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Sun et al.

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(54) **METHODS FOR HIGH-RESOLUTION, STABLE MEASUREMENT OF PITCH AND ORIENTATION IN OPTICAL GRATINGS**

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G02B 3/00	(2006.01)
G02B 5/30	(2006.01)
G02B 26/12	(2006.01)

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

CPC ***G01B 11/26*** (2013.01); ***G02B 3/00*** (2013.01); ***G02B 5/3025*** (2013.01); ***G02B 26/123*** (2013.01); *G02B 2207/123* (2013.01)

(58) **Field of Classification Search**

CPC .. G02B 2207/123; G02B 26/123; G02B 3/00; G02B 5/3025; G01B 11/14; G01B 11/26; G01B 2210/56

See application file for complete search history.

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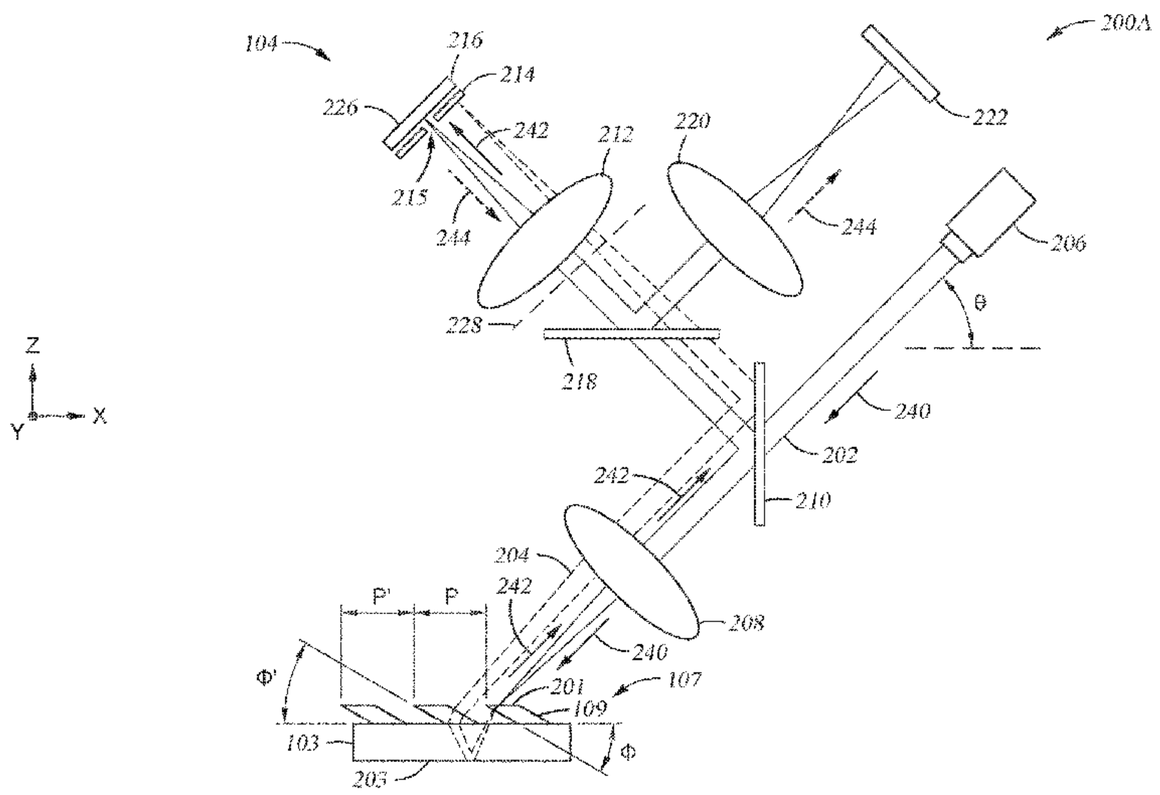
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(57) **ABSTRACT**

Embodiments described herein provide for a measurement system having an aperture filtering component and methods of utilizing the measurement system. The measurement system described herein includes a measurement arm and a stage. The measurement arm projects a light beam to a top surface of an optical device structure. Multi-reflection beams resulting from reflections and diffraction off other surfaces of a non-opaque substrate leads to interference. The measurement arm includes an aperture (e.g., an aperture filtering component) that filters the multi-reflection beams from being relayed to the detector. As such, only images of the light beam are relayed to the detector.

20 Claims, 12 Drawing Sheets



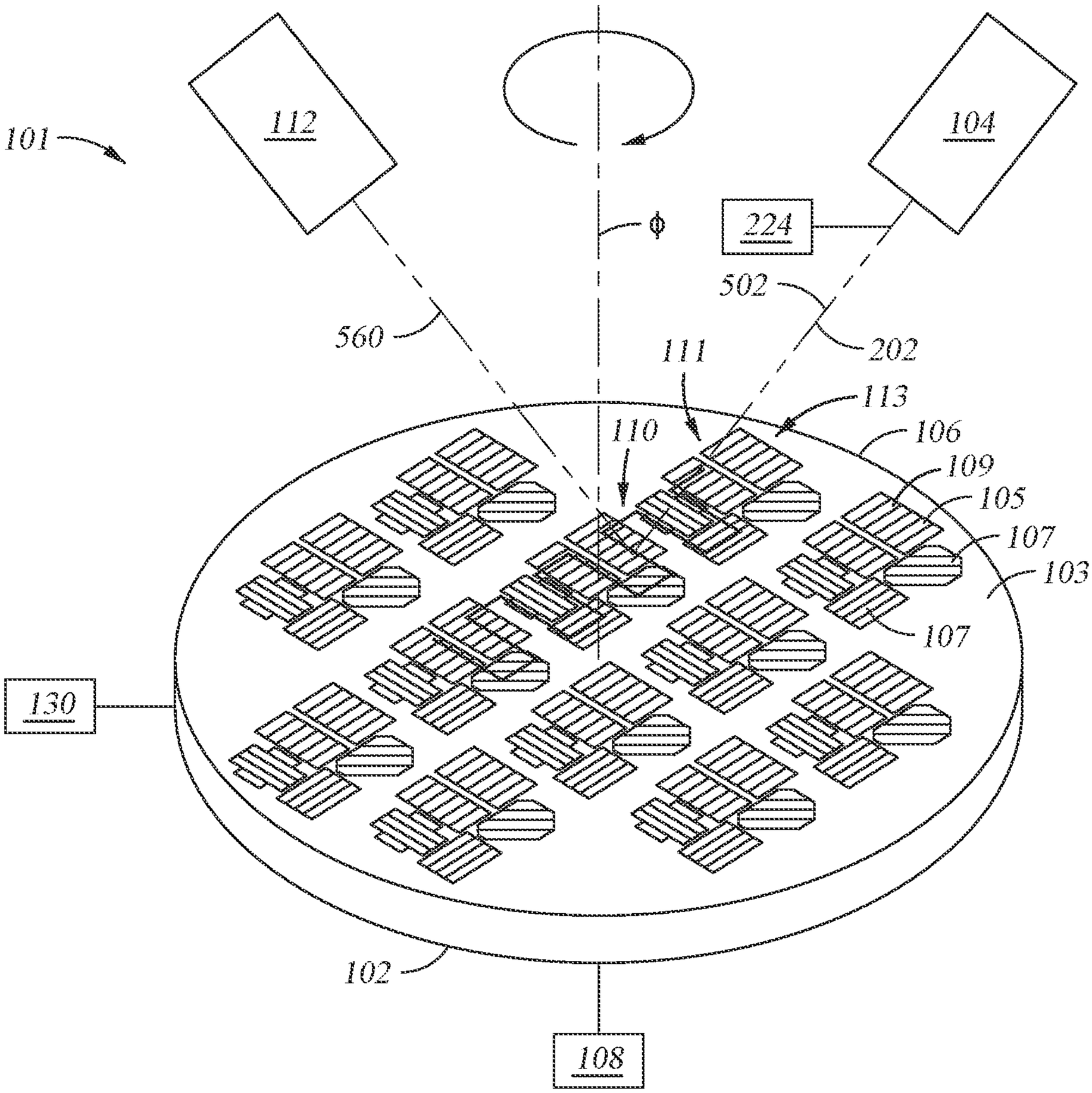

101
112
104
224
ϕ
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502
202
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113
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106
109
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103
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130
102
108
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Fig. 1

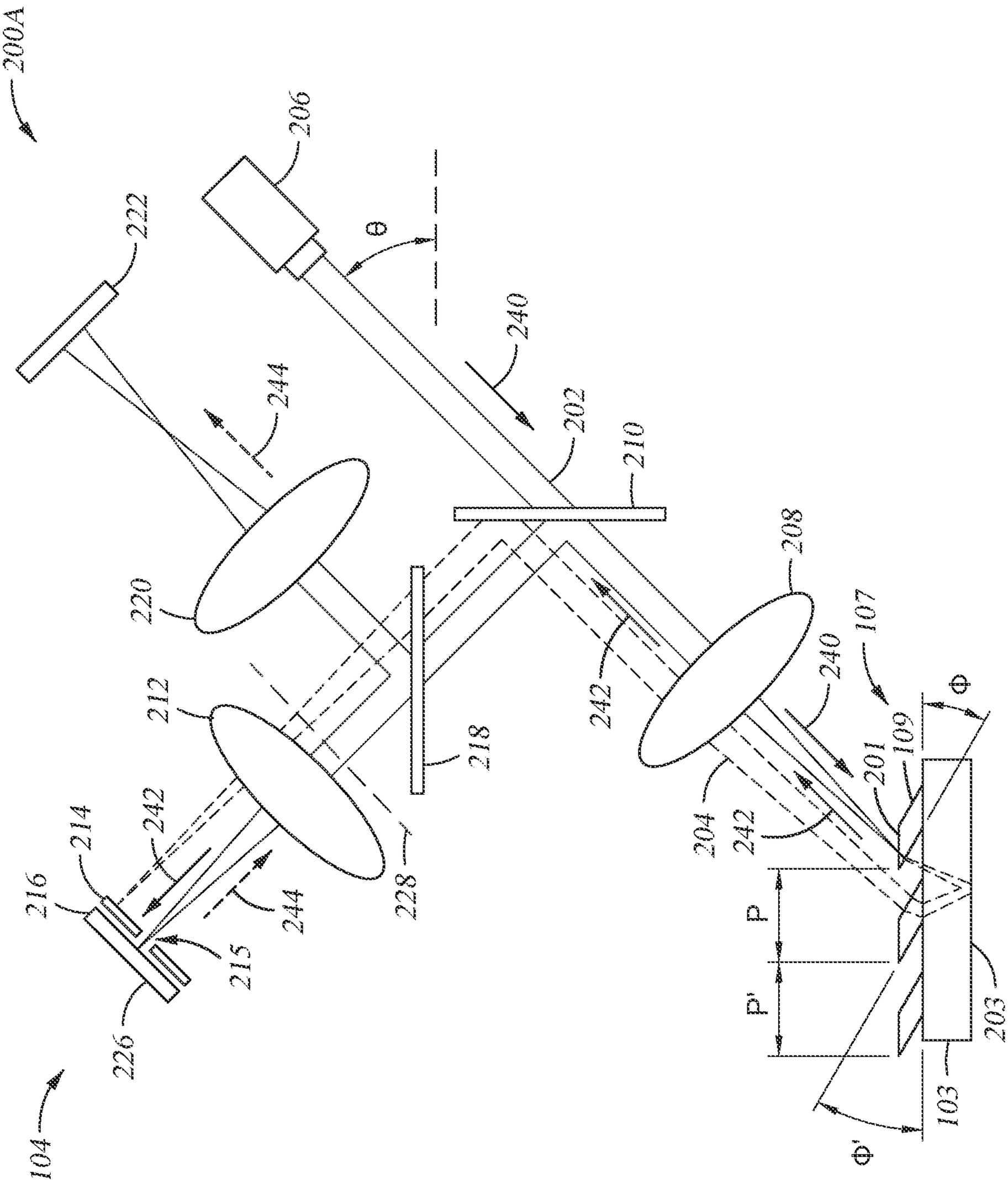

200A
206
θ
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240
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107
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240
218
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214
242
204
242
216
P
ϕ
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215
244
228
226
203
104
103
ϕ'
Z
X
Y

Fig. 2A

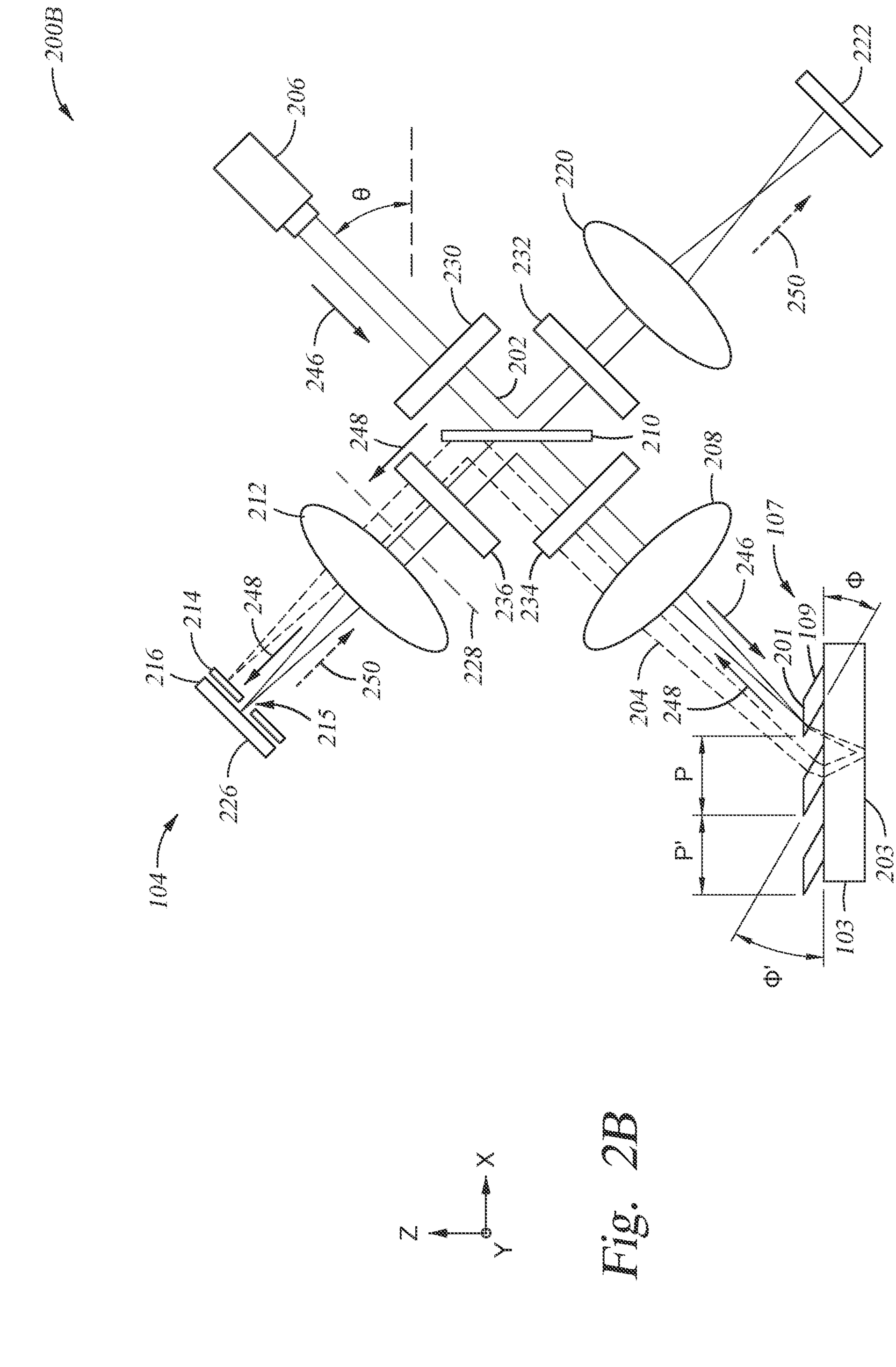

200B
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203
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104
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Fig. 2B

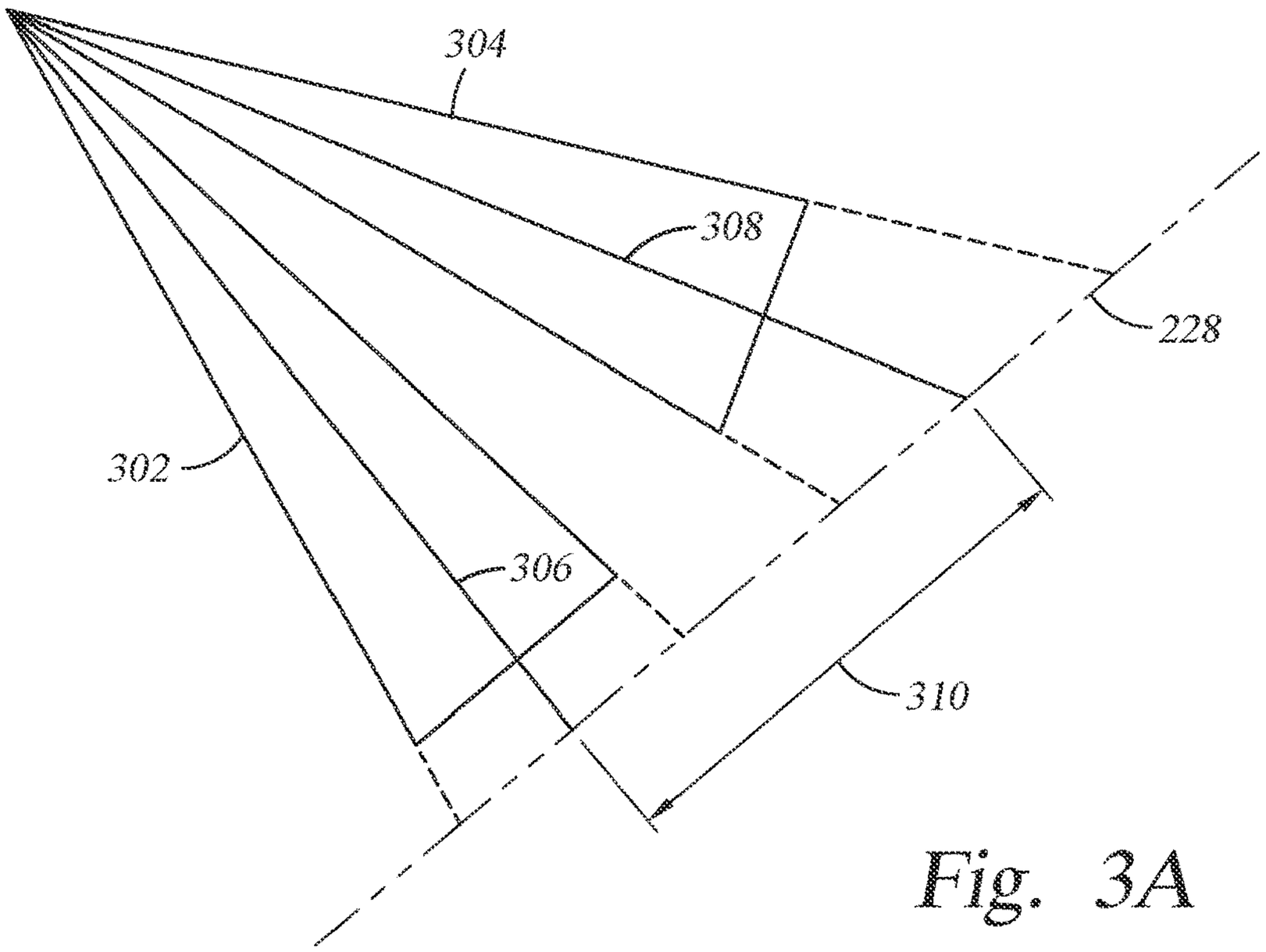


Fig. 3A

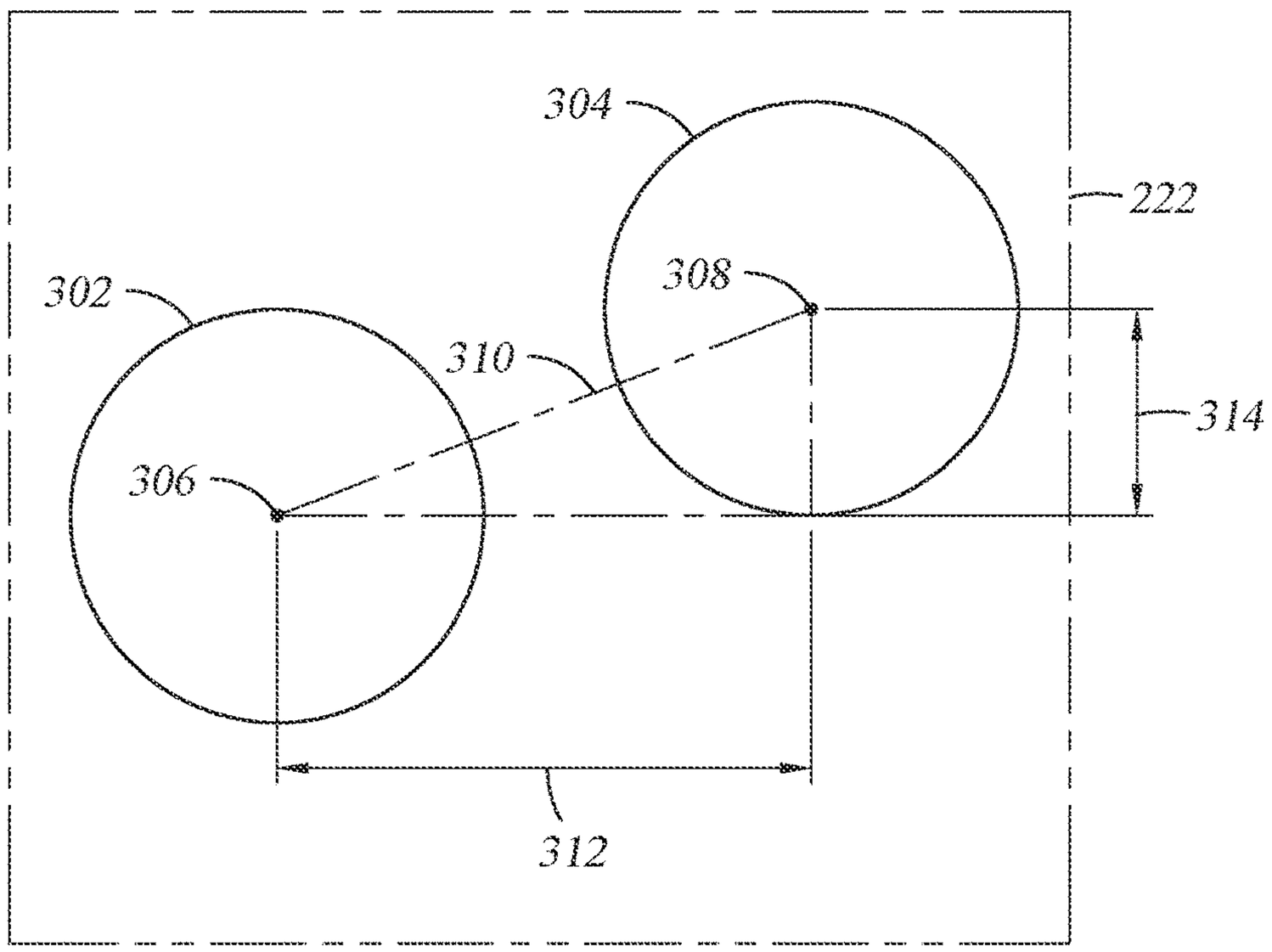


Fig. 3B

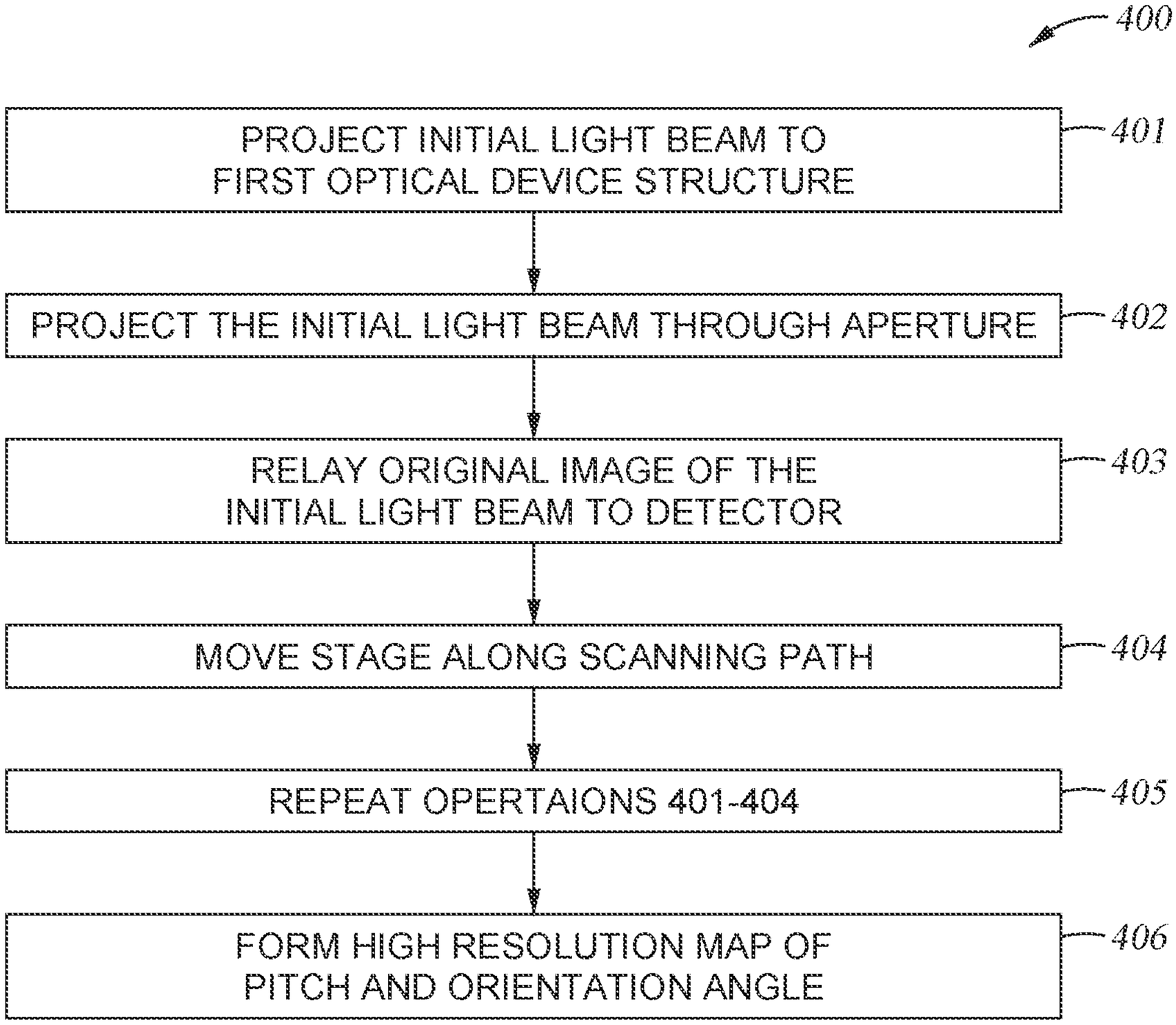

400
PROJECT INITIAL LIGHT BEAM TO FIRST OPTICAL DEVICE STRUCTURE
401
PROJECT THE INITIAL LIGHT BEAM THROUGH APERTURE
402
RELAY ORIGINAL IMAGE OF THE INITIAL LIGHT BEAM TO DETECTOR
403
MOVE STAGE ALONG SCANNING PATH
404
REPEAT OPERTAIONS 401-404
405
FORM HIGH RESOLUTION MAP OF PITCH AND ORIENTATION ANGLE
406

Fig. 4

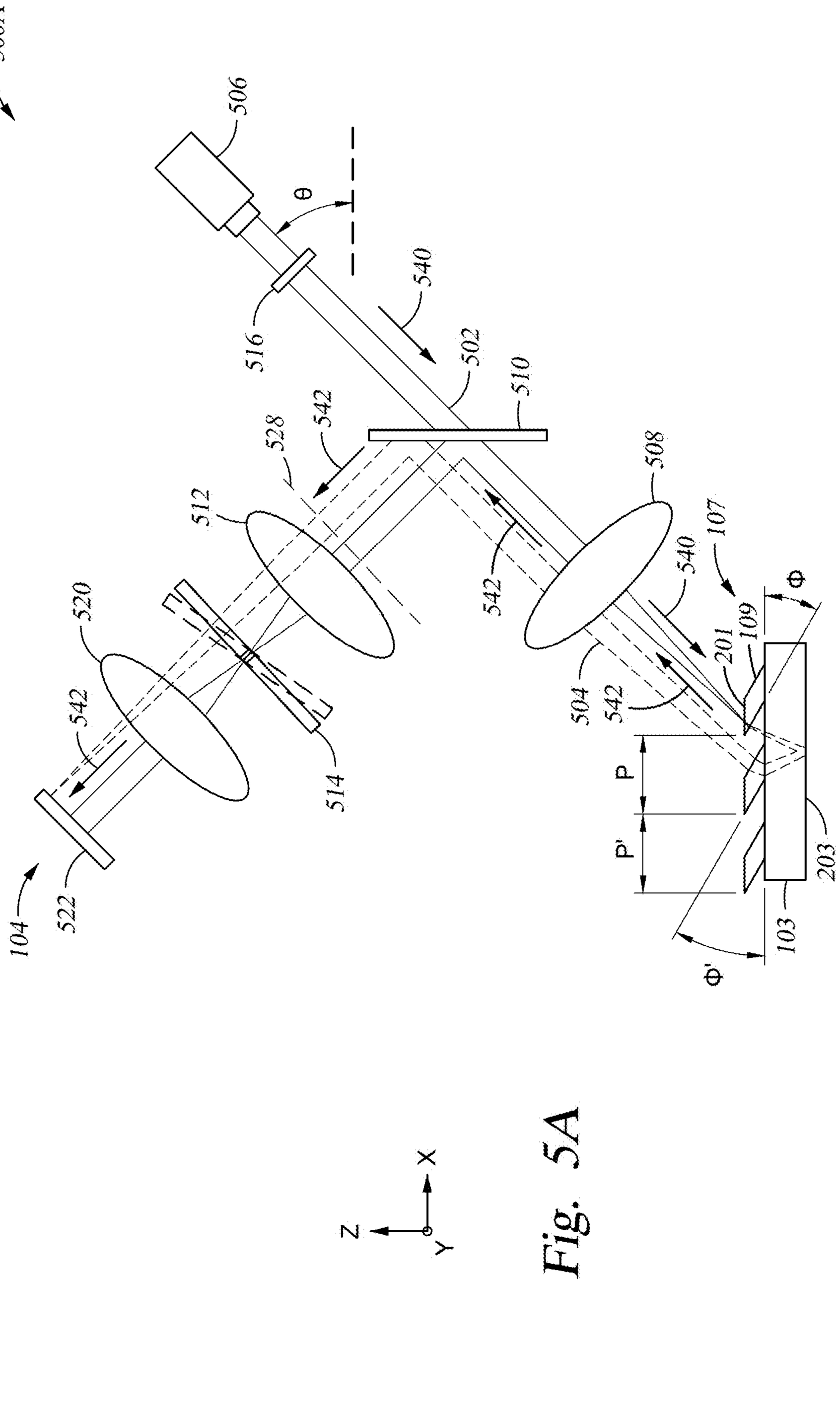

500A
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Fig. 5A

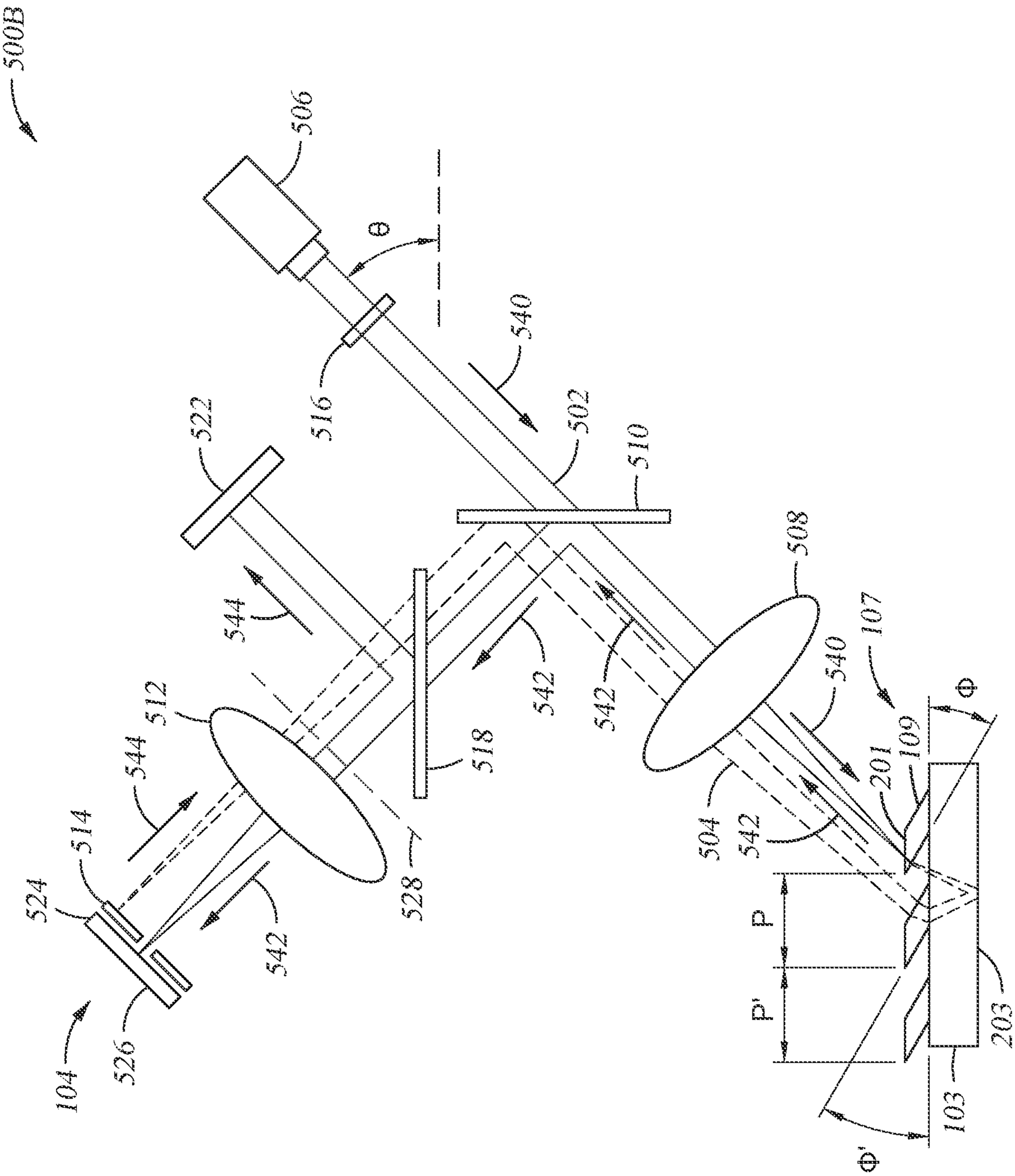

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Fig. 5B

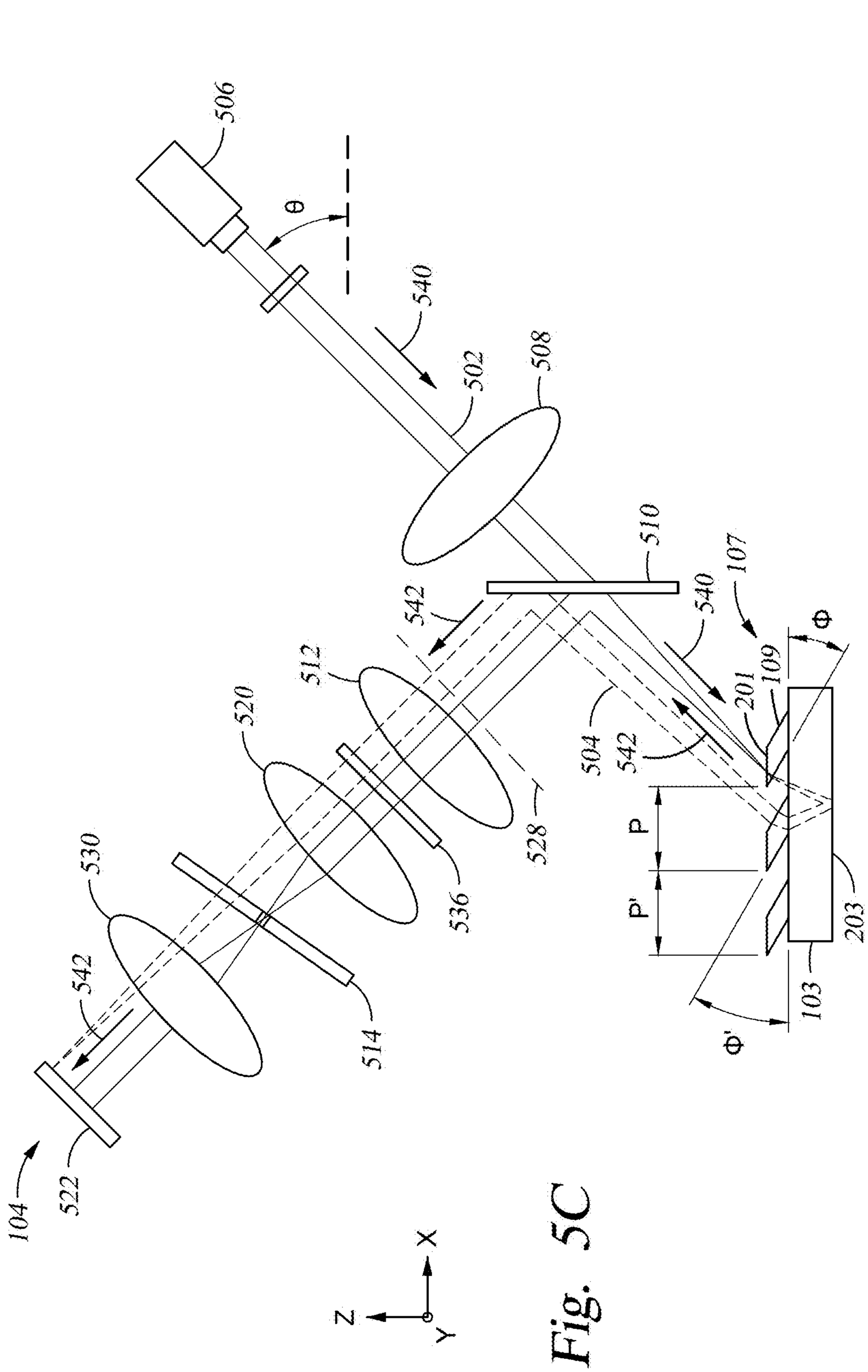

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Fig. 5C

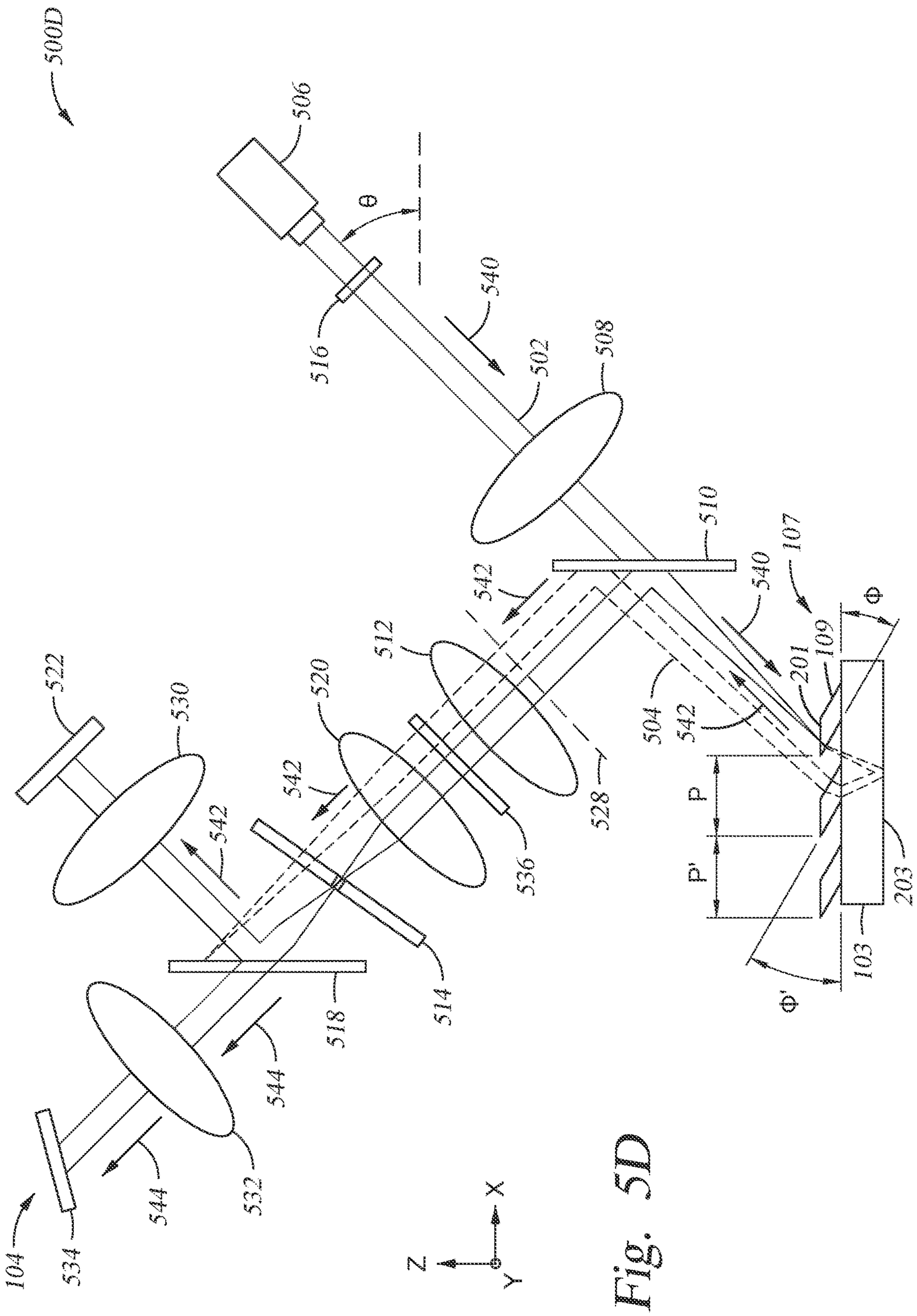

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Fig. 5D

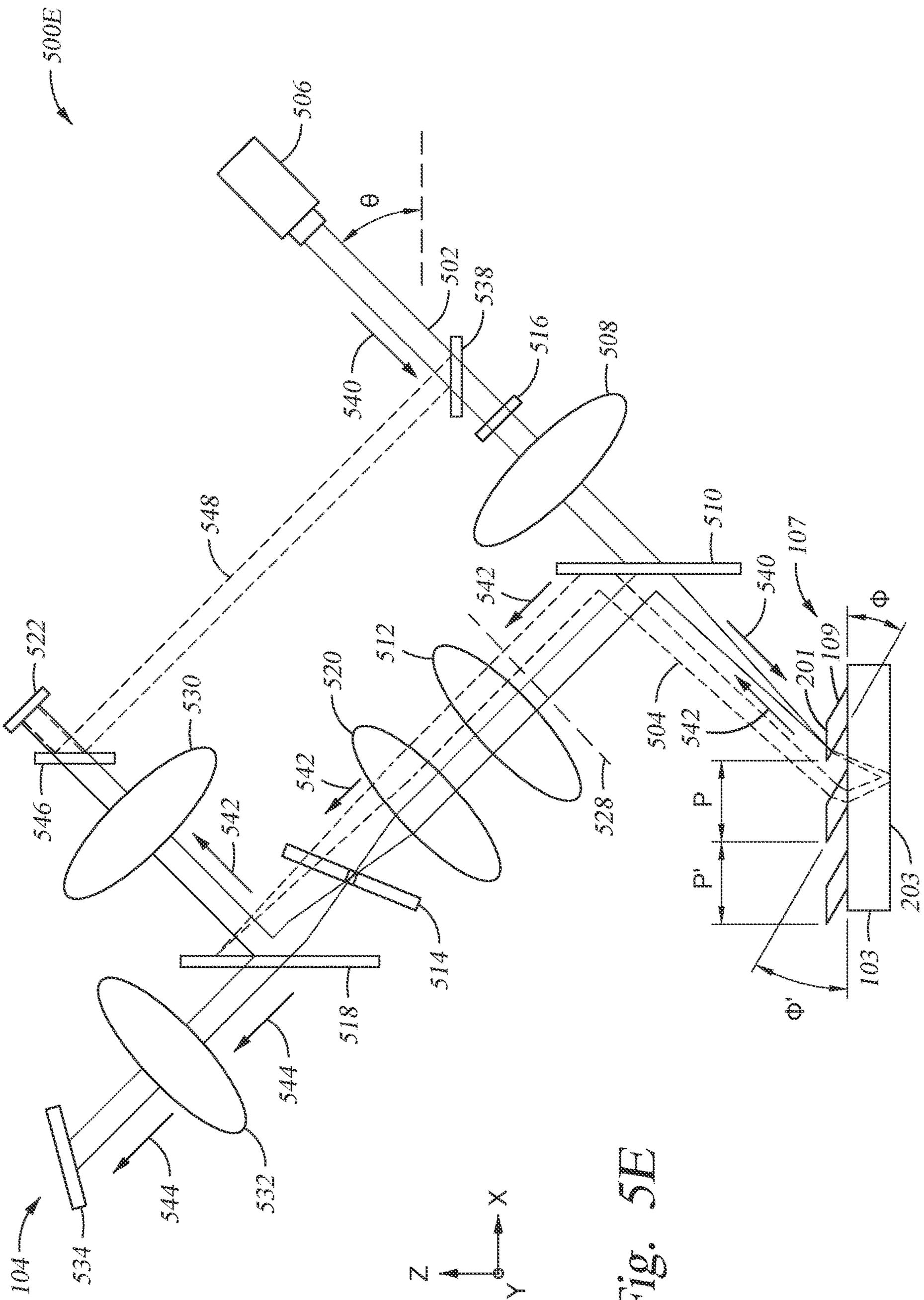

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Fig. 5E

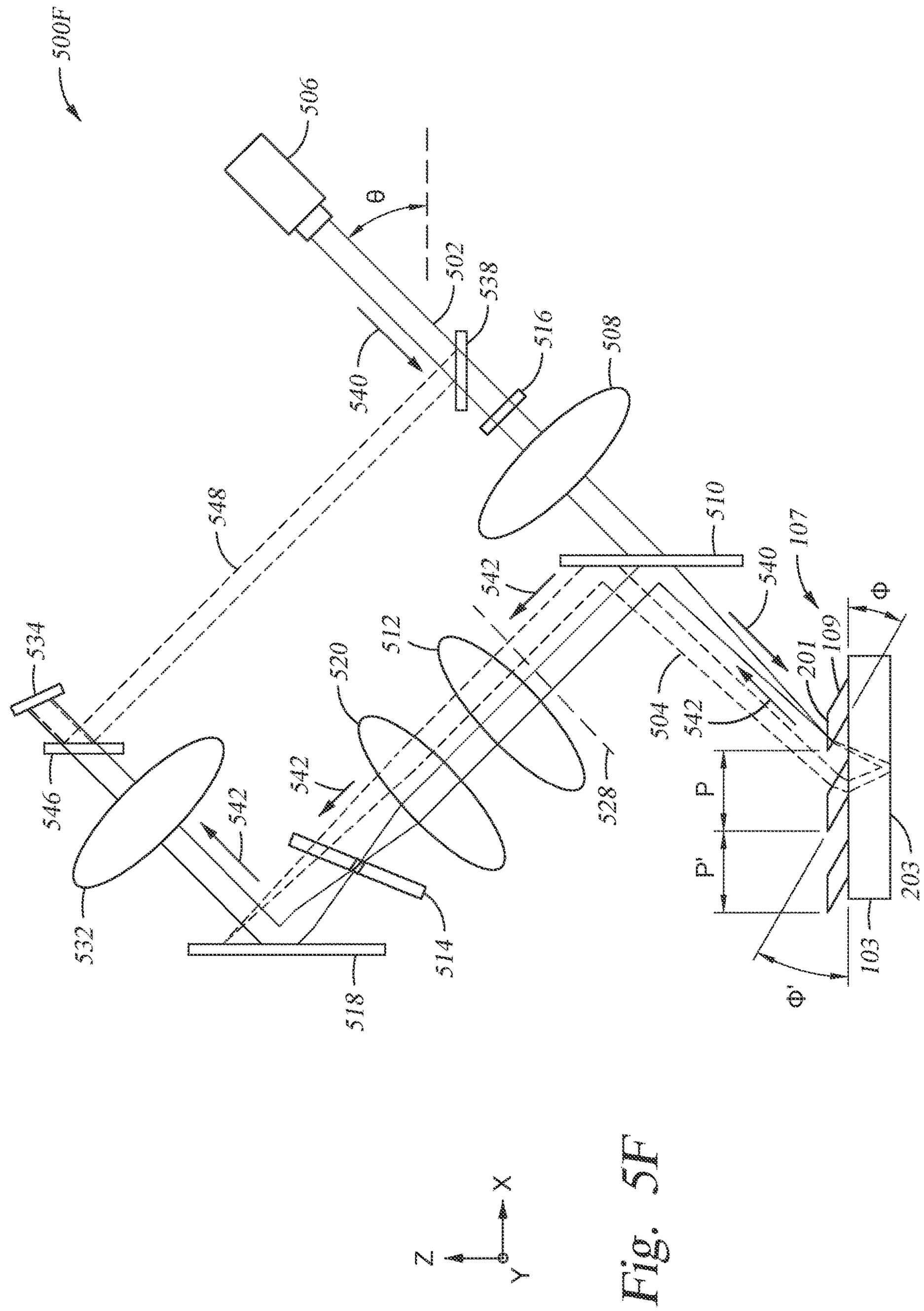

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Fig. 5F

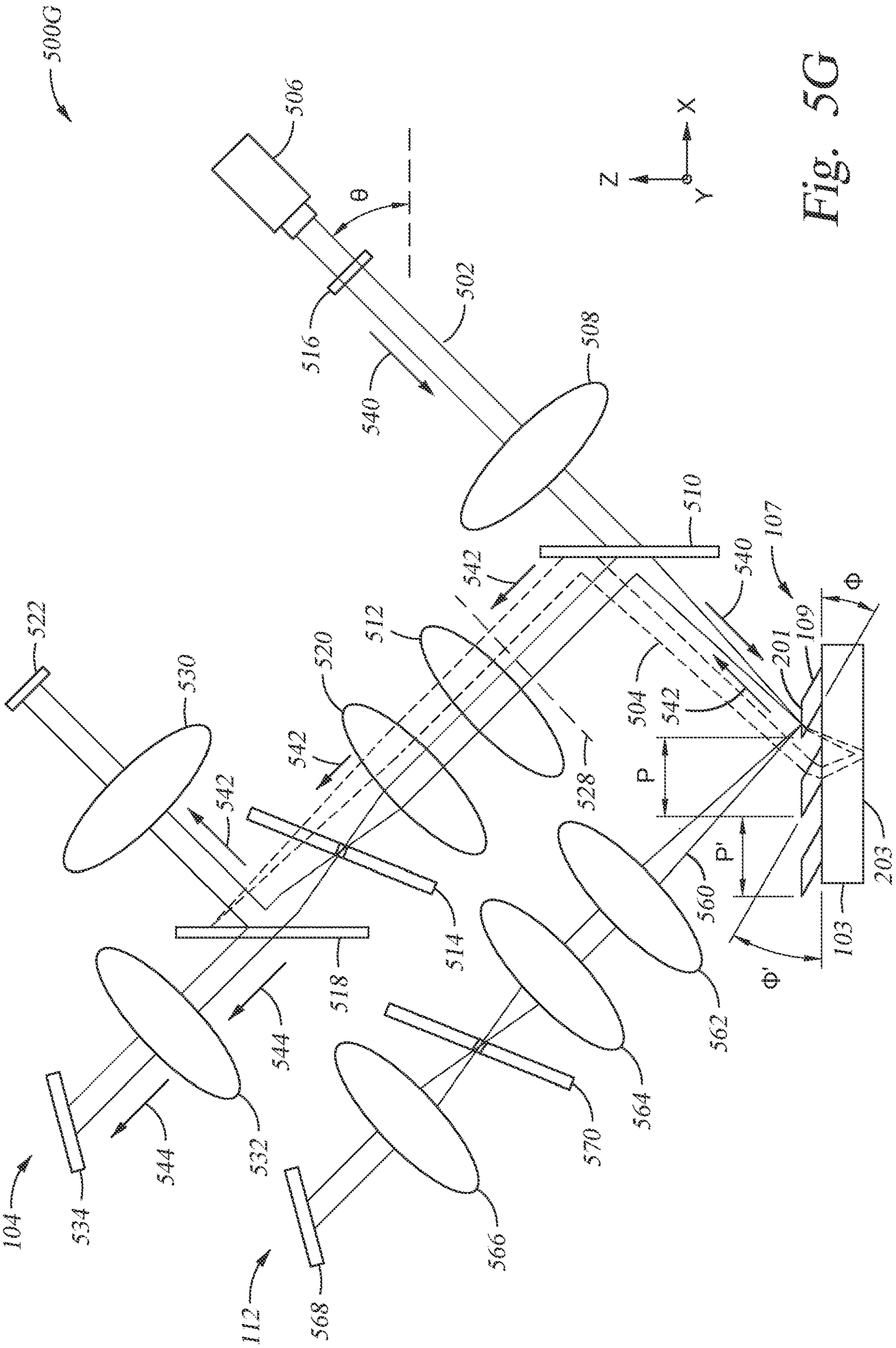

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566
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Fig. 5G

METHODS FOR HIGH-RESOLUTION, STABLE MEASUREMENT OF PITCH AND ORIENTATION IN OPTICAL GRATINGS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application Ser. No. 63/362,427, filed Apr. 4, 2022, which is incorporated by reference herein in its entirety.

BACKGROUND

Field

Embodiments of the present disclosure relate to a measurement system. Specifically, embodiments of the present disclosure relate to a measurement system having an aperture filtering component and methods of utilizing the measurement system.

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 3D and viewed with a head-mounted display (HMD), such as glasses or other wearable display devices that have near-eye display panels as lenses to display a virtual reality environment that replaces an actual environment.

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. Measurement devices are utilized to ensure that the intended pitch and orientation is achieved. Conventional systems will experience a decrease in accuracy and repeatability when measuring optical device structures on transparent substrates due to multi-reflection beams interfering with the measurement device. Accordingly, what is needed in the art is an improved measurement device and methods of filtering the multi-reflection beams.

SUMMARY

In one embodiment, a measurement system is provided. The measurement system includes a light source configured to project a light beam to a substrate disposed below the light source, a first lens disposed between the substrate and the light source and configured to focus the light beam to the substrate, and a first beam splitter disposed between the first lens and the light source. The measurement system further includes a second lens disposed adjacent to the first beam splitter and configured to direct the light beam to the second lens, and configured to direct the light beam to a mirror, an aperture disposed in front of the mirror, a second beam splitter configured to direct the light beam to a third lens from the mirror, and a detector with the light beam projected to the detector by the third lens.

In another embodiment, a measurement system is provided. The measurement system includes a stage having a substrate support surface with the stage coupled to a stage actuator configured to move the stage in a scanning path and rotate the stage about an axis, a measurement arm disposed above the stage and configured to direct a light beam to a substrate disposed on the substrate support surface. The measurement arm includes a light source configured to project the light beam to the substrate disposed below the light source, a first lens disposed between the substrate and the light source and configured to focus the light beam to the substrate, a first beam splitter disposed between the first lens and the light source, a second lens disposed adjacent to the beam splitter and configured to direct the light beam to the second lens, an aperture with the second lens configured to direct the light beam through the aperture, a third lens, and a detector with the light beam projected to the detector by the third lens.

In yet another embodiment, a method is provided. The method includes projecting a light beam to a first optical device structure from a measurement arm, the light beam diffracting off a top surface of the first optical device structure of a substrate with the substrate disposed on a stage. The method further includes projecting the light beam through an aperture disposed in front of a mirror in the measurement arm with the aperture operable to allow only the light beam to contact the mirror, relaying a first original image of the light beam to a detector in the measurement arm, moving the stage along a scanning path and projecting the light beam to a second optical device structure. A second original image is relayed to the detector. The method further includes forming a high resolution map of a pitch and orientation angle of at least the first optical device structure and the second optical device structure.

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 scope, as the disclosure may admit to other equally effective embodiments.

FIG. **1** is a schematic view of a measurement system according to one embodiment.

FIG. **2**A is a schematic, side-view of a first configuration of a measurement arm according to one embodiment.

FIG. **2**B is a schematic, side-view of a second configuration of a measurement arm according to one embodiment.

FIG. **3**A is a schematic view of a first light beam and a second light beam according to one embodiment.

FIG. **3**B is a schematic, top-view of a detector according to one embodiment.

FIG. **4** is a flow diagram of a method of determining a change in pitch P and a change in an orientation angle ϕ with a measurement system, according to embodiments described herein.

FIGS. **5**A-**5**F are schematic, side-view of configurations of a measurement arm according to one embodiment.

FIG. **5**G is a schematic, side-view of a sixth configuration of a measurement arm and a reflection arm according to one embodiment.

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 a measurement system having an aperture filtering component and methods of utilizing the measurement system. A measurement system includes a stage and a measurement arm. Light projected from the measurement arm reflects from a substrate disposed on the stage, and the reflected light from the substrate surface is incident on the measurement arm. A shift of an image projected to a detector will shift when the orientation and/or the pitch of the optical device structures change. Embodiments disclosed herein may be especially useful for, but not limited to, measuring local uniformities in optical systems.

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** and a measurement arm **104**. In some embodiments, a reflection arm **112** is included in the measurement system **101**. An arm actuator is configured to rotate the reflection arm **112** about the z-axis and scan the reflection arm **112** in a z-direction. The measurement system **101** is configured to diffract light projected by the measurement arm **104**. The light projected by the measurement arm **104** is directed at a substrate **103** disposed over the stage **102**. The light beam that is reflected and diffracted from the substrate **103** is incident on the measurement arm **104**. The measurement arm **104** is disposed above the stage **102**. The reflection arm **112** is disposed above the stage **102**.

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**. In one embodiment, which can be combined with other embodiments described herein, the substrate **103** is a transparent substrate. 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. The stage actuator **108** is also configured to rotate the stage **102** about a z-axis. The stage **102** is configured to move in the scanning path and rotate the substrate **103** such that a light beam projected from the measurement 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**. Each of optical device structures **109** have an orientation angle ϕ and a pitch P (shown in FIG. **2**). 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 measurement arm **104** and the stage **102** are in communication with 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. The support circuits may include 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 measurement arm position.

FIG. **2**A is a schematic, side-view of a first configuration **200**A of a measurement arm **104**. The measurement arm **104** is configured to direct a light beam **202** to a substrate **103**. The measurement arm **104** is configured to measure a pitch P and an orientation angle ϕ of optical device structures **109** formed on the substrate **103**. The optical device structures **109** form a grating **107**. The light beam **202** is projected to a top surface **201** of the optical device structure **109** to be measured. As shown in FIG. **2**, the light beam **202** is projected to the plurality of optical device structures **109** of the grating **107**.

In embodiments where the substrate **103** is non-opaque (e.g. transparent), which can be combined with other embodiments described herein, multi-reflection beams **204** of light will reflect off of at least a bottom surface **203** of the substrate **103**. The multi-reflection beams **204** cause interference when using the measurement arm **104**. The interference will induce a non-symmetric image of the light beam **202** e.g., the image of the light path diffracted or reflected off the substrate **103** is not circular or substantially circular, which reduces the accuracy of the measurements of the pitch P and the orientation angle ϕ. To address this, the measurement system **101** utilizes an aperture filtering component to reduce the interference.

The first configuration **200**A of the measurement arm **104** includes a light source **206**, a first lens **208**, a first beam splitter **210**, a second lens **212**, an aperture **214**, a mirror **216**, a second beam splitter **218**, a third lens **220**, and a detector **222**. The measurement arm **104** is in communication with a controller **130** (shown in FIG. **1**). The controller **130** is configured to facilitate the operation and movement of the measurement arm **104**. The measurement arm **104** may also include an arm actuator **224** (shown in FIG. **1**). The arm actuator **224** is configured to rotate the measurement

arm **104** about the z-axis and scan the measurement arm in a z-direction. The measurement arm **104** may also be fixed while the measurement is performed.

The light source **206** is configured to project the light beam **202** towards the substrate **103**. For example, the light source **206** is an LED or laser. The light source operates in a wavelength range from about 400 nm to about 700 nm. For example, the light source **206** is an LED light source operating at one of 450 nm, 530 nm, or 650 nm. The light beam **202** is projected at a beam angle θ relative to the bottom surface **203** of the substrate **103**. In one embodiment, which can be combined with other embodiments described herein, the light beam **202** is a collimated laser beam. In another embodiment, which can be combined with other embodiments described herein, the light beam **202** has a circular or substantially circular cross-section (as shown in FIG. **3**A) and/or projection shape. As depicted by first arrows **240**, the light beam **202** is projected from the light source **206**, transmitted through the first beam splitter **210** (some of the light beam **202** is reflected from the first beam splitter **210**), and projected to optical device structure **109** by the first lens **208**.

The light source **206** projects the light beam **202** towards the first lens **208**. The first lens **208** is a converging lens or focusing lens that focuses the light beam **202**. The first lens **208** is adjacent to the substrate **103**. The first lens **208** is disposed between the light source **206** and the substrate **103**. The first lens **208** is configured to focus the light beam **202** on the top surface **201** of the optical device structure **109** to be measured. The optical device structures **109** cause a phase change of the light beam **202** upon reflection from the optical device structures **109**. The first lens **208** is configured to focus the light beam **202** e.g., reduce the beam diameter of the light beam **202**, to improve the spatial resolution of the measurement arm **104**. Additionally, the improved spatial resolution will better distinguish the light beam **202** from the multi-reflection beams **204**.

The light beam **202** is diffracted from the top surface **201** of the optical device structure at the beam angle θ. As depicted by second arrows **242**, the light beam **202** is projected through the first lens **208** toward the first beam splitter **210** and to the mirror **216**. The first beam splitter **210** reflects the light beam **202** to the second lens **212** (some of the light beam **202** is transmitted through the first beam splitter **210**. The first beam splitter **210** is disposed between the first lens **208** and the light source **206**. The second lens **212** is disposed between the second beam splitter **218** and the aperture **214**. The second lens **212** is a converging lens that focuses the light beam **202**.

The second lens **212** focuses the light beam **202** to a reflective surface **226** of the mirror **216**. The second lens **212** directs the light beam **202** through the aperture **214**. The aperture **214** is disposed in front of the mirror **216**. The aperture **214** is positioned such that the light beam **202** is allowed to contact the reflective surface **226** through the aperture **214**. The aperture **214** includes an aperture size **215**. The aperture size **215** is determined based on a pre-determined spatial resolution of the results. For example, the aperture size **215** is about 50 μm to about 1 mm.

The mirror **216** reflects the light beam **202** to the second beam splitter **218**. As depicted by third arrows **244**, the light beam reflects from the mirror **216**, through the second lens **212**, the second beam splitter **218** reflects the light beam **202** to the third lens **220** (some of the light beam **202** is transmitted through the second beam splitter **218**), and is projected to the detector **222**. The second beam splitter **218** is disposed adjacent to the mirror **216**. The third lens **220** is adjacent to the detector **222**. The third lens **220** is disposed between the second beam splitter **218** and the detector **222**.

The third lens **220** relays an original image at a Fourier plane **228** to the detector **222**. The third lens **220** is a relay lens. The third lens **220** can be a single lens or multiple lenses. The Fourier plane **228** is disposed between the second beam splitter **218** and the second lens **212**. The original image of the light beam **202** at the Fourier plane **228** is projected to the detector **222**. The detector **222** is relayed the original image at the Fourier plane **228** to observe a shift in a chief ray angle (shown in FIGS. **3**A and **3**B) of the light beam **202** projected to different optical device structures **109**. The detector **222** 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 location of the Fourier plane **228** is defined as the Fourier plane of mirror **216** as well as a plane on the substrate **103**. The Fourier plane **228** is the relayed image of the original profile of the light beam **202**, as well as the original image relayed to the detector **222**. When the pitch changes, the Fourier plane **228** will shift as well as the original image on the detector **222**, but the location of the light beam **202** on the substrate **103** and the mirror **216** will not shift.

As the substrate **103** is non-opaque, the multi-reflection beams **204** are formed when the light source **206** projects light that passes through the substrate **103**. For example, as shown in FIG. **2**A, the multi-reflection beam **204** is diffracted off the bottom surface **203** of the substrate **103**. Due to the diffraction off of the bottom surface **203** (and in some embodiments, diffraction off of other optical device structures **109** or the upper surface of the substrate **103**), the multi-reflection beams **204** are not projected through the measurement arm **104** along the same path as the light beam **202**. For example, as shown in FIG. **2**A, the multi-reflection beam **204** is directed to the second lens **212** via the first beam splitter **210**. The second lens **212** focuses the multi-reflection beam **204** towards the mirror **216**. The second lens **212** is adjacent to the aperture **214**. However, the aperture **214** filters out the multi-reflection beam **204** from contacting the mirror **216**. The aperture **214** is positioned such that the multi-reflection beams **204** will not contact the reflective surface **226**. The multi-reflection beams **204** will have an image point beyond the image point of the light beam **202**. The multi-reflection beams **204** will also be shifted from the light beam **202**. Therefore, the aperture **214** filters out the multi-reflection beams **204** from being relayed to the detector **222**. The precision and accuracy of the original image relayed to the detector **222** will improve without interference from the multi-reflection beams **204**.

FIG. **2**B is a schematic, side-view of a second configuration **200**B of a measurement arm **104**. The second configuration **200**B of the measurement arm **104** includes the light source **206**, the first lens **208**, the first beam splitter **210**, the second lens **212**, an aperture **214**, a mirror **216**, the third lens **220**, the detector **222**, a first linear polarizer **230**, a second linear polarizer **232**, a first waveplate **234**, and a second waveplate **236**. The first linear polarizer **230**, the second linear polarizer **232**, the first waveplate **234**, and the second waveplate **236** are configured to increase the efficiency of the light beams in the measurement arm **104** and reduce the light beams reflected between components of the measurement arm **104**. The first linear polarizer **230**, the second linear polarizer **232**, the first waveplate **234**, and the second waveplate **236** may be interchangeable to accommodate for pre-determined wavelengths. For example, the first waveplate **234**, and the second waveplate **236** may be

quarter waveplates. The second configuration **200**B allows for a compact design compared to the first configuration **200**A. However, the first linear polarizer **230**, the second linear polarizer **232**, the first waveplate **234**, and the second waveplate **236** are included to avoid undesired light beam diffraction and reflection within the measurement arm **104**.

The light source **206** is configured to project the light beam **202** towards the substrate **103**. The light beam **202** is projected at a beam angle θ relative to the bottom surface **203** of the substrate **103**. In one embodiment, which can be combined with other embodiments described herein, the light beam **202** is a collimated laser beam. In another embodiment, which can be combined with other embodiments described herein, the light beam **202** has a circular or substantially circular cross-section (as shown in FIG. **3**A) and/or projection shape. As depicted by first arrows **246**, the light beam **202** is projected from the light source **206** to the first linear polarizer **230**, transmitted through the first beam splitter **210** (some of the light beam **202** is reflected from the first beam splitter **210**), through the first waveplate **234**, and projected to optical device structure **109** by the first lens **208**. The first beam splitter **210** is a polarized beam splitter. The first linear polarizer **230**, the second linear polarizer **232**, the first waveplate **234**, and the second waveplate **236** maximize the efficiency of the light beam **202** transmitted to the substrate **103** such that the light beam **202** remains along the path defined by the first arrows **246**. The first linear polarizer **230** is disposed between the light source **206** and the first beam splitter **210**. The first waveplate **234** is disposed between the first beam splitter **210** and the first lens **208**. The first beam splitter **210** will let a polarized light beam be transmitted and reflect another polarization light beam. The first linear polarizer **230**, the second linear polarizer **232**, the first waveplate **234**, and the second waveplate **236** changes the polarization of the light beam **202** before contacting the first beam splitter **210** in order to control whether the light beam **202** is reflected or transmitted by the first beam splitter **210**.

The light source **206** projects the light beam **202** towards the first lens **208**. The first lens **208** is a converging lens that focuses the light beam **202**. The first lens **208** is adjacent to the substrate **103**. The light beam **202** is projected from the first linear polarizer **230** to the first lens **208**. The first lens **208** is configured to focus the light beam **202** on the top surface **201** of the optical device structure **109** to be measured. The first lens **208** is configured to focus the light beam **202** e.g., reduce the beam diameter of the light beam **202**, to improve the spatial resolution of the measurement arm **104**. Additionally, the improved spatial resolution will better distinguish the light beam **202** from the multi-reflection beams **204**. The optical device structures **109** cause a phase change of the light beam **202** upon reflection from the optical device structures **109**. The first lens **208** is disposed between the first waveplate **234** and the substrate **103**.

The light beam **202** is diffracted from the top surface **201** at the beam angle θ. As depicted by second arrows **248**, the light beam **202** is projected through the first lens **208** toward the first beam splitter **210** and to the mirror **216**. Upon reflection, the light beam **202** passes through the first lens **208** and the first waveplate **234** prior to contacting the first beam splitter **210**. The first beam splitter **210** reflects the light beam **202** to the second waveplate **236**, through the second lens **212**, and to the mirror **216**. The second waveplate **236** is disposed between second lens **212** and the first beam splitter **210**. The first linear polarizer **230**, the second linear polarizer **232**, the first waveplate **234**, and the second waveplate **236** maximize the efficiency of the light beam **202** reflected to the mirror **216** such that the light beam **202** remains along the path defined by the second arrows **248**.

The second lens **212** is disposed between the second waveplate **236** and the aperture **214**. The first beam splitter **210** is disposed between the first linear polarizer **230**, the second linear polarizer **232**, the first waveplate **234**, and the second waveplate **236**. The distance between the first lens **208** and the second lens **212** is defined by the sum of each respective focal length. The second lens **212** focuses the light beam **202** to a reflective surface **226** of the mirror **216**. The second lens **212** directs the light beam **202** through the aperture **214**. The aperture **214** is disposed in front of the mirror **216**. The aperture **214** is positioned such that the light beam **202** is allowed to contact the reflective surface **226**. The aperture **214** includes the aperture size **215**.

The mirror **216** reflects the light beam **202** to the detector **222**. As depicted by third arrows **250**, the light beam reflects from the mirror **216**, through the second lens **212**, through the second waveplate **236**, the first beam splitter **210** transmits the light beam **202** (some of the light beam **202** is transmitted through the second beam splitter **218**) to the second linear polarizer **232** and the third lens **220**, and is projected to the detector **222**. The second linear polarizer is disposed between the first beam splitter **210** and the third lens **220**. The first linear polarizer **230**, the second linear polarizer **232**, the first waveplate **234**, and the second waveplate **236** maximize the efficiency of the light beam **202** transmitted to the detector **222** such that the light beam **202** remains along the path defined by the third arrows **250**.

The third lens **220** relays an original image at a Fourier plane **228** to the detector **222**. The third lens **220** is adjacent to the detector **222**. The third lens **220** is disposed between the second linear polarizer **232** and the detector **222**. The original image of the light beam **202** at the Fourier plane **228** is projected to the detector **222**. The detector **222** 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).

As the substrate **103** is non-opaque, the multi-reflection beams **204** are formed when the light source **206** projects light that passes through the substrate **103**. For example, as shown in FIG. **2**B, the multi-reflection beam **204** is diffracted off the bottom surface **203** of the substrate **103**. Due to the diffraction off of the bottom surface **203** (and in some embodiments, diffraction off of other optical device structures **109**), the multi-reflection beams **204** are not projected through the measurement arm **104** along the same path as the light beam **202**. For example, as shown in FIG. **2**B, the multi-reflection beam **204** is directed to the second lens **212** via the first beam splitter **210**. The second lens **212** focuses the multi-reflection beam **204** towards the mirror **216**. The second lens **212** is adjacent to the aperture **214**. However, the aperture **214** filters out the multi-reflection beam **204** from contacting the mirror **216**. The aperture **214** is positioned such that the multi-reflection beams **204** will not contact the reflective surface **226**. The multi-reflection beams **204** will have an image point beyond the image point of the light beam **202**. The multi-reflection beams **204** will also be shifted from the light beam **202**. Therefore, the aperture **214** filters out the multi-reflection beams **204** from being relayed to the detector **222**. The precision and accuracy of the original image relayed to the detector **222** will improve without interference from the multi-reflection beams **204**.

FIG. **3**A is a schematic view of a first light beam **302** and a second light beam **304**. In one example, the first light beam **302** and the second light beam **304** correspond to the light beam **202** shown in FIGS. **2**A and **2**B. In another example,

the first light beam **302** and the second light beam **304** correspond to the light beam **502** shown in FIGS. **5**A-**5**G. To facilitate explanation, FIG. **3**A is described with reference to FIGS. **2**A and **2**B.

The first light beam **302** corresponds to the light beam **202** projected to a first optical device structure (e.g., the optical device structures **109** shown in FIGS. **2**A and **2**B). The first light beam **302** is projected by the measurement arm **104** to measure the pitch P and the orientation angle ϕ of the first optical device structure. The second light beam **304** corresponds to the light beam **202** projected to a second optical device structure (e.g., the optical device structures **109** shown in FIGS. **2**A and **2**B). The second light beam **304** is projected by the measurement arm **104** to measure the pitch P and the orientation angle ϕ of the second optical device structure.

As shown in FIG. **3**A, the first light beam **302** includes a first chief ray angle (CRA) **306** defined as the center line of the first light beam **302**. The second light beam **304** includes a second CRA **308** defined as the center line of the second light beam **304**. As discussed with reference to FIGS. **2**A and **2**B, the original image at a Fourier plane **228** is relayed to a detector **222** in a measurement arm **104** of a measurement system **101**. The detector **222** is configured to detect a shift **310** between the positon of the first CRA **306** and the second CRA **308** on the Fourier plane **228**. The shift **310** corresponds to a change in pitch P and orientation angle ϕ between the first optical device structure and the second optical device structure.

FIG. **3**B is a schematic, top-view of a detector **222**. To facilitate explanation, FIG. **3**B is described with reference to FIGS. **2**A and **2**B, however it is contemplated that a first detector **522** and a second detector **534** are also shown in FIG. **3**B. The detector **222** includes the first light beam **302** and the second light beam **304**. The first light beam **302** and the second light beam **304** are relayed from the Fourier plane **228** to the detector **222** by the third lens **220** (shown in FIGS. **2**A and **2**B). The shift **310** between the first CRA **306** and the second CRA **308** correspond to a change in pitch, for example, a change from the pitch P to the pitch P' (shown in FIGS. **2**A and **2**B), and a change in orientation angle ϕ, for example, a change from the orientation angle ϕ to the orientation angle ϕ' (shown in FIGS. **2**A and **2**B). The detector **222** only includes the first light beam **302** and the second light beam **304**. As the aperture **214**, shown in FIGS. **2**A and **2**B, filters the multi-reflection beams **204**, the detector **222** is able to detect the first light beam **302** and the second light beam **304** without interference. Decreasing the interference with the aperture **214** increases precision, accuracy, and reliability when determining the pitch P and the orientation angle ϕ.

The shift **310** has an x component **312** and a y component **314**. In one embodiment, which can be combined with other embodiments described herein, the x component **312** corresponds to a change in pitch and the y component corresponds to a change in orientation angle ϕ. In another embodiment, which can be combined with other embodiments described herein, the x component **312** corresponds to a change in orientation angle ϕ and the y component corresponds to a change in pitch. The pitch direction and orientation direction can be pre-calibrated by adjusting the measurement arms **104** and the stage **102**. The shift **310** is decomposed into the pre-defined pitch direction and orientation direction. The pitch and the orientation angle ϕ are at least partially determined with a software algorithm executed by a controller **130** in communication with the measurement system **101**. Utilizing the measurement system **101** will allow for the formation of a high-resolution map of the pitch P and the orientation angle ϕ in a two-dimensional area of the substrate **103**.

FIG. **4** is a flow diagram of a method **400** of determining a change in pitch P and a change in an orientation angle ϕ with a measurement system **101**. In one example, the method **400** may be executed by a first configuration **200**A or a second configuration **200**B of the measurement system **101**. In another example, the method **400** may be executed by the configurations **500**A-**500**G of the measurement system **101** shown in FIGS. **5**A-**5**G below. To facilitate explanation, the method **400** will be described with reference to the first configuration **200**A of the measurement system **101**. A controller **130** is operable to facilitate the operations of the method **400**.

At operation **401**, a light beam **202** is projected to a first optical device structure. The light beam **202** is projected from a light source **206** to a top surface **201** of the first optical device structure. The light beam **202** diffracts off the top surface **201** of the first optical device structure.

At operation **402**, the light beam **202** is projected through an aperture **214**. A mirror **216** is disposed behind the aperture **214**. The light beam is operable to be projected through the aperture **214**. The image point of the light beam **202** is located on a reflective surface **226** of the mirror **216**. The aperture **214** is positioned such that the light beam **202** is allowed to contact the reflective surface **226**. The aperture **214** filters out multi-reflection beams **204** from contacting the mirror **216**. The aperture **214** is positioned such that the multi-reflection beams **204** will not contact the reflective surface **226**. Filtering the multi-reflection beams **204** will allow for improved precision, accuracy, and reliability in measurement of an original image to be relayed to a detector **222**.

At operation **403**, an original image of the light beam **202** is relayed to a detector **222**. The mirror **216** reflects the light beam **202** to the detector **222** via a second beam splitter **218**. A third lens **220** relays the original image at a Fourier plane **228**. The light beam **202** includes the first CRA **306** (shown in FIGS. **3**A and **3**B) that is relayed to the detector **222** in the original image. Additionally, the original image is recorded from the detector **222**. The original image is saved to the controller **130**.

At operation **404**, a stage **102** is moved along a scanning path **110** (shown in FIG. **1**). The stage **102** is moved such that the measurement arm **104** is disposed such that the light beam **202** may be projected to a second optical device structure.

At operation **405**, operations **401**-**404** are repeated for at least a second optical device structure. The operations **401**-**404** are repeated until the original image of a predetermined number of optical device structures have been obtained by the detector **222**.

At operation **406**, a high resolution map of the pitch P and the orientation angle ϕ is formed. The high resolution map has improved accuracy, precision, and reliability due to the aperture **214** filtering out the interference from the multi-reflection beams **204**. Additionally, the controller **130** will apply algorithms to the original images and generate the high resolution map of the pitch P and orientation angle **4**).

FIG. **5**A is a schematic, side-view of a third configuration **500**A of a measurement arm **104**. The measurement arm **104** is configured to direct a light beam **502** to a substrate **103**. The measurement arm **104** is configured to measure a pitch P and an orientation angle ϕ of optical device structures **109** formed on the substrate **103**. The optical device structures **109** form a grating **107**. The light beam **502** is projected to

a top surface **201** of the optical device structure **109** to be measured. As shown in FIG. **5**, the light beam **502** is projected to the plurality of optical device structures **109** of the grating **107**. In embodiments where the substrate **103** is non-opaque (e.g. transparent), which can be combined with other embodiments described herein, multi-reflection beams **504** of light will reflect off of at least a bottom surface **203** of the substrate **103**. The multi-reflection beams **504** cause interference when using the measurement arm **104**. To address this, the measurement system **101** utilizes an aperture filtering component to reduce the interference.

The third configuration **500**A of the measurement arm **104** includes a light source **506**, a first lens **508**, a first beam splitter **510**, a second lens **512**, an aperture **514**, a reticle **516**, a third lens **520**, and the first detector **522**.

The light source **506** is configured to project the light beam **502** towards the substrate **103**. The light source **506** operates in a wavelength range from about 250 nm to about 530 nm. The light beam **502** is projected at a beam angle θ relative to the bottom surface **203** of the substrate **103**. In one embodiment, which can be combined with other embodiments described herein, the light beam **502** is a collimated laser beam. As depicted by first arrows **540**, the light beam **502** is projected from the light source **506**, transmitted through the first beam splitter **510** (some of the light beam **502** is reflected from the first beam splitter **510**), and projected to optical device structure **109** by the first lens **508**. The reticle **516** is disposed between the first beam splitter **510** and the light source **506**. The reticle **516** includes a marker thereon. The marker may be a cross, circular, triangular, or other suitable shape. The reticle **516** may adjust the light beam **502** to project the marker to the substrate **103**. The marker will help localize the center of the light beam **502** and will allow for easier tracking on the first detector **522** for improved measurement performance.

The light source **506** projects the light beam **502** towards the first lens **508**. The first lens **508** is a converging lens that focuses the light beam **502**. The first lens **508** is adjacent to the substrate **103**. The first lens **508** is disposed between the light source **506** and the substrate **103**. The first lens **508** is configured to focus the light beam **502** on the top surface **201** of the optical device structure **109** to be measured. An original image of the top surface **201** of the optical device to be measured will be related to the first detector **522**. The optical device structures **109** cause a phase change of the light beam **502** upon reflection from the optical device structures **109**. The first lens **508** is configured to focus the light beam **502** e.g., reduce the beam diameter of the light beam **502**, to improve the spatial resolution of the measurement arm **104**. Additionally, the improved spatial resolution better distinguishes the light beam **502** from the multi-reflection beams **504**.

The light beam **502** is diffracted from the top surface **201** of the optical device structure at the beam angle θ. As depicted by second arrows **542**, the light beam **502** is projected through the first lens **508** toward the first beam splitter **510** and to the mirror **216**. The first beam splitter **510** reflects the light beam **502** to the second lens **512** (some of the light beam **502** is transmitted through the first beam splitter **510**, for example 50% of the light beam **502** is transmitted. The first beam splitter **510** is disposed between the first lens **508** and the light source **506**. The second lens **512** is disposed between the first beam splitter **510** and the aperture **514**. The second lens **512** is a converging lens that focuses the light beam **502**.

The second lens **512** focuses the light beam **502** through the aperture **514**. The aperture **514** is disposed between the second lens **512** and the third lens **520**. The aperture **514** is positioned such that the light beam **502** is allowed to pass through the aperture **514**. In one embodiment, which can be combined with other embodiments described herein, the aperture **514** may be perpendicular to the direction of projection of the light beam **502** (e.g., perpendicular to the second arrows **542**). In another embodiment, which can be combined with other embodiments described herein, the aperture **514** may be at an aperture angle relative to the direction of projection of the light beam **502** (e.g., non-perpendicular relative to the second arrows **542**).

The aperture **514** shown in phantom in FIG. **5**A is at an aperture angle. The aperture angle may be pre-determined based on the beam angle θ. The aperture angle of the aperture **514** improves the alignment of the aperture **514** relative to the top surface **201** of the optical device structures **109**. The pre-determined aperture angle will ensure that the aperture **514** allows the original image focused on the top surface **201** of the optical device structure **109** to pass therethrough and better blocks the light beam **502** from undesired region of the top surface **201** of the optical device structures **109**. An aperture position of the aperture **514** may then be determined. The aperture position is chosen to ensure that the original image to be captured is aligned in the X-Y plane on the substrate **103**. The aperture position is also adjusted to ensure that the marker is projected through the aperture **514** to the first detector **522**.

The third lens **520** is adjacent to the first detector **522**. The third lens **520** is disposed between the aperture **514** and the first detector **522**. The third lens **520** relays an original image at a Fourier plane **528** to the first detector **522**. The third lens **520** can be a single lens or multiple lenses. The Fourier plane **528** is disposed between the first beam splitter **510** and the second lens **512**. The original image of the light beam **502** at the Fourier plane **528** is projected to the first detector **522**. The first detector **522** is relayed the original image at the Fourier plane **528** to observe a shift in a chief ray angle (shown in FIGS. **3**A and **3**B) of the light beam **502** projected to different optical device structures **109**.

The aperture **514** filters out the multi-reflection beam **504** from contacting the first detector **522**. The multi-reflection beams **504** will have an image point beyond or before the image point of the light beam **502**. The multi-reflection beams **504** will also be shifted from the light beam **502**. Therefore, the aperture **514** filters out the multi-reflection beams **504** from being relayed to the first detector **522**. The precision and accuracy of the original image relayed to the first detector **522** improves without interference from the multi-reflection beams **504**.

FIG. **5**B is a schematic, side-view of a fourth configuration **500**B of a measurement arm **104**. The fourth configuration **500**B of the measurement arm **104** is similar to the third configuration **500**A. However, in the fourth configuration **500**B, the light beam **502** contacting the first beam splitter **510** after being incident on the on the top surface **201** of the optical device structure **109** is directed to a mirror **524**. The light beam **502** is directed to the mirror **524** via a second lens **512**.

The second lens **512** focuses the light beam **502** to a reflective surface **526** of the mirror **524**. The second lens **512** directs the light beam **502** through the aperture **514**. The aperture **514** is disposed in front of the mirror **524**. The aperture **514** is positioned such that the light beam **502** is allowed to contact the reflective surface **526** through the aperture **514**.

The mirror **524** reflects the light beam **502** to a second beam splitter **518**. As depicted by third arrows **544**, the light

beam **502** reflects from the mirror **524**, through the second lens **512**, the second beam splitter **518** reflects the light beam **202** to the first detector **522** (some of the light beam **502** is transmitted through the second beam splitter **518**).

In the fourth configuration **500**B, the first lens **508** is utilized for projecting and collecting the light beam **502**. The top surface of the first lens **508** will reflect the light beam **502** into the path indicated by second arrows **542**. This portion of the light beam **502** does not go through the substrate **103** but was collected by the first detector **522**.

FIG. **5**C is a schematic, side-view of a fifth configuration **500**C of a measurement arm **104**. The fifth configuration **500**C of the measurement arm **104** includes all of the elements described above regarding the third configuration **500**A. However, the fifth configuration **500**C includes the first lens **508** disposed between the first beam splitter **510** and the reticle **516**. The fifth configuration **500**C further includes a fourth lens **530**. The fourth lens **530** is disposed between the aperture **514** and the first detector **522**. The fourth lens **530** is configured to collect the light beam **502**. The fifth configuration **500**C allows for the minimization of back-reflection from the first lens **508** back into the light beam **502**. Therefore, a signal to noise ratio is improved. The distance from the reticle **516** to the first lens **508** is equal to the focal length of the first lens **508**. In the fifth configuration **500**C, the first lens **508** (projecting lens) and the second lens **512** (collecting lens) are split, so the reflection from a top surface of the first lens **508** will not travel to the first detector **522**. Therefore, back-reflection is reduced.

FIG. **5**D is a schematic, side-view of a sixth configuration **500**D of the measurement arm **104**. The sixth configuration **500**D of the measurement arm **104** includes all of the elements described above regarding the fifth configuration **500**C in addition to a second beam splitter **518**, a fifth lens **532**, and a second detector **534**. The second beam splitter **518** is disposed between the aperture **514** and the fifth lens **532**.

The fifth lens **532** is disposed between the second beam splitter **518** and the second detector **534**. The light beam **502** passes through the aperture **514** and is incident on the second beam splitter **518** (as indicated by second arrows **542**). The second beam splitter **518** reflects the light beam **502** to the fourth lens **530** (some of the light beam **502** is transmitted through the second beam splitter **518**, for example 50% of the light beam **502** is transmitted, as indicated by third arrows **544**). The light beam **502** that is transmitted through the second beam splitter **518** is directed to the fifth lens **532**. The fifth lens **532** directs the light beam **502** to the second detector **534**. The second detector **534** is disposed at an angle relative to the direction of projection of the light beam **502** (e.g., angled relative to the third arrows **544**).

Inclusion of the second detector **534** allows for monitoring the substrate **103** and alignment of the aperture **514**. In particular, the configuration facilitates monitoring of the aperture location as well as monitoring of how the light beam **502** is focused on the top surface **201** of the optical device structure **109**. The fifth lens **532** relays the original image to the second detector **534** to ensure that the top surface **201** of the optical device structure **109** and the aperture **514** are aligned as pre-determined. As such, the second detector **534** is used to monitor the focus change through the scanning of the substrate **103**.

FIG. **5**E is a schematic, side-view of a seventh configuration **500**E of measurement arm **104**. The seventh configuration **500**E of the measurement arm **104** includes all of the elements described above regarding the sixth configuration **500**D in addition to a third beam splitter **538** and a fourth beam splitter **546**. The third beam splitter **538** is disposed between the light source **506** and the reticle **516**. The fourth beam splitter **546** is disposed between the first detector **522** and the fourth lens **530**. The light beam **502** is projected from the light source **506** and is incident on the third beam splitter **538**. The third beam splitter **538** reflects the light beam **502** to form a reference beam **548**. Some of the light beam **502** is transmitted through the third beam splitter **538** to the reticle **516**. The seventh configuration **500**E includes the aperture **514**, which is at an aperture angle.

The reference beam **548** is included to generate an interferogram between the light beam **502** and the reference beam **548** directly from the light source **506**. The interferogram will be displayed on the first detector **522**, which will have improved contrast to better locate the marker of the reticle **516**. Without the reference beam **548**, the marker on the first detector **522** will be blurred, which limits the sharpness of the original image and the accuracy of the system. Generating interference fringes on the second detector **534** will help locate the marker more accurately.

FIG. **5**F is a schematic, side-view of an eighth configuration **500**F of measurement arm **104**. The eighth configuration **500**F of the measurement arm **104** includes all of the elements described above regarding the seventh configuration **500**E however, the first detector **522** and the fourth lens **530** are removed. As opposed to the seventh configuration, the second beam splitter **518** reflects the light beam **502** to the fifth lens **532**. The fifth lens **532** relays the light beam **502** to the second detector **534**. The second detector **534** is disposed at an angle relative to the direction of projection of the light beam **502** (e.g., angled relative to the second arrows **542**). The reference beam **548** will display the interferogram on the second detector **534**. The spacing and the orientation of the fringes indicates the pitch/orientation of the optical device structure **109** on the substrate **103**.

FIG. **5**G is a schematic, side-view of the sixth configuration **500**G of a measurement arm **104** and a reflection arm **112**. The sixth configuration **500**G of the measurement arm **104** is described above. The reflection arm **112** includes a first reflection arm lens **562**, a second reflection arm lens **564**, a third reflection arm lens **566**, a reflection arm detector **568**, and a reflection arm aperture **570**. The reflection arm **112** is operable to measure a reflection beam **560** reflected off a top surface **201** of the optical device structure **109** to be measured. In one example, the reflection arm **112** is disposed directly opposite of the measurement arm **104**. Although the reflection arm **112** is shown in FIG. **5**G with the sixth configuration **500**G of the measurement arm **104**, any of the configurations of the measurement arm **104** can be paired with the reflection arm **112**.

The reflection arm aperture **570** is disposed between the second reflection arm lens **564** and the third reflection arm lens **566**. The reflection arm aperture **570** is positioned such that the reflection beam **560** is allowed to pass through the reflection arm aperture **570**. In one embodiment, which can be combined with other embodiments described herein, the reflection arm aperture **570** may be perpendicular to the direction of projection of the reflection beam **560** (e.g., perpendicular to direction of propagation of the reflection beam **560**). In another embodiment, which can be combined with other embodiments described herein, the reflection arm aperture **570** may be at a reflection aperture angle relative to the direction of projection of the reflection beam **560**.

The third reflection arm lens **566** relays the reflection beam **560** from the second reflection arm lens **564** to the reflection arm detector **568**. The reflection arm detector **568** is operable to obtain data relating to stage conditions of the

stage **102**. The reflection arm **112** will monitor the angular change from the stage **102** while scanning, such that the impact of stage conditions (e.g., stage tip or tilt) during scanning are excluded from the measurement to be obtained with the measurement arm **104**. The reflection arm **112** collects the reflection beam from the substrate **103** and can collect data related to bowing of the substrate **103**. The reflection arm **112** serves as a reference to the data determined in the measurement arm **104**.

In summation, a measurement system having an aperture filtering component and methods of utilizing the measurement system are described herein. The measurement system described herein includes a measurement arm and a stage. The measurement arm projects a light beam to a top surface of an optical device structure. Multi-reflection beams resulting from reflections and diffraction off other surfaces of a non-opaque substrate leads to interference. The measurement arm includes an aperture (e.g., an aperture filtering component) that filters the multi-reflection beams from being relayed to the detector. As such, only images of the light beam are relayed to the detector. The images allow for the measurement of pitch and orientation angle across the substrate. The aperture allows for an improvement in accuracy, precision, and reliability of the measurements by filtering out the interference from the multi-reflection beams.

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 measurement 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

a measurement arm disposed above the stage, the measurement arm configured to direct a light beam to a substrate disposed on the substrate support surface, the measurement arm including:

a light source, the light source configured to project the light beam to the substrate disposed below the light source;

a first lens disposed between the substrate and the light source, the first lens configured to focus the light beam to the substrate;

a first beam splitter disposed between the first lens and the light source;

a second lens disposed adjacent to the first beam splitter, the first beam splitter configured to direct the light beam to the second lens, the second lens configured to direct the light beam to a mirror;

an aperture disposed in front of the mirror;

a second beam splitter, the second beam splitter configured to direct the light beam to a third lens from the mirror; and

a detector, wherein the light beam is projected to the detector by the third lens.

2. The measurement system of claim **1**, wherein the first lens is a focusing lens.

3. The measurement system of claim **1**, wherein the third lens is configured to relay an original image of the light beam at a Fourier plane to the detector, wherein the Fourier plan is formed adjacent to the second lens.

4. The measurement system of claim **1**, wherein the aperture has an aperture size between about 50 μm to about 1 mm.

5. The measurement system of claim **1**, further comprising a reticle disposed between the first beam splitter and the light source.

6. The measurement system of claim **5**, wherein the reticle includes a marker thereon, wherein the marker is a cross, circular, or triangular.

7. The measurement system of claim **1**, wherein the detector is a charge-coupled device (CCD) array or an active-pixel sensor (CMOS array).

8. The measurement system of claim **1**, wherein the measurement arm comprises an arm actuator and the arm actuator is configured to rotate the measurement arm about a z-axis and scan the measurement arm in a z-direction.

9. The measurement system of claim **1**, wherein the light source operates in a wavelength range from 400 nanometers to 700 nanometers.

10. The measurement system of claim **1**, wherein the second lens is a converging lens and the third lens is a relay lens.

11. A measurement 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

a measurement arm disposed above the stage, the measurement arm configured to direct a light beam to a substrate disposed on the substrate support surface, the measurement arm including:

a light source, the light source configured to project the light beam to the substrate disposed below the light source;

a first lens disposed between the substrate and the light source, the first lens configured to focus the light beam to the substrate;

a first beam splitter disposed between the first lens and the light source;

a second lens disposed adjacent to the first beam splitter, the first beam splitter configured to direct the light beam to the second lens;

an aperture, the second lens configured to direct the light beam through the aperture;

a third lens; and

a detector, wherein the light beam is projected to the detector by the third lens.

12. The measurement system of claim **11**, wherein the first lens is a focusing lens.

13. The measurement system of claim **11**, wherein the third lens is configured to relay an original image of the light beam at a Fourier plane to the detector, wherein the Fourier plan is disposed adjacent to the second lens.

14. The measurement system of claim **11**, wherein the measurement arm is coupled to an arm actuator configured to scan the measurement arm and rotate the measurement arm about the axis.

15. The measurement system of claim **11**, wherein the measurement arm further comprises:

a first linear polarizer disposed adjacent to the light source;

a second linear polarizer disposed between the first beam splitter and the third lens;

a first waveplate disposed between the first beam splitter and the first lens; and

a second waveplate disposed between the second lens and the first beam splitter.

16. The measurement system of claim 11, wherein the detector is a charge-coupled device (CCD) array or an active-pixel sensor (CMOS array).

17. The measurement system of claim 11, further comprising a reflection arm disposed above the stage.

18. The measurement system of claim 17, wherein the reflection arm is coupled to an arm actuator configured to scan the reflection arm and rotate the reflection arm about the axis.

19. The measurement system of claim 18, wherein the reflection arm comprises:

a first reflection arm lens;

a second reflection arm lens adjacent to the first reflection arm lens;

a third reflection arm lens;

a reflection arm aperture disposed between the second reflection arm lens and the third reflection arm lens; and

a reflection arm detector, wherein the third reflection arm lens directs a reflection beam to the reflection arm detector.

20. The measurement system of claim 11, wherein the aperture is disposed at an aperture angle, wherein the aperture angle is non-perpendicular relative to a projection direction of the light beam.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 12,398,998 B2
APPLICATION NO. : 18/118269
DATED : August 26, 2025
INVENTOR(S) : Yangyang Sun et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Drawings

On sheet 5 of 12, in FIG. 4, reference numeral 405, Line 1, delete “OPERTAIONS” and insert -- OPERATIONS --.

In the Specification

In Column 9, Line 25, delete “positon” and insert -- position --.

In Column 10, Line 60, delete “4).” and insert -- ϕ. --.

In Column 13, Line 38, delete “The fifth lens 532 is disposed between the second beam” and insert the same on Line 37, as a continuation of the same paragraph.

Signed and Sealed this
Tenth Day of February, 2026

John A. Squires
Director of the United States Patent and Trademark Office