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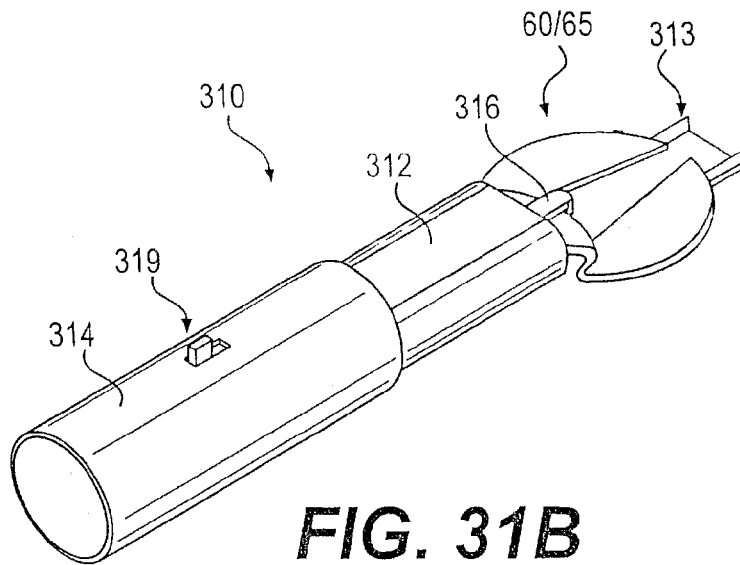
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**FIG. 31B**

(57) Abstract: Modular IOL removal systems (310) and methods that cut an optic portion of an intraocular LENS (60,65) in a single motion such to facilitate removal of the optic portion from an eye through an incision, for example a corneal incision, without increasing the size of the corneal incision. Various cutting tools having one or more blades (318) may be utilized. The cut intraocular lens may have one continuous cut or be cut into multiple smaller pieces. The single cutting step may apply balanced forces and torque to avoid damaging the surrounding eye anatomy, reducing the risk of trauma.

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MODULAR INTRAOCULAR LENS DESIGNS, TOOLS AND METHODSCross-Reference to Related Applications

[001] This application claims the benefits of priority to U.S. Application No. 14/610,360, filed January 30, 2015, which claims the benefits under 35 U.S.C. § 119(e) of priority to U.S. Provisional Patent Application No. 61/941,167, filed February 18, 2014, entitled "MODULAR INTRAOCULAR LENS DESIGNS, TOOLS AND METHODS," the entireties of which are incorporated herein by reference. This application is related to U.S. Patent Application No. 13/969,115, filed August 16, 2013, entitled "MODULAR INTRAOCULAR LENS DESIGNS & METHODS," which claims the benefits under 35 U.S.C. § 119(e) of priority to U.S. Provisional Patent Application No. 61/830,491, filed June 3, 2013, entitled "MODULAR INTRAOCULAR LENS DESIGNS AND METHODS," each of which is incorporated herein by reference. This application also is related to U.S. Patent Application No. 13/748,207, filed January 23, 2013, entitled "MODULAR INTRAOCULAR LENS DESIGNS & METHODS," which claims the benefits under 35 U.S.C. § 119(e) of priority of U.S. Provisional Patent Application No. 61/589,981, filed on January 24, 2012, entitled "LASER ETCHING OF IN SITU INTRAOCULAR LENS AND SUCCESSIVE SECONDARY LENS IMPLANTATION," and of U.S. Provisional Patent Application No. 61/677,213, filed on July 30, 2012, entitled "MODULAR INTRAOCULAR LENS DESIGNS & METHODS," each of which is incorporated herein by reference.

### Field of the Invention

[002] The present disclosure generally relates to intraocular lenses (IOLs). More specifically, the present disclosure relates to embodiments of modular IOL designs, methods and associated tools.

### Background

[003] The human eye functions to provide vision by transmitting light through a clear outer portion called the cornea, and focusing the image by way of a crystalline lens onto a retina. The quality of the focused image depends on many factors including the size and shape of the eye, and the transparency of the cornea and the lens.

[004] When age or disease causes the lens to become less transparent (e.g., cloudy), vision deteriorates because of the diminished light, which can be transmitted to the retina. This deficiency in the lens of the eye is medically known as a cataract. An accepted treatment for this condition is surgical removal of the lens from the capsular bag and placement of an artificial intraocular lens (IOL) in the capsular bag. In the United States, the majority of cataractous lenses are removed by a surgical technique called phacoemulsification. During this procedure, an opening (capsulorhexis) is made in the anterior side of the capsular bag and a thin phacoemulsification-cutting tip is inserted into the diseased lens and vibrated ultrasonically. The vibrating cutting tip liquefies or emulsifies the lens so that the lens may be aspirated out of the capsular bag. The diseased lens, once removed, is replaced by an IOL.

[005] After cataract surgery to implant an IOL, the optical result may be suboptimal or may need adjustment over time. For example, shortly after the

procedure, it may be determined that the refractive correction is erroneous leading to what is sometimes called “refractive surprise.” Also for example, long after the procedure, it may be determined that the patient needs or desires a different correction, such as a stronger refractive correction, an astigmatism correction, or a multifocal correction.

[006] In each of these cases, a surgeon may be reluctant to attempt removal of the suboptimal IOL from the capsular bag and replacement with a new IOL. In general, manipulation of the capsular bag to remove an IOL risks damage to the capsular bag including posterior rupture. This risk increases over time as the capsular bag collapses around the IOL and tissue ingrowth surrounds the haptics of the IOL. Thus, it would be desirable to be able to correct or modify the optical result without the need to remove the IOL or manipulate the capsular bag.

[007] A variety of secondary lenses have been proposed to address the aforementioned drawbacks. For example, one possible solution includes a secondary lens that resides anterior to the capsular bag with haptics that engage the ciliary sulcus. While this design may have the advantage of avoiding manipulation of the capsular bag, its primary disadvantage is engaging the ciliary sulcus. The ciliary sulcus is composed of soft vascularized tissue that is susceptible to injury when engaged by haptics or other materials. Such injury may result in complications such as bleeding, inflammation and hyphema. Thus, in general, it may be desirable to avoid placing a secondary lens in the ciliary sulcus to avoid the potential for complications.

[008] Another potential solution may include a lens system that avoids the potential problems associated with the ciliary sulcus. The lens system may include a primary lens and a secondary lens, where the secondary lens may be attached to

the primary lens, both within the capsular bag. The primary lens may have a recess into which an edge of the secondary lens may be inserted for attachment. The recess is preferably located radially outwardly of the opening (capsulorhexis) in the capsular bag to avoid interfering with light transmission. To attach the secondary lens in-situ, the capsular bag must be manipulated around the perimeter of the capsulorhexis to gain access to the recess in the primary lens. As stated previously, manipulation of the capsular bag may be undesirable given the risks associated therewith. Therefore, while such lens systems may avoid the potential for injury to the ciliary sulcus by implanting both the primary lens and the secondary lens in the capsular bag, these systems do not avoid manipulation of the capsular bag to attach the secondary lens.

[009] Thus, there remains a need for an IOL system and method that allows for correction or modification of the optical result using a lens that can be attached to a base or primary lens without the need to manipulate the capsular bag.

#### Summary of the Invention

[010] Embodiments of the present disclosure provide a modular IOL system including intraocular primary and secondary components, which, when combined, form an intraocular optical correction device. The primary component may comprise an intraocular base, and the secondary component may comprise an intraocular lens, wherein the base is configured to releasably receive the intraocular lens. In some embodiments, the base may be configured as a lens, in which case the modular IOL system may be described as including a primary lens and a secondary lens. The primary component (e.g., base or primary lens) may be placed in the capsular bag using conventional cataract surgery techniques. The primary

component may have a diameter greater than the diameter of the capsulorhexis to retain the primary component in the capsular bag. The secondary component (e.g., secondary lens) may have a diameter less than the diameter of the capsulorhexis such that the secondary component may be attached to the primary component without manipulation of the capsular bag. The secondary component may also be manipulated to correct or modify the optical result, intra-operatively or post-operatively, without the need to remove the primary component and without the need to manipulate the capsular bag. For example, the secondary component may be removed, repositioned, and/or exchanged to correct, modify, and/or fine tune the optical result.

[011] Common indications for exchanging the secondary component may be residual refractive error (e.g., for monofocal lenses), decentration error (e.g., for multifocal lenses) due to post-operative healing, astigmatism error (e.g., for toric lenses) induced by surgery, changing optical correction needs due to progressive disease, changing optical correction desires due to lifestyle changes, injury, age, etc.

[012] The primary component may have haptics (e.g., projections) extending therefrom for centration in the capsular bag, and the secondary component may exclude haptics, relying instead on attachment to the primary component for stability. The secondary component may reside radially inside the perimeter of the capsulorhexis, thereby negating the need to disturb the capsular bag to manipulate or exchange the secondary component. The attachment between the primary component and the secondary component may reside radially inside the perimeter of the capsulorhexis and radially outside the field of view to avoid interference with light transmission. Alternatively or in addition, the attachment may comprise a small

fraction of the perimeter (e.g., less than 20%) of the secondary component to minimize the potential for interference in light transmission.

[013] The primary component may have an anterior surface that is in intimate contact with a posterior surface of the secondary component to prevent fluid ingress, tissue ingrowth, and/or optical interference. The secondary component may be removably secured to the primary component by mechanical attachment and/or chemical attraction, for example. Mechanical attachment may be facilitated by mating or interlocking geometries corresponding to each of the primary and the secondary components. Such geometries may be pre-formed by molding or cutting, for example, or formed in-situ by laser etching, for example. Chemical attraction may be facilitated by using similar materials with a smooth surface finish activated by a surface treatment, for example. In some instances, it may be desirable to reduce chemical attraction and rely more on mechanical attachment for stability. In this case, the primary and secondary components may be formed of dissimilar materials or otherwise have adjacent surfaces that do not have a chemical attraction.

[014] Generally, the primary component (base or primary lens) may be delivered in a rolled configuration using a delivery tube inserted through a corneal or scleral incision, through the capsulorhexis and into the capsular bag. The primary component may be ejected from the delivery tube and allowed to unfurl inside the capsular bag. The secondary component (lens) may also be delivered in a rolled configuration via ejection from a delivery tube and allowed to unfurl anterior to the primary component. With gentle manipulation, the secondary component may be centered on the primary component and attached thereto via an attachment mechanism.

[015] The secondary component may be removed and exchanged for a replacement secondary component, such as a replacement lens with a different optical correction. Initially, the secondary component may be disconnected from the primary component to reside anteriorly to the primary component. The secondary component may be removed from the eye via the same corneal incision used to implant the modular IOL without increasing the size of the incision. This may be accomplished by either folding the secondary component prior to removal through the incision or by cutting the secondary component such that it has a smaller width than the incision. A cannula or delivery tube may be used to facilitate this removal. The IOL may be removed as a single piece or in multiple pieces.

[016] The cutting removal methods may utilize one continuous cut path or multiple cut paths. A surgical cutting tool may be employed to create the various cut patterns. The cut path or paths may be linear or nonlinear. The cutting step may be simultaneous with the removal step. For example, the secondary component may be cut as it is extracted through a cannula.

[017] The surgical cutting tools and removal methods may apply balanced forces and/or torques on the secondary lens to minimize movement thereof during cutting. This minimizes or avoids anterior-posterior forces on the capsular bag and prevents capsular rupture. The removal methods may avoid flexing the secondary lens ("tenting") and/or rotating the secondary lens in the anterior-posterior direction, again to avoid trauma to the capsular bag. The cut may be a "clean cut" so as to avoid generating small fragments, debris or jagged edges.

[018] In one embodiment, a cutting instrument may be used to cut the secondary lens into two or more pieces. The cut pattern may be horseshoe-shaped, for example. The cutting instrument may be a scissors-like punch. Alternatively, the



cutting instrument may include a retractable cutting base configured to extend either above or below the secondary lens. The cutting instrument may also include a dual-edge blade having two cutting surfaces configured to pinch the secondary lens against the retractable cutting base. As the cutting base retracts into the cutting instrument, the dual edge blade may cut the secondary lens along the face of the secondary lens opposite to the cutting base. Alternatively, the dual edge blades may extend towards the cutting base, cutting the secondary lens as it extends.

[019] In a related embodiment, an extendable grasper may replace the cutting base such that the secondary lens is secured along the length of the cut path during the cutting step. During the cutting step, the dual edge blades extend towards the grasper cutting the secondary lens.

[020] In another embodiment, a cutting instrument may be used to cut a curved "spiral" or "J-shape" cut pattern in the secondary lens. The cutting instrument may be scissors-like with curved blades. The cut secondary lens may spin or "spiral" as it is pulled through the corneal incision or cannula.

[021] In another embodiment, the secondary lens may be cut as it is removed from the anterior chamber. A cannula having a distal cutting surface may be inserted through the corneal incision and into the anterior chamber of the eye. A forceps or other appropriate grasping tool may extend through the cannula, grasp the edge of the secondary lens, and pull the secondary lens into the cannula. As the secondary lens is pulled into the cannula, it passes the cutting surface and is cut or "peeled." The secondary lens may spin as it is pulled into the cannula and removed from the anterior chamber of the eye through the corneal incision.

[022] The modular IOL systems, tools and methods according to embodiments of the present disclosure may be applied to a variety of IOL types,

including fixed monofocal, multifocal, toric, accommodative, and combinations thereof. In addition, the modular IOL systems, tools and methods according to embodiments of the present disclosure may be used to treat, for example: cataracts, large optical errors in myopic (near-sighted), hyperopic (far-sighted), and astigmatic eyes, ectopia lentis, aphakia, pseudophakia, and nuclear sclerosis.

[023] Various other aspects of embodiments of the present disclosure are described in the following detailed description and drawings.

#### Brief Description of the Drawings

[024] The drawings illustrate example embodiments of the present disclosure. The drawings are not necessarily to scale, may include similar elements that are numbered the same, and may include dimensions (in millimeters) and angles (in degrees) by way of example, not necessarily limitation. In the drawings:

[025] Figure 1 is a schematic diagram of the human eye shown in cross section;

[026] Figures 2A and 2B are front and side cross-sectional views, respectively, of a modular IOL disposed in a capsular bag according to an embodiment of the present disclosure;

[027] Figures 3A-3D and 4A-4D are front and side cross-sectional views, respectively, schematically illustrating a method for implanting a modular IOL according to an embodiment of the present disclosure;

[028] Figure 5 is a front view of a modular IOL, according to an embodiment of the present disclosure, wherein subsurface attachment mechanisms are provided for connection between the primary and secondary lenses;

[029] Figures 6A and 6B are cross-sectional views taken along line 6-6 in Figure 5, showing two embodiments of subsurface attachment mechanisms;

[030] Figure 7 is a front view of a modular IOL, according to an embodiment of the present disclosure, wherein extension attachment mechanisms are provided to connect the primary and secondary lenses;

[031] Figures 8A-8C are cross-sectional views taken along line 8-8 in Figure 7, showing three embodiments of extension attachment mechanisms;

[032] Figures 9A-9D are front views showing various positions of the attachment mechanisms to adjust the position of the secondary lens relative to the primary lens;

[033] Figure 10 is a front view of a modular IOL, according to an embodiment of the present disclosure, wherein etched subsurface attachment mechanisms are provided for connection between the primary and secondary lenses;

[034] Figures 11A-11F are cross-sectional views of the modular IOL shown in Figure 10, showing various embodiments of etched subsurface attachment mechanisms;

[035] Figures 12A-12C are schematic illustrations of front, sectional and detail views, respectively, of an alternative modular IOL, according to an embodiment of the present disclosure;

[036] Figures 13A and 13B show representative photomicrographs at 4X and 40X magnification, respectively, of a groove (see, arrow) formed by laser etching;

[037] Figures 14, 14A-14C, 15, 15A-15D, 16, 16A-16D, 17, 17A-17C, 18, 18A-18C, 19, 19A-19D, 20, 20A-20I, 21, 21A-21E, 22, and 22A-22D are various views of alternative modular IOLs according to embodiments of the present disclosure;

[038] Figures 23A-23D are schematic illustrations of a lens removal system for a modular IOL according to an embodiment of the present disclosure;

[039] Figures 23E-23H are schematic illustrations of an alternative embodiment of a lens removal system for a modular IOL;

[040] Figure 24 is a schematic flow chart of a method for using a modular IOL, according to an embodiment of the present disclosure, wherein an exchange of the secondary lens is motivated by a sub-optimal optical result detected intra-operatively;

[041] Figure 25 is a schematic flow chart of a method for using a modular IOL, according to an embodiment of the present disclosure, wherein an exchange of the secondary lens is motivated by a sub-optimal optical result detected post-operatively;

[042] Figure 26 is a schematic flow chart of a method for using a modular IOL, according to an embodiment of the present disclosure, wherein a secondary lens is attached to a primary lens by forming the attachment means *in-situ*;

[043] Figures 27, 27A-27D, 28A-28G, and 29A-29F are various views of further alternative embodiments of modular IOLs, according to the present disclosure;

[044] Figures 29A2-29E2 various views of further alternative embodiments of modular IOLs, according to the present disclosure;

[045] Figures 29G-29M are anatomical views showing insertion and removal of a modular IOL into an eye;

[046] Figures 30A and 30B are various views of a further embodiments of modular IOLs, according to the present disclosure;

[047] Figures 31A-31B are schematic illustrations of an alternative lens removal system for a modular IOL according to an embodiment of the present disclosure;

[048] Figures 31C-31N are schematic illustrations of an alternative lens removal system for a modular IOL according to an embodiment of the present disclosure;

[049] Figures 32A-32D are schematic illustrations of an embodiment of a modular IOL removal system and method; and

[050] Figures 33A-33D are schematic illustrations of an embodiment of a modular IOL removal system and method.

#### Detailed Description

[051] With reference to Figure 1, the human eye 10 is shown in cross section. The eye 10 has been described as an organ that reacts to light for several purposes. As a conscious sense organ, the eye allows vision. Rod and cone cells in the retina 24 allow conscious light perception and vision including color differentiation and the perception of depth. In addition, the human eye's non-image-forming photosensitive ganglion cells in the retina 24 receive light signals which affect adjustment of the size of the pupil, regulation and suppression of the hormone melatonin, and entrainment of the body clock.

[052] The eye 10 is not properly a sphere; rather it is a fused two-piece unit. The smaller frontal unit, more curved, called the cornea 12 is linked to the larger unit called the sclera 14. The corneal segment 12 is typically about 8 mm (0.3 in) in radius. The sclera 14 constitutes the remaining five-sixths; its radius is typically about 12 mm. The cornea 12 and sclera 14 are connected by a ring called the

limbus. The iris 16, the color of the eye, and its black center, the pupil, are seen instead of the cornea 12 due to the cornea's 12 transparency. To see inside the eye 10, an ophthalmoscope is needed, since light is not reflected out. The fundus (area opposite the pupil), which includes the macula 28, shows the characteristic pale optic disk (papilla), where vessels entering the eye pass across and optic nerve fibers 18 depart the globe.

[053] Thus, the eye 10 is made up of three coats, enclosing three transparent structures. The outermost layer is composed of the cornea 12 and sclera 14. The middle layer consists of the choroid 20, ciliary body 22, and iris 16. The innermost layer is the retina 24, which gets its circulation from the vessels of the choroid 20 as well as the retinal vessels, which can be seen within an ophthalmoscope. Within these coats are the aqueous humor, the vitreous body 26, and the flexible lens 30. The aqueous humor is a clear fluid that is contained in two areas: the anterior chamber between the cornea 12 and the iris 16 and the exposed area of the lens 30; and the posterior chamber, between the iris 16 and the lens 30. The lens 30 is suspended to the ciliary body 22 by the suspensory ciliary ligament 32 (Zonule of Zinn), made up of fine transparent fibers. The vitreous body 26 is a clear jelly that is much larger than the aqueous humor.

[054] The crystalline lens 30 is a transparent, biconvex structure in the eye that, along with the cornea 12, helps to refract light to be focused on the retina 24. The lens 30, by changing its shape, functions to change the focal distance of the eye so that it can focus on objects at various distances, thus allowing a sharp real image of the object of interest to be formed on the retina 24. This adjustment of the lens 30 is known as accommodation, and is similar to the focusing of a photographic camera via movement of its lenses.

[055] The lens has three main parts: the lens capsule, the lens epithelium, and the lens fibers. The lens capsule forms the outermost layer of the lens and the lens fibers form the bulk of the interior of the lens. The cells of the lens epithelium, located between the lens capsule and the outermost layer of lens fibers, are found predominantly on the anterior side of the lens but extend posteriorly just beyond the equator.

[056] The lens capsule is a smooth, transparent basement membrane that completely surrounds the lens. The capsule is elastic and is composed of collagen. It is synthesized by the lens epithelium and its main components are Type IV collagen and sulfated glycosaminoglycans (GAGs). The capsule is very elastic and so causes the lens to assume a more globular shape when not under the tension of the zonular fibers, which connect the lens capsule to the ciliary body 22. The capsule varies between approximately 2-28 micrometers in thickness, being thickest near the equator and thinnest near the posterior pole. The lens capsule may be involved with the higher anterior curvature than posterior of the lens.

[057] Various diseases and disorders of the lens 30 may be treated with an IOL. By way of example, not necessarily limitation, a modular IOL according to embodiments of the present disclosure may be used to treat cataracts, large optical errors in myopic (near-sighted), hyperopic (far-sighted), and astigmatic eyes, ectopia lentis, aphakia, pseudophakia, and nuclear sclerosis. However, for purposes of description, the modular IOL embodiments of the present disclosure are described with reference to cataracts.

[058] The following detailed description describes various embodiments of a modular IOL system including primary and secondary intraocular components, namely an intraocular base configured to releasably receive an intraocular lens. In

some embodiments, the base may be configured to provide optical correction, in which case the modular IOL system may be described as including a primary lens and a secondary lens. The principles and features described with reference to embodiments where the base is configured for optical correction may be applied to embodiments where the base is not configured for optical correction, and vice versa. Stated more broadly, features described with reference to any one embodiment may be applied to and incorporated into other embodiments.

[059] With reference to Figures 2A and 2B, a modular IOL system 50/60 is shown implanted in the capsular bag 34 of lens 30 having a capsulorhexis 36 formed therein. The modular IOL system may include a primary lens 50 and a secondary lens 60. The primary lens 50 may include a body portion 52, a pair of haptics 54 for anchoring and centering the primary lens 50 in the capsular bag 34, and means for attachment (not shown here, but described later) to the secondary lens 60. The secondary lens 60 may include an optic body portion 62, no haptics, and corresponding means for attachment (not shown here, but described later) to the primary lens 50. The anterior surface of the body portion 52 of the primary lens 50 may be in intimate contact with the posterior surface of the body portion 62 of the secondary lens 60, without any intervening material (e.g., adhesive, aqueous humor, tissue ingrowth, etc.) in between. For example, the anterior surface of the body portion 52 may be in directed contact with the posterior surface of body portion 62. The secondary lens 60 may be acutely and chronically releasably attached to the primary lens 50 to facilitate exchange of the secondary lens 60 while the primary lens 50 remains in the capsular bag 34 of the lens 30.

[060] The body portion 52 of the primary lens 50 may provide some refractive correction, but less than required for an optimal optical result. The optimal



optical result may be provided by the combination of the correction provided by the optical body portion 52 of the primary lens 50 together with the optical body portion 62 of the secondary lens 60. For example, the optical body portion 62 of the secondary lens 60 may change (e.g., add or subtract) refractive power (for monofocal correction), toric features (for astigmatism correction), and/or diffractive features (for multifocal correction).

[061] The secondary lens 60 may have an outside diameter  $d_1$ , the capsulorhexis 36 may have an inside diameter  $d_2$ , and the body 52 of the primary lens 50 may have an outside diameter  $d_3$ , where  $d_1 < d_2 < d_3$ . This arrangement provides a gap between the secondary lens 60 and the perimeter of the capsulorhexis 36 such that the secondary lens 60 may be attached or detached from the primary lens 50 without touching or otherwise disturbing any portion of the capsular bag 34. By way of example, not limitation, assuming the capsulorhexis has a diameter of approximately 5 to 6 mm, the body of the primary lens (i.e., excluding the haptics) may have a diameter of approximately 5 to 8 mm, and the secondary lens may have a diameter of approximately 3 to less than 5 mm, thereby providing a radial gap up to approximately 1.5 mm between the secondary lens and the perimeter of the capsulorhexis. Notwithstanding this example, any suitable dimensions may be selected to provide a gap between the secondary lens and the perimeter of the capsulorhexis in order to mitigate the need to manipulate the lens capsule to attach the secondary lens to the primary lens.

[062] With reference to Figures 3A-3D (front views) and 4A-4D (side cross-sectional views), a method for implanting a modular IOL system 50/60 is shown schematically. As seen in Figures 3A and 4A, a lens 30 with cataracts includes an opaque or clouded center 38 inside a capsular bag 34. Access to the lens 30 for

cataract surgery may be provided by one or more lateral incisions in the cornea. For illustrative purposes, the term corneal incision will be used throughout this text, though it should be understood that this includes any appropriate incision to provide access to the lens capsule, including a scleral incision.

[063] A capsulorhexis (circular hole) 36 may be formed in the anterior capsular bag 34 using manual tools or a femtosecond laser. As seen in Figures 3B and 4B, the opaque center 38 is removed by phacoemulsification and/or aspiration through the capsulorhexis 36. The primary lens 50 is delivered in a rolled configuration using a tube inserted through the capsulorhexis 36 and into the capsular bag 34. The primary lens 50 is ejected from the delivery tube and allowed to unfurl. With gentle manipulation, the haptics 54 of the primary lens engage the inside equator of the lens capsule 34 and center the lens body 52 relative to the capsulorhexis 36 as seen in Figures 3C and 4C. The secondary lens 60 is delivered in a rolled configuration using a tube, positioning the distal tip thereof adjacent the primary lens 50. The secondary lens 60 is ejected from the delivery tube and allowed to unfurl. With gentle manipulation, the secondary lens 60 is centered relative to the capsulorhexis 36. Without manipulating the capsular bag 34 or the primary lens 50, the secondary lens 60 is then attached to the primary lens 50 as seen in Figures 3D and 4D. If necessary, the secondary lens 60 may be removed and/or replaced in a similar manner, reversing the steps where appropriate. As an alternative, the primary 50 and secondary 60 lenses may be implanted as a unit, thus eliminating a delivery step.

[064] Because it may be difficult to ascertain which side of the secondary lens 60 should face the primary lens 50, the secondary lens may include a marking indicative of proper position. For example, a clockwise arrow may be placed along

the perimeter of the anterior surface of the secondary lens 60, which appears as a clockwise arrow if positioned right-side-up and a counter-clockwise arrow if positioned wrong-side-up. Alternatively, a two-layered color marking may be placed along the perimeter of the anterior surface of the secondary lens 60, which appears as a first color if positioned right-side-up and a second color if positioned wrong-side-down. Other positionally indicative markings may be employed on the secondary lens 60, and similar marking schemes may be applied to the primary lens 50.

[065] With reference to Figure 5, subsurface attachment mechanisms 70 may be used to releasably secure the secondary lens 60 to the primary lens 50. The attachment mechanisms 70 may be positioned radially inside the perimeter of the capsulorhexis 36 and radially outside the field of view to avoid interference with light transmission. Alternatively or in addition, the attachment mechanism 70 may have radial and lateral extents limited to a small fraction (e.g., less than 10-20%) of the perimeter of the secondary lens 50 to minimize the potential for interference in light transmission. Two diametrically opposed attachment mechanisms 70 are shown, but any suitable number may be used, uniformly or non-uniformly distributed about the circumference of the secondary lens 60.

[066] If the primary lens 50 and the secondary lens 60 are delivered at the same time, it may be desirable to align the attachment mechanisms 70 with the roll axis 80, around which the lenses 50 and 60 may be rolled for insertion via a delivery tool. Because the secondary lens 60 may shift relative to the primary lens 50 when rolled about axis 80, providing the attachment mechanisms 70 along the roll axis 80 minimizes stress to the attachment mechanisms 70. To this end, the attachment mechanisms 70 may be coaxially aligned relative to the roll axis 80 and may be

configured to extend a limited distance (e.g., less than 10-20% of the perimeter of the secondary lens 60) from the axis 80.

[067] The attachment mechanisms 70 may be configured to have mating or interlocking geometries as shown in Figures 6A and 6B. Generally, the geometries include a male portion and female portion that are releasably connectable. The female portion is configured to receive the male portion and limit relative motion between the primary lens 50 and the secondary lens 60 in at least two dimensions (e.g., superior-inferior and right-left). The female and male portions may be configured to have an interlocking geometry such that relative motion between the primary lens 50 and the secondary lens 60 is limited in three dimensions (e.g., superior-inferior, right-left, anterior-posterior). The attachment mechanisms 70 may be engaged and disengaged by applying orthogonal force in a posterior (push) and anterior (pull) direction, respectively. The attachment mechanisms 70 may be pre-formed by molding, cutting, etching, or a combination thereof, for example.

[068] In the examples shown, each attachment mechanism 70 comprises an interlocking cylindrical protrusion 72 and cylindrical recess or groove 74. Other mating or interlocking geometries may be used as well. The cylindrical geometry shown has the advantage of allowing slight rotation of the secondary lens 60 relative to the primary lens 50 when rolled for delivery, thus further reducing stress thereon. As shown in Figure 6A, the cylindrical protrusion 72 may extend anteriorly from the anterior surface of the body 52 of the primary lens 50, and the cylindrical recess 74 may extend anteriorly through the posterior surface of the body 62 of the secondary lens 60 adjacent a radial peripheral zone thereof. Alternatively, as shown in Figure 6B, the cylindrical protrusion 72 may extend posteriorly from the posterior surface of the body 62 of the secondary lens 60 adjacent a radial peripheral zone thereof, and

the cylindrical recess 74 may extend posteriorly through the anterior surface of the body 52 of the primary lens 50. The configuration shown in Figure 6B may be particularly suited for the case where the primary lens 50 is a pre-existing implanted IOL into which the recess 74 may be etched *in-situ*, by laser, for example.

[069] With reference to Figure 7, extension attachment mechanisms 90 may be used to releasably connect the primary 50 and secondary 60 lenses. Extension attachment mechanisms 90 may be similar to subsurface attachment mechanisms 70 except as shown and described. Extension attachment mechanisms 90 may extend radially from the perimeter of the secondary lens 60, with each including mating or interlocking geometries, examples of which are shown in Figures 8A-8C. In Figure 8A, a cylindrical portion 92 extends from the outer edge of the secondary lens 60, and a cylindrical recess 94 extends from the outer edge of the primary lens 50. In Figure 8B, the corollary is shown, with the cylindrical portion 92 extending from the outer edge of the primary lens 50, and the cylindrical recess 94 extending from the outer edge of the secondary lens 60. In both embodiments shown in Figures 8A and 8B, the attachment mechanisms 90 may be engaged and disengaged by applying orthogonal force in a posterior (push) and anterior (pull) direction, respectively. Alternatively, in the embodiment shown in Figure 8C, the attachment mechanisms 90 may be engaged and disengaged by applying rotational force in a clockwise or counterclockwise direction, depending on which lens 50/60 is attached to each of the cylindrical portion 92 and the cylindrical recess 94. In addition, although the embodiment of Figure 7 only depicts the use of two attachment mechanisms 90, any suitable number of attachment mechanisms 90 may be utilized within the principles of the present disclosure.

[070] With reference to Figures 9A-9D, the portion of attachment mechanism 90 associated with the secondary lens 60 may be positioned such that the center of the secondary lens 60 is aligned with the center of the primary lens 50. Alternatively, to adjust for misalignment of the primary lens 50 due to imbalanced post-operative healing, for example, the portion of attachment mechanism 90 associated with the secondary lens 60 may be offset as shown in Figures 9B-9D. In Figure 9B, the portion of attachment mechanism 90 associated with the secondary lens 60 is rotationally offset. In Figure 9C, the portion of attachment mechanism 90 associated with the secondary lens 60 is superiorly offset. In Figure 9D, the portion of attachment mechanism 90 associated with the secondary lens 60 is laterally offset. An anterior-posterior offset may also be employed as described in more detail with reference to Figures 11C and 11F. Each of the embodiments shown in Figures 9B, 9C, 9D, 11C and 11F are provided by way of example, and the offset may be made in any direction (anterior, posterior, superior, inferior, right, left, clockwise, counterclockwise) or combination thereof, to varying magnitudes depending on the misalignment of the primary lens 50. In addition, attachment mechanism 90 is shown by way of example, but the same principles may be applied to other attachment means described herein.

[071] With reference to Figure 10, alternative subsurface attachment mechanisms 100 may be used to releasably connect the secondary lens 50 to the primary lens 60. Subsurface attachment mechanisms 100 may be similar to subsurface attachment mechanisms 70 except as shown and described. Subsurface attachment mechanisms 100 may comprise mating or interlocking geometries extending along an arcuate path adjacent the peripheral edge of the secondary lens 60. The subsurface attachment mechanism 100 may include a protrusion 102 and a

corresponding recess or groove 104 into which the protrusion 102 may be received. The protrusion 102 may extend from the posterior surface of the secondary lens 60 and the corresponding recess or groove 104 may extend into the anterior surface of the primary lens 50 as shown in Figures 11A (separated) and 11D (attached). Alternatively, the protrusion 102 may extend from the anterior surface of the primary lens 50 and the corresponding the recess or groove 104 may extend into the posterior surface of the secondary lens 60 as shown in Figures 11B (separated) and 11E (attached). In either embodiment, the anterior-posterior dimension of the protrusion 102 may match the same dimension of the recess or groove 104 to provide intimate contact between the anterior surface of the primary lens 50 and the posterior surface of the secondary lens 60. Alternatively, the anterior-posterior dimension of the protrusion 102 may exceed the same dimension of the recess or groove 104 to provide an anterior-posterior offset as shown in Figures 11C (separated) and 11F (attached). Further, those of ordinary skill in the art will readily recognize that any suitable number of attachment mechanisms 100 may be utilized within the principles of the present disclosure.

[072] With reference to Figure 12A, alternative subsurface attachment mechanisms 105 may be used to connect the secondary lens 60 to the primary lens 50. Subsurface attachment mechanisms 105 may be similar to subsurface attachment mechanisms 100 except as shown and described. As seen in Figure 12B, which is a cross-sectional view taken along line B-B in Figure 12A, the subsurface attachment mechanism 105 may comprise mating or interlocking geometries including a protrusion 107 and a series of holes 109 into which the protrusion 107 may be received. The holes 109 may be distributed in a pattern as seen in Figure 12C, which shows several alternative detail views of box C in Figure

12A. In Figure 12C, the protrusion 107 resides in a hole 109 designated as a black circle while the remaining holes 109 designated as white circles remain open. With this arrangement, the protrusions 107 may be placed in a corresponding pair of holes 109 to achieve the desired alignment between the primary 50 and secondary 60 lenses. For example, and with continued reference to Figure 12C, the protrusions 107 may be placed in a corresponding pair of holes 109 to achieve centered (nominal), shift right, shift left, shift up, shift down, rotate clockwise or rotate counterclockwise (labeled C1-C7, respectively) alignment between the primary 50 and secondary 60 lenses. This arrangement provides a range of adjustments as described with reference to Figures 9A-9D. In addition, any suitable number of attachment mechanisms 105 may be disposed uniformly or non-uniformly about a perimeter of lenses 50 and 60.

[073] All or a portion of the various subsurface attachment means described herein may be formed by molding, cutting, milling, etching or a combination thereof. For example, with particular reference to Figure 11A, the groove 104 may be formed by *in-situ* laser etching a pre-existing implanted primary lens 50, and the protrusion may be pre-formed by molding, milling or cutting the secondary lens 60.

[074] Examples of lasers that may be used for *in-situ* etching include femtosecond lasers, ti/saph lasers, diode lasers, YAG lasers, argon lasers and other lasers in the visible, infrared and ultraviolet range. Such lasers may be controlled in terms of energy output, spatial control and temporal control to achieve the desired etch geometry and pattern. *In-situ* etching may be accomplished, for example, by transmitting a laser beam from an external laser source, through the cornea and past the pupil. Alternatively, *in-situ* etching may be accomplished by transmitting a laser beam from a flexible fiber optic probe inserted into the eye.



[075] With reference to Figures 13A and 13B, photomicrographs at 4X and 40X magnification, respectively, show how a groove (see, arrow) was experimentally etched in a primary lens by laser etching. A femtosecond laser set within the following ranges may be used to etch the groove: power of 1 nJ to 100 uJ; pulse duration of 20 fs up to the picosecond range; and a frequency of 1 to 250 kHz.

[076] The primary and secondary components of the modular IOL systems disclosed herein may be formed of the same, similar or dissimilar materials. Suitable materials may include, for example, acrylate-based materials, silicone materials, hydrophobic polymers or hydrophilic polymers, and such materials may have shape-memory characteristics. For example, materials comprising the optical portions of the modular lens system can be silicone, PMMA, hydrogels, hydrophobic acrylic, hydrophilic acrylic or other transparent materials commonly used for intraocular lenses. Non-optical components of the modular IOL might include nitinol, polyethylene sulfone and/or polyimide.

[077] Materials can be selected to aid performance of certain features of the modular lens system notably the attachment and detachment features necessary for the primary and secondary lenses as previously described. Other features of the modular lens that can be enhanced with specific material selections include manufacturability, intraoperative and post-operative handling, fixation (both intraoperative and at time of post-operative modification), reaching micro-incision sizes (<2.4mm) and exchangeability (minimal trauma on explantation of lenses).

[078] For example, in one embodiment the primary lens and the secondary lens are made from hydrophobic acrylic material having a glass transition temperature between approximately 5 and 300 C and a refractive index between approximately 1.41-1.60. In another embodiment, the primary and secondary lens

can be made from different materials having different glass transition temperatures and mechanical properties to aid fixation and detachment properties of the modular system. In another embodiment, both or either of the modular lens system is made from materials allowing for compression to an outer diameter equal to or smaller than approximately 2.4 mm.

[079] Material properties that are generally desirable in the modular IOL system include minimal to no glistening formation, minimal pitting when exposed to YAG laser application and passing standard MEM elution testing and other biocompatibility testing as per industry standards. The material may contain various chromophores that will enhance UV blocking capabilities of the base material. Generally, wavelengths that are sub 400nm are blocked with standard chromophores at concentrations  $\leq 1\%$ . Alternatively or in addition, the material may contain blue light blocking chromophores, e.g., yellow dyes which block the desired region of the blue-light spectrum. Suitable materials are generally resistant to damage, e.g., surface abrasion, cracking, or hazing, incurred by mechanical trauma under standard implantation techniques.

[080] The components of the modular IOL may be formed by conventional techniques such as molding, cutting, milling, etching or a combination thereof.

[081] As an alternative to mechanical attachment, chemical attraction between the primary and secondary components may be utilized. Using similar materials with a smooth surface finish may facilitate chemical attraction. Chemical attraction may be enhanced by surface activation techniques such as plasma or chemical activation. In some instances, it may be desirable to reduce chemical attraction to avoid sticking between the materials and rely more on mechanical attachment for stability. In this case, the primary and secondary components may be

formed of dissimilar materials or otherwise have adjacent surfaces that do not have a chemical attraction.

[082] With reference to Figures 14-14C, an alternative modular IOL 140 is shown in front, sectional and detailed views, respectively. Figure 14A shows a cross-sectional view taken along line A-A in Figure 14, Figure 14B shows a cross sectional view taken along line B-B in Figure 14, and Figure 14C shows a detail view of circle C in Figure 14B. Modular IOL 140 may include a primary lens 50 with haptics 54 and a secondary lens 60. The interfacing surfaces of the primary lens 50 (anterior surface) and secondary lens 60 (posterior surface) may be in intimate contact as best seen in Figures 14A and 14B. Maintaining intimate contact (i.e., avoiding a gap) or maintaining a consistent gap between the interfacing surfaces of the primary lens 50 and the secondary lens 60 may reduce the likelihood of induced astigmatism. In some embodiments, however, a substance (e.g., an adhesive agent) may be disposed between the respective surfaces of lenses 50 and 60. A circular extension may be formed in the secondary lens 60, with a correspondingly sized and shaped circular recess formed in the primary lens 50 to form an interference fit therebetween, thus securely connecting the two components. The depth of the recess in the primary lens 50 may be a fraction of the thickness of the secondary lens 60, with a circular extension of the secondary lens 60 extending over a portion of the primary lens 50, thereby forming an overlap joint 142 as best seen in Figure 14C. The overlap joint 142 may extend 360 degrees around the circumference of the secondary lens 60 as shown, or a fraction thereof. The circular extension of the secondary lens 60 rises above the anterior surface of the primary lens 50 to form a raised portion. In some embodiments, the raised portion may have a radially tapering configuration. The raised portion may be radially compressed with

forceps to facilitate connection and disconnection of the primary lens 50 and the secondary lens 60. Using radial compression to insert the secondary lens 60 into the primary lens 50 reduces the anterior-posterior forces applied to the capsular bag during insertion, thereby reducing the risk of capsular rupture.

[083] With reference to Figures 15-15D, an alternative modular IOL 150 is shown in front, sectional and detailed views, respectively. Figure 15A shows a cross-sectional view taken along line A-A in Figure 15, Figure 15B shows a cross sectional view taken along line B-B in Figure 15, Figure 15C shows a detail view of circle C in Figure 15B, and Figure 15D shows an alternative detail view of circle C in Figure 15B. Modular IOL 150 may include a primary lens 50 with haptics 54 and a secondary lens 60. The interfacing surfaces of the primary lens 50 (anterior surface) and secondary lens 60 (posterior surface) may be in intimate contact as best seen in Figures 15A and 15B. The primary lens 50 may include a recess defining a wall into which the correspondingly sized and shaped circular secondary lens 60 may be placed. The wall defined by the recess in the primary lens 50 may extend around the entire perimeter of the primary lens with the exception of two diametrically opposed gaps 152. The gaps 152 thus expose the perimeter edge of the secondary lens 60 as seen in Figure 15A to facilitate insertion and removal by radial compression of the secondary lens 60 using forceps, for example. The remainder of the wall defined by the recess in the primary lens provides for a flush joint as seen in Figures 15B and 15C, where the anterior surface of the secondary lens 60 may be flush with the anterior surface of the primary lens 50. As seen in Figure 15C, the wall defined by the recess in the primary lens 50 and the interfacing edge of the secondary lens 60 may be canted inwardly to provide a joint 154 with positive mechanical capture and secure connection therebetween. Alternatively, as seen in

Figure 15D, the wall defined by the recess in the primary lens 50 and the interfacing edge of the secondary lens 60 may be “S” shaped to provide a joint 156 with positive mechanical capture and secure connection therebetween. Alternative interlocking geometries may be employed.

[084] With reference to Figures 16-16D, an alternative modular IOL 160 is shown in front, sectional and detailed views, respectively. Figure 16A shows a cross-sectional view taken along line A-A in Figure 16, Figure 16B shows a cross sectional view taken along line B-B in Figure 16, Figure 16C shows a detail view of circle C in Figure 16B, and Figure 16D shows a detail view of circle D in Figure 16A. Modular IOL 160 may be configured similar to modular IOL 150 shown in Figures 15-15D with primary lens 50 including a recess defining a wall into which the correspondingly sized and shaped circular secondary lens 60 may be placed. However, in this embodiment, an angular gap 162 (rather than gap 152) is provided along a fraction of the perimeter of the secondary lens 60. The wall defined by a circumferential portion of the perimeter edge of the secondary lens 60 may have the same geometry as the wall defined by the recess in the primary lens 50 to provide a flush joint 154 as best seen in Figure 16C. The wall defined by another (e.g., the remainder) circumferential portion of the perimeter edge of the secondary lens 60 may have a more inwardly angled geometry to provide an angled gap 162 as best seen in Figure 16D. The angled gap 162 thus exposes the perimeter edge of the secondary lens 60 as seen in Figure 16D into which forceps may be placed to facilitate insertion and removal by radial compression of the secondary lens 60. Alternative gap geometries may be employed.

[085] With reference to Figures 17-17C, an alternative modular IOL 170 is shown in front, sectional, detailed and isometric views, respectively. Figure 17A

shows a cross-sectional view taken along line A-A in Figure 17, Figure 17B shows a detail view of circle B in Figure 17A, and Figure 17C shows an isometric view of the assembled components. Modular IOL 170 may be configured similar to modular IOL 150 shown in Figures 15-15D with primary lens 50 including a recess defining a wall into which the correspondingly sized and shaped circular secondary lens 60 may be placed. However, in this embodiment, the wall defining the recess in the primary lens 50 includes a portion thereof that is milled down to define two diametrically opposed tabs 172. The inside circumferential walls of the tabs 172 provide for a flush joint 174 as seen in Figure 17B, such that the anterior surface of the secondary lens 60 is flush with the anterior surface of the primary lens 50. The interface of the joint 174 along the tabs 172 may be canted, "S" shaped, or "C" shaped as shown, for example. Elsewhere along the perimeter, away from the tabs 172, in the area where the wall is milled down, the perimeter edge of the secondary lens 60 is exposed as seen in Figure 17C, to facilitate insertion and removal of the secondary lens 60 by radial compression thereof using forceps, for example.

[086] With reference to Figures 18-18C, an alternative modular IOL 180 is shown in front, sectional, detailed and isometric views, respectively. Figure 18A shows a cross-sectional view taken along line A-A in Figure 18, Figure 18B shows a detail view of circle B in Figure 18A, and Figure 18C shows an isometric view of the assembled components. Modular IOL 180 may be configured similar to modular IOL 170 shown in Figures 17-17C with primary lens 50 including a recess defining a partial wall into which the correspondingly sized and shaped circular secondary lens 60 may be placed, interlocking via flush joint 174 in tabs 172. However, in this embodiment, grasping recesses or holes 182 are provided in each of the tabs 172 and in the adjacent portions of secondary lens 60. In one embodiment, the grasping

recesses or holes 182 may not extend through an entire thickness of primary 50 and secondary 60 lenses. The grasping holes 182 in the secondary lens 60 facilitate insertion and removal by radial compression of the secondary lens 60 using forceps, for example. Adjacent grasping holes 182 in the tab portion 172 and the secondary lens 60 may be pulled together or pushed apart in a radial direction to facilitate connection and disconnection, respectively, of the joint 174 using forceps, for example.

[087] Using radial forces applied via the grasping holes 182 to connect and disconnect (or lock and unlock) the joint 174 between the primary lens 50 and the secondary lens 60 reduces the anterior-posterior forces applied to the capsular bag, thereby reducing the risk of capsular rupture. Grasping holes 182 may also be used to facilitate connecting and disconnecting different interlocking geometries while minimizing anterior-posterior forces. For example, a recess in the primary lens 50 may include internal threads that engage corresponding external threads on the perimeter edge of the secondary lens 60. In this embodiment, forceps inserted into the grasping holes 182 may be used to facilitate rotation of the secondary lens 60 relative to the primary lens 50 to screw and unscrew the primary 50 and secondary 60 lenses. In an alternative embodiment, a keyed extension of the secondary lens 60 may be inserted into an keyed opening in the primary lens 50 and rotated using forceps inserted into the grasping holes 182 to lock and unlock the primary 50 and secondary 60 lenses. In another alternative embodiment, forceps or the like may be inserted posteriorly through a hole in the secondary lens 60 to grasp an anterior protrusion on the primary lens 50 like a handle (not shown), followed by applying posterior pressure to the secondary lens 60 while holding the primary lens 50 stationary. The grasping holes 182 may also be used to rotate the secondary lens 60

relative to the primary lens 50 for purposes of rotational adjustment in toric applications, for example.

[088] With reference to Figures 19-19D, an alternative modular IOL 190 is shown in front, sectional, detailed, isometric exploded and isometric assembled views, respectively. Figure 19A shows a cross-sectional view taken along line A-A in Figure 19, Figure 19B shows a detail view of circle B in Figure 19A, Figure 19C shows an exploded isometric view of the components, and Figure 19D shows an assembled isometric view of the components. Modular IOL 190 differs from some of the previously described embodiments in that the primary component serves as a base 55 but does not necessarily provide for optical correction, whereas the secondary component serves as a lens 65 and provides for optical correction. Base 55 may be configured in the shape of an annulus or ring with a center opening 57 extending therethrough in an anterior-posterior direction. In some embodiments, base 55 may not define a complete ring or annulus. Base 55 may also include haptics 59, which are similar in function to haptics 54 described previously but differ in geometric configuration. Generally, haptics 54/59 function to center the base 55 in the capsular bag. Such haptics may also be configured to apply outward tension against the inside equatorial surface of the capsular bag, similar to capsular tension rings, to aid in symmetric healing and maintain centration of the base. The haptics 59 may include one or more openings therein.

[089] Because the base 55 includes a center opening 57, the posterior optical surface of the lens 65 is not in contact with the base 55. A circular extension may be formed in the lens 65, with a correspondingly sized and shaped circular recess formed in the base 55 to form a ledge on the base 55 and an overlapping joint 192 with an interference and/or friction fit therebetween, thus securely



connecting the two components. Alternatively, the shape of the overlapping joint 192 may form a canted angle or an "S" shape as described previously to form an interlock therebetween. The joint or junction 192 may include a modified surface to reduce light scattering caused by the junction 192. For example, one or both of the interfacing surfaces of the joint 192 may be partially to totally opaque or frosted (i.e., roughened surface) to reduce light scattering caused by the junction 192.

[090] The depth of the recess in the base 55 may be the same thickness of the circular extension of the lens 65 such that the anterior surface of the lens 65 and the anterior surface of the base 55 are flush as best seen in Figure 19B. With this arrangement, the posterior surface of the lens 65 extends more posteriorly than the anterior surface of the base 55. In some embodiments, however, the anterior surface of lens 65 may be disposed relatively higher or lower than the anterior surface of base 55. The dimensions of the recess and the corresponding ledge in the base 55 may be selected relative to the thickness of the lens 65 such that at least a portion of the posterior-most surface of the lens 65 is coplanar with the posterior-most surface of the base 55, or such that at least a portion of the posterior-most surface of the lens 65 is more posterior than the posterior-most surface of the base 55.

[091] As with prior embodiments, the lens may be exchanged for a different lens either intra-operatively or post-operatively. This may be desirable, for example, if the first lens does not provide for the desired refractive correction, in which case the first lens may be exchanged for a second lens with a different refractive correction, without disturbing the lens capsule. In cases where the lens 65 does not have the desired optical alignment due to movement or misalignment of the base, for example, it may be exchanged for a different lens with an optical portion that is

manufactured such that it is offset relative to the base 55. For example, the optical portion of the second lens may be offset in a rotational, lateral and/or axial direction, similar to the embodiments described with reference to Figures 9A-9D. This general concept may be applied to other embodiments herein where the secondary component (e.g., lens) has limited positional adjustability relative to the primary component (e.g., base).

[092] A number of advantages are associated with the general configuration of this embodiment, some of which are mentioned hereinafter. For example, because the posterior optical surface of the lens 65 is not in contact with the base 55, the potential for debris entrapment therebetween is eliminated. Also, by way of example, because the base 55 includes a center opening 57 that is devoid of material, the base 55 may be rolled into a smaller diameter than a primary lens 50 as described previously to facilitate delivery through a smaller incision in the cornea. Alternatively, the base 55 may have a larger outside diameter and be rolled into a similar diameter as primary lens 50. For example, the base lens 55 may have an outside diameter (excluding haptics) of approximately 8mm and be rolled into the same diameter as a primary lens 50 with an outside diameter 6mm. This may allow at least a portion of the junction between the base 55 and lens 65 to be moved radially outward away from the circumferential perimeter of the capsulorhexis, which typically has a diameter of 5-6mm. Moving at least a portion of the junction between the base 55 and the lens 65 radially outward from the perimeter of the capsulorhexis may reduce the amount of the junction that is in the field of view and thus reduce the potential for light scattering or optical aberrations (e.g., dysphotopsias) created thereby. Of course, notwithstanding this example, any suitable dimensions may be selected to provide a gap between the lens 65 and the perimeter edge of the

capsulorhexis in order to mitigate the need to manipulate the lens capsule to connect or disconnect the lens 65 to or from the base 55.

[093] With reference to Figures 20-20D, an alternative modular IOL 200 is shown in front, sectional, detailed, isometric exploded and isometric assembled views, respectively. Figure 20A shows a cross-sectional view taken along line A-A in Figure 20, Figure 20B shows a detail view of circle B in Figure 20A, Figure 20C shows an exploded isometric view of the components, and Figure 20D shows an assembled isometric view of the components. Modular IOL 200 includes a base 55 with associated haptics 59 and a lens 65. The base 55 includes a center hole 57 such that the posterior optical surface of the lens 65 is not in contact with the base 55. The lens 65 includes a circular extension that is sized and shaped to fit in a circular recess formed in the base 55 to form a ledge on the base 55 and an overlapping joint 202. The overlapping joint 202 may be configured with an "S" shaped interface to securely connect the two components. Thus, modular IOL 200 is similar to modular IOL 190, except that the joint 202 between the base 55 and the lens 65 may include a peg-and-hole arrangement. In this arrangement, a pair of diametrically opposed pegs 204 may extend posteriorly from the posterior perimeter of the lens 65 and fit within a selected pair of holes 206 from a series of holes 206 formed in the ledge of the joint 202 in the base 55.

[094] Figures 20E-20I show additional detail of modular IOL 200. Figure 20E shows a side view of the lens 65, Figure 20F shows a rear view of the posterior surface of the lens 65, Figure 20G is a detailed view of circle G in Figure 20E, Figure 20H is a front view of the anterior surface of the base 55, and Figure 20I is a detailed view of circle I in Figure 20H. As seen in Figures 20E-20F, a pair of diametrically opposed pegs 204 may extend posteriorly from the posterior perimeter of the lens

65. As seen in Figures 20H-20I, the inside diameter of the base 55 along the ledge of the joint 202 includes a series of holes 206, into a selected pair of which the pair of pegs 204 may be inserted. With this arrangement, the lens 65 may be selectively rotated relative to the base 55 for purposes of rotational adjustment in toric applications, for example.

[095] With reference to Figures 21-21E, an alternative modular IOL 210 is shown in front, sectional, detailed and isometric views, respectively. Figures 21A and 21B show a cross-sectional views taken along line A-A and line B-B, respectively, in Figure 21. Figures 21C and 21D show detail views of circle C in Figure 21A and circle D in Figure 21B, respectively. Figure 21E shows an isometric view of the assembled components of the modular IOL 210. Modular IOL 210 may be configured similar to a combination of modular IOL 190 shown in Figures 19-19D and modular IOL 170 shown in Figures 17-17C. Like modular IOL 190, modular IOL 210 includes a base 55 configured in the shape of an annulus or ring with a center opening and a recess defining a wall into which the correspondingly sized and shaped circular lens 65 may be placed. Like modular IOL 170, the wall defining the recess extends along the inside perimeter of the base 55, with a portion thereof milled down to define two diametrically opposed tabs 212. The inside circumferential walls of the tabs 212 provide for a flush joint 214 as seen in Figure 21C, such that the anterior surface of the lens 65 is flush with the anterior surface of the base 55. The interface of the joint 214 along the tabs 212 may be canted, "S" shaped, or "C" shaped as shown, for example. Elsewhere along the perimeter, away from the tabs 212, in the area where the wall is milled down, the perimeter edge of the lens 65 is exposed as seen in Figure 21D, to facilitate insertion and removal of the lens 65 by radial compression using forceps, for example.

[096] With reference to Figures 22-22D, an alternative modular IOL 220 is shown in front, sectional, and detailed views, respectively. Figure 22A shows a cross-sectional view taken along line A-A in Figure 22, Figure 22B a cross-sectional view taken along line B-B in Figure 22, Figure 22C shows a detail view of circle C in Figure 22A, and Figure 22D shows a detail view of circle D in Figure 22B. Modular IOL 220 includes a base 55 with associated haptics 59 and a lens 65. The base 55 includes a center hole such that the posterior optical surface of the lens 65 is not in contact with the base 55. The perimeter of the lens 65 is sized and shaped to fit in a circular recess formed in the base 55 to form a ledge on the base 55 and a flush joint 222. The flush joint 222 may be configured with an "S" shaped interface to securely connect the two components. A pair of pegs 224 extend anteriorly from the base 55 adjacent the inside perimeter thereof, and through a pair of arc-shaped slots 226 adjacent the perimeter of the lens 65. The arc-shaped slots may extend along a fraction of the circumference of the lens 65 as shown in Figure 22. With this arrangement, the lens 65 may be selectively rotated relative to the base 55 for purposes of rotational adjustment in toric applications, for example.

[097] The pegs 224 may be sized and configured to rise above the anterior surface of the lens 65 as shown in Figure 22C. Forceps or the like may be inserted posteriorly through the arc-shaped slots 226 in the lens 65 to grasp the pegs 224 like a handle, followed by applying posterior pressure to the lens 65 while holding the pegs 224 stationary. By holding the pegs 224 and thus stabilizing the base 55 during connection of the lens 65 to the base 55, anterior-posterior forces applied to the capsular bag are reduced, thereby reducing the risk of capsular rupture.

[098] As described herein, lens removal systems and methods for a lens 60/65 of a modular IOL are shown in the drawings by way of example and should be

understood to embody other modular IOL embodiments. Lens 60/65 may have dimensions as shown in the drawings by way of example, not necessarily limitation.

[099] With reference Figures 23A-23D, a lens removal system for a modular IOL according to an embodiment of the present disclosure is shown schematically. Figures 23A and 23B are side and top views, respectively, of the lens removal system. Figures 23C and 23D are top views showing how the lens removal system may be used to remove lens 60/65. The lens removal or extractor system may include a cannula 230 and a pair of forceps 235. The cannula 230 may include a lumen sized to slidably receive the forceps 235. The cannula 230 may include a tubular shaft portion 232 and a contoured distal opening 234. The cannula 230 may be formed and configured similar to conventional IOL insertion devices, for example. The forceps 235 include a pair of atraumatic grasping tips 237 and a tubular shaft 239. The tubular shaft 239 may be advanced to compress the tips 237 and grasp the lens 60/65. The forceps 235 may be formed and configured similar to conventional ophthalmology forceps, for example, except that the tips 237 may be formed of or covered by a relatively soft polymeric material to avoid damage to the lens 60/65. Generally, any devices used to manipulate the modular IOL components described herein may be formed of or covered by a relatively soft polymeric material to avoid damage to the components thereof.

[0100] With reference to Figures 23C and 23D, the cannula 230 may be inserted through a corneal incision until its distal end is adjacent the capsulorhexis. The forceps 235 may be inserted into and through the cannula 230, until the distal tips 237 extend distally beyond the distal end of the cannula 230. The lens 60/65 to be extracted may be grasped with the forceps 235 as shown in Figure 23C. With the lens 60/65 securely held by the forceps 235, the forceps 235 may be retracted

proximally into the cannula 230. As the forceps 235 are retracted into the cannula 230, the lens 60/65 enters the contoured opening 234. The contoured opening 234 encourages the edges of the lens 60/65 to roll and fold as seen in Figure 23D. Complete retraction of the forceps 235 into the cannula 230 thus captures the lens 60/65 safely in the lumen of the cannula 230 after which it may be removed from the eye. A similar approach may also be used to insert the lens 60/65, reversing the relevant steps.

[0101] In a related embodiment, surgical instruments may cut the lens 60/65 via a “peeling” mechanism. Figures 23E-23F show a lens removal system that may be used to remove a lens 60/65. The lens removal system may include a lens 60/65 of a modular IOL 290, a cannula 230, forceps 235, and a blade 650. The cannula 230 may be substantially similar to the cannula 230 described above and configured for insertion through a corneal incision 13, for example having an outer diameter less than 2.2mm. The cannula 230 may have an oval or rectangular cross-section to facilitate extraction of lens 60/65 while minimizing the size of the corneal incision. Cut path 610 is shown on the lens 60/65 of modular IOL 290. Cut path 610 may extend from the fixed tab 295, into the optic portion 297, and spiraling inward without reaching actuatable tab 296.

[0102] Figure 23G is a detailed view of the blade 650. The blade 650 may be a single sharp cutting surface of the cannula 230 (as shown) or a separate unit (not shown). As shown, forceps 235 extend distally from the cannula 230 in an open configuration.

[0103] In use, a lens 60/65 may be extracted from the capsular bag 34 and into the anterior chamber 15 using methods described herein. The cannula 230 may be inserted through a corneal incision 13 and into an anterior chamber 15 of an eye

10. The forceps 235 may be inserted into and through the cannula 230, until the distal tips 237 extend distally beyond the distal end of the cannula 230. Forceps 235 may securely grasp the lens 60/65. With the lens 60/65 securely held by the forceps 235, the forceps 235 may retract proximally into the cannula 230. As the forceps 235 are retracted into the cannula 230, the lens 60/65 may pass the blade 650, simultaneously slicing the lens 60/65 along the cut path 610. The lens 60/65 may rotate as it is cut by blade 650 and pulled into the lumen of the cannula 230. Retraction of the forceps 235 into the cannula 230 thus captures the lens 60/65 safely in the lumen of the cannula 230 after which it may be removed from the eye by pulling the cannula 230 out of the corneal incision 13. Since the cannula 230 has a maximum width less than the corneal incision 13, the cut lens 60/65 also has a maximum width less than the corneal incision 13. This lens extraction system and method may avoid harmful forces on the eye 10, for example harmful forces in the anterior-posterior direction that may damage the eye 10 and/or cause posterior rupture.

[0104] Figure 23H shows an alternative embodiment of a lens removal system that may be used to remove a lens 60/65. The lens removal system may include a lens 60/65 of a modular IOL 290, a cannula 230, blade 650, and curved grasper 240 having a curved upper arm 242 and a curved lower arm (not shown). The cannula 230 may be substantially similar to the cannula 230 described above and configured for insertion through a corneal incision 13, for example having an outer diameter less than 2.2mm. Cut path 610 is shown on the lens 60/65. Cut path 610 may extend from the fixed tab 295, into the optic portion 297, and spiraling inward without reaching actuatable tab 296.



[0105] The upper surface of the upper curved arm 242 and the lower surface of the lower curved arm (not shown) may both be generally smooth. The lower surface of the upper curved arm 242 and the upper surface of the lower curved arm (not shown) may both have surfaces configured to facilitate grasping, for example serrated surfaces. The serrated surfaces may have a plurality of teeth 246. The angle of teeth 246 may be configured with a proximal bias to further facilitate grasping the lens 60/65 during the cutting step and/or retraction.

[0106] The curved grasper 240 may be extendable and retractable relative to the cannula 230 and blade 650. In a retracted configuration, the curved grasper 240 may fit within the lumen of cannula 230. Upon extension from the cannula 230, the curved grasper 240 may curve and form a "hook" configuration, as shown in Figure 23H. Additionally, the upper curved arm 242 and lower curved arm may have a bias for an open configuration such that when the curved grasper 240 extends from the cannula 230, the curved arms separate into the open configuration while curving into the "hook" configuration. Accordingly, as the curved grasper 240 retracts into the cannula 230, the upper curved arm 242 and lower curved arm return to a closed or grasping configuration. The curved grasper 240 may be made of any suitable material to create this biased configuration of the curved grasper 240 when it is outside the cannula 230, for example, shape-memory polymers, non-shape-memory polymers, metals, alloys, stainless steel, heat-set nitinol, elastic materials, or super-elastic materials.

[0107] In use, this embodiment of a lens removal system functions similar to other disclosed embodiments. During grasping, the curved grasper 240 may extend distally from the cannula 230. Due to the bias of the curved grasper 240, upon extension, it forms a curved "hook" configuration and an open configuration. The

upper curved arm 242 and lower curved arm (not shown) may encompass the lens 60/65. The curved grasper 240 may be positioned to facilitate cutting along cut path 610. To initiate grasping, the cannula 230 may extend forward slightly or the curved grasper 240 may retract slightly such that the proximal teeth 246 begin to close around the lens 60/65 and the blade 650 approaches the lens 60/65. The curved grasper 240 may retract further such that the lens 60/65 is pulled into the blade 650, simultaneously slicing the lens 60/65 along the cut path 610.

[0108] As the curved grasper 240 retracts into the cannula 230, the teeth 246 are brought into contact with the lens 60/65. This may distribute the grasping forces along the length of the curved grasper 240. This may increase grip and prevent lens puncture and tearing. During the cut, the portion of lens 60/65 being cut at any given moment will be always adjacent to a portion of the lens 60/65 held by grasper 240. Grasping the lens 60/65 adjacent to the cut can provide a more stable cut, preventing the lens 60/65 from tearing, flexing, bowing, or crimping.

[0109] The lens 60/65 may rotate as it is cut by blade 650 and pulled into the lumen of the cannula 230. This embodiment permits the entire lens 60/65 to be retracted into the cannula 230 in one cutting step. Retraction of the grasper 240 into the cannula 230 thus captures the lens 60/65 safely in the lumen of the cannula 230 after which it may be removed from the eye by pulling the cannula 230 out of the corneal incision 13 using disclosed methods.

[0110] Figures 24-26 describe example methods of using modular IOLs according to embodiments of the present disclosure. Although described with reference to a primary lens and a secondary lens by way of example, not necessarily limitation, the same or similar methods may be applied other modular IOL

embodiments, including modular IOL embodiments described herein that comprise a base and a lens.

[0111] With reference to Figure 24, a method for using a modular IOL according to an embodiment of the present disclosure is shown in a schematic flow chart. In this example, the secondary lens may be exchanged in the event of a sub-optimal optical result detected intra-operatively. An IOL implant procedure, such as cataract surgery, may be started 110 according to conventional practice. The native lens may then be prepared 112 to receive a modular IOL using conventional steps such as making corneal access incisions, cutting the capsulorhexis in the anterior capsular bag and removing the cataract lens by phacoemulsification. The base lens (i.e., primary lens 50) is then placed 114 in the lens capsule. The secondary lens (i.e., secondary lens 60) is then placed 116 on the base lens within the perimeter of the capsulorhexis without touching or otherwise disturbing the capsular bag. The attachment means is then engaged 118 to releasably connect the secondary lens to the base lens. Alternatively, the secondary lens may be attached to the base lens before placement in the lens capsule, such that the base lens and the secondary lens are inserted together as a unit. With both the base lens and the secondary lens in place, the optical result may be measured 120, for example by intra-operative aberrometry. The optical result may take into consideration refractive correction, centricity, toric correction, etc. A decision 122 is then made as to whether the optical result is optimal or sub-optimal. If the optical result is optimal or otherwise adequate, the IOL procedure is completed 124. However, if the optical result is sub-optimal, inadequate and/or the patient is otherwise dissatisfied, the attachment means may be disengaged 126 and the secondary lens may be removed 128. A different secondary lens may be then placed 116 on the base lens, following the

same subsequent steps as shown. The different secondary lens may have, for example, a different refractive power to correct refractive error, a different offset to correct for decentration, or a different toric power to correct for toric error.

[0112] With reference to Figure 25, an alternative method for using a modular IOL according to an embodiment of the present disclosure is shown in a schematic flow chart. In this example, the secondary lens may be exchanged in the event of a sub-optimal optical result detected post-operatively. The same steps 110-118, and 124 may be performed as described previously, except that the patient is allowed to acclimate 130 to the modular IOL for a period of 1-4 weeks or more, for example. Upon a return visit, the optical result is measured 120 and a determination 122 is made as to whether the optical result is optimal or sub-optimal. If the optical result is optimal or otherwise adequate, the procedure is stopped 132. If the optical result is sub-optimal, inadequate and/or the patient is otherwise dissatisfied, a revision procedure may be initiated 134 to replace the secondary lens following steps 126, 128, 116 and 118 as described previously.

[0113] This method allows the lens capsule to heal before deciding whether the optical result is sufficient, which may be advantageous to the extent the healing process alters the position of the primary and/or secondary lens. This method may also be applied on a chronic basis, where the optical needs or desires of the patient change over the course of a longer period of time (e.g., > 1 year). In this example, the patient may require or desire a different correction such as a stronger refractive correction, a toric correction, or a multifocal correction, each of which may be addressed with a different secondary lens.

[0114] With reference to Figure 26, another alternative method for using a modular IOL according to an embodiment of the present disclosure is shown in a

schematic flow chart. In this example, the secondary lens may be implanted in a patient 138 having a pre-existing IOL that is optically sub-optimal or otherwise doesn't meet the needs and desires of the patient. After the procedure starts 110, an attachment mechanism may be formed in-situ in the pre-existing (base) IOL (step 140) using laser etching, for example, to form a groove as described previously. Formation of the groove may be performed within the perimeter of the previously cut capsulorhexis to avoid touching or otherwise disturbing the lens capsule. The secondary lens may then be placed 116 on the base lens within the perimeter of the capsulorhexis, and the attachment means may be engaged 118 to connect the secondary lens to the base lens, and the procedure may be completed 124 as described previously.

[0115] With reference to Figures 27-27D, an alternative modular IOL 270 is shown in front, sectional and detailed views, respectively. Figures 27A and 27B show cross-sectional views taken along line A-A and line B-B, respectively, in Figure 27. Figures 27C and 27D show detail views of circle C in Figure 27A and circle D in Figure 27B, respectively. Modular IOL 270 may be configured similar to modular IOL 210 shown in Figures 21-21D. Like modular IOL 210, modular IOL 270 includes a base 55 configured in the shape of an annulus or ring with a center opening and a recess defining a wall into which the correspondingly sized and shaped circular lens 65 may be placed. Also like modular IOL 210, the wall defining the recess extends along the inside perimeter of the base 55, with a portion thereof milled down to define two diametrically opposed tabs 272. The inside circumferential walls of the tabs 272 provide for a flush joint 274 as seen in Figure 27C, such that the anterior surface of the lens 65 is flush with the anterior surface of the base 55. The interface of the joint 274 along the tabs 272 may be canted, "S" shaped, or "C" shaped as

shown, for example. Elsewhere along the perimeter, away from the tabs 272, in the area where the wall is milled down, the perimeter edge of the lens 65 is exposed as seen in Figure 27D, to facilitate insertion and removal of the lens 65 by radial compression using forceps, for example.

[0116] Because the base 55 includes a center opening that is devoid of material, the base 55 may have a larger outside optic diameter (excluding haptics) of approximately 8mm, for example, and still be rolled into a delivery profile that is sufficiently small to fit through a corneal incision of less than approximately 2.4mm, for example. This may allow at least a portion of the junction between the base 55 and lens 65 to be moved radially outward away from the circumferential perimeter of the capsulorhexis, which typically has a diameter of 5-6mm. Moving at least a portion of the junction between the base 55 and the lens 65 radially outward from the perimeter of the capsulorhexis may reduce the amount of the junction that is in the field of view and thus reduce the potential for light scattering or optical aberrations (e.g., dysphotopsias) created thereby.

[0117] To further illustrate this advantage, consider a standard (single component) IOL, which typically has an optic diameter of conventional lenses is 6mm. An IOL with a 6mm diameter optic may be rolled and delivered through a 2.2mm corneal incision. In order to secure the standard IOL in the capsular bag, the capsulorhexis is typically sized to allow the capsular bag to fully capture the standard IOL after the bag collapses and heals down. This drives surgeons to form a capsulorhexis having a diameter of approximately 4.5mm to 5.5mm.

[0118] Now consider IOL 270 by comparison. The modular (two piece) nature of IOL 270 and the hole in the base 55 allow both components (base 55 and lens 65) to be rolled and delivered through a small corneal incision (e.g., 2.2mm), but don't

require a capsulorhexis of 4.5mm to 5.5mm. Rather, because the base has a diameter of 8mm (excluding haptics), the capsulorhexis diameter may be larger (e.g., 6.0mm to 6.5mm), which allows the lens 65 to comfortably fit inside the perimeter of the capsulorhexis and allows the junction 274 to be more peripheral to further minimize light scatter. Of course, notwithstanding these examples, any suitable dimensions may be selected to provide a gap between the lens 65 and the perimeter edge of the capsulorhexis in order to mitigate the need to manipulate the lens capsule to connect or disconnect the lens 65 to or from the base 55.

[0119] With reference to Figures 28A-28G, an alternative modular IOL 280 is shown. Modular IOL 280 may have dimensions as shown in the drawings by way of example, not necessarily limitation. Modular IOL 280 may be the same or similar in terms of functions and advantages as other modular IOL embodiments described herein. Modular IOL 280 provides an alternative interlocking feature used to connect the base and lens as described in more detail hereinafter.

[0120] Figures 28A-28D show the base portion 55 of the modular IOL 280, and Figures 28E-28G show the lens portion 65 of the modular IOL 280. Specifically, Figure 28A shows a front view of the base 55, Figure 28B shows a cross-sectional view taken along line B-B in Figure 28A, Figure 28C shows a cross-sectional view taken along line C-C in Figure 28A, and Figure 28D shows a perspective view of the base 55. Figure 28E shows a front view of the lens 65, Figure 28F shows a cross-sectional view taken along line F-F in Figure 28E, and Figure 28G shows a perspective view of the lens 65.

[0121] With specific reference to Figures 28A-28D, the base 55 portion of the modular IOL 280 includes a pair of haptics 54 and a center hole 57 such that all or a majority of the posterior optical surface of the lens 65 is not in contact with the base

55 when the lens 65 is attached to the base 55. A recessed ledge 282, which is sized and configured to receive the lens 65, defines the perimeter of the hole 57. The ledge 282 may include one or more keyed portions 284 that are sized and configured to receive tabs 286 on the lens 65.

[0122] With specific reference to Figures 28E-28G, the lens 65 includes an optic portion 287 and one or more tabs 286, each with a thru hole 288. Tabs 286 are sized to fit into the keyed portions 284 in the base. More particularly, the tabs 286 may be aligned with the opening (discontinuity of the ledge 282) in the keyed portion 284 and moved posteriorly to rest against a lower portion 283 of the ledge 282 within the keyed portion 284. A probe or similar device may be used to engage the hole 288 in the tab 286, and rotated (e.g., clockwise as shown) to slide the tab 286 in the keyed portion 284 until the tab 286 partially resides under an upper portion 285 of the ledge 282 within the keyed portion 284, thereby connecting the lens 65 to the base 55. Reverse steps may be followed to disconnect the lens 65 from the base 55.

[0123] With reference to Figures 29A-29F, an alternative modular IOL 290 is shown. Modular IOL 290 may have dimensions as shown in the drawings by way of example, not necessarily limitation. Modular IOL 290 may be the same or similar in terms of functions and advantages as other modular IOL embodiments described herein. Modular IOL 290 provides an alternative interlocking feature used to connect the base and lens as described in more detail hereinafter.

[0124] Figures 29A-29C show the base portion 55 of the modular IOL 290, and Figures 29D-29F show the lens portion 65 of the modular IOL 290. Specifically, Figure 29A shows a front view of the base 55 having a body portion, Figure 29B shows a cross-sectional view taken along line B-B in Figure 29A, and Figure 29C



shows a perspective view of the base 55. Figure 29D shows a front view of the lens 65, Figure 29E shows a cross-sectional view taken along line E-E in Figure 29D, and Figure 29F shows a perspective view of the lens 65. The base portion 55 may not have an optic portion, allowing lens 65 to be the sole optic portion of modular IOL 290.

[0125] With specific reference to Figures 29A-29C, the base 55 portion of the modular IOL 290 includes a pair of haptics 54 and a center hole 57 such that, except for the outermost portion, the posterior optical surface of the lens 65 is not in contact with the base 55 when the lens 65 is attached to the base 55. A recessed groove 292, which is sized and configured to receive tab portions 295 and 296 of the lens 65, defines the perimeter of the hole 57.

[0126] Recessed groove 292 includes a lower rim 291 and an upper rim 293. The upper rim 293 may have an inside diameter that is greater than the outside diameter of the lens 65 such that the lens 65 can rest inside the hole 57 of the base 55. All or a portion of the lower rim 291 may have an inside diameter that is less than the outside diameter of the lens 65 such that the lower rim 291 acts as a backstop for the lens 65 when placed in the hole 57 of the base 55. By way of example, not necessarily limitation, the upper rim 293 may have an inside diameter of about 6.0mm, the lower rim 291 may have an inside diameter of about 5.5mm, and the lens 65 may have a diameter or longitudinal dimension (including tabs 295 and 296) of about 7.125mm from the apex of tab 295 to the apex of tab 296, as shown in Fig. 29D. Further, the optical body portion 297 may have an outside diameter of about 5.8mm, as also shown in Fig. 29D. Further, as shown in Fig. 29B, the base may include a thickness of about 0.615mm. Also, the upper rim 293 may include a length of about 0.45mm. The lower rim 291 may include an anterior

surface having a length of about 0.55mm and a posterior surface having a length of about 0.75mm.

[0127] The lower 291 and upper 293 rims defining the groove 292 may extend continuously around all or a portion of the perimeter of the hole 57. Alternatively, the lower 291 and upper 293 rims defining the groove 292 may extend discontinuously around all or a portion of the perimeter of the hole 57. An example of a discontinuous arrangement is alternating segments of the lower 291 and upper 293 rims, which may lend itself well to cryo-machining the base 55 in a single part. As shown, the base 55 may be cryo-machined in two parts, including lower or posterior portion 55A and upper or anterior portion 55B, that are subsequently bonded (e.g., adhesive or solvent bond), which may lend itself well to defining a continuous groove 292. To maintain chemical and mechanical property compatibility, the adhesive and the parts 55A/55B of the base 55 may comprise the same monomeric or polymeric formulation. For example, the adhesive may be formulated from the same acrylic monomers used in making the hydrophobic acrylic parts 55A/55B of the base 55. Alternative manufacturing methods well known in the art may also be employed.

[0128] Optionally, the base posterior portion 55A may be a solid disc, rather than an annular ring with a hole 57, thereby defining a posterior surface against which the posterior side of the lens 65 would contact. The posterior surface may be flat or curved to conform to the posterior contour of the lens 65. This may have the advantage of providing a backstop for the lens 65 thereby making delivery and positioning of the lens 65 in the base 55 easier. This may also provide the advantage of reducing the rate of posterior capsular opacification.

[0129] With specific reference to Figures 29D-29F, the lens 65 of the modular IOL 290 includes an optical body portion 297 (also referred to herein as "optic

portion”) and one or more tabs 295 and 296. As shown in Fig. 29E, tab 296 may include a thickness of about 0.25mm, and optic portion 297 may include a maximum thickness of about 0.78 mm. The thickness of optic portion 297 may taper to tabs 295 and 296. As shown, tab 295 is fixed, whereas tab 296 may be actuated. As an alternative, fixed tab 295 may be replaced with an actuatable tab (e.g., like tab 296). Fixed tab 295 may include a thru hole 298 so that a probe or similar device may be used to engage the hole 298 and manipulate the tab 295. Hole 298 may include a diameter of about 0.231mm. Actuatable tab 296 may be actuated between a compressed position for delivery into the hole 57 of the base 55, and an uncompressed extended position (shown) for deployment into the groove 292 of the base 55, thus forming an interlocking connection between the base 55 and the lens 65.

[0130] The outside curvature of the fixed tab 295 may have a radius conforming the inside radius of the groove 292. Similarly, the outside curvature of the actuatable tab 296 may have a radius that conforms to the inside radius of the groove 292 when the actuatable tab 296 is in its uncompressed extended position. This arrangement limits relative movement between the base 55 and the lens 65 once connected.

[0131] Optionally, the lens 65 may be oval or ellipsoidal, rather than circular, with the tabs 295 and 296 positioned adjacent the long axis. This arrangement would thus define a gap between the edge of the lens 65 along its short axis and the inside perimeter of the upper rim 293 of the groove 292 in the base 55. The gap may have the advantage of providing access for a probe or similar device to pry apart the lens 65 from the base 55 if separation were needed.

[0132] Actuatable tab 296 may be attached to and extend from the lens 65 at two ends with the middle portion free of the lens 65 (like a leaf spring) as shown. Alternatively, actuatable tab 296 may be attached to and extend from the lens 65 at one end with the other end free (like a cantilever spring). Other spring configurations may be employed as known in the mechanical arts.

[0133] The actuatable tab 296 may elastically deform (e.g., by application of an inward lateral force) to its compressed position. To facilitate low force compression, a dimple 299 may be provided on the outside (and/or inside) curvature of the tab to form a hinge in the spring.

[0134] Figures 29A2-29E2 show an alternative base portion 55 of the modular IOL 290. Specifically, Figure 29A2 shows a front view of the base 55, Figure 29B2 shows a cross-sectional view taken along line B-B in Figure 29A2, Figure 29C2 shows a perspective view of the base 55, Figure 29D2 shows a detail view of circle D in Figure 29B2, and Figure 29E2 shows a detail view of circle E in Figure 29A2. In this alternative embodiment, all aspects of the base 55 of the modular IOL 290 are substantially the same except for the provision of a pair of cutouts 291A, a pair of notches 293A, and sharp edge 291B.

[0135] By way of example, not necessarily limitation, the following dimensions are provided. In Figure 29A2, diameter A1 may be  $13.00 \pm 0.02$  mm, diameter A2 may be  $8.50 \pm 0.10$  mm, diameter A3 may be  $7.00 \pm 0.051$  mm, diameter A4 may be  $6.30 \pm 0.051$  mm, diameter A5 may be  $5.50 +0.15/-0.05$  mm, and diameter A6 may be 7.92 mm. In Figure 29B2, dimension B1 may be  $0.615 \pm 0.020$  mm. In Figure 29D2, dimension D1 may be 0.15 mm, dimension D2 may be 0.17 mm, dimension D3 may be 0.75 mm, dimension D4 may be 0.35 mm, dimension D5 may be 0.08 mm, and dimension D6 may be  $0.30 \pm 0.02$  mm. In Figure 29E2, dimension E1

(width of cutouts 291A) may be 1.48 mm, dimension E2 (diameter at outer edge of notches 293A) may be 6.62 mm, dimension E3 (inside diameter of upper rim 293) may be 6.25 mm, and dimension E4 (radian of cutouts 291A) may be approximately 30 degrees.

[0136] As in the prior embodiment, the base 55 portion of the modular IOL 290 in this alternative embodiment includes a pair of haptics 54 and a center hole 57 such that, except for the outermost portion, the posterior optical surface of the lens 65 is not in contact with the base 55 when the lens 65 is attached to the base 55. A recessed groove 292, which is sized and configured to receive tab portions 295 and 296 of the lens 65, defines the perimeter of the hole 57. The recessed groove 292 includes a lower rim 291 and an upper rim 293.

[0137] In this alternative embodiment of the base 55 of modular IOL 290, the lower rim 291 may include one or more cutouts 291A, which aid in removing visco-elastic intra-operatively. Also in this alternative embodiment, the upper rim 293 may include one or more notches 293A to provide access for a Sinsky hook intra-operatively, which allows the base 55 to be more easily manipulated. Further in this embodiment, the lower rim 291 (or posterior side of base 55) may include at least one corner edge 291B along its posterior perimeter to reduce the tendency for posterior capsular opacification. The corner edge 291B may be in addition to corner edges formed along the anterior perimeter and the outside perimeter of the base 55. For example, in the embodiment shown, the base 55 includes two edges along the outside perimeter, one anterior perimeter edge, and one posterior perimeter edge 291B. In cross-section, the corner edge 291B may be defined by a square angle, an acute angle, or an obtuse angle. The corner edge 291B may be flush with the

posterior surface as shown, or may protrude posteriorly. The base 55 may be machined without subsequent tumbling to better form the edge 291B.

[0138] Note with reference Figures 29B, 29B2 and 29E that the lower rim 291 and the upper rim 293 may define an anterior-posterior (AP) dimension around the perimeter of the base 55 that is greater than the corresponding AP dimension of the optic 65 adjacent the tabs 295, 296 that fit into groove 292. For example, the AP dimension of the perimeter of the base 55 may be 0.615mm as shown in Figures 29B and 29B2, and the corresponding AP dimension of the optic 65 adjacent the tabs 295, 296 may be 0.25mm as shown in Figure 29E. When the modular IOL 290 is implanted in the capsular bag, these relative dimensions provide a standoff between the posterior capsule and the posterior side of the optic 65, as well as a standoff between the anterior capsule adjacent the capsulorhexis (sometimes call anterior leaflets) and the anterior side of the optic. This standoff reduces the likelihood of cellular proliferation and the potential for resulting opacification of the optic 65 and/or tissue adhesion to the optic 65 that might otherwise interfere with post-operative optic exchange. Because such cellular proliferation typically grows radially inward, the standoff may be provided adjacent the perimeter of the optic 55 adjacent the inside circumference of the lower and upper rims 291, 293, whereas the center of the optic may or may not have a standoff, with an AP dimension that is less than, the same as or greater than the AP dimension around the perimeter of the base 55. For example, the center of the optic may have an AP dimension of 0.78mm as shown in Figure 29E (depending on the diopter), which is greater than the AP dimension of the perimeter of the base 55 at 0.615mm as shown in Figures 29B and 29B2. Additionally, the lower (posterior) rim 291 may have a greater AP dimension than the upper (anterior) rim 293 recognizing the cellular proliferation may be more

likely on the posterior side than the anterior side due to the presence of the capsulorhexis on the anterior side and the corresponding lower tissue contact area on the anterior side. Those skilled in the art will recognize the importance of the relative dimensions to achieve this effect rather than the specific dimensions, which are provided by way of example, not necessarily limitation.

[0139] With specific reference to Figures 29G-29J, implantation of a modular IOL 290 is illustrated. As shown in Figure 29G, the modular IOL 290 may be implanted by initially delivering the base 55 into the capsular bag in a rolled configuration using a delivery tube inserted through a corneal incision 13, through the capsulorhexis 36, and into the capsular bag 34. As shown in Figure 29H, the base 55 may be ejected from the delivery tube and allowed to unfurl. With gentle manipulation, the haptics 54 of the base 55 engage the inside equator of the lens capsule 34 and center the hole 57 of the base 55 relative to the capsulorhexis 36.

[0140] The lens 65 may also be delivered in a rolled configuration using a delivery tube, positioning the distal tip thereof adjacent the base 55. The lens 65 may be ejected from the delivery tube and allowed to unfurl. With gentle manipulation, the lens 65 is centered relative to the capsulorhexis 36. Once the base 55 has been delivered and unfurled in the capsular bag, the lens 65 may be connected to the base 55 via an attachment mechanism 70. Modular IOL 290 uses tabs 295/296 and groove 292 to provide an interlocking connection between the base 55 and the lens 65, comprising attachment mechanism 70.

[0141] As shown in Figures 29I-29J, the lens 65 may be connected to the base 55 by first inserting the actuatable tab 296 into the groove 292. The actuatable tab 296 may then be compressed by application of a lateral force using a probe or similar device inserted into hole 298 of fixed tab 295, allowing the lens 65 to be

advanced into the hole 57 of the base 55 such that the lens 65 and base 55 are coplanar.

[0142] The compressive force may then be released from the actuatable tab 296, allowing the fixed tab 295 to slide into the groove 292 of the base 55, thus connecting the lens 65 to the base 55. By using a lateral force to compress the interlocking feature rather than an anterior-posterior force, the risk of posterior rupture of the capsular bag is reduced. The probe may be removed from hole 298. Reverse steps may be followed to disconnect the lens 65 from the base 55.

[0143] The actuatable tab 296 and groove 292 may be described as interlocking members that provide an interlocking connection between the base 55 and the lens 65, wherein at least one of the pair of interlocking members is actuatable to lock or unlock the connection therebetween. More generally, one or more interlocking connections may be provided between the base and lens. Each interlocking connection may include a pair of interlocking members, wherein one or both of the interlocking members are actuatable. The actuatable interlocking member may be associated with the lens as described with reference modular IOL 290 in Figures 29A-29F. Alternatively, the actuatable interlocking member may be associated with the base 55 as described with reference to modular IOL 300 shown in Figures 30A-30B.

[0144] Removing a lens, for example the lens 60/65, may present a challenge. The lens 60/65 may be detached from the primary component or base as described herein, yet if the diameter of the unfurled lens 60/65 is greater than the width of the corneal incision, removal through the corneal incision may risk increasing the width of the corneal incision. This may increase the risk of damage to the cornea (or sclera if a scleral incision is used) and the likelihood of negative post-operative results. On



the other hand, reducing the width of the lens 60/65, for example by re-furling, may also require substantial manipulation and risk damage to the capsular bag or the eye generally. Disclosed herein are lens removal methods and tools to allow removal of a lens 60/65 without increasing the width of the corneal incision and without damage to the eye or capsular bag. The lens removal methods and tools may be configured to minimize anterior-posterior forces and torque on the lens to prevent trauma or damage to the eye. The methods and tools may also avoid generating fragments, debris, or jagged edges.

[0145] Lens removal begins by disengaging a lens 60/65 from a base 50/55. As shown in Figure 29K, a probe or similar device may pass through the corneal incision 13, capsulorhexis 36, and enter the capsular bag 34 containing a modular IOL, for example modular IOL 290. As shown in Figure 29L, the probe or similar device may engage the hole 298 of fixed tab 295 and compress the actuatable tab 296 by application of a lateral force. Upon compression, fixed tab 295 may separate from groove 292 of the base 50/55. With gentle manipulation, the lens 60/65 may be lifted such that the lens 60/65 and base 50/55 are no longer coplanar. Once freed, the compressive force may then be released and the actuatable tab 296 may elastically expand and separate from the groove 292 of the base 50/55.

[0146] As shown in Figure 29M, the probe or similar device may be used to pass the lens 60/65 from the capsular bag 34 into the anterior chamber 15. This step does not damage the eye or expand the size of the capsulorhexis 36 because the width of the lens 60/65 is less than the width of the capsulorhexis 36. The probe or similar device may also rotate the lens 60/65 into an orientation where the fixed tab 295 is proximal to the corneal incision 13 and the actuatable tab 296 is distal to the corneal incision 13.

[0147] A typical corneal incision 13 may have a width of about 2.2mm, less than the outer diameter of the lens 60/65. Removing the lens 60/65 from the anterior chamber 15 through the corneal incision 13 may thus require mechanical manipulation of the lens 60/65. The lens 60/65 may be manipulated, for example cut, such that it can be pulled through the corneal incision, either as a single piece or in multiple pieces. A cannula or delivery tube may facilitate this removal.

[0148] Figures 30A-30B show an alternative modular IOL 300 including a base 55 and a lens 65. Figure 30A shows a front view of the base 55, and Figure 30B shows a perspective view of the lens 65. The base 55 may include a center hole 57 and a pair of haptics 54 as described previously. Base 55 may also include one or more actuatable tabs 302 sized and configured to fit within a groove 304 in the lens 65. As shown, base 55 includes a pair of actuatable tabs 302, although one of the tabs may be fixed (i.e., not actuatable). Lens 65 includes an optical portion 307 and one or more grooves 304 defined by lower 303 and upper 305 rims. Because the lens 65 may be relatively thin around the perimeter where the groove 304 resides, the groove 304 may be defined by extending the lower 303 and upper 305 rims as shown. As may be appreciated by those skilled in the art, the actuatable tabs 302 and grooves 304 in this embodiment may be the same or similar to the actuatable tab 296 and groove 292 described in the previous embodiment, including the same or similar function, use, variants and advantages.

[0149] With reference to Figures 31A-31B, a lens removal or extractor system 310 for a modular IOL according to an embodiment of the present disclosure is shown schematically. Figure 31A shows a perspective view of the extractor system 310 with the lens 60/65 captured, and Figure 31B shows a perspective view of the extractor system 310 with the lens 60/65 transected. The extractor system 310 is

shown in a foreshortened view for purposes of illustration only. The length and diameter of the extractor system 310 may be selected for manual operation through a conventional corneal incision, such as the dimensions of a conventional lens cartridge.

[0150] The extractor system includes a handle 314 and a sleeve 312 extending distally therefrom. The sleeve 312 is hollow inside and includes a tongue extension 313 to support the lens 60/65.

[0151] A grabber 316 extends distally from the sleeve 312 and is retractable therein by an actuating member (not shown) extending proximally through the handle 314. The grabber 316 may include a distal hook, forceps or other mechanism to engage and pull the lens 60/65. In this example, the grabber 316 engages the distal (opposite) edge of the lens 60/65. Alternatively, micro forceps may be used to grasp the proximal edge of the lens 60/65, or a sharp instrument may be used to penetrate the anterior surface of the lens 60/65 near the proximal edge. This can be done safely as the sharp point is introduced through the sleeve 312 and the extended tongue 313 protects eye anatomy.

[0152] A pair of blades 318 may extend slightly beyond the distal end of the sleeve 312 on opposite sides of the proximal end of the tongue extension 313 as shown. Using blade actuator 319, the blades 318 may be advanced for cutting as shown in Figure 31A or retracted into sleeve 312 for no cutting as shown in Figure 31B.

[0153] In use, with the lens 60/65 removed from the base in the capsular bag (not shown) and resident in the anterior chamber, the sleeve 312 may be inserted through the corneal incision, and the tongue extension 313 may be positioned under the lens 60/65 to be extracted. The grabber 316 may then be advanced over the

lens 60/65. With the blades 318 extended for cutting, the grabber 316 may be retracted into the sleeve 312 to form cuts in the lens 60/65 that divide the lens into a center section and two lateral sections. The grabber 316 may be retracted until the cuts extend partially (e.g., 80%) across the diameter of the lens, thus retaining a connection between the center section and the two lateral sections. At this point, the blades 318 may be retracted using actuator 319. The grabber 316 may then be retracted further, causing the center section of the lens 60/65 to be pulled into the sleeve 312 and the lateral sections of the lens 60/65 to flip or rotate. Further retraction of the grabber 316 causes the lateral sections of the lens 60/65 to overlap and follow the center section into the sleeve 312. The extractor system 310 may then be removed from the corneal incision, and the lens 60/65 is thus extracted from the eye. The extractor system 310 may also be used to extract other optics, including optics with haptics, where the haptics follow the lateral sections into the sleeve.

[0154] With reference to Figures 31C-31F, a related embodiment of a lens removal or extractor system 310 for a modular IOL is shown schematically. Figure 31C shows a detailed perspective view of the extractor system 310 with the lens 60/65 captured. Figure 31D shows a detailed perspective view of the extractor system 310 with an extendable tongue 313 partially retracted and a lens 60/65 partially cut by a pair of blades 318. Figure 31E shows a perspective view of the extractor system 310 with a center portion of lens 60/65 extracted into the lumen of hollow sleeve 312 and with the remaining "horseshoe-shaped" lens 60/65 grasped between the sleeve 312 and the extendable tongue 313. Figure 31F shows a schematic view of lens 60/65 after a center portion has been cut out and extracted. The length and diameter of the extractor system 310 may be selected for manual

operation through a conventional corneal incision, such as the dimensions of a conventional lens cartridge.

[0155] The extractor system 310 may include a hollow cannula 312 with a pair of distally facing blades 318. The hollow cannula 312 may be sized and configured to extend through a corneal incision without increasing the size of the incision. The hollow cannula 312 may have an oval or rectangular cross-section to facilitate extraction of lens 60/65 while minimizing the size of the corneal incision. The hollow cannula 312 may be formed of a rigid material and the blades 318 may be formed by sharpening the distal lateral edges of the cannula 312 with the cutting edges formed on the inside of the cannula wall to avoid cutting ocular tissue as it is passed through the corneal incision. The extractor system 310 may also include an extendable tongue 313 disposed in and extendable beyond the distal end of the hollow cannula 312. The distal tip of the extendable tongue 313 may form a grabber 316, for example a distal hook, forceps, or other mechanism to engage the lens 60/65.

[0156] The extendable tongue 313 may be configured to extend beyond the distal end of the cannula 312 and engage a far edge of the lens 60/65 in an extended position, and retract fully into the sleeve 312 in a retracted position. In the retracted position, the grabber 316 at the distal tip of the extendable tongue 313 may protrude slightly from the sleeve 312. In an extended configuration (as shown), the extendable tongue 313 may provide a support surface for the lens 60/65 as it is being cut. The grabber 316 may engage the lens 60/65 through the hole formed between optic portion 297 and actuatable tab 296 of modular IOL 290.

[0157] The tongue 313 moves relative to the hollow cannula 312 and pair of blades 318, such that retraction of the tongue 313 towards the blades 318 may be functionally equivalent to extension of the blades 318 towards the tongue 313. This

embodiment discloses cutting via retraction of the tongue 313 but should be understood to include extension of the blades 318.

[0158] In use, the lens 60/65 may be removed from the base in the capsular bag (not shown) and resident in the anterior chamber using methods described herein. The sleeve 312 may be inserted through the corneal incision 13 with the extendable tongue 313 in a retracted position. The extendable tongue 313 may be extended under (posterior to) the lens 60/65 and the grabber 316 may engage the lens 60/65 through the hole formed between optic portion 297 and actuatable tab 296 of modular IOL 290. For viewing purposes, the extendable tongue 313 is shown below (posterior to) the lens 60/65, though it could also extend above the lens 60/65, or both above and below the lens 60/65.

[0159] As the extendable tongue 313 is retracted into the cannula 312, the lens 60/65 is pulled along with and the pair of blades 318 and cuts the lens along parallel cut paths 330. The cuts may extend from the fixed tab 295 on the proximal side of lens 60/65, through the optic portion 297, and to the space between the optic portion 297 and actuatable tab 296. The lens 60/65 is thus cut into two or more pieces. For example, as shown in Figures 31E-31F, the lens 60/65 may be cut into two pieces, with the center piece drawn into the hollow sleeve 312 and the remaining two "lobes" remaining in the anterior chamber. Thus, after cutting, the actuatable tab 296 may act as a connector for the two residual "lobes" of the lens 60/65. This may facilitate removal from the eye because only a single connected piece remains in the anterior chamber after cutting. Furthermore, the notch 299 on actuatable tab 296 may act as a flexible point of rotation such that the two "lobes" may flex and rotate relative to one another, for example, during subsequent extraction from the eye.

Alternatively, if the cut paths 330 were rotated ninety degrees relative to the lens 60/65, the lens 60/65 would be cut into three pieces.

[0160] The blades 318 may be spaced apart to cut approximately one-third the diameter of the lens 60/65 to define three segments of roughly equal width that is less than the width of the corneal incision. For example, the segments may have a width of less than 2.0mm to be removed through a 2.2mm corneal incision. The width between the blades 318 may be defined by the width of the cannula 312, which is sized for insertion through the corneal incision without increasing the size of the incision. Thus, each of the three segments is also sized for removal through the corneal incision without increasing the size of the incision. The segments may be removed serially in individual pieces or interconnected pieces using an uncut portion of the lens 60/65 to connect the pieces. As shown, a generally rectangular-shaped center portion is cut (first segment) leaving a horseshoe-shaped portion 340 (second and third segment or "lobes" connected by actuatable tab 296). By way of example, not necessarily limitation, the following dimensions are provided. In Fig. 31F, dimension  $F_1$  may be 1.950 mm and dimension  $F_2$  may be 1.900 mm.

[0161] A notch or other feature in the lens 60/65 may help to position the extendable pair of blades 318 on the center of the lens. For example, the space between the optic portion 297 and the actuatable tab 296 may be sized such that lateral motion of the grabber 316 is restricted, centering the extractor system 310 relative to the lens 60/65.

[0162] The cutting step may apply substantially balanced forces (minimal to no net force) on the lens 60/65. The blades 318 may apply forces on the lens 60/65 as it cuts. These forces may be opposed by bracing forces applied by the extendable tongue 313 and grabber 316. This minimizes or avoids net forces on the lens 60/65,

preventing trauma and damage to the capsular bag. Alternative cutting mechanisms are possible. A pair of circular blades ("pizza cutters") attached to an extendable arm and configured to roll along cut path 330 may replace blades 318. In another embodiment, the pair of blades 318 may cut the lens 60/65 by applying a downward compressive force ("cookie cutter"), balanced by an upward compressive force from the extendable tongue 313.

[0163] After cutting the lens 60/65, the extendable tongue 313 may retract into the sleeve 312, extracting the center portion into the sleeve 312. The extractor system 310 may then grasp the horseshoe portion 340 between the grabber 316 and the upper or lower edges of the cannula between the blades 318, as shown in Figure 31E. The extractor system 310 may be pulled from the eye through the corneal incision 13, thereby removing the lens 60/65. Alternatively, a forceps or other appropriate surgical tool may grasp the horseshoe portion 340 and extract it from the anterior chamber 15 of the eye through the corneal incision 13. The horseshoe portion 340 may flex as it is extracted, similar to the extraction shown in Figure 32D. The extractor system 310 may also be used to extract other optics, including optics with haptics, where the haptics follow the lateral sections into the sleeve.

[0164] With specific reference to Figures 31G-31N, an alternative embodiment of a lens removal or extractor system 310 for a modular IOL is shown schematically. Figure 31G shows a detailed perspective view of the extractor system 310 with the lens 60/65 captured by an extendable/retractable grabber 320. Figure 31H shows a detailed perspective view of the extractor system 310 with an extendable/retractable hollow cannula 312 fully extended relative to grasper 320 that is grasping a lens 60/65 cut by a pair of blades 318. Figure 31I shows a transparent view of the extractor system 310. Figure 31J shows a zoom-in view of the extendable/retractable



grasper 320 with lens 60/65 captured. Figure 31K shows a zoom-in view of the grasper 320 in fully retracted and closed configuration within hollow cannula 312. Figure 31L shows a zoom-in view of the grasper 320 in fully extended and open configuration outside of hollow cannula 312. Figure 31M shows a related embodiment of a grasper 320 having a rectangular cross-section. Figure 31N shows a related embodiment of a grasper 320 having four prongs. The length and diameter of the extractor system 310 may be selected for manual operation through a conventional corneal incision, such as the dimensions of a conventional lens cartridge.

[0165] As shown in Figures 31G-31H, the extractor system 310 has an extendable/retractable hollow cannula 312 having a pair of distally facing blades 318 at the distal end and a circular base 360 at the proximal end. The hollow cannula 312 may have an oval or rectangular cross-section to facilitate extraction of lens 60/65 while minimizing the size of the corneal incision. The extractor system 310 has an extendable/retractable grasper 320 that can extend and retract relative to hollow cannula. The grasper 320 is connected to a "T-shaped" handle 350 such that when the handle 350 slides distally or proximally, the grasper 320 extends distally or proximally, respectively. As shown in Figure 31I, a spring 370 facilitates the extension/retraction of the cannula 312 relative to the grasper 320. The spring 370 is located proximal to handle 350 and distal to circular base 360 and is configured to bias the grasper 320 in an extended configuration and the cannula 312 in a retracted configuration.

[0166] As shown in Figure 31J, the grabber 320 has an upper arm 322 and a lower arm 324. The top surface of the upper arm 322 and the bottom surface of the lower arm 324 are both generally smooth. The bottom surface of the upper arm 322

and the top surface of the lower arm 324 may both have surfaces configured to facilitate grasping, for example serrated surfaces. The serrated surface may have a plurality of teeth 326. The angle of teeth 326 may be configured with a proximal bias to further facilitate grasping the lens 60/65 during cutting and/or retraction.

[0167] The grabber 320 may articulate between an open configuration and a closed grasping configuration. As shown in Figure 31K, when the grabber 320 is fully retracted within the cannula 312, it is in a closed configuration with the upper arm 322 having a slight downward angle such that the distal end of the upper arm 322 touches the distal end of lower arm 324. This pinched tip may facilitate corneal entry.

[0168] As shown in Figure 31L, when the grabber 320 is fully extended from the cannula 312, it articulates to an open configuration. In the open configuration, the upper arm 322 has two flex points 328 that bias the upper arm 322 into the open configuration when the cannula 312 is retracted. The lower arm 324 remains flat and parallel to the cannula 312. In this open configuration, the distal portion of upper arm 322 is parallel to lower arm 324 and the opening is wide enough to accommodate a lens 60/65. This parallel-arm open configuration allows a maximum number of serrated teeth 326 to contact the lens 60/65 simultaneously when the cannula 312 and blade 318 extend to close the grabber 320. This also minimizes the opening distance which keeps the upper arm 322 and lower arm 324 away from the cornea while still allowing the lens 60/65 to slide into the opening. The grabber 320 may be made of any suitable material to create this biased configuration of the upper arm 322 when it is outside the cannula 312, for example, shape-memory polymers, non-shape-memory polymers, metals, alloys, stainless steel, heat-set nitinol, elastic materials, or super-elastic materials.

[0169] As shown in Figure 31M, the grabber 320 may have a rectangular cross-section. As shown in Figure 31N, the grabber 320 may have four prongs, two upper prongs 322 and two lower prongs 324. These embodiments of the grabber 320 function almost identically to previously disclosed grabber 320.

[0170] In use, the lens 60/65 may be removed from the base in the capsular bag (not shown) and resident in the anterior chamber using methods described herein. The cannula 312 may be inserted through the corneal incision 13 with the "T-shaped" handle 350 in a proximal configuration and, accordingly, the grasper 320 retracted within the cannula 312, as shown in Figure 31K. The handle 350 may be slowly released and the spring 370 may extend the grasper 320 out from the distal end of cannula 312. The upper arm 322 and lower arm 324 may open into a parallel configuration. The grasper 320 may encompass the lens 60/65, as shown in Figure 31L.

[0171] During the cutting step, it may be preferable to extend the cannula 312 and blades 318 distally towards the lens, as opposed to pulling the grasper 320 proximally towards the blades 318, because it prevents the lens 60/65 from hitting the angle of the eye and keeps the lens 60/65 centered in a user's view. The grasper 320 may remain stationary while the spring 370 is compressed by handle 350, extending cannula 312 and blades 318 towards the lens 60/65. As the cannula 312 extends distally, it encompasses the grabber 320, closing the upper arm 322 and lower arm 324 around the lens 60/65. As the grabber 320 closes, a maximum number of serrated teeth 326 contact the lens 60/65 simultaneously to increase grip. As blades 318 cut into the lens 60/65, the grabber 320 is directly adjacent to the blades 318. Gripping the lens 60/65 directly adjacent to the blades 318 as they cut

provides stability, preventing the lens 60/65 from tearing, twisting, bowing, or crimping.

[0172] The cannula 312 and blades 318 may continue to extend towards the distal end of the lens 60/65 along cut path 330. As shown in Figure 31F, the cut path 330 may extend from the fixed tab 295 on the proximal side of lens 60/65, through the optic portion 297, and to the space between the optic portion 297 and actuatable tab 296. As described previously, after cutting, the actuatable tab 296 may act as a connector for the two residual "lobes" of the lens 60/65. This may facilitate removal from the eye because only a single piece remains in the anterior chamber. Furthermore, the notch 299 on actuatable tab 296 may act as a flexible point of rotation such that the two "lobes" may flex and rotate relative to one another, for example, during extraction from the eye.

[0173] As shown in Figure 31I, after the cut is complete, the handle 350 has compressed spring 370 and the grasper 320 is retracted within the cannula 312 along with the center portion of lens 60/65. The extractor system 310 may be removed from the anterior chamber and eye, simultaneously removing the center cut portion of lens 60/65. The remaining portion or portions of lens 340 may be removed from the eye using disclosed methods.

[0174] In another embodiment, the lens 60/65 of an IOL may be removed from the eye 10 in multiple pieces using a surgical punch 430 cutting tool. As shown in Figure 32A, the surgical punch 430 may be scissors-like, having a proximal spring 475 to bias the punch in the normally open position, a proximal handle region 480, a distal hinge 470, and a distal narrow punch 440. The distal narrow punch 440 may be configured to fit within a corneal incision, for example having tapered shape with a cross-sectional width of less than about 2.2mm. This may facilitate insertion of the

distal narrow punch 440 through the corneal incision 13 and into the anterior chamber 15.

[0175] The distal narrow punch portion 440 may have an inner blade 450 and an outer blade 460 attached at the distal hinge 470. The inner blade 450 and outer blade 460 may be configured to separate from one another in a “jaw-like” manner. The inner blade 450 may be configured to fit inside the outer blade 460 such that when the surgical punch is compressed, any material caught between the inner blade 450 and outer blade 460 is cut out, for example a center portion of a lens 60/65. The shape of the cut in the material may be substantially similar to the shape of the inner blade 450 that overlaps the material when cut. An inner blade shaft 455 may extend proximally from the inner blade 450. An outer blade shaft 465 may extend proximally from the outer blade 460. Inner blade shaft 455 and outer blade shaft 465 may each have a gripping region 485 and connect at the proximal hinge 475.

[0176] As shown in Figure 32B, the distal narrow punch 440 of surgical punch 430 may enter the anterior chamber 15 through a corneal incision 13 and grasp a lens 60/65 of an IOL 290. The distal narrow punch 440 may enter the anterior chamber 15 in a compressed or closed configuration. Once inside the anterior chamber 15, the surgical punch may expand to an “open jaw” configuration where the inner blade 450 and outer blade 460 can be configured to encompass a center portion of the lens 60/65. The surgical punch 430 may be compressed, closing the “jaw” of the narrow punch portion 440 and returning the inner blade 450 and outer blade 460 to a closed configuration. This compression may cut the center portion of the lens 60/65. Compression of the surgical punch 430 may apply opposing forces on the lens 60/65 such that the forces applied to the lens 60/65 are balanced (i.e., no

net force on the lens 60/65). Thus, compression does not apply substantial force in the anterior or posterior directions and does not damage the capsular bag.

[0177] The surgical punch 430 may be extracted from the anterior chamber 15 via the corneal incision 13. The center portion of the lens 60/65, having substantially the same shape as a portion of the inner blade 450, may also fit through the corneal incision 13. Thus, as the surgical punch 430 is extracted, the center portion may be simultaneously extracted from the anterior chamber 15 through the corneal incision 13. Alternatively, the center portion may be extracted from the anterior chamber 15 through the corneal incision 13 with another appropriate surgical instrument, for example forceps 235 having a pair of atraumatic grasping tips 237 and a tubular shaft 239, as described previously.

[0178] With specific reference to Figure 32C, a modular IOL 290 is shown with a center portion removed, leaving behind a concave horseshoe portion 420 of the lens 60/65. Both the center portion and the remaining horseshoe portion 420 of the lens 60/65 may be narrow enough at all points to fit through the corneal incision, for example less than 2.0mm in width at all points. The center portion may comprise portions of fixed tab 295, hole 298, and optic portion 297. It may be preferable for the center portion to include portions of the fixed tab 295, as opposed to portions of actuatable tab 296. Cutting the actuatable tab 296 with a surgical punch 430 may create a small third piece comprising a fragment of the actuatable tab 296, possibly containing the dimple 299. Such a fragment may be difficult to see or extract. Thus, in this embodiment, the center portion extends past the halfway point of the optic 297, but does not extend to actuatable tab 296. By way of example, not necessarily limitation, the following dimensions are provided. In Fig. 32C dimension  $C_1$  may be

5.8mm, dimension  $C_2$  may be 0.75mm, dimension  $C_3$  may be 1.69mm, and dimension  $C_4$  may be 6.92mm.

[0179] As shown in Figure 32D, the horseshoe portion 420 of the lens 60/65 may be removed through the corneal incision 13. The width of the horseshoe portion 420 at any point may be less than the width of the corneal incision, for example 2.0mm. This may be referred to as a maximum width of 2.0mm. Thus, the horseshoe portion 420 may be narrow enough at all points to fit through the corneal incision (typically 2.2mm) without increasing its size. Forceps 235 may be inserted through the corneal incision, into the anterior chamber 15, and used to grasp the horseshoe portion 420 of the lens 60/65. With gentle manipulation, the forceps 235 may rotate and pull the horseshoe portion 420 of the lens 60/65 out of the anterior chamber 15 through the corneal incision 13. Special care may be taken such that extraction of the horseshoe portion 420 of the lens 60/65 does not enlarge the corneal incision 13. After extraction, the base 50/55 of modular IOL 290 may remain in the capsular bag 34.

[0180] In another embodiment, a cutting instrument may be used to produce a curved cut 510 ("spiral cut") in the lens 60/65 while the lens 60/65 remains one unit and is not cut into multiple pieces. With specific reference to Figure 33A, a modular IOL 290 is shown having a curved cut 510. As shown, the curved cut 510 may extend from the fixed tab 295, into the optic portion 297, past the halfway point of the optic 297, but not extend to actuable tab 296. The curved cut 510 may bisect the hole 298 of fixed tab 295 of the lens 60/65.

[0181] The curved cut 510 may be configured on the lens 60/65 such that the distance from any point on the curved cut 510 to the nearest point on the perimeter of lens 60/65 is less than the width of the corneal incision 13, for example less than

2.0mm. This may be referred to as a maximum width of 2.0mm. This may facilitate extraction of the lens 60/65 having curved cut 510 from the anterior chamber 15 through the corneal incision 13 (typically 2.2mm).

[0182] The curved cut 510 may be created using any appropriate cutting tool, for example a curved micro-scissors 530 having a distal cutting portion 540 shown in Figure 33B. Figure 33B is a detailed schematic of the distal cutting portion 540. The distal cutting portion 540 of the curved micro-scissors 530 may have an inner blade 550 and an outer blade 560 attached at the distal hinge 570. The distal cutting portion 540 may be configured to fit within a corneal incision 13, for example having a cross-sectional width of less than about 2.0mm. This may facilitate insertion of the distal cutting portion 540 through the corneal incision 13 and into the anterior chamber 15. Proximal to the distal cutting portion 540 is a body portion (not shown) that may be substantially similar to the proximal handle region 480 of surgical punch 430, including a distal hinge.

[0183] The inner blade 550 and outer blade 560 may be configured to open and close in a "jaw-like" manner. Similar to the blades of an ordinary pair of scissors, the inner blade 550 and outer blade 560 may be configured to cut any material caught between the blades when the curved micro-scissors 530 is compressed or closed. As shown in Figure 33C, the curved micro-scissors 530 may make a curved cut 510 in a lens 60/65 where the cut path is substantially similar to the shape between the inner blade 550 and outer blade 560.

[0184] Compression of the curved micro-scissors 530 may apply opposing forces on the lens 60/65 such that forces applied to the lens 60/65 are balanced (i.e., the net force on the lens 60/65 is approximately zero). Additionally, the curvature of the curved micro-scissors 530 also avoids unwanted torque or rotation of the lens



60/65. Whereas a straight scissors may apply a torque to a lens as it cuts causing rotation of the lens, any torque on the lens 60/65 from the inner blade 550 and outer blade 560 is counterbalanced by an equal opposite torque on the lens 60/65 at another point of contact on the curved blades. Thus, cutting the lens 60/65 does not apply substantial force or torque in the anterior or posterior directions and does not damage the capsular bag.

[0185] Referring again to Figure 33C, the curved micro-scissors 530 is shown grasping a lens 60/65 of an IOL 290. This configuration could be within the anterior chamber 15 of an eye 10 having a corneal incision 13. Using the methods described above with reference to a surgical punch 430, the distal cutting portion 540 of curved micro-scissors 530 may be partially inserted through a corneal incision 13 and into the anterior chamber 15. Since the cross-sectional width of the distal curved blades 540 is less than the width of the corneal incision 13, the size of the corneal incision 13 is unchanged.

[0186] The distal cutting portion 540 may enter the anterior chamber 15 in a closed configuration. Once inside the anterior chamber 15, the inner blade 550 and outer blade 560 may open into an expanded configuration for cutting the lens 60/65 along curved cut path 510. The distal cutting portion 540 may compress and close on the lens 60/65 to create curved cut 510, beginning by cutting the fixed tab 295, extending into the optic portion 297 past the halfway point, then curving back towards the fixed tab 295 without reaching the actuatable tab 296. Curved cut 510 may bisect hole 298 in fixed tab 295.

[0187] After cutting the lens 60/65, the curved micro-scissors 530 may be extracted from the anterior chamber 15 via the corneal incision 13. The lens 60/65 with curved cut 510 may be extracted from the anterior chamber 15 through the

corneal incision 13 with an appropriate surgical instrument, for example forceps 235 having a pair of atraumatic grasping tips 237 and a tubular shaft 239, as described previously.

[0188] As the lens 60/65 is extracted, it may extend into a helical configuration. Similar to the extended horseshoe configuration of Figure 32D, Figure 33D shows a lens 60/65 having curved cut 510 in an extended helical configuration. The lens 60/65 may extend in a helical manner during extraction from the anterior chamber 15 through the corneal incision 13. The lens 60/65 achieves this helical configuration when a pulling force is applied to either a proximal grasping point 515 or a distal grasping point 520.

[0189] Forceps 235 may be inserted through the corneal incision 13, into the anterior chamber 15, and used to grasp the lens 60/65, for example at the proximal grasping point 515 or distal grasping point 520. With gentle manipulation, the forceps 235 may rotate and pull the lens 60/65 with curved cut 510 out of the anterior chamber 15 through the corneal incision 13. Special care may be taken such that extraction of the lens 60/65 does not enlarge the corneal incision 13. As described above, the lens 60/65 with curved cut 510 may be narrow enough at all points to fit through the corneal incision. The distance from any point on the curved cut 510 to the nearest perimeter point of the lens 60/65 may be less than the width of the corneal incision 13, for example less than 2.0mm. This may be referred to as a maximum width of less than 2.0mm.

[0190] The foregoing discussion of the invention has been presented for purposes of illustration and description. The foregoing is not intended to limit the invention to the form or forms disclosed herein. Although the description of the invention has included description of one or more embodiments and certain

variations and modifications, other variations and modifications are within the scope of the invention, e.g., as may be within the skill and knowledge of those in the art, after understanding the present disclosure. It is intended to obtain rights which include alternative embodiments to the extent permitted, including alternate, interchangeable and/or equivalent structures, functions, ranges or steps to those claimed, whether or not such alternate, interchangeable and/or equivalent structures, functions, ranges or steps are disclosed herein, and without intending to publicly dedicate any patentable subject matter.

**CLAIMS**We claim:

1. A method for removing an intraocular lens disposed in a lens capsule of an eye having an anterior chamber, comprising:
  - a. moving the intraocular lens from the lens capsule to the anterior chamber;
  - b. inserting a cutting tool into the anterior chamber;
  - c. making a single cut motion with the cutting tool to form two spaced-apart cut lines in the intraocular lens to form cut pieces; and
  - d. removing the cut pieces from the eye.
2. A method as in claim 1, wherein forming the two spaced-apart cut lines forms first, second and third cut pieces.
3. A method as in claim 2, wherein the second and third cut pieces are connected by an uncut portion of the intraocular lens to form a hinge between the second and third cut pieces.
4. A method as in claim 1, wherein the intraocular lens and the cut pieces have a lateral width, and wherein the lateral width of the cut pieces is less than half the lateral width of the optic portion.
5. A method as in claim 1, wherein the two spaced-apart cut lines are made by spaced apart blades of the cutting tool.

6. A method as in claim 1, wherein the two spaced-apart cut lines are made simultaneously.
7. A method as in claim 1, further comprising: grasping the intraocular lens with the cutting tool before cutting the intraocular lens.
8. A method as in claim 1 wherein the intraocular lens includes an optic portion connected to a base portion, further comprising: disengaging the optic portion from the base portion within the lens capsule; moving the optic portion from the lens capsule to the anterior chamber while leaving the base portion in the lens capsule; and forming the spaced-apart cut lines in the optic portion.
9. A method for removing an intraocular lens disposed in an eye, comprising:
  - a. displacing the intraocular lens within the eye;
  - b. inserting a cutting tool into the eye;
  - c. cutting the intraocular lens with the cutting tool to form a central cut portion extending between opposing first and second lateral cut portions, wherein the central cut portion is separated from the first lateral cut portion by a first cut line formed by the cutting tool, and from the second lateral cut portion by a second cut line formed by the cutting tool; and
  - d. removing the cut portions of the intraocular lens from the eye.
10. A method as in claim 9, wherein cutting fully separates the central cut portion from the opposing first and second lateral cut portions.

11. A method as in claim 10, wherein cutting leaves the opposing first and second lateral cut portions coupled to each other.

12. A method as in claim 9, wherein cutting leaves at least a portion of the central cut portion coupled to at least one of the opposing first and second lateral cut portions.

13. A method as in claim 9, wherein cutting forms the first and second cut lines simultaneously.

14. A method as in claim 9, wherein cutting forms parallel first and second cut lines.

15. A method as in claim 9, wherein cutting forms a single continuous cut line that includes the first and second cut lines.

16. A method as in claim 15, wherein a first end of the single continuous cut line is at a perimeter of the intraocular lens.

17. A method as in claim 16, wherein a second end of the single continuous cut line is spaced apart from the perimeter of the intraocular lens.

18. A method as in claim 16, wherein a second end of the single continuous cut line is at the perimeter of the intraocular lens.

19. A method for removing an intraocular lens disposed in a lens capsule of an eye having an anterior chamber, comprising:

- a. moving the intraocular lens from the lens capsule to the anterior chamber;
- b. inserting a cutting tool into the anterior chamber;
- c. actuating the cutting tool to bring a blade assembly into engagement with the intraocular lens, and to maintain the engagement between the blade assembly and the intraocular lens as the blade assembly forms spaced-apart first and second cut lines in the intraocular lens; and
- d. removing the intraocular lens from the eye.

20. A method as in claim 19, wherein actuating the cutting tool includes grasping the intraocular lens with a grasper and drawing the intraocular lens toward the blade assembly with the grasper.

21. A method as in claim 20, wherein actuating the cutting tool forms the spaced-apart first and second cut lines simultaneously.

22. A method as in claim 19, wherein the spaced-apart first and second cut lines provide the intraocular lens with a central region extending between opposing first and second lateral regions, and the central region is separated from the first lateral region by the first cut line and from the second lateral region by the second cut line.

23. A method as in claim 19, wherein bringing the blade assembly into engagement with the intraocular lens includes bringing a first blade of the blade

assembly into engagement with a first edge portion of the intraocular lens, and bringing a second blade of the blade assembly into engagement with a second edge portion of the intraocular lens, the first edge portion being spaced apart from the second edge portion.

24. A method as in claim 19, wherein actuating the cutting tool includes bringing a first blade of the blade assembly into engagement with an anterior surface of the intraocular lens, and bringing a second blade of the blade assembly into engagement with a posterior surface of the intraocular lens.

25. An apparatus for cutting an intraocular lens, comprising:

- a. at least one blade configured to cut the intraocular lens;
- b. an actuation assembly movable relative to the at least one blade, wherein the actuation assembly is configured to bring the blade into engagement with the intraocular lens to cut the intraocular lens, and to keep the blade in engagement with the intraocular lens while the blade forms spaced-apart cut lines in the intraocular lens.

26. An apparatus as in claim 25, wherein the at least one blade includes first and second blades.

27. An apparatus as in claim 26, wherein the first and second blades are fixed relative to each other.

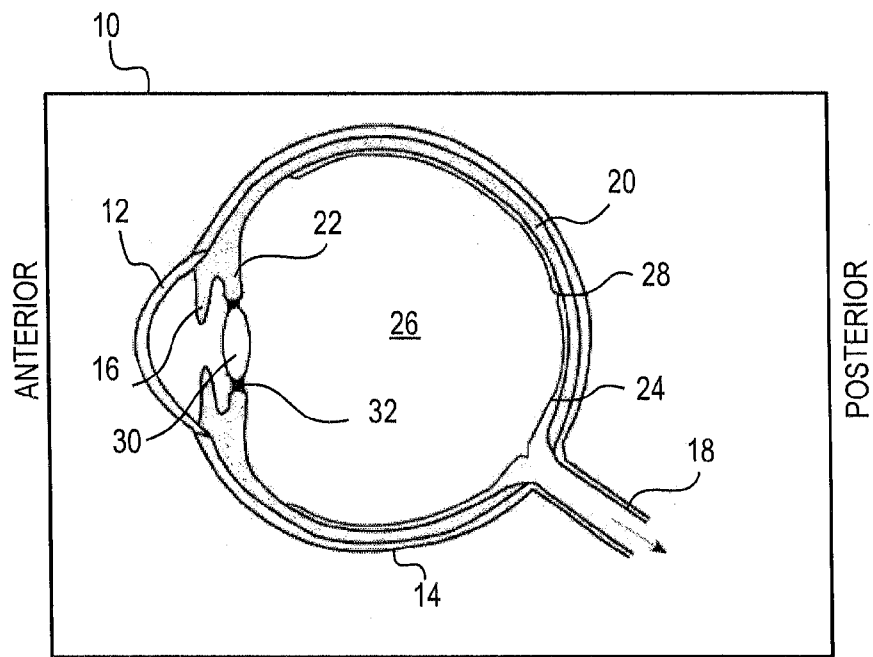


28. An apparatus as in claim 26, wherein one of the first and second blades is movable relative to the other of the first and second blades.

29. An apparatus as in claim 25, further including a sleeve, wherein the at least one blade is at an end of the sleeve.

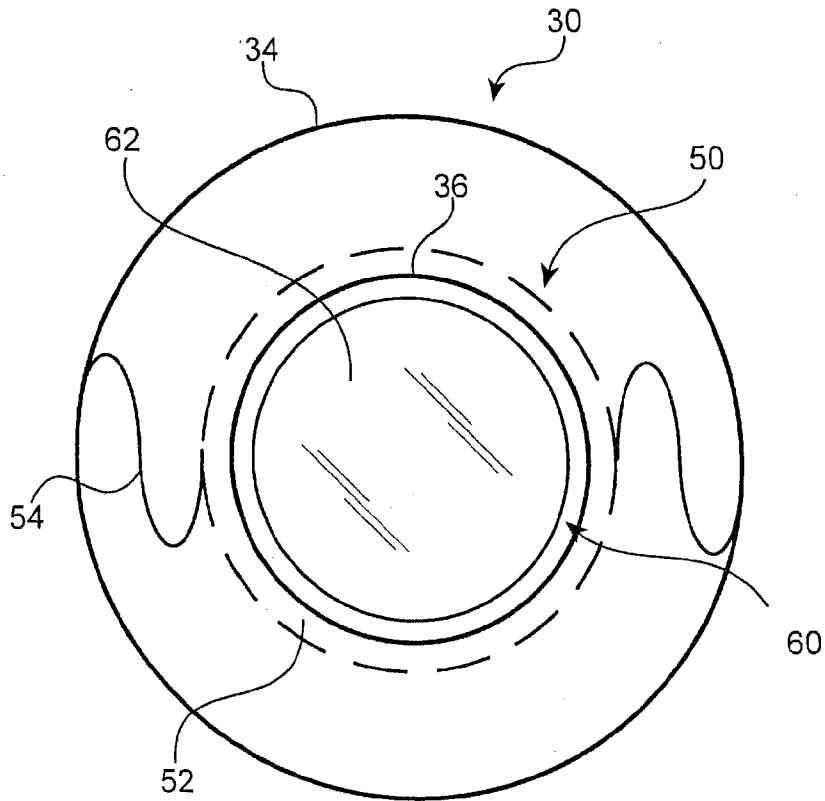
30. An apparatus as in claim 25, wherein the actuation assembly includes a grasper configured to grasp the intraocular lens.

31. An apparatus as in claim 30, wherein the grasper is selectively extendable out of and retractable into an end portion of the sleeve.

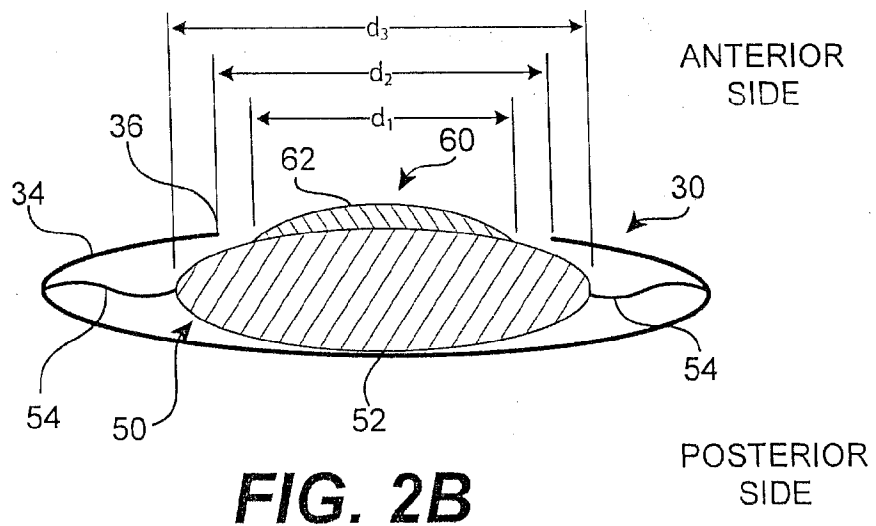


**FIG. 1**

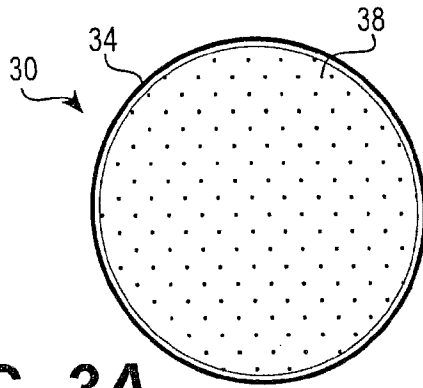
2/66



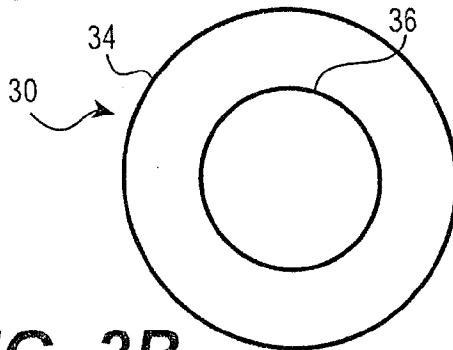
**FIG. 2A**



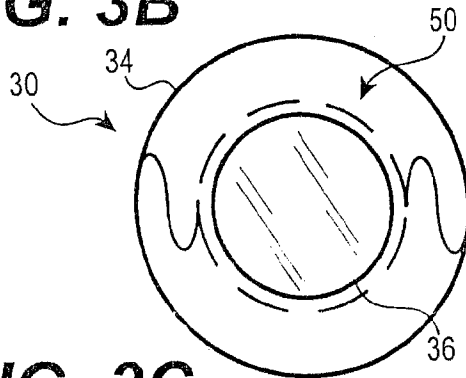
**FIG. 2B**



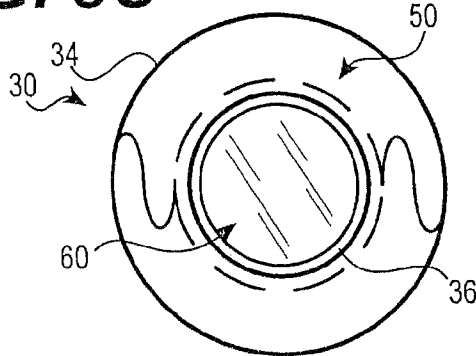
**FIG. 3A**



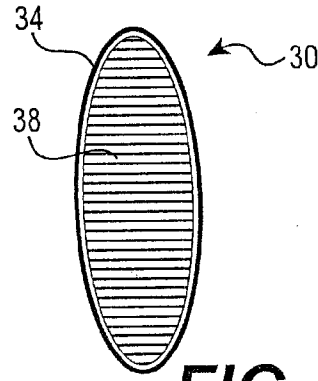
**FIG. 3B**



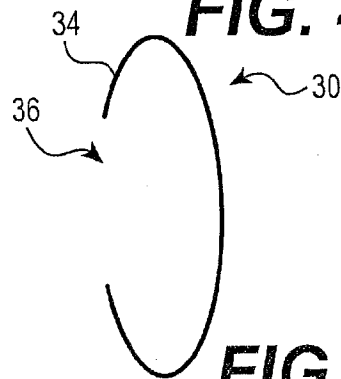
**FIG. 3C**



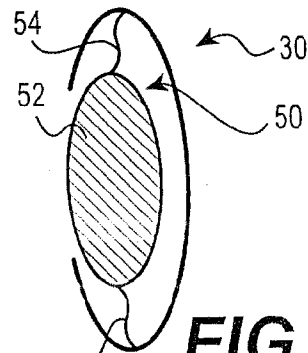
**FIG. 3D**



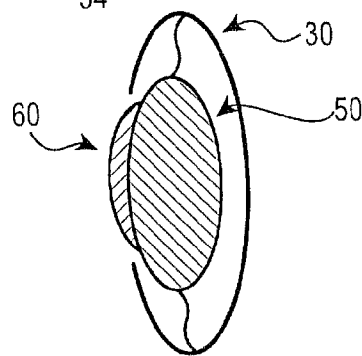
**FIG. 4A**



**FIG. 4B**

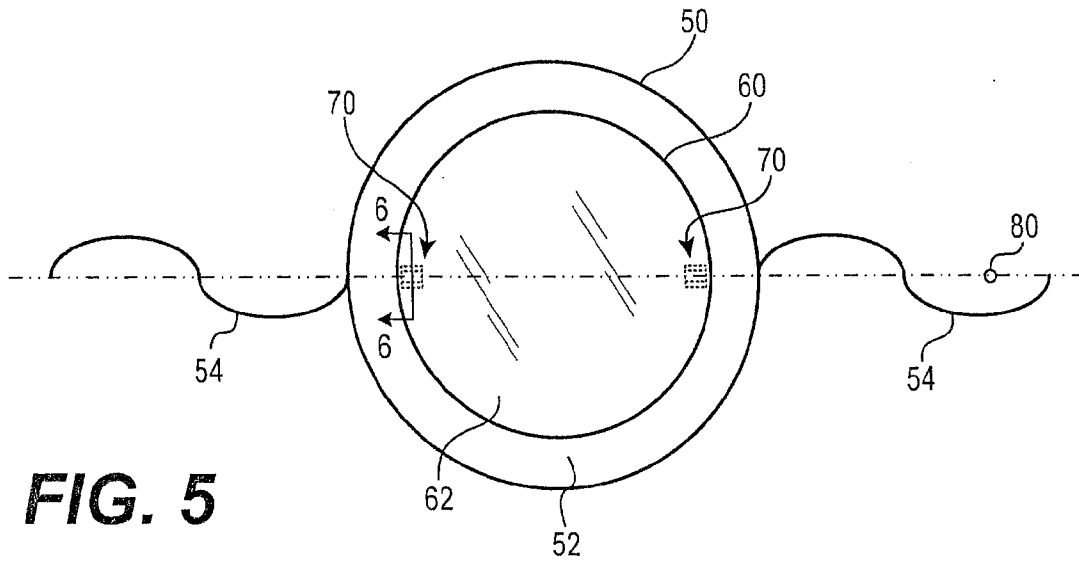


**FIG. 4C**

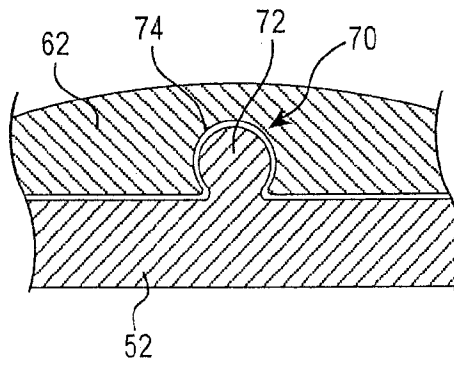


**FIG. 4D**

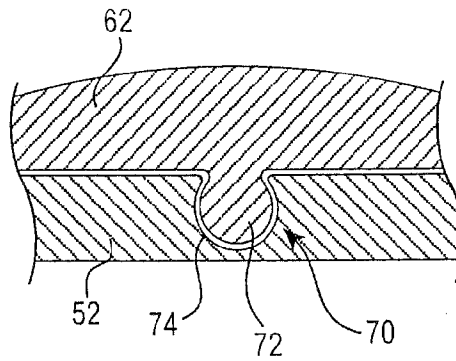
4/66



**FIG. 5**

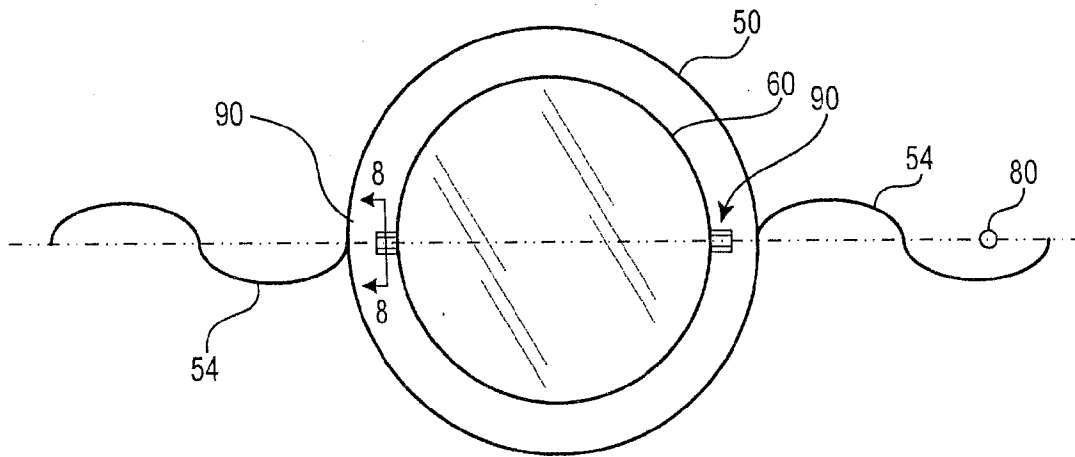


**FIG. 6A**

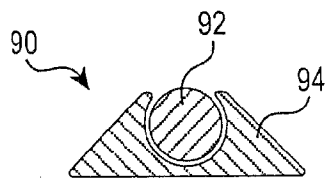


**FIG. 6B**

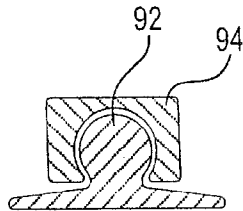
5/66



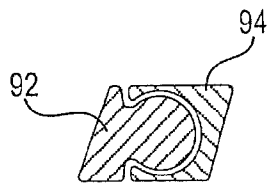
**FIG. 7**



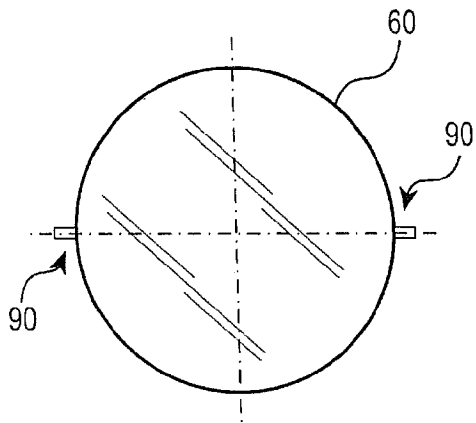
**FIG. 8A**



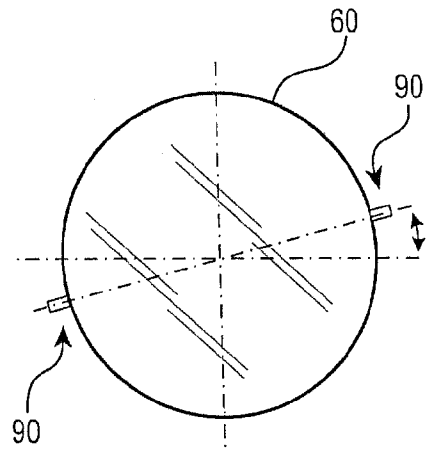
**FIG. 8B**



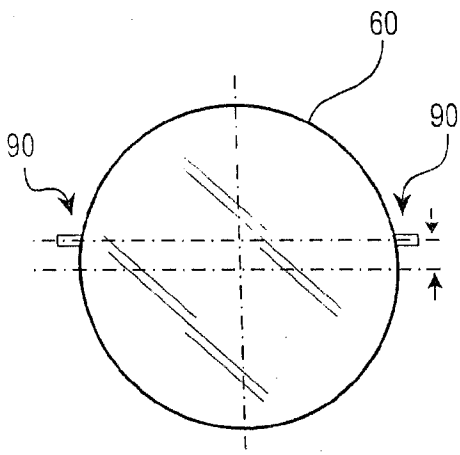
**FIG. 8C**



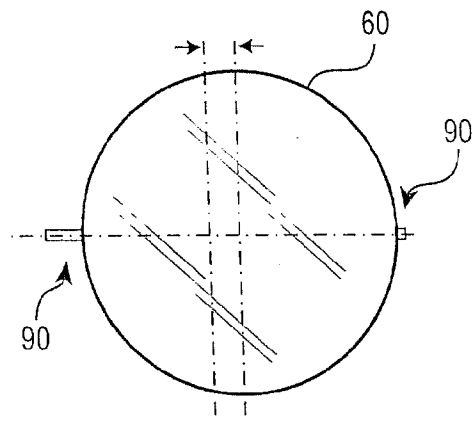
**FIG. 9A**



**FIG. 9B**

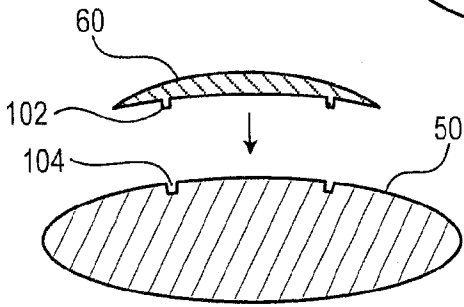
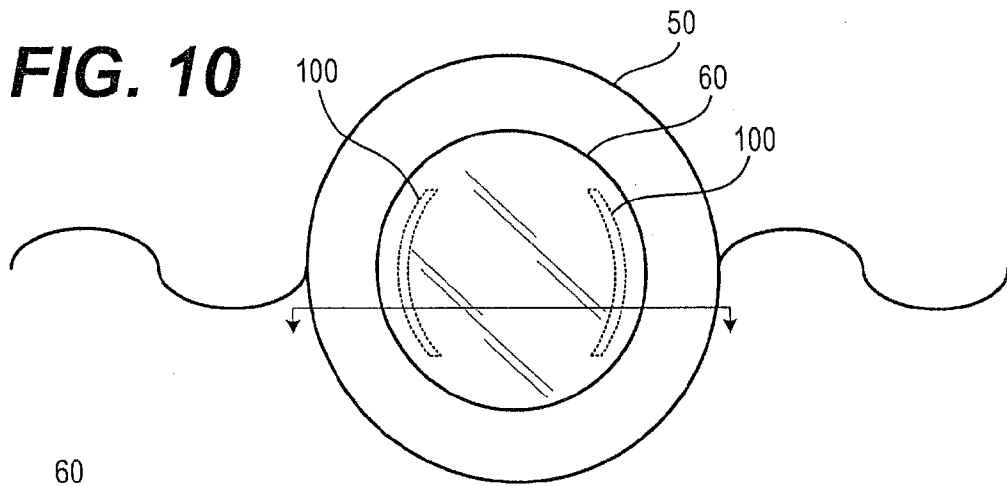


**FIG. 9C**

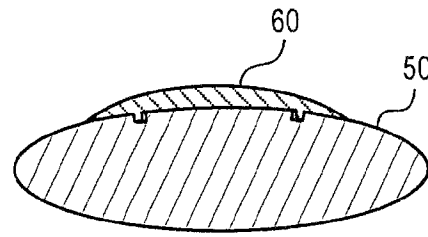


**FIG. 9D**

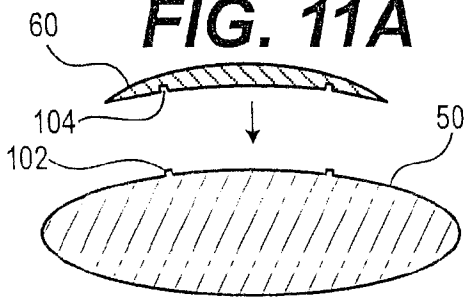
7/66



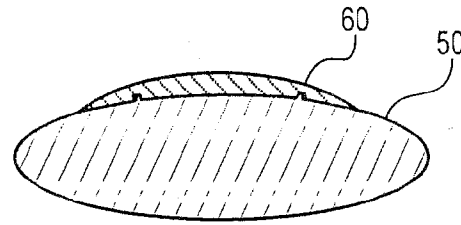
**FIG. 11A**



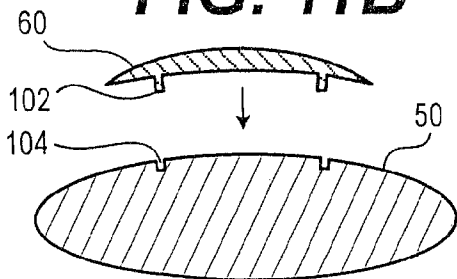
**FIG. 11D**



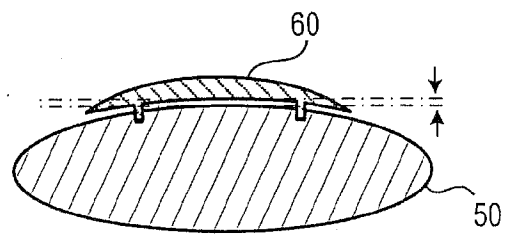
**FIG. 11B**



**FIG. 11E**



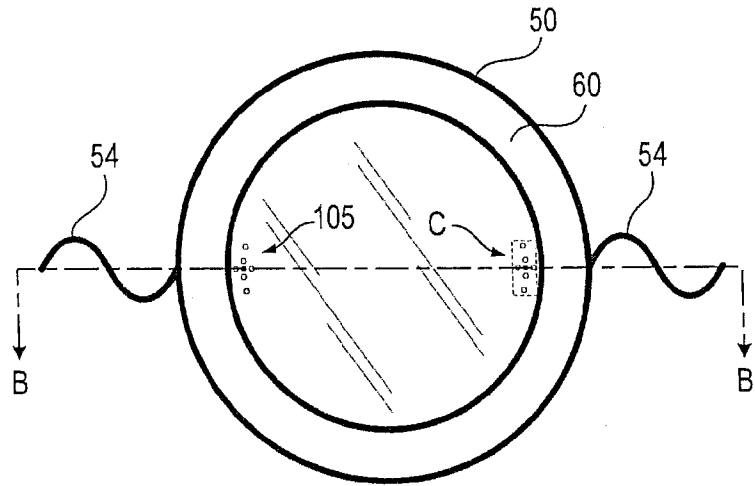
**FIG. 11C**



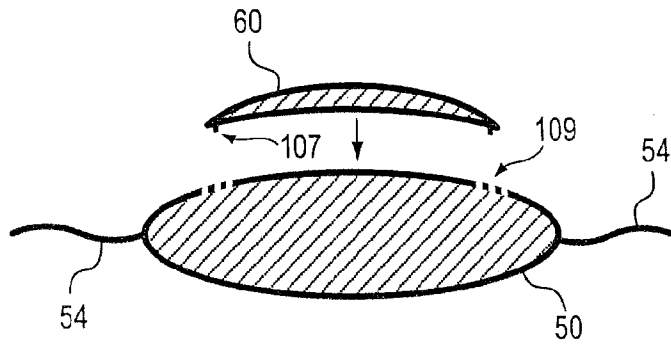
**FIG. 11F**



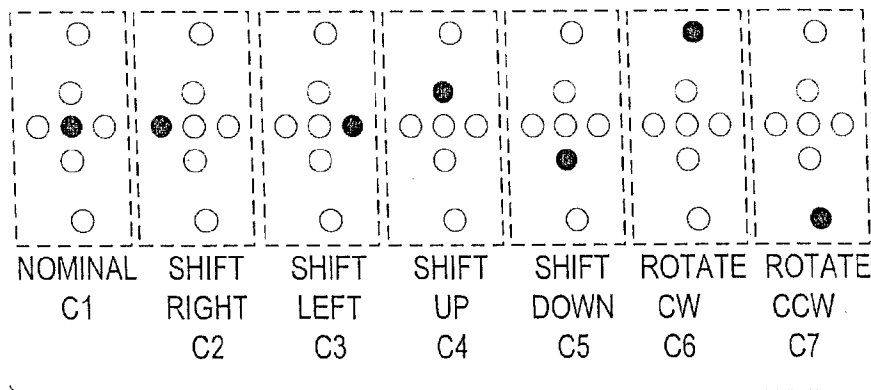
8/66



**FIG. 12A**

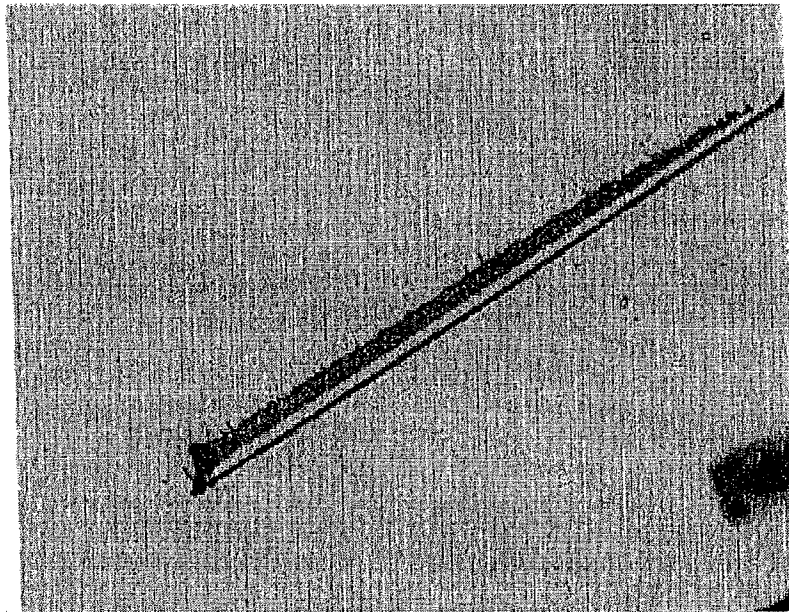


**FIG. 12B**

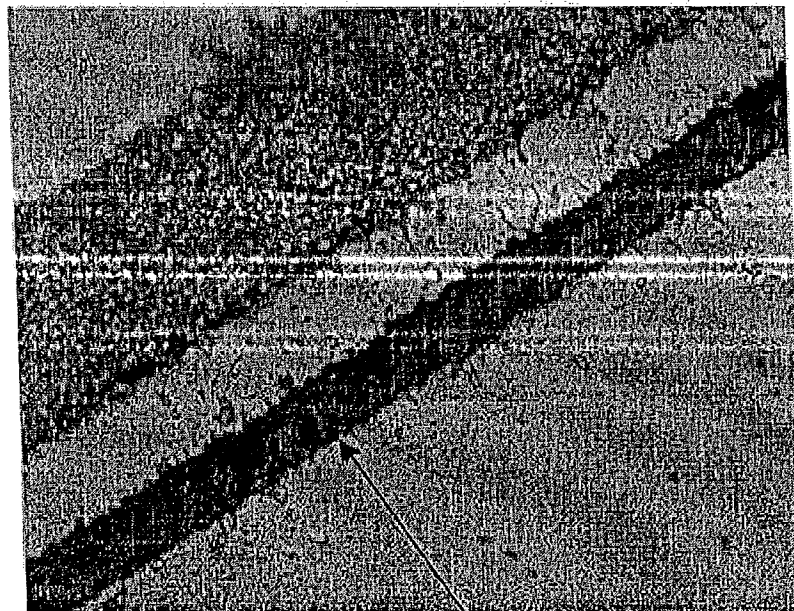


**FIG. 12C**

9/66



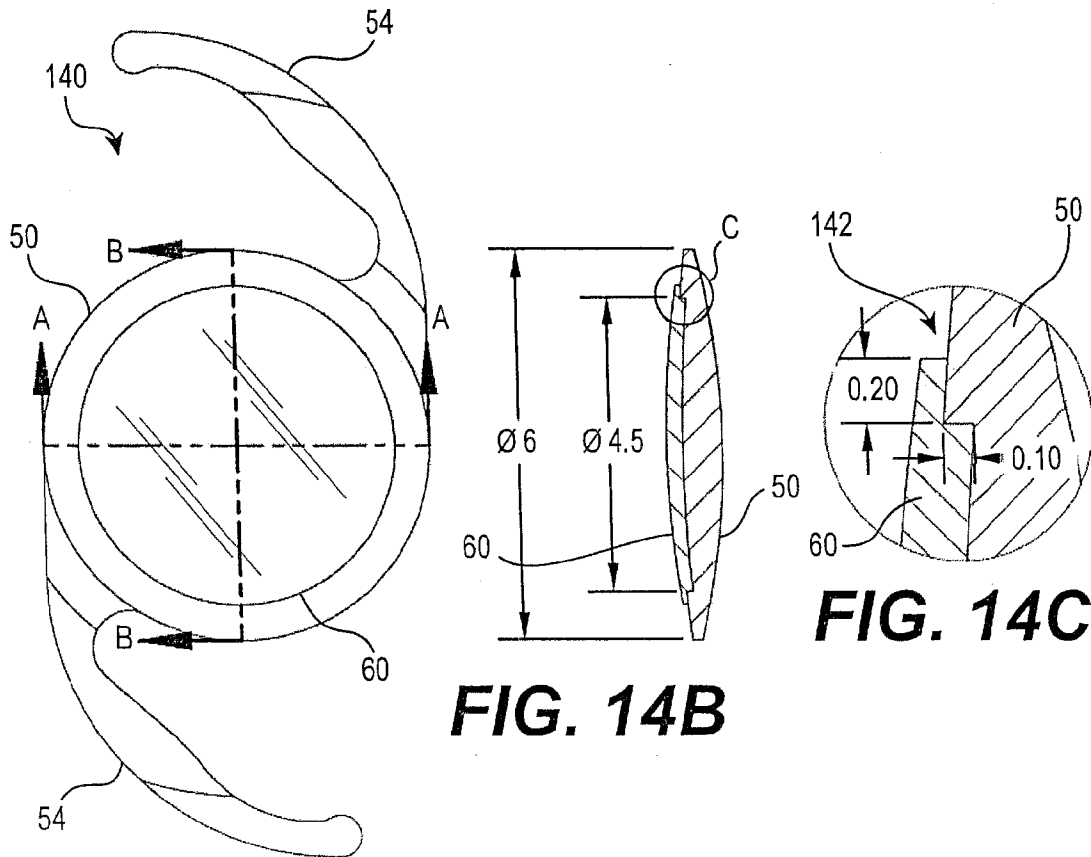
**FIG. 13A**



ETCHED GROOVE

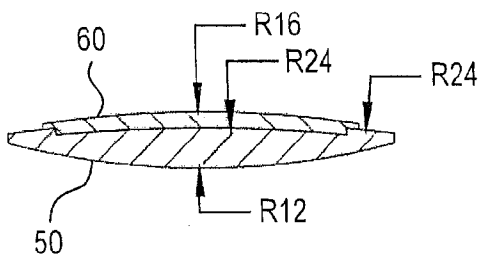
**FIG. 13B**

**FIG. 14**



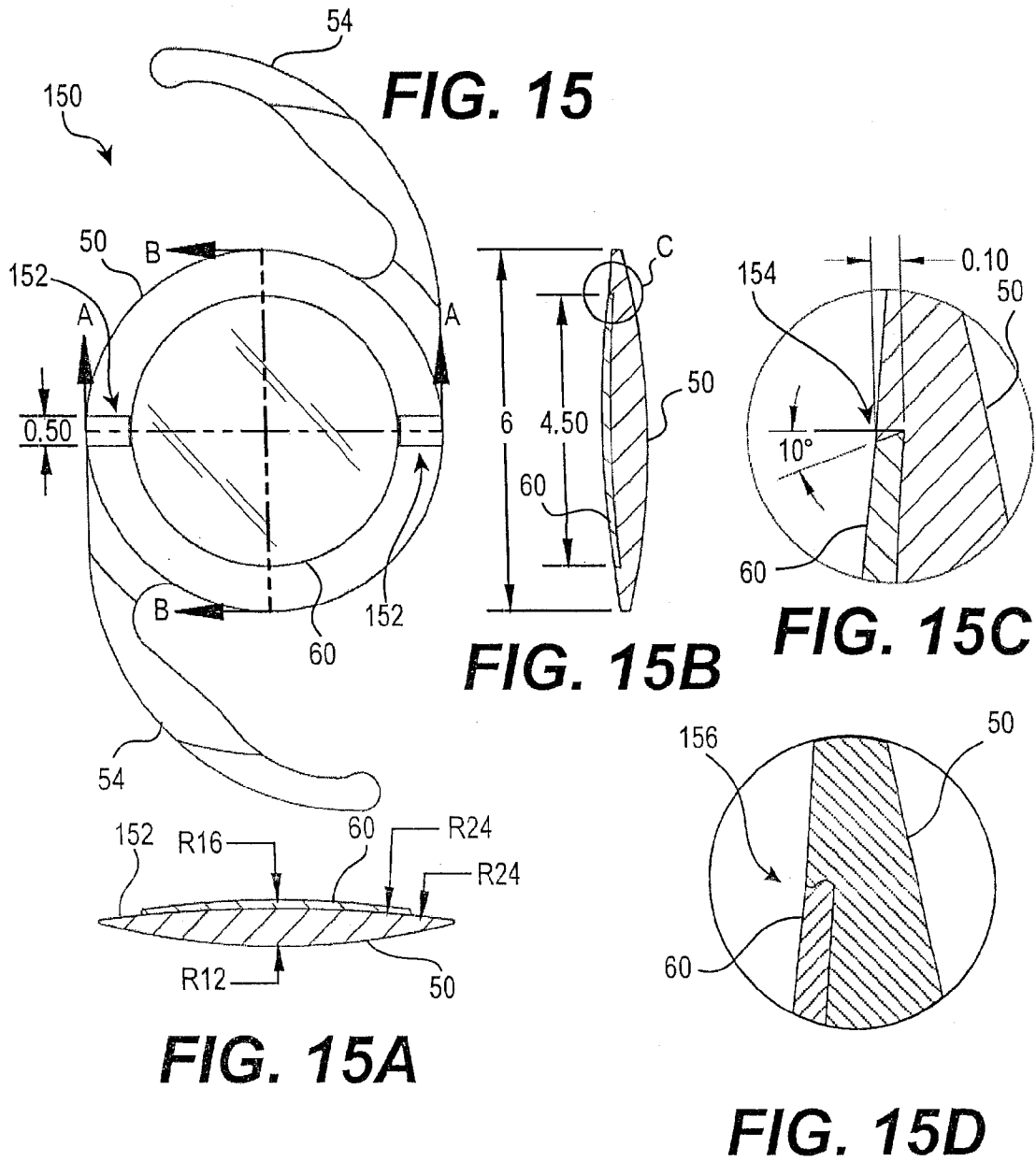
**FIG. 14B**

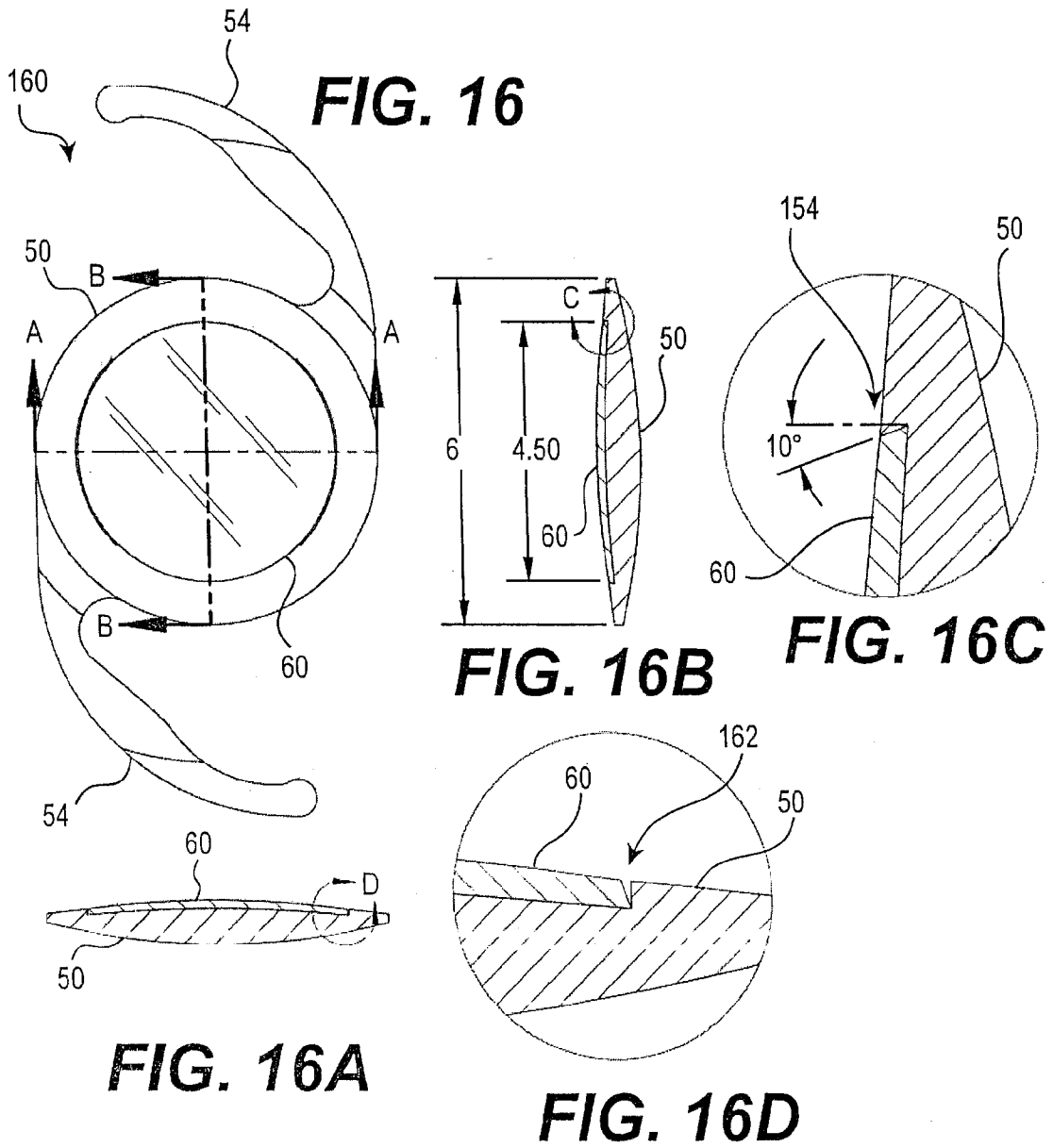
**FIG. 14C**

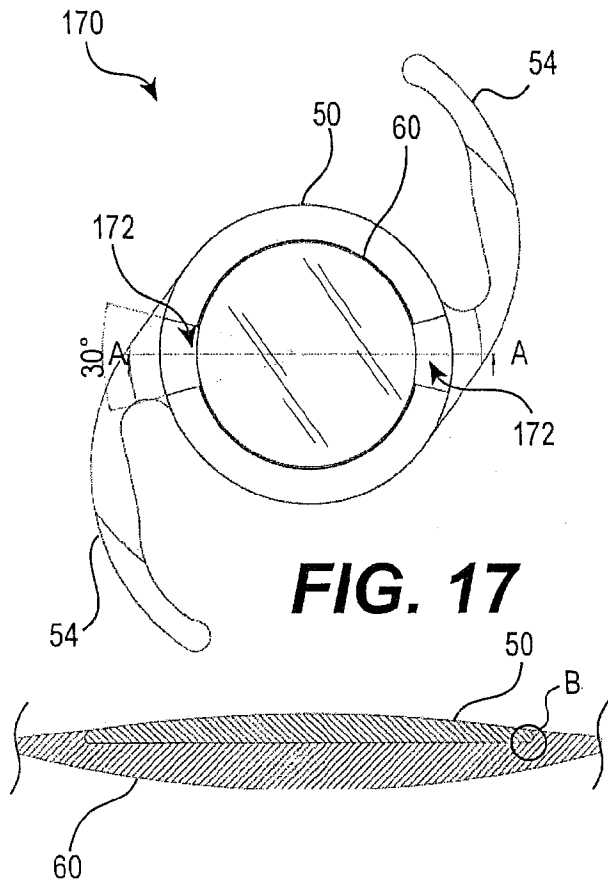


**FIG. 14A**

11/66

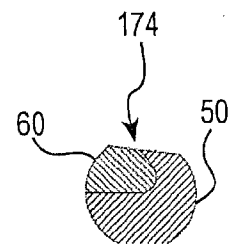




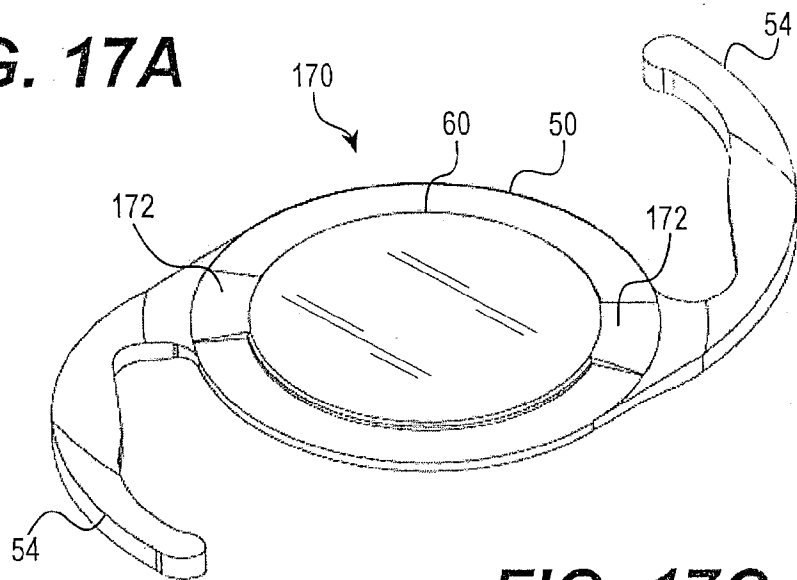


**FIG. 17**

**FIG. 17A**

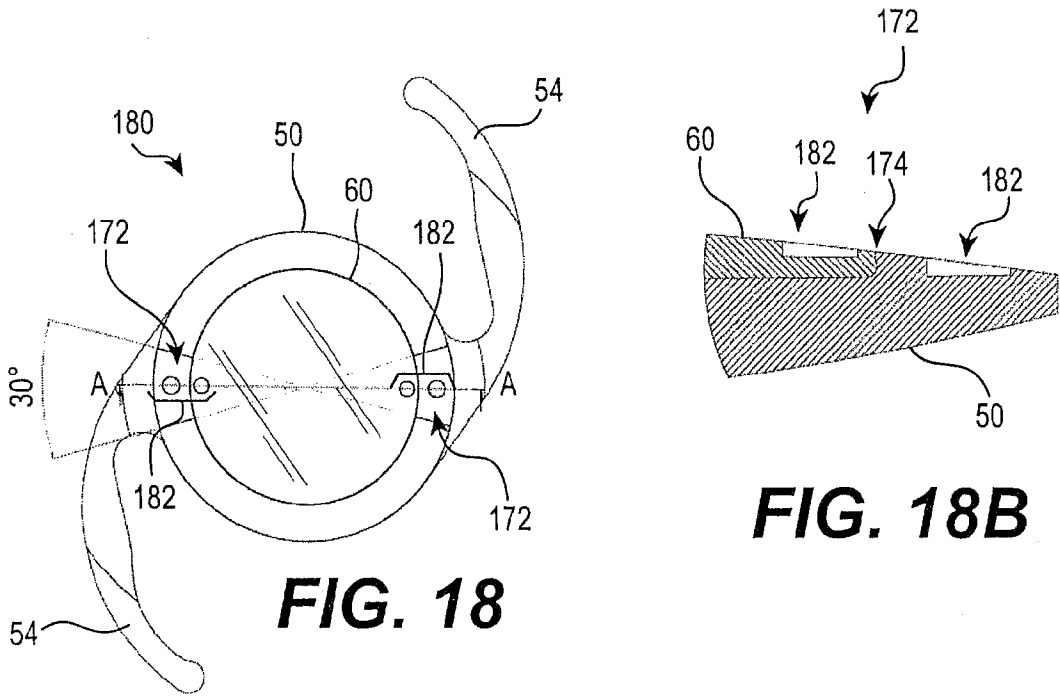


**FIG. 17B**



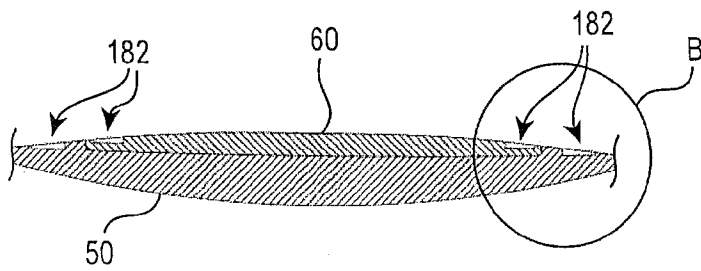
**FIG. 17C**

14/66

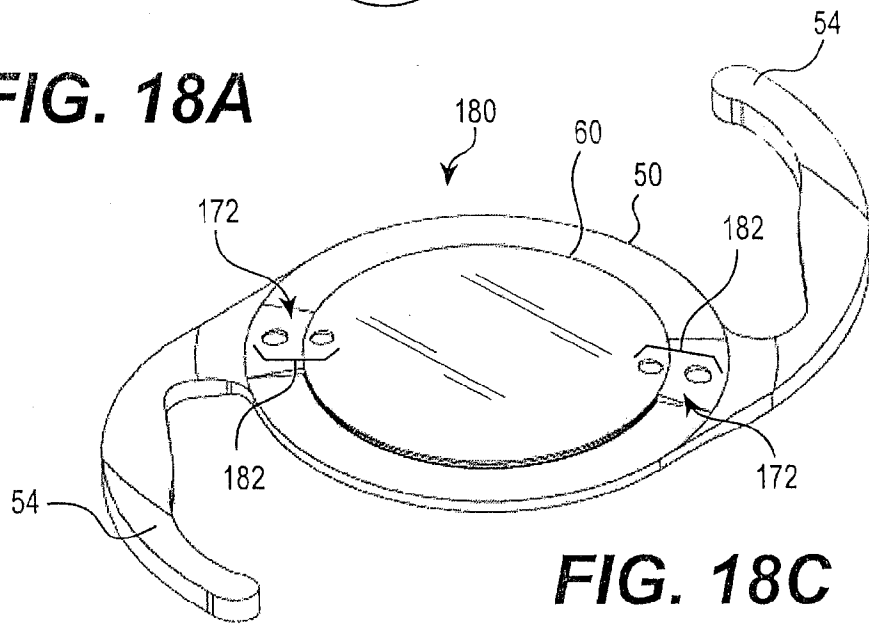


**FIG. 18**

**FIG. 18B**

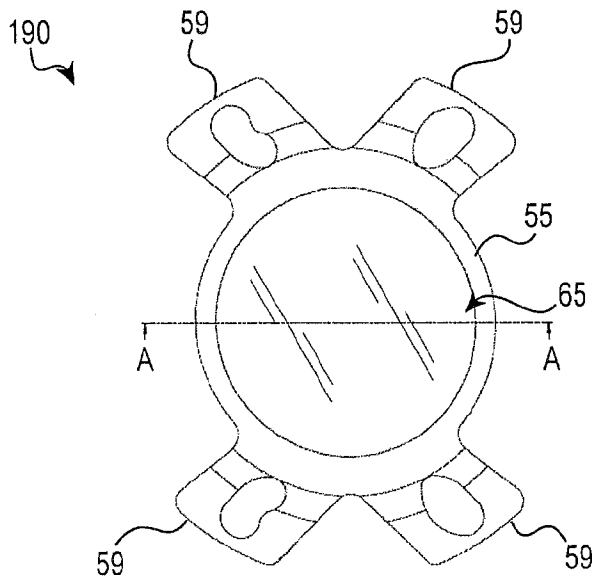


**FIG. 18A**

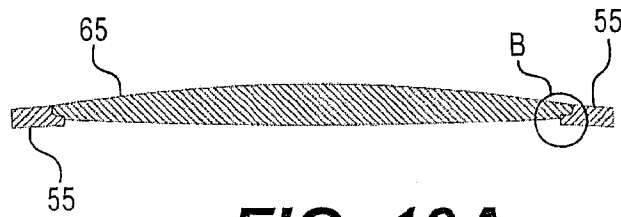


**FIG. 18C**

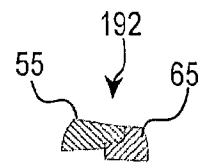
15/66



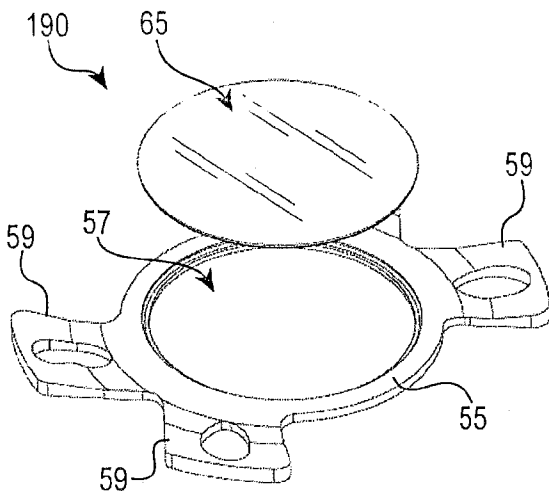
**FIG. 19**



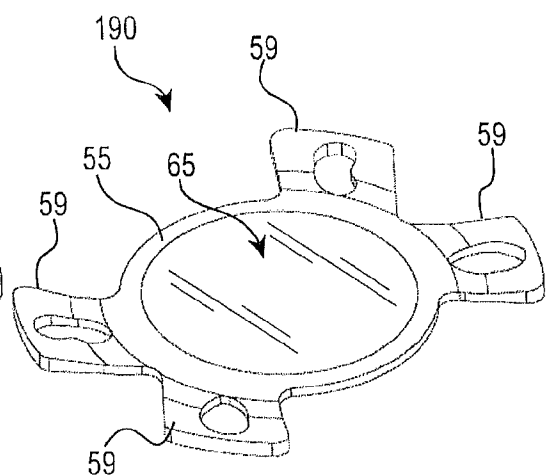
**FIG. 19A**



**FIG. 19B**

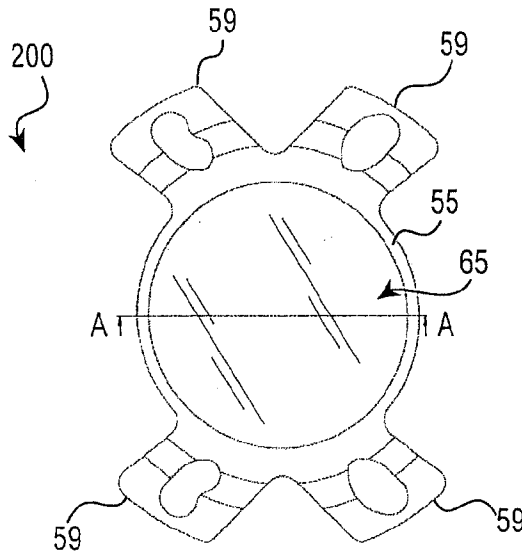


**FIG. 19C**

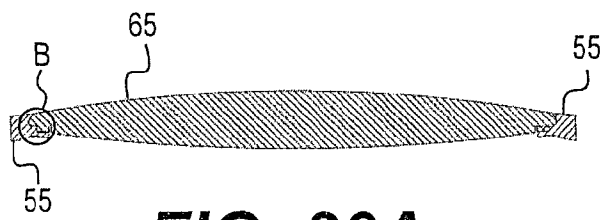


**FIG. 19D**

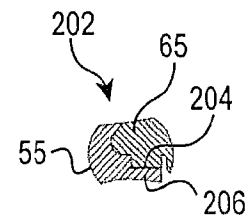




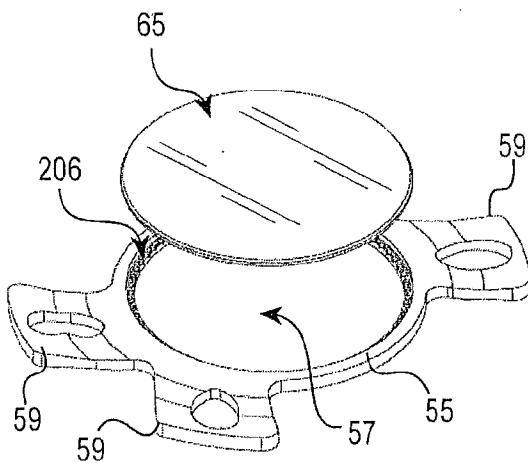
**FIG. 20**



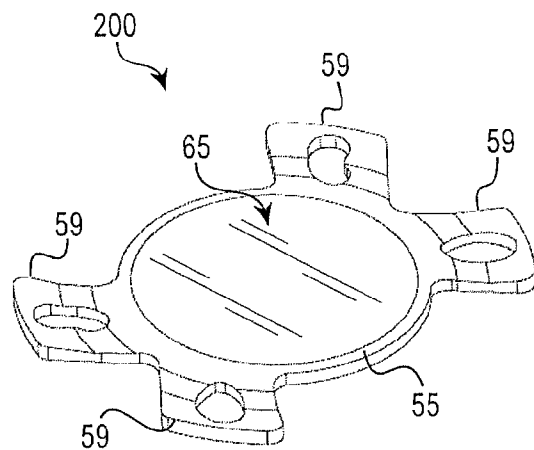
**FIG. 20A**



**FIG. 20B**

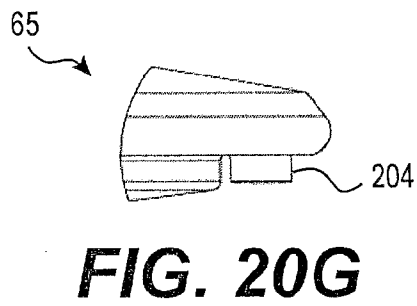
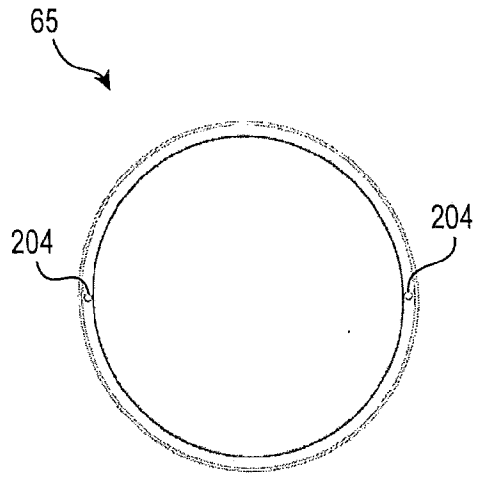
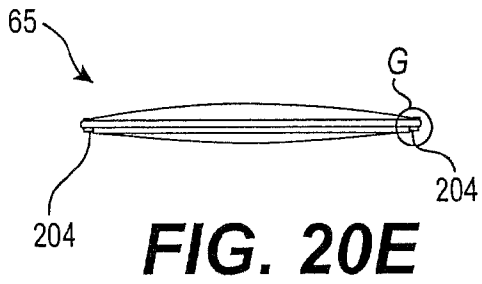


**FIG. 20C**

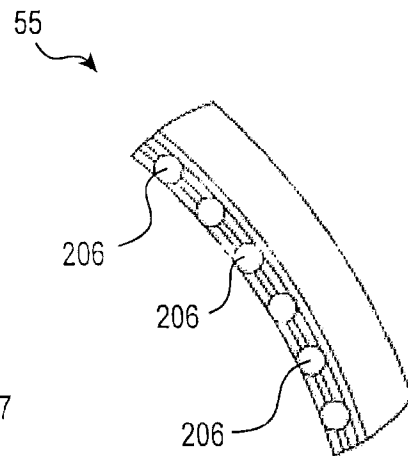
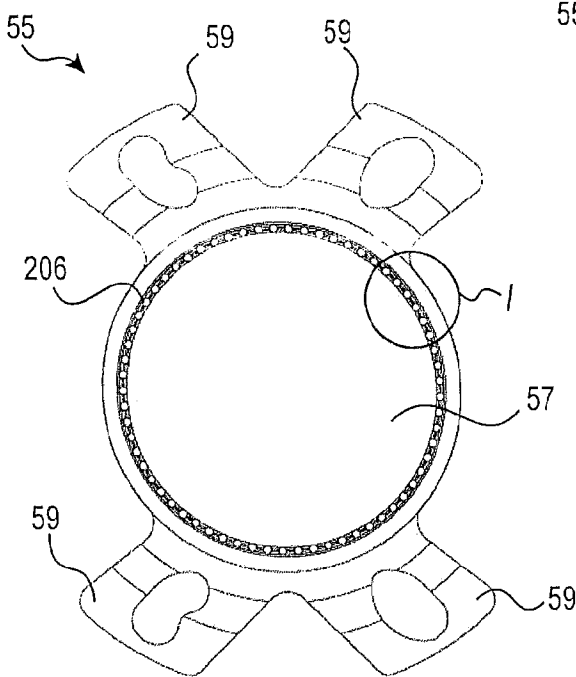


**FIG. 20D**

17/66

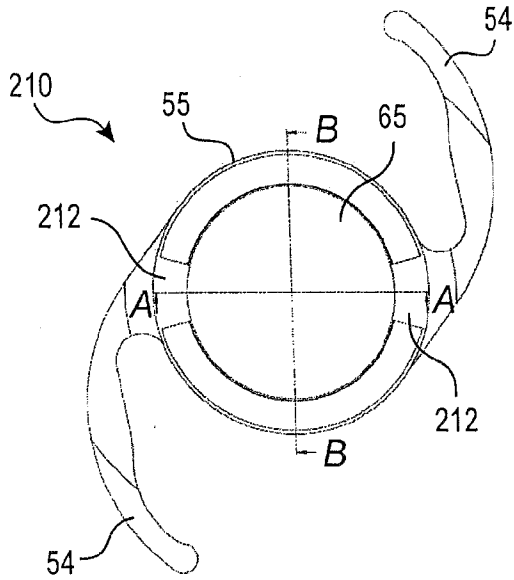


**FIG. 20F**

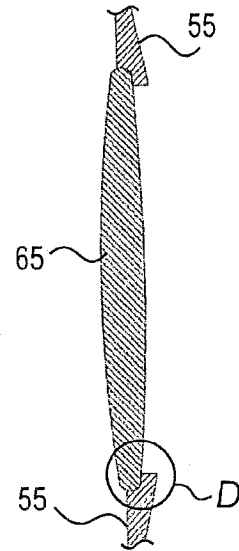


**FIG. 20H**

**FIG. 20I**



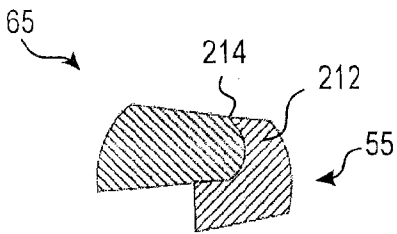
**FIG. 21**



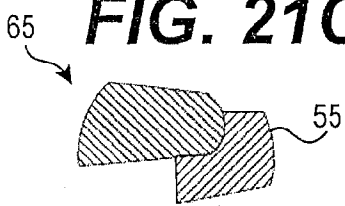
**FIG. 21B**



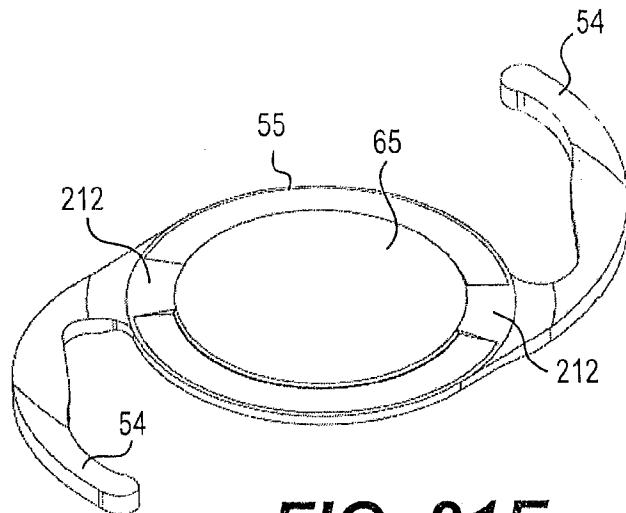
**FIG. 21A**



**FIG. 21C**

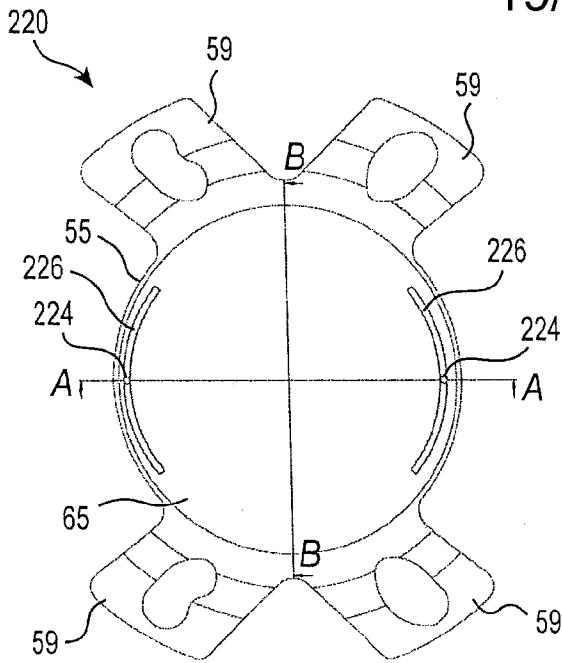


**FIG. 21D**

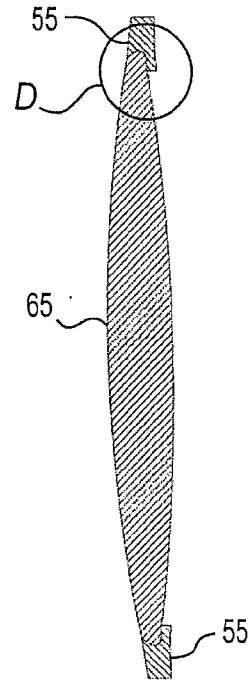


**FIG. 21E**

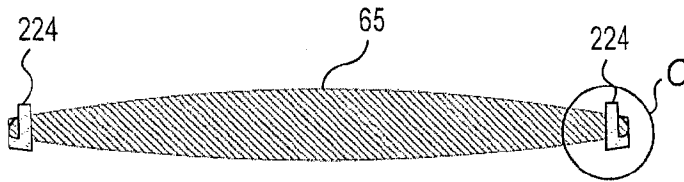
19/66



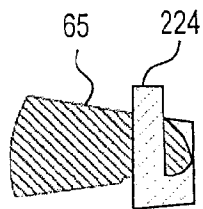
**FIG. 22**



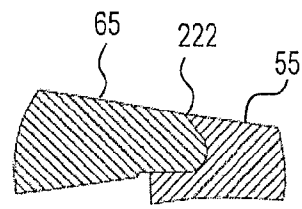
**FIG. 22B**



**FIG. 22A**

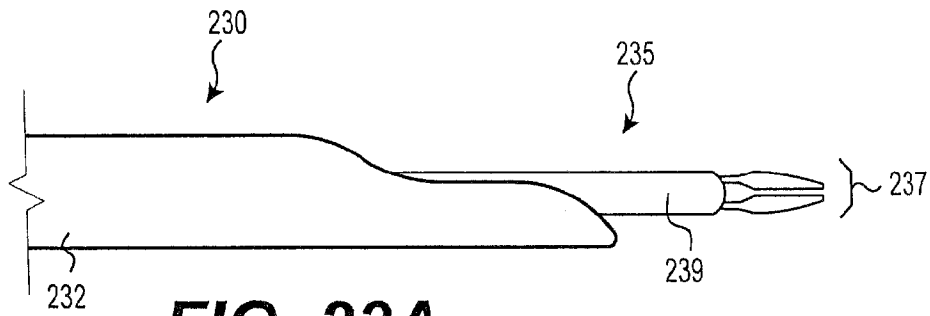


**FIG. 22C**

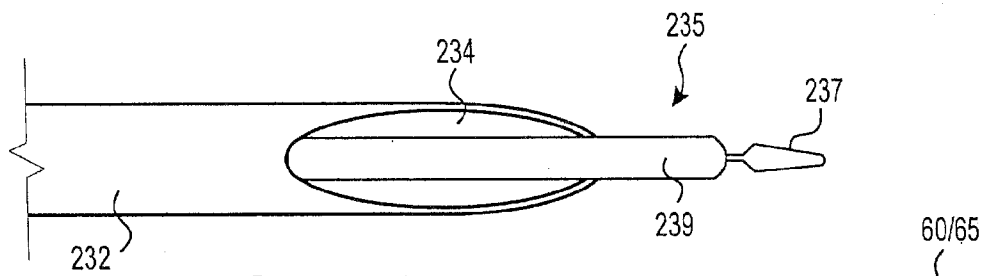


**FIG. 22D**

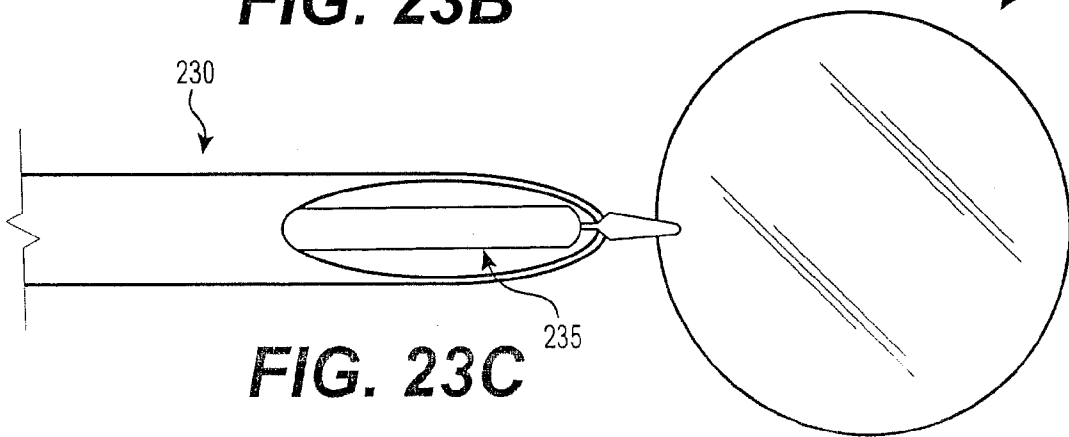
20/66



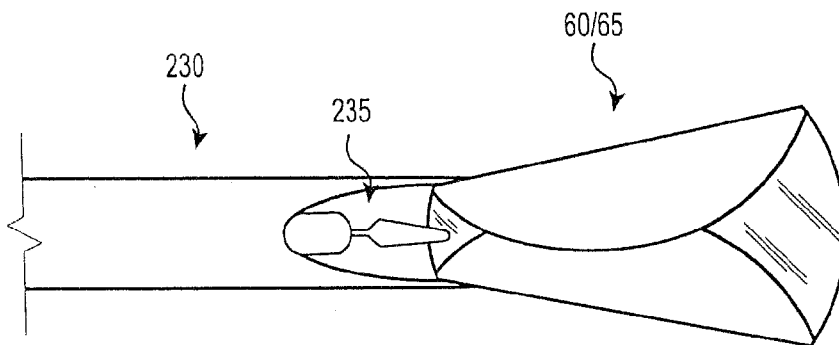
**FIG. 23A**



**FIG. 23B**

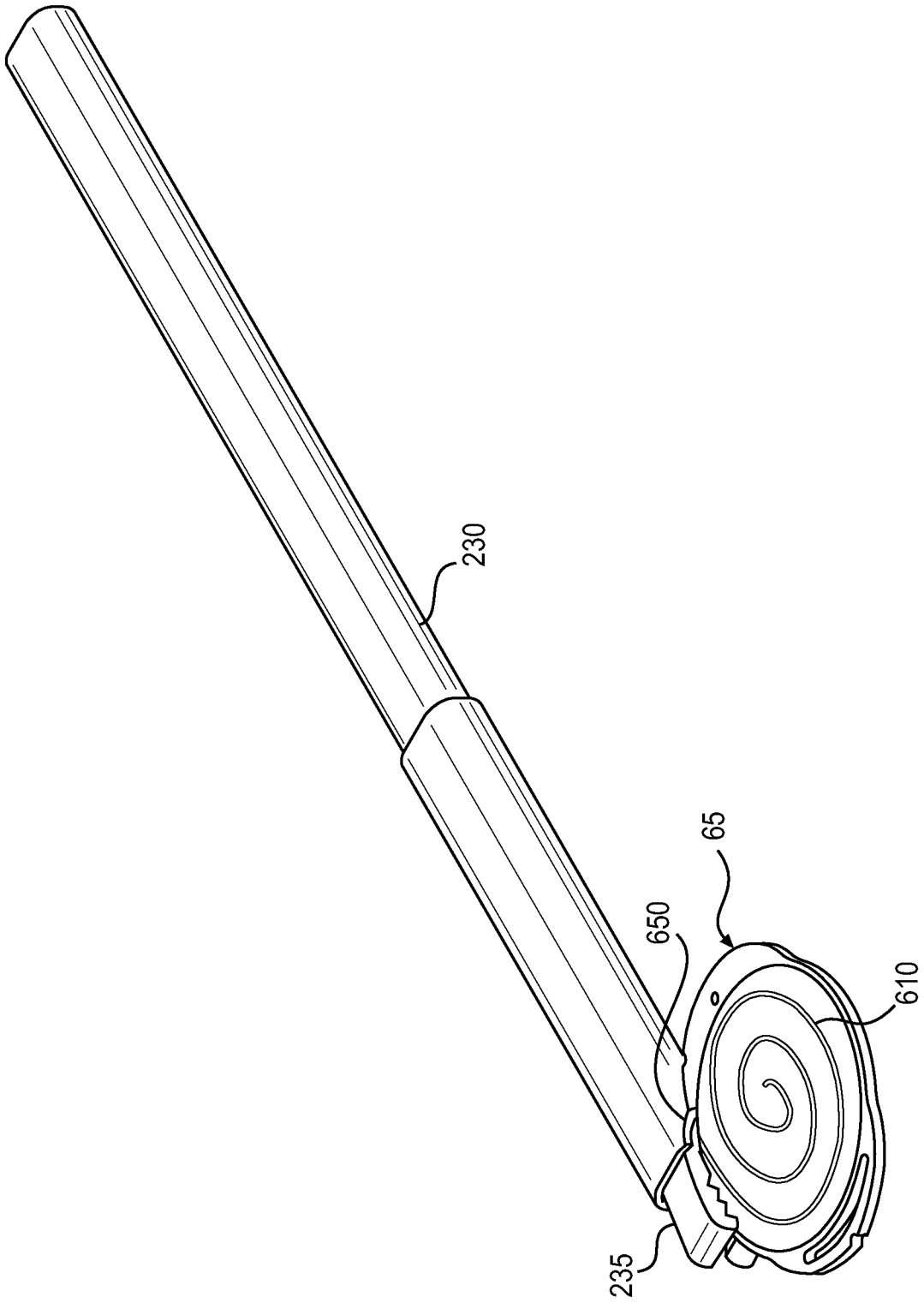


**FIG. 23C**



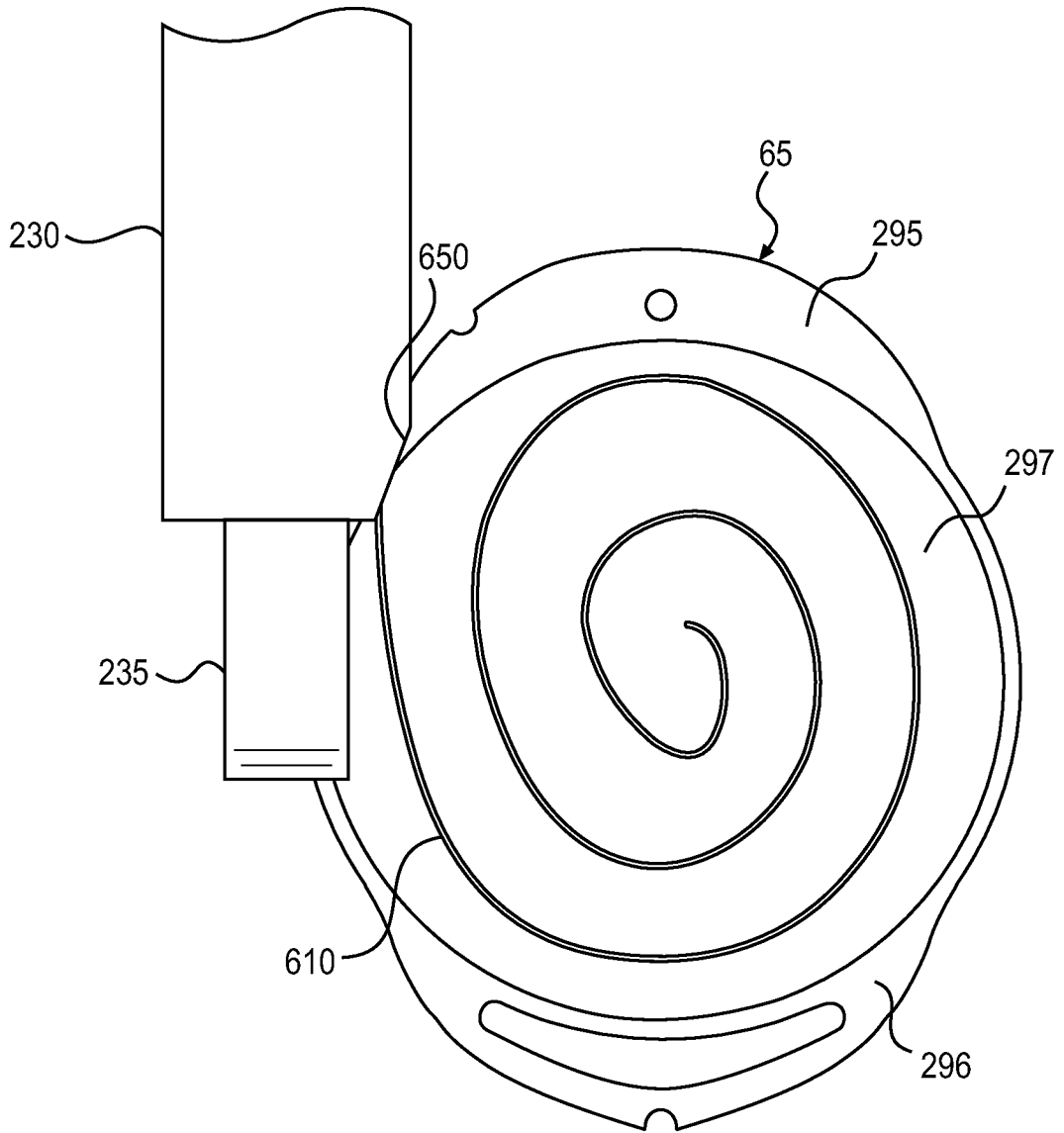
**FIG. 23D**

21/66



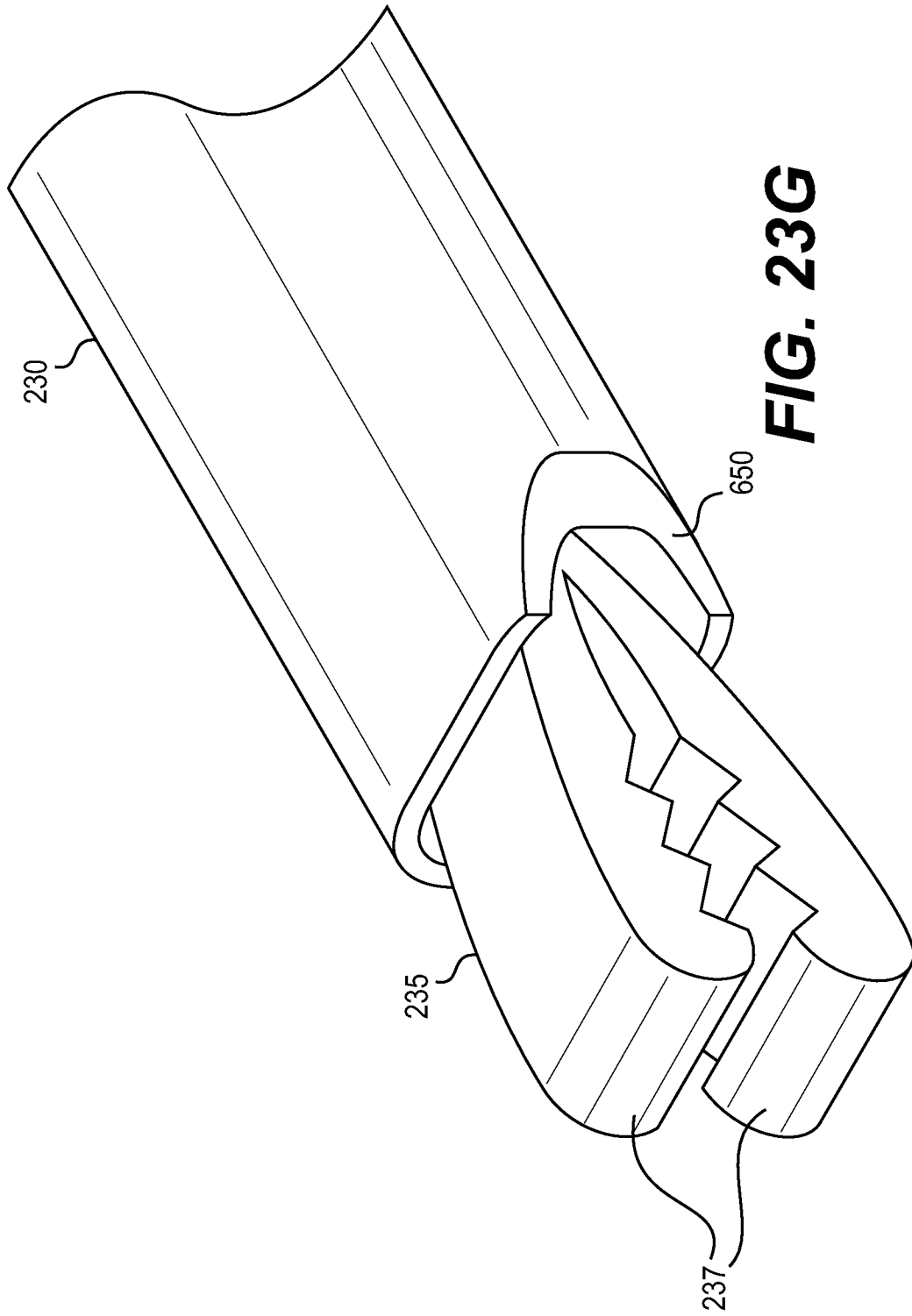
**FIG. 23E**

22/66



**FIG. 23F**

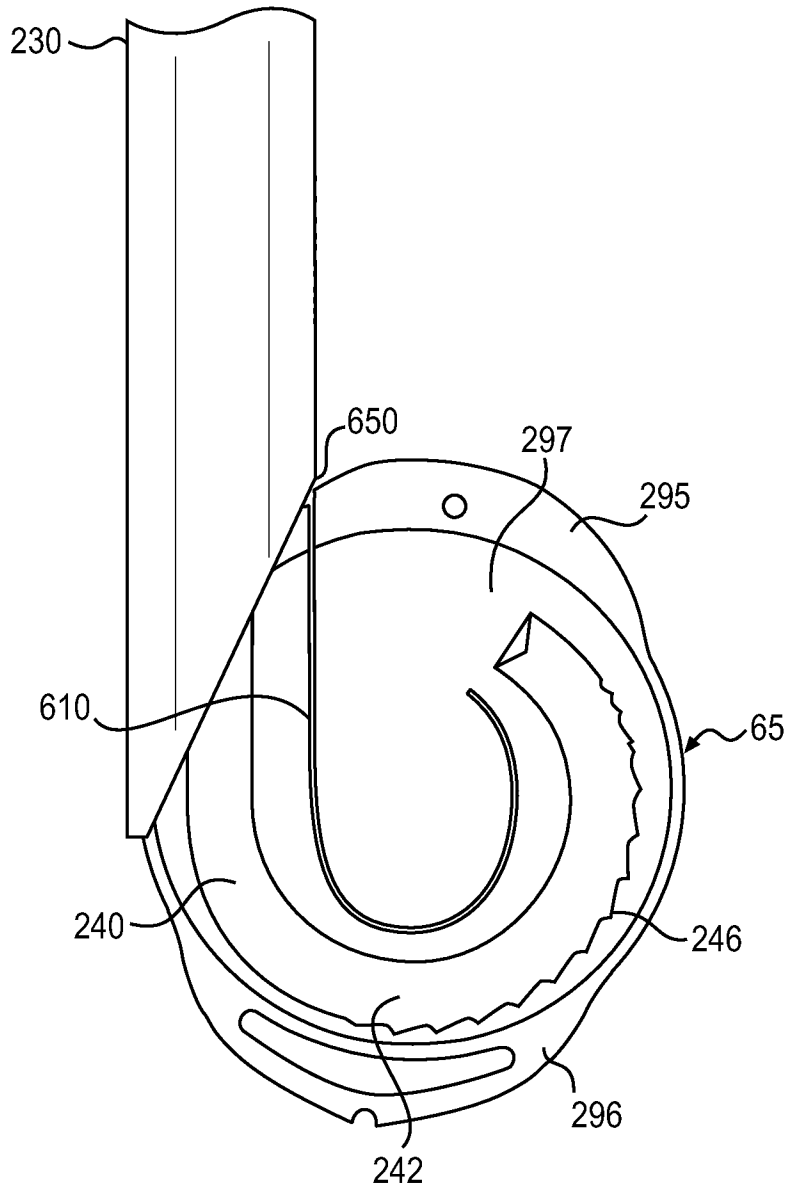
23/66



**FIG. 23G**



24/66



**FIG. 23H**

25/66

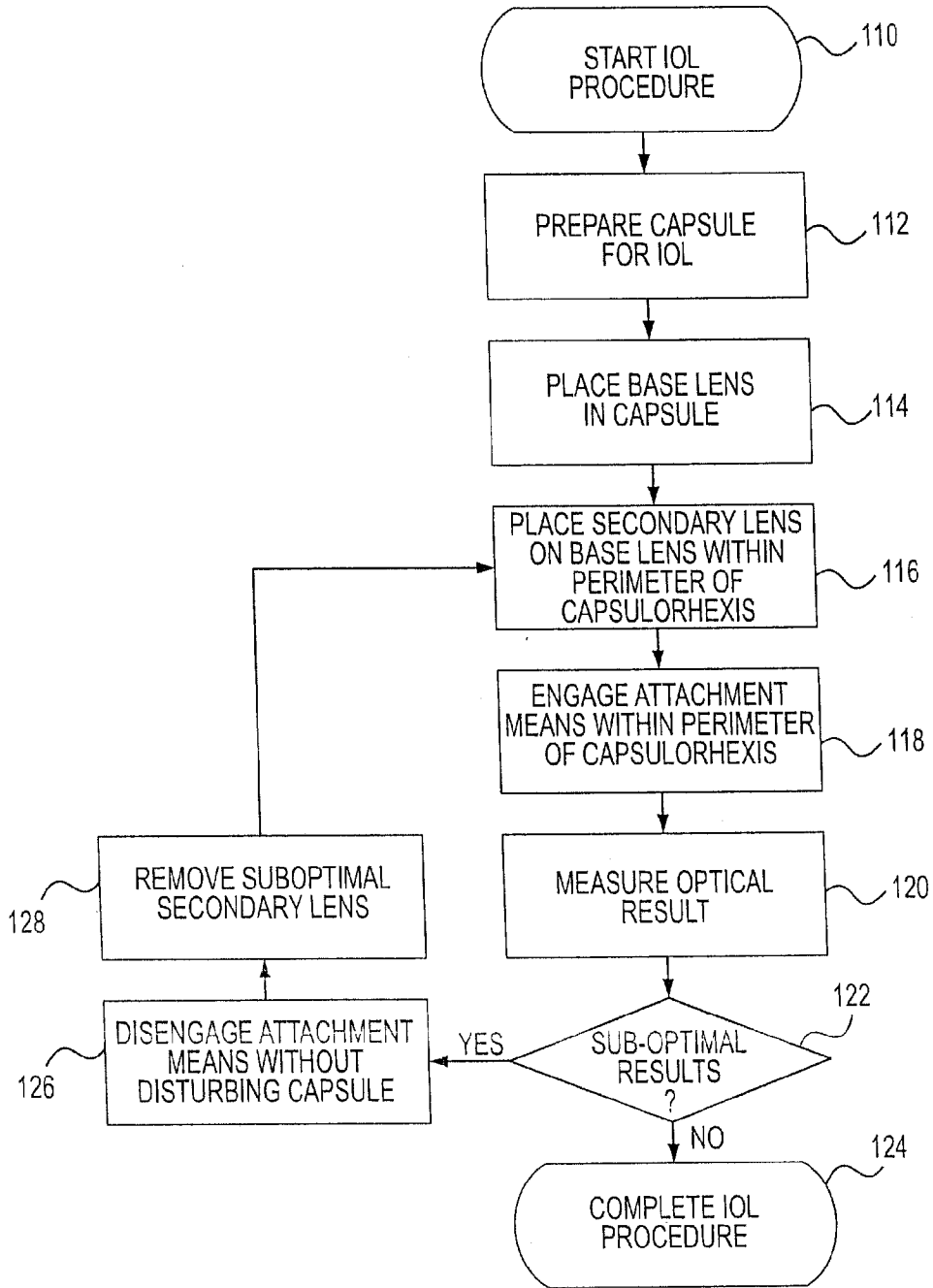


FIG. 24

26/66

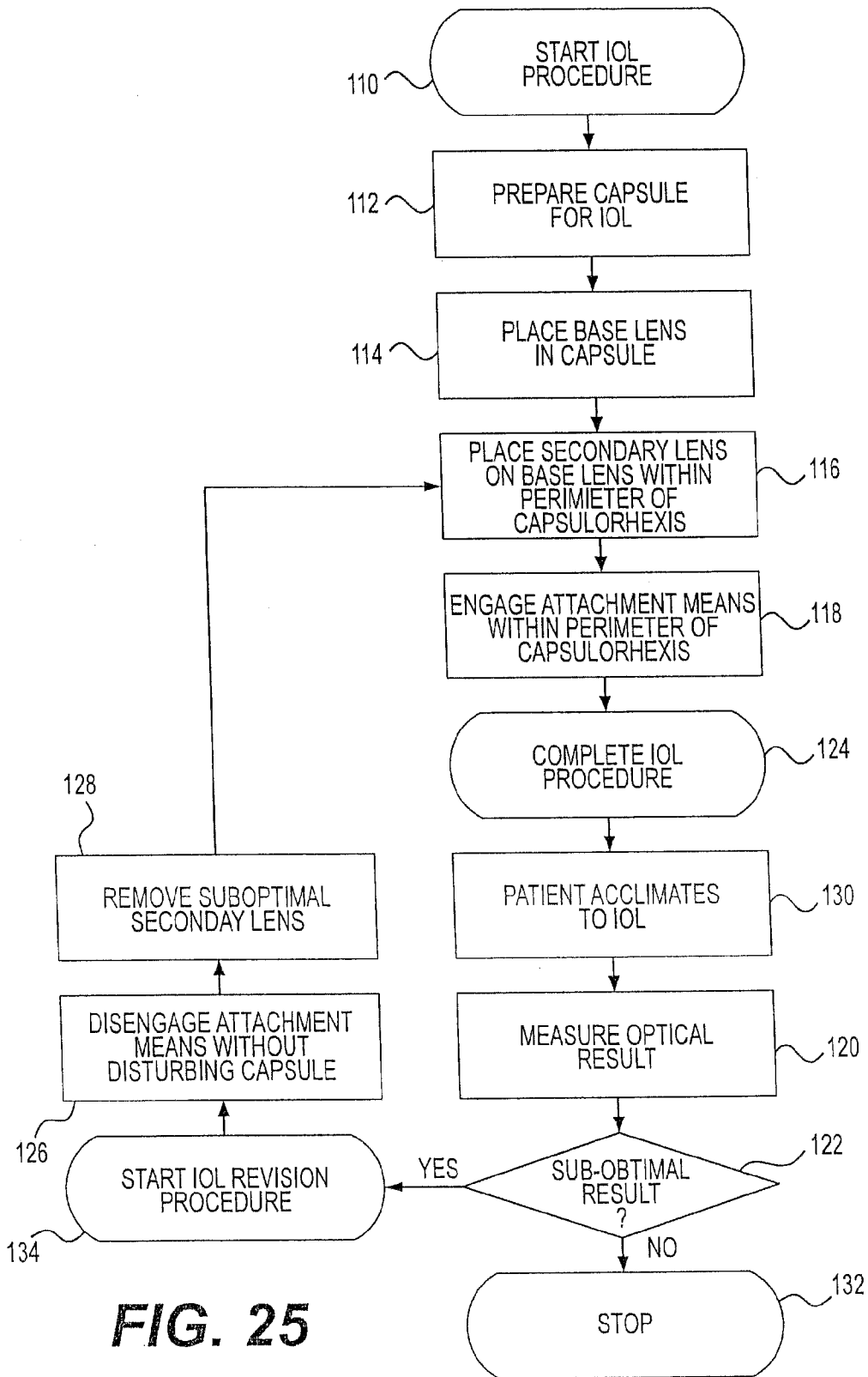
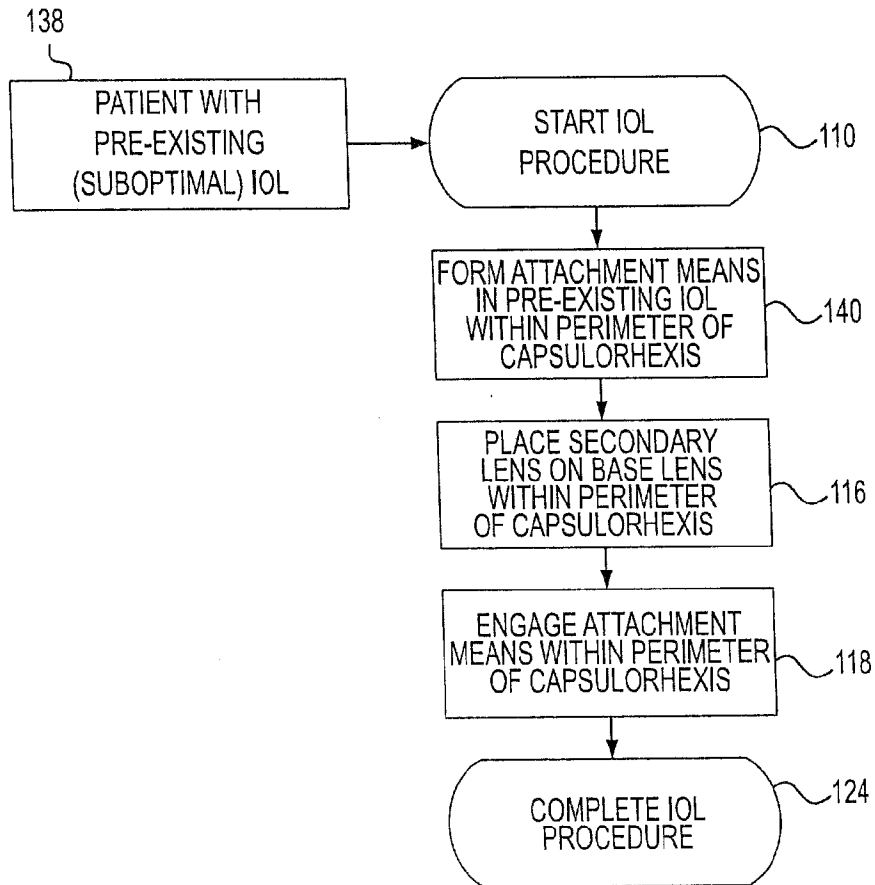


FIG. 25

27/66



**FIG. 26**

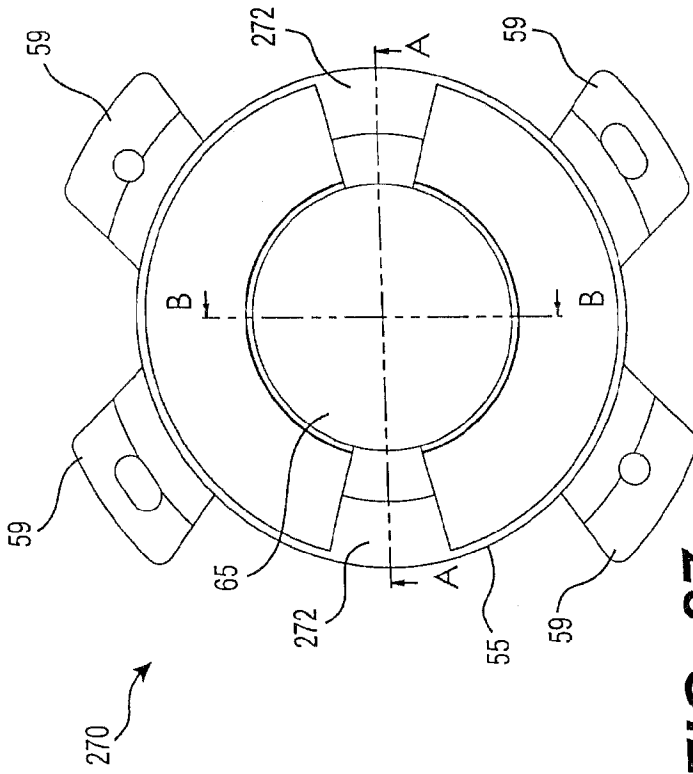


FIG. 27

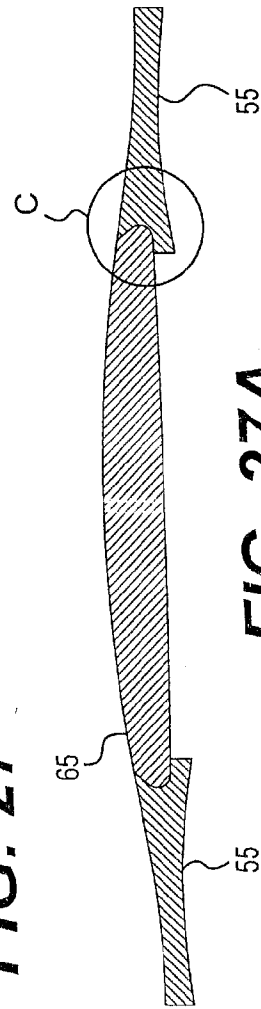


FIG. 27A

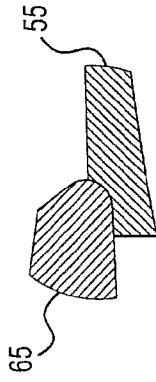


FIG. 27D



FIG. 27B

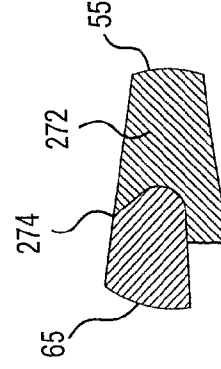
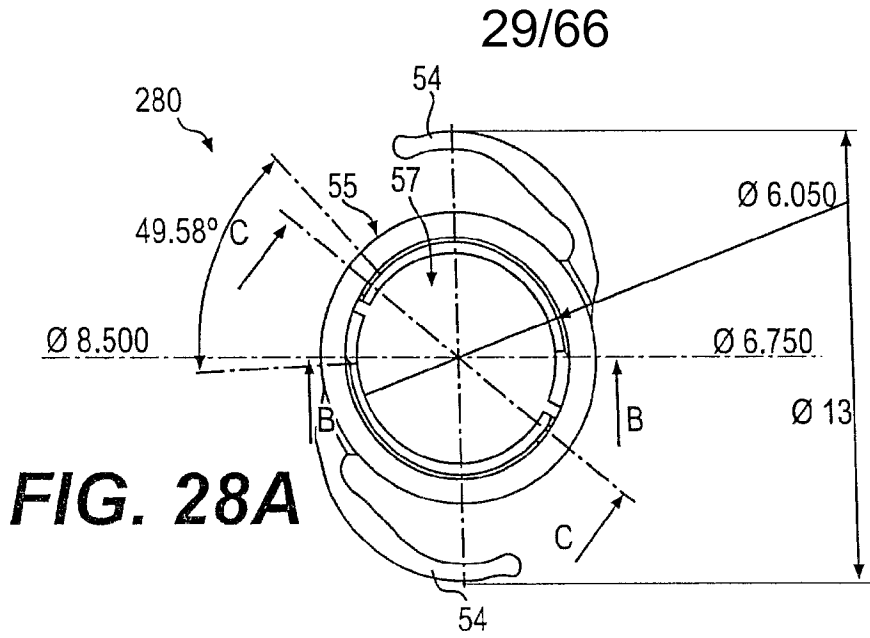
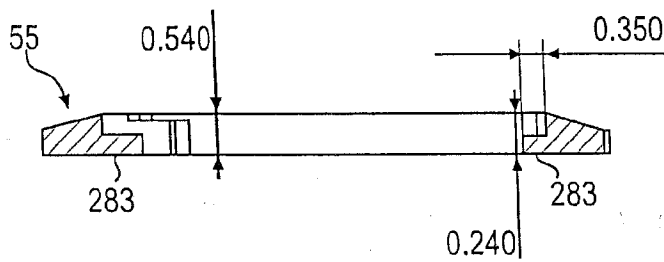


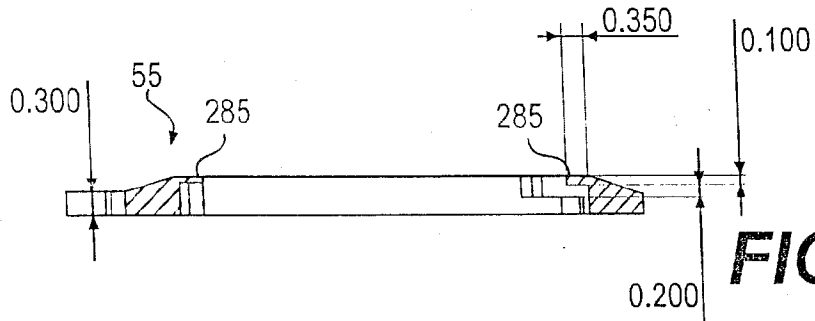
FIG. 27C



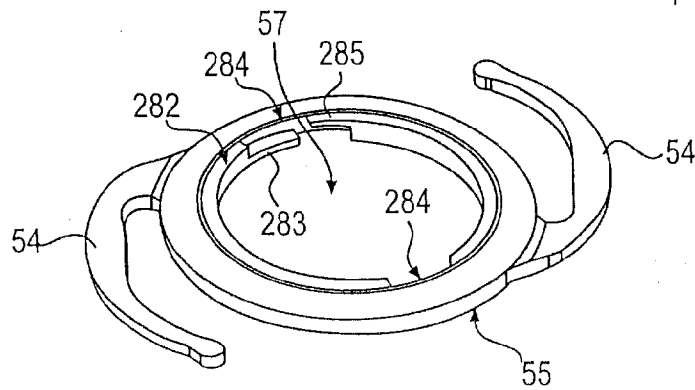
**FIG. 28A**



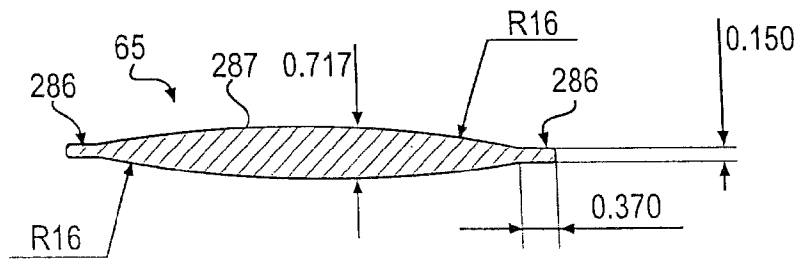
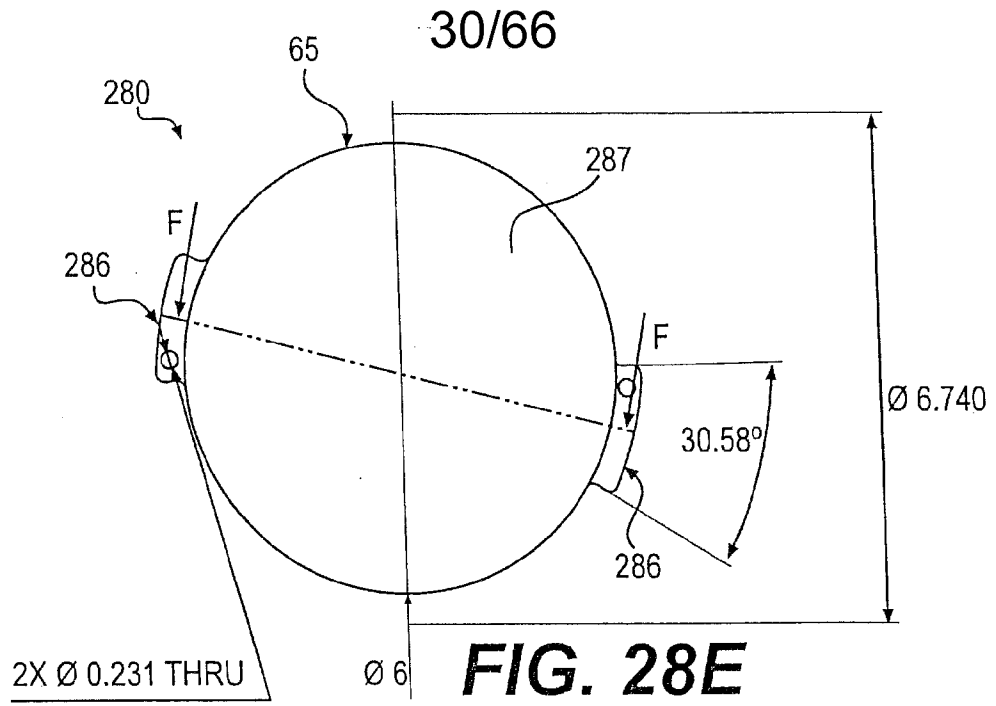
**FIG. 28B**



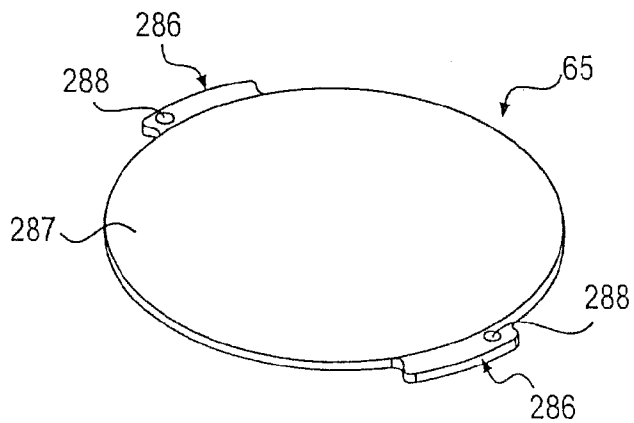
**FIG. 28C**



**FIG. 28D**

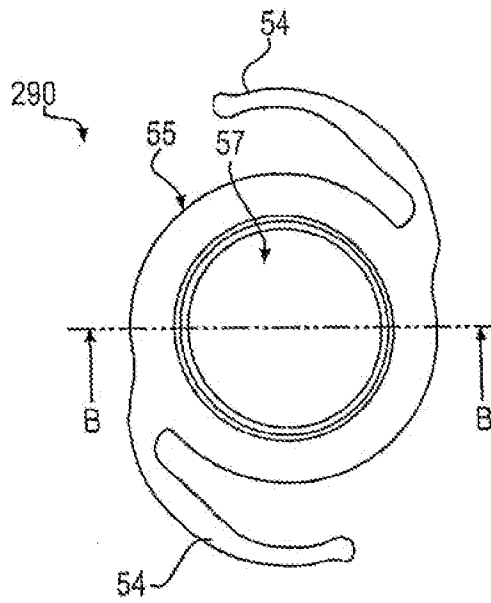


**FIG. 28F**

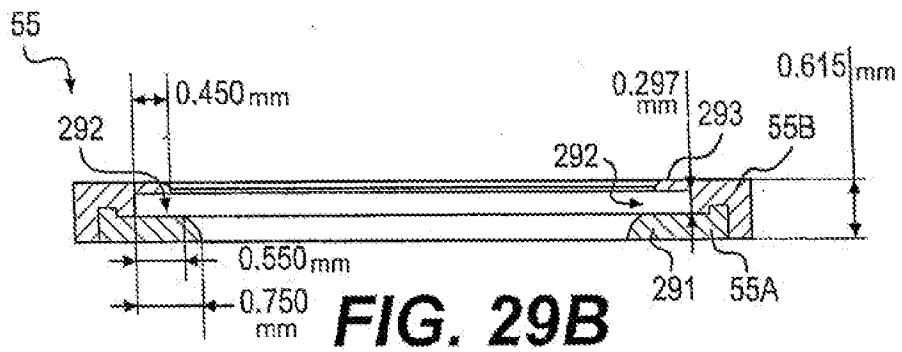


**FIG. 28G**

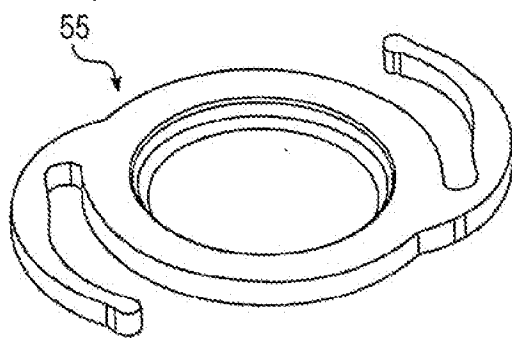
31/66



**FIG. 29A**



**FIG. 29B**



**FIG. 29C**



32/66

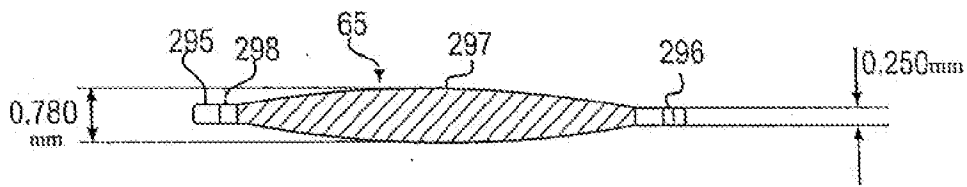
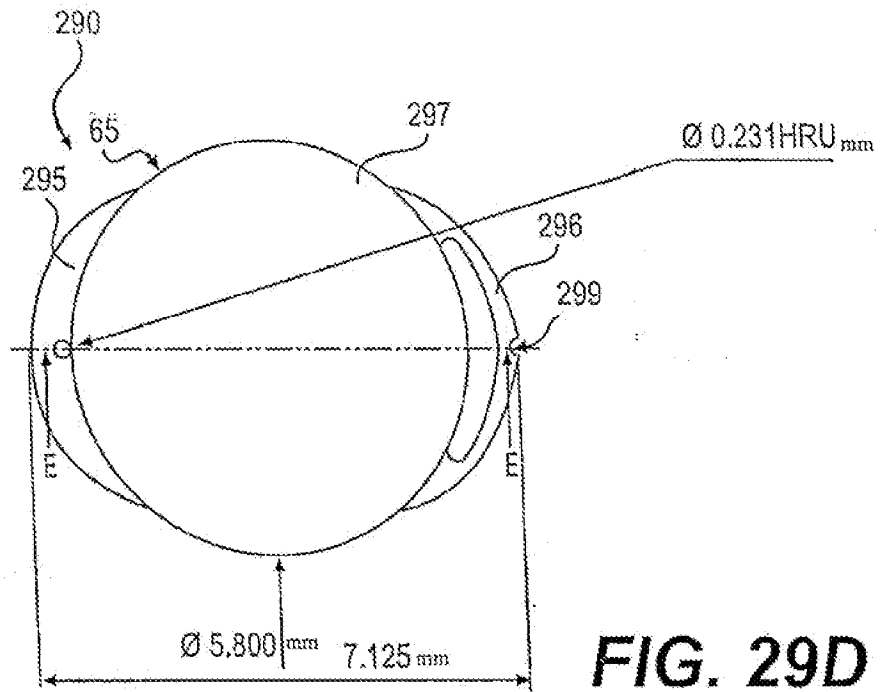


FIG. 29E

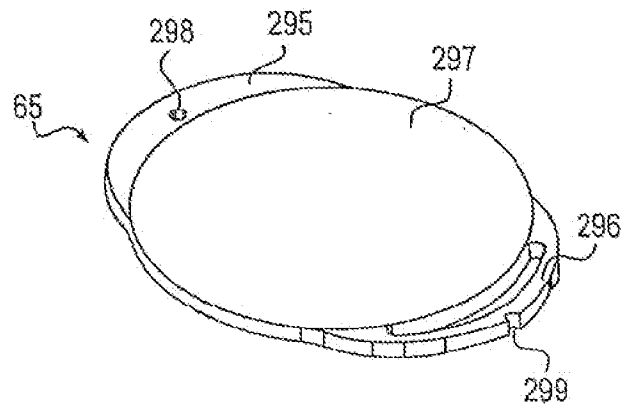
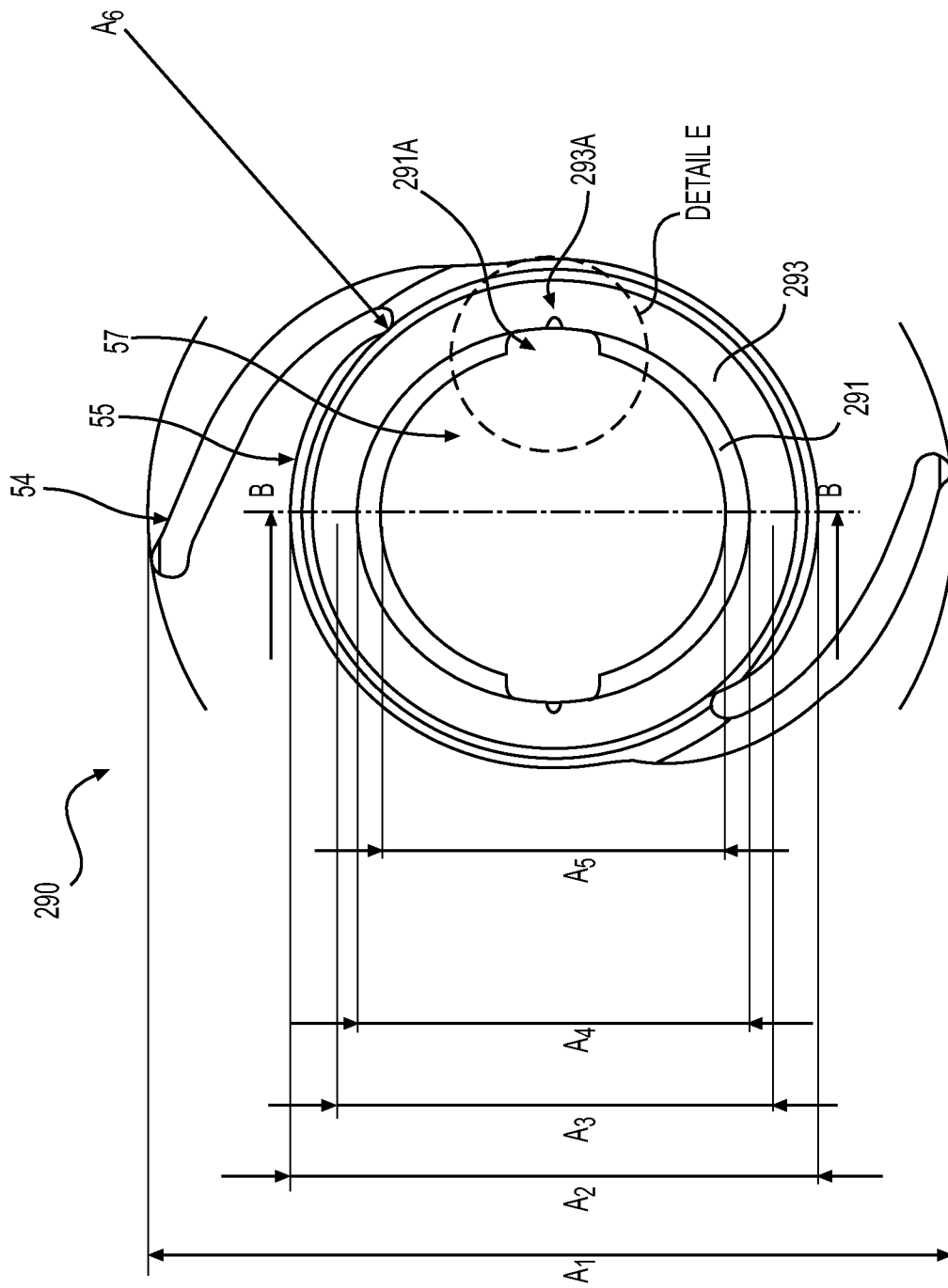
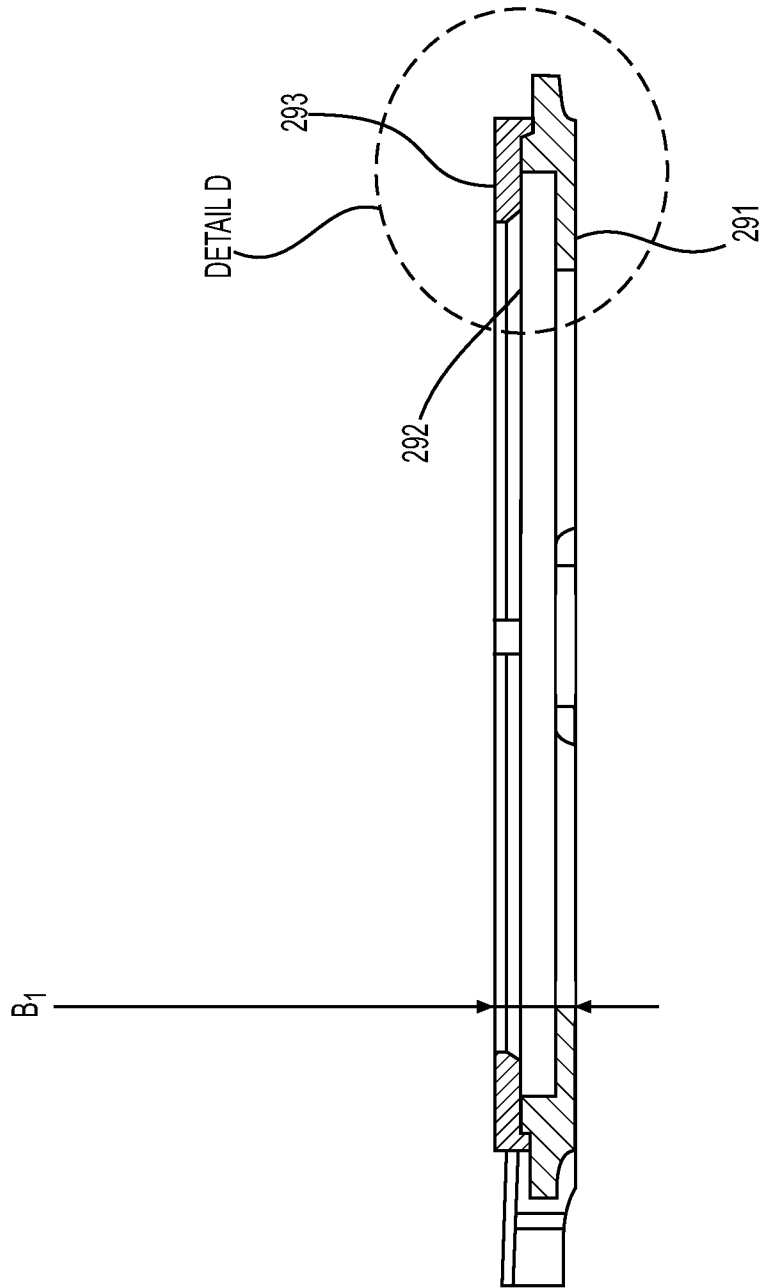


FIG. 29F



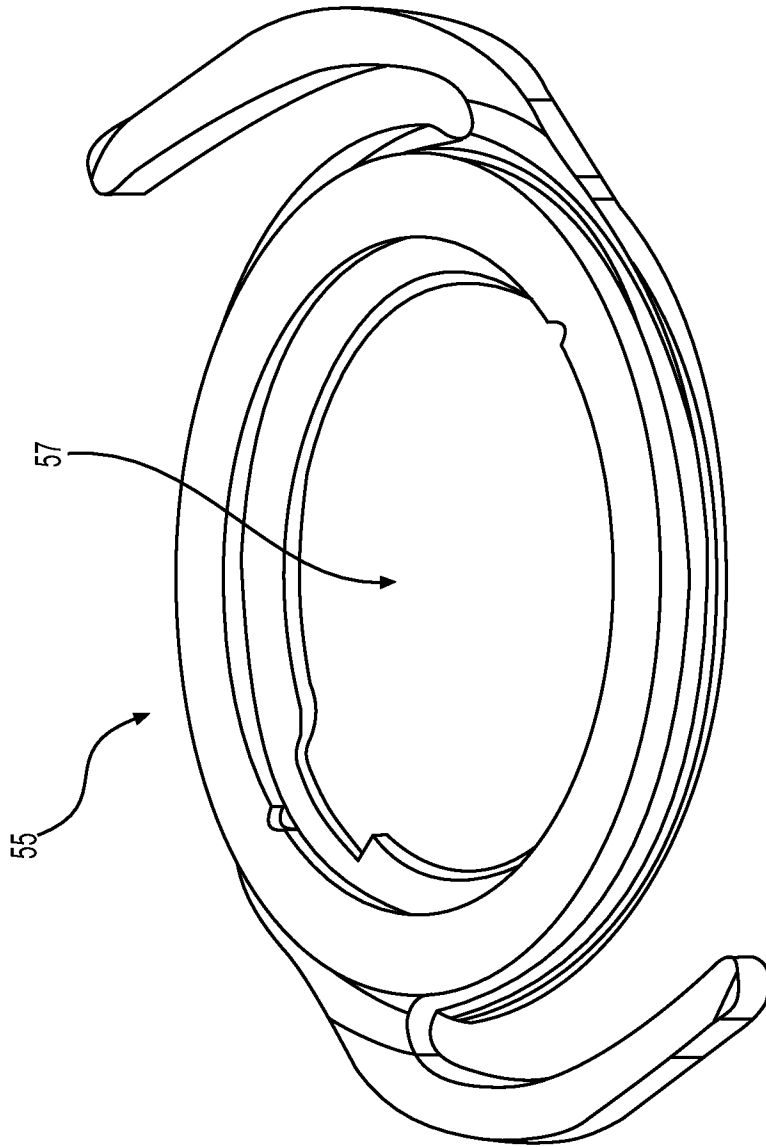
**FIG. 29A2**

34/66

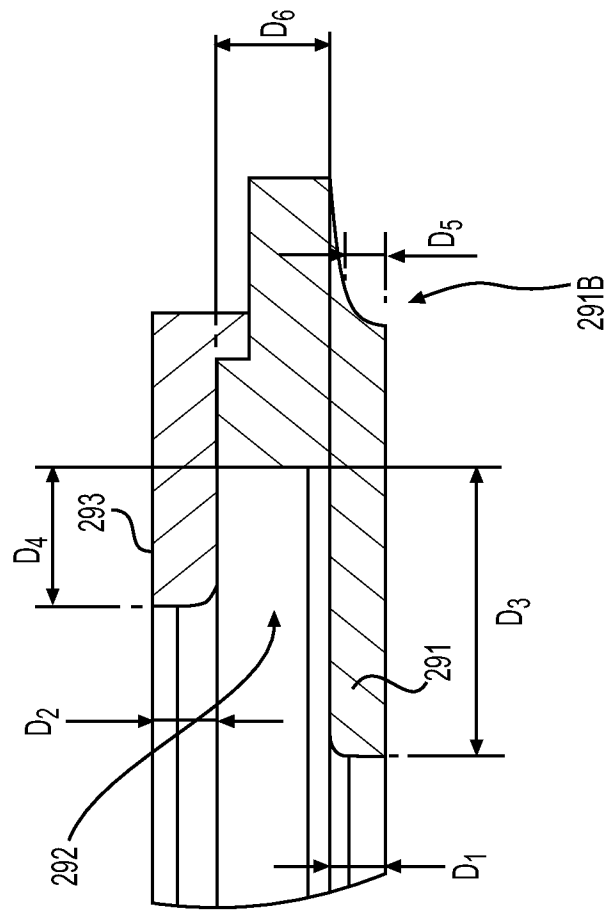


**FIG. 29B2**

35/66

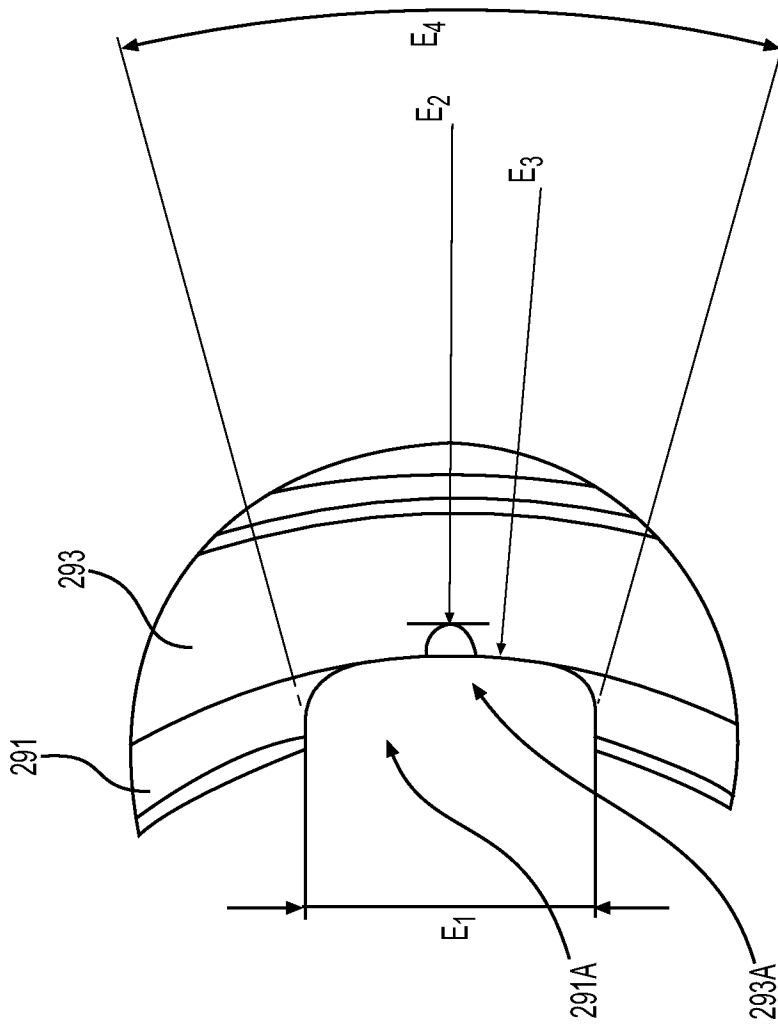


**FIG. 29C2**

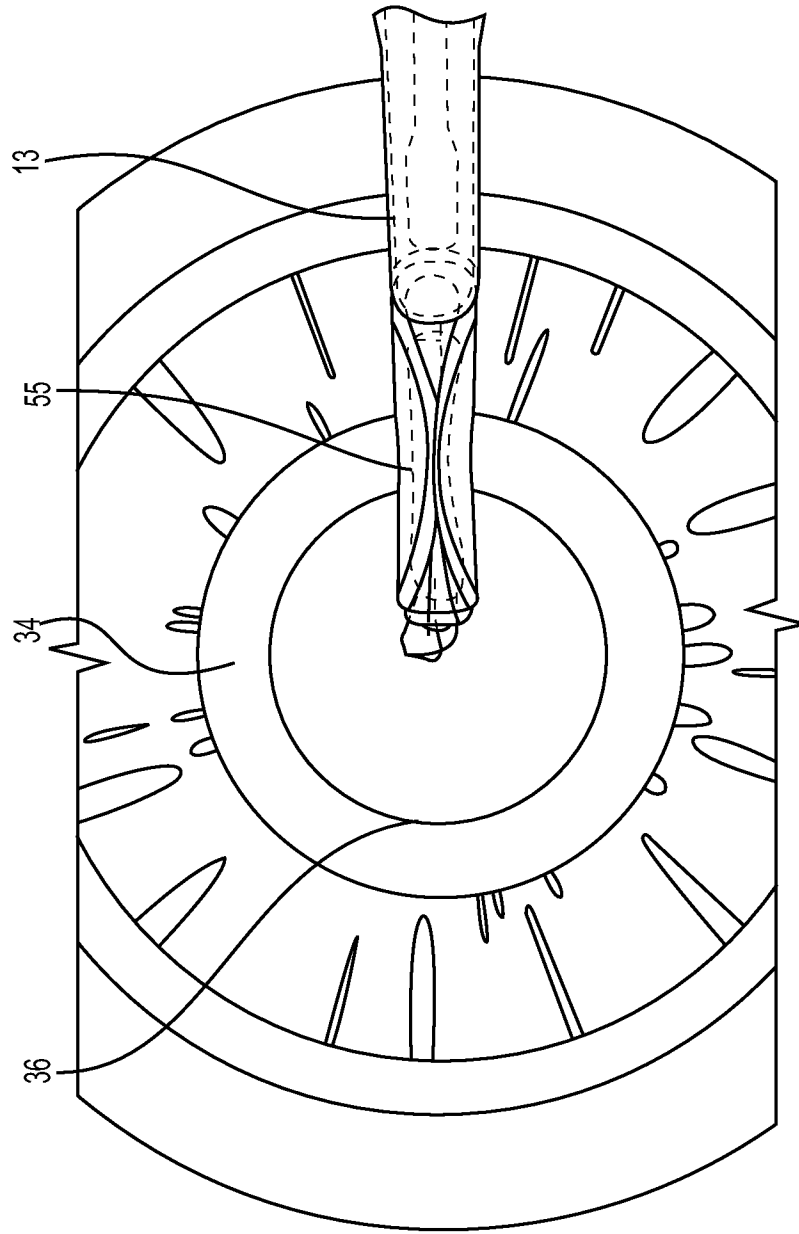


**FIG. 29D2**

37/66

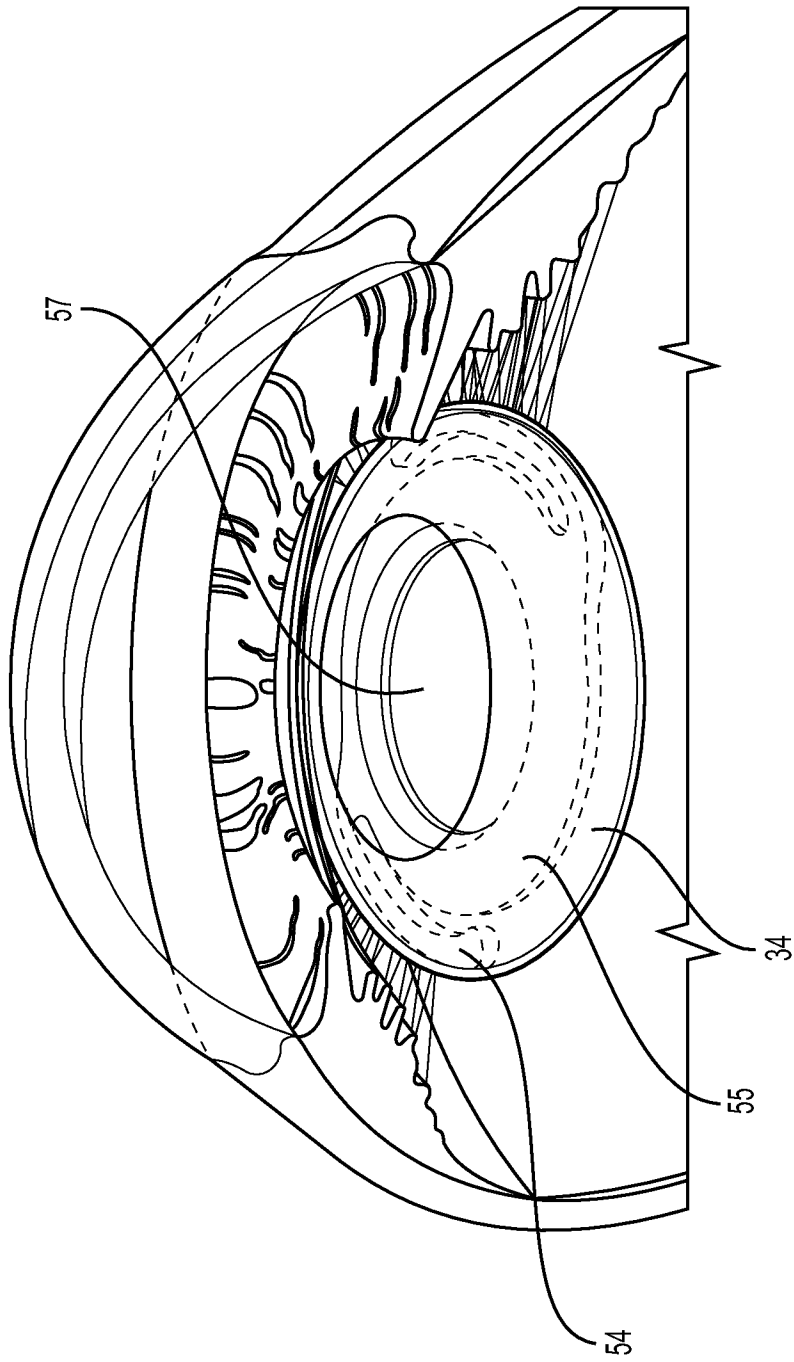


**FIG. 29E2**



**FIG. 29G**

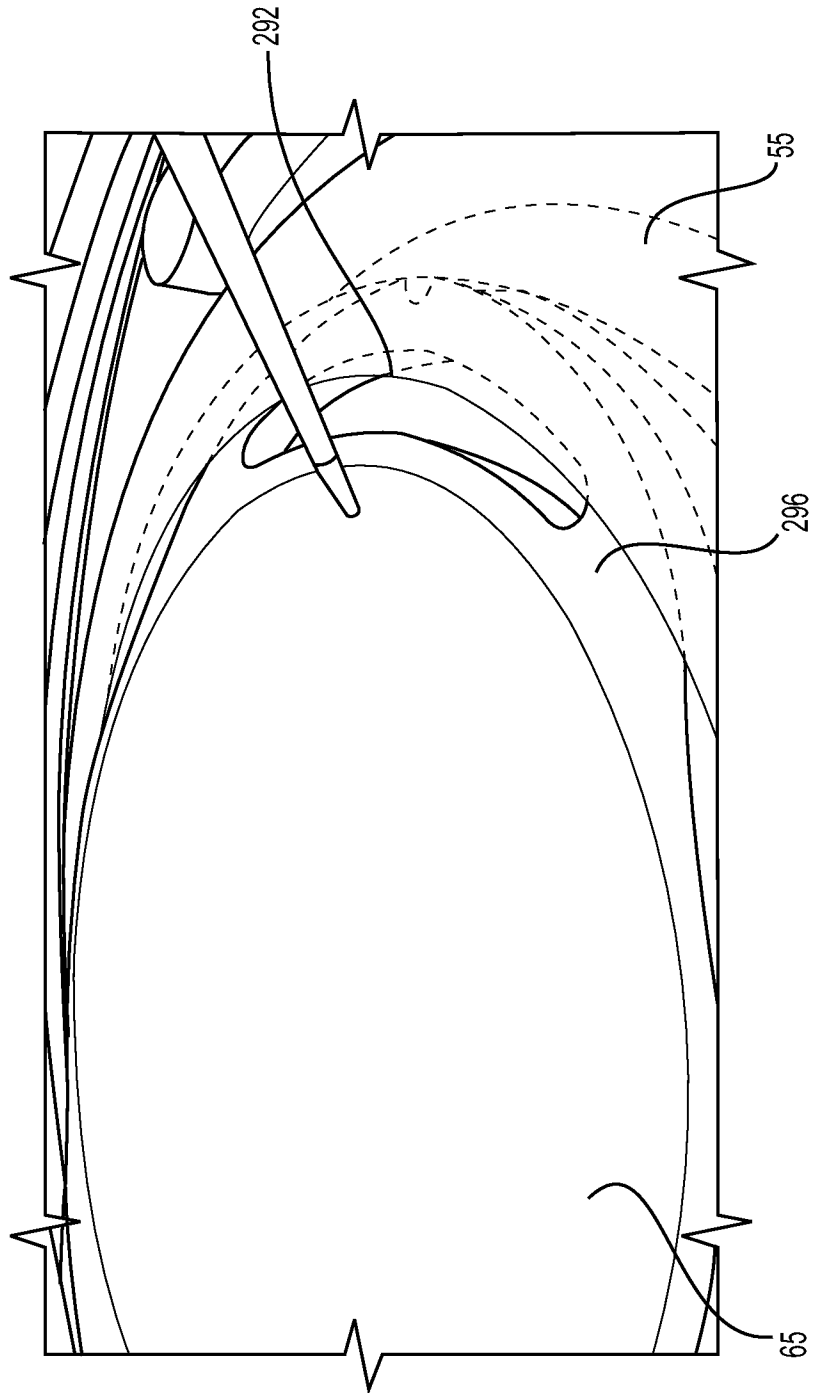
39/66



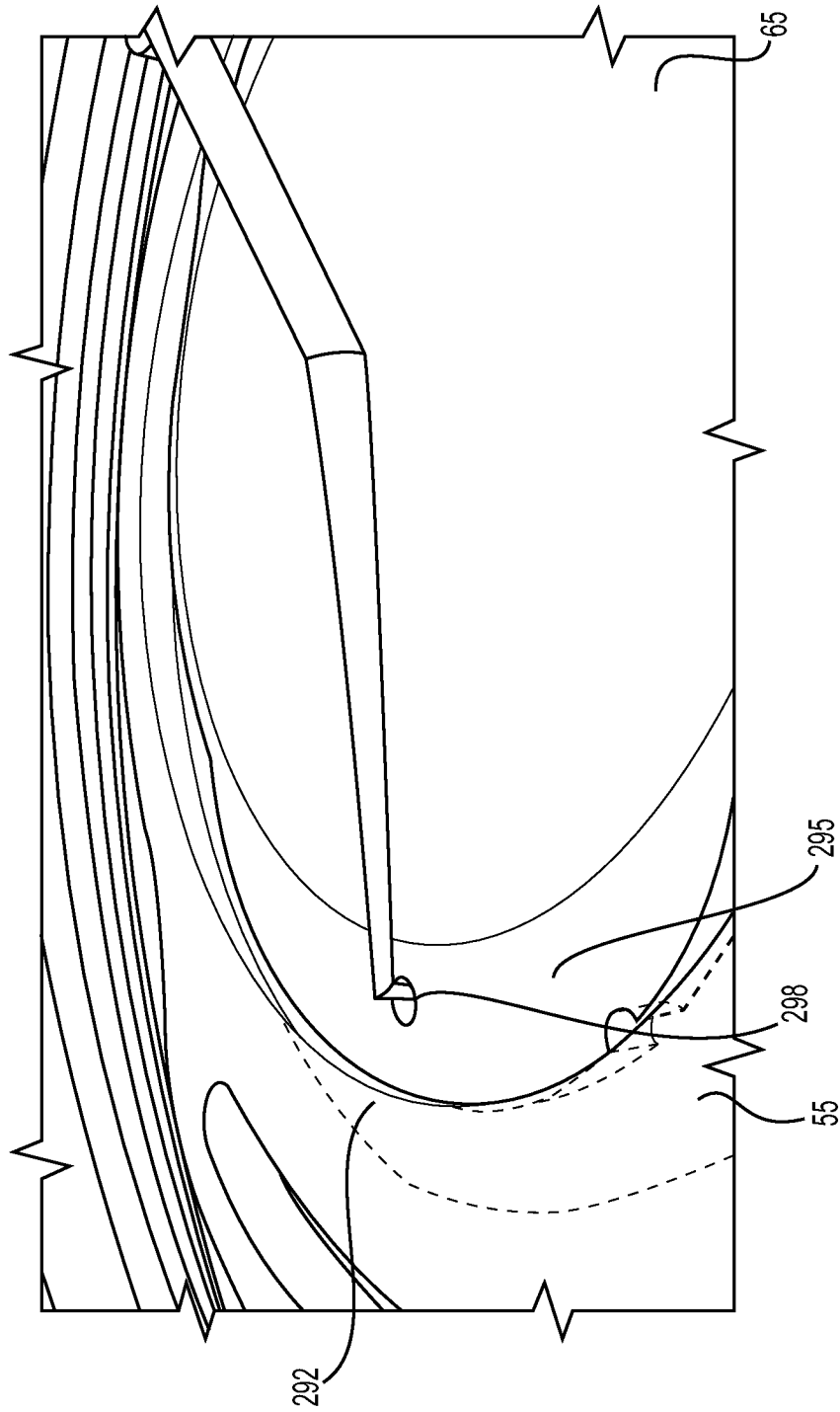
**FIG. 29H**



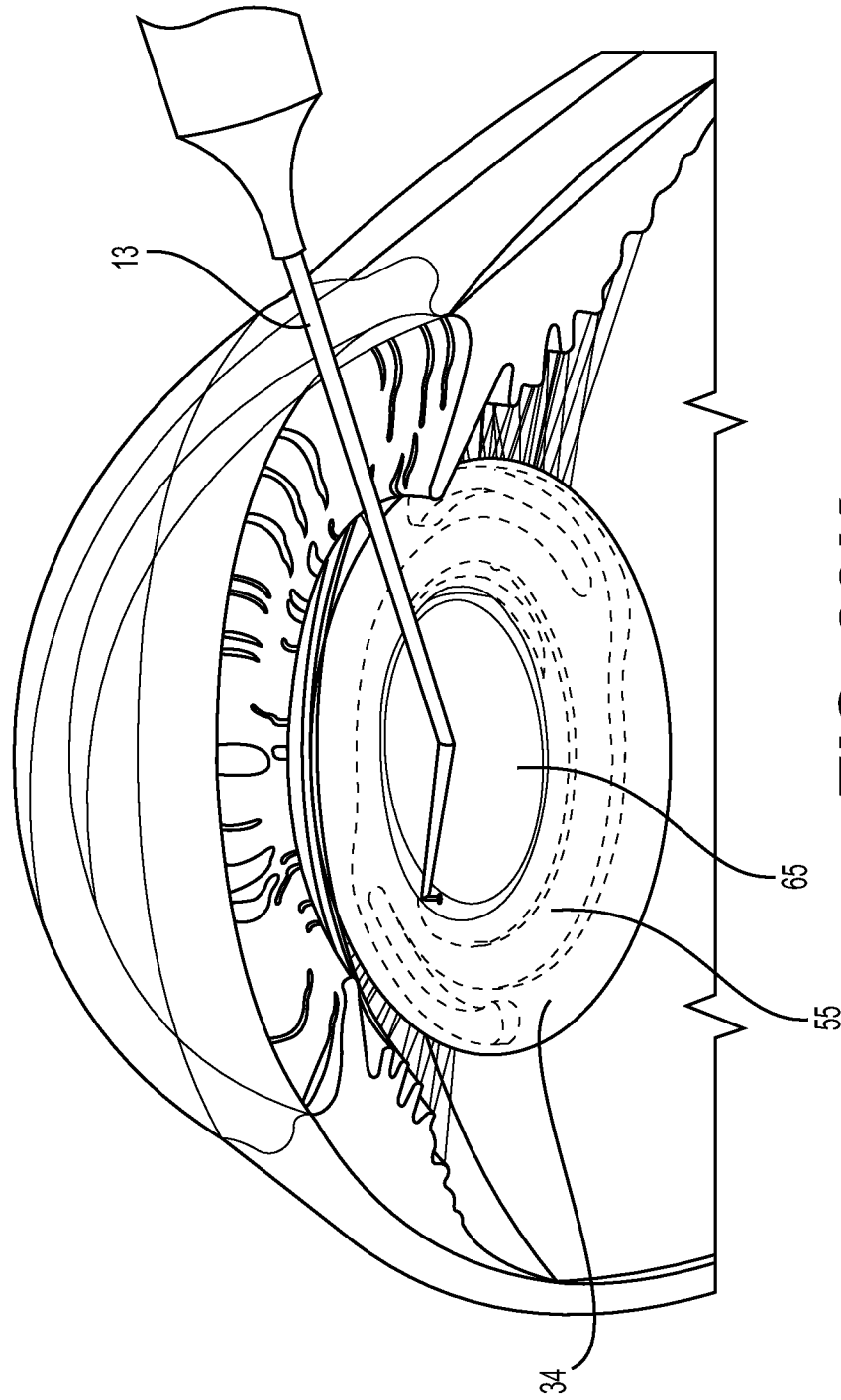
40/66



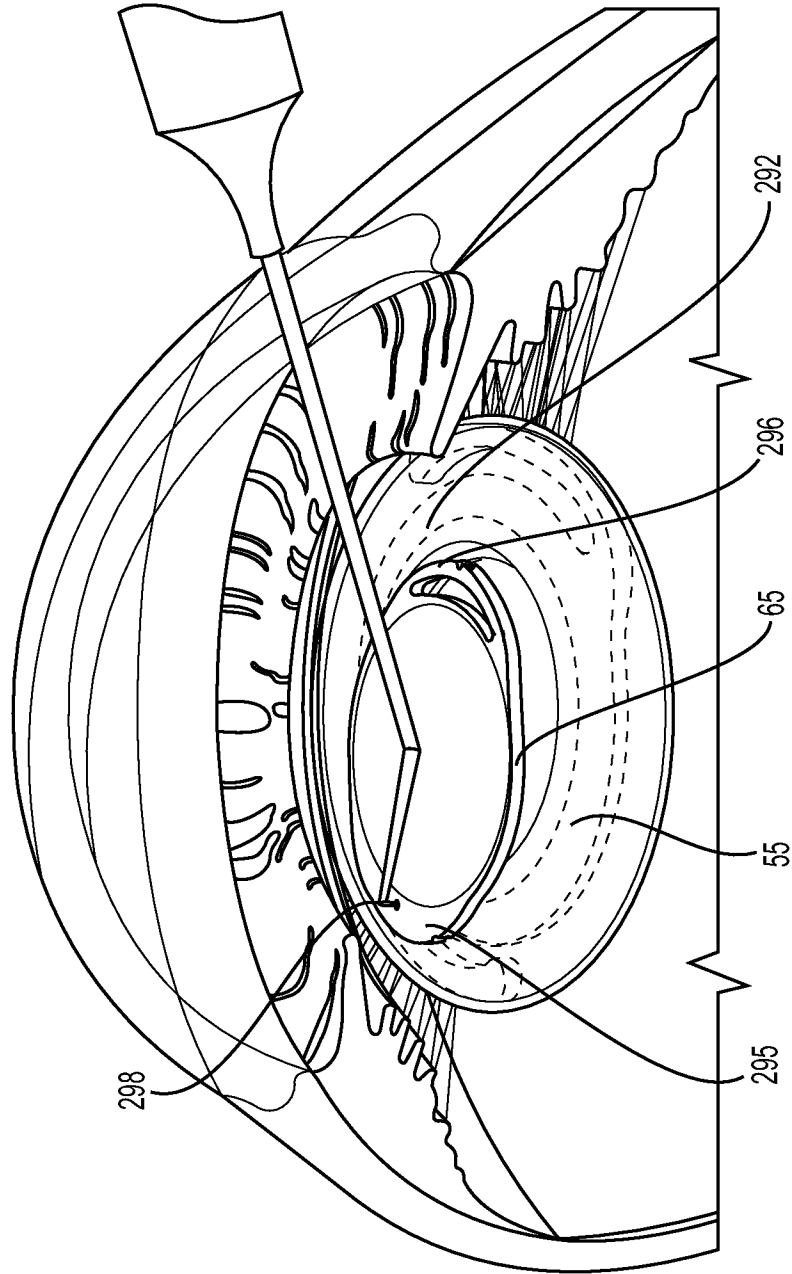
**FIG. 291**



**FIG. 29J**

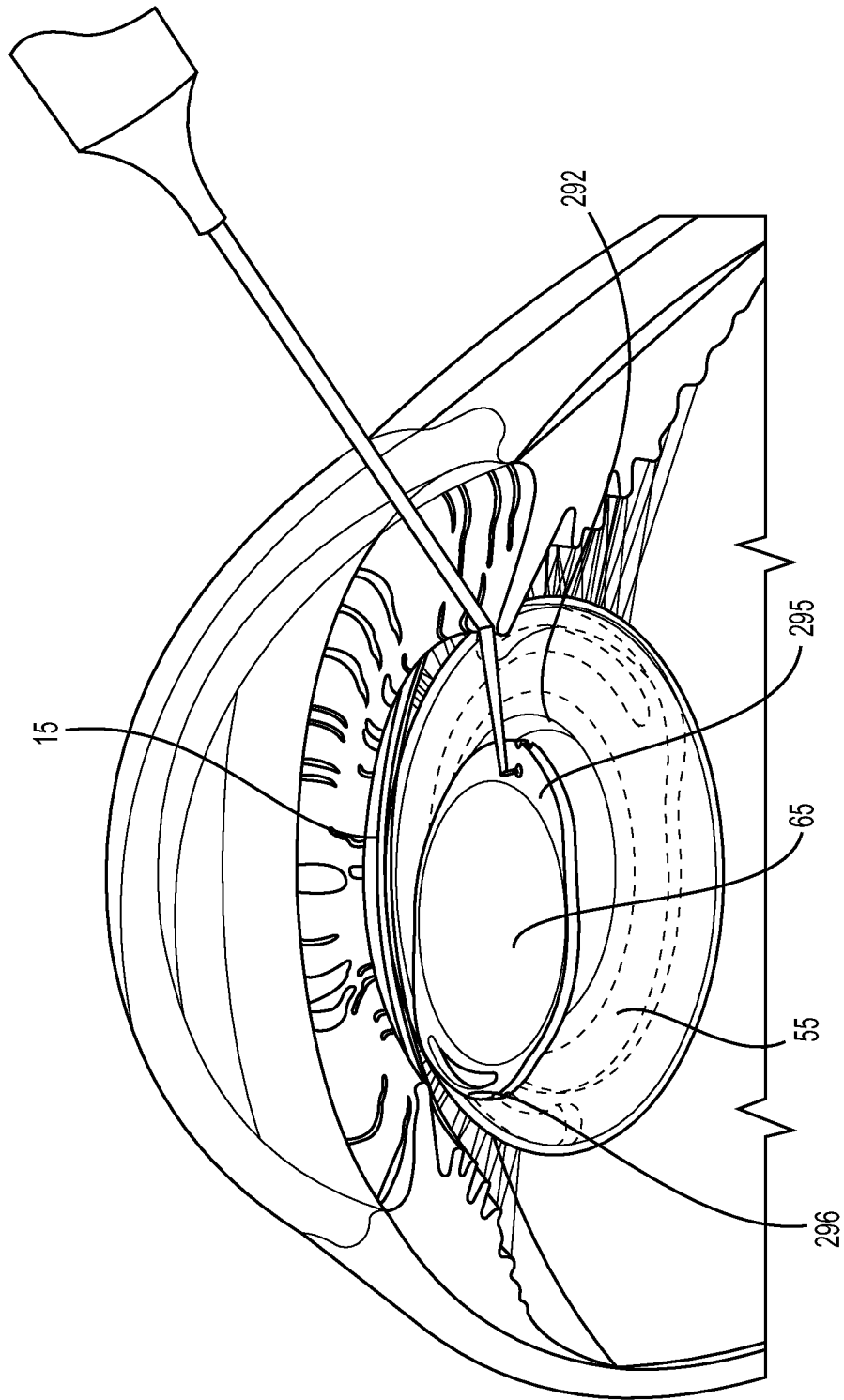


**FIG. 29K**



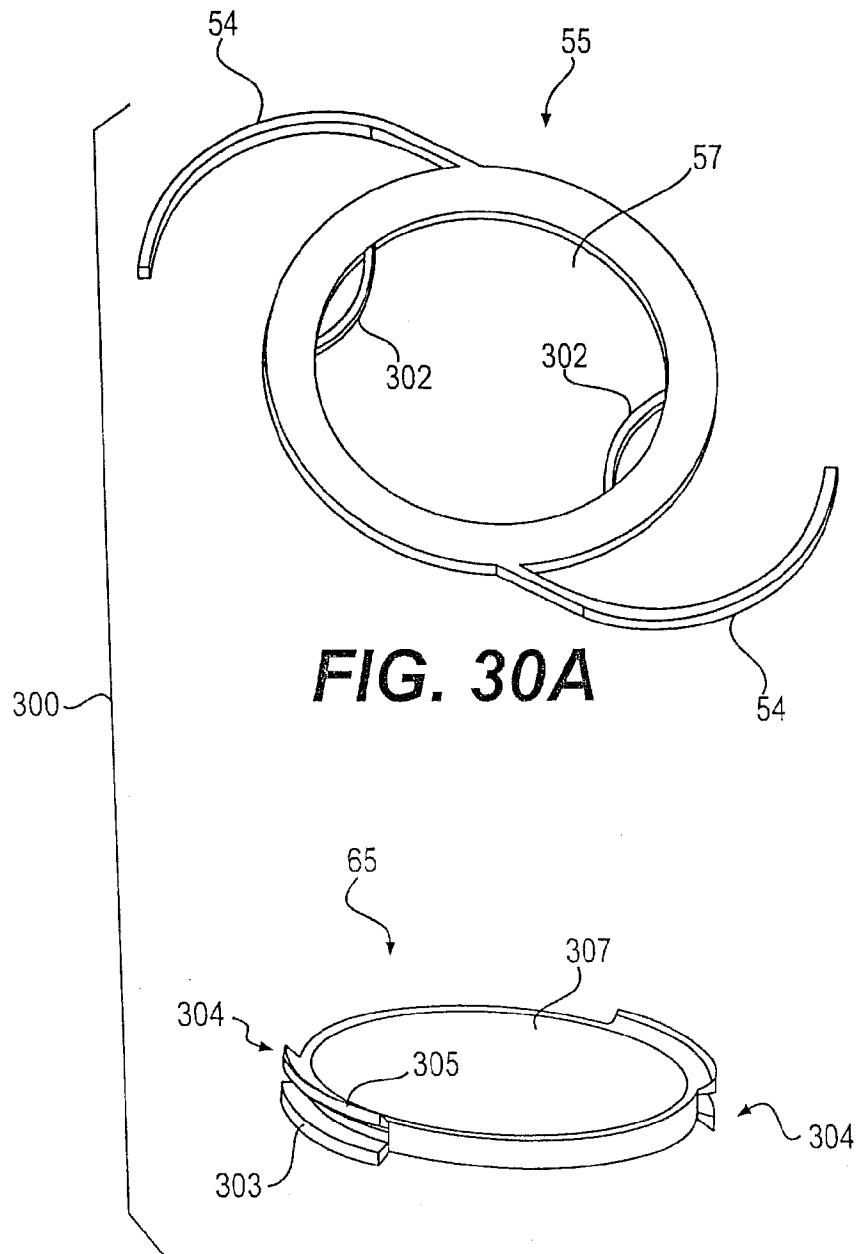
**FIG. 29L**

44/66



**FIG. 29M**

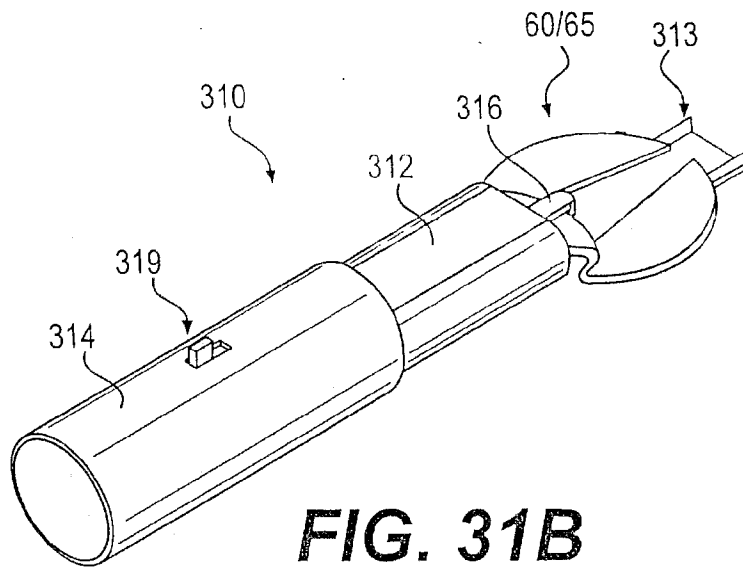
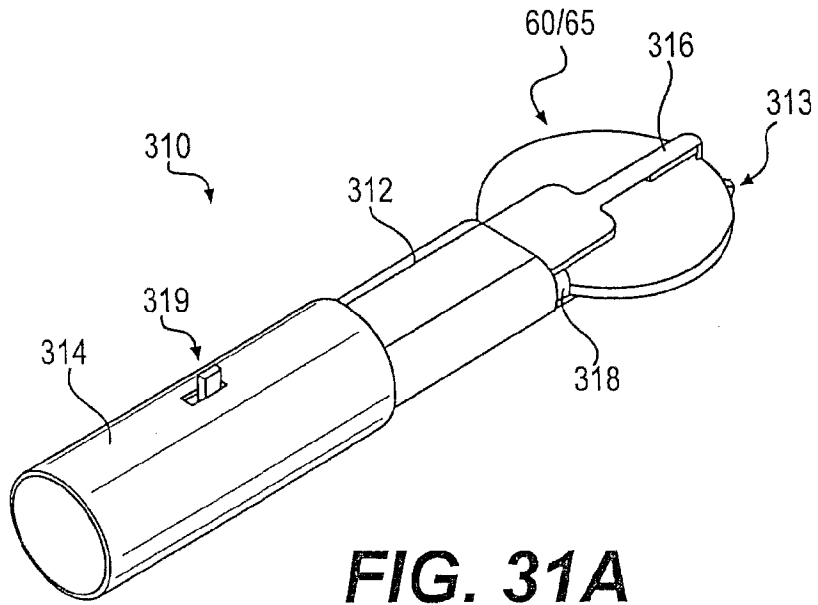
45/66



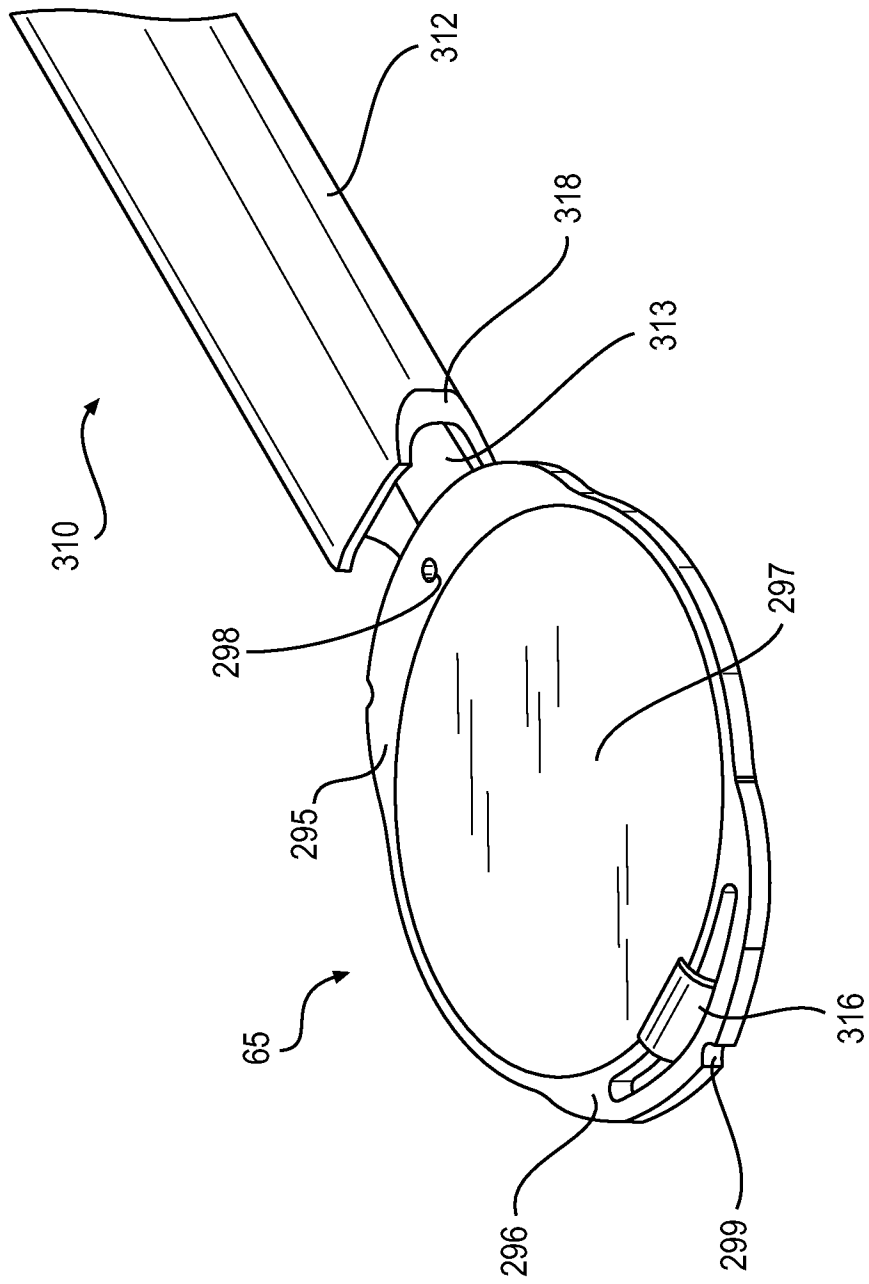
**FIG. 30A**

**FIG. 30B**

46/66



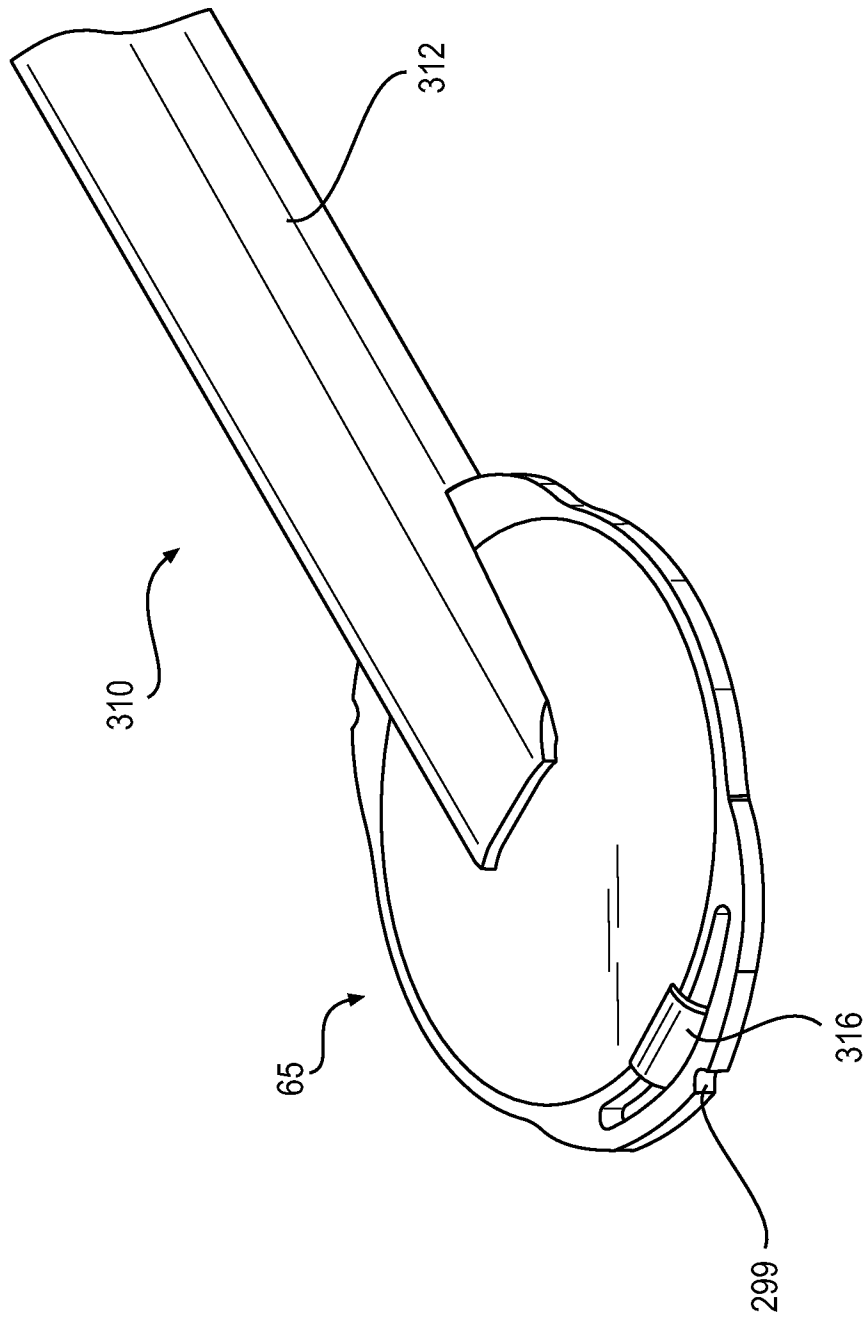
47/66



**FIG. 31C**

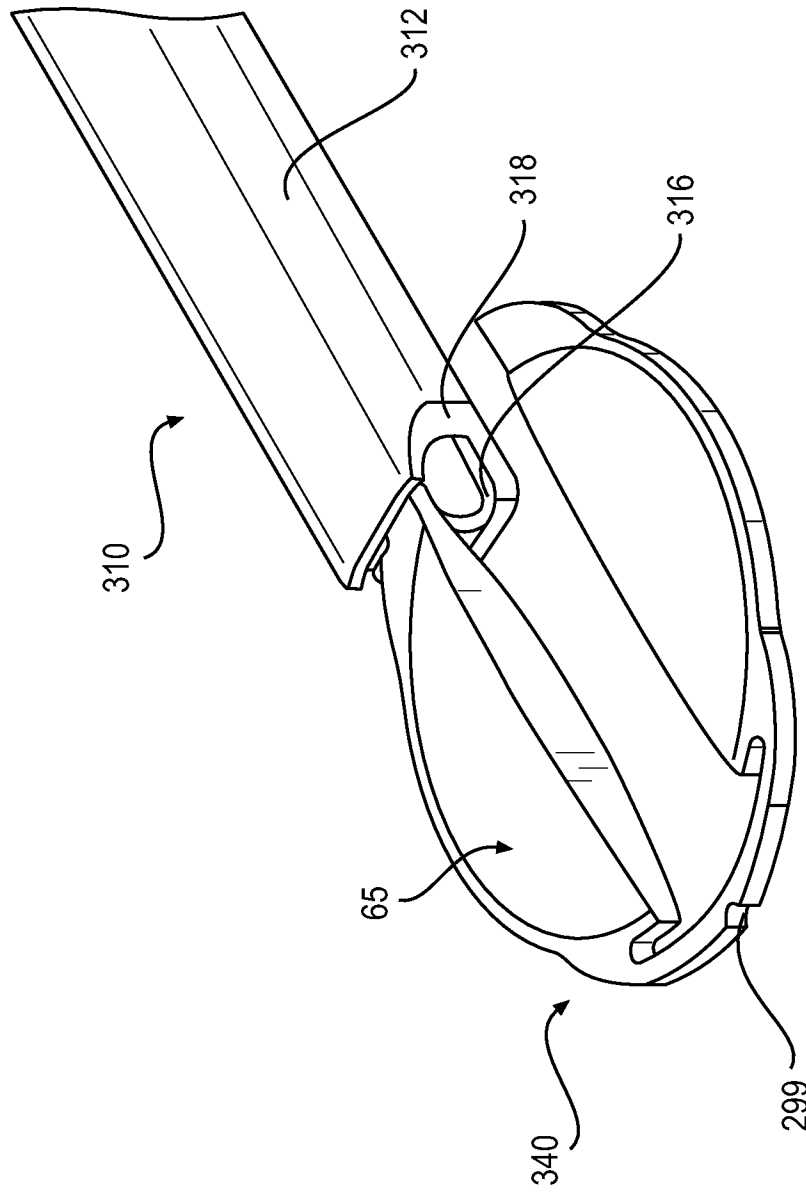


48/66



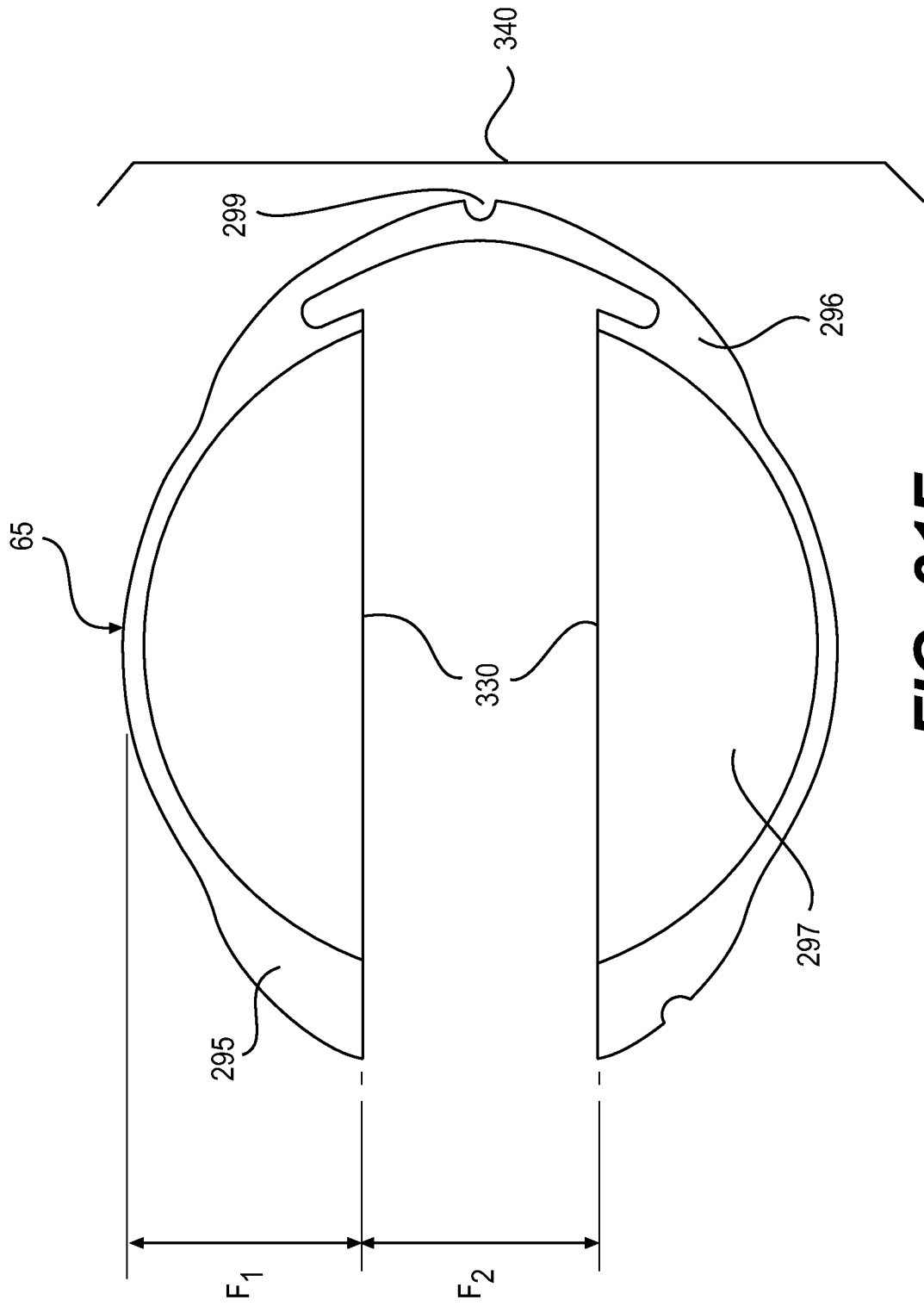
**FIG. 31D**

49/66



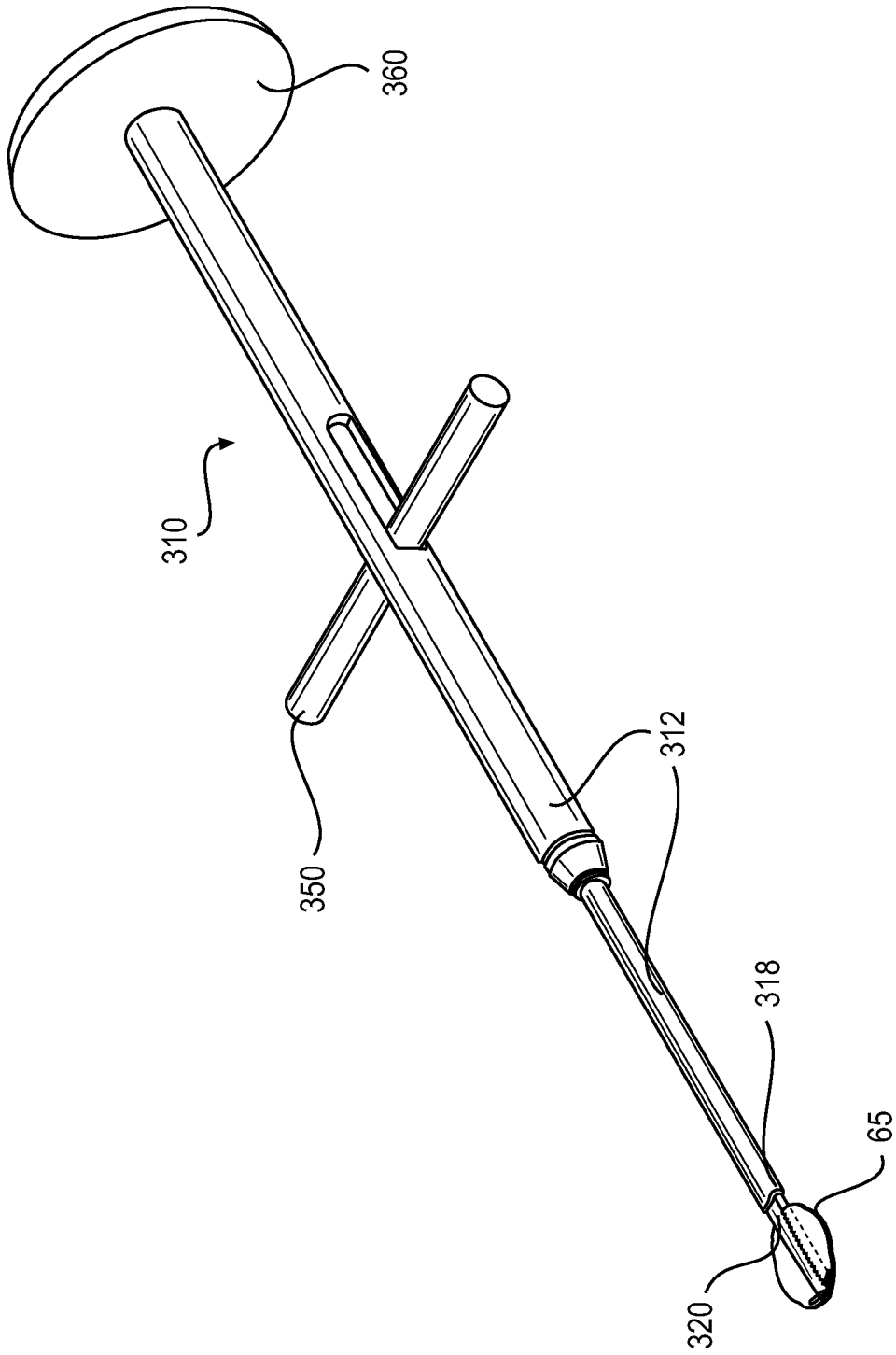
**FIG. 31E**

50/66



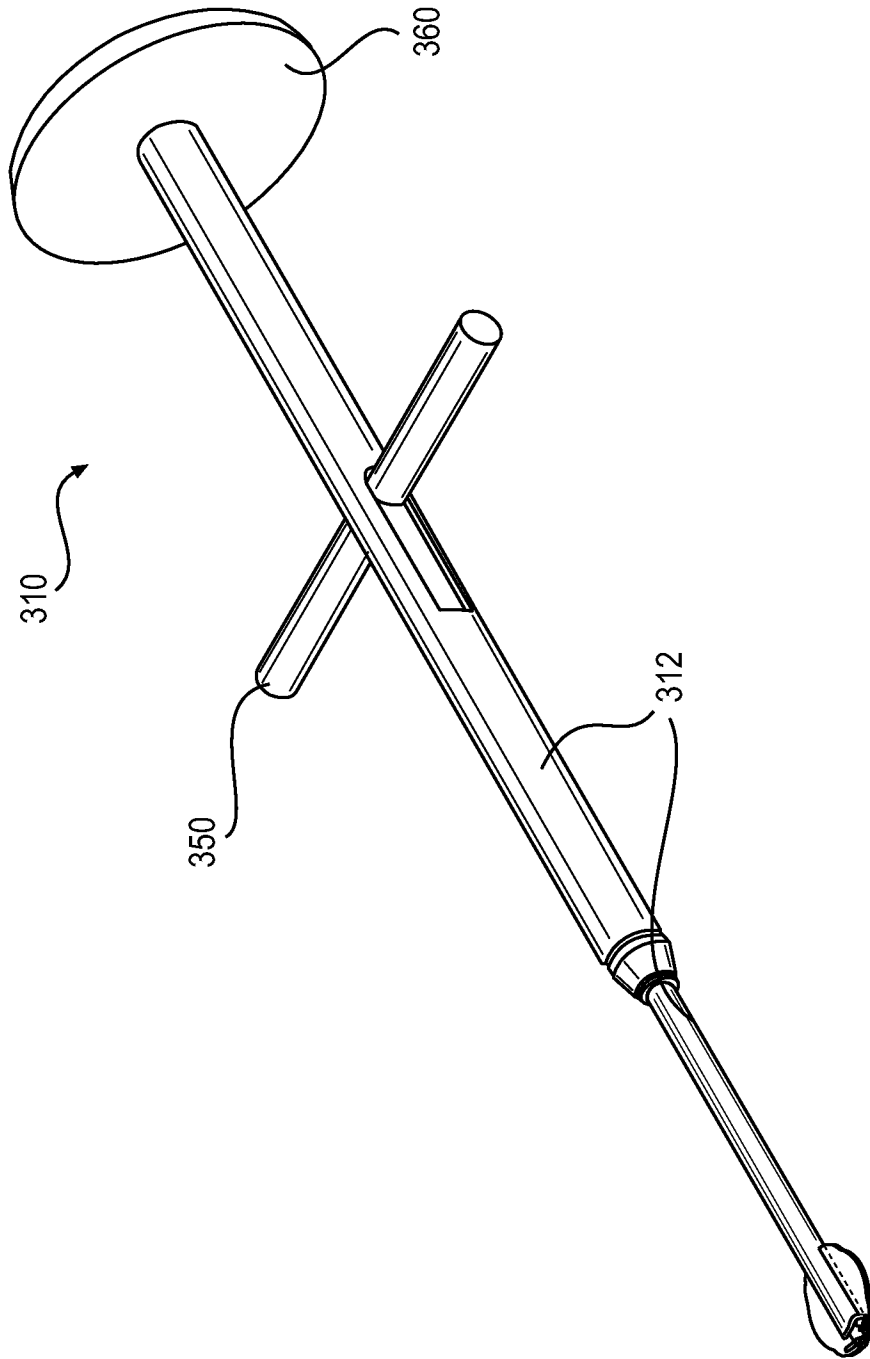
**FIG. 31F**

51/66



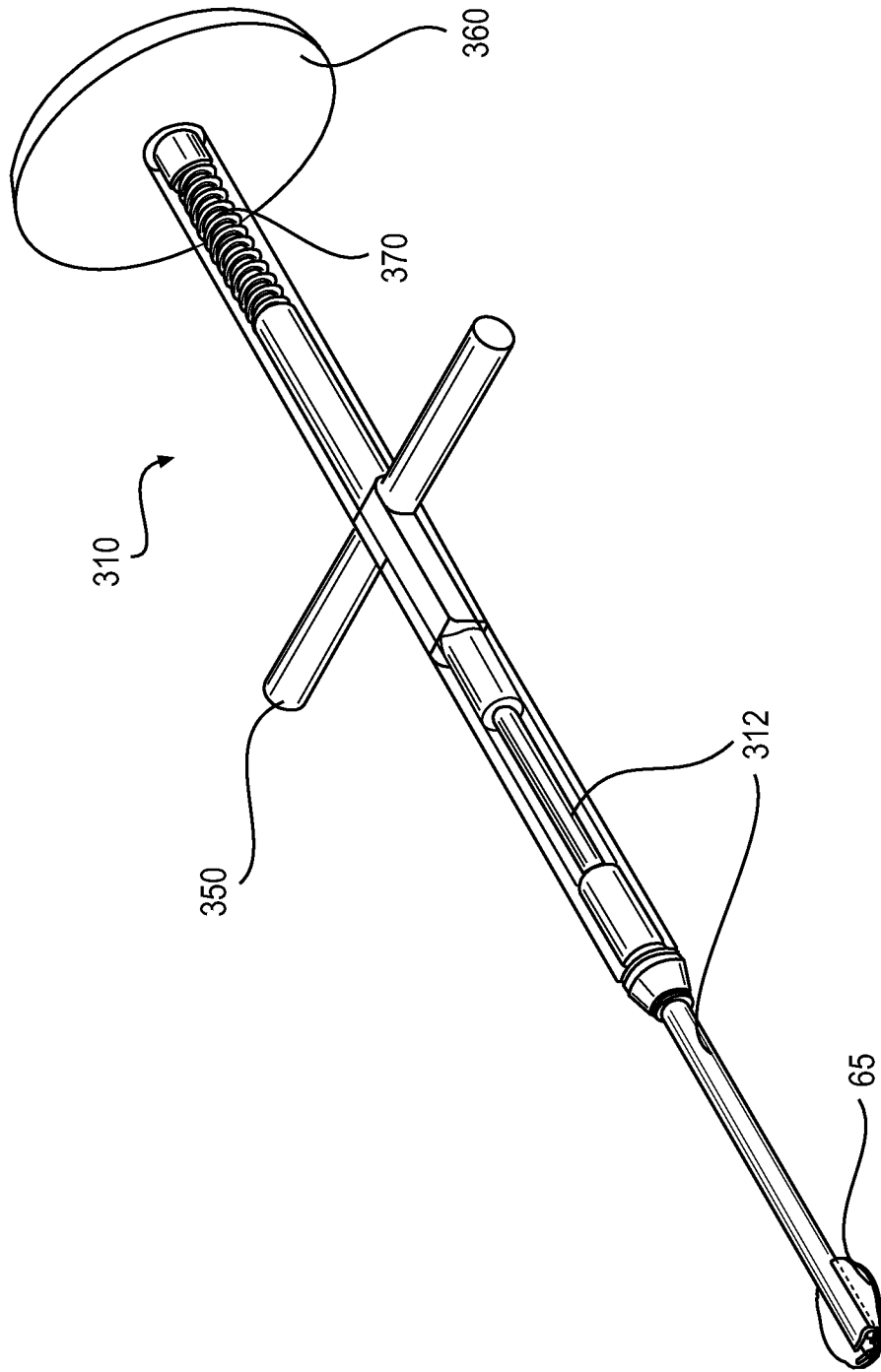
**FIG. 31G**

52/66



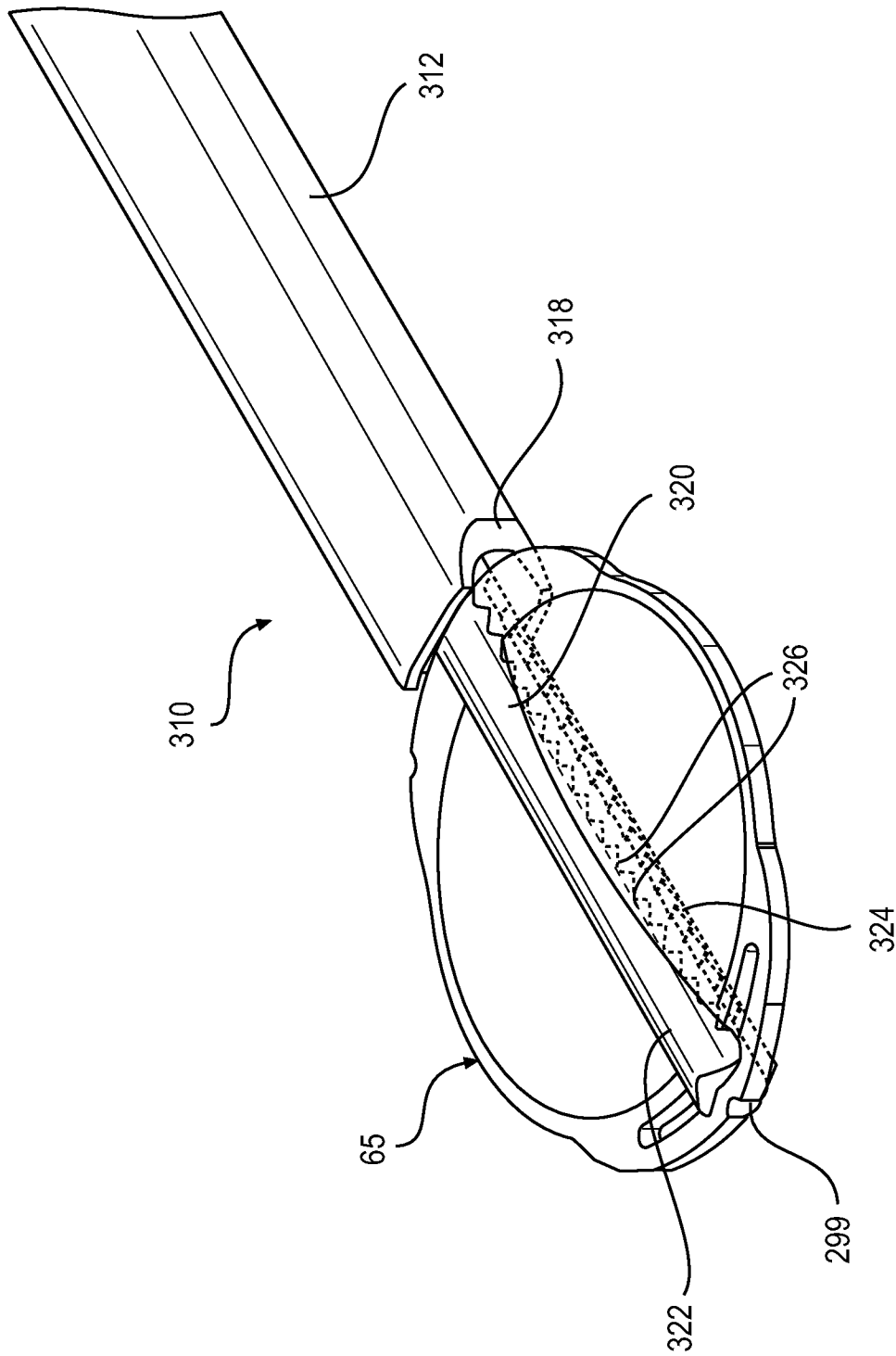
**FIG. 31H**

53/66



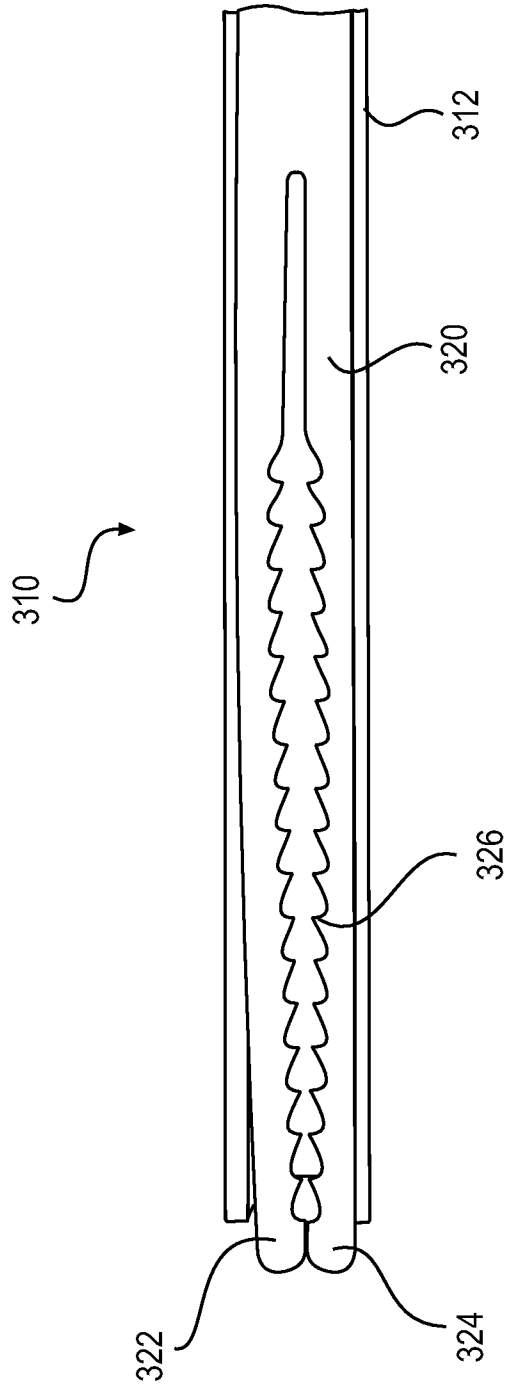
**FIG. 311**

54/66



**FIG. 31J**

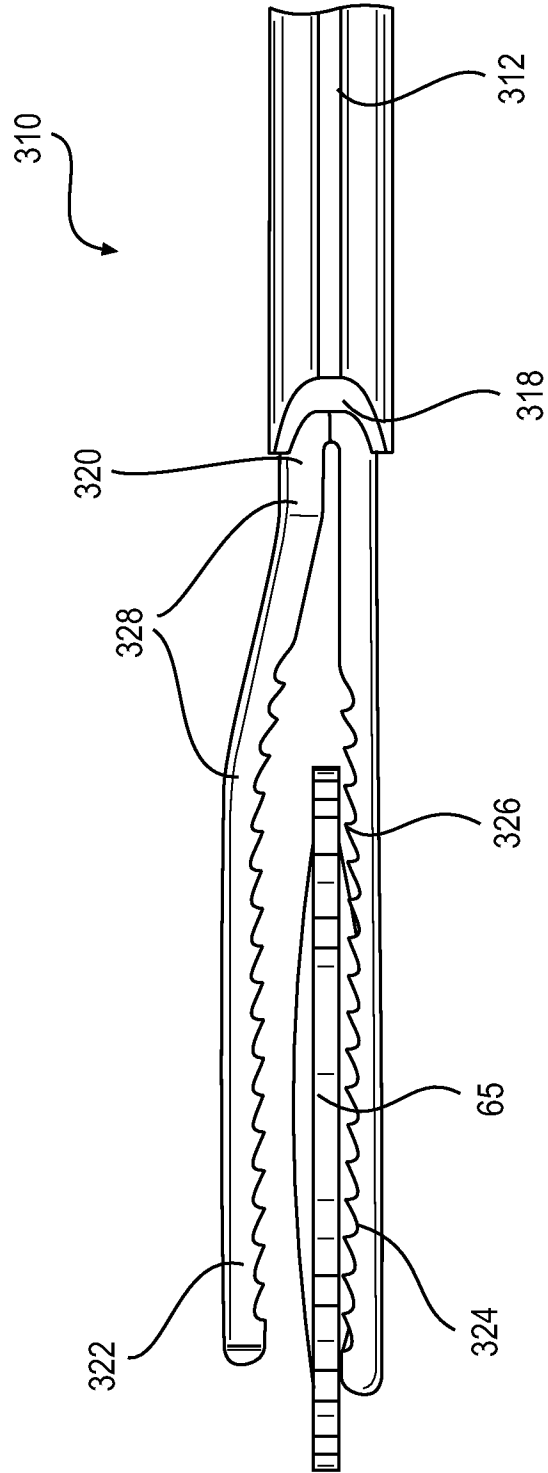
55/66



**FIG. 31K**

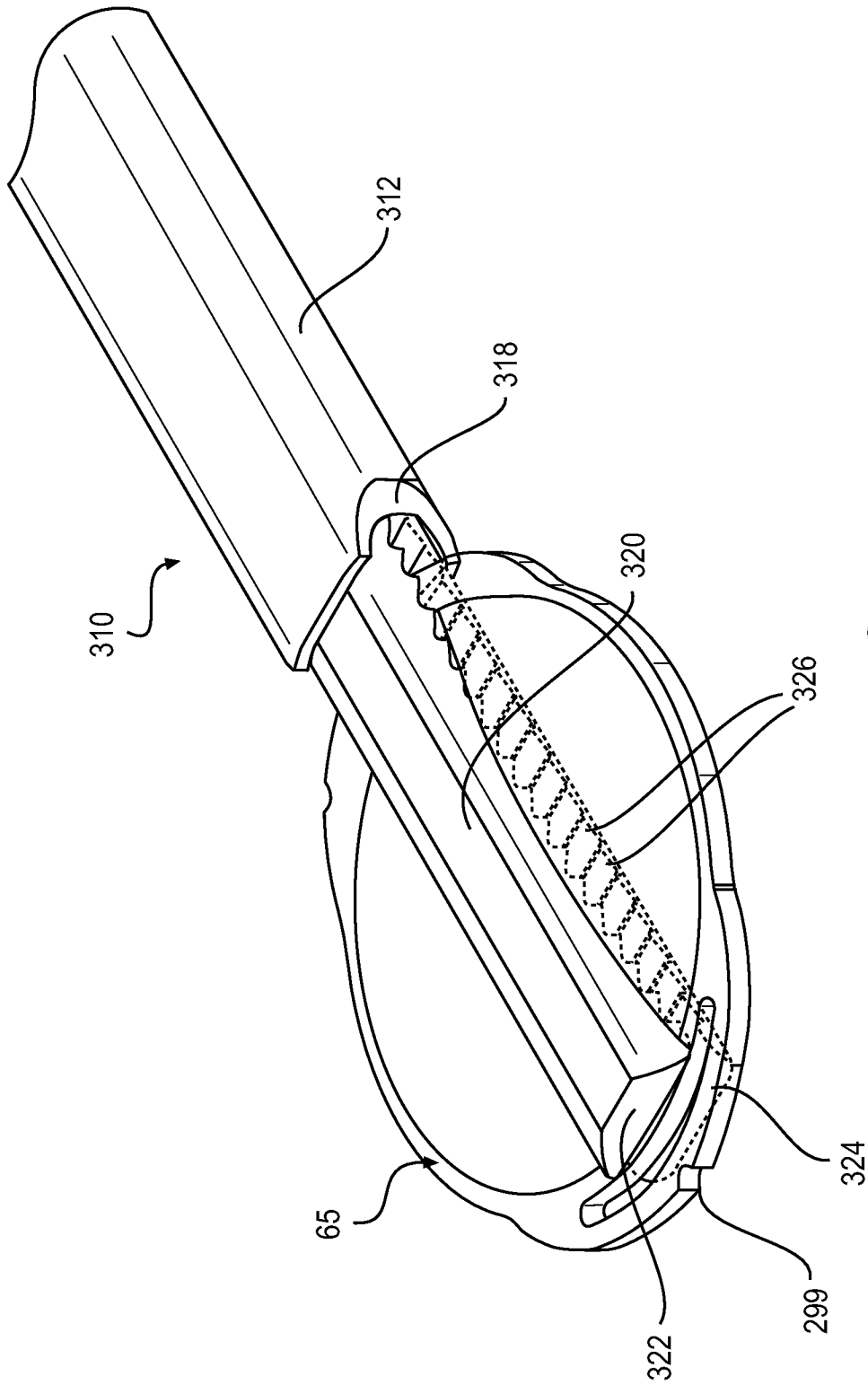


56/66



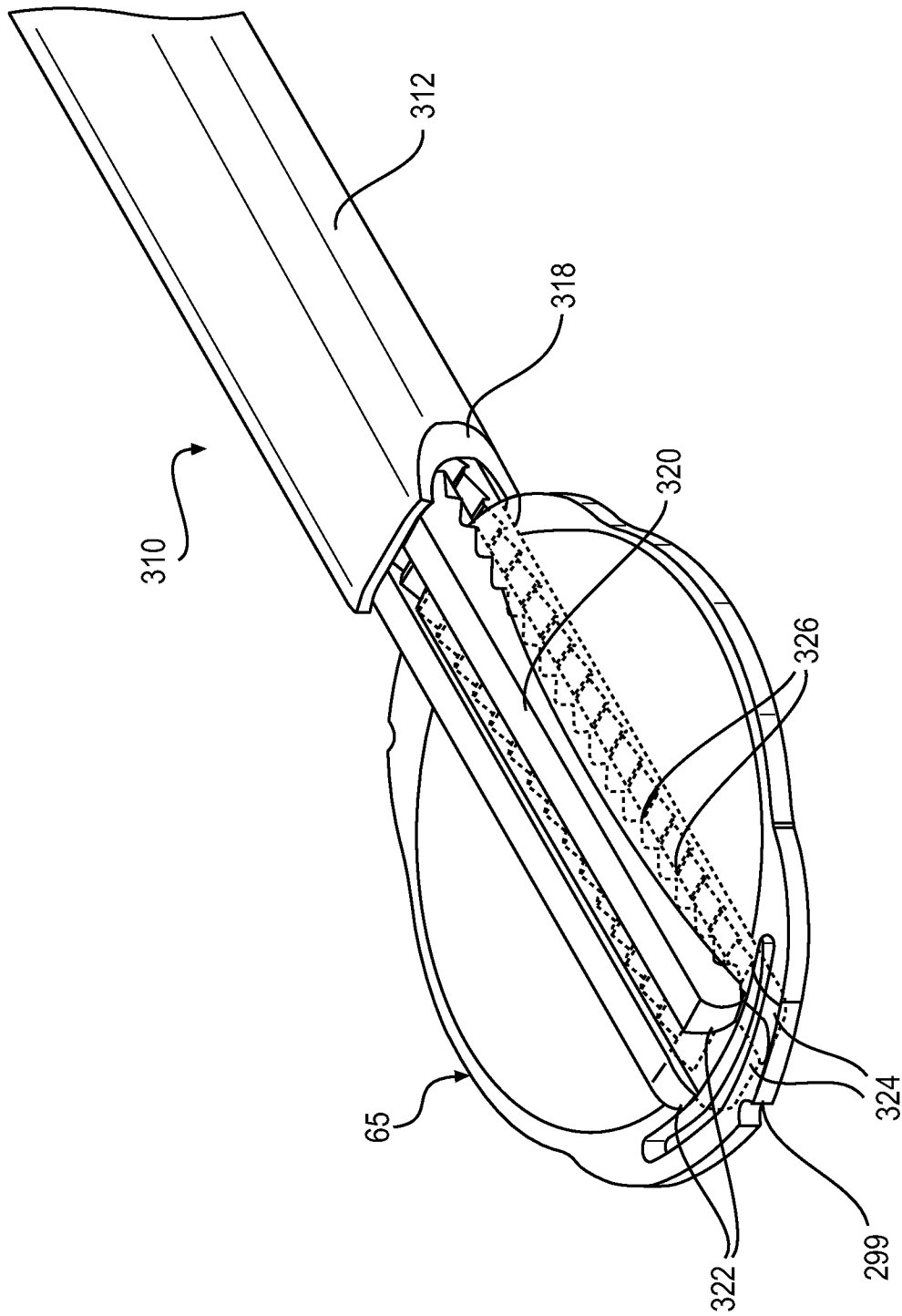
**FIG. 31L**

57/66



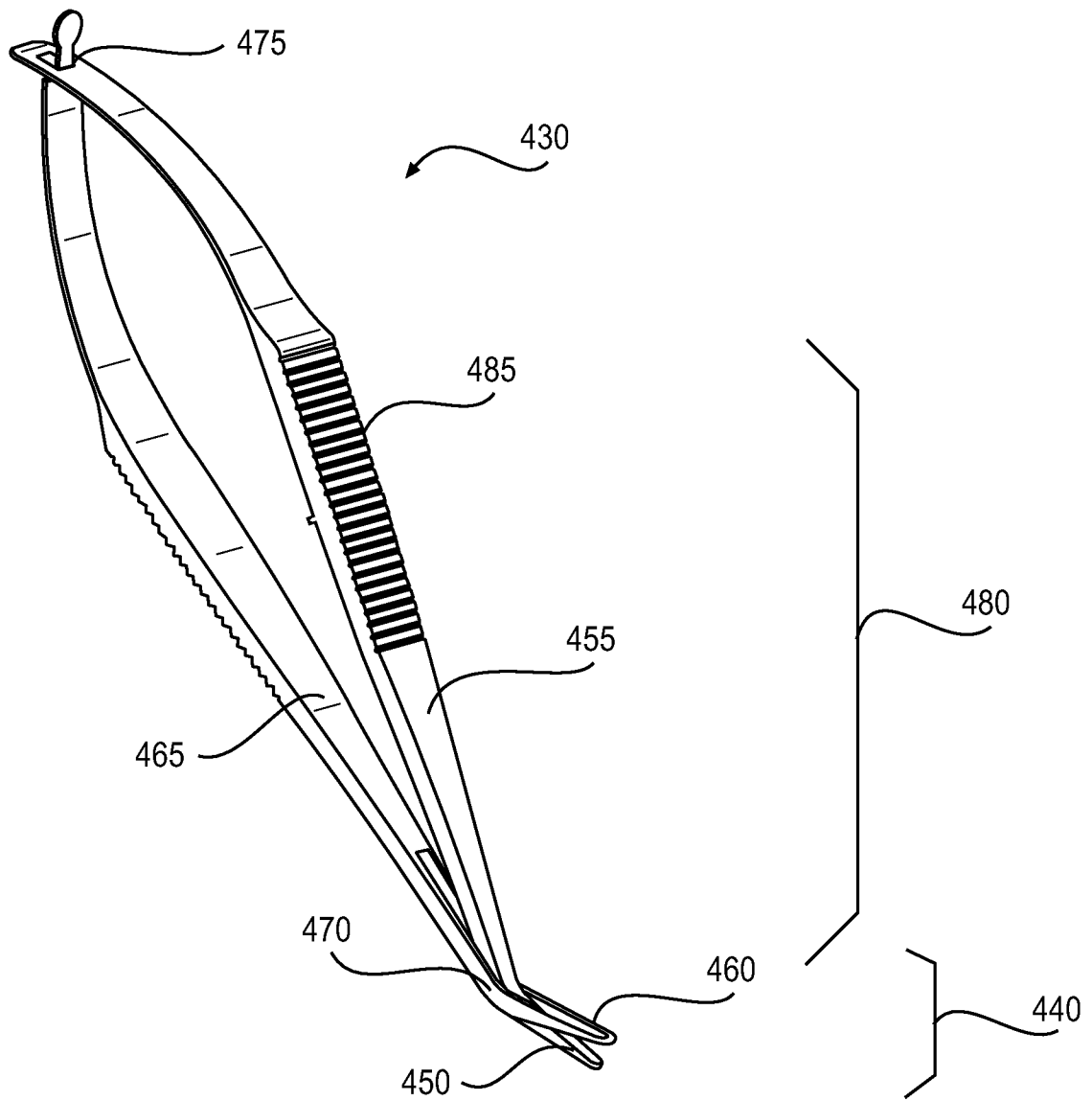
**FIG. 31M**

58/66



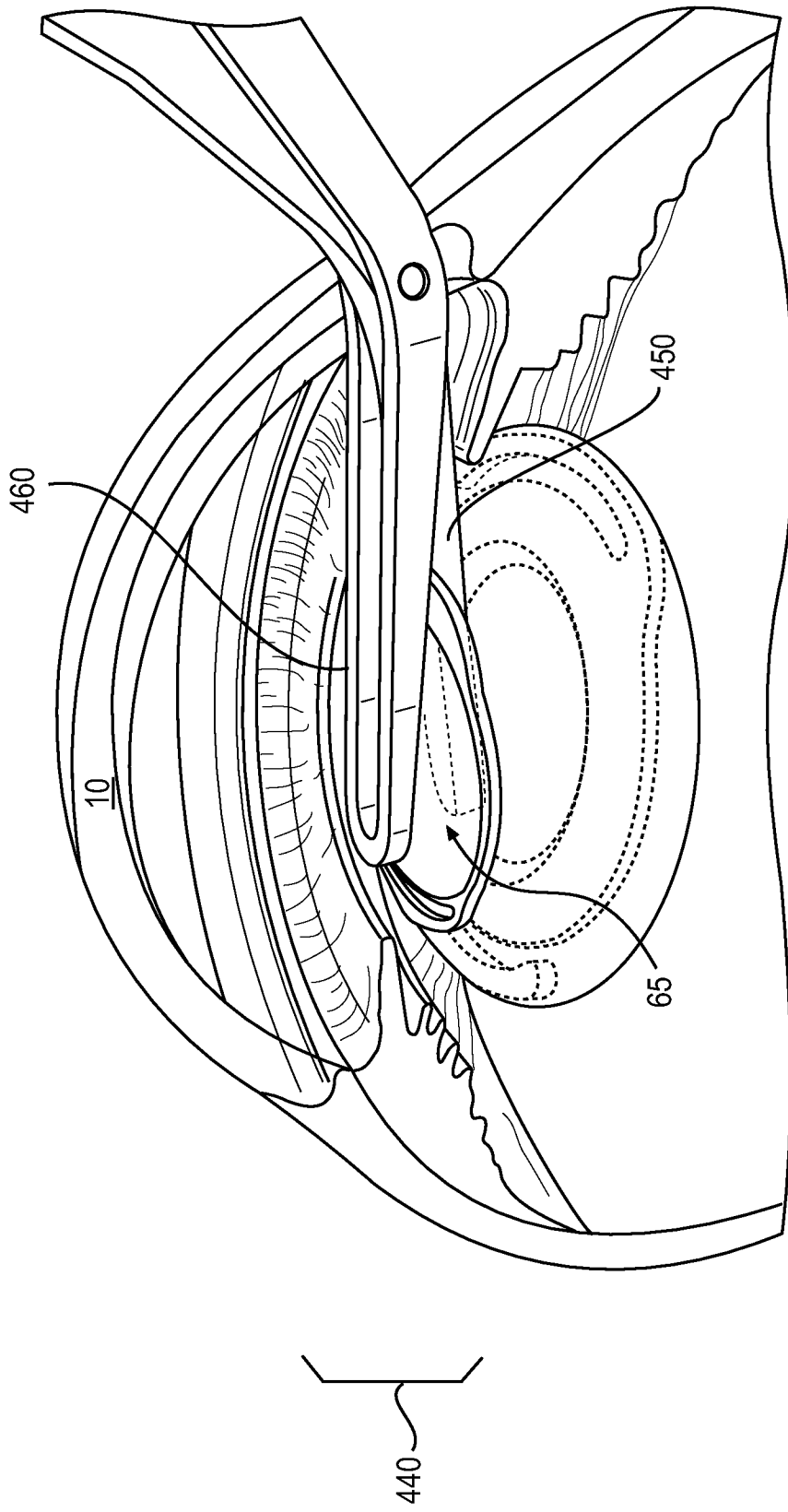
**FIG. 31N**

59/66

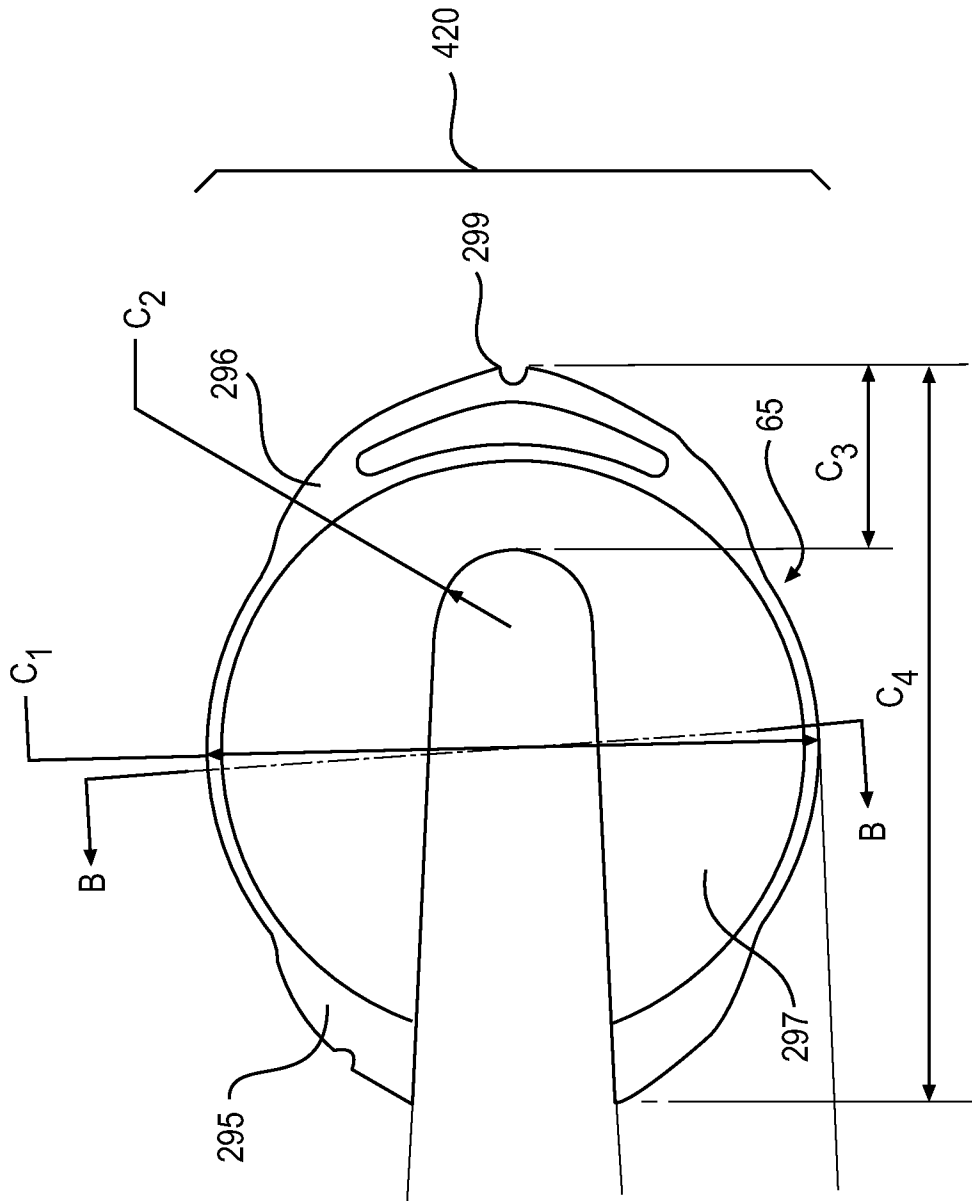


**FIG. 32A**

60/66

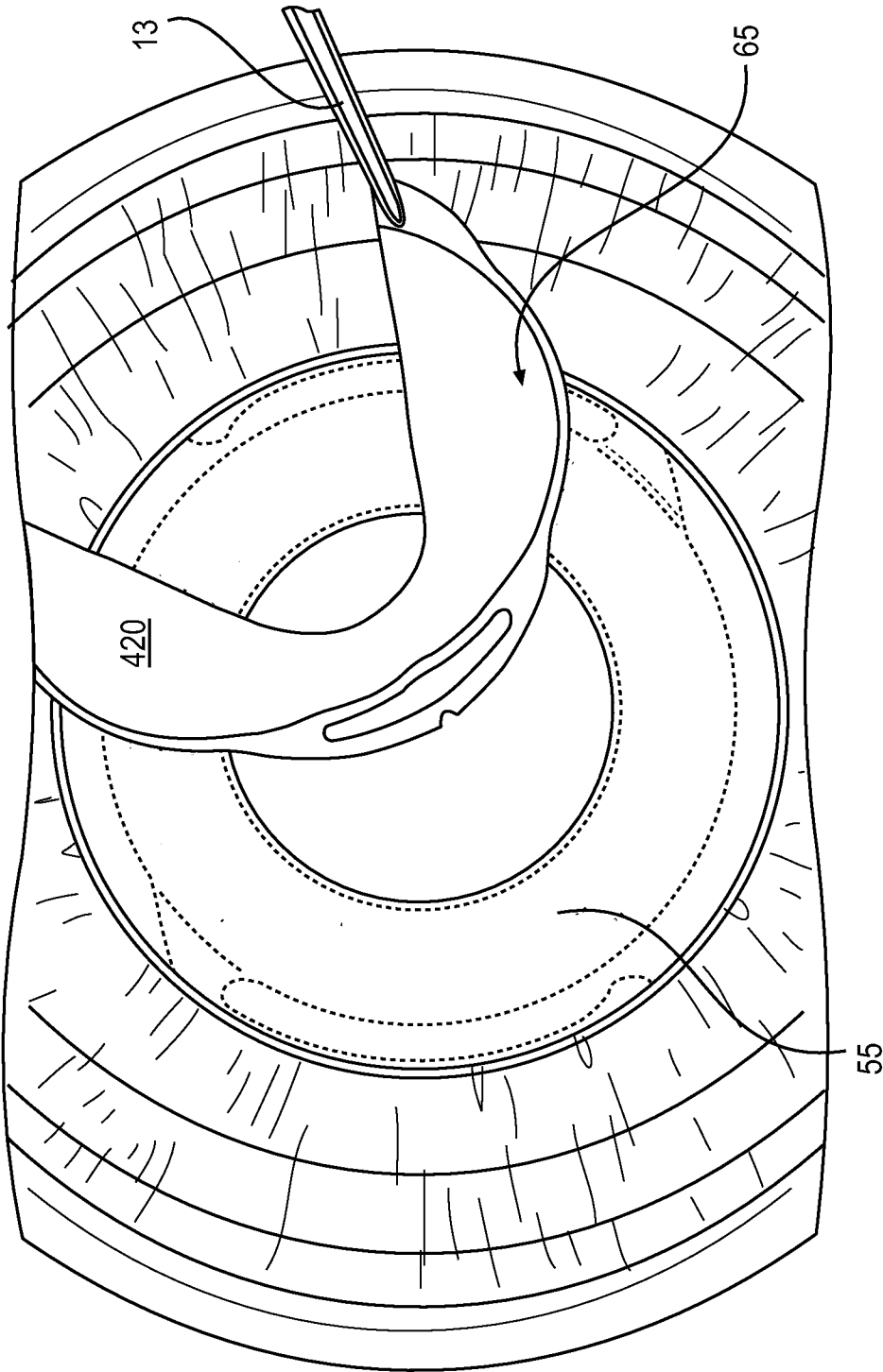


**FIG. 32B**

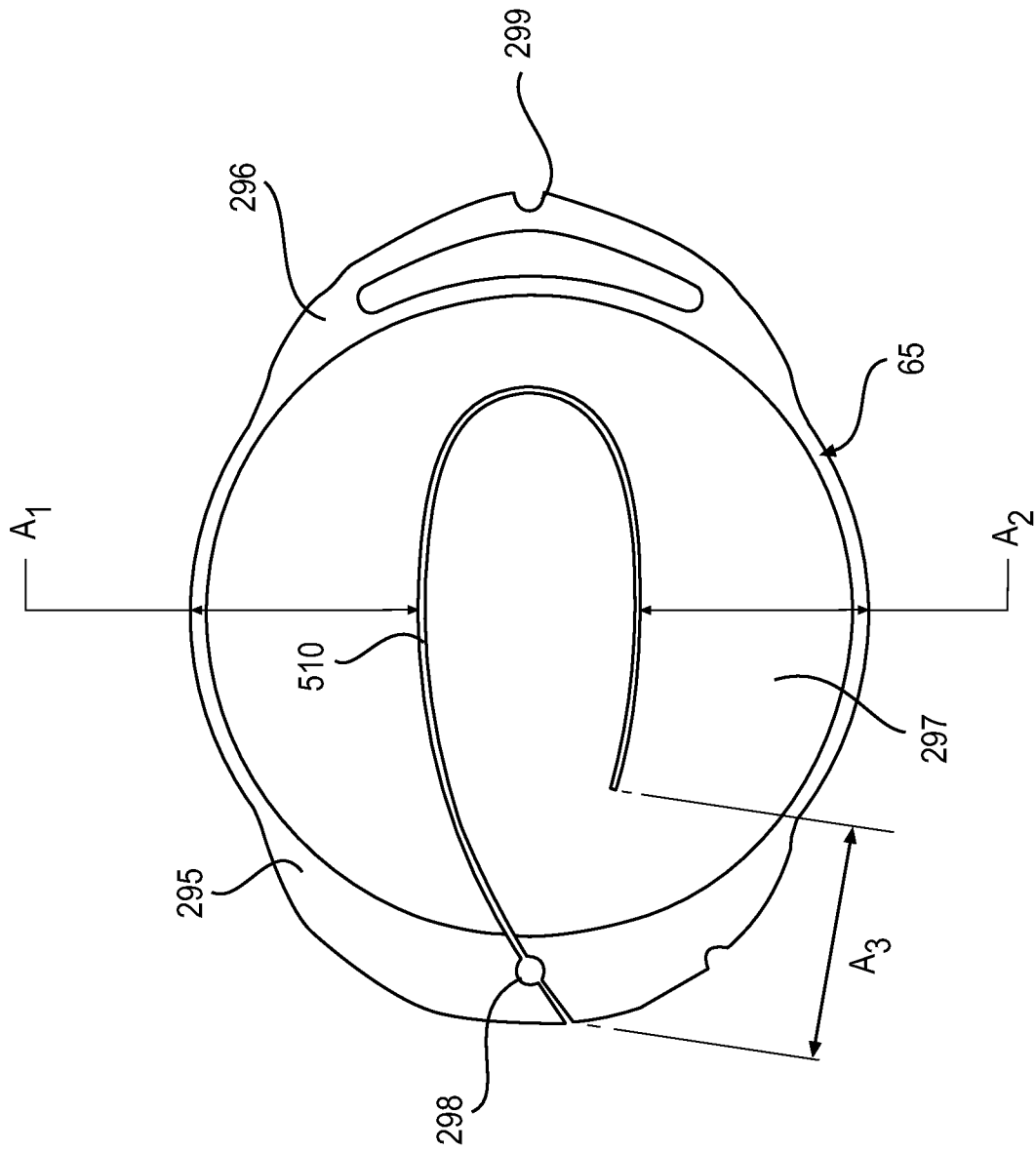


**FIG. 32C**

62/66



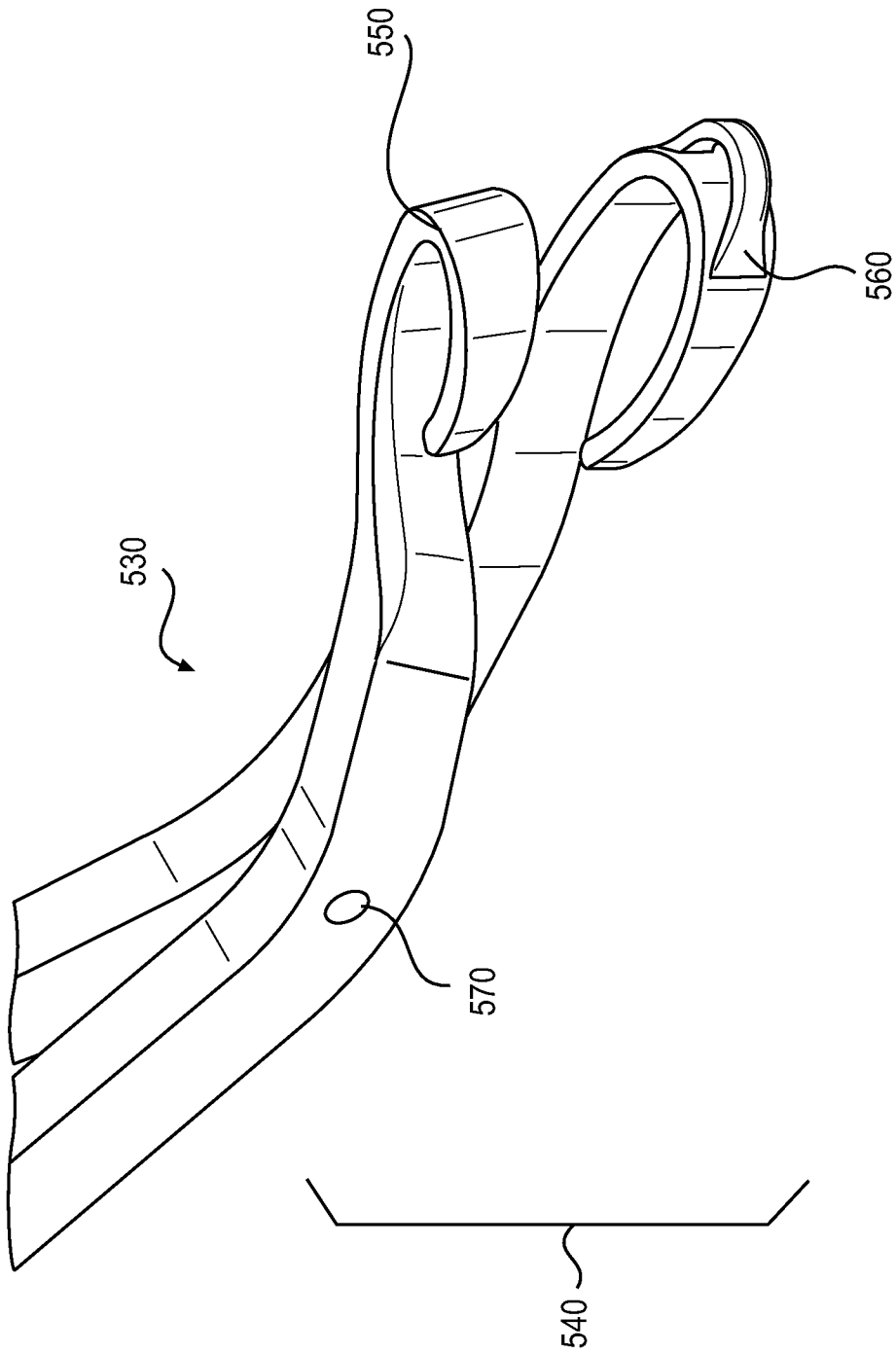
**FIG. 32D**



**FIG. 33A**

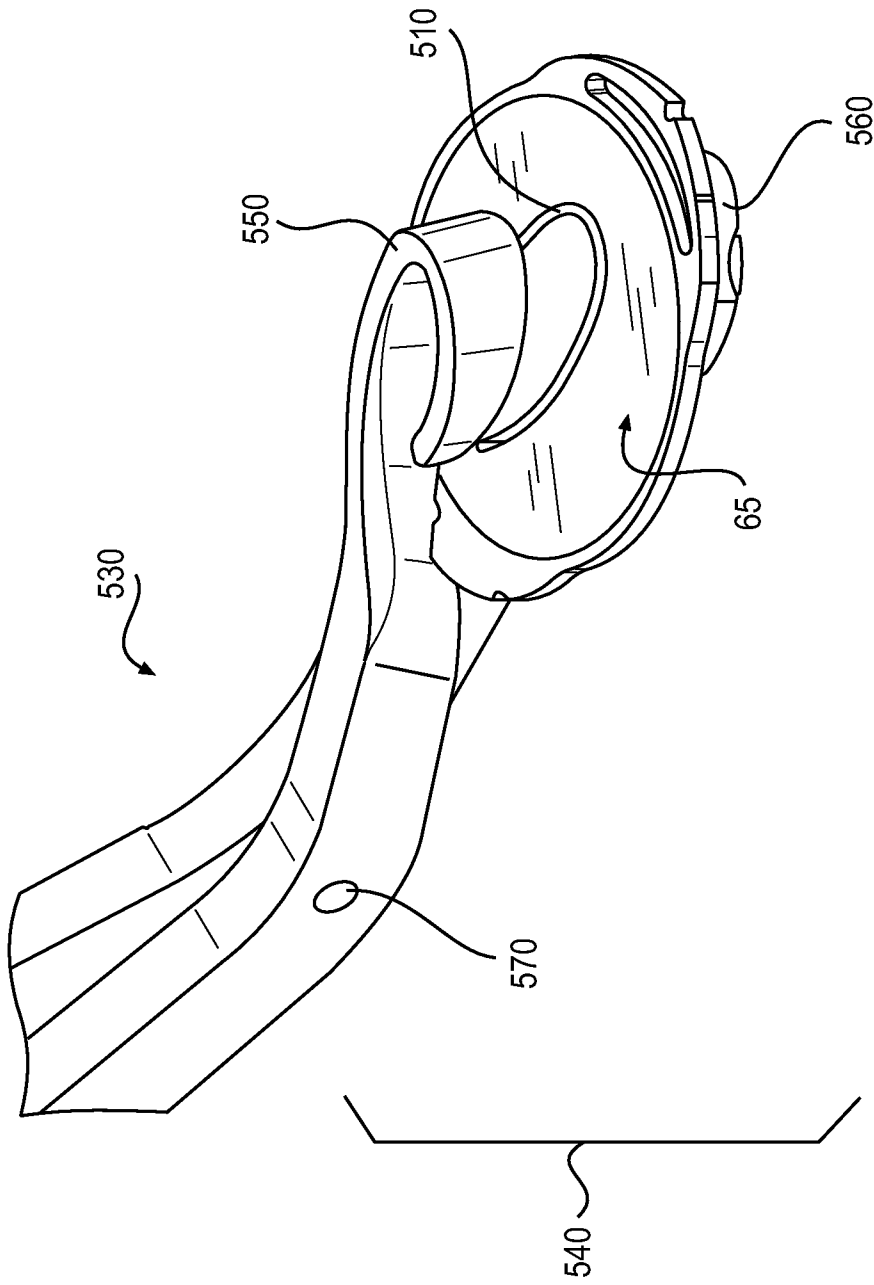


64/66

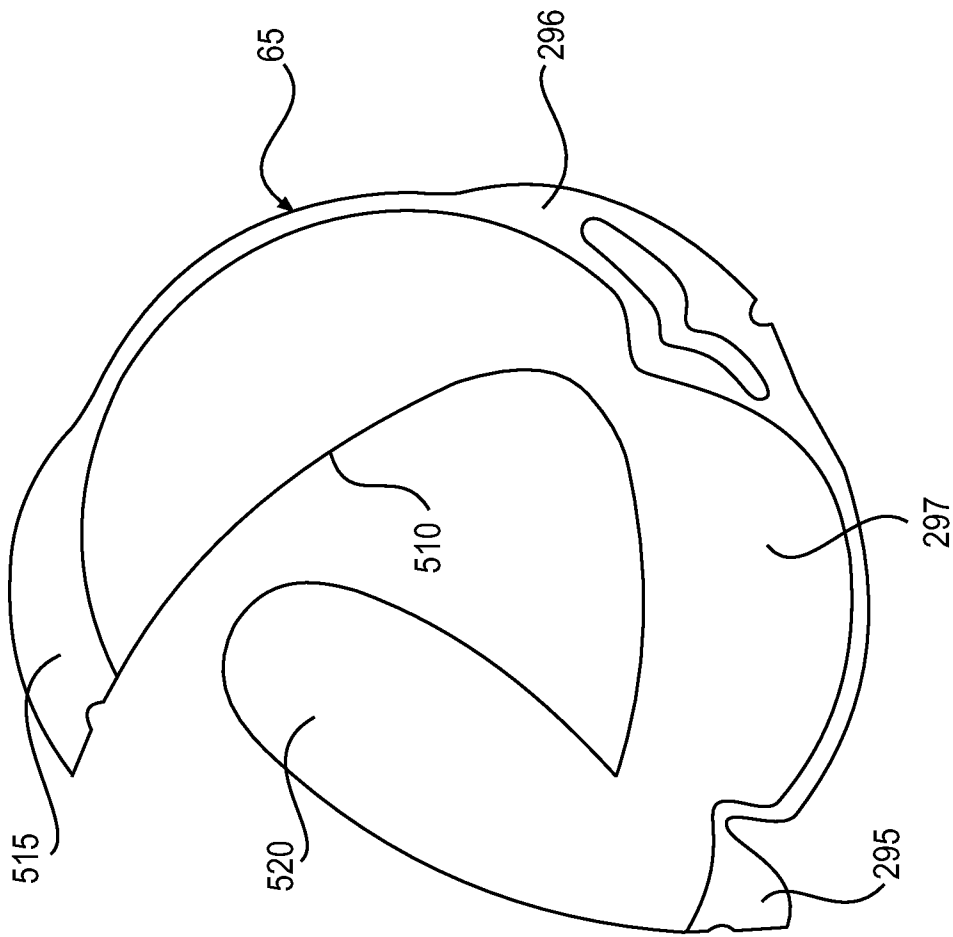


**FIG. 33B**

65/66



**FIG. 33C**



**FIG. 33D**