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(54) **MASKLESS COATING AS A PATTERNING MASK FOR EXTERNAL STIMULI IN DEPOSITIONS**

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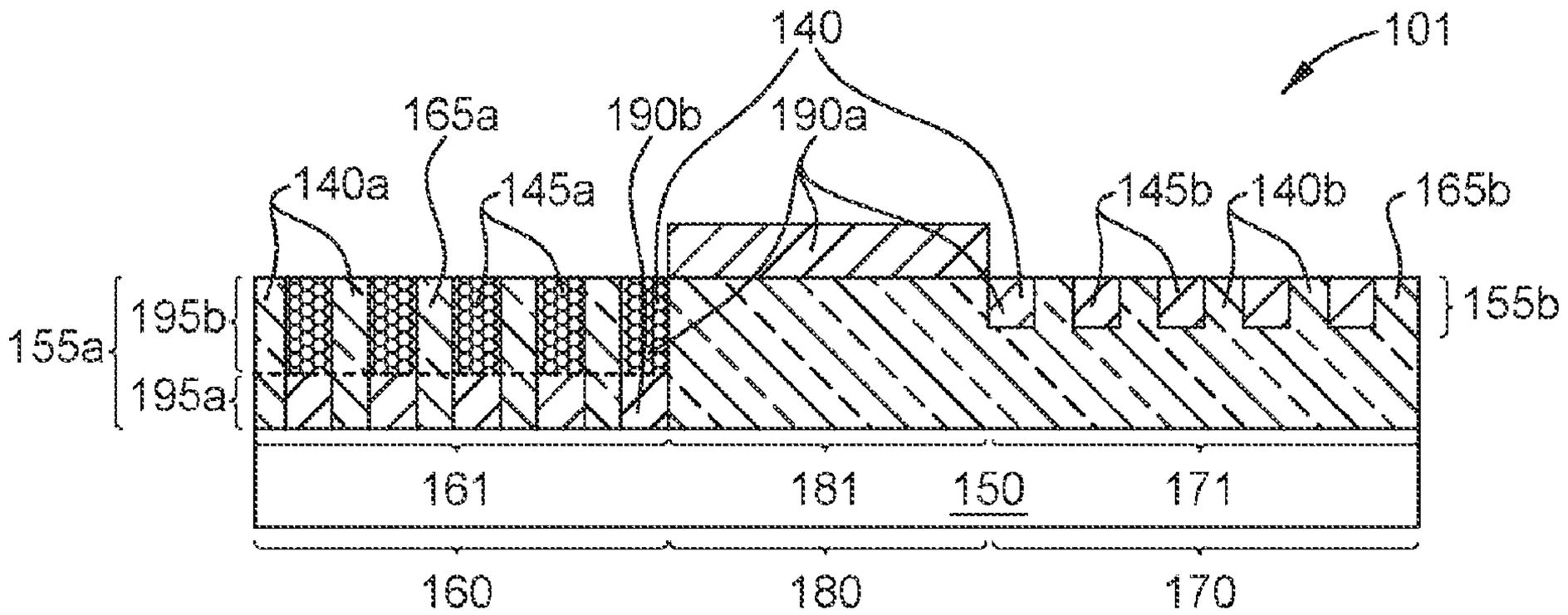
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CPC ***G02B 6/0065*** (2013.01); ***G02B 6/0036*** (2013.01); *G02B 27/0172* (2013.01)

(57) **ABSTRACT**

A method includes depositing a first precursor over a waveguide, the first precursor deposited over a first grating, a second grating, and an intermediate region between the first grating and the second grating of the waveguide and is deposited to have a first thickness. The method further includes performing a first ozone cure process, the first ozone cure process curing the first precursor, and depositing a second precursor over the waveguide. The second precursor is deposited over the first grating, the second grating, and the intermediate region and is deposited to have a second thickness. The method further includes depositing a coating over the intermediate region and the second grating, performing a second ozone cure process, the second ozone cure process curing the second precursor over the first grating, and removing the coating and the second precursor over the second grating and the intermediate region.



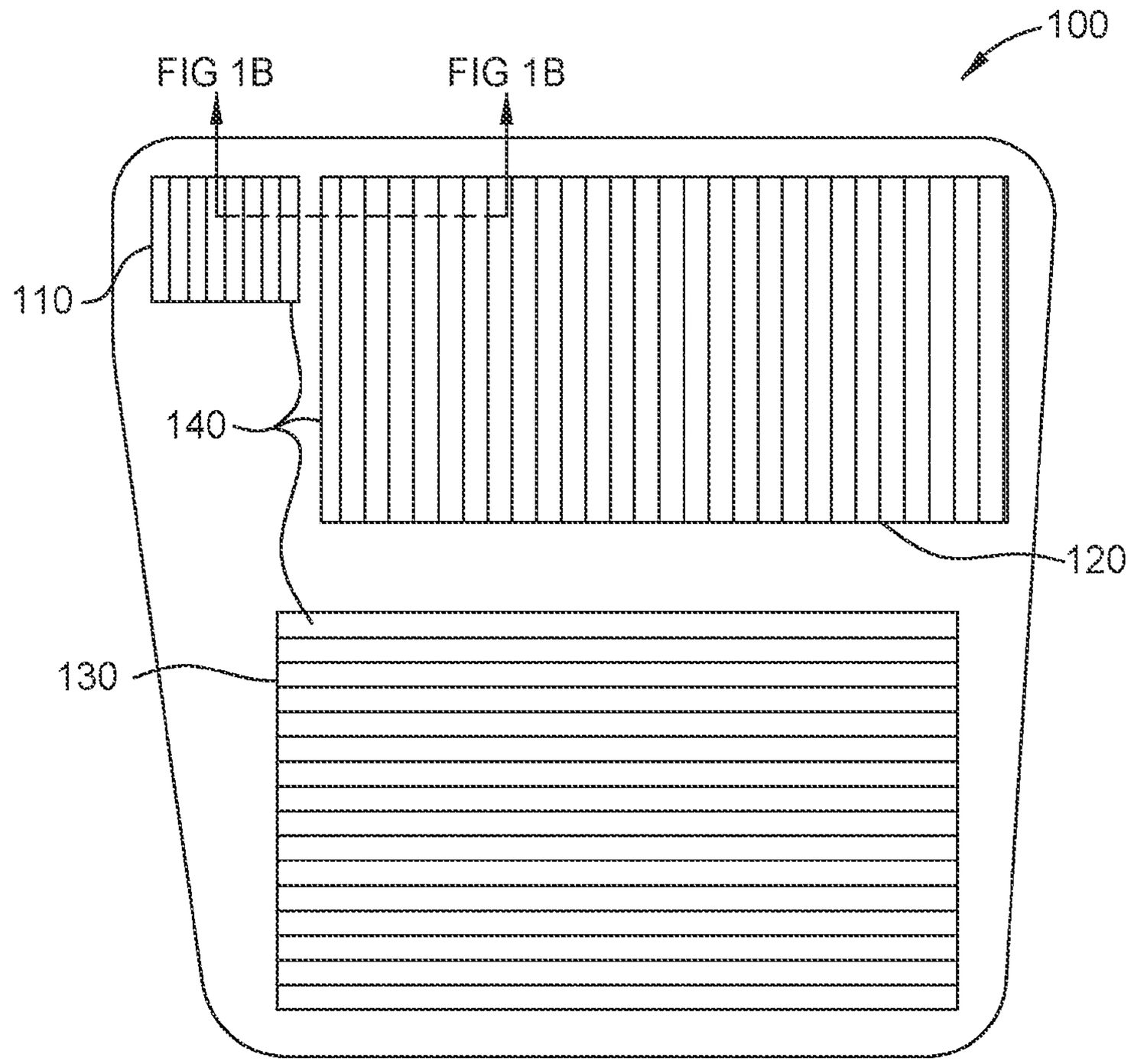

100
FIG 1B
FIG 1B
110
140
120
130

FIG. 1A

140
101
165a
190b
190a
140a
145a
145b
140b
165b
155a
195b
195a
155b
161
181
150
171
160
180
170

FIG. 1B

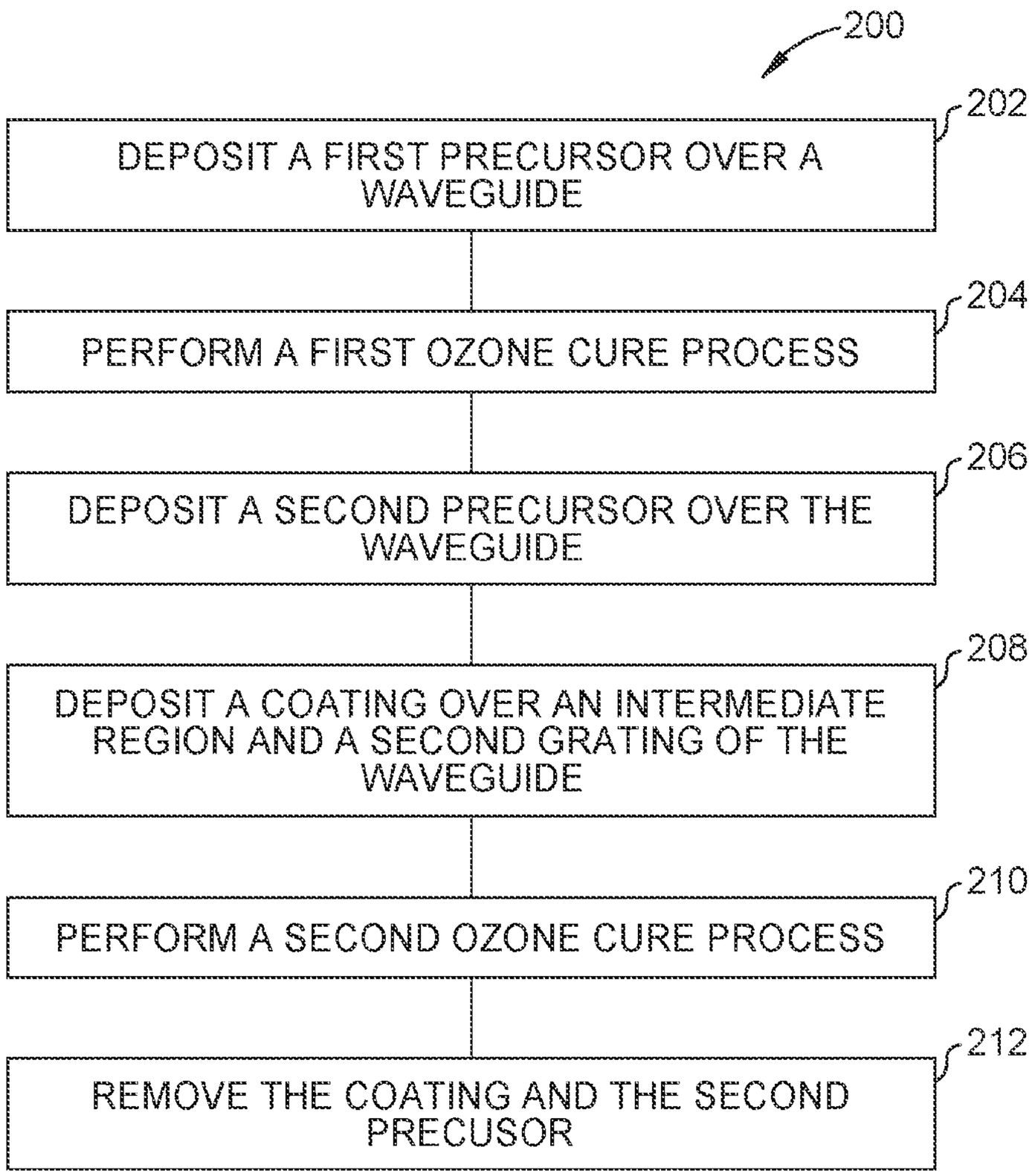

200
DEPOSIT A FIRST PRECURSOR OVER A WAVEGUIDE
202
PERFORM A FIRST OZONE CURE PROCESS
204
DEPOSIT A SECOND PRECURSOR OVER THE WAVEGUIDE
206
DEPOSIT A COATING OVER AN INTERMEDIATE REGION AND A SECOND GRATING OF THE WAVEGUIDE
208
PERFORM A SECOND OZONE CURE PROCESS
210
REMOVE THE COATING AND THE SECOND PRECUSOR
212

FIG. 2

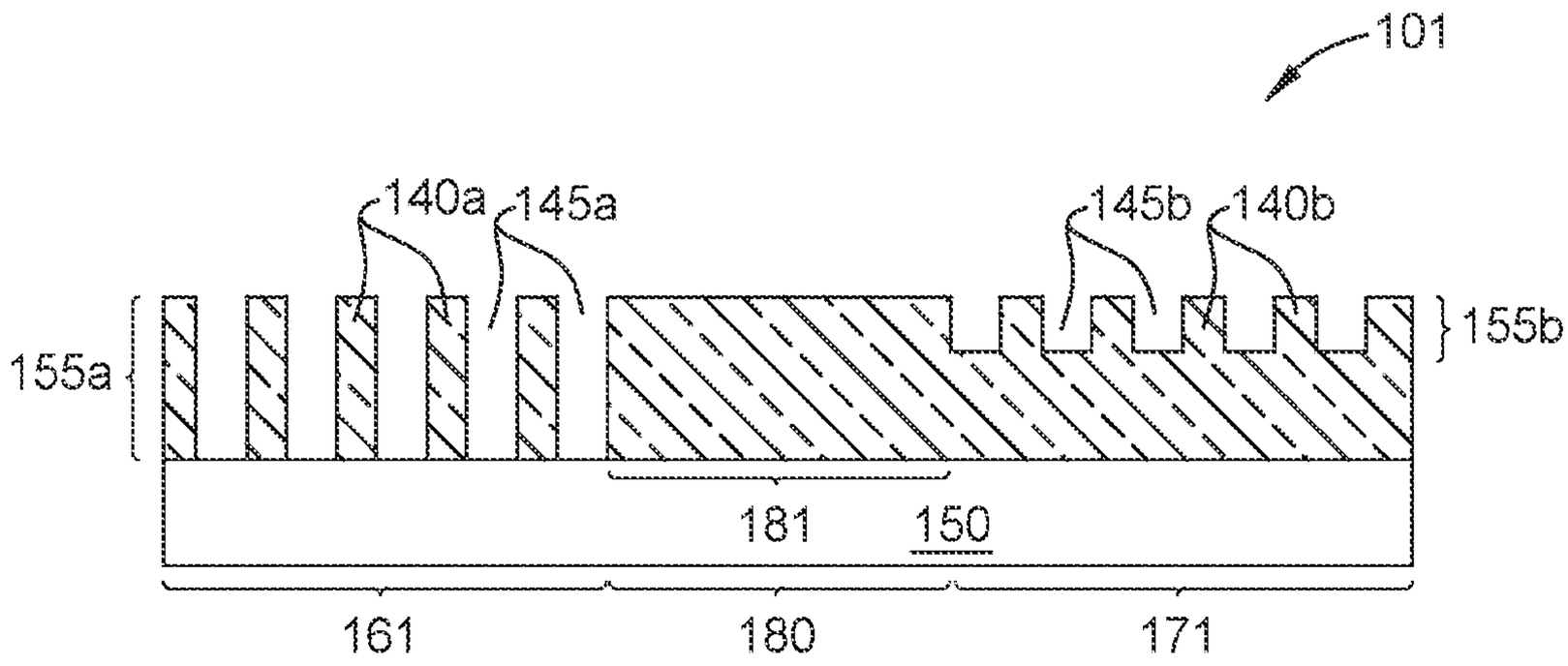


FIG. 3A

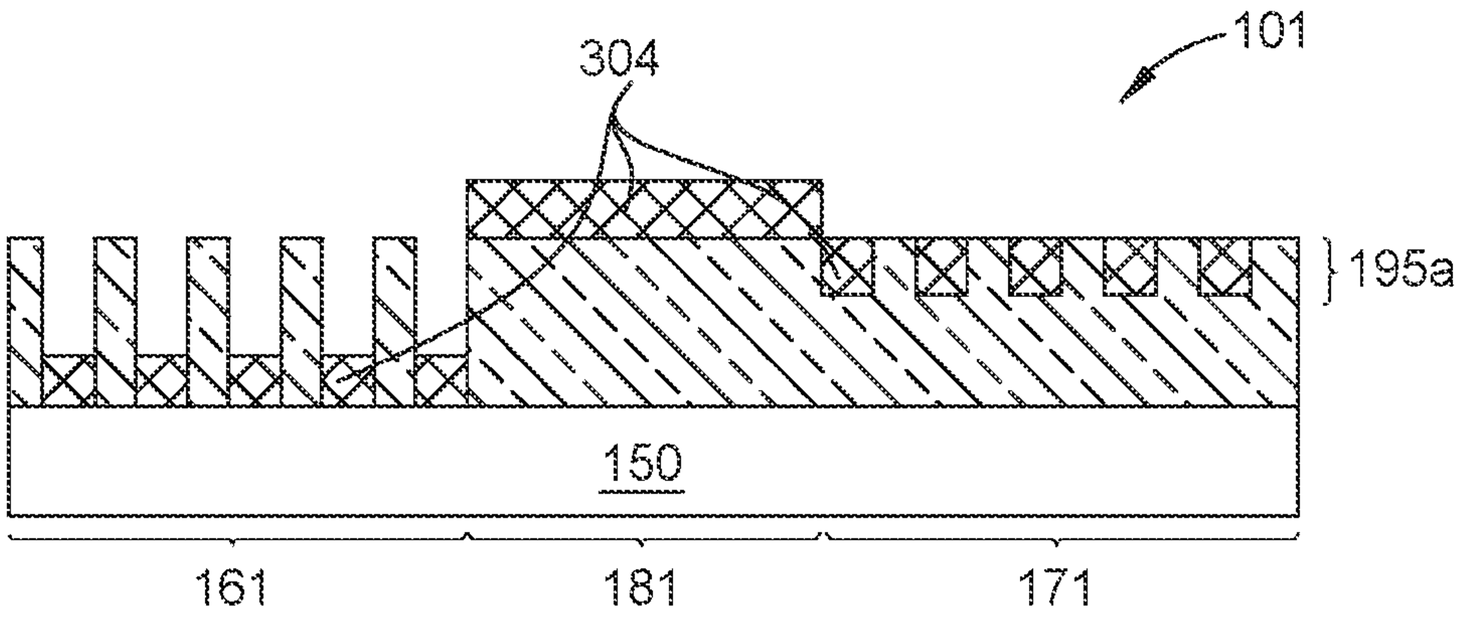


FIG. 3B

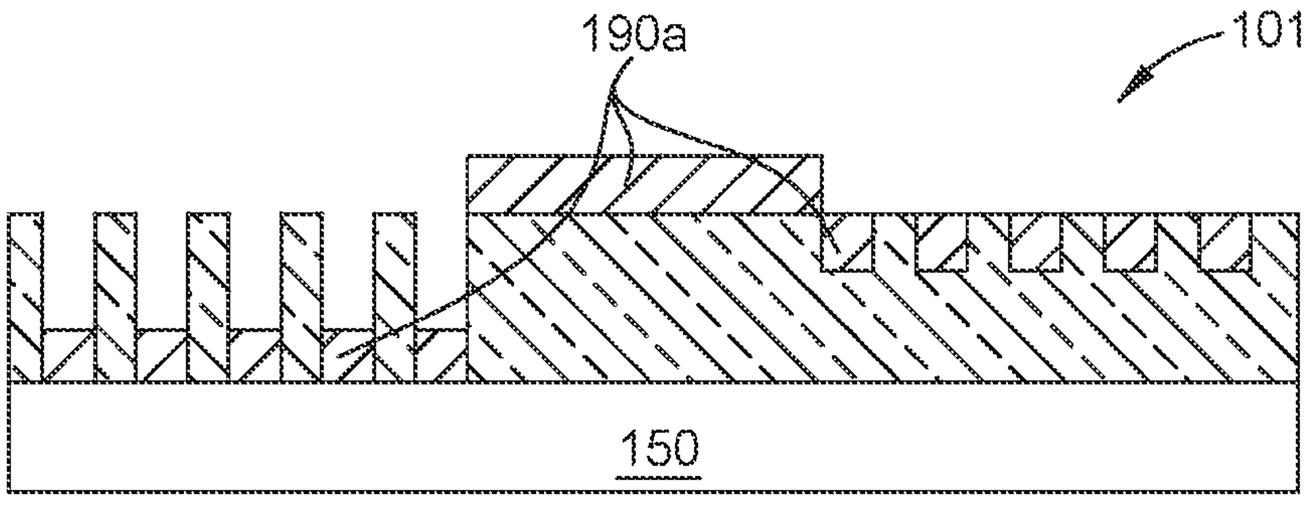


FIG. 3C

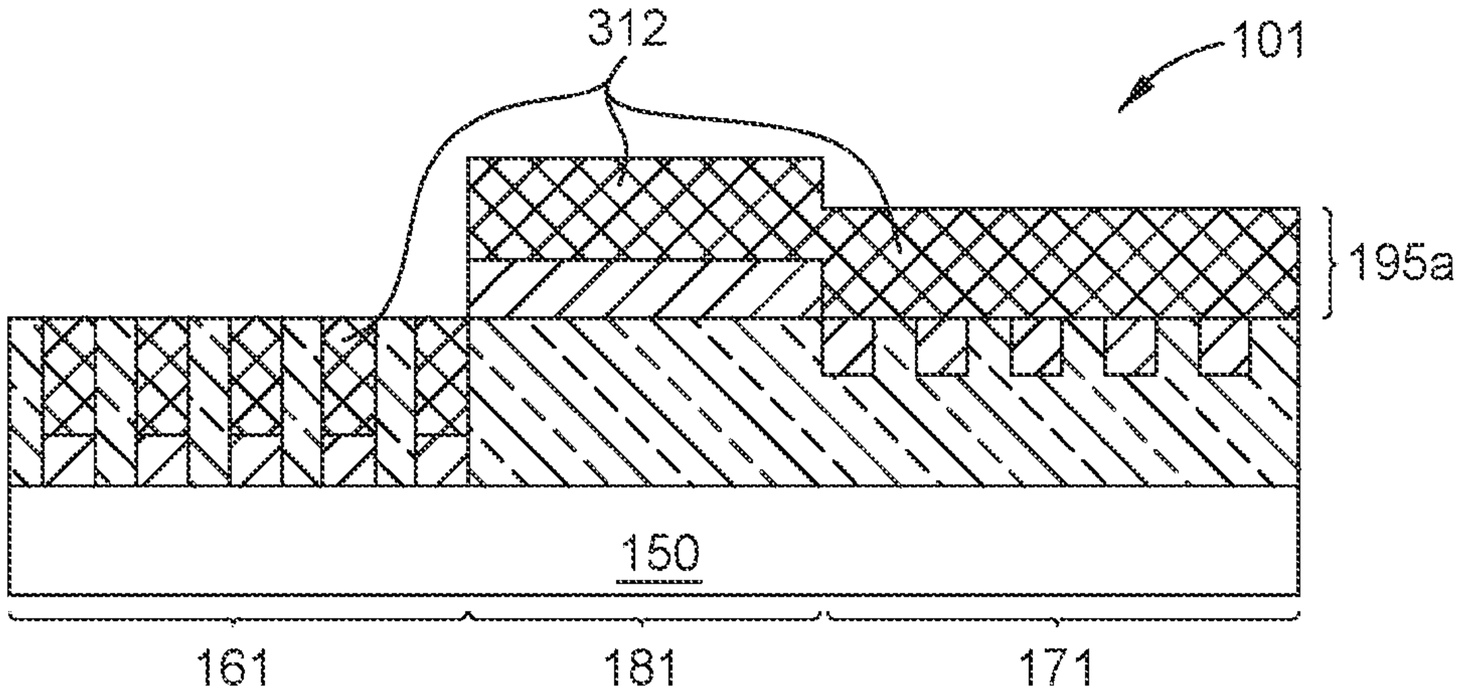


FIG. 3D

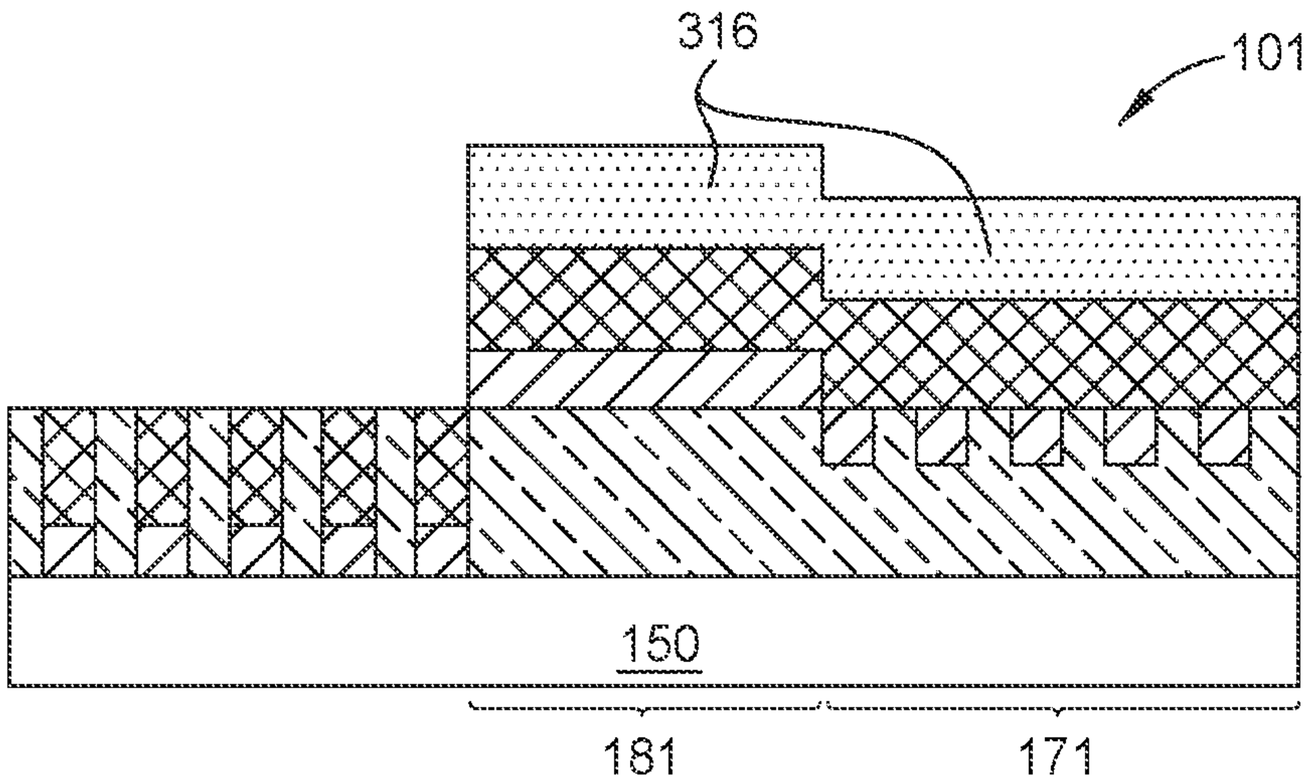


FIG. 3E

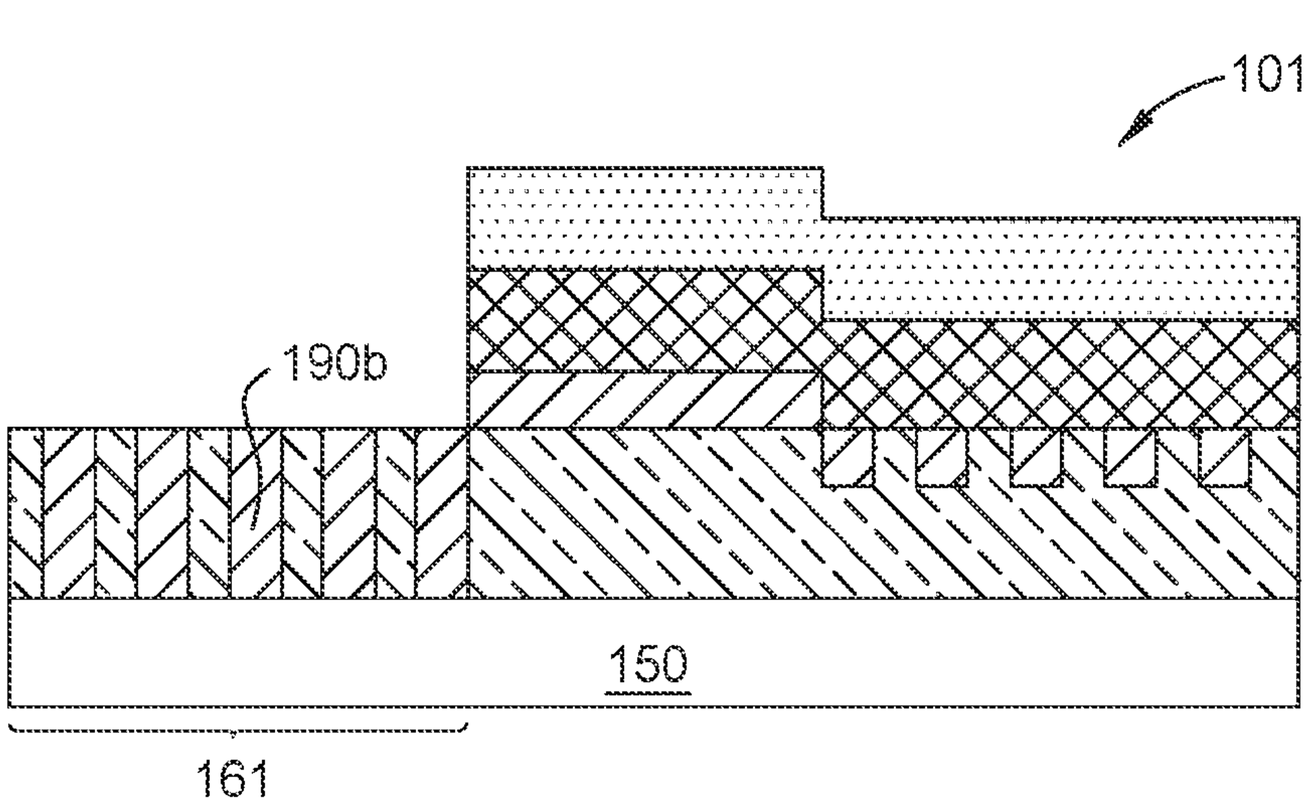


FIG. 3F

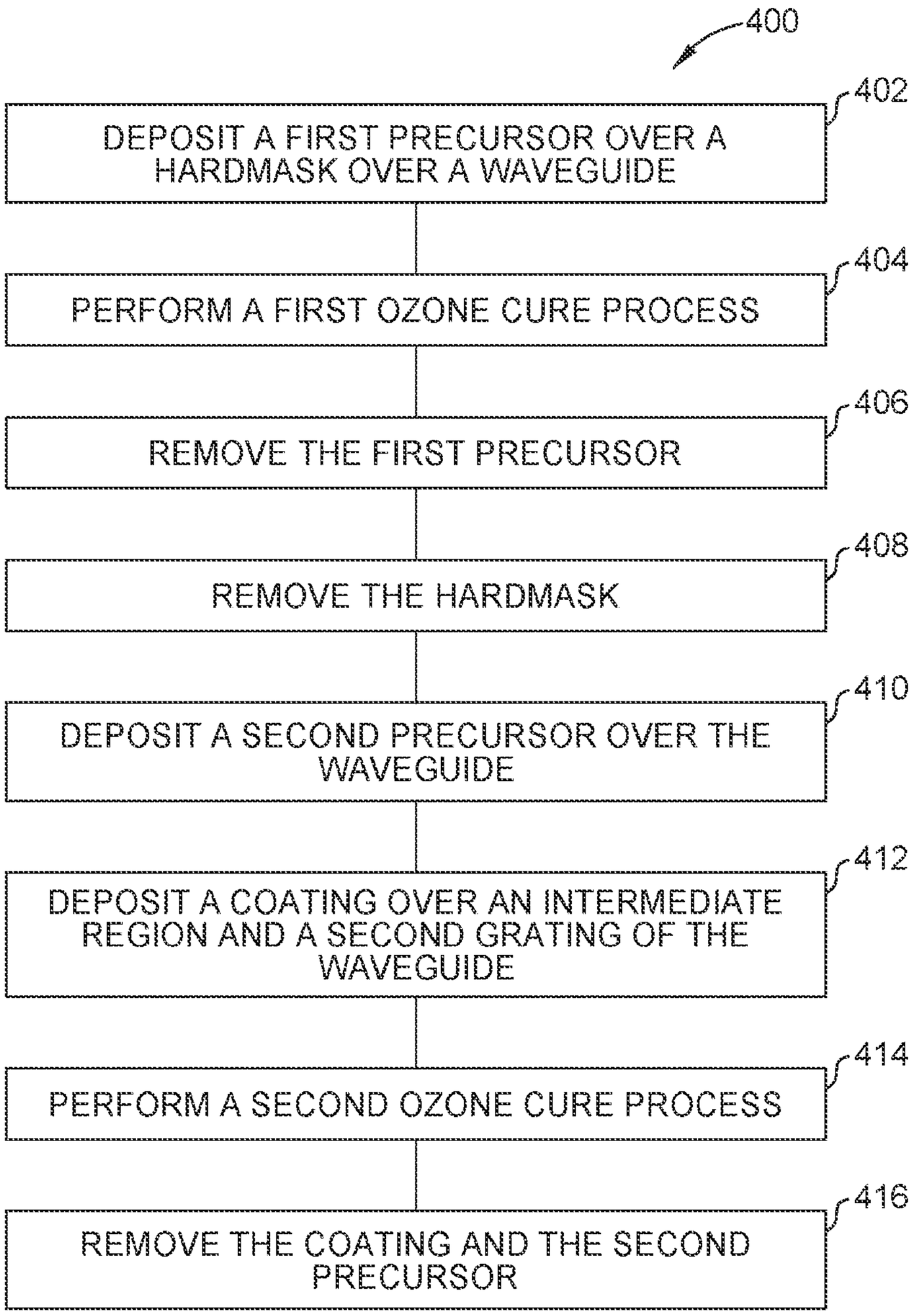

400
DEPOSIT A FIRST PRECURSOR OVER A HARDMASK OVER A WAVEGUIDE
402
PERFORM A FIRST OZONE CURE PROCESS
404
REMOVE THE FIRST PRECURSOR
406
REMOVE THE HARDMASK
408
DEPOSIT A SECOND PRECURSOR OVER THE WAVEGUIDE
410
DEPOSIT A COATING OVER AN INTERMEDIATE REGION AND A SECOND GRATING OF THE WAVEGUIDE
412
PERFORM A SECOND OZONE CURE PROCESS
414
REMOVE THE COATING AND THE SECOND PRECURSOR
416

FIG. 4

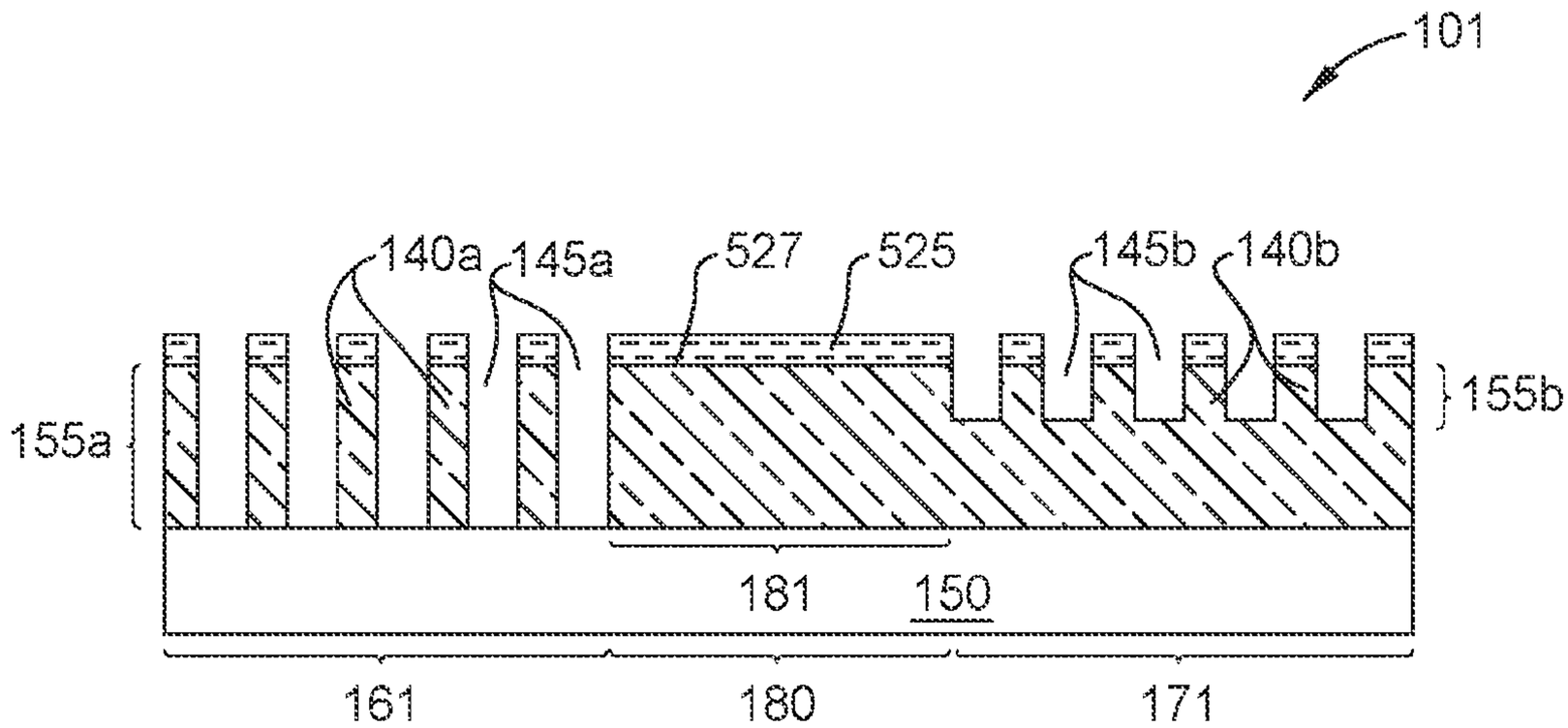


FIG. 5A

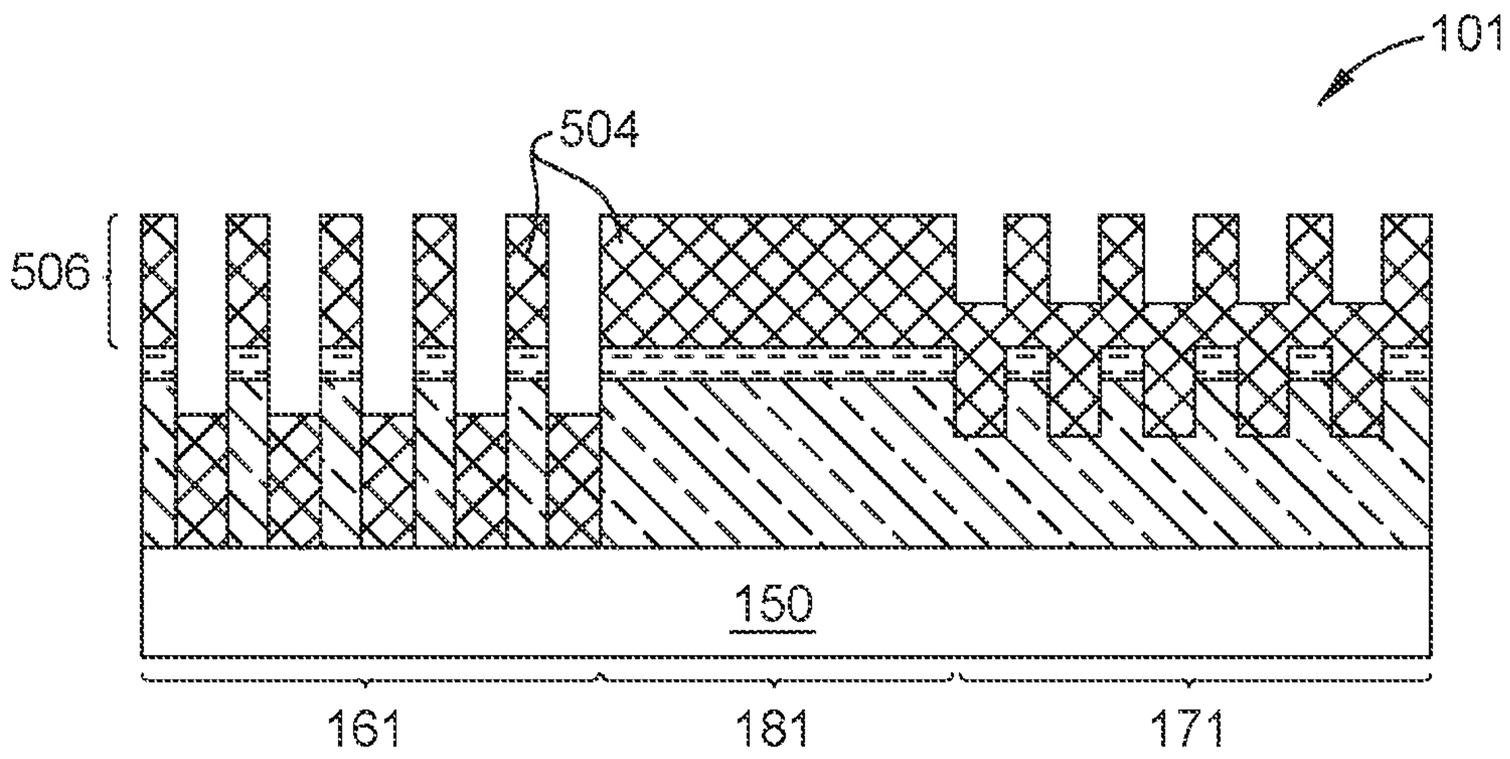


FIG. 5B

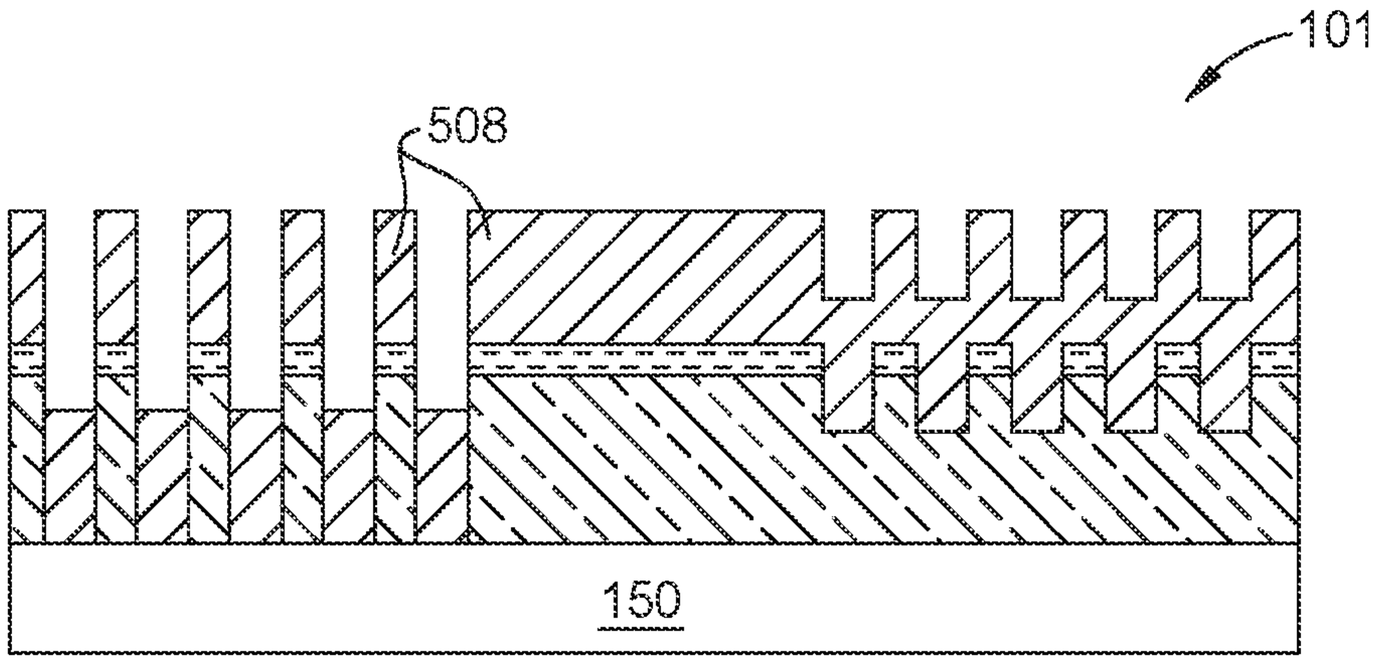


FIG. 5C

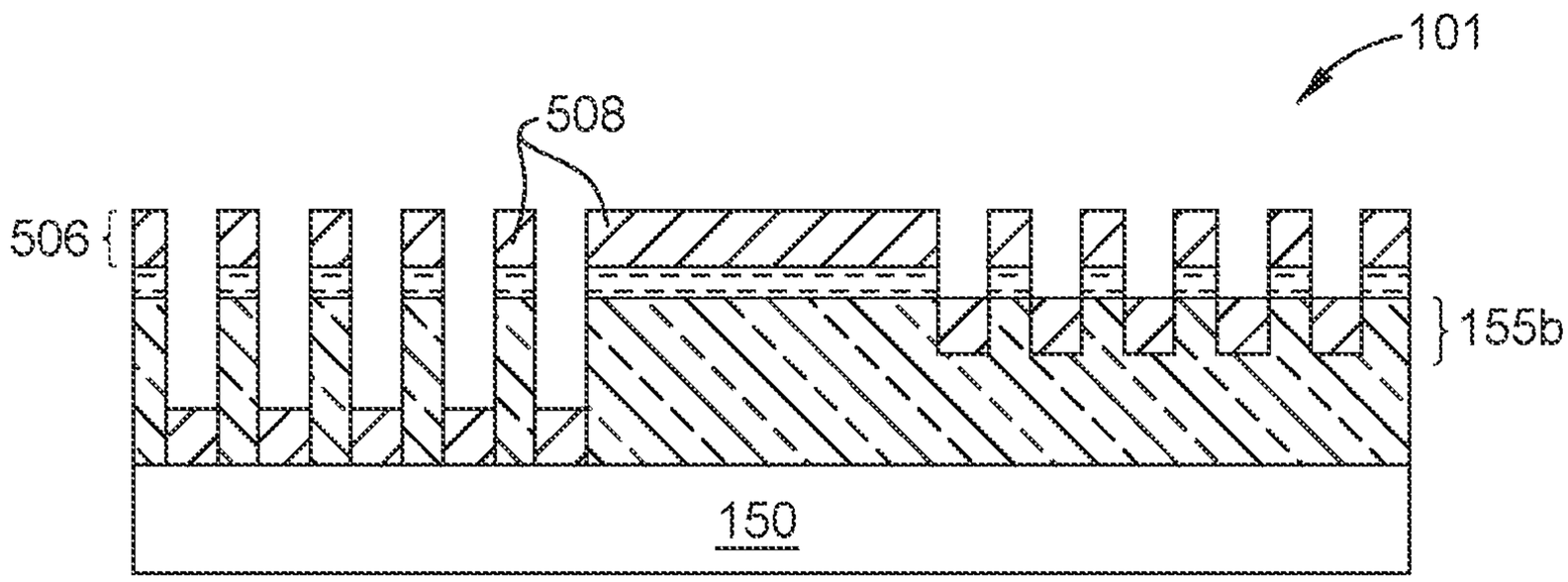


FIG. 5D

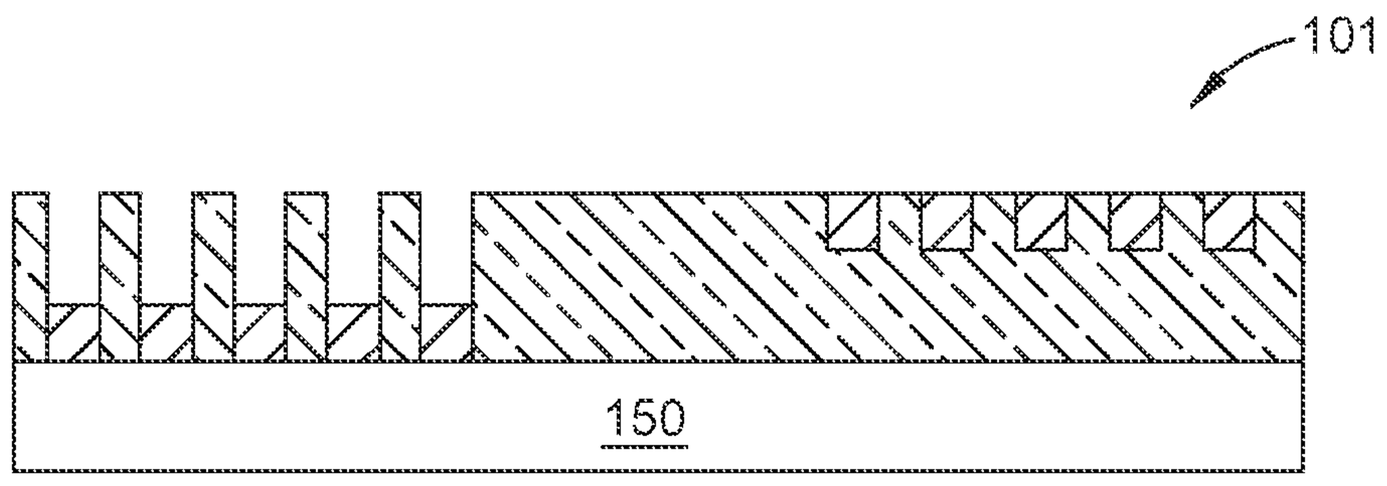


FIG. 5E

FIG. 5F

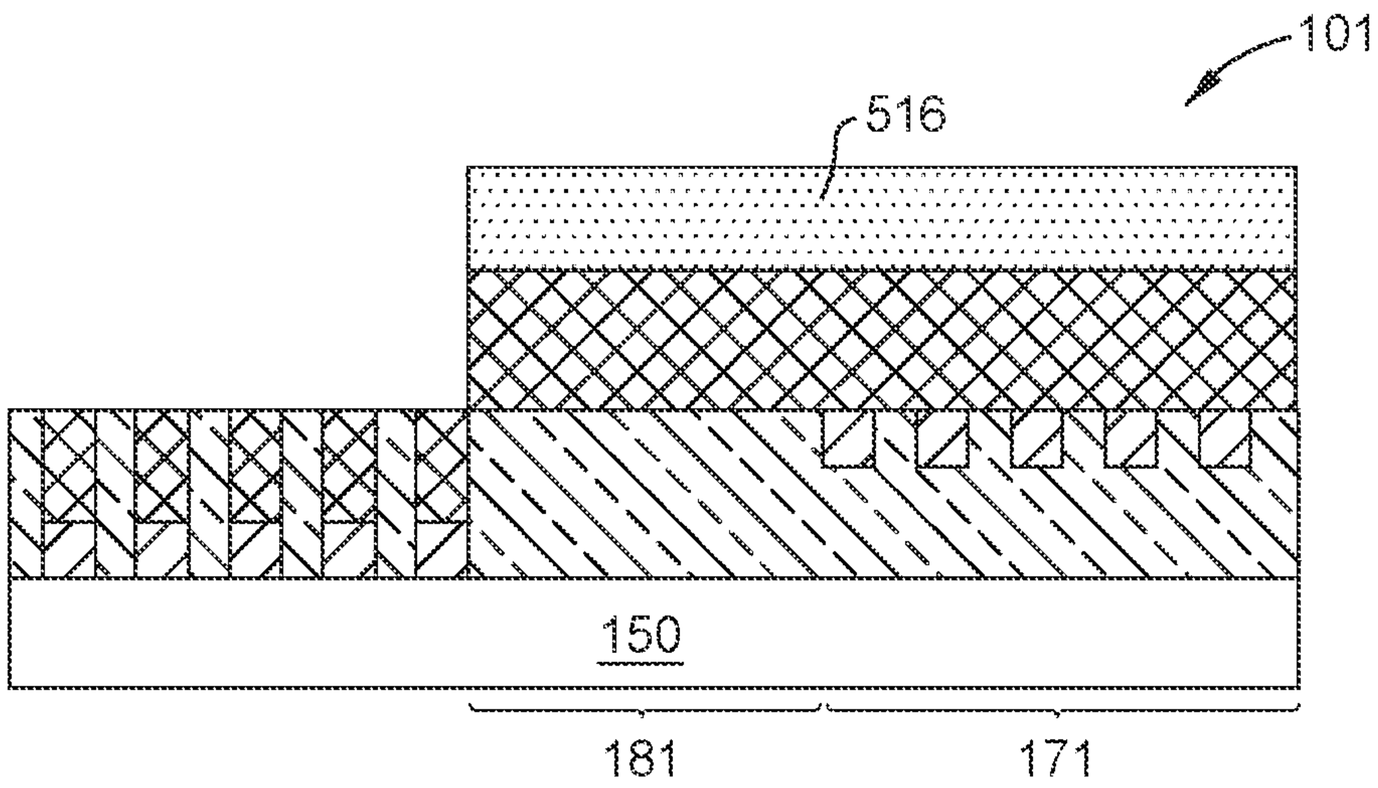


FIG. 5G

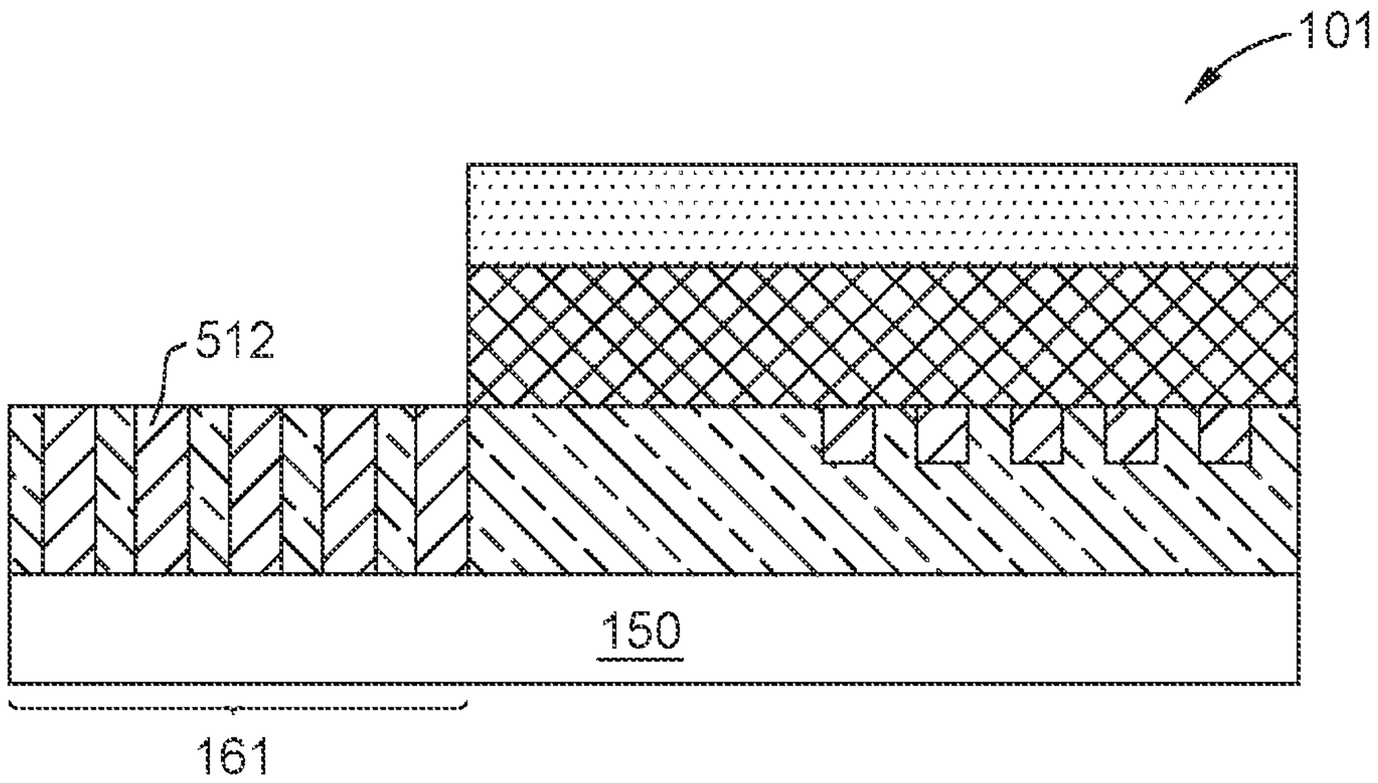


FIG. 5H

MASKLESS COATING AS A PATTERNING MASK FOR EXTERNAL STIMULI IN DEPOSITIONS

BACKGROUND

Field

[0001] Embodiments of the present disclosure generally relate to waveguides for augmented, virtual, and mixed reality. More specifically, embodiments described herein provide for forming waveguides.

Description of the Related Art

[0002] 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.

[0003] Augmented reality, 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 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. As an emerging technology, there are many challenges and design constraints with augmented reality and forming waveguides. Therefore, there is a need for an improved method of forming waveguides.

SUMMARY

[0004] In one embodiment, a method includes depositing a first precursor over a waveguide, the first precursor deposited over a first grating, a second grating, and an intermediate region between the first grating and the second grating of the waveguide. The first precursor is deposited to have a first thickness. The method further includes performing a first ozone cure process, the first ozone cure process curing the first precursor and depositing a second precursor over the waveguide. The second precursor is deposited over the first grating, the second grating, and the intermediate region. The second precursor is deposited to have a second thickness. The method further includes depositing a coating over the intermediate region and the second grating, performing a second ozone cure process, the second ozone cure process curing the second precursor over the first grating, and removing the coating and the second precursor over the second grating and the intermediate region.

[0005] In another embodiment, a method includes depositing a first precursor over a waveguide. The first precursor is deposited over a first grating, a second grating, and an intermediate region between the first grating and the second grating of the waveguide. The first precursor is deposited to have a first thickness. An upper surface of the first grating, the second grating, and the intermediate region have a hardmask material disposed thereon. The method further includes performing a first ozone cure process, the first ozone cure process curing the first precursor, removing the first precursor over the upper surface, removing the hardmask, and depositing a second precursor over the waveguide. The second precursor is deposited over the first grating, the second grating, and the intermediate region. The second precursor is deposited to have a second thickness. The method further includes depositing a coating over the intermediate region and the second grating, performing a second ozone cure process, the second ozone cure process curing the second precursor over the first grating, and removing the coating and the second precursor over the second grating and the intermediate region

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] 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 of the present disclosure and are therefore not to be considered limiting of its scope, and may admit to other equally effective embodiments.

[0007] FIG. **1**A is a perspective, frontal view of a waveguide according to one or more embodiments.

[0008] FIG. **1**B is a schematic, cross-sectional view of a portion of a waveguide according to one or more embodiments.

[0009] FIG. **2** is a flow diagram of a method of forming a waveguide according to one or more embodiments.

[0010] FIGS. **3**A-**3**F are schematic, cross-sectional views of a portion of a waveguide according to one or more embodiments.

[0011] FIG. **4** is a flow diagram of a method of forming a waveguide according to one or more embodiments.

[0012] FIGS. **5**A-**5**H are schematic, cross-sectional views of a portion of a waveguide according to one or more embodiments.

[0013] 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

[0014] Embodiments of the present disclosure generally relate to waveguides for augmented, virtual, and mixed reality. More specifically, embodiments described herein provide for forming waveguides. FIG. **1**A is a perspective, frontal view of a waveguide **100**, according to one or more embodiments. In one embodiment, which can be combined with other embodiments described herein, the waveguide **100** is a waveguide combiner, such as an augmented reality waveguide combiner. The waveguide **100** includes an in-coupler grating **110**, a pupil-expander grating **120**, an out-coupler grating **130**, and a waveguide substrate **150**. Each grating of the waveguide **100** includes a plurality of grating structures **140**.

[0015] FIG. **1**B is a schematic, cross-sectional view of a portion **101** of a waveguide, such as the waveguide **100** of FIG. **1***a*, according to one or more embodiments. In one embodiment, which can be combined with other embodiments described herein, the waveguide **100** includes a plurality of grating structures **140** disposed over the waveguide

substrate **150**. Adjacent grating structures **140** form a plurality of trenches **145** therebetween. A first section **160** of the portion **101** of the waveguide **100** includes a first grating **161**. The first grating **161** may be one of the in-coupler grating **110**, the pupil-expander grating **120**, or the out-coupler grating **130**. The first grating **161** includes a plurality of first grating structures **140***a*. A plurality of first trenches **145***a* are formed between first grating structures **140***a*. A second section **170** of the portion **101** of the waveguide substrate **150** includes a second grating **171**. The second grating **171** may be one of the in-coupler grating **110**, the pupil-expander grating **120**, the out-coupler grating **130**. The second grating **171** includes a plurality of second grating structures **140***b*. A plurality of second trenches **145***b* are formed between second grating structures **140***b*. In one embodiment, which can be combined with other embodiments described herein, a third section **180** includes an intermediate region **181** between the first grating **161** and the second grating **171**.

[0016] The first grating structures **140***a* have a first depth **155***a* and the second grating structures **140***b* have a second depth **155***b*. In one embodiment, which can be combined with other embodiments described herein, the first depth **155***a* is greater than the second depth **155***b*. In one embodiment, which can be combined with other embodiments described herein, a first cured precursor **190***a* is formed in the first trenches **145***a*, the second trenches **145***b*, and over the intermediate region **181**. The first cured precursor **190***a* has a first thickness **195***a*. A second cured precursor **190***b* is formed in the first trenches **145***a* over the first cured precursor **190***a*. The second cured precursor has a second thickness **195***b*. The second depth **155***b* is equal to the first thickness **195***a*. The first depth **155***a* is equal to the first thickness **195***a* and the second thickness **195***b*. In one embodiment, which can be combined with other embodiments described herein, the first cured precursor **190***a* over the intermediate region **181** is not present.

[0017] FIG. **2** is a flow diagram of a method **200** of forming a waveguide **100** according to one or more embodiments. FIGS. **3**A-**3**F are schematic, cross-sectional views of a portion **101** of a waveguide **100** according to one or more embodiments.

[0018] FIG. **3**A includes a plurality of first grating structures **140***a* disposed over a first grating **161** of the portion **101** of a waveguide substrate **150**. Adjacent first grating structures **140***a* form a plurality of first trenches **145***a* therebetween. FIG. **3**A further includes a plurality of second grating structures **140***b* disposed over a second grating **171** of the portion **101** of the waveguide substrate **150**. Adjacent second grating structures **140***b* form a plurality of second trenches **145***b* therebetween. A third section **180** of the portion **101** of the waveguide **100** includes an intermediate region **181** which does not include grating structures **140** thereon or thereover. In one embodiment, which can be combined with other embodiments described herein, the first grating **161** and the second grating **171** may correspond to any of the in-coupler grating **110**, the pupil-expander grating **120**, or the out-coupler grating **130**, as shown in FIG. **1**A.

[0019] The plurality of first grating structures **140***a* have a first depth **155***a*. The plurality of second grating structures **140***b* have a second depth **155***b*. In one embodiment, which can be combined with other embodiments described herein, the first depth **155***a* is greater than the second depth **155***b*.

[0020] At operation **202**, as shown in FIG. **3**B, a first precursor **304** is deposited over the waveguide **100**. The first precursor **304** is deposited over the first grating **161**, the second grating **171**, and the intermediate region **181**. The first precursor **304** has first thickness **195***a*. In one embodiment, which can be combined with other embodiments described herein, the first precursor is a trisilylamine (TSA). The first precursor **304** may be deposited via flowable chemical vapor deposition (FCVD) or chemical vapor deposition (CVD).

[0021] At operation **204**, as shown in FIG. **3**C, a first ozone cure process is performed. In one embodiment, which can be combined with other embodiments described herein, the first ozone cure process is an ozone (O_3) soak. The first ozone cure process cures the first precursor **304**, leaving a first cured precursor **190***a*.

[0022] At operation **206**, as shown in FIG. **3**D, a second precursor **312** is deposited over the waveguide **100**. The second precursor **312** is deposited over the first grating **161**, the second grating **171**, and the intermediate region **181**. The second precursor **312** has a second thickness **195***b*. In one embodiment, which can be combined with other embodiments described herein, the first thickness **195***a* and the second thickness **159***b* are different. In one embodiment, which can be combined with other embodiments described herein, the first precursor **304** and the second precursor **312** may be the same material.

[0023] At operation **208**, as shown in FIG. **3**E, a coating **316** is deposited over the intermediate region **181** and the second grating **171**. The coating **316** may be a water soluble coating. In one embodiment, which can be combined with other embodiments described herein, the coating **316** is deposited via inkjet deposition.

[0024] At operation **210**, as shown in FIG. **3**F, a second ozone cure process is performed. The second ozone cure process cures the second precursor **312** over the first grating **161**, leaving a second cured precursor **190***b*.

[0025] At operation **212**, as shown in FIG. **1**B, the coating **316** and the second precursor **312** located over the second grating **171** and the intermediate region **181** are removed.

[0026] FIG. **4** is a flow diagram of a method **400** of forming a waveguide **100** according to one or more embodiments. FIGS. **5**A-**5**H are schematic, cross-sectional views of a portion **101** of a waveguide **100** according to one or more embodiments.

[0027] FIG. **5**A includes a plurality of first grating structures **140***a* disposed over a first grating **161** of the portion **101** of a waveguide substrate **150**. Adjacent first grating structures **140***a* form a plurality of first trenches **145***a* therebetween. FIG. **5**A further includes a plurality of second grating structures **140***b* disposed over a second grating **171** of the portion **101** of the waveguide substrate **150**. Adjacent second grating structures **140***b* form a plurality of second trenches **145***b* therebetween. A third section **180** of the portion **101** of the waveguide **100** includes an intermediate region **181** which does not include grating structures **140** thereon or thereover. A hardmask **525** is disposed over an upper surface **527** of each of the first grating **161**, the second grating **171**, and the intermediate region **181**. In one embodiment, which can be combined with other embodiments described herein, the hardmask may be a metal. In one embodiment, which can be combined with other embodiments described herein, the hardmask **525** includes chromium (Cr), titanium nitride (TiN), silicon carbide (SiC),

silicon oxide (SiO_x), zirconium oxide (ZrO_x), titanium oxide (TiO_x), tantalum nitride (TaN), aluminum nitride (AlN), carbon, or combinations thereof. In one embodiment, which can be combined with other embodiments described herein, the first grating **161** and the second grating **171** may correspond to any of the in-coupler grating **110**, the pupil-expander grating **120**, or the out-coupler grating **130**, as shown in FIG. **1**A.

[0028] The plurality of first grating structures **140***a* have a first depth **155***a*. The plurality of second grating structures **140***b* have a second depth **155***b*. In one embodiment, which can be combined with other embodiments described herein, the first depth **155***a* is greater than the second depth **155***b*.

[0029] At operation **402**, as shown in FIG. **5**B, a first precursor **504** is deposited over the waveguide **100**. The first precursor **504** is deposited over the first grating **161**, the second grating **171**, and the intermediate region **181**. The first precursor **504** has a first thickness **506**.

[0030] At operation **404**, as shown in FIG. **5**C, a first ozone cure process is performed. The first ozone cure process cures the first precursor **504**, leaving a cured first precursor **508**.

[0031] At operation **406**, as shown in FIG. **5**D, the cured first precursor **508** is removed over the upper surface **527** such that the remaining first thickness **506** of the cured first precursor **508** is approximately equal to the depth **155***b* of the second trenches **145***b*. In one embodiment, which can be combined with other embodiments described herein, the cured first precursor is removed via an etch process.

[0032] At operation **408**, as shown in FIG. **5**E, the hardmask **525** is removed. In one embodiment, which can be combined with other embodiments described herein, the hardmask is removed via a chromium removal process.

[0033] At operation **410**, as shown in FIG. **5**F, a second precursor **512** is deposited over the waveguide **100**. The second precursor **512** is deposited over the first grating **161**, the second grating **171**, and the intermediate region **181**. The second precursor **512** has a second thickness **514**. In one embodiment, which can be combined with other embodiments described herein, the first thickness **506** and the second thickness **514** are different. In one embodiment, which can be combined with other embodiments described herein, the first precursor **304** and the second precursor **312** may be the same material.

[0034] At operation **412**, as shown in FIG. **5**G, a coating **516** is deposited over the intermediate region **181** and the second grating **171**. In one embodiment, which can be combined with other embodiments described herein, the coating **516** is deposited via inkjet deposition.

[0035] At operation **414**, as shown in FIG. **5**H, a second ozone cure process is performed. The second ozone cure process cures the second precursor **512** over the first grating **161**, leaving a cured second precursor **518**.

[0036] At operation **416**, the coating **516** and the second precursor **512** located over the second grating **171** and the intermediate region **181** are removed.

[0037] In one embodiment, which can be combined with other embodiments described herein, any of the ozone cure processes are replaced with another external stimuli process in order to cure the first precursor **304/504** and/or the second precursor **312/512**. External stimuli processes may include light (UV and/or visible), electron-beam, chemical (acid, base, thiol, water, and/or silanes), contact heat transfer, and/or vacuum.

[0038] In one embodiment, which can be combined with other embodiments described herein, the coating **316/516** is deposited via physical vapor deposition (PVD), chemical vapor deposition (CVD), atomic layer deposition (ALD), spincoat deposition, spray coating, electroplating, screenprint deposition, and/or dipcoating. In one embodiment, which can be combined with other embodiments described herein, the coating **316/516** includes screenprint, evaporation printing, microcontact printing, imprinting, nanoimprinting, embossing, aerosol spray, and/or aerosol jet.

[0039] 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.

1. A method, comprising:

depositing a first precursor over a waveguide, the first precursor deposited over a first grating, a second grating, and an intermediate region between the first grating and the second grating of the waveguide, the first precursor deposited to have a first thickness;

performing a first cure process, the first ozone cure process curing the first precursor;

depositing a second precursor over the waveguide, the second precursor deposited over the first grating, the second grating, and the intermediate region, the second precursor deposited to have a second thickness;

depositing a coating over the intermediate region and the second grating;

performing a second cure process, the second ozone cure process curing the second precursor over the first grating; and

removing the coating and the second precursor over the second grating and the intermediate region.

2. The method of claim **1**, wherein the first grating has a first depth, the second grating has a second depth, and the first depth is greater than the second depth.

3. The method of claim **1**, wherein the first thickness and the second thickness are different.

4. The method of claim **2**, wherein the second depth is equal to the first thickness, and the first depth is equal to the first thickness and the second thickness.

5. The method of claim **1**, wherein the first precursor and the second precursor are the same material.

6. The method of claim **1**, wherein the coating is deposited via inkjet deposition.

7. A method, comprising:

depositing a first precursor over a waveguide, the first precursor deposited over a first grating, a second grating, and an intermediate region between the first grating and the second grating of the waveguide, the first precursor deposited to have a first thickness, an upper surface of the first grating, the second grating, and the intermediate region having a hardmask material disposed thereon;

performing a first cure process, the first cure process curing the first precursor;

removing the first precursor over the upper surface;

removing the hardmask material;

depositing a second precursor over the waveguide, the second precursor deposited over the first grating, the second grating, and the intermediate region, the second precursor deposited to have a second thickness;

depositing a coating over the intermediate region and the second grating;

performing a second cure process, the second cure process curing the second precursor over the first grating; and

removing the coating and the second precursor over the second grating and the intermediate region.

8. The method of claim **7**, wherein the first grating has a first depth, the second grating has a second depth, and the first depth is greater than the second depth.

9. The method of claim **8**, wherein the removing the first precursor comprises etching the first precursor such that the first thickness and the second depth are equal.

10. The method of claim **7**, wherein the first precursor and the second precursor are the same material.

11. The method of claim **7**, wherein the coating is deposited via inkjet deposition.

12. The method of claim **7**, wherein the hardmask material includes chromium (Cr), titanium nitride (TiN), silicon carbide (SIC), silicon oxide (SiO_x), zirconium oxide (ZrO_x), titanium oxide (TiO_x), tantalum nitride (TaN), aluminum nitride (AlN), carbon, or combinations thereof.

13. A waveguide, comprising:

a first grating, a second grating, and an intermediate region between the first grating and the second grating of the waveguide;

the first grating comprising a first plurality of trenches at a first depth;

the second grating comprising a second plurality of trenches at a second depth;

a cured first fill material deposited over the first grating, the second grating, and the intermediate region;

a second fill material deposited over the first grating.

14. The waveguide of claim **13**, wherein the second fill material is the same as the first fill material.

15. The waveguide of claim **13**, wherein the second depth is larger than the first depth.

16. The waveguide of claim **13**, wherein the first plurality of trenches are filled to the first depth with the first fill material, and the second plurality of trenches are filled to the second depth with the first fill material and second fill material.

17. The waveguide of claim **13**, wherein the first fill material and the second fill material are the same material.

18. The waveguide of claim **13**, wherein the first depth is larger than the second depth.

19. The waveguide of claim **13**, wherein the intermediate region comprises a hardmask material disposed thereon

20. The waveguide of claim **19**, wherein the hardmask material includes chromium (Cr), titanium nitride (TiN), silicon carbide (SiC), silicon oxide (SiOx), zirconium oxide (ZrOx), titanium oxide (TiOx), tantalum nitride (TaN), aluminum nitride (AlN), carbon, or combinations thereof.

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