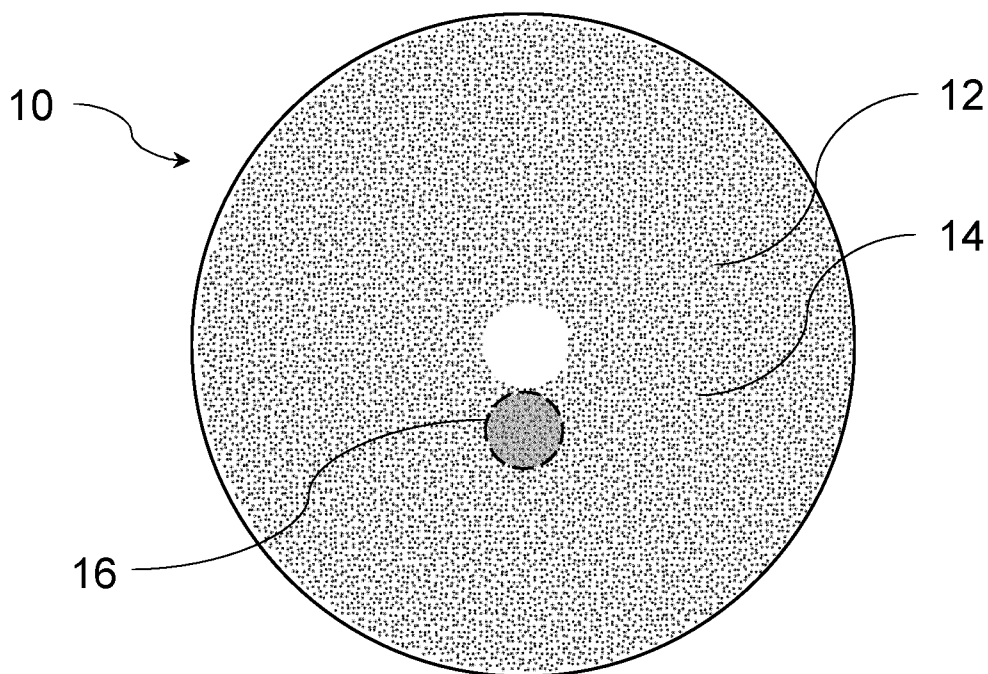


Fig. 1

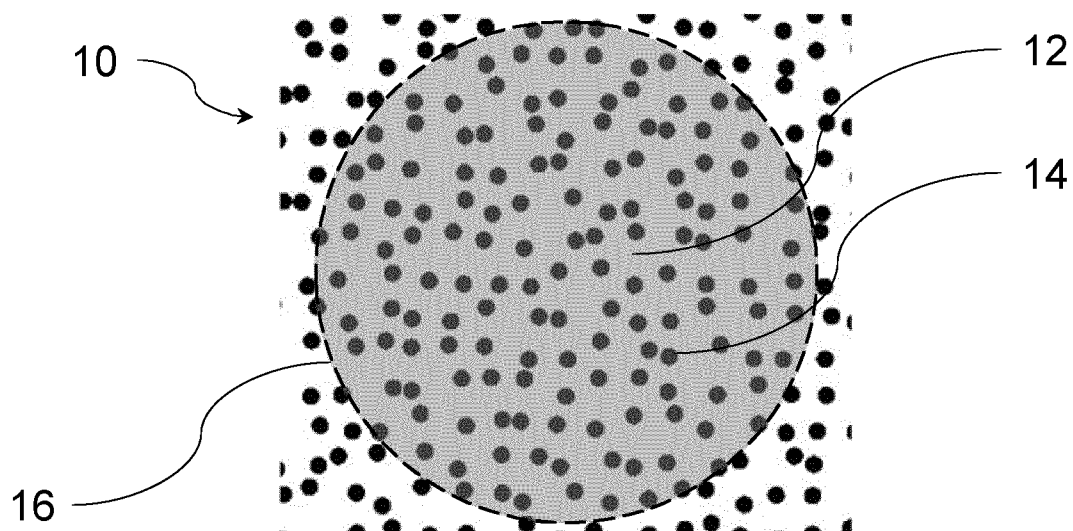
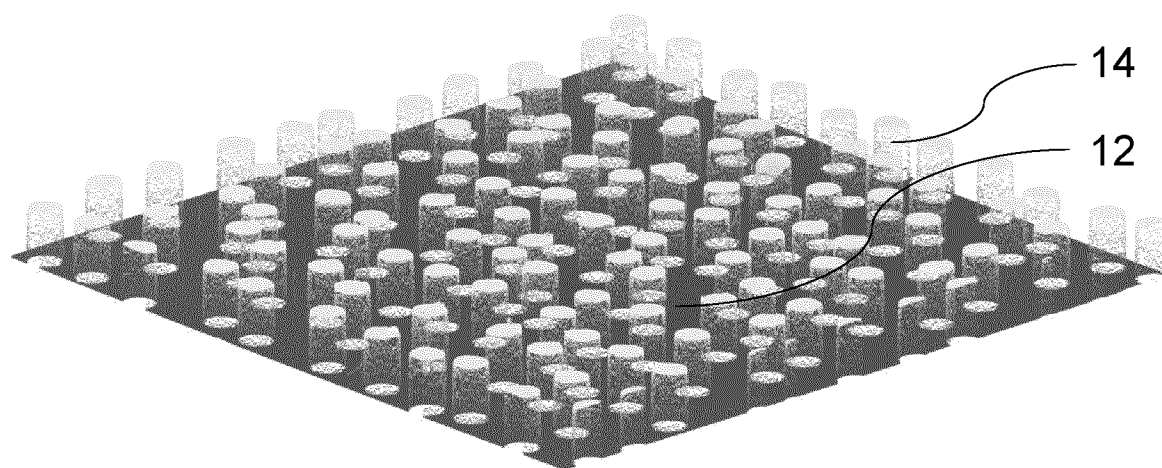
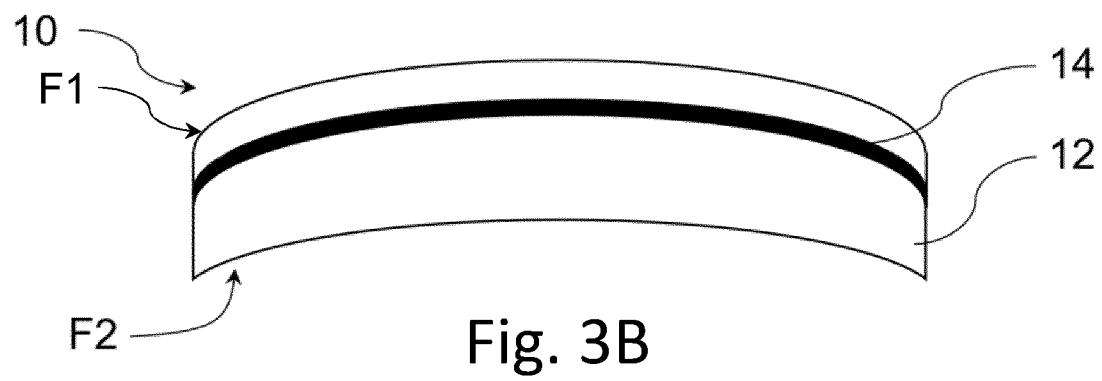
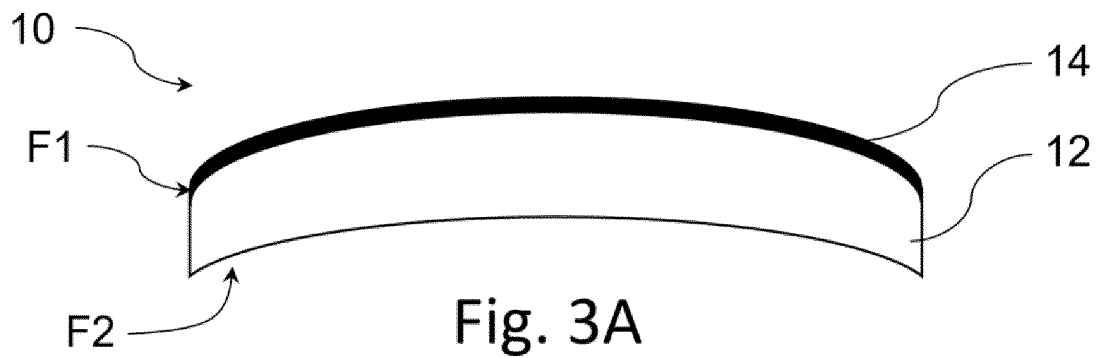


Fig. 2



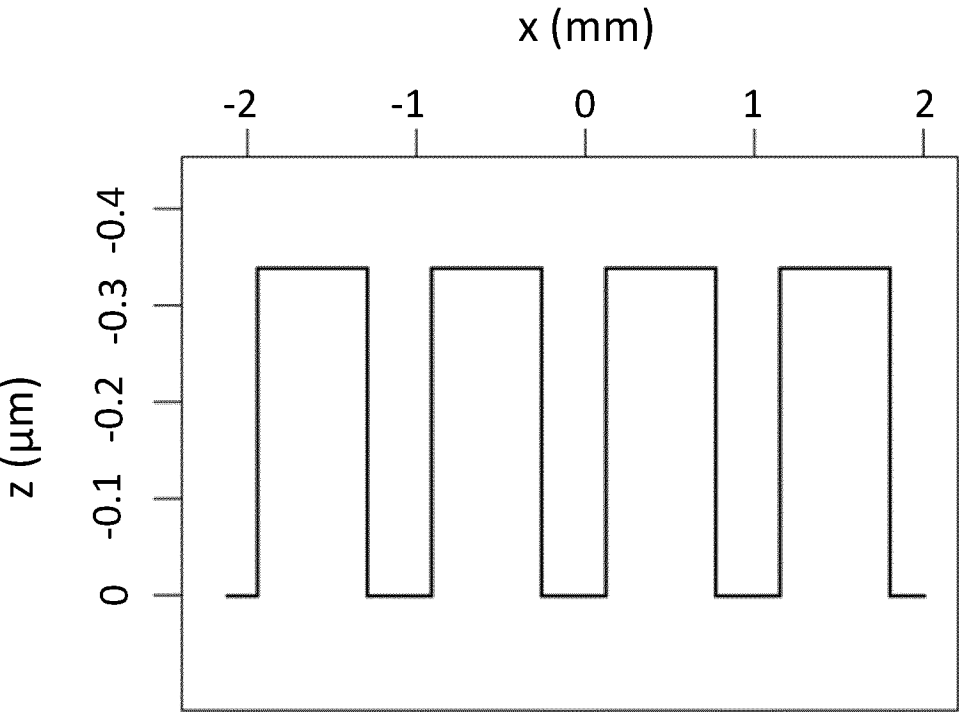


Fig. 5

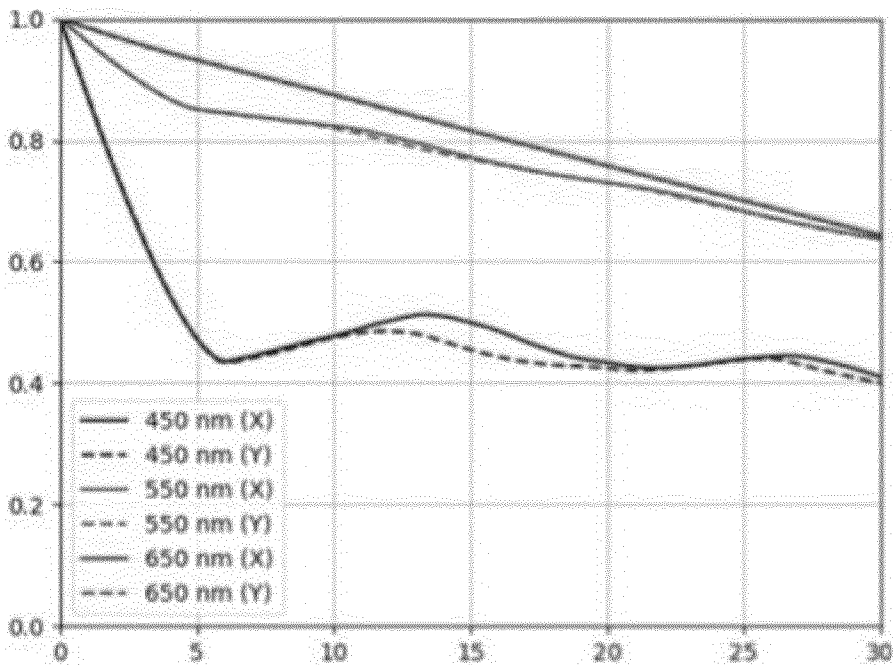


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/087931

A. CLASSIFICATION OF SUBJECT MATTER INV. G02C7/02 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) G02C		
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 practicable, search terms used) EPO-Internal		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2022/357595 A1 (GUILLOT MATTHIEU [FR] ET AL) 10 November 2022 (2022-11-10) figures 7a-7c paragraphs [0094], [0103], [0132], [0133], [0159] - [0016] -----	1 - 15
X	US 11 226 497 B2 (BRIEN HOLDEN VISION INSTITUTE LTD [AU]) 18 January 2022 (2022-01-18) figures 12D, 37 column 1, line 18 - line 32 column 25, line 44 - line 56 column 26, line 61 - line 67 column 28, line 25 - line 27 column 27, line 66 - column 28, line 15 column 28, line 51 - line 63 column 37, line 60 - column 38, line 19 column 39, line 19 - line 21 ----- - / - -	1 - 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 "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "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 14 March 2025		Date of mailing of the international search report 28/03/2025
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Vazquez Martinez, D

INTERNATIONAL SEARCH REPORT

International application No
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	RUCKER F J ET AL: "Cone signals for spectacle-lens compensation: Differential responses to short and long wavelengths", VISION RESEARCH, ELSEVIER, AMSTERDAM, NL, vol. 48, no. 19, 1 September 2008 (2008-09-01), pages 1980-1991, XP023783212, ISSN: 0042-6989, DOI: 10.1016/J.VISRES.2008.06.003 [retrieved on 2008-07-27] the whole document -----	1 - 15
A	GAWNE TIMOTHY J ET AL: "Chromatically simulated myopic blur counteracts a myopiagenic environment", EXPERIMENTAL EYE RESEARCH, ACADEMIC PRESS LTD, LONDON, vol. 222, 14 July 2022 (2022-07-14), XP087167882, ISSN: 0014-4835, DOI: 10.1016/J.EXER.2022.109187 [retrieved on 2022-07-14] the whole document -----	1 - 15
A	US 10 884 264 B2 (SIGHTGLASS VISION INC [US]) 5 January 2021 (2021-01-05) the whole document -----	5

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Information on patent family members

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