US 20200192010A1

(19) **United States**

(12) **Patent Application Publication**

OLSON et al.

(10) **Pub. No.: US 2020/0192010 A1**

(43) **Pub. Date: Jun. 18, 2020**

(54) METHOD OF FORMING GRATINGS

(71) Applicant: **Applied Materials, Inc.**, Santa Clara, CA (US)

(72) Inventors: **Joseph C. OLSON**, Beverly, MA (US); **Ludovic GODET**, Sunnyvale, CA (US); **Rutger MEYER TIMMERMAN THIJSSEN**, San Jose, CA (US); **Morgan EVANS**, Manchester, MA (US); **Jinxin FU**, Fremont, CA (US)

(73) Assignee: **Applied Materials, Inc.**, Santa Clara, CA (US)

(21) Appl. No.: **16/715,906**

(22) Filed: **Dec. 16, 2019**

Related U.S. Application Data

(60) Provisional application No. 62/780,792, filed on Dec. 17, 2018.

Publication Classification

(51) **Int. Cl.**

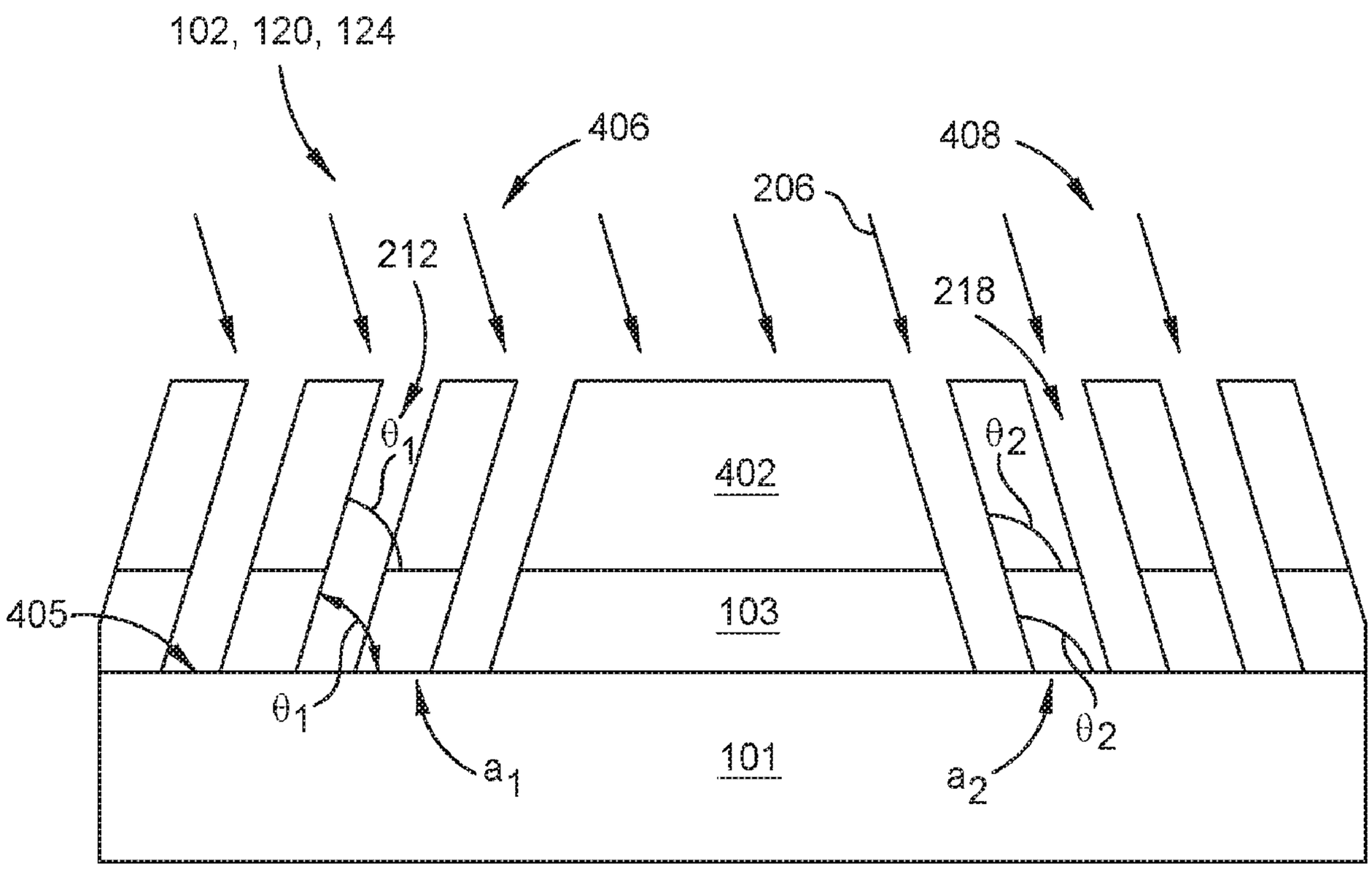
G02B 5/18	(2006.01)
G03F 7/16	(2006.01)
G03F 7/00	(2006.01)
G03F 7/20	(2006.01)

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

CPC ***G02B 5/1857*** (2013.01); ***G03F 7/2002*** (2013.01); ***G03F 7/001*** (2013.01); ***G03F 7/16*** (2013.01)

(57) **ABSTRACT**

Embodiments of the disclosure generally relate to methods of forming gratings. The method includes depositing a resist material on a grating material disposed over a substrate, patterning the resist material into a resist layer, projecting a first ion beam to the first device area to form a first plurality of gratings, and projecting a second ion beam to the second device area to form a second plurality of gratings. Using a patterned resist layer allows for projecting an ion beam over a large area, which is often easier than focusing the ion beam in a specific area.



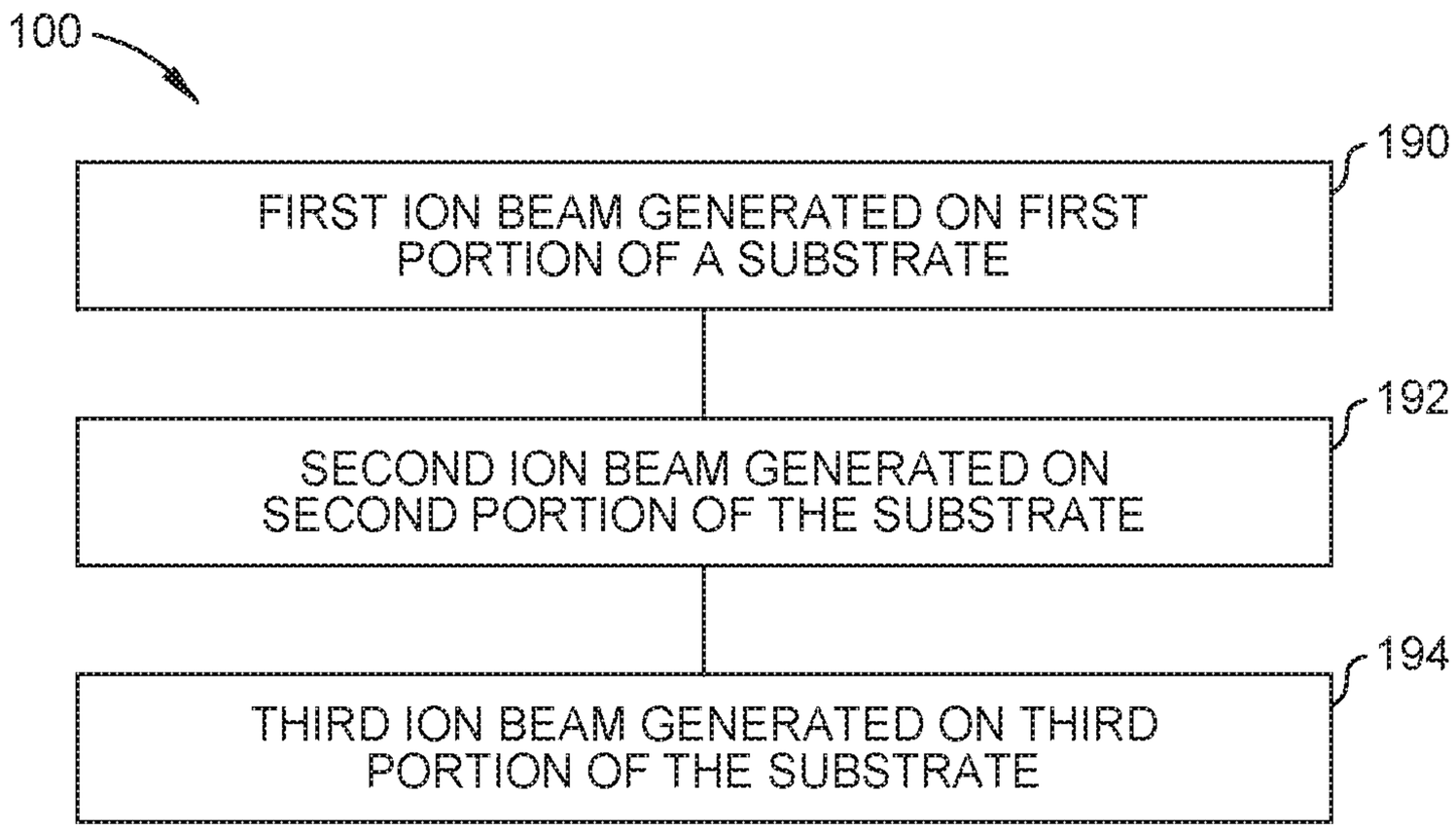

100
190
FIRST ION BEAM GENERATED ON FIRST PORTION OF A SUBSTRATE
192
SECOND ION BEAM GENERATED ON SECOND PORTION OF THE SUBSTRATE
194
THIRD ION BEAM GENERATED ON THIRD PORTION OF THE SUBSTRATE

FIG. 1A

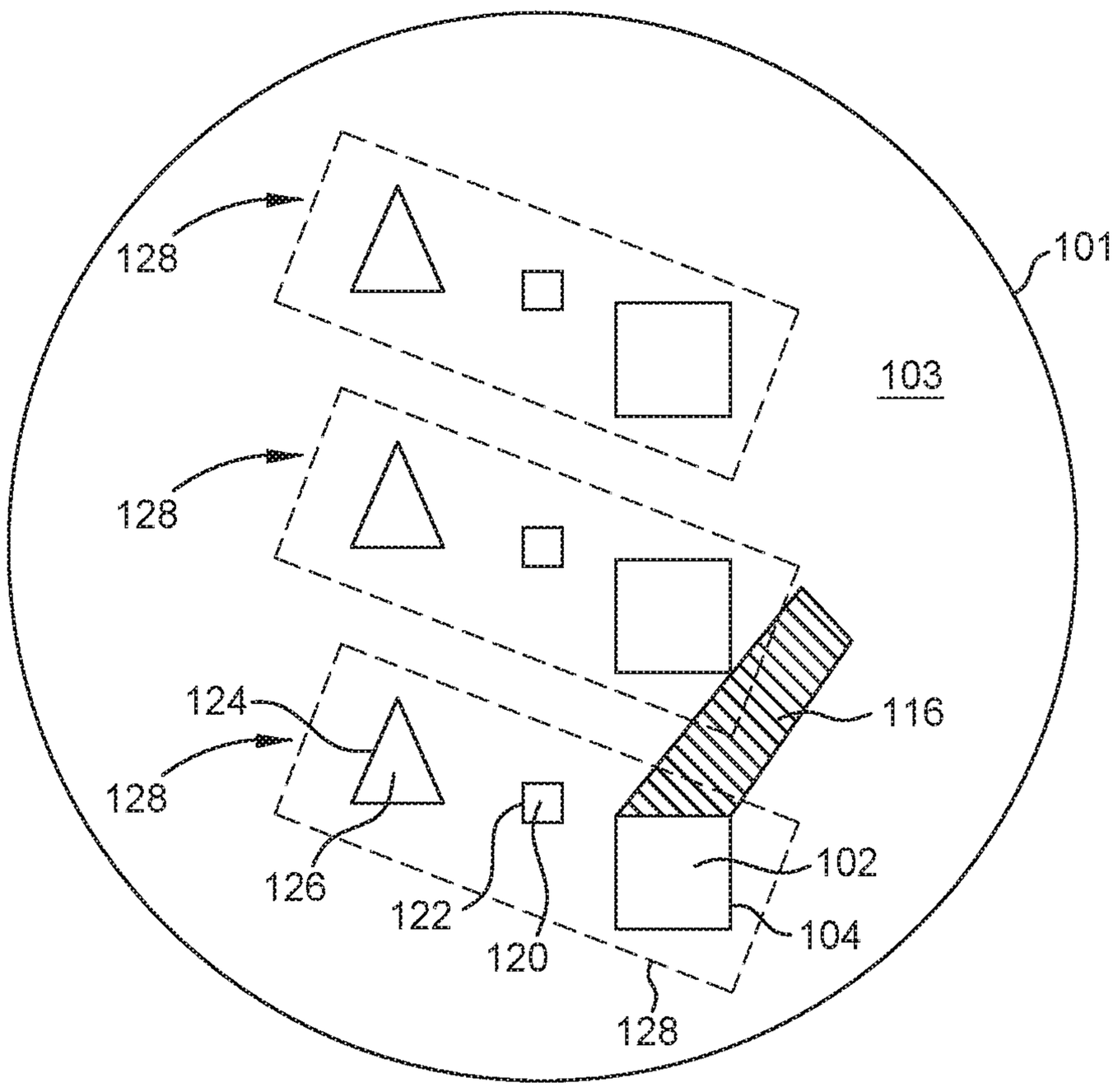

101
103
128
128
124
128
126
122
120
116
102
104
128

FIG. 1B

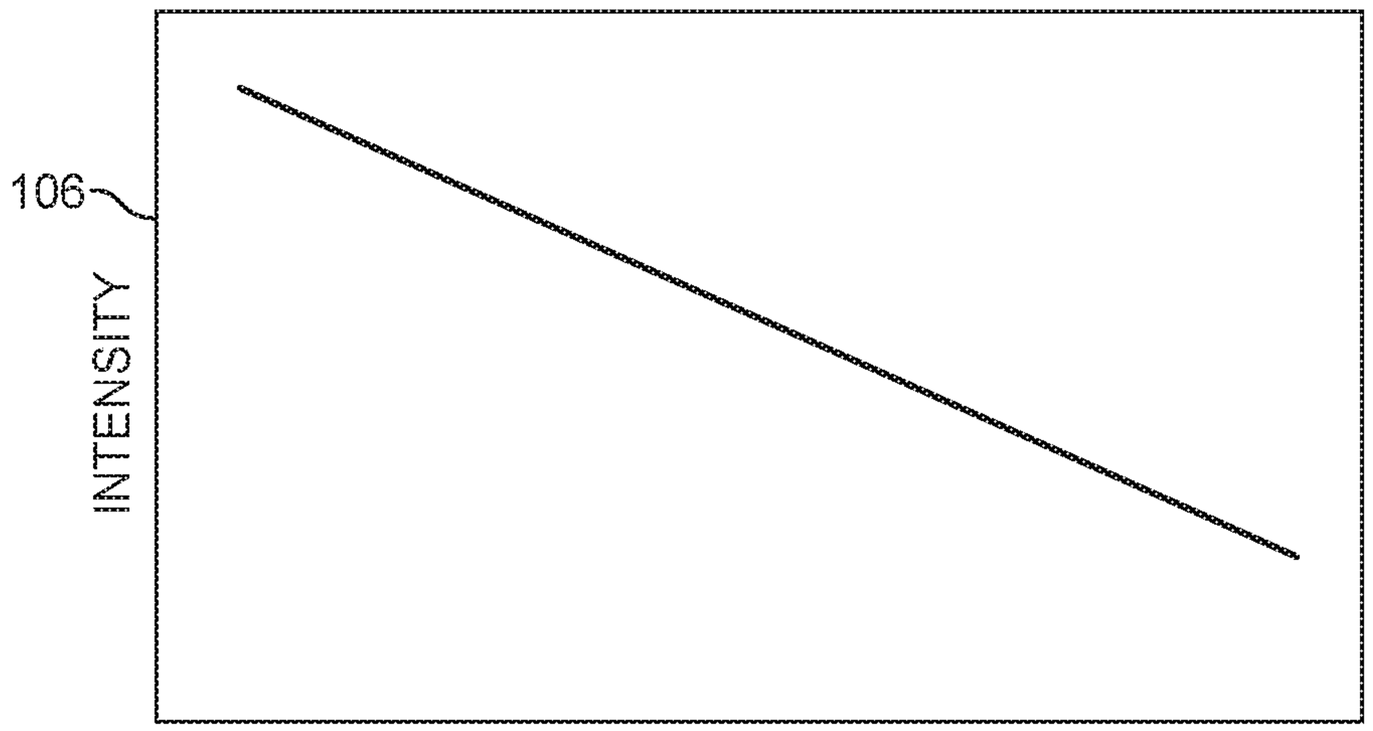


FIG. 1C

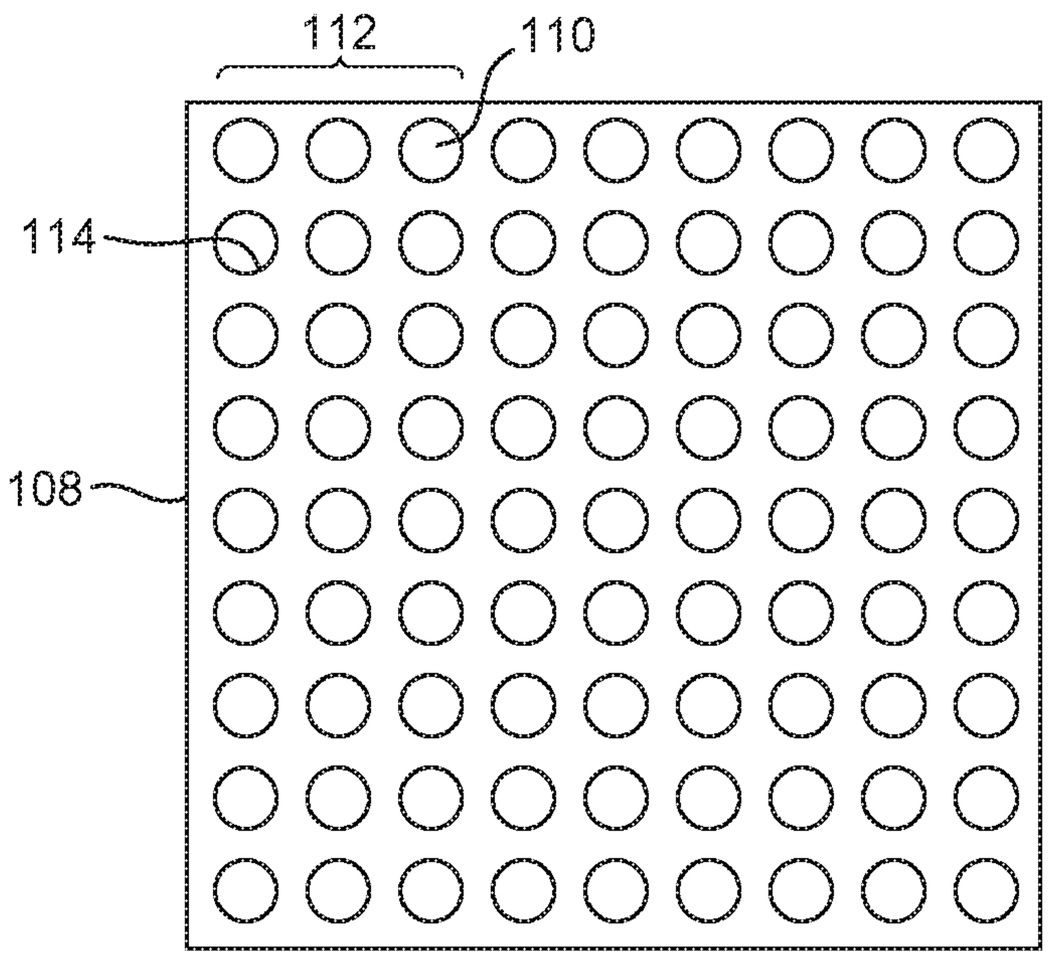


FIG. 1D

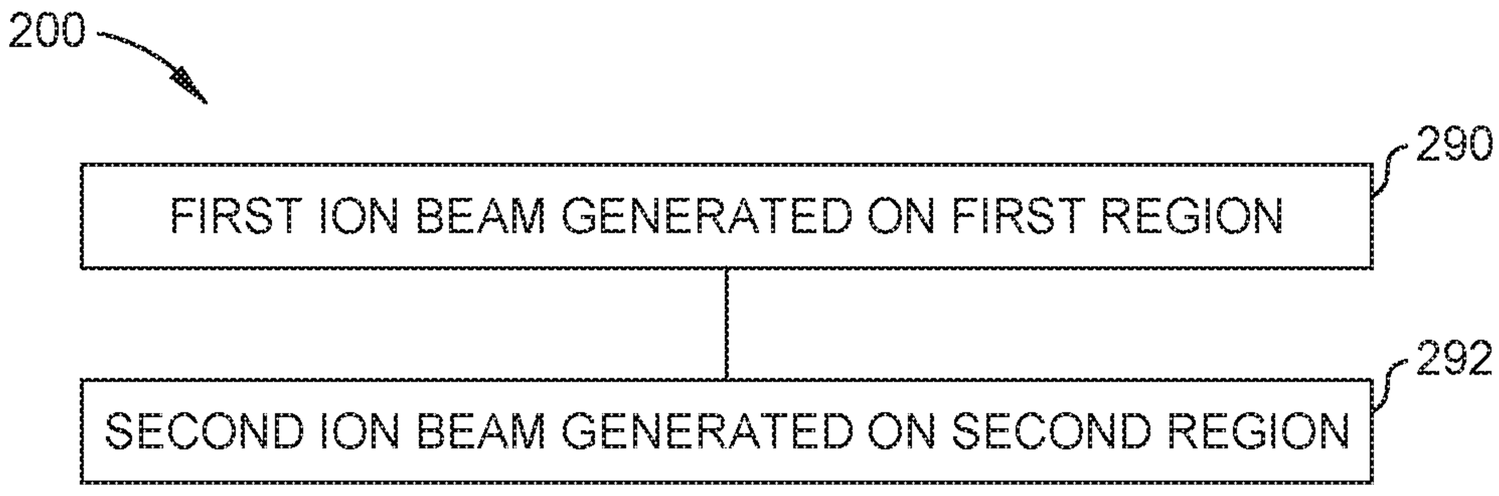

200
290
FIRST ION BEAM GENERATED ON FIRST REGION
292
SECOND ION BEAM GENERATED ON SECOND REGION

FIG. 2A

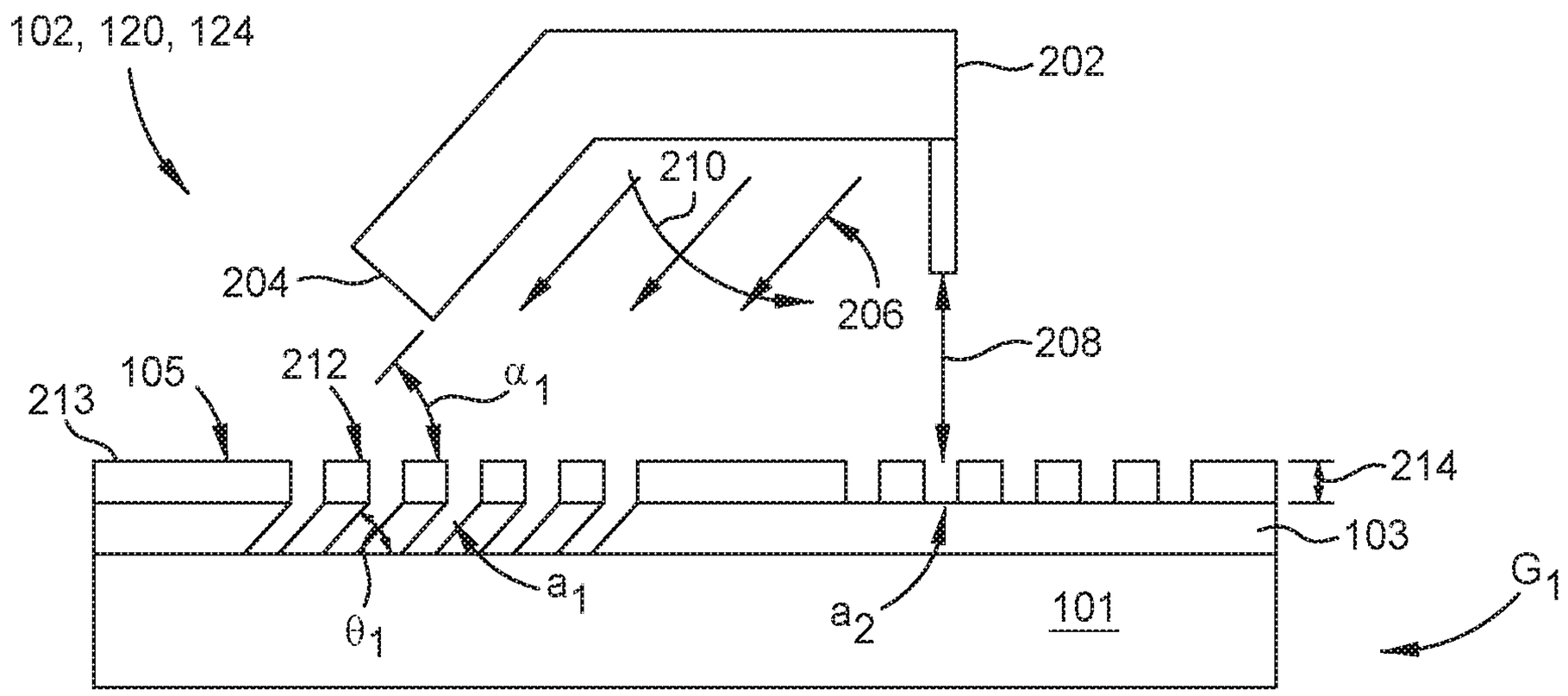

102, 120, 124
202
210
204
206
208
105
212
α_1
213
214
103
a_1
a_2
101
θ_1
G_1

FIG. 2B

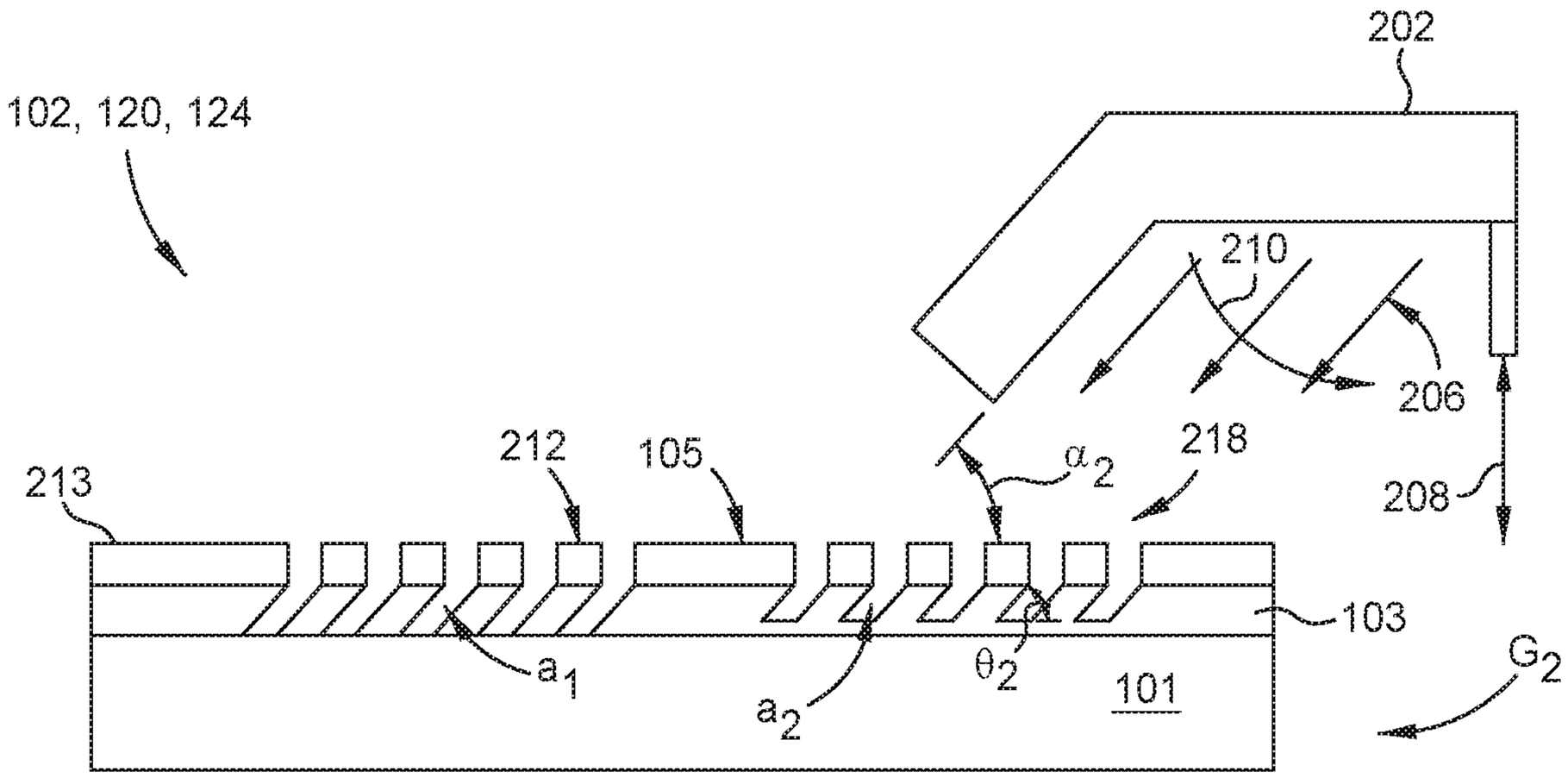


FIG. 2C

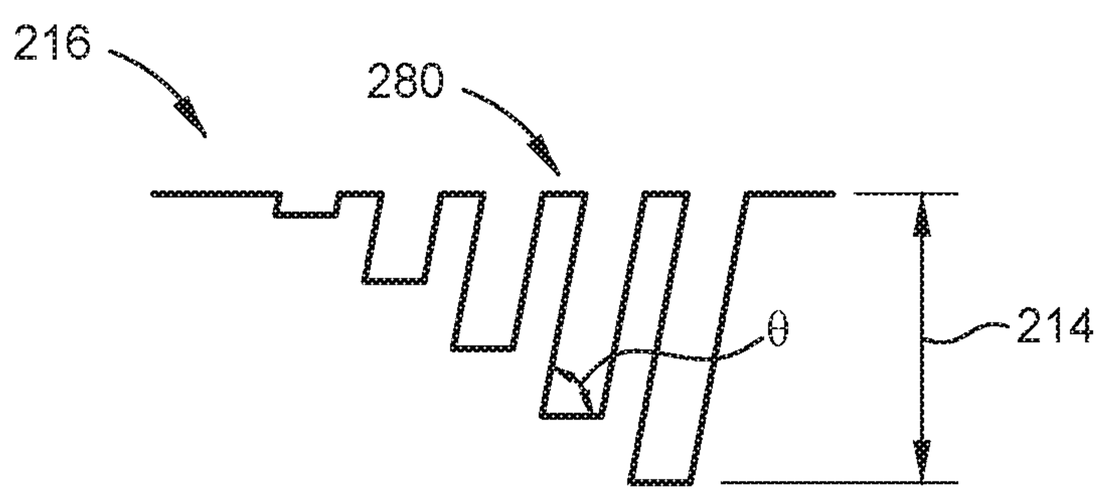


FIG. 2D

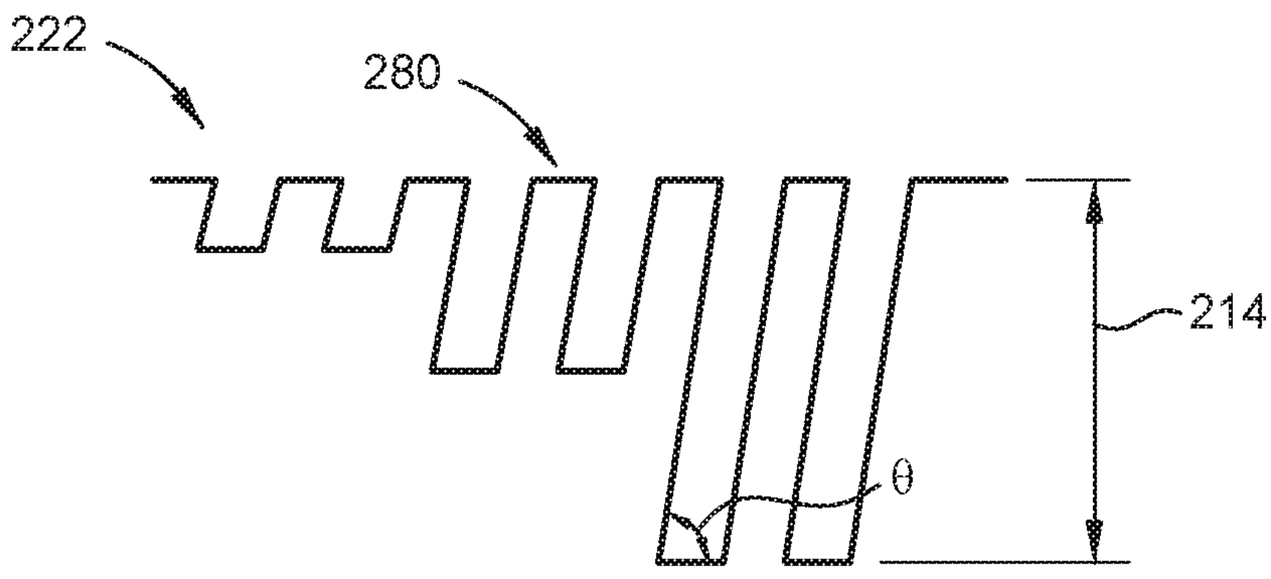


FIG. 2E

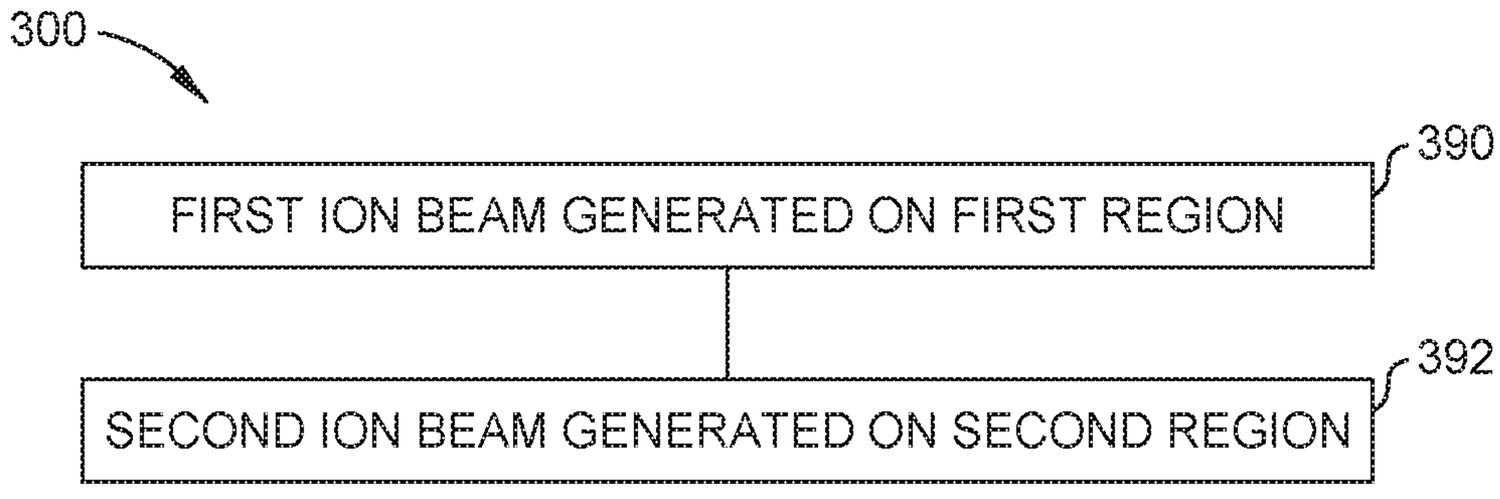

300
FIRST ION BEAM GENERATED ON FIRST REGION
390
SECOND ION BEAM GENERATED ON SECOND REGION
392

FIG. 3A

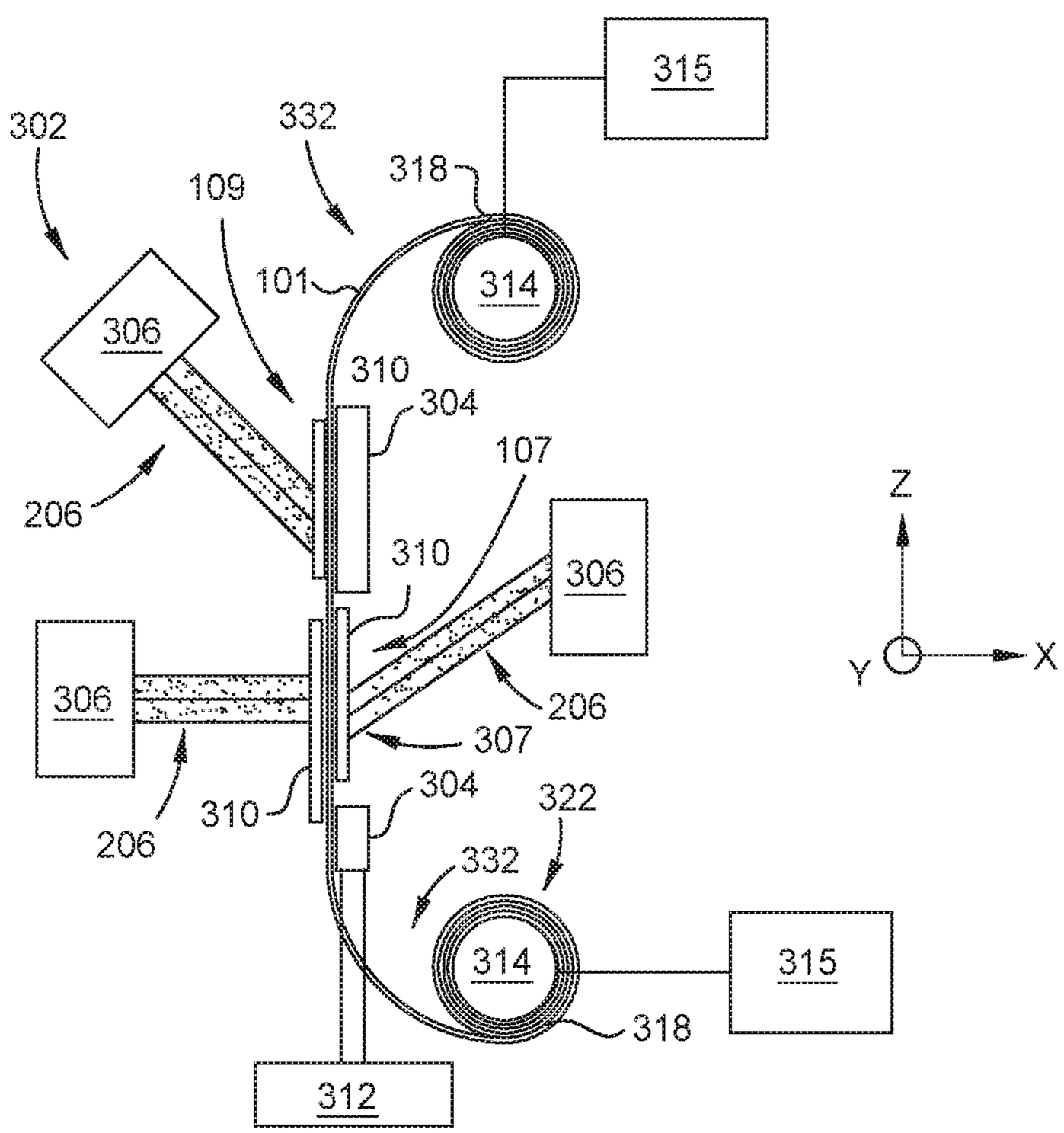

315
302
332
318
109
101
314
306
310
304
107
206
310
306
306
206
307
206
310
304
322
332
314
315
318
312
Z
Y
X

FIG. 3B

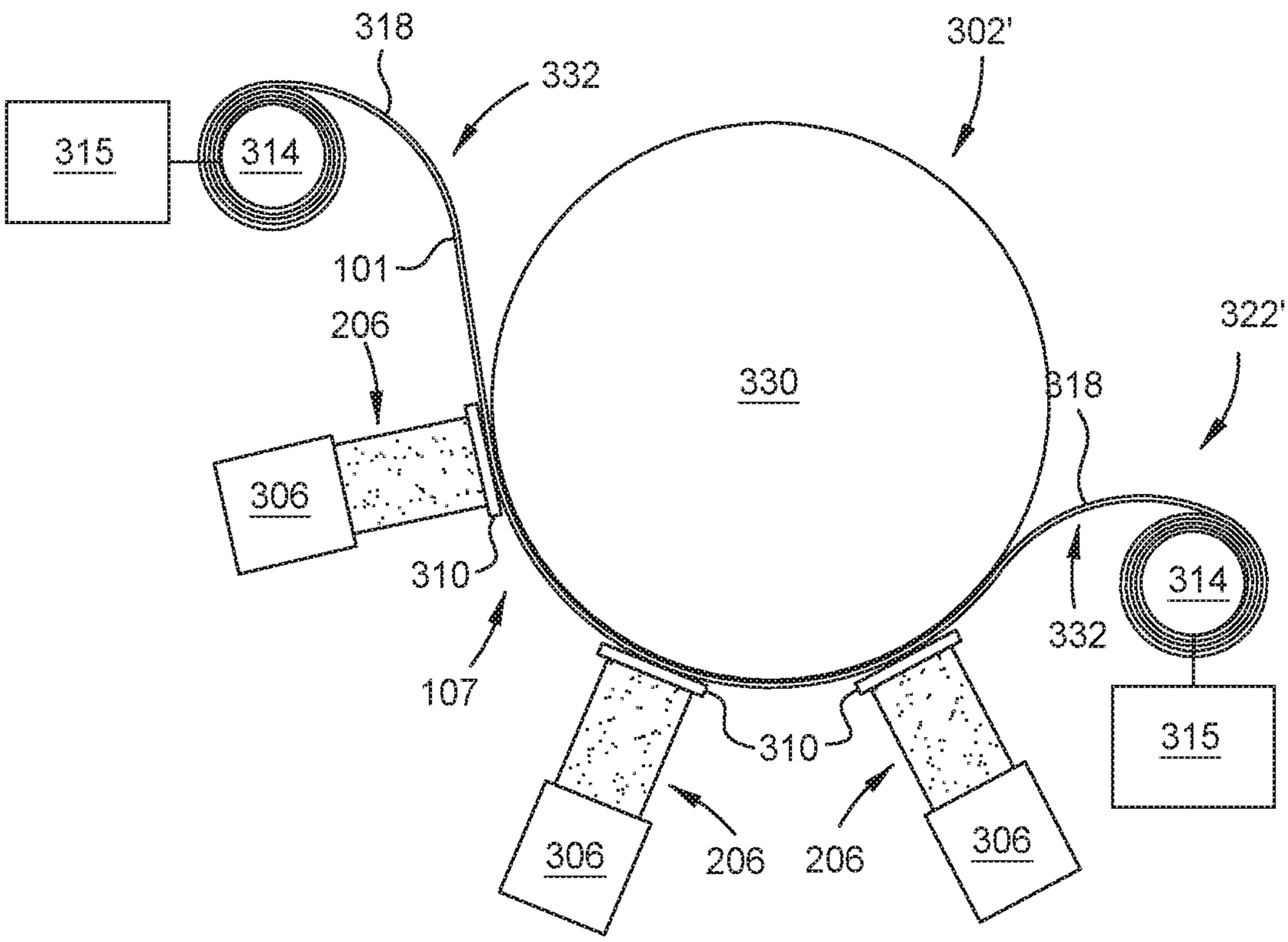

318
302'
332
315
314
101
206
322'
330
318
306
310
314
332
107
315
310
306
206
206
306

FIG. 3C

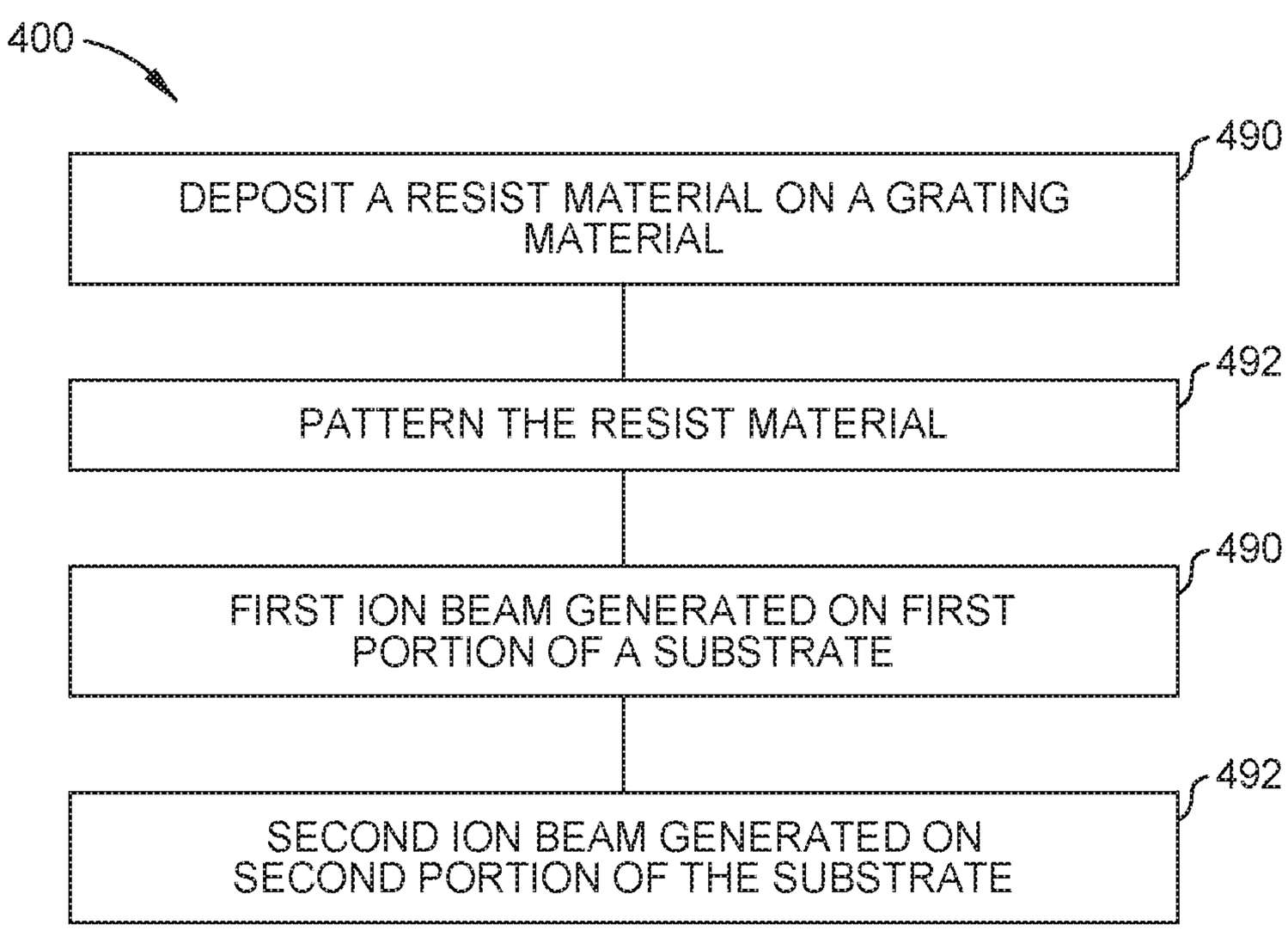

400
DEPOSIT A RESIST MATERIAL ON A GRATING MATERIAL
490
PATTERN THE RESIST MATERIAL
492
FIRST ION BEAM GENERATED ON FIRST PORTION OF A SUBSTRATE
490
SECOND ION BEAM GENERATED ON SECOND PORTION OF THE SUBSTRATE
492

FIG. 4A

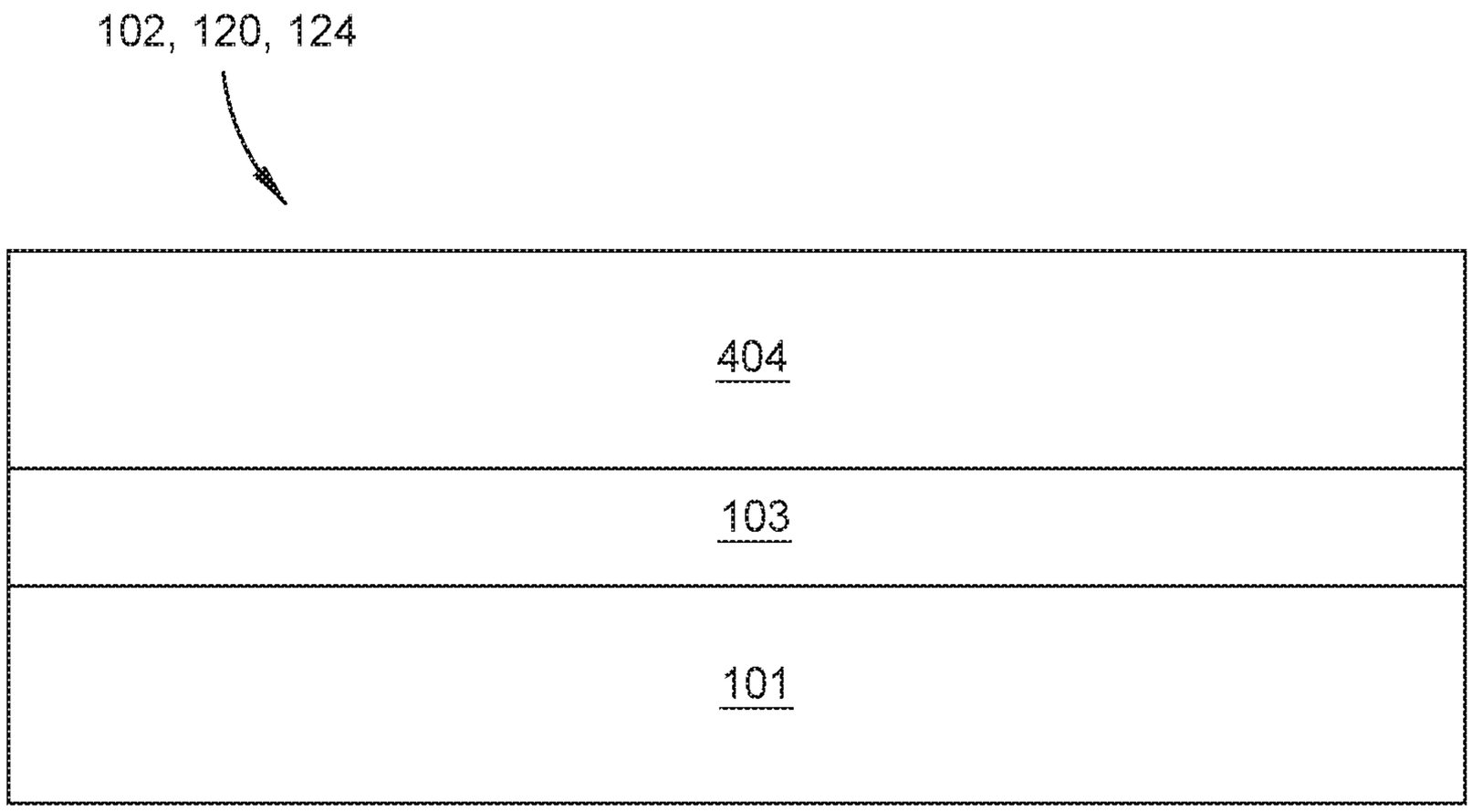

102, 120, 124
404
103
101

FIG. 4B

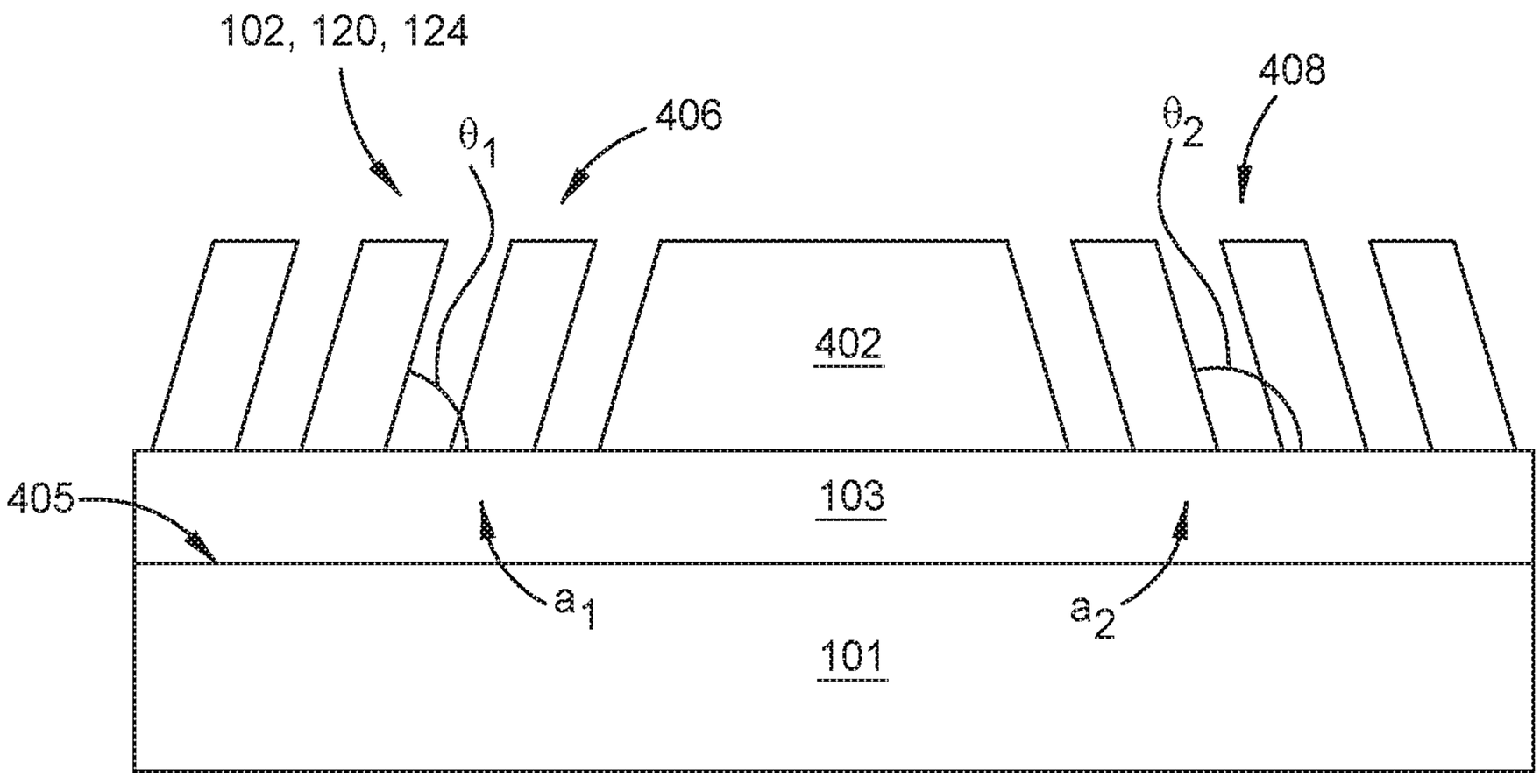

102, 120, 124
θ1
406
θ2
408
402
405
103
a1
a2
101

FIG. 4C

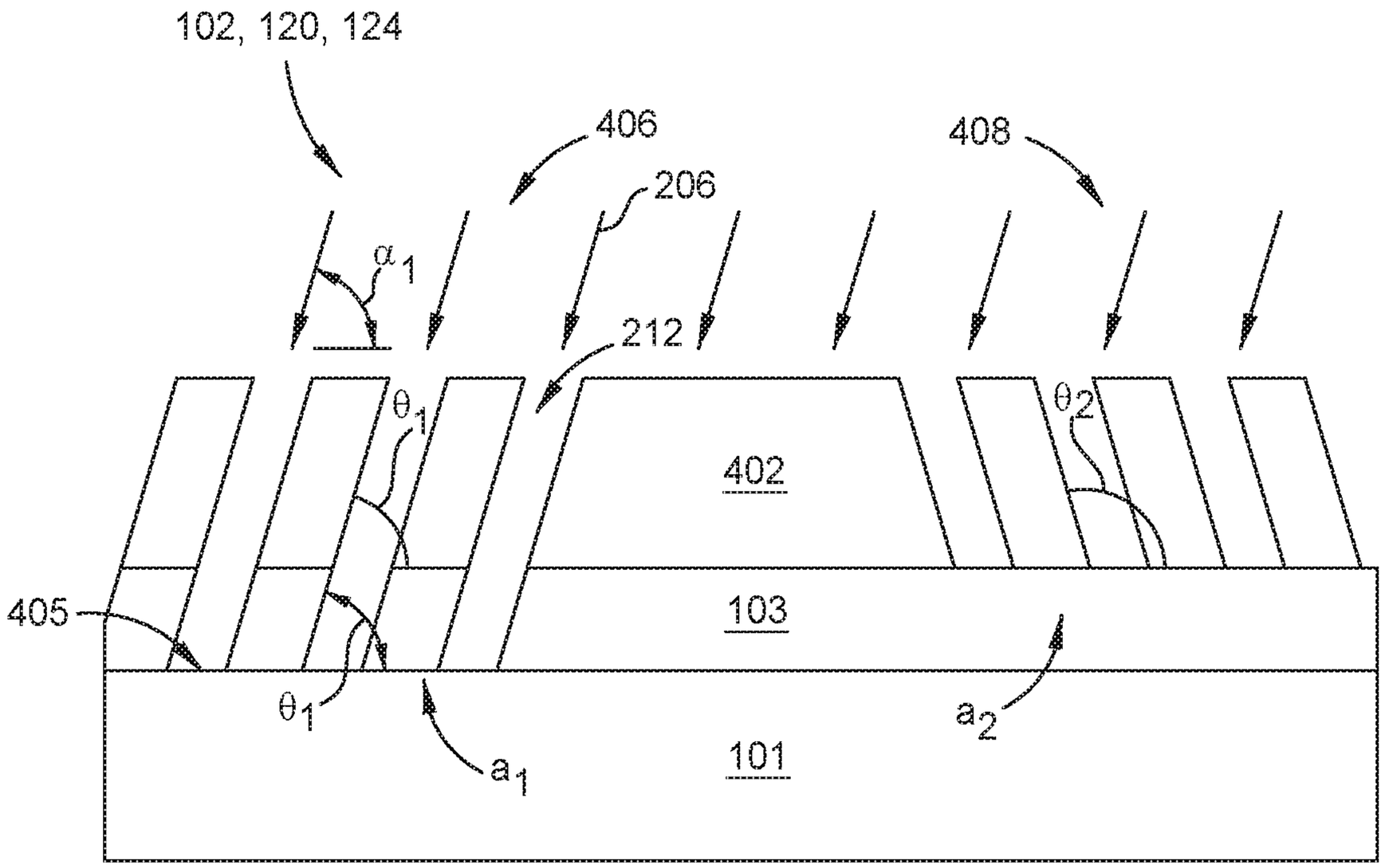

102, 120, 124
406
408
206
α_1
212
θ_1
θ_2
402
405
103
θ_1
a_2
a_1
101

FIG. 4D

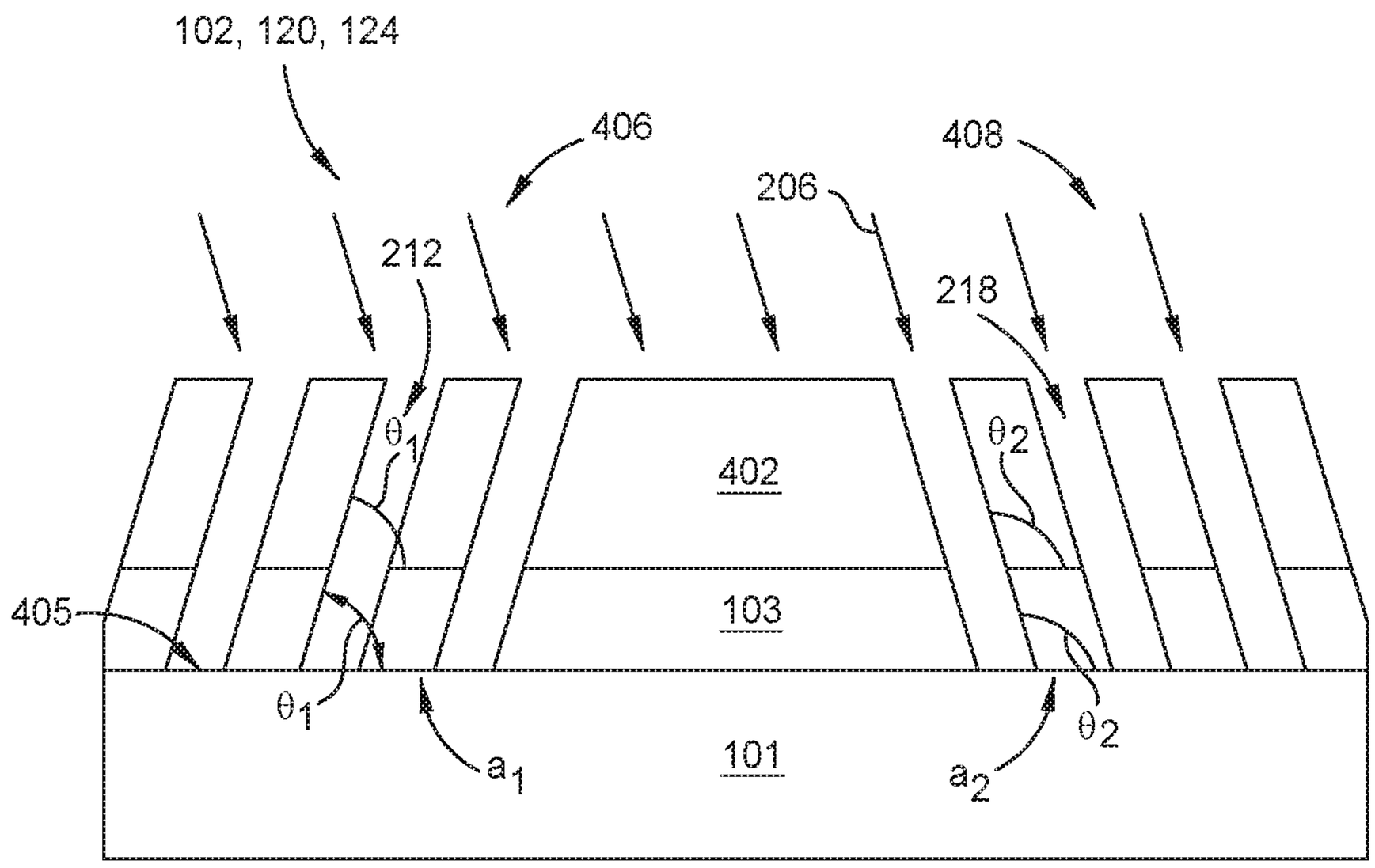

102, 120, 124
406
408
206
212
218
θ_1
θ_2
402
405
103
θ_1
a_1
101
a_2
θ_2

FIG. 4E

METHOD OF FORMING GRATINGS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 62/780,792, filed Dec. 17, 2018, which is hereby incorporated by reference in its entirety.

BACKGROUND

Field

[0002] Embodiments of the present disclosure generally relate to a method and, more specifically, to a method of forming gratings.

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, 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.

[0005] A virtual image is overlaid on an ambient environment to provide an augmented reality experience to the user. Waveguides are used to assist in overlaying images. Generated light is propagated through a waveguide until the light exits the waveguide and is overlaid on the ambient environment. Optical devices generally need multiple waveguides with different physical properties on the same substrate in order to guide light of different wavelengths.

[0006] One drawback in the art is that manufacturing waveguides on the same substrate is a time-consuming process. Different mask steps and methods are needed in photolithography in order to manufacture waveguides with different material properties. In addition, some photolithography methods do not have the capability to make varying spacing and profiles of gratings in the different waveguides.

[0007] Therefore, what is needed is a manufacturing process that allows formation of grating regions with different grating profiles.

SUMMARY

[0008] Embodiments of the disclosure generally relate to methods of forming gratings. A resist layer is disposed over grating material and patterned, allowing for more accurate formation of gratings with desired grating profiles.

[0009] In one embodiment, a method of forming gratings is provided. The method includes depositing a resist material on a grating material disposed over a substrate, patterning the resist material into a resist layer, projecting a first ion beam to the first device area for a first period of time to form a first plurality of gratings in the grating material, and projecting a second ion beam to the second device area for a second period of time to form a second plurality of gratings in the grating material. The resist material has a first and second device area. The first ion beam has a first angle to a surface of the substrate and a first ion beam profile. The second ion beam has a second angle to the surface of the substrate and a second ion beam profile. At least one of the first ion beam profile and the second ion beam profile is not uniform.

[0010] In another embodiment, a method of forming gratings is provided. The method includes depositing a resist material on a grating material disposed over a substrate, patterning the resist material into a resist layer, projecting a first ion beam to the first device area for a first period of time to form a first plurality of gratings in the grating material, and projecting a second ion beam to the second device area for a second period of time to form a second plurality of gratings in the grating material. The resist material has a first and second device area. The first ion beam has a first angle to a surface of the substrate and a first ion beam profile. The second ion beam has a second angle to the surface of the substrate and a second ion beam profile. The patterning comprises pressing a mask against the resist material. At least one of the first ion beam profile and the second ion beam profile is not uniform.

[0011] In yet another embodiment, a method of forming gratings is provided. The method includes depositing a resist material on a grating material disposed over a substrate, patterning the resist material into a resist layer, projecting a first ion beam to the first device area for a first period of time to form a first plurality of gratings in the grating material, and projecting a second ion beam to the second device area for a second period of time to form a second plurality of gratings in the grating material. The resist material has a first and second device area. The first ion beam has a first angle to a surface of the substrate and a first ion beam profile. The second ion beam has a second angle to the surface of the substrate and a second ion beam profile. The resist layer has a first pattern and a second pattern. The first pattern contains a first plurality of pattern features with the first angle to a surface of the first pattern. The second pattern contains a second plurality of pattern features with the second angle to the surface of the first pattern. At least one of the first ion beam profile and the second ion beam profile is not uniform.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] 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.

[0013] FIG. **1**A is a flow diagram of method operations for forming gratings, according to one embodiment.

[0014] FIG. **1**B illustrates an ion beam incident on a substrate, according to one embodiment.

[0015] FIG. **10** illustrates an ion beam profile of an ion beam, according to one embodiment.

[0016] FIG. **1**D illustrates a plate having a plurality of filters, according to one embodiment.

[0017] FIG. **2**A is a flow diagram of method operations for forming gratings, according to one embodiment.

[0018] FIG. **2**B illustrates an ion beam incident on a first region of a substrate, according to one embodiment.

[0019] FIG. **2**C illustrates an ion beam incident on a second region of a substrate, according to one embodiment.

[0020] FIG. 2D illustrates a plurality of gratings with a sloped profile, according to one embodiment.

[0021] FIG. **2**E illustrates a plurality of gratings with a stepped profile, according to one embodiment.

[0022] FIG. **3**A is a flow diagram of method operations for forming gratings, according to one embodiment.

[0023] FIGS. **3**B-**3**C illustrate an angled etch system, according to one embodiment.

[0024] FIG. **4**A is a flow diagram of method operations for forming gratings, according to one embodiment.

[0025] FIG. **4**B illustrates a substrate with a resist material disposed over a grating material, according to one embodiment.

[0026] FIG. **4**C illustrates a substrate with a resist layer disposed over a grating material, according to one embodiment.

[0027] FIGS. **4**D-**4**E illustrates a substrate exposed to an ion beam, according to one embodiment.

[0028] 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

[0029] Embodiments of the disclosure generally relate to methods of forming gratings. The method includes depositing a resist material on a grating material disposed over a substrate, patterning the resist material into a resist layer, projecting a first ion beam to the first device area to form a first plurality of gratings, and projecting a second ion beam to the second device area to form a second plurality of gratings. Using a patterned resist layer allows for projecting an ion beam over a large area, which is often easier than focusing the ion beam in a specific area. The angles of elements of the patterned resist facilitates ion etching for angles of the ion beam that are similar to angles of the elements of the patterned resist layer. Other regions are less patterned, due to the mismatch of the angles of the ion beam to the angles of the elements of the patterned resist layer. Elements of the disclosure may be useful for, but not limited to, forming gratings with desired profiles at certain portions of a substrate.

[0030] As used herein, the term "about" refers to a +/−10% variation from the nominal value. It is to be understood that such a variation can be included in any value provided herein.

[0031] FIG. **1**A is a flow diagram of method **100** operations for forming gratings, or fins, according to one embodiment. Although the method **100** operations are described in conjunction with FIGS. **1**A-**1**D, persons skilled in the art will understand that any system configured to perform the method operations, in any order, falls within the scope of the embodiments described herein.

[0032] The method **100** begins at operation **190**, where a first ion beam is projected onto a first portion of a substrate. The first ion beam is created by an ion source. The substrate is configured to be used in an optical device. The substrate can be glass, plastic, polycarbonate materials, or any substrate used in the art. For example, the substrate includes a semiconducting material, e.g., silicon (Si), germanium (Ge), silicon germanium (SiGe), and/or a III-V semiconductor such as gallium arsenide (GaAs). In another example, the substrate **101** includes a transparent material, (e.g., glass, plastic, and/or polycarbonate). The substrate can have any number of insulating, semiconducting, or metallic layers thereon.

[0033] FIG. **1**B illustrates an ion beam **116** incident on a substrate **101**, according to one embodiment. The ion beam has a first beam area corresponding to a first device area **102** disposed over the substrate **101**. The first device area **102** corresponds to each first device of a plurality of first devices **104** to be formed in a grating material **103** disposed on the substrate **101**. The first ion beam is projected to the first device area **102** having an ion beam profile.

[0034] The ion beam profile can have a cross-sectional pattern with different ion beam intensities and/or ion beam concentrations in different portions of the pattern. When the ion beam having a specific pattern is projected onto a material (e.g., the grating material **103**), different portions of the material is etched at different depths, depending on the intensity of the ion beam cross-sectional pattern projected onto the portion of the material. For example, a first portion of the pattern with a high ion beam intensity projected onto a first portion of the material results in a deep etch of the first portion. A second portion of the pattern with a lower ion beam intensity projected onto a second portion of the material results in a shallower etch of the second portion. Thus, a desired etch profile can be formed in the material by a corresponding ion beam profile.

[0035] The grating material **103** can include silicon oxycarbide (SiOC), titanium oxide (TiO_x), TiO_x nanomaterials, niobium oxide (NbO_x), niobium-germanium (Nb_3Ge), silicon dioxide (SiO_2), silicon oxycarbonitride (SiOCN), vanadium (IV) oxide (VO_x), aluminum oxide (Al_2O_3), indium tin oxide [InTiO] (ITO), zinc oxide (ZnO), tantalum pentoxide (Ta_2O_5), silicon nitride (Si_3N_4), silicon-rich Si_xN_y, hydrogen-doped Si_3N_4, boron-doped Si_3N_4, silicon carbon nitrate (SiCN), titanium nitride (TiN), zirconium dioxide (ZrO_2), germanium (Ge), gallium phosphide (GaP), poly-crystalline (PCD), nanocrystalline diamond (NCD), doped diamond containing materials, or any combination of the above.

[0036] FIG. **10** illustrates the ion beam profile **106** of the ion beam **116**, according to one embodiment. As shown, the intensity of the ion beam profile **106** varies with the position within the cross-section of the ion beam **116**. Thus, the depth of the gratings created by the ion beam is variable. Although the ion beam profile illustrated in FIG. **10** is linear, other variations of the ion beam profile are contemplated. In some embodiments, the ion beam profile **106** is uniform, i.e., the intensity is uniform across the entire ion beam profile **106**. In some embodiments, the ion beam profile **106** is not uniform, i.e., the intensity is not uniform across the entire ion beam profile **106**. The ion beam profile can also be a two-dimensional (2D) pattern.

[0037] In one embodiment, which can be combined with other embodiments described herein, the ion beam profile **106** of the first ion beam is provided by filtering ions of the first ion beam with a plate having a plurality of filters. FIG. **1**D illustrates a plate **108** having a plurality of filters **110**, according to one embodiment. The plate **108** is configured to

interface with and couple to the ion source to modulate the intensity or distribution of the ion beam passing through the plate **108**. The plurality of filters **110** includes portions **112** having the same or different diameters **114**. The plurality of filters **110** can include holes, or openings, which allow ions of a desired intensity and/or density to pass therethrough. The plate **108** is fabricated from a material of sufficient thickness which is resistant or inert to ion beam bombardment and prevents ions from passing therethrough. The plurality of filters **110** extend through the plate **108** to form openings through which the ion beam passes. The plurality of filters **110** are illustrated as being substantially circle-shaped with an approximately even distribution between adjacent filters of the first plurality of filters. However, any number, shape, orientation, spacing, or arrangement of the plurality of filters **110** can be utilized to modulate the intensity or distribution of the ion beam passing therethrough to create the desired ion beam profile.

[0038] In another embodiment, which can be combined with other embodiments described herein, the ion beam profile **106** is provided by changing to a plasma profile of the first ion beam. The first device area **102** is exposed to the first ion beam for a first period of time to form a first plurality of gratings of the first device **104**. The substrate **101** is repeatedly moved, i.e., stepped, such that each first device area **102** is exposed to the first ion beam **116** with the ion beam profile **106**.

[0039] At operation **192**, a second ion beam is projected onto a second portion of a substrate. Referring to FIG. **1**B, the second portion includes a second device area **120** of the substrate **101**, according to one embodiment. The second ion beam has a second beam area corresponding to the second device area **120**. The second device area **120** corresponds to each second device of a plurality of second devices **122** to be formed in the grating material **103**. The second ion beam is projected to the second device area **120** with a ion beam profile **106** as described herein. The ion beam profile of the second ion beam can be different or the same as the ion beam profile of the first ion beam. The second device area **120** is exposed to the second ion beam for a second period of time to form a second plurality of gratings of the second device **122**. The first period of time may partially overlap with the second period of time, and thus a portion of operation **190** may overlap with operation **192**, according to one embodiment. The substrate **101** is repeatedly moved, i.e., stepped, such that each second device area **120** is exposed to the second ion beam with the ion beam profile.

[0040] At operation **194**, a third ion beam is projected onto a third portion of a substrate. The third portion includes a third device area **124** of the substrate **101**, according to one embodiment. The third ion beam has a third beam area corresponding to the third device area **124**. The third device area **124** corresponds to each third device of a plurality of third devices **126** to be formed in the grating material **103**. The third ion beam is projected to the third device area **124** with a ion beam profile **106** as described herein. The ion beam profile of the third ion beam can be different or the same as the ion beam profile of the first and/or ion beam. The third device area **124** is exposed to the third ion beam for a third period of time to form a third plurality of gratings of the second device **122**. The substrate **101** is repeatedly moved, i.e., stepped, such that each third device area **124** is exposed to the third ion beam with the ion beam profile. In some embodiments, at least one of the first ion beam profile, the second ion beam profile, and the third ion beam profile is not uniform.

[0041] The first period of time may partially overlap with the third period of time, and thus at least a portion of operation **190** may overlap with operation **194**, according to one embodiment. The second period of time may partially overlap with the third period of time, and thus a portion of operation **192** may overlap with operation **194**, according to one embodiment. The first period of time may partially overlap with the second period of time and the third period of time, and thus a portion of operation **190** may overlap with operations **192**, **194**, according to one embodiment.

[0042] FIG. **2**A is a flow diagram of method **200** operations for forming gratings, according to one embodiment. Although the method **200** operations are described in conjunction with FIGS. **2**A-**2**F, persons skilled in the art will understand that any system configured to perform the method operations, in any order, falls within the scope of the embodiments described herein.

[0043] The method **200** begins at operation **290**, where a first portion of a substrate is exposed to an ion beam from an ion source. FIG. **2**B illustrates an ion beam **206** incident on a first region a_1 of the substrate **101**, according to one embodiment. An ion source **202** projects the ion beam **206** to the first region a_1. The ion source **202** has a plurality of angled segments **204** configured to project the ion beams **206** generated by the ion source to the substrate **101**, i.e., the ion source **202** is a segmented ion source. The ion beams **206** projected to the substrate **101** have at least one beam angle α_1 relative to a surface **105** of the substrate **101**. The angled segments **204** can be localized to regions of waveguide combiners fabricated by the method **100**, for example, the first device areas **102**, the second device areas **120**, and the third device areas **124**. The substrate **101** is disposed in a first position G**1**. A first plurality of gratings **212** is formed from, or in, the grating material **103**. The first plurality of gratings **212** have a slant angle ϑ_1 that is defined between a first direction parallel to the surface **105** and a second direction perpendicular to the surface. The slant angle ϑ_1 is about equal to the beam angle α_1. The slant angle ϑ_1 and/or beam angle α_1 can vary from about 5° to about 175°.

[0044] To form a plurality of gratings, a patterned hardmask **213** is disposed over the grating material **103**. The ion beam **206** contacts exposed portions of the grating material and etches gratings in the grating material **103**. In some embodiments, which can be combined with other embodiments described herein, the ion beams **206** projected to the substrate **101** have a plurality of different beam angles α corresponding to a rolling k-vector **210** such that portions of a plurality of gratings have different slant angles ϑ relative to the surface normal **105**.

[0045] At operation **292**, a second portion of the substrate is exposed to an ion beam from an ion source. FIG. **2**C illustrates an ion beam **206** incident on a second portion a_2 of the substrate **101**, according to one embodiment. In some embodiments, which can be combined with other embodiments described herein, a vertical distance **208** of the substrate **101** from the segmented ion source **202** changes. For example, the substrate **101** can be moved by a pedestal (not shown) disposed under the substrate **101**. In another example, the ion source **202** is moved in a vertical direction (e.g., perpendicular to the surface of the substrate **101**), and/or in a horizontal direction (e.g., parallel to the surface

of the substrate **101**). The ion source **202** is moved from the first position G**1**, where the first portion a_1 of the grating material **103** is exposed, to a second position G**2**, where the second portion a_2 of the grating material is exposed.

[0046] A second plurality of gratings **218** is formed from, or in, the grating material **103**. The second plurality of gratings **218** has a slant angle ϑ_1 that is defined between the first direction parallel to the surface **105** and the second direction perpendicular to the surface. The slant angle ϑ_2 is about equal to the beam angle α_2. The slant angle ϑ_2 and/or beam angle α_1 can vary from about 5° to about 175°. The first slant angle ϑ_1 is from about 5° to about 85°, and the second slant angle ϑ_2 is from about 95° to about 175°, according to one embodiment.

[0047] A profile for a plurality of gratings includes the variance in depths between individual grating elements, the variance in angles between individual grating elements, and the rate of change of the angles and/or depths between individual grating elements. FIG. 2D illustrates a plurality of gratings **280** with a sloped profile **216**, according to one embodiment. Smoothly scanning the substrate **101** from the first position G**1** to the second position G**2** can form a plurality of gratings **280** with a plurality of depths **214** having the sloped profile **216**. The ion beam profile **106** of the ion beam **206** also can create a profile in the plurality of gratings. Either, or both, of the first or second plurality of gratings **212**, **218** can have the sloped profile **216**.

[0048] FIG. **2**E illustrates a plurality of gratings **280** with a stepped profile **222**, according to one embodiment. Stepping the substrate **101** from the first position G**1** to the second position G**2** form the plurality of gratings **280** with a plurality of depths **214** having the stepped profile **222**. The ion beam profile **106** of the ion beam **206** also can create a profile in the plurality of gratings. Either, or both, of the first or second plurality of gratings **212**, **218** can have the stepped profile **222**.

[0049] In one embodiment, the first plurality of gratings **212** has a sloped profile **216**. In one embodiment, the first plurality of gratings **212** has a stepped profile **222**. In one embodiment, the first plurality of gratings **212** has a first profile, and the second plurality of gratings **218** has a different profile.

[0050] Referring to FIG. **2**B, in one embodiment, the patterned hardmask **213** has a thickness that filters ion beams **206** having the plurality of different beam angles α such that each of the plurality of gratings **212**, **218** have the same slant angles ϑ_1, ϑ_2. In another embodiment, at least one of the gratings in one or more of the plurality of gratings **212**, **218** has a different slant angle ϑ_1, ϑ_2 than one of the other gratings in the same plurality of gratings. In some embodiments, at least one of the first ion beam profile and the second ion beam profile is not uniform.

[0051] FIG. **3**A is a flow diagram of method **300** operations for forming gratings, according to one embodiment. Although the method **300** operations are described in conjunction with FIGS. **3**A-**3**C, persons skilled in the art will understand that any system configured to perform the method operations, in any order, falls within the scope of the embodiments described herein.

[0052] The method **300** begins at operation **390**, where a first portion of a flexible substrate is exposed to an ion beam with a first ion beam profile. FIG. **3**B illustrates an angled etch system **302**, according to one embodiment. The angled etch system **302** is configured expose ion beams **206** at different angles onto the substrate **101**. As shown, the angled etch system **302** includes a pedestal **304**, a plurality of ion beam chambers **306**, a scanner **312**, and a rolling system **322**.

[0053] The pedestal **304** retains the substrate **101** such that a first surface **107** of the substrate **101** is exposed to ion beams **206** generated by one or more ion beam chambers **306** oriented toward the first surface **107**. The pedestal **304** has one or more holes **307** to allow one or more ion beam **206** to pass therethrough and form one more devices **310** on the first surface **107**. A second surface **109** of the substrate **101** is exposed to the one or more ion beams **206** generated by the one or more ion beam chambers **306** oriented toward the second surface **109**. The first surface **107** and the second surface **109** are exposed to the ion beam **206** to form devices **310** on the first surface **107** and the second surface **109**. Thus, the angled etch system **302** is configured to create one or more devices **310** on both surfaces **107**, **109** of the substrate **101**.

[0054] Each of the devices **310** has a plurality of gratings having slant angles (e.g., the plurality of gratings **212**, **218**). The angled etch system **302** can include the scanner **312** operable to move the pedestal **304** along at least one of a y-direction and an x-direction.

[0055] The substrate **101** has rollable and flexible properties such that the rolling system **322** is configured to position a first segment **316** of the substrate **101** in the path of the ion beam **206** to form the devices **310**. As shown, the rolling system **322** includes a plurality of rollers **314** and a plurality of roller actuators **315**. The rollers **314** rotate rolled portions **318** of the flexible substrate **101**, so that additional portions **332** of the substrate can be exposed to the plurality of ion beam chambers. Each of the roller actuators **315** are configured to rotate one of the plurality of rollers **314** to expose different portions of the substrate **101** to the ion beam chambers **306**.

[0056] FIG. **3**C illustrates an angled etch system **302'**, according to one embodiment. As shown, the angled etch system **302'** includes a rolling system **322'** and one or more ion beam chambers **306**. In this embodiment, the ion beam chambers **306** are located on the same side **107** of the substrate **101**. As shown, the angled etch system **322'** includes a stabilizing member **330**, a plurality of rollers **314**, and a plurality of roller actuators **315**. The rollers **314** rotate rolled portions **318** of the flexible substrate **101**, so that additional portions **332** of the substrate can be exposed to the plurality of ion beam chambers. The substrate **101** is rolled along the supporting member **330**. Each of the roller actuators **315** are configured to rotate one of the plurality of rollers **314** to expose different portions of the substrate **101** to the ion beam chambers **306**.

[0057] At operation **392**, a second portion of the flexible substrate is exposed to an ion beam with a second ion beam profile. The first and second ion beam profiles can be the same or different. In some embodiments, at least one of the first ion beam profile and the second ion beam profile is not uniform. After the devices **310** are formed on the first segment **316**, additional portions **332** of the substrate **101** are exposed to the plurality of ion beam chambers. For example, the rolling system **322**, **322'** advance the additional portions **332** of the substrate **101** to be exposed to the plurality of ion beam chambers **306**.

[0058] In addition, the angled etch systems **302**, **302'** can be used in any of the methods **100**, **200**, **300**, **400** disclosed herein.

[0059] FIG. **4**A is a flow diagram of method **400** operations for forming gratings, according to one embodiment. Although the method **400** operations are described in conjunction with FIGS. **4**A-**4**C, persons skilled in the art will understand that any system configured to perform the method operations, in any order, falls within the scope of the embodiments described herein.

[0060] The method **400** begins at operation **490**, where a resist material is deposited on a grating material. FIG. **4**B illustrates the substrate **101** with a resist material **404** disposed over the grating material **103**, according to one embodiment. In some embodiments, the portion of the material illustrated in FIGS. **4**B-**4**E is the first device area **102**, the second device area **120**, or the third device area **124** described above. The resist material **404** can be any resist material used in the art, such as, but not limited to, a photoresist, a liquid resist, and the like. In one embodiment, which can be combined with other embodiments described herein, a patterned hardmask **213** is disposed over the grating material **103** and under the resist material **404**.

[0061] At operation **492**, the resist material is patterned to form a resist layer. FIG. **4**C illustrates the substrate **101** with a resist layer **402** disposed over the grating material **103**, according to one embodiment. Operation **492** includes forming the resist material **404** into a resist layer **402** having a first portion of pattern features **406** having a first slant angle ϑ_1, and a second portion of pattern features **408** having a second slant angle ϑ_2. The first portion of pattern features **406** is formed over the first region a_1, and the second portion of pattern features **408** is formed over the second region a_2, according to some embodiments.

[0062] In some embodiments, which can be combined with other embodiments described herein, the resist layer **402** is formed by a nanoimprint lithography process by pressing a mold against the resist material **404**. Heat is applied to the resist material **404** during operation **492**, according to one embodiment. Ultraviolet light (UV) is applied to the resist material **404** during operation **492**, according to one embodiment. In some embodiments, the resist material **404** includes a photoresist, and the resist layer **402** is formed by a photolithography process.

[0063] At operation **490**, a first region of a substrate is exposed to an ion beam with a first ion beam profile. FIG. **4**D illustrates the substrate **101** exposed to the ion beam **206**, according to one embodiment. The first portion of pattern features **406** of the resist layer **402** has a slant angle ϑ_1 that is defined between a first direction parallel to a surface **405** of the substrate **101** and a second direction perpendicular to the surface **405**. The slant angle ϑ_1 is about equal to a first beam angle α_1 of the ion beam, such that the ion beam etches the first plurality of gratings **212** having the slant angle ϑ_1 in the grating material **103** on the first region a_1 of the substrate **101**. However, the second portion of pattern features **408** of the resist layer **402** have a second slant angle ϑ_2 such that the ion beam **206** having the first beam angle α_1 does not etch the grating material **103** on the second region a_2 of the substrate **101**. Thus, only the first region a_1 of the grating material **103** is removed, and only the first plurality of gratings **212** is formed. The slant angle ϑ_1 can vary from about 5° to about 175°.

[0064] At operation **492**, a second region of a substrate is exposed to an ion beam with a second ion beam profile. The first and second ion beam profiles can be the same or different. In some embodiments, at least one of the first ion beam profile and the second ion beam profile is not uniform. FIG. **4**E illustrates the substrate **101** exposed to the ion beam **206**, according to one embodiment. The second portion of pattern features **408** of the resist layer **402** has a slant angle ϑ_2 that is defined between the first direction parallel to a surface **405** of the substrate **101** and the second direction perpendicular to the surface **405**. The first portion of pattern features **406** of the resist layer **402** have the first slant angle ϑ_1, such that the ion beam **206** having a second beam angle α_2 does not etch the grating material **103** on the first region a_1 of the substrate **101**. However, the second portion of pattern features **408** of the resist layer **402** have the second slant angle ϑ_2 such that the ion beam **206** having the second beam angle α_2 etches the grating material **103** on the second region a_2 of the substrate **101**. Thus, only the first region a_2 of the grating material **103** is removed, and only the second plurality of gratings **218** is formed. The slant angle ϑ_1 can vary from about 5° to about 175°. The first slant angle ϑ_1 is from about 5° to about 85°, and the second slant angle ϑ_2 is from about 95° to about 175°, according to one embodiment.

[0065] One or more waveguide combiners **128** (FIG. **1** B) can be formed from the methods **100**, **200**, **300**, **400**. The waveguide combiner **128** includes one of the first devices **104** having the first plurality of gratings, one of the second devices **122** having the plurality of gratings, and one of the third devices **126** having the third plurality of gratings, according to one embodiment.

[0066] As described above, methods of forming patterns are provided. The method includes depositing a resist material on a grating material disposed over a substrate, patterning the resist material into a resist layer, projecting a first ion beam to the first device area to form a first plurality of gratings, and projecting a second ion beam to the second device area to form a second plurality of gratings.

[0067] Using a patterned resist layer allows for projecting an ion beam over a large area, which is often easier than focusing the ion beam in a specific area. The angles of elements the patterned resist facilitates ion etching for angles of the ion beam that are similar to angles of the elements of the patterned resist layer. Other regions are less patterned, due to the mismatch of the angles of the ion beam to the angles of the elements of the patterned resist layer.

[0068] While the foregoing is directed to examples of the present disclosure, other and further examples 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 gratings, comprising:

depositing a resist material on a grating material disposed over a substrate, the resist material having a first and second device area;

patterning the resist material into a resist layer;

projecting a first ion beam to the first device area for a first period of time to form a first plurality of gratings in the grating material, the first ion beam having a first angle to a surface of the substrate, the first ion beam having a first ion beam profile; and

projecting a second ion beam to the second device area for a second period of time to form a second plurality of

gratings in the grating material, the second ion beam having a second angle to the surface of the substrate, the second ion beam having a second ion beam profile,

wherein at least one of the first ion beam profile and the second ion beam profile is not uniform.

2. The method of claim **1**, wherein

the first plurality of gratings has a first profile,

the second plurality of gratings has a second profile, and

the first profile is different than the second profile.

3. The method of claim **2**, wherein the first profile is a stepped profile.

4. The method of claim **2**, wherein the first profile is a sloped profile.

5. The method of claim **1**, wherein the resist material comprises a photoresist material.

6. The method of claim **1**, wherein

the first angle is from about 5° to about 85°, and

the second angle is from about 95° to about 175°.

7. The method of claim **1**, wherein projecting the first ion beam comprises filtering ions of the first ion beam with a plate having a plurality of filters.

8. A method of forming one or more pluralities of gratings, comprising:

depositing a resist material on a grating material disposed over a substrate, the resist material having a first and second device area;

patterning the resist material into a resist layer, wherein the patterning comprises pressing a mask against the resist material;

projecting a first ion beam to the first device area for a first period of time to form a first plurality of gratings in the grating material, the first ion beam having a first angle to a surface of the substrate, the first ion beam having a first ion beam profile; and

projecting a second ion beam to the second device area for a second period of time to form a second plurality of gratings in the grating material, the second ion beam having a second angle to the surface of the substrate, the second ion beam having a second ion beam profile,

wherein at least one of the first ion beam profile and the second ion beam profile is not uniform.

9. The method of claim **8**, wherein

the first plurality of gratings has a first profile,

the second plurality of gratings has a second profile, and

the first profile is different than the second profile.

10. The method of claim **9**, wherein the first profile is a stepped profile.

11. The method of claim **9**, wherein the first profile is a sloped profile.

12. The method of claim **8**, wherein the patterning the resist material comprises exposing the resist material to ultraviolet (UV) light.

13. The method of claim **8**, wherein the patterning the resist material comprises heating the resist material.

14. A method of forming one or more pluralities of gratings, comprising:

depositing a resist material on a grating material disposed over a substrate, the resist material having a first and second device area;

patterning the resist material into a resist layer having a first pattern and a second pattern;

projecting a first ion beam to the first device area for a first period of time to form a first plurality of gratings in the grating material, the first ion beam having a first angle to a surface of the substrate, the first ion beam having a first ion beam profile; and

projecting a second ion beam to the second device area for a second period of time to form a second plurality of gratings in the grating material, the second ion beam having a second angle to the surface of the substrate, the second ion beam having a second ion beam profile; wherein

the first pattern contains a first plurality of pattern features with the first angle to a surface of the first pattern,

the second pattern contains a second plurality of pattern features with the second angle to the surface of the first pattern, and

at least one of the first ion beam profile and the second ion beam profile is not uniform.

15. The method of claim **14**, wherein

the first plurality of gratings has a first profile,

the second plurality of gratings has a second profile, and

the first profile is different than the second profile.

16. The method of claim **15**, wherein the first profile is a stepped profile.

17. The method of claim **15**, wherein the first profile is a sloped profile.

18. The method of claim **14**, wherein the resist material comprises a photoresist material.

19. The method of claim **14**, wherein

the first angle is from about 5° to about 85°, and

the second angle is from about 95° to about 175°.

20. The method of claim **14**, wherein projecting the first ion beam comprises filtering ions of the first ion beam with a plate having a plurality of filters.

* * * * *