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(54) **Title:** OPHTHALMIC LENSES FOR TREATING MYOPIA

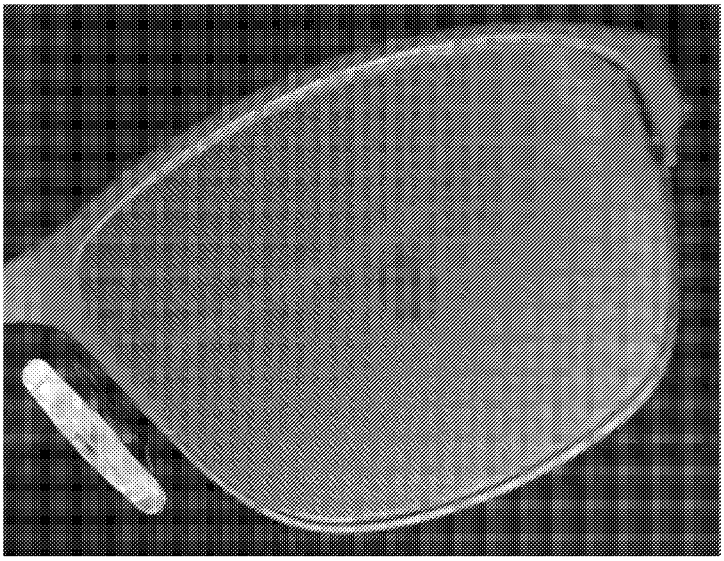

FIG. 11

(57) **Abstract:** Eyeglasses are disclosed that include eyeglass frames and a pair of ophthalmic lenses mounted in the frames. The lenses include a dot pattern distributed across each lens, the dot pattern including an array of dots spaced apart by a distance of 1 mm or less, each dot having a maximum dimension of 0.3 mm or less, the dot pattern including a clear aperture free of dots having a maximum dimension of more than 1 mm, the clear aperture being aligned with a viewing axis of a wearer of the pair of eyeglasses.

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OPHTHALMIC LENSES FOR TREATING MYOPIA

FIELD OF THE INVENTION

The invention features ophthalmic lenses for treating myopia, methods for forming such lenses, methods for using such lenses, and methods for monitoring the efficacy of such lenses.

BACKGROUND

The eye is an optical sensor in which light from external sources is focused, by a lens, onto the surface of the retina, an array of wavelength-dependent photosensors. Each of the various shapes that the eye lens can adopt is associated with a focal length at which external light rays are optimally or near-optimally focused to produce inverted images on the surface of the retina that correspond to external images observed by the eye. The eye lens, in each of the various shapes that the eye lens can adopt, optimally or near-optimally, focuses light emitted by, or reflected from external objects that lie within a certain range of distances from the eye, and less optimally focuses, or fails to focus objects that lie outside that range of distances.

In normal-sighted individuals, the axial length of the eye, or distance from the lens to the surface of the retina, corresponds to a focal length for near-optimal focusing of distant objects. The eyes of normal-sighted individuals focus distant objects without nervous input to muscles which apply forces to alter the shape of the eye lens, a process referred to as "accommodation." Closer, nearby objects are focused, by normal individuals, as a result of accommodation.

Many people, however, suffer from eye-length-related disorders, such as myopia ("nearsightedness"). In myopic individuals, the axial length of the eye is longer than the axial length required to focus distant objects without accommodation. As a result, myopic individuals can view near objects clearly, but objects further away are blurry. While myopic individuals are generally capable of accommodation, the average distance at which they can focus objects is shorter than that for normal-sighted individuals.

Typically, infants are born hyperopic, with eye lengths shorter than needed for optimal or near-optimal focusing of distant objects without accommodation. During normal development of the eye, referred to as "emmetropization," the axial length of the eye, relative to other dimensions of the eye, increases up to a length that provides near-optimal focusing of distant objects without accommodation. Ideally, biological processes maintain the near-optimal relative eye length to eye size as the eye grows to final, adult size. However, in myopic individuals, the relative axial length of the eye to overall eye size continues to increase during development, past a length that provides near-optimal focusing of distant objects, leading to increasingly pronounced myopia.

It is believed that myopia is affected by behavioral factors as well as genetic factors. Accordingly, myopia may be mitigated by therapeutic devices which address behavioral factors. For example, therapeutic devices for treating eye-length related disorders, including myopia, are described in U.S. Pub. No. 2011/0313058A1.

SUMMARY

Eyeglasses and contact lenses are disclosed that reduce signals in the retina responsible for growth of eye length. Exemplary embodiments are made using polycarbonate or Trivex lens blanks which have been treated by applying a pattern of clear liquid plastic protuberances that that are hardened and bonded to the lens by ultraviolet light. Each clear plastic protuberance has a refractive index similar to the underlying polycarbonate to which it is bonded so in the location of the protuberance it and the underlying lens act as a single optical element. The array of such optical elements behave as a highly aberrated lens array dispersing light transmitted by the array fairly uniformly in all directions. The result is a reduction in contrast in a retinal image. The eyeglass lenses have apertures free from protuberances located on the lens axes allowing a user to experience maximal visual acuity when viewing on-axis objects, while objects in the periphery of the user's visual field are viewed with reduced contrast and acuity.

In one example, an image on the retina consists of the normally focused image with an average intensity of 74% of what would be produced by the lens without the protuberance array. Superimposed on the focused image is a background of uniform retinal illumination equal to 25% of the average luminance of the normally focused image.

For these eyeglasses, the focused image is reduced in contrast compared to that normally used to correct (but not treat) refractive errors. The exact amount of contrast reduction depends on the relative amount of dark and light areas in the image being transmitted. For the example above, where 24% of the light is dispersed uniformly, the maximum contrast reduction would be 48% where contrast is defined as the Luminance difference / Average luminance. Experiments demonstrate that this amount of reduction in contrast has significant effects on the physiology of the eye related to mechanisms responsible for controlling the growth of eye length.

Various aspects of the invention are summarized as follows:

In general, in a first aspect, the invention features a pair of eyeglasses, including: eyeglass frames; and a pair of ophthalmic lenses mounted in the frames. The lenses include a dot pattern distributed across each lens, the dot pattern including an array of dots spaced apart by a distance of 1 mm or less, each dot having a maximum dimension of 0.3 mm or less.

Implementations of the eyeglasses may include one or more of the following features and/or features of other aspects. For example, each dot can have a maximum dimension of 0.2 mm or less (e.g., 0.1 mm or less, 0.05 mm or less, 0.02 mm or less, 0.01 mm or less). In some embodiments, each dot is substantially the same size. The dots may be spaced apart by 0.8 mm or less (e.g., 0.6 mm or less, 0.5 mm or less, 0.4 mm or less, 0.35 mm or less). The dots may be arranged on a square grid, a hexagonal gird, another grid, or in a semi-random or random pattern. The dots may be spaced at regular intervals, e.g., such as 0.55 mm, 0.365 mm, or 0.24 mm. Alternatively, dot spacing may vary depending on the distance of the dot from the center of the lens. For example, dot spacing may increase monotonically or decrease monotonically as the distance from the center of the lens increases.

The dot pattern can include a clear aperture free of dots having a maximum dimension of more than 1 mm, the clear aperture being aligned with a viewing axis of a wearer of the pair of eyeglasses. The clear aperture can have a maximum dimension (e.g., a diameter) of 2 mm or more (e.g., 3 mm or more, 4 mm or more, 5 mm or more, 6 mm or more, 7 mm or more, 8 mm or more) and up to 1.5 cm (e.g., 1.5 cm or less, 1.4 cm or less, 1.3 cm or less, 1.2 cm or less, 1.1 cm or less, 1.0 cm or less). The clear aperture can be substantially circular or a similar shape, such as octagonal, square, or other polygon shape.

In some embodiments, the dots are protrusions on a surface of the corresponding lens. The protrusions can be formed from a transparent material. In some cases, the transparent material is clear and/or colorless. Alternatively, or additionally, at least some of the transparent material can be tinted (e.g., with a dye that absorbs red wavelengths). The transparent material can have substantially the same refractive index as a lens material. The protrusions can be substantially spherical or semi-spherical.

In certain embodiments, the dots are recesses on a surface of the corresponding lens.

The dots can be inclusions between opposing surfaces of each lens.

The lenses can be clear lenses. In some embodiments, the lenses are tinted lenses.

The dot pattern can reduce an image contrast of an object viewed through the dot pattern by at least 30% (e.g., by at least 35%, by at least 40%, by at least 45%, by at least 50%, by at least 55%, by at least 60%) compared to an image contrast of the object viewed through the clear aperture. In some embodiments, the lenses have optical power to correct a wearer's on-axis vision to 20/20 or better (e.g., 20/15) through the clear aperture, and, for at least a portion of the wearer's peripheral vision through the dot pattern, the lenses correct the wearer's vision to 20/25 or better, 20/30 or better, 20/40 or better, and the like.

In another aspect, the invention features a method of making the eyeglasses, including: depositing discrete portions a material on a surface of the lens corresponding to the dot pattern; and curing the deposited material to provide protrusions on the lens surface forming the dot pattern. The material can be deposited using an inkjet printer. The deposited material can be cured using radiation (e.g., ultraviolet radiation).

In general, in another aspect, the invention features a pair of eyeglasses customized for a wearer, including: eyeglass frames; and a pair of ophthalmic lenses mounted in the frames, the lenses having optical power to correct the wearer's on-axis vision to 20/20 or better, the lenses including a dot pattern distributed across each lens, the dot pattern including an array of dots arranged so that, for at least a portion of the wearer's peripheral vision, the lenses correct the wearer's vision to 20/25 or better and reduce an image contrast by at least 30% compared to on-axis image contrast. Embodiments of the ophthalmic lens may include one or more of the features of other aspects.

In general, in a further aspect, the invention features a pair of eyeglasses customized for a wearer, including: eyeglass frames; and a pair of ophthalmic lenses mounted in the frames, the lenses having optical power to correct the wearer's on-axis vision to 20/20 or better. The eyeglasses include an optical diffuser distributed across each lens, the optical diffuser being configured so that, for at least a portion of the wearer's peripheral vision, the lenses correct the wearer's vision to 20/40 or better, 20/30 or better, or 20/25 or better and reduce an image contrast by at least 30% compared to on-axis image contrast.

Embodiments of the ophthalmic lens may include one or more of the following features and/or features of other aspects. For example, the optical diffuser can include a film laminated on a surface of each lens. The lenses may each include a clear aperture free of the optical diffuser having a maximum dimension of more than 1 mm, the clear aperture being aligned with a viewing axis of a wearer of the pair of eyeglasses.

In general, in a further aspect, the invention features an ophthalmic lens, including: two opposing curved surfaces collectively having an optical power to correct a wearer's on-axis vision to 20/20 or better; and a dot pattern distributed across each lens, the dot pattern comprising an array of spaced apart dots arranged so that, for at least a portion of the wearer's peripheral vision, the lenses correct the wearer's vision to 20/25 or better and reduce an image contrast by at least 30% compared to on-axis image contrast, the dot pattern including a clear aperture free of dots aligned with a viewing axis of the wearer.

Embodiments of the ophthalmic lens may include one or more of the following features and/or features of other aspects. For example, the ophthalmic lens can be an eyeglass lens. Alternatively, in some embodiments, the ophthalmic lens is a contact lens.

In general, in another aspect, the invention features a method of monitoring and arresting myopia progression in a person, including: measuring variations in a thickness of the person's choroid over a period of time; and providing the person with ophthalmic lenses which reduce an image contrast in the person's peripheral vision compared to an on-axis image contrast.

Implementations of the method can include one or more of the following features and/or features of other aspect. For example, the ophthalmic lenses may be provided in eyeglasses of the foregoing aspects. Alternatively, the ophthalmic lenses may be provided as contact lenses. In some implementations, measuring the variations includes measuring a thickness of the person's choroid using Optical Coherence Tomography (OCT).

Among other advantages, disclosed embodiments feature eyeglasses that include features that reduce signals in the retina responsible for growth of eye length on the lenses for both eyes, without diminishing the user's on-axis vision in either eye to an extent that is disruptive to the user. For example, providing a dot pattern that modestly blurs the wearer's peripheral vision while allowing normal on-axis viewing through a clear aperture allows for all-day, every-day use by the wearer. Disclosed embodiments can also provide therapeutic benefits to a user in both eyes using only a single pair of eyeglasses, in contrast to approaches which involve alternating use of different pairs of eyeglasses.

Moreover, the dot patterns can be largely unnoticeable to others, particularly where dot patterns are clear and colorless and/or where contact lenses are used. The subtlety of the dot patterns can result in more consistent use by certain wearers, especially children, who may otherwise be self-conscious during everyday (e.g., at school or otherwise among peers) use of more conspicuous devices.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A shows a pair of eyeglasses containing ophthalmic lenses for treating myopia.

FIG. 1B shows a dot pattern on the ophthalmic lenses shown in FIG. 1A.

FIG. 2 illustrates contrast reduction experienced using exemplary ophthalmic lenses for treating myopia.

FIG. 3A shows an inkjet printing system for forming dot patterns on ophthalmic lenses.

FIG. 3B is a flowchart showing steps in a method for making dot patterns using the system shown in FIG. 3A.

FIG. 3C shows a printing template for forming a dot pattern using the inkjet printing method of FIG. 3B.

FIG. 3D shows a top view of a jig used for positioning multiple lenses in an inkjet printing system.

FIGS. 4A-4C are photographs showing a dot pattern on an exemplary ophthalmic lens.

FIGS. 5A-B are optical coherence tomographic (OCT) images of an eye showing choroid thickness.

FIGS. 6A-D are OCT images showing choroid thickness.

FIG. 7 is a plot showing relative choroid thickness as a function of retinal position for a subject pre- and post-treatment.

FIG. 8 is a photograph showing a dot pattern used in prototype I lenses.

FIG. 9 is a plot comparing results of a study conducted using prototype I lenses and an Initial Study. The time progression of axial length difference measurements are plotted.

FIG. 10 is a photograph showing a dot pattern used in prototype II lenses.

FIG. 11 is a photograph showing a dot pattern used in prototype III lenses.

FIG. 12 is a bar chart comparing change in diopters after 180 days for subjects from the Initial Study (“first diffuser”), prototype III lenses (“new diffuser”), and a control group (“no diffuser”).

FIG. 13 is a schematic diagram of a laser system for forming a dot pattern on a contact lens.

FIGS. 14A-B are examples of dot patterns for contact lenses.

FIG. 15A is a photograph of a contact lens with a dot pattern.

FIG. 15B is a photograph of an eyeglass lens with a dot pattern.

DETAILED DESCRIPTION

Referring to FIG. 1A, myopia-reducing eyeglasses 100 are disclosed which allow treatment of both eyes simultaneously without substantially compromising clear vision. Moreover, the eyeglasses are sufficiently robust and inconspicuous as to allow a wearer to engage in the same day-to-day activities without the eyeglasses failing and without feeling self-conscious about their appearance, which is especially desirable because the eyeglasses are typically used to arrest eye-lengthening in children.

Myopia-reducing eyeglasses 100 are composed of a pair of frames 101 and ophthalmic lenses 110a and 110b mounted in the frames. Ophthalmic lenses 110a and 110b each have a clear aperture 120a and 120b, respectively, surrounded by reduced-contrast areas 130a and 130b, respectively. Clear apertures 120a and 120b are positioned to coincide with the wearer's on-axis viewing position, while reduced contrast areas 130a and 130b correspond to the wearer's peripheral vision. Referring also to FIG. 1B, reduced contrast areas 130a and 130b are composed of an array of dots 140, which reduce the contrast of an object in the wearer's peripheral vision by scattering light passing through those areas to the wearer's eye.

The size and shape of the clear aperture may vary. Generally, the clear aperture provides the wearer with a viewing cone for which their visual acuity may be optimally corrected (e.g., to 20/15 or 20/20). In some embodiments, the aperture has a maximum dimension (in the x-y plane) in a range from about 0.2 mm (e.g., about 0.3 mm or more, about 0.4 mm or more, about 0.5 mm or more, about 0.6 mm or more, about 0.7 mm or more, about 0.8 mm or more, about 0.9 mm or more) to about 1.5 cm (e.g., about 1.4 cm or less, about 1.3 cm or less, about 1.2 cm or less, about 1.1 cm or less, about 1 cm or less). Where the aperture is circular, e.g., as depicted in FIG. 1A, this dimension corresponds to the circle's diameter (i.e., $A_x = A_y$), however non-circular (e.g., elliptical, polygonal, $A_x \neq A_y$) apertures are also possible.

The clear aperture can subtend a solid angle of about 30 degrees or less (e.g., about 25 degrees or less, about 20 degrees or less, about 15 degrees or less, about 12 degrees or less, about 10 degrees or less, about 9 degrees or less, about 8 degrees or less, about 7 degrees or less, about 6 degrees or less, about 5 degrees or less, about 4 degrees or less, about 3 degrees or less) in the viewer's visual field. The solid angles subtended in the horizontal and vertical viewing planes may be the same or different.

The dots are formed by arrays of protuberances on a surface of each of lenses 110a and 110b. The protuberances are formed from an optically transparent material having a similar refractive index to the underlying lens, which is 1.60 for polycarbonate. For example, in embodiments where the lenses are formed from polycarbonate, the protuberances can be formed from a polymer having a similar refractive index to the PC, such as from light-activated polyurethane or epoxy based plastics. In addition to PC, the lenses themselves can also be made from allyl diglycol carbonate plastic, a urethane-based monomer or other impact resistant monomers. Alternatively, lenses could be made from one of the more-dense high-refractive index plastics with an index of refraction greater than 1.60.

In some embodiments, the protuberance material is selected to have a refractive index that is within 0.1 (e.g., within 0.09 or less, 0.08 or less, 0.07 or less, 0.06 or less, 0.05 or less, 0.04 or less, 0.03 or less, 0.02 or less, 0.01 or less, 0.005 or less, 0.002 or less, 0.001 or less) of the refractive index of the lens material (e.g., as measured at one or more wavelengths in the visible light range).

The protuberances are sized and shaped so that the dots scatter incident light to reduce contrast of an object viewed through the reduced contrast areas. The protuberances may be substantially spherical, ellipsoidal, or irregularly-shaped. Generally, the protuberances should have a dimension (e.g., diameter, as depicted in FIG. 1B) that is sufficient large to scatter visible light, yet sufficiently small so as not to be resolved by the wearer during normal use. For example, the protuberances can have a dimension (as measured in the x-y plane) in a range from about 0.001 mm or more (e.g., about 0.005 mm or more, about 0.01 mm or more, about 0.015 mm or more, about 0.02 mm or more, about 0.025 mm or more, about 0.03 mm or more, about 0.035 mm or more, about 0.04 mm or more, about 0.045 mm or more, about 0.05 mm or more, about 0.055 mm or more, about 0.06 mm or more, about 0.07 mm or more, about 0.08 mm or more, about 0.09 mm or more, about 0.1 mm) to about 1 mm or less (e.g., about 0.9 mm or less, about 0.8 mm or less, about 0.7 mm or less, about 0.6 mm or less, about 0.5 mm or less, about 0.4 mm or less, about 0.3 mm or less, about 0.2 mm or less, about 0.1 mm).

Note that for smaller protuberances, e.g., having a dimension that is comparable to the wavelength of light (e.g., 0.001 mm to about 0.05 mm), the light scattering may be considered Raleigh or Mie scattering. For larger protuberances, e.g., about 0.1 mm or more, light scattering may be due to a lensing effect of the protuberance, such as due to focusing by a lens with a very small radius of curvature to a point far in front of the user's retina. In such a case, when the light from each protuberance reaches the user's retina, it has substantially diverged from its point of focus and is not resolvable as an image by the user.

In general, the dimension of the protuberances may be the same across each lens or may vary. For example, the dimension may increase or decrease as a function of the location of the protuberance, e.g., as measured from the clear aperture and/or as a function of distance from an edge of the lens. In some embodiments, the protuberance dimensions vary monotonically as the distance from the center of the lens increases (e.g., monotonically increase or monotonically decrease). In some cases, monotonic increase/decrease in dimension includes varying the diameter of the protuberances linearly as a function of the distance from the center of the lens.

The protuberances shown in FIG. 1B are arranged on a square grid, spaced apart by a uniform amount in each direction. This is shown by D_y in the y-direction and D_x in the x-direction. In general, the dots are spaced so that, collectively, they provide sufficient contrast reduction in the viewer's periphery for myopia reduction. Typically, smaller dot spacing will result in greater contrast reduction (provided adjacent dots do not overlap or merge). In general, D_x and D_y are in a range from about 0.05 mm (e.g., about 0.1 mm or more, about 0.15 mm or more, about 0.2 mm or more, about 0.25 mm or more, about 0.3 mm or more, about 0.35 mm or more, about 0.4 mm or more, about 0.45 mm or more, about 0.5 mm or more, about 0.55 mm or more, about 0.6 mm or more, about 0.65 mm or more, about 0.7 mm or more, about 0.75 mm or more) to about 2 mm (e.g., about 1.9 mm or less, about 1.8 mm or less, about 1.7 mm or less, about 1.6 mm or less, about 1.5 mm or less, about 1.4 mm or less, about 1.3 mm or less, about 1.2 mm or less, about 1.1 mm or less, about 1 mm or less, about 0.9 mm or less, about 0.8 mm or less). As an example, dot spacing can be 0.55 mm, 0.365 mm, or 0.240 mm.

While the protuberances shown in FIG. 1B are arranged with equal spacing in the x- and y-directions, more generally spacing in each direction may be different. Furthermore, protuberances may be arrayed in grids that are not square. For example, hexagonal grids may be used. Non-regular arrays are also possible, e.g., random or semi-random dot placement may be used. In the case of a random pattern dimensions given would be the average separation of the dots in X and Y directions.

While the dots are depicted as have circular footprints in FIG. 1B, more generally the dots can have other shapes. For example, the dots can be elongated in one direction (e.g., in the x-direction or y-direction), such as in the case of elliptical dots. In some embodiments, the dots are random on shape.

It is believed that light from a scene that is incident on the lenses in reduced contrast areas 130a and 130b between the dots contributes to an image of the scene on the user's retina, while light from the scene incident on the dots does not. Moreover, the light incident on the dots is still transmitted to the retina, so has the effect of reducing image contrast without substantially reducing light intensity at the retina. Accordingly, it is believed that the amount of contrast reduction in the user's peripheral field of view is correlated to (e.g., is approximately proportional to) the proportion of the surface area of the reduced-contrast areas covered by the dots. Generally, dots occupy at least 10% (e.g., 20% or more, 30% or more, 40% or more, 50% or more, such as 90% or less, 80% or less, 70% or less, 60% or less) of the area (as measured in the x-y plane) of reduced contrast area 130a and 130b.

In general, the dot pattern reduces the contrast of images of objects in the wearer's peripheral vision without significantly degrading the viewer's visual acuity in this region. Here, peripheral vision refers to the field of vision outside of the field of the clear aperture. Image contrast in these regions can be reduced by 40% or more (e.g., 45% or more, 50% or more, 60% or more, 70% or, more, 80% or more) relative to an image contrast viewed using the clear aperture of the lens as determined. Contrast reduction may be set according to the needs of each individual case. It is believed that a typical contrast reduction would be in a range from about 50% to 55%. Contrast reductions of lower than 50% may be used for very mild cases, while subjects who are more predisposed might need a higher than 55% contrast reduction. Peripheral visual acuity can be corrected to 20/30 or better (e.g., 20/25 or better, 20/20 or better) as determined by subjective refraction, while still achieving meaningful contrast reduction.

Contrast, here, refers to the difference in luminance between two objects within the same field of view. Accordingly, contrast reduction refers to a change in this difference.

Contrast and contrast reduction may be measured in a variety of ways. In some embodiments, contrast can be measured based on a brightness difference between different portions of a standard pattern, such as a checkerboard of black and white squares, obtained through the clear aperture and dot pattern of the lens under controlled conditions.

Alternatively, or additionally, contrast reduction may be determined based on the optical transfer function (OTF) of the lens (see, e.g., http://www.montana.edu/jshaw/documents/18%20EELE582_S15_OTFMTF.pdf). For an OTF, contrast is specified for transmission of stimuli in which light and dark regions are sinusoidally modulated at different "spatial frequencies." These stimuli look like alternating light and dark bars with the spacing between bars varying over a range. For all optical systems the transmission of contrast is lowest for the sinusoidally varying stimuli having the highest spatial frequencies. The relationship describing the transmission of contrast for all spatial frequencies is the OTF. The OTF can be obtained by taking the Fourier transform of the point spread function. The point spread function can be obtained by imaging a point source of light through the lens on to a detector array and determining how light from a point is distributed across the detector.

In the event of conflicting measurements, the OTF is technique is preferred.

In some embodiments, contrast may be estimated based on the ratio of the area of the lens covered by dots compared to the area of the clear aperture. In this approximation, it is assumed that all the light that hits the dots becomes uniformly dispersed across the entire retinal area, which reduce the amount of light available in lighter areas of an image and this adds light to darker areas. Accordingly, contrast reduction may be calculated based on light transmission measurements made through the clear aperture and dot pattern of a lens

Generally, ophthalmic lenses 110a and 110b can be clear or tinted. That is, the lenses may be optically transparent to all visible wavelengths, appearing clear and/or colorless, or may include a spectral filter, appearing colored. For example, ophthalmic lenses may include a filter that reduces the amount of red light transmitted to the wearer. It is believed that excessive stimulation of L cones in a person's eye (especially in children), may result in non-optimal eye lengthening and myopia. Accordingly, spectrally filtering red light using the ophthalmic lenses may further reduce myopia in a wearer.

Spectral filtering may be provided by applying a film to a surface of the lenses. Films may be applied by physically depositing material onto a lens surface, coating a layer of material on the surface, or laminating a preformed film onto the surface. Suitable materials include absorptive filter materials (e.g., dyes) or multilayer films, providing interference filtering. In some embodiments, spectral filtering may be provided by including a filtering material in the lens material itself and/or including a filtering material in the material used to form the protuberance.

Referring to FIG. 2, the effect of spectral filtering and contrast reduction from the dot pattern is shown by viewing black text on a white background using eyeglasses 210. The white background to the text takes on a green appearance due to the filtering of red wavelengths from by the eyeglasses. Image contrast is unaffected at clear apertures 220a and 220b, but is reduced elsewhere in the viewer's visual frame.

In general, dots can be formed from lenses in a variety of ways including UV LED Direct-to-Substrate Printing, pad printing, hot stamping and screen printing technologies. In some embodiments, dots are formed by inkjetting a curable material onto a surface of a blank ophthalmic lens and then curing the material to set the dot pattern. Referring to FIG. 3A, an inkjetting and curing system 300 includes an inkjet printer 320 and a computer 310 in communication with the printer. Printer 320 includes a controller 330, a reservoir 340, an inkjet printhead 350, and a stage 360. Stage 360 supports a lens 301 and positions the lens relative to printhead 350. Reservoir 340 stores uncured material for inkjetting. Examples of curable material suitable for inkjetting includes various commercially-available proprietary monomers and oligomers that are cross-linked together, by photopolymerisation.

During operation, printhead 350 receives uncured material from reservoir 340.

Stage 360 moves lens 301 relative to printhead 350 (as depicted by arrows 361) while printhead 350 ejects drops of uncured material 302 toward the lens. Either the stage and/or printhead may be the moving part during this process. Drop volume varies depending on the desired protuberance dimensions. Drop volumes may be in a range from 0.001 mm^3 to 0.015 mm^3 (e.g., about 0.002 mm^3, about 0.003 mm^3, about 0.004 mm^3, about 0.005 mm^3, about 0.006 mm^3, about 0.008 mm^3, about 0.010 mm^3, about 0.012 mm^3). Upon contact with the lens surface, the drops wet the surface forming uncured protuberances 305. Alternatively, in some embodiments, stage 360 remains stationary while actuators move the printhead relative to the lens.

System 300 also includes a UV lamp 370. Stage 360 positions the lens adjacent lamp 370 so that the lamp can cure the deposited material, forming the final protuberances. Examples of suitable UV lamps include LEDs emitting in the wavelength range of 360-390 nm.

Controller 330 is in communication with reservoir 340, printhead 350, stage 360, and UV lamp 370 and coordinates the operation of each to facilitate printing and curing of the drops. Specifically, controller 330 controls the relative motion between printhead 350 and stage 360, the inkjet drop ejection frequency, and drop volume so that system 300 forms the desired dot pattern on lens 301. Controller 330 may also control the temperature of the uncured material (e.g., by a heater associated with reservoir 340 or elsewhere) to control the viscosity of the uncured material. The user inputs the drop pattern via computer 310, which generates corresponding control signals for the printer and communicates the signals to controller 330.

Commercially-available inkjet printers may be used. Suitable inkjet printers include Roland DGA (Irvine, CA) and Mimaki (Suwanee, GA) brands of UV LED Direct-to-Substrate Printers.

Inkjetting dot patterns allows an eye care professional to personalize dot patterns for a patient in an inexpensive and efficient manner. Referring to FIG. 3B, personalized eyeglasses are provided by a sequence 380 that may be performed entirely at the eye care professional's office. In a first step 381, the eye care professional determines the patient's prescription, e.g., by refracting the subject. This step determines the power of the ophthalmic lens upon which the dot pattern is formed. The patient also chooses their eyeglass frames in the same way they would for regular prescription glasses.

In the next step 382, the eye care professional selects a dot pattern suitable for the patient. Parameters for the dot pattern that can be varied include, for example, dot size, dot density, clear aperture size and shape, and location of the clear aperture on the lens. Each of these may be individualized depending on the desired amount of contrast reduction in the peripheral vision and clear aperture angular range. An exemplary dot pattern is shown in FIG. 3C. This pattern prints dots over an area larger than most lens blanks, ensuring complete coverage of the lens surface by the dot pattern. Commercial software suitable for generating images (e.g., Microsoft Office products such as Visio, PowerPoint, or Word) may be used in conjunction with standard inkjet driver software to generate control signals for the inkjet printer. Alternatively, custom software can be used by the eye care professional to input the chosen parameters for the pattern into the ink jet printer's computer.

Next, in step 383, the ink jet printer deposits drops of uncured material in accordance with signals from the computer to form dots in the desired pattern. In step 384, the printed pattern is then exposed to curing radiation. In some embodiments, the center of the dot pattern, such as the clear center, is aligned to the optical center of the lens. This can be achieved, for example, by measuring and marking the optical center using a lensometer and aligning the print pattern with the marked optical center. In certain implementations, the optical center of the lens is first marked, then edged in a circular shape, such that the optical center is aligned to the geometric center of the circular lens. Drops are then printed on the lens so that the dot pattern is centered on the circular lens, which now corresponds to the optical center. Alternatively, or additionally, lens blanks can be made or chosen such that the optical center always matches the geometric center of the lens.

Finally, in step 385, the lenses are edged and mounted in the frames.

In some implementations, the lenses can be mounted in the frames and the frames fit to the wearer before the dots are cured. In this way, the printed dot pattern can be cleaned off the lens and the reprinted if necessary.

Referring to FIG. 3D, in some implementations, a jig 390 is used to support multiple lens blanks during lens manufacturing. Jig 390 includes a tray 391 that features an array of lens holders 392 on one surface, each sized to securely hold a lens. For example, if 60 mm diameter lens blanks are used, the lens holders each have a diameter of 60 mm to tightly hold a respective lens. During operation, jig 390 including one or more lenses is positioned on stage 360. The jig holds each lens in precise location so that system 300 can accurately jet onto the lenses' surface. In addition, the jig allows for manufacturing multiple lenses per batch. While the jig in FIG. 3D includes 48 lens holders, generally, jigs can be designed to hold any number of lenses subject to the physical constraints imposed by the ink jetting system. Many sizes of jigs are possible, for example jigs that accommodate about 24 lenses, about 48 lenses, about 100 lenses, about 200 lenses, about 300 lenses, about 400 lenses, about 500 lenses, or more than 500 lenses per run.

FIGS. 4A-4C show photographs of a lens printed using the pattern of FIG. 3C. FIG. 4A shows the entire lens, while FIGS. 4B and 4C show an enlarged portion of the dot pattern, the portion in FIG. 4C including the clear aperture.

Other methods for forming protrusions are also possible. For example, transfer or lithographic printing can be used instead of inkjetting. Transfer printing involves forming the protrusions on a different substrate and then transferring them to the surface of the lens in a separate process step. Lithographic printing may involve forming a continuous, uniform layer of the protrusion material on the lens surface and then patterning that layer to form the dot pattern. Optical or contact lithography can be used to pattern the layer. Alternatively, the protrusions can be molded on the lens surface using the same molding process used to form the lens. In this case, the protrusions are part of the lens mold. In some embodiments, the dot pattern may be provided by a film that is laminated onto a surface of the lens.

While the dot pattern in the embodiments described above are protrusions formed on a surface of the ophthalmic lens, other implementations that provide comparable optical properties and lens durability are also possible. For example, in some embodiments, contrast reduction is provided by arrays of recesses in a lens surface. The recesses can have dimensions similar to those of the protuberances described above. Recesses can be formed using a variety of techniques, such as etching (e.g., physical etching or chemical etching) or ablating material from the lens surface (e.g., using laser radiation or a molecular or ion beam). In some embodiments, recesses are formed when molding the lens.

Alternatively, or additionally, dot patterns can be embedded in the lens material itself. For example, transparent beads of appropriate size can be dispersed in the lens material when the lens is molded, where the refractive index of the bead material and bulk lens material differ. The clear aperture is formed from bulk lens material only.

In some embodiments, contrast reduction is produced by other diffusing structures, such as a roughened surface. Holographic diffusers or ground glass diffusers may be used. In some embodiments, a diffuser may be provided by a film that is laminated onto a surface of the lens.

While the foregoing description pertains to ophthalmic lenses for eyeglasses, the principles disclosed may be applied to other forms of ophthalmic lenses, such as contact lenses. In some embodiments, dot patterns may be provided on contact lenses to provide similar therapeutic effects. The size and spacing of dots in a contact lens dot pattern may be sized so that they subtend comparable solid angles in a user's visual field to the dot patterns described for eyeglass lenses above.

Dot patterns may be formed on contact lenses in a variety of ways. For example, dot patterns may be printed or transferred to a contact lens surface using the techniques described above. Alternatively, the dot patterns may be formed by dispersing scattering materials in the contact lens.

In some embodiments, dots are formed on one or both surfaces of a contact lens by exposing a contact lens surface to laser radiation. The laser radiation locally ablates the contact lens material at the surface, leaving a small depression. By selectively exposing the contact lens surface to laser radiation, a dot pattern can be formed on the surface. For example, the laser's beam can be moved relative to the surface while the beam is pulsed. Relative motion between the beam and the contact lens surface can be caused by moving the beam while leaving the surface fixed, moving the surface while leaving the beam fixed, or moving both the beam and the surface.

Referring to FIG. 13, a laser system 1300 for forming dots on a surface of a lens includes a laser 1320, a beam chopper 1330, focusing optics 1340, a mirror 1350, and a stage 1370. Laser 1320 directs a laser beam towards mirror 1350, which deflects the beam towards a contact lens 1301 which is positioned relative to the mirror 1350 by stage 1370. An actuator 1360 (e.g., a piezoelectric actuator) is attached to mirror 1350. The stage includes a curved mounting surface 1380 which supports contact lens 1301. Laser system 1300 also includes a controller (e.g., a computer controller) in communication with laser 1320, beam chopper 1330, and actuator 1360.

Beam chopper 1330 and focusing optics 1340 are positioned in the beam path. Chopper 1330 periodically blocks the beam so that contact lens 1301 is exposed to discrete pulses of laser light. Focusing optics 1340, which generally includes one or more optically powered elements (e.g., one or more lenses), focuses the beam to a sufficiently small spot on the surface of contact lens 1301 so that the area ablated by the beam on the lens surface corresponds to the desired dot size. Actuator 1360 changes the orientation of mirror 1350 with respect to the beam to scan the pulsed beam to different target points on the contact lens surface. Controller 1310 coordinates the operation of laser 1320, chopper 1330, and actuator 1360 so that the laser system form a predetermined dot pattern on the contact lens.

In some implementations, stage 1370 also includes an actuator. The stage actuator can be a multi-axis actuator, e.g., moving the contact lens in two lateral dimensions orthogonal to the beam propagation direction. Alternatively, or additionally, the actuator can move the stage along the beam direction. Moving the stage along the beam direction can be used to maintain the exposed portion of the lens surface at the focal position of the beam, notwithstanding the curvature of the lens surface, thereby maintaining a substantially constant dot size across the lens surface. The stage actuator can also be controlled by controller 1310, which coordinates this stage motion with the other elements of the system. In some embodiments, a stage actuator is used in place of the mirror actuator.

Generally, laser 1320 can be any type of laser capable of generating light with sufficient energy to ablate the contact lens material. Gas lasers, chemical lasers, dye lasers, solid state lasers, and semiconductor lasers can be used. In some embodiments, infrared lasers, such as a CO_2 laser (having an emission wavelength at 9.4 μm or 10.6 μm) can be used. Commercially-available laser systems can be used such as, for example, CO_2 laser systems made by Universal Laser Systems, Inc. (Scottsdale, AZ), (e.g., the 60W VLS 4.60 system).

The pulse duration and pulse energy are typically selected to ablate an amount of material from the contact lens surface to provide a dot of a desired size. An example dot pattern for a contact lens is shown in FIG. 14A. Here, contact lens 1400 includes a clear aperture 1410, a reduced-contrast region 1420, and a clear outer region 1430. Reduced-contrast region 1420 is an annular region having an inner diameter ID and an outer diameter OD. ID corresponds to the diameter of clear aperture 1410. The contact lens has a lens diameter, LD, which is greater than OD.

Typically, ID is less than the user's pupil diameter under normal indoor lighting conditions (e.g., such as typical classroom or office lighting in which a user is able to easily read text from a book). This ensures that, under such lighting conditions, image contrast in the user's peripheral visual field is reduced. In some embodiments, ID is in a range from about 0.5 mm to about 2 mm (e.g., in a range from about 0.75 mm to about 1.75 mm, in a range from about 0.9 mm to about 1.2 mm, about 0.6 mm or more, about 0.7 mm or more, about 0.8 mm or more, about 0.9 mm or more, about 1 mm or more, about 1.1 mm or more, about 1.2 mm or more, about 1.9 mm or less, about 1.8 mm or less, about 1.7 mm or less, about 1.6 mm or less, about 1.5 mm or less, about 1.4 mm or less, about 1.3 mm or less).

Generally, OD is sufficiently large so that the reduced-contrast region extends beyond the user's pupil under normal indoor lighting conditions. In some embodiments, OD is about 2.5 mm or more (e.g., about 3 mm or more, about 4 mm or more, about 5 mm or more, such as about 10 mm or less, about 8 mm or less, about 7 mm or less, about 6 mm or less).

Generally, the dimensions and spacing between the dots in the contact lenses are selected so as to provide the desired optical effect (e.g., as described above), subject to the constraints of the method used to form the dots. In some embodiments, the dots can have a maximum lateral dimension in a range from about 0.005 mm or more (e.g., about 0.01 mm or more, about 0.015 mm or more, about 0.02 mm or more, about 0.025 mm or more, about 0.03 mm or more, about 0.035 mm or more, about 0.04 mm or more, about 0.045 mm or more, about 0.05 mm or more, about 0.055 mm or more, about 0.06 mm or more, about 0.07 mm or more, about 0.08 mm or more, about 0.09 mm or more, about 0.1 mm) to about 0.5 mm or less (e.g., about 0.4 mm or less, about 0.3 mm or less, about 0.2 mm or less, about 0.1 mm).

The spacing of the dots can also vary so as to provide the desired optical effect. Typically, the spacing of the depressions (i.e., as measured between the center of adjacent depressions) are in a range from about 0.05 mm (e.g., about 0.1 mm or more, about 0.15 mm or more, about 0.2 mm or more, about 0.25 mm or more, about 0.3 mm or more, about 0.35 mm or more, about 0.4 mm or more, about 0.45 mm or more) to about 1 mm (e.g., about 0.9 mm or less, about 0.8 mm or less, about 0.7 mm or less, about 0.6 mm or less, about 0.5 mm or less).

The relative area of dots in the reduced-contrast region can vary as described above for eyeglass lenses.

LD corresponds to the diameter of the contact lens and is typically in a range from about 10-20 mm. Generally, LD is greater than OD by at least 1 mm or more (e.g., about 2 mm or more, about 3 mm or more, about 4 mm or more, about 5 mm or more, about 6 mm or more, about 7 mm or more, such about 8 mm). Including at least some space at the edge of the contact lens that does not include dots ensures that the dots do not reduce the integrity of the contact lens at its edge (e.g., by tearing) or reducing the integrity of the seal between the contact lens and the user's eyeball.

While the contact lens dot pattern shown in FIG. 14A features dots that each have the same size and the same spacing between adjacent dots, other dot arrangements are possible. For example, referring to FIG. 14B, a contact lens 1450 features dots having varying sizes. Here, contact lens 1450 includes a clear aperture 1460, a reduced-contrast region 1470, and a clear outer region 1480. Reduced-contrast region 1470 includes a dot pattern in which the size of the dots increases as the radial distance of the dot position with respect to the center of the lens increases. Accordingly, dots 1471 closest to clear aperture 1460 are the smallest, while dots 1472 closest to outer region 1480 are the largest.

Although system 1300 is shown as ablating a contact lens, more generally, laser ablation can be used for eyeglass lenses too.

While myopia progression and treatment efficacy may be monitored in subjects using a variety of techniques (e.g., including subjective refraction and/or eye length measurements), it is believed that changes in choroidal thickness (i.e., an increase in the choroidal thickness) is a reliable biomarker for this purpose. Choroid thickness can be measured using optical coherence tomography (OCT). Exemplary deep field OCT images showing the choroid thickness in a subject are shown in FIGS. 5A and 5B. The choroid, shown in cross-section between the two yellow curves spanning the image field from left to right. Because OCT images may have variable magnification, an internal landmark that doesn't change thickness over the course of treatment may be used as a reference when making thickness measurements. An example of such a landmark is the retinal pigmented epithelium (RPE) layers between the choroid and the retina, whose thickness is indicated by the red line shown in FIG. 5B.

EXAMPLES

Initial Study/Comparative Example

In prior investigations, it was found that proof-of-concept eyeglasses using diffusing filters attached to the surface of the lenses could slow axial length growth in subjects but there were a number of challenges. The filter used was a commercially available Bangerter Occlusion Foil ("BOF"). These were diffusers made of thin flexible static vinyl film which was trimmed to match the lens shape and adhered to the right lens. The "foil" used was "BOF-0.8 Acuity of 20/25" which, as the name implies, nominally reduced best corrected acuity to 20/25. However, in practice, acuity of subjects who could be best corrected in the range of 20/15 – 20/20, tested in the range 20/30-20/40 with the BOF-0.8 filter in place. The subjects of this study wore the diffuser unilaterally on one eye was because of the large reduction in acuity it produced and there was concern about the tolerability and safety of wearing spectacles that reduced acuity to 20/30-40 binocularly. By making the diffuser arm monocular, subjects of this study were able to function normally because they had one eye they could use for high acuity vision. However, ideally, in a commercial product, the treatment should be done to both eyes simultaneously.

Another problem with the Initial Study was that the vinyl filters could detach from the lenses accidentally. In order to deal with this problem, in the trial, each subject was provided with two pairs of glasses with the instruction to use the second pair if the filter came off the first pair. Then, it was possible to supply the subject with a new backup pair. Ideally, in a commercial product the diffuser should be a durable as standard lenses.

New Study

Prototype lenses were designed to address problems with the spectacles used in the Initial Study and at the same time maintain or improve efficacy in slowing growth of axial length. It is believed that the main reason the BOF-0.8 filters reduced acuity so drastically was because of the very poor optical quality of the vinyl film itself. Non-uniformities in thickness produced a "wavy" pattern that distorted the image making vision difficult. However, it was believed this degradation of the image did not have any therapeutic value. Thus, one goal for the prototype lenses of the new study was to eliminate any kind of film applied to the eyeglasses and provide the diffuser as a permanent part of the lens itself. In the new design, the diffuser component of these lenses serves the purpose of lowering contrast of the image but every other aspect of the optical quality is substantially the same as the standard of care.

A first step in the development of the eyeglasses was to produce a lens that replicated the amount of diffusion (and presumably the therapeutic value) of the BOF-0.8 filter but had all the other optical properties of a standard (i.e., non-diffusing) lens. Efficacy of the new prototypes were compared with the BOF-0.8 filter of the Initial Study which was used as the standard for efficacy. In order to reduce the length of the study on new prototypes, choroid thickening measured using optical coherence tomography (OCT) was used as a biomarker for treatment efficacy. The choroid was imaged using OCT and it was demonstrated that the BOF-0.8 filter produced a thickening of the choroid that could be accurately measured. Images from this study are shown in FIGS. 6A-6D. OCT non-invasively provides a cross-sectional view of the retina through the fovea. Several layers can be resolved including the inner limiting membrane nerve fiber layer (NFL), ganglion cell layer (GCL), inner plexiform layer (IPL), inner nuclear layer (INL), junction between the inner and outer segment of the photoreceptors (IS/OS PR), outer nuclear layer (ONL), retinal pigment epithelium (RPE). The very deepest layer is the choroid. FIGS. 6A and 6C show the unsegmented images of the retina from one subject before and after treatment with the BOF-0.8 filter. A relative thickening of the choroid layer is evident post-treatment compared to pretreatment. FIGS. 6B and 6D include segment lines (in red) showing the outer bounds of the choroid. FIG. 6C shows the choroid at day 39 post-treatment. FIG. 6D shows the choroid at day 39 post-treatment with the outerbound of the choroid demarcated. Thickness was measured as the distance from the boundary line to the RPE boundary.

FIG. 7 shows a plot of relative choroid thickness as a function of location on the retina for this study. A marked post-treatment thickening (upper, blue curve) of the choroid is evident across the retina compared to the pre-treatment measurements (lower, black curve).

Example: Prototype I

A first prototype eyeglasses, prototype I, was developed to provide a lens that incorporated diffusive elements and lowered the contrast of the image substantially the same amount as the BOF-0.8 filter while being practical and durable and free of the many optical imperfections of the vinyl substrate of the BOF-0.8 filter. The lens for formed by inkjet printing a dot pattern on lenses using a UV-curable material. Printers from the Roland DG VersaUV line of inkjet printers and Mimaki UV flat bed printers were both used in different versions of prototype I. The UV-curable materials were also obtained from Roland and Mimaki.

The lenses were clear polycarbonate, shatterproof lenses, without any spectral filtering. The dot pattern was printed on a square grid having a spacing of 0.55 mm. The volume of each dot was 0.004 mm^3. The dot pattern covered the entire lens; no clear aperture remained. The printed pattern was cured using UV LEDs emitting in the range 365 nm-385 nm. A photograph of an example prototype I lens is shown in FIG. 8.

We tested prototype I lens using a within-subjects protocol. A small number of subjects were recruited and refracted to their best corrected visual acuity. The hypothesis that the initial reduction in axial length was the result of choroidal thickening was tested with an OCT study. For this,

After a week of baseline measurements, subjects wore glasses with an untreated left eye (OS) lens and a BOF-0.8 filter attached to the right eye (OD) lens. After four weeks, subjects then switched to the new prototype lenses on their left eyes (OS) and the right eyes wore untreated lenses. The absolute difference between the choroid thickness of the left and right eyes (OD-OS) increased significantly after a month of BOF-0.8 filter wear over the right eye. When the OD glasses were removed and the OS eye was treated with prototype I there was a corresponding significant decrease in the axial length of OS (p=0.0083) and an increase in the OD-OS value (p=0.0032). There was no significant difference between the effectiveness of prototype I and the BOF-0.8 filter with respect to producing an increase in choroid thickness. However, there was a drastic difference in best corrected visual acuity when wearing our prototype I compared to the BOF-0.8 filter.

Example 2: Prototype II

The goal for prototype II was to produce a lens that would allow measured best corrected visual acuities of 20/15 – 20/20 but have effectiveness as good or better than the BOF-0.8 filter. To this end, prototype II lenses were produced by modifying the prototype I dot pattern to incorporate a small central clear area. The dots were formed on a square grid pattern with a spacing of 0.55 mm. The clear aperture was formed in with a circular shape of diameter 3.8 mm. A photograph of a prototype II lens is shown in FIG. 9.

When the glasses were fitted, the clear area was positioned to match the pupil allowing the wearer to look through the clear area when viewing straight ahead. Subjects who were best corrected to 20/15-20/20 tested as 20/15-20/20 when wearing prototype II and reading the eye chart looking through the clear area.

We tested prototype II with the clear area against prototype I by recruiting a small number of subjects and having them wear the lens with the clear area on the left eye and the lens without on the right eye. We then compared increases in choroidal thickness between the two eyes and found no difference between the lenses with the clear area and the lens without. This demonstrated that it is possible to design a diffuser lens without spectral light filtering, that allowed subjects to test with best corrected acuities of 20/15 – 20/20 and still maintain the effectiveness (as measured by increases in choroid thickness) of the original lens used in the Initial Study.

Example 3: Prototype III

Further improvements were explored to simultaneously maximize tolerability and effectiveness. We felt that the larger the clear area the more tolerable the prototype would be but also hypothesized that increasing the peripheral contrast reduction might increase the effectiveness. Thus, we experimented with these two variables producing another prototype:

prototype III. Like protoypes I and II, prototype III did not have a spectral light filtering. The dot pattern for prototype III was modified to include a larger clear aperture and a greater reduction in contrast outside the clear area than prototype II. In particular, the clear aperture was enlarged to a 5.0 mm diameter and the square grid spacing reduced to 0.365 mm. Dot size remained the same as prototype II. A photograph of a prototype III lens is shown in FIG. 10.

A design goal was to develop a prototype that allows good vision that children and their parents are happy and comfortable with. Visual acuity with prototype III for children with best corrected acuity of 20/15 – 20/20 was 20/15 – 20/20 when vision was tested viewing through the clear aperture of the lens. We also tested acuity "off-axis" with the subject viewing through the peripheral diffuser. Subjects with best corrected acuity of 20/15 -20/20 through the clear aperture demonstrated 20/20-20/25 vision when viewing through the diffusing area.

We initiated a small trial with the prototype III lens worn binocularly. The main objective of the lens was to assay durability and tolerability of the lens. The trial had one arm. Subjects were aged 7 to 10 years of age with a history of myopic progression. Subjects were all referred to us by ophthalmologists because parents were concerned about rapidly progressing myopia in their children. The study had a single site, which was ophthalmology research at the University of Washington in Seattle. 8 children were enrolled. Preliminary results for 4 children who passed 6 month wearing the glasses were obtained, monitoring axial length with an optical biometer, the IOLMaster from Carl Zeiss Meditec. Children were also asked to keep a journal documenting how many hours a day they wear the lenses and noting any problems or concerns they had with the eyeglasses.

When subjects came to the lab for axial length measurements, we viewed their journal and inspected the eyeglasses for any signs change or deterioration. We also asked the subjects and their parents if they had any problems or concerns with the eyeglasses. There were no noted problems with the durability of the eyeglasses and the subjects and parents had no complaints.

However, referring to FIG. 12, it is interesting to compare axial growth the subjects wearing prototype III with the results of the Initial Study at 6 months. This figure shows a bar chart comparing the change in diopters after 180 days for subjects' eyes. The first bar represents the control eyeglasses and the second bar represents the original diffuser eyeglasses from the Initial Study. The third bar represents Prototype III after 6 months for the four children who completed 6 months in the study.

What we have demonstrated is that we are able to manufacture stable and durable spectacles that allow 20/15 – 20/20 vision. In this small group of subjects were very satisfied with the spectacles and they show a slow rate of progression after 6 months.

Example 4: Contact Lenses

Dot patterns were formed on contact lenses as follows. In each case, a -7.5 D contact lens was positioned on a ball bearing on the stage of a VLS 4.60 CO2 laser system (Universal Laser Systems, Inc., Scottsdale, AZ). The lens diameter in each case was 14 mm.

Contact lenses were exposed at 5% power, 10% power, and 20% power settings respectively. In each exposure, the laser scan speed was set to 25% and the resolution set to 0.002 inches. The exposure area had an outer diameter of 12.7 mm and an inner diameter of 1 mm. The exposure pattern within the area was a square grid with a grid spacing of 0.0116 inches.

A visible dot pattern was formed for 5% and 10% power settings. The 20% power setting resulting in cutting through the contact lens.

A photograph of one of the contact lenses is shown in FIG. 15A. The dot pattern is clearly visible.

Example 5: Eyeglass Lenses Using Laser Ablation

Dot patterns were formed on several Trivex eyeglass lenses using a 60W, 10.6 μm, VLS 4.60 CO2 laser system (Universal Laser Systems, Inc., Scottsdale, AZ). Lenses were exposed various powers between 5% and 40% and in both raster and vector print modes. The laser was set at 1,000 PPI. Speed settings were 25% or 100%.

A photograph of a lens exposed in vector mode is shown in FIG. 15B. The dot pattern in this example, which was printed in vector mode, is clearly visible.

A number of embodiments are described. Other embodiments are in the following claims.

WHAT IS CLAIMED IS:

1. A pair of eyeglasses, comprising:

eyeglass frames; and

a pair of ophthalmic lenses mounted in the frames, the lenses comprising a dot pattern distributed across each lens, the dot pattern comprising an array of dots spaced apart by a distance of 1 mm or less, each dot having a maximum dimension of 0.3 mm or less.

2. The eyeglasses of claim 1, wherein the dot pattern includes a clear aperture free of dots having a maximum dimension of more than 1 mm, the clear aperture being aligned with a viewing axis of a wearer of the pair of eyeglasses.

3. The eyeglasses of claims 1 or 2, wherein each dot has a maximum dimension of 0.2 mm or less.

4. The eyeglasses of claims 1 or 2, wherein each dot has a maximum dimension of 0.1 mm or less.

5. The eyeglasses of claims 1 or 2, wherein each dot has a maximum dimension of 0.05 mm or less.

6. The eyeglasses of claims 1 or 2, wherein each dot has a maximum dimension of 0.02 mm or less.

7. The eyeglasses of claims 1 or 2, wherein each dot has a maximum dimension of 0.01 mm or less.

8. The eyeglasses of claims 1 or 2, wherein each dot is substantially the same size.

9. The eyeglasses of claims 1 or 2, wherein the dots are spaced apart by 0.8 mm or less.

10. The eyeglasses of claims 1 or 2, wherein the dots are spaced apart by 0.6 mm or less.

11. The eyeglasses of claims 1 or 2, wherein the dots are spaced apart by 0.5 mm or less.

12. The eyeglasses of claims 1 or 2, wherein the dots are spaced apart by 0.4 mm or less.

13. The eyeglasses of claims 1 or 2, wherein the dots are spaced apart by 0.35 mm or less.

14. The eyeglasses of claims 1 or 2, wherein the dots are arranged on a square grid.

15. The eyeglasses of claim 2, wherein the clear aperture has a maximum dimension of 2 mm or more.

16. The eyeglasses of claim 2, wherein the clear aperture has a maximum dimension of 3 mm or more.

17. The eyeglasses of claim 2, wherein the clear aperture has a maximum dimension of 4 mm or more.

18. The eyeglasses of claim 2, wherein the clear aperture has a maximum dimension of 5 mm or more.

19. The eyeglasses of claim 2, wherein the clear aperture has a maximum dimension of 6 mm or more.

20. The eyeglasses of claim 2, wherein the clear aperture has a maximum dimension of 7 mm or more.

21. The eyeglasses of claim 2, wherein the clear aperture has a maximum dimension of 8 mm or more.

22. The eyeglasses of claim 2, wherein the clear aperture is substantially circular.

23. The eyeglasses of claims 1 or 2, wherein the dots are protrusions on a surface of the corresponding lens.

24. The eyeglasses of claim 23, wherein the protrusions are formed from a transparent material.

25. The eyeglasses of claim 24, wherein the transparent material is clear.

26. The eyeglasses of claim 24, wherein the transparent material is tinted.

27. The eyeglasses of claim 24, wherein the transparent material has substantially the same refractive index as a lens material.

28. The eyeglasses of claim 23, wherein the protrusions are substantially spherical.

29. The eyeglasses of claims 1 or 2, wherein the dots are recesses on a surface of the corresponding lens.

30. The eyeglasses of claims 1 or 2, wherein the dots are inclusions between opposing surfaces of each lens.

31. The eyeglasses of claims 1 or 2, wherein the lenses are clear lenses.

32. The eyeglasses of claims 1 or 2, wherein the eyeglasses are tinted eyeglasses.

33. The eyeglasses of claims 1 or 2, wherein the dot pattern reduces an image contrast of an object viewed through the dot pattern by at least 30% compared to an image contrast of the object viewed through the clear aperture.

34. The eyeglasses of claims 1 or 2, wherein the dot pattern reduces an image contrast of an object viewed through the dot pattern by at least 35% compared to an image contrast of the object viewed through the clear aperture.

35. The eyeglasses of claims 1 or 2, wherein the dot pattern reduces an image contrast of an object viewed through the dot pattern by at least 40% compared to an image contrast of the object viewed through the clear aperture.

36. The eyeglasses of claims 1 or 2, wherein the dot pattern reduces an image contrast of an object viewed through the dot pattern by at least 45% compared to an image contrast of the object viewed through the clear aperture.

37. The eyeglasses of claims 1 or 2, wherein the dot pattern reduces an image contrast of an object viewed through the dot pattern by at least 50% compared to an image contrast of the object viewed through the clear aperture.

38. The eyeglasses of claims 1 or 2, wherein the dot pattern reduces an image contrast of an object viewed through the dot pattern by at least 55% compared to an image contrast of the object viewed through the clear aperture.

39. The eyeglasses of claims 1 or 2, wherein the dot pattern reduces an image contrast of an object viewed through the dot pattern by at least 60% compared to an image contrast of the object viewed through the clear aperture.

40. The eyeglasses of claims 1 or 2, wherein the lenses having optical power to correct a wearer's on-axis vision to 20/20 or better through the clear aperture, and, for at least a portion of the wearer's peripheral vision through the dot pattern, the lenses correct the wearer's vision to 20/25 or better.

41. A method of making the eyeglasses of claims 1 or 2, comprising:

depositing discrete portions of a material on a surface of the lens corresponding to the dot pattern; and

curing the deposited material to provide protrusions on the lens surface forming the dot pattern.

42. The method of claim 41, wherein the material is deposited using an inkjet printer.

43. The method of claim 41, wherein the deposited material is cured using radiation.

44. The method of claim 43, wherein the radiation comprises ultraviolet radiation.

45. A pair of eyeglasses customized for a wearer, comprising:

eyeglass frames; and

a pair of ophthalmic lenses mounted in the frames, the lenses having optical power to correct the wearer's on-axis vision to 20/20 or better, the lenses comprising a dot pattern distributed across each lens, the dot pattern comprising an array of dots arranged so that, for at least a portion of the wearer's peripheral vision, the lenses correct the wearer's vision to 20/25 or better and reduce an image contrast by at least 30% compared to on-axis image contrast.

46. A pair of eyeglasses customized for a wearer, comprising:

eyeglass frames; and

a pair of ophthalmic lenses mounted in the frames, the lenses having optical power to correct the wearer's on-axis vision to 20/20 or better, the eyeglasses comprising an optical diffuser distributed across each lens, the optical diffuser being configured so that, for at least a portion of the wearer's peripheral vision, the lenses correct the wearer's vision to 20/25 or better and reduce an image contrast by at least 30% compared to on-axis image contrast.

47. The eyeglasses of claim 46, wherein the optical diffuser comprises a film laminated on a surface of each lens.

48. The eyeglasses of claim 46, wherein the lenses each comprise a clear aperture free of the optical diffuser having a maximum dimension of more than 1 mm, the clear aperture being aligned with a viewing axis of a wearer of the pair of eyeglasses.

49. An ophthalmic lens, comprising:

two opposing curved surfaces collectively having an optical power to correct a wearer's on-axis vision to 20/20 or better; and

a dot pattern distributed across each lens, the dot pattern comprising an array of spaced apart dots arranged so that, for at least a portion of the wearer's peripheral vision, the lenses correct the wearer's vision to 20/25 or better and reduce an image contrast by at least 30% compared to on-axis image contrast, the dot pattern including a clear aperture free of dots aligned with a viewing axis of the wearer.

50. The ophthalmic lens of claim 49, wherein the ophthalmic lens is an eyeglass lens.

51. The ophthalmic lens of claim 49, wherein the ophthalmic lens is a contact lens.

52. A method of monitoring and arresting myopia progression in a person, comprising:

measuring variations in a thickness of the person's choroid over a period of time; and

providing the person with ophthalmic lenses which reduce an image contrast in the person's peripheral vision compared to an on-axis image contrast.

53. The method of claim 52, wherein measuring the variations comprises measuring a thickness of the person's choroid using Optical Coherence Tomography (OCT).

54. A contact lens, comprising:

two opposing curved surfaces collectively having an optical power to improve a wearer's on-axis vision, the curved surfaces defining a lens axis; and

at least one of the curved surfaces comprising a first annular region surrounding a clear aperture, and a second annular region extending from the first annular region to an edge of the contact lens, wherein:

the clear aperture, and the first and second annular regions are substantially centered on the lens axis, and

the first annular region has a plurality of spaced apart depressions sized and shaped so that they reduce an image contrast for the wearer compared to the wearer's on-axis image contrast.

55. The contact lens of claim 54, wherein the clear aperture has a diameter in a range from about 0.5 mm to about 2 mm.

56. The contact lens of claim 55, wherein the clear aperture has a diameter in a range from about 0.5 mm to about 1.5 mm.

57. The contact lens of claim 56, wherein the clear aperture has a diameter in a range from about 0.5 mm to about 1.2 mm.

58. The contact lens of claim 54, wherein the first annular region has an outer diameter in a range from about 2.5 mm to about 10 mm.

59. The contact lens of claim 58, wherein the outer diameter of the first annular region is in a range from about 2.5 mm to about 8 mm.

60. The contact lens of claim 59, wherein the outer diameter of the first annular region is in a range from about 2.5 mm to about 6 mm.

61. The contact lens of claim 60, wherein the outer diameter of the first annular region is in a range from about 2.5 mm to about 5 mm.

62. The contact lens of claim 61, wherein the outer diameter of the first annular region is in a range from about 2.5 mm to about 4 mm.

63. The contact lens of claim 62, wherein the outer diameter of the first annular region is about 3 mm.

64. The contact lens of claim 54, wherein the second annular region has a radial dimension of at least 1 mm.

65. The contact lens of claim 64, wherein the radial dimension of the second annular region is about 2 mm or more.

66. The contact lens of claim 65, wherein the radial dimension of the second annular region is about 3 mm or more.

67. The contact lens of claim 64, wherein the radial dimension of the second annular region is about 5 mm or less.

68. The contact lens of claim 67, wherein the radial dimension of the second annular region is about 4 mm or less.

69. The contact lens of claim 54, wherein depressions have a maximum lateral dimension in a range from 0.001 mm to about 1 mm.

70. The contact lens of claim 69, wherein depressions have a maximum lateral dimension in a range from 0.001 mm to about 0.1 mm.

71. The contact lens of claim 70, wherein depressions have a maximum lateral dimension in a range from 0.005 mm to about 0.1 mm.

72. The contact lens of claim 71, wherein depressions have a maximum lateral dimension in a range from 0.01 mm to about 0.1 mm.

73. The contact lens of claim 54, wherein adjacent depressions are spaced apart by a lateral distance in a range from 0.01 mm to about 1 mm.

74. The contact lens of claim 73, wherein adjacent depressions are spaced apart by a lateral distance in a range from 0.01 mm to about 0.5 mm.

75. The contact lens of claim 74, wherein adjacent depressions are spaced apart by a lateral distance in a range from 0.05 mm to about 0.5 mm.

76. The contact lens of claim 54, wherein the depressions occupy at least 10% of an area of the first annular region.

77. The contact lens of claim 76, wherein the depressions occupy at least 20% of the area of the first annular region.

78. The contact lens of claim 77, wherein the depressions occupy at least 30% of the area of the first annular region.

79. The contact lens of claim 78, wherein the depressions occupy at least 40% of the area of the first annular region.

80. The contact lens of claim 76, wherein the depressions occupy 70% or less of the area of the first annular region.

81. The contact lens of claim 80, wherein the depressions occupy 60% or less of the area of the first annular region.

82. The contact lens of claim 81, wherein the depressions occupy 50% or less of the area of the first annular region.

83. The contact lens of claim 54, wherein each of the depressions is substantially the same size.

84. The contact lens of claim 54, wherein at least some of the depressions have different sizes.

85. The contact lens of claim 54, wherein each depression is separated from its adjacent depression by substantially the same distance.

86. The contact lens of claim 54, wherein a distance between adjacent depressions varies.

87. A method, comprising:
exposing a contact lens to laser radiation to form a plurality of depressions in a surface of the contact lens.

88. The method of claim 87, wherein the laser is an infrared laser.

89. The method of claim 87, wherein the laser is a CO_2 laser.

90. The method of claim 87, wherein the contact lens is exposed to pulsed laser radiation to form the depressions.

91. The method of claim 87, wherein the laser has a power in a range from 0.5W to 60W.

92. The method of claim 87, wherein the contact lens and a beam of the laser radiation are moved relative to each other to expose different parts of the contact lens surface to the laser radiation.

93. The method of claim 87, wherein the laser radiation is focused to a spot size of about 0.1 mm or less during the exposing.

94. The method of claim 93, wherein the laser radiation is focused to a spot size of about 0.05 mm or less during the exposing.

95. The method of claim 94, wherein the laser radiation is focused to a spot size of about 0.025 mm during the exposing.

96. The method of claim 87, wherein the contact lens is exposed so that each of the plurality of depressions is formed from a corresponding discrete exposure of the same duration, the same energy, and the same spot size.

97. The method of claim 87, wherein the contact lens is exposed so that each of the plurality of depressions is formed from corresponding a discrete exposure, wherein at least the duration, energy, or spot size is varied for different ones of the discrete exposures.

98. The method of claim 87, wherein the exposed surface is a convex surface.

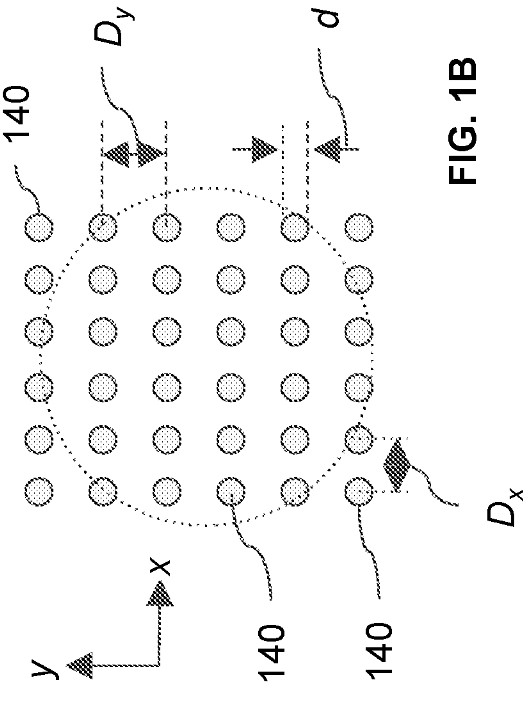
140
D_y
d
D_x
140
140
x
y

FIG. 1B

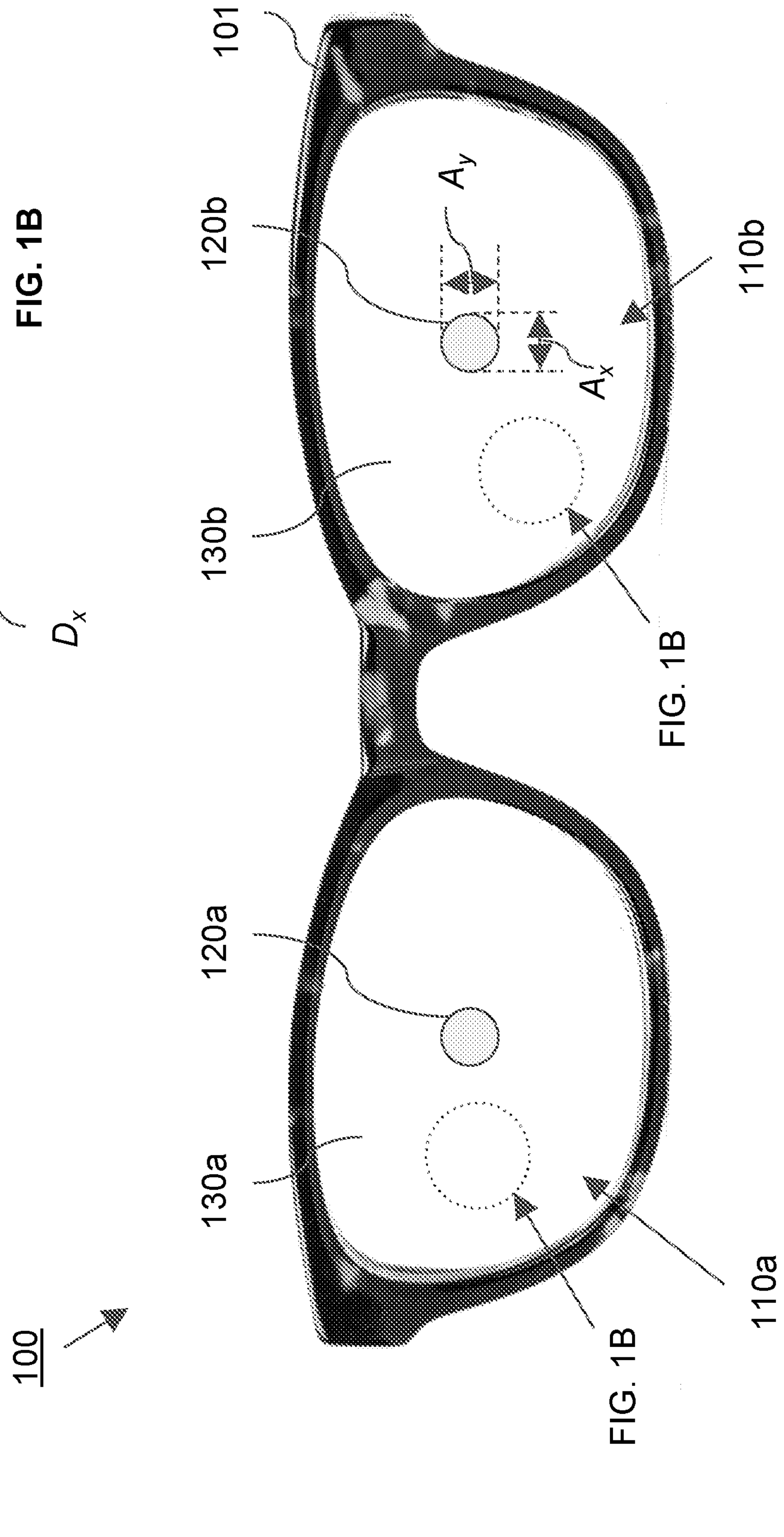
100
101
120b
A_y
A_x
110b
130b
FIG. 1B
120a
130a
110a
FIG. 1B

FIG. 1A

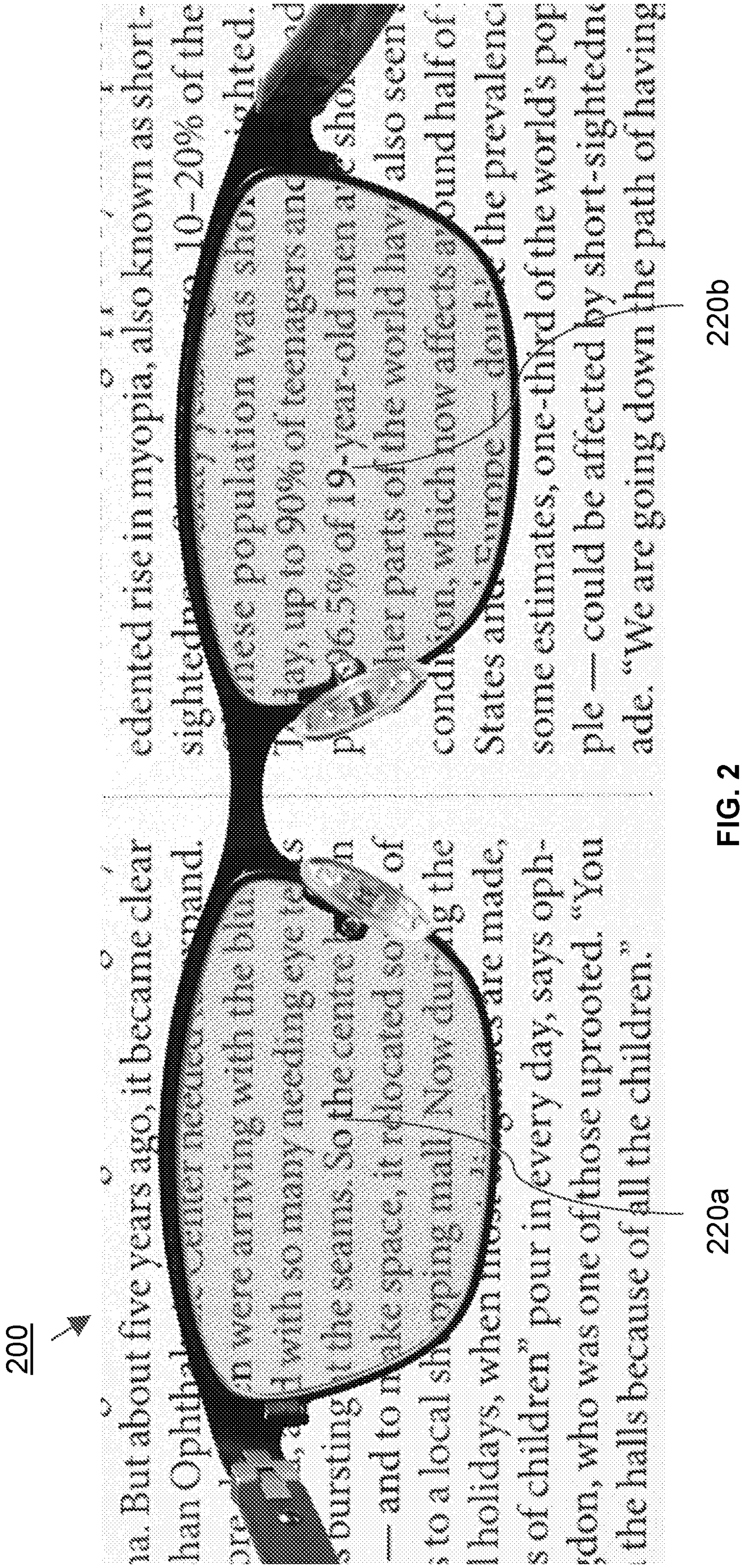

FIG. 2

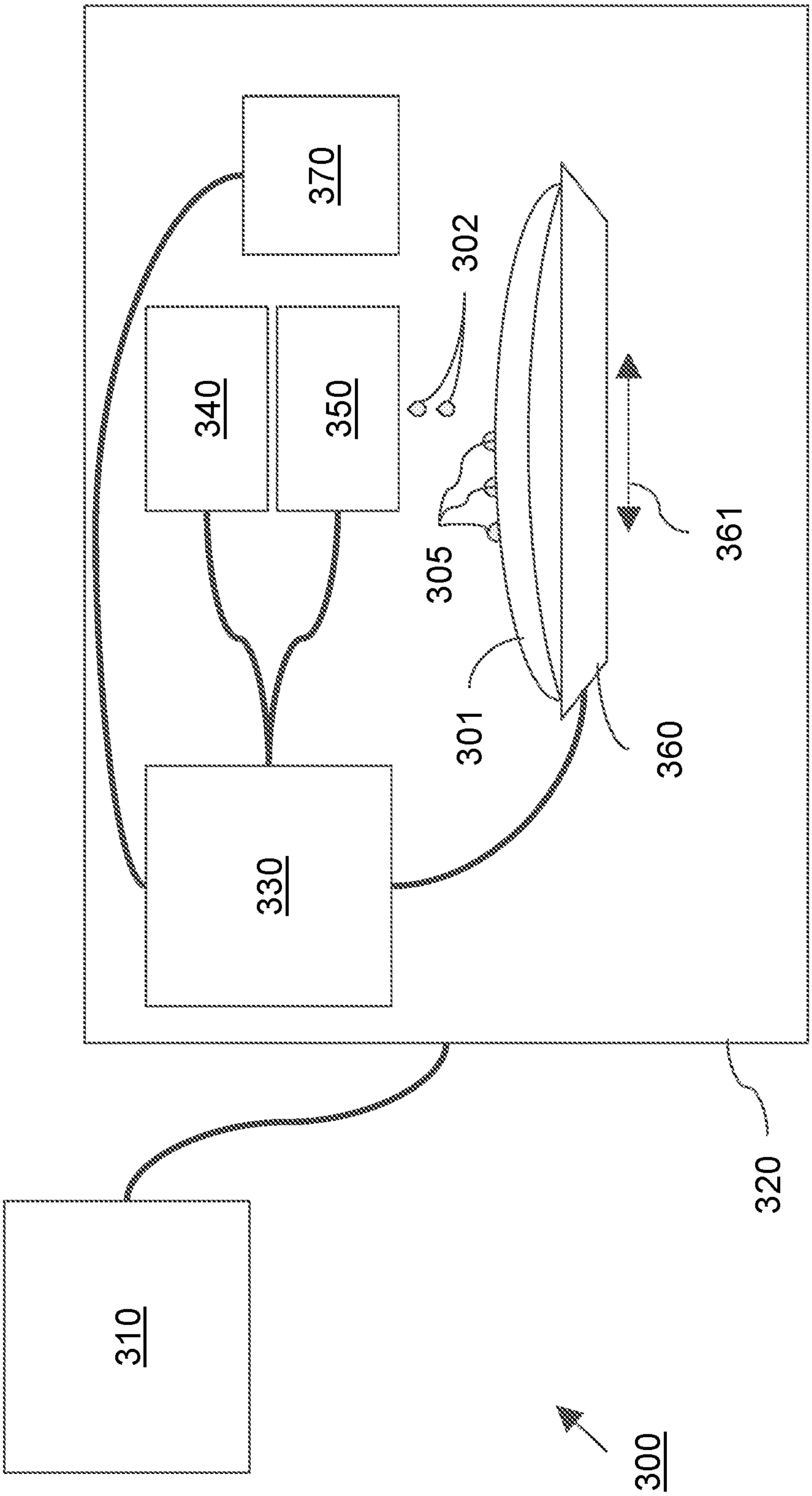

FIG. 3A

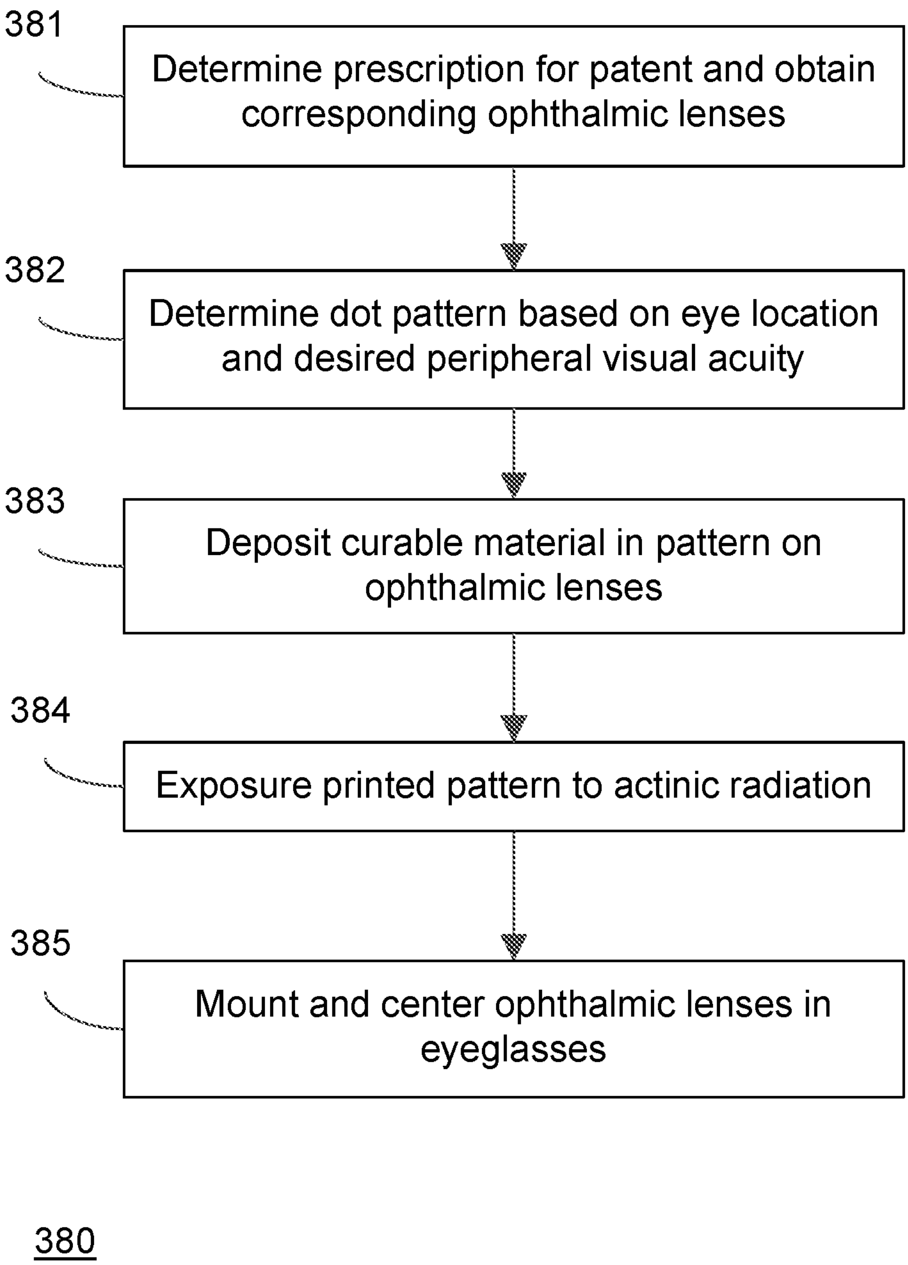
381
Determine prescription for patent and obtain corresponding ophthalmic lenses
382
Determine dot pattern based on eye location and desired peripheral visual acuity
383
Deposit curable material in pattern on ophthalmic lenses
384
Exposure printed pattern to actinic radiation
385
Mount and center ophthalmic lenses in eyeglasses
380

FIG. 3B

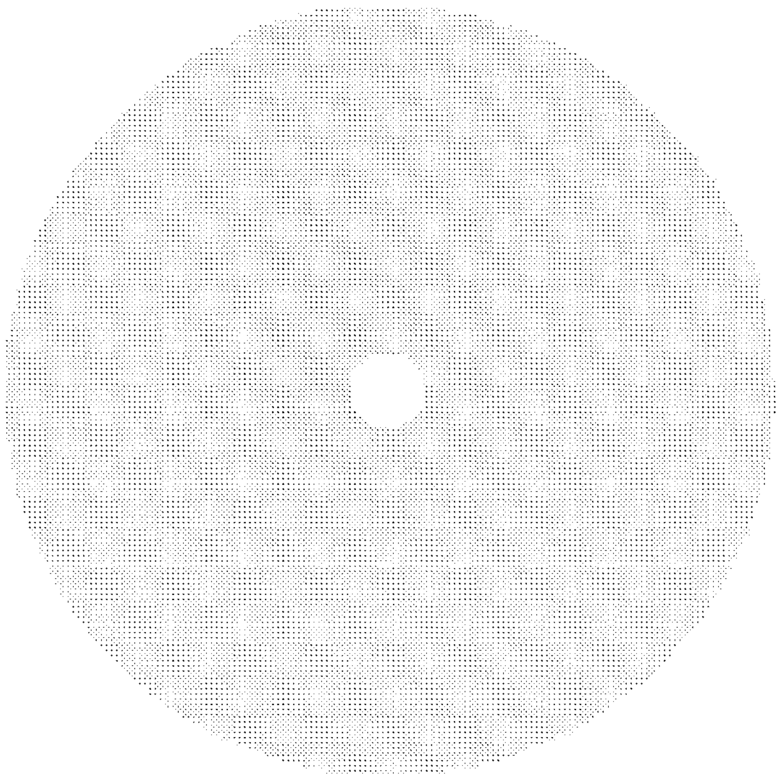

FIG. 3C

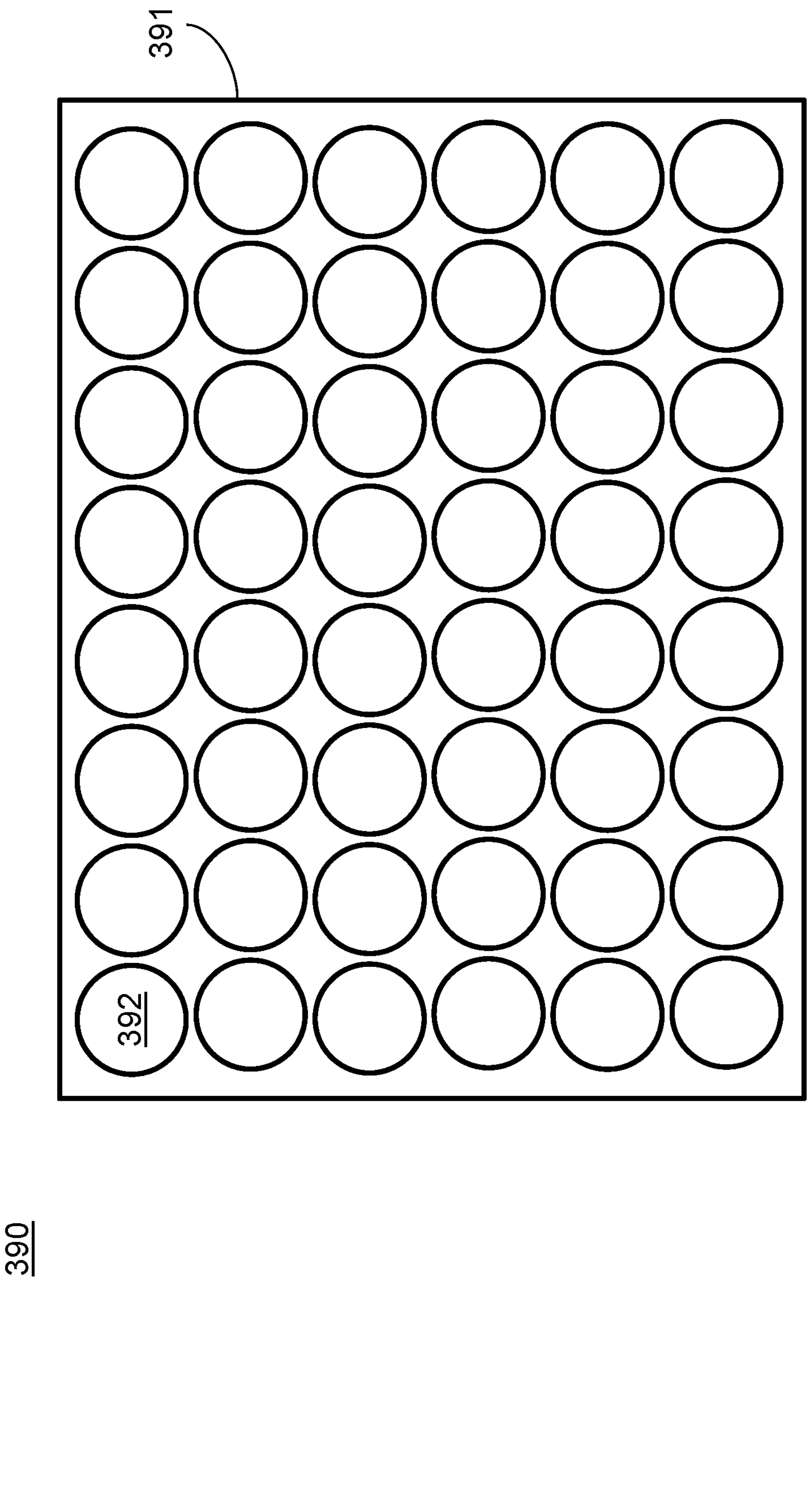

FIG. 3D

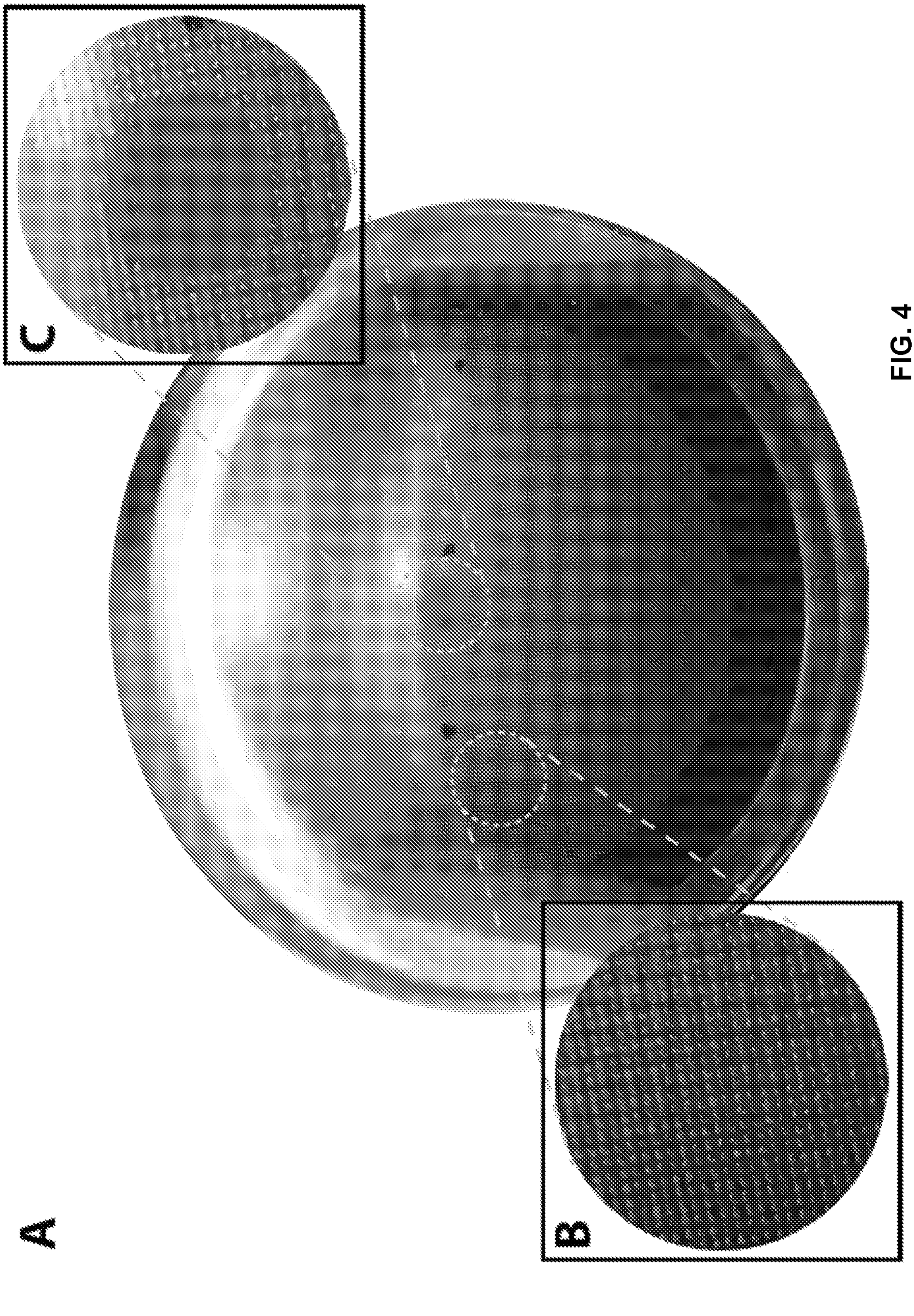

FIG. 4

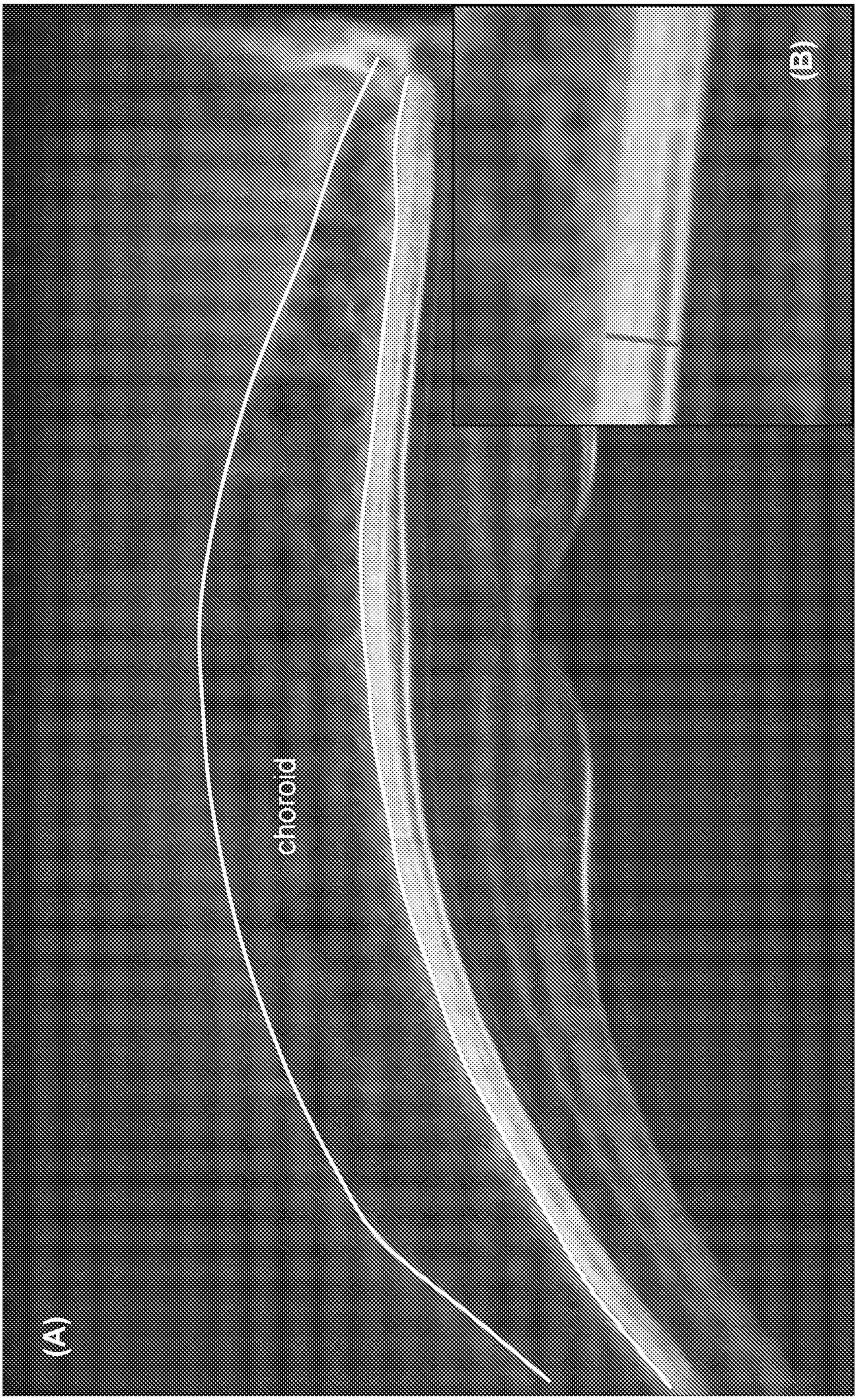

FIG. 5

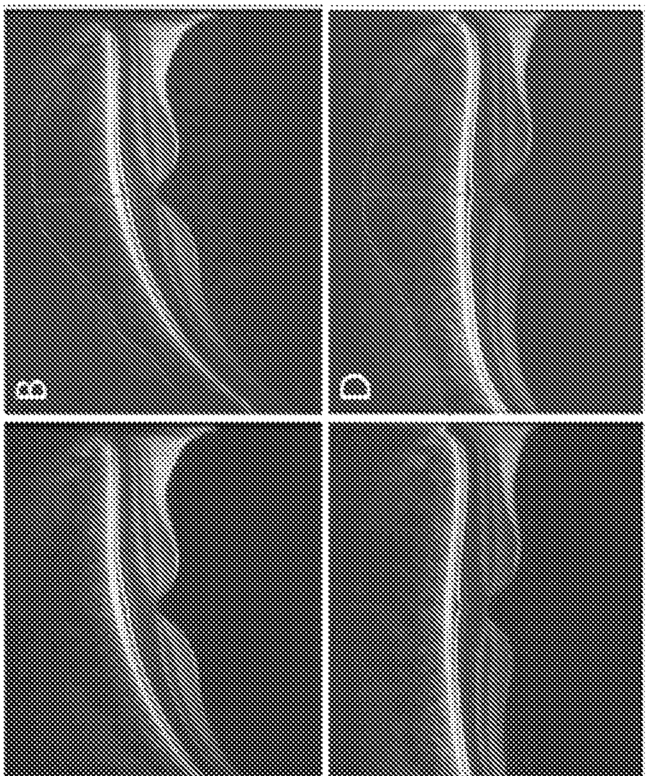
A
B
C
D

FIG. 6

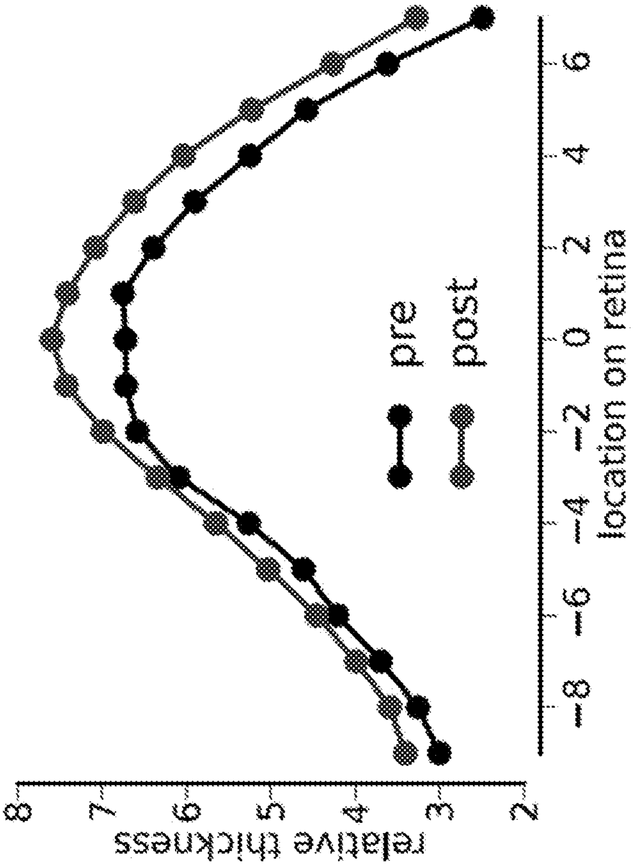
relative thickness
8
7
6
5
4
3
2
location on retina
−8
−6
−4
−2
0
2
4
6
pre
post

FIG. 7

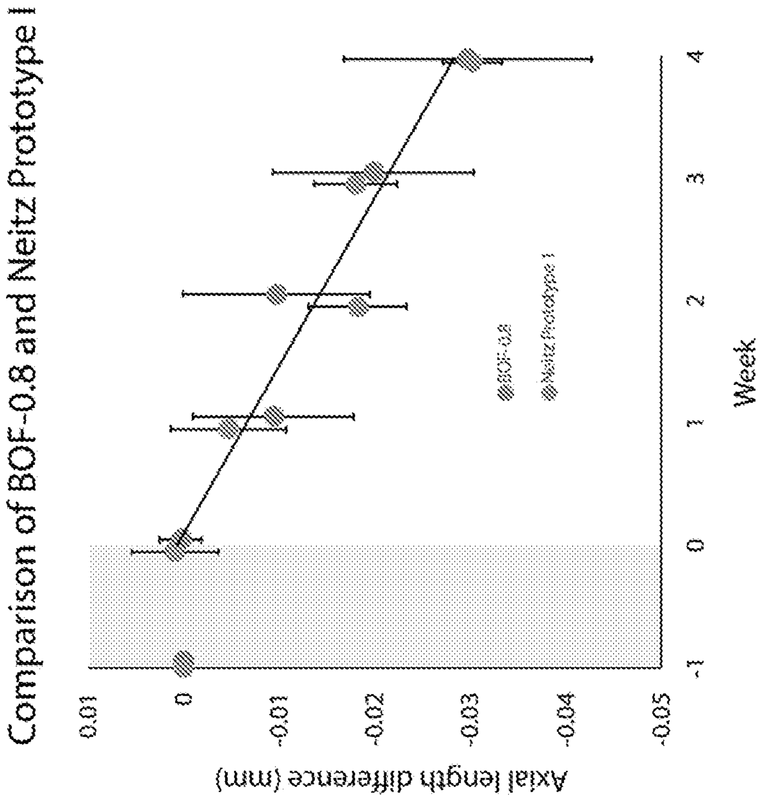
Comparison of BOF-0.8 and Neitz Prototype I
Axial length difference (mm)
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-1
0
1
2
3
4
Week
BOF-0.8
Neitz Prototype 1

FIG. 9

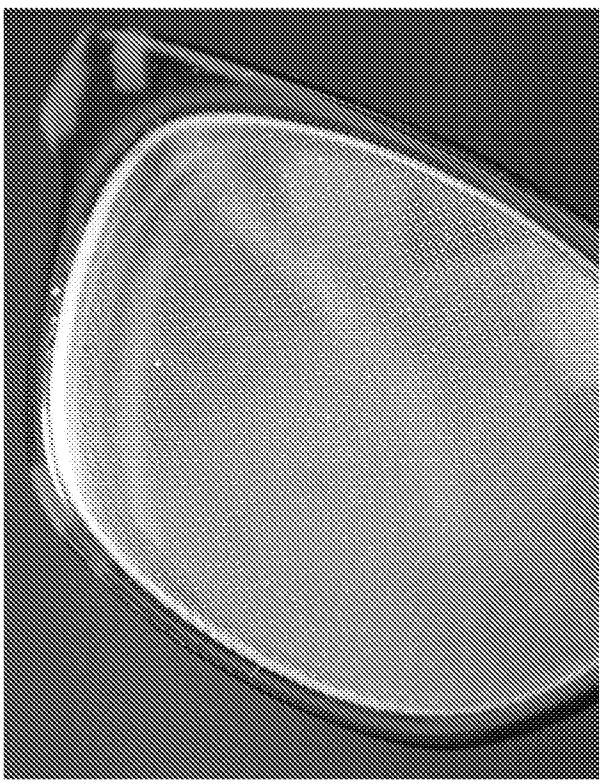

FIG. 8

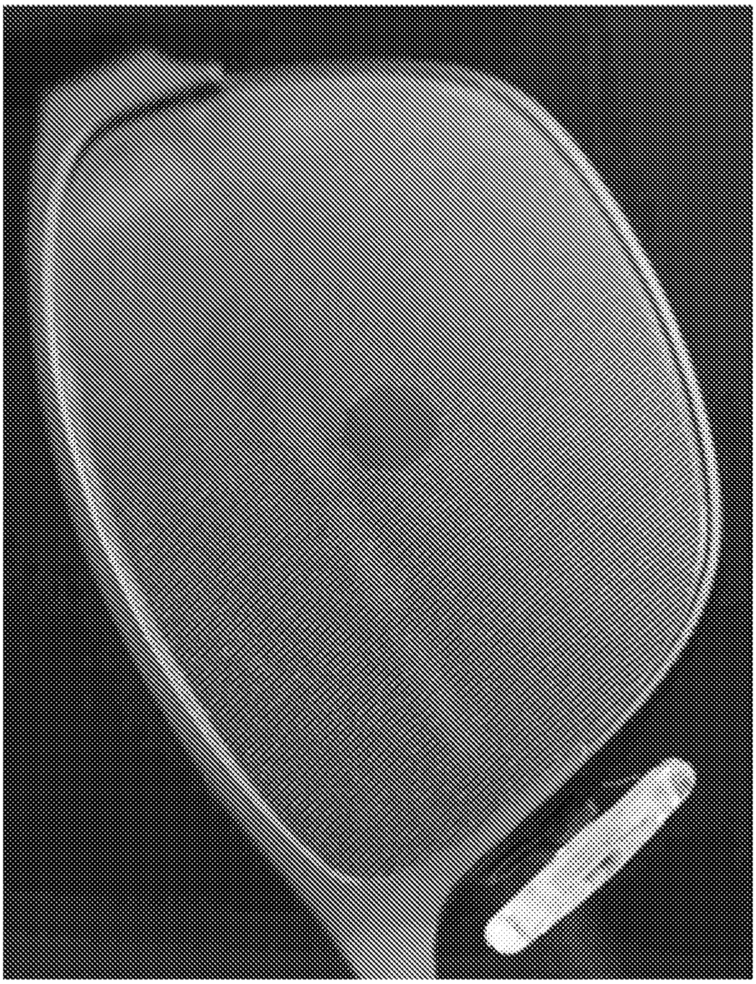

FIG. 11

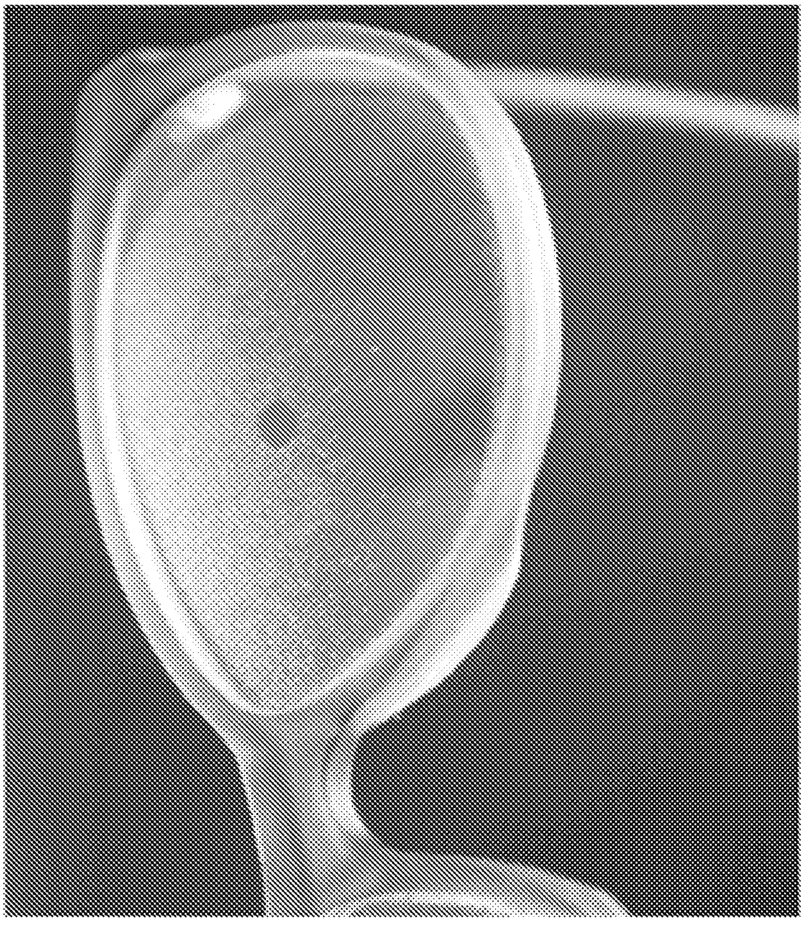

FIG. 10

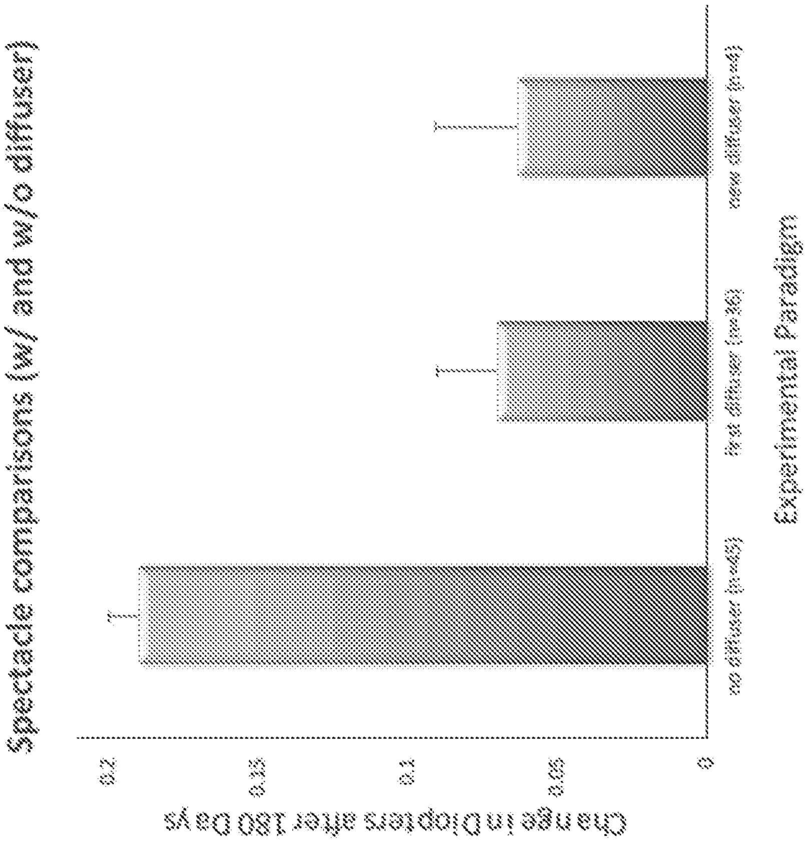
Spectacle comparisons (w/ and w/o diffuser)
Change in Diopters after 180 Days
0.2
0.15
0.1
0.05
0
no diffuser (n=45)
first diffuser (n=36)
new diffuser (n=4)
Experimental Paradigm

FIG. 12

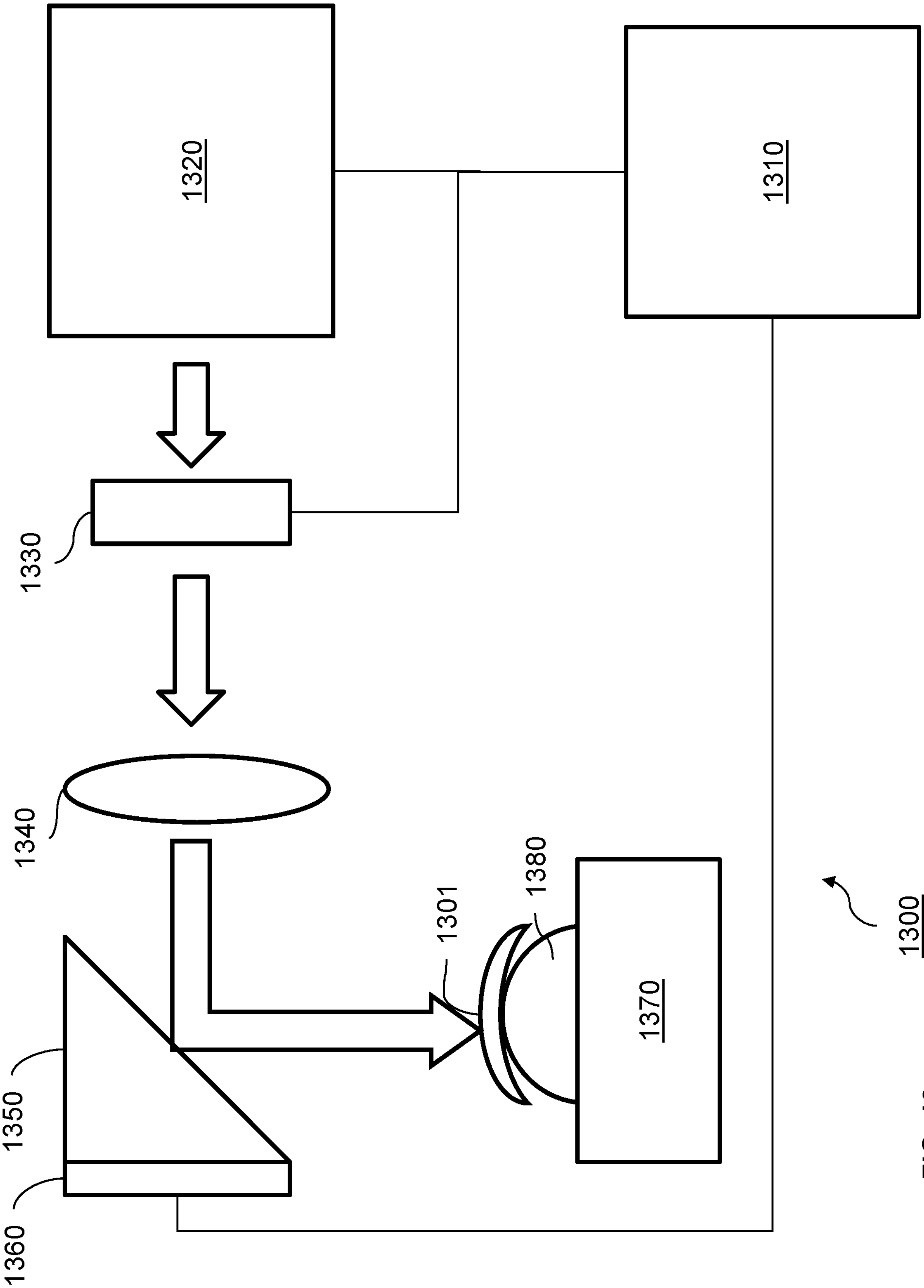

FIG. 13

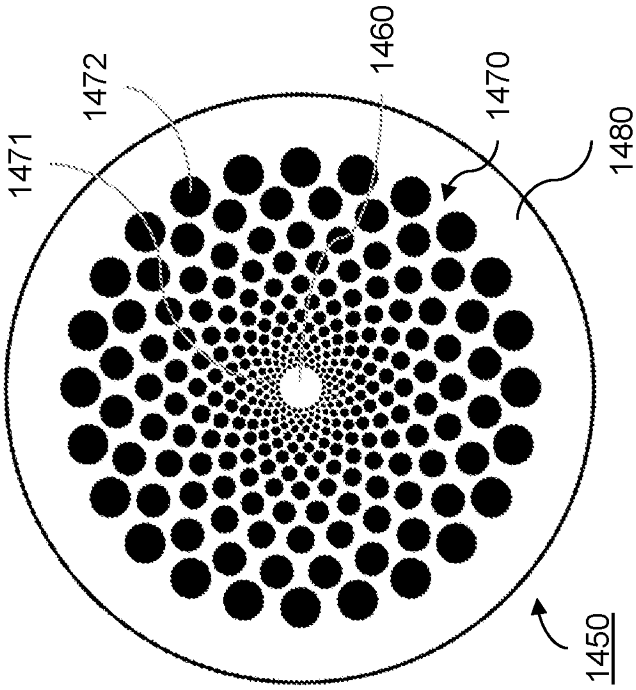

FIG. 14B

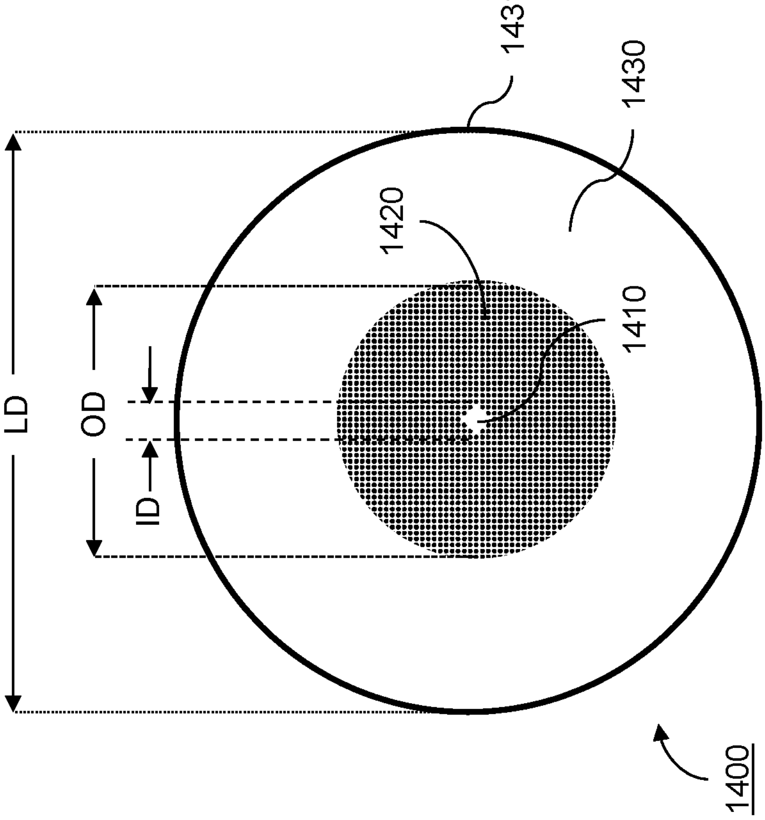

FIG. 14A

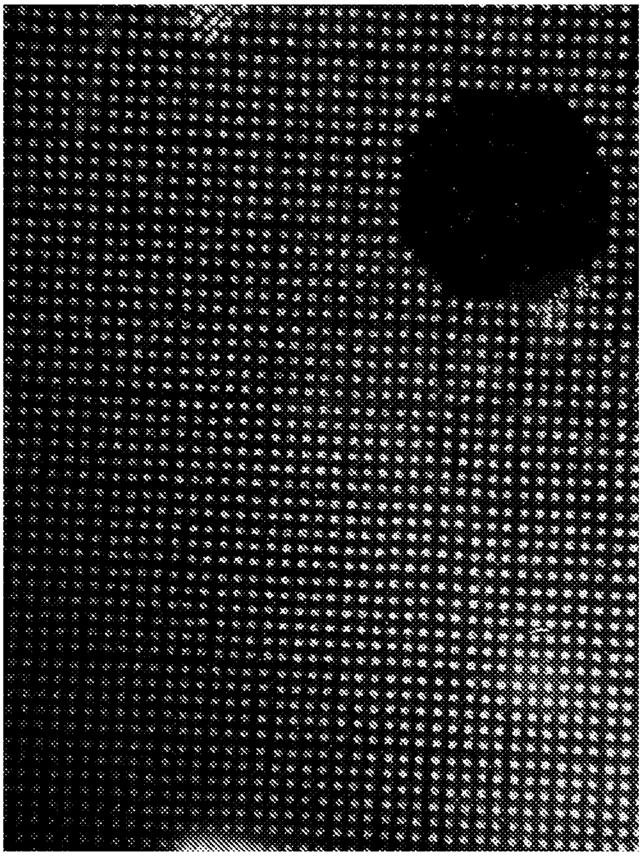

FIG. 15B

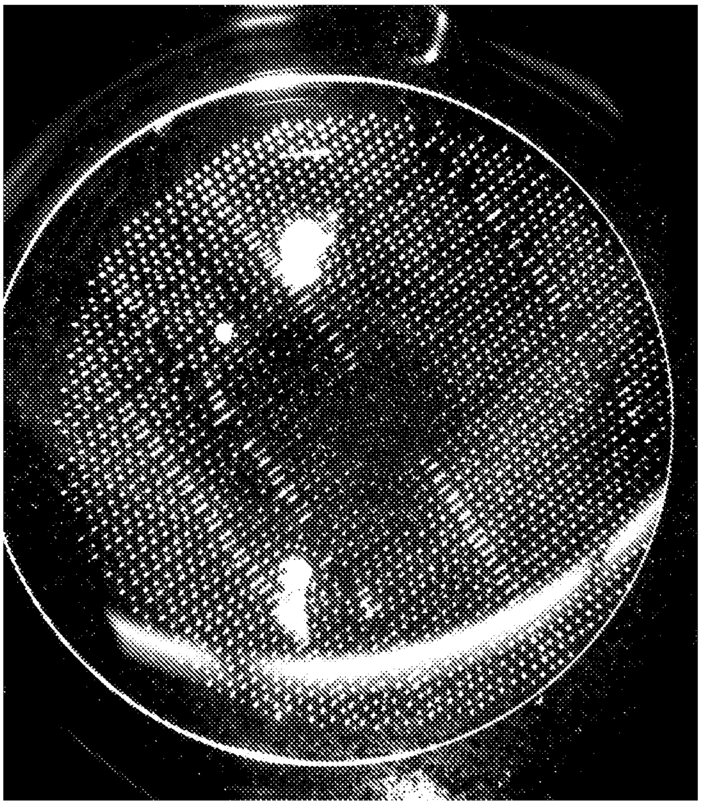

FIG. 15A

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/044635

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 52, 53
because they relate to subject matter not required to be searched by this Authority, namely:
see FURTHER INFORMATION sheet PCT/ISA/210

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/044635

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02C7/02 G02C7/04 G02C7/16 G02C7/10
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, 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	US 2011/313058 A1 (NEITZ JAY [US] ET AL) 22 December 2011 (2011-12-22) cited in the application figure 1 paragraphs [0040], [0042] - [0044], [0056], [0057]	1-51, 54-96
X	US 2008/221674 A1 (BLUM RONALD D [US] ET AL) 11 September 2008 (2008-09-11) figure 49B paragraphs [0096], [0204], [0207]	1-31, 33-46, 48-51, 54-96

-/--

[X] Further documents are listed in the continuation of Box C.

[X] 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	Date of mailing of the international search report
6 November 2017	14/11/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Vazquez Martinez, D

3

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 104 678 572 A (THE HONG KONG POLYTECHNIC UNIVERSITY; HOYA LENS THAILAND LTD.) 3 June 2015 (2015-06-03)	1,2, 23-25, 31, 33-45, 49-51
A	figures 1-9	3-22
X	WO 2015/147758 A1 (MENICON SINGAPORE PTE LTD [SG]) 1 October 2015 (2015-10-01)	49-51
A	figures 12-14 paragraphs [0006], [0078] - [0080], [0083] - [0089]	41-44, 54-84
A	US 4 194 814 A (FISCHER DAVID J [US] ET AL) 25 March 1980 (1980-03-25) column 2, line 20 - column 5, line 47	84-96

3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2017/044635

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2011313058 A1	22-12-2011	AU 2009330163 A1	01-07-2010
		CA 2747969 A1	01-07-2010
		CN 102238927 A	09-11-2011
		CO 6420401 A2	16-04-2012
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		JP 2012513252 A	14-06-2012
		KR 20110112290 A	12-10-2011
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		RU 2011130572 A	27-01-2013
		SG 172303 A1	28-07-2011
		US 2011313058 A1	22-12-2011
		WO 2010075319 A2	01-07-2010
		ZA 201103123 B	29-08-2012
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		HK 1210838 A1	06-05-2016
WO 2015147758 A1	01-10-2015	AU 2015237324 A1	06-10-2016
		CA 2943523 A1	01-10-2015
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		EP 3123236 A1	01-02-2017
		JP 2017510851 A	13-04-2017
		KR 20160136429 A	29-11-2016
		SG 10201400920R A	29-10-2015
		TW 201543107 A	16-11-2015
		US 2017184875 A1	29-06-2017
		WO 2015147758 A1	01-10-2015
US 4194814 A	25-03-1980	NONE	

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.1

Claims Nos.: 52, 53

Claims 52 and 53 refer to a method of arresting myopia progression, what necessarily requires a modification of the eye length in order to arrest such a progression. Therefore, according to Rule 39.1 (iv) PCT, the subject-matter of claims 52 and 53 is not subject from international search and preliminary examination since they refer to a therapeutic treatment of the human body.