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(54) **Title:** METHOD FOR CONTROLLING AND CLEANING A PELLICLE MEMBRANE

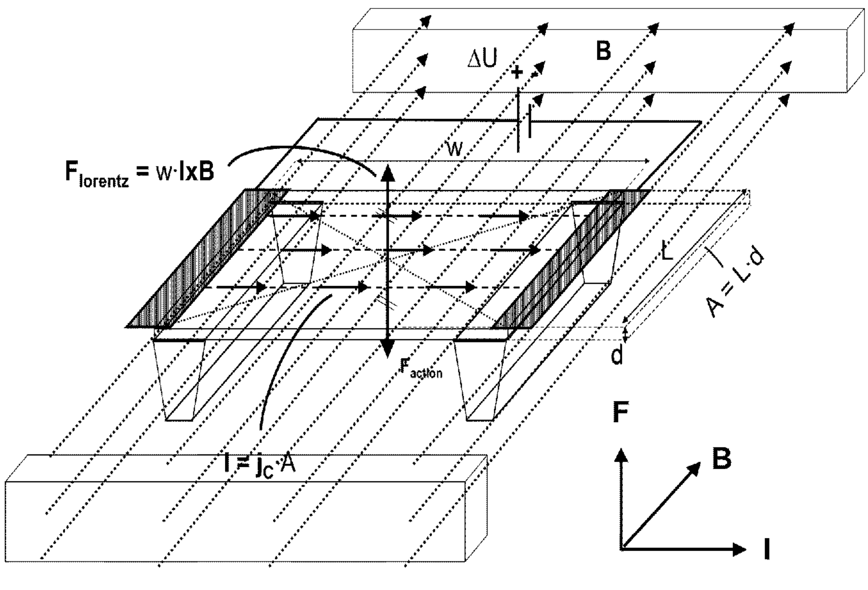

FIG. 4e

(57) **Abstract:** An assembly for controlling a pellicle membrane, the assembly including at least one magnetic element configured to provide a magnetic field, and an electrically conductive pellicle membrane electrically connectable to a voltage source and configured to conduct current in a predetermined direction, wherein the at least one magnet and electrically conductive pellicle membrane are configured such that application of a potential difference results in a Lorentz force acting upon the pellicle membrane. Also described is a lithographic apparatus and a transportation box including such an assembly as well as a method for controlling a pellicle membrane. The use of such an assembly, lithographic apparatus, transportation box and method in a lithographic method or apparatus is also described.

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METHOD FOR CONTROLLING AND CLEANING A PELLICLE MEMBRANE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority of EP application 23178171.7 which was filed on 8 June 2023, and which is incorporated herein in its entirety by reference.

FIELD

[0002] The present disclosure relates an assembly for controlling a pellicle membrane, a lithographic apparatus, comprising such an assembly, a transportation box comprising such an assembly, a method of controlling a pellicle membrane, including but not limited to controlling the deflection of a pellicle membrane, controlling the tension in at least a portion of a pellicle membrane, and controlling the movement of a pellicle membrane, such as for cleaning. The present disclosure also relates to the use of such as assembly, lithographic apparatus, transportation box, or method in a lithographic method or apparatus. The present disclosure has particular, but not exclusive, application to EUV lithography.

BACKGROUND

[0003] A lithographic apparatus is a machine constructed to apply a desired pattern onto a substrate. A lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). A lithographic apparatus may for example project a pattern from a patterning device (e.g. a mask) onto a layer of radiation-sensitive material (resist) provided on a substrate.

[0004] The wavelength of radiation used by a lithographic apparatus to project a pattern onto a substrate determines the minimum size of features which can be formed on that substrate. A lithographic apparatus which uses EUV radiation, being electromagnetic radiation having a wavelength within the range 4-20 nm, may be used to form smaller features on a substrate than a conventional lithographic apparatus (which may for example use electromagnetic radiation with a wavelength of 193 nm).

[0005] A lithographic apparatus includes a patterning device (e.g. a mask or reticle). Radiation is provided through or reflected off the patterning device to form an image on a substrate. A membrane assembly, also referred to as a pellicle, may be provided to protect the patterning device from airborne particles and other forms of contamination. Contamination on the surface of the patterning device can cause manufacturing defects on the substrate.

[0006] Pellicles may also be provided for protecting optical components other than patterning devices. Pellicles may also be used to provide a passage for lithographic radiation between regions of the lithography apparatus which are sealed from one another. Pellicles may also be used as filters, such as spectral purity filters or as part of a dynamic gas lock of a lithographic apparatus.

[0007] Due to the presence of the pellicle in the optical path of the EUV radiation beam, it is necessary for the pellicle to have high EUV transmissivity. A high EUV transmissivity allows a greater proportion of the incident radiation through the pellicle and reducing the amount of EUV radiation absorbed by the pellicle may decrease the operating temperature of the pellicle. Since transmissivity is at least partially dependent on the thickness of the pellicle, it is desirable to provide a pellicle which is as thin as possible whilst remaining reliably strong enough to withstand the sometimes hostile environment within a lithography apparatus. A pellicle membrane also needs to be sufficient strong to withstand the forces acting upon it when being transported as well as when in use. It is also necessary for a pellicle membrane to avoid distorting imaging, to avoid contaminating critical scanner components, and also to avoid deflecting outside predetermined specified limits. Since some of these requirements are conflicting, such as the need for strength but also high transmissivity, a balance of properties is required. For example, the pre-tension of a pellicle membrane can be increased in order to strengthen the pellicle membrane, but this can lead to a greater likelihood of mechanical failure of the pellicle membrane.

[0008] The present invention has been devised in an attempt to address at least some of the problems identified above.

<u>SUMMARY OF THE INVENTION</u>

[0009] According to a first aspect of the present disclosure, there is provided an assembly for controlling a pellicle membrane, the assembly including at least one magnetic element configured to provide a magnetic field, and an electrically conductive pellicle membrane electrically connectable to a voltage source and configured to conduct current in a predetermined direction, wherein the at least one magnet and electrically conductive pellicle membrane are configured such that application of a potential difference results in a Lorentz force acting upon the pellicle membrane.

[00010] The Lorentz force is the force which acts upon charged particles moving through a magnetic field. A current of electrons flowing through an electrical conductor which is located within a magnetic field is therefore subject to a Lorentz force. As such, by providing an electrical current through a pellicle membrane that is located within a magnetic field, it is possible to selectively apply a force on the pellicle membrane. The magnitude of the Lorentz force is dependent on the magnitude of the electric field and the magnetic field, so it is possible to control the magnitude of the force acting upon a pellicle membrane by controlling one or both of these parameters.

[00011] In operation, pellicle membranes are susceptible to sagging and/or deflection. This can be caused by numerous reasons, such as, for example, a pressure differential across the pellicle membrane, the force of gravity, or differential heating of the pellicle membrane. Excessive sagging and/or deflection poses reliability and contamination risks. Excessive sagging and/or deflection can also occur during loading and transportation, so it is desirable to be able to control the pellicle membrane when being transported, loaded, and when within a lithographic apparatus.

[00012] Attempts to address the sagging and/or deflection include increasing the tensile pre-tension within a pellicle membrane by adjusting the chemical and/or physical composition of the pellicle membrane. This can lead to premature failure of the pellicle membrane likely due to defect-induced localised stress concentrations. The assembly of the present disclosure allows for a current to be passed through a conductive pellicle membrane so that the current can interact with a magnetic field to provide a force on the pellicle membrane. In this way, the Lorentz force can be used to control the sagging and/or deflection of the pellicle membrane by applying the Lorentz force against the direction of sagging and/or deflection, or by increasing the tension in a portion of the pellicle membrane to prevent or reduce wrinkling of the pellicle membrane. It will also be appreciated that the direction of the current flow and/or magnetic field can be changed, such as being reversed, which can allow for the assembly to control the pellicle membrane and cause it to vibrate, which can be used to clean the pellicle membrane. It will further be appreciated that an electrically conductive pellicle membrane can include pellicle membranes comprising materials which are electrically conductive and can also pellicle membranes which comprising materials which are not electrically conductive but which include electrically conductive portions, such as, for example, wires, fibres, or strips, of material which are able to conduct electrical current. Any deflection of a pellicle membrane will be self-correcting since the direction of the Lorentz force is dependent on the direction of flow of charged particles, e.g. electrons, and the magnetic field direction. For example, if the pellicle membrane deflects, the direction of the current flow relative to the magnetic field will change and the direction of the Lorentz force will tend to bring the pellicle membrane back to a predetermined position. In this way, deflections can be self-correcting and the assembly can buffer deflections of the pellicle membrane, such as, for example, during transfer of the pellicle membrane.

[00013] The assembly may include a controller configured to control the magnetic field and/or voltage provided to the pellicle membrane. The controller may be configured to vary the direction and/or magnitude of the magnetic field and/or voltage in order to control the direction and/or magnitude of the Lorentz force acting on the pellicle membrane.

[00014] The at least one magnetic element may be a permanent magnet or an electromagnet. By including a permanent magnet, the field strength and direction are consistent and no additional power requirements are needed. An electromagnet allows for the field strength and direction to be adjusted as required. The at least one magnetic element may be moveable such that the field strength and direction acting upon the pellicle membrane can be adjusted as required.

[00015] The electrically conductive pellicle membrane may be inherently conductive and/or may include one or more conductive elements. The conductive elements can be in the form of a wire, fibre, or strip of conductive material.

[00016] The strength of the magnetic field may be less than about 40 m T, less than about 35 mT, less than about 30 mT, less than about 25 mT, less than about 20 mT, less than about 15 mT, or less than about 10 mT. The strength of the magnetic field may be about 40 mT, about 35 mT, about 30 mT, about 25 mT, about 20 mT, about 15 mT, or about 10 mT. The magnetic field strength may be from about 10 mT to about 40 mT, from about 15 mT to about 35 mT, from about 20 mT to about 30 mT, or about 25 mT.

[00017] The assembly may be configured to provide a potential difference of less than about 100 V, less than about 50 V, less than about 20 V, or less than about 10 V. The voltage may be from about 1V to about 20 V, from about 5 V to about 15 V, from about 8 V to about 12 V, or about 10 V. Since the assembly may be located in close proximity to sensitive equipment, in order to prevent sparking, it is preferable for the potential difference to be less than about 100 V. Voltages lower than 100 V are also suitable since the Lorentz force required to be provided to the pellicle membrane can be generated by magnetic fields having the strengths described herein and the application of a potential difference of 100 V or less. For example, a magnetic field strength of 25 mT and a potential difference of 10 V would provide a Lorentz force on a pellicle membrane sufficient to counteract the force of gravity.

[00018] The assembly may be configured to provide a static magnetic field such that as the pellicle membrane is scanned in use, an area being illuminated by radiation is subject to a Lorentz force to reduce wrinkling of the pellicle membrane. In use, the pellicle membrane is moved and the portion of the pellicle membrane which is illuminated by a beam of radiation used in lithography heats up the illuminated region causing it to wrinkle. By providing a static magnetic field, that is to say a magnetic field which is fixed in location, through which a moving pellicle membrane can pass during scanning, it is possible to exert a Lorentz force on the region that is being illuminated to avoid or reduced the wrinkling of the pellicle membrane.

[00019] The assembly may be configured to change one or both of a direction of the magnetic field and direction of current to vibrate the pellicle membrane. The direction of current flow through the pellicle membrane can be rapidly changed in order to alter the direction of the Lorentz force acting on the pellicle membrane, and thereby cause the pellicle membrane to vibrate. Such vibration is able to remove contaminants on the surface of the pellicle membrane.

[00020] The assembly may include a detection system configured to detect deflection of the pellicle membrane. Since the deflection of the pellicle membrane may vary over time depending, it is useful to be able to detect the direction and/or degree of deflection. This information can be used, for example, to determine whether a pellicle membrane is being deflected beyond a predetermined limit or to determine whether it has been subjected to any unwanted shocks.

[00021] The detection system may be configured to provide information relating to a detected deflection to a or the controller such that the controller adjusts one or both of the magnetic field and a current direction to counteract the detected deflection. By detecting a deflection of a pellicle membrane, it is possible to use such information to correct the deflection. This may be achieved by controlling the direction and/or magnitude or the magnetic field or electric current. For example, if it is detected that the pellicle membrane is being deflected in one direction, the controller can adjust the magnetic field and/or electric current to act in an opposite direction.

[00022] The deflection detection system may include a light source and at least one detector configured to detect changes in light falling upon the at least one detector. The light source may be a laser. The laser may be configured to direct a beam of light substantially parallel to the pellicle membrane such that in an undeformed configuration, the laser beam is not affected by the pellicle membrane, but when the pellicle membrane is deformed, it interacts with the laser beam to change the amount of light reaching a detector to thereby indicate that the pellicle membrane has been deformed. In another example, a light source may illuminate a surface of the pellicle membrane with one or more detectors arranged to detect light which is reflected by the pellicle membrane and/or passes through the pellicle membrane in order to detect deflection of the pellicle membrane.

[00023] According to a second aspect of the present disclosure, there is provided a lithography apparatus including the assembly of the first aspect of the present disclosure. The lithography apparatus may be an EUV lithography apparatus.

[00024] According to a third aspect of the present disclosure, there is provided a transportation box including the assembly according to the first aspect of the present disclosure.

[00025] Pellicle assemblies need to be transported to the lithography apparatus in which they are to be used. Since they are very thin, they are susceptible to damage during transportation. As such, a transportation box including an assembly according to the present disclosure can reduce the risk of damage occurring during transportation by controlling the deflection of a pellicle membrane using Lorentz force.

[00026] The transportation box may be configured such that the Lorentz force applied to the pellicle membrane is directed away from the reticle. In this way, where there is a mechanical shock which deflects the pellicle membrane, it is less likely to come into contact with the reticle and be damaged.

[00027] The transportation box may include a detection system to detect deflection of the pellicle membrane. The detection system may be configured to control one or both of the magnetic field direction and current direction in order to selectively control the direction of the Lorentz force to counteract the deflection of the pellicle membrane. The detection system may be an optical detection system which detects a change in light hitting a sensor to detect deflection. For example, a laser may be provided to provide a beam of light parallel to the surface of a pellicle membrane. When there is deflection of the pellicle membrane, the laser light may be at least partially blocked or deflected by the pellicle membrane. The detected deflection can be used to control a controller which adjusts the magnetic field and/or electrical current in order to provide a Lorentz force which counteracts the deflection. Additionally or alternatively, a light source may be provided which illuminates a surface of the pellicle membrane and one or more detectors configured to detect changes in the light which passes through and/or is reflected off the surface of the pellicle membrane. Again, the detected deflection can be used to control a controller which adjusts the magnetic field and/or electrical current in order to provide a Lorentz force which counteracts the deflection.

[00028] Indeed, it will be appreciated that any of the aspects of the present disclosure described herein may include such a detection system which is able to determine deflection of a pellicle membrane and control a controller to adjust the magnetic field and/or electrical current in order to provide a Lorentz force which counteracts the deflection.

[00029] According to a fourth aspect of the present disclosure, there is provided a method of controlling a pellicle membrane, the method including: providing a potential difference to a pellicle membrane such that an electrical current passes through the membrane and providing a magnetic field to induce a Lorentz force which acts upon the pellicle membrane to control the pellicle membrane.

[00030] As described in respect of the first aspect of the present disclosure, by providing an electric current through a pellicle membrane, whether that is through the material of the pellicle membrane itself or a conductive material integrated with the pellicle membrane material, in the presence of a magnetic field, a Lorentz force can be provided to the pellicle membrane. The direction and magnitude of the Lorentz force can be controlled by controlling the direction and magnitude of the electric and magnetic fields, and so the pellicle membrane can be controlled in this way. The control includes, but is not limited to, controlling the deflection of the pellicle membrane due to gravity or a pressure differential across the pellicle membrane, providing a tensioning force on the pellicle membrane to reduce or eliminate wrinkling, or vibrating the pellicle membrane to dislodge contaminants.

[00031] The strength of the magnetic field may be less than about 40 m T, less than about 35 mT, less than about 30 mT, less than about 25 mT, less than about 20 mT, less than about 15 mT, or less than about 10 mT. The strength of the magnetic field may be about 40 mT, about 35 mT, about 30 mT, about 25 mT, about 20 mT, about 15 mT, or about 10 mT. The magnetic field strength may be from about 10 mT to about 40 mT, from about 15 mT to about 35 mT, from about 20 mT to about 30 mT, or about 25 mT.

[00032] The current is provided by applying a potential difference across the pellicle membrane.

[00033] The potential difference is preferably less than about 100 V, less than about 50 V, less than about 20 V, or less than about 10 V. The potential difference may be from about 1V to about 20 V, from about 5 V to about 15 V, from about 8 V to about 12 V, or about 10 V. Since the assembly may be located in close proximity to sensitive equipment, in order to prevent sparking, it is preferable for the potential difference to be less than about 100 V. Voltages lower than 100 V are also suitable since the Lorentz force required to be provided to the pellicle membrane can be generated by magnetic fields having the strengths described herein and the application of a potential difference of 100 V or less. For example, a magnetic field strength of 25 mT and a potential difference of 10 V would provide a Lorentz force on a pellicle membrane sufficient to counteract the force of gravity.

[00034] The method may include moving the pellicle membrane through a static magnetic field and providing a potential difference to the pellicle membrane in an area which is illuminated by a radiation beam to provide a Lorentz force on the pellicle membrane. By static magnetic field, this is to be understood to cover a magnetic field which is fixed in place. It will be appreciated that the magnetic

fields may be varied in direction and magnitude as required. By scanning a pellicle membrane through a magnetic field which is fixed in place, the region of the pellicle membrane which is within the magnetic field may be subject to a Lorentz force if a current is passing though the region. As such, the Lorentz force will act on the region within the magnetic field, which can be sufficient to reduce or eliminate wrinkling of the pellicle membrane in such a region. During imaging, the radiation beam passes through the pellicle membrane and so by reducing or eliminating wrinkling of the pellicle membrane in the area through which the radiation beam passes in use, there is less likelihood of distortion caused by the pellicle membrane.

[00035] One or both of the potential difference and the magnetic field may be controlled to induce vibration of the pellicle membrane. It will be appreciated that one or both of the potential difference and the magnetic field may be altered in direction and/or magnitude in order to control the direction and magnitude of the Lorentz force. If the potential difference and/or magnetic field are changed sufficiently quickly, the pellicle membrane can be caused to vibrate.

[00036] One or both of the potential difference and magnetic field may be controlled to move the pellicle membrane to a substantially undeformed equilibrium state. The pellicle membrane may be deflected due to gravity or by a pressure differential across the pellicle membrane. As such, the potential difference, which generates an electric field, and the magnetic field can be controlled such that the force or gravity or the force caused by the pressure differential is counteracted such that the pellicle membrane is held in a substantially undeformed equilibrium state.

[00037] The method may further include detecting a deflection of the pellicle membrane, optionally using optical means. As described in respect of the first aspect, by detecting a deflection of the pellicle membrane, it can be determined whether the pellicle membrane is being deformed outside of predetermined parameters, which could potentially cause damage or reduce the lifespan of the pellicle membrane.

[00038] The method may further include controlling the potential difference and/or the magnetic field based on a detected deflection of the pellicle membrane to at least partially counteract the detected deflection. Since the deflection of the pellicle membrane may be undesired and may be dynamic, by providing a Lorentz force to counteract the deflection, it is possible to control the deflection and protect the pellicle membrane from damage.

[00039] According to a fifth aspect of the present disclosure, there is provided the use of an assembly according to the first aspect, a lithographic apparatus according to the second aspect, a transportation box according to the third aspect, or a method according to the fourth aspect in a lithographic method or apparatus.

[00040] It will be appreciated that features described in respect of one embodiment may be combined with any features described in respect of another embodiment and all such combinations are expressly considered and disclosed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[00041] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawing in which corresponding reference symbols indicate corresponding parts, and in which:

[00042] Figure 1 depicts a lithographic apparatus according to an embodiment of the disclosure;

[00043] Figures 2a to 2c depict a pellicle assembly including a pellicle membrane demonstrating the forces acting upon the pellicle membrane;

[00044] Figures 3a to 3c show wrinkling of a pellicle membrane which has been heated by a pulsed laser;

[00045] Figures 4a to 4e depict how pellicle deflection can be controlled via the Lorentz force;

[00046] Figure 5 depicts how a current flowing through a pellicle membrane induces an internal magnetic field;

[00047] Figures 6a to 6e are a schematic depiction of an embodiment according to the present disclosure showing a pellicle membrane being scanned through a stationary magnetic field; and

[00048] Figures 7a and 7b are a schematic depiction of an embodiment according to the present disclosure showing cleaning of the pellicle membrane by vibrating the pellicle membrane.

[00049] The features and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings, in which like reference characters identify corresponding elements throughout. In the drawings, like reference numbers generally indicate identical, functionally similar, and/or structurally similar elements.

DETAILED DESCRIPTION

[00050] Figure 1 shows a lithographic system according to the present invention. The lithographic system comprises a radiation source SO and a lithographic apparatus LA. The radiation source SO is configured to generate an extreme ultraviolet (EUV) radiation beam RB. The lithographic apparatus LA comprises an illumination system IL, a support structure MT configured to support a patterning device MA (e.g. a mask), a projection system PS and a substrate table WT configured to support a substrate W. A heater (not shown) may be provided in any suitable location, such as in the illumination system IL or projection system PS, in order to provide thermal energy to a substrate W, such as a wafer, positioned on the substrate table WT The illumination system IL is configured to condition the radiation beam RB before it is incident upon the patterning device MA. The projection system is configured to project the radiation beam RB (now patterned by the mask MA) onto the substrate W. The substrate W may include previously formed patterns. Where this is the case, the lithographic apparatus aligns the patterned radiation beam RB with a pattern previously formed on the substrate W. In this embodiment, a pellicle 15 is depicted in the path of the radiation and protecting the patterning device MA. It will be appreciated that the pellicle 15 may be located in any required position and may be used to protect any of the mirrors in the lithographic apparatus. The patterning device MA may be referred to as the reticle. The support structure MT may be referred to as the reticle stage.

[00051] The radiation source SO, illumination system IL, and projection system PS may all be constructed and arranged such that they can be isolated from the external environment. A gas at a pressure below atmospheric pressure (e.g. hydrogen) may be provided in the radiation source SO. A vacuum may be provided in illumination system IL and/or the projection system PS. A small amount of gas (e.g. hydrogen) at a pressure well below atmospheric pressure may be provided in the illumination system IL and/or the projection system PS.

[00052] The radiation source SO shown in Figure 1 is of a type which may be referred to as a laser produced plasma (LPP) source. A laser, which may for example be a CO_2 laser, is arranged to deposit energy via a laser beam into a fuel, such as tin (Sn) which is provided from a fuel emitter. Although tin is referred to in the following description, any suitable fuel may be used. The fuel may for example be in liquid form, and may for example be a metal or alloy. The fuel emitter may comprise a nozzle configured to direct tin, e.g. in the form of droplets, along a trajectory towards a plasma formation region. The laser beam is incident upon the tin at the plasma formation region. The deposition of laser energy into the tin creates a plasma at the plasma formation region. Radiation, including EUV radiation, is emitted from the plasma during de-excitation and recombination of ions of the plasma.

[00053] The EUV radiation is collected and focused by a near normal incidence radiation collector (sometimes referred to more generally as a normal incidence radiation collector). The collector may have a multilayer structure which is arranged to reflect EUV radiation (e.g. EUV radiation having a desired wavelength such as 13.5 nm). The collector may have an elliptical configuration, having two ellipse focal points. A first focal point may be at the plasma formation region, and a second focal point may be at an intermediate focus, as discussed below.

[00054] The laser may be separated from the radiation source SO. Where this is the case, the laser beam may be passed from the laser to the radiation source SO with the aid of a beam delivery system (not shown) comprising, for example, suitable directing mirrors and/or a beam expander, and/or other optics. The laser and the radiation source SO may together be considered to be a radiation system.

[00055] Radiation that is reflected by the collector forms a radiation beam RB. The radiation beam B is focused at a point to form an image of the plasma formation region, which acts as a virtual radiation source for the illumination system IL. The point at which the radiation beam RB is focused may be referred to as the intermediate focus. The radiation source SO is arranged such that the intermediate focus is located at or near to an opening in an enclosing structure of the radiation source.

[00056] The radiation beam RB passes from the radiation source SO into the illumination system IL, which is configured to condition the radiation beam. The illumination system IL may include a facetted field mirror device 10 and a facetted pupil mirror device 11. The faceted field mirror device 10 and faceted pupil mirror device 11 together provide the radiation beam RB with a desired cross-sectional shape and a desired angular distribution. The radiation beam RB passes from the illumination system IL and is incident upon the patterning device MA held by the support structure MT. The patterning device MA reflects and patterns the radiation beam RB. The illumination system IL may include other mirrors or devices in addition to or instead of the faceted field mirror device 10 and faceted pupil mirror device 11. A heater may be positioned and configured to provide thermal energy which is reflected by one or more of the mirror devices to the substrate W.

[00057] Following reflection from the patterning device MA the patterned radiation beam RB enters the projection system PS. The projection system comprises a plurality of mirrors 13, 14 which are configured to project the radiation beam RB onto a substrate W held by the substrate table WT. The projection system PS may apply a reduction factor to the radiation beam, forming an image with features that are smaller than corresponding features on the patterning device MA. A reduction factor of 4 may for example be applied. Although the projection system PS has two mirrors 13, 14 in Figure 1, the projection system may include any number of mirrors (e.g. six mirrors). Preferably, a heater is positioned and configured to provide thermal energy which is reflected by one or more of the mirror devices to the substrate W

[00058] The radiation sources SO shown in Figure 1 may include components which are not illustrated. For example, a spectral filter may be provided in the radiation source. The spectral filter may be substantially transmissive for EUV radiation but substantially blocking for other wavelengths of radiation such as infrared radiation.

[00059] If the patterning device MA is left unprotected, the contamination can require the patterning device MA to be cleaned or discarded. Cleaning the patterning device MA interrupts valuable manufacturing time and discarding the patterning device MA is costly. Replacing the patterning device MA also interrupts valuable manufacturing time.

[00060] Figure 2a is a schematic depiction of a pellicle 15 comprising a pellicle membrane 16 supported by a pellicle membrane support frame 17. The pellicle 15 is disposed in front of patterning device MA, which may also be referred to as a reticle. The pellicle membrane 16 experiences a downward directed force Fpressure from a pressure difference between the two sides (up and down) of the pellicle membrane 16, which can for instance arise when a pelliclized reticle 19, which is a reticle comprising a pellicle, resides in a transport box that is vented or in a load lock vessel in a lithographic scanner that is vented, such that gas that enters the volume pushes the pellicle membrane 16 towards the reticle MA. The tension in the pellicle membrane 16 is directed tangentially to the membrane surface, its combined upward components cancel the downward pressure difference force.

[00061] Figure 2b represents a 2D cross-sectional view where the combined vertical components of the pellicle membrane tension counter an oppositely directed pressure difference force, which can be directed up or down depending on the direction of the pressure difference. The pellicle membrane is shown in its undeflected state 16' as well as the states where it is deflected upwardly or downwardly 16''. As such, the tension within the pellicle membrane 16 is able to counteract the external forces acting upon it, but there will remain some deflection.

[00062] Figure 2c depicts in 2D a pellicle membrane 16' in its undeflected state and in its deflected state 16'' due to gravity. Figures 2b and 2c omit the reticle MA and other ancillary components for the sake of clarity. The present disclosure is able to assist in compensating for different external forces acting upon the pellicle membrane 16 and avoids the need for the pre-tension in the pellicle membrane 16 to be high and also prevents or mitigates large membrane deflections that occur to pellicle membranes 16 being transported or transferee, which can lead to damage or breakage of the pellicle membrane 16.

[00063] Figures 3a to 3c are images of pellicle membranes which have been locally heated by a pulsed laser at various orientations and beam sizes in order to remove particles from the surface. The heating brings about local loss of pre-tension in the pellicle membrane, which can present a risk to the pellicle membrane for pellicles which operate at high powers or high temperatures. Presently, the operating temperatures and powers in a lithographic apparatus are less than those required to cause such local loss of pre-tension, but the power used in lithographic apparatus will continue to increase until this would present an issue.

[00064] Figures 4a to 4e depict how pellicle deflection can be controlled via the Lorentz force. Figure 4a depicts a pellicle membrane 16 which is deflected by a force, such as gravity or a pressure differential. It will be appreciated that in all of the figures the deflection of the pellicle membrane is exaggerated for illustrative purposes. Figure 4b depicts how application of a force opposition to the force causing the pellicle membrane to deflect can bring the pellicle membrane back to a substantially undeformed state. As shown in Figure 4c, a potential difference applied across the pellicle membrane generates a volume current density j_c or current I through the pellicle membrane. Figure 4d depicts a magnetic field B over the pellicle membrane and Figure 4e depicts the interaction of the magnetic field B and the current I to provide Lorentz force F. It will be appreciated that by reversing the polarity of the potential difference or by reversing the direction of the magnetic field, the direction of the Lorentz force can be flipped. As such, the Lorentz force can be used to counter the force of gravity but also other forces that arise from, for example, pressure differences, which can vary in direction depending on whether a lithographic apparatus is being pumped or vented.

[00065] Figure 5 depicts a schematic representation of the internal magnetic field generated by a volume current in the pellicle membrane.

[00066] Figure 6a to 6e depict an embodiment in which a pellicle 15 including a pellicle membrane 16 supported by a frame 17 and a reticle MA (not shown in detail) is scanned through a magnetic field B. Figure 6a depicts a pellicle 15 within an assembly that includes a magnetic field B. A portion of the pellicle membrane 16 is within the magnetic field B and current flowing through the pellicle membrane 16 interacts with the magnetic field to provide a Lorentz force on the portion of the pellicle membrane 16 within the magnetic field B. This causes deflection of such a portion of the pellicle membrane 16. In operation, the pellicle membrane 16 portion which is being illuminated by a radiation beam, such as an EUV radiation beam, may wrinkle as a result of pre-tension loss due to thermal expansion. By applying a local magnetic field, the heat-induced wrinkling is mitigated by pulling the pellicle membrane 16 away from the reticle MA under the control of the Lorentz force. The direction of movement of the pellicle 15 and reticle MA is depicted by the white arrow. It will therefore be appreciated that the magnetic field is locationally static and the pellicle membrane 16 is moved through the magnetic field to apply the Lorentz force to different portions of the pellicle membrane 16.

[00067] Figure 6b is similar to Figure 6a, albeit with the pellicle 15 and the reticle MA having moved through the magnetic field B such that the Lorentz force acts upon a different portion of the pellicle membrane.

[00068] Figures 6c and 6d depict a radiation beam RB, which may be an EUV radiation beam, passing through a pellicle membrane 16. The radiation beam RB is reflected by the reticle MA and passes back through the pellicle membrane 16. Although the pellicle membrane 16 is very thin and designed to have high transmissivity to radiation of a particular wavelength, some radiation is inevitably absorbed by the pellicle membrane, which causes the temperature of the pellicle membrane to increase. At high powers, the increase in temperature can lead to loss of pre-tension and wrinkling W in the pellicle membrane.

[00069] Figure 6e depicts how the application of a magnetic field to a region of a pellicle membrane illuminated by a radiation beam RB can mitigate heat-induced wrinkling of the pellicle membrane. By passing a current through the portion of the pellicle membrane which is within a magnetic field and which is also being illuminated by a radiation beam, wrinkling of such a region of the pellicle membrane can be mitigated. It will be appreciated that, in a similar manner, a current could be passed through only a portion of a pellicle membrane such that the Lorentz force is exerted only on such a portion. In such cases, the magnetic field could cover all of or only a relevant portion of the pellicle membrane.

[00070] In the case of a moving pellicle membrane, a controller may control the potential difference applied to take account of the reduced current in such a pellicle membrane caused by an induced magnetic field which opposes the change in magnetic field according to Lenz's law, meaning that a slightly higher potential difference is required.

[00071] Figures 7a and 7b depict the cleaning of a pellicle membrane through vibration of the pellicle membrane. Figure 7a depicts some contaminants 18 on the pellicle membrane 16. As shown illustratively in Figure 7b, the pellicle membrane can be locally actuated to move up or down, and can be made to oscillate or vibrate to thereby remove particles from the surface of the pellicle membrane. This avoids the heat-induced thermal loss of pre-tension which is caused by cleaning methods which rely on local heating to produce shockwaves to dislodge particles. As mentioned, the direction of the Lorentz force can be changed by changing the polarity of the potential difference or by changing the direction of the applied magnetic field.

[00072] In summary, the present disclosure allows for the removal or reduction of sagging of pellicles due material changes, gravity, pressure differences, local heating in the EUV beam spot, omitting the necessity to make membranes with very elevated pre-tension, which is less well controlled and may result in unreliable pellicle breakage. The present disclosure allows for safe pellicle transport in a transportation box utilising the assembly and method described herein to mitigate unwanted deflections in the pellicle membrane during transportation, as well as safe usage in the scanner removing failure risks. The present disclosure also described a method to clean the pellicle surface from particle contaminations which avoid the need to heat the pellicle membrane and thereby avoids wrinkling due to loss of pre-tension. In addition, the present invention allows for the detection of deflection of the pellicle membrane and the control of such deflection by the application of a Lorentz force to counteract the deflection.

[00073] While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described.

The descriptions above are intended to be 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 and clauses set out below.

1. An assembly for controlling a pellicle membrane, the assembly including at least one magnetic element configured to provide a magnetic field, and an electrically conductive pellicle membrane electrically connectable to a voltage source and configured to conduct current in a predetermined direction, wherein the at least one magnet and electrically conductive pellicle membrane are configured such that application of a potential difference results in a Lorentz force acting upon the pellicle membrane.

2. The assembly according to clause 1, the assembly further including a controller configured to control the magnetic field and/or voltage provided to the pellicle membrane.

3. The assembly according to any preceding clause, wherein the at least one magnetic element is a permanent magnet or an electromagnet.

4. The assembly according to any preceding clause, wherein the electrically conductive pellicle membrane is inherently conductive and/or includes one or more conductive elements.

5. The assembly according to any preceding clause, wherein the strength of the magnetic field is about 40 mT or less, about 35 mT or less, about 30 mT or less, about 25 mT or less, about 20 mT or less, less about 15 mT or less, or about 10 mT or less.

6. The assembly according to any preceding clause, wherein the assembly is configured to provide a potential difference of less than about 100 V, less than about 50 V, less than about 20 V, or less than about 10 V.

7. The assembly according to any preceding clause, wherein the assembly is configured to provide a static magnetic field such that as the pellicle membrane is scanned in use, an area being illuminated by radiation is subject to a Lorentz force to reduce wrinkling of the pellicle membrane.

8. The assembly according to any preceding clause, wherein the assembly is configured to change one or both of a direction of the magnetic field and direction of current to vibrate the pellicle membrane.

9. The assembly according to any preceding clause, wherein the assembly includes a detection system configured to detect deflection of the pellicle membrane.

10. The assembly according to clause 9, wherein the detection system is configured to provide information relating to a detected deflection to a or the controller such that the controller adjusts one or both of the magnetic field and a current direction to counteract the detected deflection.

11. The assembly according to clause 9, wherein the deflection detection system includes a light source and at least one detector configured to detect changes in light falling upon the at least one detector.

12. A lithographic apparatus including the assembly according to any of clauses 1 to 11.

13. A transportation box including the assembly according to any of clauses 1 to 12.

14. A method of controlling a pellicle membrane, the method including:
providing a potential difference to a pellicle membrane such that an electrical current passes through the membrane and providing a magnetic field to induce a Lorentz force which acts upon the pellicle membrane to control the pellicle membrane.

15. The method according to clause 14, wherein the magnetic field strength is is about 40 mT or less, about 35 mT or less, about 30 mT or less, about 25 mT or less, about 20 mT or less, less about 15 mT or less, or about 10 mT or less.

16. The method of clause 14 or 15 wherein the potential difference is less than about 100V, less than about 50 V, less than about 20 V, or less than about 10 V.

17. The method of any of clauses 14 to 16 wherein the method includes moving the pellicle membrane through a static magnetic field and providing a potential difference to the pellicle membrane in an area which is illuminated by a radiation beam to provide a Lorentz force on the pellicle membrane.

18. The method according to any of clauses 14 to 16, wherein one or both of the potential difference and the magnetic field are controlled to induce vibration of the pellicle membrane.

19. The method according to any of clauses 14 to 16, wherein one or both of the potential difference and the magnetic field are controlled to move the pellicle membrane to a substantially undeformed equilibrium state.

20. The method according to any of clauses 14 to 19, wherein the method further includes detecting a deflection of the pellicle membrane, optionally using optical means.

21. The method according to clause 20, wherein the method further includes controlling the potential difference and/or the magnetic field based on a detected deflection of the pellicle membrane to at least partially counteract the detected deflection.

22. The use of an assembly according to any of clauses 1 to 11, a lithographic apparatus according to clause 12, a transportation box according to clause 13, or a method according to any of clauses 14 to 21 in a lithographic method or apparatus.

CLAIMS

1. An assembly for controlling a pellicle membrane, the assembly including at least one magnetic element configured to provide a magnetic field, and an electrically conductive pellicle membrane electrically connectable to a voltage source and configured to conduct current in a predetermined direction, wherein the at least one magnet and electrically conductive pellicle membrane are configured such that application of a potential difference results in a Lorentz force acting upon the pellicle membrane.

2. The assembly according to claim 1, the assembly further including a controller configured to control the magnetic field and/or voltage provided to the pellicle membrane.

3. The assembly according to any preceding claim, wherein the at least one magnetic element is a permanent magnet or an electromagnet.

4. The assembly according to any preceding claim, wherein the electrically conductive pellicle membrane is inherently conductive and/or includes one or more conductive elements.

5. The assembly according to any preceding claim, wherein the strength of the magnetic field is about 40 mT or less, about 35 mT or less, about 30 mT or less, about 25 mT or less, about 20 mT or less, less about 15 mT or less, or about 10 mT or less.

6. The assembly according to any preceding claim, wherein the assembly is configured to provide a potential difference of less than about 100 V, less than about 50 V, less than about 20 V, or less than about 10 V.

7. The assembly according to any preceding claim, wherein the assembly is configured to provide a static magnetic field such that as the pellicle membrane is scanned in use, an area being illuminated by radiation is subject to a Lorentz force to reduce wrinkling of the pellicle membrane.

8. The assembly according to any preceding claim, wherein the assembly is configured to change one or both of a direction of the magnetic field and direction of current to vibrate the pellicle membrane.

9. The assembly according to any preceding claim, wherein the assembly includes a detection system configured to detect deflection of the pellicle membrane.

10. The assembly according to claim 9, wherein the detection system is configured to provide information relating to a detected deflection to a or the controller such that the controller adjusts one or both of the magnetic field and a current direction to counteract the detected deflection.

11. The assembly according to claim 9, wherein the deflection detection system includes a light source and at least one detector configured to detect changes in light falling upon the at least one detector.

12. A lithographic apparatus including the assembly according to any of claims 1 to 11.

13. A transportation box including the assembly according to any of claims 1 to 12.

14. A method of controlling a pellicle membrane, the method including:
providing a potential difference to a pellicle membrane such that an electrical current passes through the membrane and providing a magnetic field to induce a Lorentz force which acts upon the pellicle membrane to control the pellicle membrane.

15. The method according to claim 14, wherein the magnetic field strength is is about 40 mT or less, about 35 mT or less, about 30 mT or less, about 25 mT or less, about 20 mT or less, less about 15 mT or less, or about 10 mT or less.

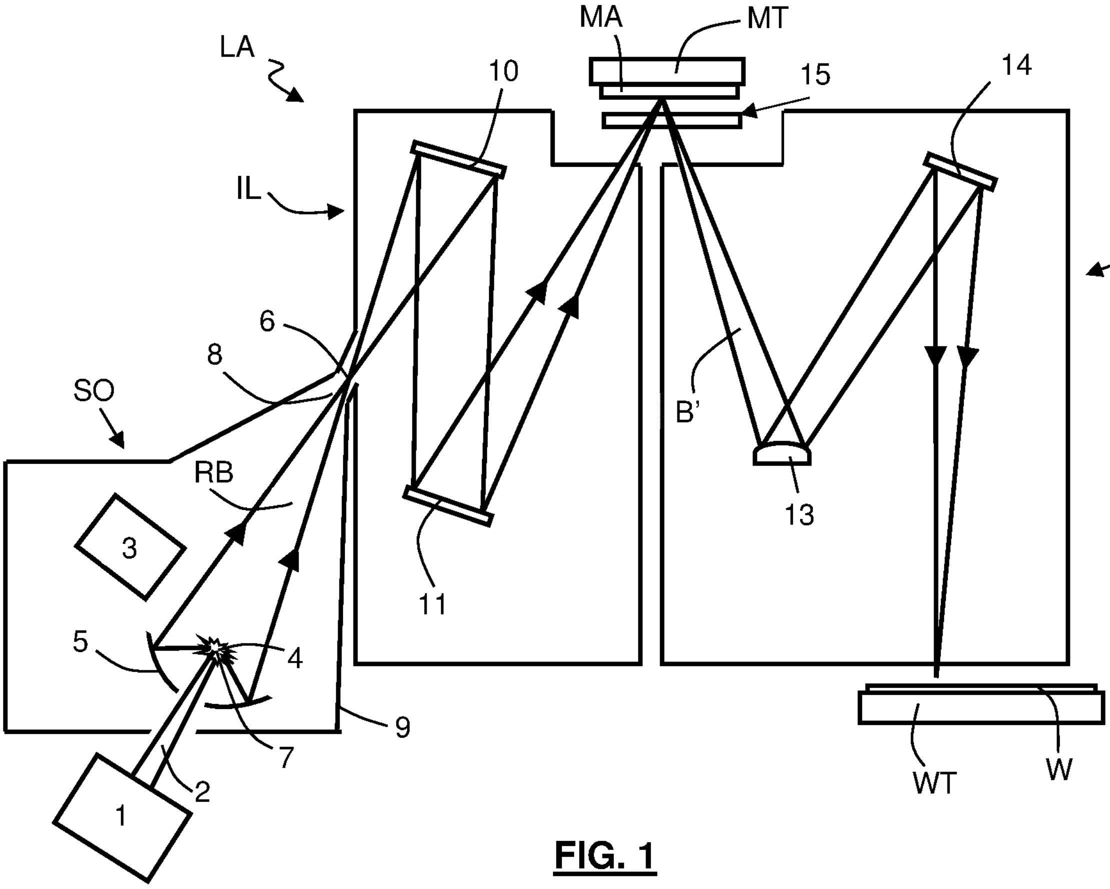


FIG. 1

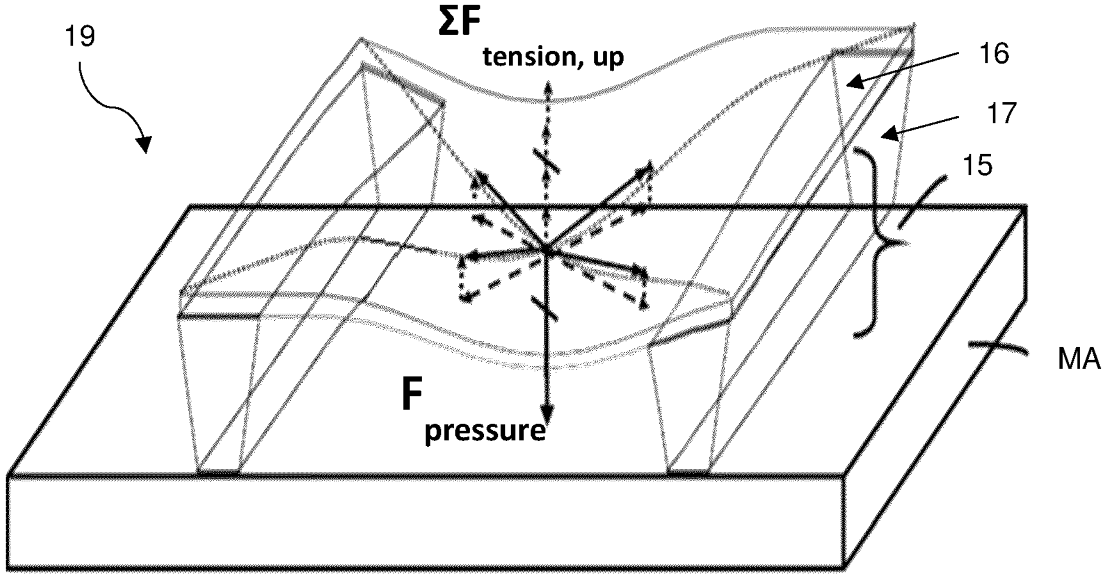
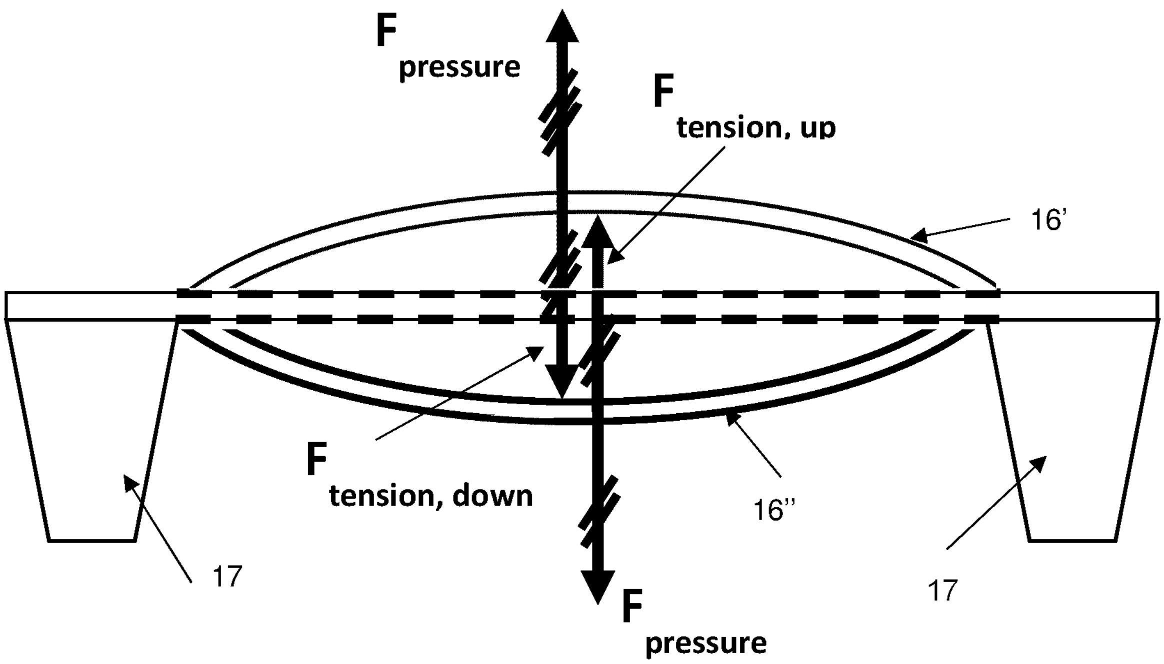

19
ΣF
tension, up
16
17
15
MA
F
pressure

FIG. 2a


F
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F
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16'
F
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16''
17
17
F
pressure

FIG. 2b

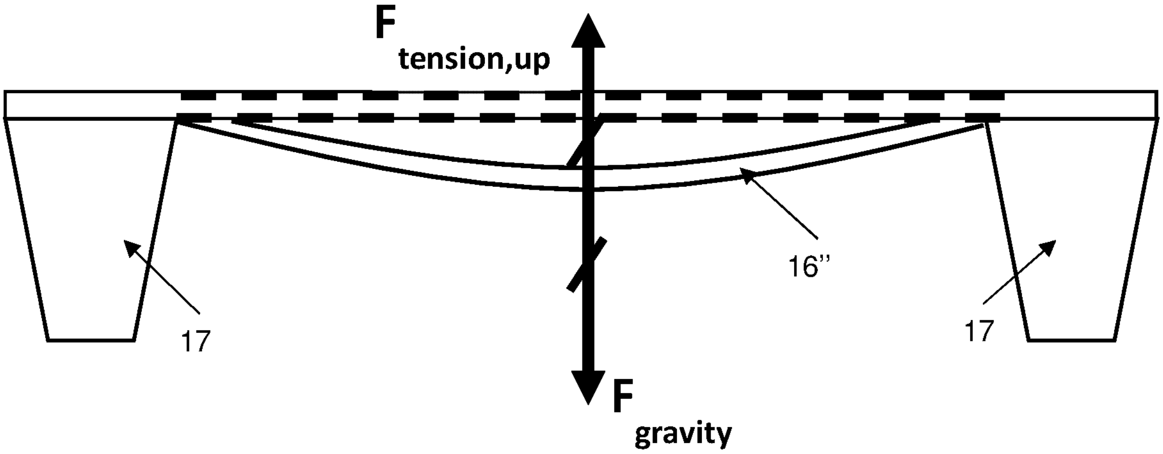

FIG. 2c

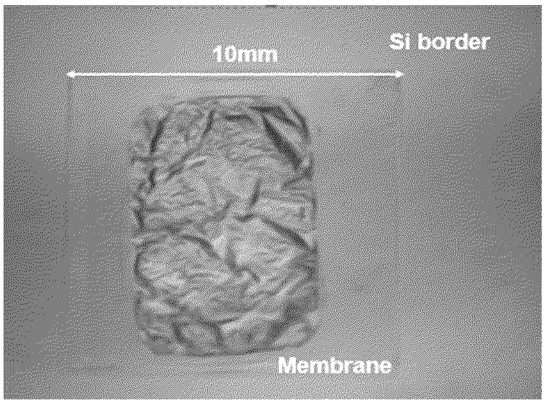

FIG. 3a

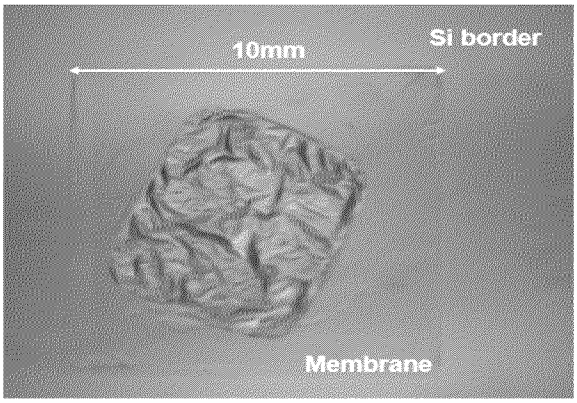

FIG. 3b

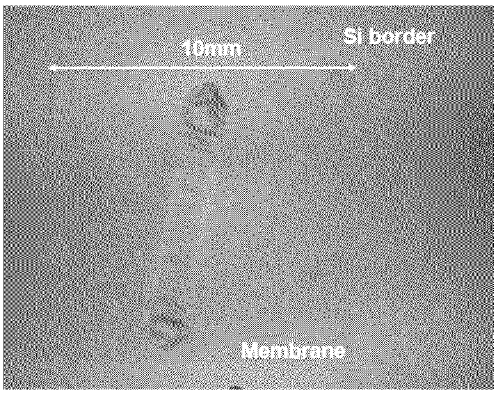

FIG. 3c

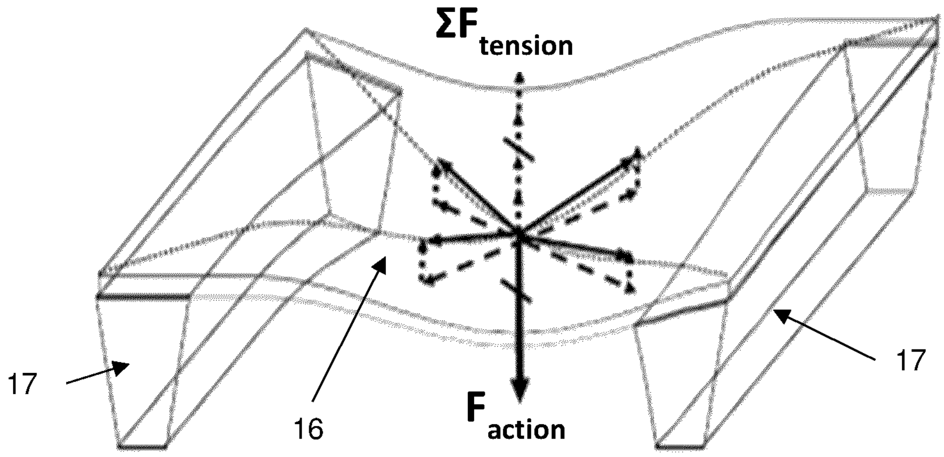

FIG. 4a

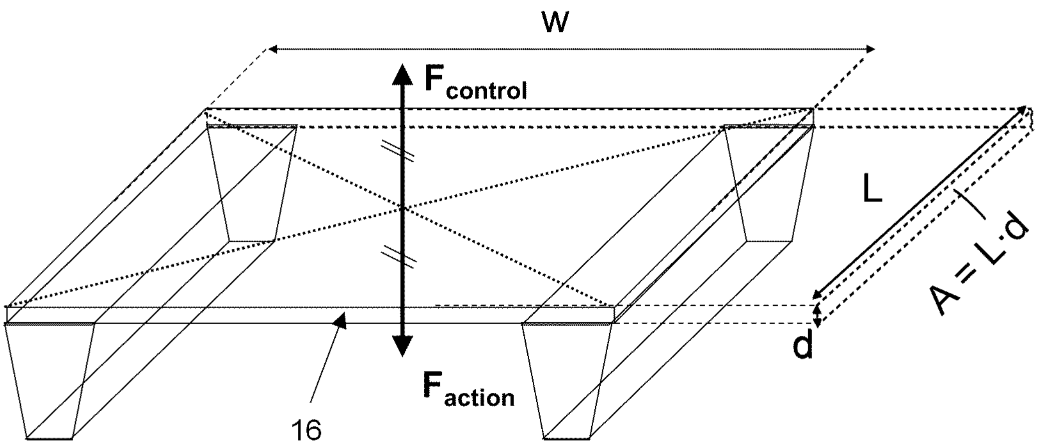

FIG. 4b

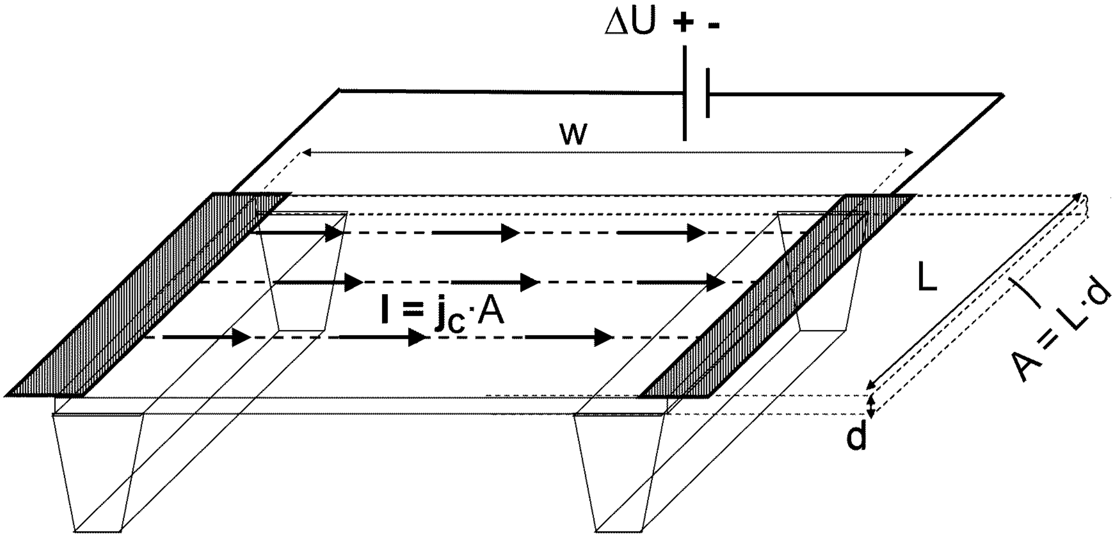

FIG. 4c

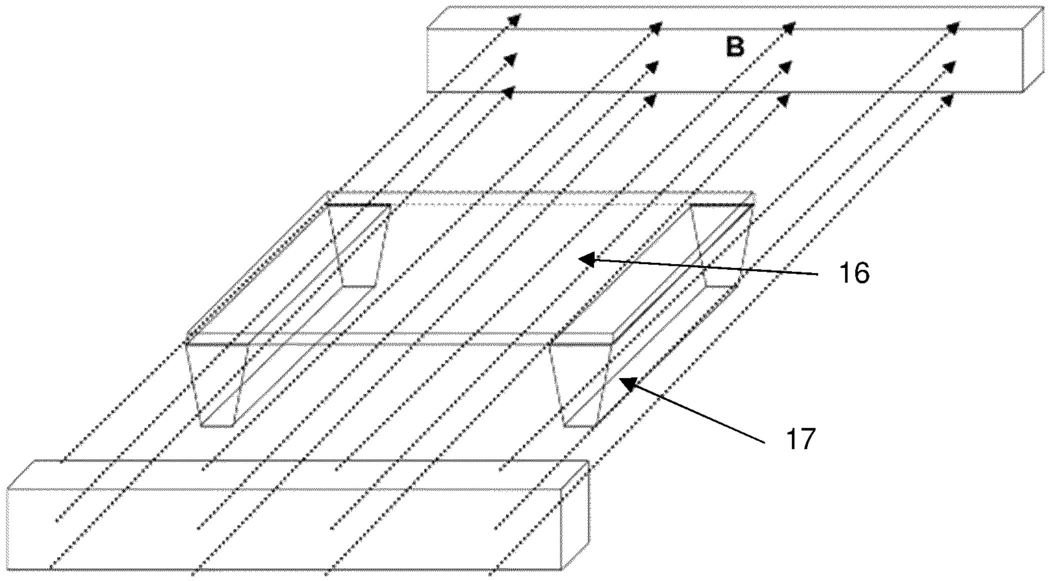

FIG. 4d

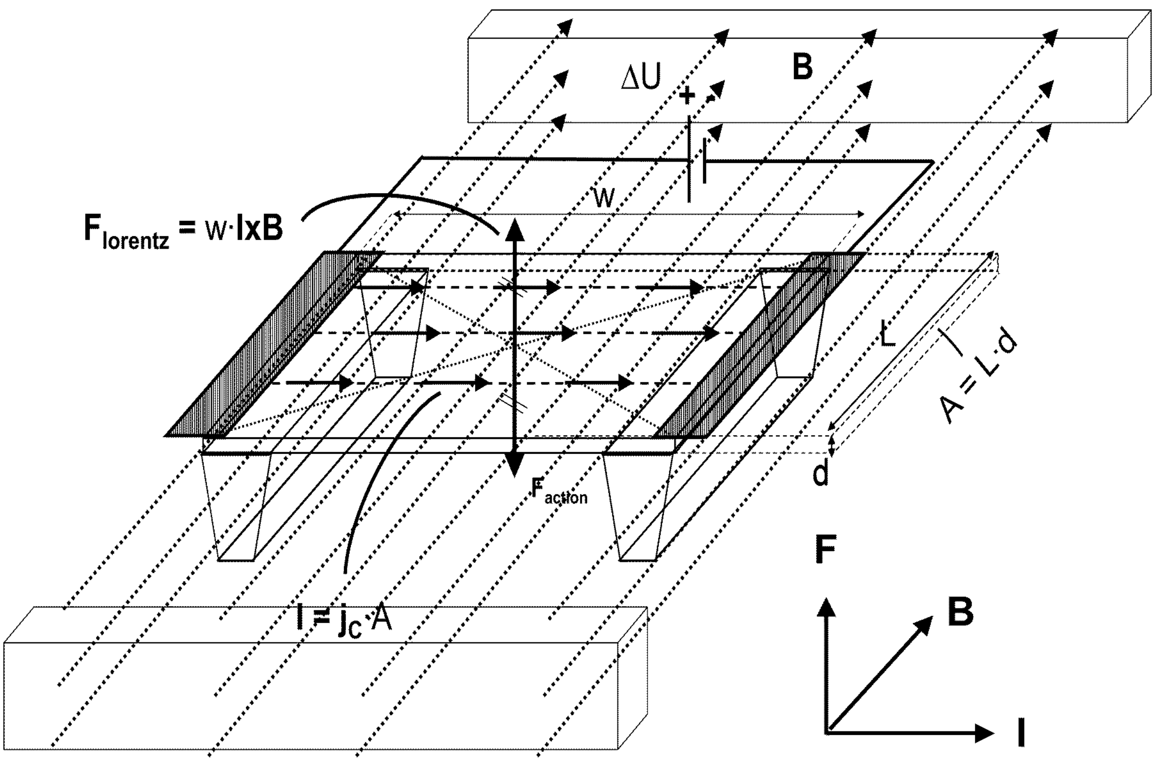

FIG. 4e

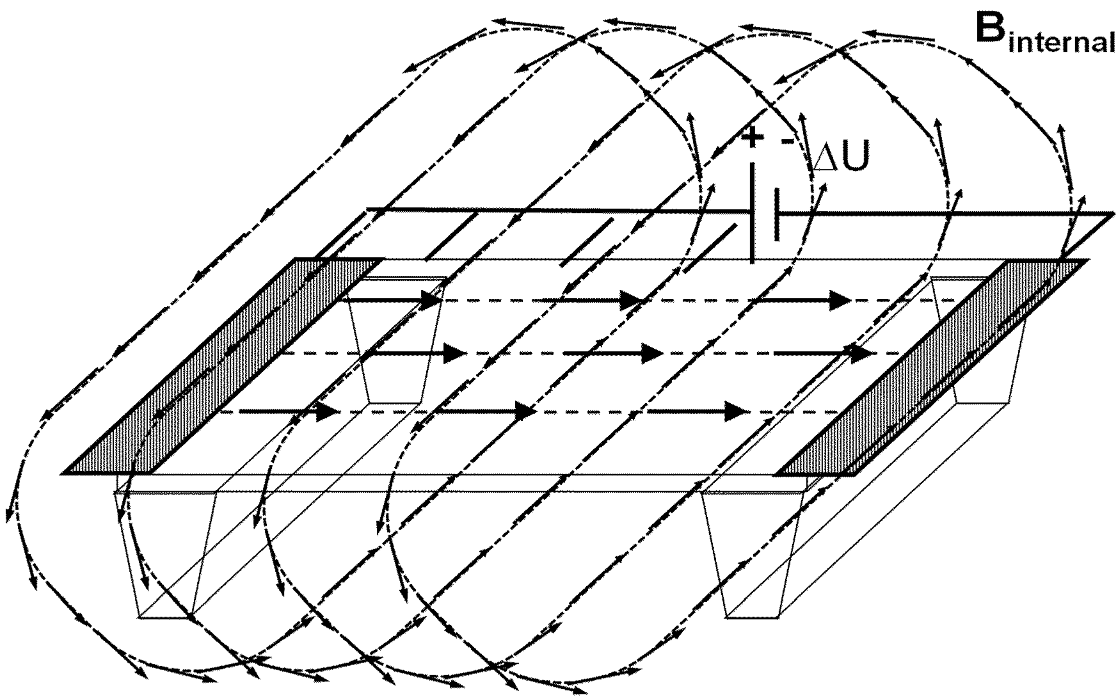

FIG. 5

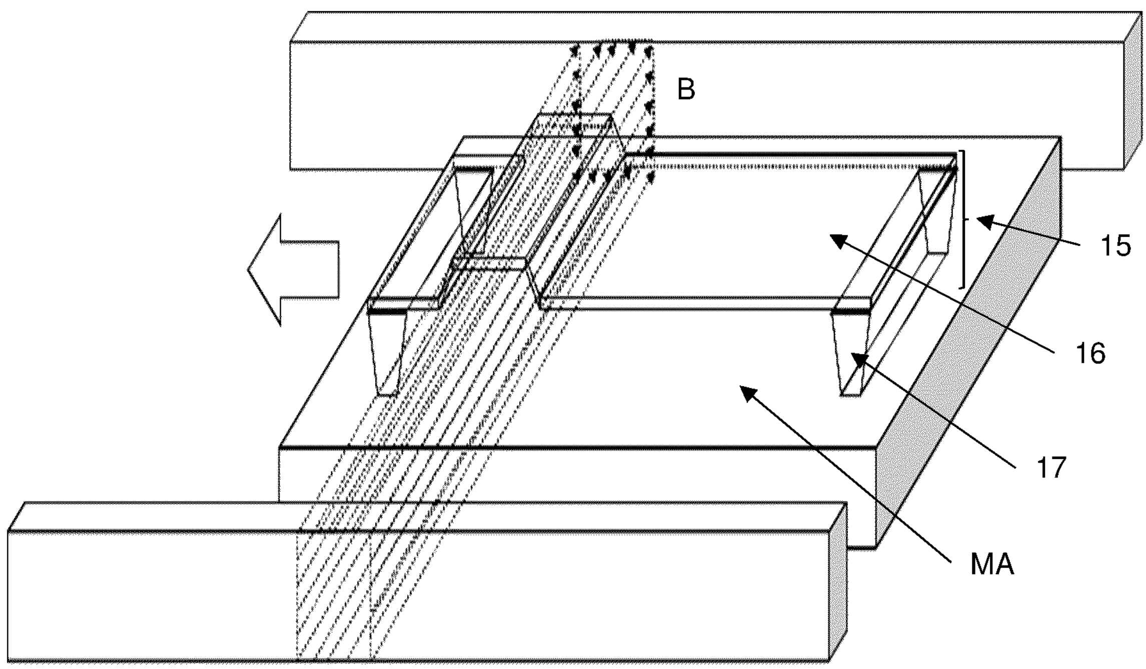

FIG. 6a

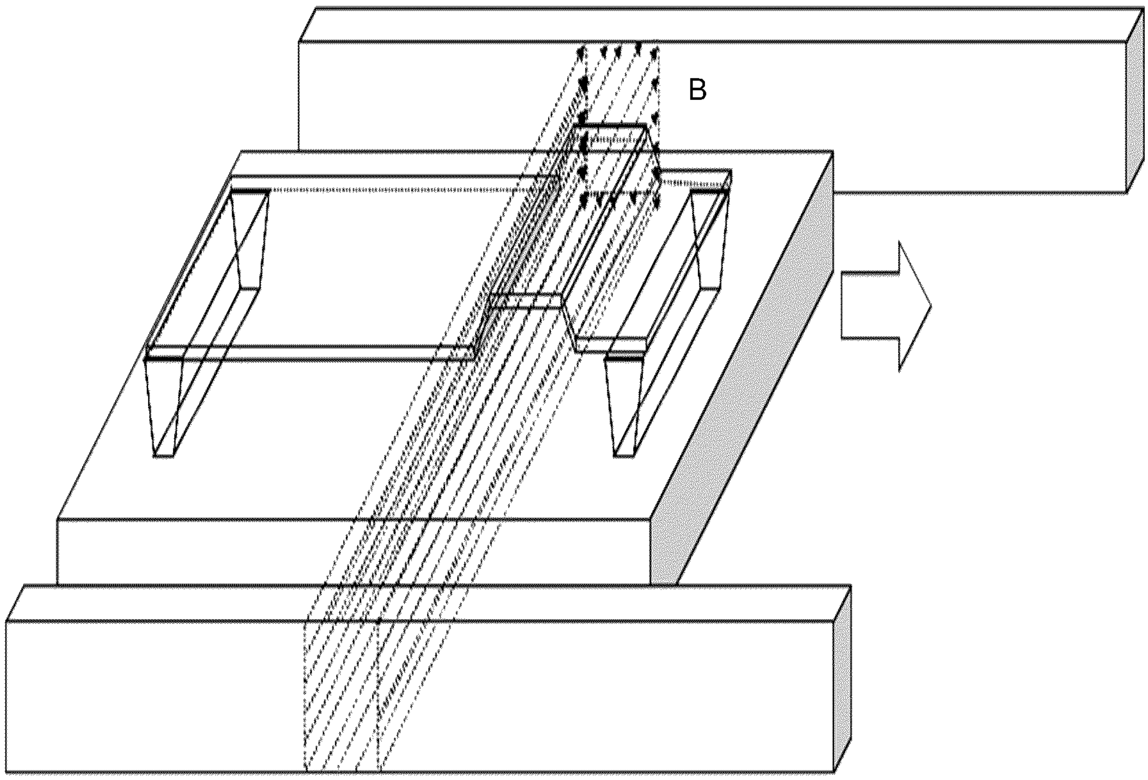

FIG. 6b

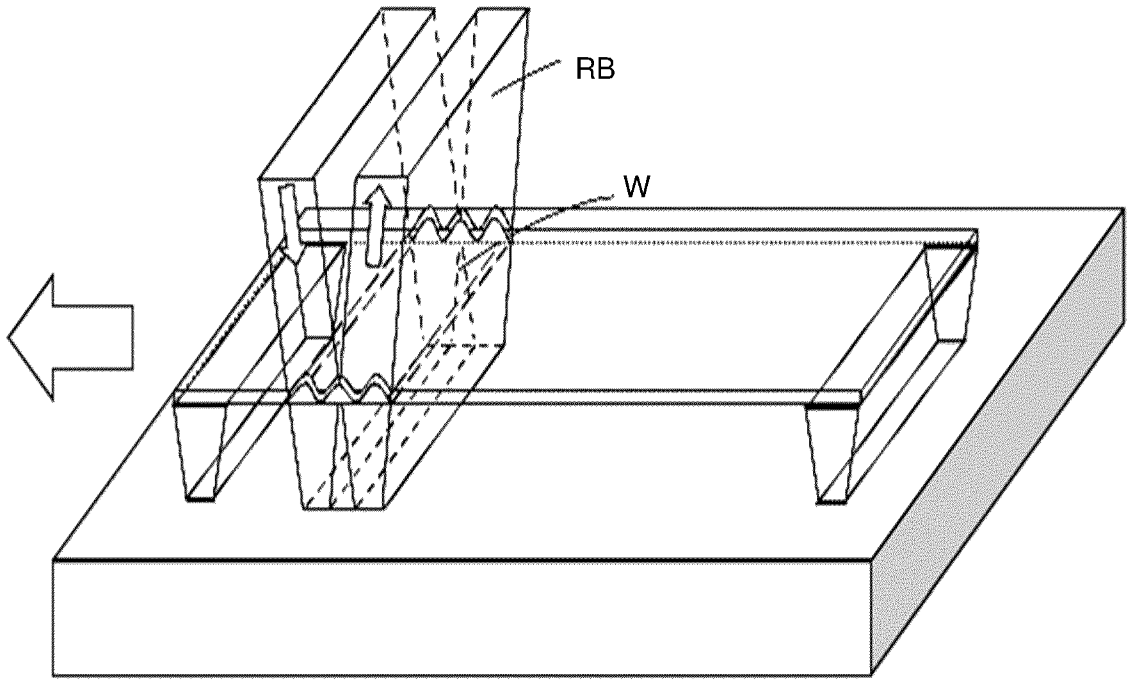

FIG. 6c

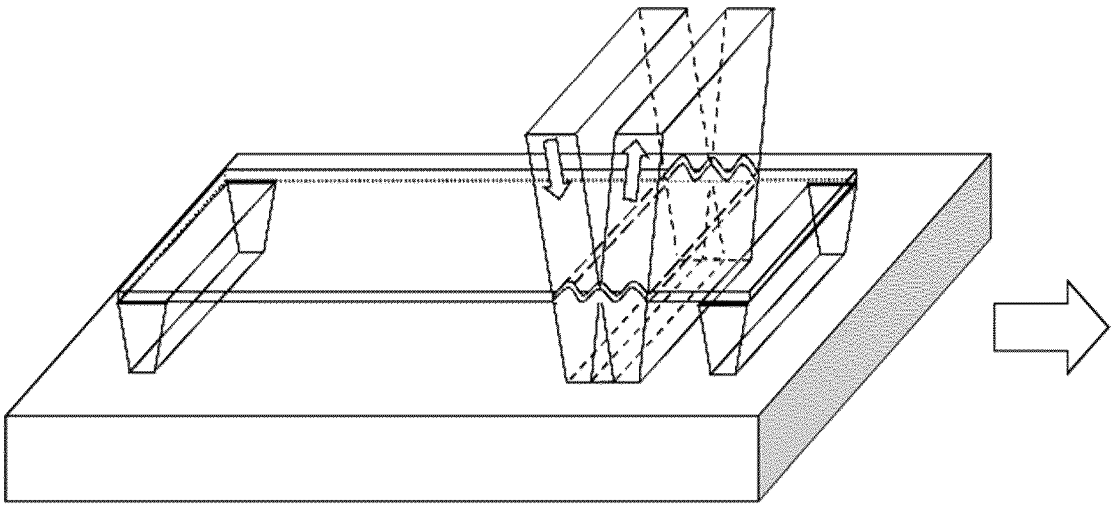

FIG. 6d

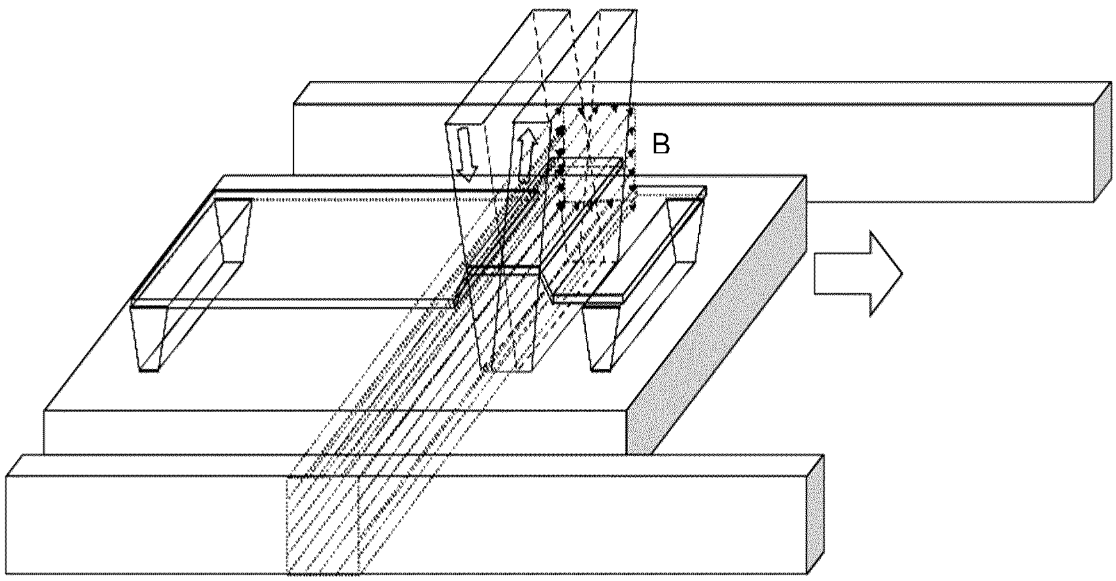

FIG. 6e

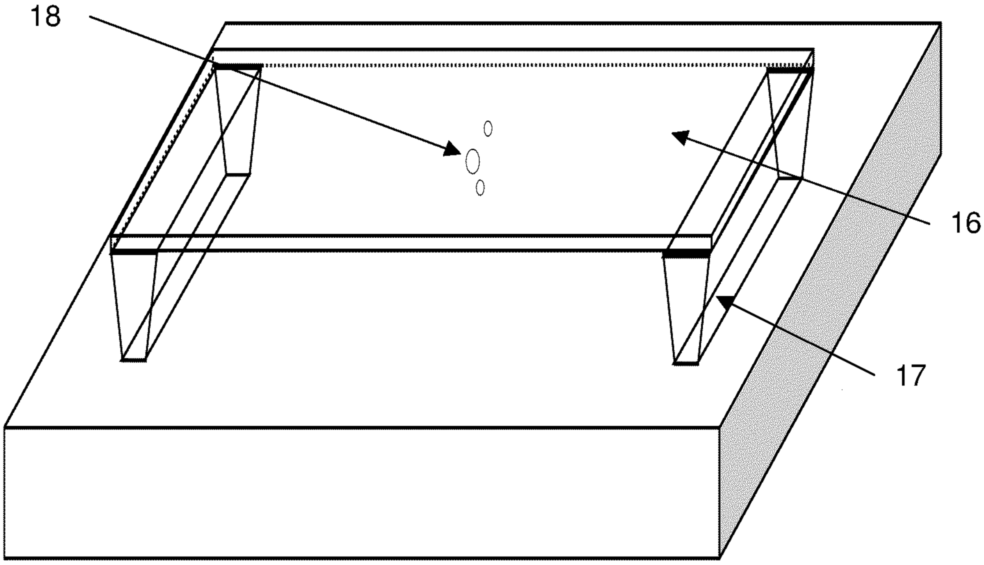

FIG. 7a

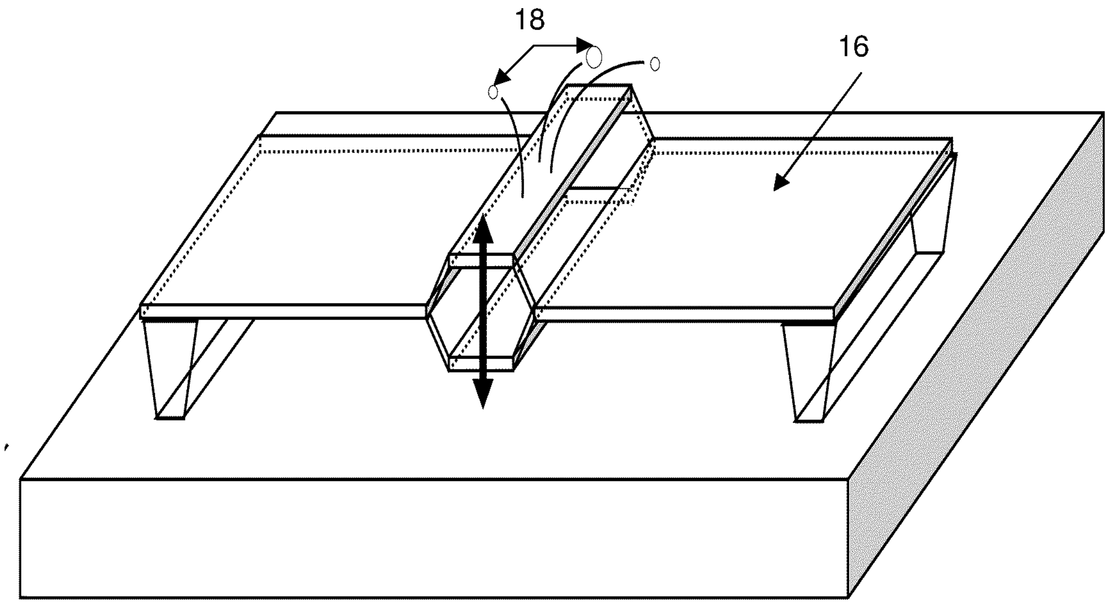

FIG. 7b

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/063201

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F1/62 G03F7/00
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

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 A	US 2007/165297 A1 (SANDNER THILO [DE] ET AL) 19 July 2007 (2007-07-19) abstract figure 16 paragraphs [0001], [0007], [0008], [0012], [0017], [0036] - [0056] -----	1-4,6-9, 11,13,14 5,10,12, 15
A	US 2020/201169 A1 (MARIANO JUSTE MARINA [BE] ET AL) 25 June 2020 (2020-06-25) abstract figure 1 paragraphs [0002], [0061] - [0065] -----	1-15

☐ 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	Date of mailing of the international search report
5 September 2024	16/09/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Andersen, Ole

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2024/063201

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2007165297 A1	19-07-2007	CN 1982201 A	20-06-2007
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		KR 20200078310 A	01-07-2020
		TW 202024770 A	01-07-2020
		US 2020201169 A1	25-06-2020