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(71) Applicant (for all designated States except US):  
**AGENCY FOR SCIENCE, TECHNOLOGY AND RESEARCH** [SG/SG]; 20 Biopolis Way, #07-01, Centros, Singapore 138668 (SG).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **DHAR-MATILLEKE, Saman** [LK/SG]; Institute of Materials Research and Engineering, 3 Research Link, Singapore 117602 (SG).

(74) Agent: **DREW & NAPIER LLC**; 20 Raffles Place, #17-00 Ocean Towers, Singapore 048620 (SG).

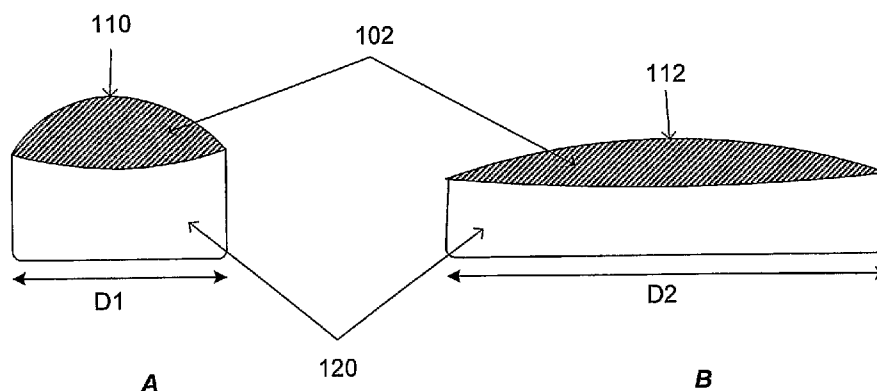
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(54) Title: VARIABLE FOCUS ZOOM LENSES



(57) Abstract: The present invention provides a variable focus semi-solid zoom lens, methods of making and using the variable focus lens and optical devices containing the variable focus semi-solid lens. The focal length is controllable by changing the shape, size, dimension, geometry, outer diameter or surface curvature of the semi-solid lens. The change of the focal length can be achieved by using a pressure control device coupled with the semi-solid lens. The semi-solid lens can also be mounted in a housing.

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## VARIABLE FOCUS ZOOM LENSES

### BACKGROUND OF THE INVENTION

[0001] In conventional optical imaging applications, such as optical communications  
5 systems and camera devices, manual tuning and physical positioning of a lens are typically  
required to focus an image onto a image sensor and to receive light from different directions  
relative to the lens. To eliminate the inefficiencies and expenses of manual tuning, tunable  
microlenses were developed to focus an optical signal by optimally coupling an optical  
source to an optical signal receiver, such as a photodetector. In some cases, the refractive  
10 index of the microlens is automatically varied to change the focus of the microlens when the  
incidence of a light beam upon the microlens varies from its nominal, aligned incidence, in  
order to maintain optimal coupling between the microlens and the photodetector.

[0002] However, tunable microlenses such as gradient index lenses have inherent  
limitations associated with the small electro-optic coefficients found in the majority of  
15 electro-optic materials used for such lenses. This often results in a small optical path  
modulation and thus requires thick lenses or high voltages. In addition, many electro-optic  
materials show strong birefringence causing polarization dependence of the microlens, which  
distorts light with certain polarization. These problems become especially severe in the case  
where arrays of tunable microlenses are required. For example, existing camera phones use  
20 tiny, fixed-focus lenses, which have poor light-gathering capabilities, limited focus range and  
limited resolution power. As a result, the image quality is low compared to conventional  
photo cameras.

[0003] A variable focus fluid lens is provided when the focal length is controlled by  
changing the contact angle or radius of curvature of a fluid meniscus, which forms the optics  
25 of the lens. The optical device also typically includes a pressure or volume control means  
fluidly coupled with the fluid for adjusting the pressure of the fluid and therefore also the  
curvature of the meniscus.

[0004] However, improvements can still be made for problems particular to some of the  
liquid lenses. First, the liquid lens may be disturbed after impact or rough handling. Second,  
30 due to gravity effect, variable focus liquid lenses having a large diameter are difficult to  
manufacture. Third, since liquid lens is typically spherical, there is little success in making

non-spherical variable focus liquid lenses based on current technologies. Fourth, in many technological applications, it is also highly desirable to modify the surface of the lens with a material, such as a non-reflective coating to improve the image quality. However, such a process has not been possible with a liquid lens.

- 5 [0005] Therefore, it is desirable to provide systems and methods that overcome the above and other problems. In particular, there is a need for a low cost and large diameter variable focus lens that can be spherical and non-spherical. It is also desirable to provide a rugged optical focusing system for small, portable, imaging applications where rough handling is anticipated. Embodiments of the invention provide for these and other needs.

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### BRIEF SUMMARY OF THE INVENTION

- [0006] The present invention provides a variable focus semi-solid lens, methods of making and using the variable focus lens and optical devices containing the variable focus semi-solid lens. The focal length is controllable by changing the shape, size, dimension, geometry,  
15 volume, pressure or surface curvature of the semi-solid lens, for example, changing the curvature or the radius of curvature of a region on the surface or the bulk of a semi-solid lens. The surface of a semi-solid forms the optics of a lens and its (adjustable) radius of curvature determines the focal length. An example of a variable focus semi-solid lens can be a polymer lens or a gel lens. Advantageously, a semi-solid variable focus lens of the present invention  
20 allows the facile production of a spherical or a non-spherical variable focus lens having a large diameter, and the easy deposition of coatings, such as a non-reflective coating on the surface of the lens for improved image quality.

- [0007] According to the present invention, the variable focus capability is achieved by changing the shape, size, dimension, geometry, volume or surface curvature of a semi-solid  
25 substance through adjusting the pressure applied to the semi-solid substance. In one aspect, the variable focus capability is achieved by changing the shape, size, dimension, geometry or surface curvature of the semi-solid lens, while keeping the volume of the lens relatively  
constant. In one embodiment, the variable focus capability is achieved by changing the  
diameter of the semi-solid substance.

- 30 [0008] According to one aspect of the present invention, an optical device is provided that typically includes an optically transparent semi-solid substance having a surface region with a defined curvature and a pressure control means coupled with the semi-solid substance for

adjusting the curvature of the surface region of the semi-solid substance. In one embodiment, the optical device includes a holding means, for example, a housing for supporting the substance, where the semi-solid substance is disposed or mounted in the housing. In another embodiment, the semi-solid substance is a thin film having a thickness in the range of  
5 micrometer to milometer.

[0009] According to another aspect of the present invention, an optical device is provided that typically includes one or more semi-solid lenses having a surface region with a defined curvature, one or more solid lenses, optionally one or more fluid lenses, a housing for mounting the lenses, at least one pressure control means coupled to at least one semi-solid  
10 lens and optionally at least one pressure control means coupled to a fluid lens.

[0010] According to yet another aspect of the present invention, a method for making an optical device is provided. The method includes fabricating an optically transparent semi-solid substance into a variable focus lens. In one embodiment, the method includes an injection moulding process. In another embodiment, the method includes an in situ curing  
15 process.

[0011] According to still another aspect of the present invention, a method for adjusting the curvature or the radius curvature of the surface of an optically transparent semi-solid substance having a surface region with a defined curvature is provided. The method includes adjusting a pressure applied to the semi-solid substance to change the curvature of the surface  
20 region of the semi-solid substance.

[0012] According to a further aspect of the present invention, a use of an optical device having a variable focus semi-solid lens for imaging application is provided.

[0013] Reference to the remaining portions of the specification, including the drawings and claims, will realize other features and advantages of the present invention. Further features  
25 and advantages of the present invention, as well as the structure and operation of various embodiments of the present invention, are described in detail below with respect to the accompanying drawings. In the drawings, like reference numbers indicate identical or functionally similar elements.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0014] FIG. 1 illustrates a variable focus semi-solid lens, where the focal length can be adjusted by changing the outer diameter of the lens according to an embodiment of the invention.

5 [0015] FIG. 2 illustrates a side view of a schematic drawing of a semi-solid lens with a piezo ring actuator for adjusting the shape of the semi-solid lens by changing the outer diameter of the lens according to an embodiment of the invention.

[0016] FIG. 3 illustrates a top view of a variable focus semi-solid lens having an artificial muscle ring, a piezo electrical ring or a mechanical ring setup for adjusting the surface  
10 curvature of the lens according to an embodiment of the invention.

[0017] FIG. 4 illustrates a cross-sectional side view of an optical device having a semi-solid lens mounted in a housing and a fluid pressure modulator for adjusting the surface curvature of the semi-solid lens according to an embodiment of the invention.

[0018] FIG. 5 illustrates a schematic drawing of an optical device with two-lens assembly.  
15 The optical device includes a semi-solid lens and a solid lens mounted in a housing according to an embodiment of the invention.

[0019] FIG. 6 illustrates an optical device having a semi-solid lens and a solid lens mounted in a housing with a transparent cover, and a fluid pressure modulator for adjusting the surface curvature of the semi-solid lens according to an embodiment of the invention.

20 [0020] FIG 7 illustrates an optical device with a semi-solid and solid lens assembly having a housing with coarse surface for increasing the adhesion of the semi-solid to the housing according to an embodiment of the invention.

[0021] FIG. 8 illustrates a side view of a schematic drawing of an optical device with a three-lens assembly, where the semi-solid lens has a convex surface according to an  
25 embodiment of the invention.

[0022] FIG. 9 illustrates an optical device with a three-lens assembly, where the fluid pressure modulators coupled to the semi-solid lenses or liquid lenses for adjusting the surface curvature of the semi-solid lenses or liquid lenses according to an embodiment of the invention.

[0023] FIG. 10 illustrates a side view of an optical device with a three-lens assembly, where the housing has a transparent cover or a cover shaped as a lens and a plurality of fluid pressure modulators are coupled to the semi-solid lens for adjusting the surface curvature of the semi-solid lenses according to an embodiment of the invention.

5 [0024] FIG. 11 illustrates a side view of an optical device with a three-lens assembly having optionally a second fluid pressure modulator coupled to the second semi-solid lenses for adjusting the surface curvature of the second semi-solid lenses according to an embodiment of the invention.

10 [0025] FIG. 12A shows a side view of an optical device with a three-lens assembly having a piezo electric actuator for adjusting the surface curvature of the semi-solid lenses or the liquid lens according to an embodiment of the invention.

[0026] FIG. 12B shows a side view of an optical device with a three-lens assembly having an actuator ring, an actuator diaphragm, a piezo ring or an electro active polymer for adjusting the surface curvature of the semi-solid lenses or the liquid lens according to an  
15 embodiment of the invention.

[0027] FIG. 13 illustrates a side view of an optical device with four-lens assembly according to an embodiment of the invention.

[0028] FIG. 14 shows the side view of a semi-solid lens or a liquid lens assembly with a lens cavity according to an embodiment of the present invention.

20 [0029] FIG. 15A shows a liquid or semi-solid lens and solid lens according to an embodiment of the invention.

[0030] FIG. 15B shows a liquid or a semi-solid lens and a solid plano convex lens according to an embodiment of the present invention.

[0031] FIG. 15C shows two liquid lenses or two semi-solid lenses and two solid lenses  
25 according to an embodiment of the present invention.

[0032] FIG. 15D shows two liquid lenses or two semi-solid lenses and one solid lens sandwiched in between according to an embodiment of the invention.

[0033] FIG. 16 shows a side view of a liquid-based or a semi-solid lens-based, auto-focus lens system according to an embodiment of the invention.

[0034] FIG. 17 shows a side view of a liquid lens-based or a semi-solid lens-based, auto-focus lens system according to another embodiment of the present invention.

[0035] FIG. 18 shows a side view of a liquid lens or a semi-solid lens system with a zoom/focus module according to an embodiment of the system.

- 5 [0036] FIG. 19 shows a side view of a liquid or a semi-solid lens system with a variable-focus and variable-diameter lens module according to an embodiment of the system.

[0037] FIG. 20 shows a side view of a liquid or a semi-solid lens system with a zoom/focus module according to another embodiment of the invention.

- 10 [0038] FIG. 21A shows a top view of a piezoelectric disc actuator according to an embodiment of the invention.

[0039] FIG. 21B shows a side view of the piezoelectric disc actuator for liquid pumping according to an embodiment of the invention.

[0040] FIG. 21C shows a top view of a piezoelectric actuator using a curved piezoelectric diaphragm according to an embodiment of the invention.

- 15 [0041] FIG. 22 shows an image of variable focus elastomeric lenses according to an embodiment of the invention.

[0042] FIG. 23A-23B illustrates a variable focus elastomeric lens module with a mechanical actuator, which can deform the lens and control the focal length of the lens according to an embodiment of the invention.

- 20 [0043] FIG. 24A-24B illustrates a demonstration of volume change in a tubular piezo actuator at an actuation voltage of about 20V according to an embodiment of the invention.

[0044] FIG. 25 illustrates a side view of a schematic drawing of a semi-solid thin foil lens assembly according to an embodiment of the present invention.

- 25 [0045] FIG. 26 illustrates a side view of a two-lens assembly with a thin foil lens and a solid lens according to an embodiment of the present invention.

[0046] FIG. 27 illustrates a side view of a fixed focus lens module using semi-solid lenses.

[0047] FIG. 28 illustrates an optical device having a three-lens assembly and the operation and functionality of a semi-solid lens.

## DETAILED DESCRIPTION OF THE INVENTION

[0048] The present invention provides a variable focus semi-solid lens and methods of making and using a variable focus semi-solid lens. The focal length is controllable by  
 5 adjusting the shape, size, dimension, geometry, diameter, pressure, volume, curvature or radius of curvature of a semi-solid lens or a region on the surface of a semi-solid lens.

[0049] As used herein, the term "semi-solid" refers to a substance having the property of both a solid and a liquid. For example, a semi-solid can be a material, which also filters ultra violet (UV) or infra red (IR) radiation. In particular, the semi-solid can change shape, size,  
 10 dimension, geometry and/or surface curvature in responding to an external stimulus, such as a change of pressure. A semi-solid can be a viscous liquid, a gel, such as an elastomeric gel; a semiconductor coating; an electro-active gel; a semi-crystalline liquid; or an elastomer, such as a thermoplastic elastomer or a siloxane. In particular, a semi-solid can be a polymeric material, such as an organic polymer, an inorganic polymer or a blend of different polymers  
 15 and additives or a composite material. As used herein, a gel can also include a colloidal material, mostly liquid, yet behaves like a solid, for example, a colloid.

[0050] As used herein, the term "fluid" refers to a gas, a liquid or a mixture of gas and liquid. A gas includes, but are not limited to, air, oxygen, nitrogen, hydrogen, carbon dioxide, carbon monoxide, a noble (inert) gas, a low boiling organic solvent, vapors of a low  
 20 boiling organic solvent or combinations thereof. A liquid can be any transparent liquid. Examples of the liquid used in the present invention include, but are not limited to, water, oil, organic solvents and combinations thereof. The liquid may or may not act as a lens in addition to the semi-solid lens.

[0051] As used herein, the side view of a device also means the cross-sectional view of the  
 25 device.

[0052] As used herein, the term "curvature" refers to the amount by which a geometric object deviates from being flat. For a plane curve, the curvature is defined as  $(x'y'' - y'x'')/(x'^2 + y'^2)^{3/2}$ , where  $x'$ ,  $x''$ ,  $y'$  and  $y''$  are the first and the second derivatives. For a two-dimensional surface, the curvature at a point P is defined as  $\lim_{r \rightarrow 0} (2\pi - C(r)) \cdot \frac{3}{\pi r^3}$ , where  $r$   
 30 is a short length from point P and  $C(r)$  is the perimeter of the circle having a distance  $r$  from



point P. For example, if the surface is flat, then  $C(r) = 2\pi r$ . Typically, a semi-solid lens has a surface region with a defined surface curvature.

[0053] FIG. 1 is a schematic showing of a variable focus semi-solid lens, where the focal length can be adjusted by changing the shape, size, dimension, outer diameter, curvature or radius of curvature of a region on the surface of the lens or of the whole lens. The lens has a semi-solid substance 102, surfaces 110 and 112, and a boundary 120. As shown in FIG.1, in one embodiment, the variable focus capability is achieved by changing the diameter of the semi-solid lens from D1 in FIG. 1A to D2 in FIG. 1B such that the surface 110 changes to surface 112 with an alteration in the surface curvature. In certain instances, the volume of the lens can be kept relatively constant. In other occasions, the semi-solid material used can be compressed to reduce its volume when a force or a pressure is applied to the semi-solid lens. The alteration of the surface curvature, shape, geometry or dimension of the lens can be accomplished by applying an external stimulus, for example, a force, a pressure or a light beam to the lens.

[0054] The present invention provides an optical device, which is composed of an optically transparent semi-solid substance having a surface region with a defined curvature and a pressure control means coupled with the semi-solid substance for adjusting the curvature of the surface region of the semi-solid. FIG. 2 is a side view of a schematic drawing of an optical device of the present invention. As shown in FIG. 2, the device has a semi-solid substance 210, a surface region 230, and a pressure control means 220 coupled with the semi-solid 210. The pressure control means 220 can be coupled directly with the semi-solid 210, for example, by contacting with the substance 210 or indirectly interact with 210 through an intermediate, for example, an intermediate layer, such as a fluid or a solid layer to adjust the curvature of surface 230. In one embodiment, the lens is surrounded by the pressure control means 220. In another embodiment, the pressure control means 220 is in contact with a portion of the lens. An exemplary pressure control means 220 is a ring, which can be contracted in its circumference, such as a piezo electric ring. A separate layer, such as a reflective or a non-reflective layer can also be added to the semi-solid lens, such as deposited on the surface of the semi-solid lens for improving the image quality.

[0055] FIG. 3 shows a top view of an embodiment of the present invention, which includes a lens 340 with a pressure control means 310 surrounding the lens. The lens 340 can be a semi-solid lens or a fluid lens.

[0056] Examples of pressure control means used in the present invention include, but are not limited to, an artificial muscle ring; a piezo electrical device, such as a piezo ring, a piezo cylinder, a piezo sleeve or a piezo coated metal ring or cylinder a piezo electric ring, which can change its diameter when an electric field is applied; a mechanical actuator; an  
5 electromechanical actuator; a fluid pressure modulator for modulation using microfluidics; a light beam; and a voltage or an electrical stimulus. The pressure control device used in the present invention can have variable shapes and dimensions. Portions of a pressure control device used in the present invention may have elliptical, circular and/or polygonal cross-sections. The number of sides of the polygonal cross-section may vary from 3 to about 16.  
10 One example is a four-sided polygon such as a square or rectangle.

[0057] Various semi-solid materials can be used in the present invention. Preferably, the material is optically transparent and stable in the operating conditions. Semi-solid materials include, but are not limited to, a viscous liquid, such as an oil; a gel, such as low molecular weight cross-linked or non-cross-linked polymers and colloids; elastomers, such as cross-  
15 linked or non-cross-linked thermoplastic and thermoset elastomers; and mixtures thereof. Examples of polymers or oligomers include, but are not limited to, homopolymers, copolymers, polymer blends and mixtures thereof. Exemplary polymers or oligomers include, siloxanes, polysiloxanes, such as poly(dimethylsiloxane); polycarbonate; polyphosphazene; and polyacrylate, such as poly(methyl methacrylate).

[0058] The optical device further includes a holding means, such as a housing. FIG. 4 illustrates a cross-sectional side view of another embodiment of the present invention. As shown in FIG. 4, the optical device has a semi-solid lens 420 having a surface region 440 with a defined curvature, a housing 430 and a pressure control means 414. The lens 420 is mounted in a housing 430. The lens 420 is coupled directly to a pressure control means 414  
20 for changing the pressure applied to the lens 420 to change the curvature of surface 440. Alternatively, the pressure control means 414 can also coupled to lens 420 indirectly through an intermediate, such as a fluid or a layer. The pressure control means can be a microfluidic modulation device, which contains fluid 410 and an inlet and/or an outlet 412. The fluid can be a liquid or a gas. A person of skill in the art will recognize that other pressure control  
25 means, such as a piezo electric device, a mechanical or an electric actuator can also be used to change the focal length of lens 420.  
30

[0059] The housings used in the present invention can have variable shapes and dimensions. In one embodiment, a tubular housing has a symmetrical cross-section and in another embodiment, a tubular housing has an unsymmetrical cross-section. In yet another embodiment, a tubular housing may have a continuous or a discrete variation of the size of the cross-section along the tubular housing. Portions of a tubular housing used in the present invention may have elliptical, circular and/or polygonal cross-sections. The number of sides of the polygonal cross-section may vary from 3 to about 16. One example is a four-sided polygon such as a square or rectangle.

[0060] In another embodiment, the present invention provides an optical device having a two-lens assembly as shown in FIG. 5. The optical device includes a semi-solid lens 510 having a surface 540 and a solid lens 520 mounted in housing 530. As shown in FIG. 5, semi-solid lens 510 and solid lens 520 are in direct contact with one other. Alternatively, the two lenses can be separated by a predetermined distance, for example, the two lenses can be separated by a fluid, such as a liquid or a gas.

[0061] In a further embodiment, similar to the device in FIG. 5, the optical device in FIG. 6A includes a semi-solid lens 640 having a surface 670 and a solid lens 650 mounted in housing 630. The device also a pressure control means 610 containing a fluid 615 and having an inlet/outlet 660. The pressure control means is used to adjust the shape, size or geometry, dimension of lens 640 and curvature of surface 670. The device also has a cover 620, preferably, the cover is transparent. In another embodiment, a semi-solid material is provided with a hollow cavity, where the semi-solid material can squeeze into when an external force or pressure is applied to change the focal length or shape or curvature of the semi-solid. For example, as shown in FIG. 6B, the optical device has a hollow cavity 680 next to the semi-solid lens to provide some additional space for the semi-solid lens to squeeze into, when a pressure is applied to the semi-solid lens 640 by the pressure control device 610.

[0062] FIG. 7 provides a further embodiment of the present invention. Similar to FIG. 6, the optical device includes a lens assembly having a semi-solid lens 750 having a surface 770 and a solid lens 760 mounted in a housing 720. A pressure control means 730 having a fluid and an inlet/outlet 740 is used to control the pressure applied to lens 750 for adjusting the shape, size, geometry and/or dimension of lens 750 and curvature of surface 770. In particular, the optical device provides a housing made of a material having an coarse surface, such as a surface with a microstructure having microscopic bumps, dents or cavities for

increasing the traction, friction and adhesion of the semi-solid to the surface of the housing. The surface can be a hydrophobic or hydrophilic. The surface can be composed of materials of nano- or micro-structures having the same or different materials than the housing, such as polymer, inorganic, metal, or ceramic materials or hybrids thereof.

5 [0063] FIG. 8 is a schematic drawing of another embodiment of the present invention providing an optical device having a three-lens assembly. The optical device has a solid lens 820 sandwiched between a first semi-solid lens 810 having a surface 850 and a second semi-solid lens 812 having a surface 855. A person skill in the art will appreciate that other arrangements of the lens is also feasible for the present invention. The lenses 810, 812 and  
10 820 are disposed or mounted in housing 830 such that a sharp edge 840 is present, which enables the formation of a semi-solid lens having a convex shape, which can prevent the lens material, for example, a gel from leaking out from the cavity on the housing.

[0064] FIG. 9 illustrates another embodiment of the present invention. Similar to FIG. 8, the optical device includes a solid lens 950 sandwiched between a first lens 940 having a  
15 surface region 970 and a second lens 960 having a surface region 975 disposed or mounted in a housing 920. The device can also have a sharp edge 901. Alternatively, the device can also have a smooth edge. Lenses 940 and 960 can be a semi-solid lens or a fluid lens. The fluid can be a gas or a liquid. The shape, size, geometry and/or dimension of the lenses 940 and 960, and the curvature of surfaces 970 and 975 can be adjusted by pressure control means  
20 910 and 912, respectively. The pressure control means 910 and 912 can be device containing a fluid to adjust the pressure applied to the lenses, leading to the change of curvature of surfaces 970 and 975. The fluid functions to transmit the pressure to the semi-solid. A person skill in the art will recognize that other arrangements of the lens are also feasible to achieve a variable focus assembly.

25 [0065] FIG. 10A-10B show other embodiments of the present invention. Similar to the optical device in FIG.9, the optical device shown in FIG. 10A has a solid lens 1040 sandwiched between a first semi-solid lenses 1030 having a surface region 1080 and a second semi-solid lens 1032 having a surface region 1085. The lenses are disposed or mounted in housing 1020. A first pressure control means 1070 is coupled to lens 1030. A second  
30 pressure control means 1072 is coupled to lens 1032. The pressure control means can be a shell containing fluids 1010 and 1012, such as a gas or a liquid. The fluid 1010 and 1012 can be the same or different kind. Preferably, the pressure control means 1070 and 1072 are

made of flexible shell materials. In one embodiment, the pressure control means 1070 and/or 1072 are transparent. The pressure control means can couple to semi-solid lens 1030 and 1032 either through a direct contact or an indirect interaction. The optical device also has transparent covers 1050 and 1060. In one embodiment, the cover is shaped as a lens. As shown in FIG. 10B, a hollow cavity 1090 is provided for the semi-solid lens to squeeze into, when a pressure is applied.

[0066] FIG. 11 shows another embodiment of the present invention. Similar to the device in FIG. 10, the optical device has a solid lens 1150 sandwiched between a first semi-solid lens 1140 having a surface 1170 and a second semi-solid lens 1142 having a surface 1175. The lens assembly is disposed or mounted in housing 1130. A first pressure control device 1110 is attached to the first semi-solid lens 1140 to adjust the shape, size, geometry and/or dimension of lenses or surface curvature of the lens 1140, and the curvature of surface 1170. The pressure control means 1110 has a fluid 1112 and a fluid inlet/outlet 1160 adapted to the device for producing a pressure to lens 1140. The optical device has an optional second pressure control means 1114 attached to the second lens 1142. It is optionally that device 1114 has a fluid inside for adjusting the pressure of lens 1142. The optical device also has covers 1120 and 1122, preferably, at least one of the covers is transparent.

[0067] FIGS. 12A-12B illustrate an embodiment of the present invention using a combination of lenses. As shown in FIG. 12A, the optical device has a lens component, a housing 1220 and a pressure control means component coupled to each of semi-solid lens. The lens component comprises of a first semi-solid lens 1240 having a surface region 1260, a solid or fluid lens 1250 and a second semi-solid lens 1242 having a surface region 1265. In one embodiment, lens 1250 is situated between lens 1240 and lens 1242. The lens component is disposed or mounted in housing 1220. A first pressure control means 1210 is coupled to lens 1240. The cavities 1230 and 1232 are for actuation of lens 1240 and lens 1242, respectively. Optionally, a second pressure control means 1212 is coupled to lens 1242. As shown in FIG 12B, in one embodiment, the lens has lens openings 1270 and 1275 and fluid 1280. The pressure control means 1210 and/or 1212 are piezo rings/curved diaphragms or metal rings/curved diaphragms coated with a piezo electric material, or rings/curved diaphragms of electro active polymer material such as artificial muscle. The metal rings/curved diaphragms provide mechanical amplification. The lens may be actuated by using a intermediate fluid such as a liquid, a gas or air to transmit the actuation of the actuator on to the lens.

[0068] FIG. 13 illustrates another embodiment of the present invention, which provides an optical device having a four-lens assembly. A first semi-solid lens 1320 having a surface 1360 is disposed on top of a fluid lens 1330 having an interface 1370 with the semi-solid lens 1320. The fluid lens 1330 is disposed on top of a solid lens 1340 forming an interface 1375. 5 the solid lens 1340 is further disposed on top of a second semi-solid lens 1322 having a surface 1365. A person of skill in the art will recognize that other arrangements of the lenses can also be used to achieve the desired variable focusing results. FIG. 13 shows that each of the lenses is in contact with one other. In other embodiments, some lenses can be in contact with each other while other lenses can be separated by a predetermined distance. In yet other 10 embodiments, each of the lenses is not in contact with one other. Lenses 1320 and 1330 are disposed or mounted in a housing 1310. Fluid lens 1330 has an inlet/outlet 1350 to allow the passage of a fluid.

[0069] FIG. 14 shows the side view of a semi-solid lens or a liquid lens assembly with a lens cavity 1404. Lens cavity 1404 can be inwardly curved, outwardly curved or straight. In 15 one embodiment, lens cavity 1404 has an inner layer, which is coated with coatings 1406 and 1410, and the top and bottom surfaces or outer layers of the lens assembly are coated with a coating 1408. The coatings 1406, 1410 and 1408 can be either a hydrophilic material or a hydrophobic material. When the lens cavity contains liquid, the coatings 1406 and 1410 are preferably a hydrophilic material. The boundary at the hydrophobic regions constrains the 20 liquid and presents a meniscus having a curvature defined in part by the static (or dynamic) contact angle of the fluid at the boundary. The hydrophobic material may be a material such as plastic, polymers, ceramics, alloys, or a fluoropolymer such as Teflon, CYTOP or zirconium oxynitride. The hydrophilic region may be made of a material such as plastic, polymer, glass, quartz, zirconium oxynitride, or fused silica. Other suitable materials include 25 ceramics, hydrophilic metals, hydrophilic alloys or hydrophilic polymers such as, for example, hydroxylic polyacrylate or polymethacrylate, polyacrylamides, cellulose polymers, polyvinyl alcohols. Coatings of these materials can also be used to cover the lens cavity walls.

[0070] Alternative embodiments of the invention include liquid or semi-solid lens 30 assemblies with several liquid lenses and/or solid lenses for focusing and zooming. FIGS. 15A-15D illustrate various possible arrangements. Figure 15A shows a combination including liquid lens 1504 and solid lens 1502. FIG. 15B shows a combination including liquid lens 1504 and a solid plano convex lens 1506. FIG. 15C shows a combination of two

liquid lenses and two solid lenses 1506. FIG. 15D shows two liquid lenses 1504 and one solid lens 1508 sandwiched in between. It should be appreciated that many other assembly configurations including various arrangements of solid and/or liquid lenses are possible based on the teachings herein.

5 [0071] FIG. 16 shows a side view of a liquid lens or semi-solid system with an auto-focus module according to an embodiment of the invention. Housing 1600 holds a variable-focus liquid lens or semi-solid lens 1604 between a first solid lens 1606 and a second solid lens 1608. Housing 1600 includes coated inner surface 1602 and channel 1612 for filling the cavity and controlling the optics (e.g., meniscus) of the liquid lens. Surface 1602 can be  
 10 either hydrophobic or hydrophilic. For the auto-focus system in the embodiment, apertures 1610 are also formed (e.g., printed) on the second solid lens.

[0072] FIG. 17 shows a side view of a liquid lens or semi-solid lens system with an auto-focus module according to another embodiment of the invention. Like the embodiment shown in FIG. 16, housing 1700 holds a variable-focus liquid lens or semi-solid lens 1704, a  
 15 first solid lens 1706 and a second solid lens 1708, but additionally holds a third solid lens 1710. Housing 1700 also includes hydrophobic surfaces 1702. The liquid lens 1704 fills the cavity through channel 1712 from liquid reservoir or a pressure control means 1714, which is coupled with an actuating means or pump 1716.

[0073] FIG. 18 shows a side view of liquid lens or a semi-solid lens system with a  
 20 zoom/focus module according to an embodiment of the present invention. Like the embodiment of FIG. 17, housing 1800, which has hydrophobic surfaces 1802, holds a first solid lens 1808, a second solid lens 1810, a third solid lens 1812, and a first variable-focus lens 1804, which can be a first liquid lens or a first semi-solid lens. But housing 1800 additionally holds a second variable-focus lens 1806, which can be a second liquid lens or a  
 25 second semi-solid lens. In one embodiment, the first variable-focus lens 1804 is the first liquid lens fills a first cavity from a first liquid reservoir or a first pressure control means 1814, which is coupled with actuator or pump 1816. The second variable-focus lens 1806 is the second liquid lens fills a second cavity from a second liquid reservoir or a second pressure control means 1818, which is coupled with actuator or pump 1820. In another embodiment,  
 30 the first variable-focus lens 1804 is the first semi-solid lens fills a first cavity from a first liquid reservoir or a first pressure control means 1814, which is coupled with actuator or pump 1816. The second variable-focus lens 1806 is the second semi-solid lens fills a second

cavity from a second liquid reservoir or a second pressure control means 1818, which is coupled with actuator or pump 1820. In another embodiment, the actuator for the semi-solid lens can be a piezo ring actuator, which is in direct contact with the semi-solid lens.

[0074] FIG. 19 shows a side view of a liquid lens or a semi-solid lens system with a variable-focus and variable-diameter module according to an embodiment of the invention. Housing 1900, which has hydrophobic surfaces 1902, holds a solid lens 1904, a first liquid lens or a first semi-solid lens 1906 and a second liquid lens or a second semi-solid lens 1912. The first liquid lens or the first semi-solid lens 1906 fills a first cavity from a first liquid reservoir or a first pressure control means 1918, which is coupled with actuator or pump 1920. The second liquid lens or the second semi-solid lens 1912 fills a second cavity from a second liquid reservoir or a second pressure control means 1922, which is coupled with actuator or pump 1924. Housing 1900 in this embodiment is stepped so that the diameter of the liquid lens or the semi-solid lens may be increased when more liquid is pumped into the cavity. For example, liquid lens or semi-solid lens 1906 may be increased in diameter to the enlarged liquid lens or semi-solid lens shown at 1908, which may be further increased in size to the enlarged liquid lens or semi-solid lens shown at 1910. Likewise, the second liquid lens or semi-solid lens 1912 may be increased in diameter to form the enlarged liquid lens or semi-solid lens 1914, and further increased to form the enlarged liquid lens or semi-solid lens 1916. In some embodiments, the semi-solid material can be compressed to reduce its volume when a pressure is applied to the semi-solid lens. In certain other embodiments, the semi-solid lens is used as a fixed focus lens having a macro function.

[0075] FIG. 20 shows a side view of a liquid lens or a semi-solid lens system with a zoom/focus module according to another embodiment of the invention. Housing 2000, which has either hydrophobic or hydrophilic surfaces 2002, holds a first solid lens 2004, a second solid lens 2006, a third solid lens 2008, and a fourth solid lens 2010. Housing 2000 also holds a first variable-focus liquid lens or semi-solid lens 2012 and a second variable-focus liquid lens or semi-solid lens 2014. The first liquid lens or semi-solid lens 2012 fills a first cavity from a first liquid reservoir or a first pressure control means 2016, which is coupled with actuator or pump 2018. The second liquid lens or semi-solid lens 2014 fills a second cavity from a second liquid reservoir or a second pressure control means 2020, which is coupled with actuator or pump 2022. All the lenses are disposed or mounted in housing 2000.



[0076] FIGS. 21A-21B show a piezoelectric disc actuator using a piezoelectric buzzer diaphragm, according to an embodiment of the invention. FIG. 21A shows a top view of a piezoelectric buzzer diaphragm, which includes a metallic diaphragm 2100 and piezoelectric layer 2102. FIG. 21B shows a cross sectional view of the piezoelectric buzzer diaphragm, including diaphragm 2100 and piezoelectric layer 2102, disposed or mounted on housing 2104 of a liquid lens or a semi-solid lens system. The diaphragm 2100 operates to pump liquid 2106 out of channel 2108 to form a liquid lens. FIG. 21C shows a variation to the embodiment of FIGS. 21A-21B, and includes a piezoelectric layer 2110 and curved metallic diaphragm 2112. Instead of being placed on top of the lens housing as for the disc embodiment of FIGS. 21A-21B, the curved piezoelectric diaphragm is disposed or mounted around the lens housing.

[0077] FIG. 22 shows an image of variable focus elastomeric lenses formed by a moulding process.

[0078] FIG. 23A-23B illustrates a variable focus elastomeric lens module with a mechanical actuator, which can deform the lens and control the focal length of the length.

[0079] FIG. 24A-24B illustrates a demonstration of volume change in a tubular piezo actuator at an actuation voltage of about 20V.

[0080] FIG. 25 illustrates a side view of a schematic drawing of a semi-solid thin foil lens assembly according to an embodiment of the present invention. As shown in Fig. 25, the optical device includes a thin foil lens 2510, which is prepared from a thin film or a layer of a semi-solid substance, and an actuator ring 2520 used for adjusting the focal length of the thin foil lens. The thickness of the semi-solid film lens can be in the range from about 1  $\mu\text{m}$  to about 5 mm, for example, from 1  $\mu\text{m}$  to 10  $\mu\text{m}$ , 10  $\mu\text{m}$  to 30  $\mu\text{m}$ , 20  $\mu\text{m}$  to 50  $\mu\text{m}$ , 40  $\mu\text{m}$  to 80  $\mu\text{m}$ , 75  $\mu\text{m}$  to 150  $\mu\text{m}$ , 100  $\mu\text{m}$  to 300  $\mu\text{m}$ , 180  $\mu\text{m}$  to 400  $\mu\text{m}$ , 200  $\mu\text{m}$  to 600  $\mu\text{m}$ , 250  $\mu\text{m}$  to 700  $\mu\text{m}$ , 350 to 800  $\mu\text{m}$ , 400  $\mu\text{m}$  to 900  $\mu\text{m}$ , 500  $\mu\text{m}$  to 850  $\mu\text{m}$ , 750  $\mu\text{m}$  to 950  $\mu\text{m}$ , 900  $\mu\text{m}$  to 1 mm, 0.5 mm to 1.5 mm, 1.0 mm to 2 mm, 1.5 mm to 2.5 mm, 2 mm to 3 mm, 2.5 mm to 3.5 mm, 3 mm to 4 mm, 2.5 mm to 4.5 mm, or 4 mm to 5 mm. In some instances, the thickness of the semi-solid film lens can be 1  $\mu\text{m}$ , 2  $\mu\text{m}$ , 3  $\mu\text{m}$ , 4  $\mu\text{m}$ , 5  $\mu\text{m}$ , 6  $\mu\text{m}$ , 7  $\mu\text{m}$ , 8  $\mu\text{m}$ , 9  $\mu\text{m}$ , 10  $\mu\text{m}$ , 15  $\mu\text{m}$ , 20  $\mu\text{m}$ , 30  $\mu\text{m}$ , 40  $\mu\text{m}$ , 50  $\mu\text{m}$ , 60  $\mu\text{m}$ , 70  $\mu\text{m}$ , 80  $\mu\text{m}$ , 90  $\mu\text{m}$ , 100  $\mu\text{m}$ , 200  $\mu\text{m}$ , 300  $\mu\text{m}$ , 400  $\mu\text{m}$ , 500  $\mu\text{m}$ , 600  $\mu\text{m}$ , 700  $\mu\text{m}$ , 800  $\mu\text{m}$ , 900  $\mu\text{m}$ , 1 mm, 2 mm, 3 mm, 4 mm, or 5 mm.

[0081] FIG. 26 illustrates a side view of a two-lens assembly according to an embodiment of the present invention. As shown in FIG. 26, the optical device includes a thin foil lens 2610 and a solid lens 2640 disposed or mounted in housing 2630. A ring actuator is attached to thin foil lens 2610 to adjust the focal length of the lens. The actuator can be any of the pressure modulating device discussed above. The thin foil lens can be either a semi-solid lens or a liquid. A person of skill in the art will recognize that other assembly of the lenses are also feasible, for example, the present invention also provides lens assemblies with two or more lenses, including a combination of one or more thin foil lenses, one or more solid lenses and one or more liquid lenses.

10 [0082] FIG. 27 illustrates a side view of a fixed focus lens module using semi-solid lenses. The optical device using semi-solid lenses as a fixed focus lenses has a macro function. The optical device includes a solid lens 2720 sandwiched between a first semi-solid lens 2710 and a second semi-solid lens 2712. The lenses are disposed or mounted in housing 2730. In other embodiments, some of the lenses can be in direct contact with one another, while others can be separated by a predetermined distance, for example, separated by a fluid, a gas or a vacuum. In yet other embodiments, all the lenses can be separated by a predetermined distance.

[0083] FIG. 28 illustrates an optical device having a three-lens assembly and the functionality of a semi-solid lens. As shown in FIG. 28, the optical device includes a solid lens 2860 sandwiched between a first semi-solid lens 2810 and a second semi-solid lens 2850, a first pressure control means 2880 having a fluid inlet 2830 and a second pressure control means 2882 having a fluid outlet 2832. The lenses are disposed or mounted in housing 2870. Semi-solid lens 2810 has surfaces 2822, 2824 and 2826 in their respective initial positions. Semi-solid lens 2850 has surfaces 2852, 2854 and 2856 in their initial positions. FIG. 5 also demonstrates that the surface curvature or radius of curvature of the semi-solid lens can be adjusted by changing the pressure applied to the lens. As the pressure control device 2880 increases in pressure through fluid 2840, the semisolid lens 2810 changes its shape to form new surfaces 2821, 2823 and 2825, which correspond to surfaces 2822, 2824 and 2826, respectively. Conversely, when the pressure control device decreases in pressure by removing fluid 2842 through outlet 2832, the semi-solid lens changes its shape to form new surfaces 2851, 2853 and 2855, which correspond to surfaces 2852, 2854 and 2856, respectively.

[0084] The present invention also provides a method of fabricating a variable focus semi-solid lens. In one embodiment, the lens is made of optically transparent semi-solid, such as a polymer. The semi-solid lens can be produced by injection moulding, dispensing into lens shaped moulds, casting or by any other method used for fabrication of semi-solid lens, such as a polymer lens. For example, the semi-solid lenses can be made by injecting or pouring a material in liquid form into cavities or moulds, then curing the liquid material into a semi-solid or a gel.

[0085] The present invention also provides a method for adjusting the curvature of a semi-solid lens having a surface region with a defined curvature. The method includes adjusting a pressure applied to the semi-solid substance to change the curvature of the surface region of the semi-solid substance.

[0086] The present invention also provides a use of the semi-solid optical device for imaging applications.

[0087] The present invention also contemplates that all the liquid lenses mentioned above can be selectively or completely replaced with semi-solid lenses. The present invention further provides that all the lenses mentioned above can be selectively or totally replaced with the semi-solid foil-like thin lenses.

[0088] While the invention has been described by way of example and in terms of the specific embodiments, it is to be understood that the invention is not limited to the disclosed embodiments. To the contrary, it is intended to cover various modifications and similar arrangements as would be apparent to those skilled in the art. For example, various possible arrangements of lens assemblies with variable focus capability of the semi-solid lenses exist and the embodiments are not limited to the ones described herein. Therefore, the scope of the appended claims should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements.

**WHAT IS CLAIMED IS:**

- 1                   1.     An optical device comprising:  
2                   an optically transparent semi-solid substance having a surface region with a  
3 defined curvature; and  
4                   a pressure control means coupled with said semi-solid substance for adjusting  
5 the curvature of the surface region of the semi-solid substance.
- 1                   2.     The device of claim 1, wherein said semi-solid substance includes a  
2 separate layer.
- 1                   3.     The device of claim 2, wherein said separate layer is a reflective or a  
2 non-reflective layer.
- 1                   4.     The device of claim 2, wherein said separate layer is in contact with  
2 said semi-solid substance.
- 1                   5.     The device of claim 1, further comprising a holding means for  
2 supporting the substance.
- 1                   6.     The device of claim 5, wherein the holding means includes a housing,  
2 wherein said semi-solid substance is mounted in said housing.
- 1                   7.     The device of claim 6, wherein said housing includes a hydrophilic  
2 inner layer and a hydrophobic outer layer.
- 1                   8.     The device of claim 6, wherein said housing includes a transparent  
2 cover.
- 1                   9.     The device of claim 1, wherein the semi-solid substance is selected  
2 from the group consisting of a gel, a viscous liquid, a colloid, an elastomer, an elastomeric  
3 gel, a semiconductor coating, an organic polymer, an inorganic polymer, a semi-crystalline  
4 liquid and a combination thereof.
- 1                   10.    The device of claim 9, wherein the semi-solid substance includes a gel.

- 1                   **11.**     The device of claim **10**, wherein the gel is selected from the group  
2     consisting of a polysiloxane, a polyacrylate, a polycarbonate, poly(methyl methacrylate) and  
3     a combination thereof.
- 1                   **12.**     The device of claim **9**, wherein the semi-solid substance includes an  
2     elastomer.
- 1                   **13.**     The device of claim **12**, wherein the elastomer is a thermoplastic  
2     elastomer or a siloxane.
- 1                   **14.**     The device of claim **12**, wherein the elastomer is  
2     polydimethylsiloxane.
- 1                   **15.**     The device of claim **1**, wherein the semi-solid substance absorbs infra  
2     red light.
- 1                   **16.**     The device of claim **1**, wherein the pressure control means is a device  
2     selected from the group consisting of a piezo electrical device, a mechanical actuator, an  
3     electromechanical actuator, a fluid pressure modulator, an artificial muscle ring and a light  
4     beam.
- 1                   **17.**     The device of claim **16**, wherein the pressure control means is a piezo  
2     electrical device.
- 1                   **18.**     The device of claim **17**, wherein the piezo electrical device is selected  
2     from the group consisting of a piezo electrical ring, a piezoelectrical layer and a tubular piezo  
3     actuator.
- 1                   **19.**     The device of claim **16**, wherein the pressure control means is a fluid  
2     pressure modulator.
- 1                   **20.**     The device of claim **19**, wherein the fluid pressure modulator contains  
2     a fluid selected from the group consisting of a liquid, a gas and a mixture thereof.
- 1                   **21.**     An optical device comprising:  
2                   an optically transparent semi-solid film having a thickness ranging from about  
3     1  $\mu\text{m}$  to about 5 mm and a surface region with a defined curvature; and

4                   a pressure control means coupled with said semi-solid substance for adjusting  
5   the curvature of the surface region of the semi-solid substance.

1                   **22.**     The device of claim **21**, further comprising a housing, wherein said  
2   semi-solid film is disposed in said housing.

1                   **23 .**    The device of claim **22**, further comprising a solid lens disposed in said  
2   housing.

1                   **24.**     An optical device comprising:  
2                   a first semi-solid lens having a surface region with a defined curvature;  
3                   a solid lens;  
4                   a housing, wherein said first semi-solid lens and said solid lens are disposed in  
5   said housing; and  
6                   a first pressure control means coupled to said first semi-solid lens for adjusting  
7   the curvature of said first semi-solid lens.

1                   **25.**     The device of claim **24**, wherein said first semi-solid lens is a gel lens.

1                   **26.**     The device of claim **24**, further comprising a fluid lens.

1                   **27.**     The device of claim **24**, further comprising a second semi-solid lens  
2   having a surface region with a defined curvature.

1                   **28.**     The device of claim **27**, wherein said solid lens is disposed between  
2   said first semi-solid lens and said second semi-solid lens.

1                   **29.**     The device of claim **27**, further comprising a second pressure control  
2   means coupled to said second semi-solid lens for adjusting the curvature of said second semi-  
3   solid lens.

1                   **30.**     The device of claim **24**, wherein said first semi-solid lens is in contact  
2   with said solid lens.

1                   **31.**     The device of claim **24**, wherein said housing includes a plurality of  
2   cavities in contact with said first semi-solid lens.

1                   **32.**     The device of claim 24, wherein said first semi-solid lens is in contact  
2     with a surface of said housing.

1                   **33.**     The device of claim 32, wherein the surface of said housing comprises  
2     a microstructure for increasing the traction of said first semi-solid lens on the surface of said  
3     housing.

1                   **34.**     The device of claim 33, wherein said microstructure includes a  
2     plurality of micro cavities.

1                   **35.**     An optical device comprising:  
2                   a first semi-solid lens having a first surface region with a defined curvature;  
3                   a fluid lens;  
4                   a second semi-solid lens having a second surface region with a defined  
5     curvature;  
6                   a housing, wherein said first semi-solid lens, said second semi-solid lens and  
7     said fluid lens are disposed in said housing; and  
8                   a first pressure control means coupled to said first semi-solid lens for adjusting  
9     the curvature of said first semi-solid lens.

1                   **36.**     The device of claim 35, further comprising a solid lens.

1                   **37.**     The device of claim 35, further comprising a second pressure control  
2     means coupled to said second semi-solid lens for adjusting the curvature of said second semi-  
3     solid lens.

1                   **38.**     An optical device comprising:  
2                   a first semi-solid lens having a first surface region with a defined curvature;  
3                   a solid lens;  
4                   a second semi-solid lens having a second surface region with a defined  
5     curvature;  
6                   a housing, wherein said first semi-solid lens, said second semi-solid lens and  
7     said solid lens are disposed in said housing;  
8                   a first pressure control means coupled to said first semi-solid lens for adjusting  
9     the curvature of said first semi-solid lens; and

10 a second pressure control means coupled to said second semi-solid lens for  
11 adjusting the curvature of said second semi-solid lens.

1 39. The device of claim 38, wherein said solid lens is disposed between  
2 said first semi-solid lens and said second semi-solid lens.

1 40. The device of claim 39, wherein said solid lens is in contact with said  
2 first semi-solid lens and said second solid lens.

1 41. The device of any one of claims 38-40, wherein said pressure control  
2 means includes an actuator or a pump.

1 42. The device as in any one of claims 1-41, wherein said pressure control  
2 means is selected from the group consisting of a fluid pressure modulator and a piezo  
3 electrical device.

1 43. An optical device comprising:  
2 a first solid lens;  
3 a semi-solid lens having a surface region with a defined curvature;  
4 a second solid lens; and  
5 a housing, wherein said first solid lens, said second solid lens and said semi-  
6 solid lens are disposed in said housing.

1 44. The device of claim 43, further comprising a pressure control means.

1 45. The device of claim 43, wherein said semi-solid lens is disposed  
2 between said first solid lens and said second solid lens.

1 46. The device of claim 45, wherein said housing has a hydrophobic  
2 surface.

1 47. The device of claim 46, wherein said surface is in contact with said  
2 semi-solid lens.

1 48. An optical device comprising:  
2 a first solid lens;  
3 a second solid lens;  
4 a third solid lens;



5 a first semi-solid lens having a surface region with a defined curvature;  
6 a housing, wherein said first solid lens, said second solid lens, said third solid  
7 lens and said first semi-solid lens are disposed in said housing; and  
8 optionally a pressure control means coupled to said first semi-solid lens.

1 49. The device of claim 48, wherein said first semi-solid lens is disposed  
2 between said first solid lens and said second solid lens.

1 50. The device of claim 49, wherein said pressure control means is coupled  
2 with an actuating means.

1 51. The device of claim 48, further comprising a second semi-solid lens,  
2 wherein said second semi-solid lens is disposed in said housing.

1 52. The device of claim 51, wherein said second semi-solid lens is  
2 disposed between said second solid lens and said third solid lens.

1 53. The device of claim 52, further comprising a pressure control means  
2 coupled to said second semi-solid lens.

1 54. An optical device comprising:  
2 a first solid lens;  
3 a second solid lens;  
4 a third solid lens;  
5 a fourth solid lens;  
6 a first semi-solid lens having a first surface region with a defined curvature;  
7 a second semi-solid lens having a second surface region with a defined  
8 curvature;  
9 a housing, wherein said first solid lens, said second solid lens, said third solid  
10 lens, said fourth solid lens, said first semi-solid lens and said second semi-solid lens are  
11 disposed in said housing;  
12 optionally a first pressure control means to said first semi-solid lens; and  
13 optionally a second pressure control means coupled to said second semi-solid  
14 lens.

1                   **55.**     The device of claim **54**, wherein said second and said third solid lens  
2 are disposed between said first and said fourth solid lenses

1                   **56.**     The device of claim **55**, wherein said first semi-solid lens is in contact  
2 with said second solid lens or said third solid lens.

1                   **57.**     The device of claim **55**, wherein said second semi-solid lens is in  
2 contact with said second solid lens or said third solid lens.

1                   **58.**     The device of claim **56** or **57**, wherein said first and said second semi-  
2 solid lenses are disposed between said second and said third solid lenses.

1                   **59.**     An optical device comprising:  
2                   a first semi-solid lens having a first surface region with a defined curvature;  
3                   a second semi-solid lens having a second surface region with a defined  
4 curvature;  
5                   a solid lens disposed between said first semi-solid lens and said second semi-  
6 solid lens; and  
7                   a housing, wherein said first semi-solid lens, said second semi-solid lens and  
8 said solid lens are mounted in said housing.

1                   **60.**     A semi-solid lens prepared by a moulding process.

1                   **61.**     A method for making a semi-solid optical device, said method  
2 comprising:  
3 fabricating a semi-solid substance into a lens.

1                   **62.**     A method for making a semi-solid optical lens, said method  
2 comprising:  
3 injection moulding of a semi-solid substance into a lens with a defined  
4 curvature.

1                   **63.**     A method for making a semi-solid optical lens, said method  
2 comprising:  
3 casting a fluid material into a mould having a defined structure; and  
4 curing said fluid material into a semi-solid lens with a defined curvature.

**64.** The method of claims **61**, **62** or **63**, further comprising mounting said lens in a housing.

**65.** A method for adjusting the curvature of a semi-solid lens, said method comprising:

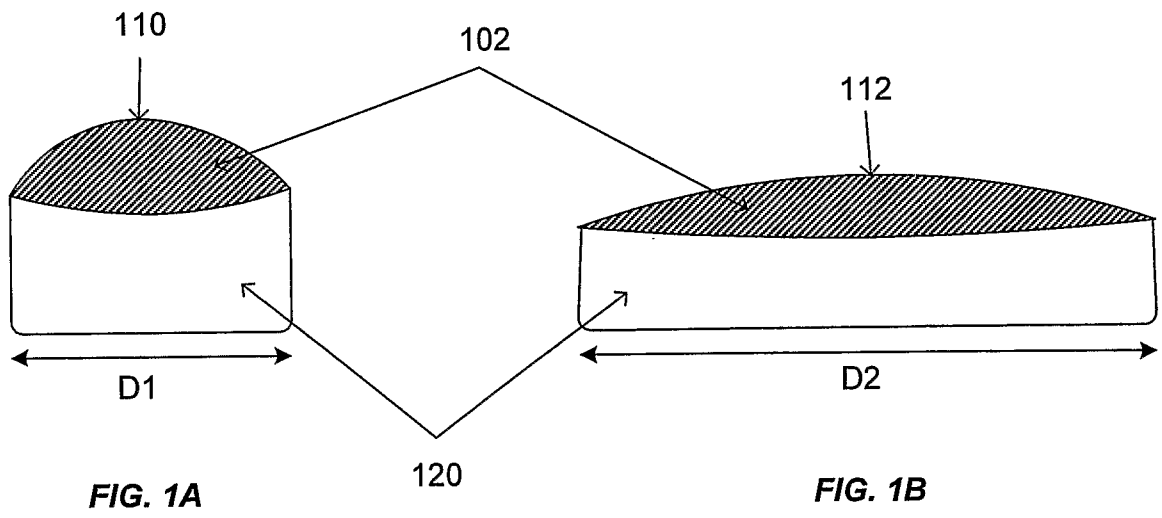
adjusting a pressure applied to a semi-solid substance having a surface region with a defined curvature to change the curvature of the surface region of the semi-solid substance.

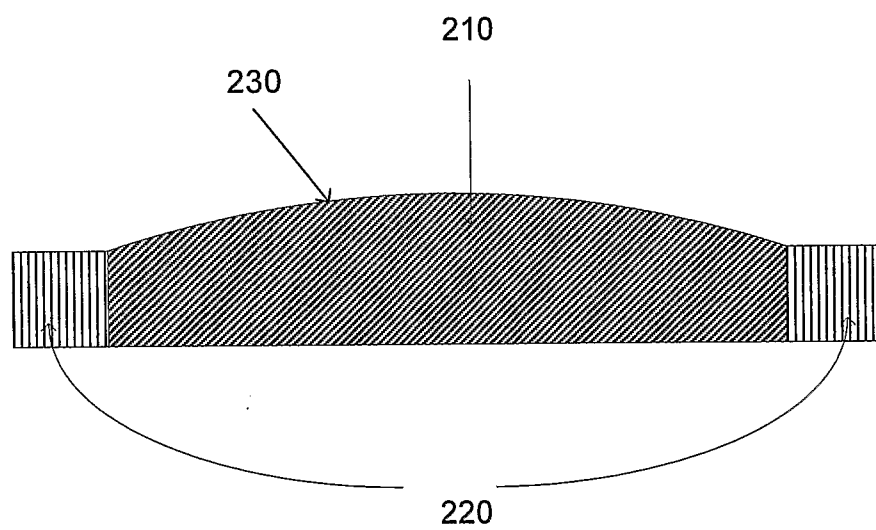
**66.** The method of claim **65**, wherein said pressure is applied from a mechanical actuator.

**67.** A use of the device of any one of claims **1** - **59** for imaging applications.

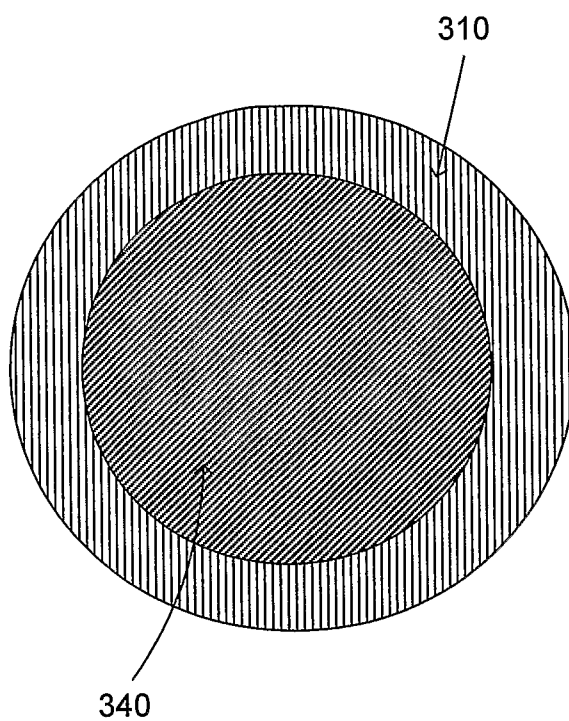
**68.** An optical device as substantially described herein.

1 **69.** A method of making an optical device as substantially described  
2 herein.

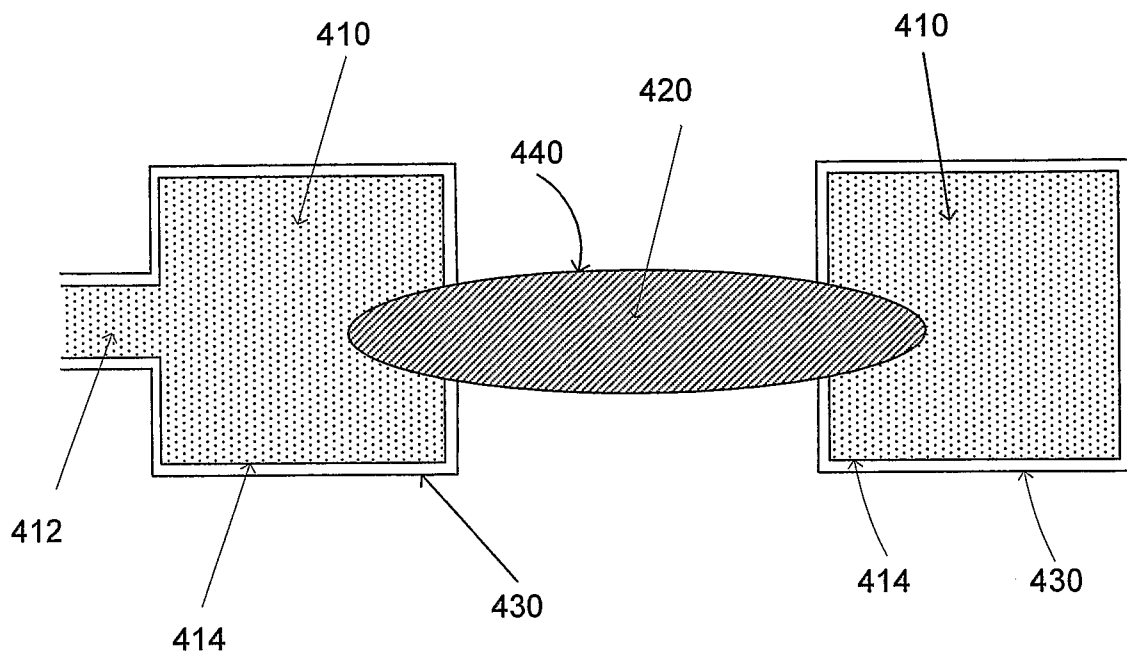


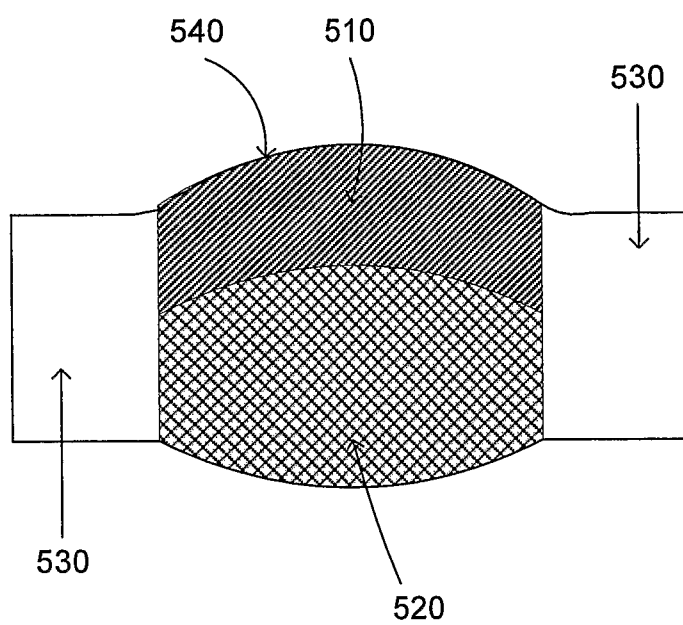


**FIG.2**



**FIG. 3**

**FIG. 4**

**FIG. 5**



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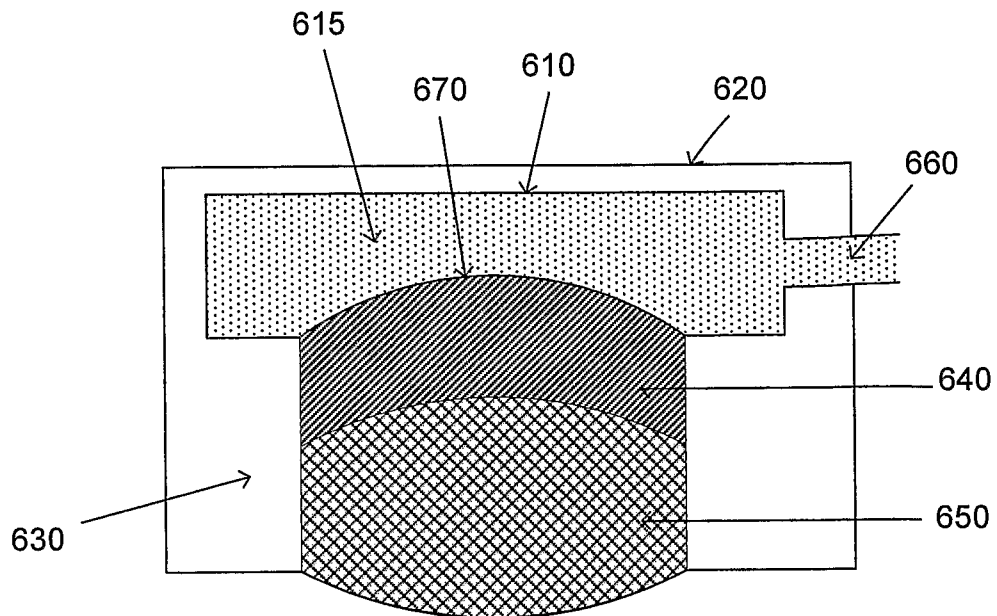


FIG. 6A

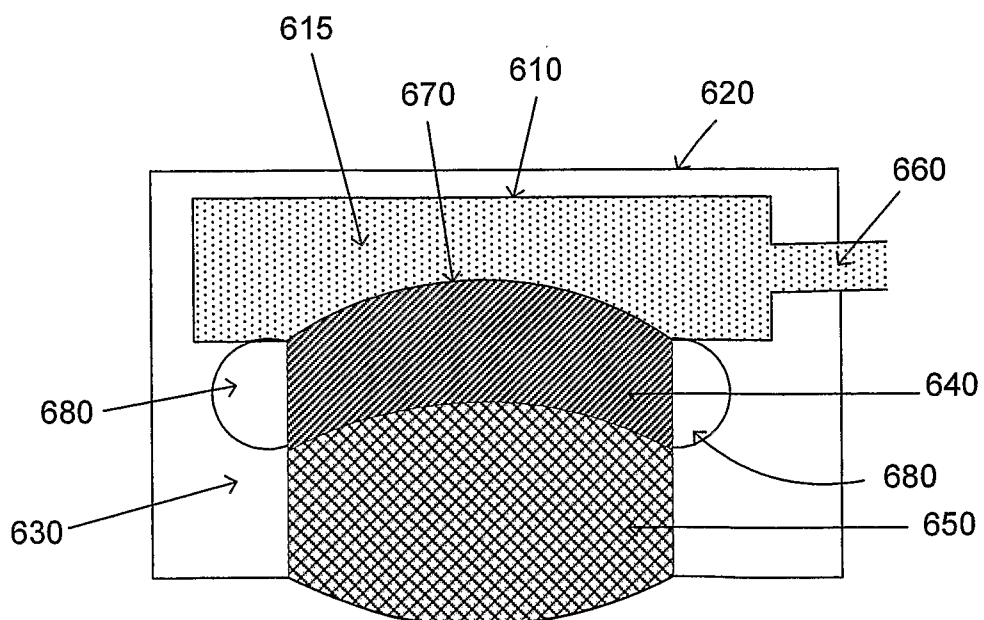


FIG. 6B

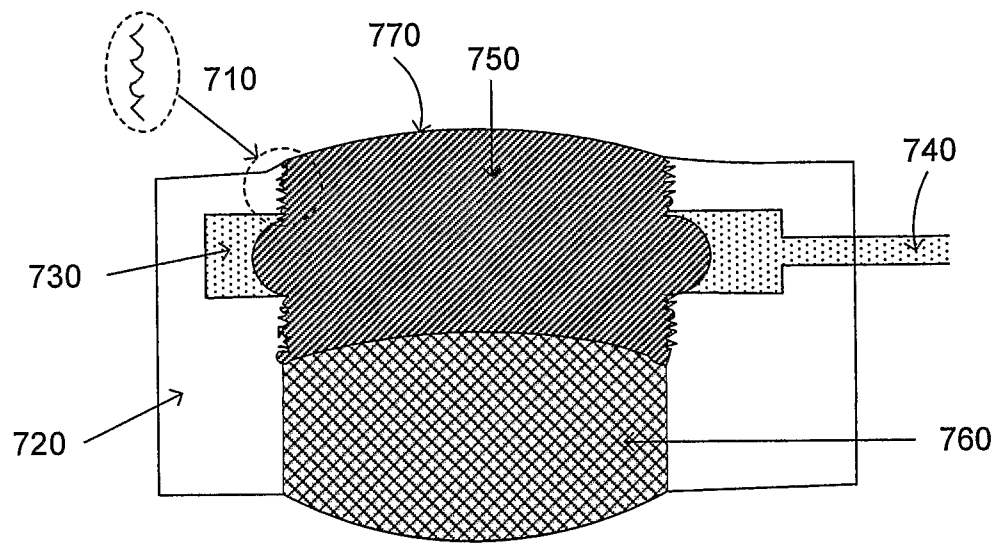


FIG. 7

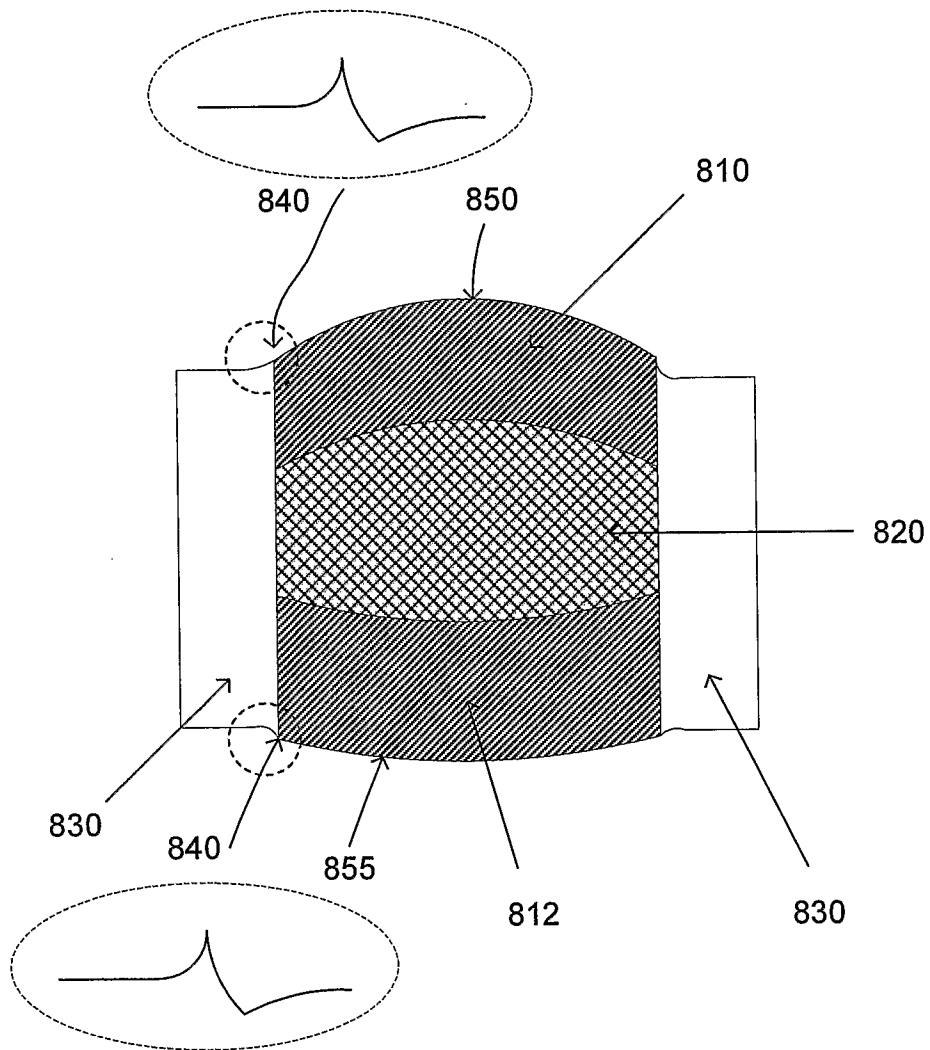


FIG. 8

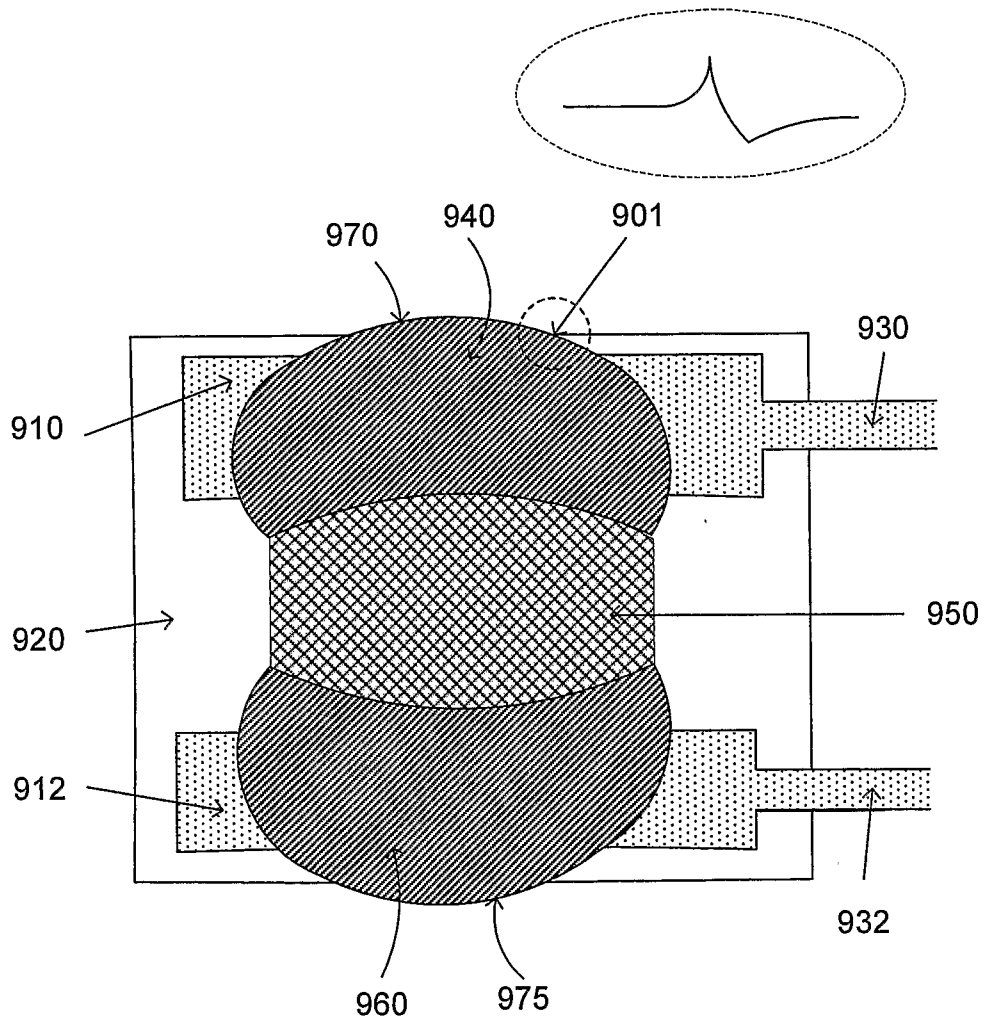


FIG. 9

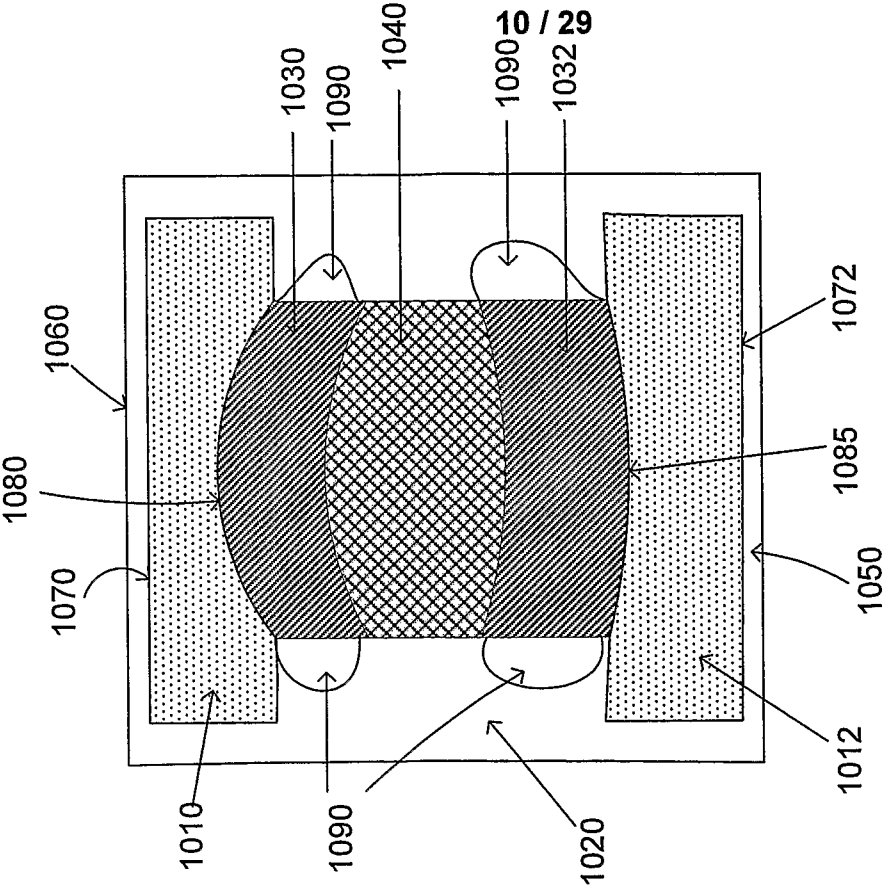


FIG. 10A

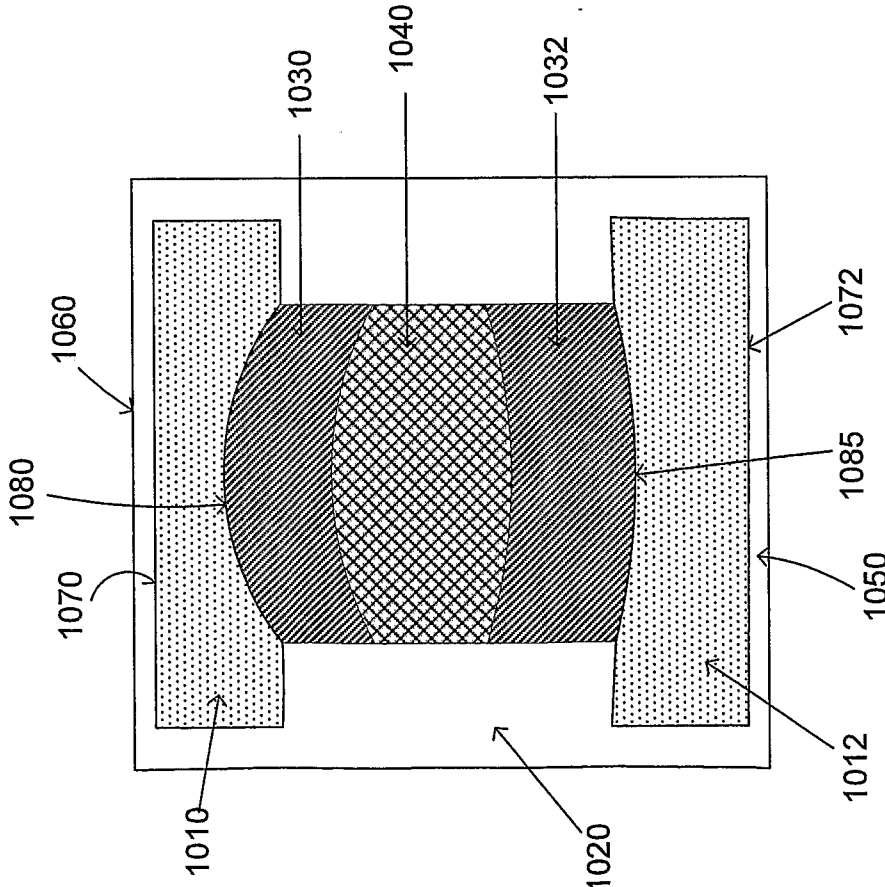


FIG. 10B

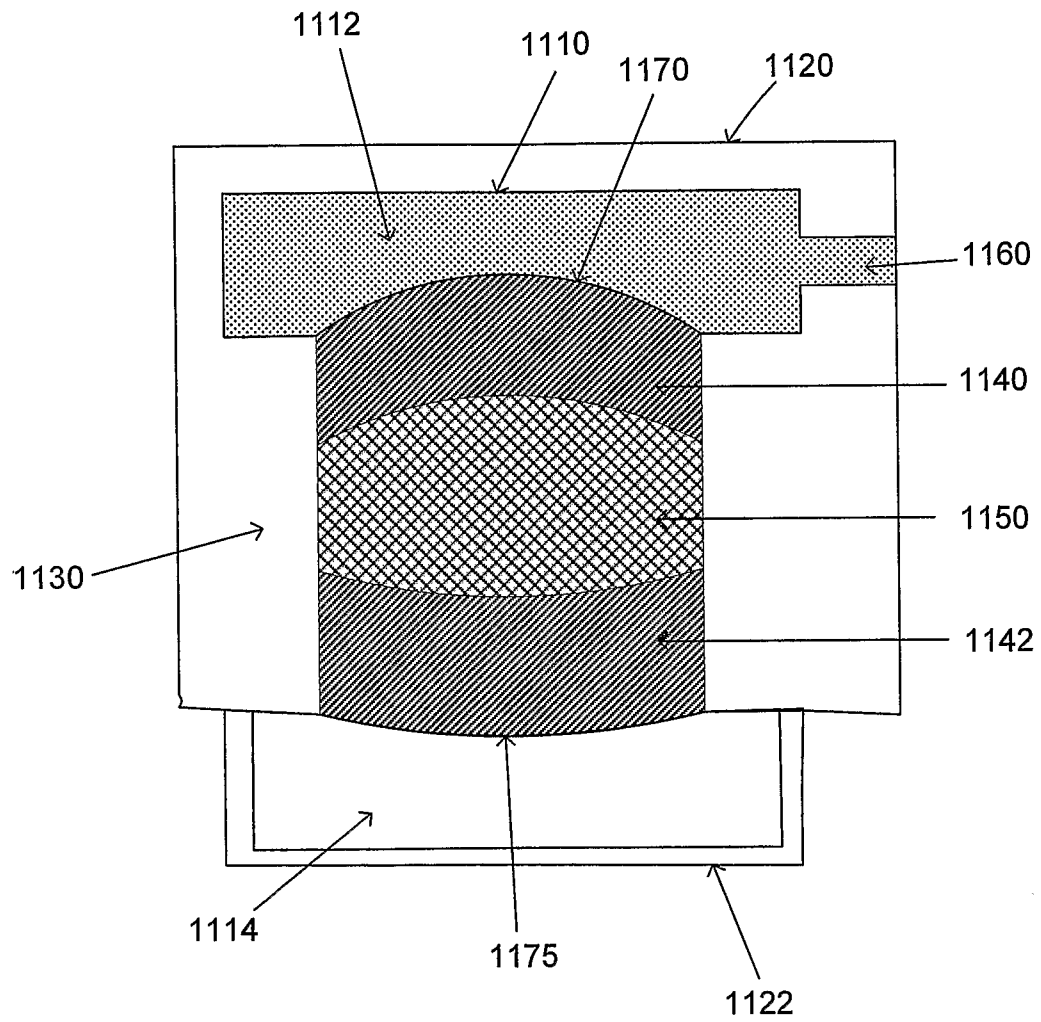


FIG. 11

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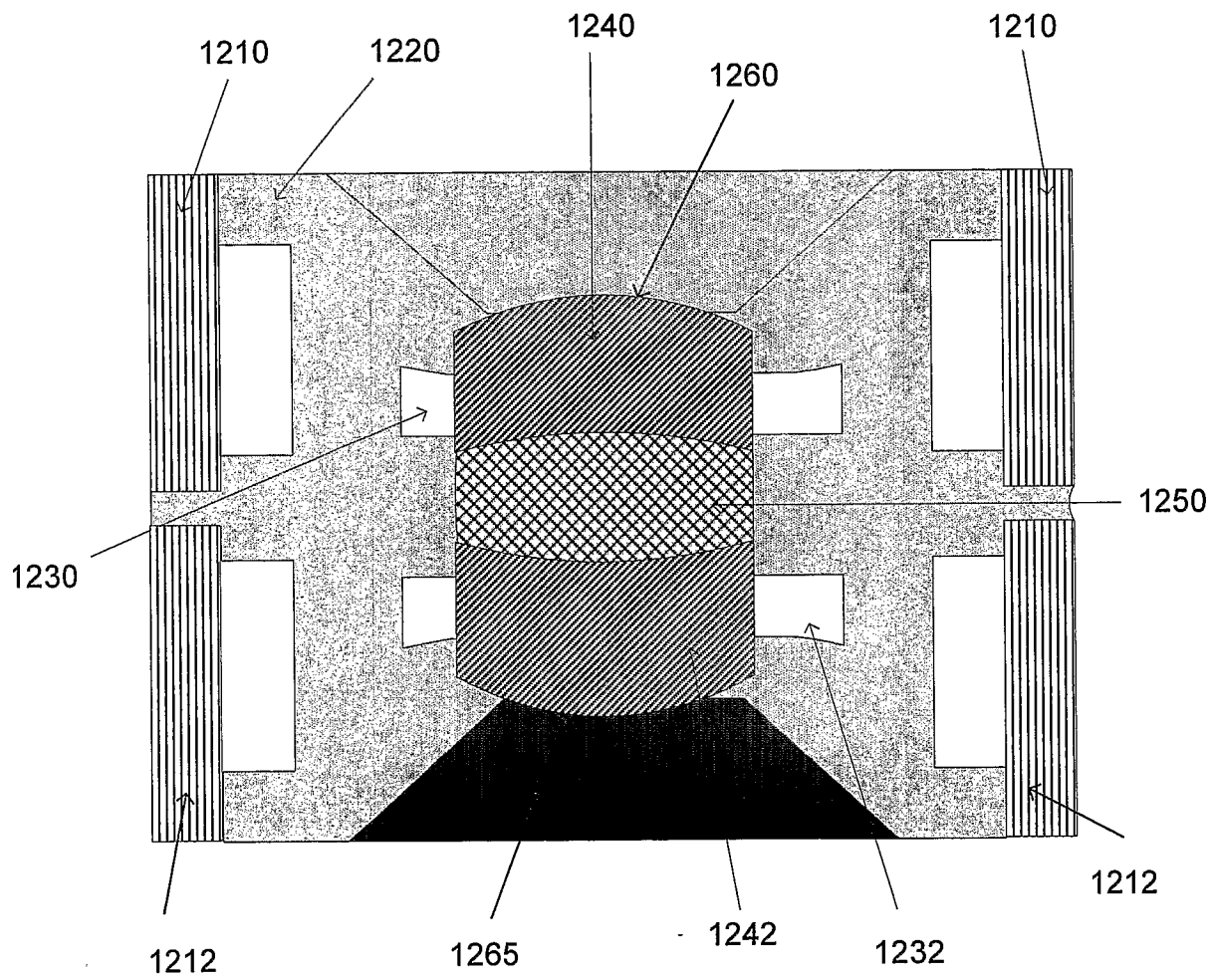


FIG. 12A

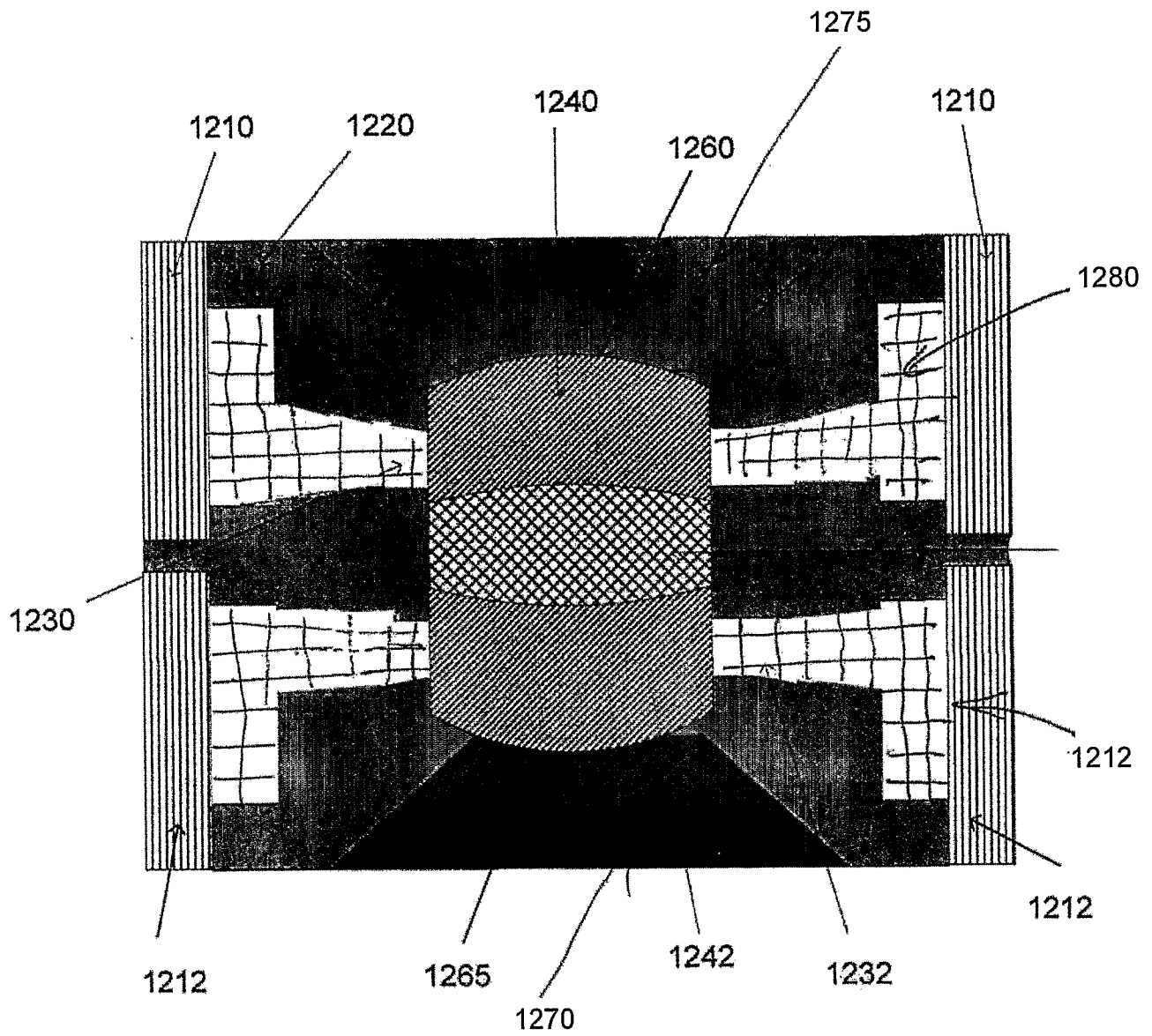


FIG. 12B



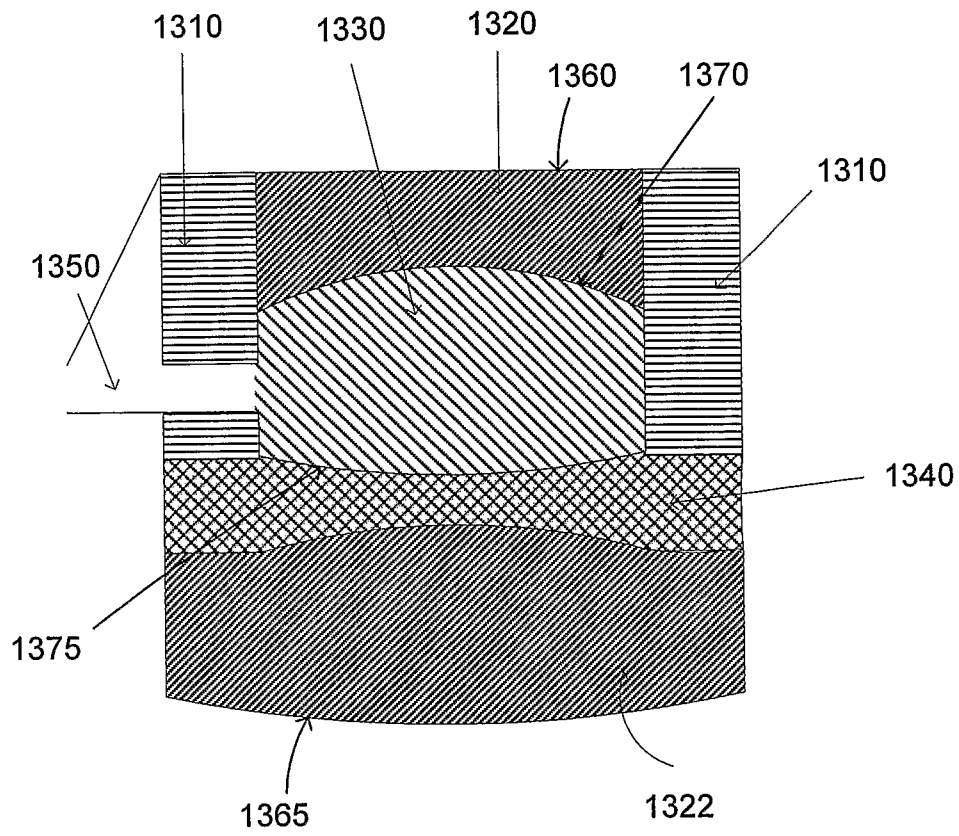
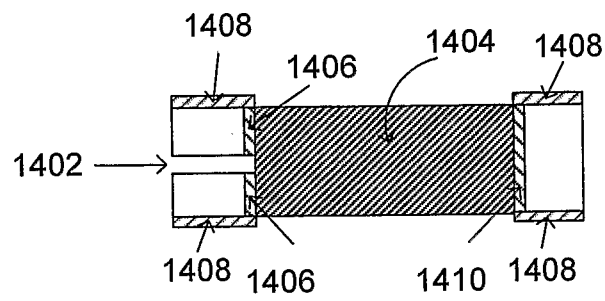
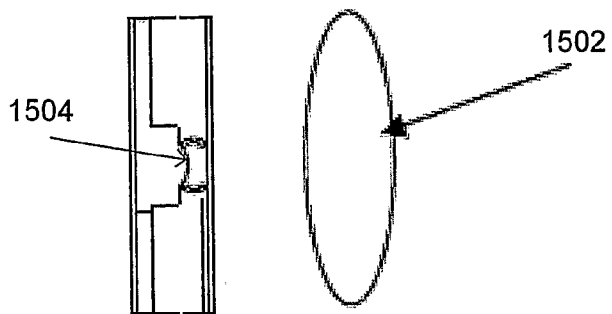


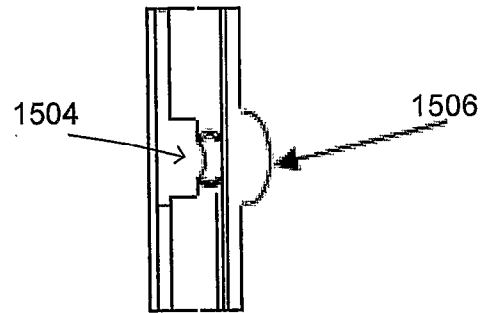
FIG. 13



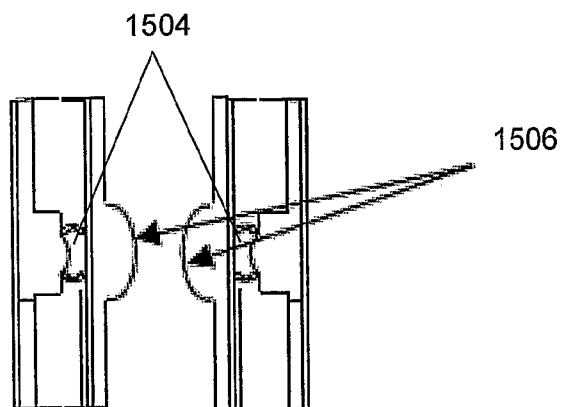
**FIG. 14**



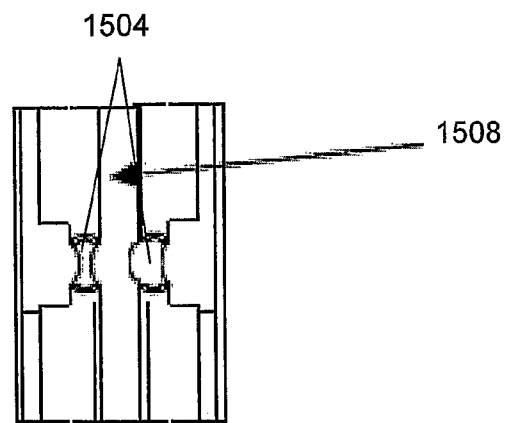
**FIG. 15A**



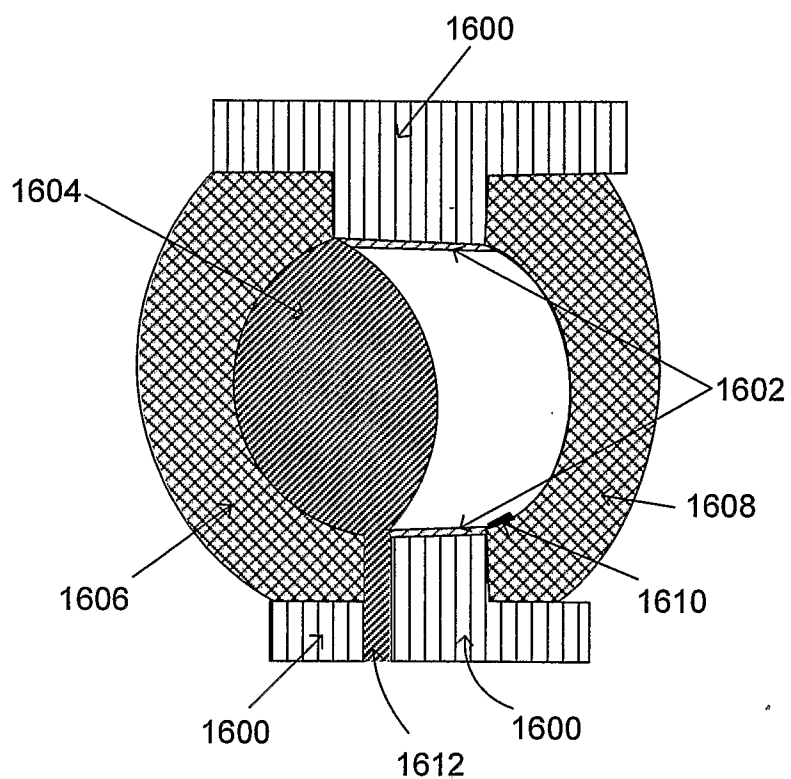
**FIG. 15B**



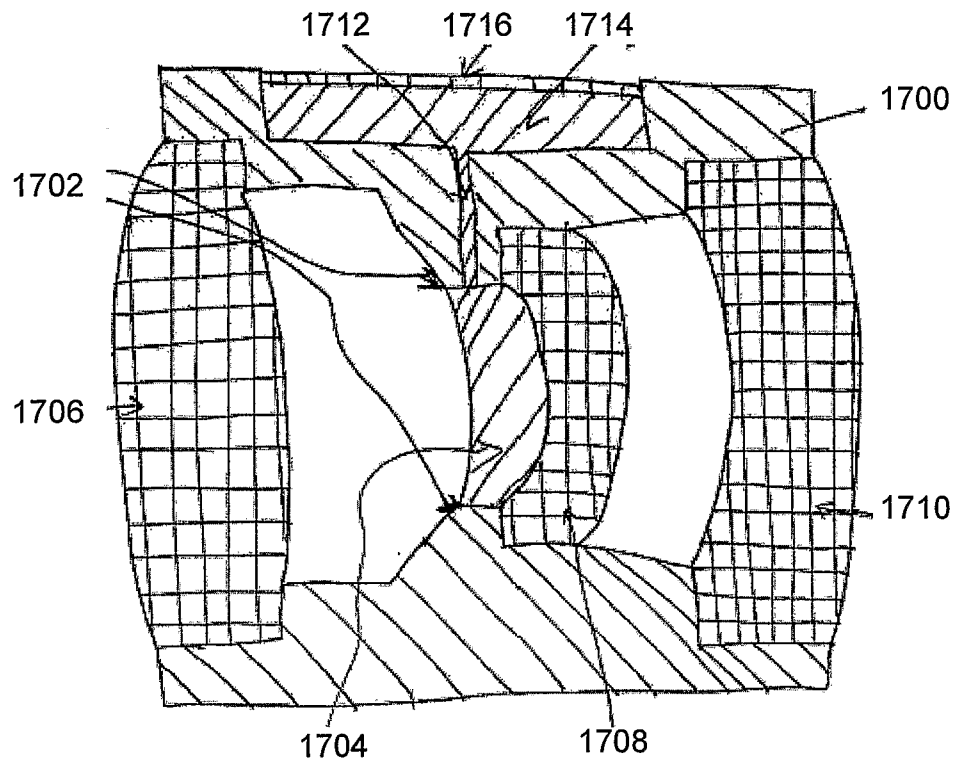
**FIG. 15C**



**FIG. 15D**



**FIG. 16**



**FIG. 17**

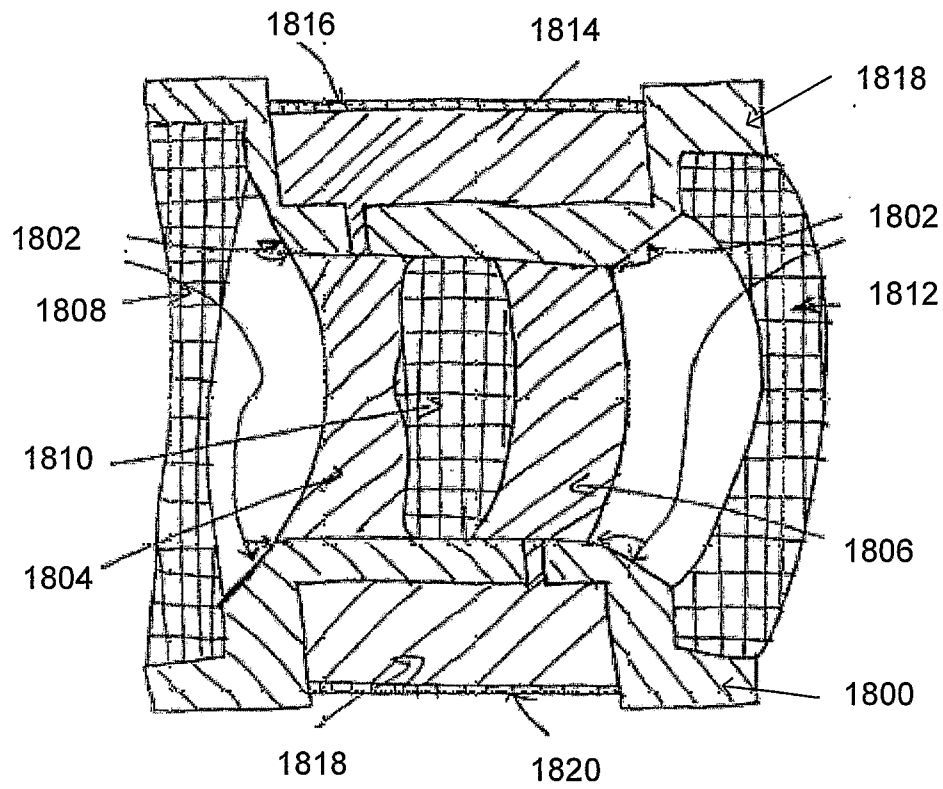


FIG. 18

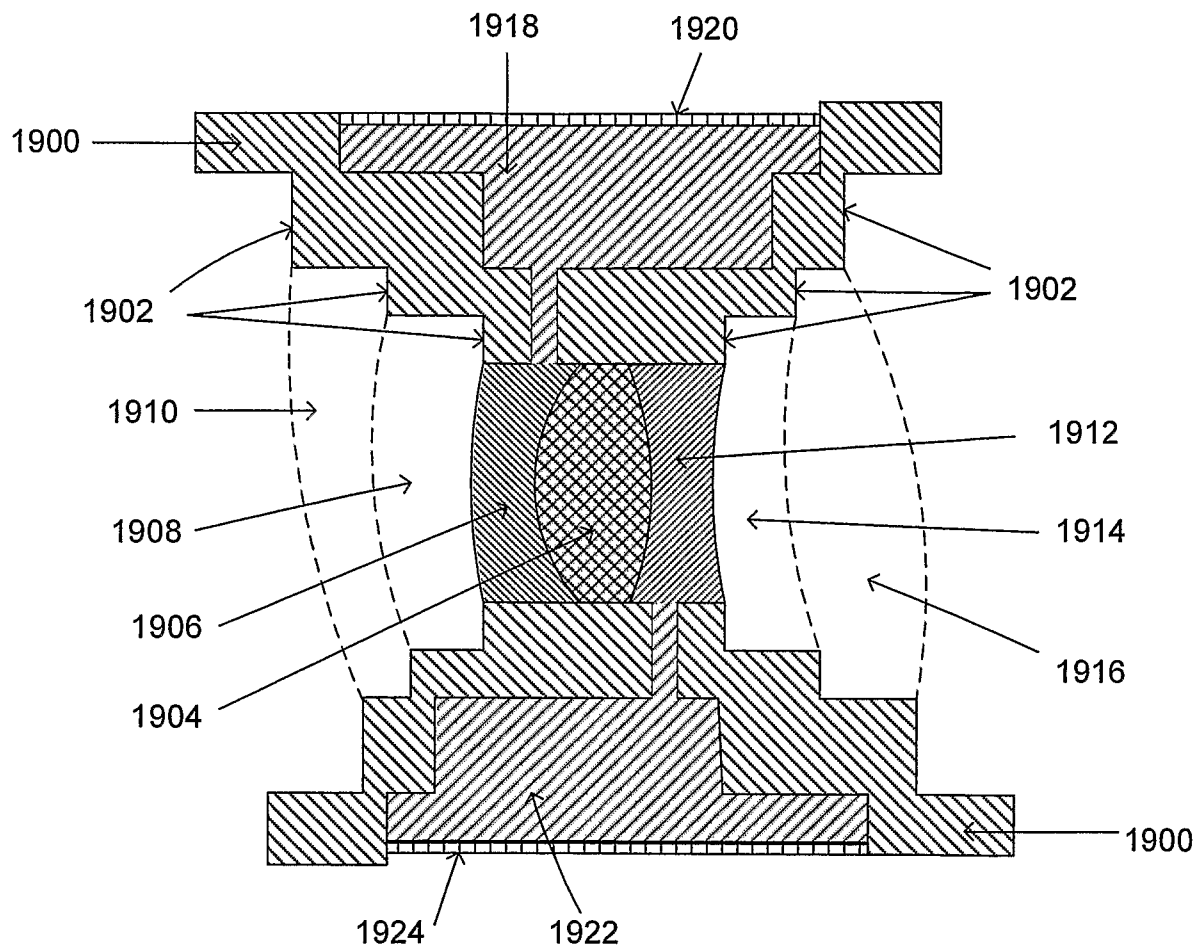


FIG. 19

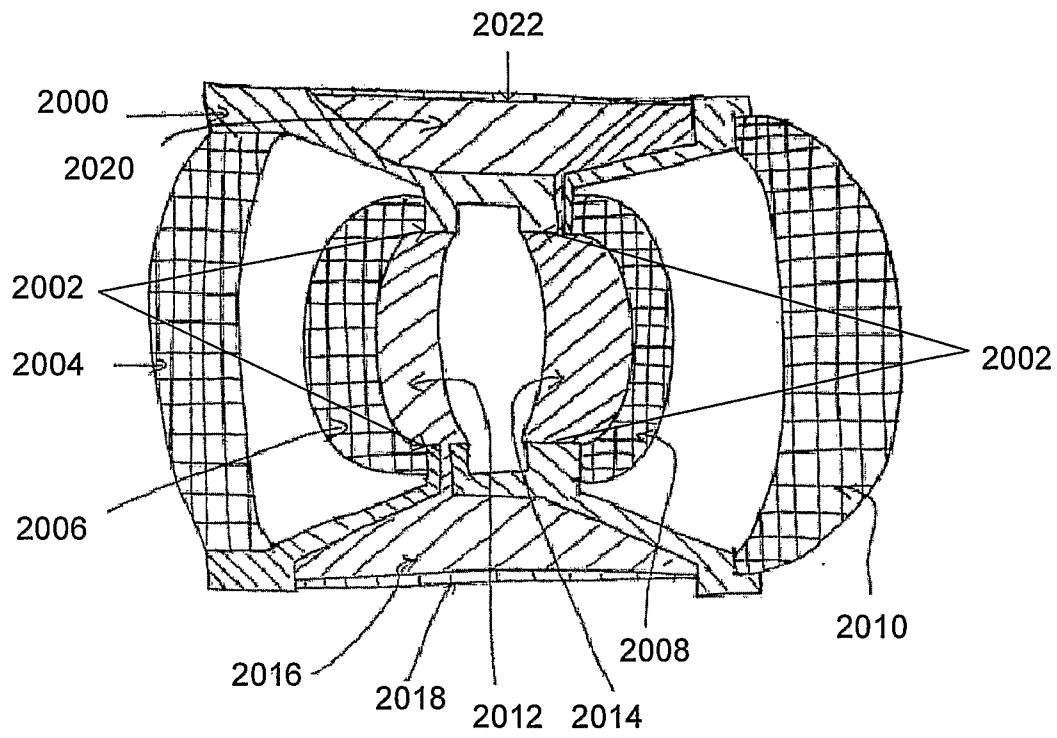


FIG. 20



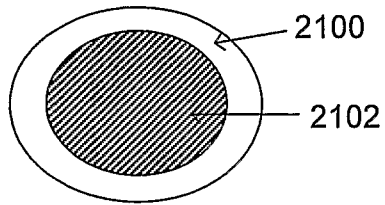


FIG. 21A

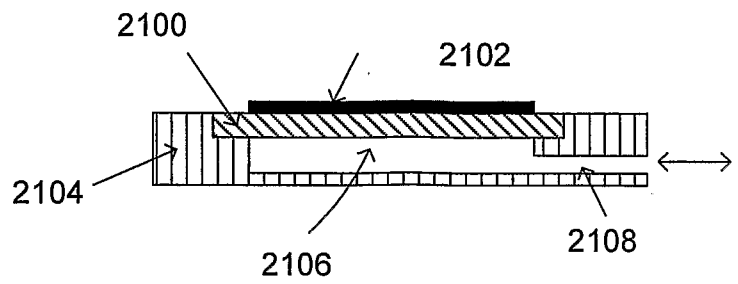


FIG. 21B

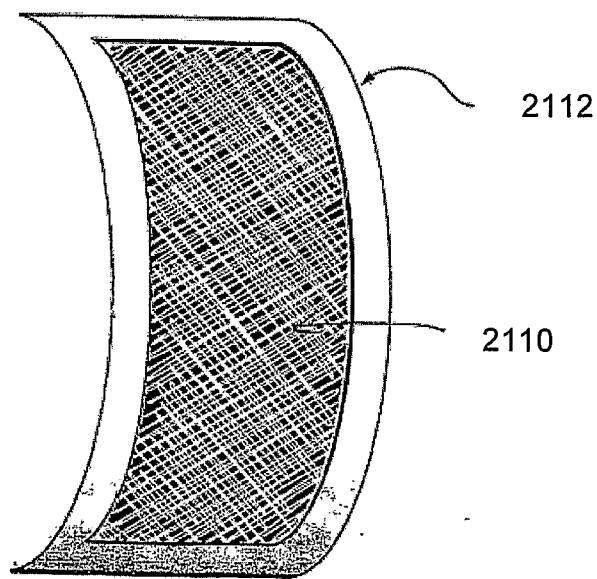
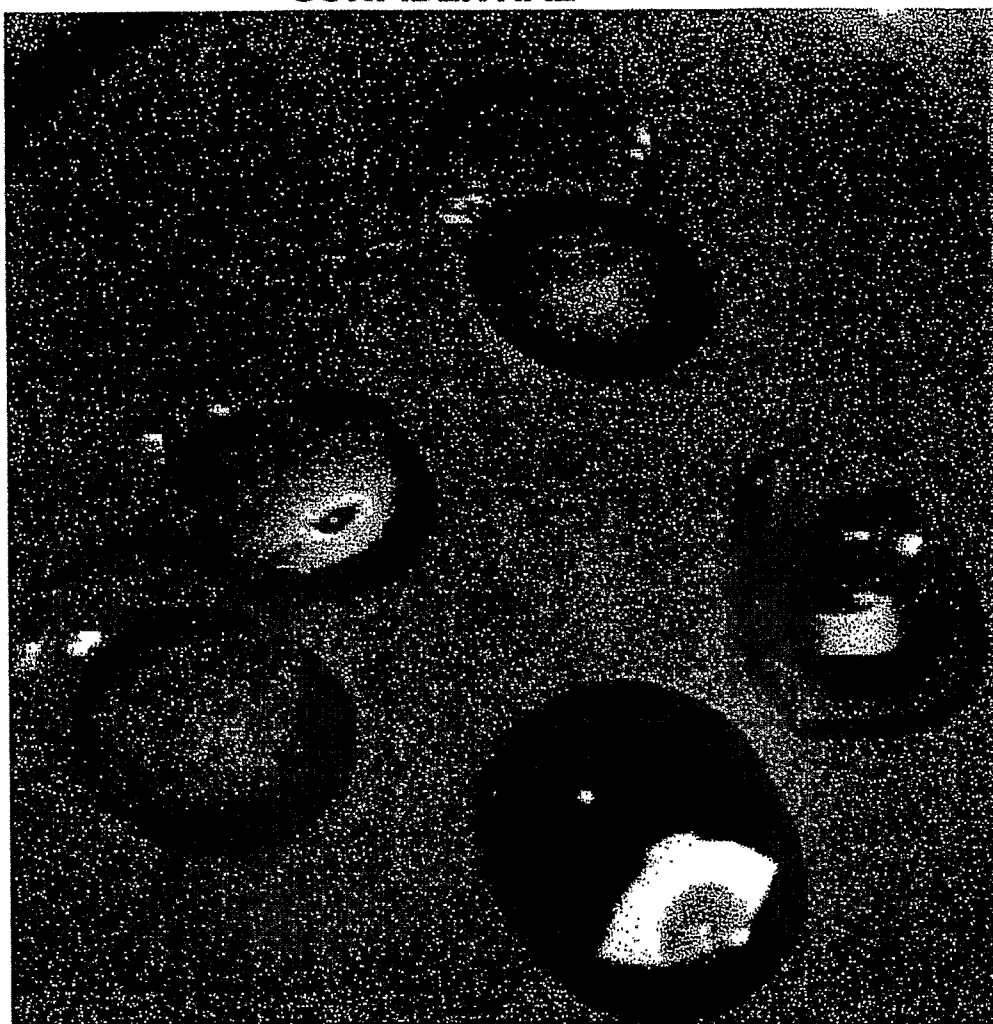


FIG. 21C



**FIG. 22**

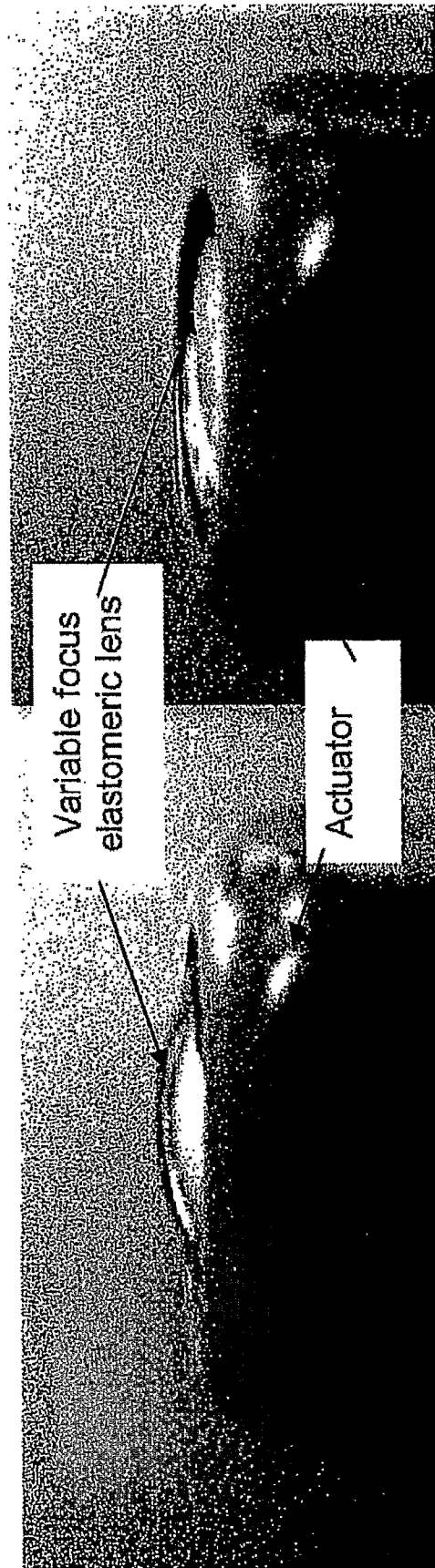


FIG. 23B

FIG. 23A

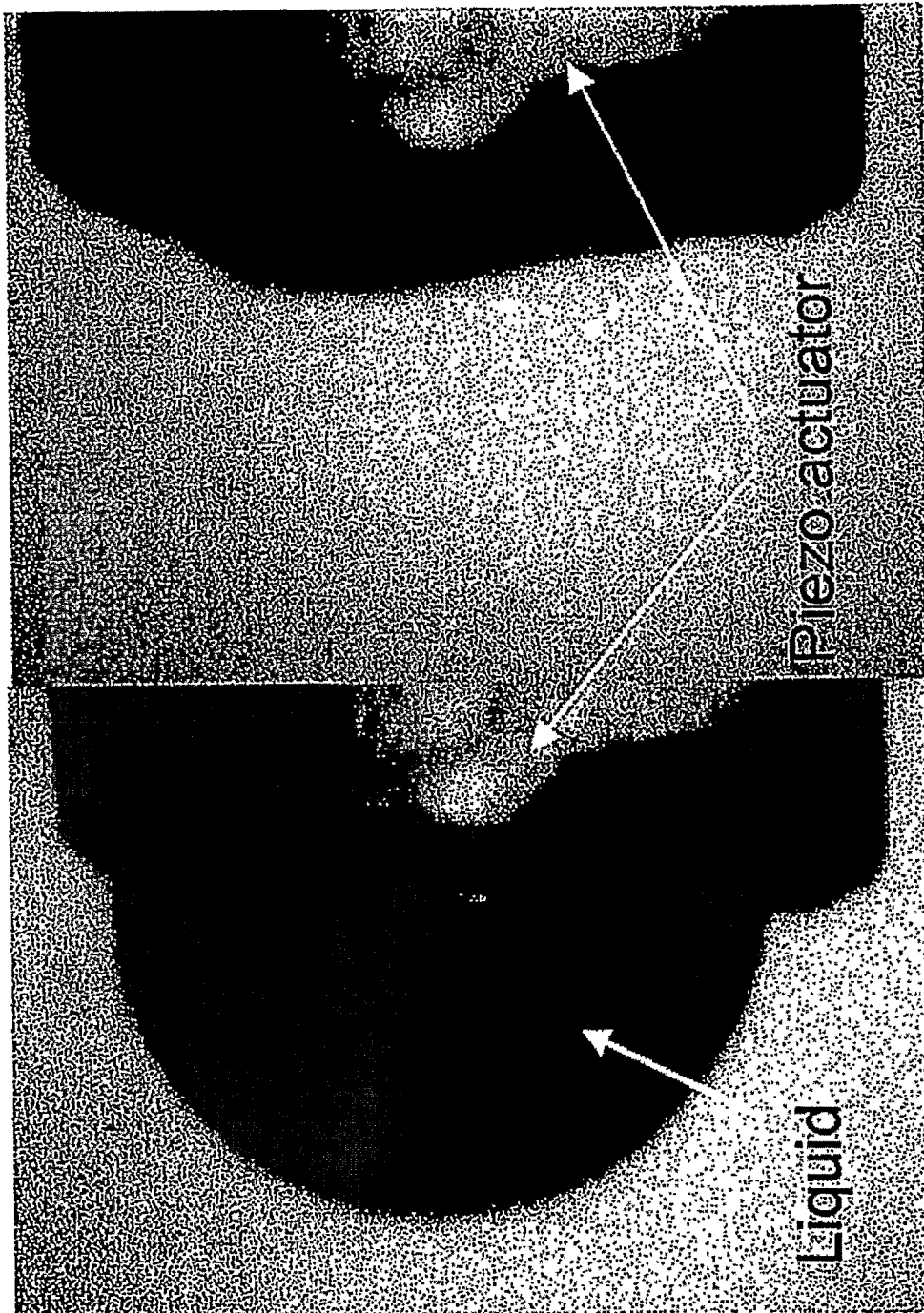
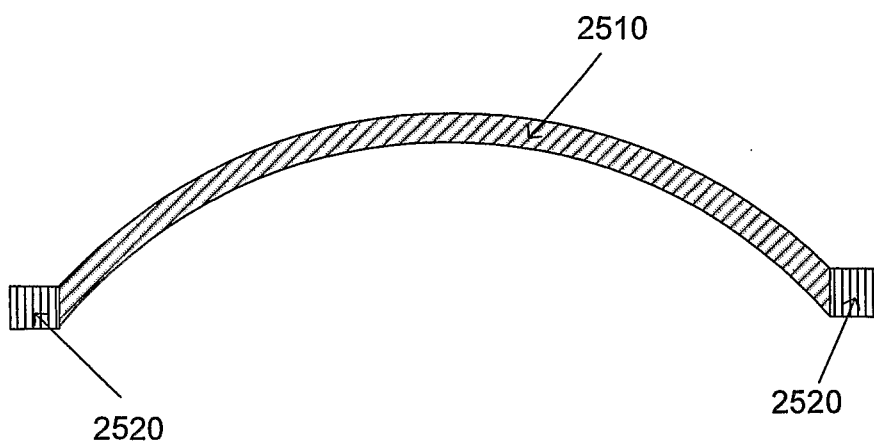
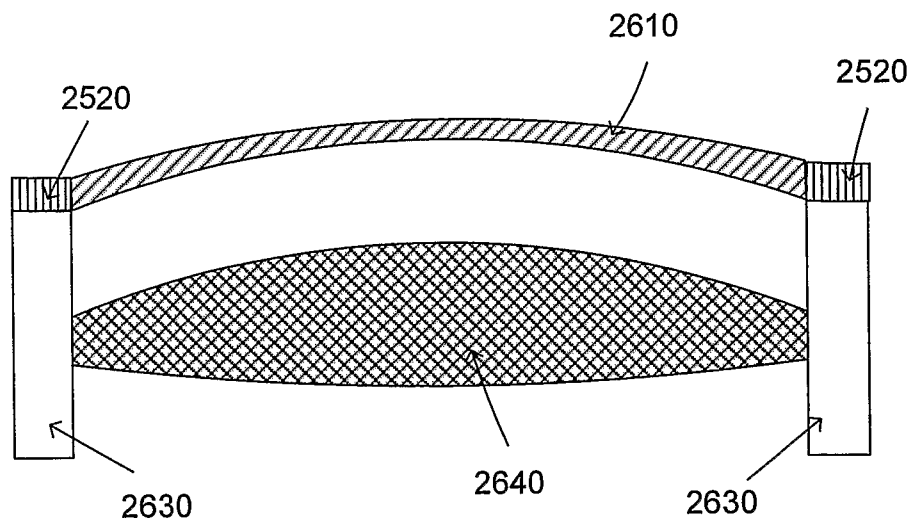


FIG. 24B

FIG. 24A



**FIG. 25**



**FIG. 26**

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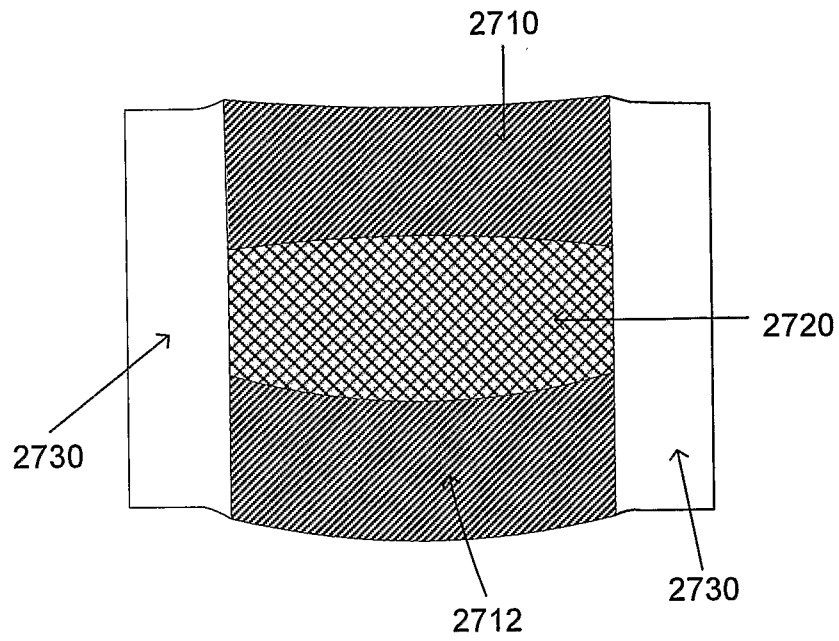


FIG. 27

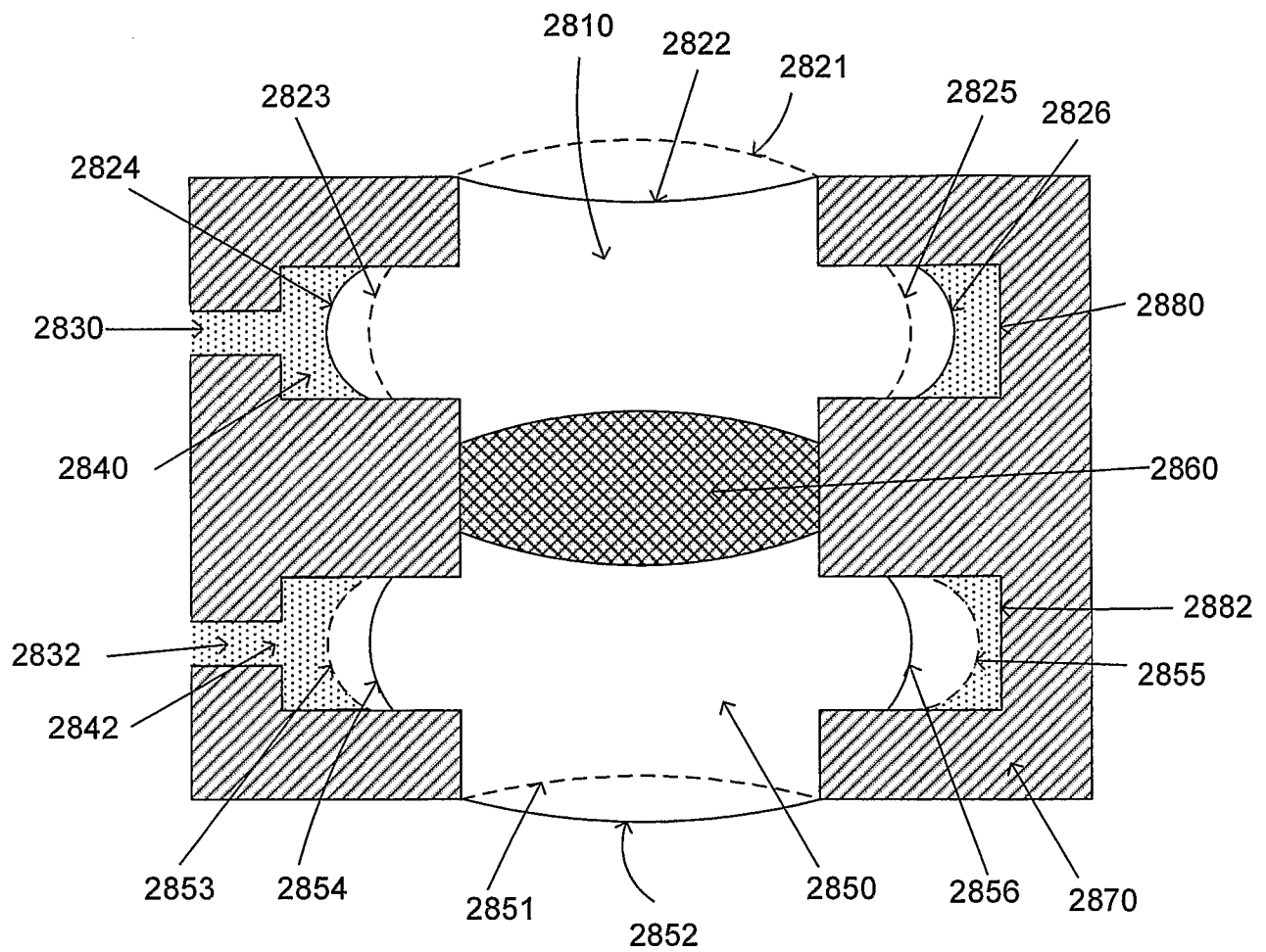


FIG. 28



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2006/000243

## A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

G02B 3/14 (2006.01) G02B 1/06 (2006.01)

B29D 11/00 (2006.01) G02B 7/04 (2006.01)

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

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

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)

DWPI, keywords: ( liquid, fluid, polymer, elastomer, gel, semisolid, deform) (5D) lens; zoom, (adjust, chang, alter, vary, vari, control) (s) (focus, focal, curvature, meniscus, shape, diameter, radius, size, dimension, geometr); pressure, force, compress, pump, actuat, piezo, deform; reflect (3D) (layer, surface, film); hous, mount, support, lens cell, hold; solid lens; cavit, channel, micro; hydrophobic, hydrophilic; IPC: G02B 3/12, 3/14, 1/06

Espacenet, a selection of keywords: mold; lens, B29D11/-; inject; cur; curvature

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 1999/47948 A1 (SILVER) 23 September 1999 Page 4 line 26 – page 5 line 11; page 15 line 31 – page 20 line 10; Figs. 1-6	1-6, 8-14, 16, 19-22, 65-68
X	JP 2000-075110 A (DENSO CORP) 14 March 2000 See abstract, drawings	1-6, 9-14, 16-18, 21-22, 65, 67, 68

☒ Further documents are listed in the continuation of Box C☒ See patent family annex

* "A"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance	"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
"E"	earlier application or patent but published on or after the international filing date	"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
"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)	"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
"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"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 23 October 2006	Date of mailing of the international search report 31 OCT 2006
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustalia.gov.au Facsimile No. (02) 6285 3929	Authorized officer  JULIA HU Telephone No : (02) 6283 2754

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2006/000243

**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. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
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:  
See separate sheet

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 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/SG2006/000243

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5917657 A (KANEKO et al.) 29 June 1999 Figs. 1-5; column 1 line 66 – column 2 line 37; column 3 line 48 – column 4 line 67	1, 5, 6, 16-18, 21-22, 65, 67, 68
X	US 6188526 B1 (SASAYA et al.) 13 February 2001 Figs. 1-2; column 3 line 1 – column 5 line 29	1, 5, 6, 9-14, 16-18, 21-22, 65, 67, 68
X	US 6859233 B1 (SASAMA) 22 February 2005 Fig. 2; column 4 lines 26-65	1, 5, 6, 16-18, 65, 67, 68
X	US 5684637 A (FLOYD) 4 November 1997 Figs. 2-4, 2A, 2B & 8-9; column 5 line 62 – column 6 line 30; column 9 lines 21-47; column 11 line 35- column 12 line 32	1, 5, 6, 15, 16, 19-25, 30, 32, 65-68
X	US 5440357 A (QUAGLIA) 8 August 1995 Figs. 1-14; column 7 lines 22-55	43-45, 67
A		9-14
X	WO 2005/021250 A1 (VISAQ LIMITED (GB) et al.) 10 March 2005 See abstract	60, 61, 63, 69
X	Derwent Abstract Accession No. 2003-280472/28, Class A32 D22 (A96), EP 1273430 A2 (JOHNSON & JOHNSON VISION PROD) 8 January 2003 See abstract	60, 61, 63, 69
X	Patent Abstracts of Japan, JP 2003-094447 A (BAUSCH & LOMB INC) 3 April 2003 See abstract	60, 61, 63, 69
X	WO 2004/011102 A1 (GUANGZHOU VANGUARD PLASTIC & HARDWARE FACTORY (CN) et al.) 5 February 2004 See abstract	60-62, 64, 69

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2006/000243

**Supplemental Box**

(To be used when the space in any of Boxes I to VIII is not sufficient)

**Continuation of Box No III:**

The international application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept. In coming to this conclusion the International Searching Authority has found that there are two inventions:

1. Claims 1-59 and 65-68 directed to an optical device comprising at least one semi-solid lens and a pressure control means coupled with said semi-solid lens for adjusting the curvature of said lens. It is considered that a semi-solid lens coupled with a pressure control means to adjust curvature comprises a first "special technical feature".
2. Claims 60-64 and 69 directed to a method for making a semi-solid lens by a moulding/injection moulding/curing process. The moulding/curing process for fabricating a semi-solid lens is considered to comprise a second separate "special technical feature".

Since the abovementioned groups of claims do not share either of the technical features identified, a "technical relationship" between the inventions, as defined in PCT rule 13.2 does not exist. Accordingly the international application does not relate to one invention or to a single inventive concept.

As the search for the second invention (which would constitute separate search areas with distinct classifications under the IPC) will require more than a negligible additional search effort over that for the first invention, an additional search fee is warranted.

**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/SG2006/000243**

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
WO	9947948	AU	27406/99	CA	2324212	CN	1300372
		CN	1776459	EP	1064569	US	6618208
		US	2006077562				
JP	2000075110						
US	5917657	DE	19706274	JP	9230252		
US	6188526	JP	2000081503				
US	6859233						
US	5684637						
US	5440357	US	5229885	US	5739959		
WO	2005021250	EP	1663629	GB	2405611		
EP	1273430	AU	20572/95	BR	9502760	CA	2151353
		CZ	9501480	EP	0686491	JP	8174699
		US	5804107	US	6039899	US	6511617
		ZA	9504791				
JP	2003094447	AU	25659/92	BR	9206432	CA	2113257
		CN	1071877	EP	0603284	HK	1001679
		MX	9205182	SG	44659	US	5271875
		US	5466147	WO	9304848		
WO	2004011102	AU	2002327302	CN	1394658	US	2006010584
Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.							
END OF ANNEX							