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(54) **METHOD TO FABRICAT FABRICATE A BLAZED GRATING TOGATHER WITH NORMAL BINARY PATTERN**

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Publication Classification

(51) **Int. Cl.**

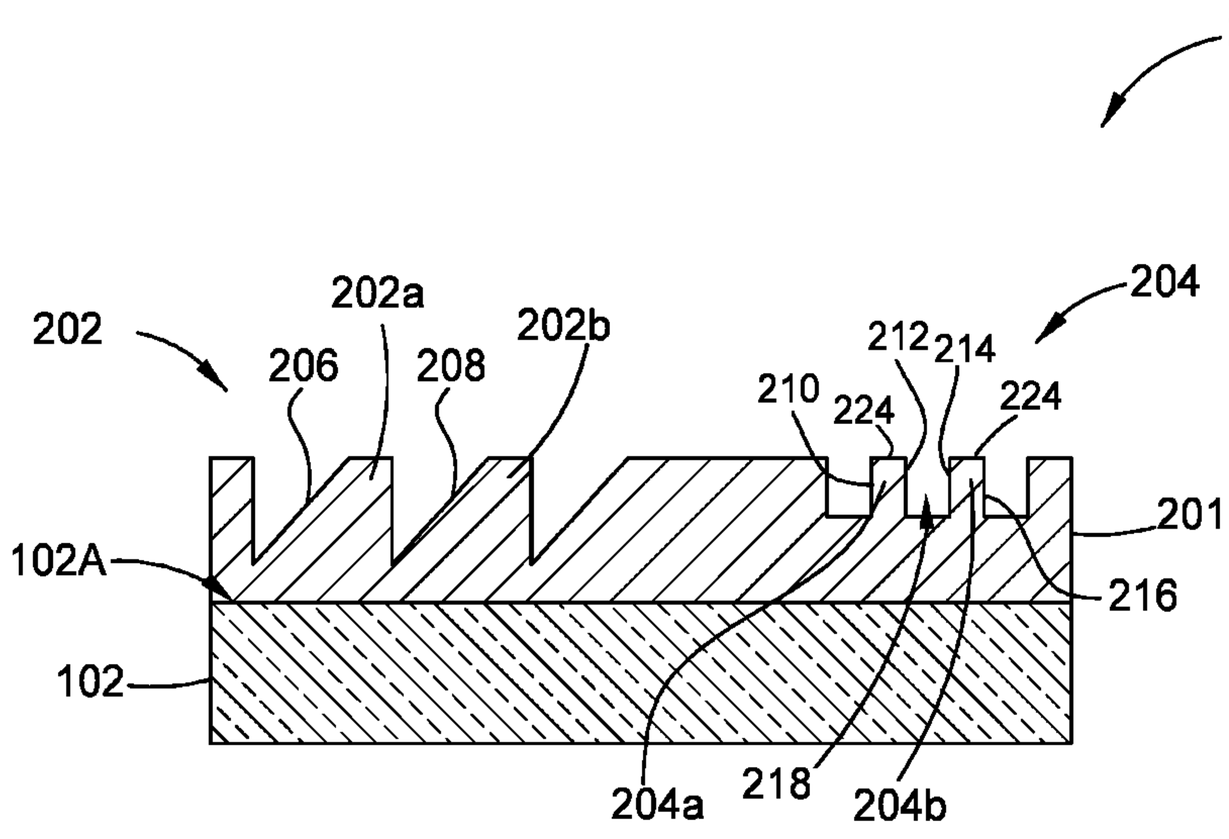
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(52) **U.S. Cl.**

CPC ***G02B 5/1857*** (2013.01); ***G02B 5/1819*** (2013.01); ***G02B 6/29305*** (2013.01)

(57) **ABSTRACT**

Methods of forming an optical device having different optical device structures in a single device material layer are provided. The method includes forming a patterned hardmask over a device material layer deposited on a top surface of a substrate and patterning a first region of the device material layer to form a first plurality of optical features. The method also includes depositing a dielectric layer over the patterned hardmask and selectively etching the dielectric layer and a second region of the device material layer to form a second plurality of optical features in the device material layer. The first plurality of optical features may be binary grating structures and the second plurality of optical features may be blazed grating structures.



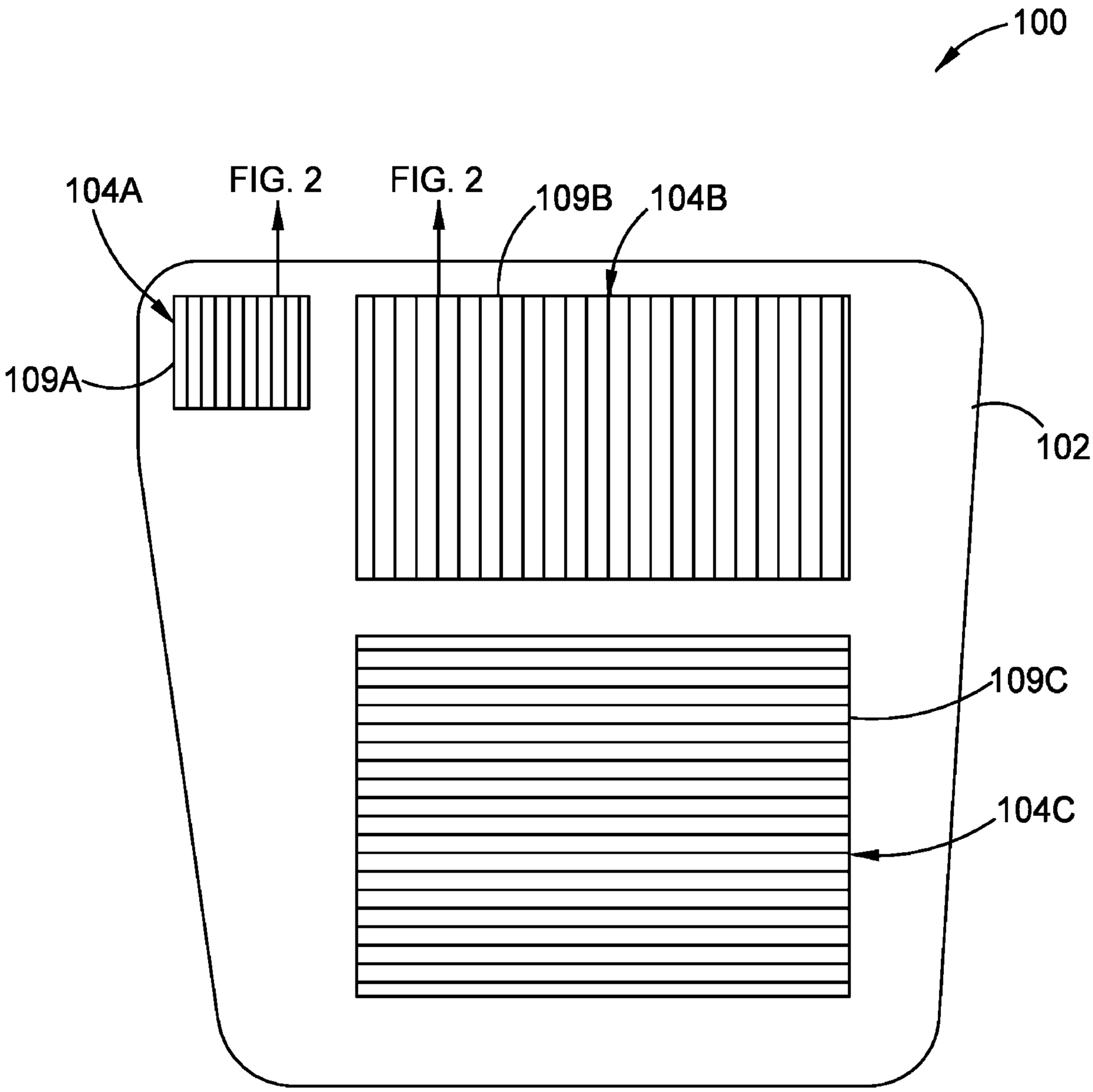


FIG. 1

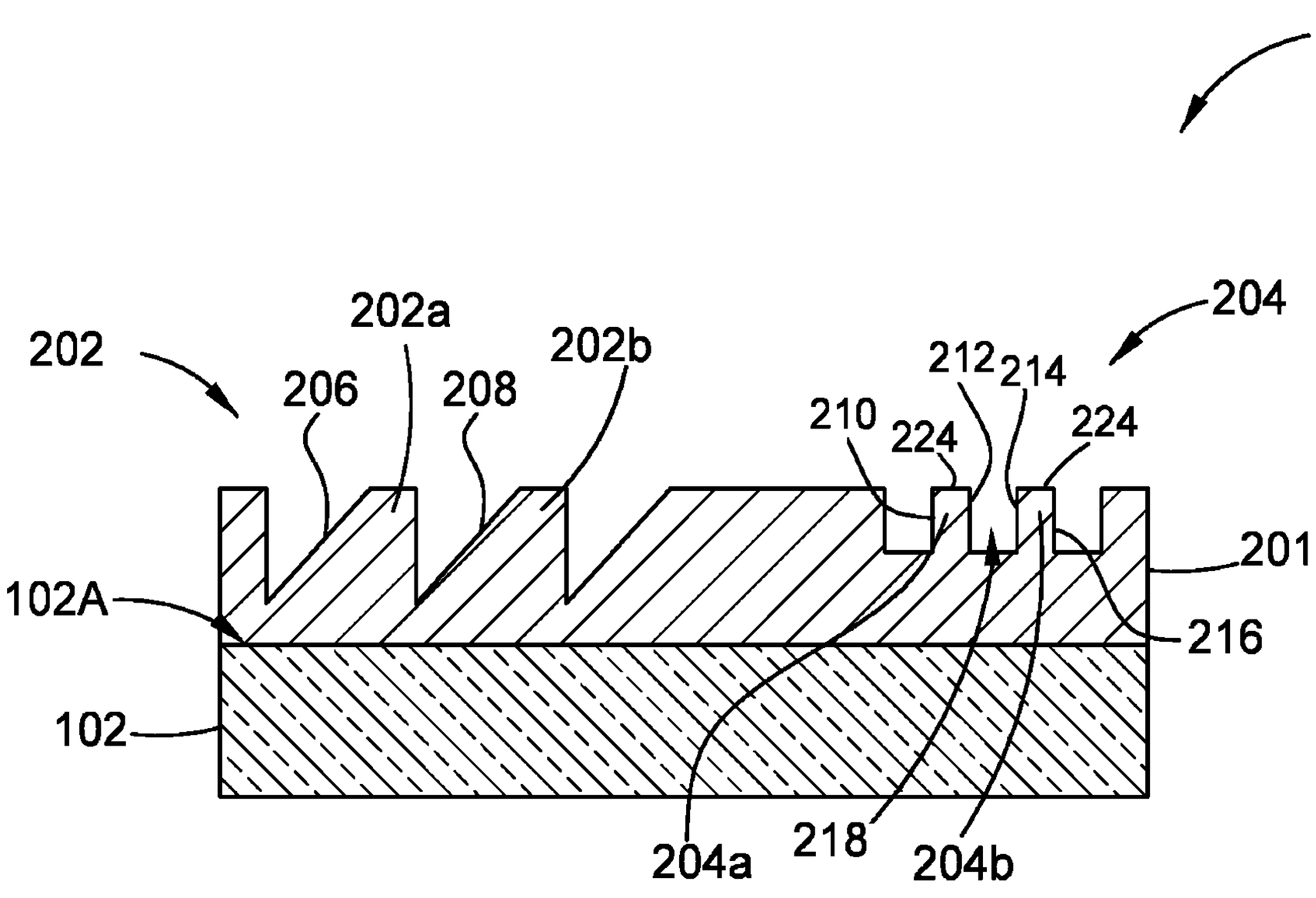

200
202
202a
202b
204
206
208
212
214
210
224
224
201
102A
216
102
204a
218
204b

FIG. 2

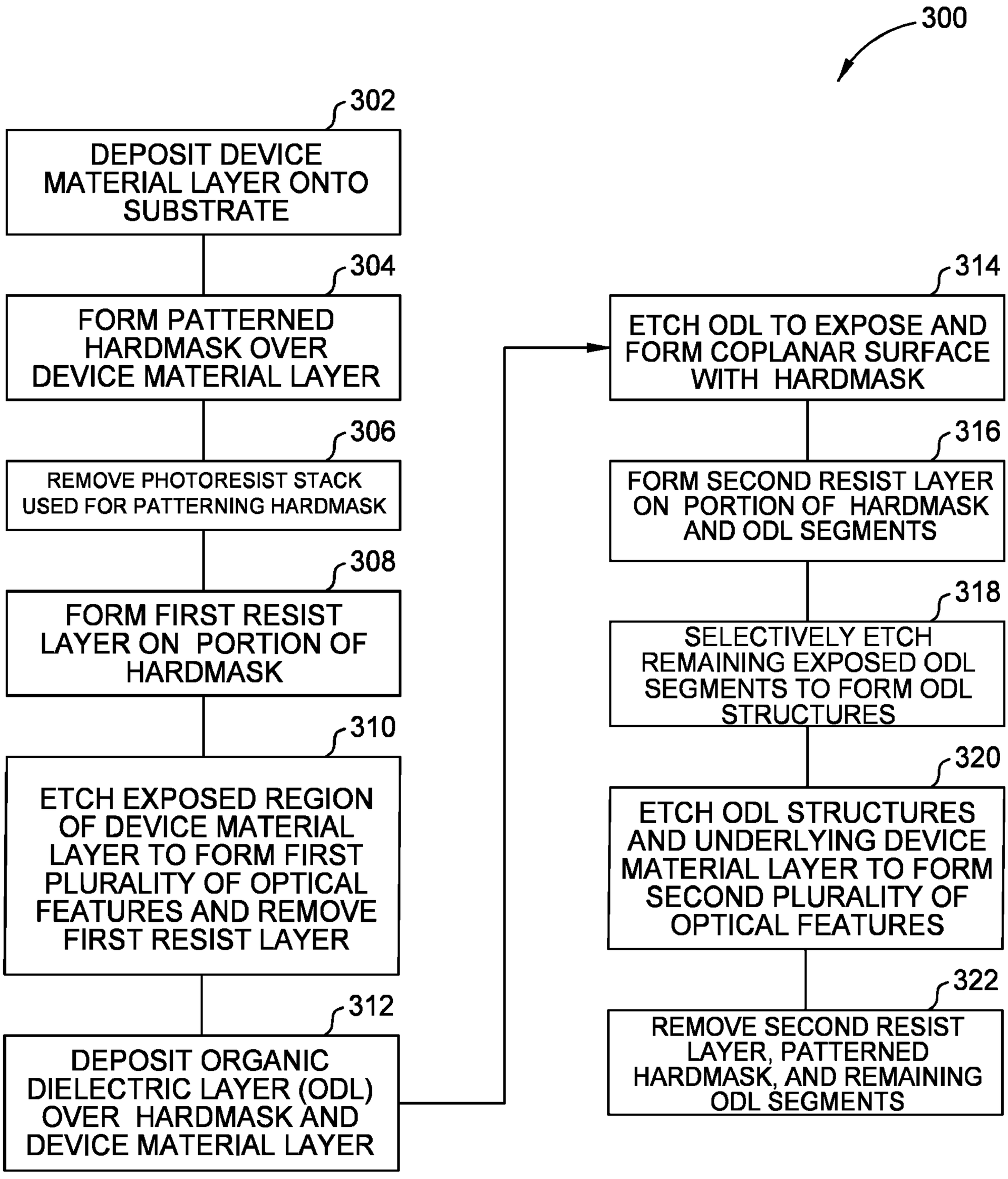

300
302
DEPOSIT DEVICE MATERIAL LAYER ONTO SUBSTRATE
304
FORM PATTERNED HARDMASK OVER DEVICE MATERIAL LAYER
306
REMOVE PHOTORESIST STACK USED FOR PATTERNING HARDMASK
308
FORM FIRST RESIST LAYER ON PORTION OF HARDMASK
310
ETCH EXPOSED REGION OF DEVICE MATERIAL LAYER TO FORM FIRST PLURALITY OF OPTICAL FEATURES AND REMOVE FIRST RESIST LAYER
312
DEPOSIT ORGANIC DIELECTRIC LAYER (ODL) OVER HARDMASK AND DEVICE MATERIAL LAYER
314
ETCH ODL TO EXPOSE AND FORM COPLANAR SURFACE WITH HARDMASK
316
FORM SECOND RESIST LAYER ON PORTION OF HARDMASK AND ODL SEGMENTS
318
SELECTIVELY ETCH REMAINING EXPOSED ODL SEGMENTS TO FORM ODL STRUCTURES
320
ETCH ODL STRUCTURES AND UNDERLYING DEVICE MATERIAL LAYER TO FORM SECOND PLURALITY OF OPTICAL FEATURES
322
REMOVE SECOND RESIST LAYER, PATTERNED HARDMASK, AND REMAINING ODL SEGMENTS

FIG. 3

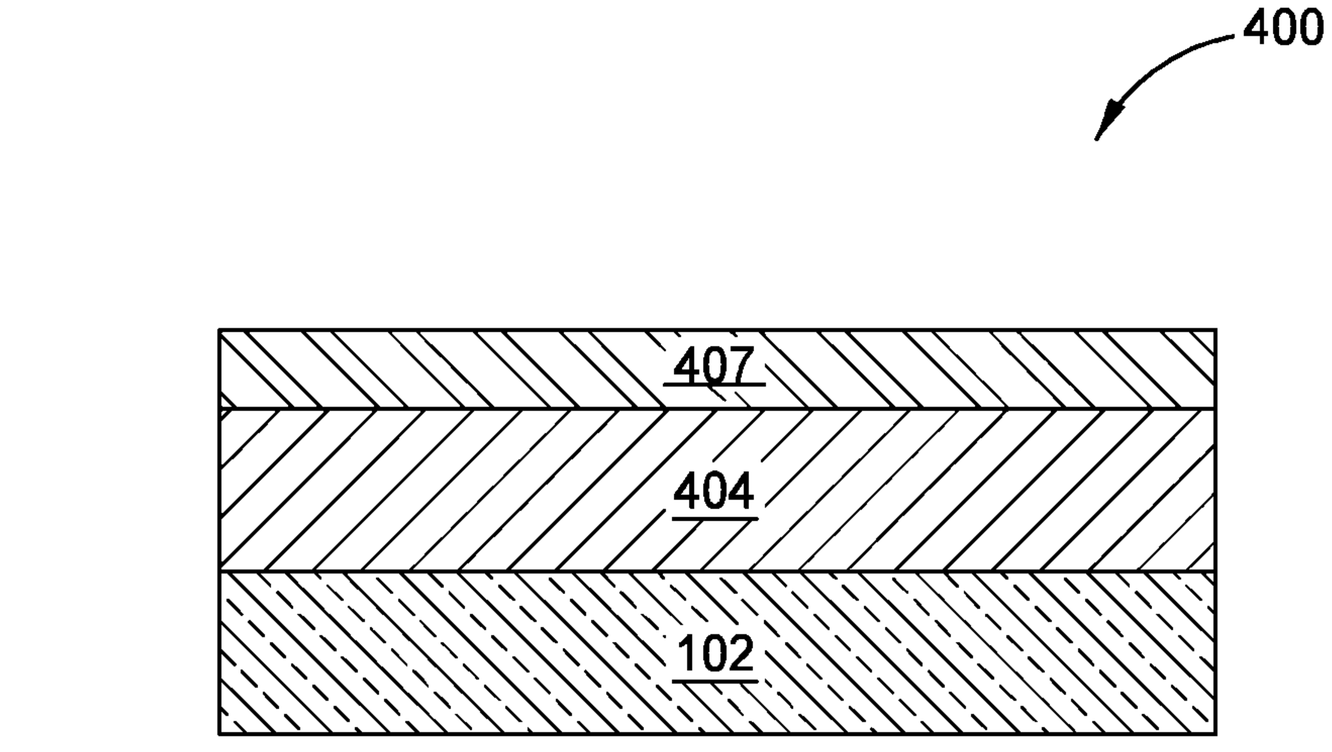


FIG. 4A

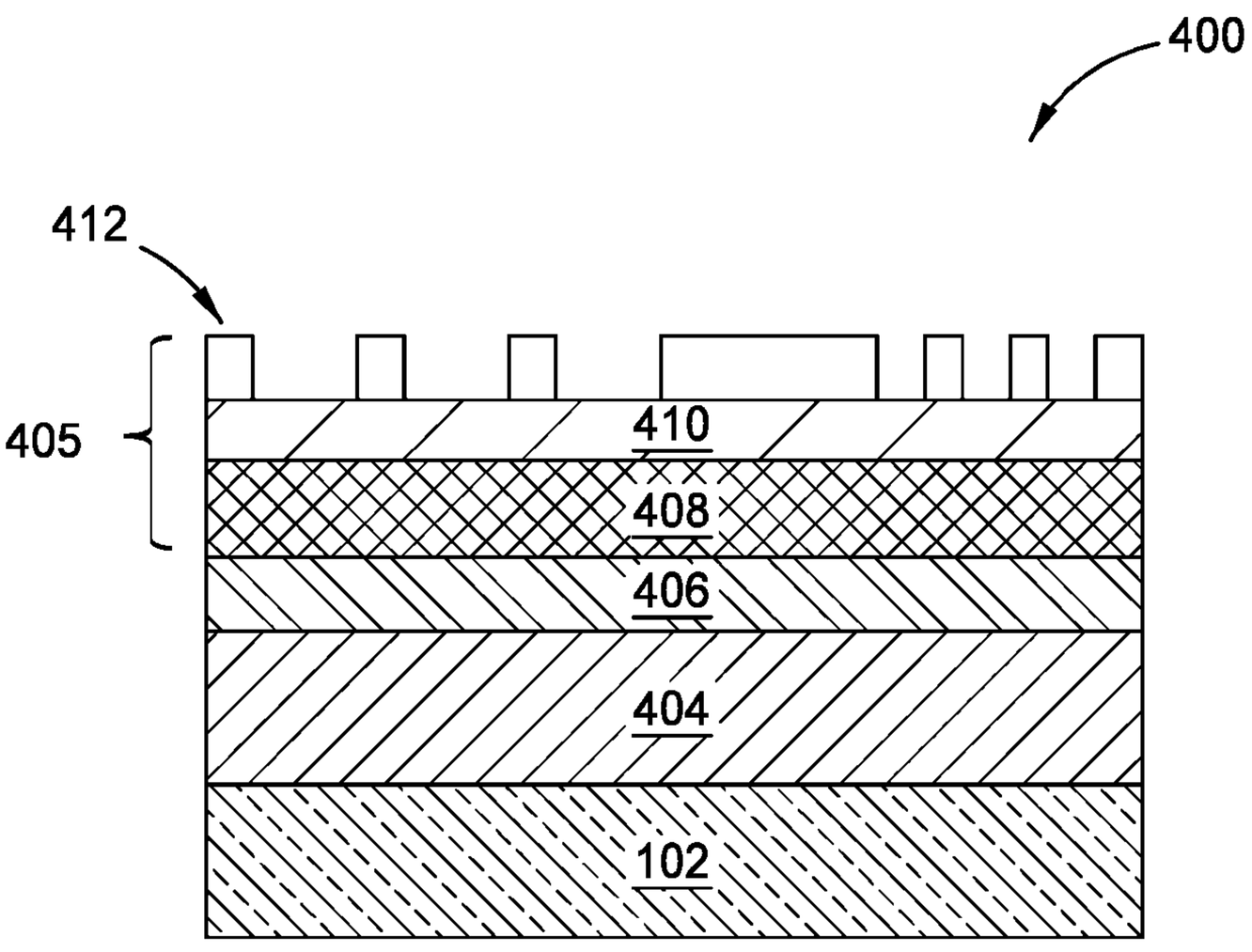


FIG. 4B

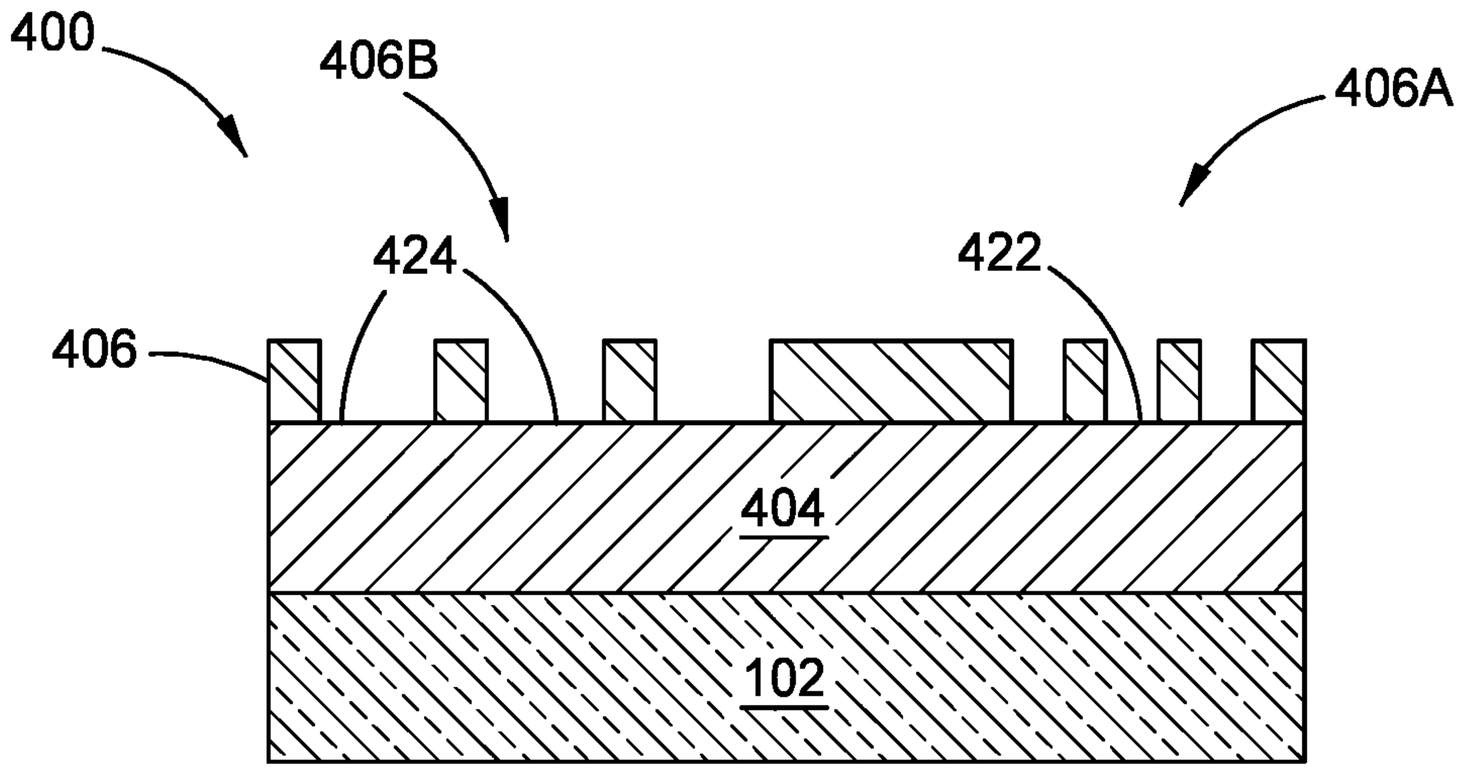


FIG. 4C

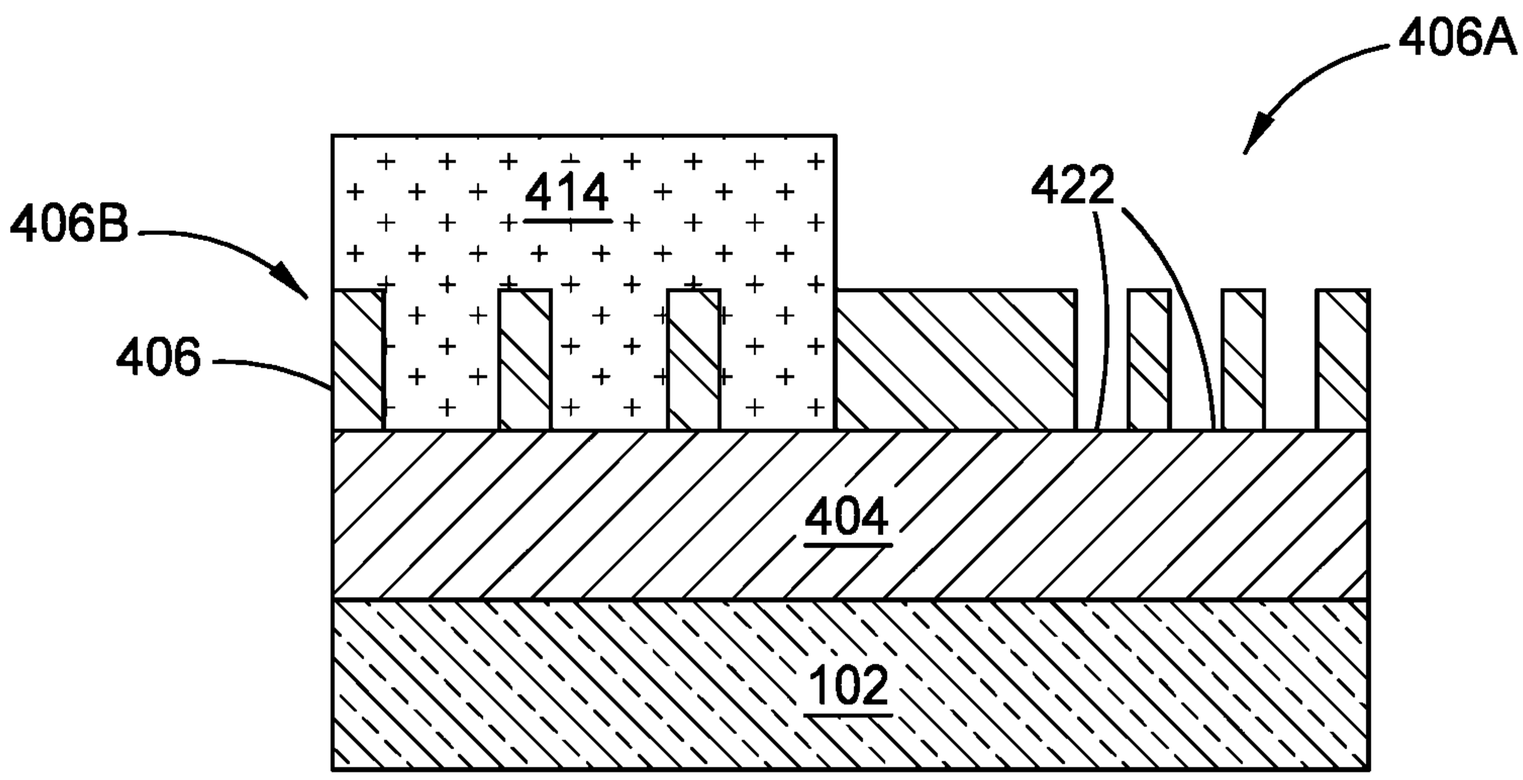


FIG. 4D

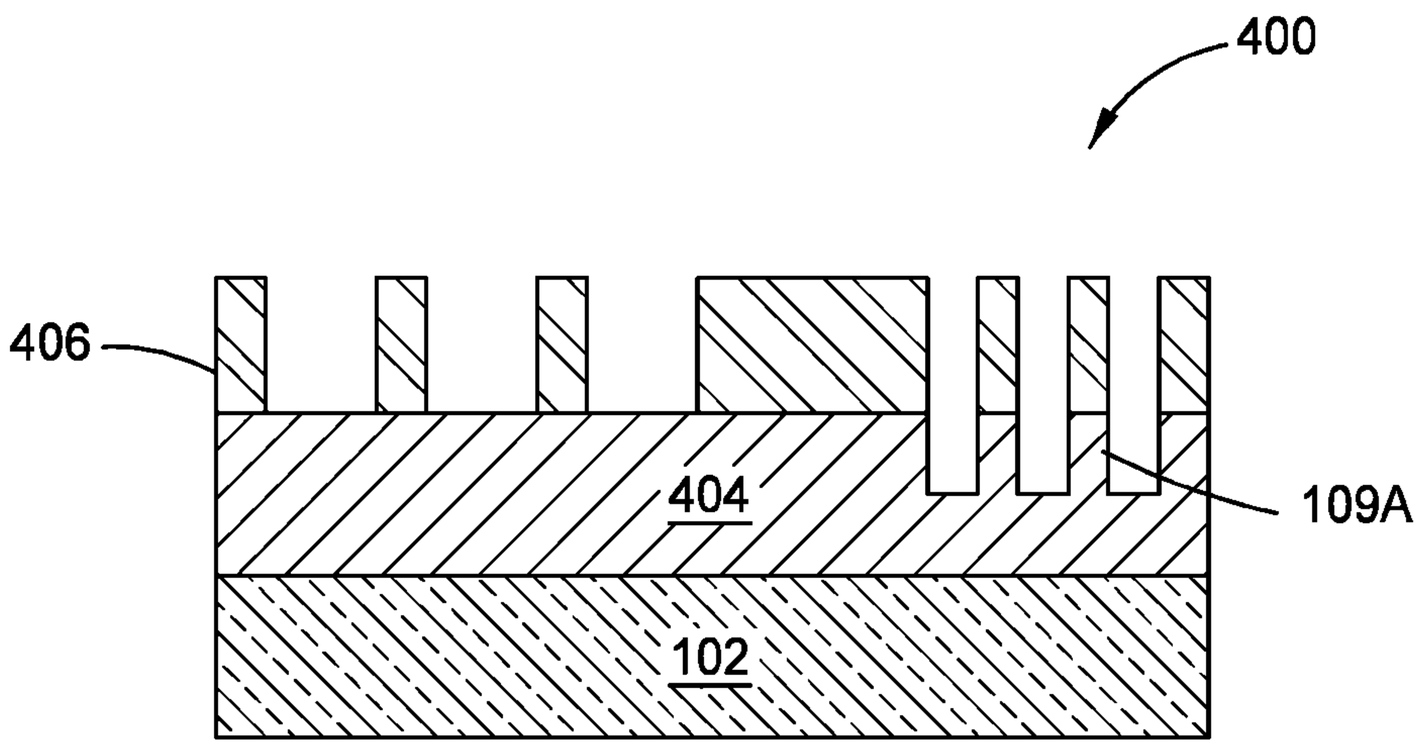


FIG. 4E

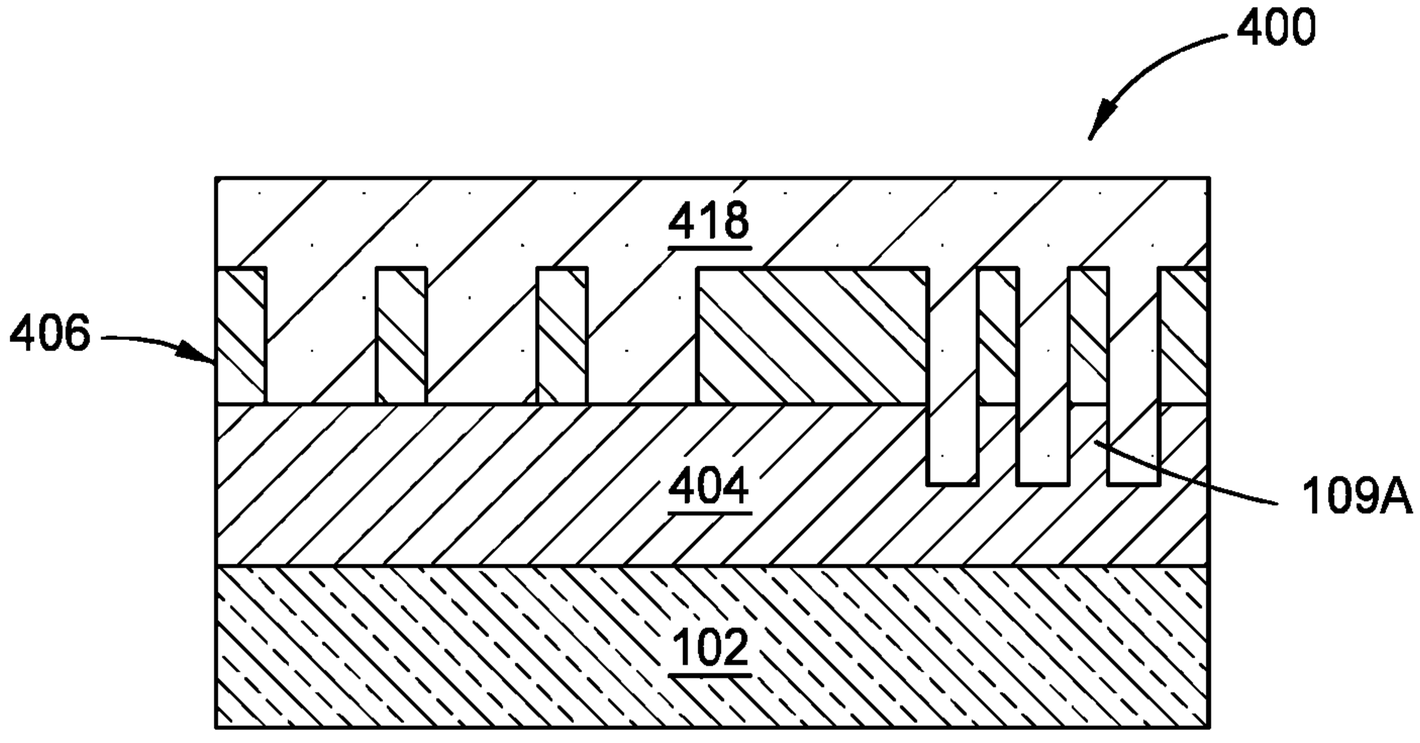


FIG. 4F

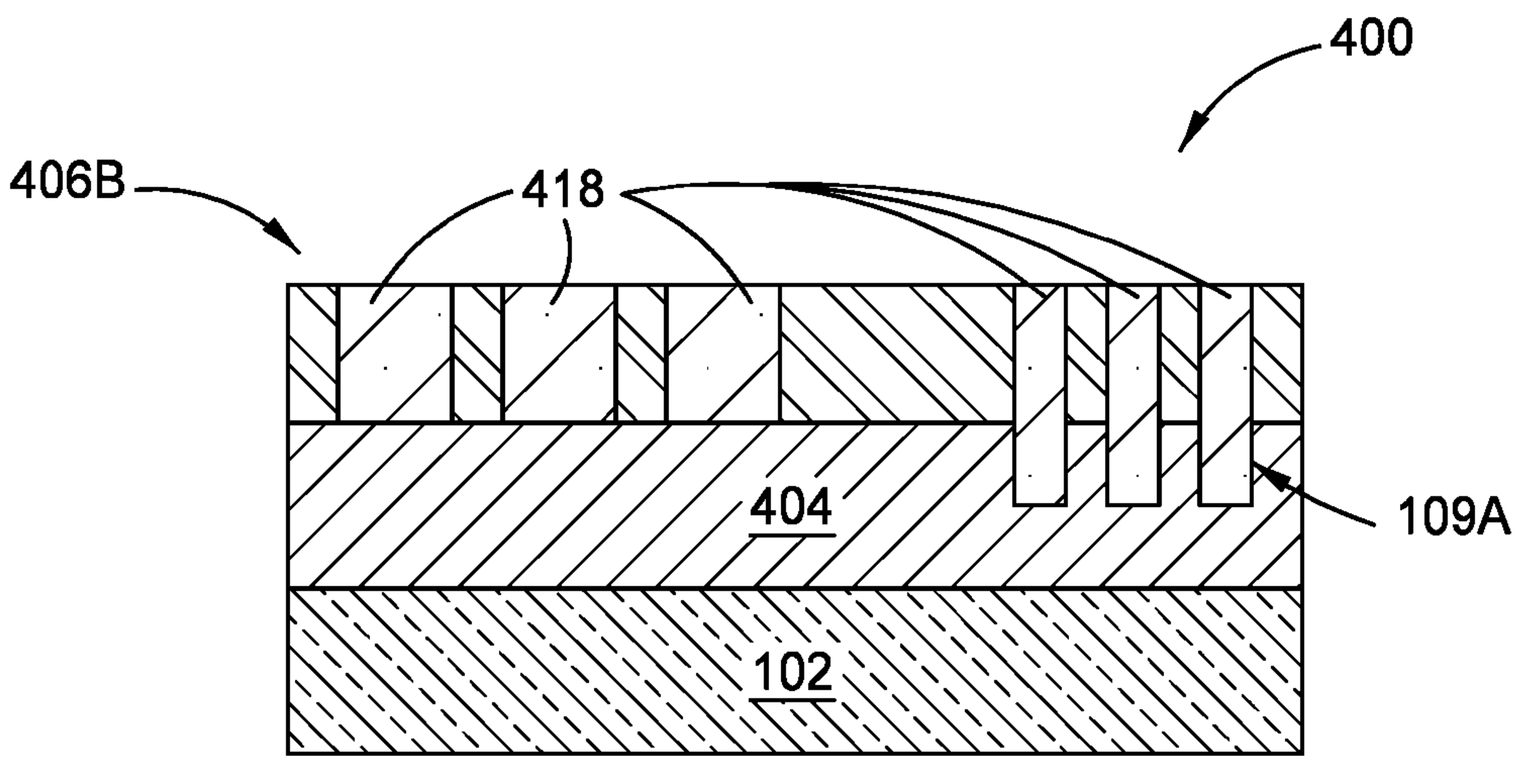

400
406B
418
404
109A
102

FIG. 4G

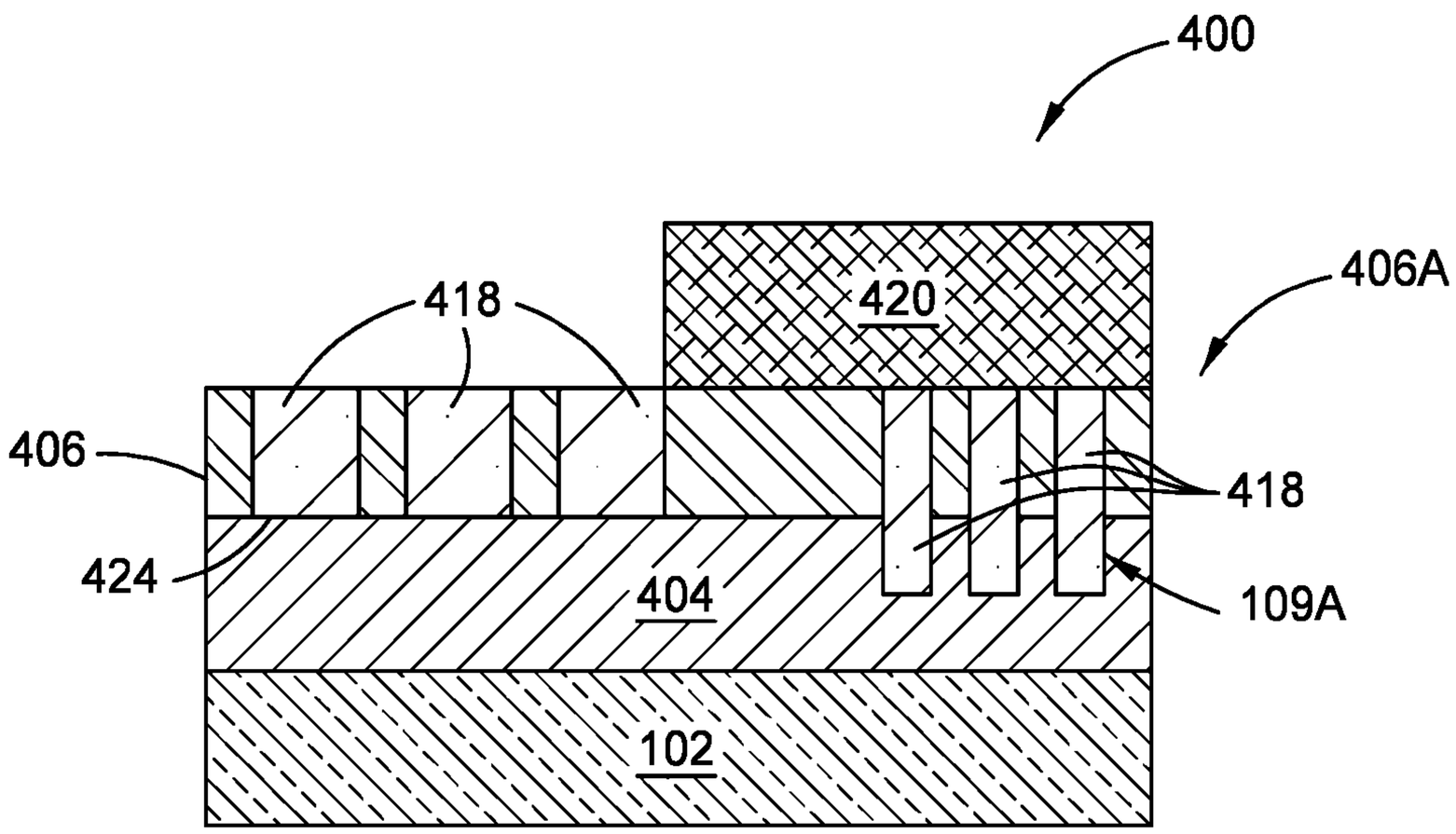

400
406A
420
418
406
418
424
404
109A
102

FIG. 4H

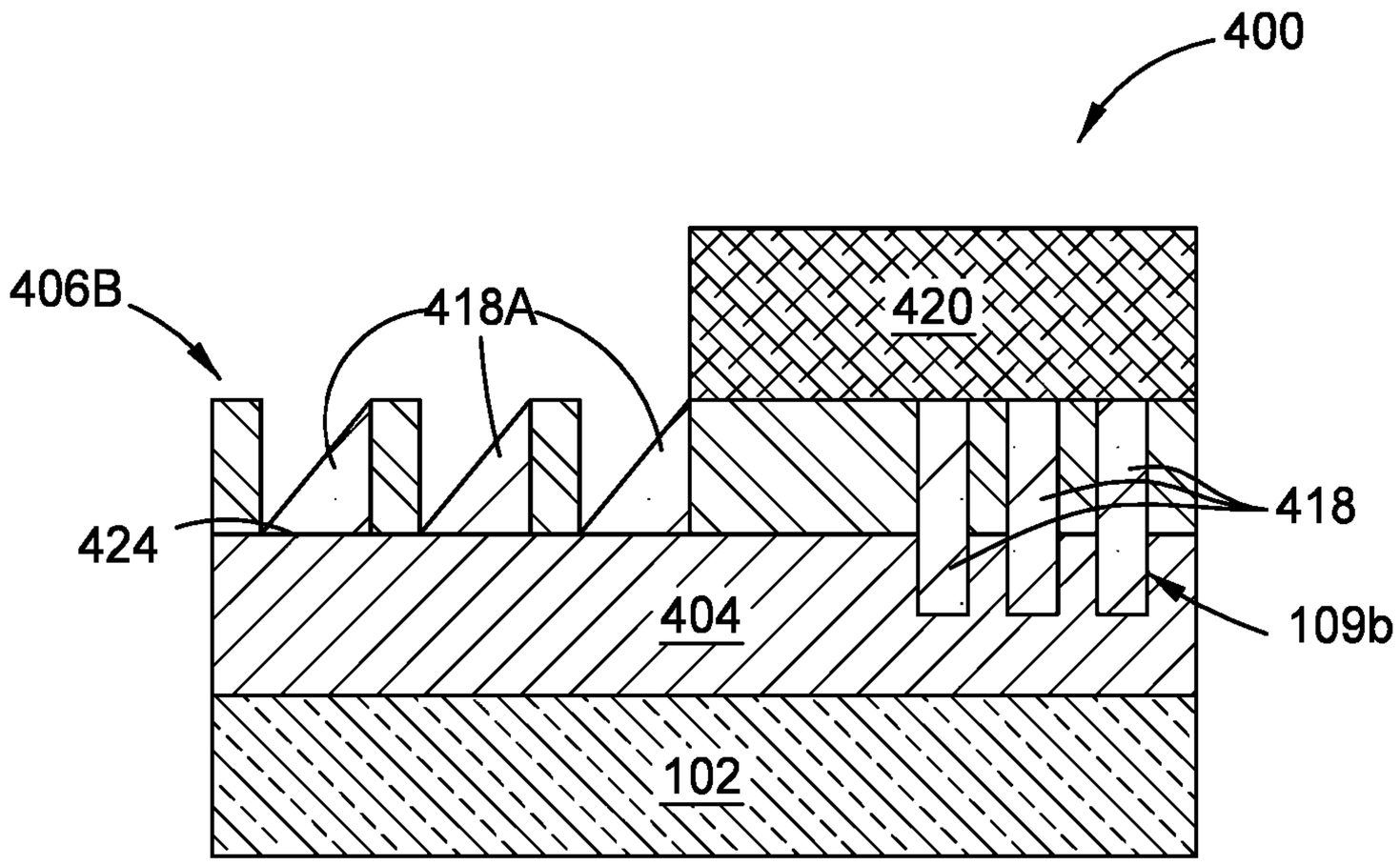

400
406B
418A
420
424
418
404
109b
102

FIG. 4I

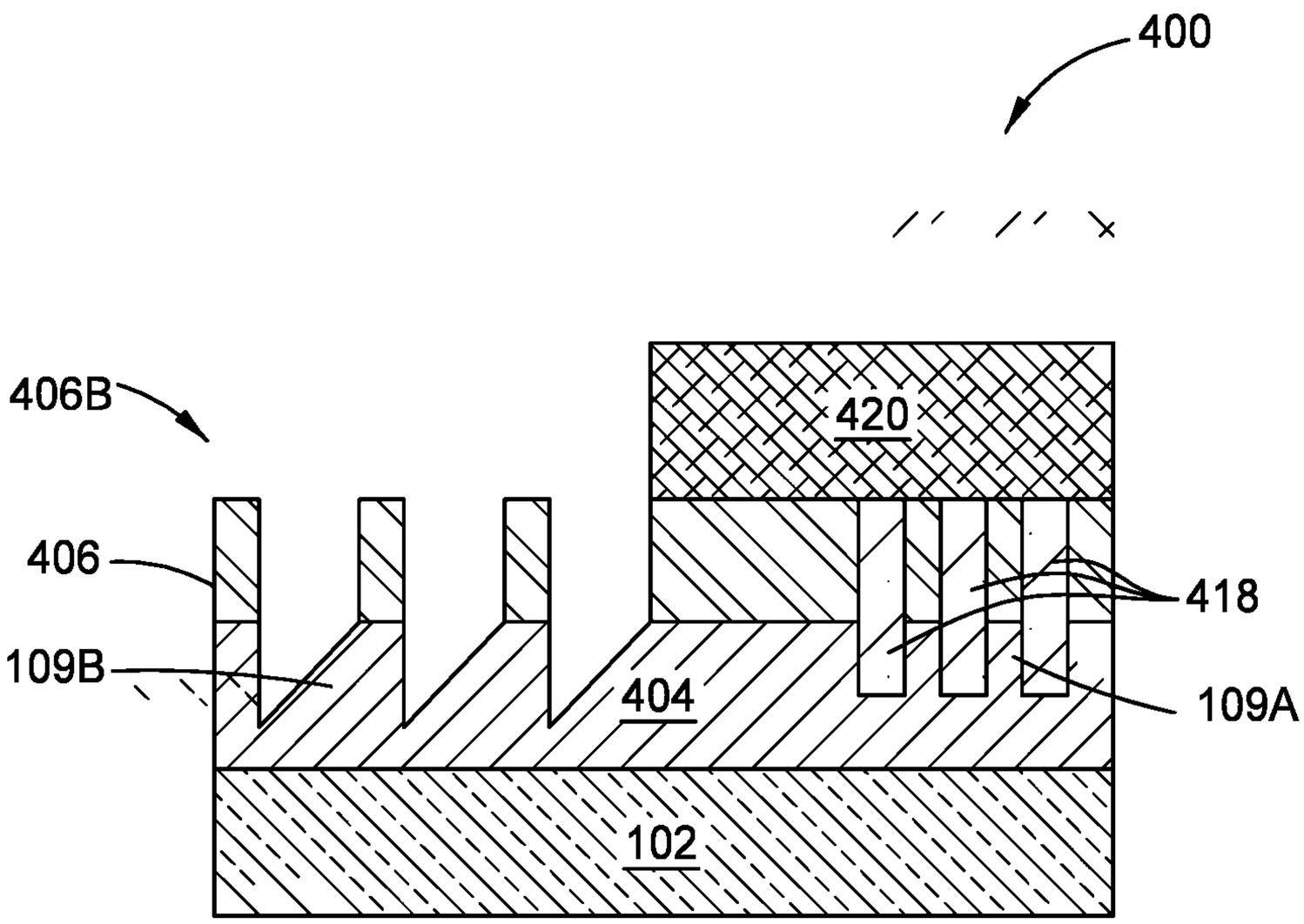

400
406B
420
406
418
109B
404
109A
102

FIG. 4J

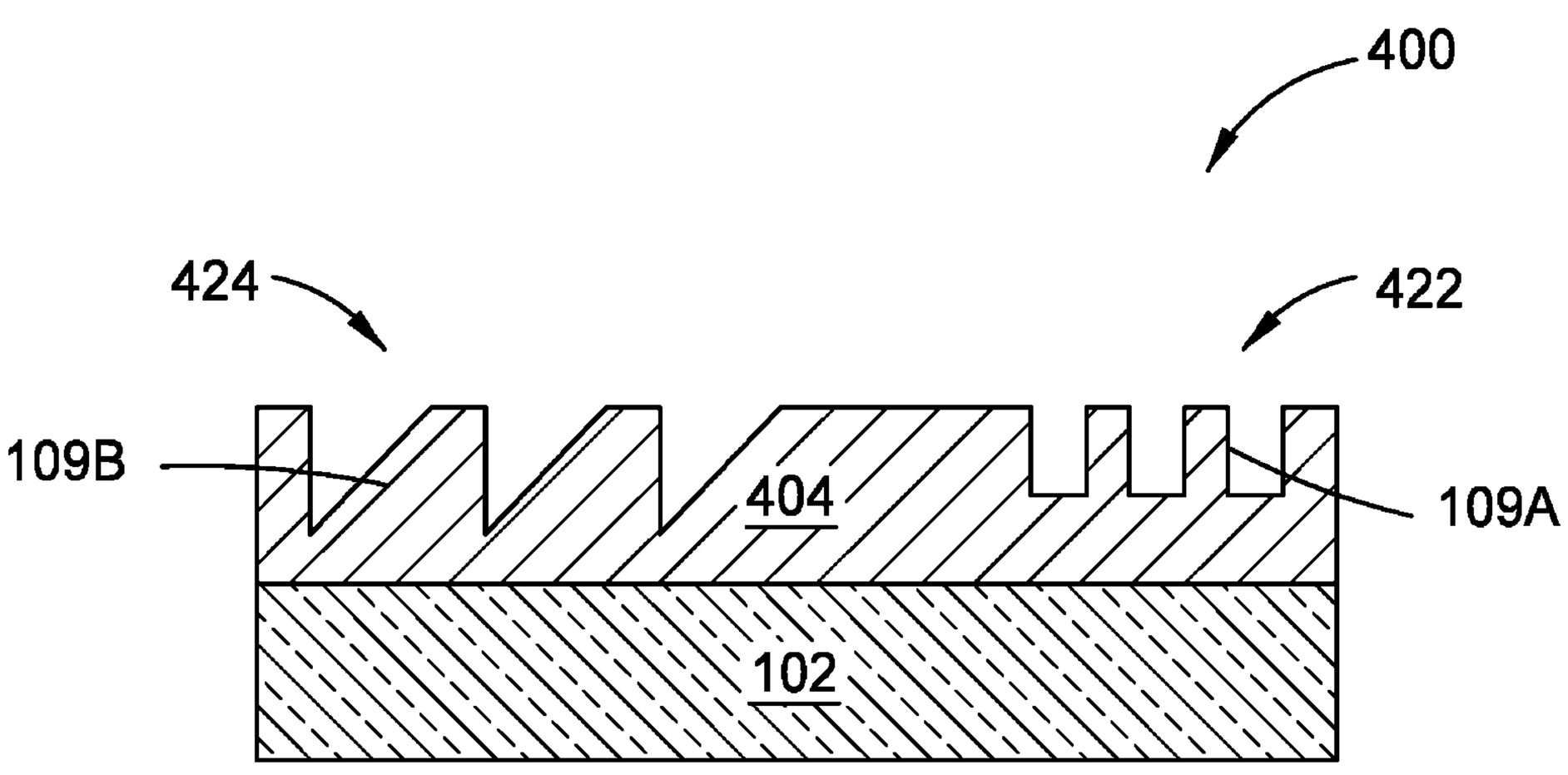


FIG. 4K

METHOD TO FABRICAT FABRICATE A BLAZED GRATING TOGATHER WITH NORMAL BINARY PATTERN

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to United States Provisional Patent Application Serial No. 63/590,260, filed on Oct. 13, 2023, which herein is incorporated by reference.

BACKGROUND

Field

[0002] Embodiments of the present disclosure generally relate to optical devices for augmented, virtual, and mixed reality. More specifically, embodiments described herein relate to an optical device and a method of forming an optical device having binary and blazed grating structures.

Description of the Related Art

[0003] An optical device may be used to manipulate the propagation of light using structures of the optical device formed on a substrate. The optical device includes an arrangement of structures with in-plane dimensions smaller than half a design wavelength of light. The structures have sub-micron critical dimensions, e.g., nanosized dimensions, to alter light propagation by manipulating photons in order to induce localized phase discontinuities (i.e., abrupt changes of phase over a distance smaller than the wavelength of light). In addition to having sub-micron critical dimensions, it is desirable for different sections of the optical device to have different structures such as binary gratings and angled or blazed grating, particularly on the same surface.

[0004] However, forming an optical device having different optical structures may be challenging. Accordingly, there is a need in the art for an optical device and a method of forming an optical device having different optical device structures.

SUMMARY

[0005] Embodiments of the present disclosure relate to optical devices including optical device films and methods of forming the optical device films of the optical devices. Specifically, embodiments described herein provide for optical devices including blazed and binary structures on the same device material layer.

[0006] In an embodiment, a method of forming an optical device is provided. The method includes forming a patterned hardmask over a device material layer deposited on a top surface of a substrate. A first portion of the patterned hardmask exposes a first region of the device material and a second portion of the patterned hardmask exposes a second region of the device material layer. The method also includes patterning the first region of the device material layer to form a first plurality of optical features in the first region of the device material layer, depositing a dielectric layer over the patterned hardmask and the device material layer, selectively etching the dielectric layer and the device material layer to form a second plurality of optical features in the second region of the device material layer, and removing remaining portions of the dielectric layer deposited on the device material layer. The first plurality of optical features may be binary structures and the second plurality of optical features may be blazed structures.

[0007] In an embodiment, a method of forming an optical device is provided. The method includes positioning a substrate in a process chamber, the substrate comprising a device material layer deposited over a top surface of the substrate, and forming a patterned hardmask over the device material layer. A first portion of the patterned hardmask exposes a first region of the device material and a second portion of the patterned hardmask exposes a second region of the device material layer. The method also includes forming a first resist layer over the patterned hardmask, the first region of the device material layer exposed by the first resist layer, and etching the first region of the device material layer to form a first plurality of optical features in the device material layer. The method further includes depositing a dielectric layer over the first and second regions of the device material layer exposed by the patterned hardmask, depositing a second resist layer over the patterned hardmask, and patterning the dielectric layer deposited over the second region of the device material layer to form a plurality of dielectric structures over the second region of the device material layer. The second resist layer exposes the dielectric layer deposited over the second region of the device material layer. The method continues with etching the plurality of dielectric structures and the second region of the device material layer to form a second plurality of optical features in the second region of the device material layer, and removing the second resist layer and remaining portions of the dielectric layer over the first region of the device material layer.

[0008] In another embodiment, an optical device is provided. The optical device includes a substrate having a device material layer disposed thereon, and a first grating region formed in a top surface of the device material layer. The first grating region is formed on a first portion of the device material layer and comprises a plurality of binary grating structures having top surfaces substantially parallel with a top surface of the substrate, and sidewalls substantially perpendicular to the top surface of the substrate. The optical device also includes a second grating region formed in the top surface of the device material layer on a second portion of the device material layer. The second grating region comprising a plurality of blazed grating structures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] 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 the present disclosure may admit to other equally effective embodiments.

[0010] FIG. **1** is a perspective, frontal view of an optical device, according to certain embodiments.

[0011] FIG. **2** illustrates a schematic, cross-sectional view of an optical device, according to certain embodiments.

[0012] FIG. **3** illustrates a flow diagram of a method of forming an optical device film, according to certain embodiments.

[0013] FIGS. **4**A-**4**K illustrate a schematic, cross-sectional view of an optical device undergoing the method of FIG. **3**, according to certain embodiments.

[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 optical devices for augmented, virtual, and mixed reality. More specifically, embodiments described herein relate to an optical device and a method of forming an optical device having different optical device structures.

[0016] FIG. **1** is a perspective, frontal view of an optical device **100**. In an embodiment, the optical device **100** is a waveguide combiner. It is to be understood that the optical device **100** described below is an exemplary waveguide combiner. The optical device **100** includes a substrate **102** having a first grating region **104**A defined by a first plurality of optical device structures **109**A, a second grating region **104**B defined by a second plurality of optical device structures **109**B, and a third grating region **104**C defined by a third plurality of optical device structures **109**C. In one embodiment, which can combined with other embodiments described herein, the optical device **100** includes at least the first grating region **104**A corresponding to an input coupling grating region of a waveguide combiner and the third grating region **104**C corresponding to an output coupling grating region of the same waveguide combiner. In other embodiments, the optical device **100** may include at least the first grating region **104**A corresponding to an input coupling grating region and the second grating region **104**B corresponding to an intermediate grating region.

[0017] FIG. **2** is a schematic, cross-sectional view of a portion **200** of the optical device **100**. The portion **200** includes a plurality of blazed grating structures **202** and a plurality of binary grating structures **204** formed in a grating material layer **201** disposed over a substrate **102**. In an embodiment, the plurality of blazed grating structures **202** and the plurality of binary grating structures **204** of the portion **200** may correspond to the first and second plurality of optical device structures **109**A, **109**B of the first and second grating regions **104**A, **104**B, respectively. In the embodiment shown, the grating material layer **201** and the plurality of binary and blazed grating structures **202**, **204** formed therein are disposed over a top surface **102**A of the substrate **102**. In another embodiment, the plurality of blazed grating structures **202** and the plurality of binary grating structures **204** of the portion **200** may be formed in the substrate **102**.

[0018] The plurality of blazed grating structures **202** and the plurality of binary grating structures **204** maybe spaced apart from each other in a direction parallel with the top surface **102**A of the substrate **102**. In an embodiment, the blazed grating structures **202** can include a blazed surface that is angled or slanted relative to the top surface **102**A of the substrate **102**. For example, FIG. **2** shows a blazed surface **206** of a first blazed grating structure **202***a* and a blazed surface **208** of a second blazed grating structure **202***b* slanted relative to the top surface **102**A of the substrate **102**.

[0019] In an embodiment, which can be combined with other embodiments described herein, the plurality of binary grating structures **204** can be formed with top surfaces **224** parallel with the top surface **102**A of the substrate **102**. Furthermore, in some embodiments, the sidewalls of the plurality of binary grating structures **204** may be parallel with each other. For example, FIG. **2** shows a first sidewall **211** and a second sidewall **212** of a first binary grating structure **204***a* parallel with a third sidewall **214** and a fourth sidewall **216** of a second binary grating structure **204***b*. Additionally, the sidewalls **211**, **212**, **214** and **216** can be oriented normal to the top surface **102**A of the substrate **102**. In certain embodiments, the plurality of binary grating structures **204** can include sub-micron critical dimensions, e.g., nanosized dimensions corresponding to a width of the space **218** between each of the plurality of binary grating structures **204**.

[0020] In an embodiment, the substrate **102** may be any suitable material that can adequately transmit light in a desired wavelength or wavelength range and can serve as an adequate support for the portion **200** of the optical device **100**. In some embodiments, which can be combined with other embodiments described herein, the material of substrate **102** includes, but is not limited to, one or more silicon (Si), silicon dioxide (SiO_2), or sapphire containing materials. For example, the material of substrate **102**, may include at least one of silicon (Si), silicon dioxide (SiO_2), silicon carbide (SiC), germanium (Ge), silicon germanium (SiGe), indium phosphide (InP), gallium arsenide (GaAs), gallium nitride (GaN), fused silica, quartz, or sapphire. In another embodiment, the material of substrate **102** includes high-index transparent materials, such as high-refractive-index (high RI) glass. In other embodiments, which can be combined with other embodiments described herein, the material of substrate **102** includes, but is not limited to, materials having a refractive index between about 1.7 and about 2.0.

[0021] In an embodiment, which can be combined with other embodiments described herein, the grating material layer **201** includes at least one of silicon oxycarbide (SiOC), titanium oxide (TiOx), TiOx nanomaterials, niobium oxide (NbOx), niobium-germanium (Nb3Ge), silicon oxycarbonitride (SiOCN), vanadium (IV) oxide (VOx), aluminum oxide (Al2O3), indium tin oxide (ITO), zinc oxide (ZnO), tantalum pentoxide (Ta2O5), silicon

nitride (Si3N4), Si3N4 silicon-rich, Si3N4 hydrogen-doped Si3N4 boron-doped, silicon carbon nitrate (SiCN), titanium nitride (TiN), zirconium dioxide (ZrO2), gallium phosphide (GaP), poly-crystalline (PCD), nanocrystalline diamond (NCD), and doped diamond containing materials.

[0022] FIG. **3** is a flow diagram of a method **300** of forming a portion of the optical device **400**, according to certain embodiments. FIGS. **4**A-**4**J are schematic, cross-sectional side views of the optical device **400** during the various operations of the method **300**.

[0023] At operation **302**, a device material layer **404** is disposed over a surface of a substrate **102**. The device material layer **404** may be a single layer or may be a matrix stack including multiple layers. The device material layer **404** may be of any of the materials described above with respect to the grating material layer **201**. For example, the device material layer **404** may include at least one of silicon (Si), silicon dioxide (SiO_2), silicon carbide (SiC), germanium (Ge), silicon germanium (SiGe), indium phosphide (InP), gallium arsenide (GaAs), gallium nitride (GaN), fused silica, quartz, or sapphire.

[0024] The device material layer **404** may be disposed over the surface of the substrate **302** by one or more (PVD), chemical vapor deposition (CVD), plasma-enhanced (PECVD), flowable CVD (FCVD), atomic layer deposition (ALD), or spin-on processes. In one embodiment, which can be combined with other embodiments described herein, the device material of device material layer **404** is selected based on the modulated depth and slant angle of the optical structures to be formed for of the portion **200** of optical device **100** and the refractive index of the substrate **102**. In some embodiments, which can be combined with other embodiments described herein, the device material layer **404** includes, but is not limited to, one or more silicon nitride (SiN), silicon oxycarbide (SiOC), titanium oxide (TiOx), titanium dioxide (TiO2), silicon dioxide (SiO2), vanadium (IV) oxide (VOx), aluminum oxide (Al2O3), indium tin oxide (ITO), zinc oxide (ZnO), tantalum pentoxide (Ta2O5), silicon nitride (Si3N4), zirconium dioxide (ZrO2), or silicon carbon-nitride (SiCN) containing materials. In some embodiments, which can be combined with other embodiments described herein, the device material of the device material layer **404** may have a refractive index between about 1.5 and about 2.65. In other embodiments, which can be combined with other embodiments described herein, the device material of the device material layer **404** may have a refractive index between about 3.5 and about 4.0.

[0025] At operation **304**, a patterned hardmask **406** is formed over the device material layer **404**. In an embodiment, the patterned hardmask **406** may be made of any suitable material for patterning the device material layer **404** using a lithography process, such as chromium or silicon nitride. In one embodiment, which can be combined with other embodiments described herein, the patterned hardmask **406** is non-transparent and is removed after the portion **200** of optical device **100** is formed. In another embodiment, the patterned hardmask **406** is transparent. In some embodiments, which can be combined with other embodiments described herein, the hardmask **312** includes, but is not limited to, chromium (Cr), silver (Ag), Si3N4, SiO2, TiN, or carbon (C) containing materials. In certain embodiments, forming the patterned hardmask **406** in operation **304** includes disposing a hardmask material layer **407** over the device material layer **404**, disposing a photoresist layer over the hardmask material layer **407**, patterning the photoresist layer to expose portions of the hardmask material layer **407**, and removing the exposed portions of the hardmask material layer **407** to form the patterned hardmask **406** with hardmask structures **406**A patterned therein.

[0026] The hardmask material layer **407** may be disposed over the device material layer **404** by one or more liquid material pour casting, spin-on coating, liquid spray coating, dry powder coating, screen printing, doctor blading, PVD, CVD, PECVD, FCVD, ALD, evaporation, or sputtering processes. The hardmask **312** can be deposited so that the thickness of the hardmask **312** is substantially uniform. In yet other embodiments, the hardmask **312** can be deposited so that the thickness varies from about 30 nm and about 50 nm at varying points on the device material layer **404**.

[0027] In an embodiment, as shown in FIG. **4**B, operation **304** may include depositing a photoresist stack **405** over the hardmask material layer **407**. In an embodiment, the photoresist stack **405** includes an organic planarizing layer (OPL) **408**, a silicon-containing anti-reflective coating (SiARC) **410**, and a patterned photoresist layer **412**. In an embodiment, The OPL **408** may include any organic polymer and a photo-active compound having a molecular structure that can attach to the molecular structure of the organic polymer. For example, the OPL **408** may include a photo-sensitive organic polymer comprising a light-sensitive material that, when exposed to electromagnetic (EM) radiation, is chemically altered and thus configured to be removed using a developing solvent. In one embodiment, which can be combined with other embodiments described herein, the OPL **408** may be disposed using a spin-on coating process. In another embodiment, which can be combined with other embodiments described herein, the OPL **408** may include, but is not limited to, one or more of polyacrylate resin, epoxy resin, phenol resin, polyamide resin, polyimide resin, unsaturated polyester resin, polyphenylenether resin, polyphenylenesulfide resin, or benzocyclobutene (BCB). Next, the SiARC **410** is formed over the OPL **408**. In an embodiment, the SiARC **410** is formed from silicon-based materials using, for example, a chemical vapor deposition process or a spin coating process.

[0028] Lastly, the patterned photoresist layer **412** is formed by disposing a photoresist material on the SiARC **410** and developing the photoresist material. The patterned photoresist layer **412** defines a hardmask pattern for patterning the hardmask material layer **407**. In one embodiment, which can be combined with other embodiments described herein, the photoresist material may be disposed on the OPL **408** using a spin-on coating process. In another embodiment, which can be combined with other embodiments described herein, the patterned photoresist layer **412** may include, but is not limited to, light-sensitive polymer containing materials. In an embodiment, the patterned photoresist layer **412** may comprise a polymer material, such as polydimethylsiloxane (PDMS). In an embodiment,

the patterned photoresist layer **412** may include a solvent, a photoresist resin, and a photoacid generator. The photoresist resin may be any positive photoresist resin or any negative photoresist resin. Representative photoresist resins include acrylates, novolak resins, poly(methylmethacrylates), and poly(olefin sulfones. Developing the photoresist material may include performing a lithography process, such as photolithography and/or digital lithography.

[0029] As discussed above, the patterned photoresist layer **412** defines the hardmask pattern for patterning the hardmask material layer **407** using the photoresist stack **405**. After the patterned photoresist layer **412** is formed, the photoresist stack **405** and the hardmask material layer **407** are patterned using an etching process. It should be understood that patterning the hardmask material layer **407** with OPL **408** and SiARC **410** is an exemplary method. Other patterning methods can be used together. In certain embodiments, the patterning method is generally selected with regard to the size and shape of the structure to be patterned.

[0030] In operation **306**, the photoresist stack **405** is removed using suitable methods, such as resist stripping. Stripping the patterned photoresist layer **412**, SiARC **410**, and OPL **408** yields the patterned hardmask **406**. The patterned hardmask **406** includes a first portion **406**A and a second portion **406**B. The pattern in the first portion **406**A exposes a first region **422** of the device material layer **404** below, and the pattern in the second portion **406**B exposes a second region **424** of the device material layer **404**.

[0031] In operation **308**, a first resist layer **414** is formed over the second portion **406**B of the patterned hardmask **406** and the second region **424** of the device material layer **404**, as shown in FIG. **4**D. The first resist layer **414** prevents the second region **424** of the device material layer **404** from being impacted by one or more etch process in subsequent operation **310**. Although non-limiting, the first resist layer **414** maybe a photoresist film or a gray tone resist film. Alternatively, the first resist layer **414** may be a hardmask, such as a Cr hardmask deposited as a thin film and lithographically patterned.

[0032] In operation **310**, the first region **422** of the device material layer **404** exposed by the first portion **406**A of the patterned hardmask **406** is etched to pattern the first region **422** of the device material layer **404** and form the plurality of optical device structures **109**A in the device material layer **404**, as shown in FIG. **4**E. In an embodiment, the plurality of optical device structures **109**A formed in operation **310** includes a plurality of binary optical features, such as the plurality of binary grating structures **204** discussed above for FIG. **2**. After the plurality of optical device structures **109**A are formed, the first resist layer **414** is removed from the patterned hardmask **406**.

[0033] In operation **312**, an organic dielectric layer (ODL) **418** is deposited over the patterned hardmask **406** and the first and second regions **422**, **424** of the device material layer **404** exposed by the patterned hardmask **406**. For example, the ODL **418** may be deposited by a vapor deposition process, such as by fluorinated chemical vapor deposition over the patterned hardmask **406**, the second region **424** of the device material layer **404**, and the first region **422** of the device material layer **404** including the spaces between the plurality optical device structures **109**A formed in the first region **422** of the device material layer **404**.

[0034] In operation **314**, the ODL **418** may be etched, for example by blanket etching, to remove excess portions of the ODL **418** and expose the patterned hardmask **406**. Operation **314** results in forming a planar surface across a top surface of the patterned hardmask **406** and the ODL **418**, as shown in FIG. **4**G.

[0035] In operation **316**, a second resist layer **420** is formed on the first portion **406**A of the patterned hardmask **406** and exposed segments of the ODL **418** deposited over the first region **422** of the device material layer **404**, as shown in FIG. **4**H. Operation **316** includes leaving the second portion **406**B of the patterned hardmask **406** and exposed segments of the ODL **418** deposited over the second region **424** of the device material layer **404** exposed. In contrast, the second resist layer **420** prevents segments of the ODL **418** exposed by the first portion **406**A of the patterned hardmask **406** from being impacted by one or more etch process in subsequent operation **318**. Although non-limiting, the second resist layer **420** maybe a photoresist film or a gray tone resist film. Alternatively, the second resist layer **420** may be a hardmask, such as a Cr hardmask deposited as a thin film and lithographically patterned.

[0036] In operation **318**, the exposed segments of the ODL **418** over the second region **424** of the device material layer **404** is selectively etched to form dielectric structures in the exposed ODL **418** segments. For example, operation **318** may include directionally etching the exposed segments of the ODL **418** to produce a plurality of blazed ODL structures **418**A within the openings in the second portion **406**B of the patterned hardmask **406**, as shown in FIG. **4**I. In an embodiment, operation **318** may be performed by a selective etch process. The selective etch process may include, but is not limited to, at least one of IBE, RIE, or directional RIE. In an embodiment in which the ODL **418** is etched by an IBE process, the ion beam generated by IBE may include, but is not limited to, at least one of a ribbon beam, a spot beam, or a full substrate-size beam. The ion beam has etch chemistry that is selective to the patterned hardmask **306**, i.e., only exposed segments of the ODL **418** is etched. Performing the selective etch process etches the exposed segments of the ODL **418** to form the plurality of blazed ODL structures **418**A.

[0037] In operation **320**, a transfer etch process is performed on the plurality of blazed ODL structures **418**A of the ODL **418** to form the second plurality of optical device structures **109**B in the underlying device material layer **404**. The results of operation **320** are shown in FIG. **4**J. In this embodiment, the transfer etch process removes the blazed ODL structures **418** and etches the device mater layer **404** to produce the second plurality of optical device structures **109**B within the second region **424** of the device material layer **404**. In an embodiment, the transfer etch process in operation **320** may be the same etch process utilized in operation **318**, such as an IBE process.

[0038] In operation **322**, the second resist layer **420**, segments of the ODL **418** deposited over the first region **422** of the device material layer **404**, and the patterned hardmask **406** may be removed, such as by resist stripping and wet etching. Removing the second photoresist layer **420**, the ODL **418**, and the patterned hardmask **406** results in the portion of optical device **400**, as shown in FIG. **4**K. In an embodiment, the the portion of optical device **400** formed from method **300** may correspond to the portion **200** of the optical device **100** having the plurality of blazed grating structures **202** and the plurality of binary grating structures **204** formed in the grating material layer **201**. In some embodiments, the patterned hardmask **406** may be made of a transparent material such that the patterned hardmask **406** is left on the device material layer **404**.

[0039] In summation, the methods for forming an optical device having blazed and binary grating structures on the same device material layer are described herein. The methods include forming binary grating structures in a first region of the device material layer and forming blazed grating structures in a second region of the device material layer. The blazed grating structures may be formed using a selective etch process, such as IBE, and the binary grating structures may be formed using a single lithography process. The methods described herein may advantageously provide for easily forming different optical structures in a device material layer to improve optical performance of an optical device. For example, the methods provide for forming blazed grating structures that can be used grating structures for an input coupling region in a waveguide combiner. Blazed grating structures are desirable for input coupling regions of AR waveguide combiners due to the high diffraction efficiency of the blazed grating structures. The method described herein can also be used to create a device structure that functions as a master for nanoimprint lithography.

[0040] When introducing elements of the present disclosure or exemplary aspects or embodiment(s) thereof, the articles "a," "an," "the" and "said" are intended to mean that there are one or more of the elements.

[0041] The terms "comprising," "including" and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements.

[0042] The term "coupled" is used herein to refer to the direct or indirect coupling between two objects. For example, if object A physically touches object B and object B touches object C, the objects A and C may still be considered coupled to one another—even if objects A and C do not directly physically touch each other. For instance, a fist object may be coupled to a second object even though the first object is never directly in physical contact with the second object.

[0043] 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 of forming an optical device, comprising:

forming a patterned hardmask over a device material layer deposited on a top surface of a substrate, a first portion of the patterned hardmask exposing a first region of the device material and a second portion of the patterned hardmask exposing a second region of the device material layer;

patterning the first region of the device material layer to form a first plurality of optical features in the first region of the device material layer,

depositing a dielectric layer over the patterned hardmask and the device material layer;

selectively etching the dielectric layer and the device material layer to form a second plurality of optical features in the second region of the device material layer; and

removing remaining portions of the dielectric layer deposited on the device material layer.

2. The method of claim **1**, wherein the first plurality of optical features comprises a plurality of binary grating structures having top surfaces substantially parallel with the top surface of the substrate, and sidewalls substantially perpendicular to the top surface of the substrate.

3. The method of claim **1**, wherein the second plurality of optical features comprises a plurality of blazed grating structures.

4. The method of claim **1**, wherein patterning the first region of the device material layer to form the first plurality of optical features comprises performing a lithographic patterning and etch process in the first region of the device material layer.

5. The method of claim **1**, wherein selectively etching the dielectric layer and the device material layer comprises directionally etching the dielectric layer deposited on the second region of the device material layer exposed by the second portion of the patterned hardmask to form a plurality of dielectric structures over the second region of the device material layer, and etching the plurality of dielectric structures and the second region of the device material layer to form the second plurality of optical features in the device material layer.

6. The method of claim **1**, wherein forming the patterned hardmask comprises depositing a hardmask material layer on the device material layer and performing a nanoimprint lithography process to pattern the hardmask material layer and form the patterned hardmask.

7. The method of claim **1**, wherein forming the patterned hardmask comprises: depositing a hardmask material layer on the device material layer; forming a photoresist stack over the hardmask material layer, the photoresist stack comprising an organic planarizing layer (OPL), a silicon anti-reflective coating (SiARC), and a photoresist; and etching the photoresist stack to form a pattern in the hardmask material layer.

8. The method of claim **1**, further comprising removing the patterned hardmask after the second plurality of optical feature are formed in the device material layer.

9. The method of claim **1**, wherein selectively etching the dielectric layer and the device material layer comprises selectively etching the dielectric layer to from a plurality of dielectric structures over the second region of the device

material layer, and performing a transfer etch process to etch the plurality of dielectric structures and the second region of the device material layer to form the second plurality of optical features in the second region of the device material layer.

10. A method of forming an optical device, comprising:

positioning a substrate in a process chamber, the substrate comprising a device material layer deposited over a top surface of the substrate;

forming a patterned hardmask over the device material layer, a first portion of the patterned hardmask exposing a first region of the device material and a second portion of the patterned hardmask exposing a second region of the device material layer;

forming a first resist layer over the patterned hardmask, wherein the first resist layer prevents the second region of the device material from being etched;

etching the first region of the device material layer to form a first plurality of optical features in the device material layer;

depositing a dielectric layer over the first and second regions of the device material layer exposed by the patterned hardmask;

forming a second resist layer over the patterned hardmask, wherein the second resist layer prevents segments of the dielectric layer deposited over the first region of the device material from being etched;

selectively etching segments of the dielectric layer exposed by the second portion of the patterned hardmask to form a plurality of dielectric structures over the second region of the device material layer;

etching the plurality of dielectric structures and the second region of the device material layer to form a second plurality of optical features in the second region of the device material layer;

removing the second resist layer and remaining portions of the dielectric layer over the first region of the device material layer.

11. The method of claim **10**, wherein depositing the dielectric layer over the first and second regions of the device material layer comprises depositing the dielectric layer over the patterned hardmask and etching the dielectric layer to expose the patterned hardmask and form a planar surface across a top surface of the dielectric layer and a top surface of the patterned hardmask.

12. The method of claim **10**, wherein the first plurality of optical features comprises a plurality of binary grating structures in which top surfaces of the plurality of binary grating structures are substantially parallel with the top surface of the substrate and sidewalls of the plurality of binary grating structures are substantially perpendicular to the top surface of the substrate.

13. The method of claim **10**, wherein the second plurality of optical features comprises a plurality of blazed grating structures.

14. The method of claim **10**, further comprising removing the first resist layer after the first plurality of optical features are formed, and removing the second resist layer after the second plurality of optical features are formed.

15. The method of claim **10**, further comprising removing the patterned hardmask after removing the remaining portions of the dielectric layer over the first region of the device material layer.

16. The method of claim **10**, wherein forming the patterned hardmask comprises:

depositing a hardmask material layer on the device material layer;

forming a photoresist stack over the hardmask material layer, the photoresist stack comprising an organic planarizing layer (OPL), a silicon anti-rfeflective coating (SiARC), and a photoresist; and

etching the photoresist stack to form a pattern in the hardmask material layer.

17. An optical device, comprising:

a substrate having a device material layer disposed thereon;

a first grating region formed in a top surface of the device material layer, the first grating region on a first portion of the device material layer and comprising a plurality of binary grating structures having top surfaces substantially parallel with a top surface of the substrate, and sidewalls substantially perpendicular to the top surface of the substrate; and

a second grating region formed in the top surface of the device material layer on a second portion of the device material layer, the second grating region comprising a plurality of blazed grating structures.

18. The optical device of claim **17**, wherein the first and second gratings regions correspond to an input coupling grating and an output coupling grating of a waveguide combiner, respectively.

19. The optical device of claim **17**, wherein the plurality of blazed grating structures comprise a blazed surface that is angled relative to the top surface of the substrate.

20. The optical device of claim **17**, further comprising a patterned hardmask disposed over the device material layer, the patterned hardmask comprising a transparent material.

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