US 20220308460A1

(19) **United States**

(12) **Patent Application Publication**

**XU et al.**

(10) **Pub. No.: US 2022/0308460 A1**

(43) **Pub. Date: Sep. 29, 2022**

(54) **METHOD TO FABRICATE LARGE SCALE FLAT OPTICS LENSES**

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

(72) Inventors: **Yongan XU**, Santa Clara, CA (US); **Naamah ARGAMAN**, San Jose, CA (US); **David SELL**, Santa Clara, CA (US); **Ludovic GODET**, Sunnyvale, CA (US)

(21) Appl. No.: **17/701,394**

(22) Filed: **Mar. 22, 2022**

**Related U.S. Application Data**

(60) Provisional application No. 63/165,572, filed on Mar. 24, 2021.

**Publication Classification**

(51) **Int. Cl.**

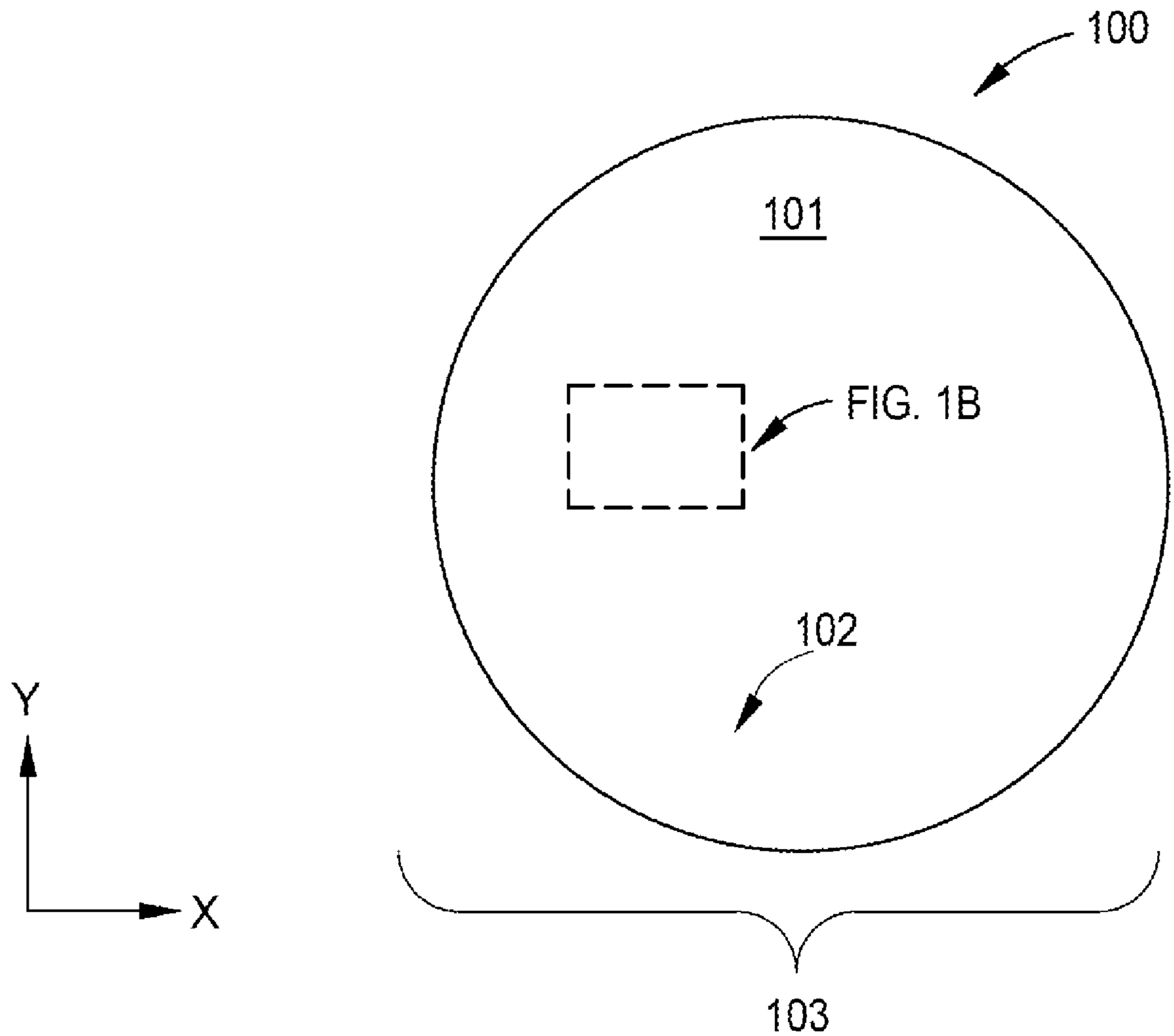
| | |
|---|---|
| ***G03F 7/20*** | (2006.01) |
| ***G03F 7/00*** | (2006.01) |

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

CPC ..... ***G03F 7/70366*** (2013.01); ***G03F 7/0005*** (2013.01)

(57) **ABSTRACT**

Methods of fabricating large-scale optical devices having sub-micron dimensions are provided. A method is provided that includes projecting a beam to a mask, the mask corresponding to a section of an optical device pattern, the optical device pattern divided into four or more equal portions, each portion corresponding to a section of a substrate. The method further includes scanning the mask over a first section of the substrate to pattern a first portion of the optical device pattern, the substrate is positioned at a first rotation angle relative to the mask. The method further includes rotating the substrate to a second rotation angle, the second rotation angle corresponding to 360° divided by a total number of portions of the optical device pattern, scanning the mask over a second section of the substrate from the initial position to the final position to pattern a second portion of the optical device pattern.



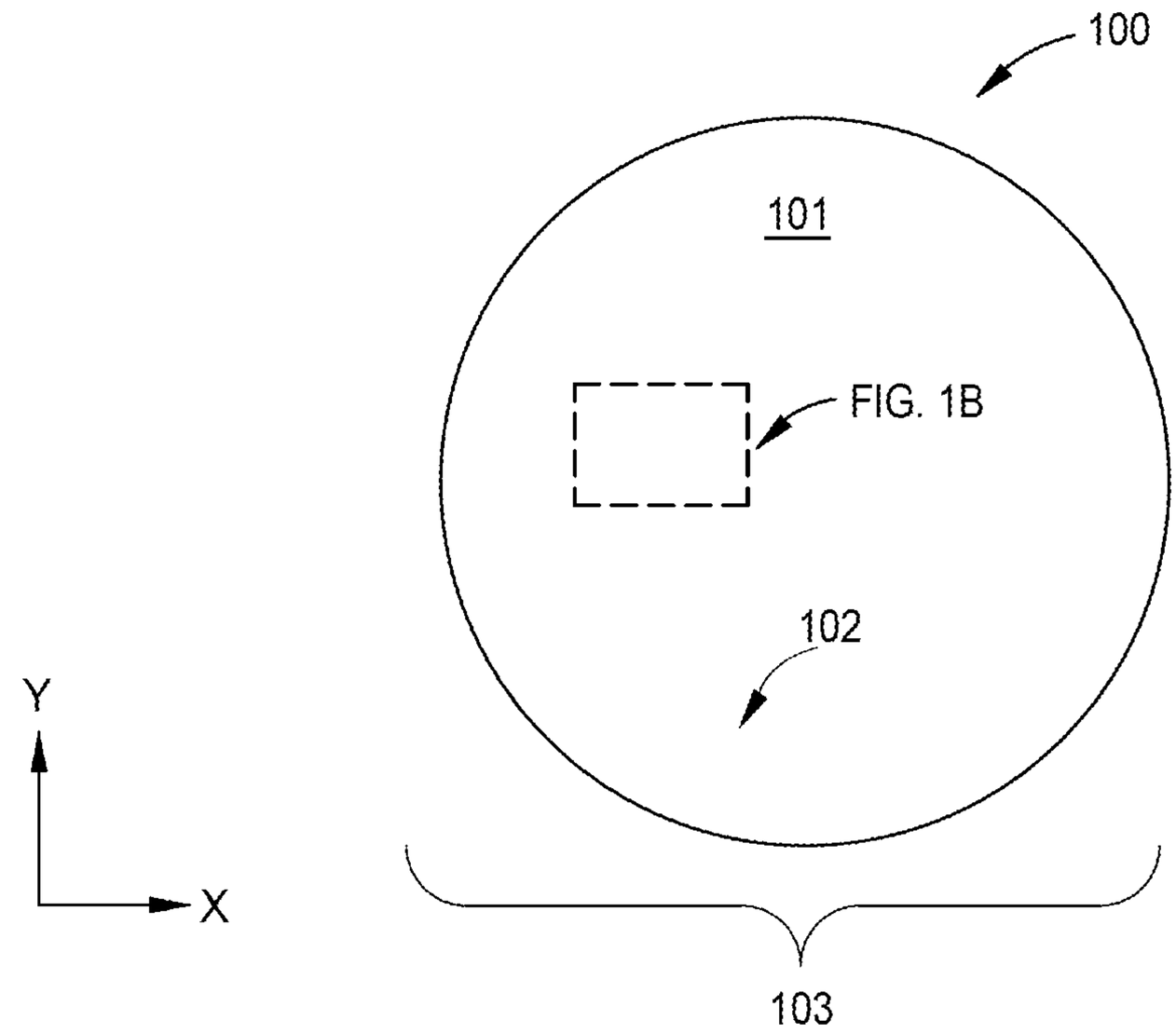

100
101
FIG. 1B
102
Y
X
103

FIG. 1A

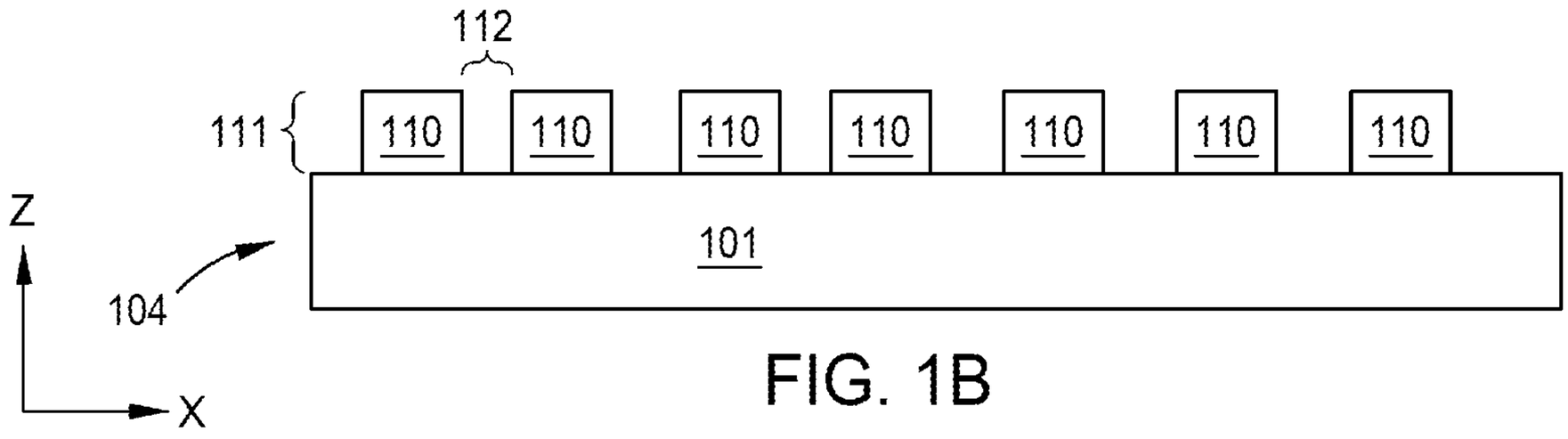

112
111
110
110
110
110
110
110
110
101
Z
104
X

FIG. 1B

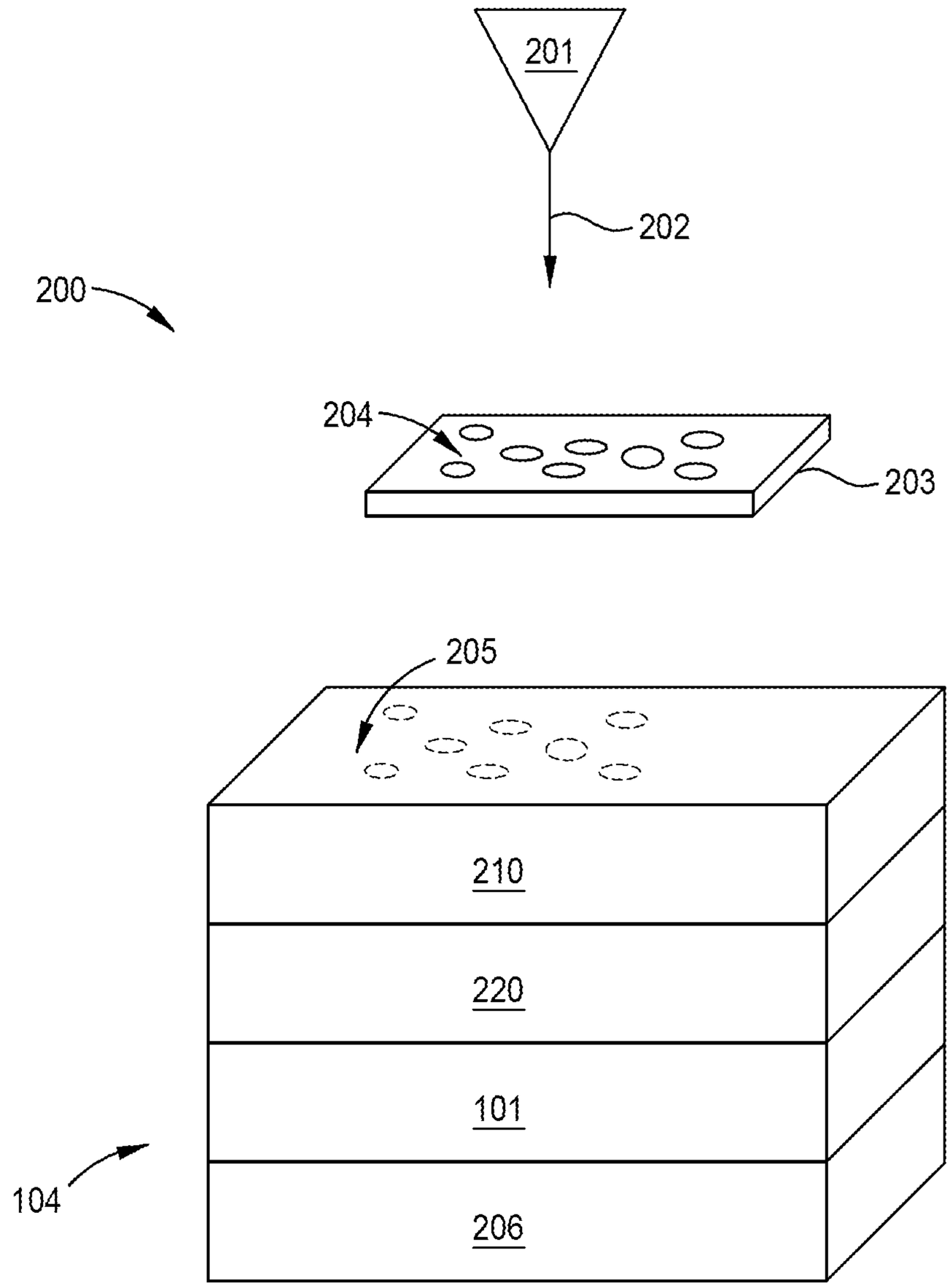



FIG. 2

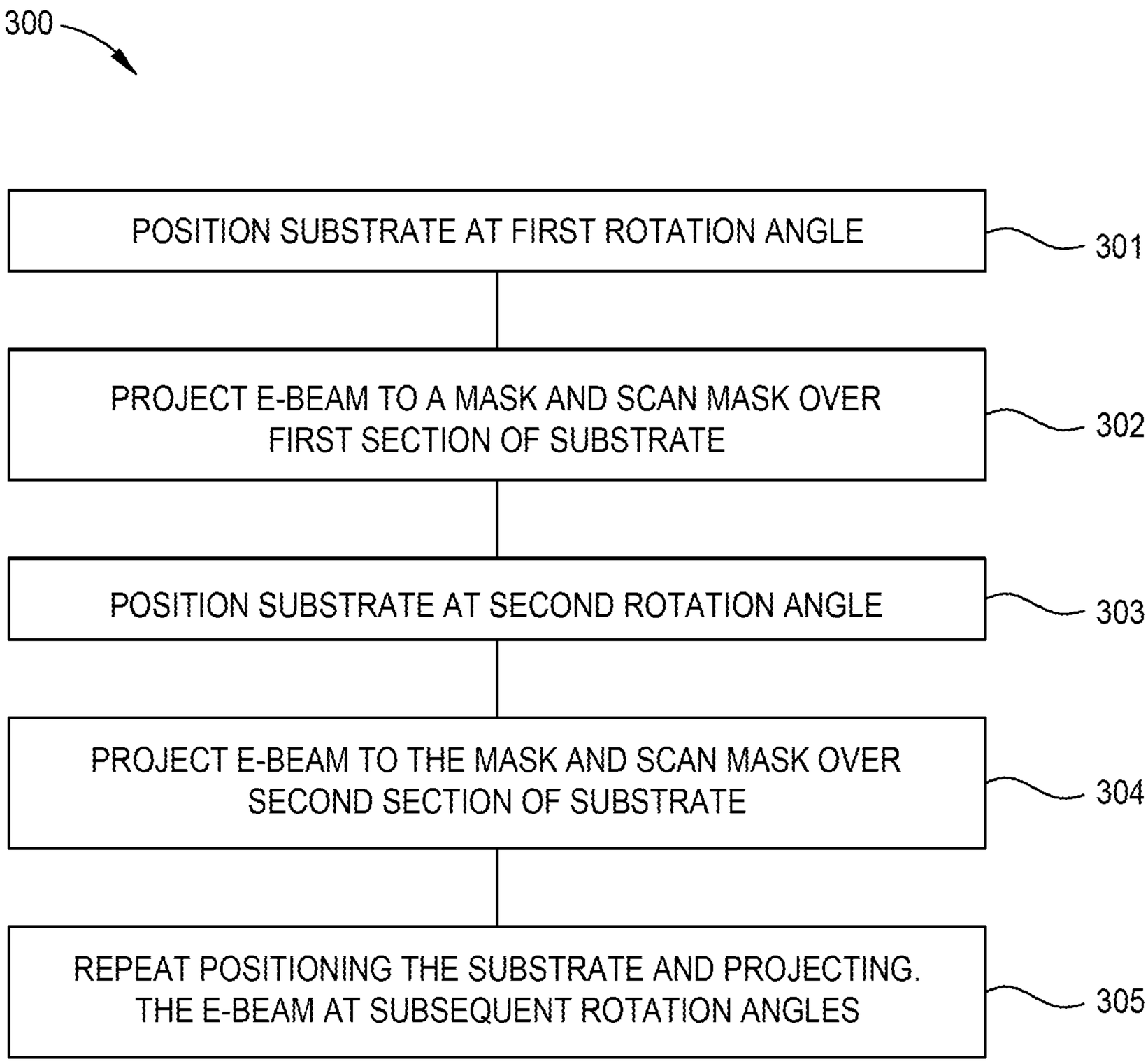

300
POSITION SUBSTRATE AT FIRST ROTATION ANGLE
301
PROJECT E-BEAM TO A MASK AND SCAN MASK OVER FIRST SECTION OF SUBSTRATE
302
POSITION SUBSTRATE AT SECOND ROTATION ANGLE
303
PROJECT E-BEAM TO THE MASK AND SCAN MASK OVER SECOND SECTION OF SUBSTRATE
304
REPEAT POSITIONING THE SUBSTRATE AND PROJECTING. THE E-BEAM AT SUBSEQUENT ROTATION ANGLES
305

FIG. 3

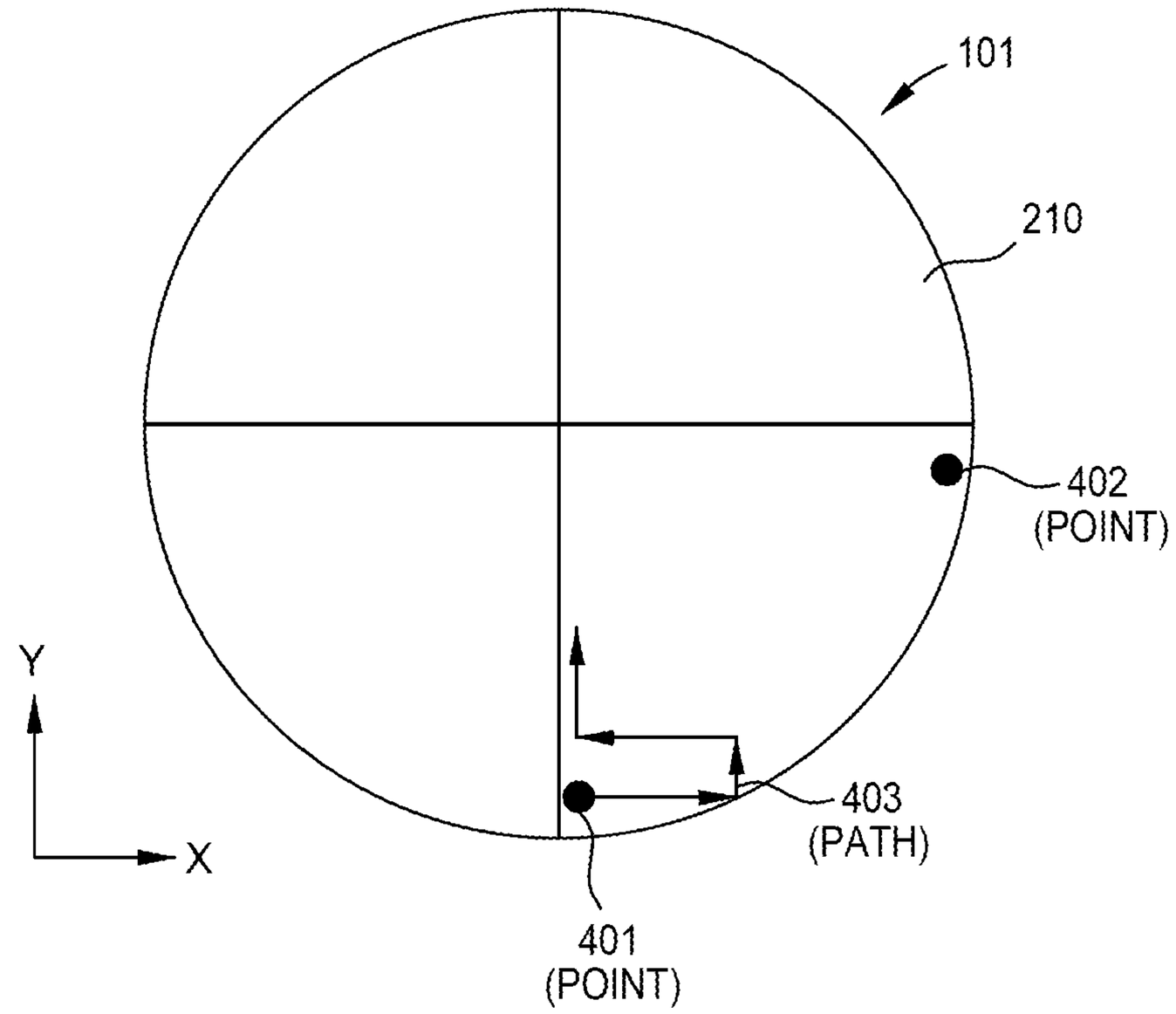



FIG. 4A

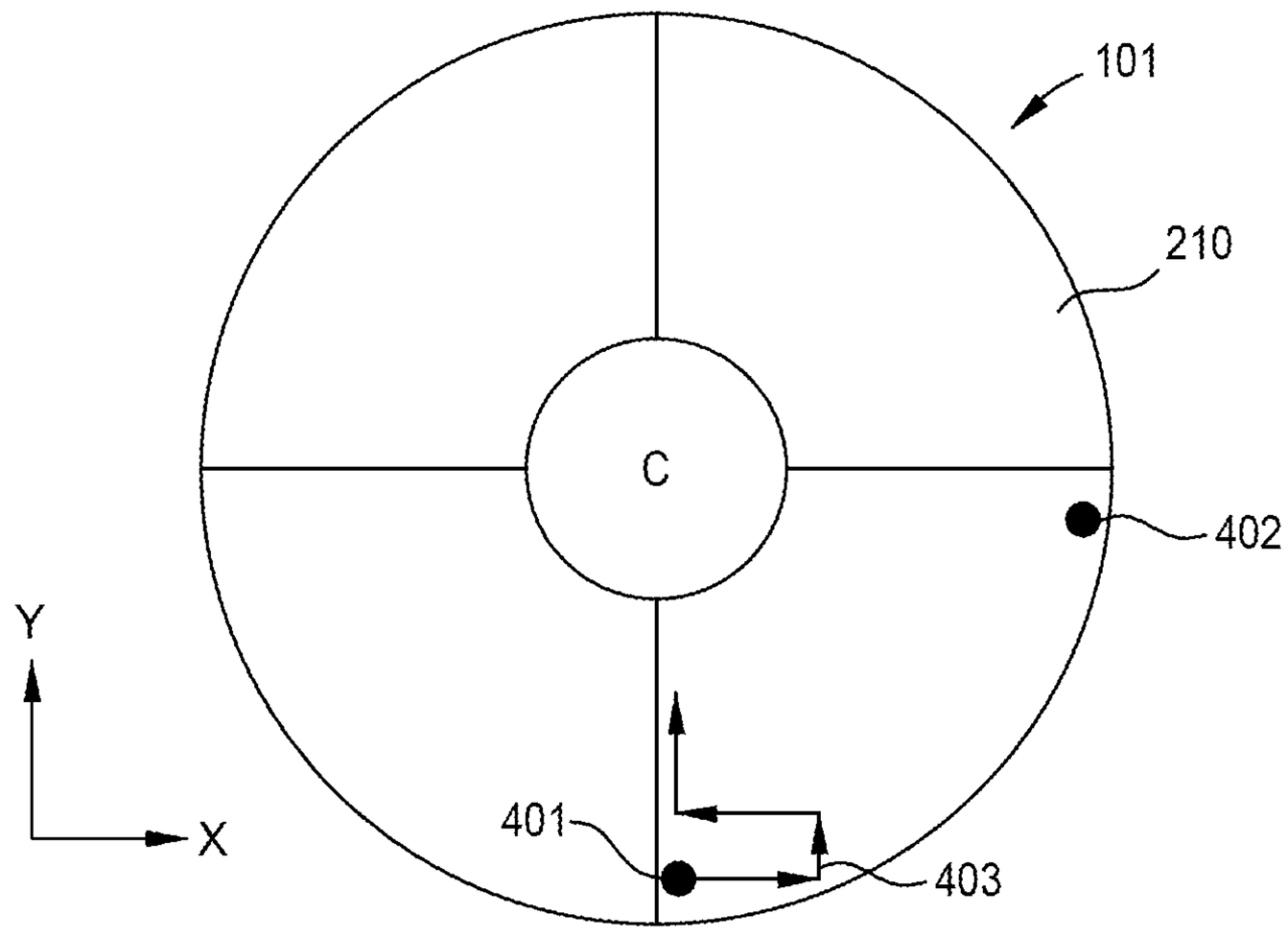



FIG. 4B

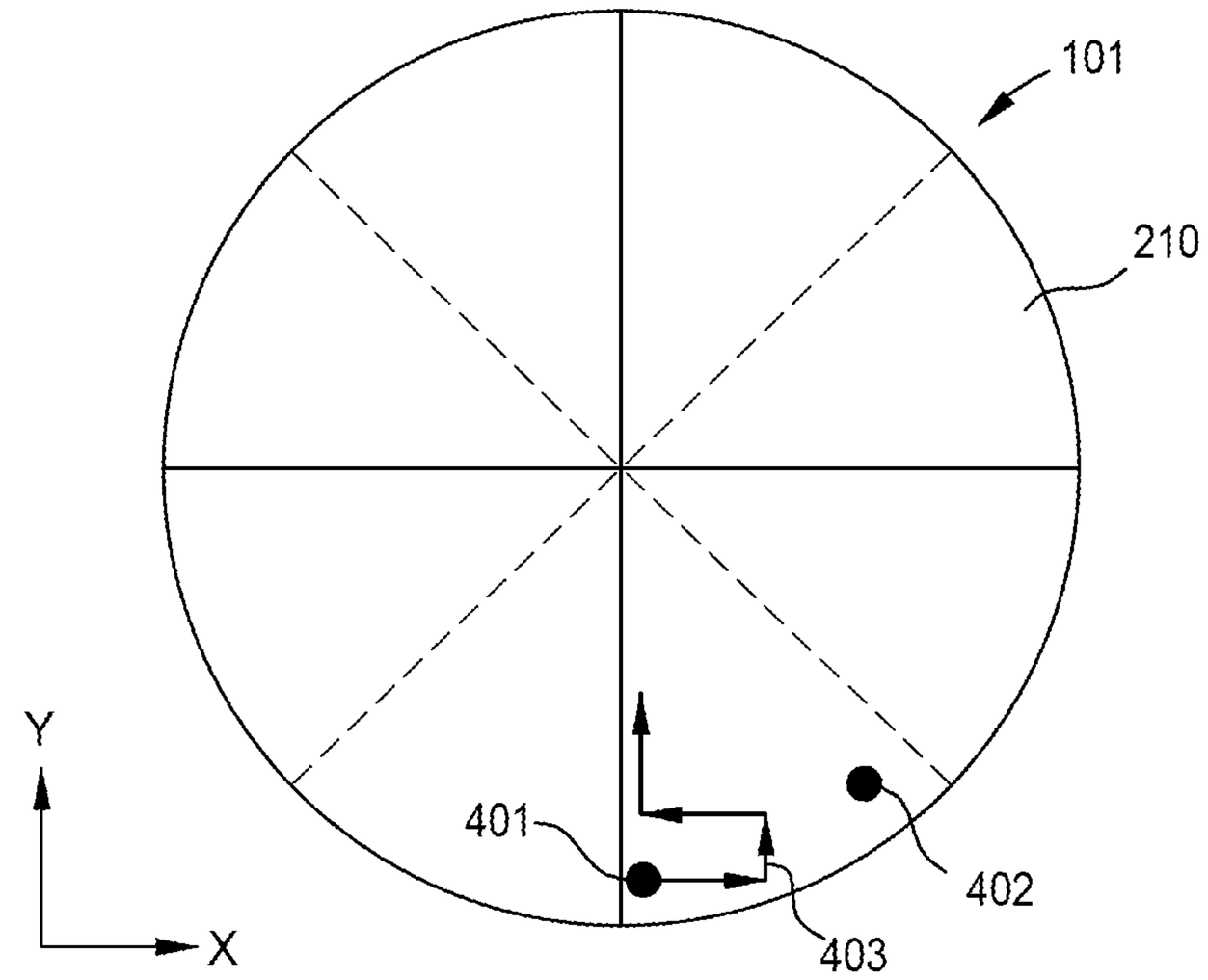



FIG. 5A

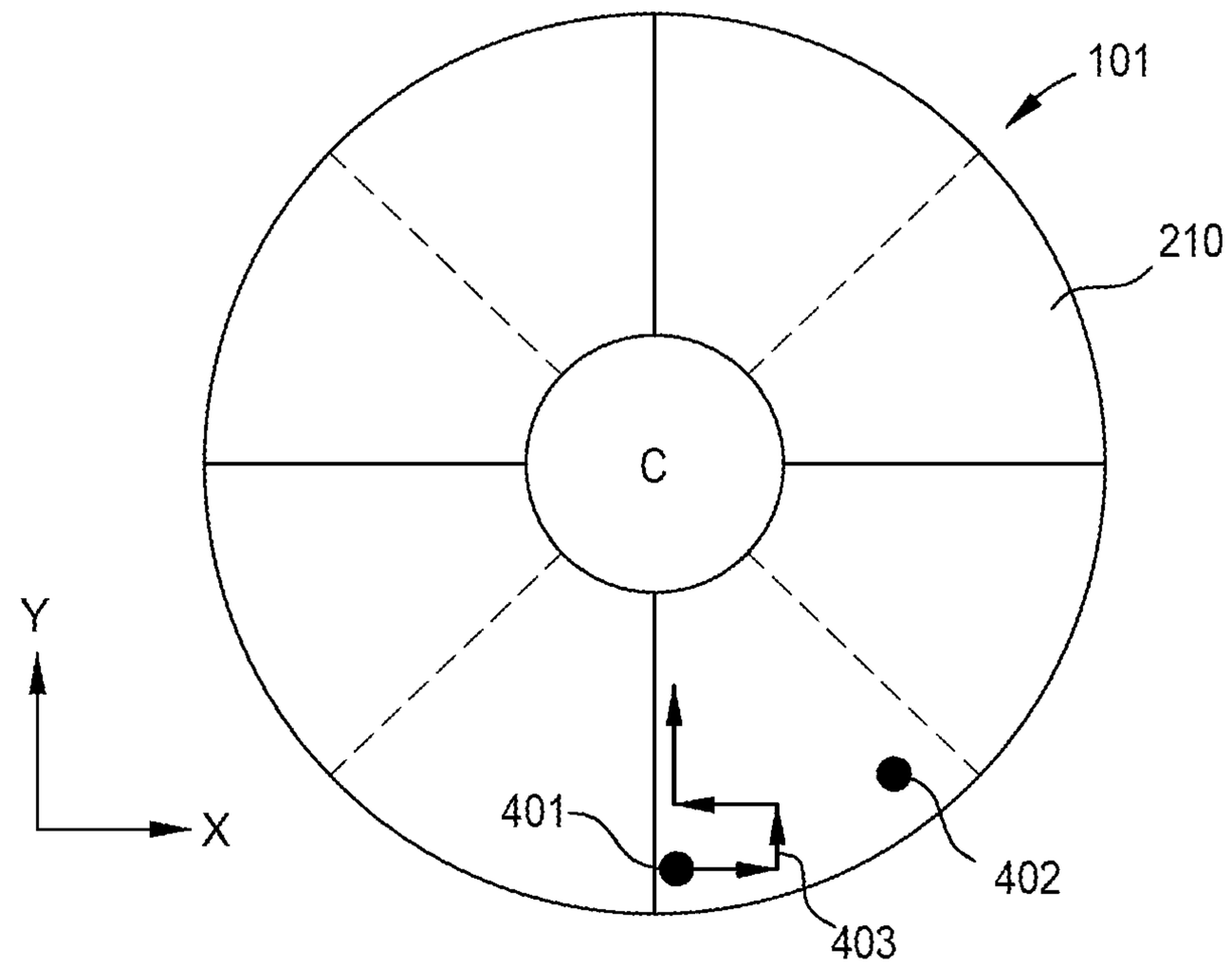



FIG. 5B

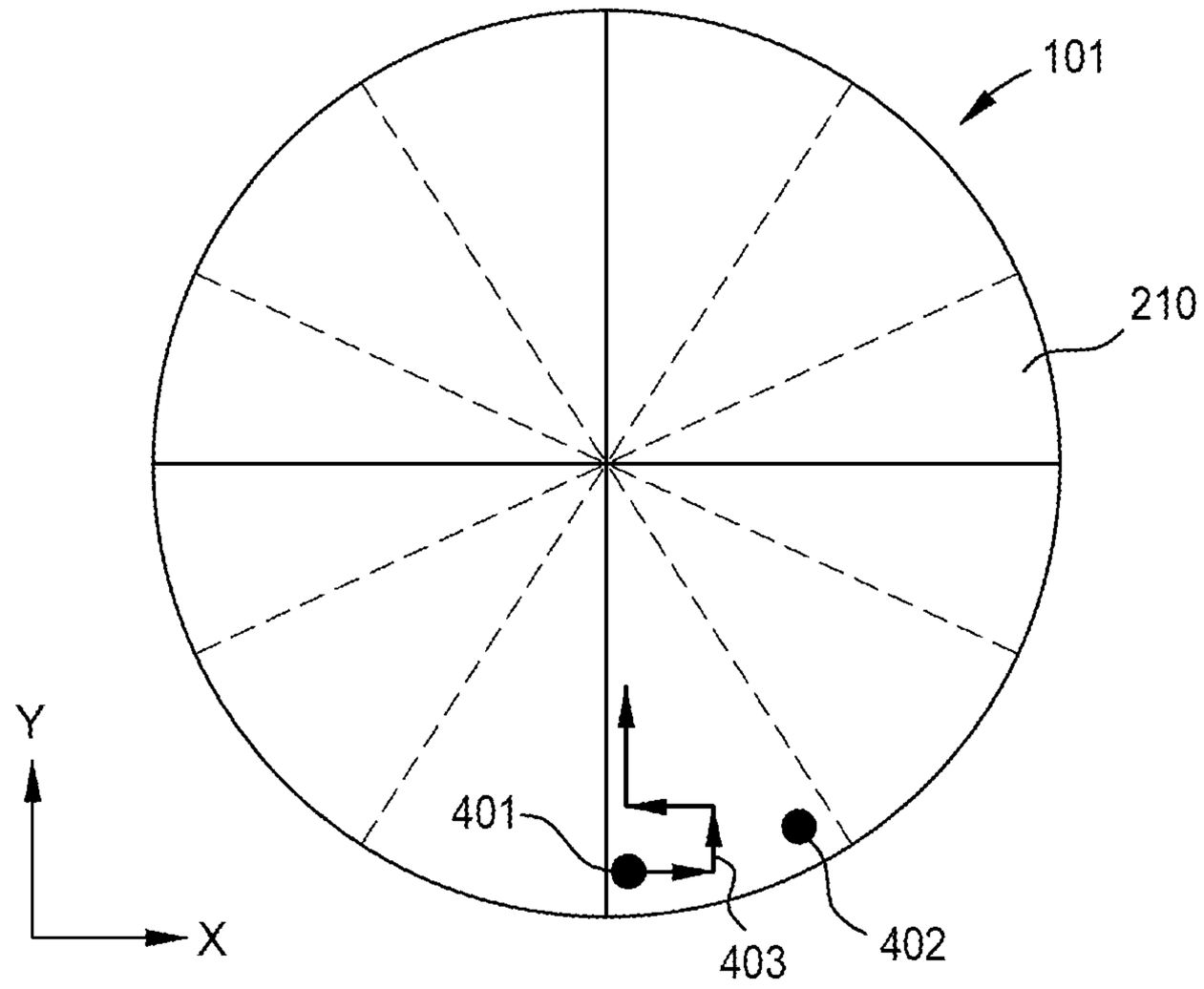



FIG. 6A

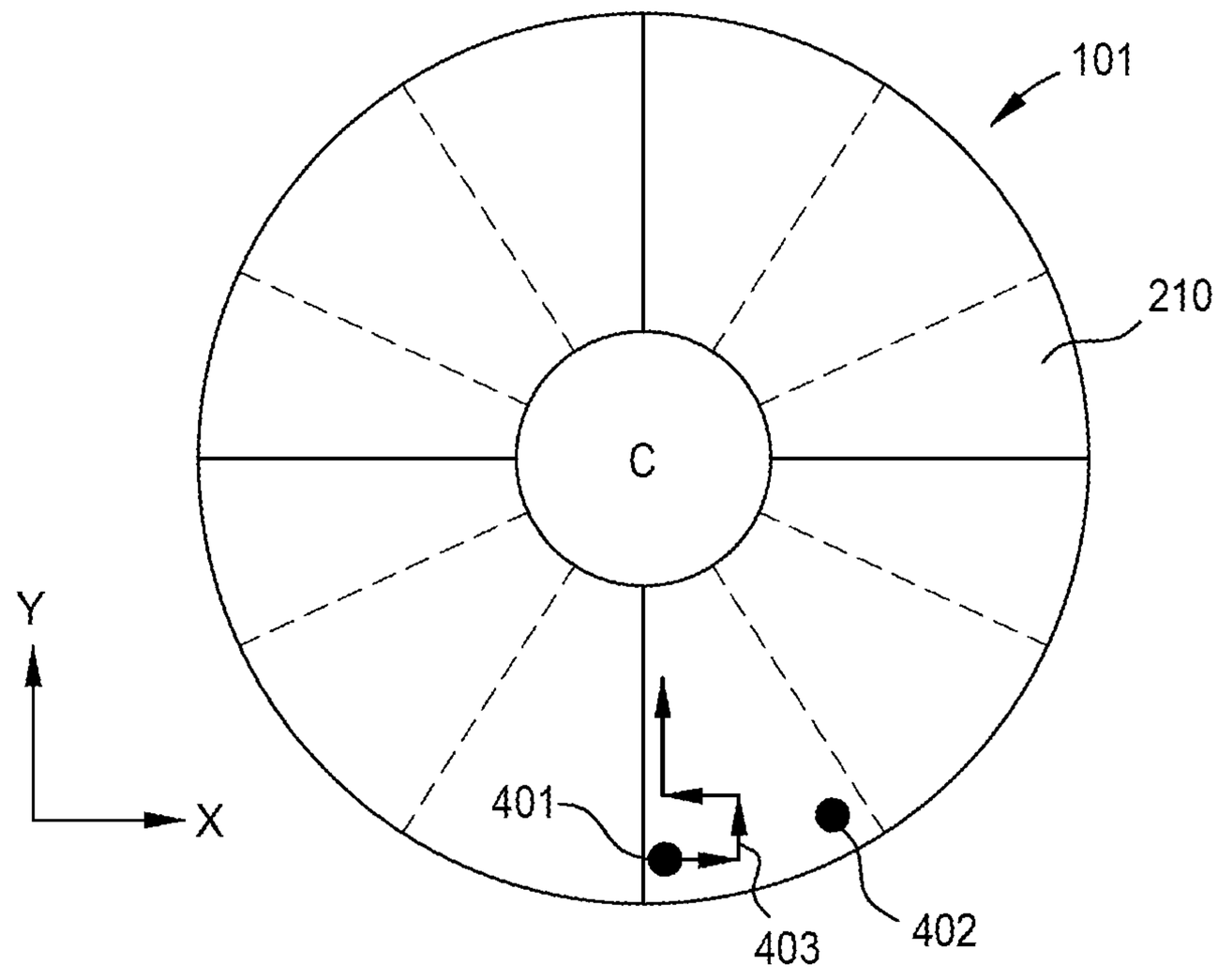



FIG. 6B

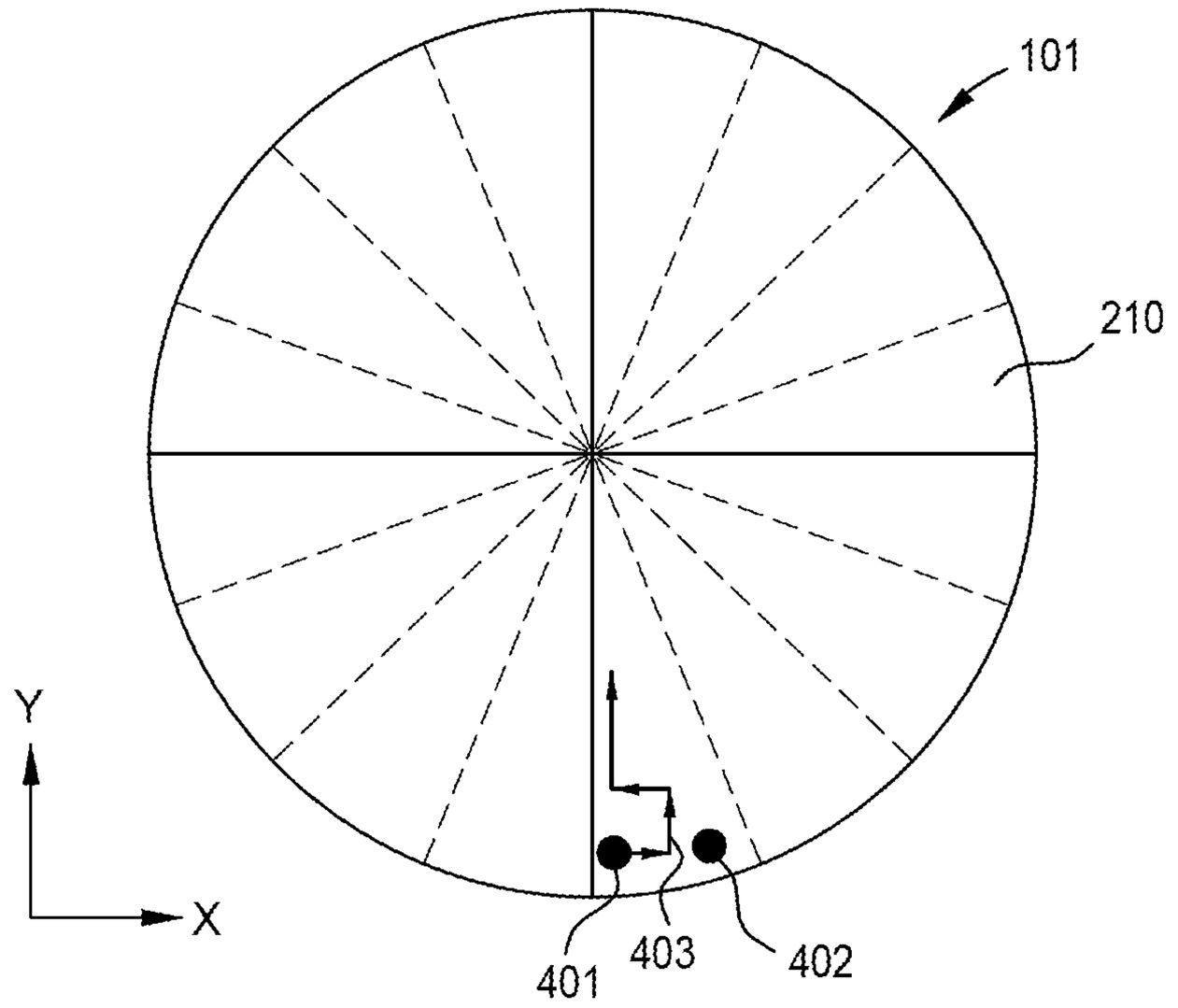



FIG. 7A

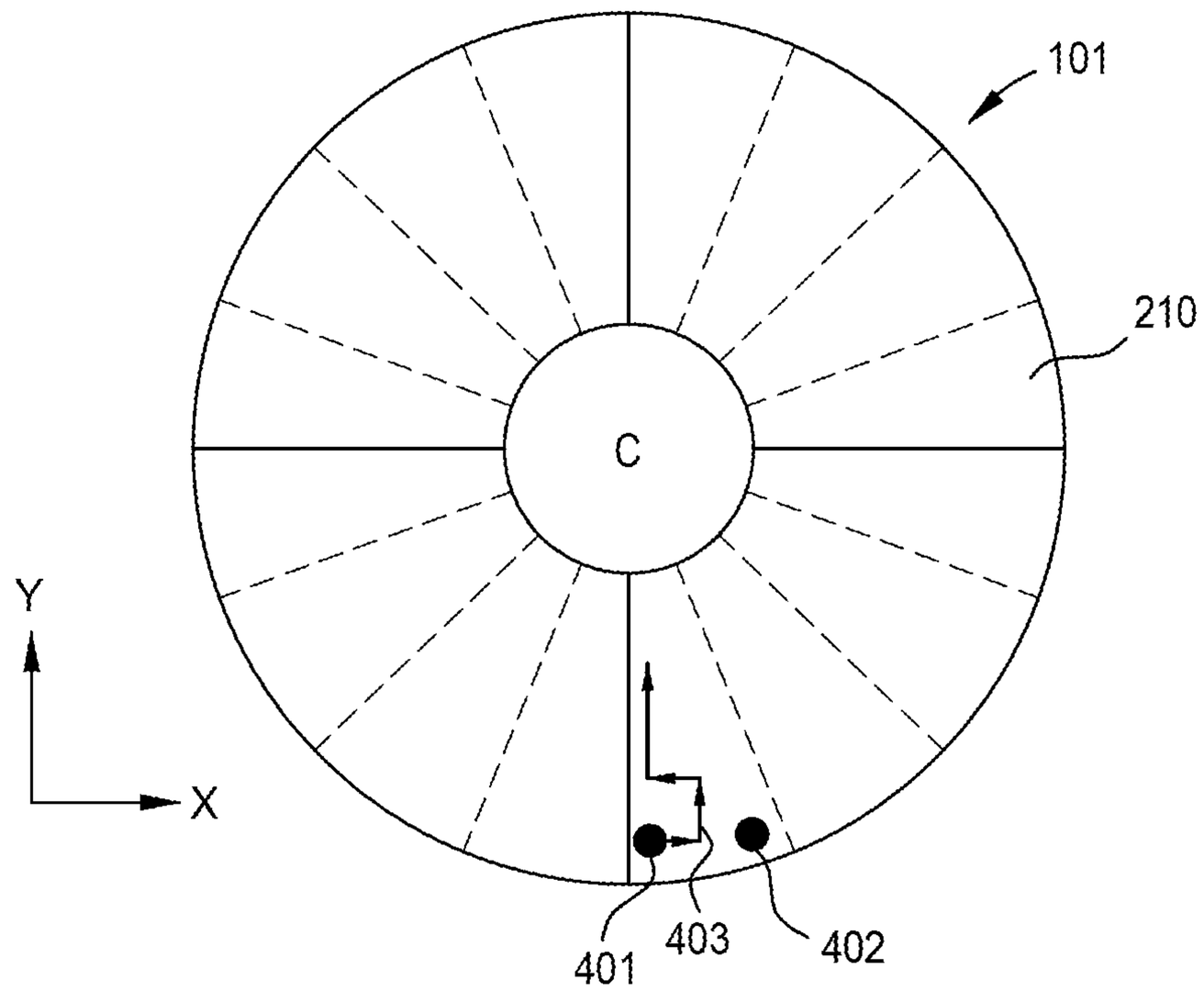



FIG. 7B

# METHOD TO FABRICATE LARGE SCALE FLAT OPTICS LENSES

## CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** This application claims benefit of U.S. Provisional Patent Application No. 63/165,572, filed Mar. 24, 2021, which is herein incorporated by reference in its entirety.

## BACKGROUND

### Field

**[0002]** Embodiments of the present disclosure generally relate to optical device fabrication. In particular, embodiments described herein relate to methods of fabricating large-scale optical devices having sub-micron dimensions.

### Description of the Related Art

**[0003]** Optical devices may be used to manipulate the propagation of light using structures of the optical device formed on a substrate. These structures alter light propagation by inducing localized phase discontinuities (i.e., abrupt changes of phase over a distance smaller than the wavelength of light). These structures may be composed of different types of materials, shapes, or configurations on the substrate and may operate based upon different physical principles.

**[0004]** Optical devices may be fabricated from a substrate having a diameter of 200 mm or greater, such as a 200 mm or 300 mm substrate. The substrate may be processed to form multiple optical devices. However, it may be beneficial to fabricate a single large-scale optical device, i.e., an optical device having a diameter of 200 mm or greater that includes optical device structures having sub-micron critical dimensions. Conventionally, lithography of a substrate to form an optical device pattern of a large-scale optical device requires either a substrate-sized mask or multiple masks stitched together. The substrate-sized mask may result in reduced resolution, and multiple masks stitched together may result in patterning errors.

**[0005]** Accordingly, what is needed in the art are methods of fabricating large-scale optical devices having sub-micron dimensions.

## SUMMARY

**[0006]** Methods of fabricating large-scale optical devices having sub-micron dimensions are provided. In one embodiment, a method is provided that includes projecting a beam to a mask, the mask corresponding to a section of an optical device pattern, the optical device pattern divided into four or more equal portions, each portion corresponding to a section of a substrate. The method further includes scanning the mask over a first section of the substrate to pattern a first portion of the optical device pattern, the substrate is positioned at a first rotation angle relative to the mask, wherein the scanning of the mask over the first section comprises moving one of the mask or the substrate from an initial position to a final position. The method further includes rotating the substrate to a second rotation angle, the second rotation angle corresponding to 360° divided by a total number of portions of the optical device pattern, scanning the mask over a second section of the substrate from the initial position to the final position to pattern a second portion of the optical device pattern, wherein the scanning of the mask over the second section comprises moving one of the mask or the substrate from the initial position to the final position, and repeating the rotating the substrate at subsequent rotation angles and the scanning of the mask over subsequent sections of the substrate until the substrate is patterned with the each of the four or more equal portions of the optical device pattern.

**[0007]** In another embodiment, a method is provided that includes projecting a beam to a mask, the mask corresponding to a section of an optical device pattern, the optical device pattern divided into four or more equal portions, each portion corresponding to a section of a substrate. The method further includes scanning the mask over a first section of the substrate to pattern a first portion of the optical device pattern, the substrate is positioned at a first rotation angle relative to the mask, wherein the scanning of the mask over the first section comprises moving one of the mask or the substrate from an initial position to a final position. The method further includes rotating the substrate to a second rotation angle, the second rotation angle corresponding to 360° divided by a total number of portions of the optical device pattern, scanning the mask over a second section of the substrate from the initial position to the final position to pattern a second portion of the optical device pattern, wherein the scanning of the mask over the second section comprises moving one of the mask or the substrate from the initial position to the final position, repeating the rotating the substrate at subsequent rotation angles and the scanning of the mask over subsequent sections of the substrate until the substrate is patterned with the each of the four or more equal portions of the optical device pattern, and etching the substrate.

**[0008]** In another embodiment, a method is provided that includes projecting a beam to a mask, the mask corresponding to a section of an optical device pattern, the optical device pattern divided into four or more equal portions, each portion corresponding to a section of a substrate. The method further includes scanning the mask over a first section of the substrate to pattern a first portion of the optical device pattern, the substrate is positioned at a first rotation angle relative to the mask, wherein the scanning of the mask over the first section comprises moving one of the mask or the substrate from an initial position to a final position, and etching the first section of the substrate. The method further includes rotating the substrate to a second rotation angle, the second rotation angle corresponding to 360° divided by a total number of portions of the optical device pattern, scanning the mask over a second section of the substrate from the initial position to the final position to pattern a second portion of the optical device pattern, wherein the scanning of the mask over the second section comprises moving one of the mask or the substrate from the initial position to the final position, and etching the second section of the substrate. The method further includes repeating the rotating the substrate at subsequent rotation angles, the scanning of the mask over subsequent sections of the substrate, and the etching of subsequent sections until the substrate is patterned with the each of the four or more equal portions of the optical device pattern.

## 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 and are therefore not to be considered limiting of scope, as the disclosure may admit to other equally effective embodiments.

**[0010]** FIG. **1**A is a schematic, plan view of an optical device according to one or more embodiments.

**[0011]** FIG. **1**B is a schematic, cross-sectional view of a portion of the optical device of FIG. **1**A according to one or more embodiments.

**[0012]** FIG. **2** is a schematic, perspective view of a lithography tool according to one or more embodiments

**[0013]** FIG. **3** is a flow diagram of a method of fabricating an optical device according to one or more embodiments.

**[0014]** FIGS. **4**A and **4**B are schematic, plan views of an optical device substrate according to one or more embodiments.

**[0015]** FIGS. **5**A and **5**B are schematic, plan views of an optical device substrate according to one or more embodiments.

**[0016]** FIGS. **6**A and **6**B are schematic, plan views of an optical device substrate according to one or more embodiments.

**[0017]** FIGS. **7**A and **7**B are schematic, plan views of an optical device substrate according to one or more embodiments.

**[0018]** 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

**[0019]** Embodiments of the present subject matter generally relate to optical device fabrication. In particular, embodiments described herein relate to methods of fabricating large-scale optical devices having sub-micron dimensions.

**[0020]** FIG. **1**A is a schematic, plan view of an optical device **100** according to one or more embodiments. The optical device **100** is fabricated from the method **300** described herein. The optical device **100** includes an optical device substrate **101** having a plurality of optical device structures **110** disposed on a surface **102**. The optical device substrate **101** has a diameter **103** that is 200 mm or greater, e.g., 300 mm or greater. The optical device substrate **101** may be any suitable substrate on which an optical device may be formed. In one embodiment, which can be combined with other embodiments described herein, the optical device substrate **101** is a silicon-containing substrate. It is also contemplated that the optical device substrate **101** may be an indium, gallium, germanium, or nitrogen containing substrate. Alternatively or additionally, the optical device substrate **101** may be a layered substrate.

**[0021]** FIG. **1**B is a schematic, cross-sectional view of a portion **104** of the optical device **100** of FIG. **1**A according to one or more embodiments. A plurality of optical device structures **110** having a depth **111** are disposed on the surface **102** of the optical device substrate **101**. The optical device structures **110** may be nanostructures having sub-micron dimensions, e.g., nano-sized dimensions. The optical device structures **110** have critical dimensions **112**, e.g., one of the width or diameter of the optical device structures **110**, the pitch of the optical device structures **110**, or the gap between the optical device structures **110**. In one embodiment, which may be combined with other embodiments described herein, the critical dimension **112** is less than 1 micrometer (μm) and corresponds to the width or diameter of the optical device structures **110**, depending on the cross-section of the optical device structures **110**. While FIG. **1**B depicts the optical device structures **110** as having square or rectangular shaped cross-sections, the cross-sections of the optical device structures **110** may have other shapes including, but not limited to, circular, triangular, elliptical, regular polygonal, irregular polygonal, and/or irregular shaped cross-sections. In some embodiments, which can be combined with other embodiments described herein, the cross-sections of the optical device structures **110** on a single optical device substrate **101** are different.

**[0022]** FIG. **2** is a schematic, perspective view of a lithography tool **200** according to one or more embodiments. The lithography tool **200** is utilized for photolithography or electron beam (e-beam) lithography. Photolithography includes, but is not limited to, I-line lithography at 365 nanometers (nm), krypton fluoride (KrF) lithography at 248 nm, argon fluoride (ArF) dry lithography at 193 nm, argon fluoride (ArF) immersion lithography at 193 nm, and extreme ultraviolet (EUV) lithography at 13.5 nm. The optical device substrate **101** shown in FIG. **2** corresponds to the portion **104** of the optical device substrate **101**. The lithography tool **200** includes a source **201** and a stage **206**. The optical device substrate **101** is disposed on the stage **206**. The stage **206** includes an actuator operable to rotate the optical device substrate **101** in order to scan the optical device substrate **101** in X and Y directions.

**[0023]** In embodiments of photolithography, a mask **203** is a physical mask and includes one or more apertures **204** corresponding to an optical device pattern **205**. A beam **202** is projected by the source **201** through the one or more apertures **204** to form the optical device pattern **205** in a resist layer **210** disposed on the optical device substrate **101**. The mask **203** is coupled to an actuator (not shown) to scan in X and Y directions in order to pattern the entirety of the optical device substrate **101**. The mask **203** is rectangular-shaped and is about 26 mm by 33 mm or less, although other sizes are also contemplated. In embodiments utilizing photolithography, the source **201** is a light source, and the beam **202** is a light beam.

**[0024]** In embodiments using e-beam lithography, the source **201** projects the beam **202** with the optical device pattern **205** such that the source **201** operates as a virtual mask. Accordingly, the mask **203** is a virtual mask corresponding to the optical device pattern **205** formed in the resist layer **210** disposed on the optical device substrate **101**. In embodiments of e-beam lithography, the source **201** is an e-beam source, and the beam **202** is an e-beam.

**[0025]** The resist layer **210** is a positive resist or a negative resist. A positive resist includes portions of the resist layer **210**, which, when exposed to a beam, are respectively soluble to a resist developer applied to the resist layer **210** after the optical device pattern **205** is written into the resist layer **210** using the beam. A negative resist includes portions of the resist layer **210**, which, when exposed to a beam, will be respectively insoluble to the resist developer applied to the resist layer **210** after the optical device pattern **205** is

written into the resist layer **210** using the beam. The chemical composition of the resist layer **210** determines whether the resist layer **210** is a positive resist or a negative resist.

**[0026]** In one embodiment, which can be combined with other embodiments described herein, a hardmask **220** is disposed between the resist layer **210** and the optical device substrate **101**. The hardmask **220** may be utilized for direct etching of the optical device substrate **101** to form the optical device structures **110** of the optical device **100**.

**[0027]** FIG. **3** is a flow diagram of a method **300** of fabricating an optical device **100** according to one or more embodiments. To facilitate explanation, the method **300** will be described with reference to the lithography tool **200** of FIG. **2**. However, it is contemplated that other suitably configured patterning tools other than the lithography tool **200** may be utilized in conjunction with method **300**. In addition, method **300** will also be described with reference to FIGS. **4**A, **4**B, **5**A, **5**B, **6**A, **6**B, **7**A, and **7**B, which are schematic, plan views of an optical device substrate **101** according to one or more embodiments.

**[0028]** The resist layer **210** is disposed on the optical device substrate **101** such that the optical device pattern **205** is formed on the resist layer **210**. The optical device substrate **101** of FIG. **4**A has four equal sections corresponding to the optical device pattern **205** divided into four equal portions. The optical device substrate **101** of FIG. **5**A has eight equal sections corresponding to the optical device pattern **205**, which is divided into eight equal portions. The optical device substrate **101** of FIG. **6**A has twelve equal sections corresponding to the optical device pattern **205**, which is divided into twelve equal portions. The optical device substrate **101** of FIG. **7**A has sixteen equal sections corresponding to the optical device pattern **205**, which is divided into sixteen equal portions.

**[0029]** As depicted in FIG. **4**B, the optical device substrate **101** may include a central section C of the optical device substrate **101** in addition to the four equal portions. The central section C eliminates an intersection point at the center of the device area of the optical device substrate **101**. As depicted in FIG. **5**B, the optical device pattern **205** is divided into eight equal portions and a central portion corresponding to eight equal sections and a central section C of the optical device substrate **101**. As depicted in FIG. **6**B, the optical device pattern **205** is divided into twelve equal portions and a central portion corresponding to twelve equal sections and central section C of the optical device substrate **101**. As depicted in FIG. **7**B, the optical device pattern **205** is divided into sixteen equal portions and a central portion corresponding to sixteen equal sections and a central section C of the optical device substrate **101**.

**[0030]** At operation **301**, the optical device substrate **101** is positioned at a first rotation angle relative to the mask. The optical device pattern **205** is divided into four or more equal portions, each portion corresponding to a section of the optical device substrate **101**, as shown in FIGS. **4**A-**7**B. The beam **202** is projected to the mask **203**, which corresponds to a portion of the optical device pattern **205**. By dividing the optical device pattern **205** into portions, high resolution (i.e., sub-micron dimensions) and reduced patterning errors can be achieved for the resulting optical device structures **110** formed on the optical device substrate **101**.

**[0031]** At operation **302**, the beam **202** is projected to the mask **203**, and the mask **203** is scanned over a first section of the optical device substrate **101** while the optical device substrate **101** is positioned at the first rotation angle relative to the mask **203**. This scan patterns a first portion of the optical device pattern **205** on the first section of the optical device substrate **101**. Scanning of the mask **203** over the first section involves moving one of the mask **203** or the optical device substrate **101** along a path **403**. The path **403** covers the designated portion of the optical device substrate **101** from an initial position **401** to a final position **402**.

**[0032]** At operation **303**, the optical device substrate **101** is positioned at second rotation angle. In one embodiment, which can be combined with other embodiments described herein, the optical device substrate **101** is rotated to the second rotation angle by activating the actuator coupled to the stage **206**. The second rotation angle corresponds to 360° divided by a total number of portions of the optical device pattern **205**. For example, if the optical device pattern **205** is divided into four portions, the second rotation angle is 90°. At the second rotation angle, the second section of the optical device pattern **205** aligns with the mask **203**, the initial position **401**, and final position **402**.

**[0033]** The proper alignment of the optical device substrate **101** during each rotation allows for uniform formation of the optical device pattern **205**. In one embodiment, which can be combined with other embodiments described herein, a plurality of alignment marks (not shown) are printed on the optical device substrate **101**. Any suitable number of alignment marks may be used; for example, in one embodiment, four or more alignment marks are disposed on the optical device substrate **101**. In one embodiment, which can be combined with other embodiments described herein, the alignment marks are formed on an outer edge of the optical device substrate **101** in order to minimize impact on the device area. When rotating the optical device substrate **101**, the position of the optical device substrate **101** relative to a pre-determined position is monitored using the alignment marks.

**[0034]** At operation **304**, the beam **202** is projected to the mask **203**, and the mask **203** is scanned over a second section of the optical device substrate **101** while the optical device substrate **101** is positioned at the second rotation angle relative to the mask **203**. This scan patterns a second portion of the optical device pattern **205** on the second section of the optical device substrate **101**. As with the scanning over the first section, scanning of the mask **203** over the second section involves moving one of the mask **203** or the optical device substrate **101** along the path **403**. The path **403** covers the designated portion of the optical device substrate **101** from the initial position **401** to the final position **402**.

**[0035]** At operation **305**, rotating the optical device substrate **101** at subsequent rotation angles and scanning the mask **203** over subsequent sections repeats until the optical device substrate **101** is patterned with the each of the four or more equal portions of the optical device pattern **205**. Scanning of the mask **203** over subsequent sections involves moving one of the mask **203** or the optical device substrate **101** along the path **403**. In one embodiment, which can be combined with other embodiments described herein, the optical device substrate **101** undergoes an etching process after the patterning process is complete for each of the four or more equal portions of the optical device pattern **205**. In another embodiment, which can be combined with other embodiments described herein, the optical device substrate **101** undergoes an etching process after each of the sections

are patterned. For example, if there are four sections, the first section undergoes the etching process before the second section is scanned and patterned.

**[0036]** In summation, embodiments described herein relate to methods of fabricating large-scale optical devices having sub-micron dimensions. By patterning the substrate in portions, high resolution (i.e., sub-micron dimensions) can be achieved for the resulting optical device structures formed on the substrate. The fabricated optical devices, or lenses, may be used in applications requiring relatively large lenses, such as satellite imaging or communication. The methods described herein reduce errors that may arise during patterning of large optical device substrates.

**[0037]** While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

**1**. A method, comprising:
projecting a beam to a mask, the mask corresponding to a section of an optical device pattern, the optical device pattern divided into four or more equal portions, each portion corresponding to a section of a substrate;
scanning the mask over a first section of the substrate to pattern a first portion of the optical device pattern, the substrate is positioned at a first rotation angle relative to the mask; wherein:
the scanning of the mask over the first section comprises moving one of the mask or the substrate from an initial position to a final position;
rotating the substrate to a second rotation angle, the second rotation angle corresponding to 360° divided by a total number of portions of the optical device pattern;
scanning the mask over a second section of the substrate from the initial position to the final position to pattern a second portion of the optical device pattern, wherein:
the scanning of the mask over the second section comprises moving one of the mask or the substrate from the initial position to the final position; and
repeating the rotating the substrate at subsequent rotation angles and the scanning of the mask over subsequent sections of the substrate until the substrate is patterned with the each of the four or more equal portions of the optical device pattern.

**2**. The method of claim **1**, further comprising:
etching the substrate.

**3**. The method of claim **1**, further comprising:
printing four or more alignment marks on the substrate.

**4**. The method of claim **3**, wherein rotating the substrate comprises rotating the substrate to a pre-determined position using the alignment marks.

**5**. The method of claim **1**, wherein a hardmask is disposed on the substrate, and a resist layer is disposed on the hardmask.

**6**. The method of claim **1**, wherein the beam is an electron beam or a light beam.

**7**. The method of claim **1**, wherein a diameter of the substrate is 200 mm or greater.

**8**. The method of claim **1**, wherein patterning the substrate comprises forming optical device structures, wherein a critical dimension of the optical device structures is less than 1 micron.

**9**. The method of claim **1**, wherein the mask is a physical mask.

**10**. The method of claim **9**, wherein the mask is rectangular-shaped, and the mask is about 26 mm by 33 mm or less.

**11**. The method of claim **1**, wherein the mask is a virtual mask corresponding to the optical device pattern.

**12**. A method, comprising:
projecting a beam to a mask, the mask corresponding to a section of an optical device pattern, the optical device pattern divided into four or more equal portions, each portion corresponding to a section of a substrate;
scanning the mask over a first section of the substrate to pattern a first portion of the optical device pattern, the substrate is positioned at a first rotation angle relative to the mask; wherein:
the scanning of the mask over the first section comprises moving one of the mask or the substrate from an initial position to a final position;
rotating the substrate to a second rotation angle, the second rotation angle corresponding to 360° divided by a total number of portions of the optical device pattern;
scanning the mask over a second section of the substrate from the initial position to the final position to pattern a second portion of the optical device pattern, wherein:
the scanning of the mask over the second section comprises moving one of the mask or the substrate from the initial position to the final position;
repeating the rotating the substrate at subsequent rotation angles and the scanning of the mask over subsequent sections of the substrate until the substrate is patterned with the each of the four or more equal portions of the optical device pattern; and
etching the substrate.

**13**. The method of claim **12**, further comprising:
printing four or more alignment marks on the substrate.

**14**. The method of claim **13**, wherein rotating the substrate comprises rotating the substrate to a pre-determined position using the alignment marks.

**15**. The method of claim **12**, wherein a diameter of the substrate is 200 mm or greater.

**16**. The method of claim **12**, wherein patterning the substrate comprises forming optical device structures, wherein a critical dimension of the optical device structures is less than 1 micron.

**17**. A method, comprising:
projecting a beam to a mask, the mask corresponding to a section of an optical device pattern, the optical device pattern divided into four or more equal portions, each portion corresponding to a section of a substrate;
scanning the mask over a first section of the substrate to pattern a first portion of the optical device pattern, the substrate is positioned at a first rotation angle relative to the mask; wherein:
the scanning of the mask over the first section comprises moving one of the mask or the substrate from an initial position to a final position;
etching the first section of the substrate;
rotating the substrate to a second rotation angle, the second rotation angle corresponding to 360° divided by a total number of portions of the optical device pattern;
scanning the mask over a second section of the substrate from the initial position to the final position to pattern a second portion of the optical device pattern, wherein:

the scanning of the mask over the second section comprises moving one of the mask or the substrate from the initial position to the final position;

etching the second section of the substrate; and

repeating the rotating the substrate at subsequent rotation angles, the scanning of the mask over subsequent sections, and etching of subsequent sections until the substrate is patterned with the each of the four or more equal portions of the optical device pattern.

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

printing four or more alignment marks on the substrate.

**19**. The method of claim **18**, wherein rotating the substrate comprises rotating the substrate to a pre-determined position using the alignment marks.

**20**. The method of claim **17**, wherein a diameter of the substrate is 200 mm or greater.

* * * * *