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(54) **SUBSTRATE-LEVEL MONOLITHIC INTEGRATION OF PRESCRIPTION LENS WITH AUGMENTED REALITY (AR) WAVEGUIDES**

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Publication Classification

(51) **Int. Cl.**

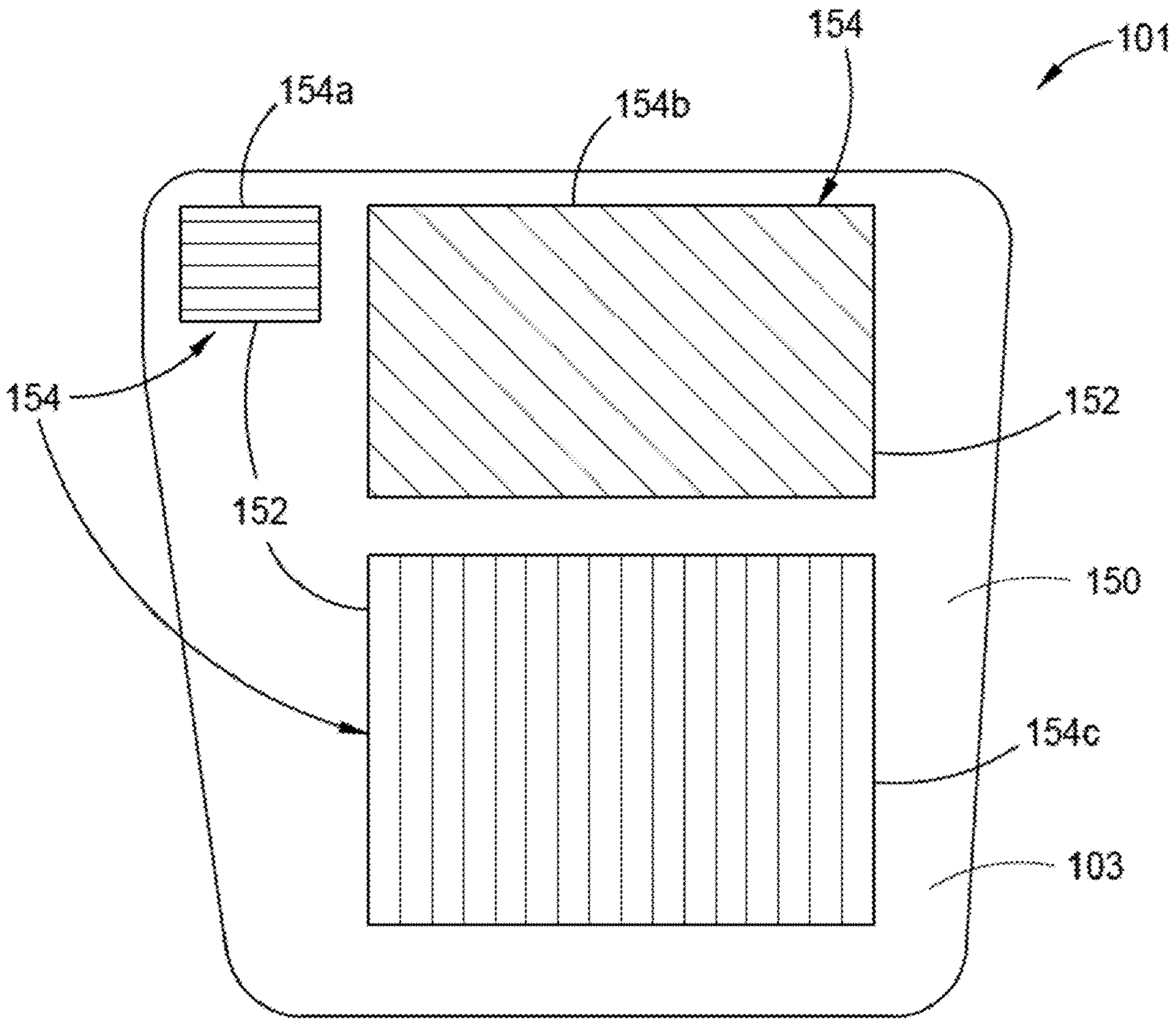
G02C 7/02	(2006.01)
B29D 11/00	(2006.01)
G02B 27/01	(2006.01)

(52) **U.S. Cl.**

CPC ***G02C 7/022*** (2013.01); ***B29D 11/00355*** (2013.01); ***B29D 11/00442*** (2013.01); *G02B 27/0172* (2013.01)

(57) **ABSTRACT**

Embodiments described herein relate to AR waveguides with attached prescription lenses. In one embodiment, an eye-piece is provided. The eye-piece includes a waveguide, a convex prescription lens, a first gap, a concave prescription lens, and a second gap. The waveguide includes a substrate with a first surface and a second surface. The convex prescription lens is disposed over the waveguide on the first surface. The convex prescription lens has a first body with a convex surface and a lower surface. The first gap is defined by the lower surface and a first extension of the convex prescription lens. The concave prescription lens is disposed over the waveguide on the second surface. The concave prescription lens has a second body with a concave surface and an upper surface. The second gap is defined by the upper surface and a second extension of the concave prescription lens.



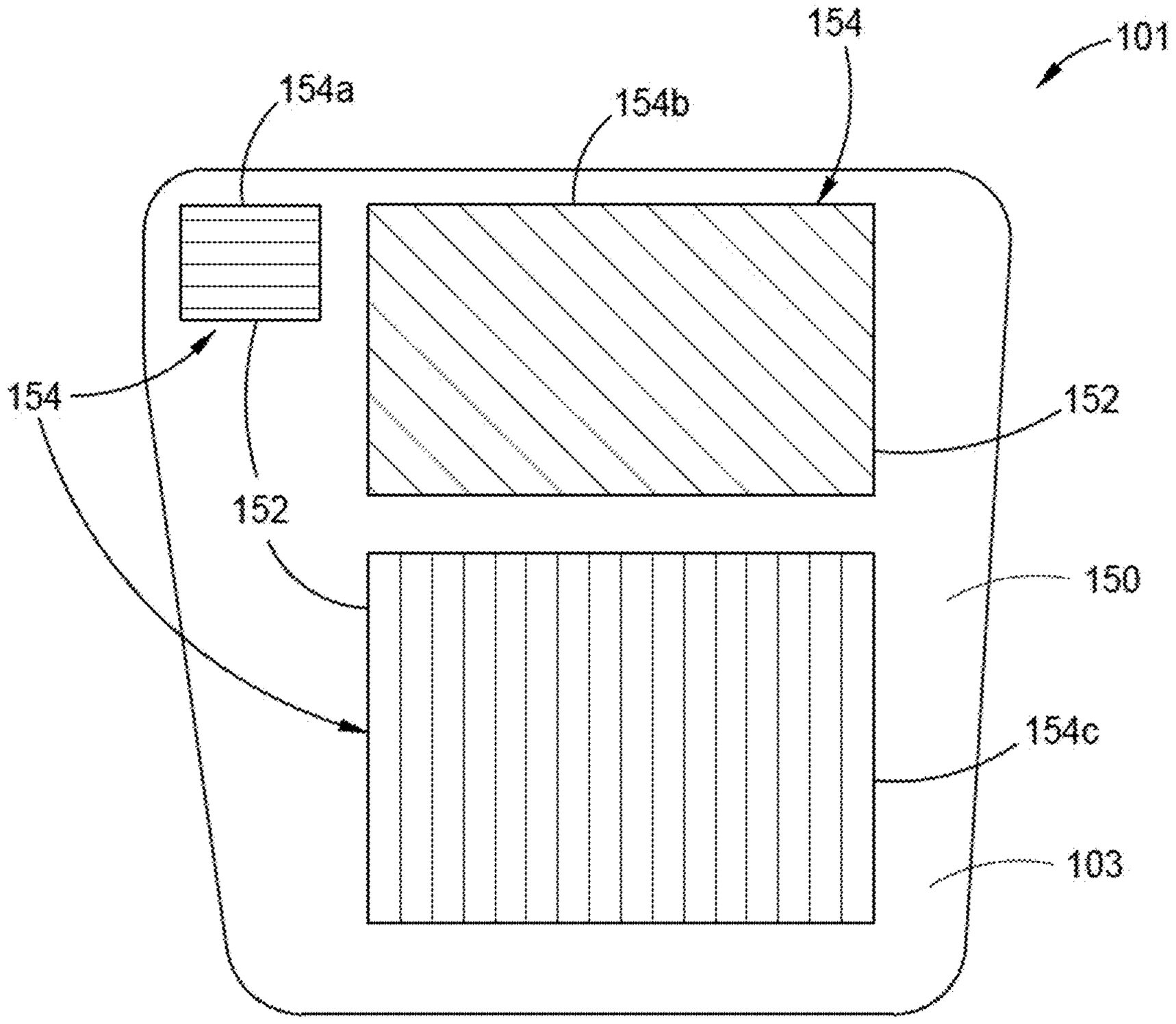


FIG. 1A

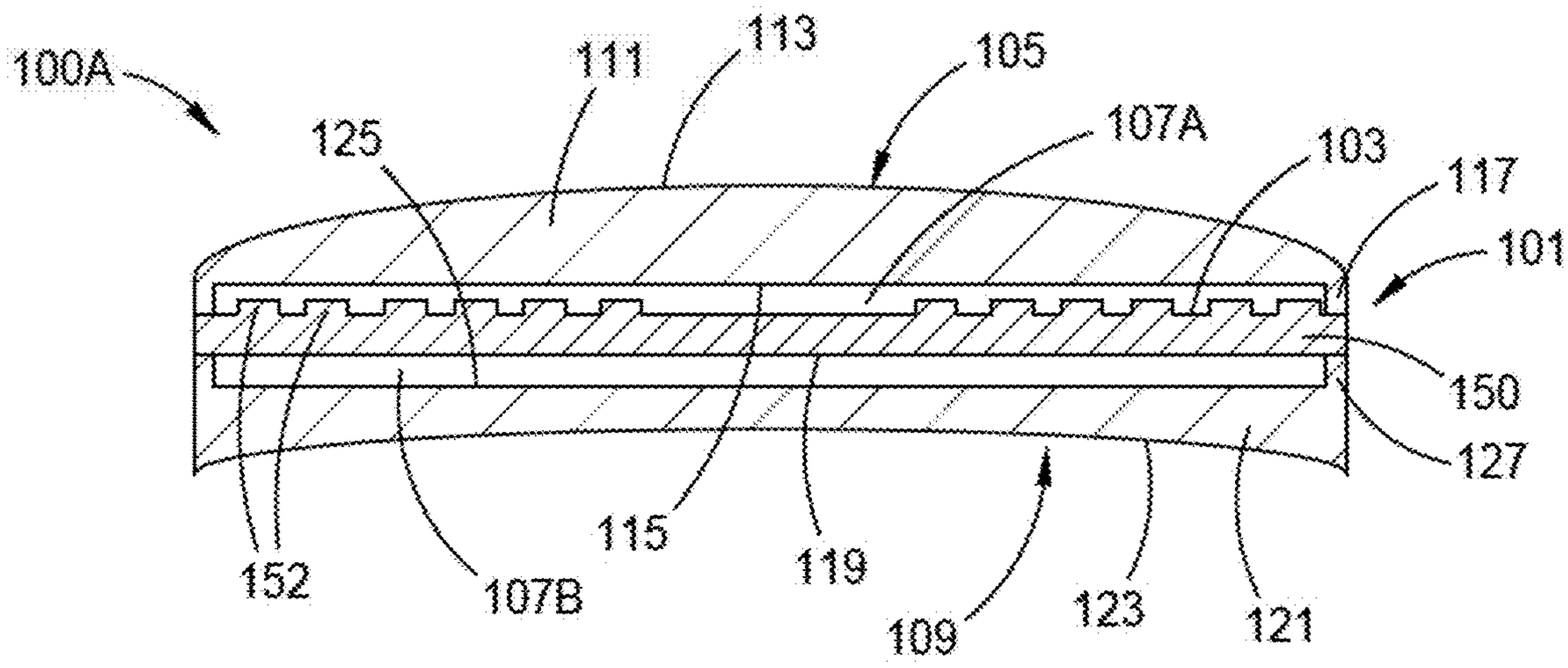

100A
111
113
105
125
107A
103
117
101
150
127
152
107B
115
119
109
123
121

FIG. 1B

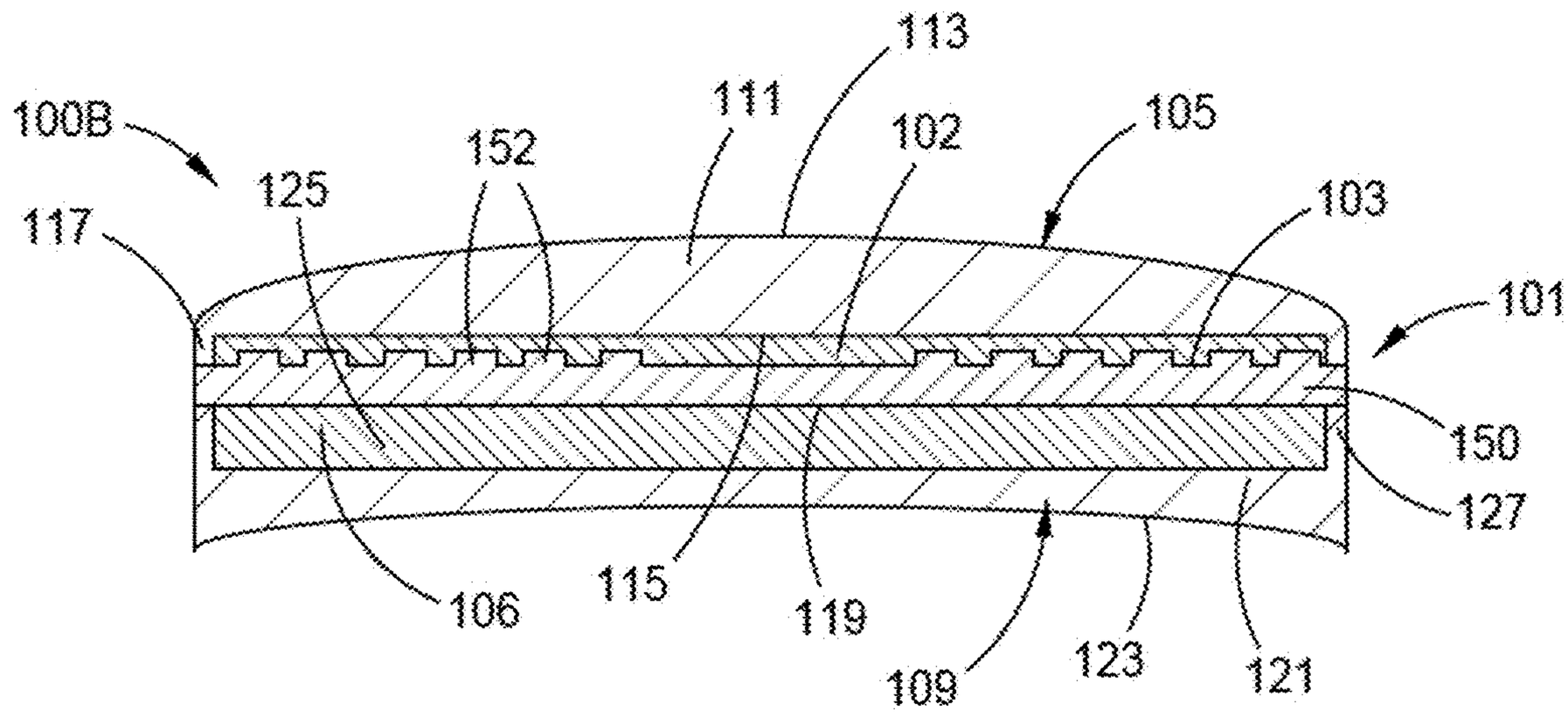

100B
113
111
152
102
105
125
103
117
101
150
127
106
115
119
109
123
121

FIG. 1C

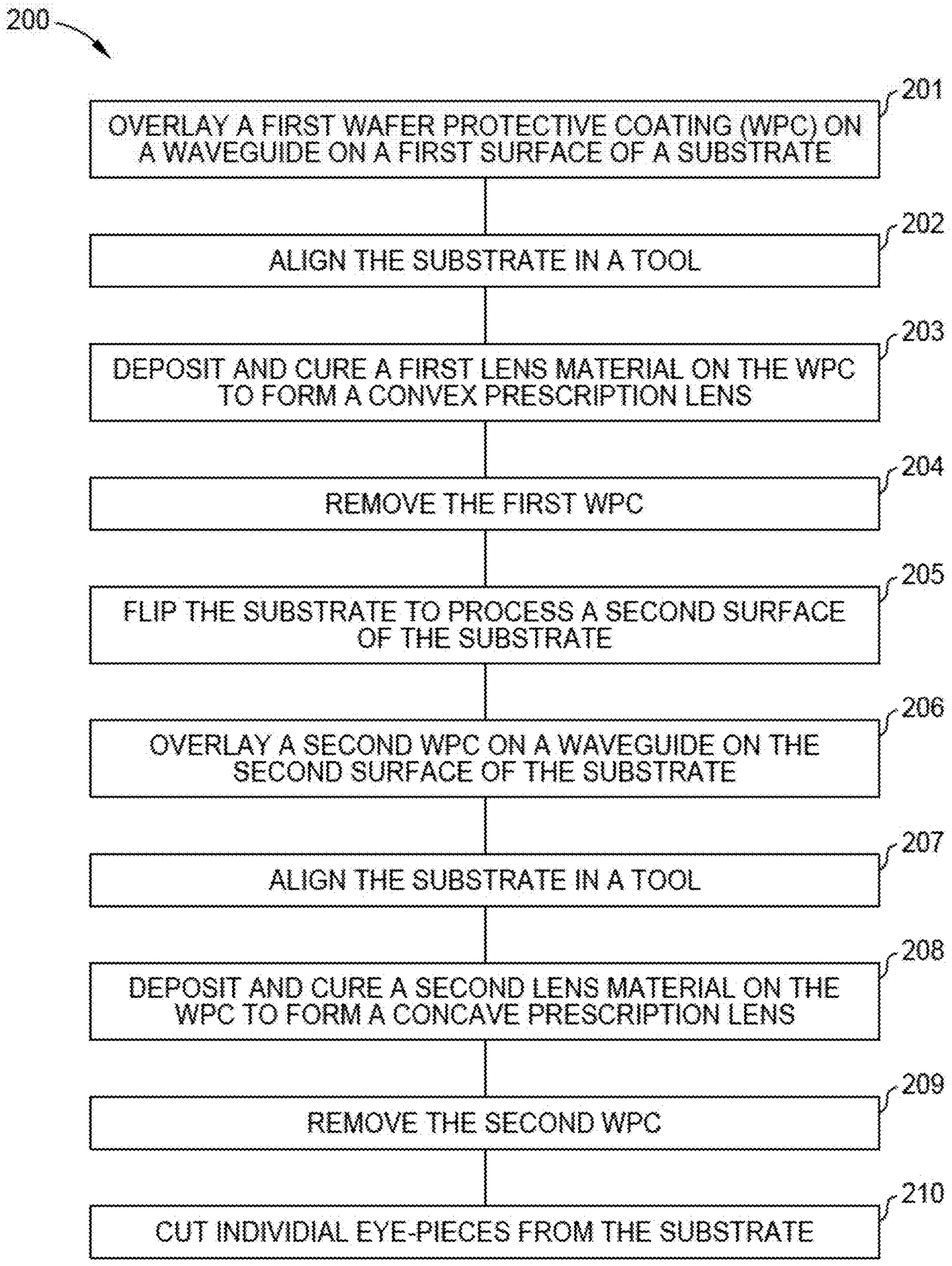

200
OVERLAY A FIRST WAFER PROTECTIVE COATING (WPC) ON A WAVEGUIDE ON A FIRST SURFACE OF A SUBSTRATE
201
ALIGN THE SUBSTRATE IN A TOOL
202
DEPOSIT AND CURE A FIRST LENS MATERIAL ON THE WPC TO FORM A CONVEX PRESCRIPTION LENS
203
REMOVE THE FIRST WPC
204
FLIP THE SUBSTRATE TO PROCESS A SECOND SURFACE OF THE SUBSTRATE
205
OVERLAY A SECOND WPC ON A WAVEGUIDE ON THE SECOND SURFACE OF THE SUBSTRATE
206
ALIGN THE SUBSTRATE IN A TOOL
207
DEPOSIT AND CURE A SECOND LENS MATERIAL ON THE WPC TO FORM A CONCAVE PRESCRIPTION LENS
208
REMOVE THE SECOND WPC
209
CUT INDIVIDIAL EYE-PIECES FROM THE SUBSTRATE
210

FIG. 2

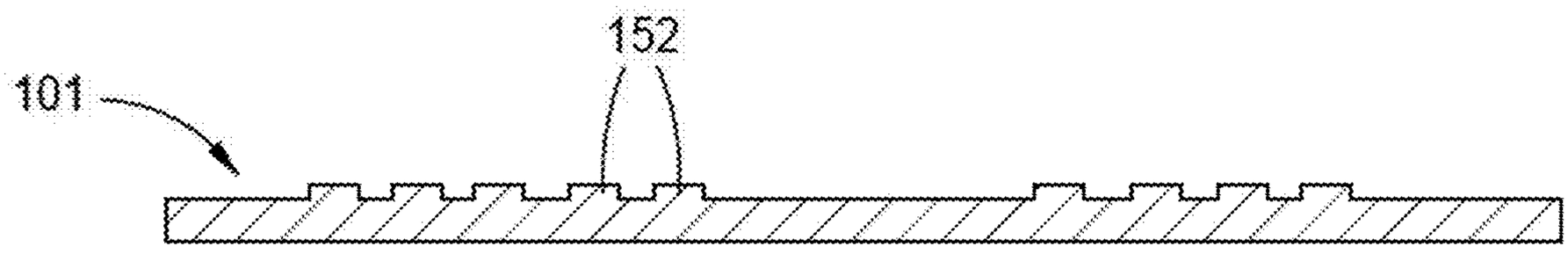


FIG. 3A

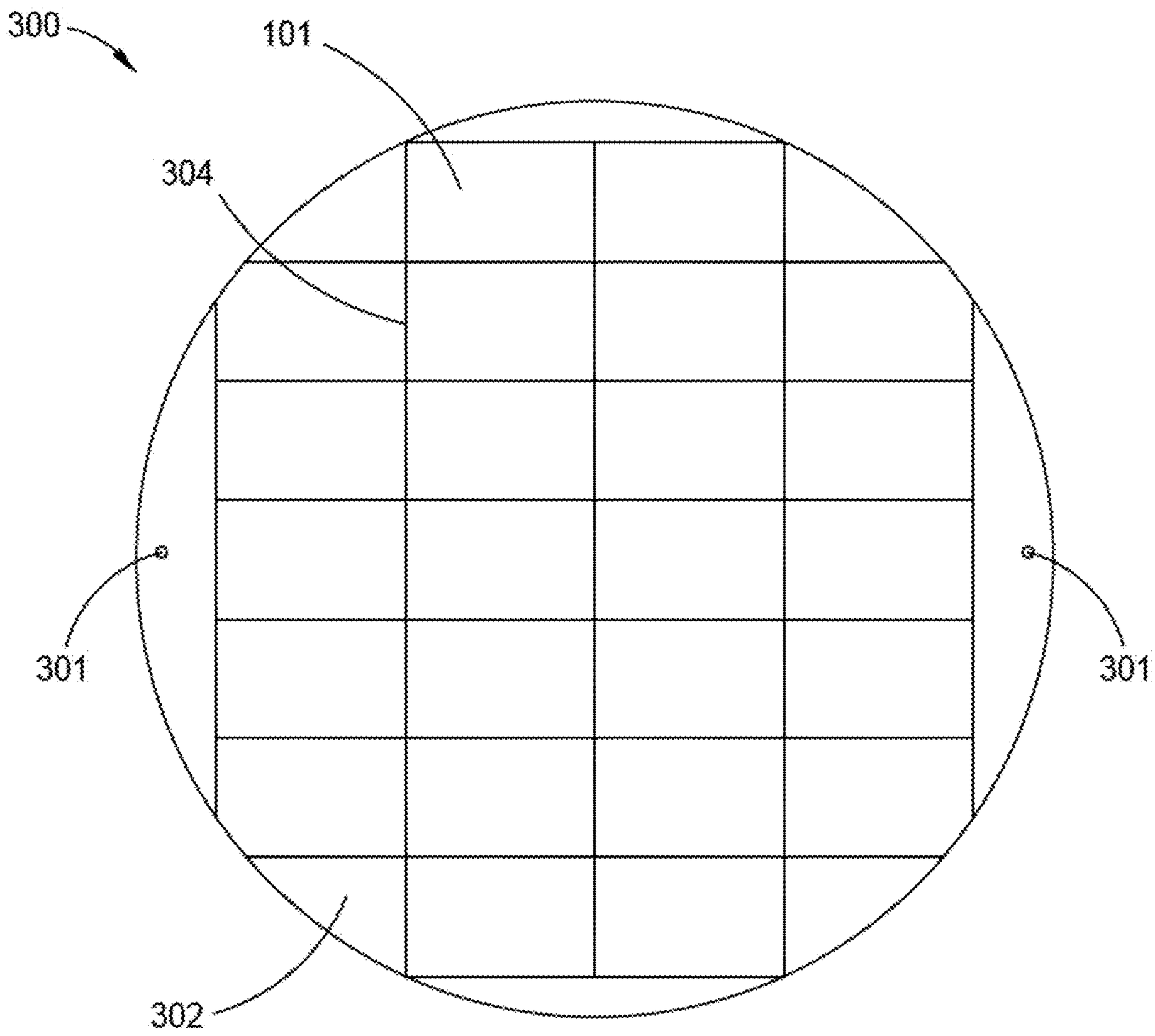


FIG. 3B

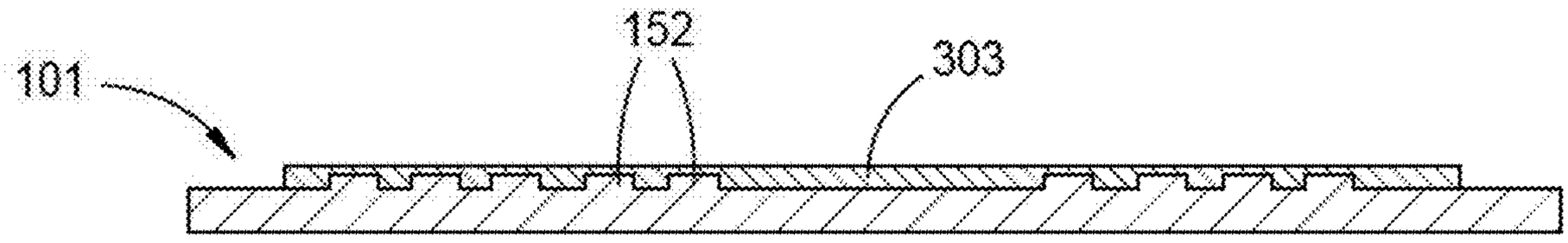


FIG. 3C

FIG. 3D

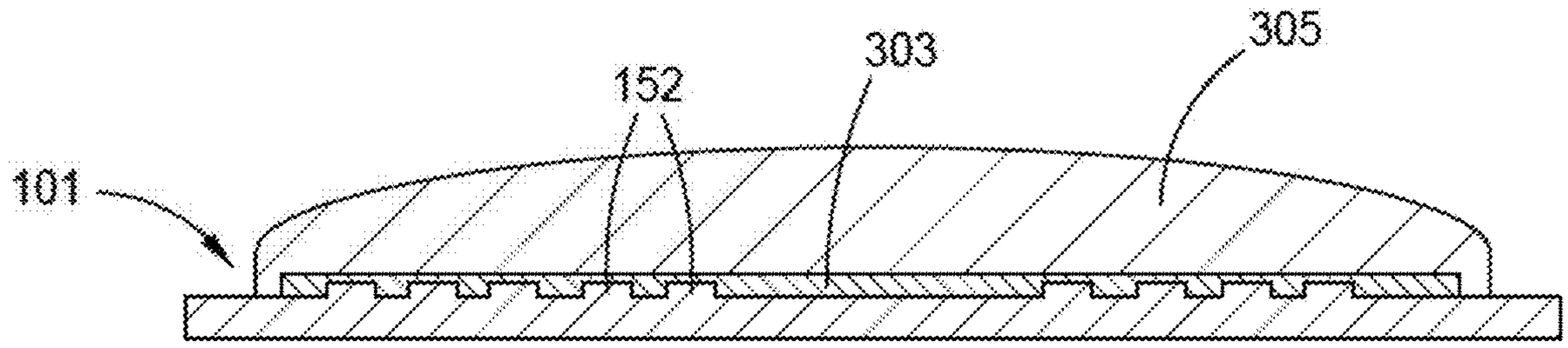


FIG. 3E

FIG. 3F

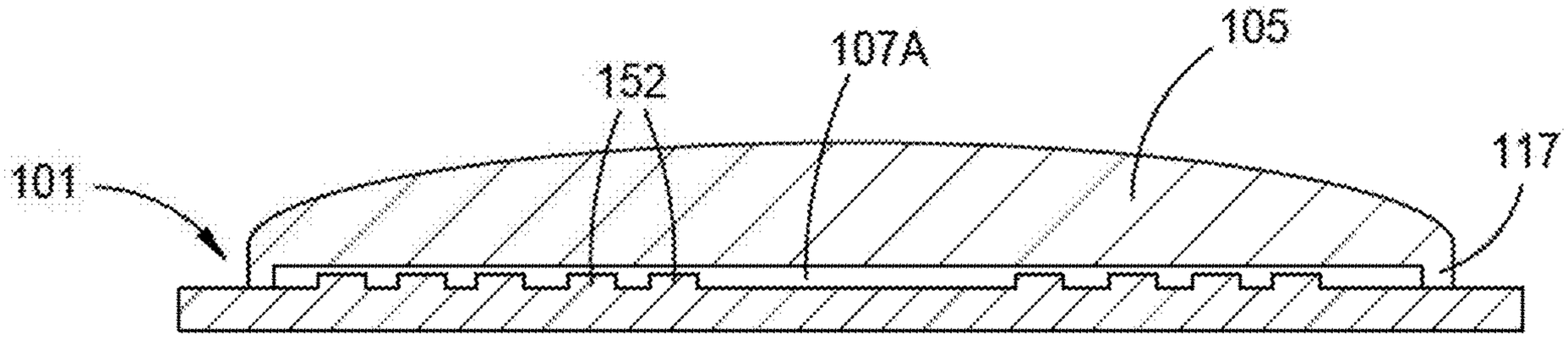


FIG. 3G

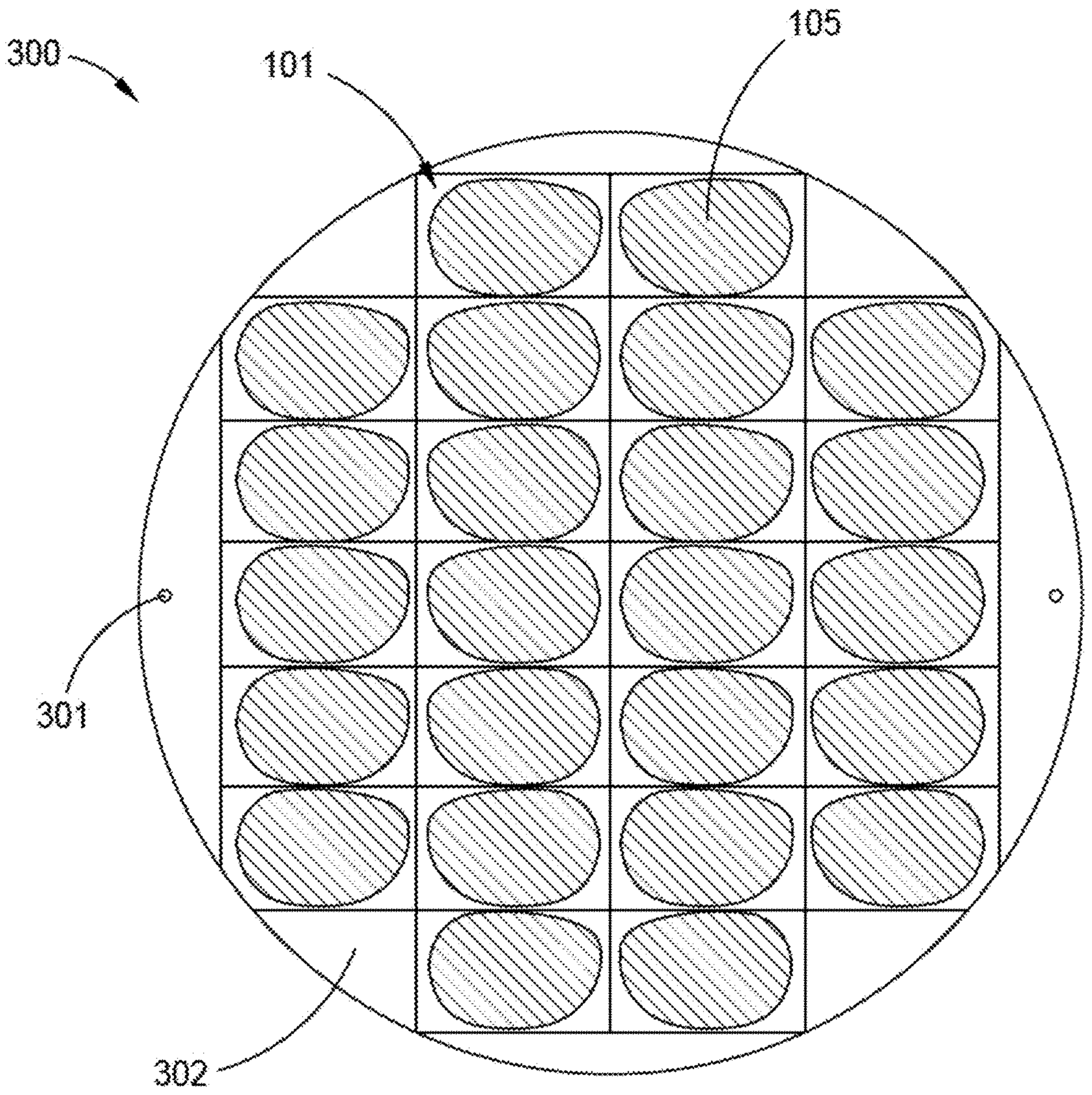


FIG. 3H

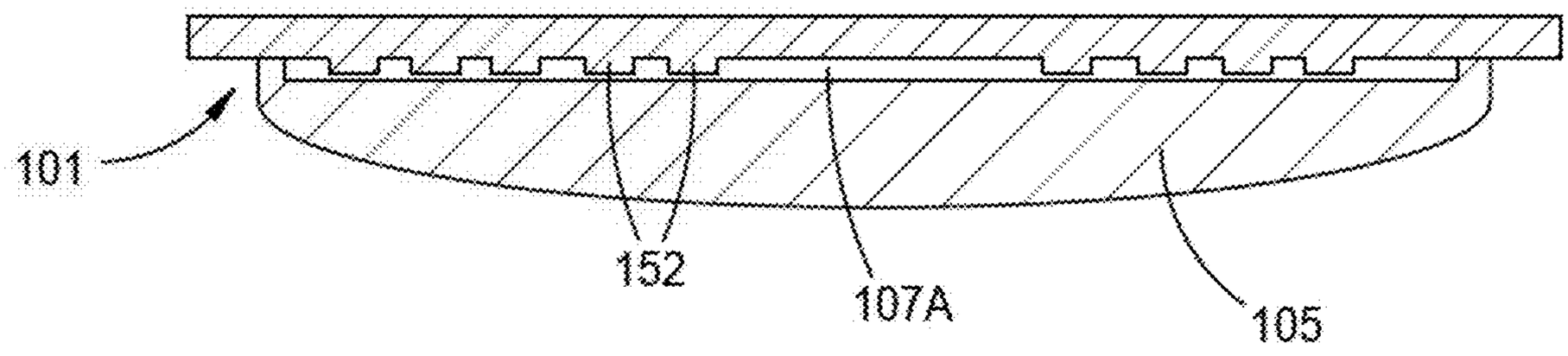


FIG. 3I

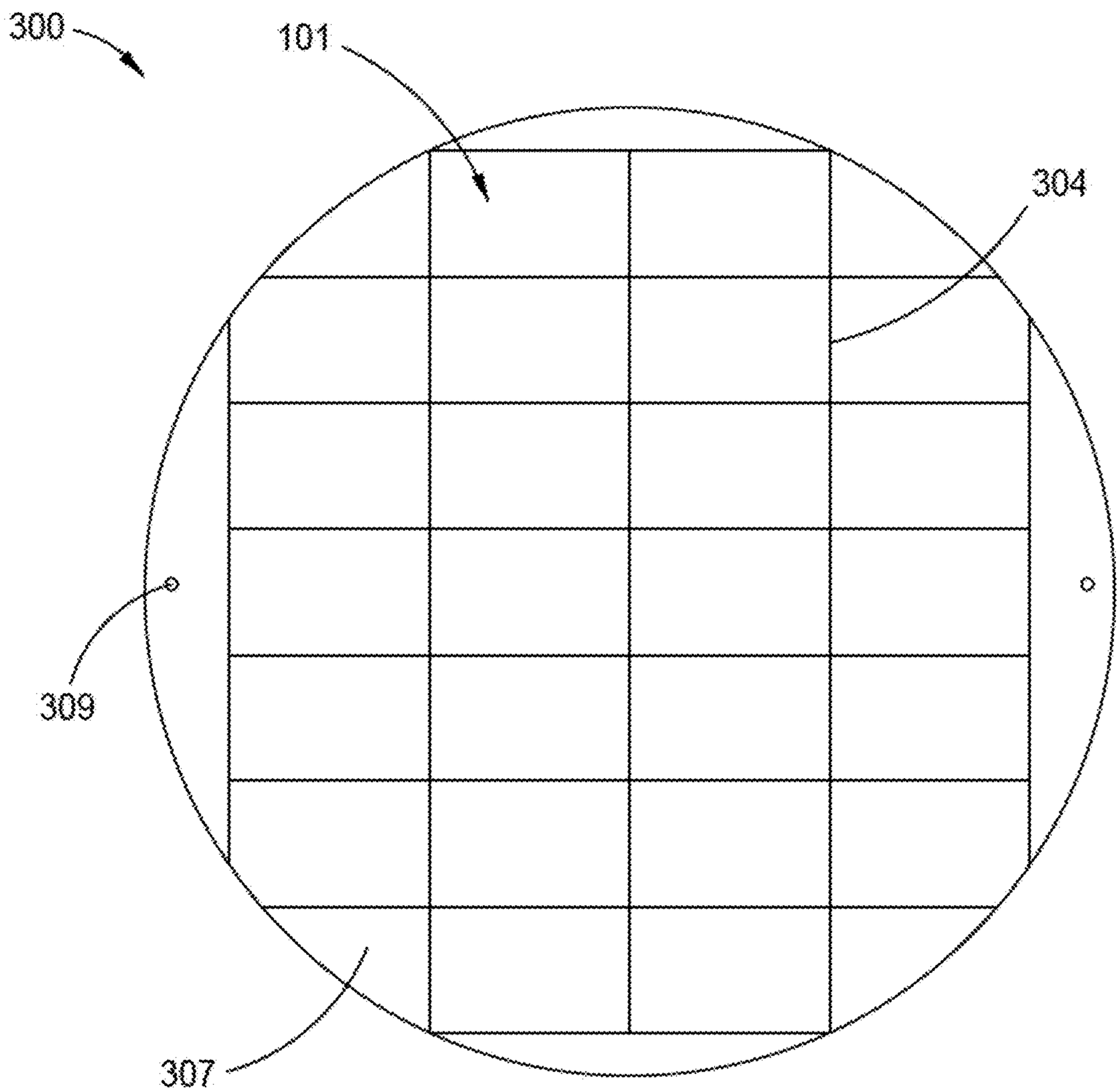


FIG. 3J

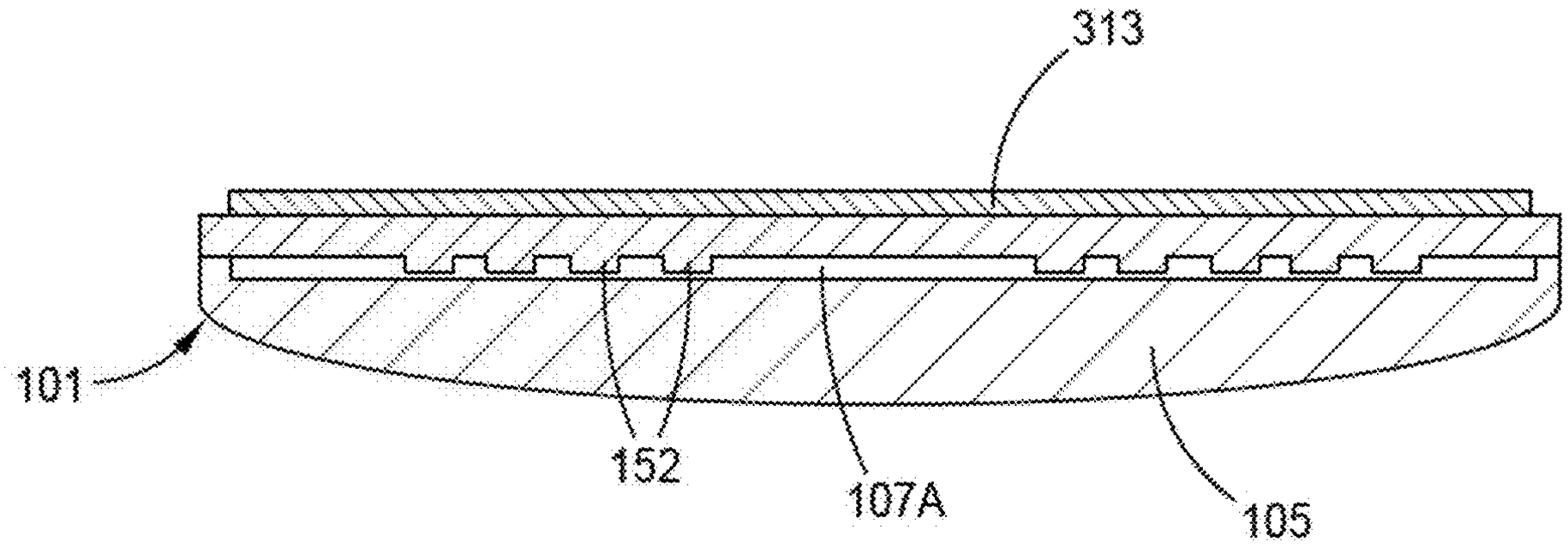


FIG. 3K

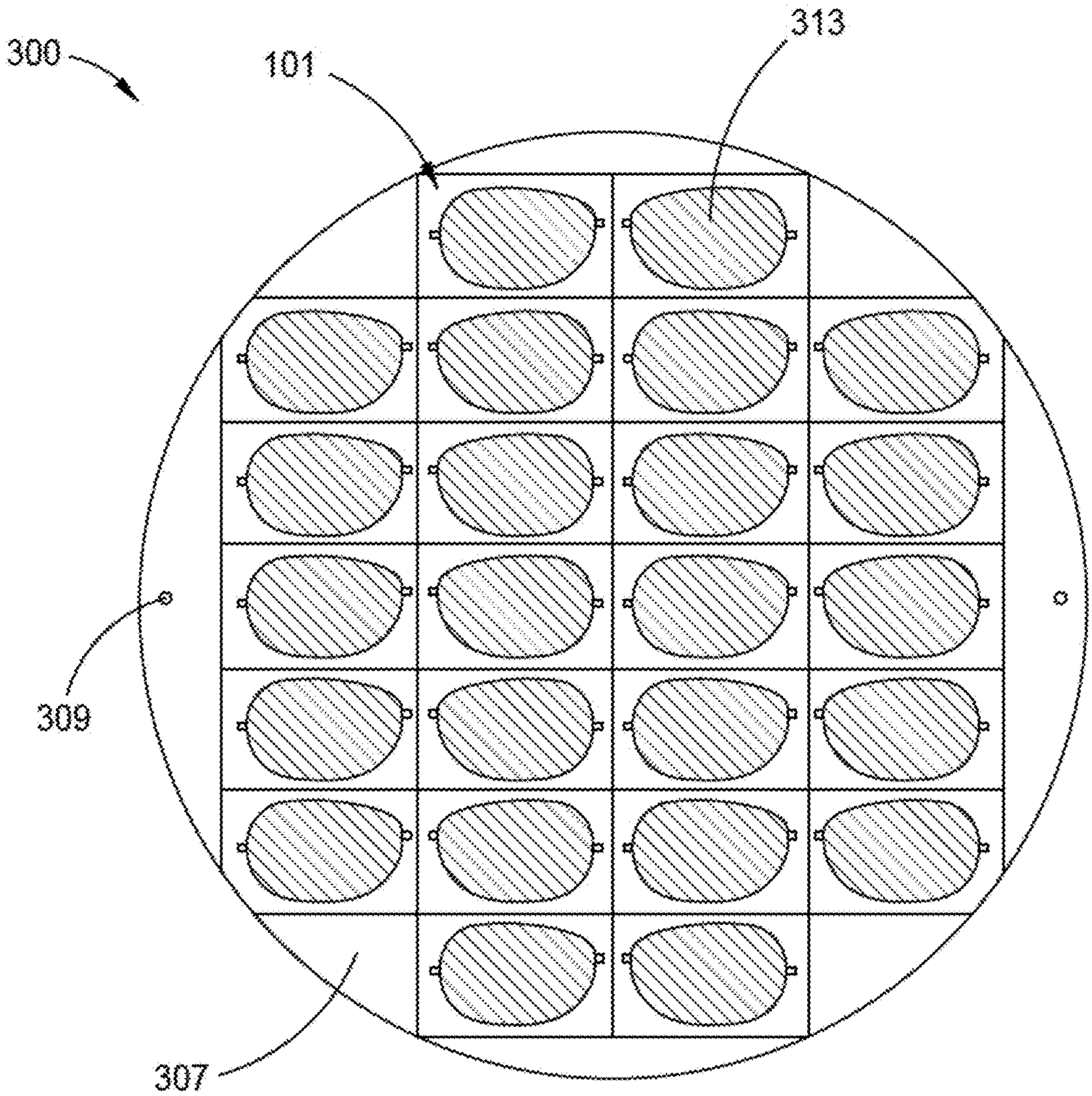


FIG. 3L

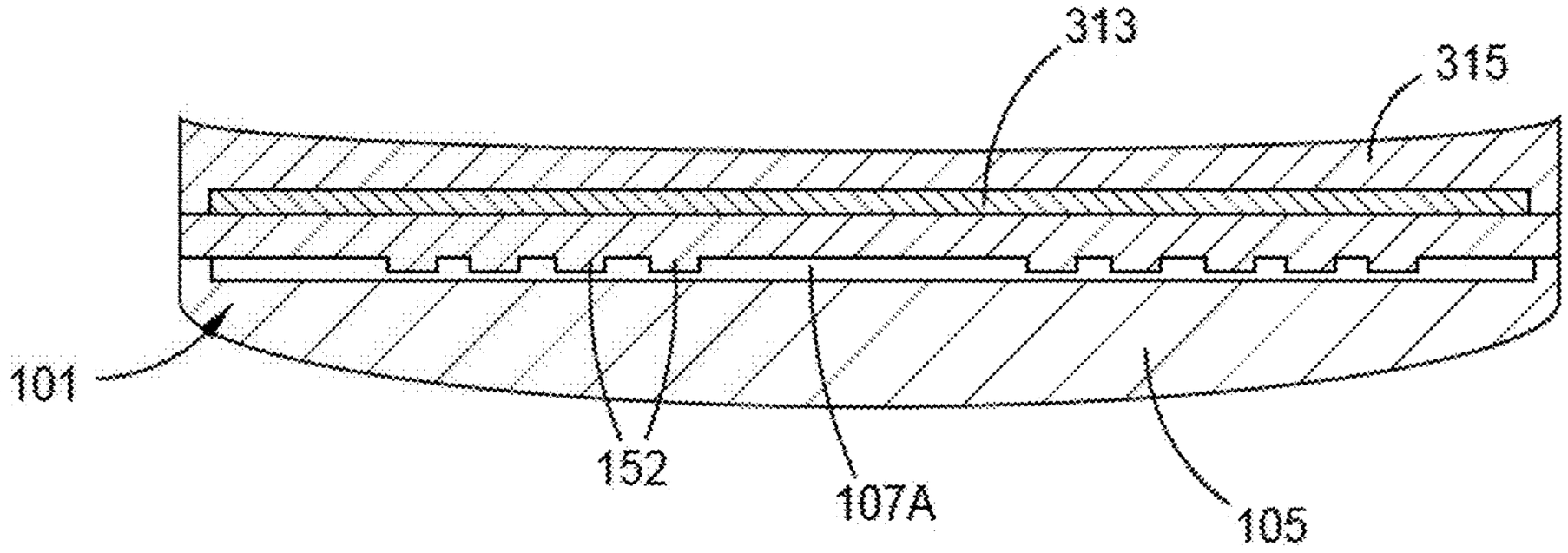


FIG. 3M

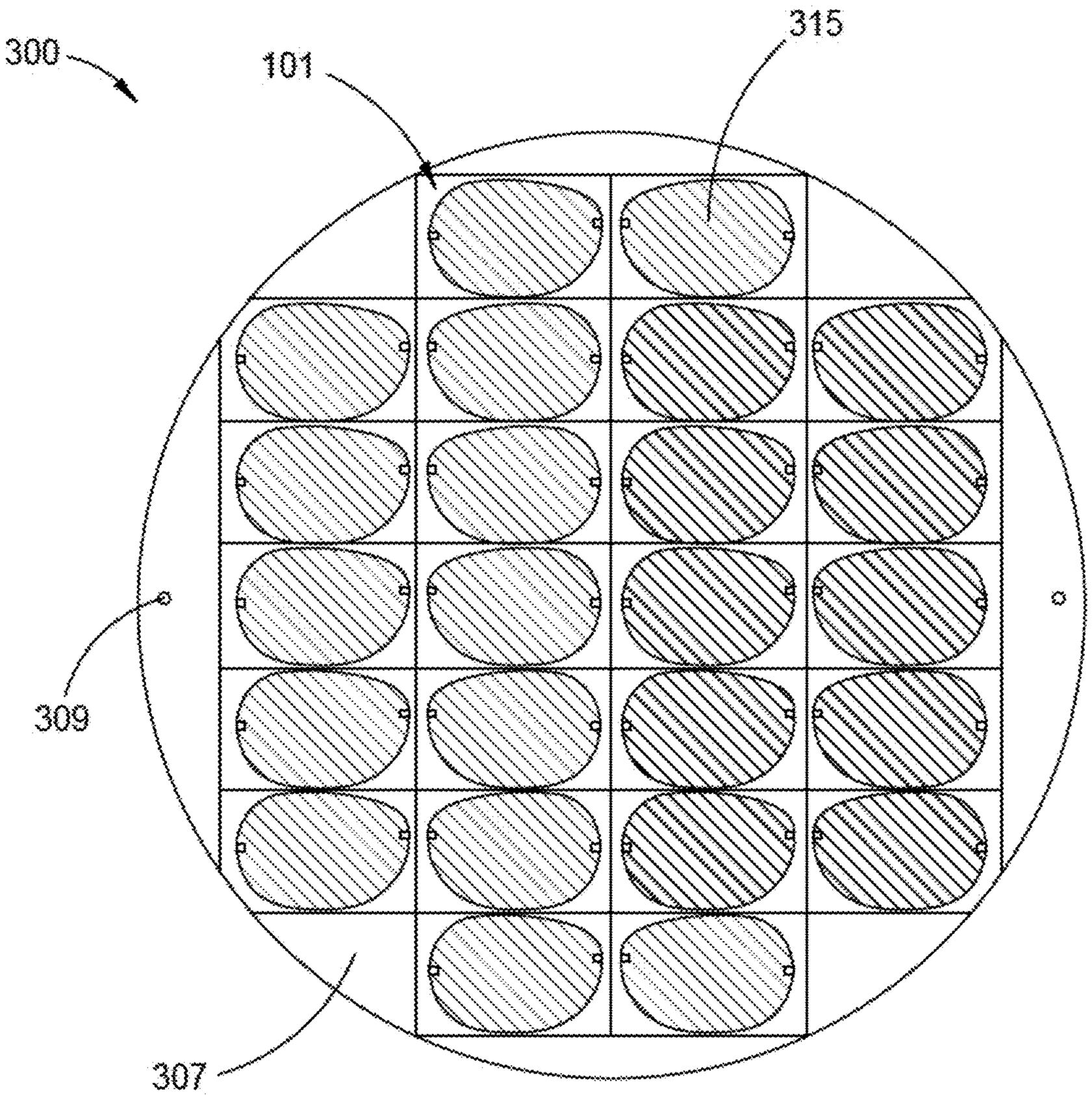


FIG. 3N

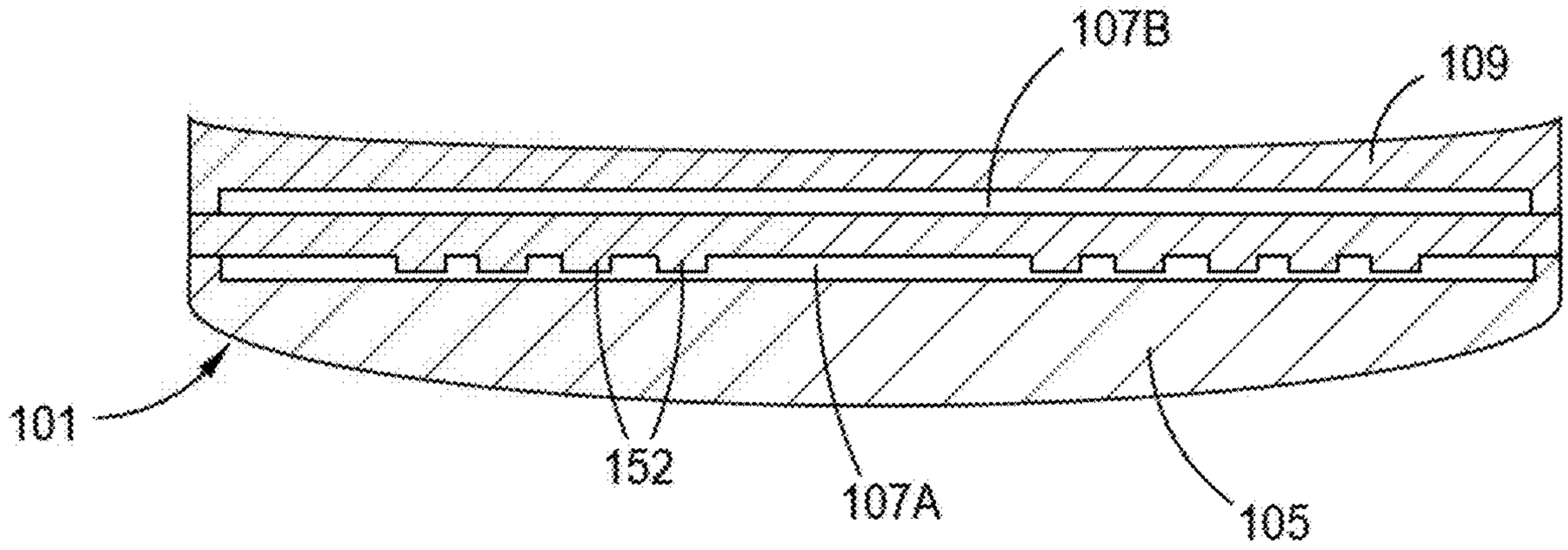


FIG. 3O

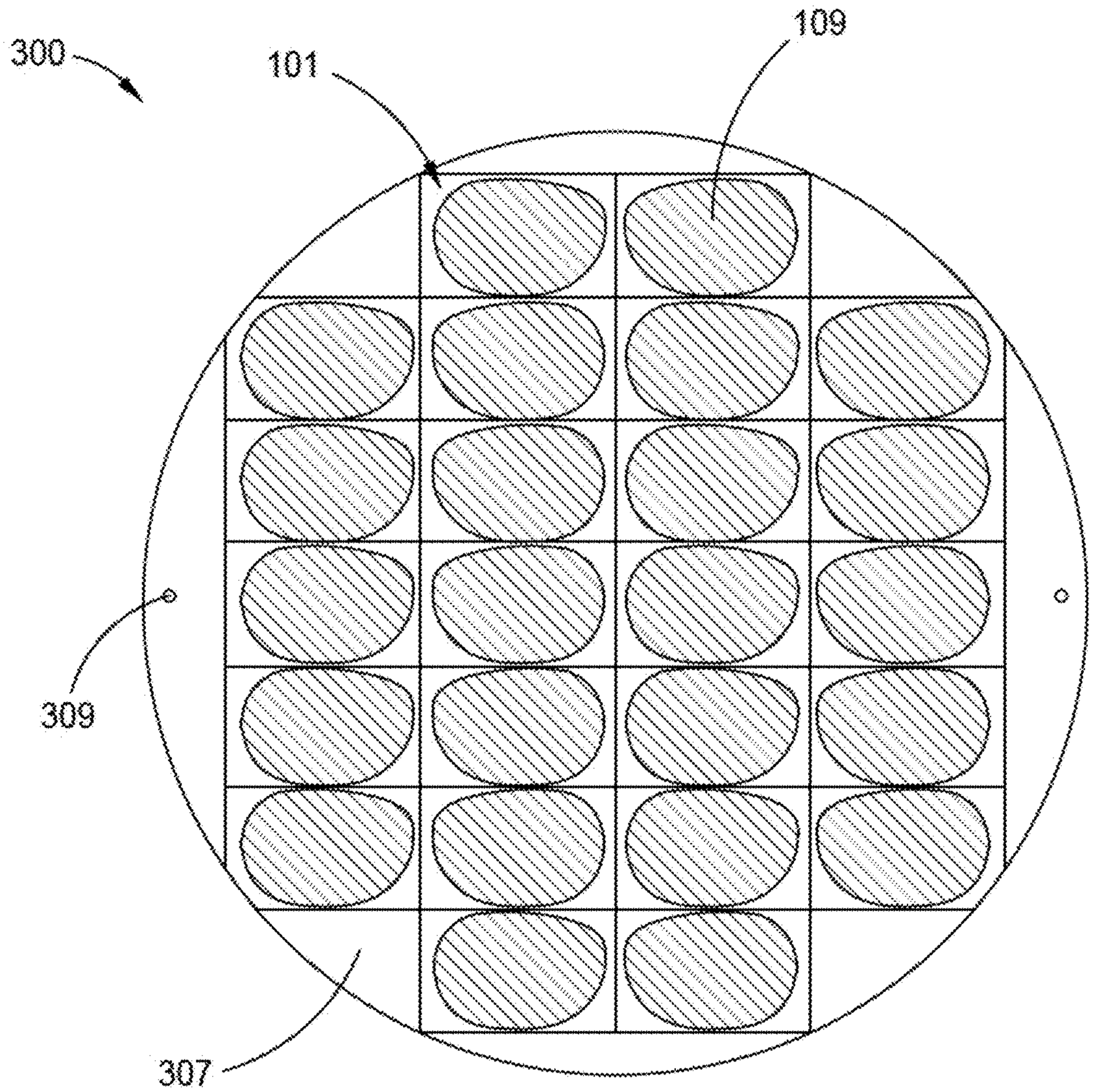


FIG. 3P

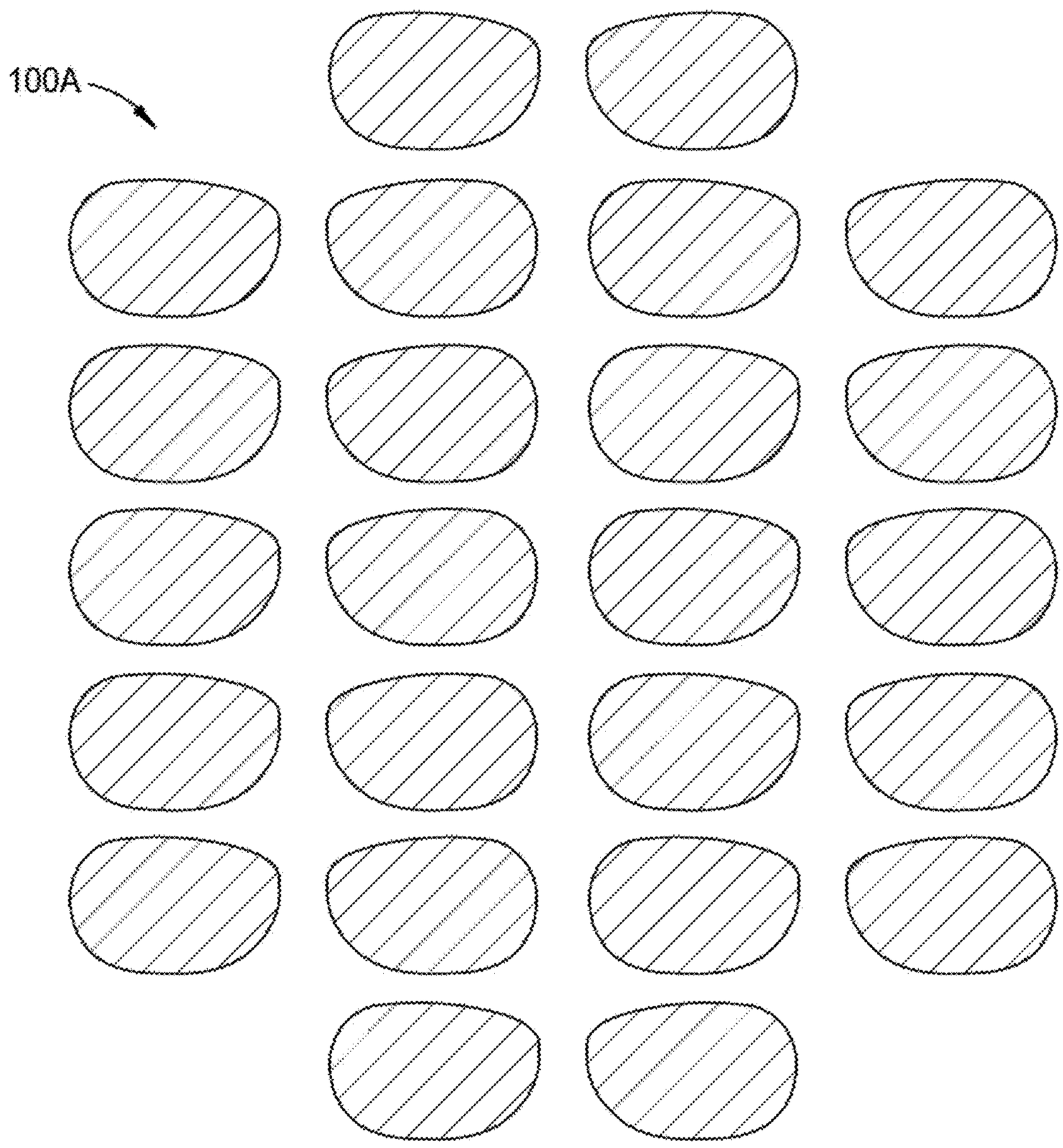


FIG. 3Q

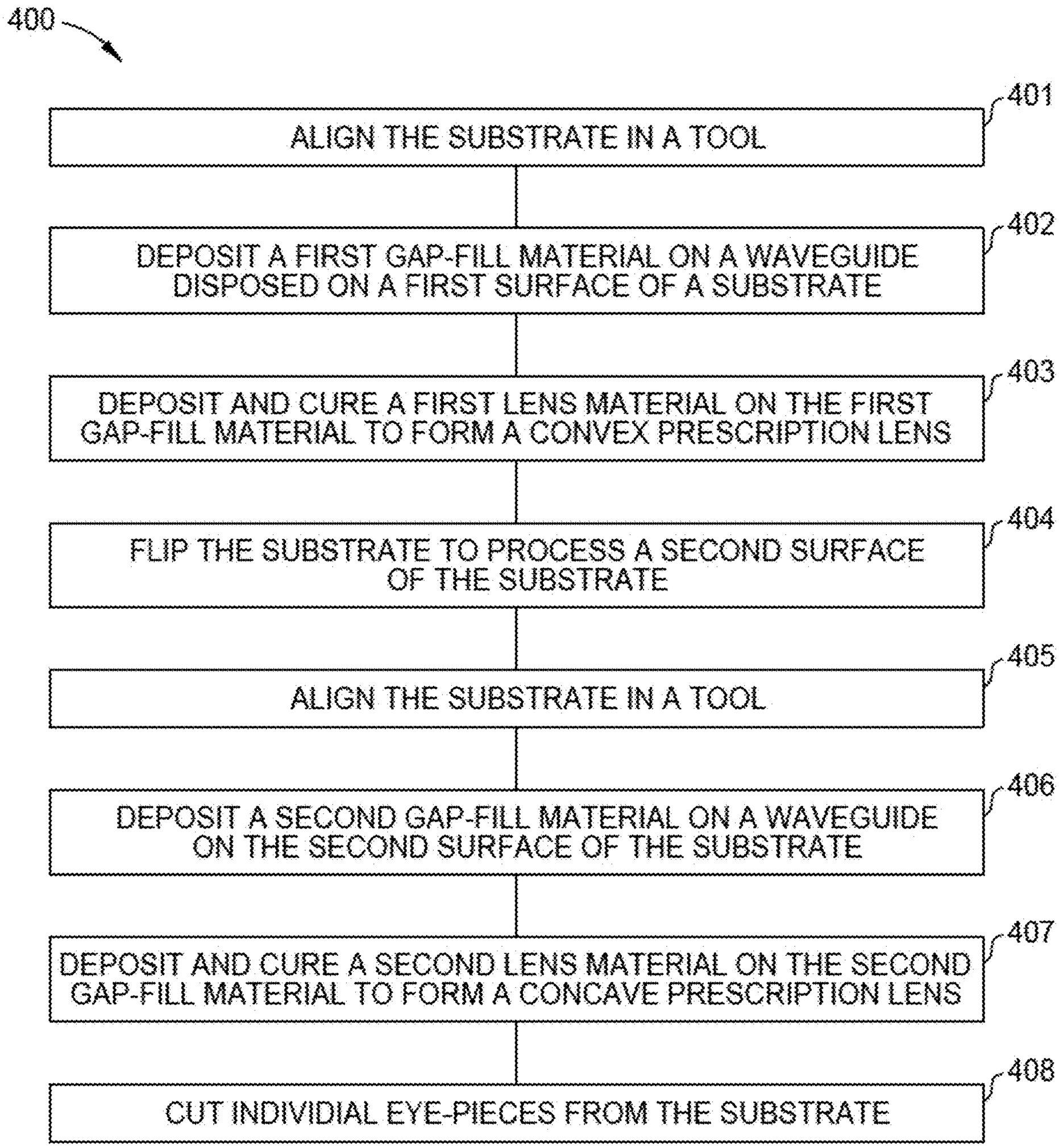

400
401
ALIGN THE SUBSTRATE IN A TOOL
402
DEPOSIT A FIRST GAP-FILL MATERIAL ON A WAVEGUIDE DISPOSED ON A FIRST SURFACE OF A SUBSTRATE
403
DEPOSIT AND CURE A FIRST LENS MATERIAL ON THE FIRST GAP-FILL MATERIAL TO FORM A CONVEX PRESCRIPTION LENS
404
FLIP THE SUBSTRATE TO PROCESS A SECOND SURFACE OF THE SUBSTRATE
405
ALIGN THE SUBSTRATE IN A TOOL
406
DEPOSIT A SECOND GAP-FILL MATERIAL ON A WAVEGUIDE ON THE SECOND SURFACE OF THE SUBSTRATE
407
DEPOSIT AND CURE A SECOND LENS MATERIAL ON THE SECOND GAP-FILL MATERIAL TO FORM A CONCAVE PRESCRIPTION LENS
408
CUT INDIVIDIAL EYE-PIECES FROM THE SUBSTRATE

FIG. 4

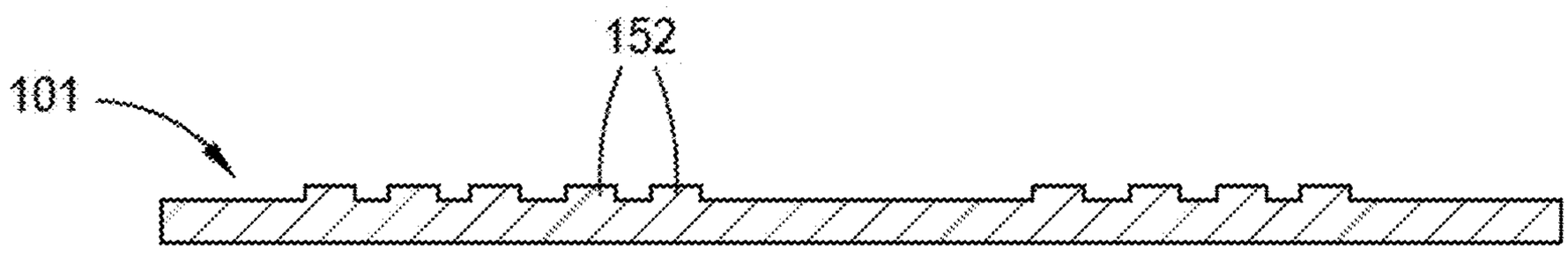


FIG. 5A

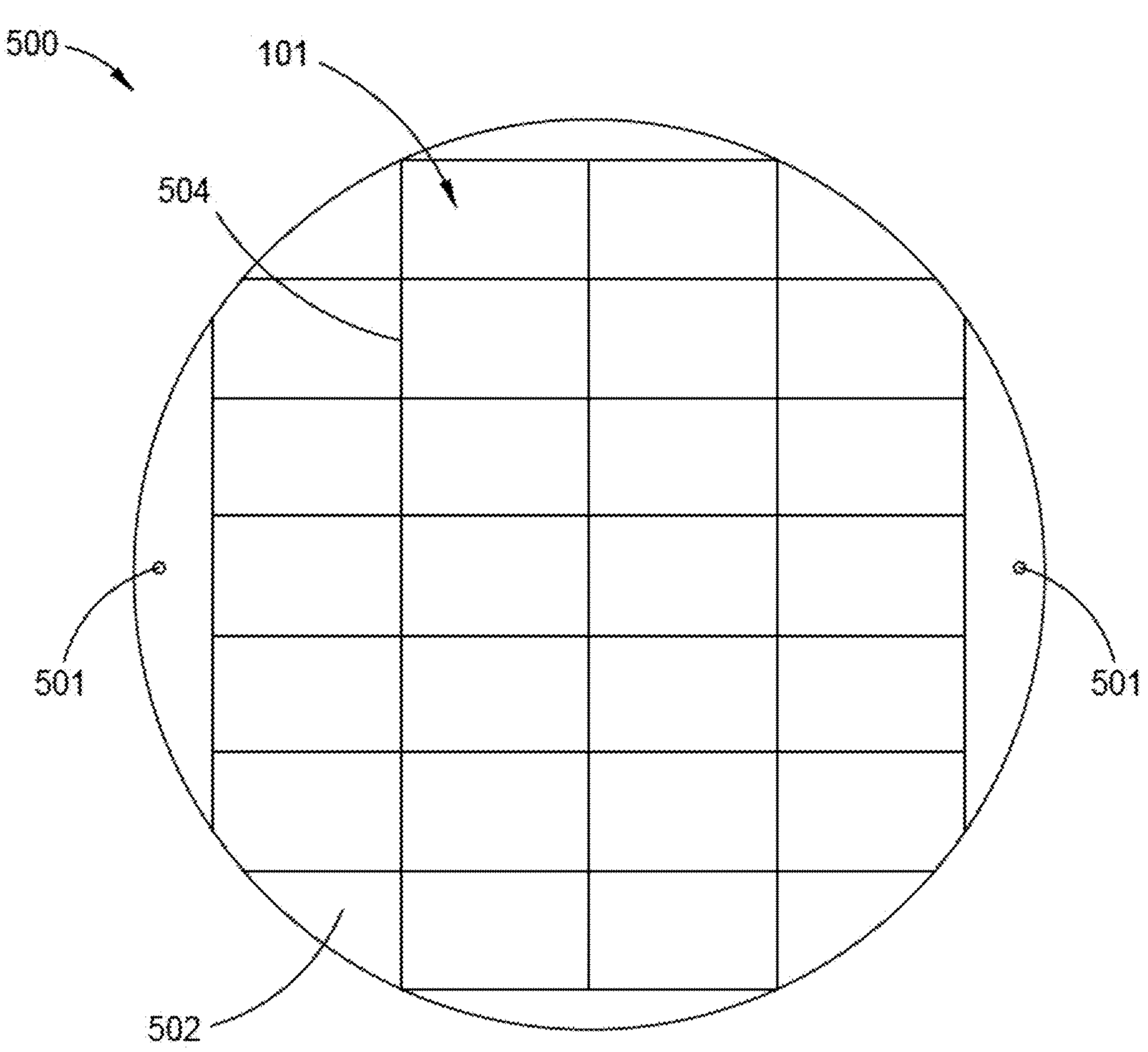


FIG. 5B

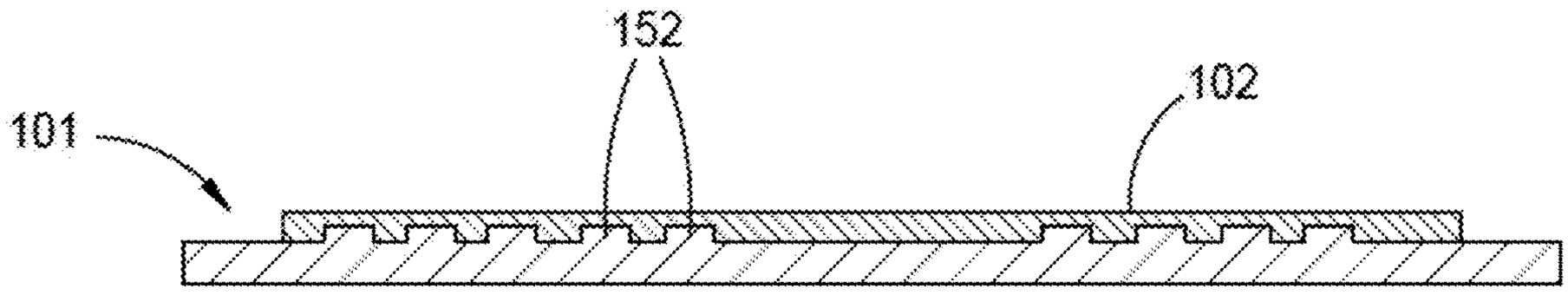


FIG. 5C

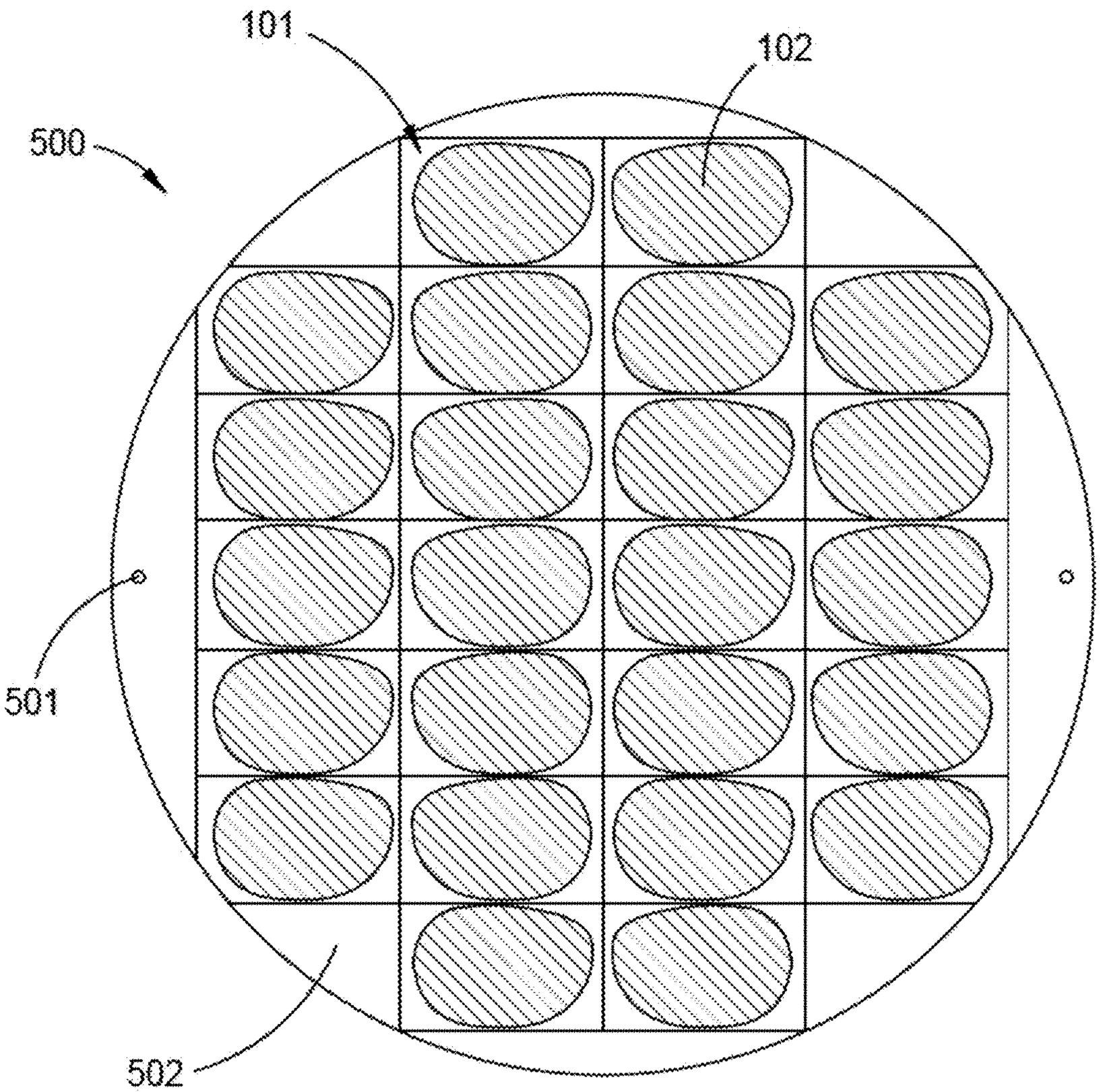


FIG. 5D

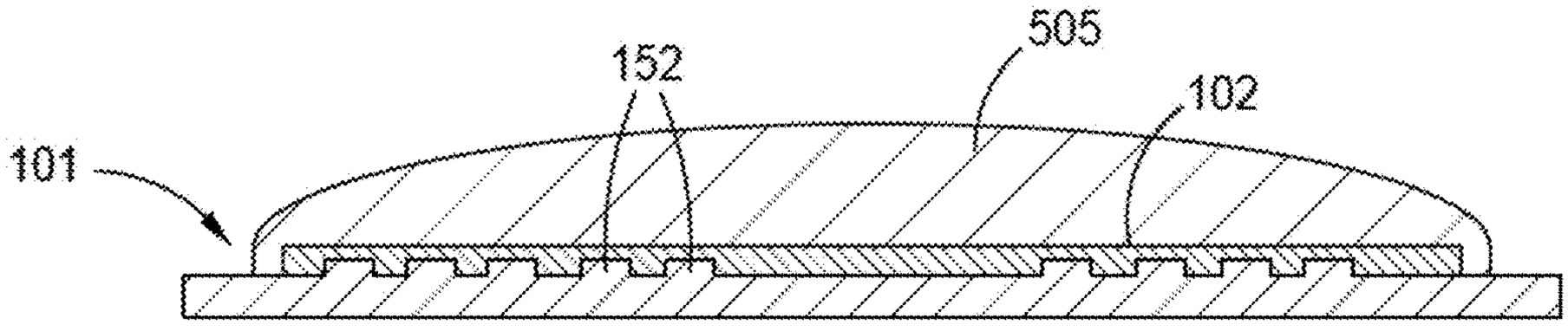


FIG. 5E

FIG. 5F

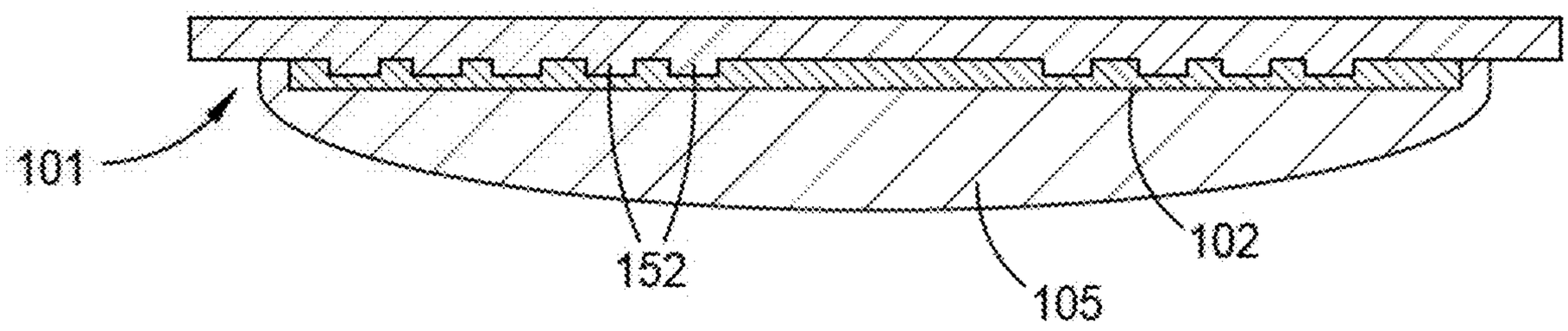


FIG. 5G

FIG. 5H

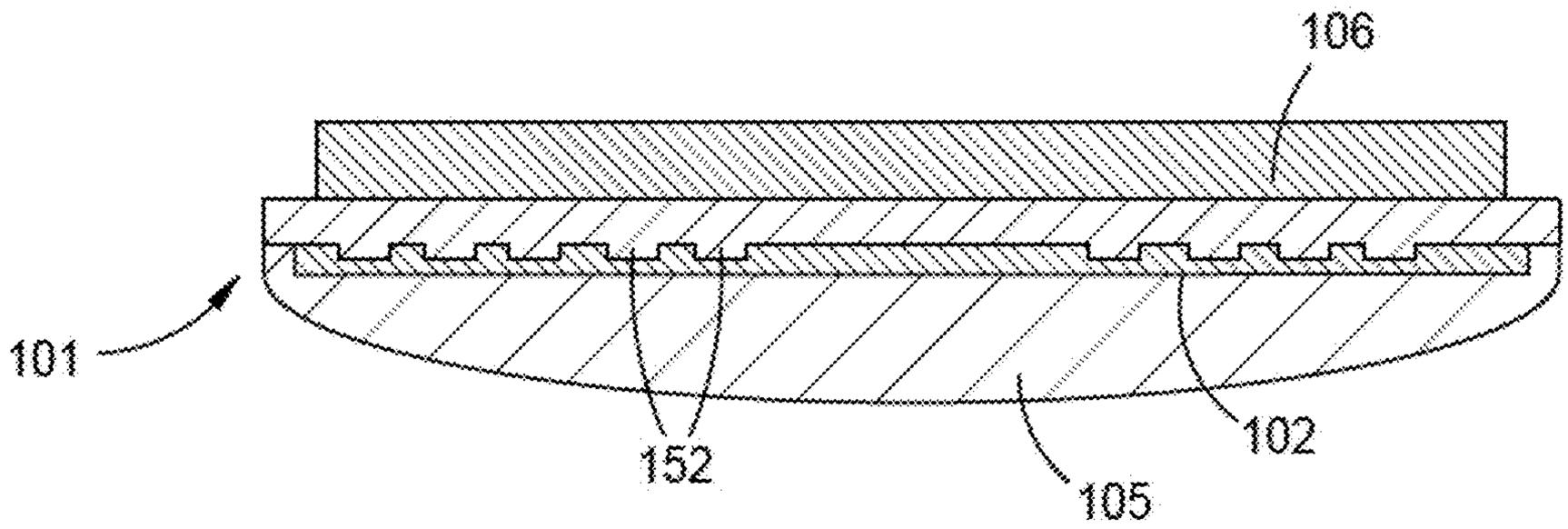


FIG. 5I

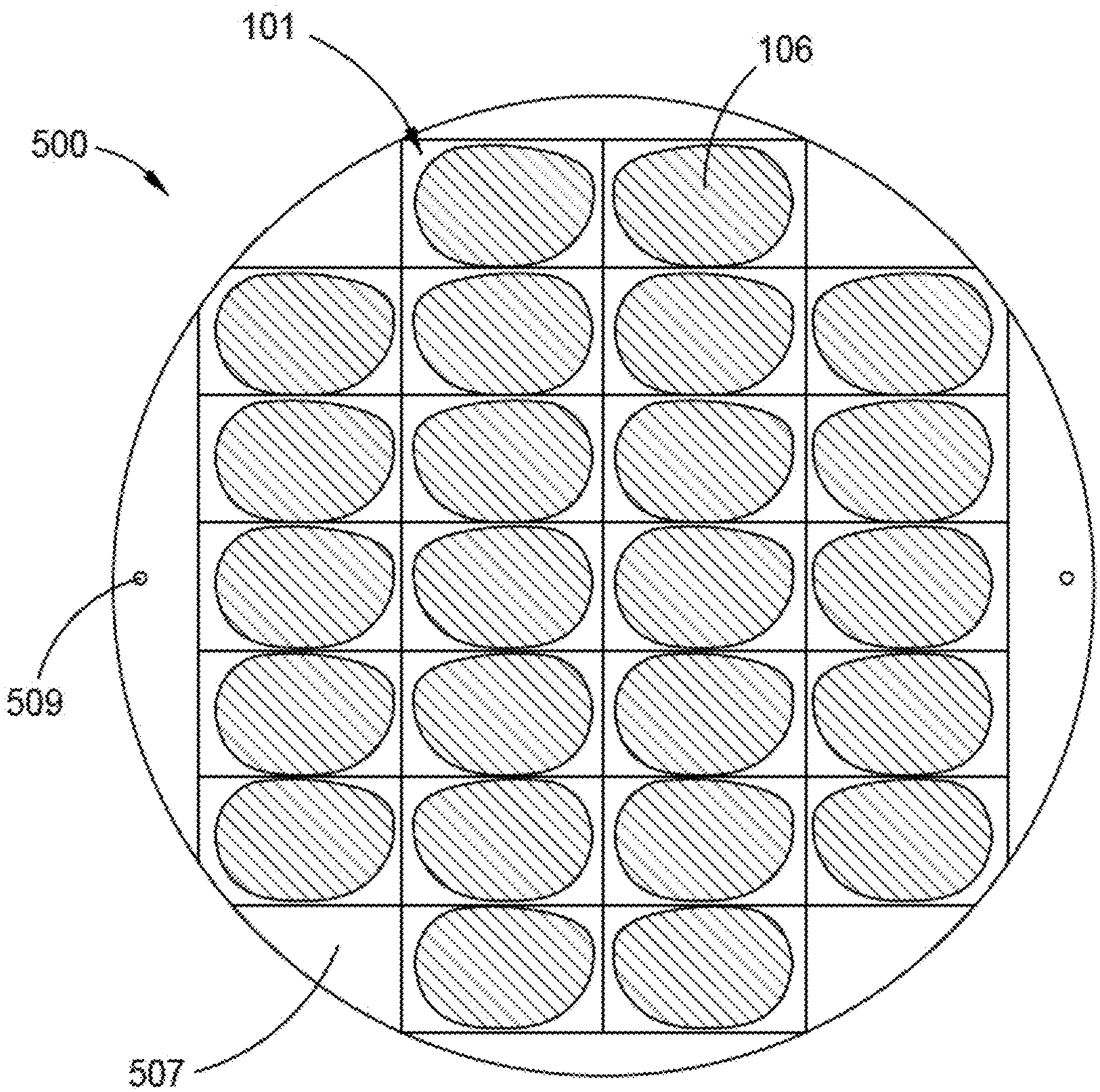


FIG. 5J

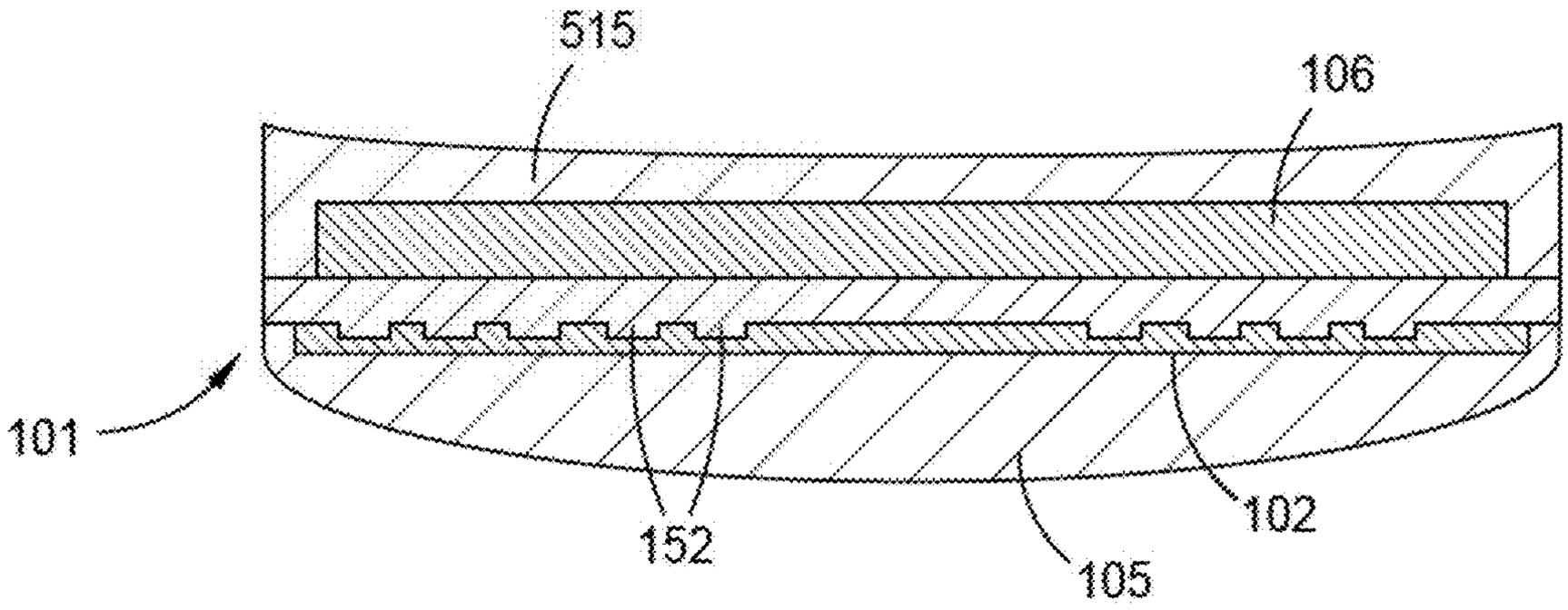


FIG. 5K

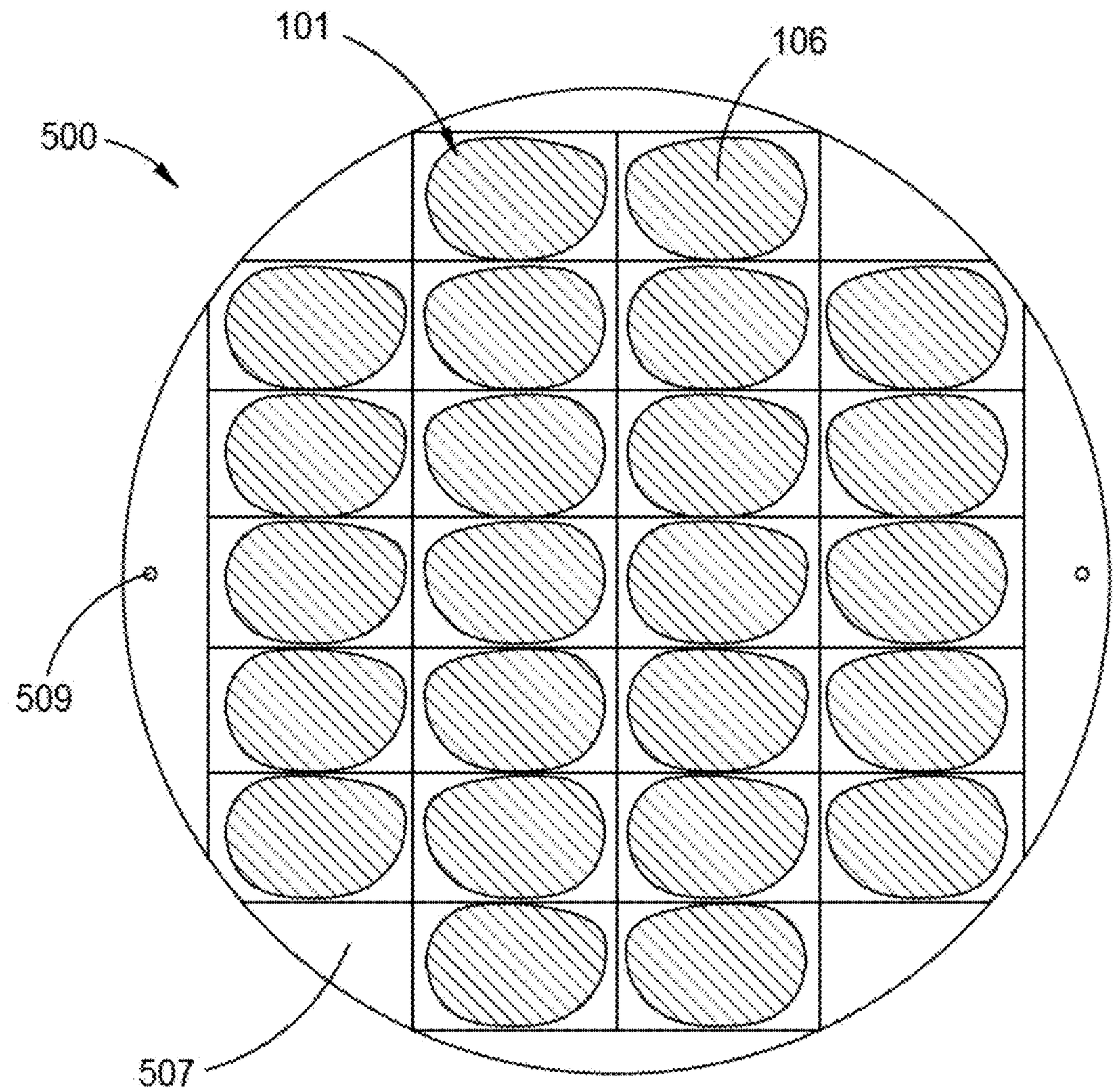


FIG. 5L

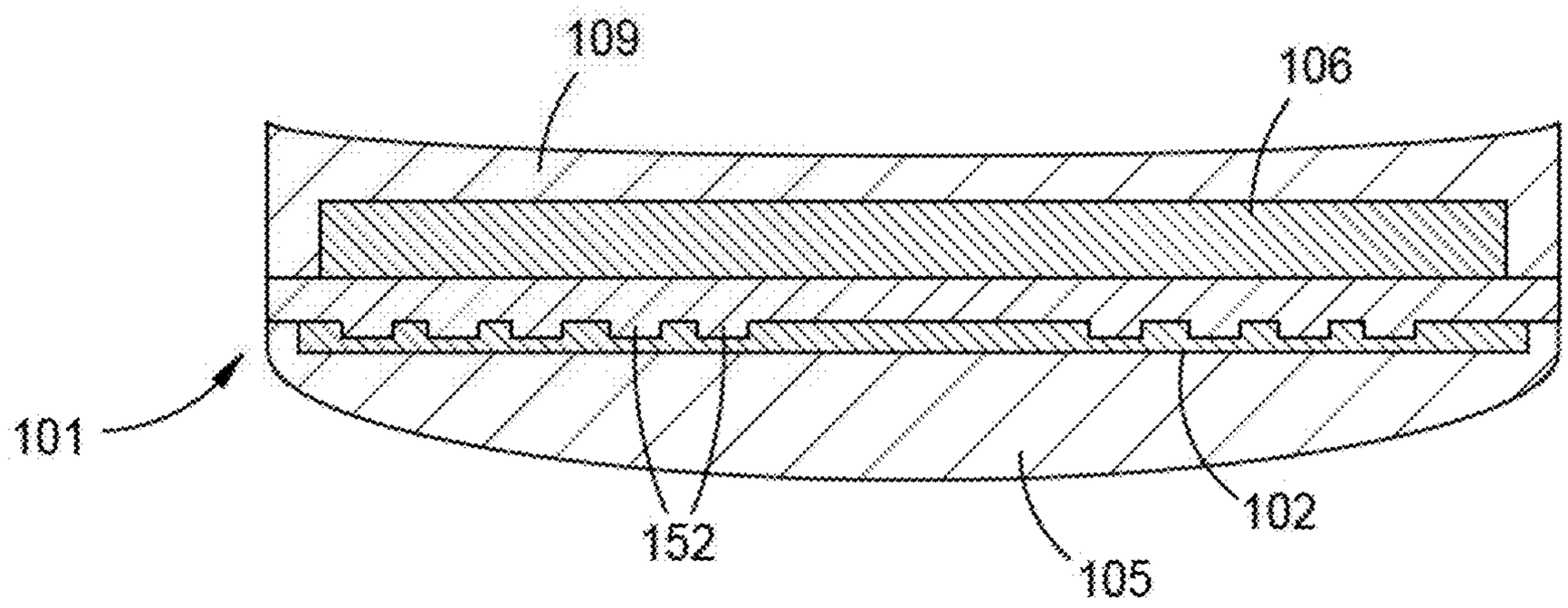


FIG. 5M

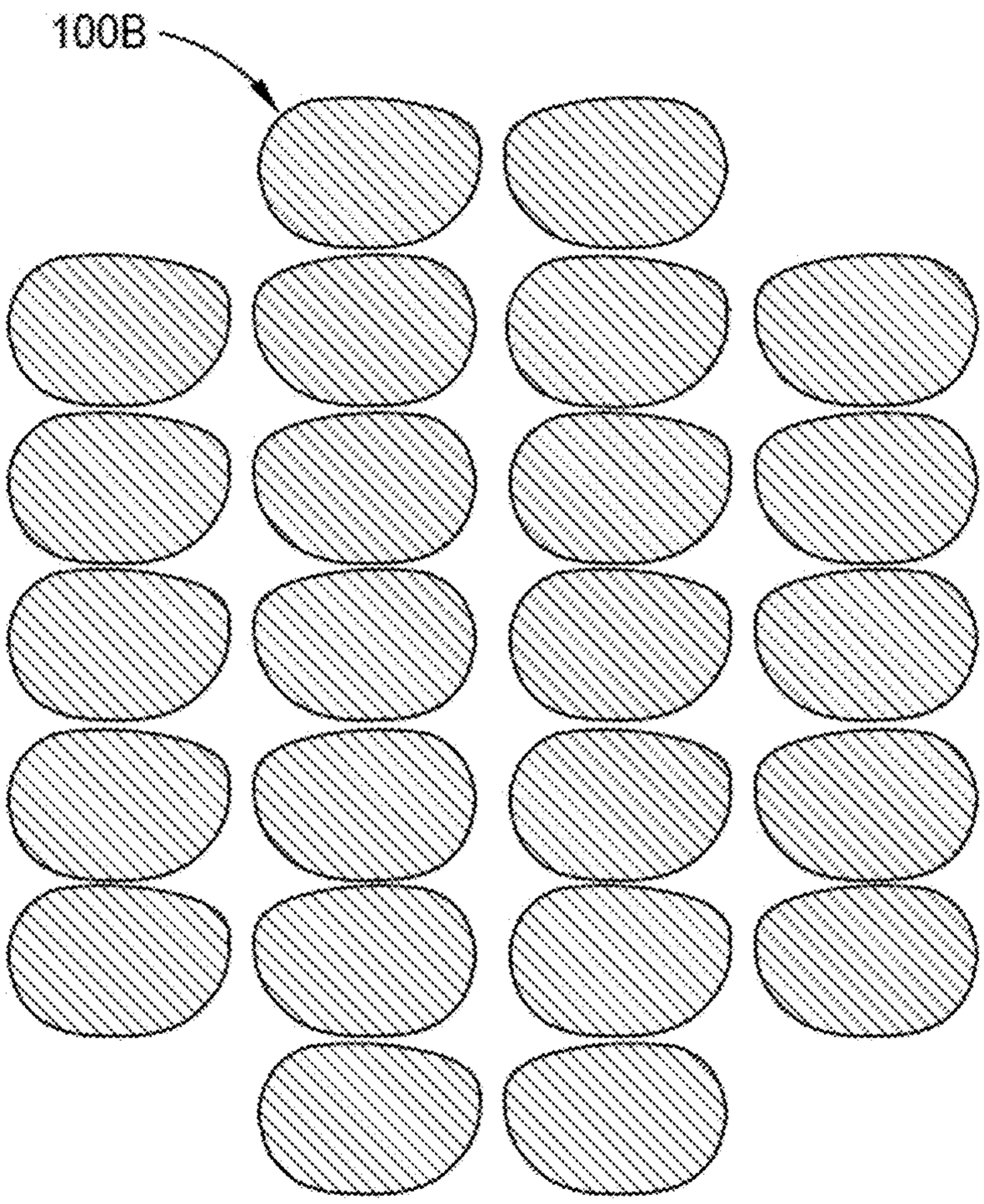


FIG. 5N

SUBSTRATE-LEVEL MONOLITHIC INTEGRATION OF PRESCRIPTION LENS WITH AUGMENTED REALITY (AR) WAVEGUIDES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims benefit of U.S. provisional patent application Ser. No. 63/563,711, filed Mar. 11, 2024, which is herein incorporated by reference.

BACKGROUND

Field

[0002] Embodiments of the present disclosure generally relate to augmented reality (AR) displays. More specifically, embodiments described herein relate to AR waveguides with attached prescription lens.

Description of the Related Art

[0003] Virtual reality is generally considered to be a computer generated simulated environment in which a user has an apparent physical presence. A virtual reality experience can be generated in 3D and viewed with a head-mounted display (HMD), such as glasses or other wearable display devices that have near-eye display panels as lenses to display a virtual reality environment that replaces an actual environment.

[0004] Augmented reality (AR), however, enables an experience in which a user can still see through the display lenses of the glasses or other HMD device to view the surrounding environment, yet also see images of virtual objects that are generated to appear as part of the environment. Augmented reality can include any type of input, such as audio and haptic inputs, as well as virtual images, graphics, and video that enhance or augment the environment that the user experiences. Users that require prescription eye glasses will still need a prescription lens to clearly see the surrounding environment. Therefore, what is needed in the art are AR waveguides with attached prescription lenses.

SUMMARY

[0005] In one embodiment, an eye-piece is provided. The eye-piece includes a waveguide, a convex prescription lens, a first gap, a concave prescription lens, and a second gap. The waveguide includes a substrate with a first surface and a second surface, and at least one grating is disposed over the first surface or the second surface. The convex prescription lens is disposed over the waveguide. The convex prescription lens has a first body with a convex surface and a lower surface. The first body is surrounded by a first extension that is disposed on the first surface of the substrate. The first gap is defined by the lower surface and the first extension of the convex prescription lens. The concave prescription lens is disposed over the waveguide. The concave prescription lens has a second body with a concave surface and an upper surface. The second body is surrounded by a second extension that is disposed on the second surface of the substrate. The second gap is defined by the upper surface and the second extension of the concave prescription lens.

[0006] In another embodiment, a method for forming eye-pieces is provided. The method includes overlaying a plurality of wafer protective coatings (WPCs) on a first surface of a plurality of waveguides disposed on a substrate, aligning the substrate in a tool, and depositing and curing a lens material on the plurality of WPCs. The lens material forming a plurality of convex prescription lenses on the first surface of the waveguides. The method further includes removing the WPCs from between the waveguides and prescription lens forming a first gap, and repeating overlaying to removing to form a plurality of concave prescription lenses on a second surface of the waveguide. The convex prescription lens and the concave prescription lens form a plurality of eye-pieces. The second surface is opposite the first surface. The method further includes cutting the eye-pieces from the substrate.

[0007] In another embodiment, a method for forming eye-pieces is provided. The method includes aligning a substrate in a tool, depositing a first gap-fill material on a first surface of a plurality of waveguides disposed in the substrate, and depositing and curing a lens material on the first gap-fill material. The lens material forms a plurality of convex prescription lenses on the first surface of the waveguides. The method further includes repeating overlaying to form a plurality of concave prescription lenses on a second surface of the waveguides. The convex prescription lens and the concave prescription lens form a plurality of eye-pieces. The second surface is opposite the first surface. The method further includes cutting the eye-pieces from the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only exemplary embodiments and are therefore not to be considered limiting of its scope, may admit to other equally effective embodiments.

[0009] FIG. **1**A is a perspective, frontal view of a waveguide, according to embodiments.

[0010] FIG. **1**B is a cross-sectional view of an eye-piece, according to embodiments.

[0011] FIG. **1**C is a cross-sectional view of a gap fill material eye-piece, according to embodiments.

[0012] FIG. **2** is a flow diagram describing a method of forming the eye-pieces, according to embodiments

[0013] FIGS. **3**A-**3**Q are views of a substrate during the method of forming the eye-pieces, according to embodiments.

[0014] FIG. **4** is a flow diagram describing a method of forming a gap fill material eye-piece, according to embodiments.

[0015] FIGS. **5**A-**5**N are views of a substrate during the method of forming the gap fill material eye-piece, according to embodiments.

[0016] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

DETAILED DESCRIPTION

[0017] The present disclosure generally relates to augmented reality (AR) displays. More specifically, embodiments described herein relate to AR waveguides with attached prescription lenses. Eye-pieces to be used for AR contain AR displays using waveguides. Users that use prescription lenses to see normally will require prescription lenses in the eye-pieces. The described methods reduce the complexity of the manufacturing process of the AR waveguides with attached prescription lenses. The methods can also improve the throughput therefore reducing the cost of the process.

[0018] Current methods include overlaying pre-fabricated prescription lenses on a first and second surface of a waveguide. The current method has complex alignment procedures and a gluing process. The gluing process holds the prescription lenses to the waveguide. The gluing process has dedicated machines raising the throughput and cost. The present disclosure describes methods that allow for monolithic integration with a plurality of prescription lenses being overlaid onto a plurality of waveguides formed from a wafer. Therefore, the methods remove the gluing process and reduce the number of alignment procedures. Benefits of the methods include no complex alignment procedures for each individual waveguide, protection of the waveguide structures by the prescription lens during cutting, and customization of corrective vision prescriptions for each prescription lens on each waveguide on the wafer.

[0019] FIG. **1**A is a perspective, frontal view of a waveguide **101**. It is to be understood that the waveguide **101** described herein is an exemplary waveguide and that other waveguides may be used with or modified to accomplish aspects of the present disclosure. The waveguide **101** includes a plurality of structures **152**. The structures **152** may be disposed over, under, or on a first surface **103** of a substrate **150**, or disposed in the substrate **150**. The structures **152** are nanostructures and have a sub-micron critical dimension, e.g., a width less than 1 micrometer. Regions of the structures **152** correspond to one or more gratings **154**. In one embodiment, which can be combined with other embodiments described herein, the waveguide **101** includes at least a first grating **154***a* corresponding to an input coupling grating and a third grating **154***c* corresponding to an output coupling grating. In another embodiment, which can be combined with other embodiments described herein, the waveguide **101** further includes a second grating **154***b*. The second grating **154***b* corresponds to a pupil expansion grating or a fold grating.

[0020] FIG. **1**B is a cross-sectional view of an eye-piece **100**A. The eye-piece **100**A includes the waveguide **101**, a first gap **107**A, a convex prescription lens **105**, a second gap **107**B, and a concave prescription lens **109**. It is to be understood that the waveguide **101** described herein is an exemplary waveguide and that other waveguides may be used with or modified to accomplish aspects of the present disclosure. The waveguide **101** is formed from the substrate described in FIGS. **1**A, **2**, and **5**. The waveguide **101** may include, a plastic material, a metal oxide material, silicon carbide (SiC), lithium niobate ($LiNbO_3$), or combinations thereof. The metal oxide material includes but it not limited to, lanthanum oxide (La_xO_y), titanium oxide (TiO_x), niobium oxide (NbO_x), zirconium oxide (ZrO_x), or a combinations thereof. The plastic material includes, polycarbonates (PC), polyethylene terephthalate (PET), a high index resin (greater than 2.0), or a combinations thereof. The waveguide **101** has a refractive index of about 1.5 to about 2.6.

[0021] The convex prescription lens **105** and the concave prescription lens **109** include at least one of a UV-curable acrylate, a UV-curable epoxy, a UV-curable oxetane, a UV-curable silicone, a UV-curable thiol-ene, or combinations thereof. A binary curing system may be utilized. The convex prescription lens **105** is disposed over the first surface **103** of the waveguide **101**. The convex prescription lens **105** has a first body **111**. The first body **111** includes a convex surface **113** and a lower surface **115**. The first body **111** is surrounded by a first extension **117**. The first extension **117** is disposed on the first surface **103** of the substrate **150**. The first gap **107**A is defined by the lower surface **115**, the first surface **103** of the waveguide **101** and the first extension **117** of the convex prescription lens **105**. A second surface **119** of the substrate **150** is disposed over the concave prescription lens **109**. The second surface **119** is opposite the first surface **103**. The concave prescription lens **109** has a second body **121**. The second body **121** includes a concave surface **123** and an upper surface **125**. A second extension **127** surrounds the second body **121**. The second surface **119** of the substrate **150** is disposed on the second extension **127**. The second gap **107**B is defined by the upper surface **125**, the second surface **119** of the waveguide **101**, and the second extension **127** of the concave prescription lens **109**.

[0022] The convex prescription lens **105** faces a world side of the resulting AR display i.e. the side away from the user. The concave prescription lens **109** faces the eye side of the resulting AR display i.e. the side facing the user's eye. The concave prescription lens **109** provides optical correction to the user as a traditional corrective prescription lens. However, the concave prescription lens **109** has a higher optical power than the prescription normally required by the user. The higher optical power of the waveguide **101** ensures that the virtual image is properly displayed. The concave prescription lens **109** allows a virtual image to appear at the proper distance from the user. Without the concave prescription lens **109**, the virtual image would be projected at an infinite focal distance. The convex prescription lens **105** corrects the prescription of the concave prescription lens **109** in order to match the prescription normally required by the user by counteracting a portion of the optical power provided by the concave prescription lens **109**. In some embodiments, the eye-piece **100**A can be used by a user without a prescription lens by the convex prescription lens **105** counteracting all the optical power of the concave prescription lens **109**. The convex prescription lens **105** causes the world images to appear corrected as they would be in a traditional corrective prescription lens. For example, for a user not needing prescription lenses, the concave prescription lens **109** will have a prescription of −2 diopter and the convex prescription lens **105** will have a prescription lens of +2 diopter, combined for an eye-piece with no correction of the users vision. For users with myopia, the concave prescription lens **109** will have a prescription of −2 diopter and the convex prescription lens **105** will have a prescription lens of +1 diopter, combined to provide −1 diopter optical power for eye-sight correction. The corrective effect of the convex prescription lens **105** and the concave prescription lens **109** is determined by the shape of the convex prescription lens **105** the concave prescription lens **109**. The convex prescription lens **105** and the concave prescription lens **109** protect the nanostructures of the waveguide **101** from contaminates.

[0023] The first gap **107**A includes air. The convex prescription lens **105** has a refractive index of about 1.5 to about 1.8. The first gap **107**A has the refractive index of air. Air has a refractive index of about 1.0. The first gap **107**A optically isolates the waveguide **101** from the convex prescription lens **105**. The optical isolation of the waveguide **101** and the convex prescription lens **105** is caused by the first gap **107**A having a lower refractive index compared to the waveguide **101** and convex prescription lens **105**. The waveguide **101** and convex prescription lens **105** are optically isolated in order for the waveguide **101** to function properly. The second gap **107**B includes air. The concave prescription lens **109** has a refractive index of 1.5 to 1.8. The second gap **107**B has the refractive index of air. The second gap **107**B optically isolates the waveguide **101** from the concave prescription lens **109**. The optical isolation of the waveguide **101** and the concave prescription lens **109** is caused by the second gap **107**B having a lower refractive index compared to the waveguide **101** and concave prescription lens **109**. The waveguide **101** and the concave prescription lens **109** are optically isolated in order for the waveguide **101** to function properly.

[0024] FIG. **1**C is a cross-sectional view of a gap fill material eye-piece **100**B. The gap fill material eye-piece **100**B includes the waveguide **101**, a first gap-fill material **102**, the convex prescription lens **105**, a second gap-fill material **106**, and the concave prescription lens **109**. The first gap **107**A is filled with the first gap-fill material **102**. The first gap-fill material **102** is disposed between the waveguide **101** and the convex prescription lens **105**. The second gap **107**B is filled with second gap-fill material **106**. The second gap-fill material **106** is disposed between the waveguide **101** and the concave prescription lens **109**. The first gap-fill material **102** and the second gap-fill material **106** include a low refractive index material such as a porous inorganic or porous organic material.

[0025] The first gap-fill material **102** has a refractive index of 1.03 to 1.4. The first gap-fill material **102** has a refractive index less than the material of the convex prescription lens **105** and the concave prescription lens **109**. The first gap-fill material **102** optically isolates the waveguide **101** from the convex prescription lens **105**. The optical isolation of the waveguide **101** and the convex prescription lens **105** is caused by the first gap-fill material **102** having a lower refractive index compared to the waveguide **101** and the convex prescription lens **105**. The waveguide **101** and the convex prescription lens **105** are optically isolated in order for the waveguide **101** to function properly. The second gap-fill material **106** has a refractive index of 1.03 to 1.4. The second gap-fill material **106** has a refractive index less than the material of the convex prescription lens **105** and the concave prescription lens **109**. The second gap-fill material **106** optically isolates the waveguide **101** from the concave prescription lens **109**. The optical isolation of the waveguide **101** and the concave prescription lens **109** is caused by the second gap-fill material **106** having a lower refractive index compared to the waveguide **101** and the concave prescription lens **109**. The gap fill material eye-piece **100**B functions in the same way as the eye-piece **100**A as described above in FIG. **1**B.

[0026] FIG. **2** is a flow diagram describing a method **200** of forming the eye-pieces **100**A. FIGS. **3**A-**3**Q are views of a substrate **300** during the method of forming the eye-pieces **100**A. FIG. **3**A is a cross-sectional view of the waveguide **101** at the beginning of method **200**. The waveguide **101** includes a plurality of structure **152**. The structures **152** are nanostructures and have a sub-micron critical dimension, e.g., a width less than 1 micrometer. Regions of the structures **152** correspond to one or more gratings. FIG. **3**B is a top view of the substrate **300** at the beginning of method **200**. A plurality of the waveguides **101** are formed on, over, or in a substrate **300**. The substrate **300** has a first surface **302**. The substrate **300** may include 20 to 30 waveguides, such as 24 waveguides. In other embodiments, different number of waveguides **101** are formed with the substrate **300**. Rectangular dice marks **304** indicate the regions where the waveguides **101** are formed in the substrate **300**. The waveguides **101** will be diced from the substrate **300** at the end of the process. The substrate **300** has two alignment points **301** on the first surface **302** to align the substrate **300** in process chambers and tools

[0027] At operation **201**, as shown in FIG. **3**C and FIG. **3**D, a plurality of first wafer protective coatings (WPCs) **303** are overlaid on the plurality of waveguides **101** on the first surface **302** of the substrate **300**. FIG. **3**C is a cross-sectional view of the waveguide **101** at operation **201**. FIG. **3**D is a top view of the waveguide **101** at operation **201**. The WPCs are disposed on the first surface **302** of the substrate **300**. In some embodiments, the first WPCs **303** are printed on each waveguide **101**. In other embodiments, the first WPCs **303** are prefabricated and placed on top of each waveguide **101**. The first WPCs **303** include a water-soluble material, a water-soluble polymer, a heat decomposable material, a UV decomposable material, a solvent strippable material, or a sacrificial layer.

[0028] At operation **202**, the substrate **300** is aligned in a tool. The alignment points **301** are used to verify the substrate **300** is in the correct position in the tool. The tool will be used to form the prescription lenses. The tool may be any suitable tool such as a three dimensional printing tool. In some embodiments, multiple tools are used during the method **200**. In those embodiments, the substrate **300** is aligned in each tool prior to the operation being performed. In some, embodiments, the substrate **300** is aligned prior to the first WPC **303** being overlaid on the plurality of waveguides **101**.

[0029] At operation **203**, as shown in FIG. **3**E and FIG. **3**F, a lens material **305** is deposited and cured on the first WPCs **303** to form a convex prescription lens **105**. FIG. **3**E is a cross-sectional view of the waveguide **101** at operation **203**. FIG. **3**F is a top view of the waveguide **101** at operation **203**. The lens material **305** is deposited on each first WPCs **303** above each waveguide **101** layer by layer. The lens material **305** is deposited by inkjet printing. The lens material **305** is cured after each layer is deposited. The lens material **305** may be UV light curable or visible light curable. In some embodiments, the curing process includes a post-UV thermal annealing process. The lens material **305** creates a convex shape. After the final layer of the lens material **305** is cured, the lens material **305** forms the convex prescription lens **105**.

[0030] At operation **204**, as shown in FIG. **3**G and **3**H, the first WPCs **303** are removed. FIG. **3**G is a cross-sectional view of the waveguide **101** at operation **204**. FIG. **3**H is a top view of the waveguide **101** at operation **204**. In some embodiments, the first WPCs **303** are removed by soaking in water. The first WPCs **303** are water-soluble. The convex prescription lens **105** includes a first extension **117**. Small

trenches exist in the first extension **117** of the convex prescription lenses **105** that allow the water to access the first WPCs **303**. The water dissolves the first WPCs **303** allowing the material to be removed from between the convex prescription lens **105** and the waveguide **101** through the small trenches. In other embodiments, the first WPCs **303** are removed by different processes. When the first WPCs **303** are removed, the first gaps **107**A are formed between the waveguides **101** and the convex prescription lenses **105**. In some embodiments, after the first WPCs **303** are removed, the small trenches are filled with lens material **305** and cured. In some embodiments, after forming the convex prescription lens **105**, the method **200** may proceed to operation **210** (i.e., the concave prescription lens **109** is not formed on the waveguide **101**). In other embodiments, the method **200** may begin at operation **205**. (i.e., the convex prescription lens **105** is not formed on the waveguide **101**).

[0031] At operation **205**, as shown in FIG. **3**I and FIG. **3**J, the substrate **300** is flipped to process a second surface **307** of the substrate **300**. The second surface **307** is opposite the first surface **302** of the substrate **300**. FIG. **3**I is a cross-sectional view of the waveguide **101** at operation **205**. FIG. **3**J is a top view of the waveguide **101** at operation **205**. The waveguides **101** formed in the substrate **300** are separated by rectangular dice marks **304**. Second alignment points **309** are disposed on the substrate **300** on the second surface **307** to align the substrate **300** in process chambers and tools.

[0032] At operation **206**, as shown in FIG. **3**K and FIG. **3**L, a plurality of second wafer protective coatings (WPCs) **313** are overlaid on the plurality of waveguides **101** on the second surface **307** of the substrate **300**. FIG. **3**K is a cross-sectional view of the waveguide **101** at operation **206**. FIG. **3**L is a top view of the waveguide **101** at operation **206**. The second WPCs **313** are disposed on the second surface **307** of the substrate **300**. In some embodiments, the second WPCs **313** are printed on each waveguide **101**. In other embodiments, the second WPCs **313** are prefabricated and placed on top of each waveguide **101**. The second WPCs **313** include a water-soluble material, a water-soluble polymer, a heat decomposable material, a UV decomposable material, a solvent strippable material, or a sacrificial layer.

[0033] At operation **207**, the substrate **300** is aligned in a tool. The alignment points **309** are used to verify the substrate **300** is in the correct position in the tool. In some embodiments, the substrate **300** is aligned prior to the second WPC **313** being overlaid on the plurality of waveguides **101**.

[0034] At operation **208**, as shown in FIG. **3**M and FIG. **3**N, a second lens material **315** is deposited and cured on the second WPCs **313** on the second surface **307** of the substrate **300**. FIG. **3**M is a cross-sectional view of the waveguide **101** at operation **208**. FIG. **3**N is a top view of the waveguide **101** at operation **208**. The second lens material **315** is deposited on each second WPCs **313** above each waveguide **101** layer by layer. The second lens material **315** is deposited by inkjet printing. The second lens material **315** is cured after each layer is deposited. The second lens material **315** may be UV light curable or visible light curable. In some embodiments, the curing process includes a post-UV thermal annealing process. The second lens material **315** creates a concave shape. After the final layer of the second lens material **315** is cured, the second lens material **315** forms the concave prescription lenses **109**.

[0035] At operation **209**, as shown in FIGS. **3**O and **3**P, the second WPCs **313** are removed. FIG. **3**O is a cross-sectional view of the waveguide **101** at operation **209**. FIG. **3**P is a top view of the waveguide **101** at operation **209**. In some embodiments, the second WPCs **313** are removed by soaking in water. The second WPCs **313** are water-soluble. The concave prescription lens **109** includes a second extension **127**. Small trenches exist in the second extension **127** of the concave prescription lenses **109** that allow the water to access the second WPCs **313**. The water dissolves the second WPCs **313** allowing the material to be removed from between the concave prescription lens **109** and the waveguide **101** through the small trenches. In other embodiments, the second WPCs **313** are removed by different processes. When the second WPCs **313** are removed, the second gaps **107**B are formed between the waveguides **101** and the concave prescription lenses **109**. In some embodiments, after the second WPCs **313** are removed, the small trenches are filled with lens material **315** and cured.

[0036] At operation **210**, as shown in FIG. **3**Q, individual eye-pieces **100**A are cut from the substrate **300**. The eye-pieces **100**A are cut by a separate tool using a laser. In some embodiments, the laser is a laser for cutting glass.

[0037] In some embodiments, the substrate **300** is aligned once or twice on both the first surface **302** and the second surface **307** for a maximum four times. If fabricating 24 eye-pieces, traditional processes require at least 48 alignments, one for each side of each eye-piece. The method **200** reduces the amount of alignments from 48 to 4.

[0038] FIG. **4** is a flow diagram describing a method **400** of forming a gap fill material eye-piece **100**B. FIG. **5**A-**5**N are views of a substrate **500** during the method **400** of forming the gap fill material eye-piece **100**B. FIG. **5**A is a cross-sectional view of the waveguide **101** at the beginning of method **400**. The waveguide **101** includes a plurality of structure **152**. The structures **152** are nanostructures and have a sub-micron critical dimension, e.g., a width less than 1 micrometer. Regions of the structures **152** correspond to one or more gratings. FIG. **5**B is a top view of the substrate **500** at the beginning of method **400**. A plurality of the waveguides **101** are formed on, over, or in a substrate **500**. The substrate **500** has a first surface **302**. The substrate 500 may include 20 to 30 waveguides, such as 24 waveguides. In other embodiments, different number of waveguides **101** are formed with the substrate **500**. Rectangular dice marks **504** indicate the regions where the waveguides **101** are formed in the substrate **500**. The waveguides **101** will be diced from the substrate **500** at the end of the process. The substrate **500** has two alignment points **501** on the first surface **502** to align the substrate **500** in process chambers and tools.

[0039] At operation **501**, the substrate **500** is aligned in the tool. The alignment points **501** are used to verify the substrate **500** is in the correct position in the tool. The tool will be used to form the prescription lens and cut the gap fill material eye-pieces **100**B out of the substrate **500**. The tool may be any suitable tool such as a three dimensional printing tool. In some embodiments, separate tools are used to form the prescription lens and cut the gap fill material eye-pieces **100**B. In those embodiments, the substrate **500** is aligned in each tool prior to the process.

[0040] At operation **402**, as shown in FIG. **5**C and FIG. **5**D, the first gap-fill material **102** is deposited on the plurality of waveguides **101**. The first gap-fill material **102**

is disposed on the first surface **502** of the substrate **500**. The first gap-fill material **102** is deposited by inkjet printing on each waveguide **101**. The first gap-fill material **102** is cured after each layer is deposited. The first gap fill material **102** is cured at a temperature of about 50° C. to about 300° C.

[0041] At operation **403**, as shown in FIG. **5**E and FIG. **5**F, a first lens material **505** is deposited and cured on the first gap-fill material **102** to form a convex prescription lens **105**. FIG. **5**E is a cross-sectional view of the waveguide **101** at operation **403**. FIG. **5**F is a top view of the waveguide **101** at operation **403**. The first lens material **505** is deposited on each first gap-fill material **102** above each waveguide **101** layer by layer. The first lens material **505** is deposited by inkjet printing. The first lens material **505** is cured after each layer is deposited. The first lens material **505** may be UV light curable or visible light curable. In some embodiments, the curing process includes a post-UV thermal annealing process. The first lens material **505** creates a convex shape. After the final layer of the first lens material **505** is cured, the first lens material **505** forms the convex prescription lens **105**. In some embodiments, after forming the convex prescription lens **105**, the method **400** may proceed to operation **408** (i.e., the concave prescription lens **109** are not formed on the waveguide **101**). In other embodiments, the method **400** may begin at operation **404**. (i.e., the convex prescription lens **105** is not formed on the waveguide **101**).

[0042] At operation **404**, as shown in FIG. **5**G and FIG. **5**H, the substrate **500** is flipped to process a second surface **507** of the substrate **500**. The second surface **507** is opposite the first surface **502** of the substrate **500**. FIG. **5**G is a cross-sectional view of the waveguide **101** at operation **404**. FIG. **5**H is a top view of the waveguide **101** at operation **404**. The waveguides **101** formed in the substrate **500** are separated by rectangular dice marks **504**. Second alignment points **509** are disposed on the substrate **500** on the second surface **507** to align the substrate **500** in process chambers and tools.

[0043] At operation **405**, the substrate **500** is aligned in a tool. The alignment points **509** are used to verify the substrate **500** is in the correct position in the tool. In some embodiments, the substrate **500** is aligned prior to a second fill material **106** being overlaid on the plurality of waveguides **101**.

[0044] At operation **406**, as shown in FIG. **5**I and FIG. **5**J, the second fill material **106** is overlaid on the plurality of waveguides **101** on the second surface **507** of the substrate **500**. FIG. **5**I is a cross-sectional view of the waveguide **101** at operation **406**. FIG. **5**J is a top view of the waveguide **101** at operation **406**. The second fill material **106** is disposed on the second surface **507** of the substrate **500**. In some embodiments, second fill material **106** is inkjet printed on each waveguide **101**. The second gap-fill material **106** is cured after each layer is deposited. The second gap fill material **106** is cured at a temperature of about 50° C. to about 300° C.

[0045] At operation **407**, as shown in FIG. **5**K and FIG. **5**L, a second lens material **515** is deposited and cured on the second fill material **106** on the second surface **507** of the substrate **500**. FIG. **5**K is a cross-sectional view of the waveguide **101** at operation **407**. FIG. **5**L is a top view of the waveguide **101** at operation **407**. The second lens material **515** is deposited on the second fill material **106** above each waveguide **101** layer by layer. The second lens material **515** is deposited by inkjet printing. The second lens material **515** is cured after each layer is deposited. The second lens material **515** may be UV light curable or visible light curable. In some embodiments, the curing process includes a post-UV thermal annealing process. The second lens material **515** creates a concave shape. After the final layer of the second lens material **515** is cured, the second lens material **515** forms the concave prescription lenses **109**.

[0046] At operation **408**, as shown in FIG. **5**M and FIG. **5**N, individual eye-pieces **100**A are cut from the substrate **500**. The eye-pieces **100**A are cut by a separate tool using a laser. In some embodiments, the laser is a laser for cutting glass.

[0047] In some embodiments, the substrate **500** is aligned once or twice on both the first surface **502** and the second surface **507** for a maximum four times. If fabricating 24 eye-pieces, traditional processes require at least 48 alignments, one for each side of each eye-piece. The method **400** reduces the amount of alignments from 48 to 4.

[0048] In summation, present disclosure generally relates to augmented reality (AR) displays. More specifically, embodiments described herein relate to AR waveguides with attached prescription lens. The embodiments include methods allowing monolithic integration with a plurality of prescription lenses being overlaid onto a plurality of waveguides formed from a wafer. Therefore, the methods remove the gluing process and reduces the amount of alignment procedures. Other benefits include no complex alignment procedures for each individual waveguide due to the eye-pieces being made in batches on the substrate. The corrective prescriptions for each prescription lens on each waveguide may be customized on the substrate due to the process used to form the prescription lenses.

[0049] While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. A lens, comprising:

a waveguide comprising a substrate with a first surface and a second surface;

a convex prescription lens disposed over the waveguide, the convex prescription lens having a first body with a convex surface and a lower surface;

a first gap defined by the lower surface and the first surface of the waveguide;

a concave prescription lens disposed over the waveguide, the concave prescription lens having a second body with a concave surface and an upper surface; and

a second gap defined by the upper surface and the second surface of the waveguide.

2. The lens of claim **1**, wherein:

a first gap-fill material is disposed in the first gap; and

a second gap-fill material is disposed in the second gap.

3. The lens of claim **2**, wherein the first gap-fill material and the second gap fill material have a refractive index of 1.03 to 1.4.

4. The lens of claim **2**, wherein the waveguide comprises silicon carbide, lithium niobate, lanthanum oxide, titanium oxide, niobium oxide, zirconium oxide, polycarbonates, or polyethylene terephthalate.

5. The lens of claim **1**, wherein the waveguide has a refractive index of 1.5 to 2.6 and includes gratings corre-

sponding to an input coupling grating, a pupil expansion grating, and an output coupling grating.

6. The lens of claim **1**, wherein the convex prescription lens and the concave prescription lens comprise UV-curable acrylate, a UV-curable epoxy, a UV-curable oxetane, a UV-curable silicone, or a UV-curable thiol-ene.

7. The lens of claim **1**, wherein the convex prescription lens and the concave prescription lens have a refractive index of 1.5 to 1.8.

8. The lens of claim **1**, wherein the first gap and the second gap comprise air.

9. A method for forming lenses, comprising:

overlaying a plurality of wafer protective coatings (WPCs) on a first surface of a plurality of waveguides disposed on a substrate;

aligning the substrate in a tool;

depositing and curing a lens material on the plurality of wafer protective coatings forming a plurality of convex prescription lenses on the first surface of the waveguides; and

cutting the lenses from the substrate.

10. The method of claim **9**, further comprising:

removing the WPCs from between the waveguides and prescription lens forming a first gap.

11. The method of claim **9**, further comprising:

repeating overlaying to cutting to form a plurality of concave prescription lenses on a second surface of the waveguide forming a plurality of lenses, the second surface being opposite the first surface.

12. The method of claim **9**, wherein the lens material comprises UV-curable acrylate, a UV-curable epoxy, a UV-curable oxetane, a UV-curable silicone, or a UV-curable thiol-ene.

13. The method of claim **9**, wherein the WPCs may be printed on or attached to the waveguides.

14. The method of claim **13**, wherein the WPCs are removed by soaking in water.

15. The method of claim **9**, wherein the lenses are cut using a laser cutting tool.

16. A method for forming lenses, comprising:

aligning a substrate in a tool;

depositing a first gap-fill material on a first surface of a plurality of waveguides disposed in the substrate;

depositing and curing a lens material on the first gap-fill material forming a plurality of convex prescription lenses on the first surface of the waveguides; and

cutting the lenses from the substrate.

17. The method of claim **16**, further comprising:

repeating overlaying to removing to form a plurality of concave prescription lenses on a second surface of the waveguides forming a plurality of lenses, the second surface opposite the first surface.

18. The method of claim **16**, wherein the lens material comprises a UV-curable acrylate, a UV-curable epoxy, a UV-curable oxetane, a UV-curable silicone, or a UV-curable thiol-ene.

19. The method of claim **16**, wherein the lens material is deposited by inkjet printing.

20. The method of claim **16**, wherein the lenses are cut using a laser cutting tool.

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