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(54) **INTERFERENCE IN-SENSITIVE LITTROW SYSTEM FOR OPTICAL DEVICE STRUCTURE MEASUREMENT**

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G01B 11/26 (2006.01)

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CPC ***G01B 11/26*** (2013.01)

(58) **Field of Classification Search**
CPC G01B 11/26; G02B 2027/0125; G02B 5/1857; G02B 27/0172
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,688,907 A * 8/1987 Kleinberg G02B 21/22 359/381
5,253,038 A * 10/1993 Bouwhuis G01B 11/26 356/492
5,583,632 A * 12/1996 Haga G01N 21/8901 356/613

(Continued)

FOREIGN PATENT DOCUMENTS

EP 0822700 B1 4/2003

OTHER PUBLICATIONS

PCT Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority for International Application No. PCT/US2021/064377; dated Apr. 12, 2022.

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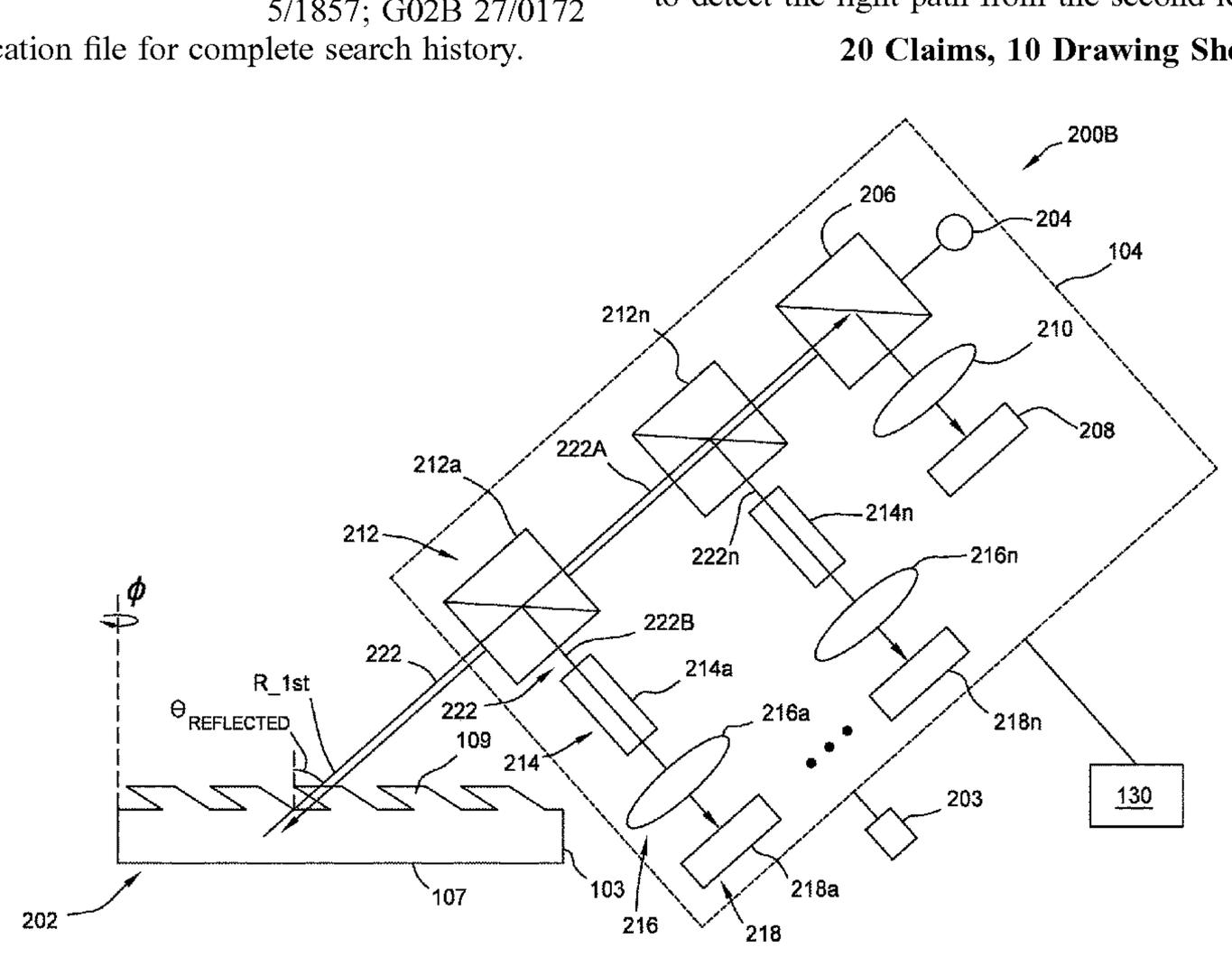
(57) **ABSTRACT**

Embodiments described herein provide for devices and methods of measuring a pitch P of optical device structures and an orientation angle ϕ of the optical device structures. One embodiment of the system includes an optical arm coupled to an arm actuator. The optical arm includes a light source. The light source emits a light path operable to be diffracted to the stage. The optical arm further includes a first beam splitter and a second beam splitter positioned in the light path. The first beam splitter directs the light path through a first lens and the second beam splitter directs the light path through a first dove prism and a second lens. The optical arm further includes a first detector operable to detect the light path from the first lens and second detector operable to detect the light path from the second lens.

20 Claims, 10 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

6,473,443	B1 *	10/2002	Kuo	G03H 1/30 372/100
8,416,402	B2 *	4/2013	Shibata	G03F 7/7065 382/145
10,331,207	B1 *	6/2019	Simmons	H04N 13/383
10,725,302	B1 *	7/2020	Sharma	G06F 3/012
2014/0285429	A1 *	9/2014	Simmons	G02B 27/0179 359/259
2015/0282707	A1 *	10/2015	Tanabe	A61B 3/14 351/205
2020/0309598	A1 *	10/2020	Fu	G02B 5/1819
2021/0356910	A1 *	11/2021	Zhang	G11B 7/0065
2023/0210365	A1 *	7/2023	Chan	G02B 27/0172 345/8

* cited by examiner

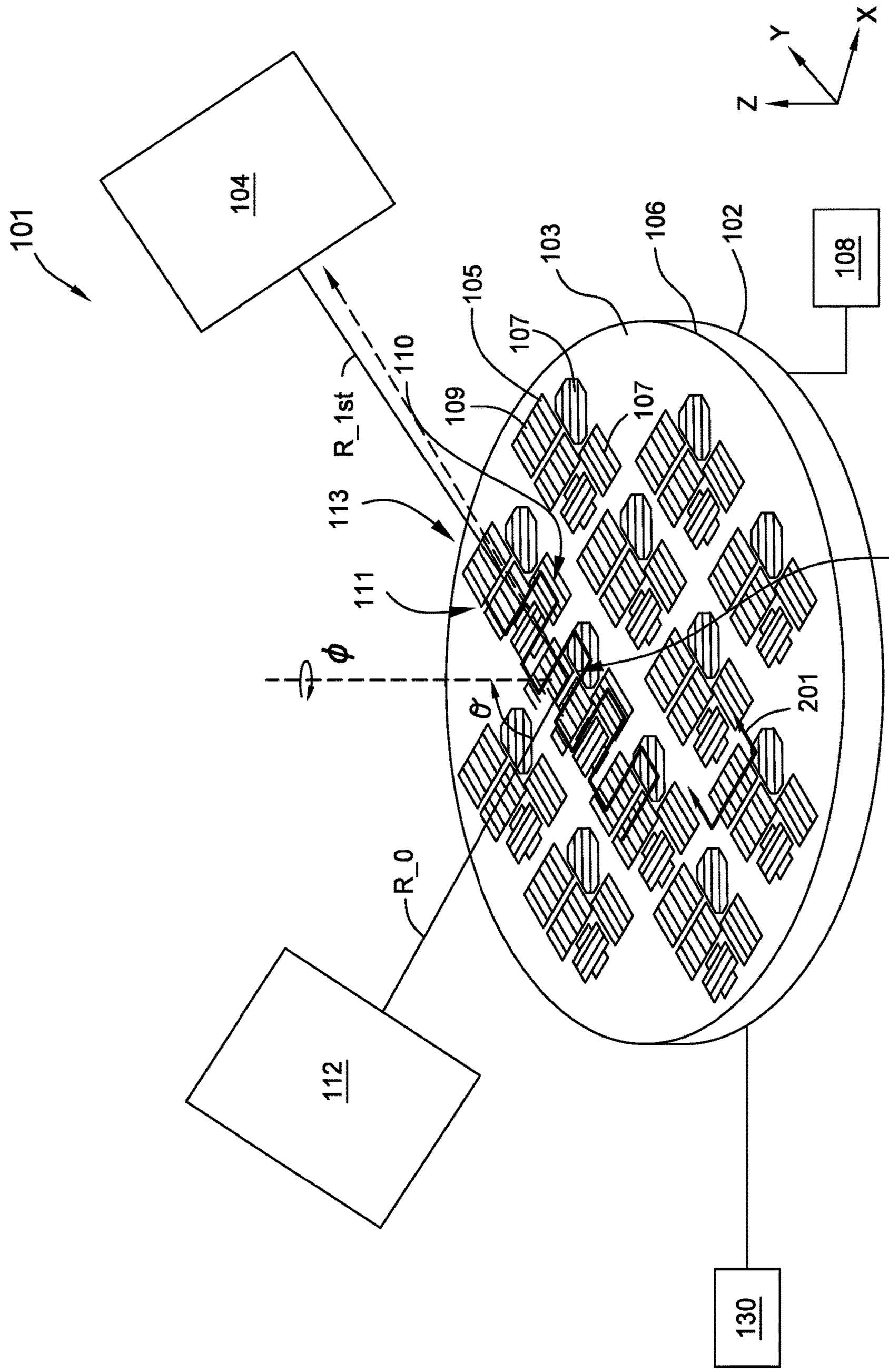

Z
Y
X
101
104
110
R_1st
113
111
105
107
103
106
102
108
109
107
115
201
ϕ
θ
R_0
112
130

FIG. 1

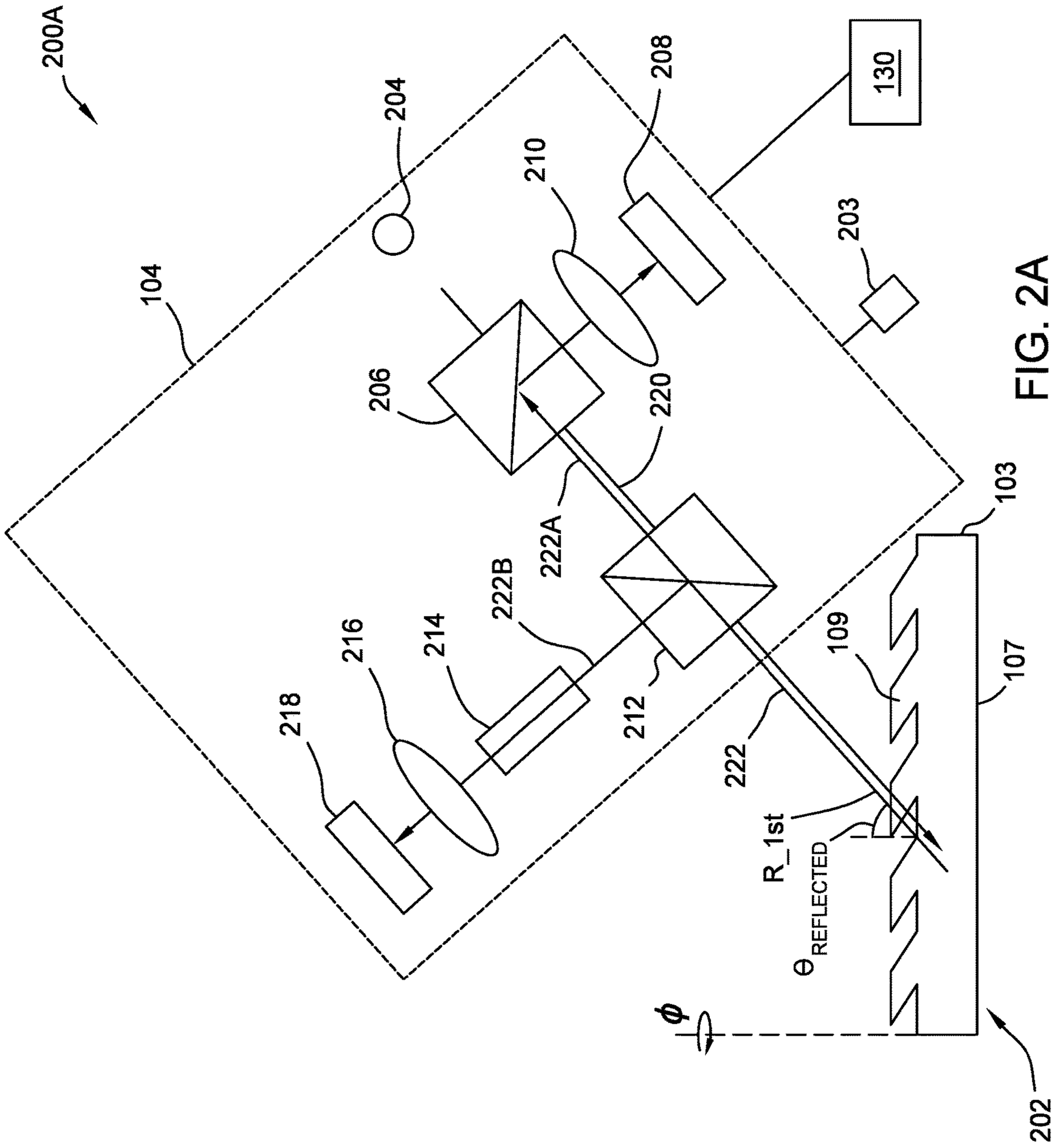

200A
104
204
208
210
130
203
206
220
222A
222B
214
216
218
212
222
103
109
107
R_1st
$\Theta_{REFLECTED}$
ϕ
202

FIG. 2A

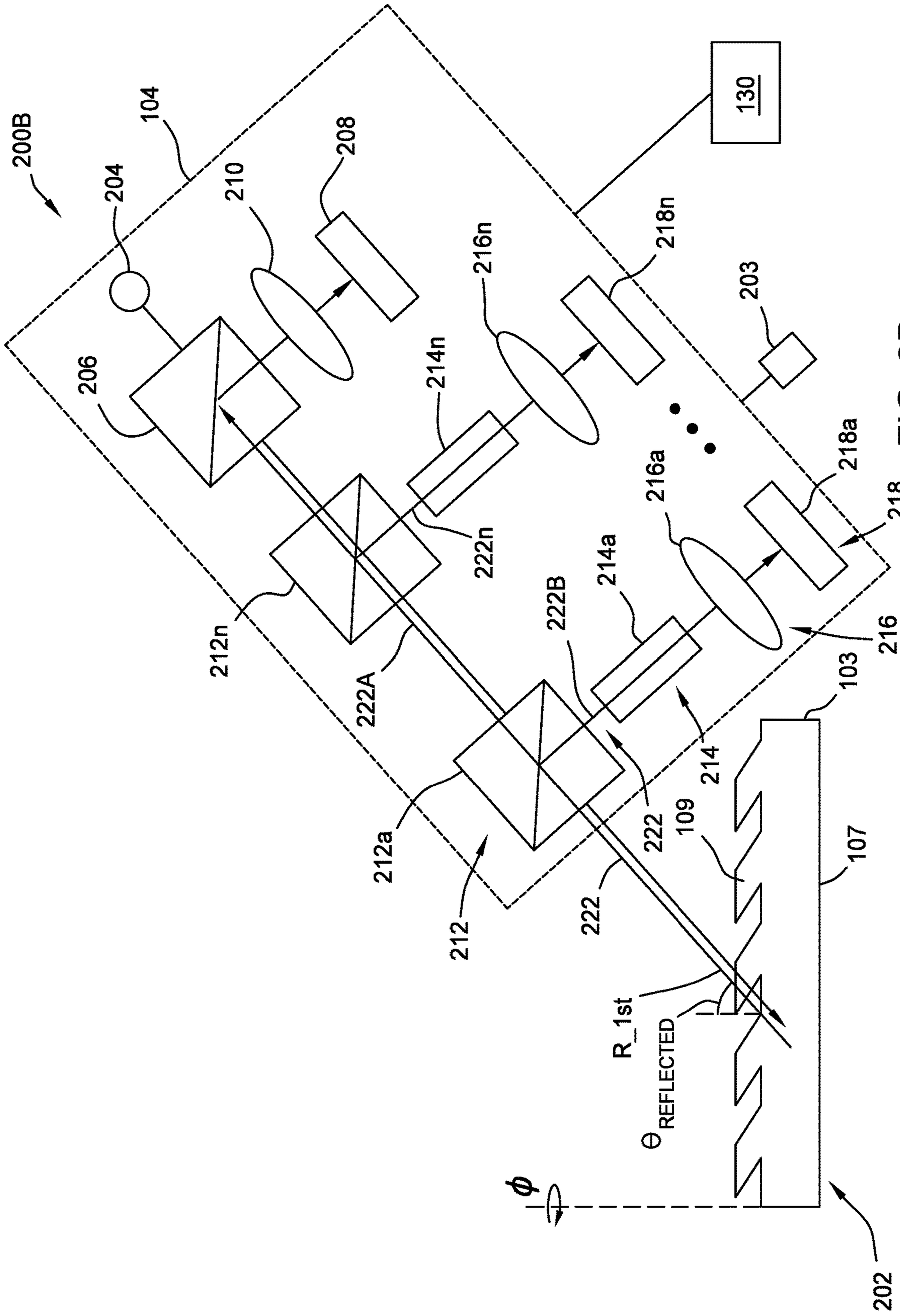

200B
104
204
210
208
130
216n
218n
203
206
214n
222n
212n
222A
222B
214a
216a
218a
218
216
103
212a
222
214
109
107
212
R_1st
$\Theta_{REFLECTED}$
ϕ
202

FIG. 2B

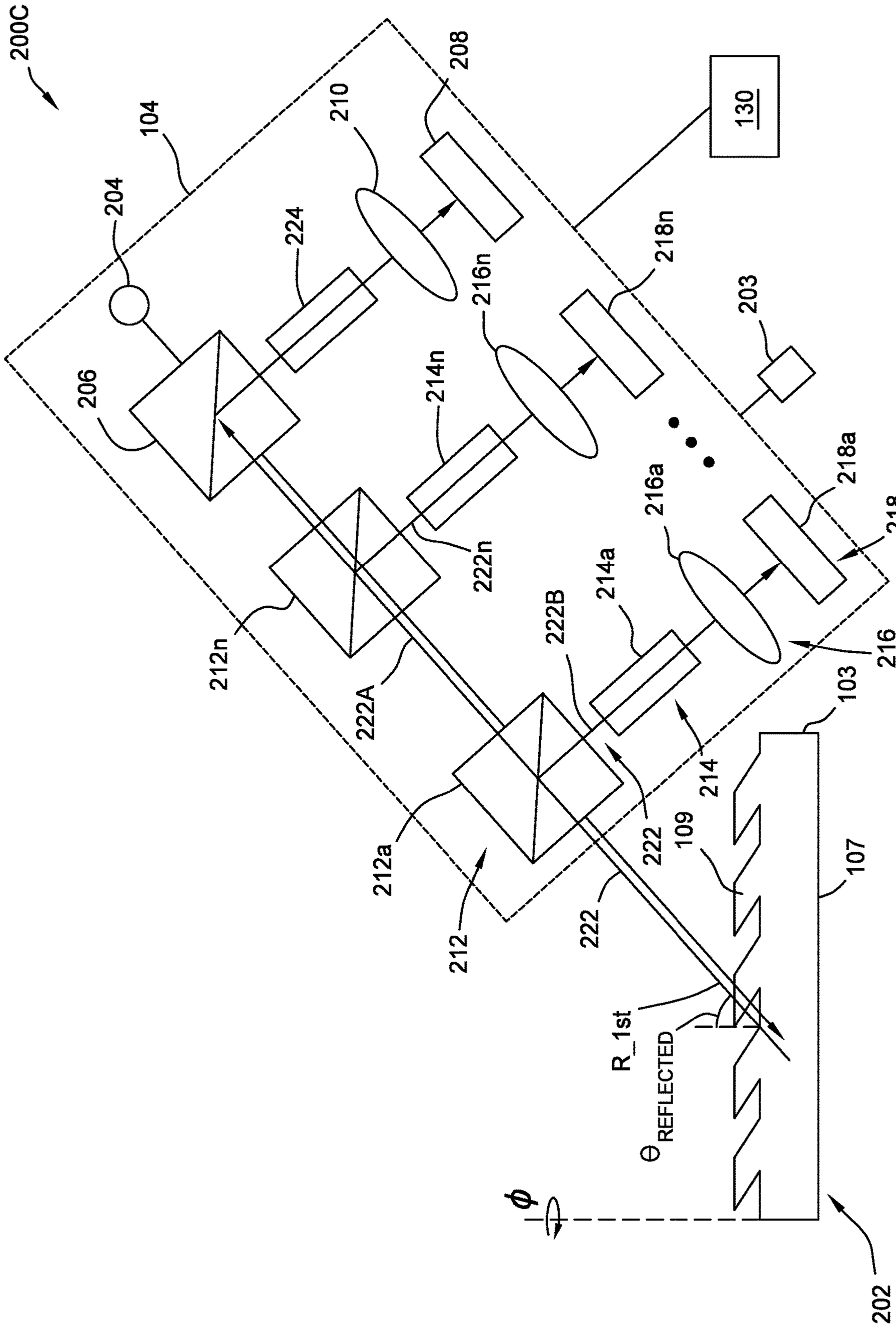

200C
104
204
206
224
210
208
130
218n
216n
203
214n
222n
212n
222A
216a
218a
218
222B
214a
212a
216
103
214
222
109
107
212
R_1st
$\Theta_{REFLECTED}$
ϕ
202

FIG. 2C

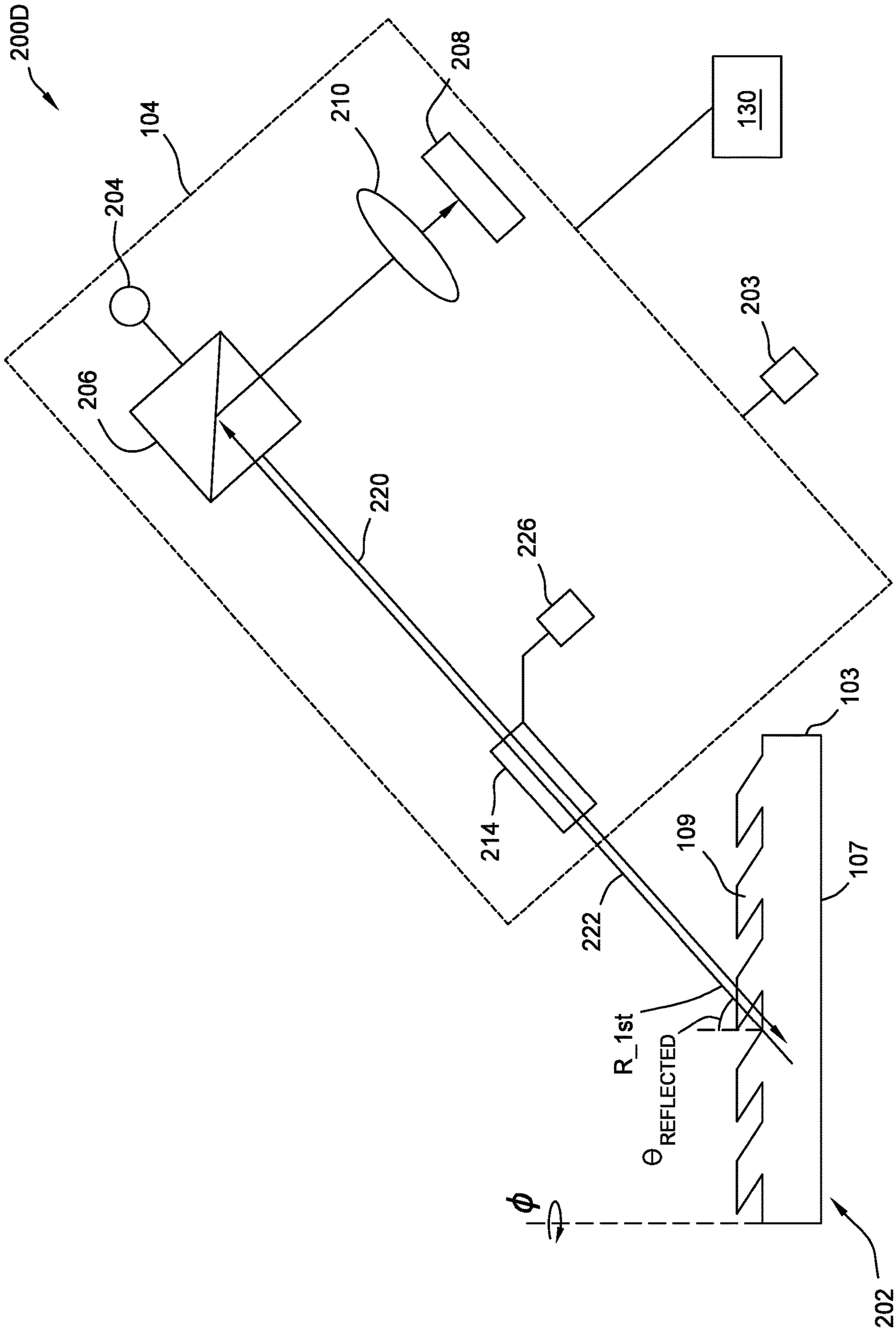

200D
104
204
206
210
208
130
203
220
226
214
222
103
109
107
R_1st
$\Theta_{REFLECTED}$
ϕ
202

FIG. 2D

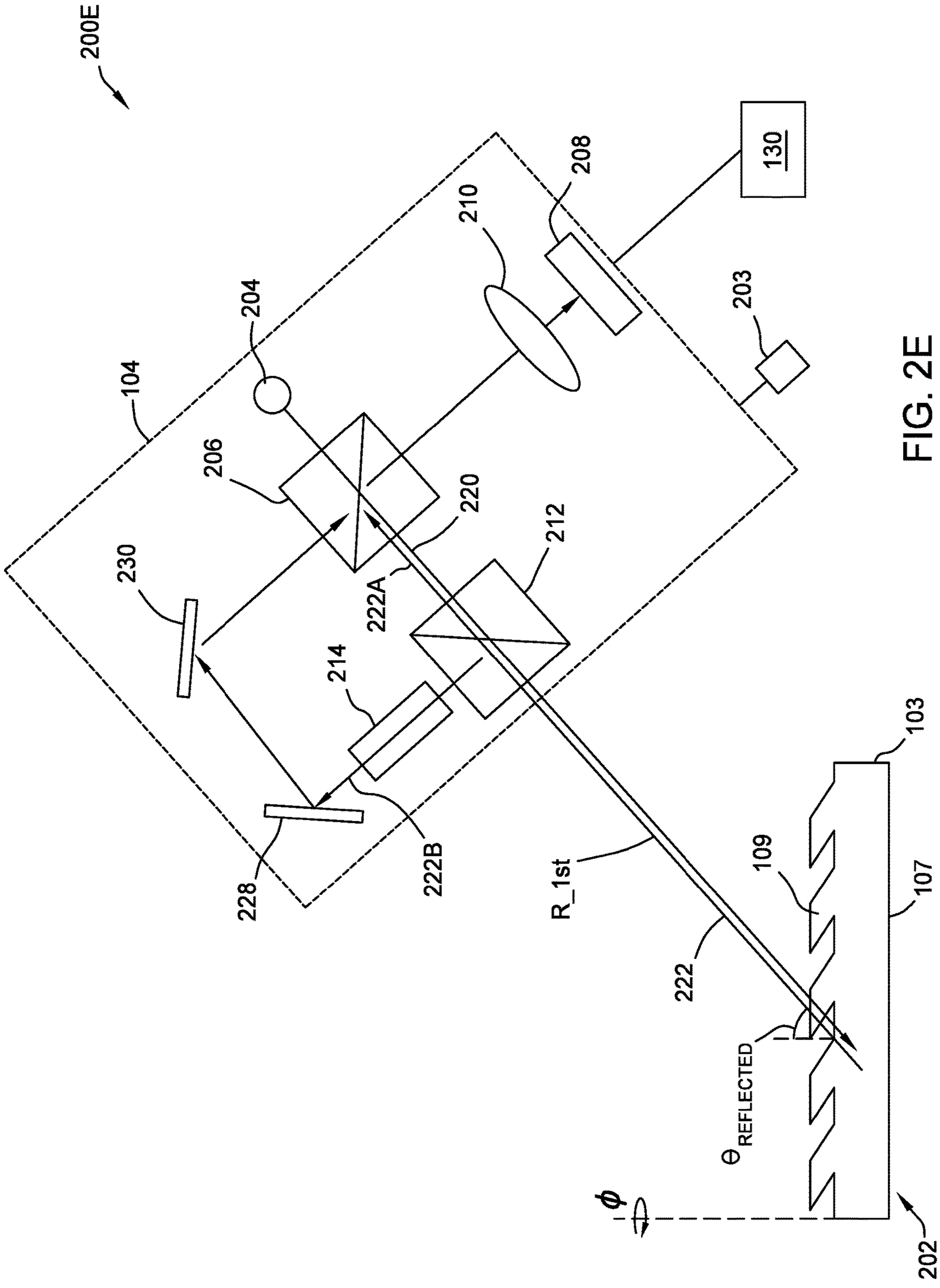

200E
104
204
206
208
210
130
203
230
220
212
222A
214
222B
228
R_1st
103
109
107
222
$\Theta_{REFLECTED}$
ϕ
202

FIG. 2E

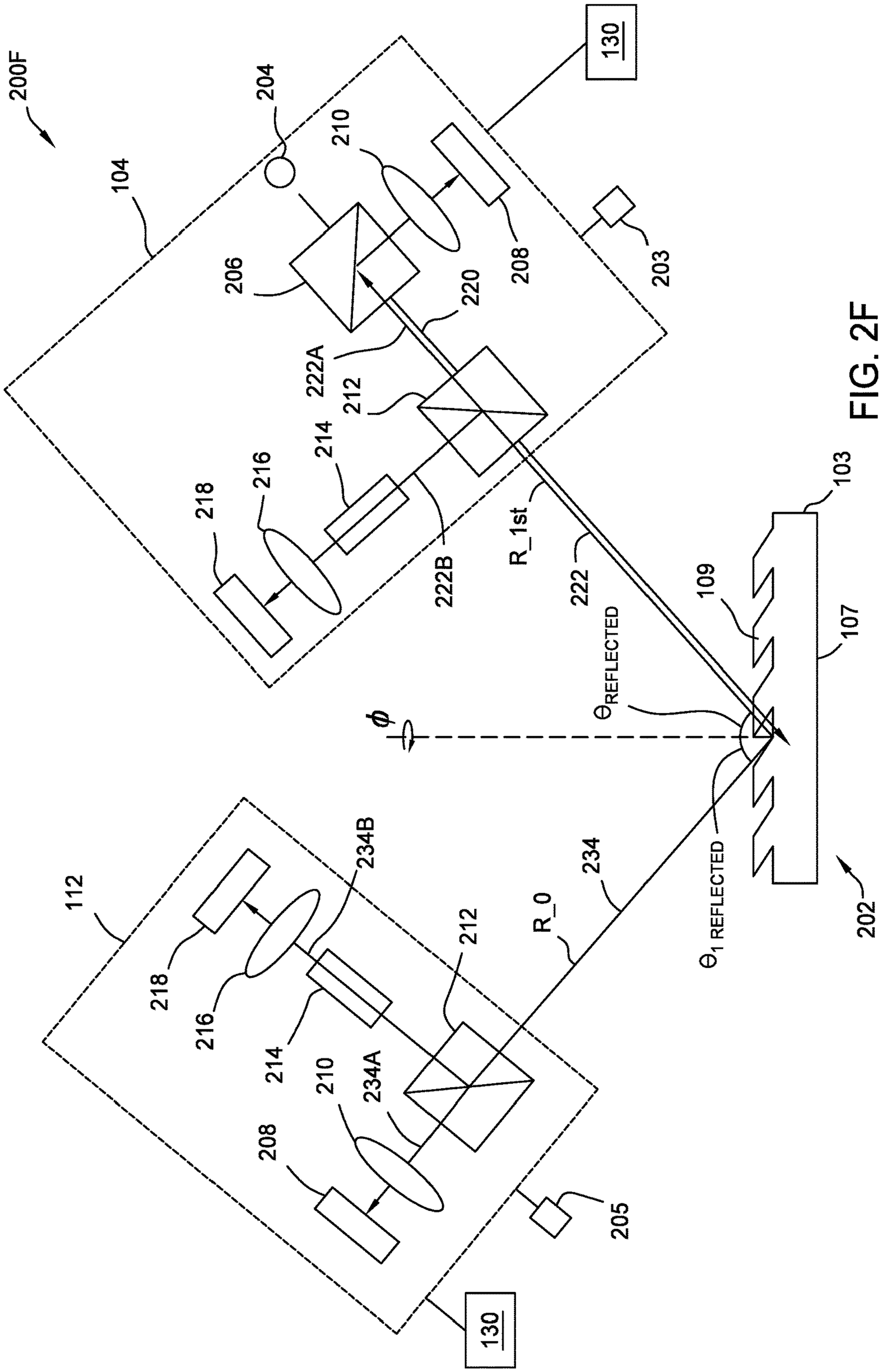

200F
104
204
210
130
206
208
203
220
222A
212
214
216
218
222B
R_1st
222
109
103
107
$\Theta_{REFLECTED}$
ϕ
234
R_0
$\Theta_{1\ REFLECTED}$
202
112
234B
234A
205

FIG. 2F

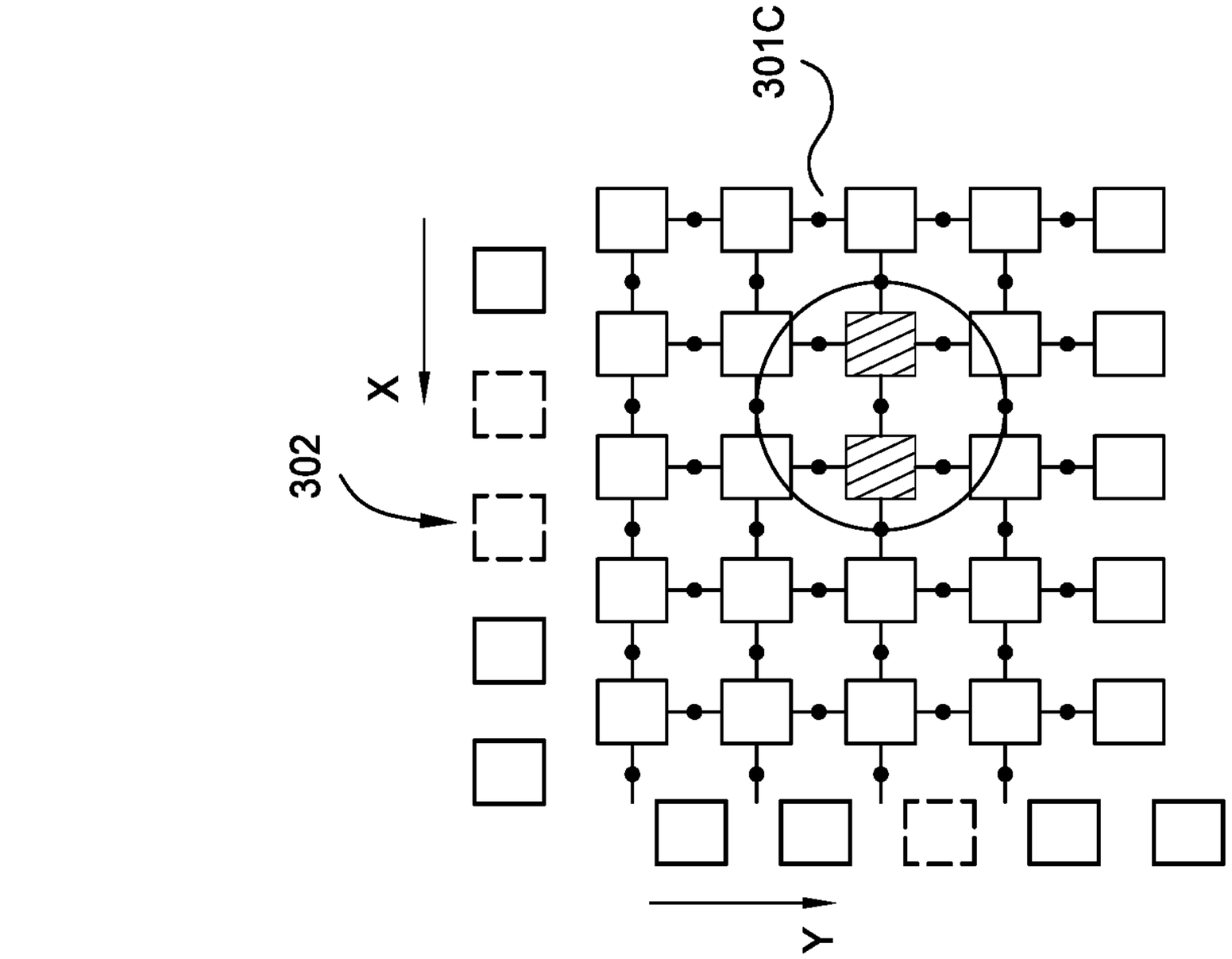


FIG. 3C

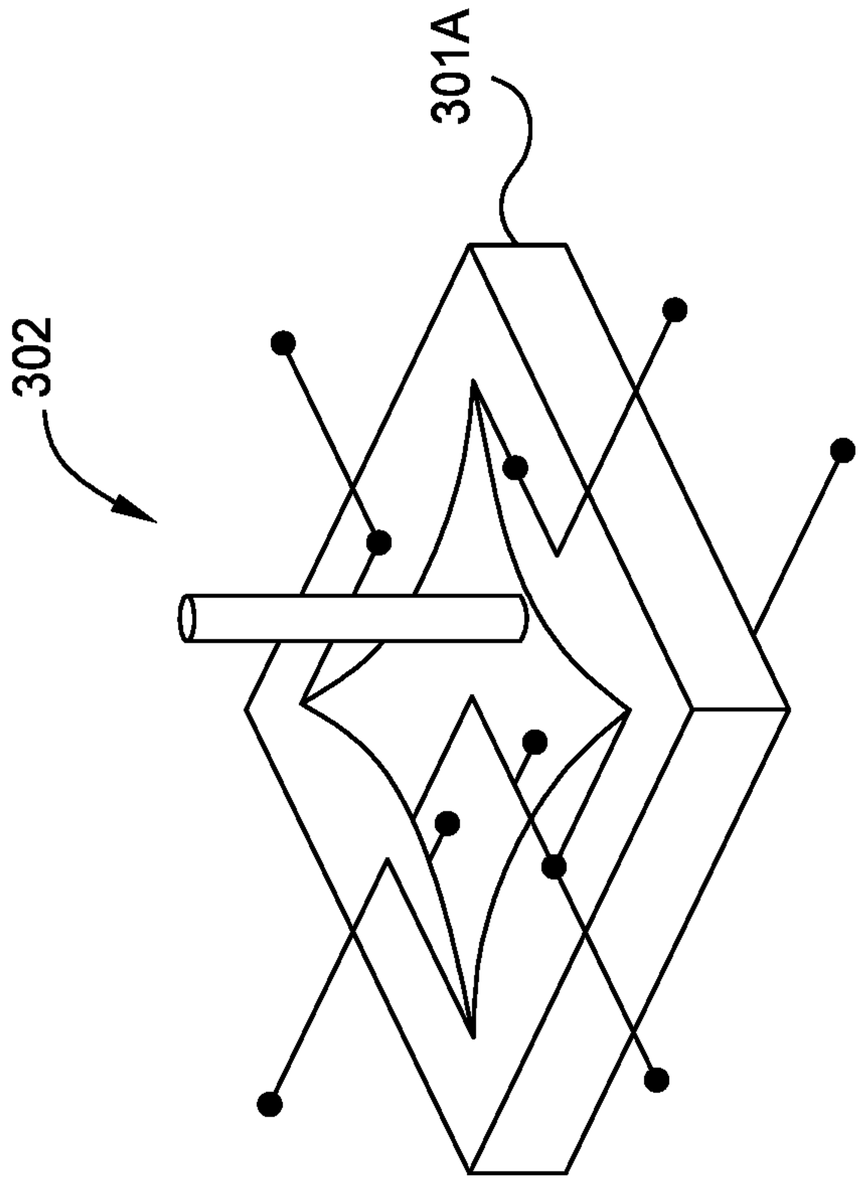


FIG. 3A

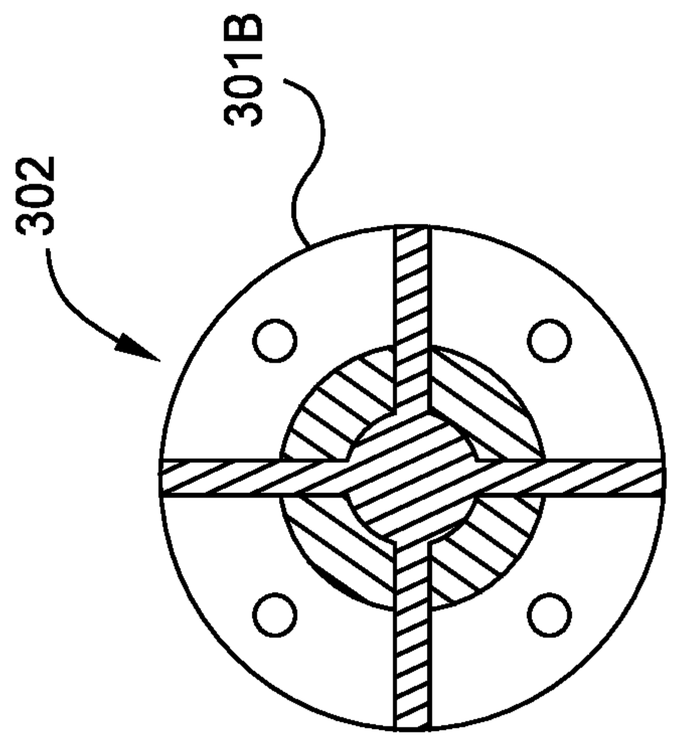


FIG. 3B

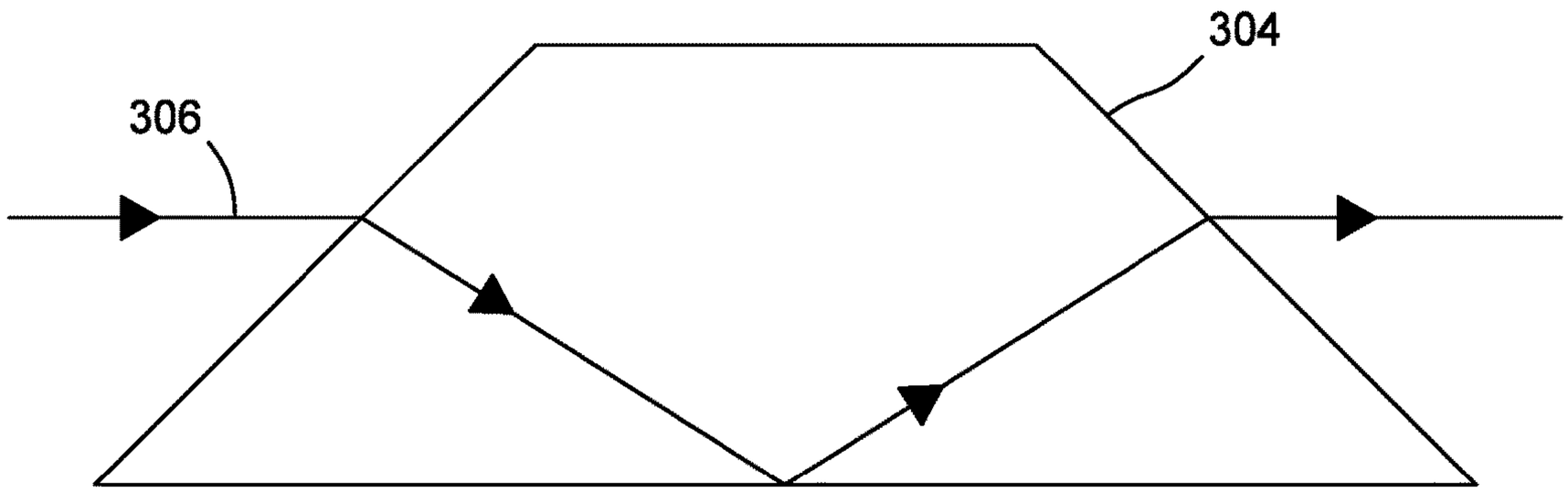


FIG. 3D

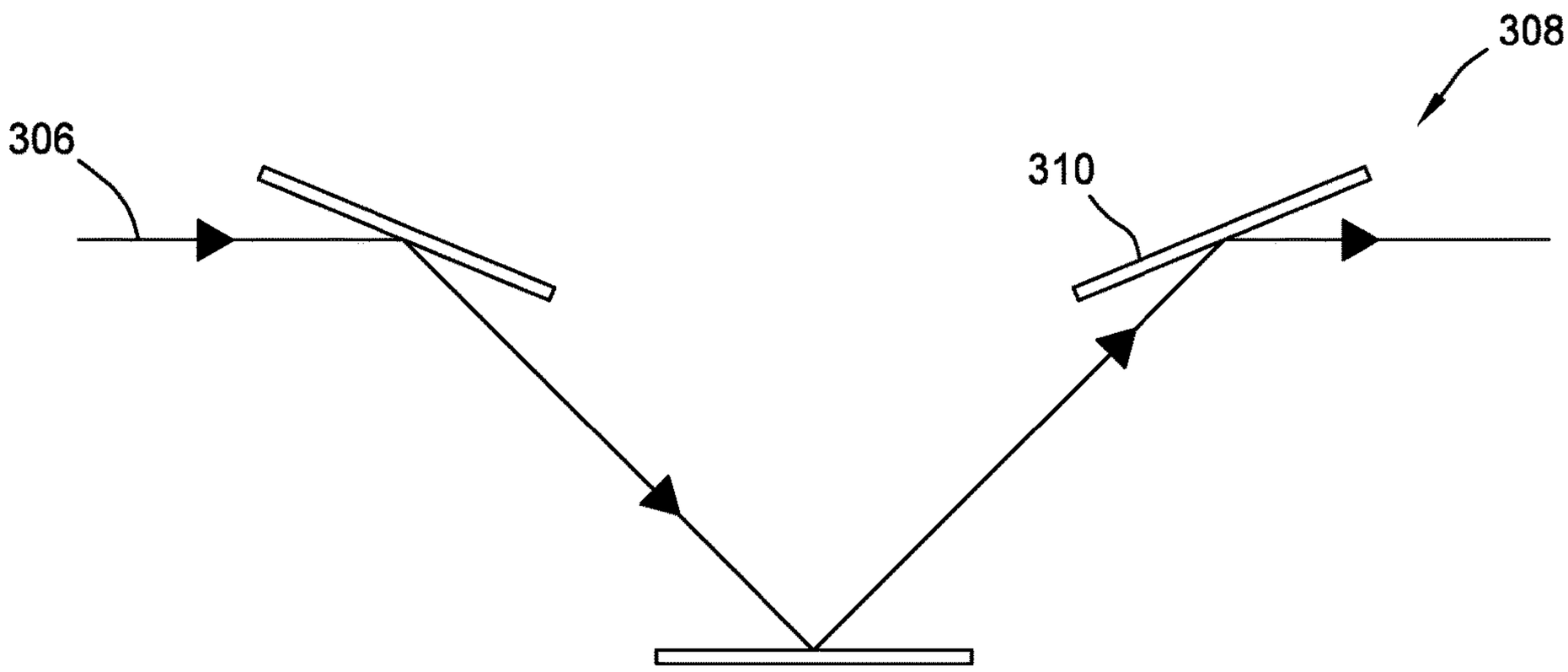


FIG. 3E

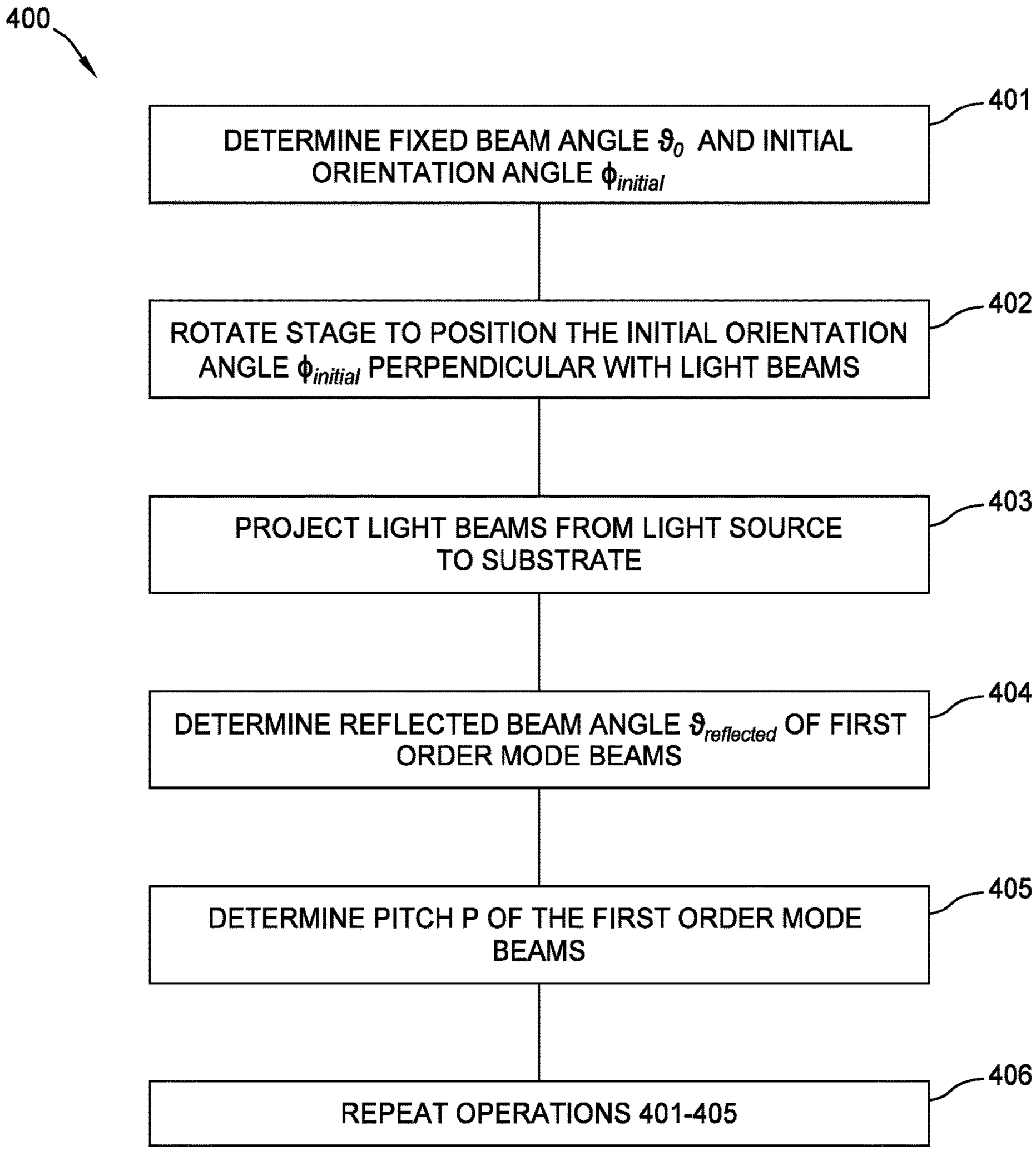

400
401
DETERMINE FIXED BEAM ANGLE ϑ_0 AND INITIAL ORIENTATION ANGLE $\phi_{initial}$
402
ROTATE STAGE TO POSITION THE INITIAL ORIENTATION ANGLE $\phi_{initial}$ PERPENDICULAR WITH LIGHT BEAMS
403
PROJECT LIGHT BEAMS FROM LIGHT SOURCE TO SUBSTRATE
404
DETERMINE REFLECTED BEAM ANGLE $\vartheta_{reflected}$ OF FIRST ORDER MODE BEAMS
405
DETERMINE PITCH P OF THE FIRST ORDER MODE BEAMS
406
REPEAT OPERATIONS 401-405

FIG. 4

INTERFERENCE IN-SENSITIVE LITTROW SYSTEM FOR OPTICAL DEVICE STRUCTURE MEASUREMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Patent Application No. 63/134,442, filed Jan. 6, 2021, the contents of which are incorporated herein in their entirety.

BACKGROUND

Field

Embodiments of the present disclosure relate to devices and methods of measuring a pitch P of optical device structures and an orientation angle ϕ of the optical device structures.

Description of the Related Art

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 **3**D 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.

Augmented reality, however, enables an experience in which a user can still see through the display lenses of the glasses or other HMD device to view the surrounding environment, yet also see images of virtual objects that are generated for display and appear as part of the environment. Augmented reality can include any type of input, such as audio and haptic inputs, as well as virtual images, graphics, and video that enhances or augments the environment that the user experiences. As an emerging technology, there are many challenges and design constraints with augmented reality.

One such challenge is displaying a virtual image overlaid on an ambient environment. Optical devices are used to assist in overlaying images. Fabricating optical devices can be challenging as optical devices tend to have properties, such as optical device structure pitches and optical device structure orientations that need to be manufactured according to specific tolerances. Conventional systems will experience a decrease in accuracy and repeatability when measuring optical device structures on non-opaque substrates due to reflection and diffraction of light. Accordingly, what is needed in the art are improved devices and methods of measuring a pitch P of optical device structures and an orientation angle ϕ of the optical device structures with increased accuracy and repeatability.

SUMMARY

In one embodiment, a system is provided. The system includes a stage having a substrate support surface. The stage is coupled to a stage actuator configured to move the stage in a scanning path and rotate the stage about an axis. The system further includes an optical arm coupled to an arm actuator configured to scan the optical arm and rotate the optical arm about the axis. The optical arm includes a light source. The light source emits a light path operable to be diffracted to the stage. The optical arm further includes a first beam splitter and a second beam splitter positioned in the light path. The first beam splitter directs the light path through a first lens and the second beam splitter directs the light path through a first dove prism and a second lens. The optical arm further includes a first detector operable to detect the light path from the first lens and second detector operable to detect the light path from the second lens.

In another embodiment, a system is provided. The system includes a stage having a substrate support surface. The stage is coupled to a stage actuator configured to move the stage in a scanning path and rotate the stage about an axis. The system further includes an optical arm coupled to an arm actuator configured to scan the optical arm and rotate the optical arm about the axis. The optical arm includes a light source. The light source emits a light path operable to be diffracted to the stage. The optical arm further includes a dove prism positioned in the light path. The dove prism includes an actuator to rotate the dove prism. The optical arm further includes a first beam splitter positioned in the light path. The first beam splitter directs the light path through a first lens and a second beam splitter directs the light path through a second lens. The optical arm further includes a first detector operable to detect the light path from the first lens.

In yet another embodiment, a system is provided. The system includes a stage having a substrate support surface. The stage is coupled to a stage actuator configured to move the stage in a scanning path and rotate the stage about an axis. An optical arm coupled to an arm actuator is configured to scan the optical arm and rotate the optical arm about the axis. The optical arm includes a light source. The light source emits a light path operable to be diffracted to the stage. A first beam splitter and a second beam splitter are positioned in the light path. The first beam splitter directs the light path through a first lens and the second beam splitter directs the light path through a first dove prism. The optical arm further includes a first mirror operable to direct the light path to a second mirror and the second mirror directs the light path through the first lens. The optical arm further includes a first detector operable to detect the light path from the first lens.

In yet another embodiment, a method is provided. The method includes determining a fixed beam angle ϑ_0 and an initial orientation angle $\phi_{initial}$ of a first zone of optical device structures of a substrate. The method further includes rotating the substrate to position the initial orientation angle $\phi_{initial}$ perpendicular to light beams to be projected to the first zone of the substrate. The method further includes projecting light beams having a wavelength (λ_{laser}) to the first zone of the substrate at the fixed beam angle ϑ_0. The method further includes measuring a reflected beam angle $\vartheta_{reflected}$ of the light beams reflected by the substrate. The reflected beam angle $\vartheta_{reflected}$ is obtained via a center of a symmetric beam profile. The symmetric beam profile is obtained from a combination of a first image and a second image of the light beams reflected by the substrate. The second image is rotated at a rotation angle different than the first image. The method further includes determining a pitch P of the optical device structures by a pitch equation $P=\lambda_{laser}/(\sin \vartheta_0+\sin \vartheta_{reflected})$.

BRIEF DESCRIPTION OF THE DRAWINGS

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.

FIG. **1** is a schematic view of a measurement system, according to embodiments.

FIGS. **2**A-**2**F are schematic views of a configuration of a measurement system, according to some embodiments.

FIGS. **3**A-**3**C are schematic views of a detector, according to embodiments.

FIG. **3**D is a schematic view of a dove prism, according to embodiments.

FIG. **3**E is a schematic view of a mirror assembly, according to embodiments.

FIG. **4** is a flow diagram of a method for measuring a pitch P of optical device structures and an orientation angle ϕ of the optical device structures, according to embodiments.

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

Embodiments of the present disclosure relate to devices and methods of measuring a pitch P of optical device structures and an orientation angle ϕ of the optical device structures. In one embodiment, a system is provided. The system includes a stage having a substrate support surface. The stage is coupled to a stage actuator configured to move the stage in a scanning path and rotate the stage about an axis. The system further includes an optical arm coupled to an arm actuator configured to scan the optical arm and rotate the optical arm about the axis. The optical arm includes a light source. The light source emits a light path operable to be diffracted to the stage. The optical arm further includes a first beam splitter and a second beam splitter positioned in the light path. The first beam splitter directs the light path through a first lens and the second beam splitter directs the light path through a first dove prism and a second lens. The optical arm further includes a first detector operable to detect the light path from the first lens and second detector operable to detect the light path from the second lens.

The measurement system includes a stage, an optical arm, and a detector arm. Light projected from the optical arm reflects from a substrate disposed on the stage, and the reflected light from the substrate surface is incident on the detector and the optical arm. The deflection from the optical center of the focusing lens is used to determine the local non-uniformity of the optical device. Methods of diffracting light include measuring scattered light beams from the substrate surface, and local distortions are obtained from the measured values. Non-opaque substrates will cause interference due to diffraction of the light from other surfaces. The interferences will be diffracted to the optical arm and the detector arm. The interference causes the accuracy and the precision of the measurement results to decrease.

FIG. **1** is a schematic view of a measurement system **101**, according to one embodiment. As shown, the measurement system **101** includes a stage **102**, an optical arm **104**, and a detector arm **112**. The measurement system **101** is configured to diffract light projected by the optical arm **104**. The light projected by the optical arm **104** is directed at a substrate **103** disposed over the stage **102**. The light that is reflected and diffracted from the substrate **103** is incident on the detector arm **112** and the optical arm **104**. In one embodiment, which can be combined with other embodiments described herein, the measurement system **101** includes the optical arm **104** and the detector arm **112**. In another embodiment, which can be combined with other embodiments described herein, the measurement system **101** includes only the optical arm **104**.

As shown, the stage **102** includes a support surface **106** and a stage actuator **108**. The stage **102** is configured to retain the substrate **103** on the support surface **106**. The stage **102** is coupled to the stage actuator **108**. The stage actuator **108** is configured to move the stage **102** in a scanning path **110** along an x-direction and a y-direction, and rotate the stage **102** about a z-axis. The stage **102** is configured to move and rotate the substrate **103** such that light projected from the optical arm **104** is incident on different portions or gratings of the substrate **103** during operation of the measurement system **101**.

The substrate **103** includes one or more optical devices **105** having one or more gratings **107** of optical device structures **109**. Each of the gratings **107** includes regions of optical device structures **109**. The optical device structures **109** have an orientation angle ϕ and a pitch P. The pitch P is defined as a distance between adjacent points, such as adjacent first edges or adjacent center of masses of the optical device structures **109**. The pitch P and the orientation angle ϕ of the optical device structures **109** for a first grating **111** can be different than the pitch P and the orientation angle ϕ of the optical device structures **109** for a second grating **113** of the one or more gratings **107**. In addition, there can be local pitch P' variations and local orientation angle ϕ' variations of the optical devices structures **109** due to local warping or other deformation of the substrate **103**. The measurement system **101** can be utilized to measure the pitch P and the orientation angle ϕ of the optical device structures **109** for each of the gratings **107** of each of the optical devices **105**. The substrate **103** can be a single crystal wafer of any size, such as having a radius from about 150 mm to about 450 mm.

The optical arm **104**, the detector arm **112**, and the stage **102** are coupled to a controller **130**. The controller **130** facilitates the control and automation of the method for measuring the pitch P and the orientation angle ϕ of optical device structures **109** described herein. The controller may include a central processing unit (CPU) (not shown), memory (not shown), and support circuits (or I/O) (not shown). The CPU may be one of any form of computer processors that are used in industrial settings for controlling various processes and hardware (e.g., motors and other hardware) and monitor the processes (e.g., transfer device position and scan time). The memory (not shown) is connected to the CPU, and may be a readily available memory, such as random access memory (RAM). Software instructions and data can be coded and stored within the memory for instructing the CPU. The support circuits (not shown) are also connected to the CPU for supporting the processor in a conventional manner. The support circuits may include conventional cache, power supplies, clock circuits, input/output circuitry, subsystems, and the like. A program (or computer instructions) readable by the controller determines which tasks are performable on the substrate **103**. The program may be software readable by the controller and may include code to monitor and control, for example, substrate position and optical arm position.

FIGS. **2**A-**2**F are schematic views of configurations **200**A-**200**F of a measurement system **101**. In embodiments

where the substrate **103** is non-opaque, which can be combined with other embodiments described herein, reflections and diffractions of light from multiple surfaces of the substrate **103** will cause interference on the optical arm **104** and the detector arm **112**. The interference is non-symmetric i.e., the image of the light path diffracted or reflected off the substrate **103** is not circular or substantially circular on a first detector **208** and a plurality of second detectors **218**, as further described below, of the optical arm **104** and the detector arm **112**. To address this, the measurement system **101** utilizes prisms, such as a dove prism to rotate the image. Multiple images are combined to generate a symmetric beam i.e., a circular beam. The centroid of the beam is determined with image processing algorithms. The image processing algorithms may be at least partially executed by a controller **130**.

FIG. **2**A is a schematic view of a configuration **200**A of a measurement system **101**. The configuration **200**A includes a portion **202** of a section line **201** (shown in FIG. **1**) across a substrate **103**. The substrate **103** has one or more gratings **107** of optical device structures **109**. As shown, an optical arm **104** includes a light source **204**, a first beam splitter **206**, a second beam splitter **212**, a first detector **208**, a second detector **218**, a first dove prism **214**, a first lens **210**, and a second lens **216**. The optical arm **104** is in communication with the controller **130**. The optical arm **104** can include an arm actuator **203**. The arm actuator **203** is configured to rotate the optical arm **104** about the z-axis and scan the optical arm in a z-direction. The optical arm **104** can be fixed while the measurement is performed.

The first beam splitter **206** is positioned in a first light path **220** adjacent to the light source **204**. In one embodiment, which can be combined with other embodiments described herein, the first light path **220** has a circular or substantially circular cross-section. The light beams described herein can be laser beams. The light source **204** is operable to project light at a beam angle θ (shown in FIG. **1**) along the first light path **220** to the substrate **103**, according to one embodiment. The light source **204** is operable to project a collimated beam of light. The first light path **220** is incident on the substrate **103** and diffracts a second light path **222** back to the optical arm **104**. The optical arm **104** delivers the first light path **220** such that the light can be diffracted by the substrate **103** and form the second light path **222**. In one embodiment, which can be combined with other embodiments described herein, the second light path **222** is a first order diffraction. The second light path **222** is split by the second beam splitter **212** into the second light path **222**A and the second light path **222**B.

The first beam splitter **206** is operable to deflect the second light path **222**A diffracted by the substrate **103** to the first detector **208**. The first lens **210** is positioned between the first beam splitter **206** and the first detector **208**. The first lens **210** is configured to focus the second light path **222**A onto the first detector **208**. A first image of the second light path **222**A is projected on the first detector **208**. The first detector **208** is any optical apparatus used in the art to detect light, such as a charge-coupled device (CCD) array or an active-pixel sensor (CMOS array).

The second beam splitter **212** is operable to deflect the second light path **222**B diffracted by the substrate **103** to the second detector **218**. The second lens **216** is positioned between the second beam splitter **212** and the second detector **218**. The second lens **216** is configured to focus the second light path **222**B onto the second detector **218**. Prior to contacting the second detector **218**, the second light path **222**B passes through the first dove prism **214**. The first dove prism **214** rotates the image of the second light path **222**B on the second detector **218**. Therefore, a second image of the second light path **222**B is projected on the second detector **218**. The second image is at a rotation angle different than the first image. The first dove prism **214** is operable to rotate the second image at any angle. In one embodiment, which can be combined with other embodiments described herein, the second image is rotated 180° from the first image. The second detector **218** is any optical apparatus used in the art to detect light, such as a CCD array or a CMOS array.

FIG. **2**B is a schematic view of a configuration **200**B of a measurement system **101**. The configuration **200**B includes a portion **202** of a section line **201** (shown in FIG. **1**) across a substrate **103**. The substrate **103** has one or more gratings **107** of optical device structures **109**. As shown, the optical arm **104** includes a light source **204**, a first beam splitter **206**, a second beam splitter **212***a*, . . . **212***n* (collectively referred to as the "plurality of second beam splitters **212**"), a first detector **208**, a second detector **218***a*, . . . **128***n* (collectively referred to as the "plurality of second detectors **218**"), a first dove prism **214***a*, . . . **214***n* (collectively referred to as the "plurality of first dove prisms **214**"), a first lens **210**, and a second lens **216***a*, . . . **216***n* (collectively referred to as the "plurality of second lenses **216**"). The optical arm **104** is in communication with the controller **130**. The optical arm **104** can include an arm actuator **203**. The arm actuator **203** is configured to rotate the optical arm **104** about the z-axis and scan the optical arm in a z-direction. The optical arm **104** can be fixed while the measurement is performed.

The first beam splitter **206** is positioned in a first light path **220** adjacent to the light source **204**. The light source **204** is operable to project light at a beam angle θ (shown in FIG. **1**) along the first light path **220** to the substrate **103**, according to one embodiment. The first light path **220** is incident on the substrate **103** and projects a second light path **222** to the optical arm **104**. The optical arm **104** delivers the first light path **220** such that the light can be diffracted by the substrate **103** and form the second light path **222**. The second light path **222** is split by the plurality of second beam splitters **212** into the second light paths **222***a* . . . **222***n* (collectively referred to as the "plurality of second light paths **222**").

The first beam splitter **206** is operable to deflect the second light path **222**A diffracted by the substrate **103** to the first detector **208**. The first lens **210** is positioned between the first beam splitter **206** and the first detector **208**. The first lens **210** is configured to focus the second light path **222**A onto the first detector **208**. A first image of the second light path **222**A is projected on the first detector **208**.

The plurality of second beam splitters **212** are operable to deflect the plurality of second light paths **222**B, . . . **222***n* diffracted by the substrate **103** to the plurality of second detectors **218**. The plurality of second lenses **216** are positioned between the plurality of second beam splitters **212** and the plurality of second detectors **218**. The plurality of second lenses **216** are configured to focus the second light paths **222**B, . . . **212***n* onto the plurality of second detectors **218**. Prior to contacting the plurality of second detectors **218**, the second light paths **222**B, . . . **222***n* pass through the plurality of first dove prisms **214**. The plurality of first dove prisms **214** rotate the image of each of the second light paths **222**B, . . . **222***n* on the plurality of second detectors **218**. Therefore, a second image from of each of the second light paths **222**B, . . . **222***n* is diffracted on the plurality of second detectors **218**. The plurality of second images are at a rotation angle different than the first image. In one embodi-

ment, which can be combined with other embodiments described herein, two second images are rotated 120° from the first image, such that the second images are at 120° and 240°. In another embodiment, which can be combined with other embodiments described herein, each second image of the plurality of second images is rotated 360°/n from the first image, where n is the number of images detected by the plurality of second detectors **218**.

FIG. **2**C is a schematic view of a configuration **200**C of a measurement system **101**. The configuration **200**C includes a portion **202** of a section line **201** across a substrate **103**. The substrate **103** has one or more gratings **107** of optical device structures **109**. As shown, the optical arm **104** includes a light source **204**, a first beam splitter **206**, a second beam splitter **212***a*, . . . **212***n* (collectively referred to as the "plurality of second beam splitters **212**"), a first detector **208**, a second detector **218***a*, . . . **128***n* (collectively referred to as the "plurality of second detectors **218**"), a first dove prism **214***a*, . . . **214***n* (collectively referred to as the "plurality of first dove prisms **214**"), a second dove prism **224**, a first lens **210**, and a second lens **216***a*, . . . **216***n* (collectively referred to as the "plurality of second lenses **216**"). The optical arm **104** is coupled to the controller **130**. The optical arm **104** can include an arm actuator **203**, and the arm actuator **203** is configured to rotate the optical arm **104** about the z-axis and scan the optical arm in a z-direction. The optical arm **104** can be fixed while the measurement is performed.

The first beam splitter **206** is positioned in a first light path **220** adjacent to the light source **204**. The light source **204** is operable to project light at a beam angle θ (shown in FIG. **1**) along the first light path **220** to the substrate **103**, according to one embodiment. The first light path **220** is incident on the substrate **103** and diffracts a second light path **222** to the optical arm **104**. The optical arm **104** delivers the first light path **220** such that the light can be diffracted by the substrate **103** and form the second light path **222**. The second light path **222** is split by the second beam splitter **212** i.e., into the plurality of second light paths **222**A, **222**B, . . . **222***n*.

The first beam splitter **206** is operable to deflect the second light path **222**A diffracted by the substrate **103** to the first detector **208**. The first lens **210** is positioned between the first beam splitter **206** and the first detector **208**. The first lens **210** is configured to focus the second light path **222**A onto the first detector **208**. Prior to contacting the first detector **208**, the second light paths **222**A passes through the second dove prism **224**. The second dove prism **224** rotates the image of the second light path **222**A on the first detector **208**. Therefore, a first image of the second light path **222**A is projected on the first detector **208**. The first image of the second light path **22**A may be rotated to any angle by the second dove prism **224**.

The plurality of second beam splitters **212** are operable to deflect the plurality of second light paths **222**B, . . . **222***n* diffracted by the substrate **103** to the plurality of second detectors **218**. The plurality of second lenses **216** are positioned between the plurality of second beam splitters **212** and the plurality of second detectors **218**. The plurality of second lenses **216** are configured to focus the second light paths **222**B, . . . **212***n* onto the plurality of second detectors **218**. Prior to contacting the plurality of second detectors **218**, the second light paths **222**B, . . . **222***n* pass through the plurality of first dove prisms **214**. The plurality of first dove prisms **214** rotate the image of each of the second light paths **222**B, . . . **222***n* on the plurality of second detectors **218**. Therefore, a second image of each of the second light paths **222**B, . . . **222***n* is projected on the plurality of second detectors **218**. The plurality of second images are at a rotation angle different than the first image. In one embodiment, which can be combined with other embodiments described herein, two second images are rotated 120° from the first image, such that the second images are at 120° and 240°. In another embodiment, which can be combined with other embodiments described herein, each second image of the plurality of second images is rotated 360°/n from the first image, where n is the number of images detected by the second detector **218**.

FIG. **2**D is a schematic view of a configuration **200**D of a measurement system **101**. The configuration **200**D includes a portion **202** of a section line **201** across a substrate **103**. The substrate **103** has one or more gratings **107** of optical device structures **109**. As shown, an optical arm **104** includes a light source **204**, a first beam splitter **206**, a first detector **208**, a first dove prism **214**, and a first lens **210**. The optical arm **104** is coupled to the controller **130**. The optical arm **104** can include an arm actuator **203**, and the arm actuator **203** is configured to rotate the optical arm **104** about the z-axis and scan the optical arm in a z-direction. The optical arm **104** can be fixed while the measurement is performed.

The first beam splitter **206** is positioned in a first light path **220** adjacent to the light source **204**. In one embodiment, which can be combined with other embodiments described herein, the first light path **220** has a circular or substantially circular cross-section. The light source **204** is operable to project light at a beam angle θ (shown in FIG. **1**) along the first light path **220** to the substrate **103**, according to one embodiment. The first light path **220** is incident on the substrate **103** and diffracts a second light path **222** to the optical arm **104**. The optical arm **104** delivers the first light path **220** such that the light can be diffracted by the substrate **103** and form the second light path **222**. In one embodiment, which can be combined with other embodiments described herein, the second light path **222** is a first order diffraction.

The first beam splitter **206** is operable to deflect the second light path **222** diffracted by the substrate **103** to the first detector **208**. The first lens **210** is positioned between the first beam splitter **206** and the first detector **208**. The first lens **210** is configured to focus the second light path **222** onto the first detector **208**. A first image of the second light path **222**A is projected on the first detector **208**. Prior to contacting the first beam splitter **206**, the second light path **222** passes through the first dove prism **214**. The first dove prism **214** rotates the image of the second light path **222** on the first detector **208**. Therefore, a first image of the second light path **222** is diffracted on the first detector **208**. In one embodiment, which can be combined with other embodiments described herein, the first dove prism **214** is coupled to a dove prism actuator **226**. The dove prism actuator is operable to rotate the first dove prism **214** such that multiple images, such as a first image and a plurality of second images of the second light path **222** can be projected onto the first detector **208**. In one embodiment, which can be combined with other embodiments described herein, the plurality of second images are 90° from the first image, such that each of the second images are at 90°, 180°, and 270°. In another embodiment, which can be combined with other embodiments described herein, each second image of the plurality of second images is rotated 360°/n from the first image, where n is the number of images detected by the second detector **218**.

FIG. **2**E is a schematic view of a configuration **200**E of a measurement system **101**. The configuration **200**E includes

a portion **202** of a section line **201** across a substrate **103**. The substrate **103** has one or more gratings **107** of optical device structures **109**. As shown, an optical arm **104** includes a light source **204**, a first beam splitter **206**, a second beam splitter **212**, a first detector **208**, a first dove prism **214**, a first mirror **228**, a second mirror **230**, and a first lens **210**. The optical arm **104** is coupled to the controller **130**. The optical arm **104** can include an arm actuator **203**, and the arm actuator **203** is configured to rotate the optical arm **104** about the z-axis and scan the optical arm in a z-direction. The optical arm **104** can be fixed while the measurement is performed.

The first beam splitter **206** is positioned in a first light path **220** adjacent to the light source **204**. In one embodiment, which can be combined with other embodiments described herein, the first light path **220** has a circular or substantially circular cross-section. The light beams described herein can be laser beams. The light source **204** is operable to project light at a beam angle θ (shown in FIG. **1**) along the first light path **220** to the substrate **103**, according to one embodiment. The first light path **220** is incident on the substrate **103** and diffracts a second light path **222** to the optical arm **104**. The optical arm **104** delivers the first light path **220** such that the light can be diffracted by the substrate **103** and form the second light path **222**. In one embodiment, which can be combined with other embodiments described herein, the second light path **222** is a first order diffraction. The second light path **222** is split by the second beam splitter **212** i.e., into the second light path **222**A and the second light path **222**B.

The first beam splitter **206** is operable to deflect the second light path **222**A diffracted by the substrate **103** to the first detector **208**. The first lens **210** is positioned between the first beam splitter **206** and the first detector **208**. The first lens **210** is configured to focus the second light path **222**A onto the first detector **208**. A first image of the second light path **222**A is projected on the first detector **208**.

The second beam splitter **212** is operable to deflect the second light path **222**B diffracted by the substrate **103** to the first mirror **228**. The second light path **222**B reflects off the first mirror **228** to the second mirror **230**. The second light path **222**B diffracts to the first lens **210**. The first lens **210** is configured to focus the second light path **222**B onto the first detector **208**. Prior to contacting the first mirror **228**, the second light path **222**B passes through the first dove prism **214**. The first dove prism **214** rotates the image of the second light path **222**B on the first detector **208**. Therefore, a second image of the second light path **222**B is projected on the first detector **208** such that the first detector **208** detects the first image and the second image. In one embodiment, which can be combined with other embodiments described herein, the second image is rotated 180° from the first image.

FIG. **2**F is a schematic view of a configuration **200**F of a measurement system **101**. The configuration **200**F includes a portion **202** of a section line **201** across a substrate **103**. The substrate **103** has one or more gratings **107** of optical device structures **109**.

As shown, an optical arm **104** includes a light source **204**, a first beam splitter **206**, a second beam splitter **212**, a first detector **208**, a second detector **218**, a first dove prism **214**, a first lens **210**, and a second lens **216**. The optical arm **104** is coupled to the controller **130**. The optical arm **104** can include an arm actuator **203**, and the arm actuator **203** is configured to rotate the optical arm **104** about the z-axis and scan the optical arm in a z-direction. The optical arm **104** can be fixed while the measurement is performed. The configuration **200**F illustrates the optical arm **104** of the configuration **200**A of the measurement system **101**. Although the optical arm **104** of the configuration **200**A is shown in FIG. **2**F, any of the optical arms **104** of the configurations **200**A-**200**E can be included in the configuration **200**F.

The configuration **200**F further includes a detector arm **112**. The detector arm **112** is operable to measure a reflection light path **234**. The reflection light path **234** is a direct reflection of the first light path **220**. The first light path **220** is incident on the substrate **103** and diffracts the reflection light path **234** to the detector arm **112**.

In one embodiment, which can be combined with other embodiment described herein, the detector arm **112** includes a second beam splitter **212**, a first detector **208**, a second detector **218**, a first dove prism **214**, a first lens **210**, and a second lens **216**. The detector arm **112** can include a detector arm actuator **205**, and the detector arm actuator **205** is configured to rotate the detector arm **112** about the z-axis and scan the optical arm in a z-direction. The detector arm **112** can be fixed while the measurement is performed. The detector arm **112** can have similar configurations to the optical arms **104** of the configurations **200**A-**200**E.

The reflection light path **234** is split by the second beam splitter **212** i.e., into the reflection light path **234**A and the reflection light path **234**B. The reflection light path **234**A diffracted by the substrate **103** is diffracted to the first detector **208**. The first lens **210** is positioned between the first beam splitter **206** and the first detector **208**. The first lens **210** is configured to focus the reflection light path **234**A onto the first detector **208**. A first image of the reflection light path **234**A is projected on the first detector **208**. The first detector **208** is any optical apparatus used in the art to detect light, such as a CCD array or a CMOS array.

The second beam splitter **212** is operable to deflect the reflection light path **234**B diffracted by the substrate **103** to the second detector **218**. The second lens **216** is positioned between the second beam splitter **212** and the second detector **218**. The second lens **216** is configured to focus the reflection light path **234**B onto the second detector **218**. Prior to contacting the second detector **218**, the reflection light path **234**B passes through the first dove prism **214**. The first dove prism **214** rotates the image of the reflection light path **234**B on the second detector **218**. Therefore, a second image of the reflection light path **234**B is projected on the second detector **218**. The second detector **218** is any optical apparatus used in the art to detect light, such as a CCD array or a CMOS array.

FIG. **3**A illustrates a detector **302** as a position sensitive detector **301**A, i.e., a lateral sensor, according to one embodiment. The detector **302** can be any detector such as the first detector **208** and the second detector **218** of the configurations **200**A-**200**F. FIG. **3**B illustrates the detector **302** as a quadrant sensor **301**B, according to one embodiment. FIG. **3**C illustrates the detector **302** as an image sensor array **301**C, such as a CCD array or a CMOS array, according to some embodiments.

FIG. **3**D is a schematic view of a dove prism **304**, such as the first dove prism **214** and the second dove prism **224**. A light path **306** such as the plurality of second light paths **222**A, **222**B, . . . **222***n* and the reflection light path **234**B can pass through the dove prism **304**. The light path **306** travels through the dove prism **304** such that the light path **306** is rotated as desired.

FIG. **3**E is a schematic view of a mirror assembly **308**. In one embodiment, which can be combined with other embodiments described herein, the mirror assembly **308** can replace the dove prism **304**. The mirror assembly **308** includes a plurality of mirrors **310**. The light path **306** travels

through the mirror assembly **308** such that the light path **306** is rotated by reflecting between the plurality of mirrors **310**.

FIG. **4** is a flow diagram of a method **400** for measuring a pitch P of optical device structures **109** and an orientation angle ϕ of optical device structures **109**. To facilitate explanation, the method **400** will be described with reference to the measurement system **101** of FIG. **1** and a first configuration **200**A of the measurement system **101** shown in FIG. **2**A. A controller **130** is operable to facilitate the operations of the method **400**.

At operation **401**, a fixed beam angle ϑ_0 and an initial orientation angle $\phi_{initial}$ of a plurality of optical device structures **109** are determined. The fixed beam angle ϑ_0 is the initial angle of light beams to be projected to a substrate **103**. The initial orientation angle $\phi_{initial}$ is the desired orientation angle of each of the plurality of optical device structures **109**. In one embodiment, which can be combined with other embodiments described herein, the fixed beam angle ϑ_0 and the initial orientation angle $\phi_{initial}$ are determined by a predetermined specification of the optical device structures **109** for each of the gratings **107** of the optical devices **105** on the substrate **103** prior to fabricating the optical devices **105**. In another embodiment, which can be combined with other embodiments described herein, the fixed beam angle ϑ_0 and the initial orientation angle $\phi_{initial}$ are determined by estimation.

At operation **402**, the stage **102** is rotated about the z-axis to positon the initial orientation angle $\phi_{initial}$ of the optical device structures **109**, of the first zone **115**, perpendicular with light beams to be projected to the first zone **115** of the substrate **103**. The first zone **115** corresponds to the first region of the optical device structures **109** to be measured. At operation **403**, the light beams from an optical arm **104** having a wavelength (λ_{laser}) are projected to the substrate **103** at the fixed beam angle ϑ_0.

At operation **404**, a reflected beam angle $\vartheta_{reflected}$ of first order mode beams (R_1^{st}) reflected by the optical device structures **109** is determined. In one embodiment, which can be combined with other embodiments described herein, the method **400** utilizes the configuration **200**A of the optical arm **104** of the measurement system **101**. A first image of a second light path **222**A is detected by a first detector **208**. A second image of a second light path **222**B is detected by a second detector **218**. The second image is rotated by a first dove prism **214** such that the second image is rotated 180° from the first image.

In another embodiment, which can be combined with other embodiments described herein, the method **400** utilizes the configuration **200**B of the optical arm **104** of the measurement system **101**. A first image of a second light path **222**A is detected by a first detector **208**. A plurality of second images of a second light path **222**B, . . . **222***n* is detected by a plurality of second detectors **218**. Each second image of the plurality of second images is rotated 360°/n from the first image, where n is the number of images detected by the second detector **218**.

In another embodiment, which can be combined with other embodiments described herein, the method **400** utilizes the configuration **200**C of the optical arm **104** of the measurement system **101**. A first image of a second light path **222**A is detected by a first detector **208**. The first image is rotated by a second dove prism **224**. A plurality of second images of a second light path **222**B, . . . **222***n* are detected by a plurality of second detectors **218**. Each second image of the plurality of second images is rotated 360°/n from the first image, where n is the number of images detected by the second detector **218**.

In another embodiment, which can be combined with other embodiments described herein, the method **400** utilizes the configuration **200**D of the optical arm **104** of the measurement system **101**. A first dove prism **214** includes a dove prism actuator **226** that rotates the first dove prism **214**. Multiple images, such as a first image and a plurality of second images are detected by a first detector **208**. Each second image of the plurality of second images is rotated 360°/n from the first image, where n is the number of images detected by the first detector **208**.

In another embodiment, which can be combined with other embodiments described herein, the method **400** utilizes the configuration **200**E of the optical arm **104** of the measurement system **101**. A first image of a second light path **222**A is detected by a first detector **208**. A second image of a second light path **222**B is detected by the second detector **218**. The second image is rotated by a first dove prism **214** and reflected by a first mirror **228** and a second mirror **230** such that the second image is rotated 180° from the first image.

In another embodiment, which can be combined with other embodiments described herein, the method **400** utilizes the configuration **200**F of the optical arm **104** and the detector arm **112** of the measurement system **101**. The optical arm **104** can be any of the configurations **200**A-**200**E. A first detector **208** of the detector arm **112** can detect a first image of a reflection light path **234**A. A second image of a reflection light path **234**B is detected by the second detector **218**. The second image is rotated by a first dove prism **214** and reflected by a first mirror **228** and a second mirror **230** such that the second image is rotated 180° from the first image.

In one embodiment, which can be combined with other embodiments described herein, at least the first image and the second image are combined to generate a symmetric beam profile. In another embodiment, which can be combined with other embodiments described herein, a plurality of second images are combined with the first image to generate a symmetric beam profile. An image processing algorithm (via an image processing software) is applied to the symmetric beam profile to calculate a center of the symmetric beam profile. The image processing algorithm is at least partially executed by the controller **130**.

Utilizing the measurement system **101** described herein allows for the combination of multiple images to determine the center of the symmetric beam profile. When non-opaque substrates **103** are utilized, interference due to multi-surface reflection may occur, which will alter the intensity profile projected to the detector. The measurement system **101** allows for the projection of the second images rotated at different angles to the plurality of second detectors. The rotated second images compensate for the non-symmetric interference by allowing for the center of the symmetric beam profile to be determined reliably with the additional images. By combining the second images with the first image, a center of the symmetric beam profile is obtained reliably despite the interference.

The reflected beam angle $\vartheta_{reflected}$ of the first order mode beams (R_1^{st}) reflected by the optical device structures **109** is calculated based one the center of the symmetric beam profile. A final orientation angle ϕ_{final} corresponding to the orientation angle ϕ of the optical device structures **109** is calculated based on the center of the symmetric beam profile.

In one embodiment, which can be combined with other embodiments described herein, during operations **401**-**404**, the detector arm **112** having the first detector **208** and the

second detector **218** measures a zero order mode beam (R_0), such as the reflection light path **234** (shown in FIG. **2**F) reflected by the optical device structures **109** to determine an inverse reflected beam angle $\vartheta_{reflected}$. The inverse reflected beam angle $\vartheta_{reflected}$ is compared to the reflected beam angle $\vartheta_{reflected}$ to account for warpage of the substrate **103**.

At operation **405**, the pitch P is determined by the equation $P=\lambda_{laser}/(\sin \vartheta_0+\sin \vartheta_{reflected})$. At operation **406**, the stage **102** is scanned along a scanning path **110** and operations **401-405** are repeated for subsequent zones of the one or more gratings **107** of the one or more optical devices **105**.

In summation, devices and methods of measuring a pitch P of optical device structures and an orientation angle ϕ of the optical device structures are provided herein. The devices and method provide for a more accurate reading of the pitch P and the orientation angle ϕ by combining a first image and a second image in a measurement system. The combination of the first image and the second image increases the accuracy and repeatability of the measurements by compensating for the non-symmetric interference by allowing for the center of the symmetric beam profile to be determined reliably with the additional images. The devices and methods described herein account for the interference when measuring non-opaque substrates.

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 system, comprising:

a stage having a substrate support surface, the stage coupled to a stage actuator configured to move the stage in a scanning path and rotate the stage about an axis; and

an optical arm coupled to an arm actuator configured to scan the optical arm and rotate the optical arm about the axis, the optical arm having:

a light source, the light source emitting a light path operable to be projected to a substrate disposed on the substrate support surface;

a first beam splitter and a second beam splitter positioned in the light path;

a first dove prism;

a first lens and a second lens, wherein the first beam splitter is configured to direct the light path through the first lens and the second beam splitter is configured to direct the light path through the first dove prism and the second lens;

a first detector operable to detect the light path from the first lens; and

a second detector operable to detect the light path from the second lens; and

a controller configured to be in communication with the first detector and the second detector such that in operation when the controller is in communication with the first detector and the second detector the controller combines a first image detected by the first detector and a second image detected by the second detector to form a symmetric beam profile.

2. The system of claim **1**, further comprising:

additional second beam splitters, the additional second beam splitters directing the light path through additional first dove prisms and additional second lenses; and

additional second detectors, each second detector operable to detect the light path projected from each of the additional second lenses, the additional second detectors each configured to detect a second image projected from each of the additional second lenses.

3. The system of claim **2**, further comprising a second dove prism, the second dove prism positioned in the light path between the first lens and the first detector.

4. The system of claim **3**, wherein the second dove prism is configured to rotate a first image projected to the first detector, wherein the first image is rotated to an angle different than each of the second images.

5. The system of claim **1**, wherein the first detector is configured to detect a first image projected from the first lens.

6. The system of claim **5**, wherein the second detector is configured to detect a second image projected from the second lens.

7. The system of claim **6**, wherein the first dove prism is configured to rotate the second image projected to the second detector, wherein the second image is rotated to an angle different than the first image.

8. The system of claim **7**, wherein the second image is rotated 180° from the first image.

9. The system of claim **1**, further comprising a detector arm coupled to a detector arm actuator configured to scan the detector arm and rotate the detector arm about the axis, the detector arm having:

a third beam splitter and a fourth beam splitter positioned in the light path, the third beam splitter directing the light path through a third lens, the fourth beam splitter directing the light path through a second dove prism and a fourth lens;

a third detector operable to detect the light path from the third lens; and

a fourth detector operable to detect the light path from the fourth lens.

10. The system of claim **1**, wherein the first detector and the second detector is one of a lateral sensor, a quadrant censor, or an image sensor array.

11. A system, comprising:

a stage having a substrate support surface, the stage coupled to a stage actuator configured to move the stage in a scanning path and rotate the stage about an axis; and

an optical arm coupled to an arm actuator configured to scan the optical arm and rotate the optical arm about the axis, the optical arm having:

a light source, the light source emitting a light path operable to be projected to a substrate disposed on the substrate support surface;

a first beam splitter and a second beam splitter positioned in the light path;

a first dove prism;

a first lens and a second lens, wherein the first beam splitter is configured to direct the light path through the first lens and the second beam splitter is configured to direct the light path through the first dove prism and the second lens;

a first detector operable to detect the light path from the first lens, the first detector is configured to detect a first image projected from the first lens; and

a second detector operable to detect the light path from the second lens, the second detector is configured to detect a second image projected from the second lens; and

a controller configured to be in communication with the first detector and the second detector such that in operation when the controller is in communication with the first detector and the second detector the controller combines a first image detected by the first detector and a second image detected by the second detector to form a symmetric beam profile, wherein the controller is configured to execute an image processing software to determine a center of the symmetric beam profile.

12. A system, comprising:

a stage having a substrate support surface, the stage coupled to a stage actuator configured to move the stage in a scanning path and rotate the stage about an axis;

an optical arm coupled to an arm actuator configured to scan the optical arm and rotate the optical arm about the axis, the optical arm having:

a light source, the light source emitting a light path operable to be projected to a substrate disposed on the substrate support surface;

a dove prism positioned in the light path between the light source and the substrate support surface, the dove prism configured to rotate to project a first image and a second image onto a first detector;

a first beam splitter positioned in the light path;

a first lens, wherein the first beam splitter is configured to direct the light path through the first lens; and

the first detector operable to detect the light path projected from the first lens; and

a controller configured to be in communication with the optical arm having the dove prism and the first detector such that in operation the controller is configured to combine the first image and the second image to form a symmetric beam profile.

13. The system of claim **12**, wherein the dove prism is coupled to an actuator, the actuator configured to rotate the dove prism.

14. The system of claim **13**, wherein the first detector is configured to detect a first image and a plurality of second images projected from the first lens.

15. The system of claim **14**, wherein the dove prism is configured to rotate such that the plurality of second images projected to the first detector are each rotated to an angle different than the first image.

16. The system of claim **12**, wherein the first detector is one of a lateral sensor, a quadrant censor, or an image sensor array.

17. A method, comprising:

determining a fixed beam angle ϑ_0 of a light source and an initial orientation angle $\phi_{initial}$ of a first zone of optical device structures of a substrate;

rotating the substrate to position the initial orientation angle $\phi_{initial}$ perpendicular to a light path to be projected to the first zone of the substrate at the fixed beam angle ϑ_0;

projecting the light path having a wavelength (λ_{laser}) to the first zone of the substrate at the fixed beam angle ϑ_0, the light path diffracting from the optical device structures to a beam splitter, the beam splitter directing a first portion of the light path to a first detector and a second portion of the light path to a second detector;

detecting a first image from the first portion of the light path with the first detector; and

detecting a second image from the second portion of the light path with the second detector, wherein the second image is rotated to an angle different than the first image, wherein a symmetric beam profile is obtained by combining the first image and the second image.

18. A method, comprising:

determining a fixed beam angle ϑ_0 of a light source and an initial orientation angle $\phi_{initial}$ of a first zone of optical device structures of a substrate;

rotating the substrate to position the initial orientation angle $\phi_{initial}$ perpendicular to a light path to be projected to the first zone of the substrate at the fixed beam angle ϑ_0;

projecting the light path having a wavelength (λ_{laser}) to the first zone of the substrate at the fixed beam angle ϑ_0, the light path diffracting from the optical device structures to a beam splitter, the beam splitter directing a first portion of the light path to a first detector and a second portion of the light path to a second detector;

detecting a first image from the first portion of the light path with the first detector;

detecting a second image from the second portion of the light path with the second detector, wherein the second image is rotated to an angle different than the first image; and

measuring a reflected beam angle $\vartheta_{reflected}$ of the light path reflected by the substrate, the reflected beam angle $\vartheta_{reflected}$ derived from a center of a symmetric beam profile, the symmetric beam profile obtained by combining a first image and a second image of the light path reflected by the substrate, and wherein the second image rotated at a rotation angle different than the first image.

19. The method of claim **18**, further comprising determining a pitch P of the optical device structures by a pitch equation $P=\lambda_{laser}(\sin \vartheta_0+\sin \vartheta_{reflected})$.

20. The method of claim **19**, further comprising detecting additional second images projected to the second detector.

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