

POSITIONING SYSTEM, LITHOGRAPHIC APPARATUS AND DEVICE MANUFACTURING METHOD

FIELD

[0001] The present invention relates to a positioning system, lithographic apparatus and method for manufacturing a device.

BACKGROUND

[0002] 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 such a case, 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. including 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. Conventional lithographic apparatus include so-called steppers, in which each target portion is irradiated by exposing an entire pattern onto the target portion at once, 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.

[0003] Figure 2 discloses a positioning system PW to position a table WT, which may be moveable with a planar motor within, for example a vacuum chamber 3. The planar motor includes stator 2 and translator 35 to position the table WT in at least the X, Y and Rz direction and if required also in Z, Rx and Ry. Reaction forces of the coarse positioning mechanism (planar motor) in the X, Y and Rz direction are transmitted to the first balance mass 6. The first balance mass 6 is moveable over bearings 5 which allow for movement of the first balance mass 6 in the X, Y and Rz direction with respect to the base plate BP, and does not allow movements, i.e. is stiffly coupled, in the Z, Rx and Ry directions with respect to the base plate BP. Reaction forces in all degrees of freedom of the fine positioning mechanism 1 are exerted on the translator 35 and transferred to the

first balance mass 6. The center of mass of the first balance mass 6 and the center of mass of the object table WT are at different positions in the Z-direction, the Z-direction being perpendicular to the X and Y directions. A consequence of the difference in center of mass is that when the planar motor exerts a horizontal force in the X and/or Y direction to the object table WT a torque around respectively the Y and/or X axes is generated in the first balance mass 6. Because the balance mass 6 is stiffly coupled to the base plate BP in the Rx and Ry directions by means of the bearings 5, this torque is transferred to the base plate BP. The torque may cause vibrations in the base plate BP which deteriorates the functioning of the positioning system or a lithographic apparatus in which it the positioning system may be used.

SUMMARY

[0004] It is desirable to provide a positioning system in which vibrations caused by a torque transferred from a balance mass to a base plate are minimized.

[0005] In an embodiment according to the invention, there is provided a positioning system to position a support, including a first actuator configured to exert an actuation force on the support, the first actuator being coupled to a first balance mass constructed and arranged to absorb a reaction force resulting from the actuation force generated by the first actuator; and a controller and a second actuator constructed and arranged to exert a compensation force to compensate a torque caused by the actuation force exerted by the first actuator on the first balance mass.

[0006] In an embodiment of the invention, there is provided a lithographic apparatus including an illumination system configured to condition a radiation beam; a patterning device support constructed to support a patterning device, the patterning device being capable of imparting the radiation beam with a pattern in its cross-section to form a patterned radiation beam; a substrate support constructed to hold a substrate; a projection system configured to project the patterned radiation beam onto a target portion of the substrate, and a positioning system constructed and arranged to position at least one of the supports, the positioning system including a first actuator configured to exert an actuation force on the support, the first actuator being coupled to a first balance mass constructed and arranged to absorb a reaction force resulting from the actuation force generated by the first actuator; and a controller and a second actuator constructed and arranged to exert a compensation force to compensate a torque caused by the actuation force exerted by the first actuator on the first balance mass.

[0007] In another embodiment of the invention, there is provided a device manufacturing method including: providing a substrate that is at least partially covered by a layer of radiation-sensitive material on a substrate support; providing a patterning device on a patterning device support; projecting a patterned beam of radiation onto the layer of radiation sensitive material; and positioning at least one of the supports, the positioning including exerting a first force between a first balance mass and the support, the first force moving the support relative to the first balance mass, and controllably exerting a second force to compensate a torque caused by a difference in position of the center of mass of the first balance mass and the support.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] 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:

[0009] Figure 1 depicts a lithographic apparatus according to an embodiment of the invention;

[00010] Figure 2 discloses a positioning system including a table which is moveable with a planar motor wherein the balance mass and the table have a center of mass on a different position;

[00011] Figure 3 discloses a positioning system according to an embodiment of the invention;

[00012] Figure 4 discloses a positioning system according to an embodiment of the invention;

[00013] Figure 5 discloses a positioning system according to an embodiment of the invention;

[00014] Figure 6 discloses a positioning system according to an embodiment of the invention; and

[00015] Figure 7 discloses a positioning system according to an embodiment of the invention.

DETAILED DESCRIPTION

[00016] Figure 1 schematically depicts a lithographic apparatus according to one embodiment of the invention. The apparatus includes an illumination system (illuminator) IL configured to condition a radiation beam B (e.g. UV radiation or any other suitable radiation), a patterning device support or support structure (e.g. a mask table) MT constructed to support a patterning device (e.g. a mask) MA and connected to a first positioning device PM configured to accurately position the patterning device in accordance with certain parameters. The apparatus also includes a substrate table (e.g. a wafer table) WT or "substrate support" constructed to hold a substrate (e.g. a resist-coated wafer) W and connected to a second positioning device PW configured to accurately position the substrate in accordance with certain parameters. The apparatus further includes 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. including one or more dies) of the substrate W.

[00017] 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.

[00018] The patterning device support 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 patterning device support can use mechanical, vacuum, electrostatic or other clamping techniques to hold the patterning device. The patterning device support may be a frame or a table, for example, which may be fixed or movable as required. The patterning device support 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."

[00019] 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 so 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.

[00020] 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.

[00021] The term “projection system” used herein should be broadly interpreted as encompassing any type of projection 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”.

[00022] 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).

[00023] The lithographic apparatus may be of a type having two (dual stage) or more substrate tables or “substrate supports” (and/or two or more mask tables or “mask supports”). In such “multiple stage” machines the additional tables or supports may be used in parallel, or preparatory steps may be carried out on one or more tables or supports while one or more other tables or supports are being used for exposure.

[00024] The lithographic apparatus may also be of a type wherein at least a portion of the substrate may be covered by a liquid having a relatively high refractive index, e.g. water, so as to fill a space between the projection system and the substrate. An immersion liquid may also be applied to other spaces in the lithographic apparatus, for example, between the mask and the projection system. Immersion techniques can be used to increase the numerical aperture of projection systems. The term “immersion” as used herein does not mean that a structure, such as a substrate, must be submerged in liquid, but rather only means that a liquid is located between the projection system and the substrate during exposure.

[00025] 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 including, 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.

[00026] The illuminator IL may include an adjuster AD 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 σ -outer and σ -inner, respectively) of the intensity distribution in a pupil plane of the illuminator can be adjusted. In addition, the illuminator IL may include 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.

[00027] The radiation beam B is incident on the patterning device (e.g., mask) MA, which is held on the patterning device support (e.g., mask table) MT, and is patterned by the patterning device. Having traversed the patterning device (e.g. mask) MA, the radiation beam B 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 positioning device 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 positioning device PM and another position sensor (which is not explicitly depicted in Figure 1) can be used to accurately position the patterning device (e.g. mask) 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 patterning device support (e.g. mask table) 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 positioning device PM. Similarly, movement of the substrate table WT or "substrate support" 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 patterning device support (e.g. mask table) MT may be connected to a short-stroke actuator only, or may be fixed. Patterning device (e.g. mask) MA and substrate W may be aligned using mask 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 (e.g. mask) MA, the mask alignment marks may be located between the dies.

[00028] The depicted apparatus could be used in at least one of the following modes:

[00029] 1. In step mode, the patterning device support (e.g. mask table) MT or "mask support" and the substrate table WT or "substrate support" 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 or "substrate support" 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.

[00030] 2. In scan mode, the patterning device support (e.g. mask table) MT or "mask support" and the substrate table WT or "substrate support" 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 or "substrate support" relative to the patterning device support (e.g. mask table) MT or "mask support" 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.

[00031] 3. In another mode, the patterning device support (e.g. mask table) MT or "mask support" is kept essentially stationary holding a programmable patterning device, and the substrate table WT or "substrate support" 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 "substrate support" 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.

[00032] The second positioning system PW, or the first positioning system PM, or both, includes: a first actuator configured to exert a force on the patterning device support (e.g. mask table) MT and/or the substrate support WT, the first actuator being connected to a first balance mass constructed and arranged to absorb reaction forces of the actuator, wherein the first balance mass and the support have a center of mass of which the position is different in a direction

perpendicular to a movement direction and the positioning system includes a controller and a second actuator constructed and arranged to compensate a torque caused by the difference in position of the center of mass of the first balance mass and the patterning device support (e.g. mask table MT) and/or the substrate support WT.

[00033] Figure 3 discloses a positioning system PW configured to position a substrate support (e.g. wafer table) WT, however it could also be used to move a patterning device support (e.g. mask table) MT. The substrate support WT is moved by a planar motor which has a magnet plate that is provided to the first balance mass 6 and a coil system that is provided to the substrate support WT. The planar motor exerts a force F_1 on the substrate support WT which makes the substrate support WT move in the direction 11 this force also creates a reaction force F_1 on the first balance mass 6. Since the first balance mass 6 has a center of mass 13 which is at a distance h_1 below the center of mass 15 of the wafer table WT, the force F_1 creates a torque on the base frame BF having a force F_2 at a distance h_2 from the center of mass of the base frame BF of magnitude $F_1 \cdot h_1$. To compensate this torque, a controller CNT is provided which is connected via connection 17 to the planar motor so that it is provided with a signal representing the quantity, direction and position of the force F_1 created by the planar motor. The controller includes an input for the quantity of actuation force exerted by the first actuator and a calculator constructed and arranged to calculate a compensation force on the basis of the actuation force. The compensation force calculated by the calculator and generated by the second actuator generates a torque that compensates a torque caused by the difference in position of the center of mass of the first balance mass and the substrate support WT. The term “compensation force” used herein may encompass the force that is actually generated by the actuator as well as the torque that results from the application of the force. The controller CNT calculates forces F_{2a} and F_{2b} that, via electrical connection 23, can be exerted by the second actuators 21 on the second balance masses M to compensate for the torque in such a manner that the resulting exerted torque on the base frame BF has an equal magnitude, but an opposite sign, to the disturbance torque with magnitude $h_1 \cdot F_1$. To ensure that no net force is exerted in addition to the compensation torque, F_{2a} must be equal to F_{2b} . The controller CNT calculates the compensation force on the basis of the direction and the position in which the second actuator can exert the compensation force so that the torque is compensated. The second actuator 21 moves the second balance mass in the first embodiment of the invention in a linear direction.

[00034] Figure 3 discloses a positioning system in which torques are compensated which are caused by accelerations of the substrate support WT in the direction 11. Since a planar motor may be used for movements in two directions the positioning system may also be constructed and arranged for compensation of the torques in two directions. A second actuator and a second balance mass, in addition to the two depicted, may be constructed and arranged to compensate for torques caused by accelerations of the substrate support WT in a direction substantially perpendicular to the direction depicted by 11. The positioning system may then be provided with three or four second actuators and balance masses. By moving the second balance masses simultaneously in one direction the positioning system may also compensate for forces in the direction of gravity.

[00035] Figure 4 discloses a positioning system according to an embodiment of the invention. This embodiment is similar to the embodiment of Figure 3 for the same reference numbers. According to the embodiment of the invention shown in Figure 4, a controller CNT is connected to the second actuator 211 which drives a second balance mass M2 in a rotational direction. The actuator rotates the second balance mass M2 so as to create a torque to compensate for the torque of the base frame BF caused by the forces F1 exerted by the planar motor on the wafer table WT and the first balance mass 6.

[00036] Figure 5 discloses a positioning system according to an embodiment of the invention. The embodiment of Figure 4 is similar to the embodiment of Figure 3 for the same reference numbers. According to the embodiment of the invention shown in Figure 5, a second actuator 21 exerts a compensation force in between the first balance mass 6 and the second balance mass M. The compensation force exerted by the second actuator 21 can be calculated by the controller CNT. The compensation force equals $F1 \cdot h1 / h2$, wherein F1 is the actuation force, h1 is the distance between the centre of mass of the substrate support and the centre of mass of the first balance mass 6 and h2 is the distance between the centre of mass of the first balance mass 6 and the centre of mass of the second balance mass M.

[00037] Figure 6 discloses a positioning system according to an embodiment of the invention. This embodiment is similar to the embodiment shown in Figure 3 for the same reference numbers. In the embodiment according to the invention shown in Figure 6, a torque resulting from the position mismatch of the center of gravity of the substrate support WT with respect to the balance mass 6 is compensated with second actuators 212, 214 exerting the compensation force

between the ground floor GF and the base frame BF. The compensation force can be calculated by the formula:

$$h_1 * F_1 = l_1 * F_{214} - l_2 * F_{212}$$

[00038] Wherein l_1 , l_2 are the distances between the centre of mass of the first balance mass 6 and the second actuators 214, 212 respectively. F_{214} and F_{212} are the compensation forces exerted by the second actuators 214, 212. To keep the base frame stable at its position the sum of compensation forces F_{214} and F_{212} should be zero. The ground floor GF may have a limited stiffness and therefore the compensation force may be generated by having a piezo actuator extending its length whereby the ground stiffness should be taken into account.

[00039] Figure 7 discloses a positioning system according to an embodiment of the invention. This embodiment is similar to the embodiment of Figure 3 for the same reference numbers. According to the embodiment shown in Figure 7, the second balance mass M is suspended from the base frame BF and a second actuator 21 can exert a compensation force on the second balance mass M to compensate for the torque. The compensation force can be calculated by the controller CNT on the basis of the distance between the centre of gravities h_1 and h_2 and the actuation force F_1 .

[00040] According to an embodiment of the invention, a torque generated by the substrate support WT and its balance mass 6 can be compensated for by a counteracting torque generated by the patterning device support MT and its balance mass. This compensation can be achieved by placing the balance mass of the patterning device support MT somewhat above or below the support MT itself, depending on the movement direction of the patterning device support MT with respect to the substrate support WT.

[00041] Combinations and/or variations on the above described modes of use or entirely different modes of use may also be employed. For example, it is possible to combine the torque compensation system of Figures 3, 4, 5, 6 and 7.

[00042] 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, 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.

[00043] 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 may be used in other applications, for example imprint lithography, and where the context allows, is not limited to optical lithography. In imprint lithography a topography in a patterning device defines the pattern created on a substrate. The topography of the patterning device may be pressed into a layer of resist supplied to the substrate whereupon the resist is cured by applying electromagnetic radiation, heat, pressure or a combination thereof. The patterning device is moved out of the resist leaving a pattern in it after the resist is cured.

[00044] 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) and extreme ultra-violet (EUV) radiation (e.g. having a wavelength in the range of 5-20 nm), as well as particle beams, such as ion beams or electron beams.

[00045] The term “lens”, where the context allows, may refer to any one or combination of various types of optical components, including refractive, reflective, magnetic, electromagnetic and electrostatic optical components.

[00046] While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. For example, the invention may take the form of a computer program containing one or more sequences of machine-readable instructions describing a method as disclosed above, or a data storage medium (e.g. semiconductor memory, magnetic or optical disk) having such a computer program stored therein.

[00047] 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.

WHAT IS CLAIMED IS:

1. A positioning system to position a support, comprising:
a first actuator configured to exert an actuation force on the support, the first actuator being coupled to a first balance mass constructed and arranged to absorb a reaction force resulting from the actuation force generated by the first actuator; and
a controller and a second actuator constructed and arranged to exert a compensation force to compensate a torque caused by the actuation force exerted by the first actuator on the first balance mass.
2. The positioning system according to claim 1, wherein the controller and the second actuator are constructed and arranged to compensate a torque caused by a difference in position of a center of mass of the first balance mass and the support.
3. The positioning system according to claim 2, wherein the center of mass of the first balance mass and the support have a difference in position in a first direction and the first actuator is constructed and arranged to exert the actuation force in a direction perpendicular to the first direction.
4. The positioning system according to claim 3, wherein the first direction is substantially parallel to gravity and the direction perpendicular to the first direction is substantially in a horizontal plane.
5. The positioning system according to claim 1, wherein the first actuator is a planar motor that includes a magnet plate and a coil system.
6. The positioning system according to claim 5, wherein the magnet plate is provided to the first balance mass and the coil system to the support.
7. The positioning system according to claim 1, wherein the positioning system includes a base frame which moveably supports the table, the first balance mass and the first actuator.

8. The positioning system according to claim 1, wherein the second actuator is constructed and arranged to exert the compensation force on a second balance mass.
9. The positioning system according to claim 8, wherein the second actuator is configured to exert the compensation force between the base frame and a ground floor which supports the base frame.
10. The positioning system according to claim 7, wherein the second balance mass is configured to be actuated in a rotational direction by the second actuator to exert the compensation torque.
11. The positioning system according to claim 7, wherein the second balance mass is moveably suspended from the base frame and the second actuator is configured to exert the compensation force between the second balance mass and the base frame.
12. The positioning system according to claim 7, wherein the second balance mass is moveably suspended from the first balance mass.
13. The positioning system according to claim 1, wherein the controller comprises an input representative of the actuation force exerted by the first actuator and a calculator constructed and arranged to calculate the compensation force based on the actuation force.
14. The positioning system according to claim 1, wherein the controller is constructed and arranged to calculate the compensation force based on a position and direction of the actuation force and a position and direction of the compensation force.
15. A lithographic apparatus comprising:
 - an illumination system configured to condition a radiation beam;
 - a patterning device support constructed to support a patterning device, the patterning device being capable of imparting the radiation beam with a pattern in its cross-section to form a patterned radiation beam;
 - a substrate support constructed to hold a substrate;

a projection system configured to project the patterned radiation beam onto a target portion of the substrate, and

a positioning system constructed and arranged to position at least one of the supports, the positioning system including

a first actuator configured to exert an actuation force on the support, the first actuator being coupled to a first balance mass constructed and arranged to absorb a reaction force resulting from the actuation force generated by the first actuator; and

a controller and a second actuator constructed and arranged to exert a compensation force to compensate a torque caused by the actuation force exerted by the first actuator on the first balance mass.

16. A device manufacturing method comprising:

providing a substrate that is at least partially covered by a layer of radiation-sensitive material on a substrate support;

providing a patterning device on a patterning device support;

projecting a patterned beam of radiation onto the layer of radiation sensitive material; and positioning at least one of the supports, the positioning including

exerting a first force between a first balance mass and the support, the first force moving the support relative to the first balance mass, and

controllably exerting a second force to compensate a torque caused by a difference in position of the center of mass of the first balance mass and the support.

17. The method according to claim 16, wherein the second force is exerted on a second balance mass.