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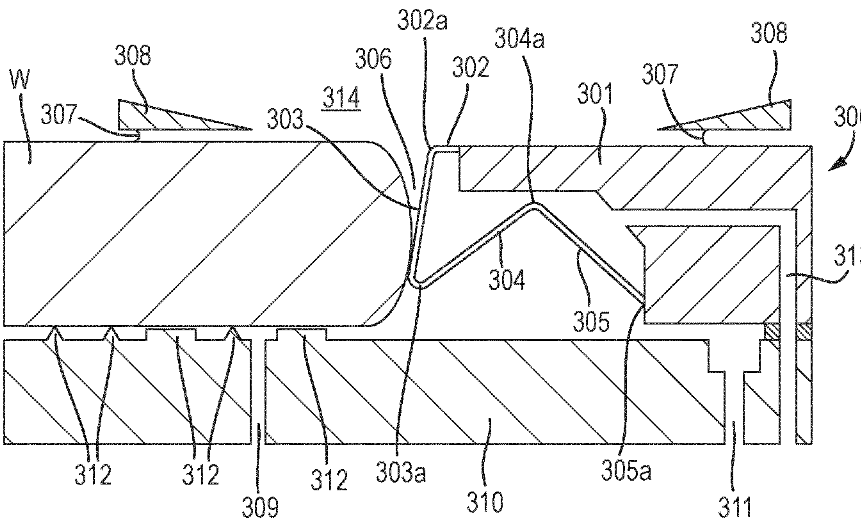
(54) Title: COVER RING, SUBSTRATE SUPPORT AND LITHOGRAPHIC APPARATUS

Fig. 3B



(57) Abstract: Disclosed herein is a cover ring for use in a substrate support, the cover ring comprising: a flexible structure with an opening for receiving a substrate; an enclosed region within the cover ring; and a fluid conduit configured provide fluid to and/or receive fluid from the enclosed region; wherein the flexible structure is configured to change between a first state and a second state in response to a fluid flow into, or a fluid flow out of, the enclosed region; and in the first state the diameter of the opening is larger than in the second state.

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COVER RING, SUBSTRATE SUPPORT AND LITHOGRAPHIC APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority of EP application 23166755.1 which was filed on 5 April 2023 and of EP application 23215658.8 which was filed on 11 December 2023 and which are incorporated herein in their entirety by reference.

FIELD

[0002] The present invention relates to a cover ring of a substrate support that is configured to support a substrate, a lithographic apparatus including the substrate support, a method of supporting a substrate and a method of manufacturing a device including the method of supporting a substrate.

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, use a projection system to project a pattern (also often referred to as “design layout” or “design”) of a patterning device (e.g., a mask) onto a layer of radiation-sensitive material (resist) provided on a substrate (e.g., a wafer). Known lithographic apparatus include so-called steppers, in which each target portion is irradiated by exposing an entire pattern onto the target portion at one time, and so-called scanners, in which each target portion is irradiated by scanning the pattern through a radiation beam in a given direction (the "scanning"-direction) while synchronously scanning the substrate parallel or anti-parallel to this direction.

[0004] As semiconductor manufacturing processes continue to advance, the dimensions of circuit elements have continually been reduced while the amount of functional elements, such as transistors, per device has been steadily increasing over decades, following a trend commonly referred to as ‘Moore’s law’. To keep up with Moore’s law the semiconductor industry is chasing technologies that enable to create increasingly smaller features. To project a pattern on a substrate a lithographic apparatus may use electromagnetic radiation. The wavelength of this radiation determines the minimum size of features which are patterned on the substrate. Typical wavelengths currently in use are 365 nm (i-line), 248 nm, 193 nm and 13.5 nm.

[0005] Further improvements in the resolution of smaller features may be achieved by providing an immersion fluid having a relatively high refractive index, such as water, on the substrate during exposure. The effect of the immersion fluid is to enable imaging of smaller features since the exposure radiation will have a shorter wavelength in the fluid than in gas. The effect of the immersion fluid may also be regarded as increasing the effective numerical aperture (NA) of the system and also increasing the depth of focus.

[0006] The immersion fluid may be confined to a localized area between the projection system of the lithographic apparatus and the substrate by a fluid handling structure.

SUMMARY

[0007] According to a first aspect of the invention, there is provided a cover ring for use in a substrate support, the cover ring comprising: a flexible structure with an opening for receiving a substrate; an enclosed region within the cover ring; and a fluid conduit configured provide fluid to and/or receive fluid from the enclosed region; wherein the flexible structure is configured to change between a first state and a second state in response to a fluid flow into, or a fluid flow out of, the enclosed region; and in the first state the diameter of the opening is larger than in the second state.

[0008] According to a second aspect of the invention, there is provided a substrate support configured to support a substrate, the substrate support comprising the cover ring according to the first aspect.

[0009] According to a third aspect of the invention, there is provided a lithographic apparatus comprising the substrate support according to the second aspect.

[0010] According to a fourth aspect of the invention, there is provided a method for supporting a substrate, the method comprising use of the substrate support according to the second aspect.

[0011] According to a fifth aspect of the invention, there is provided a method for performing lithography, the method comprising projecting a radiation beam onto a substrate in an exposure operation; wherein the substrate is supported by the substrate support according to the second aspect.

[0012] According to a sixth aspect of the invention, there is provided a cover ring for use in a substrate support, the cover ring comprising: an aperture mechanism with an opening for receiving a substrate; wherein the aperture mechanism comprises a plurality of curved segments that are arranged to move, in directions that are at least partial rotations about the mid-point of the opening, so as to change the diameter and/or shape of the opening.

[0013] According to a seventh aspect of the invention, there is provided a substrate support configured to support a substrate, the substrate support comprising the cover ring according to the sixth aspect.

[0014] According to an eighth aspect of the invention, there is provided a lithographic apparatus comprising the substrate support according to the seventh aspect.

[0015] According to a ninth aspect of the invention, there is provided a method for supporting a substrate, the method comprising use of the substrate support according to the seventh aspect.

[0016] According to a tenth aspect of the invention, there is provided a method for performing lithography, the method comprising projecting a radiation beam onto a substrate in an exposure operation; wherein the substrate is supported by the substrate support according to the seventh aspect.

[0017] Further embodiments, features and advantages of the present invention, as well as the structure and operation of the various embodiments, features and advantages of the present invention are described in detail below with reference to the accompanying drawings.

DESCRIPTION OF THE DRAWINGS

[0018] 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 schematic overview of a lithographic apparatus.

Figure 2 depicts, in cross-section, a substrate support that is not in accordance with the present invention.

Figures 3A and 3B schematically depict, in cross-section, a cover ring according to a first embodiment.

Figures 4A and 4B schematically depict, in cross-section, a cover ring according to a second embodiment.

Figures 5A and 5B schematically depict, in cross-section, a cover ring according to a third embodiment.

Figures 6A and 6B schematically depict, in cross-section, a cover ring according to a fourth embodiment.

Figures 7A and 7B schematically show, in plan view, a cover ring according to a fifth embodiment.

Figure 8 schematically depicts, in cross-section, a substrate support according to an embodiment.

The features shown in the Figures are not necessarily to scale, and the size and/or arrangement depicted is not limiting. It will be understood that the Figures include optional features which may not be essential to the invention. Furthermore, not all of the features of the apparatus are depicted in each of the figures, and the Figures may only show some of the components relevant for describing a particular feature.

DETAILED DESCRIPTION

[0019] In the present document, the terms “radiation” and “beam” are used to encompass all types of electromagnetic radiation, including ultraviolet radiation (e.g. with a wavelength of 365, 248, 193, 157 or 126 nm).

[0020] The term “reticle”, “mask” or “patterning device” as employed in this text may be broadly interpreted as referring to a generic patterning device that can be used to endow an incoming radiation beam with a patterned cross-section, corresponding to a pattern that is to be created in a target portion of the substrate. The term “light valve” can also be used in this context. Besides the classic mask (transmissive or reflective, binary, phase-shifting, hybrid, etc.), examples of other such patterning devices include a programmable mirror array and a programmable LCD array.

[0021] Figure 1 schematically depicts a lithographic apparatus. The lithographic apparatus includes an illumination system (also referred to as illuminator) IL configured to condition a radiation beam B (e.g., UV radiation or DUV radiation), a mask support (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 MA in accordance with certain parameters, a substrate support (e.g., a substrate table) WT constructed to hold a substrate (e.g., a resist coated wafer) W and connected to a second positioner PW configured to accurately position the substrate support WT 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.

[0022] In operation, the illumination system IL receives the radiation beam B from a radiation source SO, e.g. via a beam delivery system BD. The illumination system IL may include various types of optical components, such as refractive, reflective, magnetic, electromagnetic, electrostatic, and/or other types of optical components, or any combination thereof, for directing, shaping, and/or controlling radiation. The illuminator IL may be used to condition the radiation beam B to have a desired spatial and angular intensity distribution in its cross-section at a plane of the patterning device MA.

[0023] The term "projection system" PS used herein should be broadly interpreted as encompassing various types of projection system, including refractive, reflective, catadioptric, anamorphic, magnetic, electromagnetic and/or electrostatic optical systems, or any combination thereof, as appropriate for the exposure radiation being used, and/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" PS.

[0024] The lithographic apparatus is of a type wherein at least a portion of the substrate W may be covered by an immersion liquid having a relatively high refractive index, e.g., water, so as to fill an immersion space between the projection system PS and the substrate W – which is also referred to as immersion lithography. More information on immersion techniques is given in US 6,952,253, which is incorporated herein by reference.

[0025] The lithographic apparatus may be of a type having two or more substrate supports WT (also named "dual stage"). In such a "multiple stage" machine, the substrate supports WT may be used in parallel, and/or steps in preparation of a subsequent exposure of the substrate W may be carried out on the substrate W located on one of the substrate support WT while another substrate W on the other substrate support WT is being used for exposing a pattern on the other substrate W.

[0026] In addition to the substrate support WT, the lithographic apparatus may comprise a measurement stage (not depicted in figures). The measurement stage is arranged to hold a sensor and/or a cleaning device. The sensor may be arranged to measure a property of the projection system PS or a property of the radiation beam B. The measurement stage may hold multiple sensors. The cleaning device may be arranged to clean part of the lithographic apparatus, for example a part of the projection system PS or a part of a system that provides the immersion liquid. The measurement stage may move beneath the projection system PS when the substrate support WT is away from the projection system PS.

[0027] In operation, the radiation beam B is incident on the patterning device, e.g. mask, MA which is held on the mask support MT, and is patterned by the pattern (design layout) present on patterning device MA. Having traversed the mask MA, the radiation beam B passes through the projection system

PS, which focuses the beam onto a target portion C of the substrate W. With the aid of the second positioner PW and a position measurement system IF, the substrate support WT can be moved accurately, e.g., so as to position different target portions C in the path of the radiation beam B at a focused and aligned position. Similarly, the first positioner PM and possibly another position sensor (which is not explicitly depicted in Figure 1) may be used to accurately position the patterning device MA with respect to the path of the radiation beam B. 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 P1, P2 as illustrated occupy dedicated target portions, they may be located in spaces between target portions. Substrate alignment marks P1, P2 are known as scribe-lane alignment marks when these are located between the target portions C.

[0028] To clarify the invention, a Cartesian coordinate system is used. The Cartesian coordinate system has three axis, i.e., an x-axis, a y-axis and a z-axis. Each of the three axis is orthogonal to the other two axis. A rotation around the x-axis is referred to as an Rx-rotation. A rotation around the y-axis is referred to as an Ry-rotation. A rotation around about the z-axis is referred to as an Rz-rotation. The x-axis and the y-axis define a horizontal plane, whereas the z-axis is in a vertical direction. The Cartesian coordinate system is not limiting the invention and is used for clarification only. Instead, another coordinate system, such as a cylindrical coordinate system, may be used to clarify the invention. The orientation of the Cartesian coordinate system may be different, for example, such that the z-axis has a component along the horizontal plane.

[0029] Immersion techniques have been introduced into lithographic systems to enable improved resolution of smaller features. In an immersion lithographic apparatus, a liquid layer of immersion liquid having a relatively high refractive index is interposed in the immersion space between a projection system PS of the apparatus (through which the patterned beam is projected towards the substrate W) and the substrate W. The immersion liquid covers at least the part of the substrate W under a final element of the projection system PS. Thus, at least the portion of the substrate W undergoing exposure is immersed in the immersion liquid.

[0030] In commercial immersion lithography, the immersion liquid is water. Typically the water is distilled water of high purity, such as Ultra-Pure Water (UPW) which is commonly used in semiconductor fabrication plants. In an immersion system, the UPW is often purified and it may undergo additional treatment steps before supply to the immersion space as immersion liquid. Other liquids with a high refractive index can be used besides water as the immersion liquid, for example: a hydrocarbon, such as a fluorohydrocarbon; and/or an aqueous solution. Further, other fluids besides liquid have been envisaged for use in immersion lithography.

[0031] In this specification, reference will be made in the description to localized immersion in which the immersion liquid is confined, in use, to the immersion space between the final element and a surface facing the final element. The facing surface is a surface of substrate W or a surface of the supporting stage (or substrate support WT) that is co-planar with the surface of the substrate W. (Please note that reference in the following text to surface of the substrate W also refers in addition or in the alternative to the surface of the substrate support WT, unless expressly stated otherwise; and vice versa). A fluid handling structure IH present between the projection system PS and the substrate support WT is used to confine the immersion liquid to the immersion space. The immersion space filled by the immersion liquid is smaller in plan than the top surface of the substrate W and the immersion space remains substantially stationary relative to the projection system PS while the substrate W and substrate support WT move underneath.

[0032] Other immersion systems have been envisaged such as an unconfined immersion system (a so-called 'All Wet' immersion system) and a bath immersion system. In an unconfined immersion system, the immersion liquid covers more than the surface under the final element. The liquid outside the immersion space is present as a thin liquid film. The liquid may cover the whole surface of the substrate W or even the substrate W and the substrate support WT co-planar with the substrate W. In a bath type system, the substrate W is fully immersed in a bath of immersion liquid.

[0033] The fluid handling structure IH is a structure which supplies the immersion liquid to the immersion space, removes the immersion liquid from the immersion space and thereby confines the immersion liquid to the immersion space. It includes features which are a part of a fluid supply system. The arrangement disclosed in PCT patent application publication no. WO 99/49504 is an early fluid handling structure comprising pipes which either supply or recover the immersion liquid from the immersion space and which operate depending on the relative motion of the stage beneath the projection system PS. In more recent designs, the fluid handling structure extends along at least a part of a boundary of the immersion space between the final element of the projection system PS and the substrate support WT or substrate W, so as to in part define the immersion space .

[0034] The fluid handing structure IH may have a selection of different functions. Each function may be derived from a corresponding feature that enables the fluid handling structure IH to achieve that function. The fluid handling structure IH may be referred to by a number of different terms, each referring to a function, such as barrier member, seal member, fluid supply system, fluid removal system, liquid confinement structure, etc..

[0035] Immersion liquid may be used as the immersion fluid. In that case the fluid handling structure IH may be a liquid handling system. In reference to the aforementioned description, reference in this paragraph to a feature defined with respect to fluid may be understood to include a feature defined with respect to liquid.

[0036] A lithographic apparatus has a projection system PS. During exposure of a substrate W, the projection system PS projects a beam of patterned radiation onto the substrate W. To reach the substrate W, the path of the radiation beam B passes from the projection system PS through the immersion liquid confined by the fluid handling structure IH between the projection system PS and the substrate W. The projection system PS has a lens element, the last in the path of the beam, which is in contact with the immersion liquid. This lens element which is in contact with the immersion liquid may be referred to as 'the last lens element' or "the final element". The final element is at least partly surrounded by the fluid handling structure IH. The fluid handling structure IH may confine the immersion liquid under the final element and above the facing surface.

[0037] As depicted in Figure 1, the lithographic apparatus comprises a controller 600. The controller 600 is configured to control the substrate support WT.

[0038] Figure 2 illustrates part of a known lithographic apparatus that is not in accordance with the present invention. The arrangement illustrated in Figure 2 and described below may be applied to the lithographic apparatus described above and illustrated in Figure 1. Figure 2 is a cross-section through a substrate support 20 and a substrate W. In an embodiment, the substrate support 20 comprises one or more conditioning channels 61 of a thermal conditioner. A gap 5 exists between an edge of the substrate W and an edge of the substrate support 20. When the edge of the substrate W is being imaged or at other times such as when the substrate W first moves under the projection system PS (as described above), the immersion space filled with liquid by the fluid handling structure IH (for example) will pass at least partly over the gap 5 between the edge of the substrate W and the edge of the substrate support 20. This can result in liquid from the immersion space entering the gap 5.

[0039] The substrate W is held by a support body 21 (e.g. a pimple or burl table) comprising one or more burls 41 (i.e., projections from the surface). The support body 21 is an example of an object holder. Another example of an object holder is a mask holder. An under-pressure, i.e., a vacuum, applied between the substrate W and the substrate support 20 defining a clamping region helps ensure that the substrate W is held firmly in place by applying a clamping force. However, if immersion liquid gets between the substrate W and the support body 21 this can lead to difficulties, particularly when unloading the substrate W.

[0040] In order to deal with the immersion liquid entering that gap 5 at least one drain 10, 12 is provided at the edge of the substrate W to remove immersion liquid which enters the gap 5. In the example of Figure 2 two drains 10, 12 are illustrated though there may only be one drain or there could be more than two drains. In an embodiment, each of the drains 10, 12 is annular so that the whole periphery of the substrate W is surrounded.

[0041] A primary function of the first drain 10 (which is radially outward of the edge of the substrate W/support body 21) is to help prevent bubbles of gas from entering the immersion space where the liquid of the fluid handling structure IH is present. Such bubbles may deleteriously affect the imaging of the substrate W. The first drain 10 is present to help avoid gas in the gap 5 escaping into the immersion space in the fluid handling structure IH. If gas does escape into the immersion space, this can lead to a bubble which floats within the immersion space. Such a bubble, if in the path of the projection beam, may lead to an imaging error. The first drain 10 is configured to remove gas from the gap 5 between the edge of the substrate W and the edge of the recess in the substrate support 20 in which the substrate W is placed. The edge of the recess in the substrate support 20 may be defined by a cover ring 101 which is optionally separate from the support body 21 of the substrate support 20. In the x/y plane, the cover ring 101 may be shaped, as a ring that surrounds the outer edge of the substrate W. The first drain 10 extracts mostly gas and only a small amount of immersion liquid.

[0042] The second drain 12 (which is radially inward of the edge of the substrate W/support body 21) is provided to help prevent liquid which finds its way from the gap 5 to underneath the substrate W from preventing efficient release of the substrate W from the substrate support WT after imaging. The provision of the second drain 12 reduces or eliminates any problems which may occur due to liquid finding its way underneath the substrate W.

[0043] As depicted in Figure 2, the lithographic apparatus comprises a first extraction channel 102 for the passage therethrough of a two phase flow. The first extraction channel 102 is formed within a block. The first and second drains 10, 12 are each provided with a respective opening 107, 117 and a respective extraction channel 102, 113. The extraction channel 102, 113 is in fluid communication with the respective opening 107, 117 through a respective passageway 103, 114.

[0044] As depicted in Figure 2, the cover ring 101 has an upper surface. The upper surface extends circumferentially around the substrate W on the support body 21. In use of the lithographic apparatus, the substrate support 20 moves relative to the fluid handling structure IH. During this relative movement, the fluid handling structure IH passes across the gap 5 between the cover ring 101 and the substrate W. In an embodiment the relative movement is caused by the substrate support 20 moving under the fluid handling structure IH. In an alternative embodiment the relative movement is caused by the fluid handling structure IH moving over the substrate support 20. In a further alternative embodiment the relative movement is provided by movement of both the substrate support 20 under the fluid handling structure IH and movement of the fluid handling structure IH over the substrate support 20. In the following description, movements of the fluid handling structure IH will be used to mean the relative movement of the substrate support 20 relative to the fluid handling structure IH.

[0045] The known design of cover ring 101 has, in plan view, a circular opening for receiving a substrate W. The opening has a fixed diameter. The diameter of the opening is designed so that it is larger than the diameter of the substrate W under all circumstances that can reasonably be expected to occur. If the diameter of the opening is too small, the cover ring 101 may not be usable with a substrate W in all circumstances. The minimum allowable diameter of the opening is dependent on the diameter of the substrate W that the cover ring 101 is designed to surround as well as the required tolerances. The required tolerances include the manufacturing tolerances of the substrate W, the manufacturing tolerances of the opening in the cover ring 101, and any variation in the diameter of the substrate W and the opening in the cover ring 101 during use.

[0046] The gap 5 between the cover ring 101 and the substrate W is caused by opening having a larger diameter that the substrate W. In places, the gap 5 may be about 200μm. When the fluid handling structure IH passes across the gap 5, at least some of the immersion liquid flows through the gap 5.

[0047] A problem with known techniques is that the flow of immersion liquid through the gap 5 increases the thermal loading on the substrate W and substrate support 20. The flow of immersion liquid through the gap 5 may also cause bubbles to form in the immersion liquid. Bubbles may cause imaging defects, and large bubbles, that may have a diameter of up to 100μm, are a particular problem. The fixed diameter of the opening prevents the average size of the gap 5 from being decreased. Accordingly, with known techniques, the flow of immersion liquid through the gap 5 cannot be reduced by decreasing the size of the gap 5.

[0048] Embodiments improve on known techniques by providing a new cover ring. In the cover ring according to embodiments, the opening for receiving a substrate W has an adjustable diameter and/or shape. The cover ring may be substantially the same as known cover rings in other respects. Before a substrate W is loaded onto a substrate support, the diameter of the opening may be substantially the same as the fixed diameter of the opening in a known cover ring 101. After the substrate W has been loaded onto the substrate support, the diameter of the opening may then be decreased so as to reduce the size of the gap between the cover ring and the substrate W.

[0049] A cover ring 301 according to a first embodiment of the invention is schematically depicted, in cross-section, in Figures 3A and 3B.

[0050] Figures 3A and 3B show, in cross-section, the lower part of a fluid handling structure 308. The fluid handling structure 308 may be substantially the same as the earlier described fluid handling structure IH used in known techniques. The fluid handling structure 308 is located above a substrate W and a substrate support 300.

[0051] The substrate W is supported on burls 312 that protrude from a support body 310 of the substrate support 300. The burls 312 may be substantially the same as the earlier described burls 41 according to known techniques. The support body 310 may be substantially the same as the earlier described support body 21 according to known techniques. The substrate support 300 comprises a fluid extraction channel 309, with a fluid entrance that is below the substrate W, that may be substantially the same as the earlier described fluid extraction passageway 114 and/or channel 113 according to known techniques. The substrate support 300 comprises a fluid extraction channel 311, with a fluid entrance that is to the side of the substrate W, that may be substantially the same as the earlier described fluid extraction passageway 103 and/or channel 102 according to known techniques. The fluid extraction channel 311 may alternatively be connected to ambient pressure and not used for fluid extraction. The substrate support 300 comprises a cover ring 301 that, in plan view, surrounds the substrate W. An upper surface of the cover ring 301 may be substantially co-planar with an upper surface of the substrate W.

[0052] Immersion fluid, that may comprise a liquid, is present within an immersion fluid region 314, which may be substantially the same as the earlier described immersion space. There is a first meniscus 307 of the immersion fluid between the substrate W and the fluid handling structure 308. There is a second meniscus 307 of the immersion fluid between the cover ring 301 and the fluid handling structure 308. There is a gap 306 between the substrate W and the cover ring 301.

[0053] The cover ring 301 comprises a flexible structure. The flexible structure may be, and/or comprise, a bellow. The flexible structure comprises a first surface 302, a second surface 303, a third surface 304, and a fourth surface 305. There is a first corner 302a between the first surface 302 and the second surface 303. There is a second corner 303a between the second surface 303 and the third surface 304. There is a third corner 304a between the third surface 304 and the fourth surface 305. There is a fourth corner 305a between the fourth surface 305 and a main body of the cover ring 301. The first surface 302 of the flexible structure may be part of a planar upper surface of the cover ring 301 and connected at one end to the main body of the cover ring 101. The second surface 303 maybe a substrate facing surface of the cover ring 301. The third surface 304 maybe a lower surface of the cover ring 301 that faces away from the substrate W. The fourth surface 304 maybe a lower surface of the cover ring 301 that faces towards the substrate W. Each surface 302, 303, 304, 305 may, in cross-section, be substantially straight.

[0054] The main body of the cover ring 301 and the flexible structure define an enclosed region within the cover ring 301. There is a fluid conduit 313 that is arranged to supply a fluid to, and/or extract fluid from, the enclosed region. The fluid may be a gas, such as air. Alternatively, the fluid may be a liquid, such as water. The fluid may be a mixture of a gas and a liquid.

[0055] The flexible structure is arranged so that one or more of its surfaces 302, 303, 304, 305 move in response to fluid flows into and out of the enclosed region. A fluid flow into the enclosed region may increase the volume of, and/or fluid pressure in, the enclosed region. A fluid flow out of the enclosed region may decrease the volume of, and/or fluid pressure in, the enclosed region. The flexible structure may be the only part of the cover ring 301 that is arranged to move due to the change in volume and/or pressure in the enclosed region. The movement may be allowed by one or more of the surfaces 302, 303, 304, 305 of the flexible structure bending, stretching, and/or bending round one or more of the corners 302a, 303a, 304a, 305a. The movement causes the flexible structure to change between a plurality of different states. The cross-sectional shape of the flexible structure may be different in each state. To ensure that only well-defined shape changes of the flexible structure occur, the surfaces 302, 303, 304, 305 of the flexible structure may have different flexibilities. In particular, the second surface 303 may be more flexible than the first surface 302. The fourth surface 305 may be more flexible than the third surface 304. The second surface 303 may have substantially the same flexibility as the fourth surface 305. The first surface 302 may have substantially the same flexibility as the third surface 304.

[0056] Figure 3A shows the flexible structure in a first state. The first state may be referred to as a retracted state of the cover ring 301. The second corner 303a of the second surface 303 of the flexible structure is located away from the substrate W. The gap 306 between the substrate W and the second surface 303 may be similar to that when a known cover ring 101 is used. Accordingly, the gap 306 is sufficient for a substrate W to be loaded onto, and removed from, the substrate support 300 given the required tolerances. The average size of the gap 306 may be greater than about 125μm, and is preferably greater than 200μm.

[0057] Figure 3B shows the flexible structure in a second state. The second state may be referred to as an extended state of the cover ring 301. The second corner 303a of the second surface 303 of the flexible structure is located closer to the substrate W than it was in the first state. The minimum size of the gap 306 between the substrate W and the closest part of the second surface 303 is therefore less than it was in the first state. The average size of the gap 306 may be less than about 35μm, and is preferably less than 5μm.

[0058] When the flexible structure is in the second state, the smaller size of the gap 306 may substantially reduce, or entirely prevent, the flow of immersion fluid from the immersion fluid region 314 through the gap 306. Advantageously, this reduces, or avoids, the earlier described problems that such a flow of immersion fluid may cause.

[0059] The flexible structure of the cover ring 301 may be controlled to be in the first state when a substrate W is loaded onto the substrate support 300. After the substrate W has been loaded, the flexible structure of the cover ring 301 may be controlled to be in the second state so as to reduce the size of the gap 306. The amount of immersion fluid that may flow through the gap 306 when the fluid handling structure 308 passes over the gap 306 is thereby reduced. Before the substrate W is unloaded, the flexible structure of the cover ring 301 may be controlled so that it returns to the first state.

[0060] A cover ring 401 according to a second embodiment of the invention is schematically depicted, in cross-section, in Figures 4A and 4B.

[0061] The second embodiment provides a substrate support 400 with an alternative cover ring 401. The cover ring 401 of the second embodiment also comprises an enclosed region that is at least partially bounded by flexible structure. The flexible structure may be a bellow. The cover ring 401 of the second embodiment may differ from the cover ring 301 of first embodiment by the flexible structure having a different shape. The substrate support 400, and all of the other features depicted in Figures 4A and 4B, may otherwise be as described for the first embodiment.

[0062] In the second embodiment, the flexible structure comprises a first surface 402, a second surface 403, a third surface 404, and a fourth surface 405. There is a first corner 402a between the first surface 402 and the second surface 403. There is a second corner 403a between the second surface 403 and the third surface 404. There is a third corner 404a between the third surface 404 and the fourth surface 405. There is a fourth corner 405a between the fourth surface 405 and a main body of the cover ring 401. The first surface 402 of the flexible structure may be part of an upper surface of the cover ring 401 and connected at one end to the main body of the cover ring 401. The second surface 403 maybe a substrate facing surface of the cover ring 401. The third surface 404 maybe a lower surface of the cover ring 401 that faces in an opposite direction to the first surface 402. The fourth surface 404 maybe a lower surface of the cover ring 401 that faces towards the substrate W. Each surface 402, 403, 404, 405 may, in cross-section, be substantially straight.

[0063] The main body of the cover ring 401 and the flexible structure define an enclosed region within the cover ring 401. There is a fluid conduit 406 that is arranged to supply a fluid to, and/or extract a fluid from, the enclosed region. The fluid may be a gas, such as air. Alternatively, the fluid may be a liquid, such as water. The fluid may be a mixture of a gas and a liquid.

[0064] As described for the first embodiment, the flexible structure is arranged so that its shape changes in response to fluid flows into and out of the enclosed region. The flexible structure may be the only part of the cover ring 401 that is arranged to move due to the change in volume and/or pressure in the enclosed region. The movement may be allowed by one or more of the surfaces 402, 403, 404, 405 of the flexible structure bending, stretching, and/or bending round one or more of the corners 402a, 403a, 404a, 405a. The movement causes the flexible structure to change between a plurality of different states. The shape of the flexible structure may be different in each state. To ensure that only well-defined shape changes of the flexible structure occur, the surfaces 402, 403, 404, 405 of the flexible structure may have different flexibilities. In particular, the second surface 403 may be more flexible than the first surface 402. The fourth surface 405 may be more flexible than the third surface 404. The second surface 403 may have substantially the same flexibility as the fourth surface 405. The first surface 402 may have substantially the same flexibility as the third surface 404.

[0065] Figure 4A shows the flexible structure in a first state. The first state may be referred to as a retracted state of the cover ring 401. The second corner 403a of the second surface 403 of the flexible structure is located away from the substrate W. The gap 306 between the substrate W and the second surface 403 may be similar to that when a known cover ring 101 is used. Accordingly, the gap 306 is sufficient for a substrate W to be loaded onto, and removed from, the substrate support 400 given the required tolerances. The average size of the gap 306 may be greater than about 125μm, and is preferably greater than 200μm.

[0066] Figure 4B shows the flexible structure in a second state. The second state may be referred to as an extended state of the cover ring 401. The second corner 403a of the second surface 403 of the flexible structure is located closer to the substrate W than it was in the first state. The minimum size of the gap 306 between the substrate W and the closest part of the second surface 403 is therefore less than it was in the first state. The average size of the gap 306 may be less than about 35μm, and is preferably less than 5μm.

[0067] The cover ring 401 of the second embodiment has similar, or the same, advantages to those described earlier for the cover ring 301 of the first embodiment.

[0068] The flexible structure of the cover ring 401 may be controlled to be in the first state when a substrate W is loaded onto the substrate support 400. After the substrate W has been loaded, the flexible structure of the cover ring 401 may be controlled to be in the second state so as to reduce the size of the gap 306. The amount of immersion fluid that may flow through the gap 306 when the fluid handling structure 308 passes over the gap 306 is thereby reduced. Before the substrate W is unloaded, the flexible structure of the cover ring 401 may be controlled so that it returns to the first state.

[0069] In the second embodiment, the third surface 404 of the cover ring 401 remains substantially parallel to the upper surface of the support body 310 when it moves between different states. There is therefore a low risk of the shape of the flexible structure causing any fluid, such as air and/or water, from becoming trapped in this region. If any fluid is trapped in this region, then the movement of the flexible structure may cause undesired pressure changes. This is an advantage over the first embodiment in which there is a greater risk of fluid becoming trapped in the corresponding region between the lower surface of the flexible structure and the upper surface of the support body 310. Another advantage over the first embodiment is that the volume of the region between the lower surfaces 404, 405 of the cover ring 401 and the support body 310 do not substantially change when the flexible structure moves.

[0070] A cover ring 501 according to a third embodiment of the invention is schematically depicted, in cross-section, in Figures 5A and 5B.

[0071] The third embodiment provides a substrate support 500 with another alternative cover ring 501. The cover ring 501 of the third embodiment also comprises an enclosed region that is at least partially bounded by flexible structure. The flexible structure may be a bellow. The cover ring 501 of the third embodiment may differ from the cover ring 301, 401 of first or second embodiment by the flexible structure having a different shape. The substrate support 500, and all of the other features depicted in Figures 5A and 5B, may otherwise be as described for the first or the second embodiment.

[0072] In the third embodiment, the flexible structure comprises a first surface 502, a second surface 503, a third surface 504, a fourth surface 505, and a fifth surface 506. There is a first corner 502a between the first surface 502 and the second surface 503. There is a second corner 503a between the second surface 503 and the third surface 504. There is a third corner 504a between the third surface 504 and the fourth surface 505. There is a fourth corner 505a between the fourth surface 505 and the fifth surface 506. There is a fifth corner 506a between the fifth surface 506 and a main body of the cover ring 501. The first surface 502 of the flexible structure may be part of an upper surface of the cover ring 501 and connected at one end to the main body of the cover ring 501. The second surface 503 maybe a substrate facing surface of the cover ring 501. The third surface 504 maybe a lower surface of the cover ring 501 that faces in an opposite direction to the first surface 502. The fourth surface 505 maybe a lower surface of the cover ring 501 that faces away from the substrate W. The fifth surface 506 maybe a lower surface of the cover ring 501 that faces towards the substrate W. Each surface 502, 503, 504, 505, 506 may, in cross-section, be substantially straight.

[0073] The main body of the cover ring 501 and the flexible structure define an enclosed region within the cover ring 501. There is a fluid conduit 507 that is arranged to supply a fluid to, and/or extract a fluid from, the enclosed region. The fluid may be a gas, such as air. Alternatively, the fluid may be a liquid, such as water. The fluid may be a mixture of a gas and a liquid.

[0074] As described for the first or the second embodiment, the flexible structure is arranged so that its shape changes in response to fluid flows into and out of the enclosed region. The flexible structure may be the only part of the cover ring 501 that is arranged to move due to the change in volume and/or pressure in the enclosed region. The movement may be allowed by one or more of the surfaces 502, 503, 504, 505, 506 of the flexible structure bending, stretching, and/or bending round one or more of the corners 502a, 503a, 504a, 505a, 506a. The movement causes the flexible structure to change between a plurality of different states. The shape of the flexible structure may be different in each state. To ensure that only well-defined shape changes of the flexible structure occur, the surfaces 502, 503, 504, 505, 506 of the flexible structure may have different flexibilities. In particular, the second surface 503 may be more flexible than the first surface 502. The fourth surface 505 may be more flexible than the third surface 504. The second surface 503 may have substantially the same flexibility as the fourth surface 505. The first surface 502 may have substantially the same flexibility as the third surface 504.

[0075] Figure 5A shows the flexible structure in a first state. The first state may be referred to as a retracted state of the cover ring 501. The second corner 503a of the second surface 503 of the flexible structure is located away from the substrate W. The gap 306 between the substrate W and the second surface 503 may be similar to that when a known cover ring 101 is used. Accordingly, the gap 306 is sufficient for a substrate to be loaded onto, and removed from, the substrate support 500 given the required tolerances. The average size of the gap 306 may be greater than about 125μm, and is preferably greater than 200μm.

[0076] Figure 5B shows the flexible structure in a second state. The second state may be referred to as an extended state of the cover ring 501. The second corner 503a of the second surface 503 of the flexible structure is located closer to the substrate W than it was in the first state. The minimum size of the gap 306 between the substrate W and the closest part of the second surface 503 is therefore less than it was in the first state. The average size of the gap 306 may be less than about 35μm, and is preferably less than 5μm.

[0077] The cover ring 501 of the third embodiment has similar, or the same, advantages to those described earlier for the cover ring 301 of the first embodiment and/or the second embodiment.

[0078] The flexible structure of the cover ring 501 may be controlled to be in the first state when a substrate W is loaded onto the substrate support 500. After the substrate W has been loaded, the flexible structure of the cover ring 501 may be controlled to be in the second state so as to reduce the size of the gap 306. The amount of immersion fluid that may flow through the gap 306 when the fluid handling structure 308 passes over the gap 306 is thereby reduced. Before the substrate W is unloaded, the flexible structure of the cover ring 501 may be controlled so that it returns to the first state.

[0079] In the third embodiment, the relatively long lengths of the fourth surface 505 and the fifth surface 506 may facilitate the shape change of the flexible structure. This may be an advantage over the second embodiment in which a relatively high stress in the fourth surface 405 may occur.

[0080] A cover ring 301 according to a fourth embodiment of the invention is schematically depicted, in cross-section, in Figures 6A and 6B.

[0081] The fourth embodiment provides a substrate support 300 with another alternative cover ring 301. The cover ring 301 of the fourth embodiment may comprise a flexible cover 601. The substrate support 300 of the fourth embodiment may otherwise be the same as the substrate support 300 as described earlier for the first embodiment.

[0082] The flexible cover 601 may be a solid flexible material, such as a polymer. The flexible cover 601 may alternatively be a stretchable band that is secured at one end at, or near, the second corner 303a and at the other end at, or near, near the fourth corner 305a. The purpose of the flexible cover 601 is to prevent fluid, such as air and/or water, from becoming trapped in the region between the lower surfaces of the flexible structure and the upper surface of the support body 310. This may reduce any undesired pressure changes caused by the movement of the flexible structure.

[0083] In all of the first to fourth embodiments, a neutral state of the flexible structure may be defined as when it is near to, or at, the middle of its moveable range by the fluid flows into and out of the enclosed region. The flexible structure may be designed so that its neutral state is close to, or at, an intermediate position between the first state and the second state. The flexible structure may therefore be retracted from its neutral state in order to move it to the first state, and extended from the neutral state in order to move it to the second state. This ensures an efficient use of the moveable range of the flexible structure.

[0084] The first state of the flexible structure may be a predetermined position of the flexible structure that may be used with most, or all, substrates W. In the first state, the diameter of the opening in the flexible structure for receiving a substrate W may be substantially the same as the opening for receiving a substrate W in a known cover ring 101.

[0085] When the flexible structure is in the first state and a substrate W is loaded on the substrate support 300, 400, 500, the size of the gap 306 may vary around the circumference of the substrate W. The variation of the size of the gap 306 may be caused by any positioning inaccuracy of the substrate W. Additional causes of the variation may include any variations of the diameter of the substrate W and any variations in the shape of the flexible structure.

[0086] The shape of the flexible structure in the second state may be dependent on the minimum size of the gap 306 around the circumference of the substrate 306. When changing from the first state to the second state, the flexible structure may be moved until the minimum size of the gap 306 is less than about 35μm, and is preferably less than about 5μm, and is more preferably less than about 3μm. Preferably, in the second state, the flexible structure does not contact the substrate W. However, embodiments also include the flexible structure contacting the substrate W. An advantage of the flexible structure contacting the substrate W is that this may entirely close the gap 306 any prevent any fluid flow through the gap 306. However, the contact will result in forces being applied by the flexible structure to the substrate W and these may cause local position changes of the substrate W. That said, if the stiffness of the flexible structure is low so that the applied forces by the contact with the flexible structure are low, any local position changes of the substrate W may be insignificant.

[0087] To determine the second state of the flexible structure, the diameter and roundness of the substrate W may be determined. When the substrate W is loaded on a substrate support 300, 400, 500, the location of the substrate W on the substrate support 300, 400, 500 may also be determined. The substrate roundness and location determinations allow the size of the gap 306 around the circumference of the substrate W to be determined when the flexible structure is in the first state. The second state of the flexible structure may then be determined in dependence of the determined the size of the gap 306 around the circumference of the substrate W. The flexible structure may then be moved to the second state by a fluid flow into the enclosed region that increases the pressure in the enclosed region. The amount of fluid flow that is used to move the flexible structure may be determined in dependence of the expected movement of the flexible structure in response to the fluid flow.

[0088] In all of the first to fourth embodiments, the flexible structure is described as having a plurality of surfaces. The surfaces are external surfaces of respective walls of an enclosed region. The walls of the enclosed region may be made separately from each other and then joined together.

[0089] The material of the flexible structure is preferably resistant to the DUV radiation that the substrate is illuminated with. The flexible structure may be made from, for example, Titanium, spring steel or Nickel. A coating may be applied to one or more of the external surfaces of the flexible structure. The coating may help to control the flow of the immersion fluid.

[0090] The material of the rest of the substrate support 300, 400, 500 is not particularly limited, and could be any suitable material known in the art. Preferably, the substrate support 300, 400, 500 may be made out of silicon infiltrated silicon carbide (SiSiC). Alternatively, the substrate support 300, 400, 500 may be formed of Zerodur™ (a lithium-aluminosilicate glass-ceramic), cordierite, silicon carbide (SiC) or diamond SiSiC.

[0091] The radial stroke of the flexible structure, i.e. the maximum change in the radius of the opening in the flexible structure, may be about 100μm. The range of operating pressures in the enclosed region may be over the range -0.5barg to 0.5barg. The applied material stresses may be less than 275MPa. The cover ring 301, 401, 501 according to embodiments may have a similar volume to a known cover ring 101. The wall thickness of the flexible structure may be less than or equal to about 10μm. The vertical stiffness of the flexible structure may be greater than about 4E5N/m. The radial stiffness of the flexible structure may be greater than about 1E5N/m.

[0092] Figures 7A and 7B schematically show, in plan view, a cover ring 700 according to a fifth embodiment. The cover ring 700 provides an upper surface of a substrate support (not shown).

[0093] The cover ring 700 comprises an aperture mechanism 701 with an opening for receiving a substrate W. The aperture mechanism 701 comprises a plurality of segments 703a-h. Although eight segments 703a-h are shown in Figure 7A and 7B, embodiments include the aperture mechanism comprising a larger, or fewer, number of segments 703a-h. Each segment 703a-h may be in direct contact with two other segments703a-h. The contacting surfaces between two adjacent segments 703a-h are curved side surfaces of the segments 703a-h. The side surfaces of each segment 703a-h may have a depth, in a direction that is orthogonal to planar upper and/or lower surfaces of each segment 703a-h, that may be the thickness of each segment 793a-h. The width of each segment 703a-h may be defined in a plane that is parallel to the planar upper and/or lower surfaces of each segment. The width of each segment 703a-h may be at its maximum at the outer periphery of the aperture mechanism 701 and taper to a minimum in an inward spiral direction that is parallel to the planar upper and/or lower surfaces of each segment 703a-h. The upper surfaces of each segment 703a-h may be substantially co-planar with each other and also with an upper surface of the substrate W.

[0094] Figures 7A and 7B show a substrate W that is loaded on the substrate support. As described earlier, the substrate W may be supported by burls of the substrate support. The substrate W is located within the opening of the aperture mechanism 701. There is a gap 702 between the inner surface of the aperture mechanism 701 and the substrate W. The segments 703a-h of the aperture mechanism 701 are arranged to move relative to each other so as to change the size of the gap 702.

[0095] Figure 7A shows the aperture mechanism 701 in a first state. In the first state, the diameter of the opening is as described earlier for the first state of the flexible structure in the first to fourth embodiments. That is to say, the diameter of the opening is large enough for most, or all, substrates W to be accommodated given tolerances.

[0096] Figure 7B shows the aperture mechanism 701 in a second state. In the second state, the diameter of the opening is as described earlier for the second state of the flexible structure in the first to fourth embodiments. That is to say, the diameter of the opening is reduced so as to reduce, and optionally prevent, the flow of immersion fluid through the gap 702 when the fluid handling structure IH passes over the gap 702.

[0097] To change between the first and second states, the contacting surfaces of the segments 703a-h may slide relative to each other. The movement of each segment 703a-h may comprise an at least partial rotation about the mid-point of the opening. The aperture mechanism 701 may comprise an actuation system (not shown) that is arranged to move each of the segments 703a-h. The actuation system may comprise one or more piezo-electric actuators, one or more pneumatic actuators, and/or one or more hydraulic actuators. The actuation system may be configured so that all of the segments 703a-h are simultaneously moved by substantially the same amount. However, embodiments also include the movement of two or more of the segments 703a-h being independently controllable. This allows some of the segments 703a-h to be moved by different amounts. The shape of the opening may thereby be changed as may be appropriate given any positioning and roundness errors of the substrate W. By changing the shape of the opening, the variation of the size of the gap 702 around the circumference of the substrate W may be reduced. When the aperture mechanism 701 is in the second state, the average minimum size of the gap 702 may also be lower. Embodiments also include the segments 703a-h being moved so that they reduce, or entirely close, the gap 702 on only the region of the cover ring 700 that is covered by the fluid handling structure IH. The required movement of the segments 703a-h to reach the second state may be determined in a similar manner to that described for the flexible structure in the other embodiments.

[0098] In an embodiment, one or more of the surfaces of each segment 703a-h may comprise a plurality of openings (not shown), so that these surfaces are sieve-like. The diameters of the openings are preferably all large enough for the sieve-like surfaces to be gas permeable. The diameters of the openings are preferably too small for there to be a substantial liquid flow through the openings. Advantageously, the use of openings reduces the weight of the segments 703a-h.

[0099] One or more surfaces of each segment 703a-h may be coated. For example, either a hydrophobic or a hydrophilic coating may be applied to the upper surface of each segment 703a-h. A hydrophobic coating may be applied to the lower surface of each segment 703a-h to prevent liquid droplets remaining on these lower surfaces. This may also reduce the sliding resistance when adjacent segments 703a-h move relative to each other. The coating of the upper surface of each segment 703a-h may be referred to as a first coating. The coating of the lower surface of each segment 703a-h may be referred to as a second coating. The first and second coatings may be different from each other.

[0100] Embodiments include the aperture mechanism 701 being in the first state when the substrate W is loaded and unloaded. The aperture mechanism 701 may be moved so that it is in the second state at most other times. Embodiments also alternatively include the aperture mechanism 701 being moved to the second state only when the fluid handling structure IH is close to, and/or passing over, the gap 702. The aperture mechanism 701 may be in the first state at most other times.

[0101] Each of the segments 703a-h may be made (at least partially) from a metal, for example, titanium or stainless steel, a ceramic material, or a polymer.

[0102] Embodiments include a number of modifications and variations to the above described techniques.

[0103] In the above described first to fourth embodiments, the flexible structure is a single annular structure. Embodiments also include the flexible structure comprising a plurality of segments. The segments may be arranged around the opening, with each segment providing a different part of the circumference of the annular flexible structure. The number of segments may be, for example, 10, or any other suitable number. Each segment may comprise an enclosed region and a fluid conduit to the enclosed region. This may allow the movement of each segment to be controlled independently from the movement of the other segments. Each segment may be arranged to change between at least the earlier described first and second states in response to fluid flows into and out of its enclosed region. When the fluid flows into and out of the segments are all simultaneously controlled in the same way as each other, the flexible structure may respond in substantially the same way as described for the first to fourth embodiments. However, the fluid flows into and out of the segments may also be controlled differently, so that one or more of the segments are moved more than one or more of the other segments. This allows the shape of the opening in the flexible structure to be changed, as may be appropriate given any positioning and roundness errors of the substrate W. Advantageously, by changing the shape of the opening, the variation of the size of the gap 306 around the circumference of the substrate W may be reduced. For the second state of the flexible structure, the average size of the gap 306 may also be reduced. Accordingly, both the cross-sectional shape and the plan view shape of the flexible structure may be changed by the fluid flows into and out of the segments.

[0104] The first to fourth embodiments, and their variations, also include other techniques for determining the second state that the flexible structure is moved to. For example, the substrate support 300, 400, 500 may comprise sensors (not shown) for directly measuring the size of the gap 306 and controlling the movement of the flexible structure in dependence of the measured size of the gap 306. The sensors may be, for example, capacitive sensors or optical sensors.

[0105] In the above described first to fourth embodiments, and their variations, at least the first corner 302a, 402a, 502a preferably has a smooth curvature. That is to say, the first corner 302a, 402a, 502a has a curvature of a defined smooth shape/radius. The smooth curvature of the first corner 302a, 402a, 502a reduces the disturbance in, and pinning of, any flow of immersion liquid over the first corner 302a, 402a, 502a. This may result in the suction being more defined, the liquid loss being reduced and reduced bubble generation.

[0106] In the above described first to fourth embodiments, and their variations, at least the upper surface 302, 402, 502 and substrate facing surface 303, 403, 503 of each flexible structure may be adapted to promote liquid and moisture flow towards and onto the flexible structure where it may be sucked away. The adaption may comprise a one-directional roughness or a micro-meter-level pattern.

[0107] In the first to fourth embodiments, there is a single fluid conduit 313, 406, 507 for the fluid flows into and out of the enclosed region. Embodiments also include the use of separate conduits for the fluid flows into and out of the enclosed region.

[0108] The first to fourth embodiments, and their variations, also include other techniques for moving the flexible structure. For example, the flexible structure may be moved by one or more piezo-electric actuators, or the flexible structure may comprise a memory metal.

[0109] In the first to fourth embodiments, and their variations, the flexible structure may be moved to the second state only when the fluid handling structure IH is close to, and/or passing over, the gap 306. The flexible structure may be in the first state at other times.

[0110] In all embodiments, the movements to change the diameter of the opening in a cover ring 301, 401, 501, 700 may be automatically controlled by a control system (not shown). The control system may be the same controller 600 configured to control the substrate support WT. An actuator (not shown) may be provided, which is arranged in communication with the control system (or controller). The actuator may drive directly or indirectly the cover ring to change between the first and the second state.

[0111] Embodiments also include different implementations of the support body 310 of the substrate support 300, 400, 500. As described below, embodiments include the support body 310 providing a fluid flow to clamping regions at the edge of the substrate W. The fluid flow may locally reduce the clamping force at the edge of the substrate W and thereby reduce the shape deformation of the substrate

W. The fluid flow may also reduce the risk of unintended contact between the flexible structure and the substrate W.

[0112] Figure 8 schematically shows in cross-section another embodiment of the support body 310 of a substrate support 400. The support body 310 in Figure 8 is a different implementation of the support body 310 of the substrate support 400 of the second embodiment. The support body 310 further comprises a venting groove 801 and one or more venting conduits 802. The substrate support 400 may otherwise be substantially the same as that of the second embodiment.

[0113] In plan view, the venting groove 801 may be an annular groove in the substrate facing surface of the support body 310. In plan view, the annular venting groove 801 may extend around the full circumference of the substrate W and be close to the edge of the substrate W. The one or more venting conduits 802 are each arranged to supply a fluid to the venting groove 801, and thereby to the same region that the fluid extraction channel 311 is arranged to extract fluid from. The supplied fluid by each venting conduit 802 may be, for example, air or another suitable gas. There may be a plurality of venting conduits 802 with an equal radial spacing within the annular venting groove 801. The number of venting conduits 802 may be, for example, three. Although not shown in Figure 8, there may be a valve system arranged to control the rate of fluid flow through each venting conduit 802.

[0114] The substrate W is held to the support body 310 by an under-pressure, i.e., vacuum, at the underside of the substrate W that applies a clamping force to the substrate W. The under pressure created by the vacuum may cause the edge of the substrate W to curl towards the support body 310. The curling of the edge of the substrate W is a shape deformation of the substrate W that may increase manufacturing errors.

[0115] Embodiments include providing a fluid flow, such as an air flow, to the venting groove 801 via the one or more venting conduits 802. The fluid flow may locally reduce the under pressure created by the vacuum at the periphery of the substrate W so that the clamping force is lower at the edges of the substrate W. Advantageously this may prevent, or reduce, the curling at the edge of the substrate W and thereby reduce errors caused by such a shape deformation. A further advantage of the fluid flow to the venting groove 801 is that it may prevent, or reduce the risk of, the unintended closure of the gap 306. An unintended closure of the gap 306 brings the flexible structure into contact with the substrate W. Such contact may change the shape of the substrate W and thereby cause shape deformation errors. The contact may also damage the substrate W and/or the flexible structure.

[0116] Embodiments include above-described venting groove 801 and venting conduits 802 being used in any of the substrate supports 300, 400, 500 of all of the embodiments described throughout the present document.

[0117] The fluid flow to the venting groove 801 may be automatically controlled by a control system (not shown). The control system may be the same control system that controls the movements to change the diameter of the opening in the cover ring 301, 401, 501, 700.

[0118] Embodiments include the following numbered clauses:

1. A cover ring for use in a substrate support, the cover ring comprising:

a flexible structure with an opening for receiving a substrate;

an enclosed region within the cover ring; and

a fluid conduit configured provide fluid to and/or receive fluid from the enclosed region;

wherein the flexible structure is configured to change between a first state and a second state in response to a fluid flow into, or a fluid flow out of, the enclosed region; and

in the first state the diameter of the opening is larger than in the second state.

2. The cover ring according to clause 1, wherein the flexible structure is configured to change from the first state to the second state in response to a fluid flow into the enclosed region.

3. The cover ring according to clause 1 or 2, wherein the flexible structure is configured to change from the second state to the first state in response to a fluid flow out of the enclosed region.

4. The cover ring according to any preceding clause, wherein the fluid comprises air.

5. The cover ring according to any preceding clause, wherein the cross-sectional shape of the flexible structure in the first state is different from the cross-sectional shape of the flexible structure in the second state.

6. The cover ring according to any preceding clause, wherein the flexible structure comprises a bellow.

7. The cover ring according to any preceding clause, wherein a neutral state of the flexible structure is between the first state and the second state.

8. The cover ring according to any preceding clause, wherein, when there is a substrate in the opening of the flexible structure and the flexible structure is in the first state, the average separation between the outer surface of the substrate and the inner surface of the flexible structure is greater than about 125μm, and preferably about 200μm.

9. The cover ring according to any preceding clause, wherein, when there is a substrate in the opening of the flexible structure and the flexible structure is in the second state, the average separation between the outer surface of the substrate and the inner surface of the flexible structure is less than about 35μm, and preferably less than about 5μm.

10. The cover ring according to any preceding clause, wherein the flexible structure comprises a plurality of segments arranged around the opening;

each segment comprises an enclosed region and is configured to change between a first state and a second state in response to a fluid flow into, or a fluid flow out of, the enclosed region; and

fluid flows to the plurality of enclosed regions are independently controllable so as to change the shape and/or diameter of the opening.

11. The cover ring according to any preceding clause, wherein a cross-section through part of the flexible structure comprises:

a first surface for providing an upper surface of the cover ring;

a second surface for providing a substrate facing surface of the cover ring; and a corner between the first surface and the second surface;

wherein, when the cover ring changes between the first state and the second state, the first surface and/or second surface are arranged to bend and/or stretch; and/or

the second surface is arranged to bend around the corner.

12. The cover ring according to clause 11, wherein the corner has a smooth curvature.

13. The cover ring according to clause 11 or 12, wherein the corner between the first surface and the second surface is a first corner, and the cross-section through part of the flexible structure further comprises:

a third surface for providing a lower surface of the cover ring that faces away from the second surface;

a fourth surface for providing a lower surface of the cover ring that faces towards the third surface;

a second corner between the second surface and the third surface;

a third corner between the third surface and the fourth surface;

a fourth corner that is a connection between the fourth surface and a main body of the cover ring;

wherein, when the cover ring changes between the first state and the second state, the third surface and/or fourth surface are arranged to bend and/or stretch; and/or

the third surface is arranged to bend around the third corner; and/or

the fourth surface is arranged to bend around the fourth corner.

14. The cover ring according to clause 13, wherein the cover ring further comprises a flexible cover arranged to substantially close a region that is bounded by the third surface, the fourth surface and an outer surface of the flexible cover.

15. The cover ring according to clause 11 or 12, wherein the corner between the first surface and the second surface is a first corner, and the cross-section through part of the flexible structure further comprises:

a third surface for providing a lower surface of the cover ring that faces in an opposite direction to the first surface;

a fourth surface for providing a lower surface of the cover ring that faces in the same direction as the second surface;

a second corner between the second surface and the third surface;

a third corner between the third surface and the fourth surface;

a fourth corner that is a connection between the fourth surface and a main body of the cover ring;

wherein, when the cover ring changes between the first state and the second state, the third surface and/or fourth surface are arranged to bend and/or stretch; and/or

the third surface is arranged to bend around the third corner; and/or

the fourth surface is arranged to bend around the fourth corner.

16. The cover ring according to clause 11 or 12, wherein the corner between the first surface and the second surface is a first corner, and the cross-section through part of the flexible structure further comprises:

a third surface for providing a lower surface of the cover ring that faces in an opposite direction to the first surface;

a fourth surface for providing a lower surface of the cover ring that faces in the opposite direction to the second surface;

a fifth surface for providing a lower surface of the cover ring that faces towards the fourth surface;

a second corner between the second surface and the third surface;

a third corner between the third surface and the fourth surface;

a fourth corner between the fourth surface and the fifth surface;

a fifth corner that is a connection between the fifth surface and a main body of the cover ring;

wherein, when the cover ring changes between the first state and the second state, the third surface, the fourth surface and/or fifth surface are arranged to bend and/or stretch; and/or

the third surface is arranged to bend around the third corner; and/or

the fourth surface is arranged to bend around the fourth corner; and or

the fifth surface is arranged to bend around the fifth corner.

17. The cover ring according to any of clauses 13 to 16, wherein the fourth surface is more flexible than the third surface.

18. The cover ring according to any of clauses 11 to 17, wherein the second surface is more flexible than the first surface.

19. The cover ring according to any of clauses 11 to 18, wherein the neutral state of each surface of the flexible structure is substantially straight.

20. A substrate support configured to support a substrate, the substrate support comprising the cover ring according to any preceding clause; and

a support body;

wherein the support body comprises an annular venting groove in its substrate facing surface; and

a fluid supply arranged to supply fluid to the venting groove.

21. The substrate support according to clause 20, wherein the fluid supply is arranged to supply air to the venting groove.

22. The substrate support according to clause 20 or 21, wherein, when a substrate is supported by the substrate support, in plan view the venting groove is close to, or at, the edge of the substrate.

23. A lithographic apparatus comprising the substrate support according to any of clauses 20 to 22.

24. The lithographic apparatus according to clause 23, further comprising a control system arranged to control the state of the flexible structure so as to change the diameter and/or shape of the opening for a substrate.

25. The lithographic apparatus according to clause 24, wherein the control system is arranged to control the state of the flexible structure in dependence on a determined diameter and/or shape of a substrate in the opening.

26. The lithographic apparatus according to clause 24 or 25, wherein the control system is arranged to control the state of the flexible structure in dependence on the relative location of a substrate that is loaded on the substrate support relative to a fluid handling structure of the lithographic apparatus through which a radiation beam is projected.

27. The lithographic apparatus according to any of clauses 23 to 26, wherein the lithographic apparatus is configured to perform immersion lithography.

28. The lithographic apparatus according to any of clauses 23 to 27, wherein the lithographic apparatus is a DUV lithographic apparatus.

29. A method for supporting a substrate, the method comprising use of the substrate support according to any of clauses 20 to 22.

30. A method for performing lithography, the method comprising projecting a radiation beam onto a substrate in an exposure operation;
wherein the substrate is supported by the substrate support according to any of clauses 20 to 22.

31. The method according to clause 30, further comprising controlling the state of the cover ring of the substrate support in dependence on the location of the substrate relative to a fluid handling structure through which the radiation beam is projected.

32. A cover ring for use in a substrate support, the cover ring comprising:
an aperture mechanism with an opening for receiving a substrate;
wherein the aperture mechanism comprises a plurality of curved segments that are arranged to move, in directions that are at least partial rotations about the mid-point of the opening, so as to change the diameter and/or shape of the opening.

33. The cover ring according to clause 32, further comprising an actuation system arranged to move the segments of the aperture mechanism;
wherein the actuation system comprises one or more piezo-electric actuators, one or more pneumatic actuators, and/or one or more hydraulic actuators.

34. The cover ring according to clause 33, wherein the actuation system is arranged to independently move at least two of the segments of the aperture mechanism.

35. The cover ring according to any of clauses 32 to 34, wherein the movement of the segments to change the diameter and/or shape of the opening comprises contacting surfaces of adjacent segments sliding relative to each other.

36. The cover ring according to any of clauses 32 to 35, wherein each segment comprises openings so that it is gas permeable.

37. The cover ring according to clause 36, wherein the diameters of the openings are too small to allow substantial liquid flow through the openings.

38. The cover ring according to any of clauses 32 to 37, wherein an upper surface of each segment has a first coating.

39. The cover ring according to clause 38, wherein the first coating is hydrophobic or hydrophilic.

40. The cover ring according to any of clauses 32 to 39, wherein a lower surface of each segment has a second coating.

41. The cover ring according to clause 40, wherein the second coating is hydrophobic.

42. A substrate support configured to support a substrate, the substrate support comprising the cover ring according to any of clauses 32 to 41; and

a support body;

wherein the support body comprises an annular venting groove in its substrate facing surface; and

a fluid supply arranged to supply fluid to the venting groove.

43. The substrate support according to clause 42, wherein the fluid supply is arranged to supply air to the venting groove.

44. The substrate support according to clause 42 or 43, wherein, when a substrate is supported by the substrate support, in plan view the venting groove is close to, or at, the edge of the substrate.

45. A lithographic apparatus comprising the substrate support according to any of clauses 42 to 44.

46. The lithographic apparatus according to clause 45, further comprising a control system arranged to control the aperture mechanism so as to change the diameter and/or shape of the opening for a substrate.

47. The lithographic apparatus according to clause 46, wherein the control system is arranged to control the state of the aperture mechanism in dependence on a determined diameter and/or shape of a substrate in the opening.

48. The lithographic apparatus according to clause 46 or 47, wherein the control system is arranged to control the state of the aperture mechanism in dependence on the relative location of a substrate that is loaded on the substrate support relative to a fluid handling structure of the lithographic apparatus through which a radiation beam is projected.

49. The lithographic apparatus according to any of clauses 45 to 48, wherein the lithographic apparatus is configured to perform immersion lithography.

50. The lithographic apparatus according to any of clauses 45 to 49, wherein the lithographic apparatus is a DUV lithographic apparatus.

51. A method for supporting a substrate, the method comprising use of the substrate support according to any of clauses 42 to 44.

52. A method for performing lithography, the method comprising projecting a radiation beam onto a substrate in an exposure operation;

wherein the substrate is supported by the substrate support according to any of clauses 42 to 44.

53. The method according to clause 52, further comprising controlling the state of the cover ring of the substrate support in dependence on the location of the substrate relative to a fluid handling structure through which the radiation beam is projected.

[0119] The present invention may provide a lithographic apparatus. The lithographic apparatus may have any/all of the other features or components of the lithographic apparatus as described above. For example, the lithographic apparatus may optionally comprise at least one or more of a source SO, an illumination system IL, a projection system PS, a substrate support WT, etc..

[0120] Specifically, the lithographic apparatus may comprise the projection system PS configured to project the radiation beam B towards the region of the surface of a substrate W. The lithographic apparatus may further comprise the substrate support 300, 400, 500 as described in any of the above embodiments and variations.

[0121] Although specific reference may be made in this text to the use of a lithographic apparatus in the manufacture of ICs, it should be understood that the lithographic apparatus described herein may have other applications. Possible other applications include 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.

[0122] Where the context allows, embodiments of the invention may be implemented in hardware, firmware, software, or any combination thereof. Embodiments of the invention may also be implemented by instructions stored on a machine-readable medium, which may be read and executed by one or more processors. A machine-readable medium may include any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computing device). For example, a machine-readable medium may include read only memory (ROM); random access memory (RAM); magnetic storage media; optical storage media; flash memory devices; electrical, optical, acoustical or other forms of propagated signals (e.g. carrier waves, infrared signals, digital signals, etc.), and others. Further, firmware, software, routines, instructions may be described herein as performing certain actions. However, it should be appreciated that such descriptions are merely for convenience and that such actions in fact result from computing devices, processors, controllers, or other devices executing the firmware, software, routines, instructions, etc. and in doing that may cause actuators or other devices to interact with the physical world.

[0123] Although specific reference may be made in this text to embodiments of the invention in the context of a lithographic apparatus, embodiments of the invention may be used in other apparatus. Embodiments of the invention may form part of a mask inspection apparatus, a metrology apparatus, or any apparatus that measures or processes an object such as a wafer (or other substrate) or mask (or other patterning device). These apparatus may be generally referred to as lithographic tools.

[0124] 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, where the context allows, is not limited to optical lithography.

[0125] 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 set out below.

CLAIMS

1. A cover ring for use in a substrate support, the cover ring comprising:

a flexible structure with an opening for receiving a substrate;

an enclosed region within the cover ring; and

a fluid conduit configured provide fluid to and/or receive fluid from the enclosed region;

wherein the flexible structure is configured to change between a first state and a second state in response to a fluid flow into, or a fluid flow out of, the enclosed region; and

in the first state the diameter of the opening is larger than in the second state.

2. The cover ring according to claim 1, wherein the flexible structure is configured to change from the first state to the second state in response to a fluid flow into the enclosed region, and/or wherein the flexible structure is configured to change from the second state to the first state in response to a fluid flow out of the enclosed region.

3. The cover ring according to claim 1 or 2, wherein the fluid comprises air, and/or wherein the cross-sectional shape of the flexible structure in the first state is different from the cross-sectional shape of the flexible structure in the second state, and/or wherein the flexible structure comprises a bellow, and/or wherein a neutral state of the flexible structure is between the first state and the second state, and/or wherein, when there is a substrate in the opening of the flexible structure and the flexible structure is in the first state, the average separation between the outer surface of the substrate and the inner surface of the flexible structure is greater than about 125μm, and preferably about 200μm, and/or wherein, when there is a substrate in the opening of the flexible structure and the flexible structure is in the second state, the average separation between the outer surface of the substrate and the inner surface of the flexible structure is less than about 35μm, and preferably less than about 5μm.

4. The cover ring according to any preceding claim, wherein the flexible structure comprises a plurality of segments arranged around the opening;

each segment comprises an enclosed region and is configured to change between a first state and a second state in response to a fluid flow into, or a fluid flow out of, the enclosed region; and

fluid flows to the plurality of enclosed regions are independently controllable so as to change the shape and/or diameter of the opening, and/or

wherein a cross-section through part of the flexible structure comprises:

a first surface for providing an upper surface of the cover ring;

a second surface for providing a substrate facing surface of the cover ring; and a corner between the first surface and the second surface;

wherein, when the cover ring changes between the first state and the second state, the first surface and/or second surface are arranged to bend and/or stretch; and/or

the second surface is arranged to bend around the corner,

desirably wherein the corner has a smooth curvature.

5. The cover ring according to claim 4, wherein the corner between the first surface and the second surface is a first corner, and the cross-section through part of the flexible structure further comprises:

a third surface for providing a lower surface of the cover ring that faces away from the second surface;

a fourth surface for providing a lower surface of the cover ring that faces towards the third surface;

a second corner between the second surface and the third surface;

a third corner between the third surface and the fourth surface;

a fourth corner that is a connection between the fourth surface and a main body of the cover ring;

wherein, when the cover ring changes between the first state and the second state, the third surface and/or fourth surface are arranged to bend and/or stretch; and/or

the third surface is arranged to bend around the third corner; and/or

the fourth surface is arranged to bend around the fourth corner, or

wherein the corner between the first surface and the second surface is a first corner, and the cross-section through part of the flexible structure further comprises:

a third surface for providing a lower surface of the cover ring that faces in an opposite direction to the first surface;

a fourth surface for providing a lower surface of the cover ring that faces in the same direction as the second surface;

a second corner between the second surface and the third surface;

a third corner between the third surface and the fourth surface;

a fourth corner that is a connection between the fourth surface and a main body of the cover ring;

wherein, when the cover ring changes between the first state and the second state, the third surface and/or fourth surface are arranged to bend and/or stretch; and/or

the third surface is arranged to bend around the third corner; and/or

the fourth surface is arranged to bend around the fourth corner, or

wherein the corner between the first surface and the second surface is a first corner, and the cross-section through part of the flexible structure further comprises:

a third surface for providing a lower surface of the cover ring that faces in an opposite direction to the first surface;

a fourth surface for providing a lower surface of the cover ring that faces in the opposite direction to the second surface;

a fifth surface for providing a lower surface of the cover ring that faces towards the fourth surface;

a second corner between the second surface and the third surface;

a third corner between the third surface and the fourth surface;

a fourth corner between the fourth surface and the fifth surface;

a fifth corner that is a connection between the fifth surface and a main body of the cover ring;

wherein, when the cover ring changes between the first state and the second state, the third surface, the fourth surface and/or fifth surface are arranged to bend and/or stretch; and/or

the third surface is arranged to bend around the third corner; and/or

the fourth surface is arranged to bend around the fourth corner; and or

the fifth surface is arranged to bend around the fifth corner.

6. The cover ring according to claim 5, wherein the cover ring further comprises a flexible cover arranged to substantially close a region that is bounded by the third surface, the fourth surface and an outer surface of the flexible cover, and/or wherein the fourth surface is more flexible than the third surface, and/or wherein the second surface is more flexible than the first surface, and/or wherein the neutral state of each surface of the flexible structure is substantially straight.

7. A substrate support configured to support a substrate, the substrate support comprising the cover ring according to any preceding claim; and

a support body;

wherein the support body comprises an annular venting groove in its substrate facing surface; and

a fluid supply arranged to supply fluid to the venting groove.

8. The substrate support according to claim 7, wherein the fluid supply is arranged to supply air to the venting groove, and/or wherein, when the substrate is supported by the substrate support, in plan view the venting groove is close to, or at, the edge of the substrate.

9. A lithographic apparatus comprising the substrate support according to claim 7 or 8.

10. The lithographic apparatus according to claim 9, further comprising a control system arranged to control the state of the flexible structure so as to change the diameter and/or shape of the opening for a substrate, desirably wherein the control system is arranged to control the state of the flexible structure in dependence on a determined diameter and/or shape of a substrate in the opening, and/or wherein the control system is arranged to control the state of the flexible structure in dependence on the relative location of a substrate that is loaded on the substrate support relative to a fluid handling structure of the lithographic apparatus through which a radiation beam is projected, and/or wherein the lithographic apparatus is configured to perform immersion lithography, and/or wherein the lithographic apparatus is a DUV lithographic apparatus..

11. A method for supporting a substrate, the method comprising use of the substrate support according to claim 7 or 8.

12. A method for performing lithography, the method comprising projecting a radiation beam onto a substrate in an exposure operation;

wherein the substrate is supported by the substrate support according to claim 7 or 8.

13. The method according to claim 12, further comprising controlling the state of the cover ring of the substrate support in dependence on the location of the substrate relative to a fluid handling structure through which the radiation beam is projected.

Fig. 1

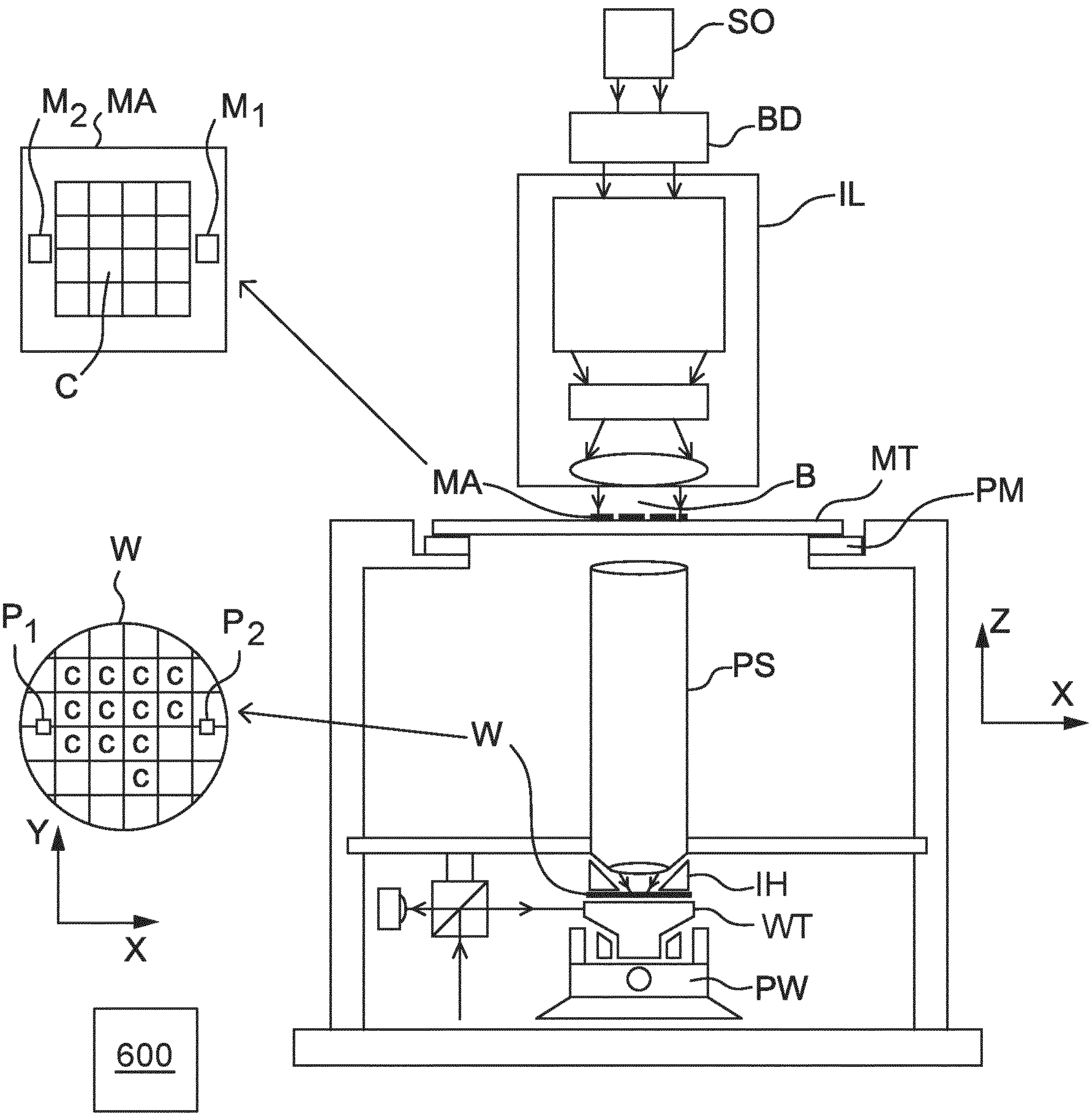
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Fig. 2

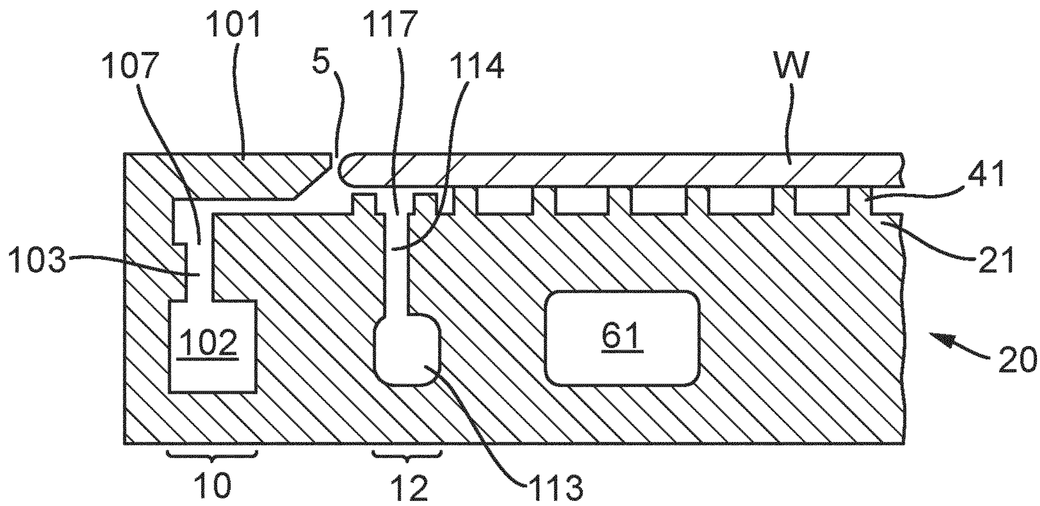

Fig. 3A

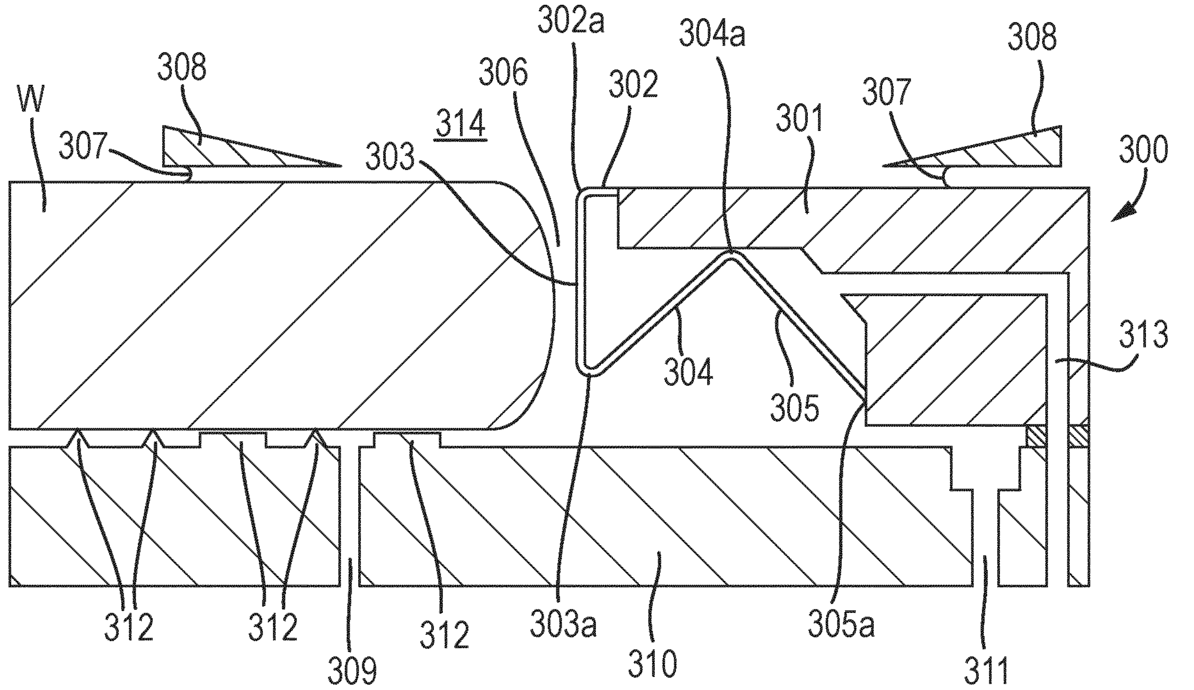
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Fig. 3B

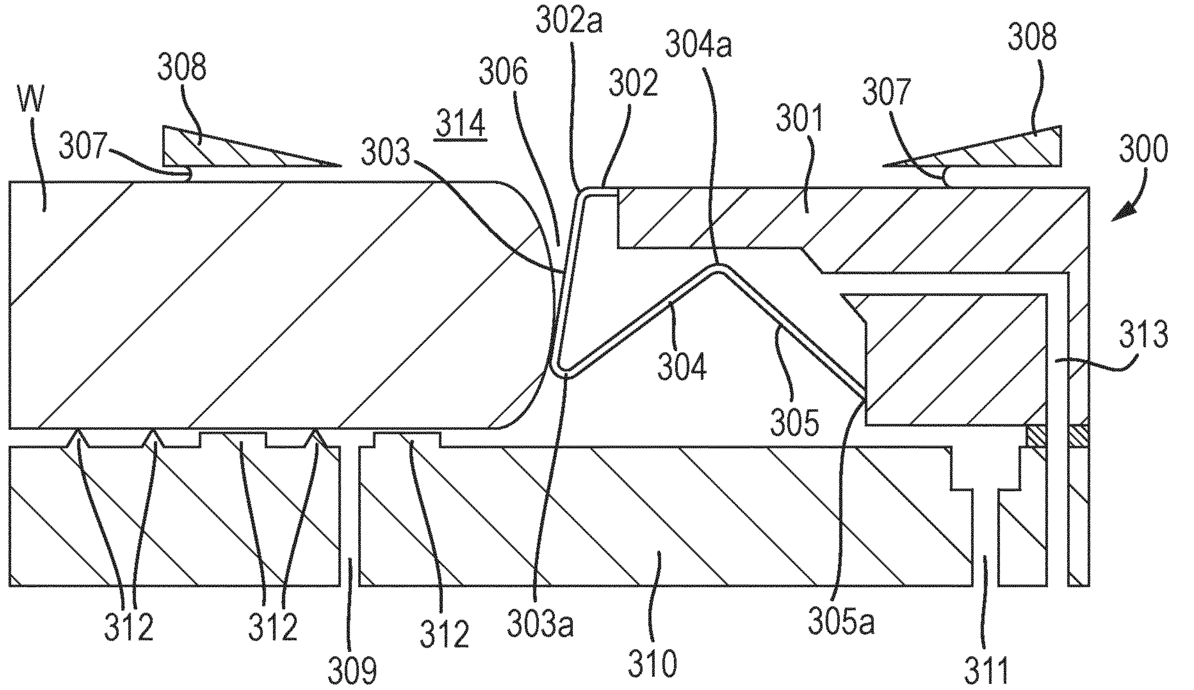
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Fig. 4A

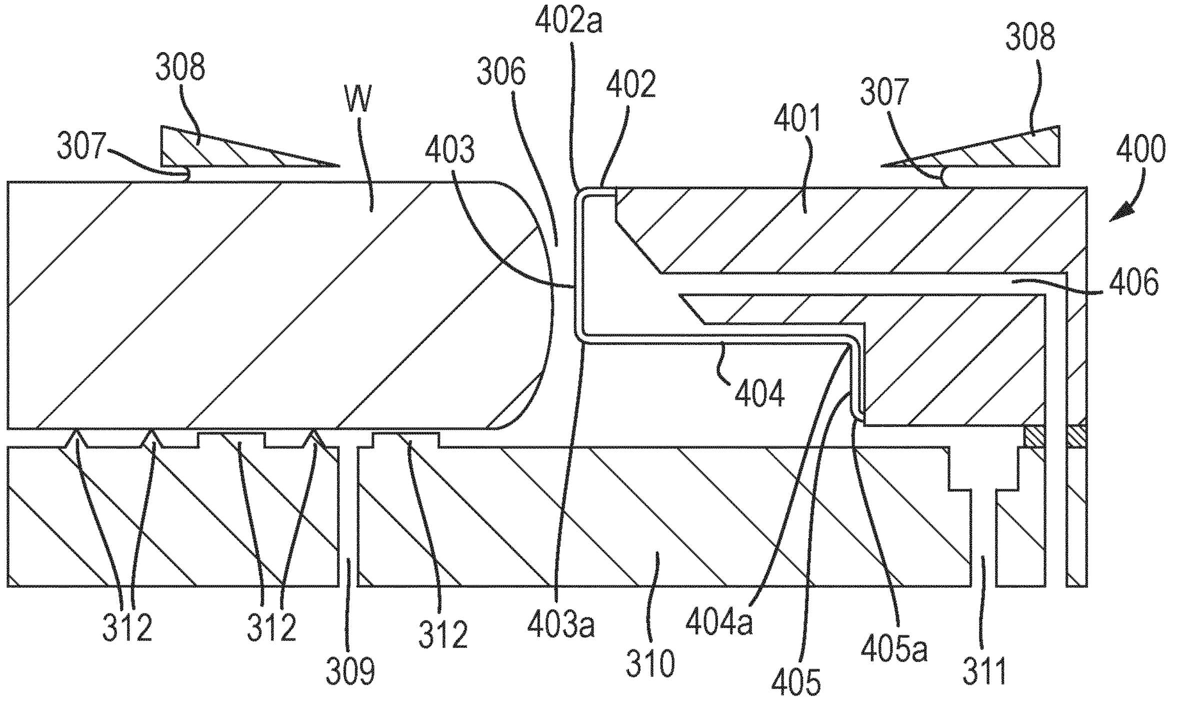
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Fig. 4B

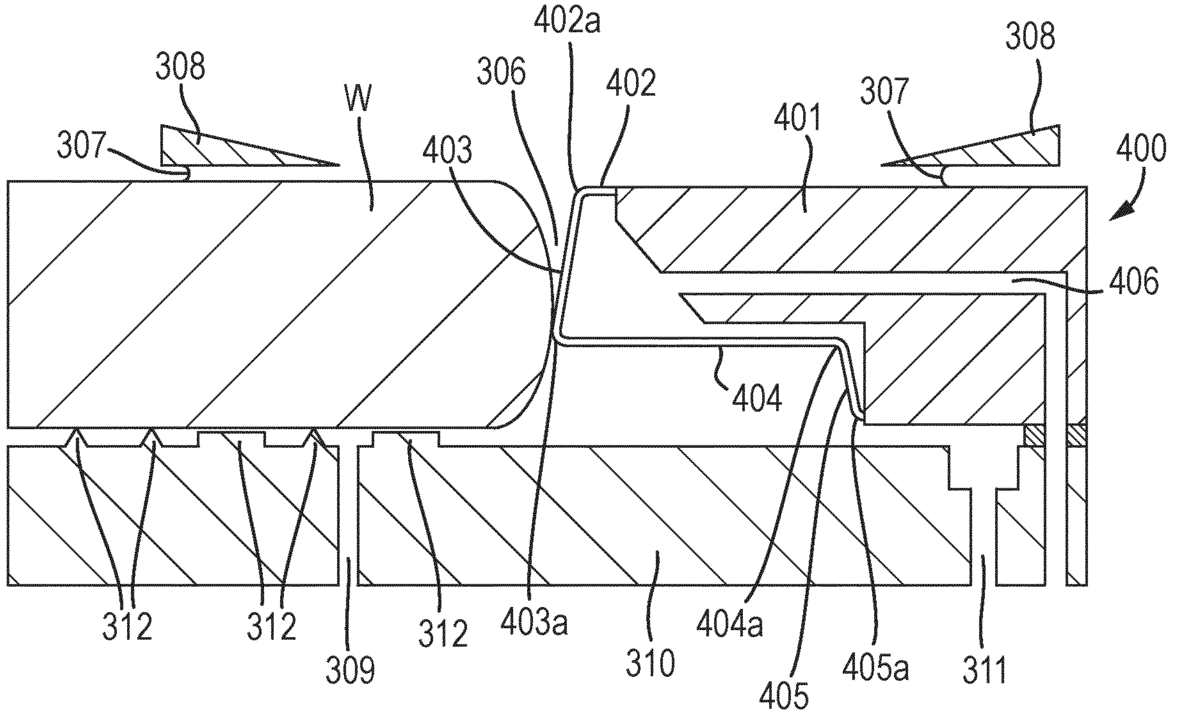
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Fig. 5A

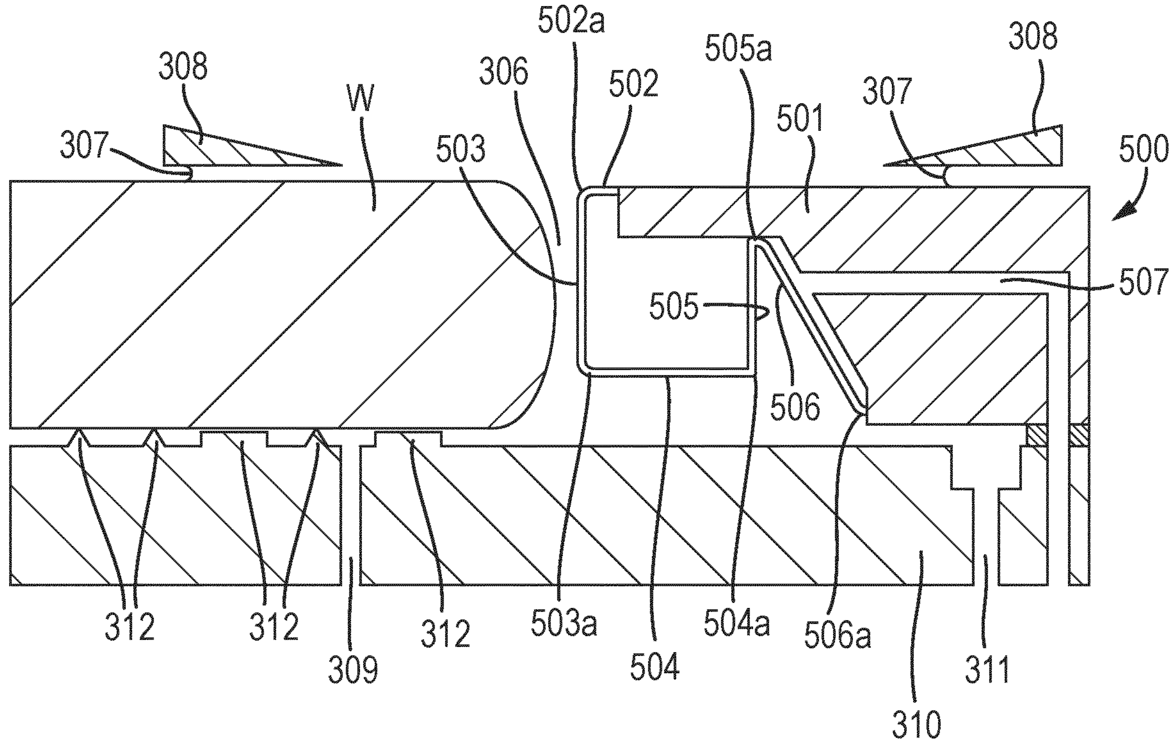
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Fig. 5B

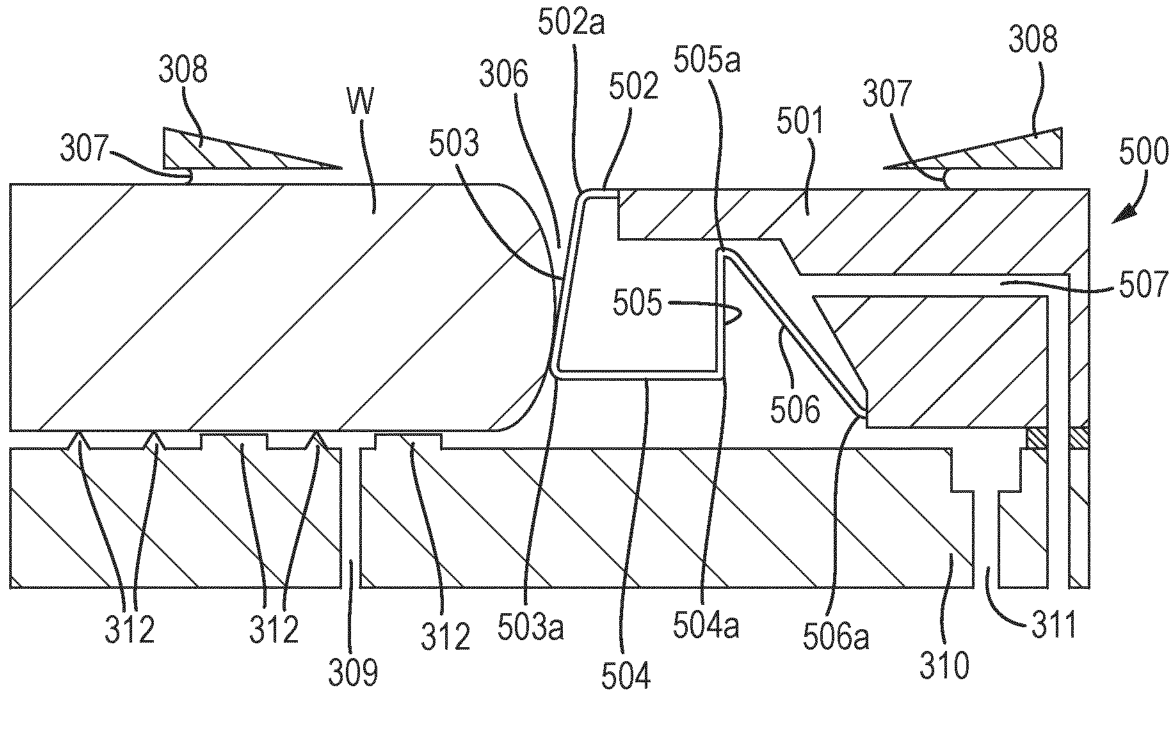
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Fig. 6A

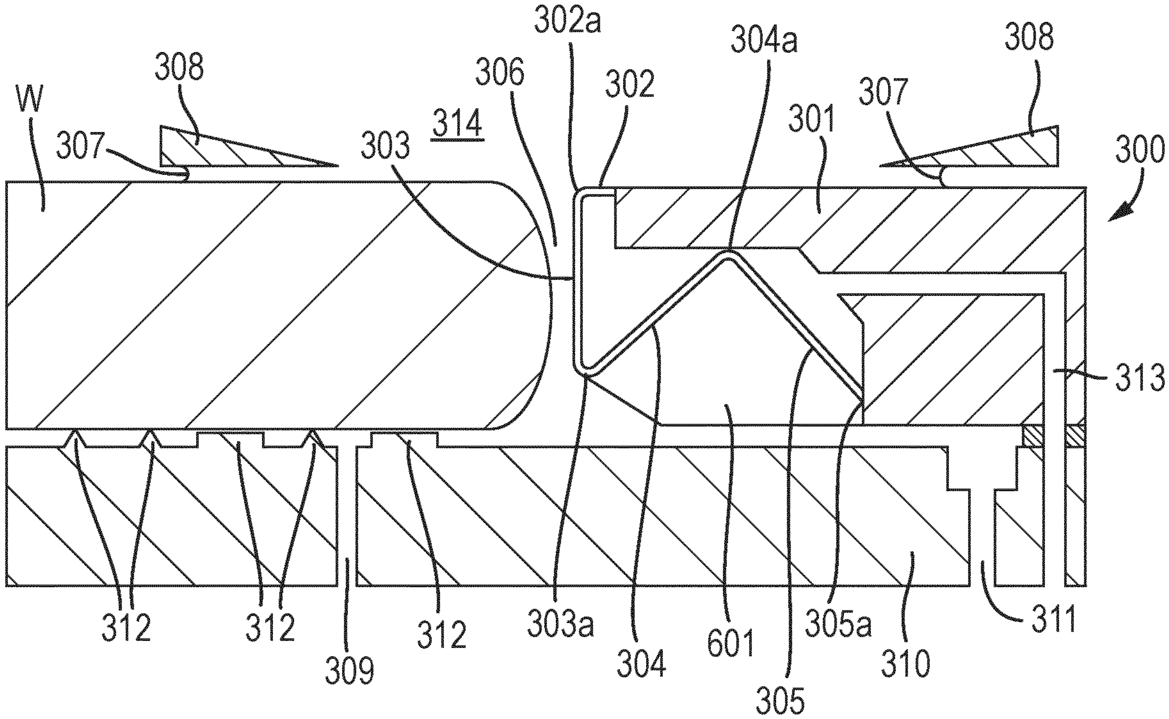
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Fig. 6B

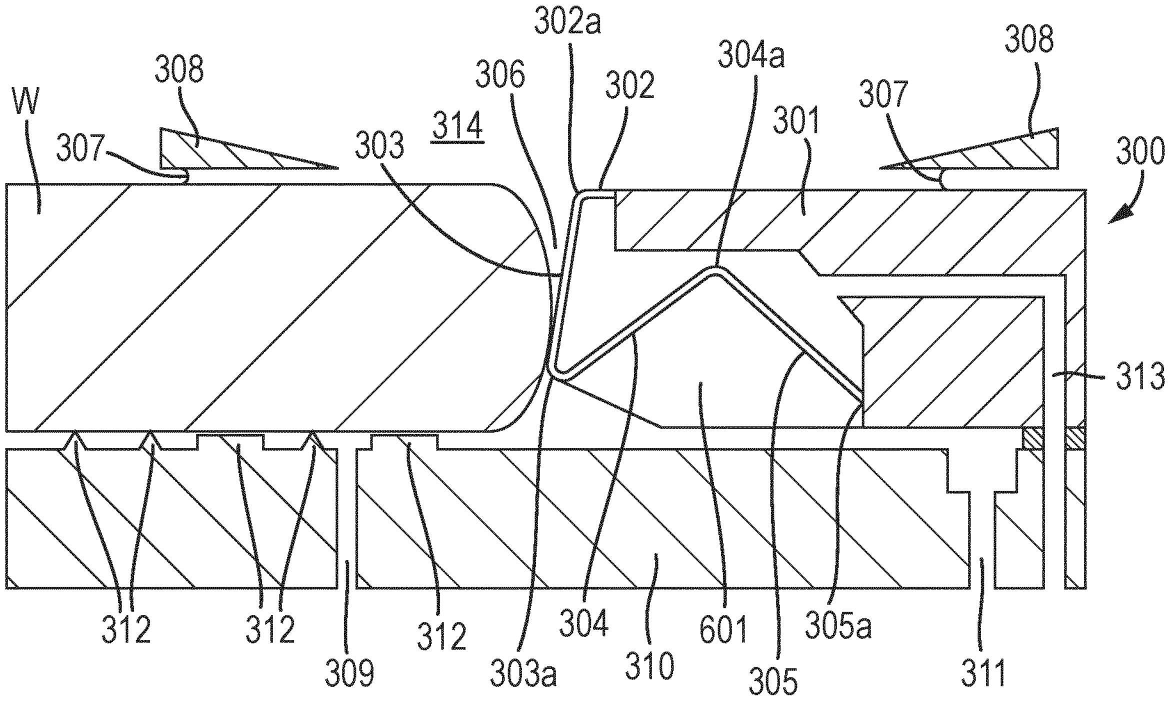
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Fig. 7A

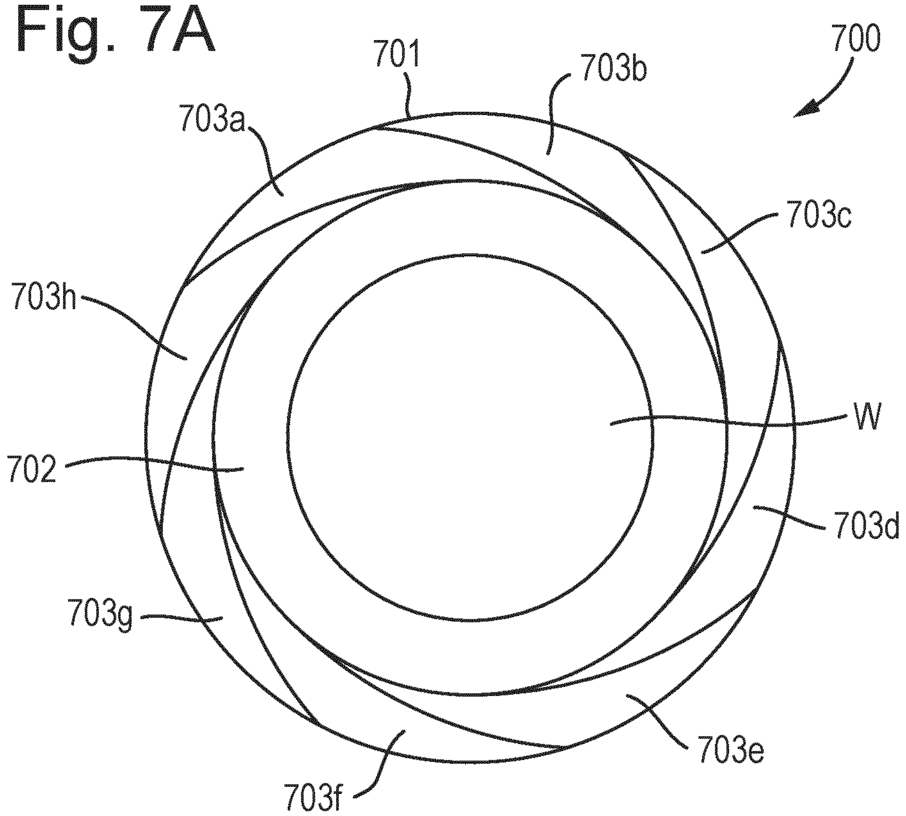
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Fig. 7B

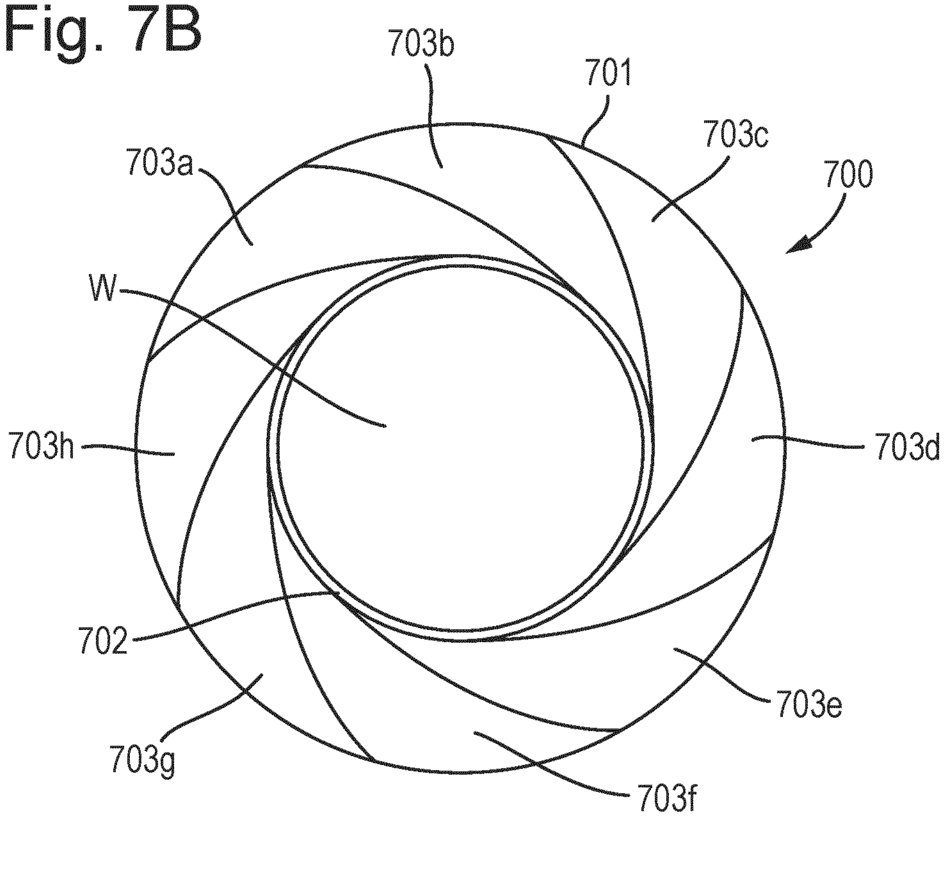
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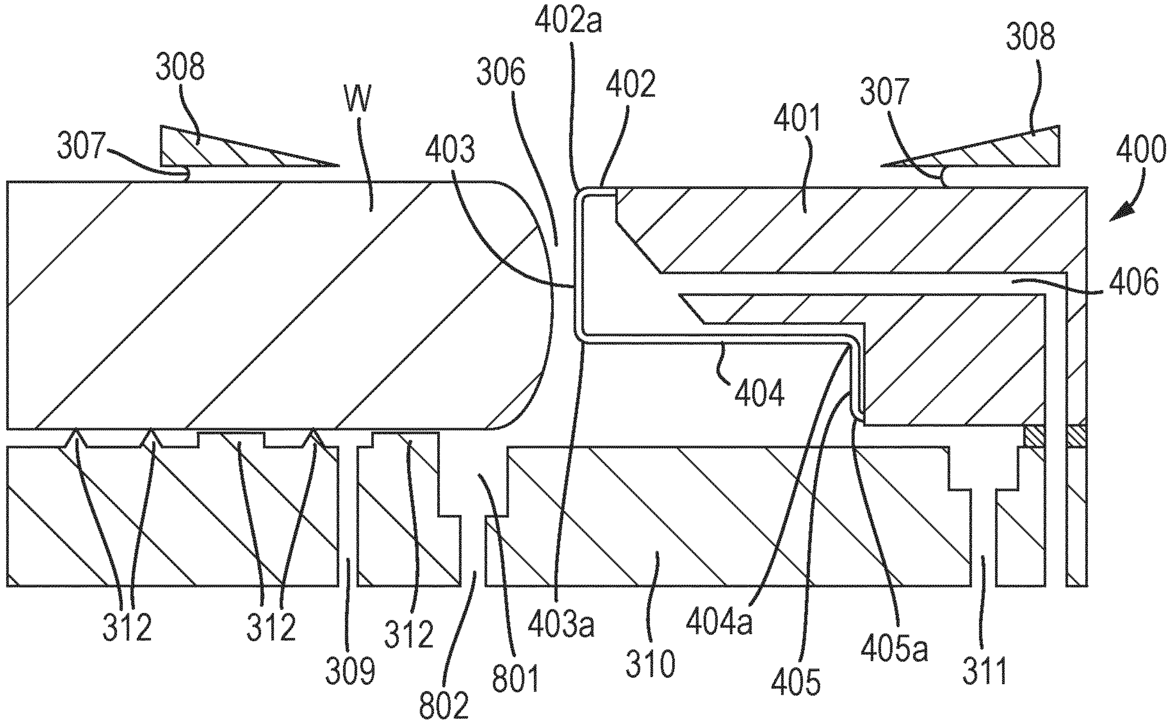
Fig. 8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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/054926

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F7/00 H01L21/687
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G03F H01L

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	US 5 294 257 A (KELLY HOWARD L [US] ET AL) 15 March 1994 (1994-03-15) column 3, line 41 - column 5, line 20 figures 1,2	1-3,7,8, 11 4,9,10, 12,13 5,6
Y A	US 2004/160582 A1 (LOF JOERI [NL] ET AL) 19 August 2004 (2004-08-19) paragraph [0095] - paragraph [0463] figures 1-4,12-15	4,9,10, 12,13 1,11
A	WO 2021/032356 A1 (ASML NETHERLANDS BV [NL]) 25 February 2021 (2021-02-25) the whole document	1,11

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"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
12 June 2024	25/06/2024

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	Meixner, Matthias

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

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