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INTERFEROMETRIC STAGE POSITIONING APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority of EP application 17194665.0 which was filed on October 04,
5 2017 and which is incorporated herein in its entirety by reference.

FIELD OF THE INVENTION

[0002] The present description relates to a stage positioning device for an electron beam inspection
10 apparatus configured to inspect a specimen such as semiconductor device.

BACKGROUND ART

[0003] In the semiconductor processes, defects are inevitably generated. Such defects may impact
device performance even up to failure. Device yield may thus be impacted, resulting in cost raise. In
order to control semiconductor process yield, defect monitoring is important. One tool useful in defect
15 monitoring is SEM(Scanning Electron Microscope) which scans a target portion of a specimen using
one or more beams of electrons.

[0004] Accurate positioning of the one or more beams of electrons on the target portion is required to
reliably monitor defects. The positioning requirements may need to be further enhanced for
monitoring even smaller defects. At the same time, a high throughput is desired which typically
20 requires to increase a velocity of a movement of the specimen, as well as accelerations and
decelerations thereof. Also, settling times during which the inspection apparatus may be allowed to
settle after a movement of the specimen has stopped, may need to be decreased. All in all, the above
may result in an enhancement of requirements on the accuracy and dynamics of the positioning of the
specimen.

25 [0005] In a known embodiment of an E-beam inspection tool an optical sensor is used to measure a
vertical height position of the substrate supported on the object table at or near the target area of the
substrate. This optical sensor is capable of measuring the height position of the substrate at this location
with high accuracy. However, the optical sensor has a limited measurement rate of about 130 Hz. This
means that the optical sensor is relatively accurate but has a low measurement rate.

30 [0006] With increasing demands on the performance of e-beam inspection tools, the bandwidth of the
positioning device is limited by this performance of the optical sensor.

SUMMARY OF THE INVENTION

[0007] It is an object of the invention to provide an e-beam inspection tool that allows relatively fast
35 and sufficiently accurate positioning of a substrate supported on the object table with respect to an e-
beam source. In particular, it is an object of the invention to provide a position measurement system
that allows relatively fast and sufficiently accurate determination of a height position of a substrate

supported on the object table.

[0008] According to an aspect of the invention, there is provided a stage apparatus comprising:

an object table comprising an supporting surface, the object table configured to support a substrate on the supporting surface;

5 a positioning device configured to a position the object table;

a position measurement system comprising a position sensor configured to measure a height position of the object table parallel to a first axis, the first axis being substantially perpendicular to the supporting surface, the position sensor comprising an interferometer measurement system having an interferometer sensor,

10 wherein a measurement beam of the interferometer sensor is configured to irradiate a reflective surface of the object table in a measurement direction, the measurement direction having a first component parallel to the first axis and a second component parallel to a second axis, the second axis being substantially perpendicular to the first axis.

[0009] Further aspect of the invention may be embodied by a particle beam apparatus, an e-beam apparatus, an e-beam inspection apparatus, a lithography apparatus, a metrology apparatus, or a vacuum apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The present invention will be readily understood by the following detailed description in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements, and in which:

[0011] FIG. 1A and 1B are schematic illustrations of an e-beam inspection tool according to an embodiment of the present invention.

25 [0012] FIG. 2 and 3 are schematic illustrations an electron optical system as can be applied in an embodiment of the present invention.

[0013] FIG. 4 schematically depicts a possible control architecture of an EBI system according to the present invention.

[0014] FIG. 5 schematically depicts a first embodiment of an e-beam inspection tool according to an embodiment of the present invention.

30 [0015] FIG. 6 schematically depicts a control scheme to control the height of a substrate supported on the object table according to the invention.

[0016] FIG. 7 schematically depicts a second embodiment of an e-beam inspection tool according to an embodiment of the present invention.

35 [0017] FIG. 8 schematically depicts a third embodiment of an e-beam inspection tool according to an embodiment of the present invention.

[0018] FIG. 9 schematically depicts a fourth embodiment of an e-beam inspection tool according to an embodiment of the present invention.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0019] Various example embodiments of the present invention will now be described more fully with reference to the accompanying drawings in which some example embodiments of the invention are shown. In the drawings, the thicknesses of layers and regions may be exaggerated for clarity.

[0020] Detailed illustrative embodiments of the present invention are disclosed herein. However, specific structural and functional details disclosed herein are merely representative for purposes of describing example embodiments of the present invention. This invention may, however, be embodied in many alternate forms and should not be construed as limited to only the embodiments set forth herein.

[0021] Accordingly, while example embodiments of the invention are capable of various modifications and alternative forms, embodiments thereof are shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that there is no intent to limit example embodiments of the invention to the particular forms disclosed, but on the contrary, example embodiments of the invention are to cover all modifications, equivalents, and alternatives falling within the scope of the invention. Like numbers refer to like elements throughout the description of the figures.

[0022] As used herein, the term “specimen” generally refers to a wafer or any other specimen on which defects of interest (DOI) may be located. Although the terms “specimen” and “sample” are used interchangeably herein, it is to be understood that embodiments described herein with respect to a wafer may configured and/or used for any other specimen (e.g., a reticle, mask, or photomask).

[0023] As used herein, the term “wafer” generally refers to substrates formed of a semiconductor or non-semiconductor material. Examples of such a semiconductor or non-semiconductor material include, but are not limited to, monocrystalline silicon, gallium arsenide, and indium phosphide. Such substrates may be commonly found and/or processed in semiconductor fabrication facilities.

[0024] In this invention, “axial” means “in the optical axis direction of an apparatus, column or a device such as a lens”, while “radial” means “in a direction perpendicular to the optical axis”. Usually, the optical axis starts from the cathode and ends at specimen. The optical axis always refers to z-axis in all drawings.

[0025] The term, crossover, refers to a point where the electron beam is focused.

[0026] The term, virtual source, means the electron beam emitted from the cathode can be traced back to a “virtual” source.

[0027] The inspection tool according to the present invention relates to a charged particle source, especially to an e-beam source which can be applied to a SEM, an e-beam inspection tool, or an EBDW. The e-beam source, in this art, may also be referred to as an e-gun (Electron Gun).

[0028] With respect to the drawings, it is noted that the figures are not drawn to scale. In particular, the scale of some of the elements of the figures may be greatly exaggerated to emphasize characteristics of the elements. It is also noted that the figures are not drawn to the same scale. Elements shown in more than one figure that may be similarly configured have been indicated using the same reference

numerals.

[0029] In the drawings, relative dimensions of each component and among every component may be exaggerated for clarity. Within the following description of the drawings the same or like reference numbers refer to the same or like components or entities, and only the differences with respect to the individual embodiments are described.

[0030] Accordingly, while example embodiments of the invention are capable of various modifications and alternative forms, embodiments thereof are shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that there is no intent to limit example embodiments of the invention to the particular forms disclosed, but on the contrary, example embodiments of the invention are to cover all modifications, equivalents, and alternatives falling within the scope of the invention.

[0031] Figures 1A and 1B schematically depict a top view and a cross-sectional view of an electron beam (e-beam) inspection (EBI) system 100 according to an embodiment of the present invention. The embodiment as shown comprises an enclosure 110, a pair of load ports 120 serving as an interface to receive objects to be examined and to output objects that have been examined. The embodiment as shown further comprises an object transfer system, referred as an EFEM, equipment front end module 130, that is configured to handle and/or transport the objects to and from the load ports. In the embodiment as shown, the EFEM 130 comprises a handler robot 140 configured to transport objects between the load ports and a load lock 150 of the EBI system 100. The load lock 150 is an interface between atmospheric conditions occurring outside the enclosure 110 and in the EFEM and the vacuum conditions occurring in a vacuum chamber 160 of the EBI system 100. In the embodiment as shown, the vacuum chamber 160 comprises an electron optics system 170 configured to project an e-beam onto an object to be inspected, e.g. a semiconductor substrate or wafer. The EBI system 100 further comprises a positioning device 180 that is configured to displace the object 190 relative to the e-beam generated by the electron optics system 170.

[0032] In an embodiment, the positioning device may comprise a cascaded arrangement of multiple positioners such as an XY-stage for positioning the object in a substantially horizontal plane, and a Z-stage for positioning the object in the vertical direction.

[0033] In an embodiment, the positioning device may comprise a combination of a coarse positioner, configured to provide a coarse positioning of the object over comparatively large distances and a fine positioner, configured to provide a fine positioning of the object over comparatively small distances.

[0034] In an embodiment, the positioning device 180 further comprises an object table for holding the object on a supporting surface during the inspection process performed by the EBI system 100. The supporting surface may be a burl table and/or a clamp. In such embodiment, the object 190 may be clamped onto the supporting surface of the object table by means of a clamp such as an electrostatic clamp. Such a clamp may be integrated in the object table.

[0035] In accordance with the present invention, the positioning device 180 comprises a first positioner

for positioning the object table and a second positioner for positioning the first positioner and the object table.

[0036] The positioning device 180 as applied in the present invention will be discussed in more detail below.

5 [0037] Figure 2 schematically depict an embodiment of an electron optics system 200 as can be applied in e-beam inspection tool or system according to the present invention. The electron optics system 200 comprises an e-beam source, referred to as the electron gun 210 and an imaging system 240.

[0038] The electron gun 210 comprises an electron source 212, suppressor 214, an anode 216, a set of apertures 218, and a condenser 220. The electron source 212 can be a Schottky emitter. More
10 specifically, the electron source 212 includes a ceramic substrate, two electrodes, a tungsten filament, and a tungsten pin. The two electrodes are fixed in parallel to the ceramic substrate, and the other sides of the two electrodes are respectively connected to two ends of the tungsten filament. The tungsten is slightly bended to form a tip for placing the tungsten pin. Next, a ZrO₂ is coated on the surface of the tungsten pin, and is heated to 1300°C so as to be melted and cover the tungsten pin but uncover the
15 pinpoint of the tungsten pin. The melted ZrO₂ can make the work function of the tungsten lowered and decrease the energy barrier of the emitted electron, and thus the electron beam 202 is emitted efficiently. Then, by applying negative electricity to the suppressor 214, the electron beam 202 is suppressed. Accordingly, the electron beam having the large spread angle is suppressed to the primary electron beam 202, and thus the brightness of the electron beam 202 is enhanced. By the positive charge of the
20 anode 216, the electron beam 202 can be extracted, and then the Coulomb's compulsive force of the electron beam 202 may be controlled by using the tunable aperture 218 which has different aperture sizes for eliminating the unnecessary electron beam outside of the aperture. In order to condense the electron beam 202, the condenser 220 is applied to the electron beam 202, which also provides magnification. The condenser 220 shown in the figure 2 may e.g. be an electrostatic lens which can
25 condense the electron beam 202. On the other hand, the condenser 220 can be also a magnetic lens.

[0039] The imaging system 240 as shown in Figure 3 comprises a blanker 248, a set of apertures 242, a detector 244, four sets of deflectors 250, 252, 254, and 256, a pair of coils 262, a yoke 260, a filter 246, and an electrode 270. The electrode 270 is used to retard and deflect the electron beam 202, and further has electrostatic lens function due to the combination of upper pole piece and sample 300.
30 Besides, the coil 262 and the yoke 260 are configured to the magnetic objective lens.

[0040] The electron beam 202, described above, is generated by heating the electron pin and applying the electric field to anode 216, so that, in order to stabilize the electron beam 202, there must be a long time for heating the electron pin. For a user end, it is surely time consuming and inconvenient. Hence, the blanker 248 is applied to the condensed electron beam 202 for temporally deflecting the electron
35 beam 202 away from the sample rather than turning off it.

[0041] The deflectors 250 and 256 are applied to scan the electron beam 202 to a large field of view, and the deflectors 252 and 254 are used for scanning the electron beam 202 to a small field of view. All

the deflectors 250, 252, 254, and 256 can control the scanning direction of the electron beam 202. The deflectors 250, 252, 254, and 256 can be electrostatic deflectors or magnetic deflectors. The opening of the yoke 260 is faced to the sample 300, which immerses the magnetic field into the sample 300. On the other hand, the electrode 270 is placed beneath the opening of the yoke 260, and therefore the sample 300 will not be damaged. In order to correct the chromatic aberration of the electron beam 202, the retarder 270, the sample 300, and the upper pole piece form a lens to eliminate the chromatic aberration of the electron beam 202.

[0042] Besides, when the electron beam 202 bombards into the sample 300, a secondary electron will be emanated from the surface of the sample 300. Next the secondary electron is directed to the detector 244 by the filter 246.

[0043] Figure 4 schematically depicts a possible control architecture of an EBI system according to the present invention. As indicated in Figure 1, the EBI system comprises a load lock, a wafer transfer system, a load/lock, an electron optics system and a positioning device, e.g. including a z-stage and a x-y stage. As illustrated, these various components of the EBI system may be equipped with respective controllers, i.e. , a wafer transporter system controller connected to the wafer transfer system, a load/lock controller, an electron optics controller, a detector controller, a stage controller. These controllers may e.g. be communicatively connected to a system controller computer and an image processing computer, e.g. via a communication bus. In the embodiment as shown, the system controller computer and the image processing computer may be connected to a workstation.

[0044] The load port loads a wafer to the wafer transfer system, such as EREM 130, and the wafer transfer system controller controls the wafer transfer to transfer the wafer to the load/lock, such as load lock 150. The load/lock controller controls the load/lock to the chamber, such that an object that is to be examiner, e.g. a wafer can be fixed on a clamp, e.g. an electrostatic clamp, also referred to as an e-chuck. The positioning device, e.g. the z-stage and the xy-stage, enable the wafer to move by the stage controller. In an embodiment, a height of the z-stage may e.g. be adjusted using a piezo component such as a piezo actuator. The electron optic controller may control all the conditions of the electron optics system, and the detector controller may receive and convert the electric signals from the electron optic system to image signals. The system controller computer is to send the commands to the corresponding controller. After receiving the image signals, the image processing computer may process the image signals to identify defects.

[0045] Figure 5 schematically depicts a side view of an embodiment of an e-beam inspection tool 100 according to an embodiment of the invention. The e-beam inspection tool 100 comprises an electron optics system 200. The electron optics system 200 comprises an electron gun 210 and an imaging system 240 as described with respect to Figure 2.

[0046] The electron optics system 200 is arranged above a movable object table 3 of a positioning device 180. The object table 3 is arranged to support an object, in particular a substrate 190. The object table 3 is movable in an x-direction, y-direction and z-direction to align a target portion of the substrate

190 with the electron optics system 200 such that an electron beam from the electron optics system 200 can be used to inspect the substrate 190, in particular its upper surface.

[0047] To properly align the target portion of the substrate 190 with the electron optics system 200, a position control system is provided that is arranged to control the position of the object table 3 with respect to the electron optics system 200.

[0048] The position control system comprises a position measurement system 5, a controller 6 and at least one actuator 7. The position measurement system 5 is arranged to determine a position of the substrate 190 supported on the object table 3 with respect to the electron optics system 200. The position measurement system 5 comprises a first position sensor 8 to measure a height position of the substrate 190. The first position sensor 8 is an optical sensor that is mounted on the electron optics system 200 to directly measure the distance between the electron optics system 200 and the substrate 190.

[0049] Since the first position sensor 8 directly measures the distance between the electron optics system 200 and the target portion of the upper surface of the substrate 190, the first position sensor 8 may determine the vertical position of the target portion of the substrate 190 relative to the electron optics system 200 with high accuracy. However, optical sensors typically used for this direct measurement of the height position of the upper surface of the substrate 190 have a relative low measurement rate, for example a measurement frequency rate of 100 – 150 Hz.

[0050] The position measurement system further comprises a first interferometer sensor 9 and a second interferometer sensor 10.

[0051] The first interferometer sensor 9 provides a first measurement beam 11 and a first reference beam 12. The first measurement beam 11 is directed in a first measurement direction to a first reflective surface 13 on the object table 3. The first reference beam 12 is directed in a first reference beam direction to a first reflective reference surface 14 provided on a first reflective element mounted on the electron optics system 200. The first measurement direction and the first reference beam direction are parallel to each other. This makes position measurements by the first interferometer sensor 9 insensitive to a displacement of the first interferometer sensor 9. Since the first reference beam 12 is directed to the first reflective reference surface 14, the first interferometer sensor 9 directly measures, in the first measurement direction, a relative displacement between the electron optics system 200 and the object table 3.

[0052] Correspondingly, the second interferometer sensor 10 provides a second measurement beam 15 and a second reference beam 16. The second measurement beam 15 is directed in a second measurement direction to a second reflective surface 17 on the object table 3. The second reference beam 16 is directed in a second reference beam direction to a second reflective reference surface 18 provided on a second reflective element mounted on the electron optics system 200. The second measurement direction and the second reference beam direction are parallel to each other. This makes position measurements by the second interferometer sensor 10 insensitive to a displacement of the second interferometer sensor 10. Since the second reference beam 16 is directed to the second reflective

reference surface 18, the second interferometer sensor 10 directly measures a relative displacement between the electron optics system 200 and the object table 3.

[0053] The first reflective surface 13 and the second reflective surface 17 may be arranged in opposite sides of the object table, preferably opposite sides of the object table with respect to the vertical axis (also further indicated as first axis) of the object table 3.

[0054] In the embodiment of Figure 5, side surfaces of the object table 3 are used as the first reflective surface 13 and the second reflective surface 17. In alternative embodiments, the first reflective surface and/or second reflective surface may be provided on a reflective surface element mounted on the object table 3.

[0055] The first reflective reference surface 14 and the second reflective reference surface 18 may be provided on any suitable location which is stiffly connected to the electron optics system 200, in particular the electron gun 210. The location may be the electron gun 210, the imaging system 240, for example a housing or frame thereof. The first reflective reference surface 14 and the second reflective reference surface 18 may be provided directly at this location or may be provided on separate reflective elements mounted on the respective location, as shown in Figure 5.

[0056] In the shown embodiment, the first measurement direction comprises a horizontal component (in the x-direction indicated in Figure 5) and a vertical component (in the z-direction indicated in Figure 5). Correspondingly, the second measurement direction comprises a horizontal component (in the x-direction indicated in Figure 5) and a vertical component (in the z-direction indicated in Figure 5). The horizontal components of the first measurement direction and the second measurement direction are opposite to each other, i.e. a positive x-direction and a negative x-direction. The vertical components of the first measurement direction and the second measurement direction both extend upwards.

[0057] By calculating predefined or calibrated linear combinations of interferometer measurements of the first interferometer sensor 9 and the second interferometer sensor 10, the displacements of the object table 3 in x- and z-direction may be determined. In the embodiment shown in Figure 5, displacement in the x-direction is proportional to the difference of interferometer measurements of the first interferometer sensor 9 and the second interferometer sensor 10, while the z displacement is proportional to the sum of interferometer measurements of the first interferometer sensor 9 and the second interferometer sensor 10. The x displacement measurement in this embodiment is not affected by some common measurement errors between the first interferometer sensor 9 and the second interferometer sensor 10 such as a measurement error due to a homogeneous expansion of the electron optics system 200 in x-direction.

[0058] The first reference beam 12 and the second reference beam 16 may be arranged to have equal lengths. This makes the x displacement measurement in this embodiment insensitive to displacements of the reflective reference surfaces 14, 18 with an equal magnitude and the opposite signs such as a homogeneous expansion of the electron optics system 200 in x-direction.

[0059] An angle between the first measurement direction and the horizontal component of the first

measurement direction may for example be in the range of 2 – 20 degrees, for instance 5 degrees. An angle between the second measurement direction and the horizontal component of the second measurement direction may also be in the range of 2 – 20 degrees, for instance 5 degrees. Preferably, these angles are the same. The first reflective surface 13, the first reflective reference surface 14, the second reflective surface 17, and the second reflective reference surface 18 are arranged perpendicular to the first measurement direction, first reference beam direction, second measurement direction and second reference beam direction, respectively.

[0060] It is remarked that movement of the object table 3 in the x-direction, y-direction and/or z-direction will result in the first measurement beam 11 being reflected at another location within a measurement range of the first reflective surface 13 and the second measurement beam 15 being reflected at another location of a measurement range of the second reflective surface 17. The measurement ranges of the first reflective surface 13 and the second reflective surface 17 may be rectangular and have a substantial dimension.

[0061] Dependent on the location at which the first measurement beam 11 is reflected on the first reflective surface 13, the reflection behavior may differ. In order to take this difference in reflection behavior between different locations within the measurement range of the first reflective surface 13 into account, the position measurement system 5 and/or the controller 6 may comprise a correction map for the first reflective surface 13 to correct for differences in reflective behavior of different locations of the first reflective surface 13. Similarly, the position measurement system 5 and/or the controller 6 may comprise a correction map for the second reflective surface 17 to correct for differences in reflective behavior of different locations of the second reflective surface 17. Also, correction maps may be provided for the combination of the first reflective surface 13 and the second reflective surface 17.

[0062] The first measurement direction of the first measurement beam 11 and the second measurement direction of the second measurement beam 15 intersect at the target location 19 on the substrate 190. When the target portion is correctly positioned with respect to the electron optics system 200, this location is also the crossover location, i.e. a point where the electron beam is focused. This enables an accurate determination of the x-position of the target location 19 without the need for correction of different orientations of the object table 3 caused by rotation of the object table 3 about a rotation axis in the y-direction. A person skilled in the art will refer to this measurement as ‘a measurement in Abbe’ or ‘a measurement with a small Abbe arm’.

[0063] However, the first reference beam direction and the second reference beam direction intersect at a location above the location of interest 20 of the electron optics system 200. It is therefore desirable that any rotation of the electron optics system 200 about an axis in x-direction and/or y-direction is compensated to prevent an Abbe error in the measurement of the first interferometer sensor 9 and the second interferometer sensor 10. An acceleration sensor 21 is mounted on the electron optics system 200 to measure accelerations of the electron optics system 200. On the basis of these measured accelerations, rotations of the electron optics system 200 may be detected and compensated. Any other

sensor suitable to determine rotations of the electron optics system 200 may also be applied.

[0064] A third interferometer sensor 22 is provided to determine with a third measurement beam 23 a position of the object table 3 in a third measurement direction, perpendicular to the x-direction and the z-direction, i.e. the y-direction. The third measurement beam 23 is reflected on a third reflective surface 24 on the object table 3. The third reflective surface 24 extends in the x-z plane, i.e. perpendicular to the y-direction. The third interferometer sensor 22 is arranged at a distance from the object table 3 to allow movement of the object table 3 in the y-direction. The third interferometer sensor 22 may be mounted on any suitable support, for example a vibration isolated support frame.

[0065] It is remarked that a reference beam of the third interferometer sensor 22 may be directed to and reflected on a third reflective reference surface on the electron optics system 200 so that the third interferometer sensor 22 directly measures the relative displacement between the object table 3 and the electron optics system 200.

[0066] The first interferometer sensor 9, the second interferometer sensor 10 and the third interferometer sensor 22 provide sufficient measurement data to determine a position of the object table 3 in three degrees of freedom, i.e. the x-direction, y-direction and the z-direction. When desired further interferometer sensors or other sensor devices may be provided to measure rotation of the object table 3 about an axis extending in the x-direction, y-direction and/or z-direction. Preferably, the position measurement system 5 comprises at least six interferometer sensors to determine a position and rotation of the object table 3 in all six degrees of freedom.

[0067] The interferometer sensors 9, 10, 22 can determine the position of the object table 3 with a relatively fast measurement rate compared with a measurement rate of the first position sensor 8 used to directly measure a height level of a substrate 190 supported on the object table 3. But the interferometer sensors 9, 10 measure the height position of the substrate 190 on the object table 3 indirectly, i.e. the interferometer sensors 9, 10 measure a relative height displacement of the object table 3 and on the basis of this measurement a height position of the substrate is calculated. However, certain local characteristics of the substrate 190, such as height differences due to thickness or unflatness of the substrate 190, cannot be measured by the interferometer sensors 9, 10, and will therefore not be taken into account when the height position of the substrate 180 is only determined on the basis of the measurement of the interferometer sensors 9, 10. However, since the first position sensor 8 directly measures the height of the upper surface of the substrate 190, these local characteristics of the substrate 190 are taken into account in the measurements of the first position sensor 8.

[0068] Therefore, in accordance with the invention, the measurement results of both the first position sensor 8 and the interferometer sensors 9, 10, 22 are used in the position control system in order to properly align the substrate 190 supported on the object table 3 with respect to the electron optics system 200.

[0069] Figure 6 shows a control scheme for controlling the position of a target portion of the substrate 190 with respect to the electron optics system 200, such that the electron beam emitted by the electron

optics system 200 can be focused on the upper surface of the substrate 190 to inspect the substrate 190. The control scheme comprises a master control loop 50 and a slave control loop 51. The controller 6 comprises a master controller 52 arranged in the master control loop 50 and a slave controller 53 arranged in the slave control loop 51.

5 [0070] A set-point generator 54 provides a set-point sp for the height position of the substrate 190, i.e. a desired height position of the substrate 190, in particular a target portion thereof, with respect to the electron optics system 200. The set-point sp is compared with the height position h_1 as measured by the first position sensor 8. On the basis of this comparison the master controller 52 provides a slave set-point signal ssp as input signal for the slave control loop 51. In the slave control loop 51 the slave set-point signal ssp is compared with the vertical position of the substrate 190 determined on the basis of the measurements of the first interferometer sensor 9 and the second interferometer sensor 10.

[0071] The slave controller 53 provides an actuation signal a that is used to actuate the at least one actuator 7 to move the object table 3 to a desired height position h .

10 [0072] Thus, in the slave control loop 51, the relatively fast measurement of the height position of the object table 3 is used to control the height position h of the substrate 190. Due to the fast measurement rate of the first and second interferometer sensors 9, 10, the bandwidth of the slave control loop is high, for example $> 300\text{Hz}$.

15 [0073] Simultaneously, the direct but less fast measurements of the first position sensor 8 are used in the master controller 52 to update the slave set-point ssp that is used as input for the slave control loop 51.

20 [0074] It has been found that the master-slave configuration as shown in Figure 6 provides an advantageous way of controlling the height position of the substrate 190 with respect to the electron optics system 200, in which the characteristics of both the first position sensor 8 and the first and second interferometer sensors 9, 10 are advantageously used.

25 [0075] Figure 7 shows an alternative embodiment of a position measurement system 5, in particular in the configuration of the interferometer sensors. The position measurement system 5 comprises a first interferometer sensor 28 and a second interferometer sensor 29. The first interferometer sensor 28 provides a first measurement beam 11 to measure a relative displacement between the first reflective surface 13 and the first interferometer sensor 28. Correspondingly, the second interferometer sensor 29 provides a second measurement beam 15 to measure a relative displacement between the second reflective surface 17 and the second interferometer sensor 29. In the position measurement system 5 shown in Figure 7, the reflective reference surfaces of the first interferometer sensor 28 and the second interferometer sensor 29 are integrated in the first interferometer sensor 28 and the second interferometer sensor 29, respectively. As a result, the first interferometer sensor 28 and the second
30 interferometer sensor 29 do not directly measure a relative displacement between the object table 3 and the electron optics system 200, but between the object table and the respective first interferometer sensor 28 or second interferometer sensor 29.
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[0076] To determine the position of the electron optics system 200 a first additional interferometer sensor 30 and a second additional interferometer sensor 31 are provided. The first additional interferometer sensor 30 provides a first additional measurement beam 712 directed perpendicular to the first reflective reference surface 714 of the electron optics system 200. The second additional
5 interferometer sensor 31 provides a second additional measurement beam 716 directed perpendicular to the second reflective reference surface 718 of the electron optics system 200. The first interferometer sensor 28, the second interferometer sensor 29, the first additional interferometer sensor 30 and the second additional interferometer sensor 31 are preferably mounted on the same frame such that the relative positions of the interferometer sensors 28, 29, 30, 31 remain the same.

10 [0077] The combination of the first interferometer sensor 28, the second interferometer sensor 29, the first additional interferometer sensor 30 and the second additional interferometer sensor 31 enables the position measurement system 5 to determine, in x-direction and z-direction, a position of the object table 3 with respect to the electron optics system 200. This measured position can be used in the slave control loop 51 as shown in Figure 6.

15 [0078] The first additional measurement beam 712 and the second additional measurement beam 716 may be arranged to have substantially equal lengths. This makes the x displacement measurement in this embodiment insensitive to displacements of the reflective reference surfaces 714, 718 with an equal magnitude and the opposite signs such as a homogeneous expansion of the electron optics system 200 in x-direction.

20 [0079] An important advantage of the embodiment of Figure 7 is that measurement directions of the first additional measurement beam 712 and the second additional measurement beam 716 intersect at the location of interest 20 of the electron optics system 200. As a result, the position measurement may not need a compensation of an Abbe error as described above with respect to the embodiment of Figure 5. However, the position measurement system 5 needs additional interferometer sensors 30, 31 to
25 measure a position of the electron optics system 200.

[0080] Figure 8 shows another alternative embodiment of the position measurement system 5, in particular in the configuration of the interferometer sensors. The first interferometer sensor 809 provides a first measurement beam 11 and a first reference beam 812. The first measurement beam 11 is directed in a first measurement direction to a first reflective surface 13 on the object table 3. The first reference
30 beam 812 is directed in a first reference beam direction, which is preferably parallel to the horizontal plane, to a first reflective reference surface 814 provided on a first reflective element mounted on the metrology frame 300.

[0081] The second interferometer sensor 810 provides a second measurement beam 15 and a second reference beam 816. The second measurement beam 15 is directed in a second measurement direction
35 to a second reflective surface 17 on the object table 3. The second reference beam 816 is directed in a second reference beam direction, which is preferably parallel to the horizontal plane, to a second reflective reference surface 818 provided on a second reflective element mounted on the metrology

frame 300.

[0082] The first reference beam 812 and the second reference beam 816 may be arranged to have substantially equal lengths. This makes the x displacement measurement in this embodiment insensitive to displacements of the reflective reference surfaces 814, 818 with an equal magnitude and the opposite signs such as a homogeneous expansion of the reference beam 300 in x-direction.

[0083] Figure 9 shows yet another alternative embodiment of the position measurement system 5, in particular in the configuration of the interferometer sensors. The first interferometer sensor 909 provides a first measurement beam 11 and a first reference beam 912. The first measurement beam 11 is directed in a first measurement direction to a first reflective surface 13 on the object table 3. The first reference beam 912 is directed in a first reference beam direction to a first reflective reference surface 914 provided on a first reflective element mounted on the metrology frame 300. The first measurement direction and the first reference beam direction are parallel to each other. This makes position measurements by the first interferometer sensor 9 insensitive to a displacement of the first interferometer sensor 9.

[0084] The second interferometer sensor 910 provides a second measurement beam 15 and a second reference beam 916. The second measurement beam 15 is directed in a second measurement direction to a second reflective surface 17 on the object table 3. The second reference beam 916 is directed in a second reference beam direction to a second reflective reference surface 918 provided on a second reflective element mounted on the metrology frame 300. The second measurement direction and the second reference beam direction are parallel to each other. This makes position measurements by the second interferometer sensor 910 insensitive to a displacement of the second interferometer sensor 910.

[0085] The first reference beam 912 and the second reference beam 916 may be arranged to have substantially equal lengths. This makes the x displacement measurement in this embodiment insensitive to displacements of the reflective reference surfaces 914, 918 with an equal magnitude and the opposite signs such as a homogeneous expansion of the reference beam 300 in x-direction.

[0086] It is remarked that in yet another alternative embodiment the first and second interferometer sensors may be arranged at a higher height level than the first reflective surfaces and the second reflective surface, such that the first and second measurement beam have a vertical downwards component, similar to the first and second additional interferometer sensor 30, 31 of Figure 7. In such embodiment, the reference beams of the first and second interferometer sensors may be directed to and reflected on first and second reflective reference surfaces on the electron optics system 200 to directly measure a relative displacement between the object table 3 and the electron optics system 200. Alternatively, additional interferometer sensors may be provided to measure a relative displacement of the electron optics system 200 with respect to a first reference frame on which the first interferometer sensor and the first additional interferometer are mounted and a second reference frame on which the second interferometer sensor and the second additional interferometer are mounted.

[0087] Further embodiments may be described in the following clauses:

1. A stage apparatus comprising:

an object table comprising an supporting surface, the object table configured to support a substrate on the supporting surface;

a positioning device configured to position the object table;

5 a position measurement system comprising a position sensor configured to measure a height position of the object table parallel an first axis, the first axis being substantially perpendicular to the supporting surface, the position sensor comprising an interferometer measurement system having an interferometer sensor,

10 wherein a measurement beam of the interferometer sensor is configured to irradiate a reflective surface of the object table in a measurement direction, the measurement direction having a first component parallel to the first axis and a second component parallel to a second axis, the second axis being substantially perpendicular to the first axis.

2. The stage apparatus according to clause 1, the position measurement system further comprising:

15 a second position sensor configured to measure a further height position of the substrate parallel to the first axis.

3. The stage apparatus according to clause 2, the second position sensor being configured to measure the further height position directly on the substrate.

20 4. The stage apparatus according to clause 2 or 3, wherein the stage apparatus is configured to measure the further height position of the substrate using the second position sensor at a lower measuring rate compared to a measuring rate of the position sensor.

5. The stage apparatus according to any of clause 2 to 4, wherein the stage apparatus is configured to measure the further height position of the substrate using the second position sensor at a higher measuring accuracy compared to a measuring accuracy of the position sensor.

25 6. The stage apparatus according to any of clause 2 to 5, further comprising:

a controller to provide an actuation signal; and

at least one actuator configured to adjust the height position of the object table on the basis of the actuation signal,

30 wherein the controller comprises a master-slave configuration having a master control loop and a slave control loop, wherein in use, in the slave control loop, the position sensor is used to control the further height position of the substrate, and wherein in use, in the master control loop, the second position sensor is used to provide a set-point for the slave control loop.

7. The stage apparatus according to any of clause 1 to 6, wherein the reflective surface is arranged substantially perpendicular to the measurement direction of the interferometer sensor.

35 8. The stage apparatus according to any of clause 1 to 7, wherein the measurement direction and a reference beam direction of a reference beam of the interferometer sensor are substantially parallel to each other.

9. The stage apparatus according to any of clause 1 to 8, wherein a side surface of the object table being a surface of the object table not supporting the substrate is configured to form the reflective surface of the object table, or wherein a reflective surface element mounted on the side surface of the object table is configured to form the reflective surface of the object table.

5 10. The stage apparatus according to any of clause 1 to 9, wherein the position measurement system and/or the controller comprise a correction map of the reflective surface of the object table configured to correct for differences in reflective behaviors at different locations of the reflective surface of the object table.

10 11. The stage apparatus according to any of clause 1 to 10, wherein the first component of the measurement direction is directed to a first direction from the object table to the substrate parallel to the first axis, or wherein the first component of the measurement direction is directed to a second direction from the substrate to the object table parallel to the first axis.

12. The stage apparatus according to any of clause 1 to 11, wherein an angle between the measurement direction and the second axis is between 2 and 20 degrees.

15 13. The stage apparatus according to any of clause 1 to 12, where in the reference beam is substantially parallel to the second axis.

14. The stage apparatus according to any of clause 1 to 13, wherein the interferometer measurement system comprises a second interferometer sensor, wherein a second measurement beam of the second interferometer sensor is directed in a second measurement direction to a second reflective surface of the object table, the second measurement direction having a third component parallel to the first axis and a fourth component parallel to a third axis, the third axis being substantially perpendicular to the first axis.

15. The stage apparatus according to clause 14, wherein the reflective surface and the second reflective surface are arranged at opposite sides of the object table.

25 16. The stage apparatus according to clause 15, wherein the reflective surface and the second reflective surface are arranged at opposite sides of the object table with respect to the first axis.

17. The stage apparatus according to any of clause 14 to 16, wherein the reference beam and a second reference beam of the second interferometer sensor have a substantially equal length.

18. The stage apparatus according to any of clause 14 to 17, wherein the third axis is the second axis.

19. The stage apparatus according to any of clause 14 to 18, wherein the first component of the measurement direction and the third component of the second measurement direction have a same direction, and wherein the second component of the measurement direction and the fourth component of the second measurement direction have opposite directions.

20. The stage apparatus according to any of clause 14 to 19, wherein the measurement

direction of the measurement beam and the second measurement direction of the second measurement beam intersect at a target position on the substrate.

21. The stage apparatus according to any of clause 14 to 20, wherein the position measurement system comprises a third interferometer sensor, wherein a third measurement beam of the third interferometer sensor is directed in a third measurement direction to a third reflective surface of the object table, the third measurement direction only having a fifth component parallel to a fourth axis, the fourth axis being perpendicular to the first axis and the third axis.

22. The stage apparatus according to any of clause 2 to 21, wherein the second position sensor is an optical sensor.

23. The stage apparatus according to any of clause 1 to 22, wherein the position measurement system is configured to determine a position of the object table in six degrees of freedom.

24. A particle beam apparatus comprising:
a particle beam generator configured to provide a particle beam to a substrate; and
the stage apparatus according to any of clause 1 to 23.

25. The particle beam apparatus according to clause 24,
wherein a reflective reference surface of the interferometer sensor configured to be irradiated by the reference beam is arranged on the particle beam generator.

26. The particle beam apparatus according to clause 24,
wherein the reflective reference surface is arranged on a frame supporting the particle beam generator.

27. The particle beam apparatus according to any of clause 24 to 26,
wherein the reference beam direction and a second reference beam direction of the second reference beam intersect at a second target position on the particle beam generator.

28. The particle beam apparatus according to any of clause 24 to 27,
wherein the optical sensor is mounted on the particle beam generator or the frame supporting the particle beam generator.

29. The particle beam apparatus according to any of clause 24 to 28,
wherein the particle beam apparatus is an e-beam apparatus and the particle beam is an electron beam.

30. The e-beam apparatus according to clause 29, wherein the e-beam apparatus is an e-beam inspection apparatus.

31. An apparatus comprising the stage apparatus according to any of clause 1 to 23, the particle beam apparatus according to any of clause 24 to 29, or the e-beam apparatus according to clause 30, further comprising a vacuum chamber.

32. An apparatus comprising the stage apparatus according to clause 1 to 23 wherein the apparatus is a lithography apparatus or a metrology apparatus.

33. The apparatus according to clause 32, further comprising a projection optical system, wherein the reflective reference surface of the interferometer sensor configured to be irradiated by the reference beam is arranged on the projection optical system.

34. The apparatus according to clause 32, further comprising the projection optical system, wherein the reflective reference surface of the interferometer sensor configured to be irradiated by the reference beam is arranged on a frame supporting the projection optical system.

35. The apparatus according to clause 32 or 34, wherein the reference beam direction and the second reference beam direction of the second reference beam intersect at a second target position on the projection optical system.

36. The apparatus according to any of clause 32 to 35, wherein the optical sensor is mounted on the projection optical system or the frame supporting the projection optical system.

[0088] The above describes the electron beam inspection apparatus according to various embodiments separately. A combination of the various embodiments may however be combined into a single electron beam inspection apparatus.

[0089] Although the embodiments described in the specification are mainly related to an e-beam inspection tool or apparatus, the applications of this invention may not be limited to these particular embodiments. The invention may be applied not only to the e-beam inspection tools but to any other kinds of e-beam tools such as CD-SEM, EBDW(E-Beam Direct Writer), EPL(E-beam Projection Lithography, and E-beam defect verification tool, any kinds of tools with a vacuum chamber, lithography apparatus, and metrology apparatus.

[0090] Although the present invention has been explained in relation to its preferred embodiment, it is to be understood that other modifications and variation can be made without departing the spirit and scope of the invention as hereafter claimed.

WHAT IS CLAIMED IS:

1. A stage apparatus comprising:

an object table comprising an supporting surface, the object table configured to support a substrate on
5 the supporting surface;

a positioning device configured to position the object table;

a position measurement system comprising a position sensor configured to measure a height position
of the object table parallel to a first axis, the first axis being substantially perpendicular to the
supporting surface, the position sensor comprising an interferometer measurement system having an
10 interferometer sensor,

wherein a measurement beam of the interferometer sensor is configured to irradiate a reflective
surface of the object table in a measurement direction, the measurement direction having a first
component parallel to the first axis and a second component parallel to a second axis, the second axis
being substantially perpendicular to the first axis.

2. The stage apparatus according to claim 1, the position measurement system further comprising:

a second position sensor configured to measure a further height position of the substrate parallel to the
first axis;

a controller to provide an actuation signal; and

at least one actuator configured to adjust the height position of the object table at least partially based
on the actuation signal,

wherein the stage apparatus is configured to measure the further height position of the substrate using
the second position sensor at a lower measuring rate compared to a measuring rate of the position
sensor, and

wherein the controller comprises a master-slave configuration having a master control loop and a
slave control loop, wherein in use, in the slave control loop, the position sensor is used to control the
further height position of the substrate, and wherein in use, in the master control loop, the second
position sensor is used to provide a set-point for the slave control loop.

3. The stage apparatus according to claim 1,

wherein the reflective surface is arranged substantially perpendicular to the measurement direction of
the interferometer sensor.

4. The stage apparatus according to claim 1,

wherein an angle between the measurement direction and the second axis is between 2 and 20
degrees.

5. The stage apparatus according to claim 1,
wherein a reference beam direction of a reference beam of the interferometer sensor is substantially parallel to the measurement beam or is substantially parallel to the second axis.

5 6. The stage apparatus according to claim 1,
wherein a side surface of the object table being a surface of the object table not supporting the
substrate is configured to form the reflective surface of the object table, or wherein a reflective surface
element mounted on the side surface of the object table is configured to form the reflective surface of
the object table.

10

7. The stage apparatus according to claim 1 or 2,
wherein the position measurement system and/or the controller comprise a correction map of the
reflective surface of the object table configured to correct for differences in reflective behaviors at
different locations of the reflective surface of the object table.

15

8. The stage apparatus according to claim 1,
wherein the interferometer measurement system comprises a second interferometer sensor, wherein a
second measurement beam of the second interferometer sensor is directed in a second measurement
direction to a second reflective surface of the object table, the second measurement direction having a
third component parallel to the first axis and a fourth component parallel to a third axis, the third axis
being substantially perpendicular to the first axis.

20

9. The stage apparatus according to claim 8,
wherein the reflective surface and the second reflective surface are arranged at opposite sides of the
object table with respect to the first axis, and
wherein the first component of the measurement direction and the third component of the second
measurement direction have a same direction, and the second component of the measurement
direction and the fourth component of the second measurement direction have opposite directions.

25

10. The stage apparatus according to claim 8,
wherein the reference beam and a second reference beam of the second interferometer sensor have a
substantially equal length.

30

11. The stage apparatus according to claim 8,
wherein the measurement direction of the measurement beam and the second measurement direction
of the second measurement beam intersect at a target position on the substrate.

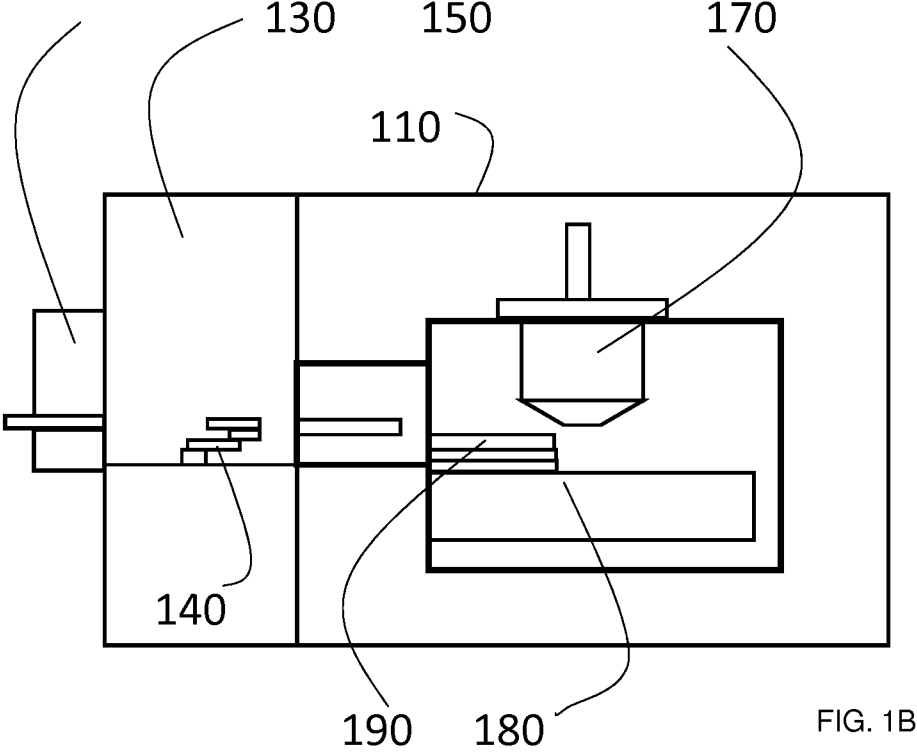
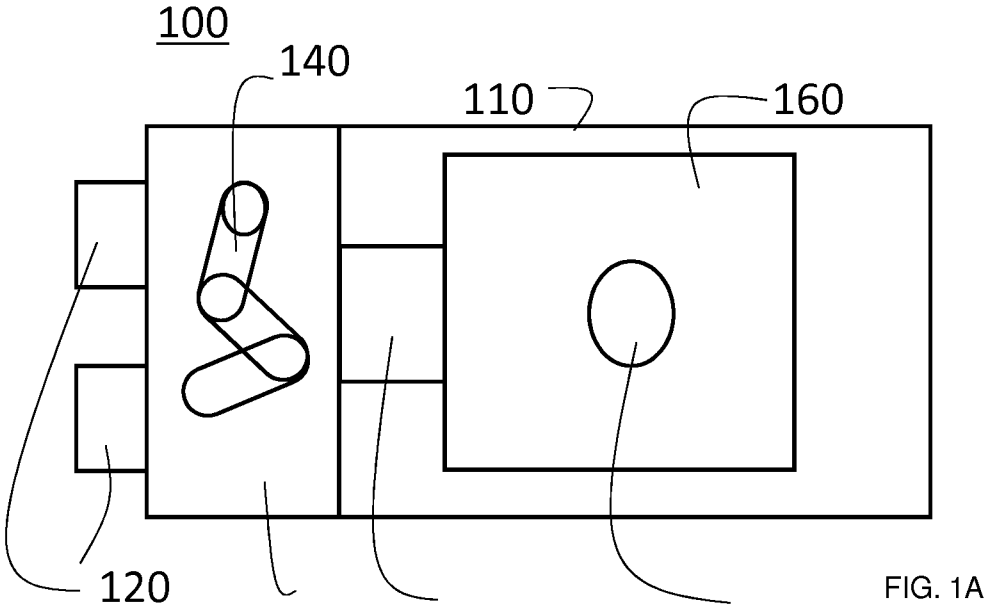
35

12. A particle beam apparatus comprising:
a particle beam generator configured to provide a particle beam on a substrate; and
the stage apparatus according to claim 1,
wherein a reflective reference surface of the interferometer sensor configured to be irradiated by the
5 reference beam is arranged on the particle beam generator.

13. A particle beam apparatus comprising:
the particle beam generator configured to provide the particle beam on the substrate; and
the stage apparatus according to claim 1,
10 wherein the reflective reference surface is arranged on a frame supporting the particle beam generator.

14. A particle beam apparatus comprising:
the particle beam generator configured to provide the particle beam on the substrate; and
the stage apparatus according to claim 8,
15 wherein the reference beam direction and a second reference beam direction of the second reference
beam intersect at a second target position on the particle beam generator.

15. An apparatus comprising the stage apparatus according to claim 1,
wherein the apparatus is a particle beam apparatus, an e-beam apparatus, an e-beam inspection
20 apparatus, a lithography apparatus, a metrology apparatus, or a vacuum apparatus.



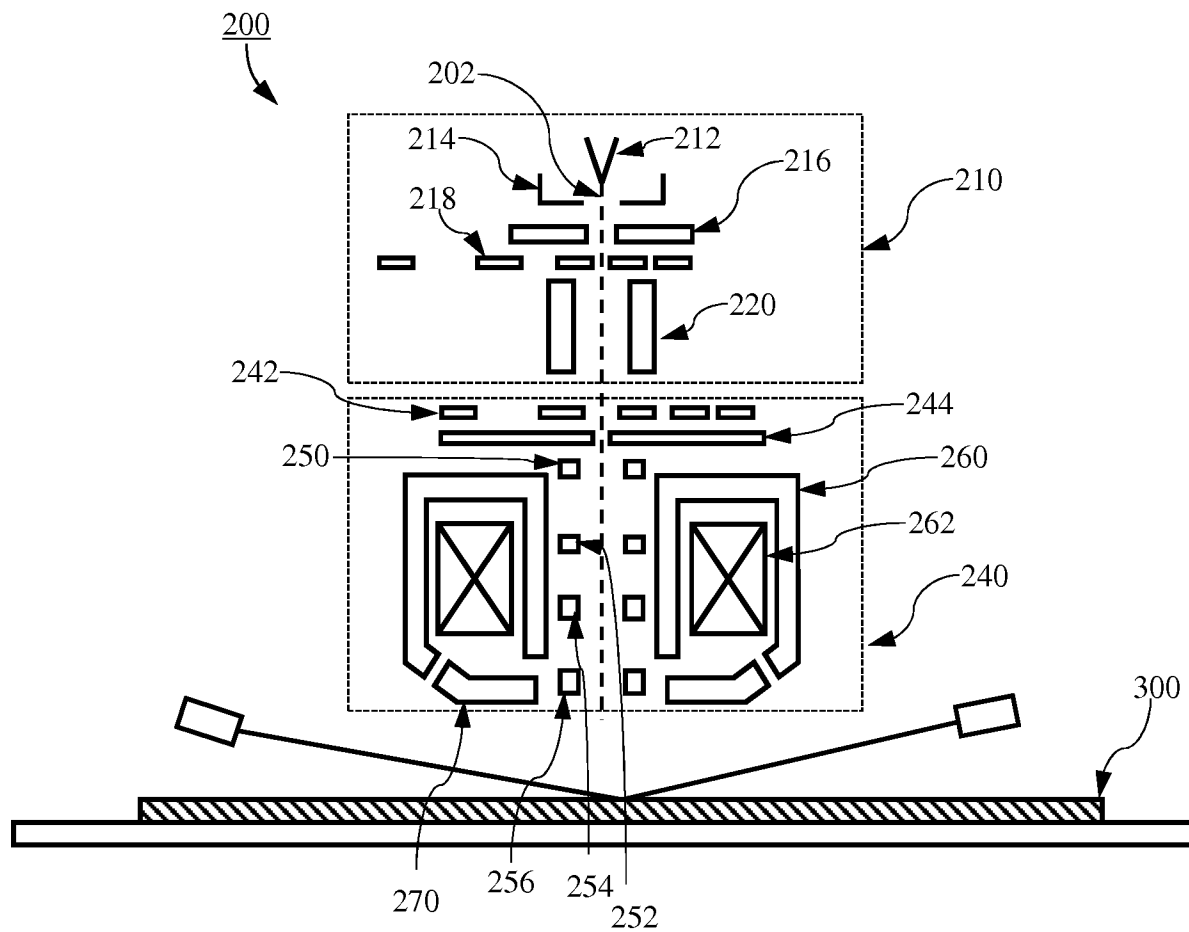


FIG. 2

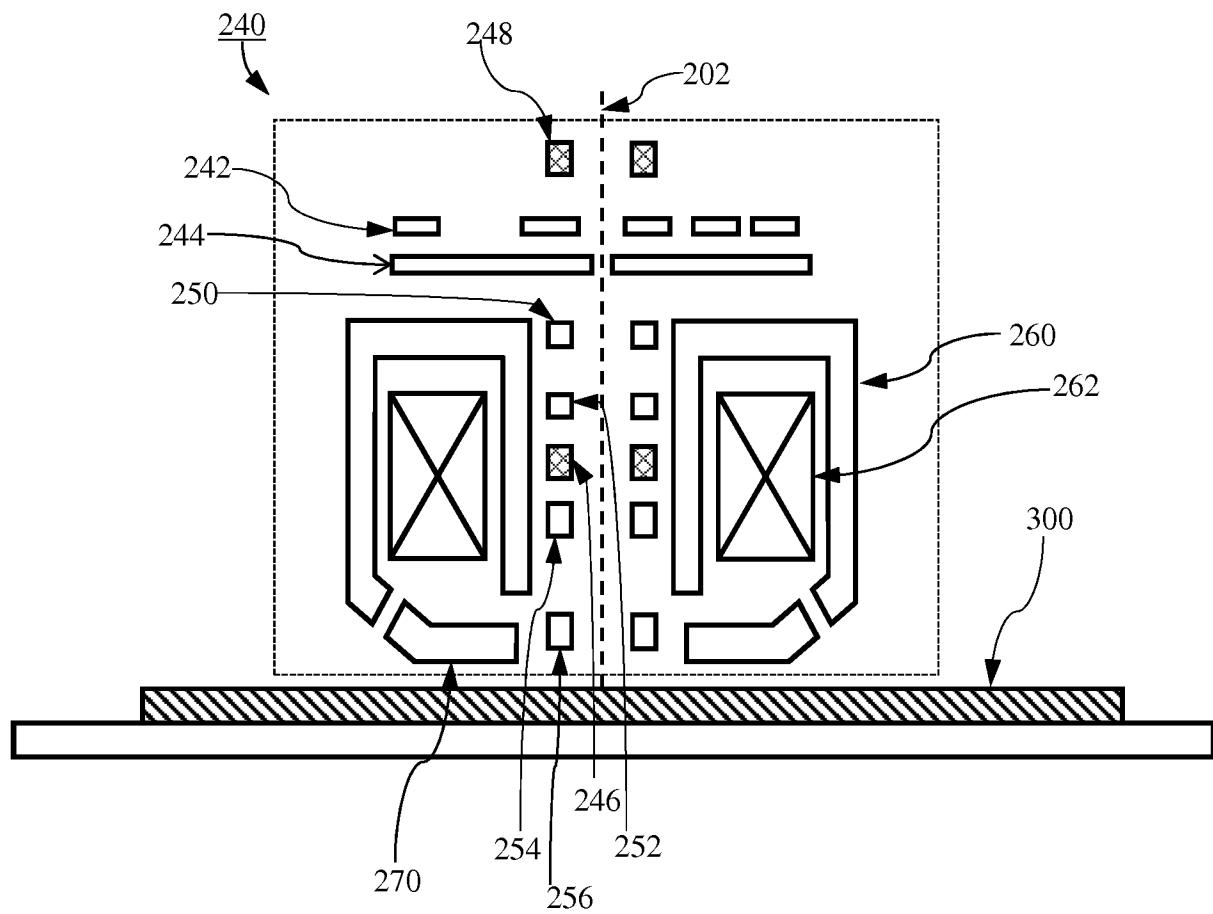


FIG. 3

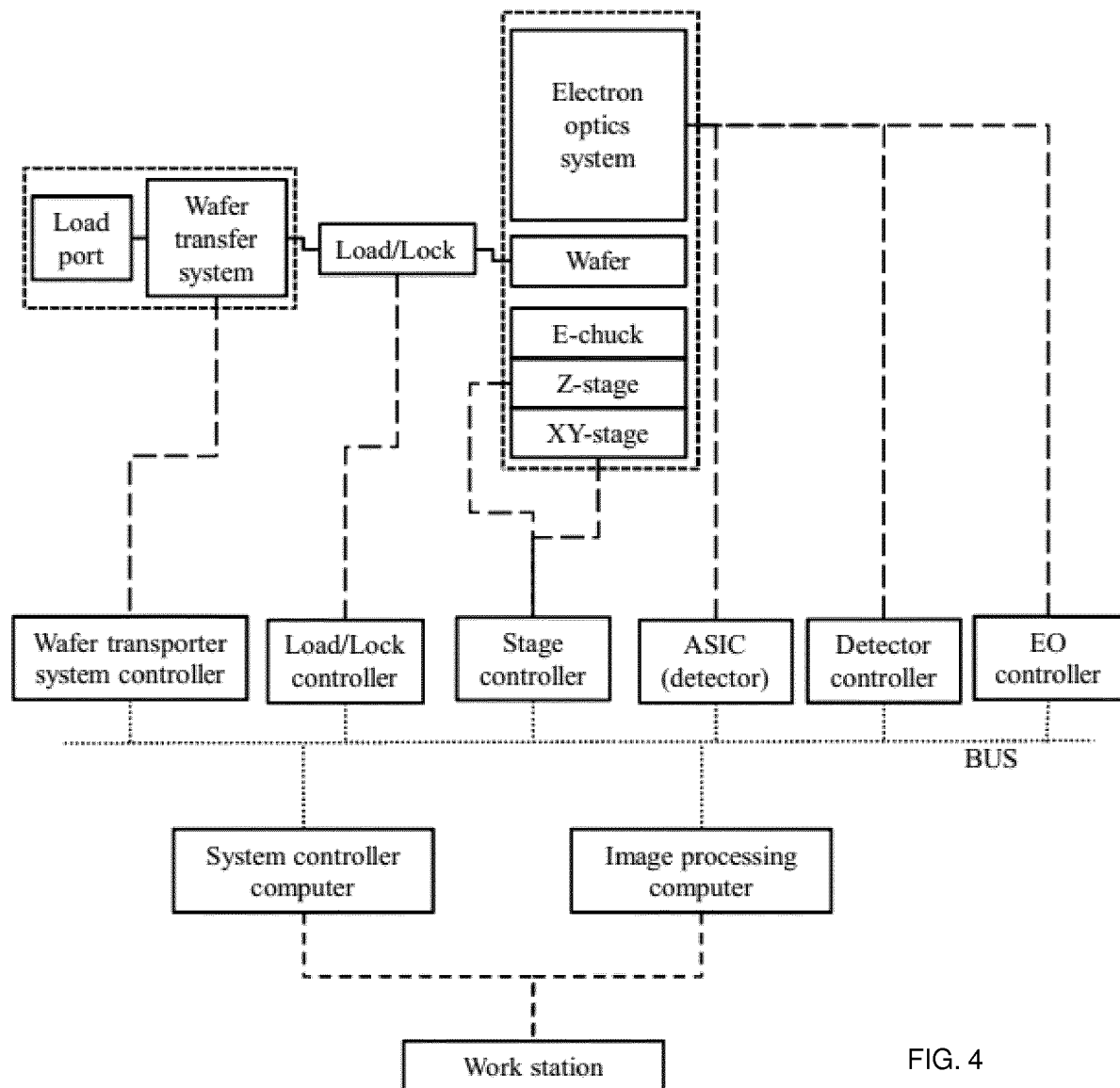


FIG. 4

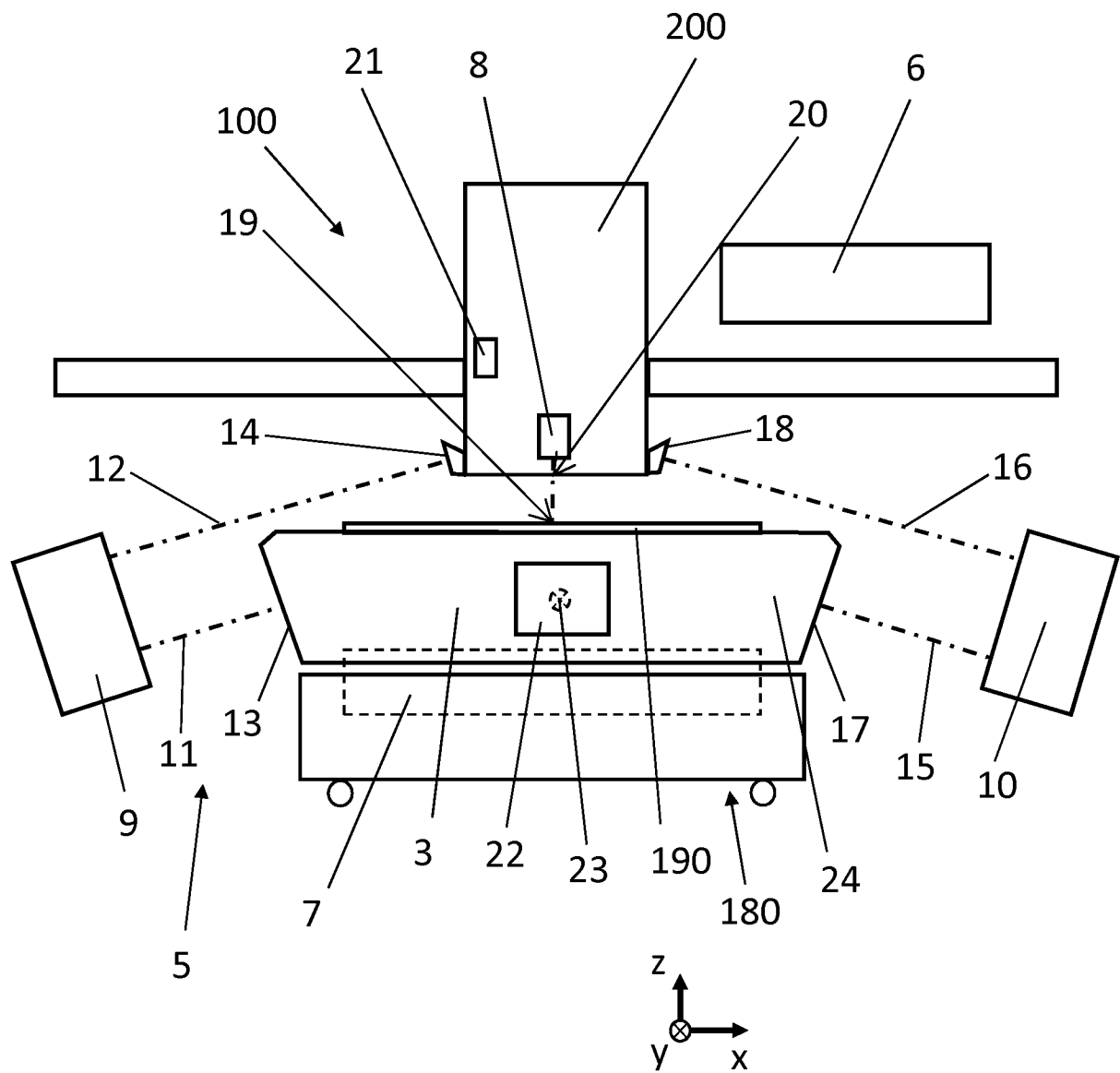


FIG. 5

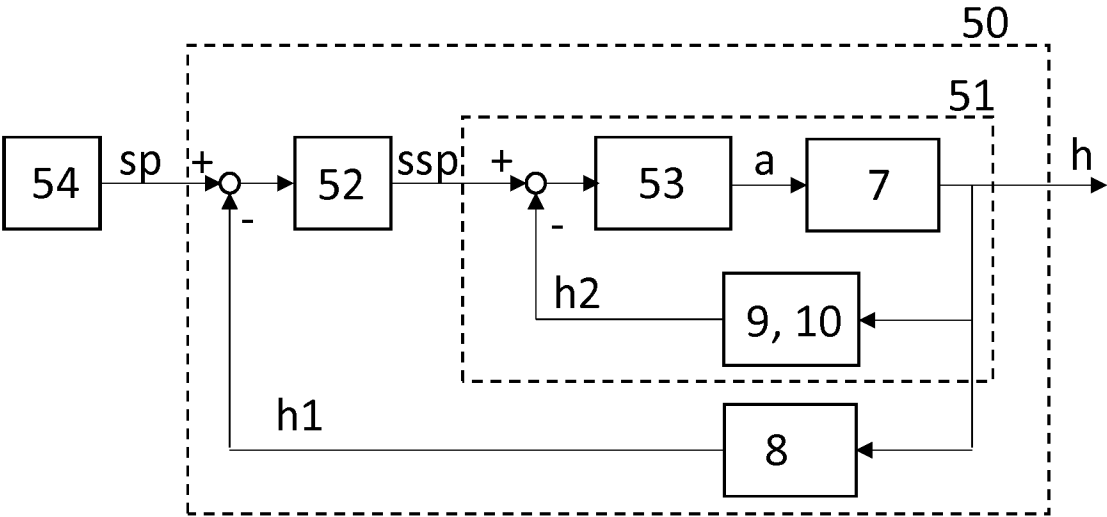


FIG. 6

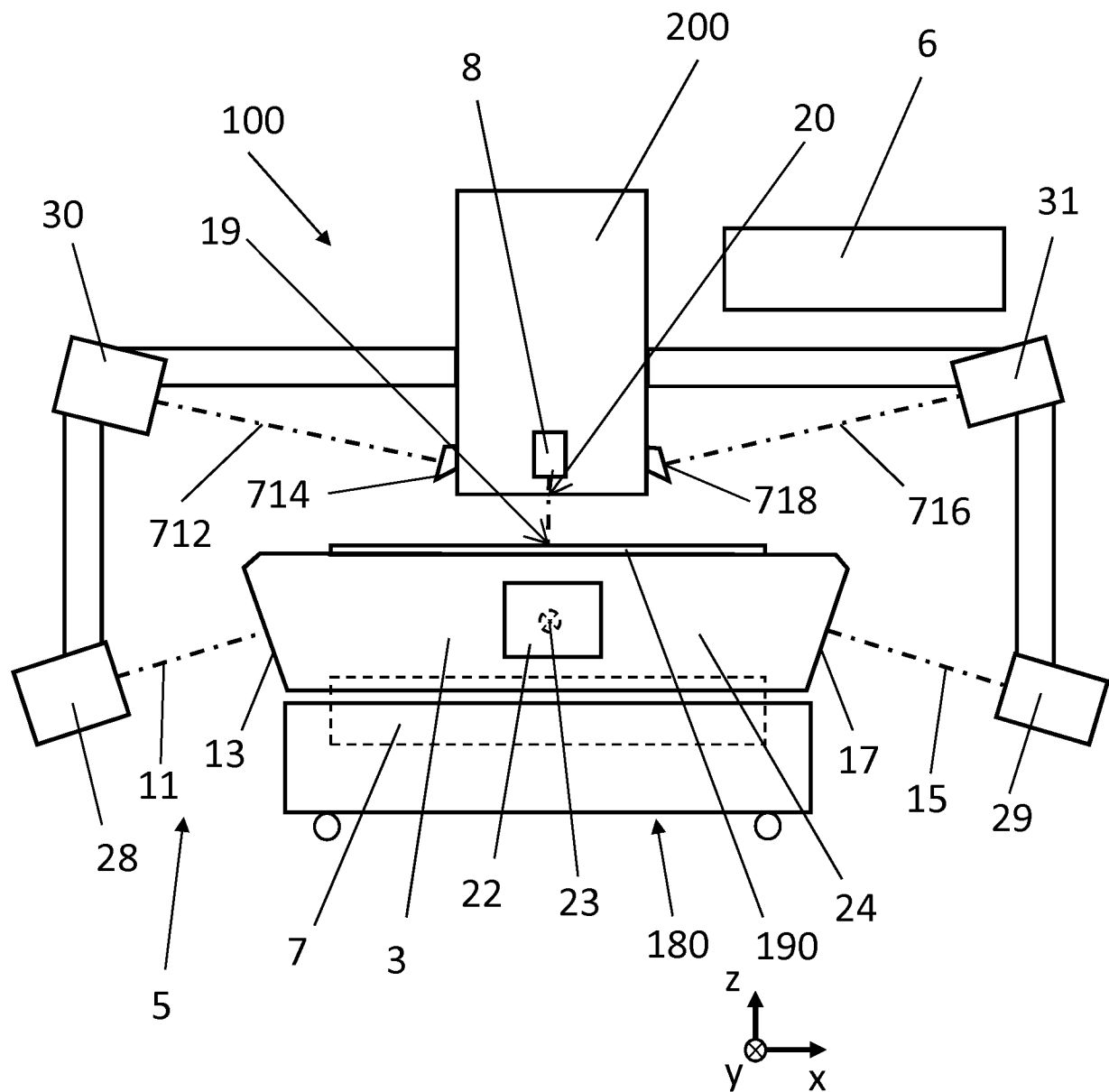


FIG. 7

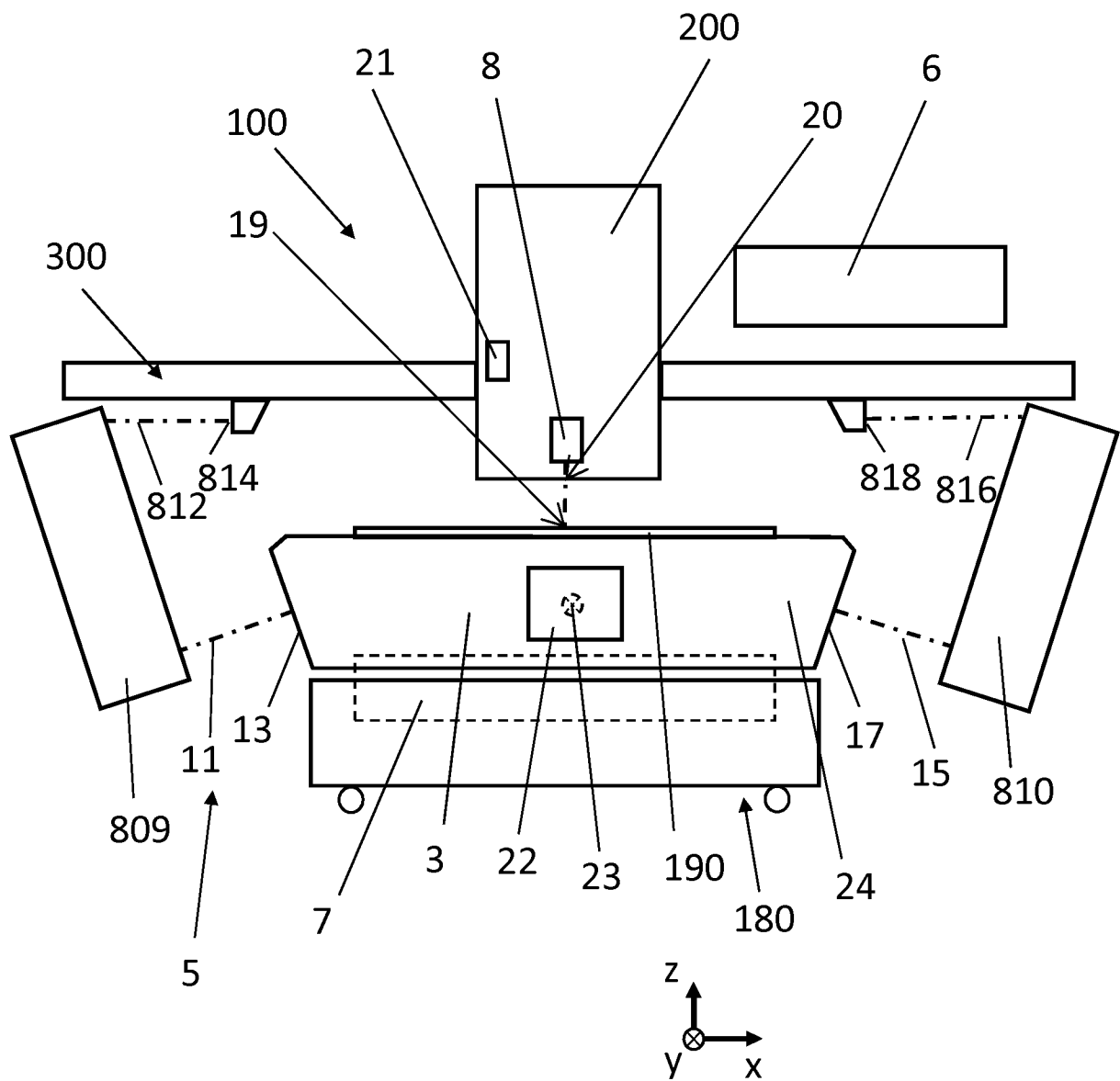


FIG. 8

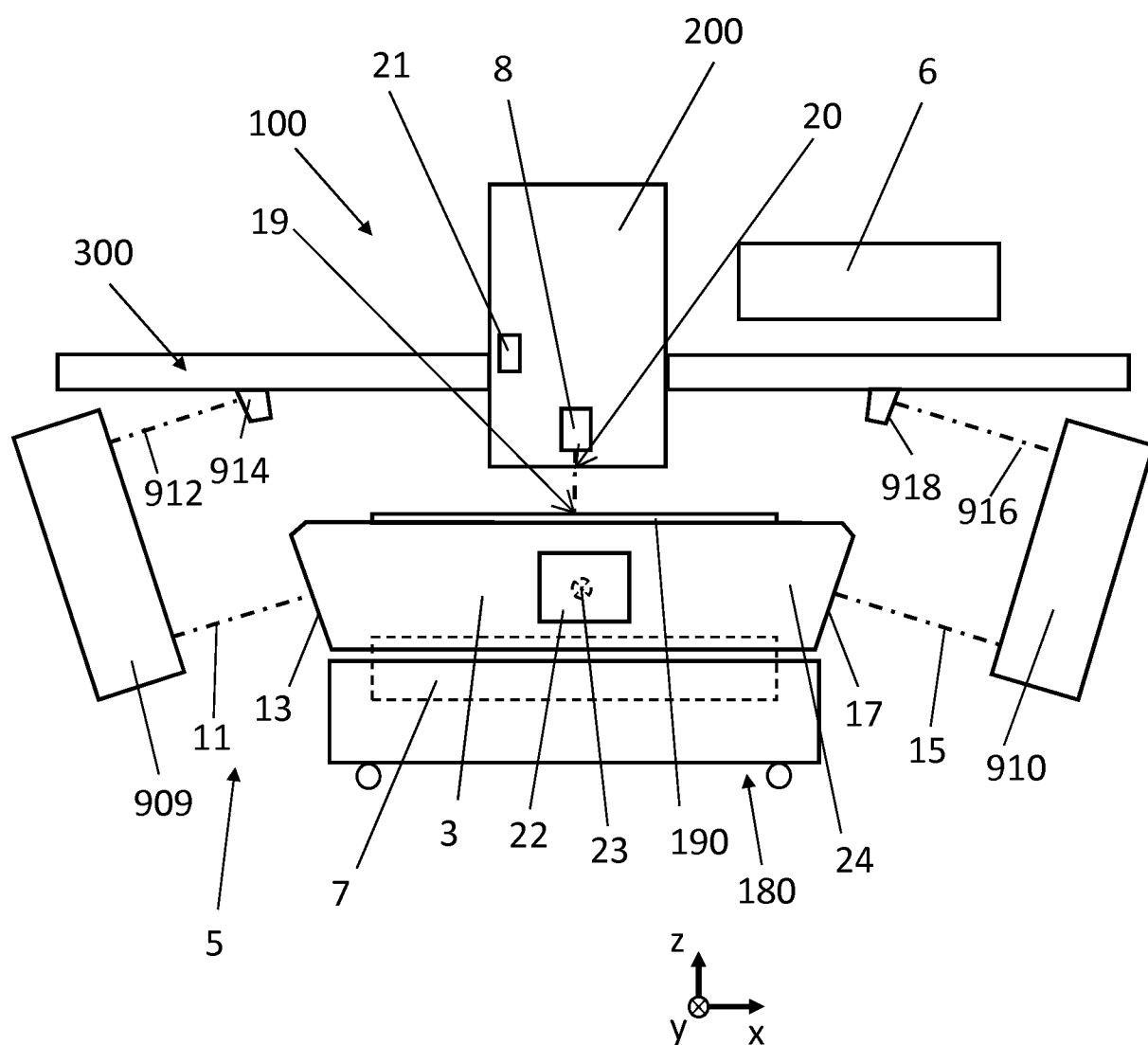


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/076571

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01J37/20
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)
H01J

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/259268 A1 (SCHLUCHTER W C [US]) 24 November 2005 (2005-11-24) abstract paragraphs [0004], [0008] - [0034]; claims 7,17; figures 2-7 -----	1,3-6
A	US 2007/041022 A1 (SCHLUCHTER WILLIAM C [US]) 22 February 2007 (2007-02-22) abstract paragraphs [0016] - [0035]; figures 1,2 -----	1,3-6
A	US 6 084 673 A (VAN DEN BRINK MARINUS A [NL] ET AL) 4 July 2000 (2000-07-04) abstract; figure 1 column 26, lines 36-45 -----	2



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

18 December 2018

Date of mailing of the international search report

04/03/2019

Name and mailing address of the ISA/

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Authorized officer

Lang, Thomas

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2018/076571

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-6

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-6

A stage apparatus comprising an object table comprising an supporting surface, the object table configured to support a substrate on the supporting surface; a positioning device configured to position the object table; a position measurement system comprising a position sensor configured to measure a height position of the object table parallel to a first axis, the first axis being substantially perpendicular to the supporting surface, the position sensor comprising an interferometer measurement system having an interferometer sensor, wherein a measurement beam of the interferometer sensor is configured to irradiate a reflective surface of the object table in a measurement direction, the measurement direction having a first component parallel to the first axis and a second component parallel to a second axis, the second axis being substantially perpendicular to the first axis (claim 1), the position measurement system further comprising a second position sensor configured to measure a further height position of the substrate parallel to the first axis; a controller to provide an actuation signal; and at least one actuator configured to adjust the height position of the object table at least partially based on the actuation signal, wherein the stage apparatus is configured to measure the further height position of the substrate using the second position sensor at a lower measuring rate compared to a measuring rate of the position sensor, and wherein the controller comprises a master-slave configuration having a master control loop and a slave control loop, wherein in use, in the slave control loop, the position sensor is used to control the further height position of the substrate, and wherein in use, in the master control loop, the second position sensor is used to provide a set-point for the slave control loop (claim 2).

2. claim: 7

The stage apparatus according to claim 1, wherein the position measurement system and/or the controller comprise a correction map of the reflective surface of the object table configured to correct for differences in reflective behaviors at different locations of the reflective surface of the object table.

3. claims: 8-11

The stage apparatus according to claim 1, wherein the interferometer measurement system comprises a second interferometer sensor, wherein a second measurement beam of

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

the second interferometer sensor is directed in a second measurement direction to a second reflective surface of the object table, the second measurement direction having a third component parallel to the first axis and a fourth component parallel to a third axis, the third axis being substantially perpendicular to the first axis

4. claims: 12-15

A particle beam apparatus comprising a particle beam generator configured to provide a particle beam on a substrate; and the stage apparatus according to claim 1, wherein a reflective reference surface of the interferometer sensor configured to be irradiated by the reference beam is arranged on the particle beam generator (claim 12); or wherein the reflective reference surface is arranged on a frame supporting the particle beam generator (claim 13); or wherein the interferometer measurement system comprises a second interferometer sensor, wherein a second measurement beam of the second interferometer sensor is directed in a second measurement direction to a second reflective surface of the object table, the second measurement direction having a third component parallel to the first axis and a fourth component parallel to a third axis, the third axis being substantially perpendicular to the first axis, wherein the reference beam direction and a second reference beam direction of the second reference beam intersect at a second target position on the particle beam generator (claim 14); or

an apparatus comprising the stage apparatus according to claim 1, wherein the apparatus is a particle beam apparatus, an e-beam apparatus, an e-beam inspection apparatus, a lithography apparatus, a metrology apparatus, or a vacuum apparatus.

15. An apparatus comprising the stage apparatus according to claim 1, wherein the apparatus is a particle beam apparatus, an e-beam apparatus, an e-beam inspection apparatus, a lithography apparatus, a metrology apparatus, or a vacuum apparatus (claim 15).

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2018/076571

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		NL 1029084	C2 30-11-2007
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		DE 69709584	T2 13-06-2002
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