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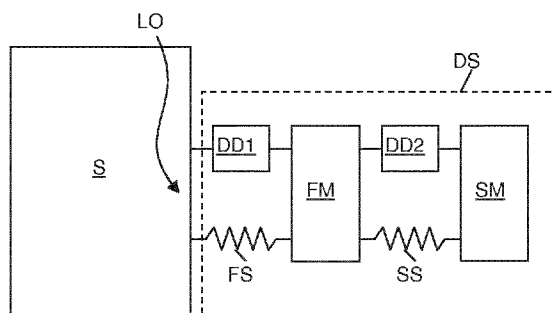
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FIG 2



(57) Abstract: The invention relates to an apparatus comprising a structure (S) and a damping system (DS). The structure has a first eigenmode and a second eigenmode. The damping system comprises a first mass (FM), a first damping device (DD1), a first spring (FS), a second mass (SM), a second damping device (DD2) and a second spring (SS). The first mass is connected to the structure using the first damping device and the first spring. The second mass is connected to the first mass using the second damping device and the second spring. The damping system is arranged to dampen the first eigenmode by movement of the first mass and the second mass, and is arranged to dampen the second eigenmode by movement of the second mass.



APPARATUS, SUBSTRATE HANDLER, PATTERNING DEVICE HANDLER, DAMPING SYSTEM AND METHOD
OF
MANUFACTURING A DAMPING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

- 5 [01] This application claims priority of EP Application No. 17163838.0, which was filed on March 30, 2017, and which is incorporated herein in its entirety by reference.

BACKGROUND

[02] *Field of the Invention*

- 10 [03] The present invention relates to an apparatus comprising a structure having a first eigenmode and a second eigenmode and a damping system to dampen both the first and second eigenmodes. The invention further relates to such an apparatus being a lithographic apparatus, a substrate handler, and a patterning device handler. The invention relates further to a damping system for use in such an apparatus and a device manufacturing method.

- 15 [04] *Description of the Related Art*

- [05] 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
20 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
25 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.

- [06] Lithographic apparatus comprise structures that are either movable or stationary, but which may have
30 eigenmodes that need to be damped by a damping system to increase the obtainable accuracy of the lithographic apparatus. Both active damping devices and tuned damping devices are a well-known way of providing damping to a structure.

- [07] In general, the achievable performance and robustness of a damping device, whether active or tuned,

are directly proportional to their mass. However, the mass is limited by the available volume, especially when the damping system is added to an existing structure to solve dynamical performance issues that are discovered after the development phase, e.g. when the lithographic apparatus is already in use at a customer location.

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SUMMARY

[08] It is desirable to provide an apparatus including a structure and a damping system to dampen eigenmodes of the structure in which the available damping mass within a predetermined volume is improved.

10 **[09]** According to an embodiment of the invention, there is provided an apparatus comprising:

- a structure having a first eigenmode and a second eigenmode; and
- a damping system comprising a first mass, a first damping device, a first spring, a second mass, a second damping device and a second spring,

wherein the first mass is connected to the structure using the first damping device and the first spring,

15 wherein the second mass is connected to the first mass using the second damping device and the second spring, and

wherein the damping system is arranged to dampen the first eigenmode by movement of the first mass and the second mass, and is arranged to dampen the second eigenmode by movement of the second mass.

20 **[10]** According to another embodiment of the invention, there is provided a substrate handler configured for use in an apparatus according to the invention.

[11] According to a further embodiment of the invention, there is provided a patterning device handler configured for use in an apparatus according to the invention.

25 **[12]** According to yet another embodiment of the invention, there is provided a damping system for use in an apparatus according to the invention.

[13] According to yet a further embodiment of the invention, there is provided a method of manufacturing a damping system, comprising the steps of:

- selecting a first spring, a first damping device, a first mass, a second spring, a second damping device and a second mass based on information of a first eigenmode and a second eigenmode of a structure;
- 30 - coupling the first mass to an interface element via the first spring and the first damping device, wherein the interface element is arranged to be coupled to the structure;
- coupling the second mass to the first mass via the second spring and the second damping device, wherein the damping system is arranged to dampen the first eigenmode by movement the first mass and the second mass, and wherein the damping system is arranged to dampen the second eigenmode by movement

of the second mass.

BRIEF DESCRIPTION OF THE DRAWINGS

[14] 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 structure of the lithographic apparatus of Fig. 1 and corresponding damping system according to an embodiment of the invention;
- Figure 3 schematically depicts a damping system when only the first eigenmode of the structure of Fig. 2 is excited;
- Figure 4 schematically depicts a damping system when only the second eigenmode of the structure of Fig. 2 is excited;
- Figure 5 schematically depicts a top view of a structure and corresponding damping system according to another embodiment of the invention;
- Figure 6 schematically depicts a side view of the structure and corresponding damping system of Fig. 5; and
- Figure 7 schematically depicts another side view of the structure and corresponding damping system of Fig. 5.

DETAILED DESCRIPTION

[15] 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 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) WTa or WTb 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.

[16] 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, and/or controlling radiation.

[17] 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.”

[18] 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.

[19] 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.

[20] 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 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.

[21] 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”.

[22] 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).

[23] 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 fashion, but in particular it can provide additional functions in the pre-exposure measurement stage of either single- or multi-stage apparatuses.

[24] 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.

[25] 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 source 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.

[26] 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.

[27] 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.

[28] 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.

[29] 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 utilizes programmable patterning device, such as a programmable mirror array of a type as referred to above.

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

[31] Lithographic apparatus LA is of a so-called dual stage type which has two substrate tables WTa 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 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.

[32] 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 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.

[33] Fig. 2 schematically depicts a structure S of the lithographic apparatus of Fig. 1. The structure S may be or comprise a substrate handler configured to provide substrates W to the substrate table WT, a patterning device handler configured to provide patterning devices MA to the support structure MT (further referred to as support MT), or the projection system PS, or parts thereof.

[34] In the embodiment of Fig. 2, a damping system DS comprises a first mass FM, a first damping device

DD1, a first spring FS, a second mass SM, a second damping device DD2, and a second spring SS. The first mass FM is connected to the structure S using the first damping device DD1 and the first spring FS. The second mass SM is connected to the first mass FM using the second damping device DD2 and the second spring SS. The second mass SM is connected to the structure S via the first mass FM.

5 [35] At a location LO, the first mass FM is connected to the structure S. The first mass FM may be directly connected to the structure S via the first spring FS and the first damping device DD1, or an interface element may be provided. The interface element may be connected to the first damping device DD1 and the first spring FS. The interface element may be arranged to be coupled to the structure S, so as to couple the first damping device DD1 and the first spring FS to the structure S. The first eigenmode of the structure S
10 has a corresponding mode shape such that the structure S at the location LO will vibrate in a first direction with a first eigenfrequency when the first eigenmode is excited. The second eigenmode of the structure S further has a corresponding mode shape such the structure S at the location LO will vibrate in a second direction with a second eigenfrequency when the second eigenmode is excited.

[36] The damping system DS is arranged to dampen the first eigenmode by movement of the first mass
15 FM and the second mass SM, and arranged to dampen the second eigenmode by movement of the second mass SM. When the damping system DS is damping the second eigenmode, the first mass FM may be not moving, may be stationary or may be stationary relative to the structure S.

[37] In the following example it is assumed that the first direction and the second direction are non-parallel to each other, e.g. orthogonal to each other. The first and second eigenfrequency may be equal
20 or close to each other, but may also be significantly different. However, the first and second eigenmode are assumed to be limiting the obtainable accuracy of the lithographic apparatus if no appropriate measures are taken as described in relationship to the current invention.

[38] In order to dampen the first eigenmode, the first damping device DD1 and the first spring FS are configured to act in the first direction. Similarly, the second damping device DD2 and the second spring SS
25 are configured to act in the second direction in order to dampen the second eigenmode.

[39] When only the first eigenmode is excited, the location LO of the structure S will vibrate in the first direction. Because the second mass SM is connected to the first mass FM via the second damping device DD2 and second spring SS that both act in the second direction, the second mass SM seems to be rigidly connected to the first mass FM seen in the first direction. Hence, when only the first eigenmode is excited,
30 the first and second mass FM, SM move as a single mass FM+SM. As a result, the first damping device DD1 and the first spring FS together with the first and second mass FM, SM can be configured to dampen the first eigenmode. The damping situation when only the first eigenmode is excited is schematically depicted in Fig. 3. The single mass FM+SM may move as a tuned-mass-damper. The single mass FM+SM may move in anti-phase with the first eigenmode to dampen the first eigenmode. The movement in

anti-phase may be achieved by selection of the first spring FS, the first damping device DD1, the second spring SS, the second damping device DD2, the first mass FM and the second mass SM.

[40] When only the second eigenmode is excited, the location LO of the structure will vibrate in the second direction. Because the first mass FM is connected to the structure S via the first damping device

5 DD1 and first spring FS that both act in the first direction, the first mass FM seems to be rigidly connected to the structure S seen in the second direction. Hence, when only the second eigenmode is excited, the structure S and the first mass FM move as a single mass S+FM. As a result, the second damping device DD2 and the second spring SS in combination with the second mass SM can be configured to dampen the second eigenmode. The damping situation when only the second eigenmode is excited is schematically
10 depicted in Fig. 4. The second mass SM may move as a tuned-mass-damper. The second mass SM may move in anti-phase with the second eigenmode to dampen the second eigenmode. The movement in anti-phase may be achieved by selection of the first spring FS, the first damping device DD1, the second spring SS, the second damping device DD2, the first mass FM and the second mass SM.

[41] An advantage of the damping system according to the invention is that the first mass FM and second
15 mass SM are connected to the structure S in series instead of parallel as in the prior art. Where in the prior art damping system, the first eigenmode is damped using the first mass FM and the second eigenmode is damped using the second mass SM, the first eigenmode can now, in case of the damping system according to the invention, be damped using both the first and second mass FM, SM while the total mass FM+SM has not been increased and no additional volume has been used. Hence, damping is optimized without using
20 more space.

[42] In an embodiment, the first damping device DD1 comprises a damper such that the combination of first and second mass FM, SM, said damper and the first spring FS is tuned to the first eigenmode as in a tuned mass damping system. Alternatively, the first damping device DD1 may be an active damping device.

[43] In an embodiment, the second damping device DD2 comprises a further damper such that the
25 combination of second mass SM, the further damper and the second spring SS is tuned to the second eigenmode as in a tuned mass damping system. Alternatively, the second damping device DD2 may be an active damping device.

[44] In order to further reduce the volume taken by the damping system DS or to increase the damping mass, the first mass and/or the second mass FM, SM comprises a non-structural part of the structure S. A
30 non-structural part of the structure S is a part of the structure that has no substantial contribution to the strength or rigidity of the structure S and thus could be removed without compromising the mechanical function and integrity of the structure S. Examples of non-structural parts of the structure are electronics, power supplies and/or their housings mounted to the structure S, which non-structural parts can be used as damping mass in the damping system DS according to the invention.

[45] Although the above example assumes that the first and second direction are non-parallel, the invention can be applied to the situation in which the first and second direction are parallel to each other, but the first eigenfrequency is substantially different from the second eigenfrequency.

[46] The first spring FS and the second spring SS may each be implemented as a helical spring, a leaf spring or any other suitable shape. The first spring FS may have the same shape as the second spring SS. The first spring FS may have the same shape as the second spring SS with different dimensions than the second spring SS. The first spring FS may have a different shape than the second spring SS.

[47] The first spring FS may be implemented as a single spring element, or as a plurality of spring elements. For example, the first spring FS may comprises two leaf springs parallel to each other, wherein the main surfaces of the two leaf springs face each other at an offset. This way, the first spring FS may be flexible in one degree of freedom, while being substantially rigid in all other degrees of freedom.

[48] In the Figs. 2 and 3, the first spring FS and the first damping device DD1 are depicted as two separate components. In an embodiment, the first spring FS and the first damping device DD1 are integrated as a single component. For example, the first damping device DD1 may be applied as a coating on the first spring FS. The coating may comprise an elastomer or a rubber or any other type of material with damping properties.

[49] Figs. 5 to 7 schematically depict a top view, a side view and another side view, respectively, of a structure S and a damping system DS according to another embodiment of the invention. The structure S may be a component or part thereof of the lithographic apparatus of Fig. 1.

[50] The damping system DS comprises a first mass FM, a second mass SM, wherein the first mass FM is connected to the structure S via four leaf springs DFS, and wherein the second mass SM is connected to the first mass FM via leaf springs DSS. The second mass SM is rigidly connected to the leaf springs DSS using connection beams CB.

[51] The leaf springs DFS are coated or provided with energy dissipating elements, such as rubber, so that they simultaneously provide a spring function and a damping function. Hence, the leaf springs DFS combine a first spring FS and a first damping device DD1 and may also be referred to as damped first springs DFS.

[52] The leaf springs DSS are in this embodiment also coated or provided with energy dissipating elements, such as rubber, so that the simultaneously provide a spring function and a damping function. Hence, the leaf springs DSS combine a second spring and a second damping device and may also be referred to as damped second springs DSS.

[53] The damped first springs DFS are configured to allow movement of the first mass FM in Y-direction and to be rigid in the X-direction and Z-direction. The damped second springs DSS are configured to allow movement of the second mass SM in Z-direction and to be rigid in the X-direction and the Y-direction.

[54] When the structure S at a location LO, where the first mass FM is connected to the structure S, vibrates in a first eigenmode in Y-direction, this may cause relative movement between the first mass FM and the structure S in the Y-direction due to the damped first springs DFS allowing movement in that direction. As the damped second springs DSS are rigid in the Y-direction the second mass SM follows the movement of the first mass FM, so that the combined first and second mass FM, SM can be used to damp motion of the structure S in the Y-direction using the damped first springs DFS.

[55] When the structure S at the location LO vibrates in a second eigenmode in Z-direction, the first mass FM will follow movement of the structure S as the damped first springs DFS are rigid in the Z-direction. However, movement of the structure S and thus the first mass FM in the Z-direction may cause relative movement between the first mass FM and the second mass SM in the Z-direction due to the damped second springs DSS allowing movement in that direction. The second mass SM can thus be used to damp motion of the structure S in the Z-direction using the damped second springs DSS.

[56] As a result of the damping being provided by dampers provided on the leaf springs DFS, DSS, i.e. the first and second damping device comprising dampers, the combination of first and second mass FM, SM and leaf springs DFS is tuned to the first eigenmode of the structure S, and the combination of the second mass SM and leaf springs DSS is tuned to the second eigenmode of the structure S.

[57] Although the damping systems have been described to dampen a structure of the lithographic apparatus of Fig. 1, the damping system DS according to the invention can be used to dampen a structure S of any apparatus. For example, such an apparatus is a robot arm in manufacturing or measuring equipment. The damping system DS may be used in any type of machinery that has a structure S that suffers from the first and second eigenmodes.

[58] 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.

[59] 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
5 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.

[60] 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
10 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.

[61] 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
15 scope of the claims set out below.

WHAT IS CLAIMED IS:

1. An apparatus comprising:
a structure having a first eigenmode and a second eigenmode; and
5 a damping system comprising a first mass, a first damping device, a first spring, a second mass, a second damping device and a second spring,
wherein the first mass is connected to the structure using the first damping device and the first spring,
wherein the second mass is connected to the first mass using the second damping device and
10 the second spring, and
wherein the damping system is arranged to dampen the first eigenmode by movement of the first mass and the second mass, and is arranged to dampen the second eigenmode by movement of the second mass.
- 15 2. An apparatus according to claim 1, wherein the damping system is arranged to dampen the first eigenmode by movement of the first mass and the second mass in a first direction, and is arranged to dampen the second eigenmode by movement of the second mass in a second direction which is non-parallel to the first direction.
- 20 3. An apparatus according to claim 1 or 2, wherein the first damping device and the first spring are configured to act in a first direction, and wherein the second damping device and the second spring are configured to act in a second direction which is non-parallel to the first direction.
4. An apparatus according to claim 2 or 3, wherein the first direction is orthogonal to the second
25 direction.
5. An apparatus according to any of claims 1-4, wherein the first damping device comprises a damper such that the combination of the first mass, the second mass, the damper and the first spring is tuned to the first eigenmode.
30
6. An apparatus according to any of claims 1-5, wherein the second damping device comprises a further damper such that the combination of the second mass, the further damper and the second spring is tuned to the second eigenmode.

7. An apparatus according to any of claims 1-6, wherein the first mass and/or the second mass comprises a non-structural part of the structure.

8. An apparatus according to any of claims 1-7, wherein the apparatus is a lithographic apparatus
5 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;

a substrate table constructed to hold a substrate;

10 a projection system configured to project the patterned radiation beam onto a target portion of the substrate.

9. An apparatus according to claim 8, wherein the projection system comprises the structure.

15 10. An apparatus according to claim 8, comprising a substrate handler for providing the substrate to the substrate table, wherein the substrate handler comprises the structure.

11. An apparatus according to any of claims 8, comprising a patterning device handler for providing the patterning device to the support, wherein the patterning device handler comprises the structure.

20 12. A substrate handler configured for use in an apparatus according to claim 10.

13. A patterning device handler configured for use in an apparatus according to claim 11.

25 14. A damping system for use in an apparatus according to any of the claims 1-11.

15. A method of manufacturing a damping system, comprising the steps of:

selecting a first spring, a first damping device, a first mass, a second spring, a second damping device and a second mass based on information of a first eigenmode and a second eigenmode of a structure;

30 coupling the first mass to an interface element via the first spring and the first damping device, wherein the interface element is arranged to be coupled to the structure;

coupling the second mass to the first mass via the second spring and the second damping device, wherein the damping system is arranged to dampen the first eigenmode by movement the first mass and the second mass, and

wherein the damping system is arranged to dampen the second eigenmode by movement of the second mass.

FIG 1

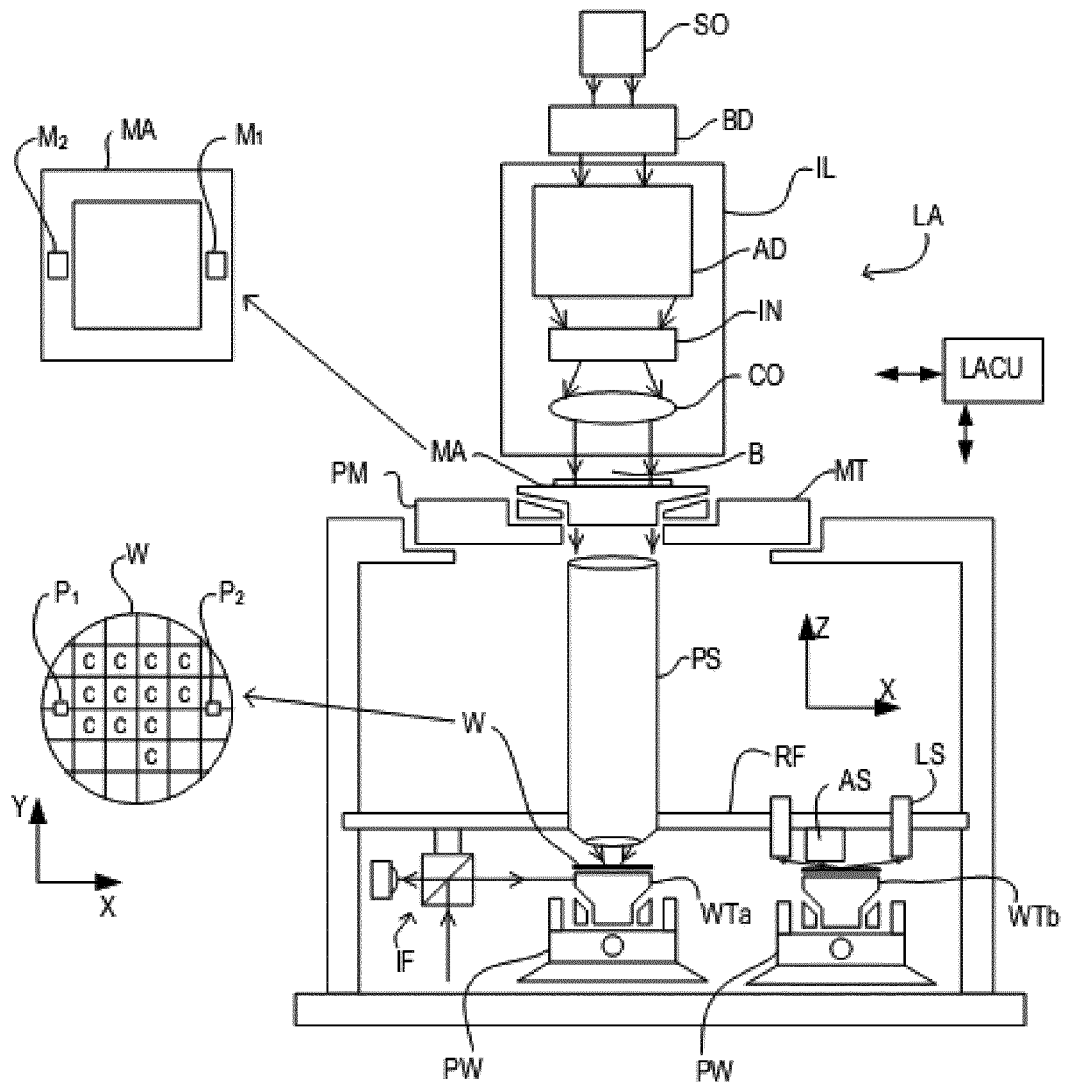


FIG 2

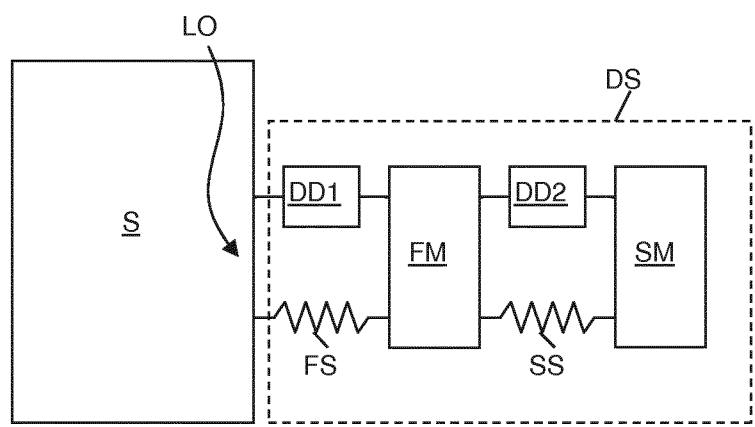


FIG 3

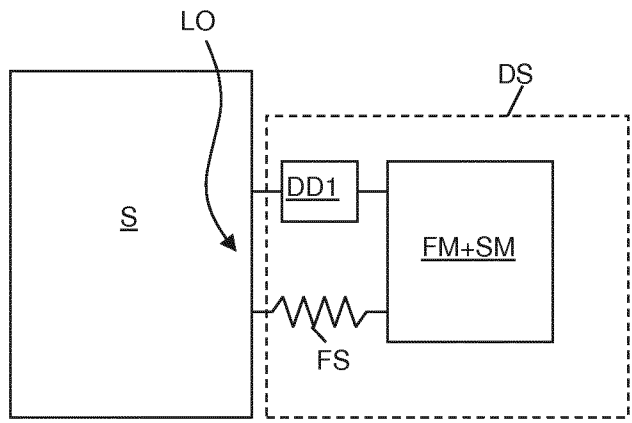


FIG 4

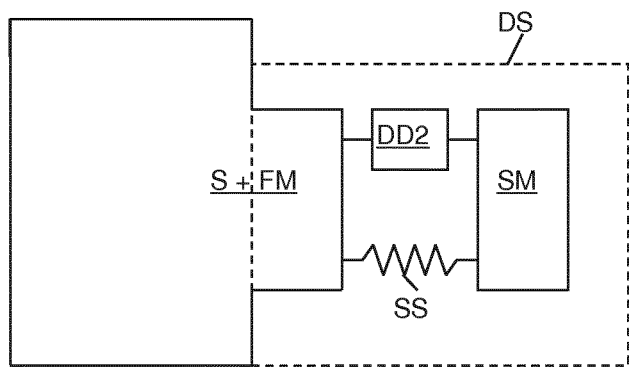


FIG 5

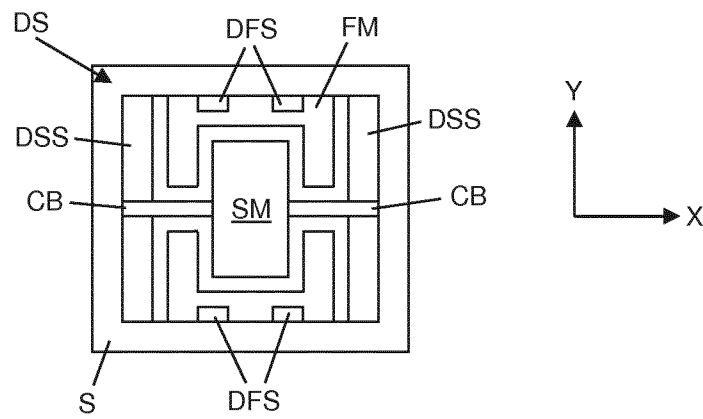


FIG 6

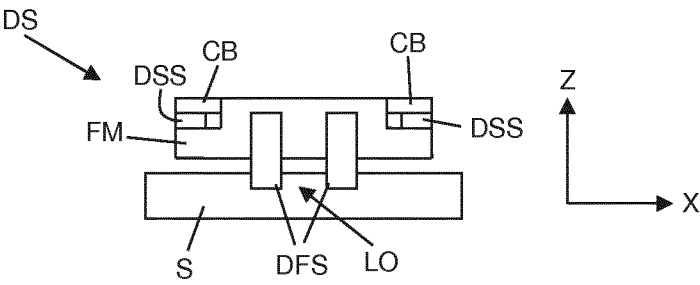
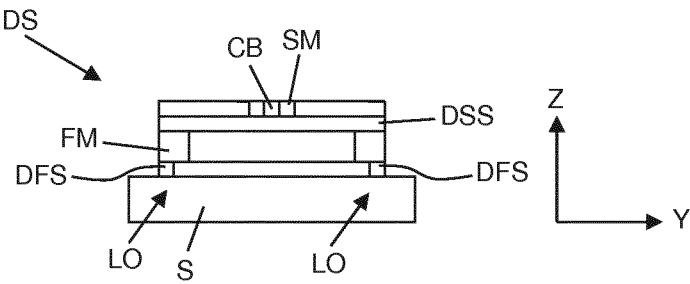


FIG 7



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/054871

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F7/20 F16F7/104
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 F16F

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

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Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/054871

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