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(54) **USING FLOWABLE CVD TO GAP FILL MICRO/NANO STRUCTURES FOR OPTICAL COMPONENTS**

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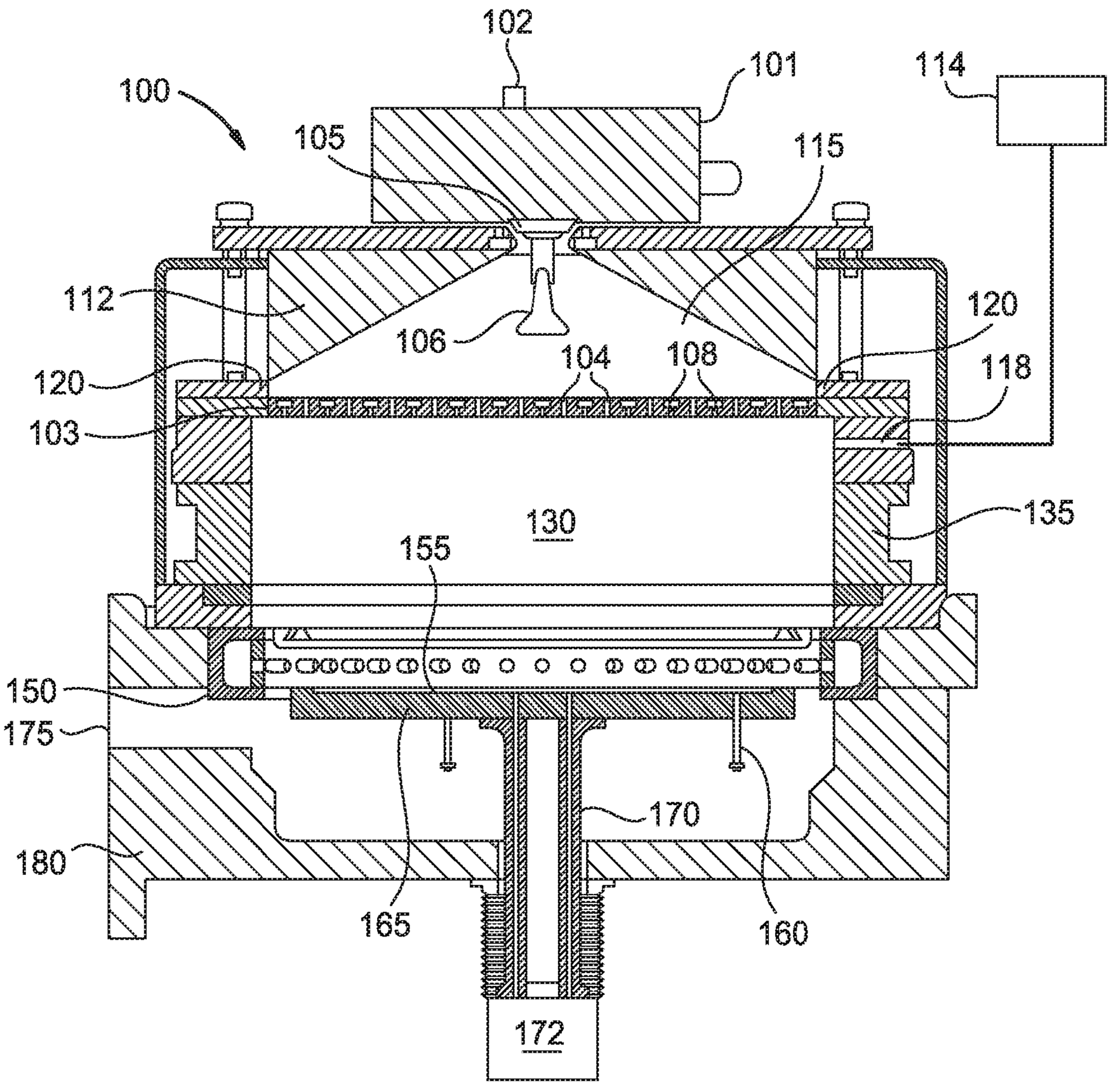
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C23C 16/56	(2006.01)

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(57) **ABSTRACT**

Embodiments of the present disclosure generally relate to a method for forming an optical component, for example, for a virtual reality or augmented reality display device. In one embodiment, the method includes forming a first layer having a pattern on a substrate, and the first layer has a first refractive index. The method further includes forming a second layer on the first layer by a flowable chemical vapor deposition (FCVD) process, and the second layer has a second refractive index less than the first refractive index.



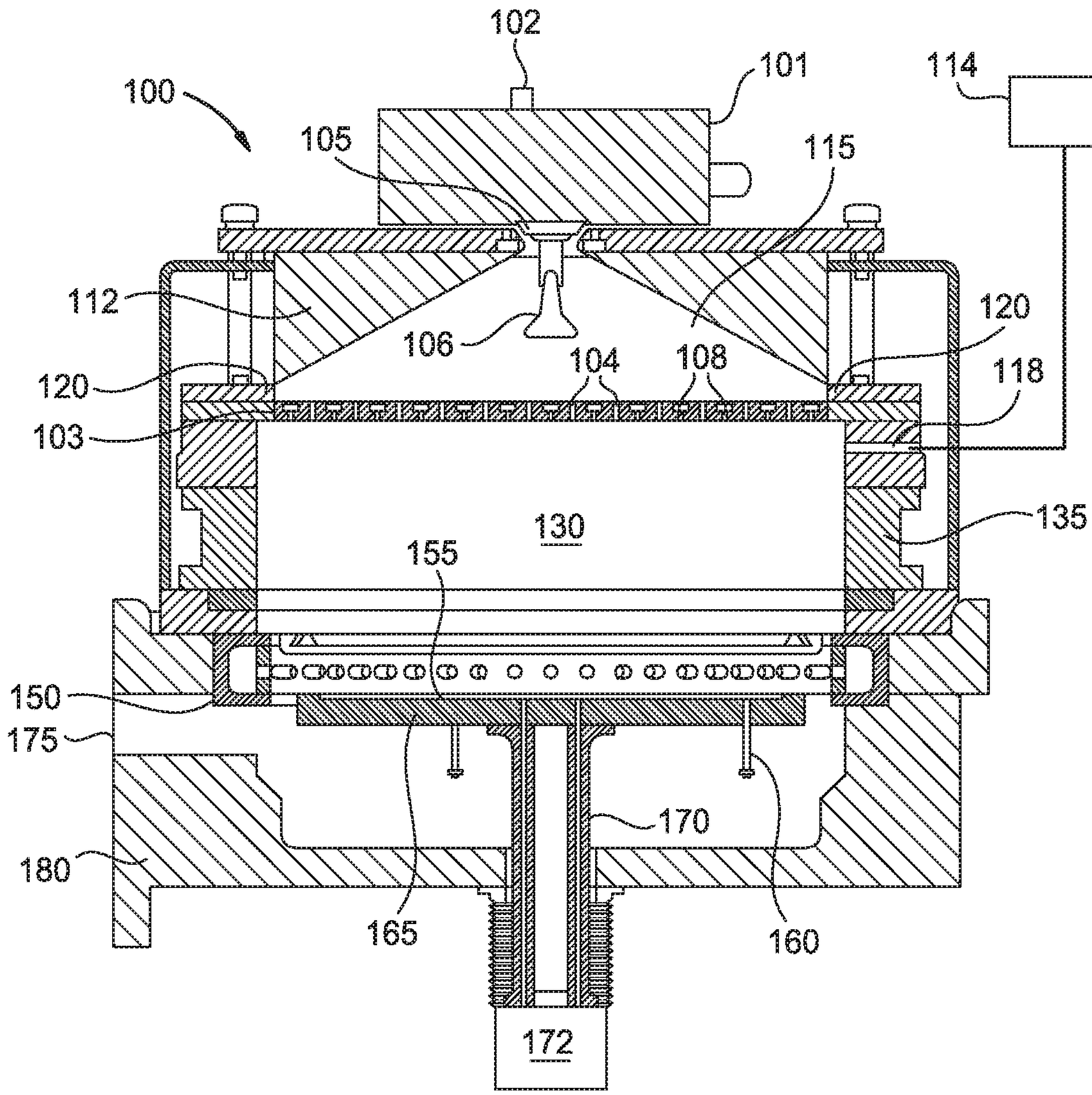

102
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FIG. 1

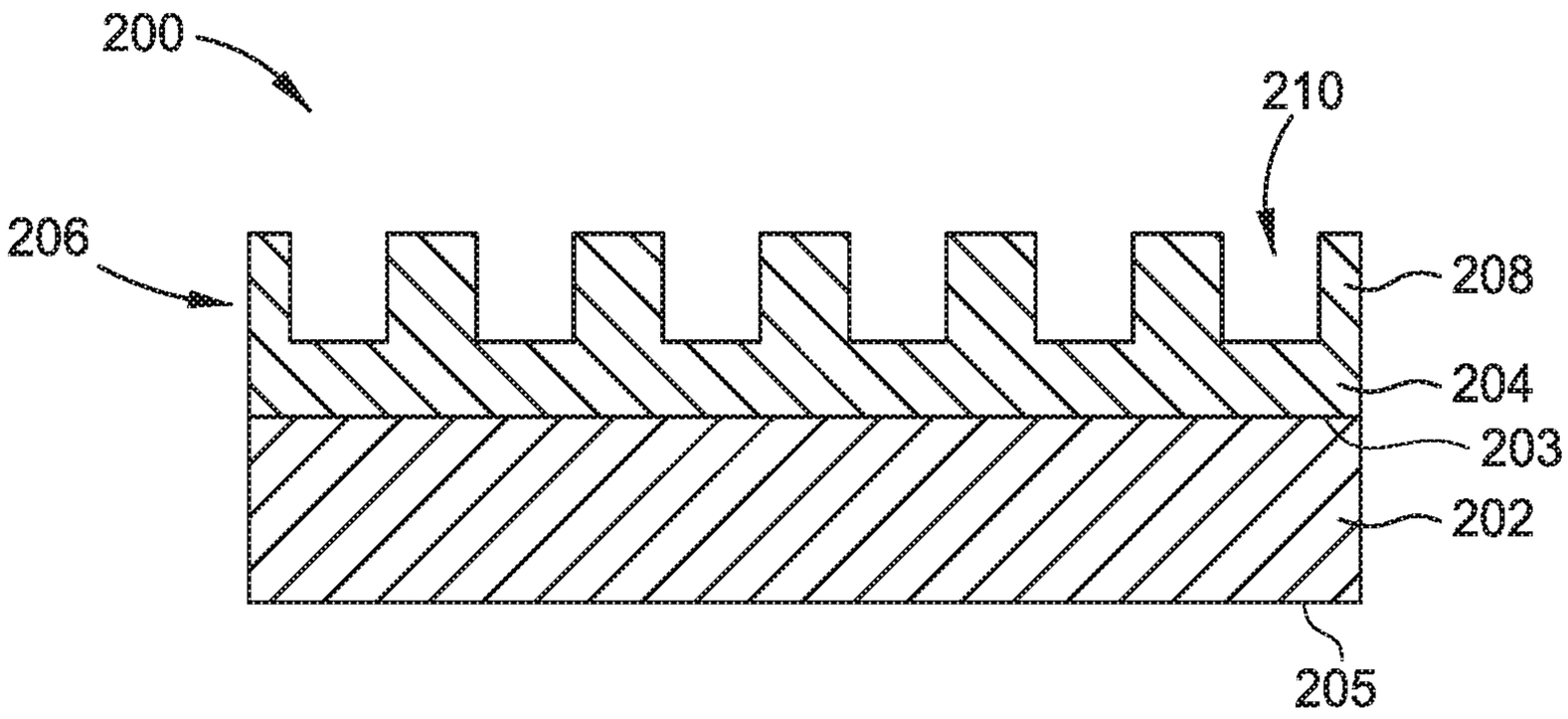


FIG. 2A

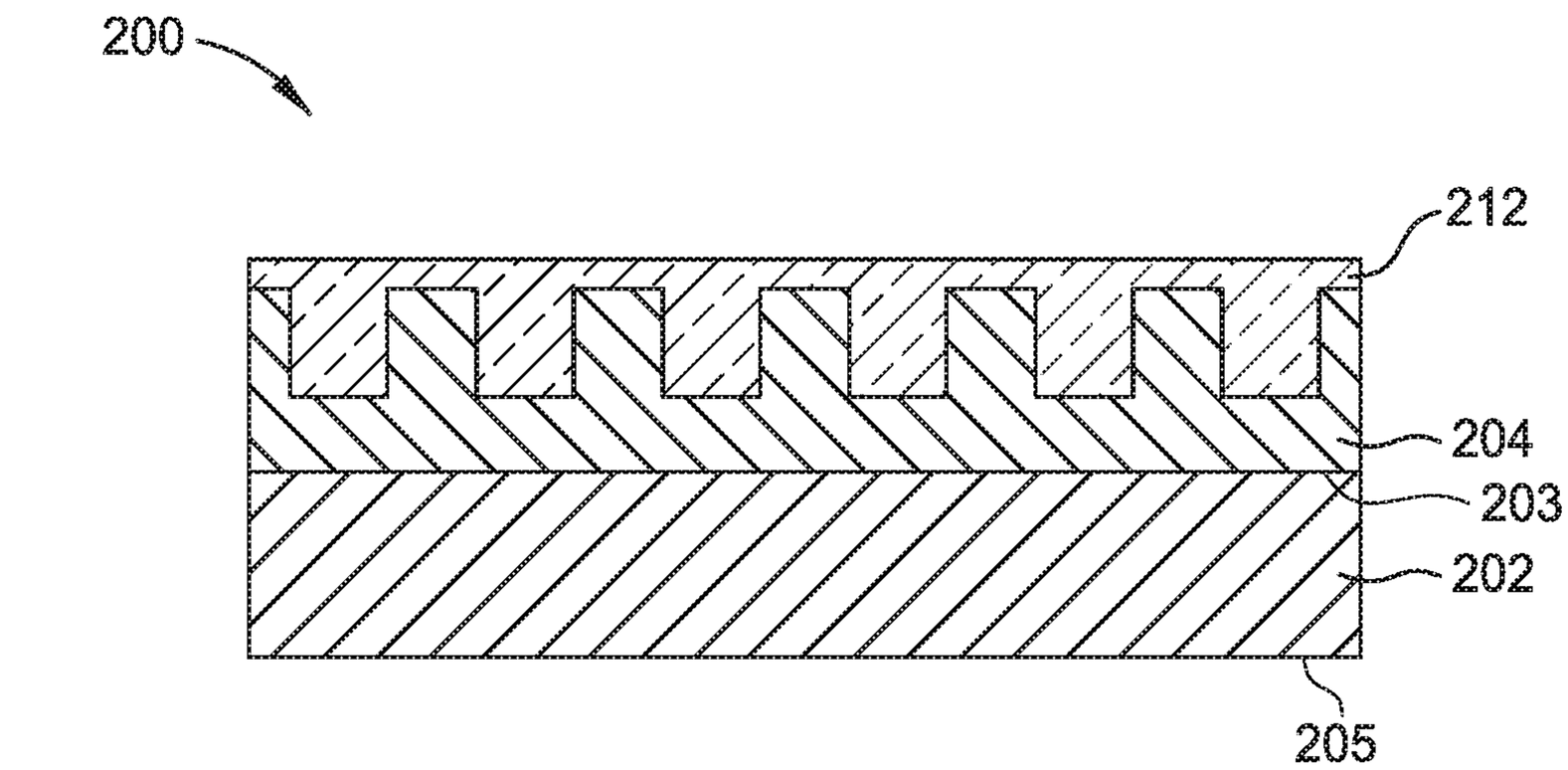


FIG. 2B

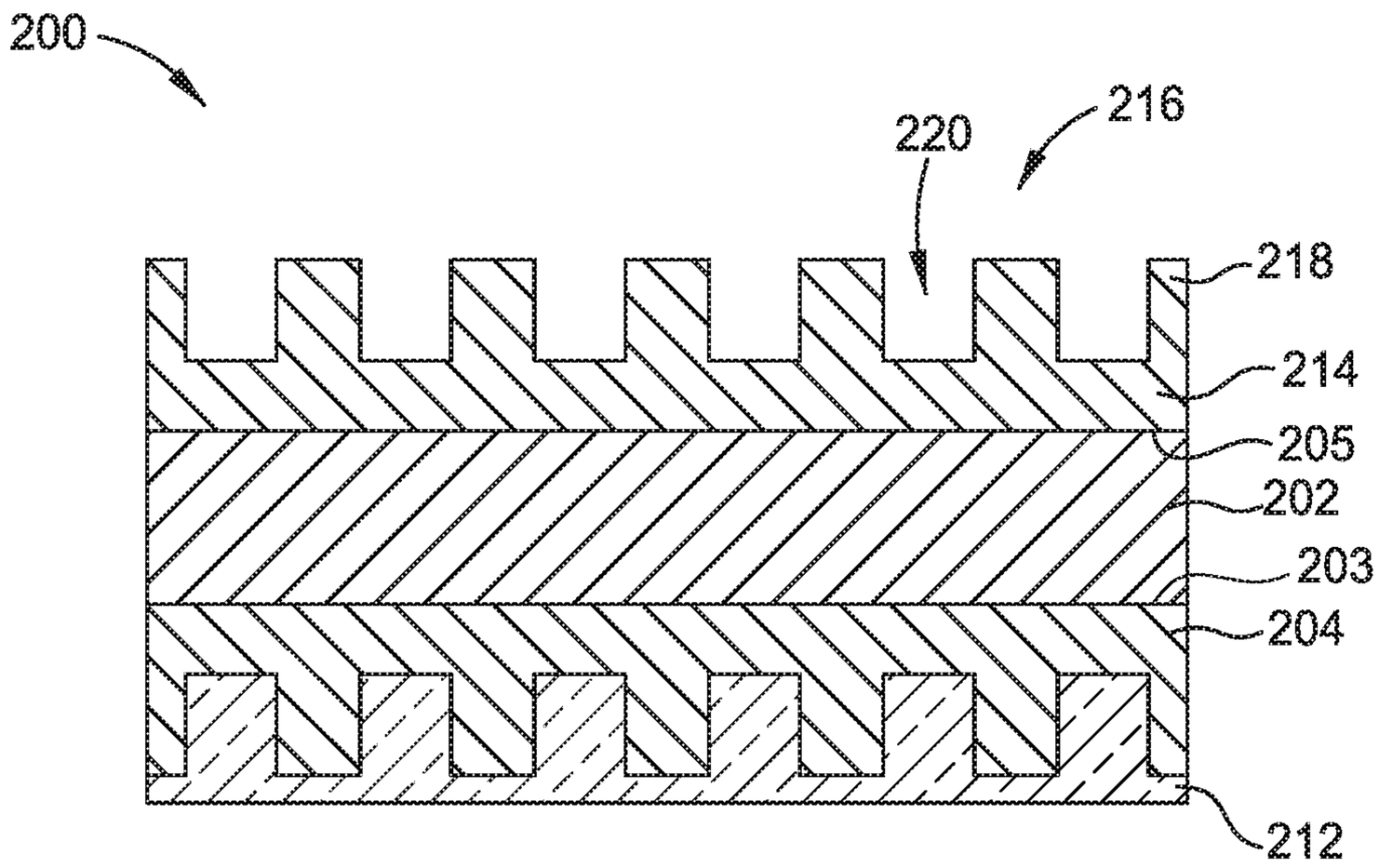

200
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FIG. 2C

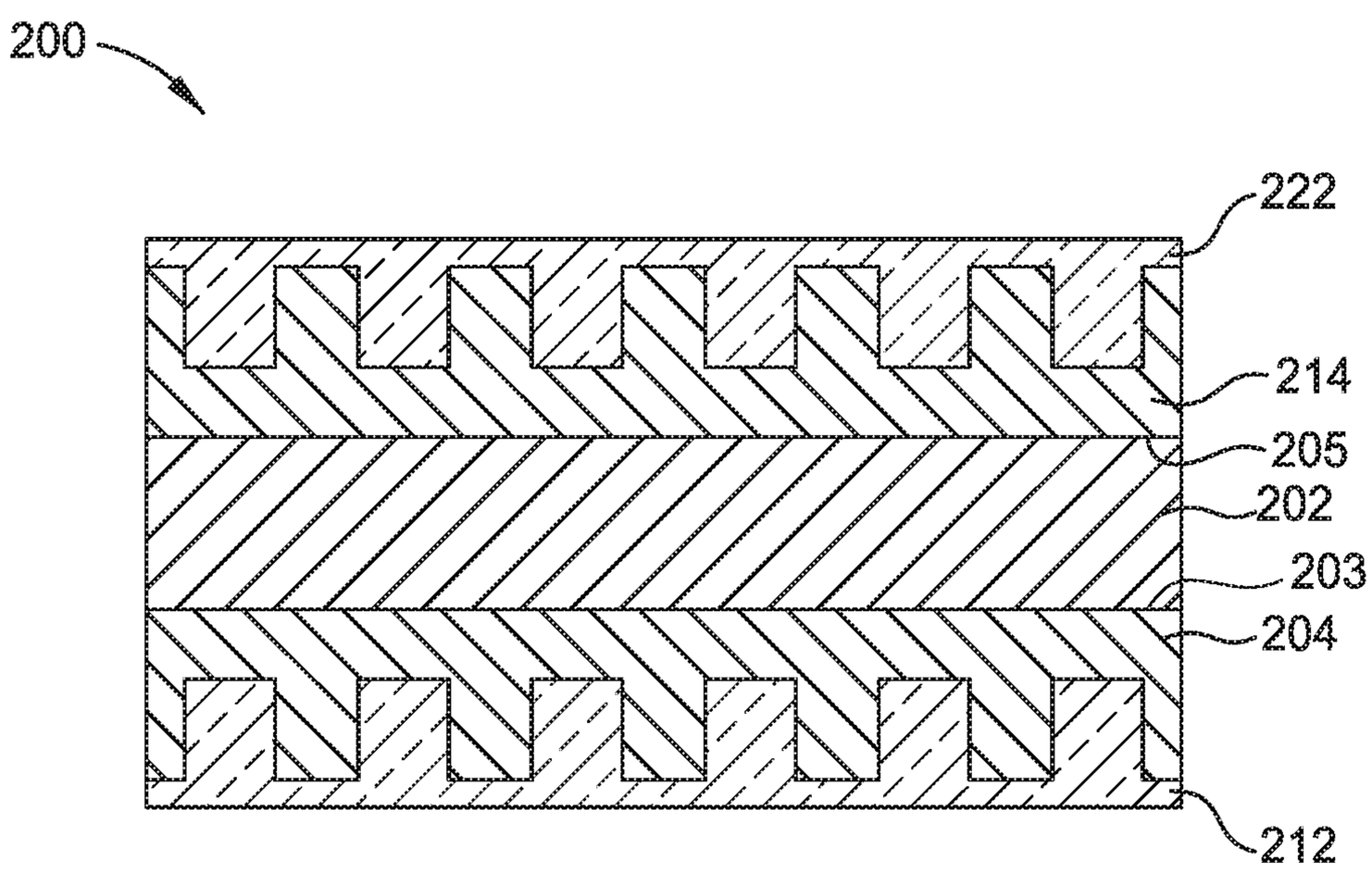

200
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FIG. 2D

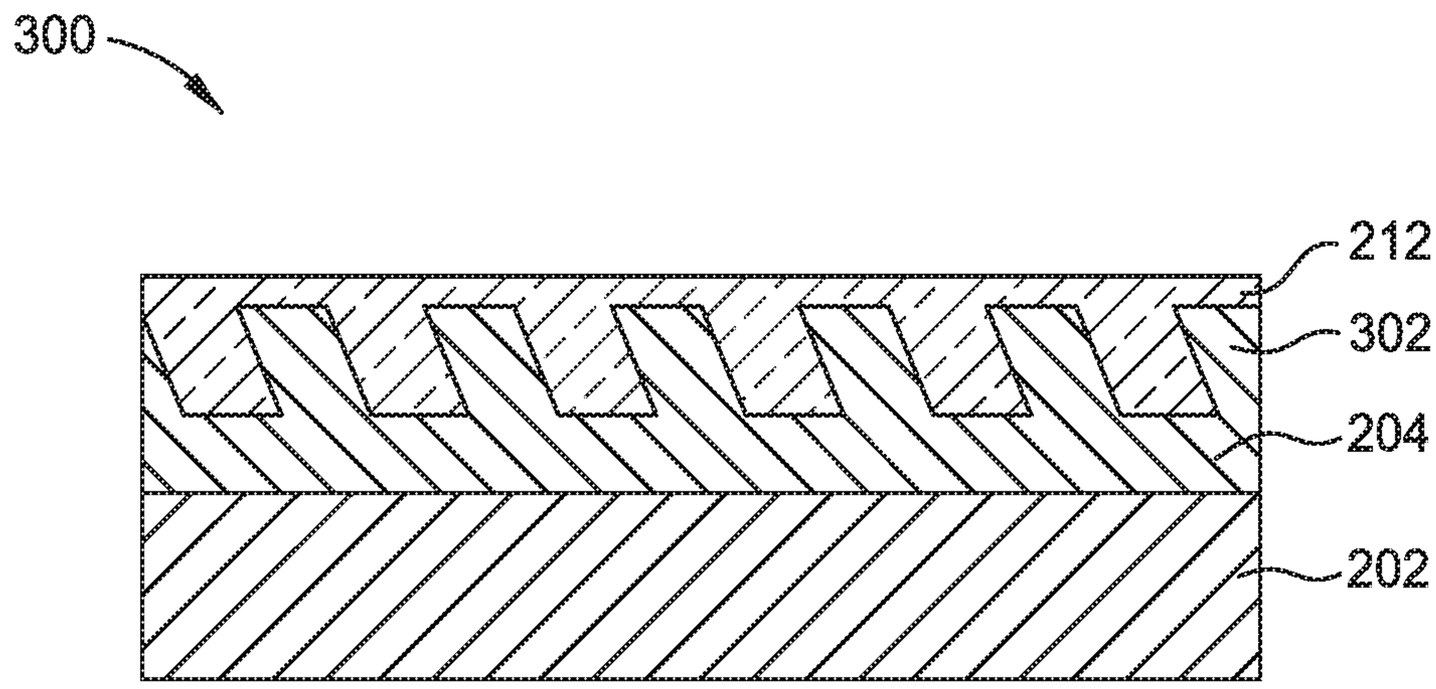


FIG. 3A

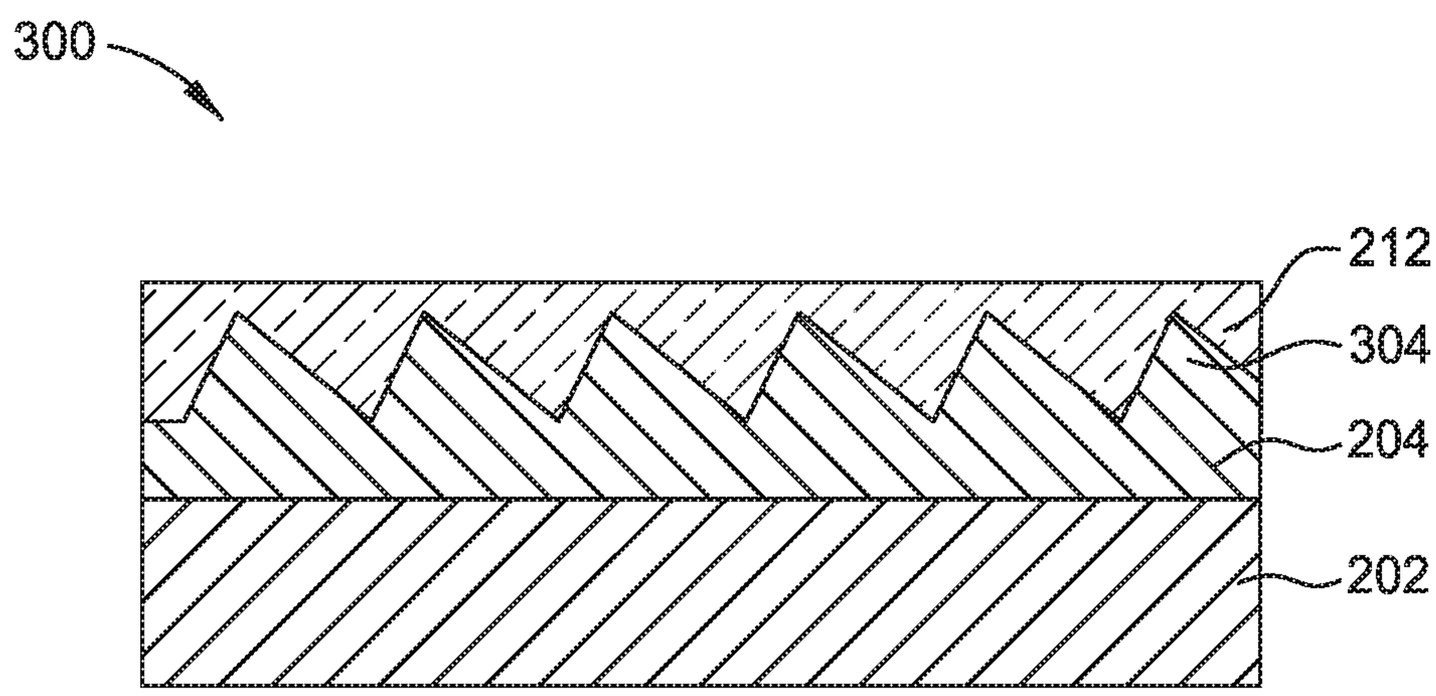


FIG. 3B

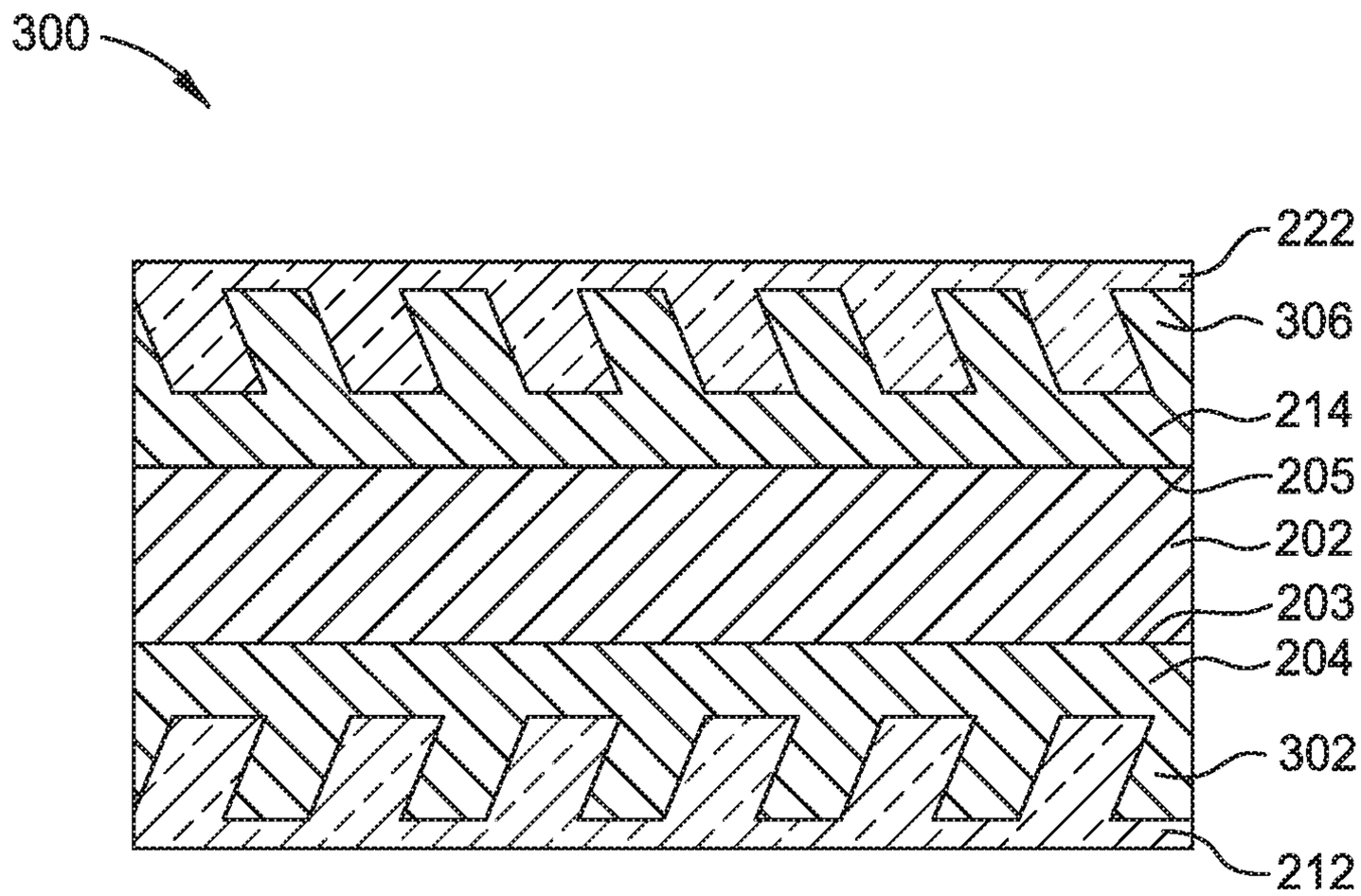

300
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302
212

FIG. 3C

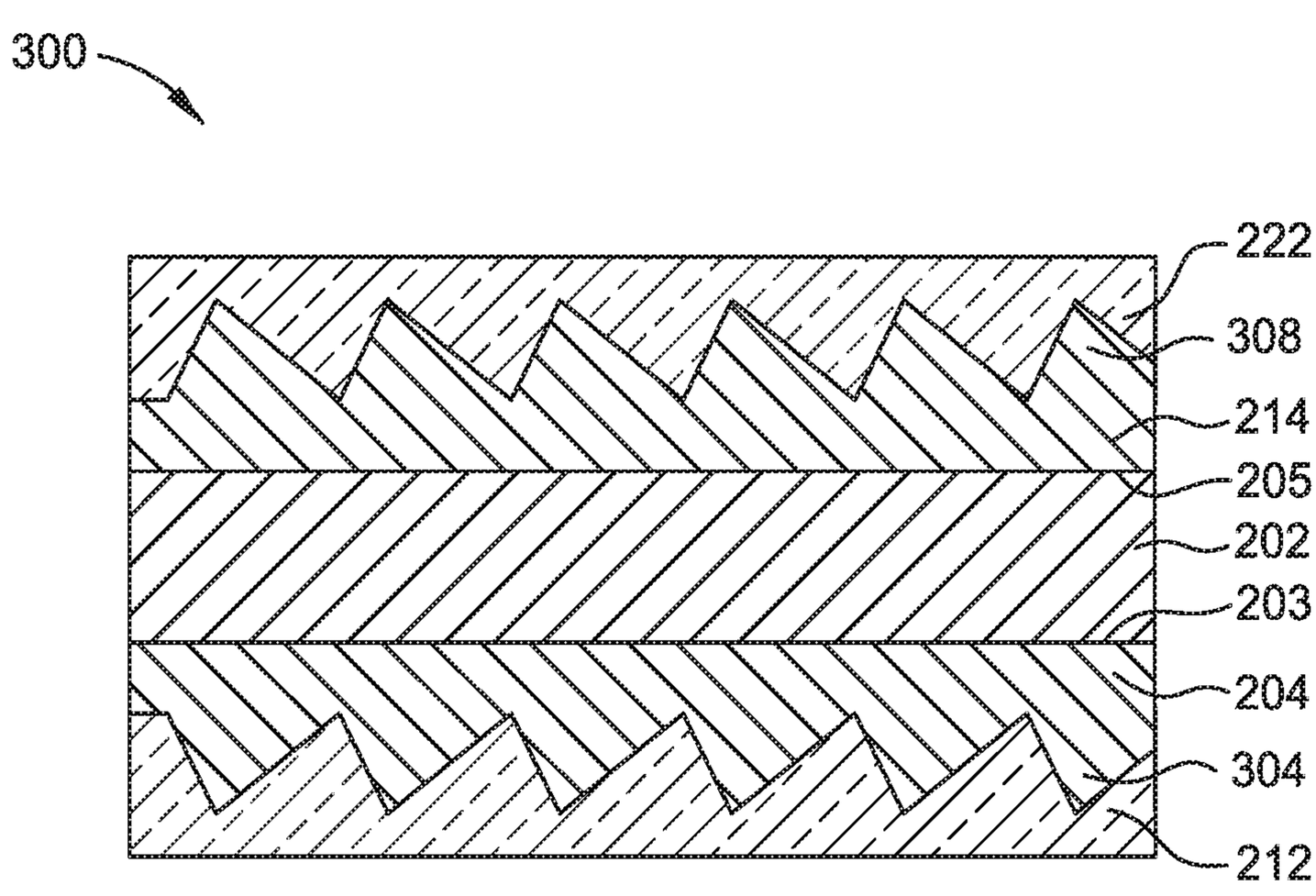

300
222
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212

FIG. 3D

USING FLOWABLE CVD TO GAP FILL MICRO/NANO STRUCTURES FOR OPTICAL COMPONENTS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application Ser. No. 62/692,255, filed on Jun. 29, 2018, which herein is incorporated by reference.

BACKGROUND

Field

[0002] Embodiments of the present disclosure generally relate to display devices for augmented, virtual, and mixed reality. More specifically, embodiments described herein provide a method for forming an optical component for a display device.

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 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 for display and 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 enhances or augments the environment that the user experiences.

[0005] Both virtual reality and augmented reality display devices utilize optical components, such as waveguides or flat lens/meta surfaces, including micro or nano structures with contrasting refractive index (RI). Conventionally, a layer having a lower RI is patterned using light, e-beam, or nanoimprint lithography process, and a layer having a higher RI is formed on the patterned lower RI layer using atomic layer deposition (ALD) process. However, the film deposition rate of the ALD process is very slow.

[0006] Accordingly, an improved method for forming optical components for virtual reality or augmented reality display devices is needed.

SUMMARY

[0007] Embodiments of the present disclosure generally relate to a method for forming an optical component, for example, for a virtual reality or augmented reality display device. In one embodiment, a method includes forming a first layer having a pattern on a substrate, and the first layer has a first refractive index. The method further includes forming a second layer on the first layer by a flowable chemical vapor deposition process. The second layer has a second refractive index less than the first refractive index.

[0008] In another embodiment, a method includes forming a first layer having a pattern on a substrate. The first layer has a first refractive index ranging from about 1.7 to about 2.4. The method further includes forming a second layer on the first layer by a flowable chemical vapor deposition process. The second layer has a second refractive index ranging from about 1.1 to about 1.5.

[0009] In another embodiment, a method includes forming a first layer having a first pattern on a substrate. The first layer has a first refractive index and includes a metal oxide. The method further includes forming a second layer on the first layer by a flowable chemical vapor deposition process. The second layer has a second refractive index ranging from about 1.1 to about 1.5.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] 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, and may admit to other equally effective embodiments.

[0011] FIG. **1** illustrates a schematic cross-sectional view of a processing chamber according to one embodiment described herein.

[0012] FIGS. **2**A-**2**D illustrate schematic cross-sectional views of an optical component during different stages according to one embodiment described herein.

[0013] FIGS. **3**A-**3**D illustrate schematic cross-sectional views of an optical component according to embodiments described herein.

[0014] 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

[0015] Embodiments of the present disclosure generally relate to a method for forming an optical component, for example, for a virtual reality or augmented reality display device. In one embodiment, the method includes forming a first layer having a pattern on a substrate, and the first layer has a first refractive index. The method further includes forming a second layer on the first layer by a flowable chemical vapor deposition (FCVD) process, and the second layer has a second refractive index less than the first refractive index.

[0016] FIG. **1** is a schematic cross-sectional side view of a processing chamber **100** according to one embodiment described herein. The processing chamber **100** may be a deposition chamber, such as a CVD chamber. The processing chamber **100** may be configured at least to deposit a flowable film on a substrate. The processing chamber **100** includes a lid **112** disposed over a chamber wall **135**, and an insulating ring **120** disposed between the lid **112** and the chamber wall **135**. A first remote plasma source (RPS) **101** is disposed on the lid **112** and precursor radicals formed in the first RPS **101** are flowed into a plasma zone **115** of the processing chamber **100** via a radical inlet assembly **105** and a baffle **106**. While the first RPS **101** is illustrated as coupled to the lid **112**, it is contemplated that he first RPS **101** may

be spaced from the lid **112** and fluidly coupled to the lid **112** by one or more conduits. A precursor gas inlet **102** is formed on the first RPS **101** for flowing one or more precursor gases into the first RPS **101**.

[0017] The processing chamber **100** further includes a dual-zone showerhead **103**. The dual-zone showerhead **103** includes a first plurality of channels **104** and a second plurality of channels **108**. The first plurality of channels **104** and the second plurality of channels **108** are not in fluid communication. During operation, radicals in the plasma zone **115** flow into a processing region **130** through the first plurality of channels **104** of the dual-zone showerhead **103**, and one or more precursor gases flow into the processing region **130** through the second plurality of channels **108**. With the dual-zone showerhead **103**, premature mixing and reaction between the radicals and the precursor gases are avoided.

[0018] The processing chamber **100** includes a substrate support **165** for supporting a substrate **155** during processing. The processing region **130** is defined by the dual-zone showerhead **103** and the substrate support **165**. A second RPS **114** is fluidly coupled to the processing region **130** through the chamber wall **135** of the processing chamber **100**. The second RPS **114** may be coupled to an inlet **118** formed in the chamber wall **135**. Since the precursor gas and precursor radicals mix and react in the processing region **130** below the dual-zone showerhead **103**, deposition primarily occurs below the dual-zone showerhead **103** except some minor back diffusion. Thus, the components of the processing chamber **100** disposed below the dual-zone showerhead **103** may be cleaned after periodic processing. Cleaning refers to removing material deposited on the chamber components. The cleaning radicals are introduced into the processing region **130** at a location below (downstream of) the dual-zone showerhead **103**.

[0019] The first RPS **101** is configured to excite a precursor gas, such as a silicon containing gas, an oxygen containing gas, and/or a nitrogen containing gas, to form precursor radicals that form a flowable film on the substrate **155** disposed on the substrate support **165**. The second RPS **114** is configured to excite a cleaning gas, such as a fluorine containing gas, to form cleaning radicals that clean components of the processing chamber **100**, such as the substrate support **165** and the chamber wall **135**.

[0020] The processing chamber **100** further includes a bottom **180**, a slit valve opening **175** formed in the bottom **180**, and a pumping ring **150** coupled to the bottom **180**. The pumping ring **150** is utilized to remove residual precursor gases and radicals from the processing chamber **100**. The processing chamber **100** further includes a plurality of lift pins **160** for raising the substrate **155** from the substrate support **165** and a shaft **170** supporting the substrate support **165**. The shaft **170** is coupled to a motor **172** which can rotate the shaft **170**, which in turn rotates the substrate support **165** and the substrate **155** disposed on the substrate support **165**. Rotating the substrate support **165** during processing or cleaning can achieve improved deposition uniformity as well as clean uniformity.

[0021] FIGS. **2**A-**2**D illustrate schematic cross-sectional views of an optical component **200** during different stages according to one embodiment described herein. As shown in FIG. **2**A, the optical component **200** includes a patterned first layer **204** having a first RI disposed on a first surface **203** of a substrate **202**. The substrate **202** may be the substrate **155** shown in FIG. **1**. In one embodiment, the substrate **202** is fabricated from a visually transparent material, such as glass. The substrate **202** has a RI ranging from about 1.4 to about 2.0. The patterned first layer **204** is fabricated from a transparent material, and the first RI ranges from about 1.7 to about 2.4. In one embodiment, the RI of the substrate **202** is the same as the first RI of the patterned first layer **204**. In another embodiment, the RI of the substrate **202** is different from the first RI of the patterned first layer **204**. The patterned first layer **204** is fabricated from a metal oxide, such as titanium oxide (TiO_x), tantalum oxide (TaO_x), zirconium oxide (ZrO_x), hafnium oxide (HfO_x), or niobium oxide (NbO_x). The patterned first layer **204** includes a pattern **206**, and the pattern **206** includes a plurality of protrusions **208** and a plurality of gaps **210**. Adjacent protrusions **208** are separated by a gap **210**. As shown in FIG. **2**A, the protrusion **208** has a rectangular shape. The protrusion **208** may have any other suitable shape. Examples of the protrusion **208** having different shapes are shown in FIGS. **3**A-**3**D. In one embodiment, the protrusions **208** are gratings. Gratings are a plurality of parallel elongated structures that splits and diffracts light into several beams traveling in different directions. Gratings may have different shapes, such as sine, square, triangle, or sawtooth gratings. The patterned first layer **204** may be formed by any suitable method, such as e-beam lithography, nanoimprint lithography, or etching.

[0022] Next, the substrate **202** and the patterned first layer **204** formed thereon are placed into a processing chamber, such as the processing chamber **100** shown in FIG. **1**. A second layer **212** is formed on the patterned first layer **204** by an FCVD process. The flowable nature of the second layer **212** allows the second layer **212** to flow into small gaps, such as gaps **210**. The second layer **212** has a second RI that is less than the first RI. In one embodiment, the layer **212** has a RI ranging from about 1.1 to about 1.5.

[0023] The second layer may be formed by the following process steps. An atomic oxygen precursor is generated in an RPS, such as the first RPS **101** of the processing chamber **100**. The atomic oxygen may be generated by the dissociation of an oxygen containing precursor such as molecular oxygen (O_2), ozone (O_3), an nitrogen-oxygen compound (e.g., NO, NO_2, N_2O, etc.), a hydrogen-oxygen compound (e.g., H_2O, H_2O_2, etc.), a carbon-oxygen compound (e.g., CO, CO_2, etc.), as well as other oxygen containing precursors and combinations of precursors. The reactive atomic oxygen is then introduced to a processing region, such as the processing region **130** of the processing chamber **100** shown in FIG. **1**, where the atomic oxygen may mix for the first time with a silicon precursor, which is also introduced to the processing region. The atomic oxygen reacts with the silicon precursor (and other deposition precursors that may be present in the reaction chamber) at moderate temperatures (e.g., reaction temperatures less than 100° C.) and pressures (e.g., about 0.1 Torr to about 10 Torr; 0.5 to 6 Torr total chamber pressure, etc.) to form the second layer **212**, such as a silicon dioxide layer. In one embodiment, the second layer **212** is a quartz layer.

[0024] The silicon precursor may include an organosilane compound and/or silicon compound that does not contain carbon. Silicon precursors without carbon may include silane (SiH_4), among others. Organosilane compounds may include compounds with direct Si—C bonding and/or compounds with Si—O—C bonding. Examples of organosilane

silicon precursors may include dimethylsilane, trimethylsilane, tetramethylsilane, diethylsilane, tetramethylorthosilicate (TMOS), tetraethylorthosilicate (TEOS), octamethyltrisiloxane (OMTS), octamethylcyclotetrasiloxane (OMCTS), tetramethyldimethyldimethoxydisilane, tetramethylcyclotetrasiloxane (TOMCATS), DMDMOS, DEMS, methyl triethoxysilane (MTES), phenyldimethylsilane, and phenylsilane, among others.

[0025] The atomic oxygen and silicon precursors are not mixed before being introduced to the processing region. The precursors may enter the processing region through a dual-zone showerhead, such as the dual-zone showerhead **103** shown in FIG. **1**. As the atomic oxygen and silicon precursors react in the processing region, the second layer **212** is formed on the patterned first layer **204**. The second layer **212** as deposited has excellent flowability, and can quickly migrate into gaps, such as gaps **210**.

[0026] A post deposition anneal of the second layer **212** may be performed. In one embodiment, the second layer **212** is heated to about 300° C. to about 1000° C. (e.g., about 600° C. to about 900° C.) in a substantially dry atmosphere (e.g., dry nitrogen, helium, argon, etc.). The anneal removes moisture from the deposited second layer **212**.

[0027] In some embodiments, both sides of the substrate **202** can be utilized to form layers having different RIs thereon. As shown in FIG. **2**C, a patterned third layer **214** having a third RI is formed on a second surface **205** of the substrate **202**. The patterned third layer **214** has a pattern **216**, and the pattern **216** includes a plurality of protrusions **218** and a plurality of gaps **220**. The patterned third layer **214** may be fabricated from the same materials as the patterned first layer **204**. The patterned third layer **214** may be formed by the same process as the patterned first layer **204**. In one embodiment, the patterned third layer **214** is identical to the patterned first layer **204**. In another embodiment, the patterned third layer **214** has a different pattern than the patterned first layer **204**.

[0028] Next, as shown in FIG. **2**D, a fourth layer **222** is formed on the patterned third layer **214**. The fourth layer **222** may be fabricated from the same materials as the second layer **212**. The fourth layer **222** may be formed by the same process as the second layer **212**. The optical component **200** may be used in any suitable display devices. For example, in one embodiment, the optical component **200** is used as a waveguide or waveguide combiner in augmented reality display devices. Waveguides are structures that guide optical waves. Waveguide combiners are used in augmented reality display devices that combine real world images with virtual images. In another embodiment, the optical component **200** is used as a flat lens/meta surfaces in augmented and virtual reality display devices and 3D sensing devices, such as face ID and LIDAR.

[0029] FIGS. **3**A-**3**D illustrate schematic cross-sectional views of an optical component **300** according to embodiments described herein. As shown in FIG. **3**A, the optical component **300** includes the substrate **202**, the patterned first layer **204** disposed on the substrate **202**, and the second layer **212** disposed on the patterned first layer **204**. The patterned first layer **204** includes a plurality of protrusions **302**. Each of the protrusions **302** has a parallelogramical cross-sectional area, as shown in FIG. **3**A. The protrusions **302** may be gratings.

[0030] As shown in FIG. **3**B, the optical component **300** includes the substrate **202**, the patterned first layer **204** disposed on the substrate **202**, and the second layer **212** disposed on the patterned first layer **204**. The patterned first layer **204** includes a plurality of protrusions **304**. Each of the protrusions **304** has a triangular cross-sectional area, as shown in FIG. **3**B. The protrusions **304** may be gratings.

[0031] As shown in FIG. **3**C, the optical component **300** includes the substrate **202**, the patterned first layer **204** disposed on the first surface **203** of the substrate **202**, and the second layer **212** disposed on the patterned first layer **204**. The patterned first layer **204** includes the plurality of protrusions **302**. The optical component **300** further includes the patterned third layer **214** disposed on the second surface **205** of the substrate **202** and the fourth layer **222** disposed on the patterned third layer **214**. The patterned third layer **214** includes a plurality of protrusions **306**. In one embodiment, the protrusions **306** may be the same as the protrusions **302**. In another embodiment, the protrusions **306** may not be the same as the protrusions **302**. The protrusions **302**, **306** may be gratings.

[0032] As shown in FIG. **3**D, the optical component **300** includes the substrate **202**, the patterned first layer **204** disposed on the first surface **203** of the substrate **202**, and the second layer **212** disposed on the patterned first layer **204**. The patterned first layer **204** includes the plurality of protrusions **304**. The optical component **300** further includes the patterned third layer **214** disposed on the second surface **205** of the substrate **202** and the fourth layer **222** disposed on the patterned third layer **214**. The patterned third layer **214** includes a plurality of protrusions **308**. In one embodiment, the protrusions **308** may be the same as the protrusions **304**. In another embodiment, the protrusions **308** may not be the same as the protrusions **304**. The protrusions **304**, **308** may be gratings.

[0033] The optical component **300** may be used in any suitable display devices. For example, in one embodiment, the optical component **300** is used as a waveguide or waveguide combiner in augmented reality display devices. In another embodiment, the optical component **300** is used as a flat lens/meta surfaces in augmented and virtual reality display devices and 3D sensing devices, such as face ID and LIDAR.

[0034] A method for forming an optical component including layers having different RIs is disclosed. A patterned first layer having a higher RI is formed on a substrate, and a second layer is formed on the patterned first layer using FCVD process. The application of the optical component is not limited to augmented and virtual reality display devices and 3D sensing devices. The optical component can be used in any suitable applications.

[0035] 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 method, comprising:

forming a first layer having a pattern on a substrate, the first layer having a first refractive index; and

forming a second layer on the first layer by a flowable chemical vapor deposition process, the second layer having a second refractive index less than the first refractive index.

2. The method of claim **1**, wherein the first refractive index ranges from about 1.7 to about 2.4.

3. The method of claim **1**, wherein the first layer comprises a metal oxide.

4. The method of claim **1**, wherein the first layer comprises titanium oxide, tantalum oxide, zirconium oxide, hafnium oxide, or niobium oxide.

5. The method of claim **1**, wherein the second layer comprises porous silicon dioxide or quartz.

6. The method of claim **1**, wherein the second refractive index ranges from about 1.1 to about 1.5.

7. A method, comprising:

forming a first layer having a pattern on a substrate, the first layer having a first refractive index ranging from about 1.7 to about 2.4; and

forming a second layer on the first layer by a flowable chemical vapor deposition process, the second layer having a second refractive index ranging from about 1.1 to about 1.5.

8. The method of claim **7**, wherein the second layer comprises porous silicon dioxide or quartz.

9. The method of claim **7**, wherein the first layer comprises a metal oxide.

10. The method of claim **7**, wherein the first layer comprises titanium oxide, tantalum oxide, zirconium oxide, hafnium oxide, or niobium oxide.

11. The method of claim **7**, further comprising annealing the second layer.

12. The method of claim **11**, wherein the annealing the second layer comprises heating the second layer to about 300° C. to about 1000° C.

13. A method, comprising:

forming a first layer having a first pattern on a first surface of a substrate, the first layer having a first refractive index and comprising a metal oxide; and

forming a second layer on the first layer by a flowable chemical vapor deposition process, the second layer having a second refractive index ranging from about 1.1 to about 1.5.

14. The method of claim **13**, wherein the first refractive index ranges from about 1.7 to about 2.4.

15. The method of claim **13**, wherein the second layer comprises porous silicon dioxide or quartz.

16. The method of claim **13**, wherein the first layer comprises titanium oxide, tantalum oxide, zirconium oxide, hafnium oxide, or niobium oxide.

17. The method of claim **13**, wherein the first layer is formed on the first surface of the substrate by e-beam lithography or nanoimprint lithography.

18. The method of claim **13**, further comprising forming a third layer having a third refractive index on a second surface of the substrate, the third layer having a second pattern.

19. The method of claim **18**, further comprising:

forming a fourth layer having a fourth refractive index less than the third refractive index on the third layer by the flowable chemical vapor deposition process.

20. The method of claim **19**, wherein the second pattern is different from the first pattern.

* * * * *