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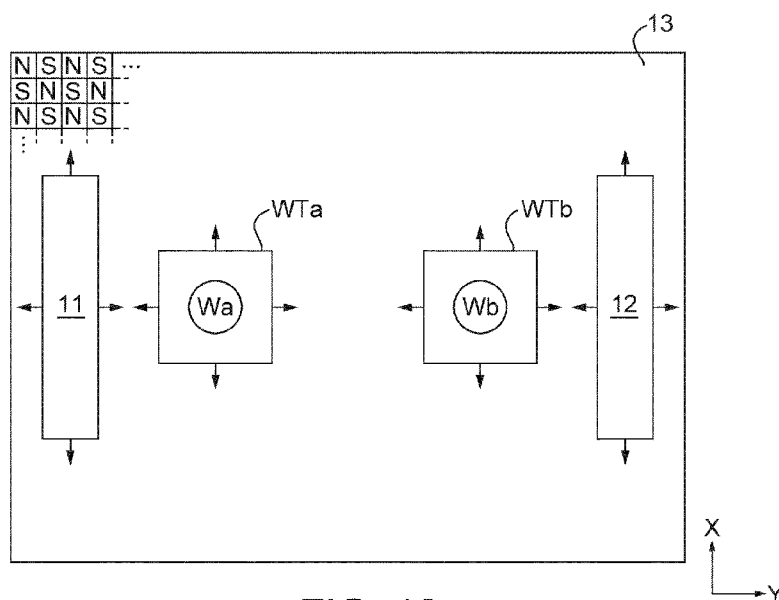


FIG. 10

(57) **Abstract:** A lithographic apparatus having two substrate tables or two support structures for patterning devices that are positioned by planar motors acting against a magnet plate has one or more balance masses also driven against the magnet plate so as to minimize movement of the magnet plate. Thereby, non-repeating positioning errors related to variations in the position of the magnet plate are reduced.

## LITHOGRAPHIC APPARATUS AND DEVICE MANUFACTURING METHOD

## CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of US provisional application 61/658,224 which was filed on June 11, 2012, and which is incorporated herein in its entirety by reference.

FIELD

[0002] The present invention relates to a lithographic apparatus and a device manufacturing method using such an apparatus, in particular an apparatus having an object driven by a coil unit acting against a magnet array that is moveable in at least one degree of freedom.

BACKGROUND

[0003] A lithographic apparatus is a machine that applies a desired pattern onto a substrate, usually onto a target portion of the substrate. A lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In that instance, a patterning device, which is alternatively referred to as a mask or a reticle, may be used to generate a circuit pattern to be formed on an individual layer of the IC. This pattern can be transferred onto a target portion (e.g. comprising part of, one, or several dies) on a substrate (e.g. a silicon wafer). Transfer of the pattern is typically via imaging onto a layer of radiation-sensitive material (resist) provided on the substrate. In general, a single substrate will contain a network of adjacent target portions that are successively patterned. Known lithographic apparatus include so-called steppers, in which each target portion is irradiated by exposing an entire pattern onto the target portion at one time, and so-called scanners, in which each target portion is irradiated by scanning the pattern through a radiation beam in a given direction (the “scanning”-direction) while synchronously scanning the substrate parallel or anti-parallel to this direction. It is also possible to transfer the pattern from the patterning device to the substrate by imprinting the pattern onto the substrate.

[0004] It has been proposed to immerse the substrate in the lithographic projection apparatus in a liquid having a relatively high refractive index, e.g. water, so as to fill a space between the final element of the projection system and the substrate. However, another fluid may be suitable, particularly a wetting fluid, an incompressible fluid and/or a fluid with higher

refractive index than air, desirably a higher refractive index than water. Fluids excluding gases are particularly desirable. The point of this is to enable imaging of smaller features since the exposure radiation will have a shorter wavelength in the liquid. The effect of the liquid may also be regarded as increasing the effective numerical aperture (NA) of the system and also increasing the depth of focus. Other immersion liquids have been proposed, including water with solid particles (e.g. quartz) suspended therein, or a liquid with a nano-particle suspension (e.g. particles with a maximum dimension of up to 10 nm). The suspended particles may or may not have a similar or the same refractive index as the liquid in which they are suspended. Other liquids which may be suitable include a hydrocarbon, such as an aromatic, a fluorohydrocarbon, and/or an aqueous solution.

## SUMMARY

**[0005]** In lithography processes, multiple layers are patterned accurately relative to one another.

Positioning errors between device layers, known as overlay errors, should be kept within acceptable limits, which tend to become stricter as the sizes of features to be formed reduce. At the same time, in order to provide a high throughput the substrate table and the support structure for a patterning device (e.g. a mask table) should be moved at high speed and with high accelerations. For example, a substrate stage or a support structure for a patterning device may have a mass of greater than 50 kg and may be subjected to accelerations of greater than  $10 \text{ ms}^{-2}$ . To provide the desired drive forces it is known to use e.g. linear or planar motors. Planar motors using drive coils in the object to be positioned acting against Halbach magnet arrays have become common.

**[0006]** Many lithographic apparatus use balance masses to minimize vibrations. A balance mass is a mass that is driven with a force opposite to that applied to the object being positioned so that it moves in the opposite direction to the object being positioned. The balance mass may have a greater mass than the object being driven so that the amplitude of its movements is proportionately less. An actuator, such as a linear or planar motor, can act directly between the object to be positioned and the balance mass. For example, permanent magnets are mounted on the balance mass and coils on the object to be positioned. Alternatively, separate actuators can be used to drive the balance mass and object to be positioned from a stationary frame. In either case, the intention is to create as far as possible a closed force system so that

greatly reduced forces are exerted outside the force system. A low frequency force is applied from outside the closed force system to prevent the balance mass drifting too far.

[0007] To achieve the desired overlay performance, the movements of a substrate table or a support structure for a patterning device must be highly repeatable. The present inventors have discovered certain non-repeating positioning errors in lithographic apparatus having an object driven with respect to a balance mass system.

[0008] It is desirable, for example, to provide an improved arrangement for positioning a driven object, for example a substrate table and/or a support structure for a patterning device, in which the movements of the substrate table or support structure are more repeatable.

[0009] According to an aspect of the invention, there is provided a lithographic apparatus, comprising: a driven object; and a positioning system arranged to position the driven object in at least one degree of freedom, the positioning system comprising: an array of permanent magnets and a coil unit arranged so that energization of a coil unit causes a drive force to be exerted between the coil unit and the array of permanent magnets wherein one of the array of permanent magnets and the coil unit is mounted on a member that is free to move in the at least one degree of freedom and the other of the array of permanent magnets and the coil unit is mounted on the driven object; a balance mass that is free to move in the at least one degree of freedom; and a balance mass driving system configured to exert a balancing force on the balance mass that is substantially opposite in direction to the drive force.

[0010] According to an aspect of the invention, there is provided a lithographic apparatus comprising: two substrate tables each configured to support a substrate; and a positioning system arranged to position the substrate tables in at least one degree of freedom, the positioning system comprising: two arrays of permanent magnets each mounted on a respective magnet plate that is free to move in the at least one degree of freedom; a coil unit in each of the substrate tables arranged so that energization of a coil unit causes a drive force to be exerted between a substrate table and a magnet plate; wherein the two magnet plates are arranged to move independently of one another in the at least one degree of freedom.

[0011] According to an aspect of the invention, there is provided a lithographic apparatus comprising: two substrate tables each configured to support a substrate; and a positioning system arranged to position the substrate tables in at least one degree of freedom, the positioning system comprising: an array of permanent magnets mounted on a magnet plate

that is free to move in the at least one degree of freedom; a coil unit in each of the substrate tables arranged so that energization of a coil unit causes a drive force to be exerted between a substrate table and the magnet plate; wherein the positioning system is arranged so that the array of permanent magnets is substantially stationary or moves predictably during exposure of a substrate.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, and in which:

[0013] Figure 1 depicts a lithographic apparatus according to an embodiment of the invention;

[0014] Figures 2 and 3 depict a liquid supply system for use in a lithographic projection apparatus;

[0015] Figure 4 depicts a further liquid supply system for use in a lithographic projection apparatus;

[0016] Figure 5 depicts, in cross-section, a barrier member which may be used in an embodiment of the present invention as an immersion liquid supply system;

[0017] Figure 6 depicts a lithographic apparatus according to an embodiment of the invention;

[0018] Figure 7 is a more detailed view of the apparatus of Figure 6;

[0019] Figure 8 is a more detailed view of the source collector apparatus of the apparatus of Figures 6 and 7;

[0020] Figure 9 depicts substrate table positioning arrangements according to an embodiment of the invention;

[0021] Figure 10 depicts in plan the substrate table positioning arrangements of Figure 9;

[0022] Figure 11 depicts substrate table positioning arrangements according to an embodiment of the invention;

[0023] Figure 12 depicts in plan the substrate table positioning arrangements of Figure 11;

[0024] Figure 13 depicts substrate table positioning arrangements according to an embodiment of the invention; and

[0025] Figure 14 depicts substrate table positioning arrangements according to an embodiment of the invention.

#### DETAILED DESCRIPTION

[0026] Figure 1 schematically depicts a lithographic apparatus according to one embodiment of the invention. The apparatus comprises:

[0027] - an illumination system (illuminator) IL configured to condition a radiation beam B (e.g. UV radiation, DUV radiation or EUV radiation);

[0028] - a support structure (e.g. a mask table) MT constructed to support a patterning device (e.g. a mask) MA and connected to a first positioner PM configured to accurately position the patterning device in accordance with certain parameters;

[0029] - a substrate table (e.g. a wafer table) WT constructed to hold a substrate (e.g. a resist-coated wafer) W and connected to a second positioner PW configured to accurately position the substrate in accordance with certain parameters; and

[0030] - a projection system (e.g. a refractive projection lens system) PS configured to project a pattern imparted to the radiation beam B by patterning device MA onto a target portion C (e.g. comprising one or more dies) of the substrate W.

[0031] The illumination system may include various types of optical components, such as refractive, reflective, magnetic, electromagnetic, electrostatic or other types of optical components, or any combination thereof, for directing, shaping, or controlling radiation.

[0032] The support structure MT holds the patterning device. The support structure MT holds the patterning device in a manner that depends on the orientation of the patterning device, the design of the lithographic apparatus, and other conditions, such as for example whether or not the patterning device is held in a vacuum environment. The support structure MT can use mechanical, vacuum, electrostatic or other clamping techniques to hold the patterning device. The support structure MT may be a frame or a table, for example, which may be fixed or movable as required. The support structure MT may ensure that the patterning device is at a desired position, for example with respect to the projection system. Any use of the terms “reticle” or “mask” herein may be considered synonymous with the more general term “patterning device”.

[0033] The term “patterning device” used herein should be broadly interpreted as referring to any device that can be used to impart a radiation beam with a pattern in its cross-section such as to create a pattern in a target portion of the substrate. It should be noted that the pattern imparted to the radiation beam may not exactly correspond to the desired pattern in the target portion of the substrate, for example if the pattern includes phase-shifting features or so called assist features. Generally, the pattern imparted to the radiation beam will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit.

[0034] The patterning device may be transmissive or reflective. Examples of patterning devices include masks, programmable mirror arrays, and programmable LCD panels. Masks are well known in lithography, and include mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. An example of a programmable mirror array employs a matrix arrangement of small mirrors, each of which can be individually tilted so as to reflect an incoming radiation beam in different directions. The tilted mirrors impart a pattern in a radiation beam which is reflected by the mirror matrix.

[0035] The terms “projection system” used herein should be broadly interpreted as encompassing any type of system, including refractive, reflective, catadioptric, magnetic, electromagnetic and electrostatic optical systems, or any combination thereof, as appropriate for the exposure radiation being used, or for other factors such as the use of an immersion liquid or the use of a vacuum. Any use of the term “projection lens” herein may be considered as synonymous with the more general term “projection system”.

[0036] As here depicted, the apparatus is of a transmissive type (e.g. employing a transmissive mask). Alternatively, the apparatus may be of a reflective type (e.g. employing a programmable mirror array of a type as referred to above, or employing a reflective mask).

[0037] The lithographic apparatus may be of a type having two or more substrate support structures, such as substrate stages or substrate tables, and/or two or more support structures for patterning devices. In an apparatus with multiple substrate stages, all the substrate stages can be equivalent and interchangeable. In an embodiment, at least one of the multiple substrate stages is particularly adapted for exposure steps and at least one of the multiple substrate stages is particularly adapted for measurement or preparatory steps. In an embodiment of the invention one or more of the multiple substrate stages is replaced by a

measurement stage. A measurement stage includes at least a part of one or more sensor systems such as a sensor detector and/or target of the sensor system but does not support a substrate. The measurement stage is positionable in the projection beam in place of a substrate stage or a support structure for a patterning device. In such apparatus the additional stages may be used in parallel, or preparatory steps may be carried out on one or more stages while one or more other stages are being used for exposure.

[0038] Referring to Figure 1, the illuminator IL receives a radiation beam from a radiation source SO. The source and the lithographic apparatus may be separate entities, for example when the source is an excimer laser. In such cases, the source is not considered to form part of the lithographic apparatus and the radiation beam is passed from the source SO to the illuminator IL with the aid of a beam delivery system BD comprising, for example, suitable directing mirrors and/or a beam expander. In other cases the source may be an integral part of the lithographic apparatus, for example when the source is a mercury lamp. The source SO and the illuminator IL, together with the beam delivery system BD if required, may be referred to as a radiation system.

[0039] The illuminator IL may comprise an adjuster AM configured to adjust the angular intensity distribution of the radiation beam. Generally, at least the outer and/or inner radial extent (commonly referred to as  $\sigma$ -outer and  $\sigma$ -inner, respectively) of the intensity distribution in a pupil plane of the illuminator can be adjusted. In addition, the illuminator IL may comprise various other components, such as an integrator IN and a condenser CO. The illuminator may be used to condition the radiation beam, to have a desired uniformity and intensity distribution in its cross-section. Similar to the source SO, the illuminator IL may or may not be considered to form part of the lithographic apparatus. For example, the illuminator IL may be an integral part of the lithographic apparatus or may be a separate entity from the lithographic apparatus. In the latter case, the lithographic apparatus may be configured to allow the illuminator IL to be mounted thereon. Optionally, the illuminator IL is detachable and may be separately provided (for example, by the lithographic apparatus manufacturer or another supplier).

[0040] The radiation beam B is incident on the patterning device (e.g., mask) MA, which is held on the support structure (e.g., mask table) MT, and is patterned by the patterning device. Having traversed the patterning device MA, the radiation beam B passes through the

projection system PS, which focuses the beam onto a target portion C of the substrate W. Substrate W is held on the substrate table WT by a substrate holder according to an embodiment of the present invention and described further below. With the aid of the second positioner PW and position sensor IF (e.g. an interferometric device, linear encoder or capacitive sensor), the substrate table WT can be moved accurately, e.g. so as to position different target portions C in the path of the radiation beam B. Similarly, the first positioner PM and another position sensor (which is not explicitly depicted in Figure 1) can be used to accurately position the patterning device MA with respect to the path of the radiation beam B, e.g. after mechanical retrieval from a mask library, or during a scan. In general, movement of the support structure MT may be realized with the aid of a long-stroke module (coarse positioning) and a short-stroke module (fine positioning), which form part of the first positioner PM. Similarly, movement of the substrate table WT may be realized using a long-stroke module and a short-stroke module, which form part of the second positioner PW. In the case of a stepper (as opposed to a scanner) the support structure MT may be connected to a short-stroke actuator only, or may be fixed. Patterning device MA and substrate W may be aligned using patterning device alignment marks M1, M2 and substrate alignment marks P1, P2. Although the substrate alignment marks as illustrated occupy dedicated target portions, they may be located in spaces between target portions (these are known as scribe-lane alignment marks). Similarly, in situations in which more than one die is provided on the patterning device MA, the patterning device alignment marks may be located between the dies.

[0041] The depicted apparatus could be used in at least one of the following modes:

[0042] 1. In step mode, the support structure MT and the substrate table WT are kept essentially stationary, while an entire pattern imparted to the radiation beam is projected onto a target portion C at one time (i.e. a single static exposure). The substrate table WT is then shifted in the X and/or Y direction so that a different target portion C can be exposed. In step mode, the maximum size of the exposure field limits the size of the target portion C imaged in a single static exposure.

[0043] 2. In scan mode, the support structure MT and the substrate table WT are scanned synchronously while a pattern imparted to the radiation beam is projected onto a target portion C (i.e. a single dynamic exposure). The velocity and direction of the substrate table

WT relative to the support structure MT may be determined by the (de-)magnification and image reversal characteristics of the projection system PS. In scan mode, the maximum size of the exposure field limits the width (in the non-scanning direction) of the target portion in a single dynamic exposure, whereas the length of the scanning motion determines the height (in the scanning direction) of the target portion.

[0044] 3. In another mode, the support structure MT is kept essentially stationary holding a programmable patterning device, and the substrate table WT is moved or scanned while a pattern imparted to the radiation beam is projected onto a target portion C. In this mode, generally a pulsed radiation source is employed and the programmable patterning device is updated as required after each movement of the substrate table WT or in between successive radiation pulses during a scan. This mode of operation can be readily applied to maskless lithography that utilizes programmable patterning device, such as a programmable mirror array of a type as referred to above.

[0045] Combinations and/or variations on the above described modes of use or entirely different modes of use may also be employed.

[0046] In many lithographic apparatuses, a fluid, in particular a liquid, is provided between the final element of the projection system using a liquid supply system IH to enable imaging of smaller features and/or increase the effective NA of the apparatus. An embodiment of the invention is described further below with reference to such an immersion apparatus, but may equally be embodied in a non-immersion apparatus. Arrangements to provide liquid between a final element of the projection system and the substrate can be classed into at least two general categories. These are the bath type arrangement and the localized immersion system. In the bath type arrangement substantially the whole of the substrate and optionally part of the substrate table is submersed in a bath of liquid. The localized immersion system uses a liquid supply system in which liquid is only provided to a localized area of the substrate. In the latter category, the space filled by liquid is smaller in plan than the top surface of the substrate and the area filled with liquid remains substantially stationary relative to the projection system while the substrate moves underneath that area. Another arrangement, to which an embodiment of the invention is directed, is the all wet solution in which the liquid is unconfined. In this arrangement substantially the whole top surface of the substrate and all or part of the substrate table is covered in immersion liquid. The depth of the liquid covering

at least the substrate is small. The liquid may be a film, such as a thin-film, of liquid on the substrate.

[0047] In an embodiment, the liquid is distilled water, although another liquid can be used. An embodiment of the present invention will be described with reference to liquid.

[0048] Four different types of localized liquid supply systems are illustrated in Figures 2 to 5.

Any of the liquid supply devices of Figures 2 to 5 may be used in an unconfined system; however, sealing features are not present, are not activated, are not as efficient as normal or are otherwise ineffective to seal liquid to only the localized area.

[0049] One of the arrangements proposed for a localized immersion system is for a liquid supply system to provide liquid on only a localized area of the substrate and in between the final element of the projection system and the substrate using a liquid confinement system (the substrate generally has a larger surface area than the final element of the projection system). One way which has been proposed to arrange for this is disclosed in PCT patent application publication no. WO 99/49504. As illustrated in Figures 2 and 3, liquid is supplied by at least one inlet onto the substrate, desirably along the direction of movement of the substrate relative to the final element, and is removed by at least one outlet after having passed under the projection system. That is, as the substrate is scanned beneath the element in a  $-X$  direction, liquid is supplied at the  $+X$  side of the element and taken up at the  $-X$  side.

[0050] Figure 2 shows the arrangement schematically in which liquid is supplied via inlet and is taken up on the other side of the element by outlet which is connected to a low pressure source. The arrows above the substrate W illustrate the direction of liquid flow, and the arrow below the substrate W illustrates the direction of movement of the substrate table. In the illustration of Figure 2 the liquid is supplied along the direction of movement of the substrate relative to the final element, though this does not need to be the case. Various orientations and numbers of in-and out-lets positioned around the final element are possible, one example is illustrated in Figure 3 in which four sets of an inlet with an outlet on either side are provided in a regular pattern around the final element. Arrows in liquid supply and liquid recovery devices indicate the direction of liquid flow.

[0051] A further immersion lithography solution with a localized liquid supply system is shown in Figure 4. Liquid is supplied by two groove inlets on either side of the projection system PS and is removed by a plurality of discrete outlets arranged radially outwardly of the inlets. The

inlets and outlets can be arranged in a plate with a hole in its center and through which the projection beam is projected. Liquid is supplied by one groove inlet on one side of the projection system PS and removed by a plurality of discrete outlets on the other side of the projection system PS, causing a flow of a thin-film of liquid between the projection system PS and the substrate W. The choice of which combination of inlet and outlets to use can depend on the direction of movement of the substrate W (the other combination of inlet and outlets being inactive). In the cross-sectional view of Figure 4, arrows illustrate the direction of liquid flow in to inlets and out of outlets.

**[0052]** Another arrangement which has been proposed is to provide the liquid supply system with a liquid confinement member which extends along at least a part of a boundary of the space between the final element of the projection system and the substrate table. Such an arrangement is illustrated in Figure 5. The liquid confinement member is substantially stationary relative to the projection system in the XY plane, though there may be some relative movement in the Z direction (in the direction of the optical axis). A seal is formed between the liquid confinement member and the surface of the substrate. In an embodiment, a seal is formed between the liquid confinement member and the surface of the substrate and may be a contactless seal such as a gas seal. Such a system is disclosed in United States patent application publication no. US 2004-0207824.

**[0053]** The fluid handling structure 12 includes a liquid confinement member and at least partly contains liquid in the space 11 between a final element of the projection system PS and the substrate W. A contactless seal 16 to the substrate W may be formed around the image field of the projection system so that liquid is confined within the space between the substrate W surface and the final element of the projection system PS. The space is at least partly formed by the fluid handling structure 12 positioned below and surrounding the final element of the projection system PS. Liquid is brought into the space below the projection system and within the fluid handling structure 12 by liquid inlet 13. The liquid may be removed by liquid outlet 13. The fluid handling structure 12 may extend a little above the final element of the projection system. The liquid level rises above the final element so that a buffer of liquid is provided. In an embodiment, the fluid handling structure 12 has an inner periphery that at the upper end closely conforms to the shape of the projection system or the final element thereof

and may, e.g., be round. At the bottom, the inner periphery closely conforms to the shape of the image field, e.g., rectangular, though this need not be the case.

**[0054]** In an embodiment, the liquid is contained in the space 11 by a gas seal 16 which, during use, is formed between the bottom of the fluid handling structure 12 and the surface of the substrate W. The gas seal is formed by gas, e.g. air, synthetic air, N<sub>2</sub> or another inert gas. The gas in the gas seal is provided under pressure via inlet 15 to the gap between fluid handling structure 12 and substrate W. The gas is extracted via outlet 14. The overpressure on the gas inlet 15, vacuum level on the outlet 14 and geometry of the gap are arranged so that there is a high-velocity gas flow 16 inwardly that confines the liquid. The force of the gas on the liquid between the fluid handling structure 12 and the substrate W contains the liquid in a space 11. The inlets/outlets may be annular grooves which surround the space 11. The annular grooves may be continuous or discontinuous. The flow of gas 16 is effective to contain the liquid in the space 11. Such a system is disclosed in United States patent application publication no. US 2004-0207824.

**[0055]** The example of Figure 5 is a localized area arrangement in which liquid is only provided to a localized area of the top surface of the substrate W at any one time. Other arrangements are possible, including fluid handling systems which make use of a single phase extractor or a two phase extractor as disclosed, for example, in United States patent application publication no US 2006-0038968.

**[0056]** Many other types of liquid supply system are possible. Embodiments of the present invention are neither limited to any particular type of liquid supply system, nor to immersion lithography. An embodiment of the invention may be applied equally in any lithography. In an EUV lithography apparatus, the beam path is substantially evacuated and immersion arrangements described above are not used.

**[0057]** A control system 500 shown in Figure 1 controls the overall operations of the lithographic apparatus and in particular performs an optimization process described further below. Control system 500 can be embodied as a suitably-programmed general purpose computer comprising a central processing unit and volatile and non-volatile storage. Optionally, the control system may further comprise one or more input and output devices such as a keyboard and screen, one or more network connections and/or one or more interfaces to the various parts of the lithographic apparatus. It will be appreciated that a one-

to-one relationship between controlling computer and lithographic apparatus is not necessary. In an embodiment of the invention one computer can control multiple lithographic apparatuses. In an embodiment of the invention, multiple networked computers can be used to control one lithographic apparatus. The control system 500 may also be configured to control one or more associated process devices and substrate handling devices in a lithocell or cluster of which the lithographic apparatus forms a part. The control system 500 can also be configured to be subordinate to a supervisory control system of a lithocell or cluster and/or an overall control system of a fab.

**[0058]** Figure 6 schematically depicts an EUV lithographic apparatus 4100 including a source collector apparatus SO. The apparatus comprises:

- an illumination system (illuminator) EIL configured to condition a radiation beam B (e.g. EUV radiation);
- a support structure (e.g. a mask table) MT constructed to support a patterning device (e.g. a mask or a reticle) MA and connected to a first positioner PM configured to accurately position the patterning device;
- a substrate table (e.g. a wafer table) WT constructed to hold a substrate (e.g. a resist-coated wafer) W and connected to a second positioner PW configured to accurately position the substrate; and
- a projection system (e.g. a reflective projection system) PS configured to project a pattern imparted to the radiation beam B by patterning device MA onto a target portion C (e.g. comprising one or more dies) of the substrate W.

**[0059]** These basic components of the EUV lithographic apparatus are similar in function to the corresponding components of the lithographic apparatus of Figure 1. The description below mainly covers areas of difference and duplicative description of aspects of the components that are the same is omitted.

**[0060]** In an EUV lithographic apparatus, it is desirable to use a vacuum or low pressure environment since gases can absorb too much radiation. A vacuum environment can therefore be provided to the whole beam path with the aid of a vacuum wall and one or more vacuum pumps.

**[0061]** Referring to Figure 6, the EUV illuminator EIL receives an extreme ultra violet radiation beam from the source collector apparatus SO. Methods to produce EUV radiation include,

but are not necessarily limited to, converting a material into a plasma state that has at least one element, e.g., xenon, lithium or tin, with one or more emission lines in the EUV range. In one such method, often termed laser produced plasma ("LPP") the plasma can be produced by irradiating a fuel, such as a droplet, stream or cluster of material having the desired line-emitting element, with a laser beam. The source collector apparatus SO may be part of an EUV radiation system including a laser, not shown in Figure 6, to provide the laser beam exciting the fuel. The resulting plasma emits output radiation, e.g., EUV radiation, which is collected using a radiation collector, disposed in the source collector apparatus. The laser and the source collector apparatus may be separate entities, for example when a CO<sub>2</sub> laser is used to provide the laser beam for fuel excitation.

[0062] In such cases, the laser is not considered to form part of the lithographic apparatus and the radiation beam is passed from the laser to the source collector apparatus with the aid of a beam delivery system comprising, for example, suitable directing mirrors and/or a beam expander. In other cases the source may be an integral part of the source collector apparatus, for example when the source is a discharge-produced plasma EUV generator, often termed as a DPP source.

[0063] The EUV illuminator EIL may comprise an adjuster to adjust the angular intensity distribution of the radiation beam EB. Generally, at least the outer and/or inner radial extent (commonly referred to as  $\sigma$ -outer and  $\sigma$ -inner, respectively) of the intensity distribution in a pupil plane of the illuminator can be adjusted. In addition, the EUV illuminator EIL may comprise various other components, such as faceted field and pupil mirror devices. The EUV illuminator EIL may be used to condition the radiation beam EB, to have a desired uniformity and intensity distribution in its cross section.

[0064] The radiation beam EB is incident on the patterning device (e.g., mask) MA, which is held on the support structure (e.g., mask table) MT, and is patterned by the patterning device. After being reflected from the patterning device (e.g. mask) MA, the radiation beam EB passes through the projection system PS, which focuses the beam onto a target portion C of the substrate W. With the aid of the second positioner PW and position sensor PS2 (e.g. an interferometric device, linear encoder or capacitive sensor), the substrate table WT can be moved accurately, e.g. so as to position different target portions C in the path of the radiation beam EB. Similarly, the first positioner PM and another position sensor PS1 can be used to

accurately position the patterning device (e.g. mask) MA with respect to the path of the radiation beam EB. Patterning device (e.g. mask) MA and substrate W may be aligned using mask alignment marks M1, M2 and substrate alignment marks P1, P2.

[0065] The depicted apparatus can be used in the same modes as the apparatus of Figure 1.

[0066] Figure 7 shows the EUV apparatus 4100 in more detail, including the source collector apparatus SO, the EUV illumination system EIL, and the projection system PS. The source collector apparatus SO is constructed and arranged such that a vacuum environment can be maintained in an enclosing structure 4220 of the source collector apparatus SO. An EUV radiation emitting plasma 4210 may be formed by a discharge produced plasma source. EUV radiation may be produced by a gas or vapor, for example Xe gas, Li vapor or Sn vapor in which the plasma 4210 is created to emit radiation in the EUV range of the electromagnetic spectrum. The plasma 4210 is created by, for example, an electrical discharge causing an at least partially ionized plasma. Partial pressures of, for example, 10 Pa of Xe, Li, Sn vapor or any other suitable gas or vapor may be required for efficient generation of the radiation. In an embodiment, a plasma of excited tin (Sn) is provided to produce EUV radiation.

[0067] The radiation emitted by the plasma 4210 is passed from a source chamber 4211 into a collector chamber 4212 via an optional gas barrier and/or contaminant trap 4230 (in some cases also referred to as contaminant barrier or foil trap) which is positioned in or behind an opening in source chamber 4211. The contaminant trap 4230 may include a channel structure. Contamination trap 4230 may also include a gas barrier or a combination of a gas barrier and a channel structure. The contaminant trap or contaminant barrier 4230 further indicated herein at least includes a channel structure, as known in the art.

[0068] The collector chamber 4212 may include a radiation collector CO which may be a so-called grazing incidence collector. Radiation collector CO has an upstream radiation collector side 4251 and a downstream radiation collector side 4252. Radiation that traverses collector CO can be reflected by a grating spectral filter 4240 to be focused in a virtual source point IF. The virtual source point IF is commonly referred to as the intermediate focus, and the source collector apparatus is arranged such that the intermediate focus IF is located at or near an opening 4221 in the enclosing structure 4220. The virtual source point IF is an image of the radiation emitting plasma 4210.

[0069] Subsequently the radiation traverses the illumination system IL, which may include a faceted field mirror device 422 and a faceted pupil mirror device 424 arranged to provide a desired angular distribution of the radiation beam 421, at the patterning device MA, as well as a desired uniformity of radiation intensity at the patterning device MA. Upon reflection of the beam of radiation 421 at the patterning device MA, held by the support structure MT, a patterned beam 426 is formed and the patterned beam 426 is imaged by the projection system PS via reflective elements 428, 430 onto a substrate W held by the substrate stage or substrate table WT.

[0070] More elements than shown may generally be present in illumination optics unit IL and projection system PS. The grating spectral filter 4240 may optionally be present, depending upon the type of lithographic apparatus. There may be more mirrors present than those shown in the Figures, for example there may be from 1 to 6 additional reflective elements present in the projection system PS than shown in Figure 7.

[0071] Collector optic CO, as illustrated in Figure 7, is depicted as a nested collector with grazing incidence reflectors 4253, 4254 and 4255, just as an example of a collector (or collector mirror). The grazing incidence reflectors 4253, 4254 and 4255 are disposed axially symmetric around an optical axis O and a collector optic CO of this type is used, in an embodiment, in combination with a discharge produced plasma source, often called a DPP source.

[0072] Alternatively, the source collector apparatus SO may be part of an LPP radiation system as shown in Figure 8. A laser LA is arranged to deposit laser energy into a fuel, such as xenon (Xe), tin (Sn) or lithium (Li), creating the highly ionized plasma 4210 with electron temperatures of several 10's of eV. The energetic radiation generated during de-excitation and recombination of these ions is emitted from the plasma, collected by a near normal incidence collector optic CO and focused onto the opening 4221 in the enclosing structure 4220.

[0073] The present inventors have determined that in a lithographic apparatus having two substrate tables, significant non-repeatable positioning errors (overlay errors) sometimes occur. The positioning errors are not repeatable in that they do not repeat consistently between different substrates of a lot. A lot is generally referred to as a set of wafers being processed together in a semiconductor fabrication plant from start to finish (i.e. all wafers

receiving the very same treatment). Such non-repeatable errors cannot be accurately predicted and cannot be compensated for by corrections to the planned stage movements. The present inventors have determined that a source of such non-repeatable errors is variation in the positioning of a combined balance mass and magnet plate forming part of a positioning system for the substrate tables.

**[0074]** In a lithographic apparatus having two substrate tables, it has been proposed that the two substrate tables are positioned by planar motors formed by coil units mounted in the bottom of the substrate table acting against a magnet array mounted to a large plate which is supported by, e.g., air bearings and is free to move in at least the X and Y directions. Other low-friction bearings can also be used. The support plate including the magnet array therefore acts as a balance mass for the two substrate tables. The two substrate tables and the balance mass form a closed force system minimizing the transmission of forces and vibrations to and from the outside world. The balance mass moves in reaction to the drive forces applied to the substrate tables but the amplitude of its movements is much less than the movements of the substrate tables since it has a much higher mass, e.g. more than ten times the combined mass of the substrate tables. The position of the substrate tables relative to the magnet array of the balanced mass is taken account of in the commutation algorithm which determines the energization currents for the coils that must be applied resulting in a desired force.

**[0075]** In such a lithographic apparatus, while one substrate table is being used for exposure of a substrate the other substrate table goes through a process of substrate exchange and pre-characterization, e.g. measuring a substrate topography map and horizontal alignment, for the next substrate to be exposed. The movements of the two substrate tables are independent and so the positions of the two substrate tables and the balance mass are not the same from substrate to substrate. The present inventors have determined that even though the relative position of the magnet plate in the balance mass and a substrate table being driven is taken into account in the commutation algorithm, variations in the balance mass position between corresponding exposures in subsequent substrates are a cause of non-repeatable overlay errors. It is possible that this is caused by interactions between stray fields from the magnet array and other parts of the apparatus. The stray fields vary with position of the magnet array.

[0076] These variations can also arise in an apparatus with just one driven object and one balance mass because the position of the balance mass at a given exposure is determined by the long term history of the forces applied thereto, including reaction forces to the drive forces and drift correction forces. It can also apply in an apparatus with multiple tables where the tables are any combination of substrate tables and calibration tables (measurement stages) which may or may not be capable of supporting a substrate.

[0077] Accordingly, an embodiment of the present invention proposes an arrangement for positioning one or more driven objects, e.g. one or more substrate tables, one or more calibration tables and/or one or more support structures for patterning devices which are driven by coils acting against a magnet array wherein the magnet array is arranged to be substantially stationary during operation. However, it is desirable that the magnet array is not to be fixed to avoid transmission of vibrations to and from the outside world. Therefore, according to an embodiment of the present invention at least one balance mass is provided, the balanced mass being driven relative to the magnet array by forces substantially opposite in direction, and optionally substantially equal in magnitude to forces applied to the driven object(s) that the magnet array remains substantially stationary. It is not necessary that movement of the magnet array be totally eliminated. The present inventors have determined that any reduction in movements of the magnet array is desirable and results in a reduction of the non-repeatable errors. In an embodiment of the present invention movement of the balance mass during exposure of a substrate is less than about 1 mm. In an embodiment the balance mass has a nominal home position to which it is returned by a drift correction mechanism when no reaction forces are acting on it and the balance mass does not move more than 1 mm from that home position during exposure of a substrate.

[0078] In an embodiment two balance masses are provided, one paired with each of the two objects to be positioned so that each balance mass is driven by forces equal and opposite to the forces applied to the respective one of the objects to be positioned. In an embodiment where objects to be positioned are exchanged between a measurement station and an exposure station, the pairing may be exchanged at the same time. In another embodiment, a single balance mass is driven by forces equal in magnitude but opposite in direction to the combination of the forces applied to the objects to be positioned. In an embodiment two or more balance masses are provided. A first balance mass is driven by forces equal in

magnitude but opposite in sense to the sum of the forces in a first direction that are applied to the objects to be positioned. A second balance mass is driven by forces equal in magnitude but opposite in sense to the forces in a second direction applied to the objects to be positioned. The first and second directions are mutually orthogonal. For example, one balance mass balances the forces in the X direction and another balance mass balances the forces in the Y direction.

**[0079]** In an embodiment the magnet array is mounted to the upper surface of a plate member.

In one example of such an embodiment the objects to be positioned and the or each balance mass are located above the plate member. In another example of this embodiment, the objects to be positioned are located above the plate member and the or each balance mass is located below the plate member. In that example, a separate magnet array can be provided on a lower surface of the plate member and the balance masses can be provided with coils which are selectively energized to exert forces between the balance mass or masses and the plate member. Alternatively, coils may be provided on the lower surface of the magnet plate and magnets on the or each balance mass. In an embodiment the magnet array used for driving the balance masses is different than the magnet array used for driving the driven object(s).

**[0080]** Figures 9 and 10 depict schematically arrangements at substrate level in an embodiment of the invention. Figure 9 is a side view and Figure 10 is a plan view. There are two substrate tables WTa, WTb which may be exchanged between an exposure station and a measurement station. At the exposure station, a substrate table WTa, WTb is positioned in the field of view of the projection system PS in order to expose target portions on a substrate in turn. As discussed above, exposures of target portions can be performed in a single exposure or a scanning exposure. After each target portion is exposed, the substrate table is moved to position the next substrate portion in the field of view of the projection system PS. The substrate table is also moved to position sensors, such as transmission image sensors, spot sensors and interferometric sensors, in the projection beam in order to effect measurements of the projection beam and/or to determine the position of the substrate table relative to an image of a mark projected from the patterning device. In the measurement station, the substrate table is moved to enable exchange of substrates by a substrate handling robot and to enable pre-exposure characterization of the substrate table. Pre-exposure

characterization processes can include measurement of a wafer topography map and a measurement of relative positions of marker on the substrate and fiducials on the substrate table. It is also possible to carry out post-exposure measurement processes.

[0081] Positioning of the substrate tables WTa, WTb is achieved by a planar drive arrangement comprising a permanent magnet array 131 provided on the upper surface of magnet plate 13 and coils 14 mounted in the lower portions of substrate tables WTa, WTb. In an embodiment the planar drive arrangement positions the substrate table WTa, WTb in two horizontal degrees of freedom, e.g. X and Y directions. In an embodiment the planar drive arrangement also magnetically levitates the substrate tables WTa, WTb, (i.e. counteracts the force of gravity) and/or positions the substrate tables WTa, WTb in other degrees of freedom such as the Z direction and rotation about X, Y and Z axes ( $R_x$ ,  $R_y$ ,  $R_z$ ). In an embodiment, permanent magnets are provided in the driven objects and coils are provided in the balance mass.

[0082] In an embodiment, the planar drive arrangement positions the substrate tables WTa, WTb in all six degrees of freedom. The range of movement that can be effected by the planar drive arrangement in the X and Y directions is large enough to ensure that all target portions of the substrate can be exposed and the substrate table can be appropriately positioned for all desired measurements. The range of motion effected by the planar drive arrangement may however be much less in other degrees of freedom. In an embodiment, each of the wafer tables WTa, WTb is provided with a short stroke module which allows for positioning of the substrate W in at least one degree of freedom with greater accuracy than is possible with the planar drive arrangement but over a shorter range of movement.

[0083] As mentioned, the planar drive arrangement comprises an array of permanent magnets 131 and sets of coils 14 provided in the object to be positioned, that is the substrate tables WTa, WTb. As is well known, a commutation algorithm is used to determine the energization currents that are applied to respective ones of the coils 14 in order to affect the desired force to be exerted on the object to be positioned. For the purposes of the commutation algorithm, the relative positions of the object to be positioned and the magnet array should be known. This can be determined by reference to the position or displacement measuring system IF and/or a separate system for determining the relative position. Control system 500 carries out the necessary calculations of the commutation algorithm and controls

the energization currents in the coils 14. Although illustrated as a simple checkerboard pattern, the magnet array in an embodiment is desirably a Halbach array and oriented on the diagonal. Magnet plate 13 is supported by bearings 133, e.g. air bearings, which allow movement in at least the horizontal directions (X and Y) while counteracting the force of gravity in the Z direction. When the planar drive is operated to exert a desired force on the object to be positioned, an equal and opposite reaction force is exerted on the magnet plate 13. Because the magnet plate 13 is free to move in at least the X and Y directions, it will move in the opposite direction than the object to be positioned. In an embodiment of the invention, the magnet plate 13 has a mass that is equal to or greater than ten times the mass of the substrate table WTa, in an embodiment about twenty times the mass of the substrate table WTa, WTb. Therefore, the amplitude of the movements of the magnet plate 13 is proportionally smaller than the amplitude of the movements of the substrate table. However, as described above, the movements of the magnet plate 13 are determined by the sum of the reaction forces deriving from the drive forces applied to each of the substrate tables WTa, WTb. Since the movements of the substrate tables WTa, WTb are independent, the movements of the magnet plate 13 do not repeat from substrate to substrate leading to non-repeating positioning errors.

**[0084]** Balance masses 11, 12 are therefore provided to reduce or eliminate movements of magnet plate 13. Balance masses 11, 12 have mounted in their lower portions coil arrays 111, 121. Coil arrays 111, 121 are energized to exert on the balance masses balancing forces substantially equal in magnitude but opposite in direction to the drive forces applied to the substrate tables WTa, WTb. In this way, the reaction forces exerted on the magnet plates 13 because of the balancing forces exerted on the balance masses at least partially cancel out the reaction forces exerted on the magnet plates 13 as a result of the drive forces exerted on the substrate tables WTa, WTb. The net force on the magnet plate 13, i.e. the sum of all forces exerted on the magnet plate, is substantially reduced compared to the forces that would arise if no balancing forces were exerted on the balance masses. Desirably the net force is reduced to substantially zero. Reduced forces result in reduced acceleration and reduced movements. In an embodiment of the present invention each of the balance masses has a mass that is greater than or equal to 10 times the mass of a substrate table, desirably about 20 times the mass of a substrate table.

[0085] In an embodiment, each balance mass, 11, 12 is paired with one of the substrate tables WTa, WTb so that balance forces exerted on a balance mass are equal and opposite to the drive forces exerted on the respective substrate table. In an embodiment the pairing is maintained permanently which simplifies control arrangements. In an embodiment the pairing between balance masses and substrate tables is exchanged when the substrate tables are exchanged between exposure and management stations so that each balance mass is paired with its closest substrate table at all times. Such an arrangement can reduce bending moments in the magnet plate 13. Desirably, multiple spaced apart coil units are used to drive each balance mass. Control system 500 is used to calculate the energization currents to be applied to coils 111, 121 in order to affect the desired balancing forces. This calculation is performed using a commutation algorithm taking account of the relevant positions of the balance masses 11, 12 and the magnet plate 13. These relative positions are determined using, i.e. an interferometric or encoder based position measurement system.

[0086] In an embodiment of the invention the trajectory, and driving forces to be applied to the substrate tables WTa, WTb are calculated in advance, in other words control of the substrate table positioning is largely feedforward based control. The required balancing forces to be applied to the balance masses can therefore also be calculated in advance and feedforward control may be used. In an embodiment of the invention, feedforward control of the substrate table position is supplemented by a feedback control to correct for any deviations from the intended trajectory. In an embodiment of the invention corrections to the drive forces indicated by the feedback control are also applied to the balancing forces. However, since it is not always needed to completely eliminate movements of the magnet plate 13, the feedback corrections need not be applied to the balancing forces also. In an embodiment of the invention, it is desirable that there is no time delay between the application of drive forces to the substrate tables and the application of balancing forces to the balance masses. In other words, it is desirable that the drive forces and balancing forces be in phase.

[0087] In an embodiment of the invention, the balance masses 11, 12 are used to limit drift of the magnet plate 13. A feedback loop is provided whereby if the displacement of the magnet plate 13 exceeds a predetermined threshold, forces are applied via the balance masses 11, 12 to return the magnet plate 13 to its nominal center position. In an embodiment, a drift control system, external to the closed force system of drive object(s) – magnet plate – balance

mass(es), is provided. The drift control system applies low frequency forces to the magnet plate and/or balance masses to prevent or limit long-term drift in the positions of the magnet plate or balance masses. The drift control system comprises actuators of any suitable type, e.g. voice coil motors. The frequency of the forces applied by the drift control system is sufficiently low as not to cause an undesirable disturbance on exposures. In an embodiment the drift control system is only active between exposures.

[0088] Another embodiment of the invention is shown in Figures 11 and 12 which are side and plan views of arrangements at substrate level in the embodiment. The embodiment of Figures 11 and 12 is the same as the embodiment of Figures 9 and 10 except that the two separate balance masses 11, 12 are replaced by a single balance mass 11a. Balancing forces are exerted on balance mass 11a via coils 111 acting against magnet array 131 on magnet plate 13. The balance forces applied to balance mass 11a are equal in magnitude but opposite in direction to the sum of the drive forces applied to the two substrate tables WTa, WTb. In an embodiment, balance mass 11a takes the form of an open rectangle or frame surrounding the area over which the substrate tables WTa, WTb are positioned. Such an arrangement enables the balance mass to have a large mass without substantially increasing the footprint of the magnet plate. Additionally, the center of mass of the balance mass 11a is close to the center of mass of the magnet plate 13 which reduces bending moments in the magnet plate 13.

[0089] Another embodiment of the invention is shown in Figure 13 which is a plan view of the arrangement at substrate level. This embodiment is the same as the previously described embodiments as discussed below. In the embodiment of Figure 13 two balance masses 11c, 11d are provided. Rather than being driven by planar motors, balance masses 11c, 11d are driven by respective linear motor arrangements. The linear motor arrangements comprise coil units (not shown) in the lower parts of balance masses 11c, 11d acting against magnet arrays 133, 134 mounted in the upper surface of magnet plate 13. The linear drive arrangements are arranged so that balance masses 11c, 11d are driven in orthogonal directions, for example balance mass 11c is driven in the X direction and balance mass 11d is driven in the Y direction. In this arrangement, the balancing forces applied to the respective balance masses 11c, 11d are equal in magnitude but opposite in sign to the sum of the

components in the respective direction of the drive forces applied to substrate tables WTa, WTb.

[0090] Thus, in this example, the balancing forces applied to balance mass 11c are equal in magnitude but opposite in sign to the sum of the X components of the drive forces applied to substrate tables WTa, WTb. The balancing forces applied to balance mass 11d are equal in magnitude but opposite in sign to the sum of the Y components of the drive forces applied to substrate tables WTa, WTb. A benefit of the arrangement of Figure 13 is that linear drive arrangements can be more efficient than a planar drive. Depending on the mass of balance masses 11c, 11d and hence their range of movement, it can be possible to use particularly efficient motors such as reluctance motors or voice coil motors.

[0091] A benefit of the embodiments of Figures 9 to 13 is that the centers of mass of the balance masses can be positioned in the same horizontal plane as the centers of mass of the substrate tables WTa, WTb or close thereto. In this way, it is possible to minimize the torque exerted on the support structure by the force system comprising driven object(s), balance mass(es) and magnet plate 13 since the torques of the drive forces will also be cancelled by the torques of the balance forces. However, the arrangements shown in Figures 9 to 13 do increase the footprint of the substrate table positioning arrangement.

[0092] Figure 14 shows an arrangement which can avoid increasing the footprint of the substrate table drive arrangements. Figure 14 is a side view of substrate table drive arrangements in an embodiment of the invention. In this embodiment, which is the same as previous embodiments except as described below, a single balance mass 21 is provided below magnet plate 23. Balance mass 21 can be substantially the same size and shape as magnet plate 23. Balance mass 21 is supported by bearings 213, e.g. gas bearings, so that it is movable horizontally, e.g. in X and Y directions. Magnet plate 23 has a magnet array 231 in its upper surface against which coils 14 act to generate drive forces for substrate tables WTa, WTb in the same way as the previous embodiments. Magnet plate 23 is also provided with a second magnet array 232 in its lower surface. Coil units 211 are provided in the upper surface of balance mass 21 and are energized to exert balancing forces equal and opposite to the drive forces exerted on substrate tables WTa, WTb. In this way, the net force exerted on magnet plate 23 is reduced and therefore also its movements.

[0093] In an embodiment of the invention, magnet plate 23 is magnetically levitated through the action of the energization currents in coils 211 against the second magnet array 232. In an embodiment of the invention a separate bearing arrangement is provided, e.g. a gas bearing or permanent magnetic bearing, so that the energization currents in coil units 211 only generate horizontal drive forces. Such an arrangement can have a reduced power consumption compared to an arrangement in which energization currents in coil units 211 also support magnet plate 21 against the force of gravity.

[0094] An arrangement as shown in Figure 14 can be beneficial in that the balance mass 21 can have a large area and hence a large volume without an excessive height. This allows the balance mass to have a large mass. Its movements can therefore be very small whilst those of the magnet array 23 can be almost completely eliminated. Therefore, the footprint of the apparatus can be reduced.

[0095] A further or alternative solution to the problem of non-repeatable positioning errors is to ensure that the movements of the magnet plate are repeatable from substrate to substrate. If that is the case, the positioning errors can be compensated for by corrections to the position set points in the exposure recipe for a substrate. In an embodiment of the invention, the effects on the position of the magnet plate due to drive forces applied to a substrate table at the measurement station are isolated from the effects of drive forces applied to the other substrate table.

[0096] In an embodiment, this is achieved by separating the magnet plate and magnet array into two parts, one for the exposure station and one for the measurement station. The two parts of the magnet plate are mechanically isolated from one another. Therefore movements of the substrate table at the measurement station do not affect the position of the magnet plate at the exposure station. Therefore, the position of the magnet plate at the exposure station will depend only on the movements of the substrate table being used for exposure. The effect of the magnet plate position, e.g. due to stray fields, can therefore be predicted and compensated for.

[0097] The use of two separate magnet plates also allows for a removable barrier to be interposed between the measurement and exposure stations during exposures. The barrier is removed to allow substrate table exchange between the stations when exposures of a substrate are complete. The barrier further isolates the exposure and measurement stations,

e.g. by preventing air currents or pressure changes due to movement of the substrate table at the measurement station affecting the environment at the exposure station.

[0098] As will be appreciated, any of the above described features can be used with any other feature and it is not only those combinations explicitly described which are covered in this application.

[0099] 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 in manufacturing components with microscale, or even nanoscale features, such as 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. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms “wafer” or “die” herein may be considered as synonymous with the more general terms “substrate” or “target portion”, respectively. The substrate referred to herein may be processed, before or after exposure, in for example a track (a tool that typically applies a layer of resist to a substrate and develops the exposed resist), a metrology tool and/or an inspection tool. Where applicable, the disclosure herein may be applied to such and other substrate processing tools. Further, the substrate may be processed more than once, for example in order to create a multi-layer IC, so that the term substrate used herein may also refer to a substrate that already contains multiple processed layers.

[00100] The terms “radiation” and “beam” used herein encompass all types of electromagnetic radiation, including ultraviolet (UV) radiation (e.g. having a wavelength of or about 365, 248, 193, 157 or 126 nm).

[00101] The term “lens”, where the context allows, may refer to any one or combination of various types of optical components, including refractive and reflective optical components.

[00102] While specific embodiments of the invention have been described above, it will be appreciated that the invention, at least in the form of a method of operation of an apparatus as herein described, may be practiced otherwise than as described. For example, the embodiments of the invention, at least in the form of a method of operation of an apparatus, may take the form of one or more computer programs containing one or more

sequences of machine-readable instructions describing a method of operating an apparatus as discussed above, or a data storage medium (e.g. semiconductor memory, magnetic or optical disk) having such a computer program stored therein. Further, the machine readable instruction may be embodied in two or more computer programs. The two or more computer programs may be stored on one or more different memories and/or data storage media.

**[00103]** Any controllers described herein may each or in combination be operable when the one or more computer programs are read by one or more computer processors located within at least one component of the lithographic apparatus. The controllers may each or in combination have any suitable configuration for receiving, processing and sending signals. One or more processors are configured to communicate with at least one of the controllers. For example, each controller may include one or more processors for executing the computer programs that include machine-readable instructions for the methods of operating an apparatus as described above. The controllers may include data storage media for storing such computer programs, and/or hardware to receive such media. So the controller(s) may operate according to the machine readable instructions of one or more computer programs.

**[00104]** An embodiment of the invention may be applied to substrates with a width (e.g., diameter) of 300 mm or 450 mm or any other size.

**[00105]** One or more embodiments of the invention may be applied to any immersion lithography apparatus, in particular, but not exclusively, those types mentioned above, whether the immersion liquid is provided in the form of a bath, only on a localized surface area of the substrate, or is unconfined on the substrate and/or substrate table. In an unconfined arrangement, the immersion liquid may flow over the surface of the substrate and/or substrate table so that substantially the entire uncovered surface of the substrate table and/or substrate is wetted. In such an unconfined immersion system, the liquid supply system may not confine the immersion liquid or it may provide a proportion of immersion liquid confinement, but not substantially complete confinement of the immersion liquid. The invention can also be applied to non-immersion lithography apparatus.

**[00106]** A liquid supply system as contemplated herein should be broadly construed. In certain embodiments, it may be a mechanism or combination of structures that provides a liquid to a space between the projection system and the substrate and/or substrate table. It may comprise a combination of one or more structures, one or more liquid inlets, one or

more gas inlets, one or more gas outlets, and/or one or more liquid outlets that provide liquid to the space. In an embodiment, a surface of the space may be a portion of the substrate and/or substrate table, or a surface of the space may completely cover a surface of the substrate and/or substrate table, or the space may envelop the substrate and/or substrate table. The liquid supply system may optionally further include one or more elements to control the position, quantity, quality, shape, flow rate or any other features of the liquid.

**[00107]** The descriptions above are intended to be illustrative, not limiting. Thus, it will be apparent to one skilled in the art that modifications may be made to the invention as described without departing from the scope of the claims set out below.

## CLAIMS

1. A lithographic apparatus, comprising:  
a driven object; and  
a positioning system arranged to position the driven object in at least one degree of freedom, the positioning system comprising:  
an array of permanent magnets and a coil unit arranged so that energization of a coil unit causes a drive force to be exerted between the coil unit and the array of permanent magnets wherein one of the array of permanent magnets and the coil unit is mounted on a member that is free to move in the at least one degree of freedom and the other of the array of permanent magnets and the coil unit is mounted on the driven object;  
a balance mass that is free to move in the at least one degree of freedom; and  
a balance mass driving system configured to exert a balancing force on the balance mass that is substantially opposite in direction to the drive force.
2. Apparatus according to claim 1 wherein the positioning system comprises two balance masses.
3. Apparatus according to claim 2 comprising two driven objects each having mounted therein a coil unit or an array of permanent magnets and wherein the balance mass driving system is configured to exert a first balancing force on a first one of the balance masses that is substantially opposite in direction to a drive force exerted on a first one of the driven objects and to exert a second balancing force on the other one of the balance masses that is substantially opposite in direction to a drive force exerted on the other one of the driven objects.
4. Apparatus according to claim 2 wherein the balance driving system is configured to exert a first balancing force in a first direction on a first one of the balance masses that is opposite in sign to the component of the drive force exerted on the driven object in a first direction and to exert on the other of the balance masses a second balancing force in a second direction that is opposite in sign to the component of the drive force applied to the driven object in a second direction, the second direction being orthogonal to the first direction.

5. Apparatus according to claim 4 comprising two driven objects each having mounted therein a coil unit or an array of permanent magnets and wherein the first balancing force is opposite in sign to the sum of the components in the first direction of the drive forces exerted on the two driven objects and the second balancing force is opposite in sign to the sum of the components in the second direction of the drive forces exerted on the two driven objects.
6. Apparatus according to claim 1 comprising two driven objects each having mounted therein a coil unit or an array of permanent magnets and wherein the balancing force applied to the balance mass is substantially opposite in direction to the sum of the drive forces applied to the driven objects.
7. Apparatus according to any one of the preceding claims wherein the balancing force is substantially equal in magnitude to the drive force.
8. Apparatus according to claim 1 comprising two driven objects each having mounted therein a coil unit or an array of permanent magnets and wherein the balancing force is substantially equal in magnitude to the vector sum of the drive forces applied to the two driven objects.
9. Apparatus according to any one of the preceding claims wherein the driven object(s) and the balance mass are both located on the same side of the member.
10. Apparatus according to any one of claims 1 to 9 wherein the driven object(s) are located on a first side of the member and the balance mass is located on a second side of the member opposite to the first side.
11. Apparatus according to any one of the preceding claims wherein the balance mass driving system comprises an actuator selected from the group consisting of planar motors, linear motors, reluctance motors and voice coil motors.

12. Apparatus according to any one of the preceding claims wherein the or a driven object is a substrate table.
13. Apparatus according to any one of the preceding claims wherein the or a driven object is a measurement table.
14. Apparatus according to any one of the preceding claims wherein the or a driven object is a support structure for a patterning device.
15. Apparatus according to any one of the preceding claims wherein the magnet array is mounted on the member and the member is a plate.
16. Apparatus according to any one of the preceding claims further comprising:
  - a support structure configured to support a patterning device; and
  - a projection system arranged to project a beam patterned by the patterning device onto a substrate.
17. A lithographic apparatus comprising:
  - two substrate tables each configured to support a substrate; and
  - a positioning system arranged to position the substrate tables in at least one degree of freedom, the positioning system comprising:
    - two arrays of permanent magnets each mounted on a respective magnet plate that is free to move in the at least one degree of freedom;
    - a coil unit in each of the substrate tables arranged so that energization of a coil unit causes a drive force to be exerted between a substrate table and a magnet plate;
    - wherein the two magnet plates are arranged to move independently of one another in the at least one degree of freedom.
18. Apparatus according to claim 17 wherein the magnet plates are arranged with a gap there between.

19. Apparatus according to claim 18 further comprising a movable barrier selectively interposable between the two substrate tables.
20. Apparatus according to claim 19 wherein the movable barrier is arranged to be movable through the gap.
21. A lithographic apparatus comprising:  
two substrate tables each configured to support a substrate; and  
a positioning system arranged to position the substrate tables in at least one degree of freedom, the positioning system comprising:  
an array of permanent magnets mounted on a magnet plate that is free to move in the at least one degree of freedom;  
a coil unit in each of the substrate tables arranged so that energization of a coil unit causes a drive force to be exerted between a substrate table and the magnet plate;  
wherein the positioning system is arranged so that the array of permanent magnets is substantially stationary or moves predictably during exposure of a substrate.
22. A device manufacturing method using a lithographic apparatus, the method comprising:  
projecting a beam patterned by a patterning device onto a substrate while holding the substrate in a substrate holder,  
wherein the lithographic apparatus is according to any one of claims 1 to 21.

23. A lithographic apparatus comprising:

an object; and

a positioning system arranged to position the object in a degree of freedom, the positioning system comprising:

an array of magnets and a coil unit arranged so that energization of the coil unit causes a drive force to be exerted between the coil unit and the array of magnets, wherein one of the array of magnets and the coil unit is mounted on a member that, in use, is free to move in the degree of freedom and the other of the array of magnets and the coil unit is mounted on the object;

a balance mass that, in use, is free to move in the degree of freedom; and

a balance mass driving system configured to exert a balancing force on the balance mass that is substantially opposite in direction to the drive force.

24. The apparatus of claim 23, wherein the positioning system comprises two balance masses.

25. A lithographic apparatus comprising:

a first and a second substrate table each configured to support a substrate; and

a positioning system arranged to position the first and the second substrate table in a degree of freedom, the positioning system comprising:

a first and a second array of magnets mounted on, respectively, a first and a second magnet plate that, in use, are free to move in the degree of freedom;

a first and a second coil unit arranged in respectively the first and the second substrate table, the first and the second coil unit arranged so that energization of the first and the second coil unit causes a drive force to be exerted between the first substrate table and the first magnet plate and between the second substrate table and the second magnet plate;

wherein the first and the second magnet plate are arranged to move independently of one another in the degree of freedom.

26. The apparatus of claim 25, wherein the first and the second magnet plate are arranged with a gap there between.

27. The apparatus of claim 25, further comprising a movable barrier selectively interposable between the first and the second substrate table.

28. The apparatus of claim 27, wherein the movable barrier is arranged to be movable through the gap.

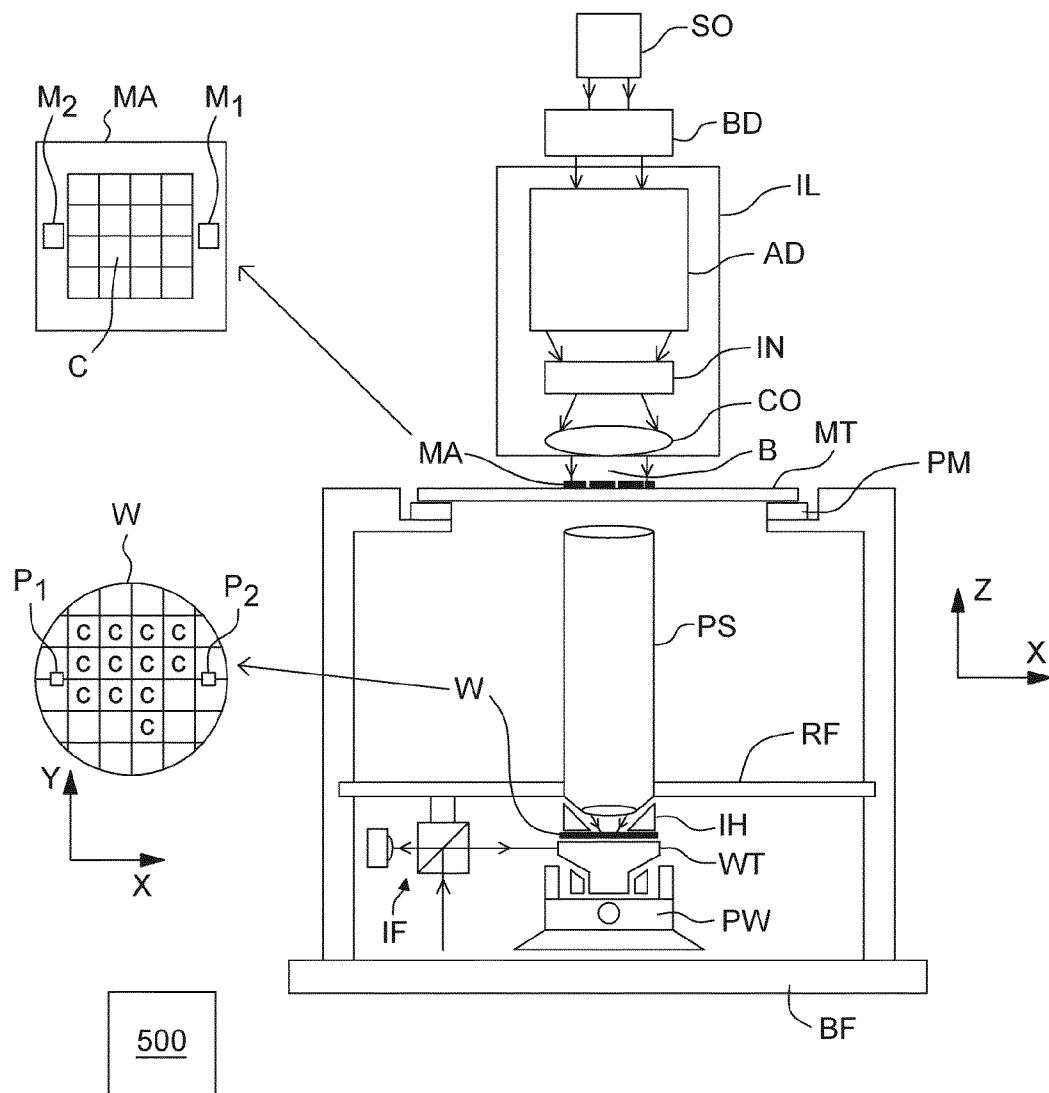
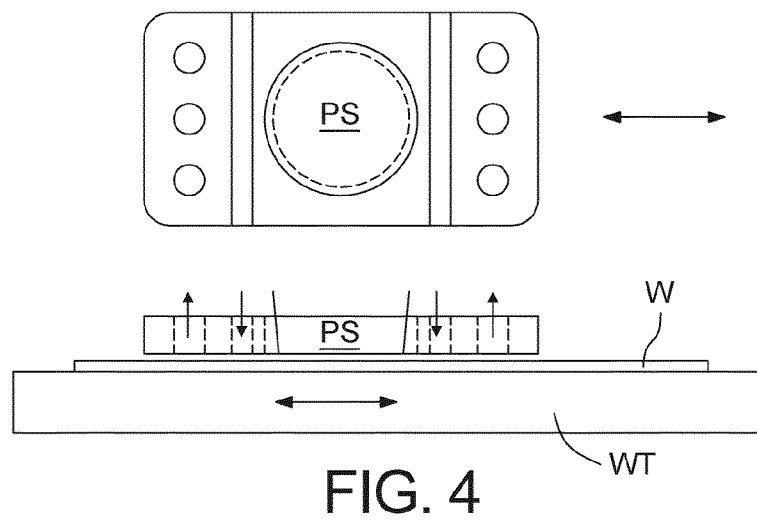
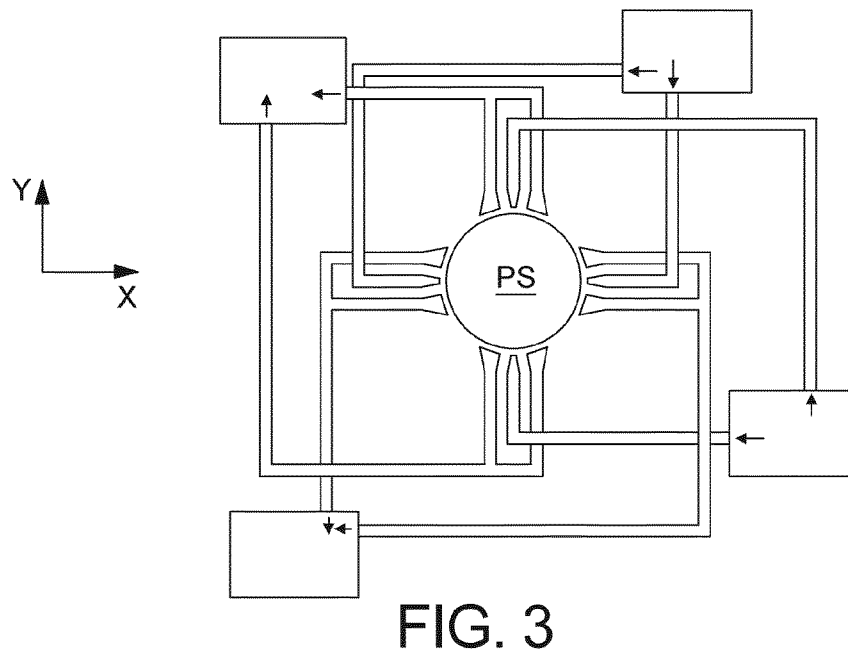
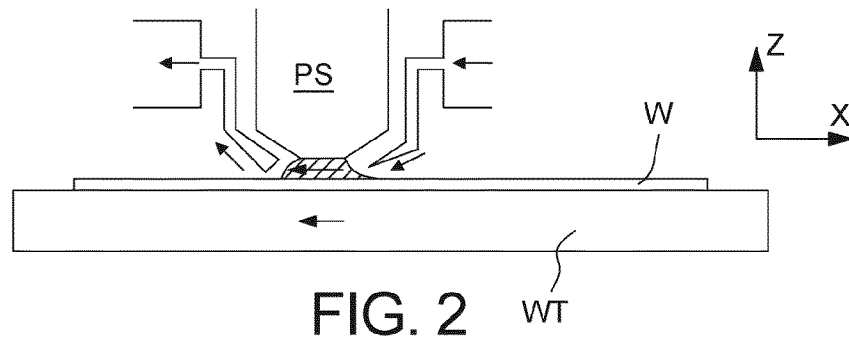


FIG. 1

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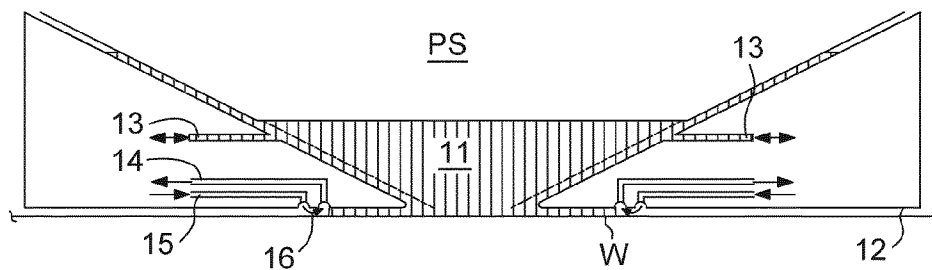


FIG. 5

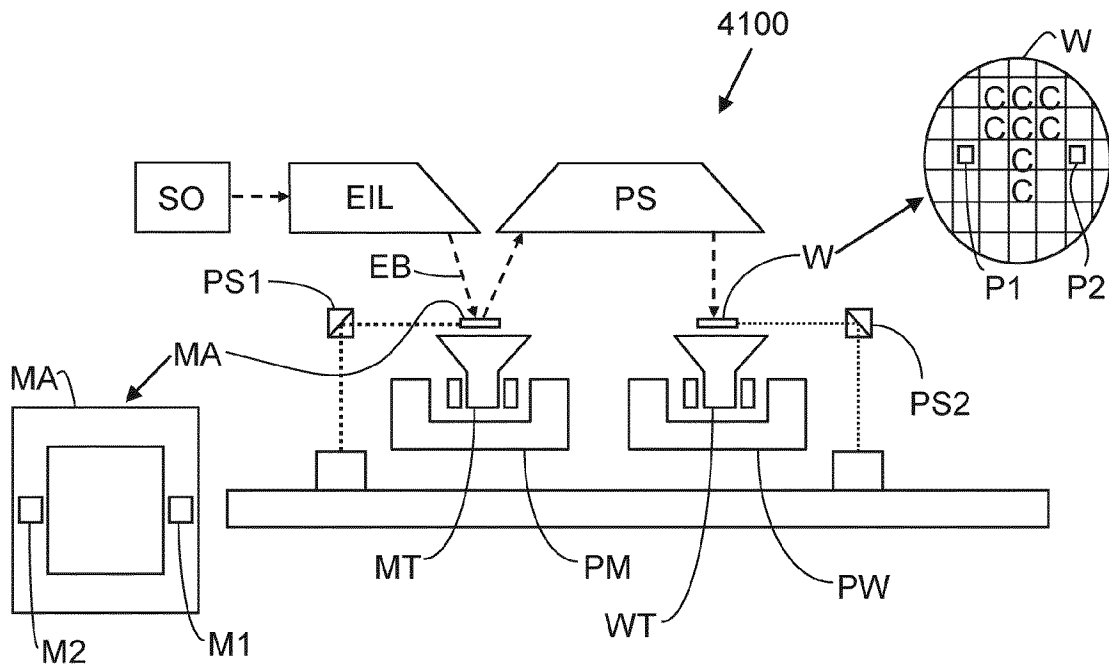
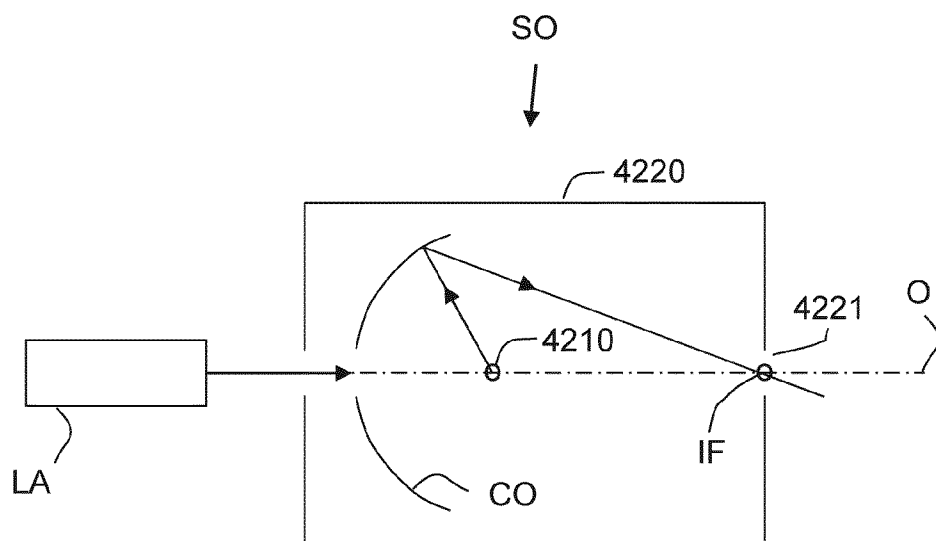
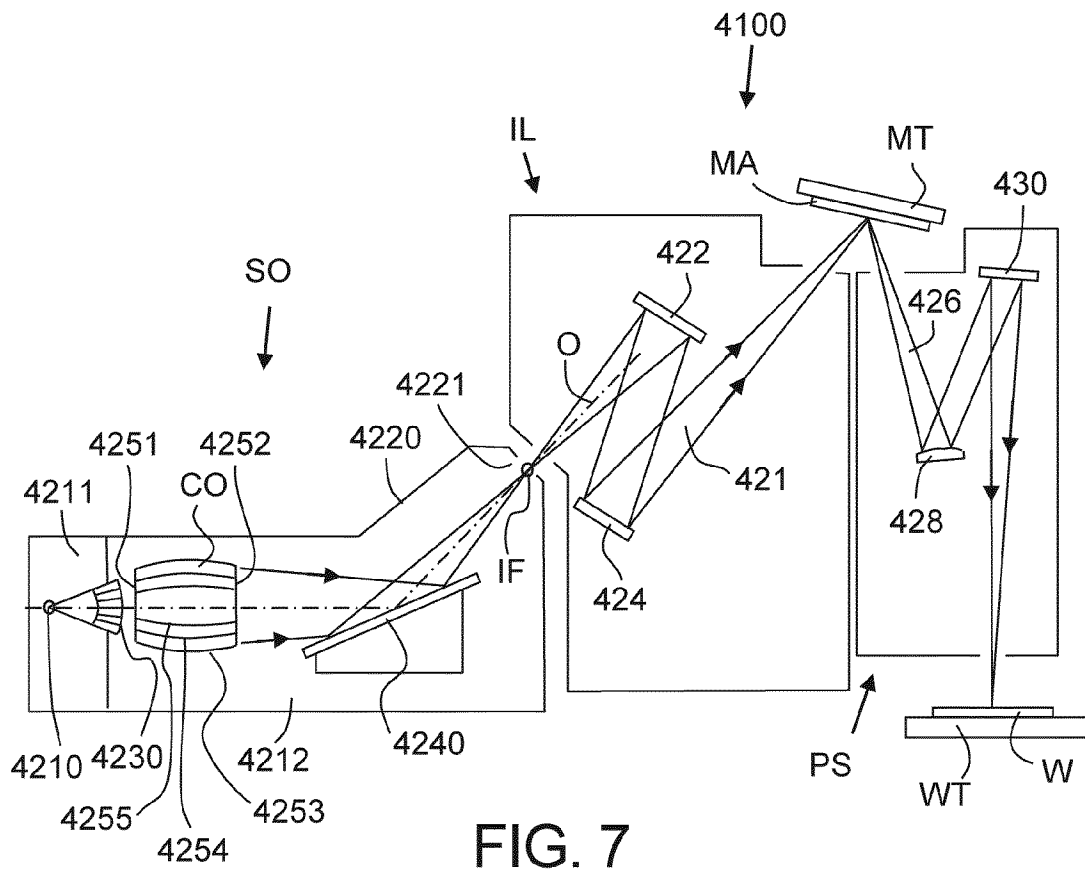


FIG. 6

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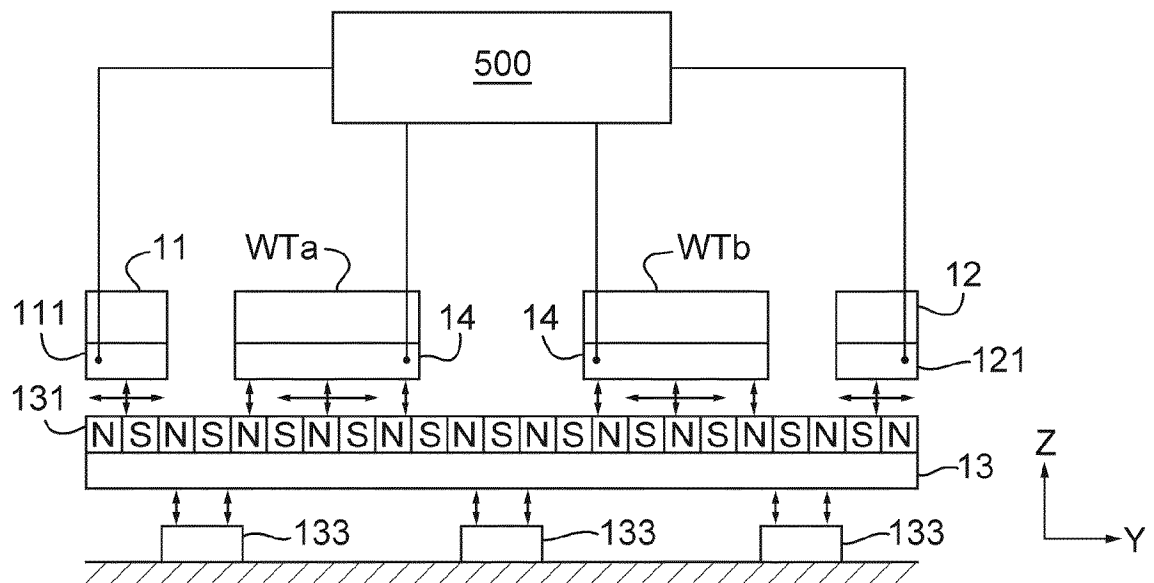


FIG. 9

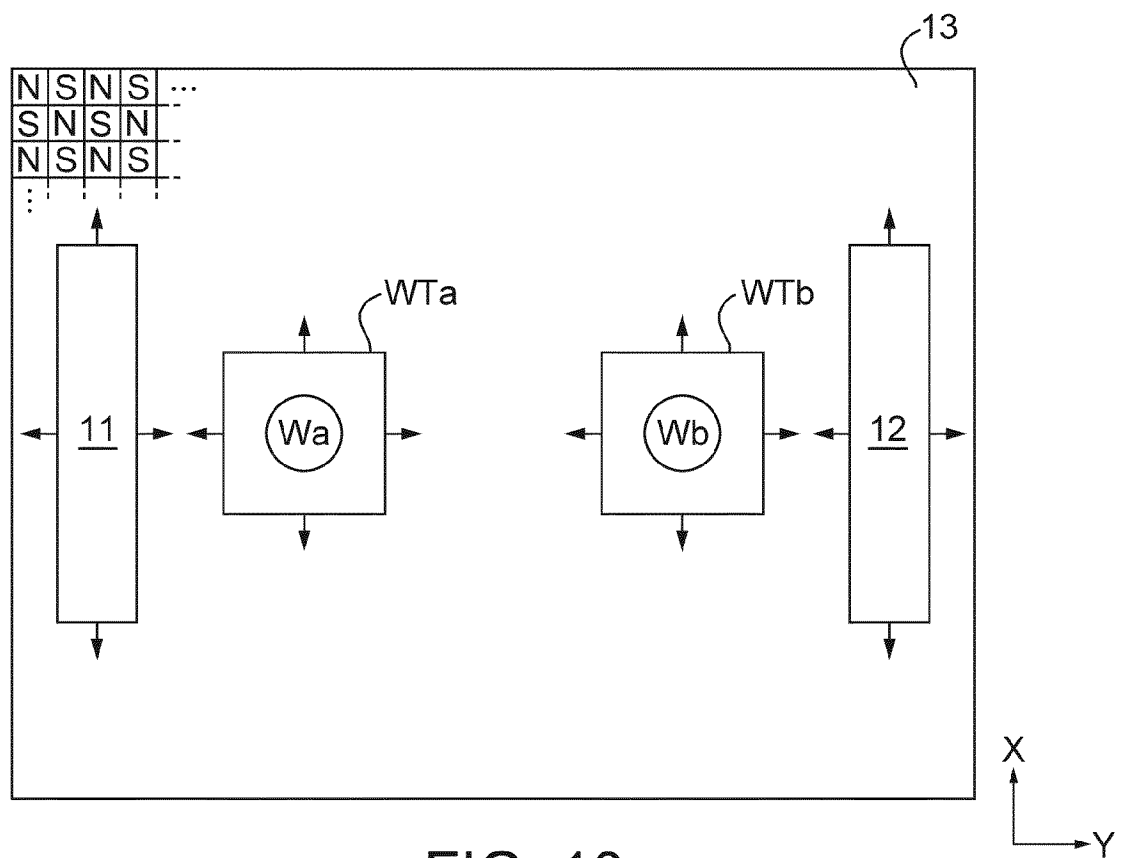


FIG. 10

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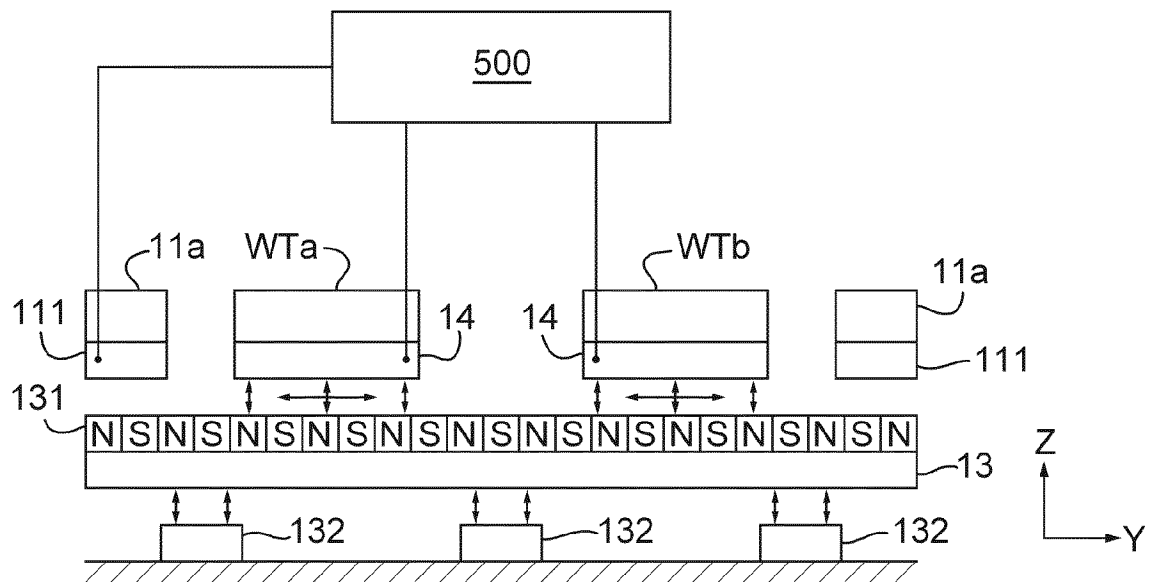


FIG. 11

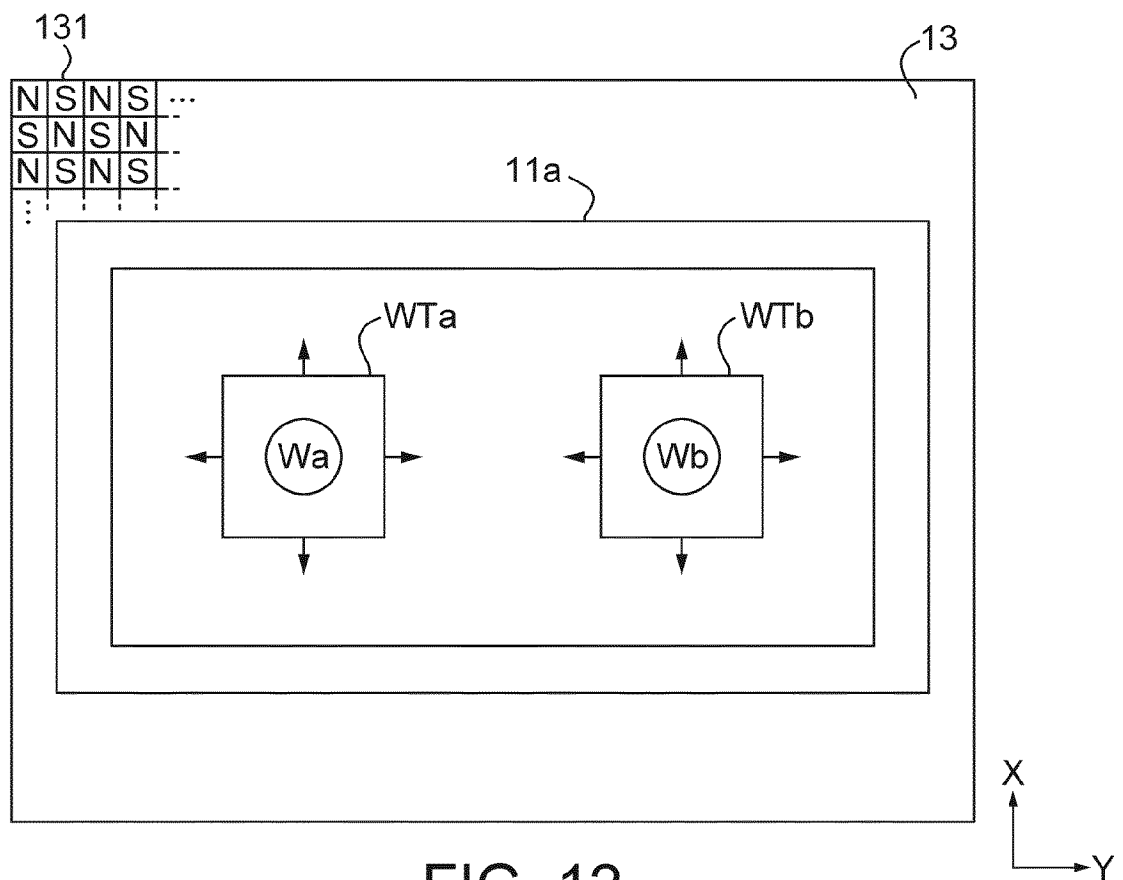
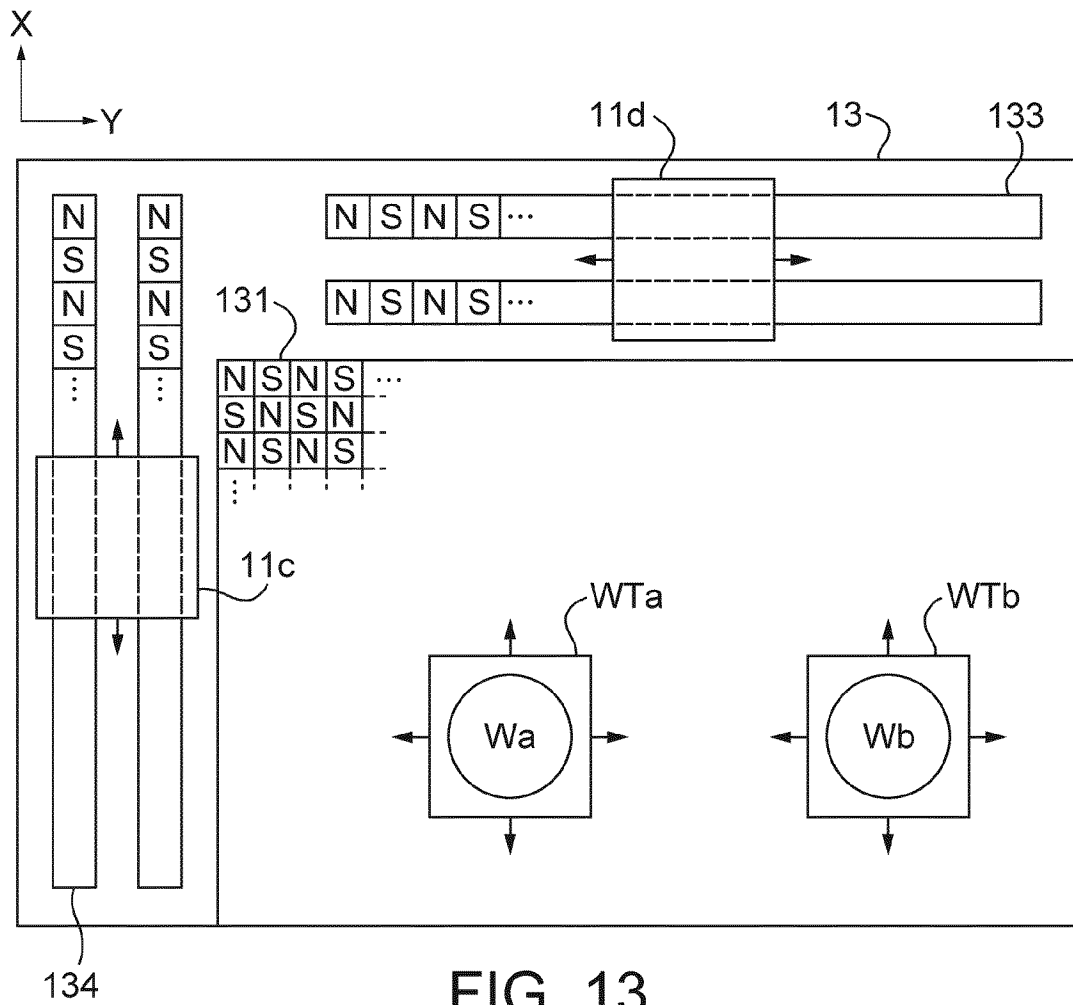


FIG. 12

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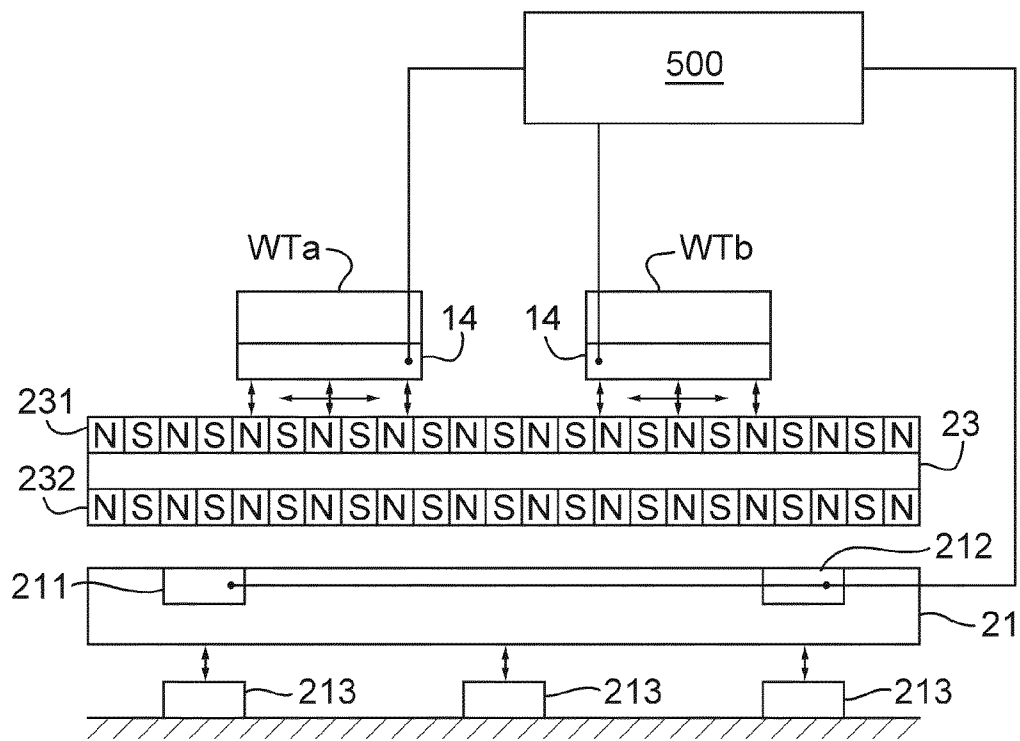


FIG. 14