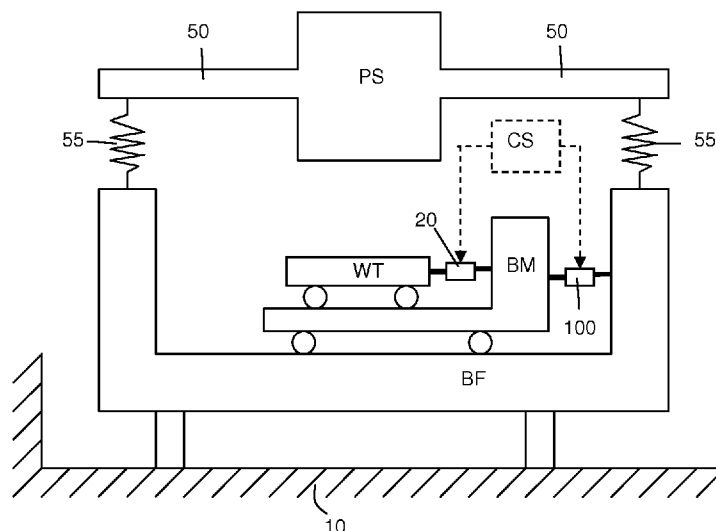




- (51) International Patent Classification:
G03F 7/20 (2006.01) *H01L 21/68* (2006.01)
- (21) International Application Number:
PCT/EP2017/068639
- (22) International Filing Date:
24 July 2017 (24.07.2017)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
16182694.6 04 August 2016 (04.08.2016) EP
- (71) Applicant: ASML NETHERLANDS B.V. [NL/NL]; P.O. Box 324, 5500 AH Veldhoven (NL).
- (72) Inventors: SCHNEIDERS, Mauritius, Gerardus, Elisabeth; P.O. Box 324, 5500 AH Veldhoven (NL). AAN-
- GENENT, Wilhelmus, Henricus, Theodorus, Maria; P.O. Box 324, 5500 AH Veldhoven (NL).
- (74) Agent: RAS, Michael; ASML Netherlands B.V., P.O. Box 324, 5500 AH Veldhoven (NL).
- (81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH,

(54) Title: POSITIONING SYSTEM, CONTROL SYSTEM, METHOD TO POSITION, LITHOGRAPHIC APPARATUS AND DEVICE MANUFACTURING METHOD

FIG 2



(57) Abstract: The invention relates to a positioning system for positioning an object, comprising a base frame, a balance mass, a position actuator, a drift actuator and a control system, wherein the position actuator is arranged to apply a first force between the object and the balance mass to position the object, wherein the drift actuator is arranged to apply a second force between the balance mass and the base frame to position the balance mass relative to the base frame, wherein the control system is configured to control the position actuator based on a sequence of setpoints that is representative for desired positions of the object relative to a reference, wherein the control system is configured to determine a determined trajectory based on the sequence of setpoints before using the sequence of setpoints to control the position actuator, and to control the drift actuator based on the determined trajectory.



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

Published:

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

**POSITIONING SYSTEM, CONTROL SYSTEM, METHOD TO POSITION,
LITHOGRAPHIC APPARATUS AND DEVICE MANUFACTURING METHOD**

CROSS-REFERENCE TO RELATED APPLICATIONS

- 5 This application claims priority of EP application 16182694.6 which was filed on August 4, 2016 and which is incorporated herein in its entirety by reference

BACKGROUND

FIELD OF THE INVENTION

- 10 The present invention relates to a positioning system, a control system, a method to position, a lithographic apparatus and a device manufacturing method.

DESCRIPTION OF THE RELATED ART

- 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.
- Lithographic apparatus usually comprise one or more objects that need to be positioned accurately. Examples thereof are the support for supporting the patterning device and the substrate table
- 15
20
25

constructed to hold the substrate.

In a simple configuration, positioners are provided to apply forces between the object and a base frame to position the object. However, especially in case of relatively large accelerations, the forces may excite the base frame, which in turn may have an impact on other systems supported by the base frame, e.g. a metrology frame and/or the projection system.

In order to reduce the excitations in the base frame, a balance mass is provided between the positioner and the base frame, so that the reaction forces from the positioner are transformed into balance mass motion instead of being directly exerted onto the base frame.

In practice, the moving range of the balance mass is not sufficient to accommodate all possible positioner movements, so that a drift actuator is provided between the balance mass and the base frame to keep the balance mass in its moving range. For this reason, a low-bandwidth feedback controller may be used to regulate the combined center-of-gravity of the positioner and the balance mass to a fixed reference position.

However, this introduces a trade-off between required moving range for the balance mass and the magnitude of the forces applied to the base frame limiting the performance. Reducing the forces will increase the required moving range and vice versa.

SUMMARY

It is desirable to provide a positioning system in which for a required moving range of the balance mass the maximum force to be applied by the drift actuator is reduced.

According to an embodiment of the invention, there is provided a positioning system for positioning an object, comprising:

- a base frame;
- a balance mass;
- a position actuator;
- a drift actuator;
- a control system;

wherein the position actuator is arranged to apply a first force between the object and the balance

mass to position the object relative to the balance mass,
wherein the drift actuator is arranged to apply a second force between the balance mass and the
base frame to position the balance mass relative to the base frame,
wherein the control system is configured to control the position actuator based on a sequence of
5 setpoints that is representative for desired positions of the object relative to a reference,
wherein the control system is configured to determine a trajectory based on the sequence of
setpoints before using the sequence of setpoints to control the position actuator, and to control the
drift actuator based on the determined trajectory.

According to another embodiment of the invention, there is provided a method to position an
10 object relative to a reference using a base frame, a balance mass, a position actuator and a drift
actuator, wherein the position actuator is arranged to apply a first force between the object and the
balance mass to position the object relative to the balance mass, wherein the drift actuator is
arranged to apply a second force between the balance mass and the base frame to position the
balance mass relative to the base frame, and wherein the method comprises the following steps:

- 15 a) obtaining a sequence of setpoints that is representative for desired positions of the object
relative to a reference;
- b) determining a trajectory for the balance mass based on the sequence of setpoints before using
the sequence of setpoints to drive the position actuator;
- c) controlling the position actuator to position the object based on the sequence of setpoints; and
- 20 d) controlling the drift actuator to position the balance mass based on the determined trajectory.

According to yet another embodiment of the invention, there is provided a lithographic apparatus
comprising a positioning system according to the invention.

According to a further embodiment of the invention, there is provided a device manufacturing
method wherein use is made of a positioning system, a method or a lithographic apparatus
25 according to the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

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:

- Figure 1 depicts a lithographic apparatus according to an embodiment of the invention;
- Figure 2 schematically depicts a positioning system according to an embodiment of the invention implemented in the lithographic apparatus of Fig. 1 to control the position of a single
5 substrate table;
- Figure 3 schematically depicts the control system of the positioning system of Fig. 2;
- Figure 4 depicts a comparison of the determined trajectory of the balance mass according to the invention and the trajectory followed by the balance mass in the prior art in case of small motions of the object;
- 10 - Figure 5 depicts the forces applied to the base frame for both situations of Fig. 4;
- Figure 6 depicts a comparison of the determined trajectory of the balance mass according to the invention and the trajectory followed by the balance mass in the prior art in case of large motions of the object;
- Figure 7 depicts the forces applied to the base frame for both situations of Fig. 6;
- 15 - Figure 8 schematically depicts a positioning system according to another embodiment of the invention implemented in the lithographic apparatus of Fig. 1 to control the position of both substrate tables in the dual stage system.

DETAILED DESCRIPTION

- 20 Figure 1 schematically depicts a lithographic apparatus according to one embodiment of the invention. The apparatus comprises:
- an illumination system (illuminator) IL configured to condition a radiation beam B (e.g. UV radiation or EUV radiation).
 - a support structure (e.g. a mask table) MT constructed to support a patterning device (e.g. a
25 mask) MA and connected to a first positioner PM configured to accurately position the patterning device in accordance with certain parameters;
 - a substrate table (e.g. a wafer table) WT_a or WT_b 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

- 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.

The illumination system IL 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, and/or controlling radiation.

The support structure MT supports, i.e. bears the weight of, the patterning device MA. It holds the patterning device MA in a manner that depends on the orientation of the patterning device MA, the design of the lithographic apparatus, and other conditions, such as for example whether or not the patterning device MA is held in a vacuum environment. The support structure MT can use

mechanical, vacuum, electrostatic or other clamping techniques to hold the patterning device MA.

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 MA is at a desired position, for example with respect to the projection system PS. Any use of the terms “reticle” or “mask” herein may be considered synonymous with the more general term “patterning device.”

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 W. 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 W, 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.

The patterning device MA 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.

The term “radiation 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 ultraviolet (EUV) radiation (e.g. having a wavelength in the range of 5-20nm), as well as particle beams, such as ion beams or electron beams.

- 5 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
10 term “projection system”.

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).

- 15 The lithographic apparatus may be of a type having two (dual stage) or more substrate tables (and/or two or more mask tables). In such “multiple stage” machines the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposure. The two substrate tables WTa and WTb in the example of Figure 1 are an illustration of this. The invention disclosed herein can be used in a stand-alone
20 fashion, but in particular it can provide additional functions in the pre-exposure measurement stage of either single- or multi-stage apparatuses. An additional table may be arranged to hold at least one sensor, instead of holding a substrate W. The at least one sensor may be a sensor to measure a property of the projection system PS, a sensor to detect a position of a marker on the patterning device MA relative to the sensor or any other type of sensor. The additional table may
25 comprise a cleaning device, for example for cleaning part of the projection system PS or any other part of the lithographic apparatus.

The lithographic apparatus may also be of a type wherein at least a portion of the substrate W 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 PS and the substrate W. An immersion liquid may also be applied to

other spaces in the lithographic apparatus, for example, between the patterning device MA and the projection system PS. Immersion techniques are well known in the art for increasing the numerical aperture of projection systems. The term “immersion” as used herein does not mean that a structure, such as a substrate W, must be submerged in liquid, but rather only means that liquid is located between the projection system PS and the substrate W during exposure.

Referring to Figure 1, the illuminator IL receives a radiation beam from a radiation source SO. The radiation source SO and the lithographic apparatus may be separate entities, for example when the radiation source SO is an excimer laser. In such cases, the radiation source SO is not considered to form part of the lithographic apparatus and the radiation beam is passed from the radiation 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 radiation source SO is a mercury lamp. The radiation source SO and the illuminator IL, together with the beam delivery system BD if required, may be referred to as a radiation system.

The illuminator IL may comprise an adjuster AD for adjusting 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 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.

The radiation beam B is incident on the patterning device MA (e.g., mask), which is held on the support structure MT (e.g., mask table), and is patterned by the patterning device MA. 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. 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 WTa/WTb 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 WTa/WTb 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 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 MA, the mask alignment marks M1, M2 may be located between the dies. The depicted apparatus can at least be used in scan mode, in which the support structure MT and the substrate table WTa/WTb 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 WTa/WTb 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.

In addition to the scan mode, the depicted apparatus could be used in at least one of the following modes:

1. In step mode, the support structure MT and the substrate table WTa/WTb 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 WTa/WTb 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.
2. In another mode, the support structure MT is kept essentially stationary holding a programmable patterning device, and the substrate table WTa/WTb 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 WTa/WTb or in between successive radiation pulses during a scan. This mode of operation can be readily applied to maskless lithography that
5 utilizes programmable patterning device, such as a programmable mirror array of a type as referred to above.

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

Lithographic apparatus LA is of a so-called dual stage type which has two substrate tables WTa
10 and WTb and two stations – an exposure station and a measurement station– between which the substrate tables can be exchanged. While one substrate on one substrate table is being exposed at the exposure station, another substrate can be loaded onto the other substrate table at the measurement station so that various preparatory steps may be carried out. The preparatory steps may include mapping the surface of the substrate using a level sensor LS and measuring the
15 position of alignment markers on the substrate using an alignment sensor AS. This enables a substantial increase in the throughput of the apparatus. If the position sensor IF is not capable of measuring the position of the substrate table while it is at the measurement station as well as at the exposure station, a second position sensor may be provided to enable the positions of the substrate table to be tracked at both stations.

20 The apparatus further includes a lithographic apparatus control unit LACU which controls all the movements and measurements of the various actuators and sensors described. Control unit LACU also includes signal processing and data processing capacity to implement desired calculations relevant to the operation of the apparatus. In practice, control unit LACU will be realized as a system of many sub-units, each handling the real-time data acquisition, processing and control of a
25 subsystem or component within the apparatus. For example, one processing subsystem may be dedicated to servo control of the substrate positioner PW. Separate units may even handle coarse and fine actuators, or different axes. Another unit might be dedicated to the readout of the position sensor IF. Overall control of the apparatus may be controlled by a central processing unit, communicating with these sub-systems processing units, with operators and with other

apparatuses involved in the lithographic manufacturing process.

Fig. 2 schematically depicts a positioning system according to an embodiment of the invention implemented in the lithographic apparatus of Fig. 1 to position the substrate table WT as an object.

Fig. 2 clearly depicts a base frame BF which may be stiffly connected to the ground 10. The

5 projection system PS is isolated from vibrations of the base frame BF by being mounted on a metrology frame 50 which is compliantly connected to the base frame BF with a soft suspension system 55 or an active vibration isolation system.

The positioning system further comprises a balance mass BM, a position actuator 20 to apply a first force between the substrate table WT and the balance mass BM, and a drift actuator 100 to

10 apply a second force between the balance mass BM and the base frame BF.

The positioning system further comprises a control system CS, which may be part of the lithographic apparatus control unit LACU or may be a separate unit. The control system CS drives the position actuator 20 and the drift actuator 100.

The control system CS including its inputs and outputs is depicted in more detail in Fig. 3.

15 A first input to the control system CS is a measurement signal MS1 representative for the position of the substrate table WT relative to a reference, in this case the metrology frame 50, allowing the substrate table WT to be positioned accurately relative to the projection system PS.

A second input to the control system CS, and associated to the first input MS1, is a setpoint SP1 representative for a desired position of the substrate table WT relative to the reference.

20 The control system CS is now able to control the position actuator 20 based on a difference between the setpoint SP1 and the measurement signal MS1 to urge the substrate table WT towards the desired position. The control system CS therefore outputs a drive signal DS1 to the position actuator 20.

25 A third input to the control system CS is a measurement signal MS2 representative for the position of the balance mass BM, in this case relative to the base frame BF, allowing to determine for instance where the balance mass BM is within its moving range on the base frame BF.

In the prior art, the measurement signal MS1 and the measurement signal MS2 are used to determine the position of a combined center-of-gravity of the substrate table WT and the balance mass BM, and a low-bandwidth feedback controller is used to keep the combined center-of-gravity

to a fixed reference position, i.e. control to zero. In the prior art, the combined center-of-gravity is not moved by the low-bandwidth feedback controller, because the low-bandwidth feedback controller is arranged to maintain the combined center-of-gravity at the same fixed reference position. The combined center-of-gravity may deviate marginally from the fixed reference position, for example due to disturbances caused by cables connected to the balance mass, but the low-bandwidth feedback controller is arranged to maintain the combined center-of-gravity at substantially the same fixed reference position.

However, according to the invention, the control system CS will obtain a sequence of setpoints SP1, so that the behavior of the substrate table WT so that the behavior of the substrate table WT is known beforehand. Because the first force that moves the substrate table WT is also applied to the balance mass BM, the behavior of the balance mass BM is also known beforehand. The control system CS is able to determine a determined trajectory for the balance mass BM taking into account the behavior of the balance mass BM due to the first force, the available moving range and the second force to be applied to the base frame BF. The determined trajectory for the balance mass BM is determined before the sequence of setpoints is used to position the position actuator 20. The position actuator 20 is then driven by drive signal DS1 in accordance with the sequence of setpoints and the drift actuator 100 is then driven by drive signal DS2 in accordance with the determined trajectory.

Determining the determined trajectory for the balance mass BM based on future movements of the substrate table WT allows to keep the balance mass BM within the moving range without using a large second force as it can be predicted when the balance mass BM will tend to move out of a maximum moving range and the determined trajectory can subsequently be chosen to minimize the second force applied to the base frame BF to follow the determined trajectory. For example, when the control system CS predicts that the balance mass BM will move out of the maximum moving range in a direction, the control system CS may determine the determined trajectory such that the drift actuator 100 moves the balance mass BM in the opposite direction. By moving the balance mass BM in the opposite direction, the combined center-of-gravity moves. The control system CS is arranged to move the combined center-of gravity of the balance mass BM and the substrate table WT. Since the control system CS is able to determine the determined trajectory

before using the sequence of setpoints to control the position actuator 20, the determined trajectory may lead the balance mass BM slowly in the opposite direction, which results in a small second force on the base frame BF.

This control configuration according to the invention can be used for existing designs to minimize the second force applied to the base frame BF using the same moving range and/or can be used for new designs to minimize the maximum moving range using the same second force and/or or can be used for new designs to minimize both the second force and the maximum moving range as an intermediate solution.

In an embodiment, the control system CS comprises a feedback controller to control the drift actuator 100. In that case the feedback controller compares the determined trajectory of the balance mass BM with the actual position of the balance mass BM via measurement signal MS2, and controls the drift actuator 100 in order to urge the balance mass BM to follow the determined trajectory. The determined trajectory then functions as setpoint to the feedback controller.

Alternatively or in addition to the feedback controller, the control system CS may be improved by including a feedforward controller to control the drift actuator 100. Based on the determined trajectory and the behavior of the substrate table WT, the feedforward controller can determine the second force to be applied by the drift actuator 100 to allow the balance mass BM to follow the determined trajectory. The feedforward controller is then configured to control the drift actuator 100 accordingly in a feedforward manner. In that case, the feedback controller may be used to correct deviations from the determined trajectory, e.g. caused by disturbances, which may reduce the second force applied between the balance mass BF and the base frame BM considerably.

In order to determine the determined trajectory for the balance mass BM, the control system CS may comprise a scheduler. The scheduler has a first mode in which the determined trajectory corresponds to a trajectory of a freely moving balance mass BM reacting on the first force applied by the position actuator 20. This first mode may be used in case it is predicted by the scheduler that the balance mass BM will not tend to move out of the maximum moving range during the sequence of setpoints. In the first mode, the combined center-of-gravity is not moved by the control system CS. The combined center-of-gravity substantially remains at a fixed position in the first mode.

Fig. 4 depicts an example of a determined trajectory when the scheduler is in the first mode (solid

line). The determined trajectory corresponds to small movements of the substrate table WT, e.g. during exposure scans, of which it can be predicted that the balance mass BM stays within the maximum moving range when reacting to the first force applied by the position actuator 20.

In Fig 4, the determined trajectory according to the invention is compared to the trajectory the balance mass BM follows in case of using a low-bandwidth feedback controller which regulates the combined center-of-gravity of the substrate table WT and the balance mass BM.

Although the differences between the trajectories in Fig. 4 may be considered small, the impact on the second force applied to the base frame BF are significant as shown in Fig. 5. Fig. 5 depicts the second force as applied by the drift actuator 100 between the balance mass BM and the base frame BF in case of the determined trajectory in accordance with the invention (solid line) and the trajectory followed in case of the prior art feedback controller (dashed line). The second force in accordance with the invention is substantially zero where the prior art applies an oscillating non-zero force.

When the motions of the substrate table WT become larger, the chance of the balance mass BM exceeding the maximum moving range increases. The scheduler therefore also has a second mode in which the determined trajectory deviates from the trajectory corresponding to a freely moving balance mass BM reacting on the first force applied by the position actuator 20. In the second mode, the control system CS is arranged to move the combined center-of-gravity.

An example thereof is shown by reference to Fig. 6. The drawing depicts in a solid line the determined trajectory for the balance mass BM corresponding to relatively large motions of the substrate table WT, e.g. a measure move. The trajectory as a result of prior art control is shown as a comparison in dashed lines.

Although again, the difference between the trajectories in Fig. 6 does not seem large. However, the impact on the second force applied to the base frame BF is significant as shown in Fig. 7. Fig. 7 depicts the second force as applied by the drift actuator 100 between the balance mass BM and the base frame BF in case of the determined trajectory in accordance with the invention (solid line) and the trajectory followed in case of the prior art feedback controller (dashed line). The applied second force using the determined trajectory according to the invention may be about 20% of the second force applied by the prior art feedback controller. This is mainly achieved by distributing

the second force over the a large part of the substrate table motion, for example the complete substrate table motion, and/or by using a feedforward configuration.

In the example of Figs. 6 and 7, the second force applied to the base frame BF is reduced considerably. However, in case the second force is still within an acceptable range, the invention
5 can be used to reduce the maximum moving range of the balance mass BM without exceeding a desired maximum value of the second force applied to the base frame BF. By reducing the maximum moving range of the balance mass BM, the size of the positioning system may be reduced.

Fig. 8 depicts a positioning system similar to the positioning system of Fig. 2, but now for
10 positioning two substrate tables WTa, WTb of the lithographic apparatus of Fig. 1, which substrate tables WTa, WTb share a balance mass BM. Each substrate table WTa, WTb has an associated position actuator 20a, 20b. Instead of the substrate table WTb, a table is provided that is arranged to support a sensor instead of a substrate W.

The position actuator 20a is arranged to apply a first force between the substrate table WTa and the
15 balance mass BM to position the substrate table WTa relative to the balance mass BM.

The drift actuator 100 is arranged to apply a second force between the balance mass BM and the base frame BF to position the balance mass BM relative to the base frame BF.

The position actuator 20b is arranged to apply a third force between the substrate table WTb and the balance mass BM to position the substrate table WTb relative to the balance mass BM.

In order to predict the behavior of the balance mass BM, the control system CS may obtain a
20 sequence of setpoints that is representative for desired positions of the substrate table WTa as well as a further sequence of setpoints that is representative for desired setpoints of the substrate table WTb.

The control system CS is configured to determine the determined trajectory for the balance mass
25 BM based on both the sequence of setpoints and the further sequence of setpoints. The control system CS is further configured to control the position actuator 20a based on the sequence of setpoints corresponding to substrate table WTa, to control the position actuator 20b based on the further sequence of setpoints corresponding to substrate table WTb, and to control the drift actuator 100 based on the determined trajectory.

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.

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.

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.

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 for positioning an object, comprising:

- a base frame;
- a balance mass;
- 5 - a position actuator;
- a drift actuator;
- a control system;

wherein the position actuator is arranged to apply a first force between the object and the balance mass to position the object relative to the balance mass,

10 wherein the drift actuator is arranged to apply a second force between the balance mass and the base frame to position the balance mass relative to the base frame,

wherein the control system is configured to control the position actuator based on a sequence of setpoints that is representative for desired positions of the object relative to a reference,

wherein the control system is configured to determine a determined trajectory based on the
15 sequence of setpoints before using the sequence of setpoints to control the position actuator, and to control the drift actuator based on the determined trajectory.

2. A position system according to claim 1, wherein the balance mass and the object have a combined center-of-gravity, wherein the control system is arranged to move the combined
20 center-of gravity.

3. A positioning system according to claim 1 or 2, wherein the control system comprises a feedback controller to control the drift actuator based on a difference between the determined trajectory and a position of the balance mass relative to the base frame.

25

4. A positioning system according to one of the preceding claims, wherein the control system comprises a feedforward controller to control the drift actuator, wherein the feedforward controller is configured to predict the second force based on the predetermined trajectory.

5. A positioning system according to one of the preceding claims, wherein the control system comprises a scheduler to determine the determined trajectory, wherein the scheduler has a first mode in which the determined trajectory corresponds to the trajectory of a freely moving balance mass reacting on the first force, and wherein the scheduler has a second mode in which the
5 determined trajectory deviates from the trajectory of a freely moving balance mass by applying the second force.
6. The position system according to claim 5, wherein the balance mass and the object have a combined center-of-gravity, wherein the control system is arranged to move the combined
10 center-of gravity when the scheduler is in the second mode.
7. A positioning system according to claim 5 or 6, wherein the scheduler is configured to predict a predicted moving range of the balance mass in the first mode, and to operate in the first mode when the predicted moving range is within a maximum moving range, and to operate in the
15 second mode when the predicted moving range exceeds the maximum moving range.
8. A control system for use in a position system according to one of the preceding claims.
9. A method to position an object relative to a reference using a base frame, a balance mass, a
20 position actuator and a drift actuator, wherein the position actuator is arranged to apply a first force between the object and the balance mass to position the object relative to the balance mass, wherein the drift actuator is arranged to apply a second force between the balance mass and the base frame to position the balance mass relative to the base frame, and wherein the method comprises the following steps:
- 25 a) obtaining a sequence of setpoints that is representative for desired positions of the object relative to a reference;
- b) determining a trajectory for the balance mass based on the sequence of setpoints before using the sequence of setpoints to control the position actuator;
- c) controlling the position actuator based on the sequence of setpoints; and

d) controlling the drift actuator based on the determined trajectory.

10. A method according to claim 9, wherein the balance mass and the object have a combined center-of-gravity, the method comprising the step of: moving the object and the balance mass such
5 that the combined center-of gravity is moved.

11. A method according to claim 9 or 10, comprising predicting a predicted moving range of the balance mass when the determined trajectory corresponds to a trajectory of a freely moving balance mass reacting on the first force, comparing the predicted moving range with a maximum
10 moving range, and controlling the drift actuator based on the determined trajectory when the predicted moving range exceeds the maximum moving range.

12. A lithographic apparatus comprising a positioning system according to claim 1-7 to position an object that is part of the lithographic apparatus.

13. A lithographic apparatus according to claim 12, further comprising:
- an illumination system configured to condition a radiation beam;
- a 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;
20 - a substrate table constructed to hold a substrate; and
- a projection system configured to project the patterned radiation beam onto a target portion of the substrate,
wherein the object comprises the support or the substrate table.

14. A lithographic apparatus according to claim 13, comprising a dual stage system including the substrate table and a further table, wherein the object comprises the substrate table,
wherein the positioning system comprises a further position actuator arranged to apply a third force between the further table and the balance mass to position the further table,
25 wherein the control system is configured to control the further position actuator based on a further

sequence of setpoints that is representative for desired positions of the further table relative to the reference,

wherein the control system is further configured to determine the determined trajectory based on the further sequence of setpoints before using the further sequence of setpoints to control the

5 further position actuator.

15. A device manufacturing method wherein use is made of a positioning system according to claim 1-7, a method according to claim 9-11 or a lithographic apparatus according to claim 12-14.

FIG 1

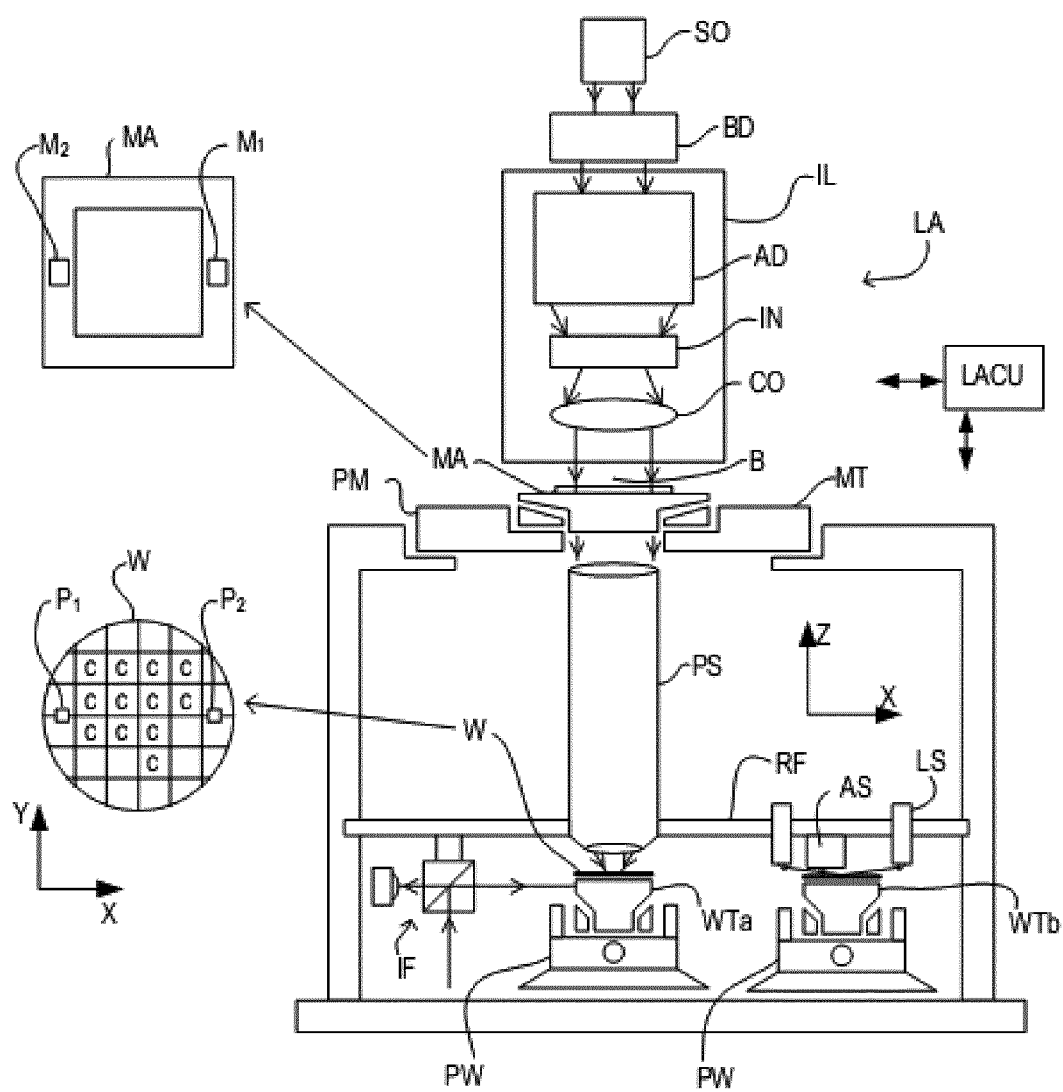


FIG 2

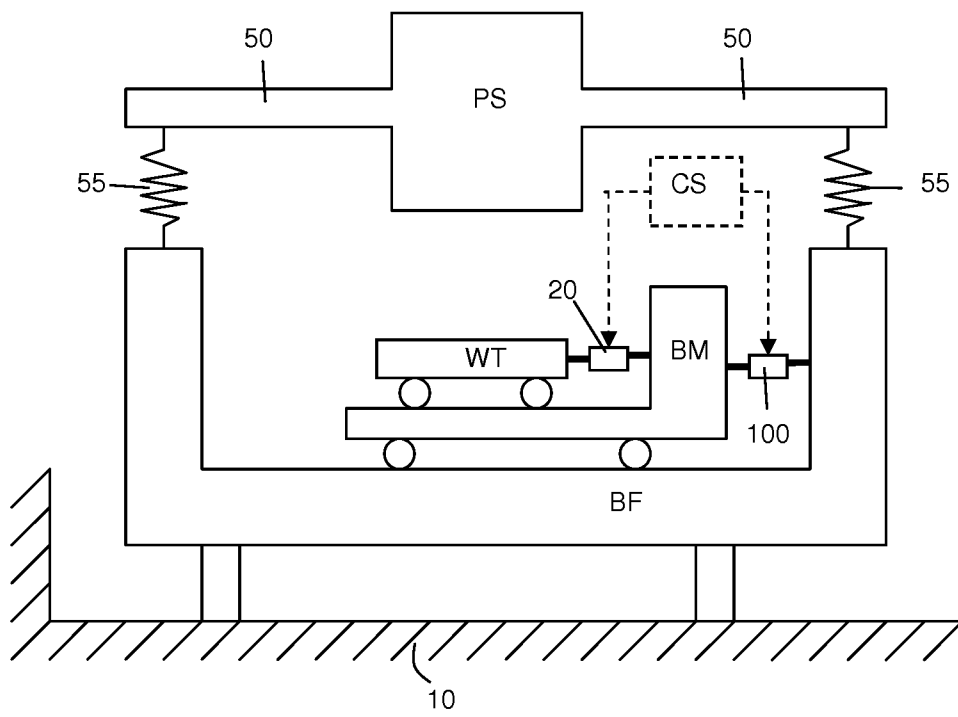


FIG 3

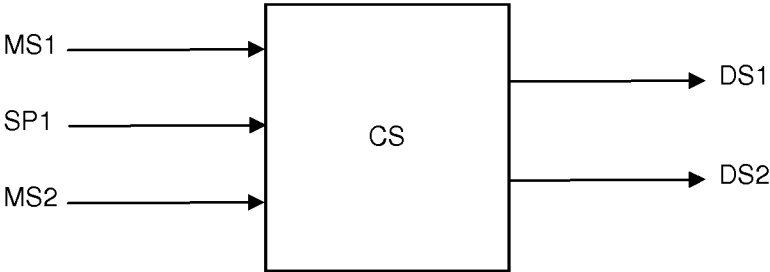


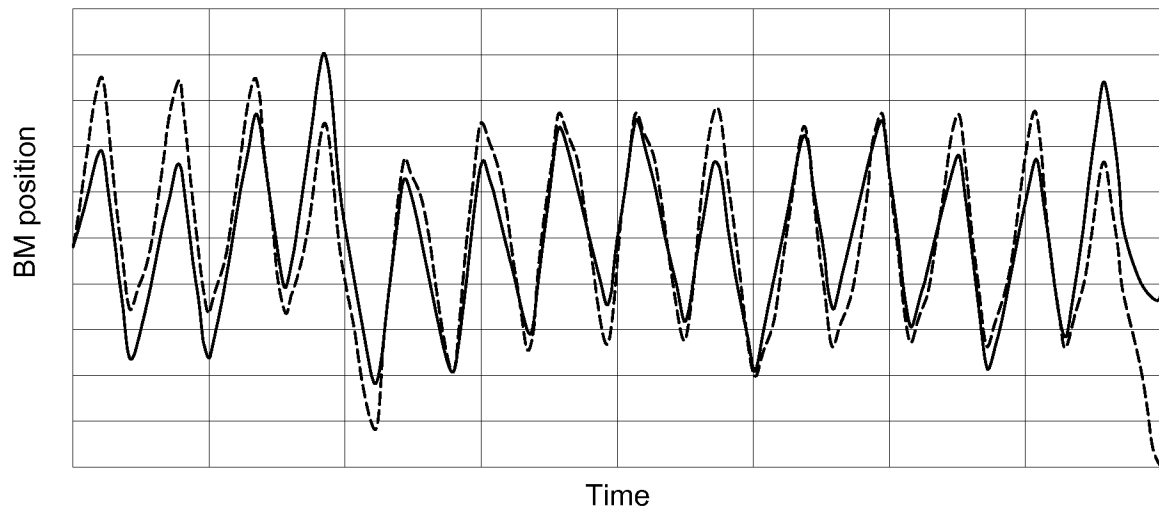
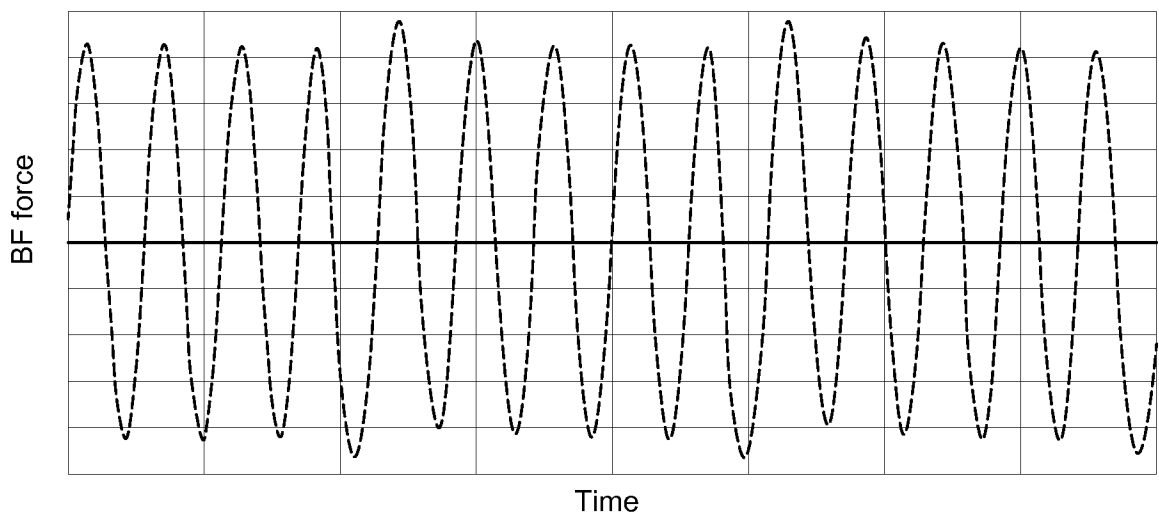
FIG 4**FIG 5**

FIG 6

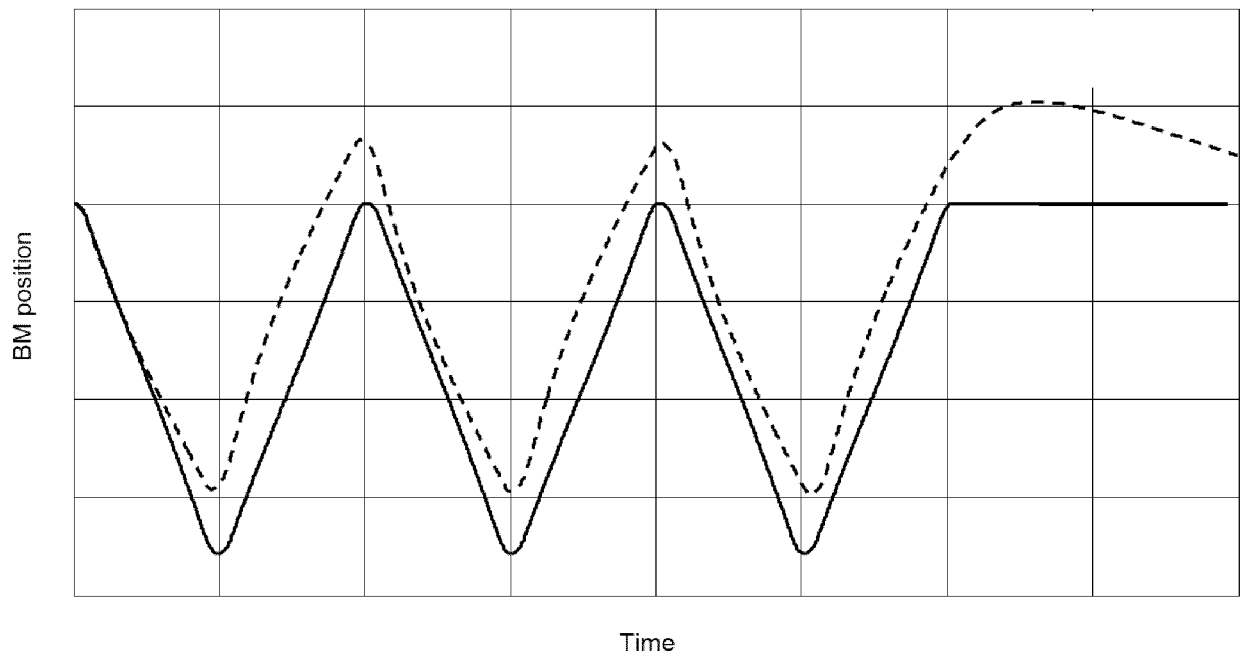


FIG 7

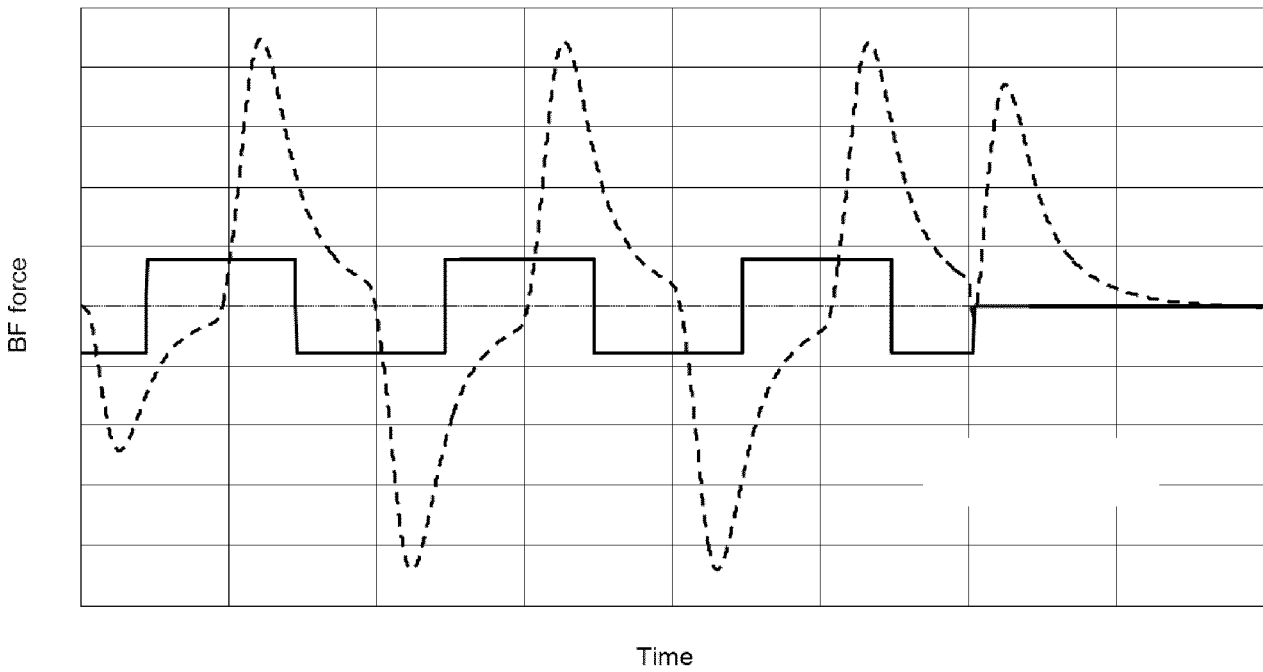
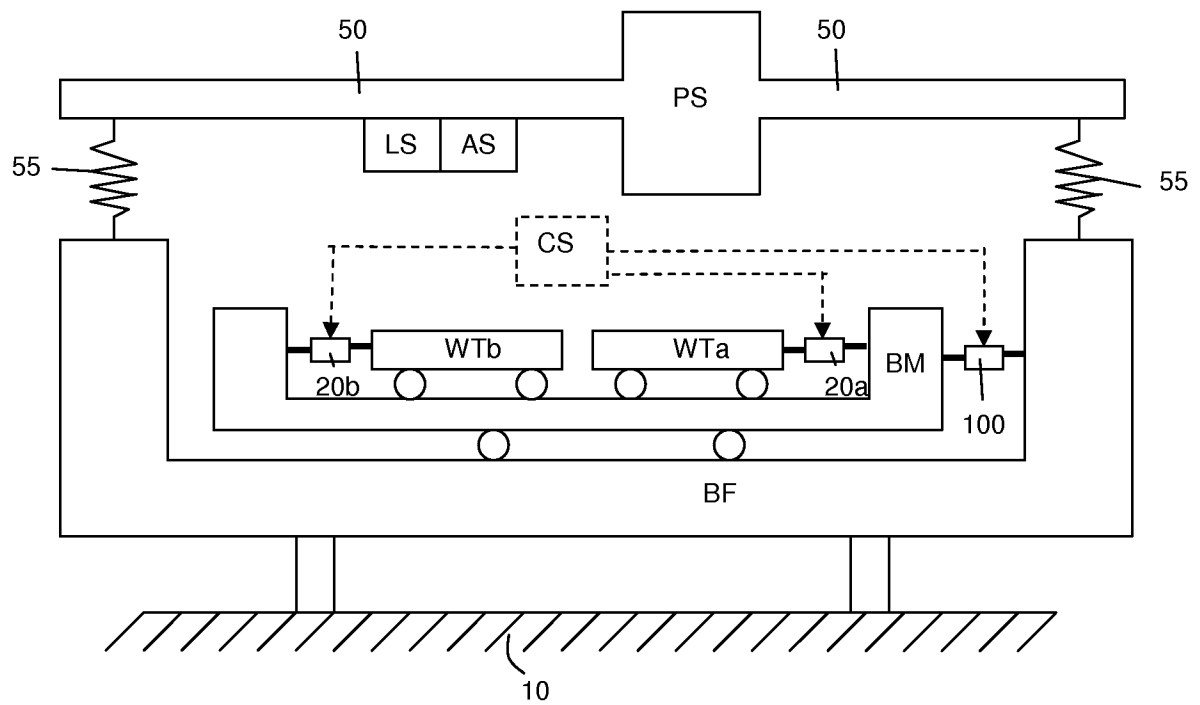


FIG 8



INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2017/068639

A. CLASSIFICATION OF SUBJECT MATTER

INV. G03F7/20 H01L21/68
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G03F H01L

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2004/239910 A1 (UKAJI TAKAO [JP]) 2 December 2004 (2004-12-02) paragraphs [0022] - [0032], [0059] - [0066], [0084]; claim 6; figures 1A-3,5A -----	1-15
X	US 2008/143994 A1 (SHIBAZAKI YUICHI [JP]) 19 June 2008 (2008-06-19) paragraphs [0017] - [0019], [0071] - [0073], [0109] - [0113], [0137]; figures 2,10 -----	1,2,9,10
A	WO 2013/186136 A2 (ASML NETHERLANDS BV [NL]) 19 December 2013 (2013-12-19) paragraphs [0006], [0086], [0087] -----	3-8, 11-15
A	WO 2013/186136 A2 (ASML NETHERLANDS BV [NL]) 19 December 2013 (2013-12-19) paragraphs [0006], [0086], [0087] -----	1,7,14
A	US 2004/051854 A1 (TANAKA KEIICHI [JP] ET AL) 18 March 2004 (2004-03-18) paragraph [0234]; figure 1 -----	14



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

17 October 2017

Date of mailing of the international search report

26/10/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Roesch, Guillaume

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2017/068639

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2004239910 A1	02-12-2004	JP 2004356222 A US 2004239910 A1	16-12-2004 02-12-2004
US 2008143994 A1	19-06-2008	EP 1746637 A1 JP 5130714 B2 JP W02005098911 A1 KR 20070011366 A US 2008143994 A1 WO 2005098911 A1	24-01-2007 30-01-2013 06-03-2008 24-01-2007 19-06-2008 20-10-2005
WO 2013186136 A2	19-12-2013	NONE	
US 2004051854 A1	18-03-2004	NONE	