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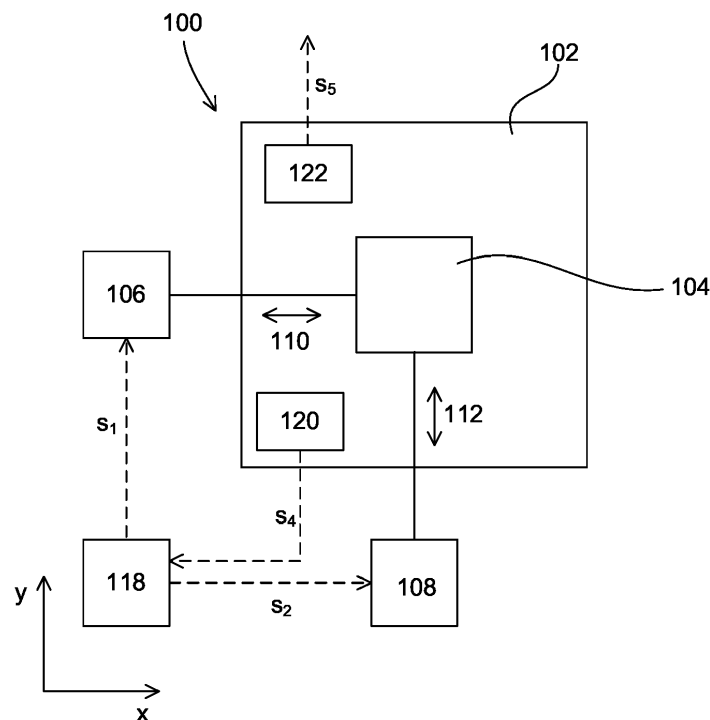
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(54) POLISHING TOOL AND ASSOCIATED METHODS

(57) A new polishing tool comprises: a main support member; a polishing head support member; a first drive mechanism; and a second drive mechanism. The polishing head support member is coupled to the main support member such that the polishing head support member is linearly movable relative to the main support member in a first direction and a second direction that is different to the first direction. The first and second directions may be

mutually orthogonal. The first drive mechanism is operable to move the polishing head support member relative to the main support member in the first direction. The second drive mechanism operable to move the polishing head support member relative to the main support member in the second direction. The new polishing head uses linear actuators rather than a rotary motor and, as a result, is advantageous over known polishing tools.

**Fig. 2A**

Description

FIELD

[0001] The present invention relates to a polishing tool and associated polishing methods. The present invention also relates to an apparatus comprising the polishing tool in which the polishing tool may be supported by a movable member (for example a robotic arm or the like). The polishing tool, apparatus and methods may be particularly suited for extremely precise polishing. Such polishing tool, apparatus and methods may have application in the polishing of optical components, in particular optical components of precision optical apparatus such as, for example, lithographic apparatus.

BACKGROUND

[0002] 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 at a patterning device (e.g., a mask) onto a layer of radiation-sensitive material (resist) provided on a substrate.

[0003] To project a pattern on a substrate a lithographic apparatus may use electromagnetic 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.

[0004] The lithographic apparatus comprises a plurality of high precision optical elements. In particular, in EUV lithographic apparatus the optical components are typically mirrors. For example, a lithographic apparatus typically comprises illumination optics arranged to condition a radiation beam and to project it onto the reticle having a desired spatial and angular distribution. In addition, the lithographic apparatus typically comprises projection optics arranged to receive a portion of the radiation beam that has interacted with the reticle and to project it onto the substrate so as to form a (diffraction-limited) image of the reticle on the substrate.

[0005] Within a lithographic apparatus it is important for the optical components to have precisely controlled surfaces. Any deviations from a target surface shape may result in optical aberrations, leading to undesirable printing errors in the pattern formed on the substrate. It may be desirable to polish the optical components so as to avoid such optical aberrations (or at least to limit their effect on the image formed on the substrate).

[0006] It may be desirable to provide new polishing tools, apparatus and polishing methods that at least partially address one or more problems associated with

known arrangements, whether such problems are identified herein or otherwise.

SUMMARY

[0007] According to a first aspect of the present disclosure there is provided a polishing tool suitable for polishing a semiconductor processing apparatus component, the polishing tool comprising: a main support member; a polishing head support member, wherein the polishing head support member is coupled to the main support member such that the polishing head support member is linearly movable relative to the main support member in a first direction and a second direction that is different to the first direction; a first drive mechanism operable to move the polishing head support member relative to the main support member in the first direction; and a second drive mechanism operable to move the polishing head support member relative to the main support member in the second direction.

[0008] The main support member may be referred to as a machine mounting plate and may allow the polishing tool to be connected to a machine such as, for example, a robotic arm or the like. The polishing head support member may be arranged to support a polishing head. Such a polishing head may comprise an abrasive material as is known in the art such as, for example, a polishing foil. In use, the polishing tool may be used to polish a work piece (for example a surface of an optical component such as a mirror).

[0009] Typically, in known polishing tools, a rotary drive mechanism is provided such that the polishing head can be moved (for example using a rotary motor) relative to a work piece but wherein the axis of rotation of the polishing head is offset from an axis of the polishing head itself. Therefore, the polishing head does not rotate about its axis. Rather the polishing head as a whole describes a circular motion. Such an arrangement may be referred to as an eccentric arrangement (since the axis of rotation of the polishing head is offset from an axis of the polishing head itself). In known arrangements, the movement of the polishing head is effected by a rotary actuator (for example a rotary motor). For example, a rotary member is provided that can be rotated by a motor and a mechanical linkage is provided between the rotary member and the polishing head.

[0010] Eccentric polishing head arrangements are desirable. In particular, it is particularly desirable for an orientation of the polishing head to remain fixed with respect to a work piece that it is polishing (while the whole polishing head moves in a circular fashion). Such an arrangement has a number of advantages and is particularly well-suited for high precision processes. Some known polishing arrangements comprise a mechanism that is arranged to constrain, or pin, the polishing head so as to limit rotation of the polishing head about its own axis. However, there are a number of problems with such known arrangements.

[0011] In contrast, the polishing tool according to the first aspect comprises linear couplings and linear drive mechanisms. The coupling between the polishing head support member and the main support member allows the polishing head support member to move relative to the main support member in the first and second directions. With suitable oscillatory actuation of these two couplings, the polishing head support member (and any polishing head supported thereby) can be rotated relative to the main support member in an eccentric manner (i.e. rotated about an axis that is offset from the polishing head itself). Such an arrangement has a number of advantages over known arrangements.

[0012] First, the polishing tool according to the first aspect provides an arrangement wherein the polishing head can be moved in a circular fashion and wherein an orientation of the polishing head remains perfectly fixed with respect to the work piece (with no rotation of such orientation). In particular, the orientation of the polishing head remains fixed at all points on the generally circular motion of the polishing head. Advantageously, this ensures that the speed of the polishing head is uniform across the surface of the polishing head and around the entire circular motion, which results in an extremely high precision polishing process. In contrast, in most known arrangements, the mechanical linkage between the (rotary) drive motor and the polishing head is complex and, in some known arrangements, the polishing head is not sufficiently constrained so as to prevent any rotation of the polishing head about its axis. As a result, the orientation of the polishing head does not remain fixed with respect to the work piece. For example, the orientation of the polishing head may be permitted to rotate through an angle of the order of 10° to 15°.

[0013] Second, since the first and second drive mechanisms are operable to move the polishing head support member relative to the main support member in two linear directions, a size of the circular motion described by the polishing head can be easily controlled and/or varied. For example, if the first and second drive mechanisms control the polishing head support member so as to exhibit synchronized simple harmonic motion relative to the main support member in the two linear directions (the first and second directions) then the entire polishing head will move in a circular fashion. By controlling the amplitude of the harmonic motion in the two linear directions the size of this circle can be controlled. Advantageously, this may allow for a more easily adaptable polishing tool. It may even be possible to dynamically control the size of the circle during the polishing process. For example, a first size of circular motion may be used for one portion of the work and a second size of circular motion may be used for another portion of the work. Such a variable polishing tool allows surfaces to be polished more economically. For example, a large circular motion may be used in a central portion of the work (high relative speed) and at the edge of the work the circular motion can be changed to a smaller motion without any reconfiguration

of the polishing tool. Edge effects can be further reduced using such a method.

[0014] Third, since the first and second drive mechanisms provide independent control over the movement in two independent linear axes, the polishing tool allows for the polishing head to be better controlled with respect to a work piece even in cases when the main support member is moving relative to the work. For example, in general, the main support member may be mounted on a robotic arm or the like, which may be operable to move the polishing tool relative to the work. For example, the polishing tool may be scanned over a surface of the work. In addition, the polishing head support member can be moved (using the first and second drive mechanisms) in a circular fashion relative to the main support member or robotic arm. Suppose the robotic support arm moves the entire polishing tool in the first direction. With such an arrangement, if the first and second drive mechanisms control the polishing head support member so as to exhibit synchronized simple harmonic motion relative to the main support member in the two linear directions then the polishing head will no longer be moving in a perfect circle and the speed of the polishing head relative to the work will no longer be constant around the generally circular motion. Rather, when the circular motion is in the same direction as the movement of the robotic arm the speed of the polishing head will be greater and when the circular motion is in the opposite direction to the movement of the robotic arm the speed of the polishing head will be less. However, by suitable control via the first drive mechanism (with a variable harmonic motion) such effects can be corrected for such that the speed of the polishing head relative to the work remains constant. Advantageously, this increases the consistency of the polishing process.

[0015] Fourth, since there is no rotary coupling, the polishing tool according to the first aspect does not need ball bearings or belt drives. Advantageously, this removes, or at least significantly reduces, external vibrations that result from such ball bearings and belt drives. In contrast, in most known arrangements, the mechanical linkage between the (rotary) drive motor and the polishing head is complex and typically gives rise to a large number of exciting frequencies that are unwanted. Note that a high number of different ball bearings in existing arrangements leads to a large number of exciting frequencies. Each ball bearing has a total of 6 exciting frequencies (including rollover frequencies of the rolling elements over the inner and outer ring). These sources of external vibrations are responsible for the transmission and overshoot or undershoot of the rotary motion in known systems.

[0016] Fifth, due to the complexity of existing arrangements it is difficult to attach sensors to existing polishing tools that can monitor useful process data. In particular, since existing arrangements typically comprise a rotary drive mechanism (for example a rotary member) it can be particularly challenging to run wires or cables to such

sensors (if, for example, they are provided on a rotary part of the polishing tool. In contrast, since the first and second drive mechanisms of the polishing tool according to the first aspect are operable to move the polishing head support member relative to the main support member in two linear directions sensors can be more easily provided to monitor process data. Advantageously, such process data may be used as part of an Industry 4.0 and/or a machine learning system.

[0017] Note that as used herein an axis of the polishing head may be perpendicular to a plane of the polishing head (i.e. perpendicular to the polishing surface or foil).

[0018] The polishing tool may further comprise an intermediate support member. The intermediate support member may be coupled to the main support member such that the intermediate head support member is linearly movable relative to the main support member in the first direction. The polishing head support member may be coupled to the intermediate support member such that the polishing head support member is linearly movable relative to the intermediate support member in the second direction.

[0019] Advantageously, such an arrangement (having three components) can provide for particularly desirable couplings between the main support member and the polishing head support member. For example, it can allow for two separate linear bearings to be provided (one for each of the first and second directions) and/or can better allow for the first and second drive mechanisms to control the position of the polishing head support member relative to the main support member.

[0020] The polishing head support member may be coupled to the main support member via at least one spring member that allows the polishing head support member to be linearly movable relative to the main support member in the first and second directions.

[0021] The polishing head support member may be coupled to the main support member via at least one hinge member that allows the polishing head support member to be linearly movable relative to the main support member in the first and second directions.

[0022] The polishing head support member may be integrally formed with the main support member.

[0023] The polishing head support member may be formed separately from with the main support member and the polishing tool may comprise at least one bearing coupling the polishing head support to the main support member.

[0024] In some embodiments, the polishing tool comprises two bearings coupling the polishing head support to the main support member. For example, the polishing tool may comprise: a first bearing and a second bearing. The first bearing may couple the polishing head support to the main support member and accommodate linear movement of the polishing head support member relative to the main support member in the first direction. The second bearing may couple the polishing head support to the main support member and accommodate linear

movement of the polishing head support member relative to the main support member in the second direction.

[0025] At least one of the at least one bearing may comprise a linear aerostatic bearing.

[0026] Such embodiments offer a number of additional advantages, as now discussed. First, process vibrations are eliminated or damped by the air gap in the aerostatic bearing (disposed between the the polishing head support and the main support member). Second, embodiments using linear aerostatic bearings are subject to no, or a negligible amount of, wear during use. Third, due to a constant volume flow of air through the linear aerostatic bearings, the polishing tool is very temperature-stable. This is in contrast to known arrangements which have rotatory motors that typically have a temperature-dependent speed. For example, due to the viscosity of the bearing grease in arrangements using rotatory motors, and the slow warming up at start up, there is a variation in the rotational speed of such arrangements over time (particularly shortly after start up). If the motors are not intelligently readjusted (a complex and costly arrangement), the speed of the motor depends on the temperature.

[0027] Alternatively, at least one of the at least one bearing may comprise a plain bearing.

[0028] The at least one linear aerostatic bearing may be inverted so as to compensate for its own weight.

[0029] That is, the at least one linear aerostatic bearing may be arranged such that the force exerted on the moving part by the air provided to the bearings at least partially compensates for the weight of that moving part. In other words, the linear aerostatic bearings may be arranged such that the force exerted on the moving part by the air provided to the bearings acts upwards. This is different to the arrangements of current commercially available linear aerostatic bearings.

[0030] The or each linear aerostatic bearing may comprise two members having complementary or interlocking profiles which are moveable relative to each other in a linear direction. For example, one of the members may define an elongate dovetail shaped protrusion and the other member may define an elongate dovetail shaped groove. One or more seals may be provided to seal a region in the vicinity of an interface between the two members from a surrounding environment. In addition, a source of pressurized gas (for example air) is provided and is operable to provide pressurized gas in a region in the vicinity of an interface between the two members. Advantageously, the one or more seals may prevent damage to the bearing that may be caused if polishing agent was able to enter the region in the vicinity of an interface between the two members.

[0031] The first drive mechanism and/or the second drive mechanism may comprise a direct drive motor.

[0032] That is, the first drive mechanism may be arranged to directly act on the load, i.e. the polishing head support member, so as to move it in the first direction. Similarly, the second drive mechanism may be arranged

to directly act on the load, i.e. the polishing head support member, so as to move it in the second direction. This is in contrast to known polishing tools in which a (typically rotary) motor is used to indirectly move the polishing head via a mechanical linkage or transmission.

[0033] The first drive mechanism and/or the second drive mechanism may comprise an ironless motor.

[0034] Ironless motors have no cogging (i.e. no attraction force between the coil and the magnet track). Advantageously, such ironless motors are extremely precise.

[0035] The polishing tool may further comprise a third drive mechanism operable to move the polishing head support member in a third direction generally perpendicular to the first and second directions.

[0036] The third drive mechanism may bias the drive head towards a surface of a work piece.

[0037] The polishing tool may further comprise a controller operable to control the first and second drive mechanisms.

[0038] For embodiments that comprise one or more linear aerostatic bearings, the controller may also be operable to control said one or more linear aerostatic bearings.

[0039] The controller may be configured to control the first and second drive mechanisms so as to ensure that the polishing head support member moves with a constant velocity relative to a work piece.

[0040] If the main support member is stationary then this may be achieved by controlling the first and second drive mechanisms so as to ensure that the polishing head support member moves with a constant velocity relative to the main support member. Alternatively, if the main support member is moving relative to the work piece then the first and second drive mechanisms may be controlled so as to compensate for such movement and ensure that the polishing head support member moves with a constant velocity relative to the work piece.

[0041] One or more sensors may be provided to determine the position, speed and/or acceleration of the main support member. Said one or more sensors may provide signals to the controller that are indicative of the movement of the main support member. The controller may be operable to receive said signals and, in response thereto, to control the first and second drive mechanisms so as to compensate for movement of the main support member and ensure that the polishing head support member moves with a constant velocity relative to the work piece.

[0042] The controller may be operable to control a size of a circular movement of the polishing head support member.

[0043] For example, if the first and second drive mechanisms control the polishing head support member so as to exhibit synchronized simple harmonic motion relative to the main support member in the two linear directions (the first and second directions) then the entire polishing head will move in a circular fashion. By con-

trolling the amplitude of the harmonic motion in the two linear directions the size of this circle can be controlled. Advantageously, this may allow for a more easily adaptable polishing tool. The controller may be operable to dynamically control the size of the circle during a polishing process. For example, a first size of circular motion may be used for one portion of the work and a second size of circular motion may be used for another portion of the work. Such a variable polishing tool allows surfaces to be polished more economically. For example, a large circular motion may be used in a central portion of the work (high relative speed) and at the edge of the work the circular motion can be changed to a smaller motion without any reconfiguration of the polishing tool.

[0044] The polishing tool may further comprise one or more sensors arranged to determine and/or monitor polishing process data.

[0045] The sensors may be operable to send signals indicative of polishing process data to another component. For example, the polishing tool may comprise a memory and the sensors may be operable to send signals indicative of polishing process data to the memory. Additionally or alternatively, the sensors may be operable to send signals indicative of polishing process data to an external memory that is not part of the polishing tool. Additionally or alternatively, the sensors may be operable to send signals indicative of polishing process data to the controller. Advantageously, such process data may be used as part of an Industry 4.0 and/or a machine learning system.

[0046] The first and second directions are different. It will be appreciated that this may mean that the first and second directions are linearly independent. For example, the first and second directions may be mutually perpendicular.

[0047] The first and second directions may be mutually perpendicular.

[0048] According to a second aspect of the present disclosure there is provided an apparatus comprising the polishing tool according to the first aspect of the present disclosure.

[0049] The apparatus may further comprise: a support structure; and a movable member movably mounted to the support structure. The main support member of the polishing tool may be connected to the movable member.

[0050] It will be appreciated that the support structure may comprise any structure for supporting the movable member. The movable member may comprise, for example, a robotic arm or the like.

[0051] The apparatus may further comprise a main controller operable to control a position of the movable member relative to the support structure.

[0052] The main controller may also be operable to control the polishing tool, either directly, or indirectly via a controller of the polishing tool.

[0053] The main controller may be further operable to control the first and second drive mechanisms of the polishing tool.

[0054] For embodiments wherein the polishing tool comprises one or more linear aerostatic bearings, the main controller may also be operable to control said one or more linear aerostatic bearings.

[0055] The main controller may be configured to control the first and second drive mechanisms so as to ensure that the polishing head support member moves with a constant velocity relative to the support structure.

[0056] Note that, in use, the apparatus may be used to polish a work piece (for example a surface of an optical component such as a mirror). The work piece may be stationary relative to the support structure. Therefore, if the polishing head support member moves with a constant velocity relative to the support structure then it will also move with a constant velocity relative to the work piece.

[0057] Note that the main controller is operable to control both: (a) the position of the movable member (to which the main support member of the polishing tool is connected) relative to the support structure; and (b) the first and second drive mechanisms of the polishing tool (to control the position of the polishing head support member relative to the main support member). If the movable member is stationary then the main controller may control the first and second drive mechanisms so as to ensure that the polishing head support member moves with a constant velocity relative to the main support member. Alternatively, if the movable member is moving relative to the work piece then the first and second drive mechanisms may be controlled so as to compensate for such movement and ensure that the polishing head support member moves with a constant velocity relative to the work piece.

[0058] The main controller may be operable to control a size of a circular movement of the polishing head support member.

[0059] Advantageously, this may allow for a more easily adaptable apparatus and polishing tool.

[0060] According to a third aspect of the present disclosure there is provided a method of polishing a work piece, the method comprising: urging a polishing head towards a surface of the work piece; and actuating the polishing head to move relative to the work piece so as to oscillate in a first linear direction; and actuating the polishing head to move relative to the work piece so as to oscillate in a second linear direction that is different to the first direction.

[0061] Advantageously, the method according to the third aspect of the present disclosure is a corresponding method to, and may be performed using, the polishing tool according to the first aspect and/or the apparatus according to the second aspect. Therefore, the method according to the third aspect of the present disclosure is advantageous over known methods for the same reasons as set out above.

[0062] First, the method ensures that the polishing head can be moved in a circular fashion and wherein an orientation of the polishing head remains perfectly

fixed with respect to the work piece (with no rotation of such orientation). Second, a size of the circular motion described by the polishing head (as a result of the oscillation in the first and second directions) can be easily controlled and/or varied. Third, the polishing head can be better controlled with respect to a work piece even in cases when main member supporting the polishing head is moving relative to the work. Fourth, the polishing head can be better isolated from sources of external vibrations. Fifth, process data can be more easily monitored.

[0063] The method may comprise moving the polishing head with a constant velocity relative to a work piece.

[0064] The method may comprise: actuating the polishing head to move relative to a support member so as to oscillate in the first and second linear directions relative thereto; and moving the movable member relative to the work piece.

[0065] The method may comprise controlling a size of a circular movement of the polishing head.

[0066] The method may further comprise urging the polishing head towards the work piece in a third direction that is generally perpendicular to the first and second directions.

[0067] The method may further comprise determining and/or monitoring polishing process data.

[0068] The first and second directions may be mutually perpendicular.

BRIEF DESCRIPTION OF THE DRAWINGS

[0069] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings, in which:

- Figure 1 depicts a lithographic system comprising a lithographic apparatus and a radiation source;
- Figure 2A is a schematic illustration of a plan view of a first polishing tool according to an embodiment of the present disclosure;
- Figure 2B is a schematic illustration of a side view of the first polishing tool shown in Figure 2A;
- Figure 3A is a schematic illustration of a first side view of a second polishing tool according to an embodiment of the present disclosure;
- Figure 3B is a schematic illustration of a second side view of the second polishing tool shown in Figure 3A, the second side view being orthogonal to the first side view
- Figure 4 is a schematic perspective view of a polishing tool that is generally of the form of the second polishing tool as shown in Figures 3A and 3B and which shows an arrangement of bearings;
- Figure 5 is a schematic illustration of a plan view of third polishing tool according to an embodiment of the present disclosure;
- Figure 6 is a schematic illustration of an apparatus according to an embodiment of the present disclosure which comprises a polishing tool of the type

shown in Figures 2A to 5; and

- Figure 7 is a schematic illustration of a method according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0070] Figure 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.

[0071] 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. Therefore, 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.

[0072] 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 Figure 1, the projection system PS may include a different number of mirrors (e.g. six or eight mirrors).

[0073] 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.

[0074] The radiation source SO, illumination system IL, and projection system PS may all be constructed and arranged such that they can be isolated from the external environment. 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.

[0075] The radiation source SO shown in Figure 1 is of a type that may be referred to as a laser produced plasma (LPP) source. A laser 1, which may for example be a CO₂ laser, is arranged to deposit energy via a laser beam 2 into a fuel, such as tin (Sn) that is provided from a fuel emitter 3. Although tin is referred to in the following description, any suitable fuel may be used. The fuel may for example be in liquid form, and may for example be a metal or alloy. The fuel emitter 3 may comprise a nozzle configured to direct tin, e.g., in the form of droplets, along a trajectory towards a plasma formation region 4. The laser beam 2 is incident upon the tin at the plasma formation region 4. The deposition of laser energy into the tin creates a plasma 7 at the plasma formation region 4. Radiation, including EUV radiation, is emitted from the plasma 7 during de-excitation and recombination of ions of the plasma.

[0076] The EUV radiation is collected and focused by a near normal incidence radiation collector 5 (sometimes referred to more generally as a normal incidence radiation collector). The collector 5 may have a multilayer structure that is arranged to reflect EUV radiation (e.g., EUV radiation having a desired wavelength such as 13.5 nm). The collector 5 may have an elliptical configuration, having two ellipse focal points. A first focal point may be at the plasma formation region 4, and a second focal point may be at an intermediate focus 6, as discussed below.

[0077] In other embodiments of a laser produced plasma (LPP) source the collector 5 may be a so-called grazing incidence collector that is configured to receive EUV radiation at grazing incidence angles and focus the EUV radiation at an intermediate focus. A grazing incidence collector may, for example, be a nested collector, comprising a plurality of grazing incidence reflectors. The grazing incidence reflectors may be disposed axially symmetrically around an optical axis.

[0078] The laser 1 may be separated from the radiation source SO. Where this is the case, the laser beam 2 may be passed from the laser 1 to the radiation source SO with the aid of a beam delivery system (not shown) comprising, for example, suitable directing mirrors and/or a beam expander, and/or other optics. The laser 1 and the radiation source SO may together be considered to be a radiation system.

[0079] Radiation that is reflected by the collector 5 forms a radiation beam B. The radiation beam B is focused at point 6 to form an image of the plasma formation region 4, which acts as a virtual radiation source for the illumination system IL. The point 6 at which the radiation beam B is focused may be referred to as the intermediate focus. The radiation source SO is arranged such that the intermediate focus 6 is located at or near to an opening 8 in an enclosing structure 9 of the radiation source SO.

[0080] Although the radiation source SO shown in Figure 1 is a laser produced plasma (LPP) source, in other embodiments, the radiation source SO may com-

prise: a discharge produced plasma (DPP) source, a free electron laser (FEL) or any other radiation source that is capable of generating EUV radiation.

[0081] Some embodiments of the present disclosure relate to polishing tool. In particular, such embodiments relate to a polishing tool suitable for processing a semiconductor processing apparatus component. For example, in use, the polishing tool may be used to polish a surface of an optical component such as a mirror. For example, the polishing tool may be used to polish any of the mirrors in the lithographic system of the type shown in Figure 1.

[0082] A polishing tool 100 according to an embodiment of the present disclosure is shown schematically in Figures 2A and 2B. Figure 2A shows a plan view of the polishing tool 100 and Figure 2B shows a side view of the polishing tool 100.

[0083] The polishing tool 100 comprises a main support member 102 and a polishing head support member 104. The main support member 102 may be referred to as a machine mounting plate and may allow the polishing tool 100 to be connected to a machine such as, for example, a robotic arm or the like. The polishing head support member 104 may be arranged to support a polishing head. Such a polishing head may comprise an abrasive material as is known in the art such as, for example, a polishing foil. In use, the polishing tool 100 may be used to polish a work piece (for example a surface of an optical component such as a mirror).

[0084] The polishing head support member 104 is coupled to the main support member 102 such that the polishing head support member 104 is linearly movable relative to the main support member in a first direction (the x direction) and a second direction (the y direction) that is different to the first direction.

[0085] The polishing tool 100 further comprises a first drive mechanism 106 and a second drive mechanism 108. The first drive mechanism 106 is operable to move the polishing head support member 104 relative to the main support member 102 in the first direction (the x direction), as indicated schematically by arrow 110. The second drive mechanism 108 is operable to move the polishing head support member 104 relative to the main support member 102 in the second direction (the y-direction), as indicated schematically by arrow 112.

[0086] Typically, in known polishing tools, a rotary drive mechanism is provided such that the polishing head can be moved (for example using a rotary motor) relative to a work piece but wherein the axis of rotation of the polishing head is offset from an axis of the polishing head itself. Therefore, the polishing head does not rotate about its axis. Rather the polishing head as a whole describes a circular motion. Such an arrangement may be referred to as an eccentric arrangement (since the axis of rotation of the polishing head is offset from an axis of the polishing head itself). In known arrangements, the movement of the polishing head is effected by a rotary actuator (for example a rotary motor). For example, a rotary member is

provided that can be rotated by a motor and a mechanical linkage is provided between the rotary member and the polishing head.

[0087] Eccentric polishing head arrangements are desirable. In particular, it is particularly desirable for an orientation of the polishing head to remain fixed with respect to a work piece that it is polishing (while the whole polishing head moves in a circular fashion). Such an arrangement has a number of advantages and is particularly well-suited for high precision processes. Some known polishing arrangements comprise a mechanism that is arranged to constrain, or pin, the polishing head so as to limit rotation of the polishing head about its own axis. However, there are a number of problems with such known arrangements.

[0088] In contrast, the polishing tool 100 shown schematically in Figures 2A and 2B comprises linear couplings and linear drive mechanisms 106, 108. The coupling between the polishing head support member 104 and the main support member 102 allows the polishing head support member 104 to move relative to the main support member 102 in the first and second directions. With suitable oscillatory actuation of these two couplings, the polishing head support member 104 (and any polishing head supported thereby) can be rotated relative to the main support member 102 in an eccentric manner (i.e. rotated about an axis that is offset from the polishing head itself). Such an arrangement has a number of advantages over known arrangements.

[0089] First, the polishing tool 100 shown schematically in Figures 2A and 2B provides an arrangement wherein the polishing head can be moved in a circular fashion and wherein an orientation of the polishing head remains perfectly fixed with respect to the work piece (with no rotation of such orientation). In particular, the orientation of the polishing head remains fixed at all points on the generally circular motion of the polishing head. Advantageously, this ensures that the speed of the polishing head is uniform across the surface of the polishing head and around the entire circular motion, which results in an extremely high precision polishing process. In contrast, in most known arrangements, the mechanical linkage between the (rotary) drive motor and the polishing head is complex and, in some known arrangements, the polishing head is not sufficiently constrained so as to prevent any rotation of the polishing head about its axis. As a result, the orientation of the polishing head does not remain fixed with respect to the work piece. For example, the orientation of the polishing head of known polishing tools may be permitted to rotate through an angle of the order of 10° to 15°.

[0090] Second, since the first and second drive mechanisms 106, 108 are operable to move the polishing head support member 104 relative to the main support member 102 in two linear directions, a size of the circular motion described by the polishing head 104 can be easily controlled and/or varied. For example, if the first and second drive mechanisms 106, 108 control the polishing

head support member 104 so as to exhibit synchronized simple harmonic motion relative to the main support member 102 in the two linear directions (the first and second directions) then the entire polishing head will move in a circular fashion. By controlling the amplitude of the harmonic motion in the two linear directions the size of this circle can be controlled. Advantageously, this may allow for a more easily adaptable polishing tool 100. It may even be possible to dynamically control the size of the circle during the polishing process. For example, a first size of circular motion may be used for one portion of the work and a second size of circular motion may be used for another portion of the work. Such a variable polishing tool allows surfaces to be polished more economically. For example, a large circular motion may be used in a central portion of the work (high relative speed) and at the edge of the work the circular motion can be changed to a smaller motion without any reconfiguration of the polishing tool. Edge effects can be further reduced using such a tool 100 and/or such a method.

[0091] Third, since the first and second drive mechanisms 106, 108 provide independent control over the movement in two independent linear axes, the polishing tool allows for the polishing head to be better controlled with respect to a work piece even in cases when the main support member 102 is moving relative to the work. For example, in general, the main support member 102 may be mounted on a robotic arm or the like, which may be operable to move the polishing tool 100 relative to the work. For example, the polishing tool 100 may be scanned over a surface of the work. In addition, the polishing head support member 102 can be moved (using the first and second drive mechanisms 106, 108) in a circular fashion relative to the main support member 102 or robotic arm. Suppose the robotic support arm moves the entire polishing tool 100 in the first direction (the x-direction). With such an arrangement, if the first and second drive mechanisms 106, 108 control the polishing head support member 104 so as to exhibit synchronized simple harmonic motion relative to the main support member 102 in the two linear directions then the polishing head will no longer be moving in a perfect circle and the speed of the polishing head relative to the work will no longer be constant around the generally circular motion. Rather, when the circular motion is in the same direction as the movement of the robotic arm the speed of the polishing head will be greater and when the circular motion is in the opposite direction to the movement of the robotic arm the speed of the polishing head will be less. However, by suitable control via the first drive mechanism 106 (with a variable harmonic motion) such effects can be corrected for such that the speed of the polishing head relative to the work remains constant. Advantageously, this increases the consistency of the polishing process.

[0092] Fourth, since there is no rotary coupling, the polishing tool 100 shown schematically in Figures 2A and 2B does not need ball bearings or belt drives. Advanta-

geously, this removes, or at least significantly reduces, external vibrations that result from such ball bearings and belt drives. In contrast, in most known arrangements, the mechanical linkage between the (rotary) drive motor and the polishing head is complex and typically gives rise to a large number of exciting frequencies that are unwanted. Note that a high number of different ball bearings in existing arrangements leads to a large number of exciting frequencies. Each ball bearing has a total of 6 exciting frequencies (including rollover frequencies of the rolling elements over the inner and outer ring). These sources of external vibrations are responsible for the transmission and overshoot or undershoot of the rotary motion in known systems.

[0093] Fifth, due to the complexity of existing arrangements it is difficult to attach sensors to existing polishing tools that can monitor useful process data. In particular, since existing arrangements typically comprise a rotary drive mechanism (for example a rotary member) it can be particularly challenging to run wires or cables to such sensors (if, for example, they are provided on a rotary part of the polishing tool). In contrast, since the first and second drive mechanisms 106, 108 of the polishing tool 100 shown schematically in Figures 2A and 2B are operable to move the polishing head support member 104 relative to the main support member 102 in two linear directions sensors can be more easily provided to monitor process data. Advantageously, such process data may be used as part of an Industry 4.0 and/or a machine learning system.

[0094] Note that as used herein an axis of the polishing head may be perpendicular to a plane of the polishing head (i.e. perpendicular to the polishing surface or foil). In general, an axis of the polishing head is perpendicular to the first and second directions. In the schematic views of Figures 2A and 2B the axis of the polishing head is parallel to the z-direction.

[0095] The first and second directions (x and y directions) are different. It will be appreciated that this may mean that the first and second directions are linearly independent. For example, in the example shown in Figures 2A and 2B, the first and second directions are mutually perpendicular.

[0096] The first drive mechanism 106 and/or the second drive mechanism 108 may comprise a direct drive motor. That is, the first drive mechanism 106 may be arranged to directly act on the load, i.e. the polishing head support member 104, so as to move it in the first direction (the x-direction). Similarly, the second drive mechanism 108 may be arranged to directly act on the load, i.e. the polishing head support member 104, so as to move it in the second direction (the y-direction). This is in contrast to known polishing tools in which a (typically rotary) motor is used to indirectly move the polishing head via a mechanical linkage or transmission.

[0097] The first drive mechanism 106 and/or the second drive mechanism 108 may comprise an ironless motor. Ironless motors have no cogging (i.e. no attraction

force between the coil and the magnet track). Advantageously, such ironless motors are extremely precise.

[0098] Optionally, in some embodiments the polishing tool 100 may further comprise a third drive mechanism 114 that is operable to move the polishing head support member 104 in a third direction (the z-direction), as indicated schematically by arrow 116 in Figure 2B. The third direction is generally perpendicular to the first and second directions. In use, the third drive mechanism 114 may bias the drive head towards a surface of a work piece.

[0099] Optionally, in some embodiments the polishing tool 100 may further comprise a controller 118 that is operable to control the first and second drive mechanisms 106, 108. For example, as shown schematically in Figure 2A, the controller 118 may be operable to: send a first control signal s_1 to the first drive mechanism 106 and/or send a first control signal s_2 to the second drive mechanism 108.

[0100] For embodiments that comprise a third drive mechanism 114, the controller 118 may also be operable to control the third drive mechanism 114. For example, as shown schematically in Figure 2B, the controller 118 may be operable to send a third control signal s_3 to the third drive mechanism 114.

[0101] In some embodiments, the controller 118 may be configured to control the first and second drive mechanisms 106, 108 so as to ensure that the polishing head support member 104 moves with a constant velocity relative to a work piece.

[0102] If the main support member 102 is stationary then this may be achieved by controlling the first and second drive mechanisms 106, 108 so as to ensure that the polishing head support member 104 moves with a constant velocity relative to the main support member 102. Alternatively, if the main support member 102 is moving relative to the work piece then the first and second drive mechanisms 106, 108 may be controlled so as to compensate for such movement and ensure that the polishing head support member 104 moves with a constant velocity relative to the work piece.

[0103] One or more sensors 120 may be provided to determine the position, speed and/or acceleration of the main support member 102. Said one or more sensors 120 may provide one or more signals s_4 to the controller 118 that are indicative of the movement of the main support member 102. The controller 118 may be operable to receive said signals and, in response thereto, to control the first and second drive mechanisms 106, 108 so as to compensate for movement of the main support member 102 and ensure that the polishing head support member 104 moves with a constant velocity relative to the work piece.

[0104] In some embodiments, the controller 118 may be operable to control a size of a circular movement of the polishing head support member 104. For example, if the first and second drive mechanisms 106, 108 control the polishing head support member 104 so as to exhibit

synchronized simple harmonic motion relative to the main support member 102 in the two linear directions (the x and y directions) then the entire polishing head will move in a circular fashion. By controlling the amplitude of the harmonic motion in the two linear directions the size of this circle can be controlled. Advantageously, this may allow for a more easily adaptable polishing tool 100. The controller 118 may be operable to dynamically control the size of the circle during a polishing process. For example, a first size of circular motion may be used for one portion of the work and a second size of circular motion may be used for another portion of the work. Such a variable polishing tool 100 allows surfaces to be polished more economically. For example, a large circular motion may be used in a central portion of the work (high relative speed) and at the edge of the work the circular motion can be changed to a smaller motion without any reconfiguration of the polishing tool.

[0105] The controller 118 may be operable to implement the method 300 shown in Figure 7 and described below.

[0106] Optionally, in some embodiments, the polishing tool 100 may further comprise one or more sensors 122 arranged to determine and/or monitor polishing process data.

[0107] The one or more sensors 122 may be operable to send one or more signals s_5 indicative of polishing process data to another component. For example, the polishing tool 100 may comprise a memory (not shown) and the one or more sensors 122 may be operable to send signals s_5 indicative of polishing process data to the memory. Additionally or alternatively, the one or more sensors 122 may be operable to send signals s_5 indicative of polishing process data to an external memory that is not part of the polishing tool 100. Additionally or alternatively, the one or more sensors 122 may be operable to send signals s_5 indicative of polishing process data to the controller 118. Advantageously, such process data may be used as part of an Industry 4.0 and/or a machine learning system.

[0108] In some embodiments, the polishing tool 100 may comprise an intermediate support member 124 that is disposed between the main support member 102 and the polishing head support member 104, as now discussed with reference to Figures 3A to 4.

[0109] A second polishing tool 100a according to an embodiment of the present disclosure is shown schematically in Figures 3A and 3B. Figures 2A and 2B shows two orthogonal side views of the second polishing tool 100a. The second polishing tool 100a shown in Figures 3A and 3B shares many features in common with the polishing tool 100 shown in Figures 2A and 2B. Features of the second polishing tool 100a shown in Figures 3A and 3B that are generally that same as features of the polishing tool 100 shown in Figures 2A and 2B share common reference numerals therewith. Only the differences between the second polishing tool 100a shown in Figures 3A and 3B and the polishing tool 100 shown in Figures 2A

and 2B will be described in detail below.

[0110] The second polishing tool 100a further comprises an intermediate support member 124. The intermediate support member 124 is coupled to the main support member 102 such that the intermediate head support member 124 is linearly movable relative to the main support member 102 in the first direction (the x direction), again indicated schematically by arrow 110. The polishing head support member 104 is coupled to the intermediate support member 124 such that the polishing head support member 104 is linearly movable relative to the intermediate support member 124 in the second direction (the y direction), again indicated schematically by arrow 112.

[0111] Advantageously, such an arrangement 100a (having three components: the main support member 102, the intermediate support member 124 and the polishing head support member 104) can provide for particularly desirable couplings between the main support member 102 and the polishing head support member 104. For example, such an arrangement comprising an intermediate support member 124 can allow for two separate linear bearings to be provided (one for each of the first and second directions) and/or can better allow for the first and second drive mechanisms to control the position of the polishing head support member relative to the main support member.

[0112] In some embodiments of the polishing tool the polishing head support 104 may be formed separately from with the main support member 102 and the polishing tool 100 may comprise at least one bearing coupling the polishing head support 104 to the main support member 102.

[0113] In some embodiments, the polishing tool comprises two bearings coupling the polishing head support member 104 to the main support member 102. For example, the polishing tool may comprise: a first bearing and a second bearing. The first bearing may couple the polishing head support member 104 to the main support member 102 and accommodate linear movement of the polishing head support member 104 relative to the main support member 102 in the first direction (the x-direction). The second bearing may couple the polishing head support member 104 to the main support member 102 and accommodate linear movement of the polishing head support member 104 relative to the main support member 102 in the second direction (the y-direction).

[0114] An example of an embodiments wherein the polishing head support 104 is formed separately from with the main support member 102 and the polishing tool 100 comprises bearings coupling the polishing head support 104 to the main support member 102 is now discussed with reference to Figure 4.

[0115] Figure 4 is a schematic perspective view of a polishing tool that is generally of the form of the second polishing tool 100a as shown in Figures 3A and 3B although some parts of the polishing tool 100a are not shown for ease of understanding. It will be understood that

the polishing tool 100a shown in Figure 4 may have any of the features of the second polishing tool 100a shown in Figures 3A and 3B shares or the polishing tool 100 shown in Figures 2A and 2B.

[0116] The polishing tool 100a shown in Figure 4 comprises an intermediate support member 124 that is disposed between the main support member 102 and the polishing head support member 104. Furthermore, the main support member 102, the intermediate support member 124 and the polishing head support member 104 are all formed separately.

[0117] The polishing tool 100a shown in Figure 4 further comprises two sets of bearings coupling the polishing head support 104 to the main support member 102. In particular, the polishing tool 100a comprises: a first set of linear bearings 126, 128 and a second set of linear bearings 130, 132.

[0118] The first set of linear bearings 126, 128 couple the main support member 102 to the intermediate support member 124 and accommodate linear movement of the intermediate head support member 124 relative to the main support member 102 in the first direction (the x-direction). The second set of linear bearings 130, 132 couple the intermediate support member 124 to the polishing head support member 104 and accommodate linear movement of the polishing head support member 104 relative to the intermediate support member 124 in the second direction (the y-direction).

[0119] In this embodiment, each of the bearings 126, 128, 130, 132 comprises a linear aerostatic bearing.

[0120] Such embodiments offer a number of additional advantages, as now discussed. First, process vibrations are eliminated or damped by the air gap in the aerostatic bearings 126, 128, 130, 132 (disposed between the the polishing head support 104 and the main support member 102). Second, embodiments using linear aerostatic bearings 126, 128, 130, 132 are subject to no, or a negligible amount of, wear during use. Third, due to a constant volume flow of air through the linear aerostatic bearings 126, 128, 130, 132, the polishing tool 100 is very temperature-stable. This is in contrast to known arrangements which have rotatory motors that typically have a temperature-dependent speed. For example, due to the viscosity of the bearing grease in arrangements using rotary motors, and the slow warming up at start up, there is a variation in the rotational speed of such arrangements over time (particularly shortly after start up). If the motors are not intelligently readjusted (a complex and costly arrangement), the speed of the motor depends on the temperature.

[0121] Alternatively, in other embodiments, at least one of the at least one of the bearings 126, 128, 130, 132 may comprise a plain bearing.

[0122] In this embodiment, the linear aerostatic bearings 126, 128, 130, 132 are inverted so as to compensate for their own weight. That is, the linear aerostatic bearings 126, 128, 130, 132 are arranged such that the force exerted on the moving part (i.e. the lower part in Figure

4) by the air provided to the bearings 126, 128, 130, 132 at least partially compensates for the weight of that moving part. In other words, the linear aerostatic bearings 126, 128, 130, 132 are arranged such that the force exerted on the moving part (i.e. the lower part in Figure 4) by the air provided to the bearings 126, 128, 130, 132 acts upwards. This is different to the arrangements of current commercially available linear aerostatic bearings.

[0123] Each of the linear aerostatic bearings 126, 128, 130, 132 comprises two members having complementary or interlocking profiles which are moveable relative to each other in a linear direction (either the x-direction or the y-direction). For example, using a first one 126 of the first set of linear bearings as an example, one of the members 126a defines an elongate dovetail shaped protrusion and the other member 126b defines an elongate dovetail shaped groove. One or more seals may be provided to seal a region in the vicinity of an interface between the two members 126a, 126b from a surrounding environment. In addition, a source (not shown) of pressurized gas (for example air) is provided and is operable to provide pressurized gas in a region in the vicinity of an interface between the two members 126a, 126b. Advantageously, the one or more seals may prevent damage to the bearing 126 that may be caused if polishing agent was able to enter the region in the vicinity of an interface between the two members 126a, 126b.

[0124] For such embodiments that comprise linear aerostatic bearings 126, 128, 130, 132, the controller 118 may also be operable to control the linear aerostatic bearings 126, 128, 130, 132.

[0125] In some embodiments, rather than using separate members and bearings, the polishing head support member 104 may be coupled to the main support member 102 via at least one spring member and/or at least one hinge member and the polishing head support member 104 may be integrally formed with the main support member 102. Such embodiments are now discussed with reference to Figure 5.

[0126] A third polishing tool 100b according to an embodiment of the present disclosure is shown schematically in Figure 5, which shows a plan view of the third polishing tool 100b. The third polishing tool 100b shown in Figures 3A and 3B shares many features in common with the polishing tool 100 shown in Figures 2A and 2B. Features of the third polishing tool 100b shown in Figure 5 that are generally the same as features of the polishing tool 100 shown in Figures 2A and 2B share common reference numerals therewith. Only the differences between the third polishing tool 100b shown in Figure 5 and the polishing tool 100 shown in Figures 2A and 2B will be described in detail below.

[0127] In the embodiment of the third polishing tool 100b, the main support member 102 is generally of the form of a frame that surrounds the polishing head support member 104. The polishing head support member 104 is integrally formed with the main support member 102.

[0128] The polishing head support member 104 is

coupled to the main support member 102 via two spring members 134, 136 that allow the polishing head support member 104 to be linearly movable relative to the main support member 102 in the first and second directions (the x and y directions).

[0129] The two spring members 134, 136 may alternatively be considered to be hinge members.

[0130] In this example, each of the two spring members 134, 136 is generally L-shaped and extends from the generally square frame of the main support member 102 inwards towards the central polishing head support member 104. In particular, each of the two spring members 134, 136 comprises: a first portion 134a, 136a; a second portion 134b, 136b; and a third portion 134c, 136c.

[0131] The first portion 134a, 136a of each of the two spring members 134, 136 is elongate and extends from the main support member 102 in the second portion 134b, 136b of that spring member 134, 136 in a first direction. Similarly, the third portion 134a, 136a of each of the two spring members 134, 136 is elongate and extends from the second portion 134b, 136b of that spring member 134, 136 to the polishing head support member 104 in a second direction.

[0132] Each of the two spring members 134, 136 is provided with a plurality of regions 138 of reduced thickness, which act as living hinges. In particular, a region 138 of reduced thickness is provided at each end of the first portions 134a, 136a and at each end of the third portions 134c, 136c. That is, a region 138 of reduced thickness is provided: between the main support member 102 and the first portion 134a, 136a; between the first portion 134a, 136a and the second portion 134b, 136b; between the second portion 134b, 136b and the third portion 134c, 136c; and between the third portion 134c, 136c and the polishing head support member 104.

[0133] These regions 138 of reduced thickness act as living hinges and provide some freedom for the polishing head support member 104 to move relative to the main support member 102 in the first and second directions in response to forces from the first and second drive mechanisms 106, 108 (not shown in Figure 5 for ease of understanding) of the polishing tool 100b.

[0134] Some embodiments of the present disclosure relate to an apparatus comprising a polishing tool 100, 100a, 100b of the type described above with reference to Figures 2A to 5. Such an apparatus 200 is now described further with reference to Figure 6.

[0135] The apparatus 200 shown in Figure 6 comprises: a polishing tool 202, a support structure 204; and a movable member 206.

[0136] The movable member 206 is movably mounted to the support structure 204. The movable member 206 may, for example, be operable to move relative to the support structure in three directions. It will be appreciated that the support structure 204 may comprise any structure for supporting the movable member 206. The movable member 206 may comprise, for example, a robotic arm or the like.

[0137] The polishing tool 202 is of the polishing tool 100, 100a, 100b of the type described above with reference to Figures 2A to 5. The main support member 102 of the polishing tool 202, which may be referred to as a machine mounting plate, is connected to the movable member 206. In use, the polishing head support member 104 of the polishing tool 202 supports a polishing head 208. The polishing head 208 may comprise an abrasive material as is known in the art such as, for example, a polishing foil.

[0138] The apparatus 200 further comprises a work support 210 for supporting a work piece 212. The work support 210 is connected to, or supported by, the support structure 204. The work piece 212 may comprise, for example, a semiconductor processing apparatus component. For example, the work piece 212 may comprise an optical component such as a mirror. For example, the work piece 212 may be any of the mirrors in the lithographic system of the type shown in Figure 1.

[0139] The apparatus 200 further comprises a main controller 214. The main controller 214 is operable to control a position of the movable member 206 relative to the support structure 204. For example, as shown schematically in Figure 6, the main controller 214 may be operable to send one or more control signals s_6 to the movable member 206 and/or an actuator of the movable member 206.

[0140] The main controller 214 may also be operable to control the polishing tool 202, either directly, or indirectly via a controller 118 of the polishing tool 202. For example, as shown schematically in Figure 6, the main controller 214 may be operable to send one or more control signals s_7 to the polishing tool 202. In some embodiments, the main controller 214 may be operable to control the first and second drive mechanisms 106, 108 of the polishing tool 202. For embodiments wherein the polishing tool 202 comprises one or more linear aerostatic bearings, the main controller 214 may also be operable to control said one or more linear aerostatic bearings.

[0141] The main controller 214 may be configured to control the first and second drive mechanisms 106, 108 of the polishing tool 202 so as to ensure that the polishing head support member 104 (and the polishing head 208 supported thereby) moves with a constant velocity relative to the support structure 204 (by which the work piece 212 is also supported via the work support 210).

[0142] Note that, in use, the apparatus 200 may be used to polish a work piece 212 (for example a surface of an optical component such as a mirror). The work piece 212 may be stationary relative to the support structure 204. Therefore, if the polishing head support member 104 moves with a constant velocity relative to the support structure 204 then it will also move with a constant velocity relative to the work piece 212.

[0143] Note that the main controller 214 is operable to control both: (a) the position of the movable member 206 (to which the main support member 102 of the polishing tool 202 is connected) relative to the support structure

204; and (b) the first and second drive mechanisms 106, 108 of the polishing tool 202 (to control the position of the polishing head support member 104 relative to the main support member 102). If the movable member 206 is stationary (relative to the support structure 204) then the main controller 214 may control the first and second drive mechanisms 106, 108 so as to ensure that the polishing head support member 104 moves with a constant velocity relative to the main support member 102. Alternatively, if the movable member 206 is moving relative to the work piece 212 then the first and second drive mechanisms 106, 108 may be controlled so as to compensate for such movement and ensure that the polishing head support member 104 moves with a constant velocity relative to the work piece 212.

[0144] The main controller 214 may be operable to control a size of a circular movement of the polishing head support member 104. Advantageously, this may allow for a more easily adaptable apparatus 200 and polishing tool 202.

[0145] Some embodiments of the present disclosure relate to a method of polishing a work piece 212. Such a method 300 is now described further with reference to Figure 7.

[0146] The method 300 comprises a step 302 of contacting a surface of the work piece 212 with a polishing head 208. Note that, as will be appreciated by the skilled person, in use the polishing head 208 will not contact the work piece 212 directly as in practice there will be a polishing slurry provided between the polishing head 208 and the work piece 212. Any reference herein to the polishing head 208 contacting the work piece 212 should be interpreted accordingly. Such reference may be understood by the skilled person to mean biasing the polishing head 208 towards the work piece 212 and/or the polishing head 208 contacting the work piece 212 indirectly via a polishing slurry.

[0147] The method 300 further comprises a step 304 of actuating the polishing head 208 to move relative to the work piece 212 so as to oscillate in a first linear direction (for example the x-direction). The method 300 further comprises a step 306 of actuating the polishing head 208 to move relative to the work piece 212 so as to oscillate in a second linear direction (for example the y-direction) that is different to the first direction.

[0148] It will be appreciated that the steps 304, 306 of actuating the polishing head 208 to move relative to the work piece 212 so as to oscillate in the first and second linear directions may be performed simultaneously. For example, the steps 304, 306 of actuating the polishing head 208 to move relative to the work piece 212 so as to oscillate in the first and second linear directions may each comprise control the polishing head 208 so as to exhibit synchronized simple harmonic motion (relative to a support) in the first and second directions respectively such that the entire polishing head 208 will move in a circular fashion.

[0149] It will be appreciated that, in some embodi-

ments, the first and second directions may be mutually perpendicular.

[0150] The step 302 of contacting a surface of the work piece 212 with a polishing head 208 may comprise urging the polishing head 208 towards the work piece 212 in a third direction (z-direction) that is generally perpendicular to the first and second directions.

[0151] Advantageously, the method 300 shown schematically in Figure 7 is a corresponding method to, and may be performed using, the polishing tools 100, 100a, 100b described above with reference to Figures 2A to 5 and/or the apparatus 200 described above with reference to Figure 6. Therefore, the method 300 shown schematically in Figure 7 is advantageous over known methods for the same reasons as set out above.

[0152] First, the method 300 ensures that the polishing head 208 can be moved in a circular fashion and wherein an orientation of the polishing head 208 remains perfectly fixed with respect to the work piece 212 (with no rotation of such orientation). Second, a size of the circular motion described by the polishing head 208 (as a result of the oscillation in the first and second directions) can be easily controlled and/or varied. Third, the polishing head 208 can be better controlled with respect to a work piece 212 even in cases when the main member 102 supporting the polishing head 208 is moving relative to the work 212. Fourth, the polishing head 208 can be better isolated from sources of external vibrations. Fifth, process data can be more easily monitored.

[0153] Optionally, the method 300 may comprise a step 308 of moving the polishing head 208, for example with a constant velocity, relative to a work piece 212. That is, the method 300 may comprise: actuating the polishing head 208 so to move relative to a support member 204 so as to oscillate in the first and second linear directions relative thereto (steps 304 and 306); and moving the movable member 206 relative to the work piece 212 (step 308). Again, it will be appreciated that the step 308 of moving the polishing head 208 relative to a work piece 212 may be performed at the same time as the steps 304, 306 of actuating the polishing head 208 to move relative to the work piece 212 so as to oscillate in the first and second linear directions.

[0154] Optionally, the method 300 may comprise a step 310 of controlling a size of a circular movement of the polishing head 208. It will be appreciated that the step 310 of controlling a size of a circular movement of the polishing head 208 may be performed at the same time as the steps 304, 306 of actuating the polishing head 208 to move relative to the work piece 212 so as to oscillate in the first and second linear directions.

[0155] Optionally, the method 300 may comprise a step 312 of determining and/or monitoring polishing process data. The step 312 of determining and/or monitoring polishing process data may, for example, use one or more sensors 122 of a polishing tool 100 (see Figures 2A and 2B) and/or one or more signals s_5 indicative of polishing process data output thereby. It will be appre-

ciated that the step 312 of determining and/or monitoring polishing process data may be performed at the same time as the steps 304, 306 of actuating the polishing head 208 to move relative to the work piece 212 so as to oscillate in the first and second linear directions.

[0156] 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.

[0157] Although specific reference may be made in this text to embodiments of the invention in the context of a lithographic apparatus, embodiments of the invention may be used in other apparatus. Embodiments of the invention 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 apparatus may be generally referred to as lithographic tools. Such a lithographic tool may use vacuum conditions or ambient (non-vacuum) conditions.

[0158] Although specific reference may have been made above to the use of embodiments of the invention in the context of optical lithography, it will be appreciated that the invention, where the context allows, is not limited to optical lithography and may be used in other applications, for example imprint lithography.

[0159] Where the context allows, embodiments of the invention may be implemented in hardware, firmware, software, or any combination thereof. Embodiments of the invention 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 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, 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.

[0160] While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The descriptions above are intended to be illus-

trative, not limiting. Thus it will be apparent to one skilled in the art that modifications may be made to the invention as described without departing from the scope of the claims set out below.

Claims

1. A polishing tool suitable for polishing a semiconductor processing apparatus component, the polishing tool comprising:
 - a main support member;
 - a polishing head support member, wherein the polishing head support member is coupled to the main support member such that the polishing head support member is linearly movable relative to the main support member in a first direction and a second direction that is different to the first direction;
 - a first drive mechanism operable to move the polishing head support member relative to the main support member in the first direction; and
 - a second drive mechanism operable to move the polishing head support member relative to the main support member in the second direction.
2. The polishing tool of claim 1, further comprising: an intermediate support member, wherein the intermediate support member is coupled to the main support member such that the intermediate head support member is linearly movable relative to the main support member in the first direction; and wherein the polishing head support member is coupled to the intermediate support member such that the polishing head support member is linearly movable relative to the intermediate support member in the second direction.
3. The polishing tool of claim 1 wherein the polishing head support member is coupled to the main support member via at least one spring member that allows the polishing head support member to be linearly movable relative to the main support member in the first and second directions.
4. The polishing tool of claim 1 or claim 3 wherein the polishing head support member is coupled to the main support member via at least one hinge member that allows the polishing head support member to be linearly movable relative to the main support member in the first and second directions.
5. The polishing tool of any one of claims 1, 3 or claim 4 wherein the polishing head support member is integrally formed with the main support member.
6. The polishing tool of any preceding claim wherein the polishing head support member is formed separately from with the main support member and the polishing tool comprises at least one bearing coupling the polishing head support to the main support member.
7. The polishing tool of claim 6 wherein at least one of the at least one bearing comprises a linear aerostatic bearing.
8. The polishing tool of claim 7 wherein the at least one linear aerostatic bearing is inverted so as to compensate for its own weight.
9. The polishing tool of any preceding claim wherein the first drive mechanism and/or the second drive mechanism comprises a direct drive motor.
10. The polishing tool of any preceding claim wherein the first drive mechanism and/or the second drive mechanism comprises an ironless motor.
11. The polishing tool of any preceding claim further comprising a third drive mechanism operable to move the polishing head support member in a third direction generally perpendicular to the first and second directions.
12. The polishing tool of any preceding claim further comprising a controller operable to control the first and second drive mechanisms.
13. The polishing tool of claim 12 wherein the controller is configured to control the first and second drive mechanisms so as to ensure that the polishing head support member moves with a constant velocity relative to a work piece.
14. The polishing tool of claim 12 or claim 13 wherein the controller is operable to control a size of a circular movement of the polishing head support member.
15. The polishing tool of any preceding claim further comprising one or more sensors arranged to determine and/or monitor polishing process data.
16. The polishing tool of any preceding claim wherein the first and second directions are mutually perpendicular.
17. An apparatus comprising the polishing tool of any preceding claim.
18. The apparatus of claim 17 further comprising:
 - a support structure; and
 - a movable member movably mounted to the support structure and wherein the main support member of the polishing tool is connected to the

movable member.

process data.

- 19.** The apparatus of claim 18 further comprising a main controller operable to control a position of the movable member relative to the support structure. 5
- 20.** The apparatus of claim 19 wherein the main controller is further operable to control the first and second drive mechanisms of the polishing tool. 10
- 21.** The apparatus of claim 20 wherein the main controller is configured to control the first and second drive mechanisms so as to ensure that the polishing head support member moves with a constant velocity relative to the support structure. 15
- 22.** The apparatus of claim 20 or claim 21 wherein the main controller is operable to control a size of a circular movement of the polishing head support member. 20
- 23.** A method of polishing a work piece, the method comprising:
- urging a polishing head towards a surface of the work piece; and 25
- actuating the polishing head to move relative to the work piece so as to oscillate in a first linear direction; and
- actuating the polishing head to move relative to the work piece so as to oscillate in a second linear direction that is different to the first direction. 30
- 24.** The method of claim 23 comprising moving the polishing head with a constant velocity relative to a work piece. 35
- 25.** The method of claim 23 or claim 24 comprising: 40
- actuating the polishing head to move relative to a support member so as to oscillate in the first and second linear directions relative thereto; and
- moving the movable member relative to the work piece. 45
- 26.** The method of any one of claims 23 to 25 comprising controlling a size of a circular movement of the polishing head. 50
- 27.** The method of claim any one of claims 23 to 26 further comprising urging the polishing head towards the work piece in a third direction that is generally perpendicular to the first and second directions. 55
- 28.** The method of any one of claims 23 to 27 further comprising determining and/or monitoring polishing
- 29.** The method of any one of claims 23 to 28 wherein the first and second directions are mutually perpendicular.

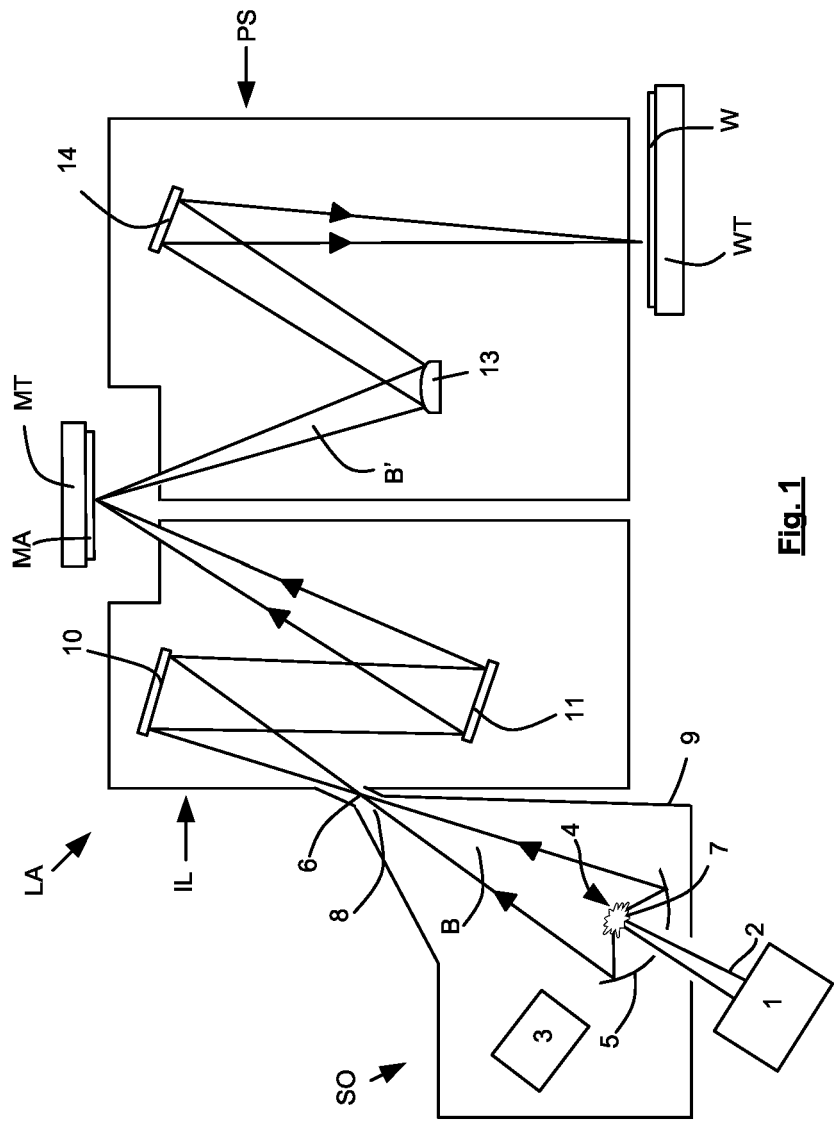
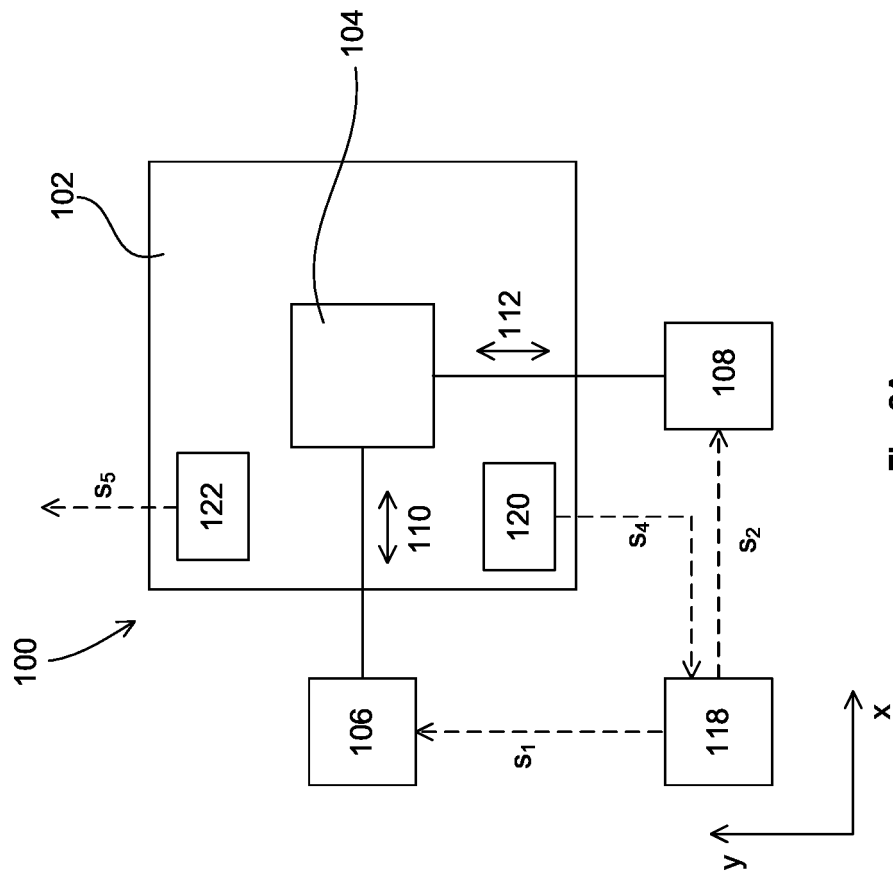
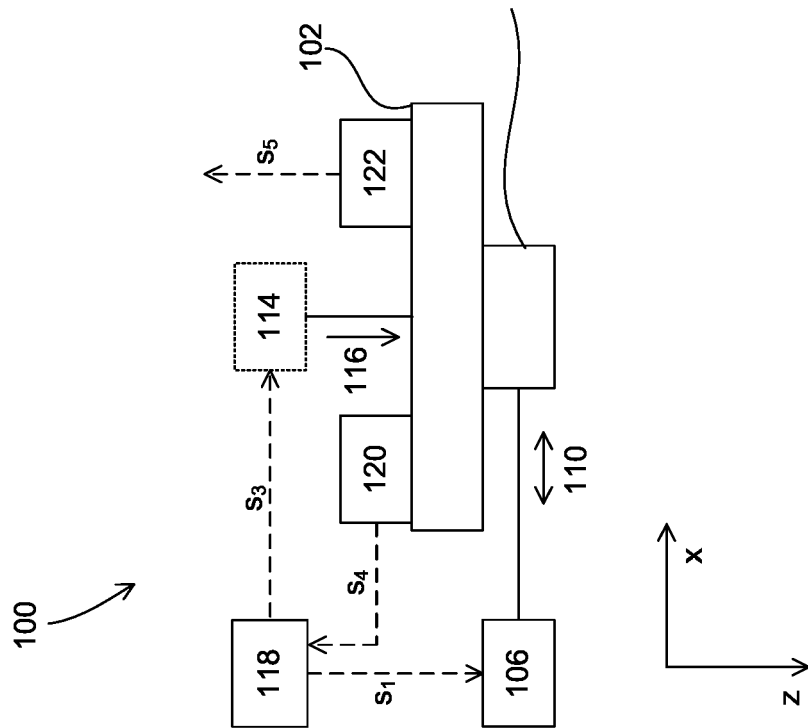


Fig. 1



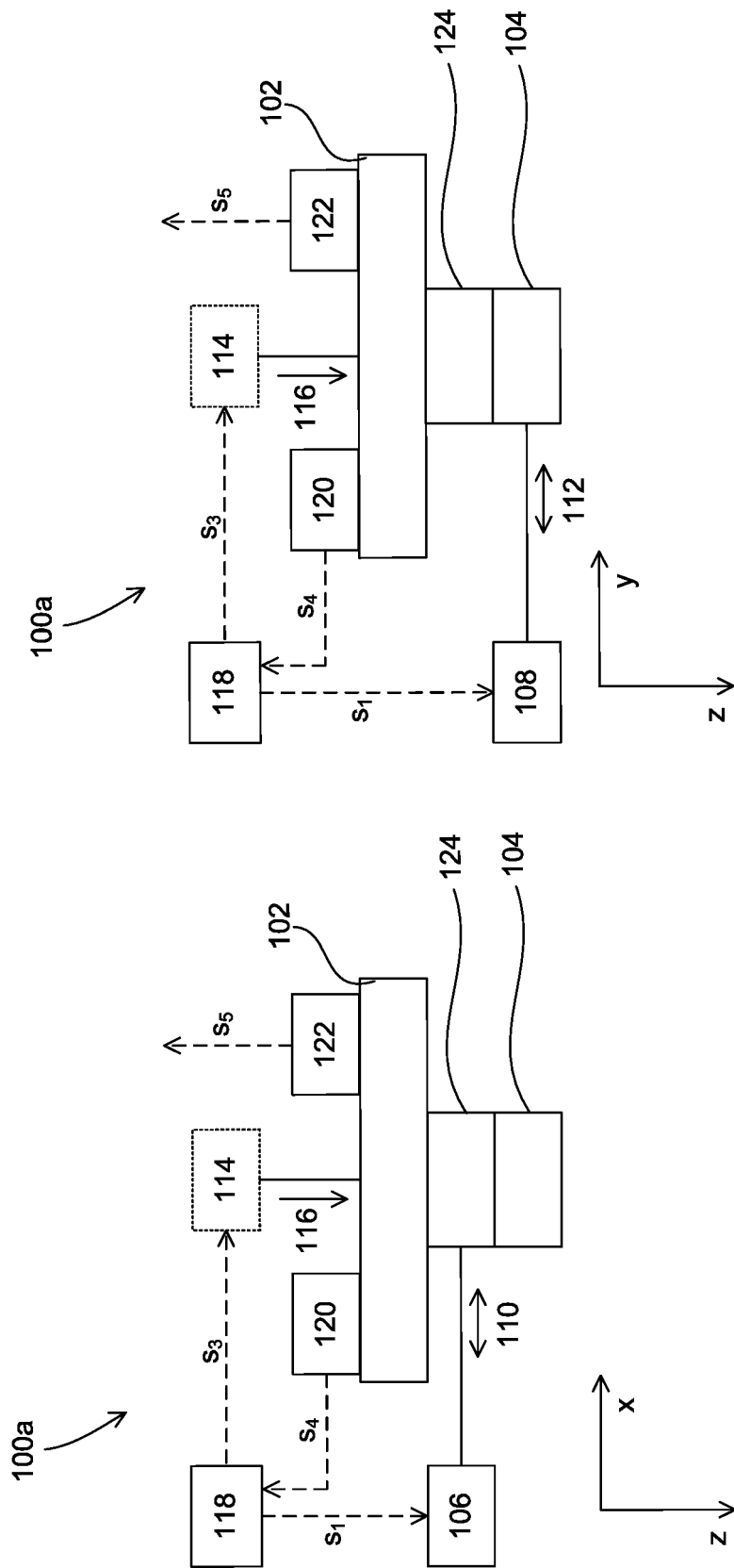


Fig. 3B

Fig. 3A

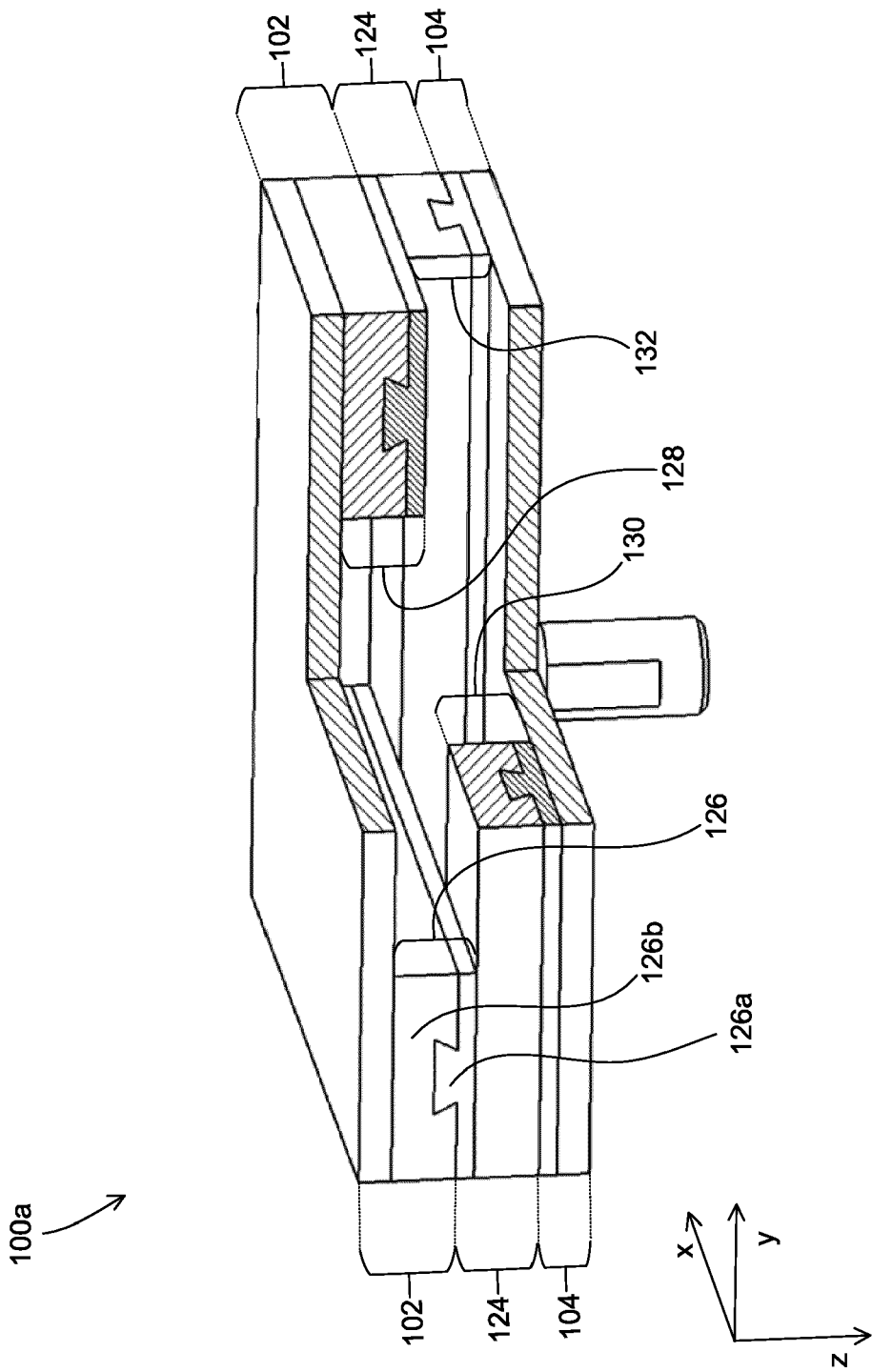


Fig. 4

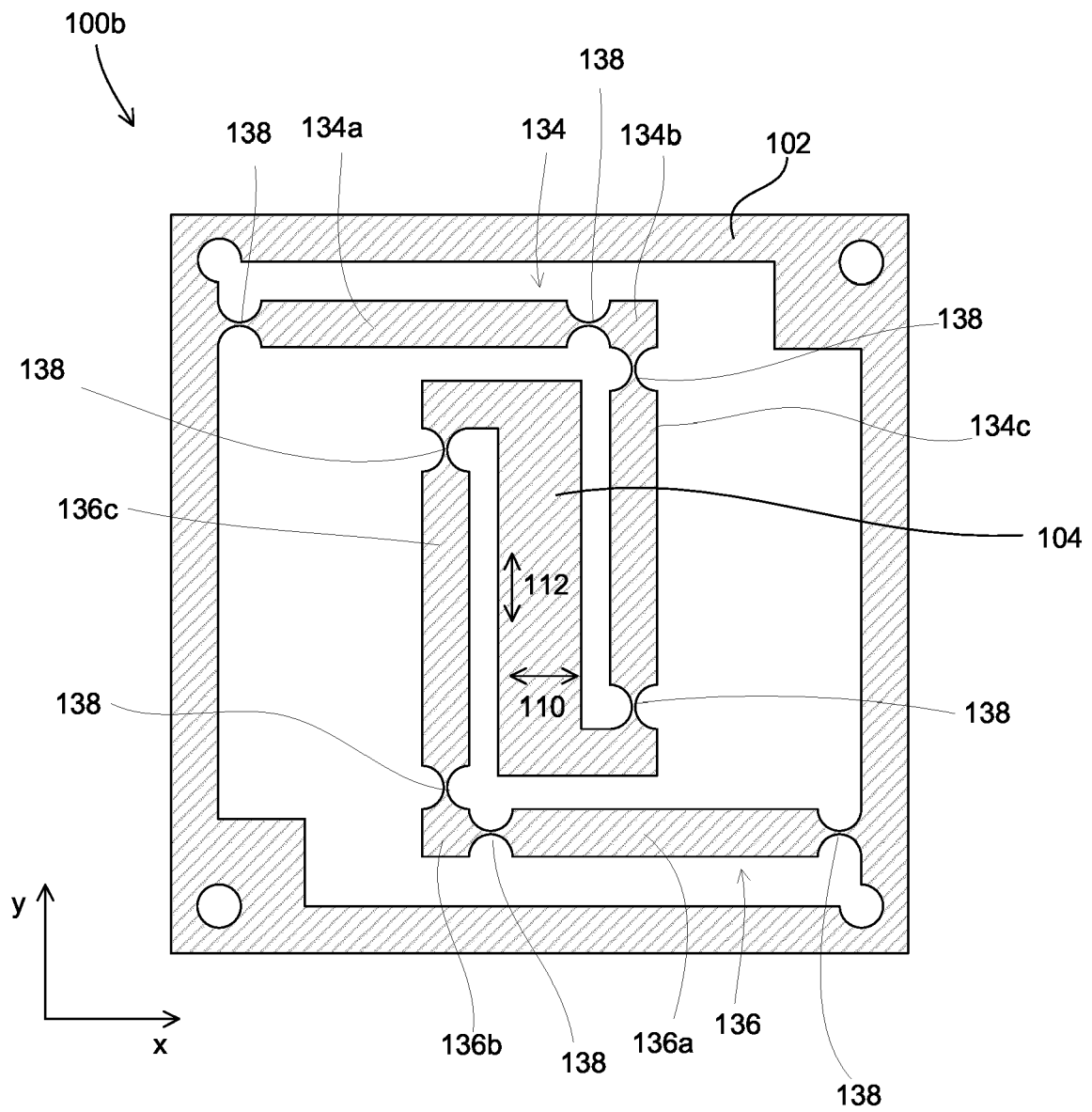


Fig. 5

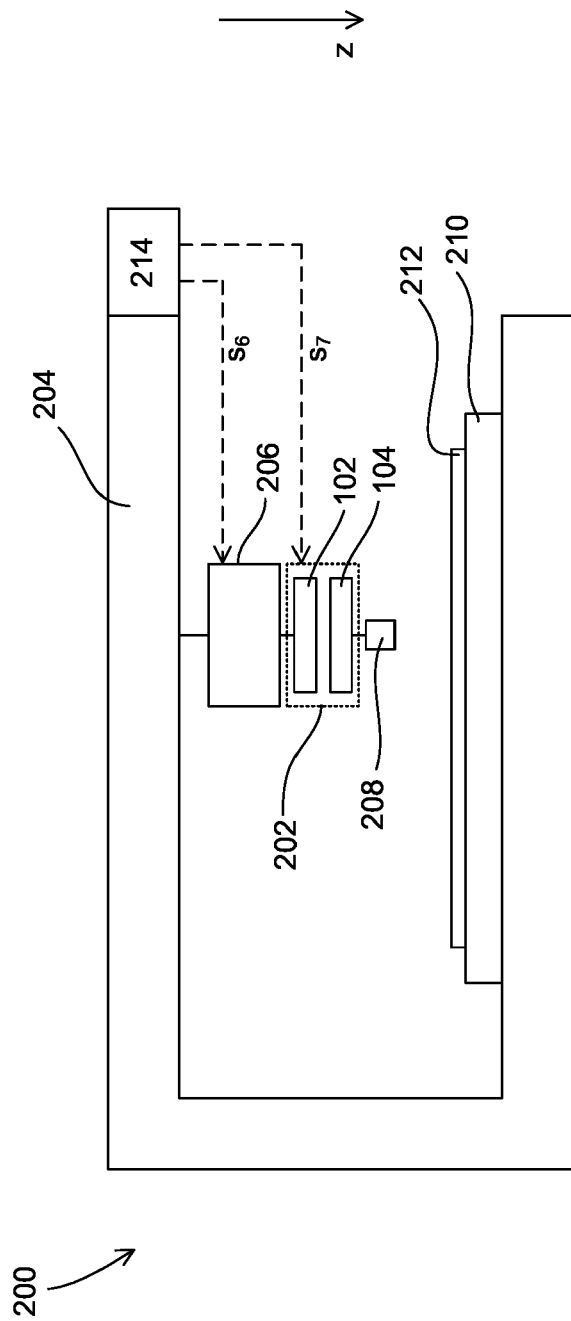


Fig. 6

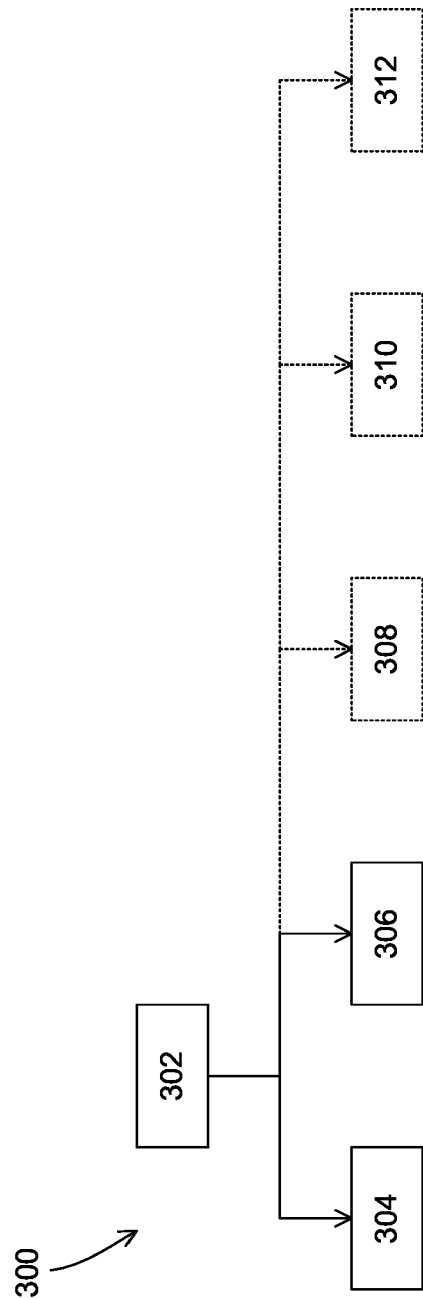


Fig. 7



EUROPEAN SEARCH REPORT

Application Number

EP 23 18 4618

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X	WO 2015/087294 A1 (TONCELLI LUCA [IT]) 18 June 2015 (2015-06-18)	1, 2, 5-29	INV. B24B41/047
A	* page 12, line 8 - page 14, line 15; figures 1-4, 13-16 * * page 5, line 34 - page 6, line 21 *	3, 4	B24B7/07 B24B7/24
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Place of search		Date of completion of the search	Examiner
Munich		23 November 2023	Kornmeier, Martin
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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