(51) International Patent Classification:
G02B 3/14 (2006.01)

(21) International Application Number:
PCT/US2012/071836

(22) International Filing Date:
27 December 2012 (27. 12.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

(71) Inventors:


(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
[Continued on next page]

(54) Title: PHOTOCHROMIC FLUID FILLED LENSES AND METHODS OF MANUFACTURE THEREOF

(57) Abstract: A method of manufacturing a fluid lens assembly includes dissolving a photochromic additive in a solvent to form a solution, adding the solution to a fluid to form a photochromic fluid, stirring the photochromic fluid, degassing the photochromic fluid, introducing the degassed photochromic fluid into the fluid lens assembly, and sealing the fluid lens assembly. Another method includes encapsulating a photochromic additive in a vesicle that is soluble in a fluid for use in the fluid lens assembly, stirring the photochromic fluid, introducing the photochromic fluid into the fluid lens assembly, and sealing the fluid lens assembly. A fluid lens assembly includes a rigid lens, a membrane fluidly attached to the rigid lens to create a cavity therebetween, and a photochromic fluid disposed within the cavity.
Published: with international search report (Art. 21(3))
PHOTOCHROMIC FLUID FILLED LENSES AND METHODS OF MANUFACTURE THEREOF

BACKGROUND

Field

[0001] Certain embodiments of the present invention relate to fluid filled lenses and methods of manufacture thereof.

Background Art

[0002] Basic fluid lenses have been known since about 1958, as described in U.S. Pat. No. 2,836,101 to Swart, incorporated herein by reference in its entirety. More recent examples may be found in "Dynamically Reconfigurable Fluid Core Fluid Cladding Lens in a Microfluidic Channel" by Tang et al., Lab Chip, 2008, vol. 8, p. 395, and in WIPO publication WO2008/063442, each of which is incorporated herein by reference in their entirety. These applications of fluid lenses are directed towards photonics, digital phone and camera technology, and microelectronics.

[0003] Fluid lenses have also been proposed for ophthalmic applications (see, e.g., U.S. Patent No. 7,085,065 to Silver, which is incorporated herein by reference in its entirety). Power adjustment in fluid lenses has been accomplished for example by injecting fluid into a lens cavity, by electrowetting, application of ultrasonic impulse, and by utilizing swelling forces in a cross-linked polymer upon introduction of a swelling agent, such as water.

BRIEF SUMMARY

[0004] Certain embodiments of the present invention relate to fluid filled lenses and methods of manufacture thereof. In some embodiments, a method of manufacturing a fluid lens assembly includes dissolving a photochromic additive in a solvent to form a solution, adding the solution to a fluid to form a photochromic fluid for the fluid lens assembly, stirring the photochromic fluid such that the photochromic additive is substantially dispersed after stirring, degassing the photochromic fluid, introducing the
degassed photochromic fluid into the fluid lens assembly, and sealing the fluid lens assembly.

[0005] In some embodiments, a method of manufacturing a fluid lens assembly includes encapsulating a photochromic additive in a vesicle that is soluble in a fluid for use in the fluid lens assembly, stirring the photochromic fluid, introducing the photochromic fluid into the fluid lens assembly, and sealing the fluid lens assembly.

[0006] In some embodiments, a fluid lens assembly includes a rigid lens, a membrane fluidly attached to the rigid lens to create a cavity therebetween, and a photochromic fluid disposed within the cavity. The photochromic fluid may include photochromic additives having one or more spiropyran, napthoxazine, or benzoaxazine compounds that are able to transition the photochromic fluid between a substantially clear state and a darkened state.

[0007] Some embodiments of the present application are designed to form a stable suspension of a photochromic additive in a fluid at a concentration that will provide adequate blockage of light when transitioned to a darkened state. Current photochromic lenses can suffer from one or more deficiencies. For example, achieving a stable solution of a photochromic additive can be challenging because certain photochromic dyes that are superior in performance may not be desirable for fluids used in fluid-filled lenses using current manufacturing methods. For example, certain photochromic additives may not be soluble in certain fluids, such as certain non-polar fluids. As another example, in some situations, water or certain acidic solvents may cause certain photochromic additives to degrade. As another example, the speed to clear for certain existing photochromic lenses when brought indoors after being exposed to sunlight or ultraviolet ("UV") radiation can be undesirably slow, such as greater than one minute for some lenses.

[0008] Certain embodiments, features, and advantages of the present invention, as well as the structure and operation of various embodiments of the present invention, are described in detail herein with reference to the accompanying drawings.

**BRIEF DESCRIPTION OF THE DRAWINGS/FIGURES**

[0009] The accompanying drawings, which are incorporated herein and form a part of the specification, illustrate certain embodiments of the present invention and, together with the description, further serve to explain principles of the embodiments of the invention and enable a person skilled in the pertinent art to make and use the embodiments.
FIG. 1 illustrates a fluid lens module in accordance with an embodiment.

FIG. 2 is a flow chart of a method in accordance with an embodiment for manufacturing a fluid lens module.

FIG. 3 illustrates another fluid lens module in accordance with an embodiment.

FIG. 4 illustrates another fluid lens module in accordance with an embodiment.

FIG. 5 illustrates a fluid lens assembly in accordance with an embodiment.

FIG. 6 illustrates eyewear including the fluid lens assembly of FIG. 5.

FIG. 7 illustrates eyewear in accordance with an embodiment.

Embodiments of the present invention will be described with reference to the accompanying drawings.

DETAILED DESCRIPTION

Although specific configurations, arrangements, and methods are discussed, it should be understood that this is done for illustrative purposes only. A person skilled in the pertinent art will recognize that other configurations, arrangements, and methods may be used without departing from the spirit and scope of the present invention. It will be apparent to a person skilled in the pertinent art that this invention may also be employed in a variety of other applications.

It is noted that references in the specification to "one embodiment," "an embodiment," "an example embodiment," "some embodiments," etc., indicate that the embodiment described may include for example a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases may not refer to the same embodiment. Further, when a particular feature, structure or characteristic is described in connection with an embodiment, it would be within the knowledge of one skilled in the art to effect such feature, structure or characteristic in connection with other embodiments whether or not explicitly described.

FIG. 1 illustrates a cross-sectional view of a simplified fluid lens module 10. Fluid lens module 10 includes a rigid lens 12 connected to a membrane 14. As described further herein, membrane 14 may be connected to rigid lens 12 to form a cavity 16 for receiving a fluid. When fluid is introduced to cavity 16, the resulting fluid, rigid lens 12 and membrane 14 forms a fluid lens. In some embodiments, the term "fluid lens" describes
the optical lens formed by the fluid by itself or in addition to surfaces containing fluid, such as, for example, rigid lens 12 and membrane 14.

In some embodiments, membrane 14 and rigid lens 12 form a plurality of cavities. As described further herein, membrane 14 may be connected to rigid lens 12 by bonding a portion of membrane 14 to rigid lens 12.

Fluid may be introduced or removed from fluid lens module 10 to cause a change in curvature of membrane 14, which may thereby alter the optical power of fluid lens module 10. Rigid lens 12 may be configured to achieve desired optical properties as described further herein. For example, rigid lens 12 may have one or more positive, negative, and/or zero fixed optical powers as described further below. Rigid lens 12 may form an anterior surface and/or a posterior surface of fluid lens module 10. Rigid lens 12 may be made from a single piece of material or may be made from several pieces of material.

Rigid lens 12 may be made of glass, plastic, and/or other suitable materials. For example, some suitable materials of rigid lens 12 may include diethylglycol bisallyl carbonate (DEG-BAC), poly(methyl methacrylate) (PMMA), a proprietary polyurea complex, such as a TRIVEX® polyuria complex, manufactured by PPG Industries of Pittsburgh, Pennsylvania, polycarbonate of bisphenol A, polymeth(acrylates), polyacrylates, polyureas, polyurethanes, epoxides, crosslinkable thermoset polymers, and/or combinations thereof. Rigid lens 12 may be made of an impact resistant polymer, such as an impact resistant plastic. Rigid lens 12 may have a scratch resistant coating and/or an anti-reflective coating. Rigid lens 12 may be tinted.

A refractive index of rigid lens 12 may range from about 1.45 to about 1.80 measured at the sodium D line. A refractive index of rigid lens 12 may range from about 1.49 to about 1.77 measured at the sodium D line.

Rigid lens 12 may be formed via a manufacturing operation that trims a lens blank to a desired lens shape and size. Rigid lens 12 may be trimmed by any suitable cutting and/or machining method, such as, for example, through a glass cutter, saw, drill, scissors, knife, laser, plasma cutter, or water jet cutter. Rigid lens 12 may be any suitable shape and size. Rigid lens 12 may have a diameter ranging from about 55 mm to about 95 mm. Rigid lens 12 may have a diameter ranging from about 60 mm to about 90 mm.
[0026] Rigid lens 12 may include a thin photochromic layer. This layer may include one or more photochromic additives. The thickness of the layer may range from about 100 microns to about 150 microns.

[0027] Fluid lens module 10 may be filled with a fluid to form a fluid lens. FIG. 2 illustrates a flow chart 18 for an example method of manufacturing a fluid lens module, such as fluid lens module 10.

[0028] In step 20, photochromic additives are dissolved in a solvent to form a solution. In some embodiments, such photochromic additives are able to darken the resulting fluid when exposed to a level of ultraviolet radiation above a predetermined threshold and are able to lighten the photochromic fluid when exposed to a level of ultraviolet radiation below a predetermined threshold. Putting additives in the fluid rather than in rigid lens 12 and/or membrane 14 may reduce the number of stock-keeping units (SKU) for fluid lens module 10. Further, the addition of photochromic additives to the fluid may substantially improve the transition time compared to putting the photochromic additives into a solid substance. In some embodiments, photochromic additives are added to rigid lens 12 and/or membrane 14.

[0029] Photochromic additives may be configured to allow for transition between a darkened state of the fluid and a clear state of the fluid. In some embodiments, fluid lens module 10 is configured to allow fluid to transition from dark to clear in about 1 minute or less. In some embodiments, fluid lens module 10 is configured to allow fluid to transition from dark to clear in about 30 seconds or less. In some embodiments, the fluid is configured to transition from dark to clear in about 5 seconds or less. In some embodiments, the fluid is configured to transition from dark to clear in about 1 second or less.

[0030] Suitable photochromic additive may be selected from commercially available additive, such as, for example, one or more photochromic additives manufactured by Vivimed Corporation of New Jersey, USA. In some embodiments, the photochromic additive includes napthoxazine and/or napthopyran derivatives. In some embodiments, the photochromic additive includes benzoxazine and/or benzopyran derivatives. The photochromic additive may include molecules in one or more of the following classes: triarylmethanes, stilbenes, azastilbenes, nitrones, spiropyrans, naphthopyrans, spiro-oxazines, quinones. Photochromic additives may be in the form of photochromic dyes. In
some embodiments, the photochromic fluid is configured such that the switching speed of
the photochromic additives are approximately equal to each other to ensure a single color
through the switching process. The single color may, for example, be a desired tint color
such as gray or brown.

[0031] Photochromic additives may be configured to enhance optical absorption in a
visible range of light upon exposure to sunlight and become less absorptive when
withdrawn from sunlight. The lens may be configured such that a change in optical
absorption of the photochromic additives is effected by exposure to ultraviolet radiation.

[0032] The photochromic additive may be dissolved in a solvent. In some embodiments,
a solution is added to the fluid in order to accelerate the dissolving rate in such a way as
to reduce the likelihood of the additive precipitating out when the solution is added to the
fluid. In some embodiments, the photochromic additive is dissolved in an oligomeric fluid.
The oligomeric fluid may include, for example, short siloxane chains terminated with
polar groups such as furans, hydroxyls, nitriles, or halogenated aromatic groups, such as
chlorophenyl or chlorobenzyl groups. The oligomeric fluid may be of high viscosity
and/or may be selected for miscibility with the fluid used in the fluid lens module.
Photochromic dye may be added into the fluid so as to saturate the fluid with the dye. The
resulting mixture may then be added to the fluid used in the fluid lens module, such as for
example a silicone fluid, at a desired concentration. In some cases, the mixing of such
oligomers with silicone fluid will produce a finely dispersed suspension, especially if
groups with surfactant properties are used as end groups to create the oligomer.

[0033] In step 21, the resulting solution is added to a fluid to form a photochromic fluid.
The fluid may be a colorless fluid, for example air or distilled water. One example of
fluid that may be used is manufactured by Dow Corning of Midland, MI, under the name
"diffusion pump oil," which is also generally referred to as "silicone oil." The fluid may
be an organic solvent or another suitable fluid. The fluid may be a transparent silicone oil.
In some embodiments, the fluid is tinted, depending on the application. The fluid may be
an aliphatic polysiloxane having a refractive index matching rigid lens 12 or another
cOMPONENT of fluid lens module 10.

[0034] In some embodiments, the fluid is configured to have a dynamic viscosity from
about 10 centipoise (cP) to about 150 cP at about 20 degrees Celsius. In some
embodiments, the fluid is configured to have a dynamic viscosity from about 15 cP to
about 45 cP at about 20 degrees Celsius. The fluid may have a refractive index ranging from about 1.45 to about 1.65. The fluid may have a refractive index ranging from about 1.48 to about 1.60.

[0035] The concentration of photochromic additives in the fluid may range from about 0.1% to about 2.0%. In some embodiments the concentration of the photochromic additives in the fluid range from about 0.5% to 1.0%. The base fluid and photochromic additive may be selected as a pair so that the photochromic additive dissolves in the fluid and remains stable when dissolved in the fluid.

[0036] In step 22, the photochromic fluid is then stirred. The solution may be treated by ultrasonically stirring the solution. The solution can be stirred such that the photochromic additives are substantially dispersed. In some embodiments, the photochromic fluid is stirred at a temperature, such as an elevated temperature for example, that ensures the photochromic additives remain substantially in solution after stirring. In some embodiments, the maximum temperature used to form the solution does not exceed about 100 degrees Celsius. In some embodiments, the temperature used to form the solution ranges from about 30 degrees Celsius to about 80 degrees Celsius.

[0037] In step 24, the photochromic fluid is brought to its freezing point or near its freezing point. In some embodiments, the temperature at which the solution is pumped is within about 5 degrees Celsius of the freezing point of the fluid.

[0038] In step 26, the photochromic fluid is degassed. The fluid may be reheated and stirred if the photochromic additive comes out of solution during the degassing process. The solution may be degassed using one or more suitable degassing procedures. For example, the solution may be degassed by placing the solution under reduced pressure, such as by subjecting the solution to a vacuum. The solution may alternatively or additionally be degassed by other methods, such as for example, heating the solution, membrane degasification, substitution by an inert gas, adding a reactant, and/or freeze-pump-thaw cycling.

[0039] Additional or alternative methods of dissolving photochromic additives in fluid may be used. For example, the photochromic additives may be encapsulated into a microscopic gel particle that has greater solubility in the fluid. For example, the gel particle may have a structure that allows it to wrap around a photochromic molecule. The gel particle may be in the form of a polymer chain and may, for example, range in size
from about 50 nm to about 100 nm. Another method for dissolving photochromic additives in fluid may include using encapsulating the photochromic additive in a surfactant. The surfactant may, for example, have a hydrophobic core and a hydrophilic surface. In some embodiments, the photochromic additive is encapsulated within a liposome vesicle. In some embodiments, the liposome vesicle has surfactant properties.

In step 28, the degassed photochromic fluid is introduced to the fluid lens module. Fluid lens module 10 may include an inlet for introducing fluid into the fluid lens module 10. For example, the fluid may be first introduced to fluid lens module 10 during manufacture through an inlet.

In step 30, the fluid lens module is sealed. The inlet may be sealed after fluid lens module 10 is filled with a desired amount of fluid and/or when the fluid lens module 10 reaches a desired pressure.

As described above, fluid lens module 10 may include membrane 14. Membrane 14 may be made from a single piece of material or may be made from several pieces of material. Membrane 14 may be made from a flexible, transparent, and/or water impermeable material. Suitable materials for membrane 14 may include suitable polyolefins, polyhalocarbons, polycycloaliphatics, polyethers, polymethacrylates, polyacrylates, polyesters, polyimides, polyureas, polyurethanes, polyvinylidene difluoride, dichloride, polysulfones, polythiourethanes, polyethylene terephthalate, polymers of cycloolefins and aliphatic or alicyclic polyethers. Membrane 14 may be made of a biocompatible impermeable material, such as a cyclo-aliphatic hydrocarbon.

Membrane 14 may have a uniform thickness ranging from about 10 microns to 2.0 mm. Membrane 14 may have a non-uniform thickness. For example, the thickness of a portion of membrane 14 may be varied to offset a curvature of a portion of rigid lens 12, such as an aspheric portion of rigid lens 12. Membrane 14 may have a desired variation in a mechanical property, such as sag, or an optical property, such as astigmatism or power in the x, y plane. A varied thickness of membrane 14 may modulate the extent of inflation over the overall surface area. A varied thickness of membrane 14 may offset an asphericity of rigid lens 12 when membrane 14 is both inflated and uninflated. A varied thickness of membrane 14 may offset an asphericity of rigid lens 12 when membrane 14 is inflated or uninflated.
The material of membrane 14 and/or rigid lens 12 may have an approximately equal refractive index compared to the refractive index of the fluid and/or another component of fluid lens module 10.

The material of membrane 14 and/or rigid lens 12 may include glassy polymers having, for example, a glass transition temperature of about 50 degrees Celsius or higher. A glass transition temperature may range from about 60 degrees Celsius to about 150 degrees Celsius. The material of membrane 14 and/or rigid lens 12 may have about 100% or greater elongation at break. The material of membrane 14 and/or rigid lens 12 may have 125% or greater elongation at break.

The Abbe number of the material of the membrane 14 and/or rigid lens 12 may range from about 15 to about 60. The Abbe number of the material of the membrane and/or rigid lens 12 may be about 25 or greater.

One or more external surfaces of membrane 14 and/or rigid lens 12 may be treated with a hard coating configured to enhance scratch resistance. Membrane 14 may be impact and tear resistant.

Rigid lens 12 and membrane 14 are impermeable to fluid used in fluid lens module 10. Rigid lens 12 and membrane 14 are configured to not craze, swell, or become hazy when placed in contact with fluid used in fluid lens module 10.

As described above, membrane 14 may be connected to rigid lens 12. At least a portion of membrane 14 may be bonded or otherwise attached to rigid lens 12. The bond between membrane 14 and rigid lens 12 may allow for a fluid seal between membrane 14 and rigid lens 12, which may be configured to prevent fluid from leaking out of fluid lens module 10. In some embodiments, membrane 14 and rigid lens 12 are attached to each other such that fluid may enter cavity 16 via an opening between membrane 14 and rigid lens 12. The opening may be formed in rigid lens 12, with membrane 14 being substantially flush against rigid lens 12.

Membrane 14 may be bonded to rigid lens 12 using a suitable bonding process. Membrane 14 may be bonded to rigid lens 12 via a heat seal. In some embodiments, membrane 14 is bonded to rigid lens 12 via laser welding. In some embodiments, membrane 14 is bonded to rigid lens 12 via one or more suitable adhesives.

In some embodiments, membrane 14 is attached directly to rigid lens 12. Membrane 14 may be attached to rigid lens 12 through an intermediate component, such
as a frame, spacer, or another suitable component. In some embodiments, a layer of material, such as a stiffening layer, is sandwiched between membrane 14 and rigid lens 12. Membrane 14 may be attached to rigid lens 12 in such a way as to provide an environmentally robust diffusion barrier to fluid within fluid lens module 10.

[0052] In some embodiments where adhesive is used to bond membrane 14 to rigid lens 12, the adhesive is matched to one or more of the fluid, membrane 14, rigid lens 12, or another component of fluid lens module 10. For example, a refractive index of one or more of the adhesive, rigid lens 12, membrane 14, and the fluid may be substantially equal. The refractive indexes may be equal to three significant figures, such as about 0.002 units at one or more wavelengths, such as at about 550 nm. The refractive indexes of one or more of the components of fluid lens module 10 may be in a range from about 1.47 to about 1.78 measured at about 550 nm. The refractive indexes of one or more of the components of fluid lens module 10 may be in a range from about 1.52 to about 1.70 measured at about 550 nm.

[0053] Membrane 14 may not be precisely the same size or shape as rigid lens 12 or may not be perfectly aligned with rigid lens 12 during the manufacturing process of fluid lens module 10. Membrane 14 may be selected to be a different size, shape, and/or alignment compared to rigid lens 12.

[0054] As described above, fluid lens module 10 may be configured such that a cavity between membrane 14 and rigid lens 12 is at least partially filled with fluid. The optical power of fluid lens module 10 may be adjusted by inflating membrane 14. As a volume of fluid is altered in the cavity, membrane 14 may inflate or deflate. This inflation or deflation may serve to alter the optical power of fluid lens module 10. Fluid lens module 10 may be configured such that there is a direct and proportional relationship between the change in power of a fluid lens and the level of inflation effected.

[0055] The optical power of fluid lens module 10 may be determined by a combination of surface topography of the optical surfaces and refractive indexes of the optical components of the fluid lens, represented by the two surfaces of the rigid lens, the two surfaces of the fluid and the two surfaces of the membrane. In some embodiments, one or more components of fluid lens module 10 do not provide a substantial optical power.

[0056] Fluid lens module 10 may be configured such that membrane 14 may be inflated to about 6D without causing significant loss of image quality. In some embodiments, this
may correspond to a radius of curvature of about 88 mm for a fluid having a refractive index of about 1.53. In some embodiments, the optical power of the variable portion ranges from about -1.0D in an uninflated state to about +1.0D in an inflated state. In some embodiments, the optical power of the variable portion ranges from about +0.25D in an uninflated state to about +4.0D in an inflated state. In some embodiments, the optical power of the variable portion ranges from about -1.2.00D in an uninflated state to about +12.0D in an inflated state. In some embodiments, a fixed optical power of rigid lens 12 is in the range from about -1.0 to about +1D.

Fluid lens module 10 may include an adjustable optical power that ranges from about 0.0D to about 3.0D. In some embodiments, the optical power may range from about -1.00D to about +3.00D. In some embodiments, the optical power of fluid lens module 10 may be configured for nearsighted or farsighted individuals.

In some embodiments, at least a portion of a first surface 32 of rigid lens 12 is substantially the same shape as at least a portion of a second surface 34, which may result in a substantially zero optical power for rigid lens 12. First surface 32 and second surface 34 may, for example, be located on opposite sides of rigid lens 12. In some embodiments, first surface 32 is located on a "front" side of rigid lens 12 with second surface 34 on a "rear" side of rigid lens 12 facing the wearer. Rigid lens 12 may be convex, concave, spherical, aspheric, and/or another desired shape. Rigid lens 12 may include a compensation to its front or back surface to provide a desired optical power at a predetermined level of membrane inflation. The compensation of rigid lens 12 may, for example, be designed based on factors such as the geometry of membrane 14, the desired level of inflation, or any combination thereof or other suitable factors.

Rigid lens 12 may be in the form of a single vision lens comprising a base curve and a fixed optical power. Rigid lens 12 may have a negative optical power. A negative optical power lens may be formed by having rigid lens 12 having a biconvex geometry. Rigid lens 12 may have a zero optical power. A zero optical power lens may be formed by having rigid lens 12 be a piano lens. Rigid lens 12 may have substantially parallel surfaces, such as substantially flat parallel surfaces.

Fluid lens module 10 may be configured to provide zero net optical power. A zero net optical power may result from one or more planar lenses. In some embodiments, a zero net optical power results from a positive lens being combined with a negative lens of
equal optical power. A zero net optical power may be result from a combination of more than two lenses.

[0061] Fluid lens module 10 may have a fixed optical power. In some embodiments, fluid lens module 10 has a variable optical power. A variable optical power fluid lens module 10 may be configured for use in visual tasks in at least near distances and intermediate distances.

[0062] The term "central optical zone" may be used to denote a viewing zone in the fluid lens centered on an optic axis corresponding to the location of a user's eye. In some embodiments, the optic axis is aligned to the center of the pupil of an average or individual wearer. In some embodiments, the optical zone is approximately 15 mm wide (along the x axis) and approximately 12 mm high (along the y axis), which may correspond to a horizontal gaze angle of approximately +/- 15 degrees and a vertical gaze angle of approximately +/- 12 degrees.

[0063] The central optical zone of fluid lens module 10 may be configured based on potential vertical movement of a pupil. For example, the vertical dimension of the central optical zone may be determined based on the point of regard of the human eye along the principal meridian of the optic following a path of the pupil when gazing directly forward. For example, this vertical dimension may be about 25 mm. In a further example, the vertical dimension may be in the range from about 18 mm to about 24 mm.

[0064] The rigid lens may include an optical transmission in a visible range (including light having a wavelength from about 400 nm to about 800 nm) of about 65% or greater (i.e., having an absorbance of about 0.65 or greater).

[0065] In some embodiments, fluid lens module 10 is configured to provide vision correction from about 1.0D to about 3.0D. In some embodiments, fluid lens module 10 is configured to provide vision correction from about 0.0D to about 3.0D.

[0066] The optical power of fluid lens module 10 may be adjusted based on the curvature of one or more of the rigid lens surface, such as the surface in contact with fluid, the curvature of membrane 14, the base thickness of the rigid lens 12 and its area, and/or the refractive index of the fluid.

[0067] The range of optical power for fluid lens module 10 may be based on the range of change of curvature of membrane 14 upon inflation, a refractive index of the fluid used in fluid lens module 10, the optical design of fluid lens module 10 including its shape, such
as its degree of asphericity, and a maximum amount of liquid that may be introduced or
removed from fluid lens module 10.

[0068] In some embodiments, the average optical area of fluid lens module 10 is about
2100 mm² or less. In some embodiments, the vertical diameter of the optical area of fluid
lens module 10 is about 45 mm or less. In some embodiments, the horizontal diameter of
the optical area of fluid lens module 10 is about 60 mm or less.

[0069] In some embodiments, one or more surfaces of fluid lens module 10 are aspherical
to provide a desired optical range. For example, in some embodiments, one or more
surfaces are aspherical to provide a range of optical power of about 4.0D to an optic of
2100 mm². In some embodiments, of such a fluid lens module 10, the fluid volume of
fluid lens module 10 is about 150 microliters or less. In some embodiments, such a
configuration may allow for a target spherical power of about 350 mm² or less in order to
keep excess liquid for inflating the membrane to about 150 microliters or less.

[0070] The volume of fluid in fluid lens module 10 may range from about 50 microliters
to about 150 microliters. The volume of fluid in fluid lens module 10 may range from
about 75 microliters to about 125 microliters.

[0071] Fluid lens module 10 may be configured to provide an upper limit of about 4.0D.
Greater or lower ranges of adjustability may alternatively be provided.

[0072] Fluid lens module 10 may be configured to provide a target power range from
about -2.00D to about +2.00D. Fluid lens module 10 may be configured to provide a
target power range from about -1.00D to about +3.00D. Fluid lens module 10 may be
configured to provide a target power range from about -2.00D to about +5.00D. Fluid lens
module 10 may be configured to provide a target power range having an upper limit of
about +3.00D.

[0073] Fluid lens module 10 may include a UV light absorbing component, such as a UV
light absorbing rigid lens 12 and/or membrane. In some embodiments, rigid lens 12 forms
an anterior surface of fluid lens module 10. In some embodiments, UV light absorbing
rigid lens 12 is configured to achieve an optical transmission of about 380 nm or greater
may be at least about 0.5 absorbance units.

[0074] In some embodiments, an anterior optic of fluid lens module 10 is more UV
transmissive than a posterior optic. In some embodiments, the posterior optic is
configured to provide a desired UV protection to a user's eye. In some embodiments, a posterior optic of fluid lens module 10 is more UV transmission than an anterior optic.

[0075] Fluid lens module 10 may be configured for use with a left eye and/or a right eye of a user. A single fluid lens assembly may be configured for use with multiple eyes at the same time.

[0076] FIG. 3 illustrates a cross-sectional view of another simplified fluid lens module 36. Fluid lens module 36 includes a rigid lens 38 connected to a membrane 39. Rigid lens 38 has a convex geometric shape, which may result in a negative power for the rigid lens optic. In some embodiments, one or both of a first surface 40 and a second surface 42 are convex. In some embodiments, only a portion of first surface 40 and/or second surface 42 is convex.

[0077] FIG. 4 illustrates a cross-sectional view of another simplified fluid lens module 44. Fluid lens module 44 includes a rigid lens 46 connected to a membrane 48 (48'). As illustrated in FIG. 4, membrane 48 is shown in solid lines in an uninflated state. Membrane 48' is shown in broken lines in an inflated state. Rigid lens 46 has a flat and parallel geometric shape, which may result in a zero power for the rigid lens optic. In some embodiments, one or both of a first surface 50 and a second surface 52 are flat. In some embodiments, only a portion of first surface 50 and/or second surface 52 are flat. In some embodiments, only a portion of first surface 50 and second surface 52 are parallel.

[0078] FIG. 5 illustrates one embodiment of a fluid lens assembly 54 incorporating a fluid lens module 56. Fluid lens assembly 54 may include fluid lens module such as one or more of fluid lens modules 10, 36, and 44 or another suitable fluid lens module. Fluid lens assembly 54 may include a conduit 58 connected to fluid lens module 56 and a reservoir 60 as described further herein. Fluid lens assembly 54 may further include a port 65 for receiving fluid within fluid lens module 56 from conduit 58.

[0079] In some embodiments, fluid lens assembly 54 is configured for use indoors and/or outdoors. In some embodiments, fluid lens assembly 54 is configured for use as a reader lens assembly. Fluid lens assembly 54 may include a multi-focal lens, such as for example a bi-focal lens or a tri-focal lens. The fluid lens assembly may include a progressive lens. Fluid lens assembly 54 may form an air- and/or fluid- sealed unit. In some embodiments, such a sealed unit may be configured to avoid air bubbles from entering fluid lens module 56.
Conduit 58 may be configured to allow fluid to pass between reservoir 60 and fluid lens module 56 to allow a membrane 62 to inflate or deflate. Conduit 58 may be made of one or more materials, such as TYGON (polyvinyl chloride), PVDF (Polyvinyiedene fluoride), and natural rubber. For example, the material of conduit 58 may be suitable based on its durability, permeability, and resistance to crimping. In some embodiments, at least a portion of conduit 58 is transparent, translucent, and/or opaque. Conduit 58 may have substantially the same refractive index as one or more other components in fluid lens assembly 54. In some embodiments, conduit 58 is made of the same materials as the reservoir or another component of fluid lens assembly 54.

Reservoir 60 may be configured to contain excess fluid for introduction or removal from fluid lens module 56. As described further herein, in some embodiments, reservoir 60 may be compressed to push fluid into fluid lens module 56.

In some embodiments, fluid lens module 56 is connected to reservoir 60 via conduit 58. In some embodiments, fluid lens module 56, conduit 58, and reservoir 60 together form a fluid-sealed unit. In some embodiments, reservoir 60 is directly connected to fluid lens module 56. Reservoir 60 may be configured to hold about 150 microliters of fluid or less.

In some embodiments, reservoir 60 holds fluid that may be introduced into fluid lens module 56. In some embodiments, the introduction of additional fluid into fluid lens module 56 raises the pressure between a rigid lens 64 and membrane 62, which in some embodiments causes membrane 62 to inflate in a controllable manner. Fluid may be introduced into fluid lens module 56 to cause membrane 62 to inflate.

Reservoir 60 may be made of a flexible, transparent, water impermeable material. For example and without limitation, the reservoir may be made of Polyvinyiedene Difluoride, such as Heat-shrink VITON(R), supplied by DuPont Performance Elastomers LLC of Wilmington, DEL DERAY- KYF 190 manufactured by DSG-CANUSA of Meckenheim, Germany (flexible), RW-175 manufactured by Tyco Electronics Corp. of Berwyn, PA (formerly Raychem Corp.) (semi-rigid), or other suitable material. Additional embodiments of reservoirs are described in U.S. Publication No. 20110102735, which is incorporated herein by reference in its entirety.

FIG. 6 illustrate a partially exploded view of one embodiment of eyewear 66. Eyewear 66 may include fluid lens assembly 68, a frame 70, a temple 72, an actuator 74,
and an inner temple piece 76. As shown therein, a reservoir 78 may be housed in temple 72. In some embodiments, reservoir 78 is not housed within eyewear 66. Reservoir may be housed in frame 70, or another suitable location. Conduit 80 may be threaded through temple 72 of eyewear 66.

[0086] Reservoir 78 may be compressed via an actuator 82. In some embodiments, reservoir 78 is in direct contact with actuator 74. In some embodiments, reservoir 78 is in indirect contact with actuator 74.

[0087] Actuator 74 may include a compression arm that may be pushed against reservoir 78. In some embodiments, the compression arm includes a thin plate as a screw is moved along a length of temple 72. In some embodiments, the compression arm is pushed against reservoir 78, fluid is pushed out of reservoir 78 and flows through conduit 80 to a fluid lens module 86.

[0088] Actuator 74 may include a plunger configured to directly or indirectly press against reservoir 78. Reservoir 78 may be compressed via a caliper. Other suitable actuator configurations may be used. One or more suitable configurations are disclosed, for example, in U.S. Publication No. 20120287512, which is incorporated by reference herein in its entirety. Actuator 74 may, for example, be mechanically, electrically, magnetically, and/or manually operated.

[0089] FIG. 7 is a photograph of eyewear 88 in accordance with an embodiment. Eyewear 88 includes two fluid lens modules 90 and 92 within a frame 94. Frame 94 is attached to two temples 96 and 98. In this embodiment, a reservoir for each respective fluid lens module are housed in respective temples 96 and 98.

[0090] While various embodiments of the present invention have been described above, it should be understood that they have been presented by way of example only, and not limitation. It will be apparent to persons skilled in the relevant art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention. Thus, the breadth and scope of the present invention should not be limited by any of the above-described embodiments, but should be defined only in accordance with the following claims and their equivalents.

[0091] The choice of materials for each of the pieces in the embodiments of the assemblies described herein may be informed by the requirements of mechanical properties, temperature sensitivity, optical properties, such as dispersion, moldability
properties, or any other factor apparent to a person having ordinary skill in the art. For example, the pieces of the various assemblies described may be manufactured through any suitable process, such as metal injection molding (MIM), cast, machining, plastic injection molding, and the like. The assemblies may be any suitable shape, and may be made of plastic, metal, or other suitable material. Lightweight material may be used such as, for example and without limitation, high impact resistant plastics material, aluminum, titanium, or the like. One or more of the parts may be made entirely or partly of a transparent material.

Further, the purpose of the Abstract is to enable the U.S. Patent and Trademark Office and the public generally, and especially the scientists, engineers and practitioners in the art who are not familiar with patent or legal terms or phraseology, to determine quickly from a cursory inspection the nature and essence of the technical disclosure of the application. The Abstract is not intended to be limiting as to the scope of the present invention in any way.
CLAIMS

1. A method of manufacturing a fluid lens assembly, the method comprising:
   dissolving a photochromic additive in a solvent to form a solution;
   adding the solution to a fluid to form a photochromic fluid for the fluid lens assembly;
   stirring the photochromic fluid at a temperature that ensures that the photochromic additive is substantially dispersed after stirring;
   degassing the photochromic fluid;
   introducing the degassed photochromic fluid into the fluid lens assembly; and
   sealing the fluid lens assembly.

2. The method of claim 1, wherein the fluid is a transparent silicone oil.

3. The method of claim 1, wherein the photochromic additive comprises derivatives of napthoxazine and naphthopyran.

4. The method of claim 1, wherein the photochromic additive comprises derivatives of benzoxazine and benzopyran.

5. The method of claim 1, wherein a concentration of the photochromic additive in the photochromic fluid ranges from about 0.1% to about 2.0%.

6. The method of claim 1, wherein the photochromic fluid is brought to within about 5 degrees Celsius of its freezing point before the photochromic fluid is degassed.

7. The method of claim 1, wherein stirring the photochromic fluid includes keeping the temperature of the photochromic fluid within a range from about 30 degrees Celsius to about 80 degrees Celsius.

8. The method of claim 1, wherein degassing the photochromic fluid includes subjecting the photochromic fluid to a vacuum.

9. The method of claim 1, wherein stirring the photochromic fluid includes ultrasonically stirring the photochromic fluid.
10. The method of claim 1, wherein the fluid has a dynamic viscosity in a range from about 15 cP to about 45 cP.

11. A method of manufacturing a fluid lens assembly, the method comprising:
encapsulating a photochromic additive in a vesicle that is soluble in a fluid for use in the fluid lens assembly;
stirring the photochromic fluid;
introducing the photochromic fluid into the fluid lens assembly; and
sealing the fluid lens assembly.

12. The method of claim 11, wherein the vesicle is a liposome vesicle.

13. The method of claim 12, wherein the vesicle is a gel particle wrapped around the photochromic additive.

14. A fluid lens assembly comprising:
a rigid lens;
a membrane fluidly attached to the rigid lens to create a cavity therebetween; and
a photochromic fluid disposed within the cavity,
wherein the photochromic fluid includes photochromic additives having one or more spiropyran, napthoxazine, or benzoxazine compounds that are able to transition the photochromic fluid between a substantially clear state and a darkened state.

15. The fluid lens assembly of claim 14, wherein the fluid lens assembly has an adjustable optical power range from about 0.0D to about 3.0D.

16. The fluid lens assembly of claim 14, wherein the fluid lens assembly has an adjustable optical power range from about 0.0D to about 4.0D.

17. The fluid lens assembly of claim 14, further comprising:
a reservoir fluidly connected to the fluid lens module; and
an actuator coupled to the reservoir for compressing the reservoir to introduce fluid into the fluid lens module,
wherein the actuator is coupled to the reservoir to allow the reservoir to controllably expand to extract fluid from the fluid lens module.
18. The fluid lens assembly of claim 14, wherein the photochromic additive is able to darken the photochromic fluid when exposed to a level of ultraviolet radiation above a predetermined threshold and are able to lighten the photochromic fluid when exposed to a level of ultraviolet radiation below a predetermined threshold.

19. The fluid lens assembly of claim 18, wherein the predetermined threshold of ultraviolet radiation is based on the level of ultraviolet radiation in daylight.

20. Eyewear comprising:

a first fluid lens assembly;

a second fluid lens assembly; and

a frame housing the first fluid lens assembly and the second fluid lens assembly,

wherein each of the first fluid lens assembly and the second fluid lens assembly comprises:

a rigid lens;

a membrane fluidly attached to the rigid lens to create a cavity therebetween; and

a photochromic fluid disposed within the cavity, the photochromic fluid including photochromic additives having one or more spiropyran, napthoxazine, or benzoxazine compounds that are able to transition the photochromic fluid between a substantially clear state and a darkened state; and

wherein the frame is shaped to position the first fluid lens assembly over a first eye of a wearer and to position the second fluid lens assembly over a second eye of the wearer.
DISSOLVE PHOTOCHROMIC ADDITIVES IN SOLVENT

ADD SOLUTION TO FLUID TO FORM PHOTOCHROMIC FLUID

STIR PHOTOCHROMIC FLUID

BRING PHOTOCHROMIC FLUID TO NEAR FREEZING POINT

DEGAS PHOTOCHROMIC FLUID

INTRODUCE DEGASSED PHOTOCHROMIC FLUID TO FLUID LENS MODULE

SEAL FLUID LENS MODULE

FIG. 2
INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/071836

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G02B 3/14 (2013.01)
USPC - 359/666

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

- FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - G02B 3/14, G02B 5/23, G03C 1/72 (2013.01 )
USPC - 359/665, 666, 351/1 59.68, 252/586

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - G02B 26/004, G02C 7/061, G03C 1/732

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

PatBase, MicroPatent, Google Patents, Google Scholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>US 6,106,744 A (VAN GEMERT et al) 22 August 2000 (22.08.2000) entire document</td>
<td>1-10, 14-20</td>
</tr>
<tr>
<td>Y</td>
<td>US 2008/0142441 A1 (PASHLEY) 19 June 2008 (19.06.2008) entire document</td>
<td>6, 8</td>
</tr>
<tr>
<td>Y</td>
<td>US 201 1/0051254 A1 (LEE et al) 03 March 2011 (03.03.2011) entire document</td>
<td>10</td>
</tr>
<tr>
<td>A</td>
<td>US 201 1/0242480 A1 (REICHOW et al) 06 October 2011 (06.10.2011) entire document</td>
<td>1-20</td>
</tr>
</tbody>
</table>

Further documents are listed in the continuation of Box C.

* 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

Date of the actual completion of the international search

20 February 2013

Date of mailing of the international search report

08 MAR 2013

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313 3-1450
Facsimile No. 571-273-3201

 Authorized officer: Blaine R. Copenheaver
PCT Helpdesk: 571-272-4300
PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (July 2009)