



(51) International Patent Classification:
G03F 7/20 (2006.01)

(21) International Application Number:
PCT/EP2019/079552

(22) International Filing Date:
29 October 2019 (29.10.2019)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/758,093 09 November 2018 (09.11.2018) US
62/801,888 06 February 2019 (06.02.2019) US

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,

(54) Title: SENSOR ARRAY FOR REAL TIME DETECTION OF RETICLE POSITION AND FORCES

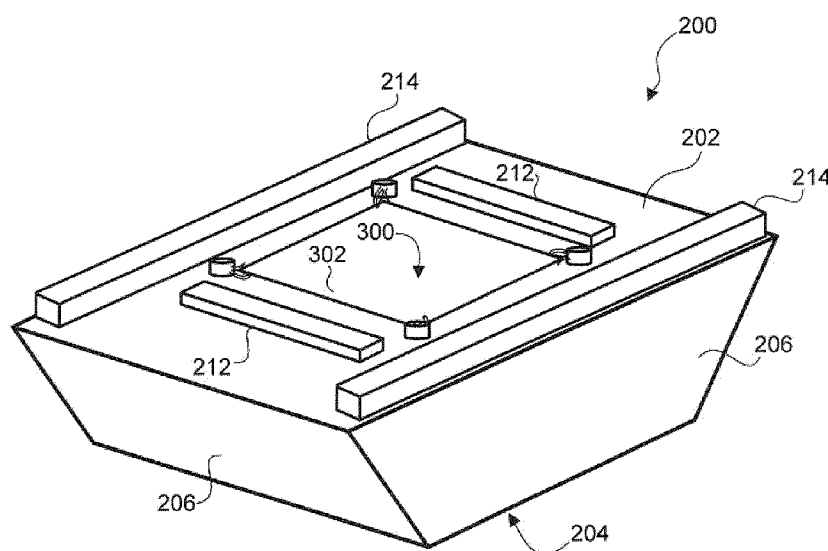


FIG. 2

(57) Abstract: A clamp apparatus configured to hold a reticle in a fixed plane on a reticle stage includes a clamp, a sensor, and a controller. The sensor is disposed on a frontside of the clamp and configured to detect a position of the reticle in a reticle exchange area during a reticle exchange process. The position of the reticle includes a vertical distance between a backside of the reticle and the frontside of the clamp and a relative tilt between the backside of the reticle and the frontside of the clamp. The controller is coupled to the sensor and configured to control a position of the clamp based on the position of the reticle detected by the sensor.



UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

SENSOR ARRAY FOR REAL TIME DETECTION OF RETICLE POSITION AND FORCES

CROSS-REFERENCE TO RELATED APPLICATIONS

5 [0001] This application claims priority of (1) U.S. Provisional Patent Application Number 62/758,093, which was filed on November 9, 2018, and (2) U.S. Provisional Patent Application Number 62/801,888, which was filed on February 6, 2019, both of which are incorporated herein in their entirety by reference.

10 FIELD

[0002] The present disclosure relates to sensors, for example, positioning and force sensors for a reticle in lithography apparatuses and systems.

BACKGROUND

15 [0003] A lithographic apparatus is a machine constructed to apply a desired pattern onto a substrate. A lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). A lithographic apparatus may, for example, project a pattern of a patterning device (e.g., a mask, a reticle) onto a layer of radiation-sensitive material (resist) provided on a substrate.

[0004] To project a pattern on a substrate a lithographic apparatus may use electromagnetic
20 radiation. The wavelength of this radiation determines the minimum size of features which can be formed on the substrate. A lithographic apparatus, which uses extreme ultraviolet (EUV) radiation, having a wavelength within the range 4-20 nm, for example 6.7 nm or 13.5 nm, may be used to form smaller features on a substrate than a lithographic apparatus which uses, for example, radiation with a wavelength of 193 nm.

25 [0005] During a reticle exchange process, a reticle handoff from a reticle handler to a clamp of a reticle stage includes an unknown reticle position offset and reticle tilt offset. Tilt or excessive non-alignment between the clamp and reticle can be a source of particle generation and can damage the reticle or clamp over time. Despite calibration, variations still exist due to reticle mechanical and positioning tolerances, which can lead to high corner impacts and unpredictable
30 first contact points on the clamp and reticle. There is a need to reduce damage to the reticle and clamp in a reliable, uniform, and efficient manner.

SUMMARY

[0006] In some embodiments, a clamp apparatus includes a clamp, a sensor, and a controller. In some embodiments, the clamp apparatus is configured to hold a reticle in a fixed plane on a reticle stage. In some embodiments, the sensor is disposed on a frontside of the clamp. In some embodiments, the sensor is configured to detect a position of a reticle in a reticle exchange area during a reticle exchange process. In some embodiments, the position of the reticle includes a vertical distance between a backside of the reticle and the frontside of the clamp and a relative tilt between the backside of the reticle and the frontside of the clamp. In some embodiments, the controller is coupled to the sensor and configured to control a position of the clamp based on the position of the reticle detected by the sensor. In some embodiments, the sensor is a sensor array.

[0007] In some embodiments, the controller is configured to correct for a vertical distance offset and a relative tilt offset between the backside of the reticle and the frontside of the clamp in real time. In some embodiments, the controller is configured to control the reticle stage to allow compliant movement of the clamp until the frontside of the clamp and the backside of the reticle are in contact and coplanar. In some embodiments, the controller is configured to reduce contact forces and minimize particle generation between the reticle and the clamp. In some embodiments, the controller is configured to move a reticle stage at a first velocity until the sensor detects the position of the reticle and at a second velocity, the first velocity being greater than the second velocity.

[0008] In some embodiments, the sensor is capacitive and includes a planar electrode. In some embodiments, the sensor is optical and includes a light source and a light detector. In some embodiments, the light source is directed towards the backside of the reticle at an acute angle relative to the frontside of the clamp. In some embodiments, the sensor is pressurized and includes a gas gauge. In some embodiments, the sensor includes a plurality of sensor arrays.

[0009] In some embodiments, a clamp apparatus includes a clamp, a sensor, and a controller. In some embodiments, the clamp apparatus is configured to hold a reticle in a fixed plane on a reticle stage. In some embodiments, a sensor is disposed on a frontside of the clamp. In some embodiments, the sensor is configured to detect a force of the reticle in a reticle exchange area during a reticle exchange process. In some embodiments, the force of the reticle includes a stress or a strain from a backside of the reticle or the frontside of the clamp. In some embodiments,

the controller is coupled to the sensor and configured to control a position of the clamp based on the force of the reticle detected by the sensor. In some embodiments, the sensor is a sensor array.

[0010] In some embodiments, the controller is configured to correct for a stress or a strain from the backside of the reticle or the frontside of the clamp in real time. In some embodiments, the controller is configured to control a reticle stage to allow compliant movement of the clamp until the frontside of the clamp and the backside of the reticle are in contact and coplanar.

[0011] In some embodiments, the sensor is resistive and includes a planar strain gauge. In some embodiments, the sensor is resistive and includes a lithographically patterned resistor. In some embodiments, the lithographically patterned resistor is configured to change an electrical resistance in proportion to an applied pressure.

[0012] In some embodiments, a plate apparatus includes a plate, a sensor, and a controller. In some embodiments, the plate apparatus is configured to adjust a reticle to a fixed plane on a clamp on a reticle stage in a lithographic apparatus. In some embodiments, the plate includes a reticle exchange port. In some embodiments, the sensor is disposed in the reticle exchange port. In some embodiments, the sensor is configured to detect a position of a reticle in a reticle exchange area during a reticle exchange process. In some embodiments, the position of the reticle includes a vertical distance between a backside of the reticle and a fixed plane of the sensor and a relative tilt between the backside of the reticle and the fixed plane of the sensor. In some embodiments, the controller is coupled to the sensor and configured to control a position of the clamp based on the position of the reticle detected by the sensor. In some embodiments, the sensor is a sensor array.

[0013] In some embodiments, the controller is configured to correct for a vertical distance offset and a relative tilt offset between the backside of the reticle and a frontside of the clamp in real time. In some embodiments, the controller is configured to control a reticle stage to allow compliant movement of the clamp until a frontside of the clamp and the backside of the reticle are in contact and coplanar.

[0014] In some embodiments, the sensor is optical and includes a light source and a light detector. In some embodiments, the light source is a projected light pattern and configured to allow for structured light stereoscopic detection by the sensor. In some embodiments, the sensor is optical and includes a confocal sensor configured to be time synchronized.

[0015] In some embodiments, a plate apparatus includes a plate, a sensor, and a controller. In some embodiments, the plate apparatus is configured to calibrate a reticle to a fixed plane on a clamp on a reticle stage in a lithographic apparatus. In some embodiments, the plate includes a reticle exchange port. In some embodiments, the sensor is disposed on a backside of the plate and
5 away from the reticle exchange port. In some embodiments, the sensor is configured to calibrate a position of a reticle in a reticle exchange area during a reticle exchange process based on a fixed plane of the sensor. In some embodiments, the position of the reticle includes a vertical distance between a backside of the reticle and the fixed plane of the sensor and a relative tilt between the backside of the reticle and the fixed plane of the sensor. In some embodiments, the controller is
10 coupled to the sensor and configured to control a position of the clamp based on the position of the reticle detected by the sensor. In some embodiments, the sensor is a sensor array.

[0016] In some embodiments, the controller is configured to correct for a vertical distance offset and a relative tilt offset between the backside of the reticle and a frontside of the clamp based on a vertical distance offset and a relative tilt offset between the backside of the reticle and the
15 fixed plane of the sensor. In some embodiments, the sensor is configured to synchronously measure the backside of the reticle. In some embodiments, the sensor is capacitive and includes a planar electrode. In some embodiments, the sensor is optical and includes one or more confocal sensors.

[0017] In some embodiments, a method includes detecting, with a sensor, a position of a
20 reticle on a reticle stage that includes a clamp for the reticle. In some embodiments, the position including a vertical distance between a backside of the reticle and a frontside of the clamp and a relative tilt between the backside of the reticle and the frontside of the clamp. In some embodiments, the method further includes calculating a vertical distance offset and a relative tilt offset between the backside of the reticle and the frontside of the clamp based on the position of
25 the reticle detected by the sensor. In some embodiments, the method further includes adjusting the clamp or the reticle to reduce the vertical distance offset and the relative tilt offset until the backside of the reticle and the frontside of the clamp are in contact and coplanar. In some embodiments, the method is for reducing contact forces and minimizing particle generation between a reticle and a clamp on a reticle stage.

[0018] In some embodiments, detecting, calculating, and adjusting are conducted in real
30 time. In some embodiments, the method further includes moving the reticle stage at a first velocity

until the sensor detects the position of the reticle and moving the reticle stage at a second velocity. In some embodiments, the first velocity is greater than the second velocity.

[0019] In some embodiments, an in-vacuum robot apparatus includes a baseplate, a sensor, and a controller. In some embodiments, the baseplate includes a first through hole. In some
5 embodiments, the sensor is disposed below the baseplate. In some embodiments, the sensor is configured to detect a position of a reticle in a reticle exchange area through the first through hole of the baseplate during a reticle exchange process. In some embodiments, the position of the reticle includes a vertical distance between a frontside of the reticle and a fixed plane of the sensor and a
10 relative tilt between the frontside of the reticle and the fixed plane of the sensor. In some embodiments, the controller is coupled to the sensor and configured to control a position of a clamp based on the position of the reticle detected by the sensor.

[0020] In some embodiments, the controller is configured to correct for a vertical distance offset and a relative tilt offset between the frontside of the reticle and a frontside of the clamp in real time. In some embodiments, the controller is configured to control a reticle stage to allow
15 compliant movement of the clamp until a frontside of the clamp and a backside of the reticle are in contact and coplanar.

[0021] In some embodiments, the sensor is optical and includes a confocal sensor configured to be time synchronized. In some embodiments, the sensor is acoustic and includes an ultrasonic sensor configured to be time synchronized. In some embodiments, the sensor is optical
20 and comprises a high-resolution optical sensor for cadastral mapping, remote pilot assistance, or reverse parking assistance.

[0022] In some embodiments, the sensor is optical and includes a light source and a light detector. In some embodiments, the light source is focused through the first through hole of the baseplate onto the frontside of the reticle, and is configured to allow for scattered light detection
25 by the sensor. In some embodiments, the light source is infrared. In some embodiments, the sensor further includes one or more beam shaping optics.

[0023] In some embodiments, the in-vacuum robot apparatus further includes a second through hole in the baseplate and a second sensor disposed below the baseplate. In some
30 embodiments, the second sensor is configured to detect a second position of the reticle in the reticle exchange area through the second through hole of the baseplate during the reticle exchange process. In some embodiments, the second position of the reticle includes a vertical distance

between the frontside of the reticle and a fixed plane of the sensor and a relative tilt between the frontside of the reticle and the fixed plane of the sensor. In some embodiments, the controller is coupled to the second sensor and configured to control a position of the clamp based on the second position of the reticle detected by the second sensor. In some embodiments, the controller is configured to correct for a vertical distance offset and a relative tilt offset between the frontside of the reticle and a frontside of the clamp in real time based on a comparison between the position of the reticle detected by the sensor and the second position of the reticle detected by the second sensor.

[0024] Further features and advantages of the invention, as well as the structure and operation of various embodiments of the invention, are described in detail below with reference to the accompanying drawings. It is noted that the invention is not limited to the specific embodiments described herein. Such embodiments are presented herein for illustrative purposes only. Additional embodiments will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

BRIEF DESCRIPTION OF THE DRAWINGS/FIGURES

[0025] The accompanying drawings, which are incorporated herein and form part of the specification, illustrate the present invention and, together with the description, further serve to explain the principles of the invention and to enable a person skilled in the relevant art(s) to make and use the invention. Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings, in which:

[0026] FIG. 1 is a schematic illustration of a lithographic apparatus, according to an exemplary embodiment;

[0027] FIG. 2 is a perspective schematic illustration of a reticle stage, according to an exemplary embodiment;

[0028] FIG. 3 is a top plan view of the reticle stage of Figure 2;

[0029] FIG. 4 is a perspective schematic illustration of a reticle exchange apparatus, according to an exemplary embodiment;

[0030] FIG. 5 is a partial cross-sectional view of the reticle exchange apparatus of Figure 4;

[0031] FIG. 6A is a partial schematic illustration of a reticle exchange apparatus in an approach configuration, according to an exemplary embodiment;

[0032] FIG. 6B is a partial schematic illustration of a reticle exchange apparatus in a first contact configuration, according to an exemplary embodiment;

5 [0033] FIG. 6C is a partial schematic illustration of a reticle exchange apparatus in a full contact configuration, according to an exemplary embodiment;

[0034] FIG. 7 is a top schematic illustration of a clamp, according to an exemplary embodiment;

10 [0035] FIG. 8 is a top schematic illustration of a clamp, according to an exemplary embodiment;

[0036] FIG. 9 is a top schematic illustration of a clamp, according to an exemplary embodiment;

[0037] FIG. 10 is a top schematic illustration of a clamp, according to an exemplary embodiment;

15 [0038] FIG. 11 is a top schematic illustration of a clamp, according to an exemplary embodiment;

[0039] FIG. 12 is a top schematic illustration of a clamp, according to an exemplary embodiment;

20 [0040] FIG. 13 is a perspective schematic illustration of a reticle exchange apparatus, according to an exemplary embodiment;

[0041] FIG. 14 is a partial cross-sectional view of the reticle exchange apparatus of Figure 13;

[0042] FIG. 15 is a bottom schematic illustration of a plate in a reticle exchange configuration, according to an exemplary embodiment;

25 [0043] FIG. 16 is a bottom schematic illustration of a plate in a calibration configuration, according to an exemplary embodiment;

[0044] FIG. 17 is a partial cross-sectional schematic illustration of a reticle exchange apparatus, according to an exemplary embodiment; and

30 [0045] FIG. 18 is an enlarged partial cross-sectional view of the reticle exchange apparatus of Figure 17.

[0046] The features and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings, in which like reference characters identify corresponding elements throughout. In the drawings, like reference numbers generally indicate identical, functionally similar, and/or structurally similar elements. Additionally, generally, the left-most digit(s) of a reference number identifies the drawing in which the reference number first appears. Unless otherwise indicated, the drawings provided throughout the disclosure should not be interpreted as to-scale drawings.

DETAILED DESCRIPTION

[0047] This specification discloses one or more embodiments that incorporate the features of this invention. The disclosed embodiment(s) merely exemplify the invention. The scope of the invention is not limited to the disclosed embodiment(s). The invention is defined by the claims appended hereto.

[0048] The embodiment(s) described, and references in the specification to “one embodiment,” “an embodiment,” “an example embodiment,” etc., indicate that the embodiment(s) described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is understood that it is within the knowledge of one skilled in the art to effect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described.

[0049] Spatially relative terms, such as “beneath,” “below,” “lower,” “above,” “on,” “upper” and the like, may be used herein for ease of description to describe one element or feature’s relationship to another element(s) or feature(s) as illustrated in the figures. The spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. The apparatus may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein may likewise be interpreted accordingly.

[0050] The term “about” as used herein indicates the value of a given quantity that can vary based on a particular technology. Based on the particular technology, the term “about” can

indicate a value of a given quantity that varies within, for example, 10–30% of the value (e.g., $\pm 10\%$, $\pm 20\%$, or $\pm 30\%$ of the value).

[0051] Embodiments of the disclosure may be implemented in hardware, firmware, software, or any combination thereof. Embodiments of the disclosure may also be implemented as instructions stored on a machine-readable medium, which may be read and executed by one or more processors. A machine-readable medium may include any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computing device). For example, a machine-readable medium may include read only memory (ROM); random access memory (RAM); magnetic disk storage media; optical storage media; flash memory devices; electrical, optical, acoustical or other forms of propagated signals (e.g., carrier waves, infrared signals, digital signals, etc.), and others. Further, firmware, software, routines, and/or instructions may be described herein as performing certain actions. However, it should be appreciated that such descriptions are merely for convenience and that such actions in fact result from computing devices, processors, controllers, or other devices executing the firmware, software, routines, instructions, etc., and in doing that may cause actuators or other devices to interact with the physical world.

[0052] Before describing such embodiments in more detail, however, it is instructive to present an example environment in which embodiments of the present disclosure may be implemented.

[0053] *Exemplary Lithographic System*

[0054] FIG. 1 shows a lithographic system comprising a radiation source SO and a lithographic apparatus LA. The radiation source SO is configured to generate an EUV radiation beam B and to supply the EUV radiation beam B to the lithographic apparatus LA. The lithographic apparatus LA comprises an illumination system IL, a support structure MT configured to support a patterning device MA (e.g., a mask), a projection system PS, and a substrate table WT configured to support a substrate W.

[0055] The illumination system IL is configured to condition the EUV radiation beam B before the EUV radiation beam B is incident upon the patterning device MA. Thereto, the illumination system IL may include a faceted field mirror device 10 and a faceted pupil mirror device 11. The faceted field mirror device 10 and faceted pupil mirror device 11 together provide the EUV radiation beam B with a desired cross-sectional shape and a desired intensity distribution.

The illumination system IL may include other mirrors or devices in addition to, or instead of, the faceted field mirror device 10 and faceted pupil mirror device 11.

[0056] After being thus conditioned, the EUV radiation beam B interacts with the patterning device MA. As a result of this interaction, a patterned EUV radiation beam B' is generated. The projection system PS is configured to project the patterned EUV radiation beam B' onto the substrate W. For that purpose, the projection system PS may comprise a plurality of mirrors 13, 14 which are configured to project the patterned EUV radiation beam B' onto the substrate W held by the substrate table WT. The projection system PS may apply a reduction factor to the patterned EUV radiation beam B', thus forming an image with features that are smaller than corresponding features on the patterning device MA. For example, a reduction factor of 4 or 8 may be applied. Although the projection system PS is illustrated as having only two mirrors 13, 14 in FIG. 1, the projection system PS may include a different number of mirrors (e.g. six or eight mirrors).

[0057] The substrate W may include previously formed patterns. Where this is the case, the lithographic apparatus LA aligns the image, formed by the patterned EUV radiation beam B', with a pattern previously formed on the substrate W.

[0058] A relative vacuum, i.e. a small amount of gas (e.g. hydrogen) at a pressure well below atmospheric pressure, may be provided in the radiation source SO, in the illumination system IL, and/or in the projection system PS.

[0059] The radiation source SO may be a laser produced plasma (LPP) source, a discharge produced plasma (DPP) source, a free electron laser (FEL), or any other radiation source that is capable of generating EUV radiation.

[0060] *Exemplary Reticle Stage*

[0061] FIGS. 2 and 3 show schematic illustrations of an exemplary reticle stage 200, according to some embodiments of this disclosure. Reticle stage 200 can include top stage surface 202, bottom stage surface 204, side stage surfaces 206, and clamp 300. In some embodiments, reticle stage 200 with clamp 300 can be implemented in lithographic apparatus LA. For example, reticle stage 200 can be support structure MT in lithographic apparatus LA. In some embodiments, clamp 300 can be disposed on top stage surface 202. For example, as shown in FIG. 2, clamp 300 can be disposed at a center of top stage surface 202 with clamp frontside 302 facing perpendicularly away from top stage surface 202.

[0062] In some lithographic apparatuses, for example, lithographic apparatus LA, a reticle stage 200 with a clamp 300 can be used to hold and position a reticle 408 for scanning or patterning operations. In one example, the reticle stage 200 may require powerful drives, large balance masses, and heavy frames to support it. In one example, the reticle stage 200 may have a large inertia and can weigh over 500 kg to propel and position a reticle 408 weighing about 0.5 kg. To accomplish reciprocating motions of the reticle 408, which are typically found in lithographic scanning or patterning operations, accelerating and decelerating forces can be provided by linear motors that drive the reticle stage 200.

[0063] In some embodiments, as shown in FIGS. 2 and 3, reticle stage 200 can include first encoder 212 and second encoder 214 for positioning operations. For example, first and second encoders 212, 214 can be interferometers. First encoder 212 can be attached along a first direction, for example, a transverse direction (i.e., X-direction) of reticle stage 200. And second encoder 214 can be attached along a second direction, for example, a longitudinal direction (i.e., Y-direction) of reticle stage 200. In some embodiments, as shown in FIGS. 2 and 3, first encoder 212 can be orthogonal to second encoder 214.

[0064] As shown in FIGS. 2 and 3, reticle stage 200 can include clamp 300. Clamp 300 is configured to hold reticle 408 in a fixed plane on reticle stage 200. Clamp 300 includes clamp frontside 302 and can be disposed on top stage surface 202. In some embodiments, clamp 300 can use mechanical, vacuum, electrostatic, or other suitable clamping techniques to hold and secure an object. In some embodiments, clamp 300 can be an electrostatic clamp, which can be configured to electrostatically clamp (i.e., hold) an object, for example, reticle 408 in a vacuum environment. Due to the requirement to perform EUV in a vacuum environment, vacuum clamps cannot be used to clamp a mask or reticle and instead electrostatic clamps can be used. For example, clamp 300 can include an electrode, a resistive layer on the electrode, a dielectric layer on the resistive layer, and burls projecting from the dielectric layer. In use, a voltage can be applied to clamp 300, for example, several kV. And current can flow through the resistive layer, such that the voltage at an upper surface of the resistive layer will substantially be the same as the voltage of the electrode and generate an electric field. Also, a Coulomb force, attractive force between electrically opposite charged particles, will attract an object to clamp 300 and hold the object in place. In some embodiments, clamp 300 can be a rigid material, for example, a metal, a dielectric, a ceramic, or a combination thereof.

[0065] *Exemplary Reticle Exchange Apparatus*

[0066] FIGS. 4 through 6 show schematic illustrations of an exemplary reticle exchange apparatus 100, according to some embodiments of this disclosure. Reticle exchange apparatus 100 can be configured to minimize reticle exchange time, particle generation, and contact forces or stresses from clamp 300 and/or reticle 408 to reduce damage to clamp 300 and reticle 408 and increase overall throughput in a reticle exchange process, for example, in a lithographic apparatus LA.

[0067] As shown in FIGS. 4 and 5, reticle exchange apparatus 100 can include reticle stage 200, clamp 300, and in-vacuum robot 400. In-vacuum robot 400 can include reticle handler 402.

[0068] In some embodiments, reticle handler 402 can be a rapid exchange device (RED), which is configured to efficiently rotate and minimize reticle exchange time. For example, reticle handler 402 can save time by moving multiple reticles from one position to another substantially simultaneously, instead of serially.

[0069] In some embodiments, as shown in FIG. 4, reticle handler 402 can include one or more reticle handler arms 404. Reticle handler arm 404 can include reticle baseplate 406. Reticle baseplate 406 can be configured to hold an object, for example, reticle 408.

[0070] In some embodiments, reticle baseplate 406 can be an extreme ultraviolet inner pod (EIP) for a reticle. In some embodiments, reticle baseplate 406 includes reticle baseplate frontside 407, and reticle 408 includes reticle backside 409.

[0071] In some embodiments, as shown in FIGS. 4 and 5, reticle baseplate 406 can hold reticle 408 such that reticle baseplate frontside 407 and reticle backside 409 each face top stage surface 202 and clamp frontside 302. For example, reticle baseplate frontside 407 and reticle backside 409 can be facing perpendicularly away from top stage surface 202 and clamp frontside 302.

[0072] As shown in FIG. 5, reticle exchange apparatus 100 can include reticle exchange area 410, which is the cross-sectional area between clamp 300, reticle 408, reticle baseplate 406, and reticle handler arm 404 during a reticle exchange process.

[0073] In some embodiments, as shown in FIG. 4, reticle handler arms 404 can be arranged symmetrically about reticle handler 402. For example, reticle handler arms 404 can be spaced from each other by about 90 degrees, 120 degrees, or 180 degrees. In some embodiments, reticle handler arms 404 can be arranged asymmetrically about reticle handler 402. For example, two reticle

handler arms 404 can be spaced from each other by about 135 degrees, while another two reticle handler arms 404 can be spaced from each other by about 90 degrees.

[0074] In one example, during a reticle exchange process, reticle handler arm 404 of reticle handler 402 positions reticle 408 on reticle baseplate 406 towards clamp 300 in reticle exchange area 410. As described above, a reticle handoff from reticle handler 402 to clamp 300 includes an unknown reticle position offset, which includes a reticle vertical distance offset (i.e., Z-direction offset) and a reticle tilt offset (i.e., R_X offset and R_Y offset). Tilt or excessive non-alignment between clamp 300 and reticle 408 can be a source of particle generation and can damage reticle 408 or clamp 300 over time. Reticle backside 409 and clamp frontside 302 need to be in optimal coplanar alignment for a final handoff. Despite calibration, variations still exist due to reticle mechanical and positioning tolerances, which can lead to high corner impacts and unpredictable first contact points between clamp 300 and reticle 408.

[0075] In one example, the reticle exchange process can involve lowering reticle stage 200 with clamp 300, which starts far away from reticle handler 402, as close to reticle 408 as possible until clamp 300 contacts reticle 408 to account for all possible offsets and/or tilts. During a reticle exchange process, reticle stage 200 with clamp 300 can be adjusted in a multi-stage movement.

[0076] As shown in FIGS. 6A through 6C, reticle exchange apparatus 100 can include clamp 300, reticle 408, and reticle baseplate 406. The multi-stage movement can occur in four stages: (1) approach; (2) first contact; (3) full contact; and (4) voltage applied to clamp.

[0077] First, as shown in FIG. 6A, reticle exchange apparatus 100 can be in an approach configuration 20 and clamp 300 can be adjusted in a substantially vertical direction (i.e., Z-direction) toward reticle backside 409. In approach configuration 20, clamp 300 is turned off (i.e., no applied voltage) and reticle handler 402 deactivates the vertical direction (i.e., Z-direction) and tilt (i.e., R_X and R_Y , rotation about X-direction and rotation about Y-direction, respectively) servo motors of reticle handler arm 404 in reticle exchange area 410. The motors (i.e., Z, R_X , and R_Y) brake and rotation about Z-direction (i.e., R_Z) activates.

[0078] Second, as shown in FIG. 6B, reticle exchange apparatus 100 can be in a first contact configuration 30 and clamp 300 can be adjusted in a substantially vertical direction (i.e., Z-direction) toward reticle backside 409 until clamp 300 makes contact with reticle backside 409.

In first contact configuration 30, clamp 300 is turned off and clamp 300 makes contact with reticle

backside 409, for example, a corner of reticle 408, and then rotates or tilts about the contact (i.e., R_X and R_Y).

[0079] Third, as shown in FIG. 6C, reticle exchange apparatus 100 can be in a full contact configuration 40 and clamp 300 can be rotationally adjusted about the contact (i.e., R_X and R_Y) toward reticle backside 409 until clamp 300 makes full contact with reticle backside 409. In full contact configuration 40, clamp 300 is turned off and clamp 300 makes full contact with reticle backside 409, for example, all four corners of reticle 408, and is coplanar with reticle backside 409.

[0080] In some embodiments, in full contact configuration 40, clamp 300 makes contact with all four corners of reticle 408 and continues to move in a substantially vertical direction (i.e., Z-direction) until a mechanical force of at least 5 N is achieved.

[0081] Fourth, with clamp frontside 302 and reticle backside 409 aligned and coplanar, clamp 300 is turned on (i.e., a voltage is applied to clamp 300) and reticle 408 is held in a fixed plane on clamp 300.

[0082] In some embodiments, as shown in FIG. 5, reticle exchange apparatus 100 can include clamp controller 360. Clamp controller 360 can be coupled to clamp 300 and be configured to control a position of clamp 300. For example, clamp controller 360 can be configured to control reticle stage 200 to allow compliant movement of clamp 300. In some embodiments, clamp controller 360 can be coupled to servo motors or servo actuators (i.e., X-direction, Y-direction, Z-direction, R_X , R_Y , R_Z) of reticle stage 200 and/or clamp 300. For example, clamp controller 360 can control translations of reticle stage 200 with clamp 300 along an x-axis, y-axis, and z-axis (i.e., X-direction, Y-direction, Z-direction) and rotations about the x-axis, y-axis, and z-axis (i.e., R_X , R_Y , R_Z), where the x-axis, y-axis, and z-axis are orthogonal coordinates.

[0083] *Exemplary Clamps for Real Time Reticle Position Detection*

[0084] FIGS. 7 through 10 show schematic illustrations of exemplary clamps 300 of exemplary reticle exchange apparatus 100, according to some embodiments of this disclosure. Reticle exchange apparatus 100 can include clamp 300, sensor array 310, 320, 330, and clamp controller 360.

[0085] Sensor array 310, 320, 330 can be configured to detect a position of reticle 408 in reticle exchange area 410 during a reticle exchange process. For example, the reticle position can

include a vertical distance (i.e., Z-direction) between reticle backside 409 and clamp frontside 302 and a relative tilt (i.e., R_X and R_Y) between reticle backside 409 and clamp frontside 302.

[0086] Sensor array 310, 320, 330 can be disposed on clamp 300 or on reticle stage 200. For example, sensor array 310, 320, 330 can be disposed on clamp frontside 302. Sensor array
5 310, 320, 330 can be configured to detect the reticle position (i.e., Z-direction, R_X , R_Y).

[0087] Clamp controller 360 can be coupled to sensor array 310, 320, 330 and be configured to calculate and control a position of clamp 300 based on the reticle position (i.e., Z-direction, R_X , R_Y) detected by sensor array 310, 320, 330.

[0088] In some embodiments, clamp controller 360 can be disposed on or in clamp 300.

10 In some embodiments, clamp controller 360 can be disposed on reticle stage 200 and coupled to clamp 300. For example, clamp controller 360 can be electrically or wirelessly (e.g., radio frequency) coupled to clamp 300.

[0089] In some embodiments, clamp controller 360 can be configured to correct for a vertical distance offset (i.e., Z-direction offset) and a relative tilt offset (i.e., R_X offset and R_Y offset) between reticle backside 409 and clamp frontside 302 in real time. For example, reticle
15 position data (i.e., Z-direction, R_X , R_Y) detected by sensor array 310, 320, 330 can be compared to clamp position data (i.e., Z-direction, R_X , R_Y) by clamp controller 360 to calculate a position offset (i.e., Z-direction offset, R_X offset, R_Y offset), which can be reduced for each detection cycle (e.g., 1.0 ms).

20 [0090] In some embodiments, clamp controller 360 can be configured to control reticle stage 200 and/or clamp 300 to allow compliant movement of clamp 300 until clamp frontside 302 and reticle backside 409 are in full contact and coplanar and/or reduce contact forces and minimize particle generation between reticle 408 and clamp 300. For example, clamp controller 360 can calculate and reduce a position offset (i.e., Z-direction offset, R_X offset, R_Y offset) between reticle
25 backside 409 and clamp frontside 302 by adjusting clamp 300 position (i.e., Z-direction, R_X , R_Y) for each sensor array 310, 320, 330 detection cycle (e.g., 1.0 ms).

[0091] In some embodiments, clamp controller 360 can be configured to move reticle stage 200 at a first velocity until sensor array 310, 320, 330 detects a reticle position (i.e., Z-direction, R_X , R_Y) and then move reticle stage 200 at a second velocity less than the first velocity. For
30 example, during approach configuration 20, reticle stage 200 with clamp 300 can move substantially in a vertical direction (i.e., Z-direction) at the first velocity (e.g., 1.0 m/s) until sensor

array 310, 320, 330 detects a threshold (e.g., predetermined) signal (i.e., Z-direction) of reticle backside 409, at which point clamp controller 360 controls and moves reticle stage 200 at the second velocity (e.g., 0.1 mm/s).

[0092] In some embodiments, reticle backside 409 damage can be mitigated by reducing speed or velocity of reticle stage 200 and/or clamp 300 during first contact (i.e., first contact configuration 30). In some embodiments, reticle backside 409 lifetime can be increased by alternating an area on reticle backside 409 that is first contacted (i.e., during first contact configuration 30). In some embodiments, a partially damaged reticle 408 or clamp 300 can be safely used by altering a load area or a load condition.

[0093] As shown in FIG. 7, clamp 300 can include sensor array 310. Sensor array 310 can be capacitive. Sensor array 310 can include one or more planar electrodes 312, 314, 316, 318. In some embodiments, sensor array 310 can be disposed on clamp frontside 302. In some embodiments, sensor array 310 can be disposed in clamp 300. In some embodiments, sensor array 310 can be disposed between clamp 300 and reticle stage 200. In some embodiments, planar electrodes 312, 314, 316, 318 can be arranged symmetrically. For example, as shown in FIG. 7, planar electrodes 312, 314, 316, 318 can be spaced by about 90 degrees. In some embodiments, sensor array 310 can be arranged to improve sensitivity to reticle backside 409 offsets (i.e., R_X and R_Y). For example, sensor array 310 can include a plurality of electrodes disposed around a perimeter or edge of clamp frontside 302.

[0094] As shown in FIG. 8, clamp 300 can include sensor array 320. Sensor array 320 can be optical. Sensor array 320 can include light source 322 and light detector 324. For example, light source 322 can be a laser or a light emitting diode (LED) and light detector 324 can be a photodiode, for example, a quadrant avalanche photodiode (APD). Light detector 324 can include first detector 325, second detector 326, third detector 327, and fourth detector 328.

[0095] In some embodiments, light source 322 can be directed towards reticle backside 409 and a light reflectance of light source 322 off reticle backside 409 can be detected by light detector 324 to determine a reticle position (i.e., Z-direction, R_X , R_Y) based on the location of the light reflectance on light detector 324. For example, light source 322 can be directed towards reticle backside 409 at an acute angle, for example, 45 degrees, relative to clamp frontside 302. In some embodiments, sensor array 320 can be disposed on clamp frontside 302. In some embodiments, sensor array 320 can be disposed in or recessed in clamp 300. In some embodiments,

light source 322 and light detector 324 can be arranged symmetrically. For example, as shown in FIG. 8, light source 322 and light detector 324 can both be arranged along a diagonal of clamp frontside 302, for example, light source 322 in a lower left quadrant and light detector 324 in an upper right quadrant.

5 [0096] As shown in FIG. 9, clamp 300 can include sensor array 330. Sensor array 330 can be pressurized. Sensor array 330 can include one or more pressure gauges 332, 334, 336, 338. In some embodiments, sensor array 330 can be disposed on clamp frontside 302. In some embodiments, sensor array 330 can be disposed in or recessed in clamp 300. In some embodiments, as shown in FIG. 9, two or more pressure gauges 332, 334, 336, 338 can be arranged
10 symmetrically. For example, four pressure gauges 332, 334, 336, 338 can be spaced by about 90 degrees or three pressure gauges 332, 334, 336 can be spaced by about 120 degrees.

[0097] In some embodiments, one or more pressure gauges 332, 334, 336, 338 can be directed towards reticle backside 409 and a pressure difference from reticle backside 409 can be detected by the corresponding one or more pressure gauges 332, 334, 336, 338 to determine a
15 reticle position (i.e., Z-direction, R_X , R_Y) based on the pressure difference. For example, pressure gauges 332, 334, 336, 338 can be air gauge nozzles directed perpendicularly towards reticle backside 409 at four locations on clamp frontside 302. For example, pressure gauges 332, 334, 336 can be air gauge nozzles directed perpendicularly towards reticle backside 409 at three symmetric locations on clamp frontside 302.

20 [0098] As shown in FIG. 10, clamp 300 can include sensor arrays 310, 320, 330. Clamp 300 can include a plurality of sensor arrays 310, 320, 330 for better accuracy and detection of reticle backside 409 position (i.e., Z-direction, R_X , R_Y). In some embodiments, clamp controller 360 can receive and analyze multiple signals from the plurality of sensor arrays 310, 320, 330 in real time (e.g., 1.0 ms).

25 [0099] *Exemplary Clamps for Real Time Reticle Force Detection*

[0100] FIGS. 11 and 12 show schematic illustrations of exemplary clamps 300 of exemplary reticle exchange apparatus 100, according to some embodiments of this disclosure. Reticle exchange apparatus 100 can include clamp 300, sensor array 340, 350, and clamp controller 360. Sensor array 340, 350 can be configured to detect a force of reticle 408 in reticle exchange area 410 during a reticle exchange process, for example, the reticle force can include a stress (σ)
30 or a strain (ϵ) from reticle backside 409 or clamp frontside 302. Sensor array 340, 350 can be

disposed on clamp 300 or on reticle stage 200. For example, sensor array 340, 350 can be disposed on clamp frontside 302. Sensor array 340, 350 can be configured to detect the reticle force (i.e., σ_x , σ_y , σ_z , ϵ_x , ϵ_y , ϵ_z). Clamp controller 360 can be coupled to sensor array 340, 350 and configured to calculate and control a position of clamp 300 based on the reticle force (i.e., σ_x , σ_y , σ_z , ϵ_x , ϵ_y , ϵ_z) detected by sensor array 340, 350.

[0101] In some embodiments, clamp controller 360 can be disposed on or in clamp 300. In some embodiments, clamp controller 360 can be disposed on reticle stage 200 and coupled to clamp 300. For example, clamp controller 360 can be electrically or wirelessly (e.g., radio frequency) coupled to clamp 300. In some embodiments, clamp controller 360 can be configured to correct for a stress (i.e., σ_x , σ_y , σ_z) or a strain (i.e., ϵ_x , ϵ_y , ϵ_z) from reticle backside 409 or clamp frontside 302 in real time. For example, reticle force data (i.e., σ_x , σ_y , σ_z , ϵ_x , ϵ_y , ϵ_z) detected by sensor array 340, 350 can be compared to clamp position data (i.e., Z-direction, R_x , R_y) and reduced by clamp controller 360 for each detection cycle (e.g., 1.0 ms). In some embodiments, clamp controller 360 can be configured to control reticle stage 200 and/or clamp 300 to allow compliant movement of clamp 300 until clamp frontside 302 and reticle backside 409 are in full contact and coplanar and/or reduce contact forces and minimize particle generation between reticle 408 and clamp 300. For example, clamp controller 360 can calculate and reduce a stress (i.e., σ_x , σ_y , σ_z) or a strain (i.e., ϵ_x , ϵ_y , ϵ_z) from reticle backside 409 or clamp frontside 302 by adjusting clamp 300 position (i.e., Z-direction, R_x , R_y) for each sensor array 340, 350 detection cycle (e.g., 1.0 ms).

[0102] As shown in FIG. 11, clamp 300 can include sensor array 340. Sensor array 340 can be resistive. Sensor array 340 can include one or more planar strain gauges 342, 344. In some embodiments, sensor array 340 can be disposed on clamp frontside 302. In some embodiments, sensor array 340 can be disposed in clamp 300. In some embodiments, sensor array 340 can be disposed between clamp 300 and reticle stage 200. In some embodiments, planar strain gauges 342, 344 can be arranged symmetrically or in a patterned array. For example, as shown in FIG. 11, planar strain gauges 342, 344 can be arranged in a 3 x 4 array. In some embodiments, sensor array 340 can be used to monitor the reticle forces (i.e., σ_x , σ_y , σ_z , ϵ_x , ϵ_y , ϵ_z) in real time (e.g. 1.0 ms). For example, sensor array 340 can monitor local force variations during a reticle exchange process. In some embodiments, sensor array 340 can be arranged to improve sensitivity to reticle backside

409 forces (i.e., σ_x , σ_y , σ_z , ϵ_x , ϵ_y , ϵ_z). For example, sensor array 340 can include a plurality of strain gauges 342, 344 disposed around a perimeter or edge of clamp frontside 302.

[0103] As shown in FIG. 12, clamp 300 can include sensor array 350. Sensor array 350 can be resistive. Sensor array 350 can include one or more planar resistors 352, 354, 356, 358. In some embodiments, planar resistors 352, 354, 356, 358 can be lithographically patterned resistors. In some embodiments, planar resistors 352, 354, 356, 358 can be configured to change an electrical resistance in proportion to an applied pressure. For example, planar resistors 352, 354, 356, 358 can be a piezoelectric material (e.g., lead zirconate titanate (PZT), gallium phosphate (GaPO_4), quartz, lead magnesium niobate-lead titanate (PMN-PT), etc.).

[0104] In some embodiments, sensor array 350 can be disposed on clamp frontside 302. For example, sensor array 350 can be lithographically patterned on clamp frontside 302. In some embodiments, sensor array 350 can be disposed in clamp 300. In some embodiments, sensor array 350 can be disposed between clamp 300 and reticle stage 200.

[0105] In some embodiments, planar resistors 352, 354, 356, 358 can be arranged symmetrically or in a patterned array. For example, as shown in FIG. 12, planar resistors 352, 354, 356, 358 can be arranged in a 2 x 2 array. In some embodiments, sensor array 350 can be used to monitor the reticle forces (i.e., σ_x , σ_y , σ_z , ϵ_x , ϵ_y , ϵ_z) in real time (e.g. 1.0 ms). For example, sensor array 350 can monitor local force variations during a reticle exchange process. In some embodiments, sensor array 350 can be arranged to improve sensitivity to reticle backside 409 forces (i.e., σ_x , σ_y , σ_z , ϵ_x , ϵ_y , ϵ_z). For example, sensor array 350 can include a plurality of planar resistors 352, 354, 356, 358 disposed around a perimeter or edge of clamp frontside 302.

[0106] *Exemplary Reticle Exchange Apparatus*

[0107] FIGS. 13 and 14 show schematic illustrations of an exemplary reticle exchange apparatus 100', according to some embodiments of this disclosure. Reticle exchange apparatus 100' shown in FIGS. 13 and 14 is similar to reticle exchange apparatus 100 shown in FIGS. 4 and 5, except that reticle exchange apparatus 100' can include plate 500. Reticle exchange apparatus 100' can be configured to minimize reticle exchange time, particle generation, and contact forces or stresses from clamp 300 and/or reticle 408 to reduce damage to clamp 300 and reticle 408 and increase overall throughput in a reticle exchange process, for example, in a lithographic apparatus LA.

[0108] As shown in FIGS. 13 and 14, reticle exchange apparatus 100' can include reticle stage 200, clamp 300, in-vacuum robot 400, and plate 500. Plate 500 can be configured to provide a reticle mini-environment (RME) for reticle 408, reticle baseplate 406, and in-vacuum robot 400. Plate 500 can be arranged between reticle stage 200 with clamp 300 and in-vacuum robot 400. Plate 500 can include plate frontside 502, plate backside 504, reticle exchange port 506, first reticle baseplate cavity 508, second reticle baseplate cavity 510, and third reticle baseplate cavity 512. Reticle exchange port 506 can be configured to receive reticle 408 on reticle baseplate 406 during a reticle exchange process. Plate backside 504 is opposite plate frontside 502. Plate frontside 502 faces perpendicularly towards top stage surface 202 and clamp frontside 302.

[0109] In some embodiments, as shown in FIG. 13, reticle exchange port 506 and reticle baseplate cavities 508, 510, 512 can be arranged symmetrically. For example, reticle exchange port 506 and reticle baseplate cavities 508, 510, 512 can correspond to reticle handler 402, for example, with reticle handler arms 404 spaced from each other by about 90 degrees. In some embodiments, reticle handler arms 404, reticle exchange port 506, and reticle baseplate cavities 508, 510, 512 can be arranged asymmetrically about reticle handler 402.

[0110] During a reticle exchange process, reticle handler arm 404 of reticle handler 402 positions reticle 408 on reticle baseplate 406 towards clamp 300 through reticle exchange port 506 in reticle exchange area 410. As described above, a reticle handoff from reticle handler 402 to clamp 300 includes an unknown reticle position offset, which includes a reticle vertical distance offset (i.e., Z-direction offset) and a reticle tilt offset (i.e., R_X offset and R_Y offset).

[0111] In some embodiments, as shown in FIG. 14, reticle exchange apparatus 100' can include plate controller 560. Plate controller 560 can be coupled to plate 500 and be configured to control a position of clamp 300 and/or reticle handler arm 404 in reticle exchange area 410. For example, plate controller 560 can be configured to control reticle stage 200 to allow compliant movement of clamp 300. In some embodiments, plate controller 560 can be coupled to servo motors or servo actuators (i.e., X-direction, Y-direction, Z-direction, R_X , R_Y , R_Z) of reticle stage 200 and/or clamp 300. For example, plate controller 560 can control translations of reticle stage 200 with clamp 300 along an x-axis, y-axis, and z-axis (i.e., X-direction, Y-direction, Z-direction) and rotations about the x-axis, y-axis, and z-axis (i.e., R_X , R_Y , R_Z), where the x-axis, y-axis, and z-axis are orthogonal coordinates.

[0112] *Exemplary Plates for Real Time Reticle Position Detection*

[0113] FIGS. 14 and 15 show schematic illustrations of exemplary plates 500 of exemplary reticle exchange apparatus 100', according to some embodiments of this disclosure. Reticle exchange apparatus 100' can include plate 500, sensor array 520, 530, and plate controller 560. Sensor array 520, 530 can be configured to detect a position of reticle 408 through reticle exchange port 506 and/or in reticle exchange area 410 during a reticle exchange process.

[0114] For example, the position of reticle 408 can include a vertical distance (i.e., Z-direction) between reticle backside 409 and clamp frontside 302 and a relative tilt (i.e., R_X and R_Y) between reticle backside 409 and clamp frontside 302. Sensor array 520, 530 can be disposed on or in plate 500 near reticle exchange area 410.

[0115] For example, as shown in FIG. 14, sensor array 520, 530 can be disposed in reticle exchange port 506, for example, along an inner surface 507 of reticle exchange port 506, between plate frontside 502 and plate backside 504. Sensor array 520, 530 can be configured to detect the reticle position (i.e., Z-direction, R_X , R_Y). Plate controller 560 can be coupled to sensor array 520, 530 and configured to calculate and control a position of clamp 300 and/or reticle handler arm 404 based on the reticle position (i.e., Z-direction, R_X , R_Y) detected by sensor array 520, 530.

[0116] In some embodiments, plate controller 560 can be disposed on or in plate 500. In some embodiments, plate controller 560 can be coupled to plate 500, reticle stage 200, reticle handler arm 404, and/or clamp 300. For example, plate controller 560 can be electrically or wirelessly (e.g., radio frequency) coupled to plate 500, reticle stage 200, reticle handler arm 404, and/or clamp 300. In some embodiments, plate controller 560 can be configured to correct for a vertical distance offset (i.e., Z-direction offset) and a relative tilt offset (i.e., R_X offset and R_Y offset) between reticle backside 409 and clamp frontside 302 in real time. For example, reticle position data (i.e., Z-direction, R_X , R_Y) detected by sensor array 520, 530 can be compared to clamp position data (i.e., Z-direction, R_X , R_Y) by plate controller 560 in order to calculate a position offset (i.e., Z-direction offset, R_X offset, R_Y offset), which can be reduced for each detection cycle (e.g., 1.0 ms). In some embodiments, plate controller 560 can be configured to control reticle stage 200, reticle handler arm 404, and/or clamp 300 to allow compliant movement of clamp 300 until clamp frontside 302 and reticle backside 409 are in full contact and coplanar and/or reduce contact forces and minimize particle generation between reticle 408 and clamp 300. For example, plate controller 560 can calculate and reduce a position offset (i.e., Z-direction offset, R_X offset, R_Y

offset) between reticle backside 409 and clamp frontside 302 by adjusting clamp 300 position (i.e., Z-direction, R_X , R_Y) for each sensor array 520, 530 detection cycle (e.g., 1.0 ms).

[0117] In some embodiments, plate controller 560 can be configured to move reticle stage 200 or reticle handler arm 404 at a first velocity until sensor array 520, 530 detects a reticle position (i.e., Z-direction, R_X , R_Y) and then move reticle stage 200 or reticle handler arm 404 at a second velocity less than the first velocity. For example, during approach configuration 20, reticle stage 200 with clamp 300 can move substantially in a vertical direction (i.e., Z-direction) at the first velocity (e.g., 1.0 m/s) until sensor array 520, 530 detects a threshold (e.g., predetermined) signal (i.e., Z-direction) of reticle backside 409, at which point plate controller 560 controls and moves reticle stage 200 at the second velocity (e.g., 0.1 mm/s). In some embodiments, reticle backside 409 damage can be mitigated by reducing speed or velocity of reticle stage 200 and/or clamp 300 during first contact (i.e., first contact configuration 30). In some embodiments, reticle backside 409 lifetime can be increased by alternating an area on reticle backside 409 that is first contacted (i.e., during first contact configuration 30). In some embodiments, a partially damaged reticle 408 or clamp 300 can be safely used by altering a load area or a load condition.

[0118] As shown in FIGS. 14 and 15, plate 500 can include sensor array 520. Sensor array 520 can be optical. Sensor array 520 can include light source 522 and one or more light detectors 524, 526. For example, light source 522 can be a laser, an LED, a structured light projector, or diffractive optical element (DOE), and light detectors 524, 526 can be a photodiode (e.g., quadrant APD) or a camera.

[0119] In some embodiments, light source 522 can be directed towards reticle backside 409 and a light reflectance of light source 522 off reticle backside 409 can be detected by light detectors 524, 526 to determine a reticle position (i.e., Z-direction, R_X , R_Y) based on the location of the light reflectance on light detectors 524, 526. For example, light source 522 can be directed towards reticle backside 409 at an acute angle, for example, 45 degrees, relative to clamp frontside 302.

[0120] In some embodiments, sensor array 520 can be disposed on plate 500. In some embodiments, sensor array 520 can be disposed in or recessed in reticle exchange port 506 of plate 500, for example, along an inner surface 507 of reticle exchange port 506 between plate frontside 502 and plate backside 504. In some embodiments, light source 522 and light detectors 524, 526 can be arranged symmetrically. For example, as shown in FIGS. 14 and 15, light source 522 and

light detectors 524, 526 can be arranged along opposite sides of inner surface 507 along a horizontal (i.e., Y-direction) centerline of reticle exchange port 506.

[0121] In some embodiments, light source 522 can be a plurality of lasers and configured for structured light stereoscopic detection via laser interference. For example, light source 522 can include two planar laser beam fronts whose interference can be detected by one or more light detectors 524, 526 in order to measure a three-dimensional shape (i.e., Z-direction, R_X , R_Y) of reticle backside 409. In some embodiments, light source 522 can be a projected light pattern and configured for structured light stereoscopic detection via pattern projection. For example, light source 522 can include a fringe pattern (e.g., parallel stripes) whose displacement can be detected by light detectors 524, 526 in order to measure a three-dimensional shape (i.e., Z-direction, R_X , R_Y) of reticle backside 409. In some embodiments, light source 522 can be a DOE pattern projected onto reticle backside 409 and light detectors 524, 526 can be a stereo pair of cameras opposite light source 522. For example, a reflectance of light source 522 off reticle backside 409 can determine a tilt (i.e., R_X and R_Y) of reticle backside 409.

[0122] In some embodiments, light source 522 and light detectors 524, 526 can be fiber optics. In some embodiments, sensor array 520 can include light source 522 and light detector 524. For example, light detector 524 can include a bi-prism to detect two displaced images of a fringe pattern from light source 522 for structured light stereoscopic detection and tilt calculation (i.e., R_X and R_Y) of reticle backside 409 with a single light detector 524. In some embodiments, light source 522 and light detectors 524, 526 can be time synchronized. For example, light source 522 can include a fringe pattern (e.g., parallel stripes) whose displacement can be detected synchronously by light detectors 524, 526 in order to measure stereo depth and tilt (i.e., Z-direction, R_X , R_Y) of reticle backside 409.

[0123] As shown in FIGS. 14 and 15, plate 500 can include sensor array 530. Sensor array 530 can be optical. Sensor array 530 can include one or more light sensors 532, 534, 536, 538. In some embodiments, light sensors 532, 534, 536, 538 can be confocal sensors. For example, light sensors 532, 534, 536, 538 can be time synchronized confocal sensors with a narrow measurement range (e.g., 22.0 mm) or a wide measurement range (e.g., 30.0 mm). By using time synchronized confocal sensors, a difference in detection times can be measured and used to calculate a position (i.e., Z-direction, R_X , R_Y) of reticle backside 409. In some embodiments, one or more light sensors 532, 534, 536, 538 can be arranged symmetrically. For example, as shown in FIG. 15, sensor array

530 can be arranged as a quadrilateral around inner surface 507 of reticle exchange port 506, with two light sensors 532, 534 on a first side of reticle exchange port 506 and two light sensors 536, 538 on a second side of reticle exchange port 506 opposite light sensors 532, 534.

[0124] In some embodiments, spatial constraints of reticle exchange area 410 can be used to calculate a position (i.e., Z-direction, R_X , R_Y) of reticle backside 409. For example, sensor array 530 can monitor an outer perimeter (e.g., an edge) of reticle baseplate 406, an outer perimeter (e.g., an edge) of reticle 408, or a leading edge of reticle backside 409 translating through reticle exchange port 506. In some embodiments, sensor array 530 can be used to monitor a condition or state of reticle exchange apparatus 100'. For example, sensor array 530 can detect if reticle 408 is disposed on reticle baseplate 406 or if tilt (i.e., R_X and R_Y) of reticle backside 409 exceeds a predetermined threshold. In some embodiments, sensor array 530 can be a fiber optic system. For example, sensor array 530 can include a single pulsed laser source (e.g., 10kHz NIR laser) coupled to four optical couplers with vacuum ports, which each include a collimator and confocal sensor in reticle exchange port 506. The fiber optic system detection output can be received by plate controller 560, for example, a field programmable gate array (FPGA), to calculate a position (i.e., Z-direction, R_X , R_Y) of reticle backside 409.

[0125] As shown in FIGS. 14 and 15, plate 500 can include sensor arrays 520, 530. Plate 500 can include a plurality of sensor arrays 520, 530 for better accuracy and detection of reticle backside 409 position (i.e., Z-direction, R_X , R_Y). In some embodiments, plate controller 560 can receive and analyze multiple signals from the plurality of sensor arrays 520, 530 in real time (e.g., 1.0 ms).

[0126] *Exemplary Plates for Reticle Position Calibration*

[0127] FIGS. 15 and 16 show schematic illustrations of exemplary plates 500 of exemplary reticle exchange apparatus 100', according to some embodiments of this disclosure. Reticle exchange apparatus 100' can include plate 500, sensor array 540, 550, and plate controller 560. Sensor array 540, 550 can be configured to calibrate a position of reticle 408 in reticle exchange port 506 and/or in reticle exchange area 410 during a reticle exchange process based on a fixed plane of sensor array 540, 550. For example, the position of reticle 408 can include a vertical distance (i.e., Z-direction) between reticle backside 409 and clamp frontside 302 and a relative tilt (i.e., R_X and R_Y) between reticle backside 409 and clamp frontside 302. Sensor array 540, 550 can be disposed on plate backside 504. For example, as shown in FIG. 15, sensor array 540, 550 can

be disposed on plate backside 504 away from reticle exchange port 506. Sensor array 540, 550 can be configured to calibrate the reticle position (i.e., Z-direction, R_X , R_Y). Plate controller 560 can be coupled to sensor array 540, 550 and be configured to calculate and control a position of clamp 300 and/or reticle handler arm 404 based on the calibrated reticle position (i.e., calibrated Z-direction, calibrated R_X , calibrated R_Y) detected by sensor array 540, 550.

[0128] In some embodiments, plate controller 560 can be disposed on plate 500. In some embodiments, plate controller 560 can be coupled to plate 500 and/or clamp 300. For example, plate controller 560 can be electrically or wirelessly (e.g., radio frequency) coupled to plate 500 and/or clamp 300. In some embodiments, plate controller 560 can be configured to correct for a vertical distance offset (i.e., Z-direction offset) and a relative tilt offset (i.e., R_X offset and R_Y offset) between reticle backside 409 and clamp frontside 302 based on a vertical distance offset (i.e., Z-direction offset) and a relative tilt offset (i.e., R_X offset and R_Y offset) between reticle backside 409 or reticle baseplate frontside 407 and the fixed plane of sensor array 540, 550. For example, sensor array 540, 550 can be calibrated by a tooling reticle, and subsequently, calibrated reticle position data (i.e., calibrated Z-direction, calibrated R_X , calibrated R_Y) detected by sensor array 540, 550 can be compared to clamp position data (i.e., Z-direction, R_X , R_Y) by plate controller 560 to calculate a clamp position offset (i.e., Z-direction offset, R_X offset, R_Y offset), which can be reduced or corrected before reticle 408 is loaded onto reticle baseplate 406. This calibration process can be conducted for each reticle 408 prior to the reticle exchange process in reticle exchange area 410.

[0129] In some embodiments, plate controller 560 can be configured to control reticle stage 200, reticle handler arm 404, and/or clamp 300 to allow compliant movement of clamp 300 until clamp frontside 302 and reticle backside 409 are in full contact and coplanar and/or reduce contact forces and minimize particle generation between reticle 408 and clamp 300. For example, plate controller 560 can calculate and reduce a position offset (i.e., Z-direction offset, R_X offset, R_Y offset) between reticle backside 409 and clamp frontside 302 by adjusting clamp 300 position (i.e., Z-direction, R_X , R_Y) based on a calibrated position offset (i.e., Z-direction offset, R_X offset, R_Y offset) between reticle backside 409 or reticle baseplate frontside 407 and a fixed plane of sensor array 540, 550, detected by sensor array 540, 550 prior to reticle 408 being loaded in reticle exchange area 410.

[0130] In some embodiments, plate controller 560 can be configured to move reticle stage 200 or reticle handler arm 404 at a first velocity until a calibrated reticle position (i.e., calibrated Z-direction, calibrated R_X , calibrated R_Y) is reached and then move reticle stage 200 at a second velocity less than the first velocity. For example, during approach configuration 20, reticle stage 200 with clamp 300 or reticle handler arm 404 with reticle 408 can move substantially in a vertical direction (i.e., Z-direction) at the first velocity (e.g., 1.0 m/s) until a calibrated reticle position (i.e., calibrated Z-direction, calibrated R_X , calibrated R_Y) is reached, at which point plate controller 560 controls or moves reticle stage 200 or reticle handler arm 404 at the second velocity (e.g., 0.1 mm/s). In some embodiments, reticle backside 409 damage can be mitigated by reducing speed or velocity of reticle stage 200, reticle handler arm 404, and/or clamp 300 prior to first contact (i.e., first contact configuration 30) based on reaching a calibrated reticle position (i.e., calibrated Z-direction, calibrated R_X , calibrated R_Y).

[0131] As shown in FIGS. 15 and 16, plate 500 can include sensor array 540. Sensor array 540 can be capacitive. Sensor array 540 can include one or more planar electrodes 542, 544, 546, 548. In some embodiments, as shown in FIG. 15, sensor array 540 can be disposed on plate backside 504. For example, sensor array 540 can be disposed at an angle 562, for example, 45 degrees, relative to a horizontal (i.e., Y-direction) axis of reticle handler arms 404 of reticle handler 402, such that, for example, sensor array 540 is disposed symmetrically between second reticle baseplate cavity 510 and third reticle baseplate cavity 512. In some embodiments, planar electrodes 542, 544, 546, 548 can be arranged symmetrically. For example, as shown in FIG. 15, planar electrodes 542, 544, 546, 548 can be spaced by about 90 degrees. In some embodiments, planar electrodes 542, 544, 546, 548 form a fixed plane, for example, plate backside 504, where each planar electrode 542, 544, 546, 548 is coplanar.

[0132] In some embodiments, sensor array 540 can be configured to synchronously measure reticle backside 409 or reticle baseplate frontside 407 to determine a relative position offset (i.e., Z-direction offset, R_X offset, R_Y offset) between reticle backside 409 or reticle baseplate frontside 407 and a fixed plane of sensor array 540. For example, sensor array 540 can detect a capacitance in each planar electrode 542, 544, 546, 548, and plate controller 560 can calculate a difference in capacitance between each planar electrode 542, 544, 546, 548 in order to determine a reticle backside 409 or reticle baseplate frontside 407 position (i.e., Z-direction, R_X , R_Y) relative to a fixed plane of sensor array 540, for example, plate backside 504. Plate controller

560 can calculate the offset position, and later adjust reticle stage 200, reticle handler arm 404, and/or clamp 300 to reduce the offset when reticle 408 is loaded in reticle exchange area 410 during the multi-stage movement.

[0133] As shown in FIGS. 15 and 16, plate 500 can include sensor array 550. Sensor array 550 can be optical. Sensor array 550 can include one or more light sensors 552, 554, 556. In some embodiments, light sensors 552, 554, 556 can be confocal sensors. For example, light sensors 552, 554, 556 can be time synchronized confocal sensors with a very narrow measurement range (e.g., 8.0 mm) or a narrow measurement range (e.g., 22.0 mm). By using time synchronized confocal sensors, a difference in detection times can be measured and used to detect a calibrated position (i.e., calibrated Z-direction, calibrated R_X , calibrated R_Y) of reticle backside 409 or reticle baseplate frontside 407. In some embodiments, as shown in FIG. 15, sensor array 550 can be disposed on plate backside 504. For example, sensor array 550 can be disposed at an angle 562, for example, 45 degrees, relative to a horizontal (i.e., Y-direction) axis of reticle handler arms 404 of reticle handler 402, such that, for example, sensor array 550 is disposed symmetrically between first reticle baseplate cavity 508 and second reticle baseplate cavity 510. In some embodiments, light sensors 552, 554, 556 can be arranged symmetrically. For example, as shown in FIG. 15, light sensors 552, 554, 556 can be arranged at the intersecting points of an isosceles triangle, such that a distance (e.g., 122.0 mm) between two light sensors 554, 556 is equal to an altitude (e.g., 122.0 mm) separating another light sensor 552. In some embodiments, light sensors 552, 554, 556 form a fixed plane, for example, plate backside 504, where each light sensor 552, 554, 556 is coplanar.

[0134] In some embodiments, sensor array 550 can be configured to synchronously measure reticle backside 409 or reticle baseplate frontside 407 to determine a relative position offset (i.e., Z-direction offset, R_X offset, R_Y offset) between reticle backside 409 or reticle baseplate frontside 407 and a fixed plane of sensor array 550. For example, sensor array 550 can detect an index of refraction based on wavelength in each light sensor 552, 554, 556, and plate controller 560 can calculate a difference in index of refraction based on wavelength between each light sensor 552, 554, 556 in order to determine a reticle backside 409 or reticle baseplate frontside 407 position (i.e., Z-direction, R_X , R_Y) relative to the fixed plane of sensor array 550, for example, plate backside 504. Plate controller 560 can calculate the offset position, and later adjust reticle

stage 200, reticle handler arm 404, and/or clamp 300 to reduce the offset when reticle 408 is loaded in reticle exchange area 410 during the multi-stage movement.

[0135] As shown in FIG. 16, reticle exchange apparatus 100' can be in a calibration configuration 60. In calibration configuration 60, reticle backside 409 or reticle baseplate frontside 407 can be measured by sensor array 540, 550 and calibrated by plate controller 560. In some embodiments, sensor array 540, 550 can be previously calibrated by a tooling reticle. For example, a tooling reticle can be used to measure clamp frontside 302 position (i.e., Z-direction, R_X , R_Y) during the multi-stage movement by subsequently measuring reticle baseplate frontside 407 position (i.e., Z-direction, R_X , R_Y) with sensor array 540, 550. In some embodiments, sensor array 540, 550 can be configured to synchronously measure reticle backside 409 or reticle baseplate frontside 407 to determine a relative position offset (i.e., Z-direction offset, R_X offset, R_Y offset) between reticle backside 409 or reticle baseplate frontside 407 and a fixed plane of sensor array 540, 550. For example, plate controller 560 can determine a reticle backside 409 or reticle baseplate frontside 407 position (i.e., Z-direction, R_X , R_Y) relative to a fixed plane of sensor array 540, 550, for example, plate backside 504, and calculate the offset position based on the measurement of sensor array 540, 550. As shown in FIG. 15, reticle exchange apparatus 100' can be in a reticle exchange configuration 50. In reticle exchange configuration 50, plate controller 560 can adjust reticle stage 200, reticle handler arm 404, and/or clamp 300 to reduce the previously calculated (e.g., in calibration configuration 60) offset position when reticle 408 is loaded in reticle exchange area 410 during the multi-stage movement.

[0136] Methods of operating a reticle exchange apparatus 100, 100', 100" can be accomplished according to the manners of operation disclosed herein. In some embodiments, reticle exchange apparatus 100, 100', 100" can be configured to reduce contact forces and minimize particle generation between reticle 408 and clamp 300 on reticle stage 200. In some embodiments, this can be accomplished, for example, by detecting a reticle backside 409 or reticle baseplate frontside 407 position (i.e., Z-direction, R_X , R_Y) with sensor array 310, 320, 330, 340, 350, 520, 530, 540, 550. In some embodiments, a vertical distance offset (i.e., Z-direction offset) and a relative tilt offset (i.e., R_X offset and R_Y offset) between reticle backside 409 and clamp frontside 302 can be calculated based on a reticle backside 409 or reticle baseplate frontside 407 position (i.e., Z-direction, R_X , R_Y), for example, by clamp controller 360 and/or plate controller 560. In some embodiments, reticle stage 200, clamp 300, reticle handler arm 404, and/or reticle 408 can

be adjusted, for example, by clamp controller 360 and/or plate controller 560, to reduce a vertical distance offset (i.e., Z-direction offset) and a relative tilt offset (i.e., R_X offset and R_Y offset) until reticle backside 409 and clamp frontside 302 are in contact and coplanar. In some embodiments, detecting a reticle backside 409 or reticle baseplate frontside 407 position (i.e., Z-direction, R_X , R_Y) with sensor array 310, 320, 330, 340, 350, 520, 530, 540, 550, calculating a vertical distance offset (i.e., Z-direction offset) and a relative tilt offset (i.e., R_X offset and R_Y offset) between reticle backside 409 and clamp frontside 302, and adjusting reticle stage 200, clamp 300, reticle handler arm 404, and/or reticle 408 to reduce a vertical distance offset (i.e., Z-direction offset) and a relative tilt offset (i.e., R_X offset and R_Y offset) until reticle backside 409 and clamp frontside 302 are in contact and coplanar can be done in real time (e.g., 1.0 ms). In some embodiments, reticle stage 200 can be moved at a first velocity until sensor array 310, 320, 330, 340, 350, 520, 530, 540, 550 detects a reticle backside 409 position (i.e., Z-direction, R_X , R_Y) and then moved at a second velocity less than the first velocity.

[0137] *Exemplary In-Vacuum Robot for Real Time Reticle Position Detection*

[0138] FIG. 17 shows a schematic illustration of an exemplary reticle exchange apparatus 100", according to some embodiments of this disclosure. Reticle exchange apparatus 100" shown in FIG. 17 is similar to reticle exchange apparatus 100 shown in FIGS. 4 and 5 and reticle exchange apparatus 100' shown in FIGS. 13 and 14. Reticle exchange apparatus 100" includes reticle stage 200, clamp 300, and in-vacuum robot (IVR) 400. IVR 400 shown in FIG. 17 is similar to in-vacuum robot 400 shown in FIGS. 4 and 5 and in-vacuum robot 400 shown in FIGS. 13 and 14, except that reticle baseplate 406 can include first and second through holes 412, 413 for first and second detection sensors 1702, 1706, respectively. IVR 400 can be configured to minimize reticle exchange time, particle generation, and contact forces or stresses from clamp 300 and/or reticle 408 to reduce damage to clamp 300 and reticle 408 and increase overall throughput in a reticle exchange process, for example, in a lithographic apparatus LA. In some embodiments, IVR 400 shown in FIG. 17 can be incorporated into reticle exchange apparatus 100 shown in FIGS. 4 and 5 or reticle exchange apparatus 100' shown in FIGS. 13 and 14.

[0139] FIGS. 17 and 18 show schematic illustrations of an exemplary IVR 400 of exemplary reticle exchange apparatus 100", according to some embodiments of this disclosure. FIG. 18 depicts a schematic enlarged cross-sectional view of a region 1800 shown in FIG. 17 of reticle exchange apparatus 100" including IVR 400 with first optical system 1720 including one

or more beam shaping optics 1722, 1724, 1726, 1728, 1730, according to some embodiments of the present disclosure.

[0140] IVR 400 can include reticle handler 402. Reticle handler 402 can include one or more reticle handler arms 404. In some embodiments, reticle handler 402 can be a rapid exchange device (RED), which is configured to efficiently rotate and minimize reticle exchange time. For example, reticle handler 402 can save time by moving multiple reticles from one position to another substantially simultaneously, instead of serially. Reticle handler arm 404 can include reticle baseplate 406.

[0141] Reticle baseplate 406 can be configured to hold an object, for example, reticle 408. In some embodiments, reticle baseplate 406 can be an extreme ultraviolet inner pod (EIP) for a reticle. In some embodiments, reticle baseplate 406 includes reticle baseplate frontside 407, and reticle 408 includes reticle backside 409 and reticle frontside 411. As shown in FIG. 17, reticle baseplate 406 can include first through hole 412 and second through hole 413.

[0142] Reticle exchange apparatus 100" can include reticle exchange area 410, which is the cross-sectional area between clamp 300, reticle 408, reticle baseplate 406, and part of reticle handler arm 404 during a reticle exchange process.

[0143] As shown in FIG. 17, IVR 400 can include first detection sensor 1702 and second detection sensor 1706. First detection sensor 1702 is similar to second detection sensor 1706. First detection sensor 1702 is configured to detect a position of reticle 408 in reticle exchange area 410 through first through hole 412 of reticle baseplate 406 during a reticle exchange process. Second detection sensor 1706 is configured to detect a position of reticle 408 in reticle exchange area 410 through second through hole 413 of reticle baseplate 406 during a reticle exchange process.

[0144] For example, the position of reticle 408 can include a vertical distance (i.e., Z-direction) between reticle frontside 411 and a fixed plane (i.e., reference position) of first detection sensor 1702 and a relative tilt (i.e., R_x and R_y) between reticle frontside 411 and the fixed plane (i.e., reference position) of first detection sensor 1702. First and second detection sensors 1702, 1706 can be disposed on or in IVR 400 near reticle exchange area 410.

[0145] As shown in FIG. 17, first detection sensor 1702 includes first light source 1740 and first light detector 1732. For example, first light source 1740 can be a laser (e.g., visible spectrum (VIS), near-infrared (NIR), infrared (IR)), an LED, a structured light projector, or diffractive optical element (DOE), and first light detector 1732 can be a photodiode (e.g., quadrant

APD) or a camera. First light source 1740 provides first illumination beam 1703. First illumination beam 1703 is configured to be focused through first through hole 412 onto reticle frontside 411. First illumination beam 1703 can be scattered off reticle frontside 411 to produce first signal beam 1704. First signal beam 1704 can be detected by first light detector 1732. For example, first light source 1740 can be directed towards reticle frontside 411 and a light reflectance of first light source 1740 off reticle frontside 411 (i.e., first signal beam 1704) can be detected by first light detectors 1732 to determine a reticle position (i.e., Z-direction, R_x , R_y) based on the location and/or intensity of first signal beam 1704 on first light detector 1732.

[0146] In some embodiments, first detection sensor 1702 can include first beamsplitter 1735 between first light source 1740 and first light detector 1732. First beamsplitter 1735 can be used for a more compact design of first detection sensor 1702. First beamsplitter 1735 can transmit first illumination beam 1703 from first light source 1740 and reflect first signal beam 1704 to first light detector 1732. In some embodiments, first beamsplitter 1735 can be a polarizing beamsplitter and first illumination beam 1703 can be polarized. In some embodiments, first detection sensor 1702 can include first optical system 1720. First optical system 1720 can include one or more beam shaping optics. For example, as shown in FIG. 18, first optical system 1720 can include first optic 1722, second optic 1724, third optic 1726, fourth optic 1728, and/or fifth optic 1730. First, second, third, fourth, and/or fifth optic 1722, 1724, 1726, 1728, 1730 can include plano concave lens, plano convex lens, double concave lens, double convex lens, positive meniscus lens, negative meniscus lens, positive achromatic lens, negative achromatic lens, beam expander, collimator, or some combination thereof.

[0147] As shown in FIG. 17, second detection sensor 1706 includes second light source 1770 and second light detector 1762. For example, second light source 1770 can be a laser (e.g., visible spectrum (VIS), near-infrared (NIR), infrared (IR)), an LED, a structured light projector, or diffractive optical element (DOE), and second light detector 1762 can be a photodiode (e.g., quadrant APD) or a camera. Second light source 1770 provides second illumination beam 1707. Second illumination beam 1707 is configured to be focused through second through hole 413 onto reticle frontside 411. Second illumination beam 1707 can be scattered off reticle frontside 411 to produce second signal beam 1708. Second signal beam 1708 can be detected by second light detector 1762. For example, second light source 1770 can be directed towards reticle frontside 411 and a light reflectance of second light source 1770 off reticle frontside 411 (i.e., second signal

beam 1708) can be detected by second light detectors 1762 to determine a reticle position (i.e., Z-direction, R_X , R_Y) based on the location and/or intensity of second signal beam 1708 on second light detector 1762.

[0148] In some embodiments, second detection sensor 1706 can include second beamsplitter 1765 between second light source 1770 and second light detector 1762. Second beamsplitter 1765 can be used for a more compact design of second detection sensor 1706. Second beamsplitter 1765 can transmit second illumination beam 1707 from second light source 1770 and reflect second signal beam 1708 to second light detector 1762. In some embodiments, second beamsplitter 1765 can be a polarizing beamsplitter and second illumination beam 1707 can be polarized. In some embodiments, second detection sensor 1706 can include second optical system 1750. Second optical system 1750 can include one or more beam shaping optics. For example, as shown in FIG. 18, second optical system 1750 can be similarly arranged as first optical system 1720 including first optic 1722, second optic 1724, third optic 1726, fourth optic 1728, and/or fifth optic 1730.

[0149] In some embodiments, as shown in FIG. 17, reticle exchange apparatus 100" can include controller 1780. Controller 1780 can be coupled to first detection sensor 1702 and/or second detection sensor 1706. First and second detection sensors 1702, 1706 can be configured to detect the reticle position (i.e., Z-direction, R_X , R_Y). Controller 1780 can be coupled to first and second detection sensors 1702, 1706 and be configured to calculate and control a position of clamp 300 and/or reticle handler arm 404 based on the reticle position (i.e., Z-direction, R_X , R_Y) detected by first and second detection sensors 1702, 1706. In some embodiments, first and second detection sensors 1702, 1706 can be disposed external to IVR 400.

[0150] In some embodiments, controller 1780 can be disposed external to IVR 400. In some embodiments, controller 1780 can be coupled to plate 500, reticle stage 200, reticle handler arm 404, and/or clamp 300. For example, controller 1780 can be electrically or wirelessly (e.g., radio frequency) coupled to plate 500, reticle stage 200, reticle handler arm 404, and/or clamp 300. In some embodiments, controller 1780 can be configured to correct for a vertical distance offset (i.e., Z-direction offset) and a relative tilt offset (i.e., R_X offset and R_Y offset) between reticle frontside 411 and clamp frontside 302 in real time. For example, reticle position data (i.e., Z-direction, R_X , R_Y) detected by first and/or second detection sensors 1702, 1706 can be compared to clamp position data (i.e., Z-direction, R_X , R_Y) by controller 1780 in order to calculate a position

offset (i.e., Z-direction offset, R_X offset, R_Y offset), which can be reduced for each detection cycle (e.g., 1.0 ms). In some embodiments, controller 1780 can be configured to control reticle stage 200, reticle handler arm 404, and/or clamp 300 to allow compliant movement of clamp 300 until clamp frontside 302 and reticle backside 409 are in full contact and coplanar and/or reduce contact forces and minimize particle generation between reticle 408 and clamp 300. For example, controller 1780 can calculate and reduce a position offset (i.e., Z-direction offset, R_X offset, R_Y offset) between reticle backside 409 and clamp frontside 302 by adjusting clamp 300 position (i.e., Z-direction, R_X , R_Y) for each first and second detection sensors 1702, 1706 detection cycle (e.g., 1.0 ms). In some embodiments, controller 1780 can be configured to correct for a vertical distance offset (i.e., Z-direction offset) and a relative tilt offset (i.e., R_X offset and R_Y offset) between reticle frontside 411 and clamp frontside 302 in real time based on a comparison between a first position (i.e., Z-direction, R_X , R_Y) of reticle 408 detected by first detection sensor 1702 and a second position (i.e., Z-direction, R_X , R_Y) of reticle 408 detected by second detection sensor 1706.

[0151] In some embodiments, controller 1780 can be configured to move reticle stage 200 or reticle handler arm 404 at a first velocity until first and/or second detection sensors 1702, 1706 detects a reticle position (i.e., Z-direction, R_X , R_Y) and then move reticle stage 200 or reticle handler arm 404 at a second velocity less than the first velocity. For example, during approach configuration 20, reticle stage 200 with clamp 300 can move substantially in a vertical direction (i.e., Z-direction) at the first velocity (e.g., 1.0 m/s) until first and/or second detection sensors 1702, 1706 detects a threshold (e.g., predetermined) signal (i.e., Z-direction) of reticle frontside 411, at which point controller 1780 controls and moves reticle stage 200 at the second velocity (e.g., 0.1 mm/s). In some embodiments, reticle 408 damage can be mitigated by reducing speed or velocity of reticle stage 200 and/or clamp 300 during first contact (i.e., first contact configuration 30). In some embodiments, reticle 408 lifetime can be increased by alternating an area on reticle 408 that is first contacted (i.e., during first contact configuration 30). In some embodiments, a partially damaged reticle 408 or clamp 300 can be safely used by altering a load area or a load condition.

[0152] In some embodiments, first and/or second detection sensors 1702, 1706 can be disposed on IVR 400. In some embodiments, first and/or second detection sensors 1702, 1706 can be disposed in or recessed in reticle baseplate 406 or IVR 400, for example, below an upper exterior surface of reticle handler arm 404. In some embodiments, first and second detection sensors 1702, 1706 can be arranged symmetrically. For example, as shown in FIG. 17, first and

second detection sensors 1702, 1706 can be arranged near opposite sides of reticle baseplate 406 about a vertical (i.e., Z-direction) centerline of reticle baseplate 406.

[0153] In some embodiments, first and/or second light sources 1740, 1770 can be a plurality of lasers and configured for structured light stereoscopic detection via laser interference.

5 For example, first light source 1740 can include two planar laser beam fronts whose interference can be detected by first light detector 1732 in order to measure a three-dimensional shape (i.e., Z-direction, R_X , R_Y) of reticle frontside 411. In some embodiments, first and/or second light sources 1740, 1770 can be a projected light pattern and configured for structured light stereoscopic detection via pattern projection. For example, first light source 1740 can include a fringe pattern
10 (e.g., parallel stripes) whose displacement can be detected by first light detector 1732 in order to measure a three-dimensional shape (i.e., Z-direction, R_X , R_Y) of reticle frontside 411. In some embodiments, first and/or second light sources 1740, 1770 can be a DOE pattern projected onto reticle frontside 411 and first and/or second light detectors 1732, 1762 can be a stereo pair of cameras. For example, first and/or second signal beams 1704, 1708 off reticle frontside 411 can
15 determine a tilt (i.e., R_X and R_Y) of reticle frontside 411.

[0154] In some embodiments, first and/or second detection sensors 1702, 1706 can include fiber optics. In some embodiments, first detection sensor 1702 can include first light source 1740 and first light detector 1732. For example, first light detector 1732 can include a bi-prism to detect
20 two displaced images of a fringe pattern from first light source 1740 for structured light stereoscopic detection and tilt calculation (i.e., R_X and R_Y) of reticle frontside 411 with first light detector 1732. In some embodiments, first and/or second detection sensors 1702, 1706 can be time synchronized. For example, first light source 1740 can include a fringe pattern (e.g., parallel stripes) whose displacement can be detected synchronously by first light detector 1732 in order to measure stereo depth and tilt (i.e., Z-direction, R_X , R_Y) of reticle frontside 411.

25 **[0155]** In some embodiments, first and/or second detection sensors 1702, 1706 can be confocal sensors. For example, first and/or second detection sensors 1702, 1706 can be time synchronized confocal sensors with a narrow measurement range (e.g., 22.0 mm) or a wide measurement range (e.g., 30.0 mm). By using time synchronized confocal sensors, a difference in detection times can be measured and used to calculate a position (i.e., Z-direction, R_X , R_Y) of
30 reticle frontside 411. In some embodiments, first and second detection sensors 1702, 1706 can be arranged symmetrically. In some embodiments, first and/or second detection sensors 1702, 1706

can be acoustic sensors. For example, first and/or second detection sensors 1702, 1706 can be time synchronized ultrasonic sensors with a narrow measurement range (e.g., 22.0 mm) or a wide measurement range (e.g., 30.0 mm).

[0156] In some embodiments, first and/or second detection sensors 1702, 1706 can be a high-resolution optical sensor. For example, first and/or second detection sensors 1702, 1706 can include a high-resolution optical sensor for cadastral mapping, a remote pilot assistance sensor (RPAS), a parking assistance sensor (PAS), a reverse parking assistance sensor (RPAS), or some combination thereof.

[0157] The embodiments may further be described using the following clauses:

1. A clamp apparatus comprising:

a clamp;

a sensor disposed on a frontside of the clamp, wherein the sensor is configured to detect a position of a reticle in a reticle exchange area during a reticle exchange process, wherein the position of the reticle comprises a vertical distance between a backside of the reticle and the frontside of the clamp and a relative tilt between the backside of the reticle and the frontside of the clamp; and

a controller coupled to the sensor and configured to control a position of the clamp based on the position of the reticle detected by the sensor.

2. The clamp apparatus of clause 1, wherein the controller is configured to correct for a vertical distance offset and a relative tilt offset between the backside of the reticle and the frontside of the clamp in real time.

3. The clamp apparatus of clause 1, wherein the controller is configured to control a reticle stage to allow compliant movement of the clamp until the frontside of the clamp and the backside of the reticle are in contact and coplanar.

4. The clamp apparatus of clause 1, wherein the controller is configured to reduce contact forces and minimize particle generation between the reticle and the clamp.

5. The clamp apparatus of clause 1, wherein the controller is configured to move a reticle stage:

at a first velocity until the sensor detects the position of the reticle; and

at a second velocity, the first velocity being greater than the second velocity.

6. The clamp apparatus of clause 1, wherein the sensor is capacitive and comprises a planar electrode.

7. The clamp apparatus of clause 1, wherein:

the sensor is optical and comprises a light source and a light detector; and

5 the light source is directed towards the backside of the reticle at an acute angle relative to the frontside of the clamp.

8. The clamp apparatus of clause 1, wherein the sensor is pressurized and comprises a gas gauge.

9. The clamp apparatus of clause 1, wherein the sensor comprises a plurality of sensor arrays.

10 10. A clamp apparatus comprising:

a clamp;

a sensor disposed on a frontside of the clamp, wherein the sensor is configured to detect a force of the reticle in a reticle exchange area during a reticle exchange process, wherein the force of the reticle comprises a stress or a strain from a backside of the reticle or the frontside of the clamp; and

15 a controller coupled to the sensor and configured to control a position of the clamp based on the force of the reticle detected by the sensor.

11. The clamp apparatus of clause 10, wherein the controller is configured to correct for a stress or a strain from the backside of the reticle or the frontside of the clamp in real time.

20 12. The clamp apparatus of clause 10, wherein the controller is configured to control a reticle stage to allow compliant movement of the clamp until the frontside of the clamp and the backside of the reticle are in contact and coplanar.

13. The clamp apparatus of clause 10, wherein the sensor is resistive and comprises a planar strain gauge.

25 14. The clamp apparatus of clause 10, wherein the sensor is resistive and comprises a lithographically patterned resistor configured to change an electrical resistance in proportion to an applied pressure.

15. A plate apparatus comprising:

a plate comprising a reticle exchange port;

30 a sensor disposed in the reticle exchange port, wherein the sensor is configured to detect a position of a reticle in a reticle exchange area during a reticle exchange process, wherein the

position of the reticle comprises a vertical distance between a backside of the reticle and a fixed plane of the sensor and a relative tilt between the backside of the reticle and the fixed plane of the sensor; and

a controller coupled to the sensor and configured to control a position of a clamp based on the position of the reticle detected by the sensor.

16. The plate apparatus of clause 15, wherein the controller is configured to correct for a vertical distance offset and a relative tilt offset between the backside of the reticle and a frontside of the clamp in real time.

17. The plate apparatus of clause 15, wherein the controller is configured to control a reticle stage to allow compliant movement of the clamp until a frontside of the clamp and the backside of the reticle are in contact and coplanar.

18. The plate apparatus of clause 15, wherein:

the sensor is optical and comprises a light source and a light detector, and

the light source is a projected light pattern and configured to allow for structured light stereoscopic detection by the sensor.

19. The plate apparatus of clause 15, wherein the sensor is optical and comprises a confocal sensor configured to be time synchronized.

20. A plate apparatus comprising:

a plate comprising a reticle exchange port;

a sensor disposed on a backside of the plate and away from the reticle exchange port, wherein the sensor is configured to calibrate a position of a reticle in a reticle exchange area during a reticle exchange process based on a fixed plane of the sensor, wherein the position of the reticle comprises a vertical distance between a backside of the reticle and the fixed plane of the sensor and a relative tilt between the backside of the reticle and the fixed plane of the sensor; and

a controller coupled to the sensor and configured to control a position of the clamp based on the position of the reticle detected by the sensor.

21. The plate apparatus of clause 20, wherein the controller is configured to correct for a vertical distance offset and a relative tilt offset between the backside of the reticle and a frontside of the clamp based on a vertical distance offset and a relative tilt offset between the backside of the reticle and the fixed plane of the sensor.

22. The plate apparatus of clause 20, wherein the sensor is configured to synchronously measure the backside of the reticle.

23. The plate apparatus of clause 22, wherein the sensor is capacitive and comprises a planar electrode.

5 24. The plate apparatus of clause 22, wherein the sensor array is optical and comprises one or more confocal sensors.

25. A method comprising:

10 detecting, with a sensor, a position of a reticle on a reticle stage that includes a clamp for the reticle, the position including a vertical distance between a backside of the reticle and a frontside of the clamp and a relative tilt between the backside of the reticle and the frontside of the clamp;

calculating a vertical distance offset and a relative tilt offset between the backside of the reticle and the frontside of the clamp based on the position of the reticle detected by the sensor; and

15 adjusting the clamp or the reticle to reduce the vertical distance offset and the relative tilt offset until the backside of the reticle and the frontside of the clamp are in contact and coplanar.

26. The method of clause 25, wherein detecting, calculating, and adjusting are conducted in real time.

27. The method of clause 25, further comprising:

20 moving the reticle stage at a first velocity until the sensor detects the position of the reticle; and

moving the reticle stage at a second velocity, wherein the first velocity is greater than the second velocity.

28. An in-vacuum robot apparatus comprising:

25 a baseplate comprising a first through hole;

a sensor disposed below the baseplate, wherein the sensor is configured to detect a position of a reticle in a reticle exchange area through the first through hole of the baseplate during a reticle exchange process, wherein the position of the reticle comprises a vertical distance between a frontside of the reticle and a fixed plane of the sensor and a relative tilt between the frontside of the reticle and the fixed plane of the sensor; and

30

a controller coupled to the sensor and configured to control a position of a clamp based on the position of the reticle detected by the sensor.

29. The in-vacuum robot apparatus of clause 28, wherein the controller is configured to correct for a vertical distance offset and a relative tilt offset between the frontside of the reticle and a frontside of the clamp in real time.

30. The in-vacuum robot apparatus of clause 28, wherein the controller is configured to control a reticle stage to allow compliant movement of the clamp until a frontside of the clamp and a backside of the reticle are in contact and coplanar.

31. The in-vacuum robot apparatus of clause 28, wherein the sensor is optical and comprises a confocal sensor configured to be time synchronized.

32. The in-vacuum robot apparatus of clause 28, wherein the sensor is acoustic and comprises an ultrasonic sensor configured to be time synchronized.

33. The in-vacuum robot apparatus of clause 28, wherein the sensor is optical and comprises a high-resolution optical sensor for cadastral mapping, remote pilot assistance, or reverse parking assistance.

34. The in-vacuum robot apparatus of clause 28, wherein:
the sensor is optical and comprises a light source and a light detector, and
the light source is focused through the first through hole of the baseplate onto the frontside of the reticle, and configured to allow for scattered light detection by the sensor.

35. The in-vacuum robot apparatus of clause 34, wherein the light source is infrared.

36. The in-vacuum robot apparatus of clause 34, wherein the sensor further comprises one or more beam shaping optics.

37. The in-vacuum robot apparatus of clause 28, further comprising:
a second through hole in the baseplate; and

a second sensor disposed below the baseplate, wherein the second sensor is configured to detect a second position of the reticle in the reticle exchange area through the second through hole of the baseplate during the reticle exchange process, wherein the second position of the reticle comprises a vertical distance between the frontside of the reticle and a fixed plane of the sensor and a relative tilt between the frontside of the reticle and the fixed plane of the sensor,

wherein the controller is coupled to the second sensor and configured to control a position of the clamp based on the second position of the reticle detected by the second sensor.

38. The in-vacuum robot of clause 37, wherein the controller is configured to correct for a vertical distance offset and a relative tilt offset between the frontside of the reticle and a frontside of the clamp in real time based on a comparison between the position of the reticle detected by the sensor and the second position of the reticle detected by the second sensor.

5 [0158] Although specific reference may be made in this text to the use of lithographic apparatus in the manufacture of ICs, it should be understood that the lithographic apparatus described herein may have other applications. Possible other applications include the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, flat-panel displays, liquid-crystal displays (LCDs), thin film magnetic heads, etc.

10 [0159] Although specific reference may be made in this text to embodiments of the disclosure in the context of a lithographic apparatus, embodiments of the disclosure may be used in other apparatuses. Embodiments of the disclosure may form part of a mask inspection apparatus, a metrology apparatus, or any apparatus that measures or processes an object such as a wafer (or other substrate) or mask (or other patterning device). These apparatuses may be generally referred to as lithographic tools. Such lithographic tools may use vacuum conditions or ambient (non-vacuum) conditions.

[0160] Although specific reference may have been made above to the use of embodiments of the disclosure in the context of optical lithography, it will be appreciated that the disclosure, where the context allows, is not limited to optical lithography and may be used in other applications, for example imprint lithography.

20 [0161] It is to be understood that the phraseology or terminology herein is for the purpose of description and not of limitation, such that the terminology or phraseology of the present specification is to be interpreted by those skilled in relevant art(s) in light of the teachings herein.

[0162] The above examples are illustrative, but not limiting, of the embodiments of this disclosure. Other suitable modifications and adaptations of the variety of conditions and parameters normally encountered in the field, and which would be apparent to those skilled in the relevant art(s), are within the spirit and scope of the disclosure.

25 [0163] While specific embodiments of the disclosure have been described above, it will be appreciated that the disclosure may be practiced otherwise than as described. The descriptions above are intended to be illustrative, not limiting. Thus it will be apparent to one skilled in the art

that modifications may be made to the disclosure as described without departing from the scope of the claims set out below.

[0164] It is to be appreciated that the Detailed Description section, and not the Summary and Abstract sections, is intended to be used to interpret the claims. The Summary and Abstract
5 sections may set forth one or more but not all exemplary embodiments of the present invention as contemplated by the inventor(s), and thus, are not intended to limit the present invention and the appended claims in any way.

[0165] The present invention has been described above with the aid of functional building blocks illustrating the implementation of specified functions and relationships thereof. The
10 boundaries of these functional building blocks have been arbitrarily defined herein for the convenience of the description. Alternate boundaries can be defined so long as the specified functions and relationships thereof are appropriately performed.

[0166] The foregoing description of the specific embodiments will so fully reveal the general nature of the invention that others can, by applying knowledge within the skill of the art,
15 readily modify and/or adapt for various applications such specific embodiments, without undue experimentation, without departing from the general concept of the present invention. Therefore, such adaptations and modifications are intended to be within the meaning and range of equivalents of the disclosed embodiments, based on the teaching and guidance presented herein.

[0167] The breadth and scope of the present invention should not be limited by any of the
20 above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

CLAIMS

1. A clamp apparatus comprising:
a clamp;
5 a sensor disposed on a frontside of the clamp, wherein the sensor is configured to detect a position of a reticle in a reticle exchange area during a reticle exchange process, wherein the position of the reticle comprises a vertical distance between a backside of the reticle and the frontside of the clamp and a relative tilt between the backside of the reticle and the frontside of the clamp; and
10 a controller coupled to the sensor and configured to control a position of the clamp based on the position of the reticle detected by the sensor.
2. The clamp apparatus of claim 1, wherein the controller is configured to correct for a vertical distance offset and a relative tilt offset between the backside of the reticle and the frontside of the
15 clamp in real time.
3. The clamp apparatus of claim 1, wherein the controller is configured to control a reticle stage to allow compliant movement of the clamp until the frontside of the clamp and the backside of the reticle are in contact and coplanar.
20
4. The clamp apparatus of claim 1, wherein the controller is configured to reduce contact forces and minimize particle generation between the reticle and the clamp.
5. The clamp apparatus of claim 1, wherein the controller is configured to move a reticle
25 stage:
at a first velocity until the sensor detects the position of the reticle; and
at a second velocity, the first velocity being greater than the second velocity.
6. The clamp apparatus of claim 1, wherein the sensor is capacitive and comprises a planar
30 electrode.

7. The clamp apparatus of claim 1, wherein:
the sensor is optical and comprises a light source and a light detector; and
the light source is directed towards the backside of the reticle at an acute angle relative to the frontside of the clamp.

5

8. The clamp apparatus of claim 1, wherein the sensor is pressurized and comprises a gas gauge.

9. The clamp apparatus of claim 1, wherein the sensor comprises a plurality of sensor arrays.

10

10. A clamp apparatus comprising:
a clamp;

a sensor disposed on a frontside of the clamp, wherein the sensor is configured to detect a force of the reticle in a reticle exchange area during a reticle exchange process, wherein the force of the reticle comprises a stress or a strain from a backside of the reticle or the frontside of the clamp; and

15

a controller coupled to the sensor and configured to control a position of the clamp based on the force of the reticle detected by the sensor.

20

11. The clamp apparatus of claim 10, wherein the controller is configured to correct for a stress or a strain from the backside of the reticle or the frontside of the clamp in real time.

12. The clamp apparatus of claim 10, wherein the controller is configured to control a reticle stage to allow compliant movement of the clamp until the frontside of the clamp and the backside of the reticle are in contact and coplanar.

25

13. The clamp apparatus of claim 10, wherein the sensor is resistive and comprises a planar strain gauge.

14. The clamp apparatus of claim 10, wherein the sensor is resistive and comprises a lithographically patterned resistor configured to change an electrical resistance in proportion to an applied pressure.

5 15. A plate apparatus comprising:

a plate comprising a reticle exchange port;

a sensor disposed in the reticle exchange port, wherein the sensor is configured to detect a position of a reticle in a reticle exchange area during a reticle exchange process, wherein the position of the reticle comprises a vertical distance between a backside of the reticle and a fixed
10 plane of the sensor and a relative tilt between the backside of the reticle and the fixed plane of the sensor; and

a controller coupled to the sensor and configured to control a position of a clamp based on the position of the reticle detected by the sensor.

15 16. The plate apparatus of claim 15, wherein the controller is configured to correct for a vertical distance offset and a relative tilt offset between the backside of the reticle and a frontside of the clamp in real time.

17. The plate apparatus of claim 15, wherein the controller is configured to control a reticle
20 stage to allow compliant movement of the clamp until a frontside of the clamp and the backside of the reticle are in contact and coplanar.

18. The plate apparatus of claim 15, wherein:

the sensor is optical and comprises a light source and a light detector, and

25 the light source is a projected light pattern and configured to allow for structured light stereoscopic detection by the sensor.

19. The plate apparatus of claim 15, wherein the sensor is optical and comprises a confocal sensor configured to be time synchronized.

30 20. A plate apparatus comprising:

a plate comprising a reticle exchange port;

a sensor disposed on a backside of the plate and away from the reticle exchange port, wherein the sensor is configured to calibrate a position of a reticle in a reticle exchange area during a reticle exchange process based on a fixed plane of the sensor, wherein the position of the reticle comprises a vertical distance between a backside of the reticle and the fixed plane of the sensor and a relative tilt between the backside of the reticle and the fixed plane of the sensor; and

a controller coupled to the sensor and configured to control a position of the clamp based on the position of the reticle detected by the sensor.

21. The plate apparatus of claim 20, wherein the controller is configured to correct for a vertical distance offset and a relative tilt offset between the backside of the reticle and a frontside of the clamp based on a vertical distance offset and a relative tilt offset between the backside of the reticle and the fixed plane of the sensor.

22. The plate apparatus of claim 20, wherein the sensor is configured to synchronously measure the backside of the reticle.

23. The plate apparatus of claim 22, wherein the sensor is capacitive and comprises a planar electrode.

24. The plate apparatus of claim 22, wherein the sensor array is optical and comprises one or more confocal sensors.

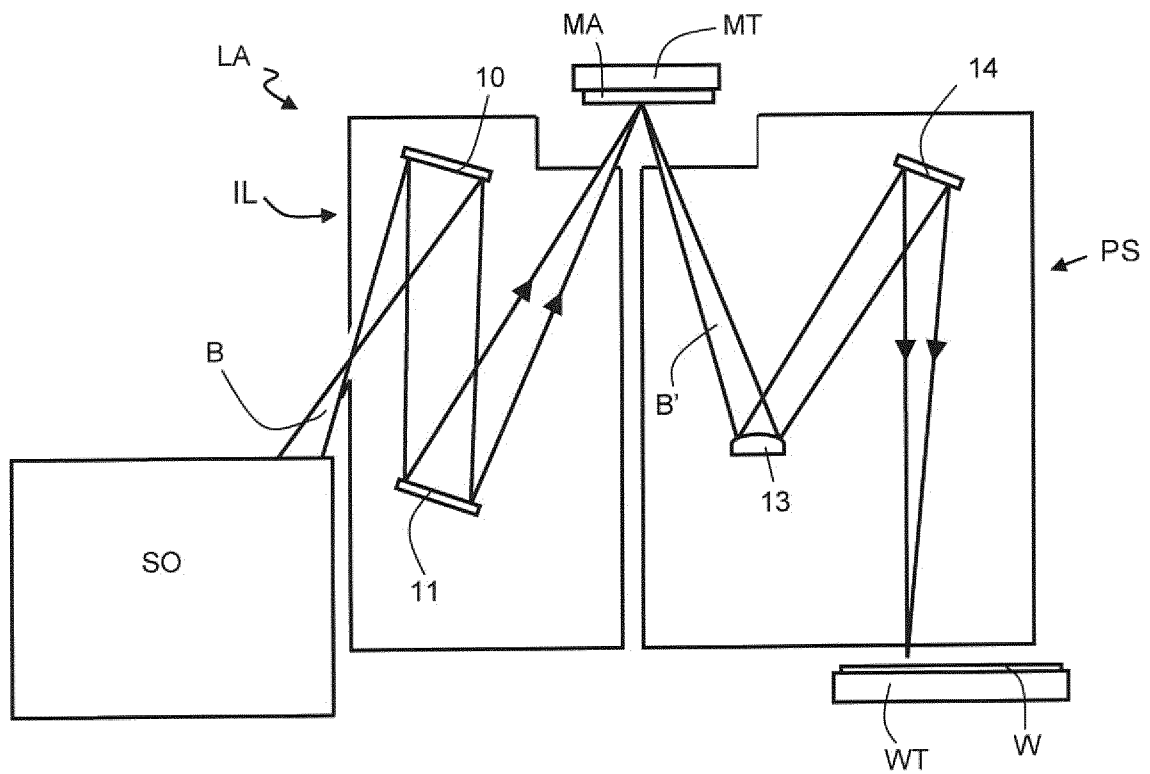


FIG. 1

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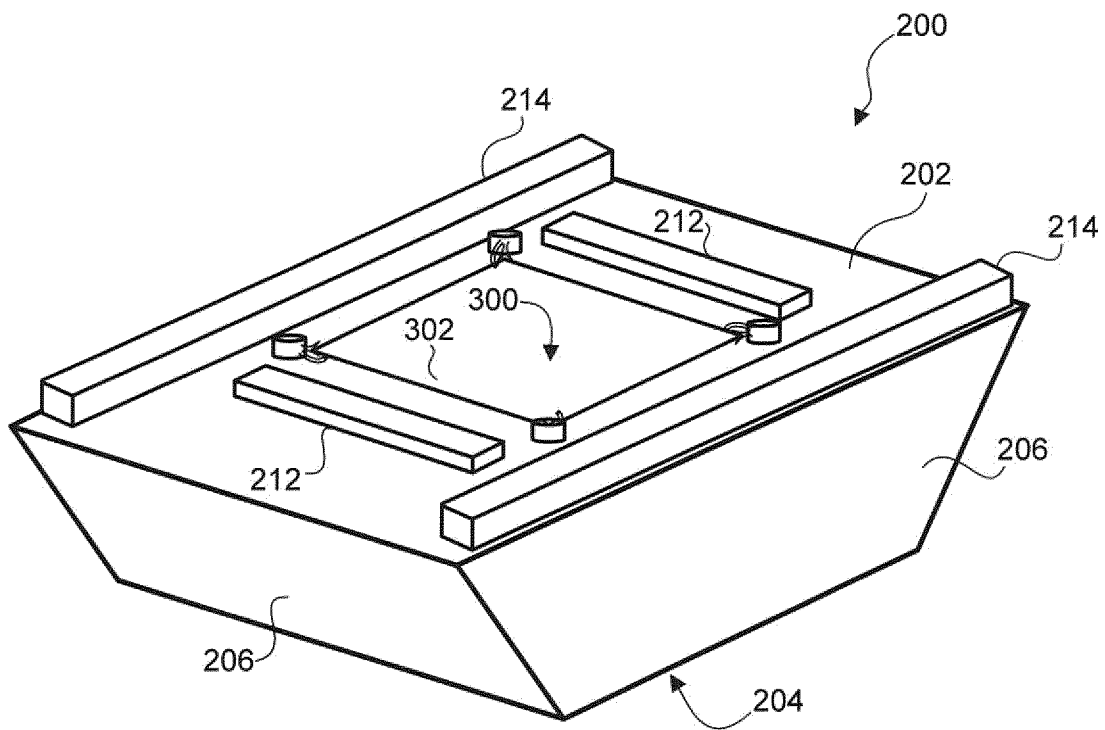


FIG. 2

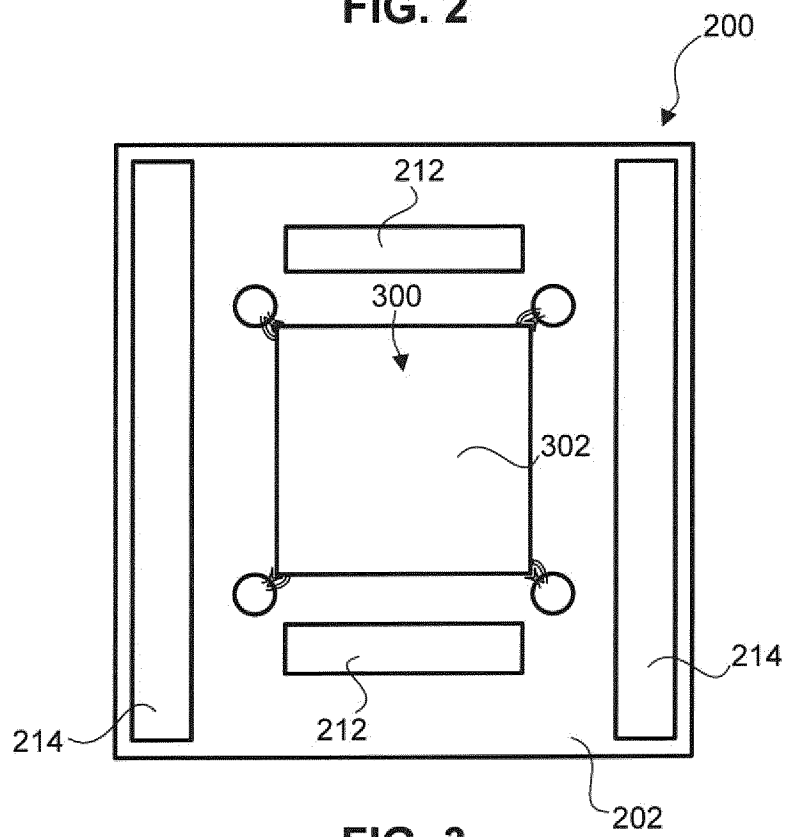


FIG. 3

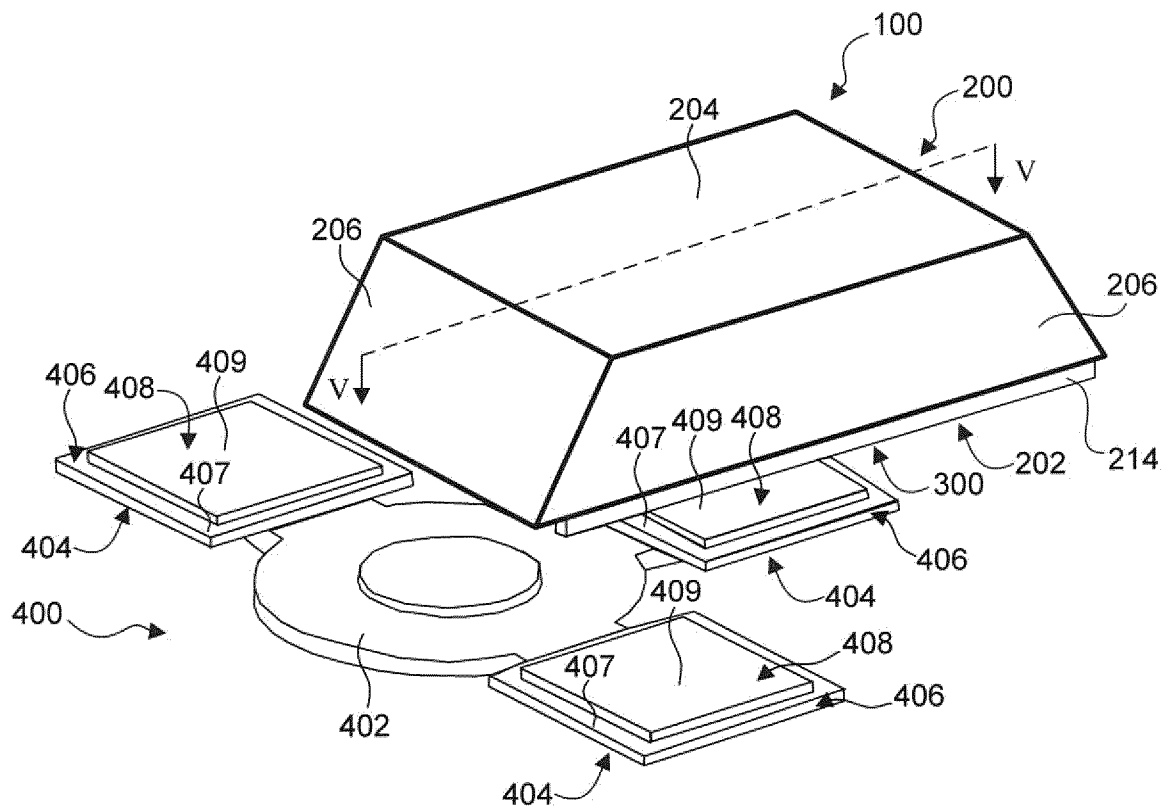


FIG. 4

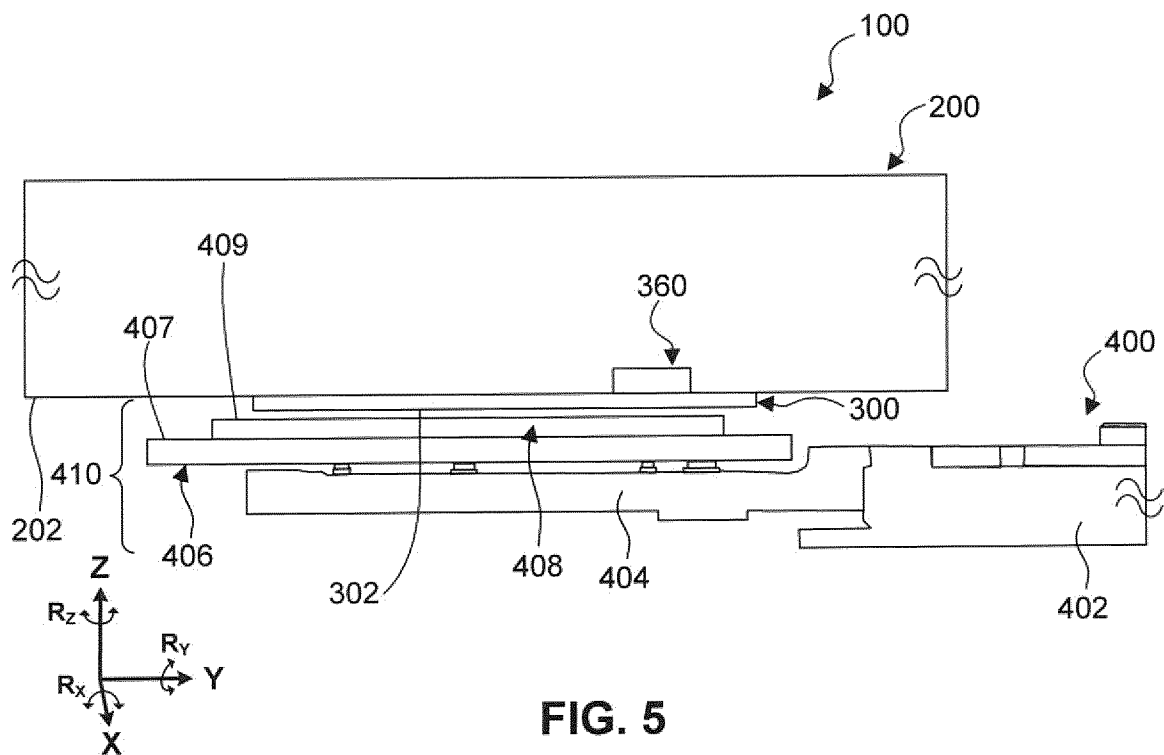
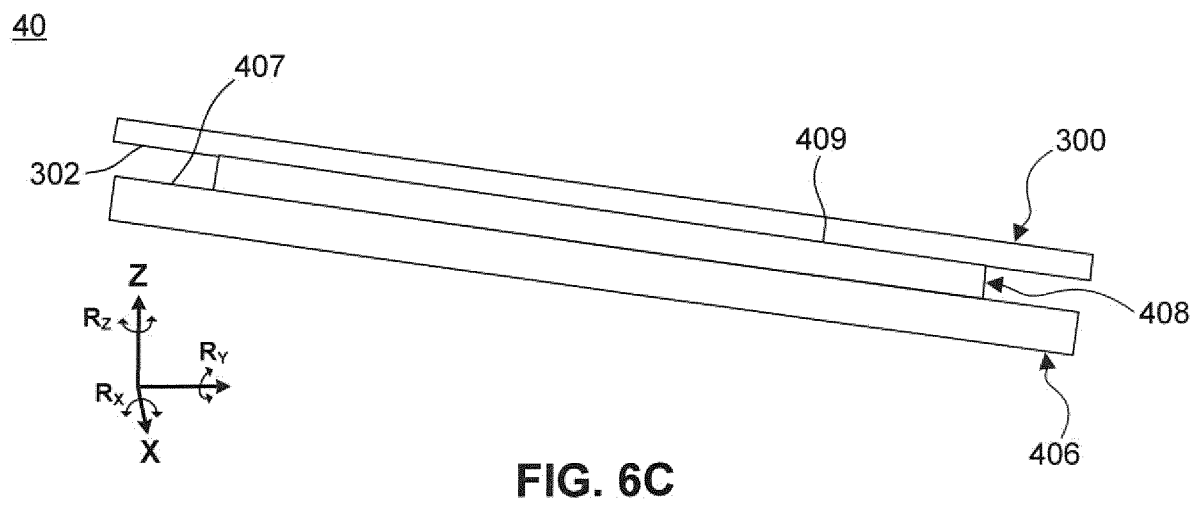
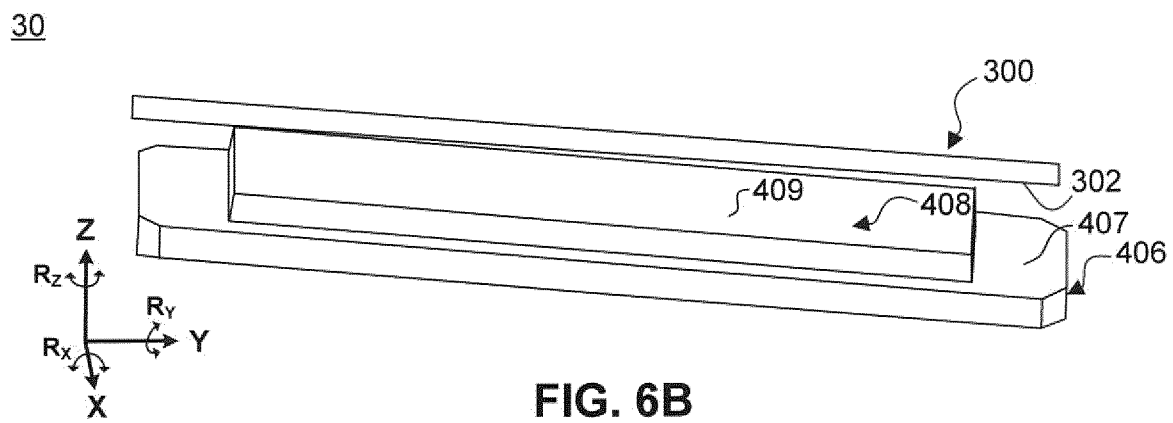
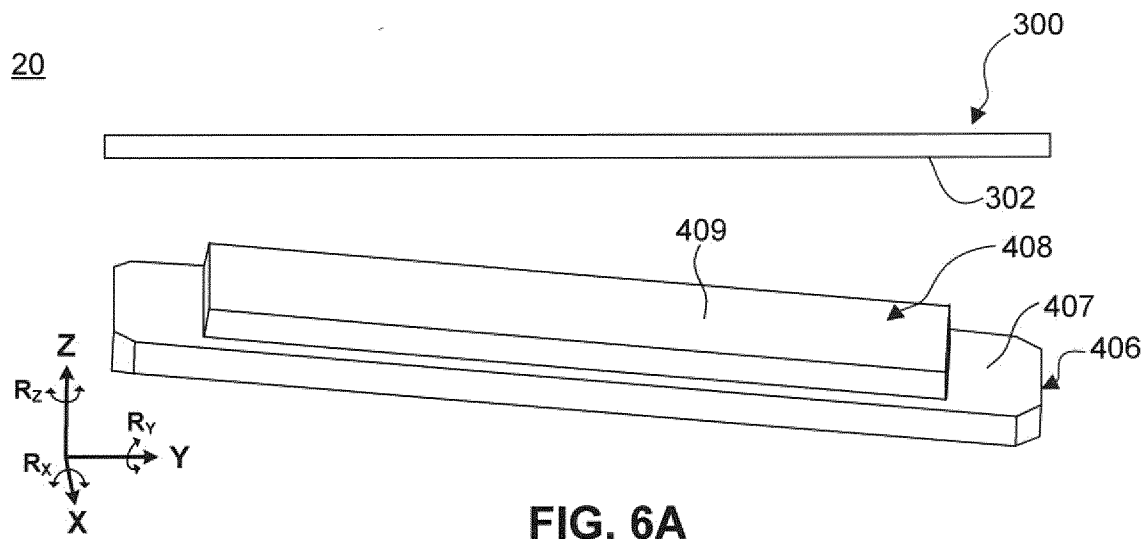


FIG. 5



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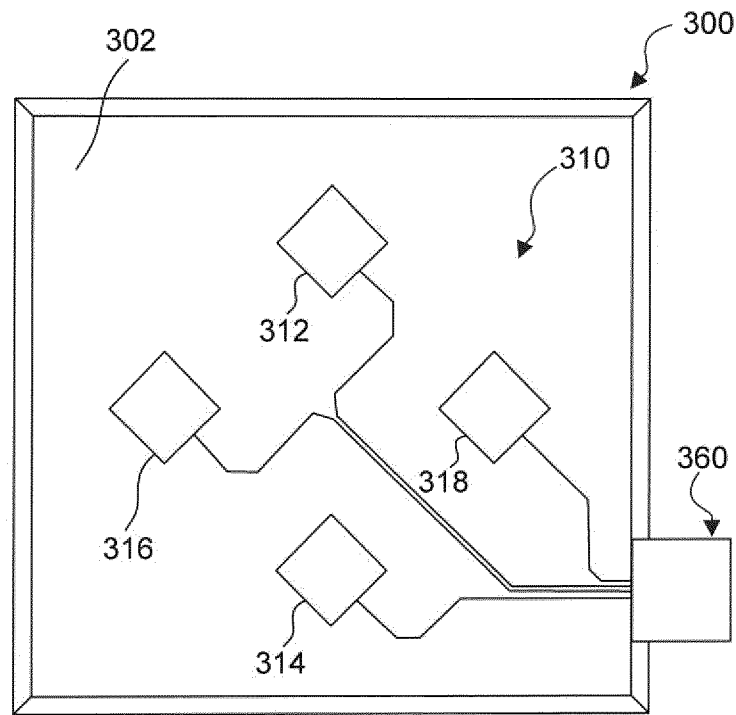


FIG. 7

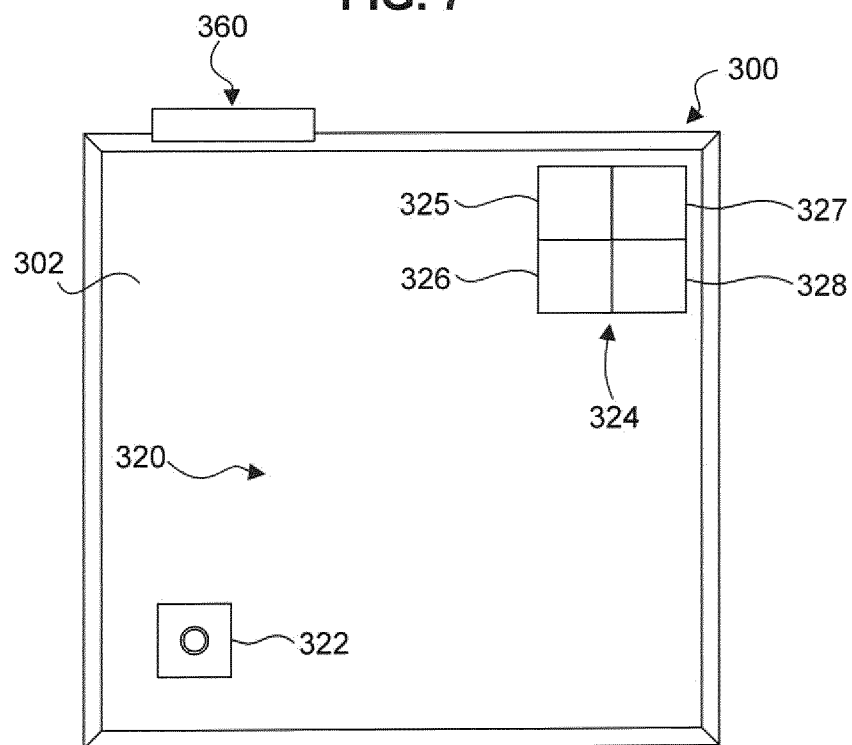


FIG. 8

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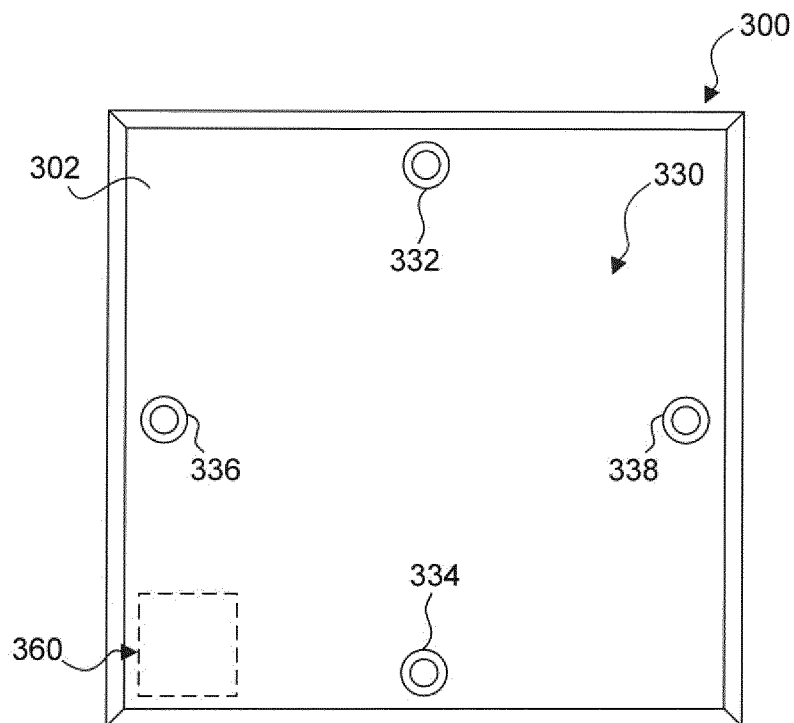


FIG. 9

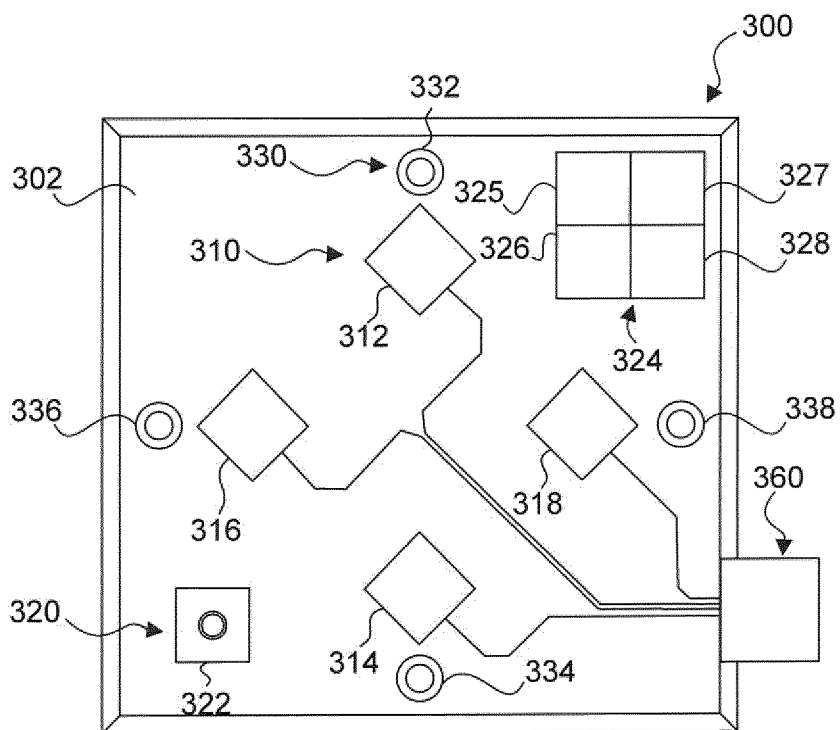


FIG. 10

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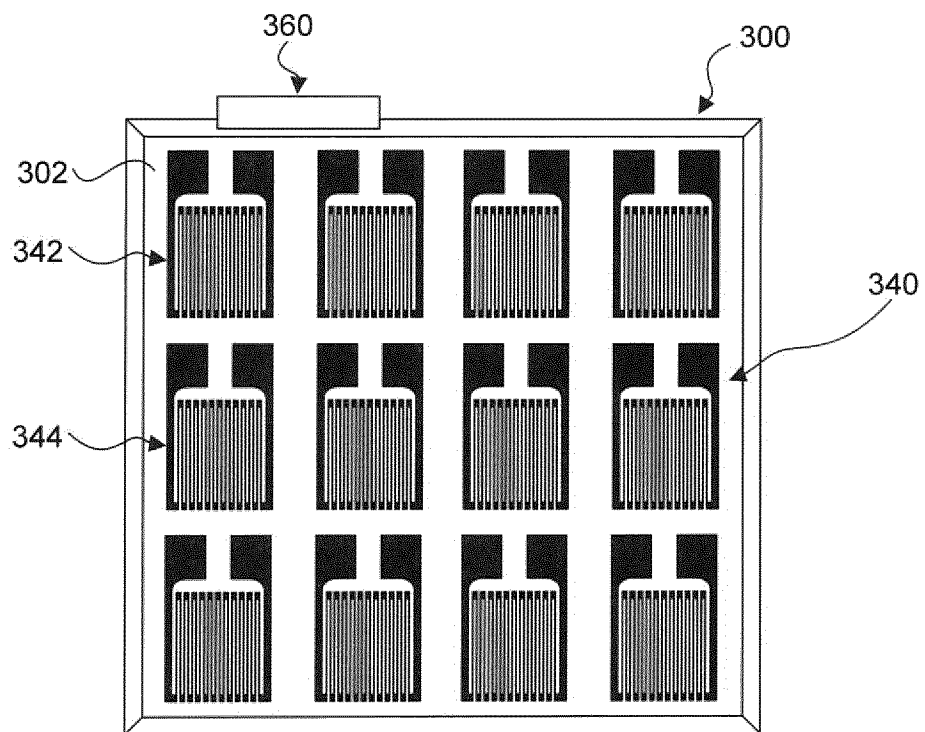


FIG. 11

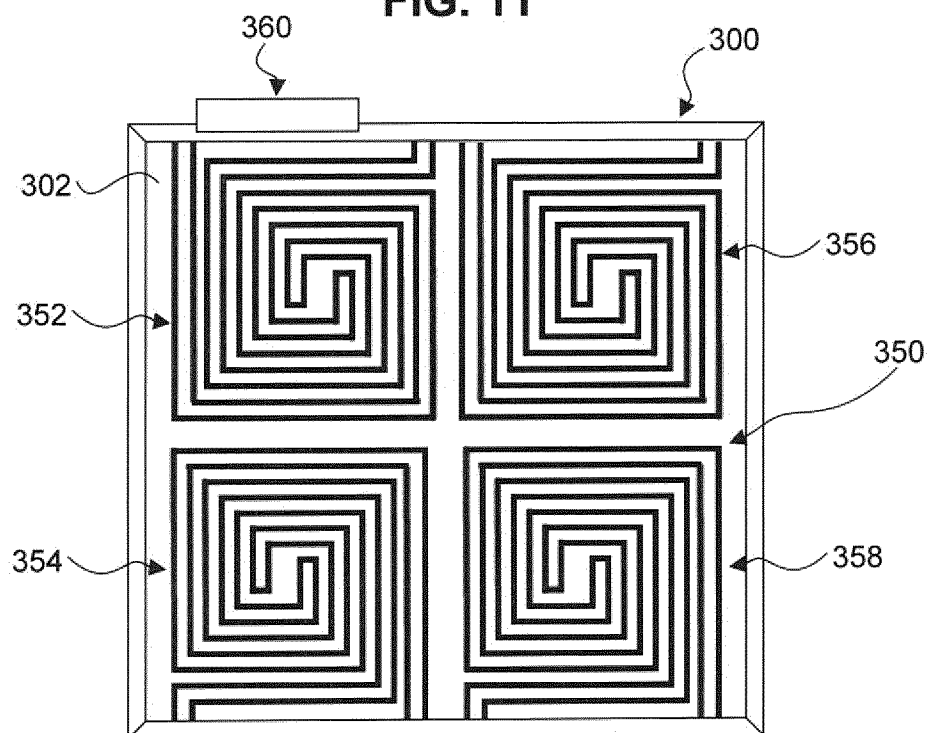


FIG. 12

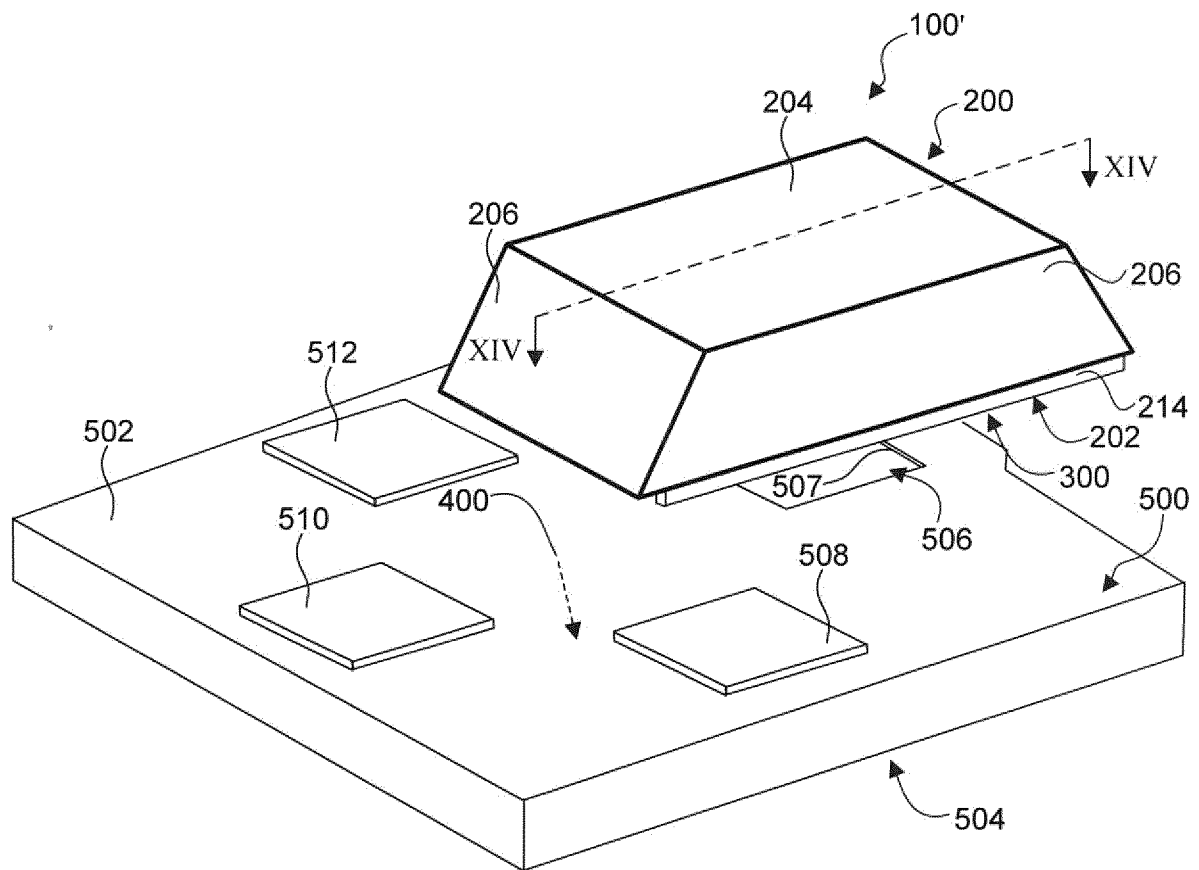


FIG. 13

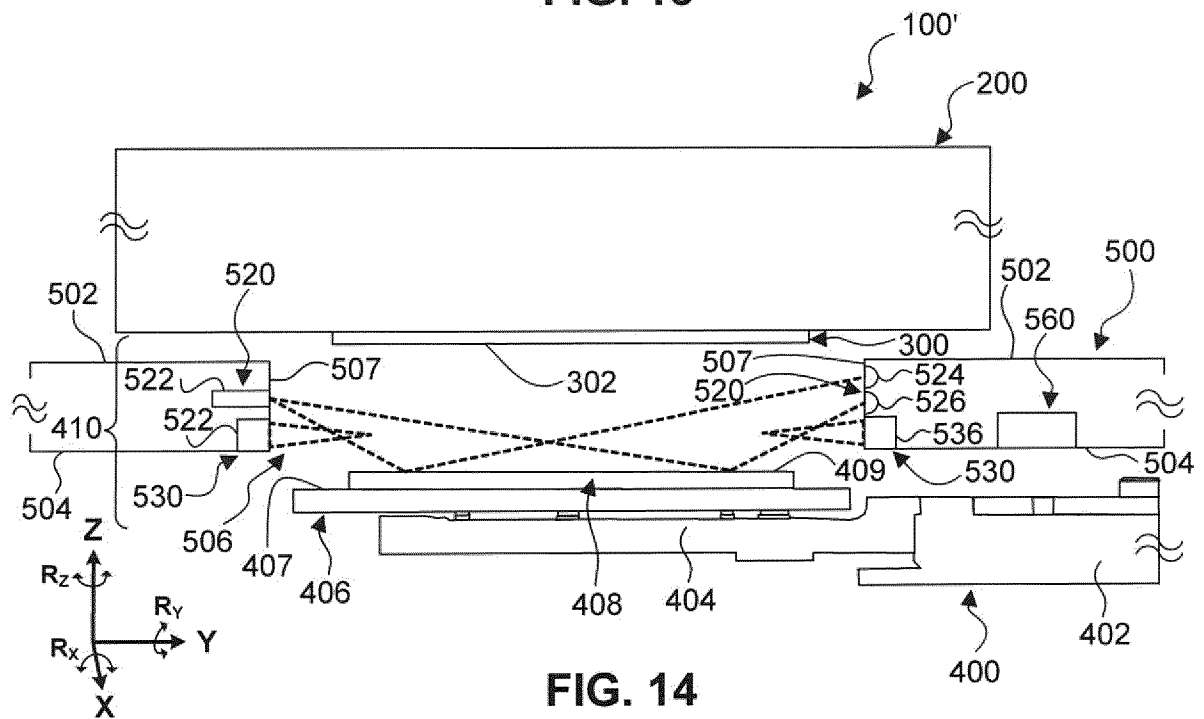


FIG. 14

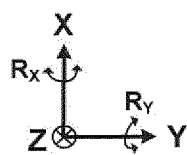
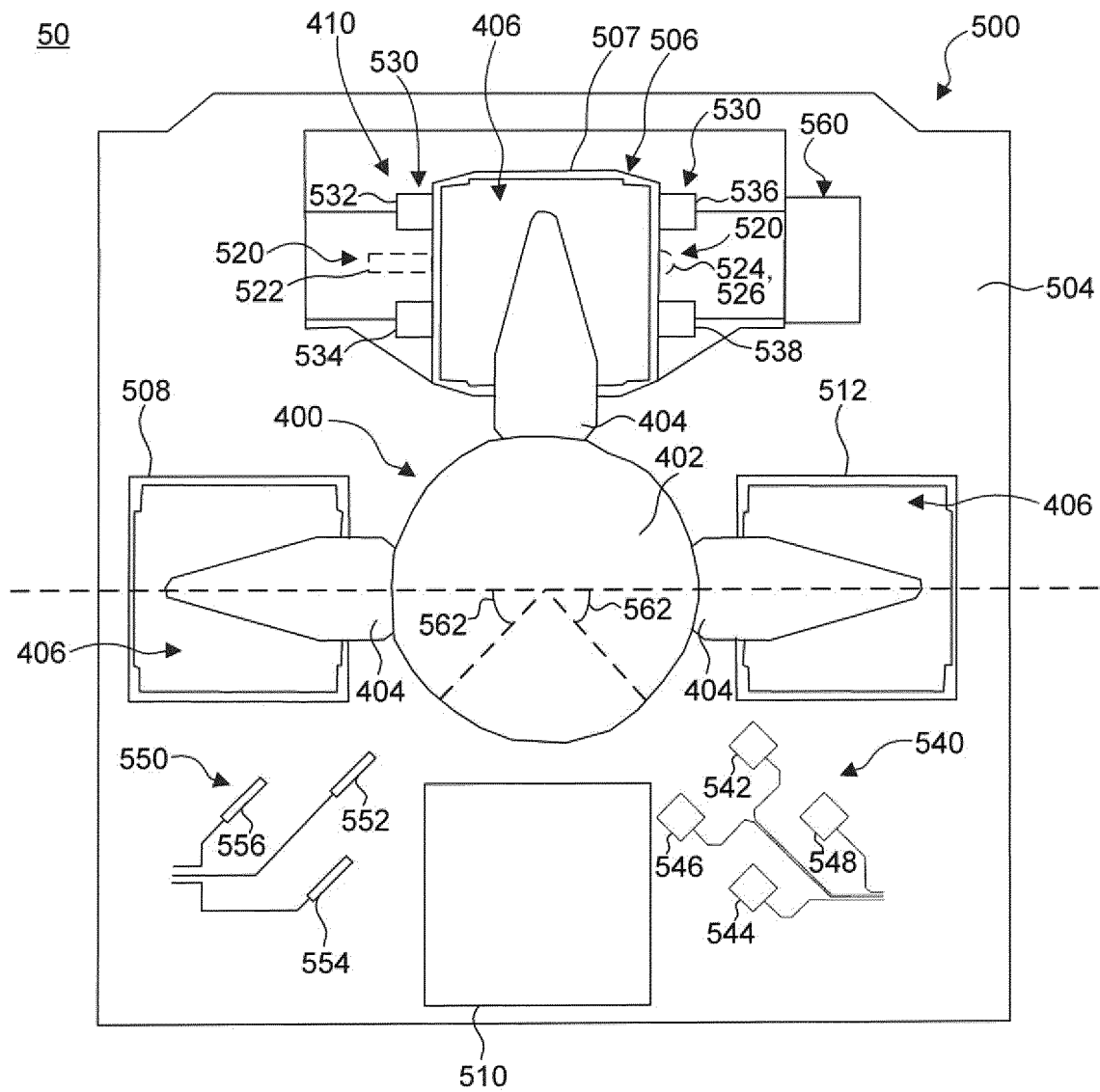


FIG. 15

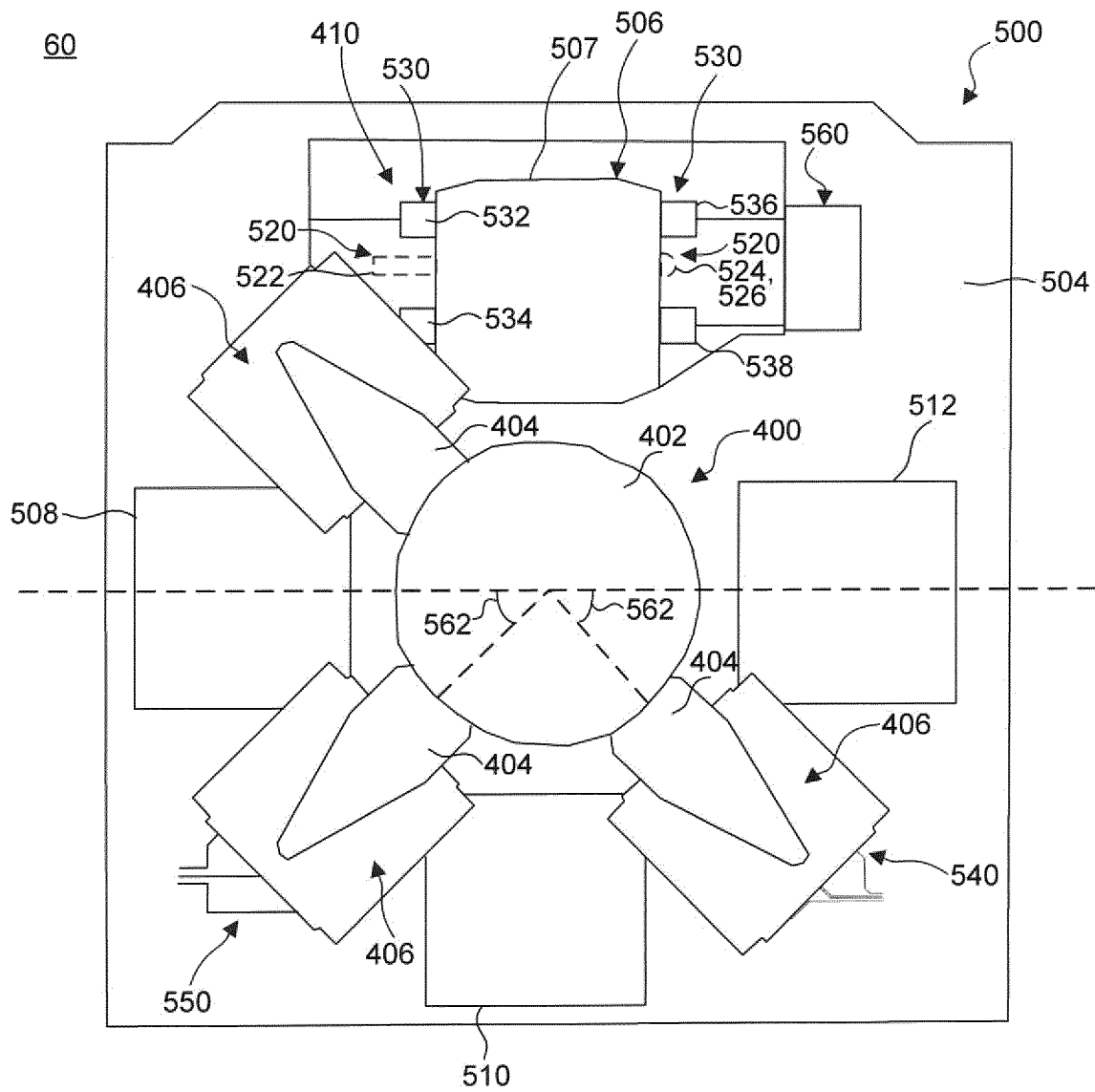


FIG. 16

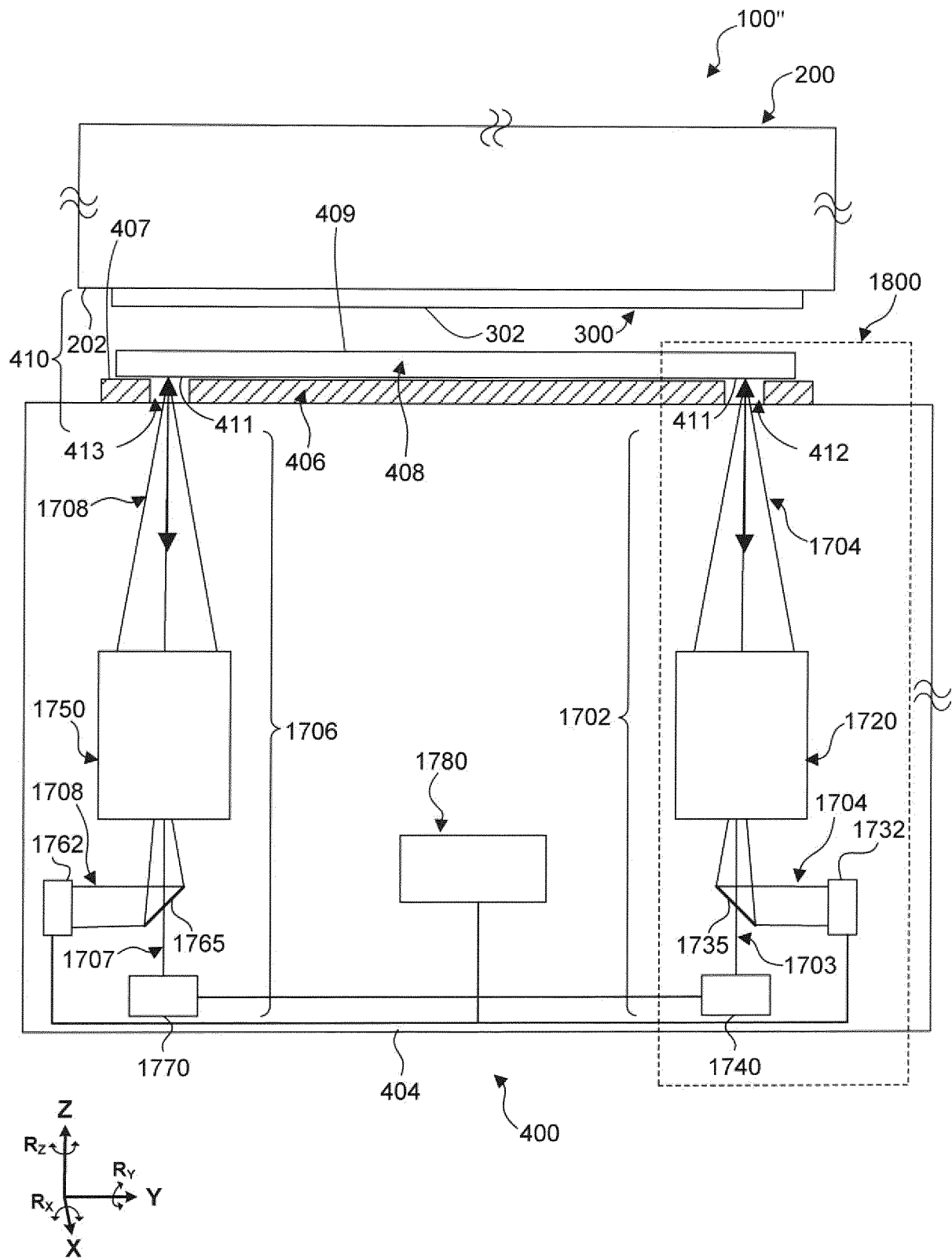


FIG. 17

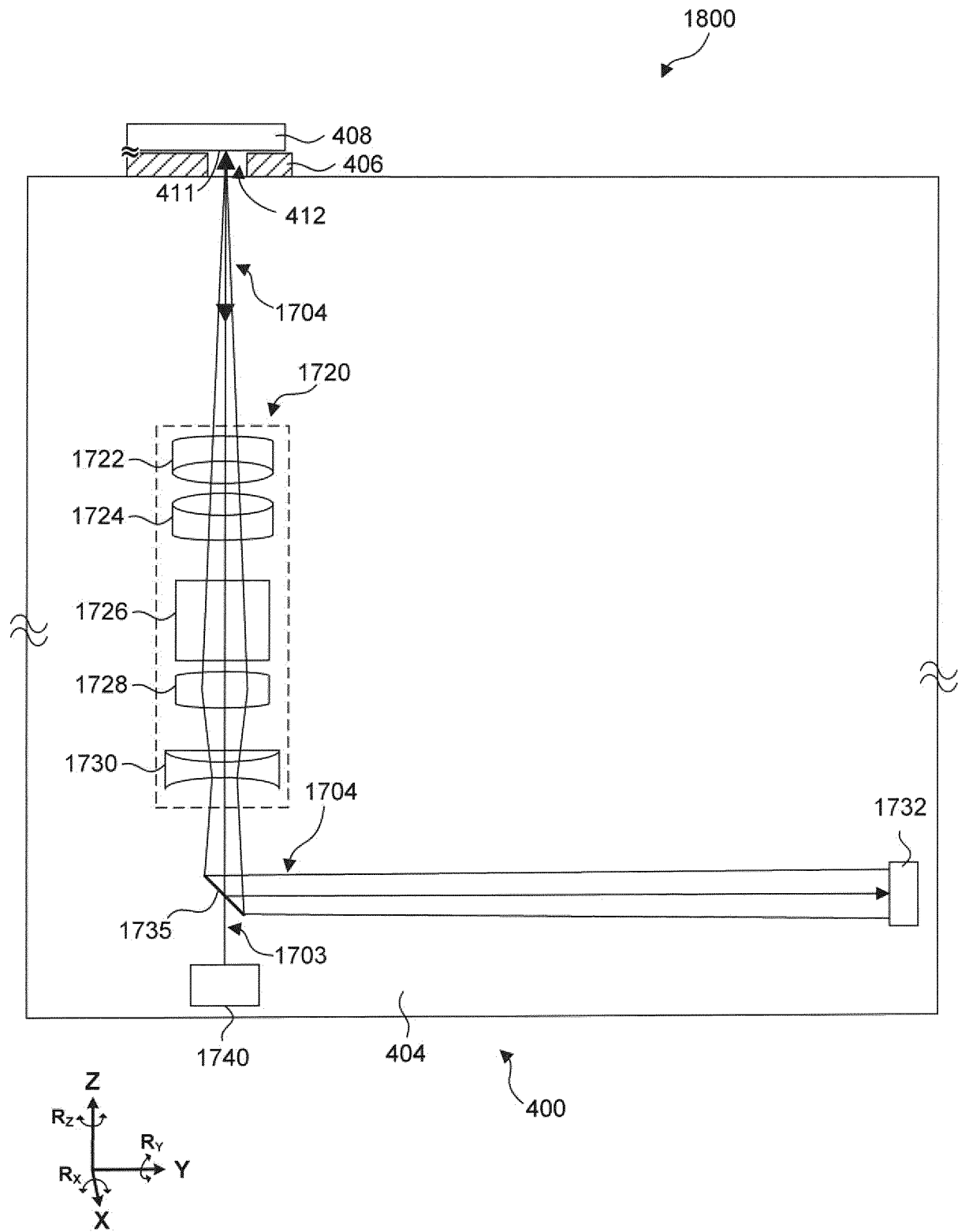


FIG. 18

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/079552

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F7/20
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G03F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2010/115657 A1 (ASML HOLDING NV [NL]; JOHNSON RICHARD [US] ET AL.) 14 October 2010 (2010-10-14)	10-14
A	paragraph [0082] - paragraph [0090]; figure 10	1-9, 15-24
A	----- WO 2012/123144 A1 (ASML NETHERLANDS BV [NL]; BANINE VADIM [NL] ET AL.) 20 September 2012 (2012-09-20)	1-24
	paragraphs [0040] - [0042], [0052] - [0055]; figures 5,6,9,11	
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	paragraph [0131]; claim 9; figure 22	
	----- -/-	



Further documents are listed in the continuation of Box C.



See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

28 January 2020

Date of mailing of the international search report

06/02/2020

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
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Fax: (+31-70) 340-3016

Authorized officer

Angioni, Catherine

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/079552

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	US 2002/006180 A1 (HARA SHINICHI [JP] ET AL) 17 January 2002 (2002-01-17) paragraph [0043]; figure 1 -----	10
A	US 2007/152690 A1 (SUNG MIN-SANG [KR]) 5 July 2007 (2007-07-05) paragraphs [0052] - [0054], [0069] - [0072]; figure 7 -----	1-24
A	US 7 331 250 B2 (APPLIED MATERIALS INC [US]) 19 February 2008 (2008-02-19) the whole document -----	1-24

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Information on patent family members

International application No

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