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A lithographic apparatus and cooling apparatus

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A lithographic apparatus comprising: a projection system configured to project a patterned radiation beam via a projection path onto an exposure area at a substrate held on a substrate table that is moveable in a region underneath the projection system; and a cooling apparatus configured to cool the substrate via heat transfer from the substrate to a cooling element positioned above the substrate and adjacent the projection path; wherein the cooling apparatus comprises a membrane system positioned in the projection path so as to physically separate the projection system from the region.

A lithographic apparatus and cooling apparatus

FIELD

[0001] The present invention relates to a lithographic apparatus and a lithographic method. The present invention also relates to a cooling apparatus.

BACKGROUND

[0002] A lithographic apparatus is a machine constructed to apply a desired pattern onto a substrate. A lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). A lithographic apparatus may, for example, project a pattern at a patterning device (e.g., a mask) onto a layer of radiation-sensitive material (resist) provided on a substrate.

[0003] 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 can be formed on the substrate. A lithographic apparatus, which uses extreme ultraviolet (EUV) radiation, having a wavelength within the range 4-20 nm, for example 6.7 nm or 13.5 nm, may be used to form smaller features on a substrate than a lithographic apparatus which uses, for example, radiation with a wavelength of 193 nm.

[0004] There is a risk of contaminants coming from the substrate (e.g. gas-phase organic compounds coming from resist on the substrate) reaching optical components (i.e. the projection system) of the lithographic apparatus.

[0005] It may be desirable to provide a lithographic apparatus which addresses the problem identified above or some other problem associated with the prior art.

SUMMARY

[0006] According to a first aspect of the invention, there is provided a lithographic apparatus comprising: a projection system configured to project a patterned radiation beam via a projection path onto an exposure area at a substrate held on a substrate table that is moveable in a region underneath the projection system; and a cooling apparatus configured to cool the substrate via heat transfer from the substrate to a cooling element positioned above the substrate and adjacent the projection path; wherein the cooling apparatus comprises a membrane system positioned in the projection path so as to physically separate the projection system from the region.

[0007] This has an advantage of isolating the projection system from the region such that gas and/or contaminants cannot enter the projection system from the region. An advantage may be the removal of parasitic heat loads, related heatshields, conditioning solutions and reduction in pumping power when compared to other systems.

[0008] The gas flow system may be configured to provide a flow of a gas below the membrane system. This may provide an advantage of increasing the fly height of the cooling apparatus.

[0009] The gas flow system may be configured to provide the flow of the gas between the cooling element and the substrate, the flow may be configured to increase heat transfer from the substrate to the cooling element.

[00010] The gas flow system may be configured to provide the flow of the gas onto the exposure area on the substrate. This may provide more efficient cooling of the substrate W.

[00011] The gas flow system may comprise a gas delivery conduit in the cooling apparatus.

[00012] The gas may comprise nitrogen. This has an advantage that nitrogen is 5 times more stable than hydrogen with respect to the thermal accommodation coefficient (TAC) for different surface materials.

[00013] The lithographic apparatus may further comprise an additional gas flow system which may be configured to provide a flow of an additional gas above the membrane system. This may avoid contamination at the membrane.

[00014] The membrane system may comprise a single membrane. An advantage may be the provision of a more robust membrane.

[00015] The membrane system may comprise a first membrane and a second membrane.

[00016] The lithographic apparatus may further comprise a further gas flow system which may be configured to provide a flow of a further gas through a volume defined by the cooling apparatus, the first membrane and the second membrane. This may provide an advantage of increased cooling of one or both of the membranes.

[00017] The lithographic apparatus may further comprise a barrier positioned at an outer periphery of the cooling apparatus and extending outwards and/or upwards from the cooling apparatus.

[00018] The barrier may be connected to the cooling apparatus.

[00019] The cooling apparatus may comprise a slit which is configured such that the projection path passes through the slit, wherein the membrane system may physically close the slit.

[00020] The cooling element may comprise fingers extending away from a body of the cooling element towards the substrate, wherein the membrane system may be positioned between the fingers. This may have the advantage of providing better distribution of the cooling flow below the membrane for cleaning purposes.

[00021] The gas flow system may be configured to provide the flow of gas out from the fingers.

[00022] According to a second aspect of the invention, there is provided a cooling apparatus configured for use in the lithographic apparatus as described above. According to a third aspect of the invention, there is provided a lithographic method comprising: projecting a patterned radiation beam through a projection system via a projection path to form an exposure area on a substrate held on a substrate table, and using a cooling apparatus to cool the substrate via a cooling element positioned above the substrate and adjacent the projection path, the cooling element acting to remove heat from the substrate, wherein the cooling apparatus comprises a membrane system positioned in the projection path so as to physically separate the projection system from the region.

[00023] The lithographic method may further comprise providing a flow of gas below the membrane system from a gas flow system.

[00024] The lithographic method may further comprise providing the flow of gas between the cooling element and the substrate, the flow may be configured to increase heat transfer from the substrate to the cooling element.

[00025] The lithographic method may further comprise providing a flow of a further gas from a further gas system through a volume defined by the cooling apparatus, a first membrane and a second membrane of the membrane system.

BRIEF DESCRIPTION OF THE DRAWINGS

[00026] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings, in which:

- Figure 1 depicts a lithographic system comprising a lithographic apparatus and a radiation source according to an embodiment of the invention;

- Figure 2 depicts a schematic cross sectional side view of a cooling apparatus and a barrier above a substrate according to an embodiment of the invention;

- Figure 3 depicts a schematic cross sectional view of a cooling apparatus, a barrier and a funnel according to an embodiment of the invention;

- Figure 4a depicts a perspective view of a cooling apparatus above a substrate according to an embodiment of the invention;

- Figure 4b depicts a perspective view of a cooling apparatus above a substrate according to an embodiment of the invention;

- Figure 5 depicts a schematic cross sectional side view of a cooling apparatus according to an embodiment of the invention;

- Figure 6 depicts a cross sectional view of the cooling apparatus taken through line A-A' of Figure 5 according to an embodiment of the invention.

DETAILED DESCRIPTION:

[00027] Figure 1 shows a lithographic system comprising a radiation source SO and a lithographic apparatus LA. The radiation source SO is configured to generate an EUV radiation beam B and to supply the EUV radiation beam B to the lithographic apparatus LA. The lithographic apparatus LA comprises an illumination system IL, a support structure MT configured to support a patterning device MA (e.g., a mask), a projection system PS and a substrate table WT configured to support a substrate W.

[00028] The illumination system IL is configured to condition the EUV radiation beam B before the EUV radiation beam B is incident upon the patterning device MA. Thereto, the illumination system IL may include a faceted field mirror device 10 and a faceted pupil mirror device 11. The faceted

field mirror device 10 and faceted pupil mirror device 11 together provide the EUV radiation beam B with a desired cross-sectional shape and a desired intensity distribution. The illumination system IL may include other mirrors or devices in addition to, or instead of, the faceted field mirror device 10 and faceted pupil mirror device 11.

5 [00029] After being thus conditioned, the EUV radiation beam B interacts with the patterning device MA. As a result of this interaction, a patterned EUV radiation beam B' is generated. The projection system PS is configured to project the patterned EUV radiation beam B' onto the substrate W. For that purpose, the projection system PS may comprise a plurality of mirrors 13,14 which are configured to project the patterned EUV radiation beam B' onto the substrate W held by the substrate
10 table WT. The projection system PS may apply a reduction factor to the patterned EUV radiation beam B', thus forming an image with features that are smaller than corresponding features on the patterning device MA. For example, a reduction factor of 4 or 8 may be applied. Although the projection system PS is illustrated as having only two mirrors 13, 14 in Figure 1, the projection system PS may include a different number of mirrors (e.g. six or eight mirrors).

15 [00030] The substrate W may include previously formed patterns. Where this is the case, the lithographic apparatus LA aligns the image, formed by the patterned EUV radiation beam B', with a pattern previously formed on the substrate W.

[00031] A relative vacuum, i.e. a small amount of gas (e.g. hydrogen) at a pressure well below atmospheric pressure, may be provided in the radiation source SO, in the illumination system IL, and/or
20 in the projection system PS.

[00032] The radiation source SO may be a laser produced plasma (LPP) source, a discharge produced plasma (DPP) source, a free electron laser (FEL) or any other radiation source that is capable of generating EUV radiation.

[00033] The projection system PS is configured to project the patterned EUV radiation beam B' via
25 a projection path onto an exposure area on the substrate W. The substrate table WT is moveable in a region 18 (shown in dashed lines) underneath the projection system PS.

[00034] The lithographic apparatus comprises a cooling apparatus 20 located above the substrate W. The cooling apparatus 20 provides localised cooling of the substrate W in the vicinity of the radiation beam B. The cooling apparatus 20 is described in detail further below.

30 [00035] Figure 2 shows the cooling apparatus 20 positioned above the substrate W. The cooling apparatus 20 comprises a first cooling element 22 and a second cooling element 24. In some examples, the cooling apparatus 20 may have a single cooling element. The region 18 in which the substrate table WT is moveable is shown schematically in dashed lines. The size of the region 18 depicted is only exemplary and it will be appreciated that the region may have any size as required, for example, the
35 region 18 may extend further in the y direction.

[00036] Cartesian coordinates are shown in Figure 2, and use the notation which is conventionally used for lithographic apparatus, i.e. the Y-direction is the direction of scanning movement of the

substrate W during exposure, the X-direction is transverse to the Y-direction and lies in the plane of the substrate, and the Z-direction generally corresponds with the optical axis of the radiation beam B.

[00037] The cooling elements 22, 24 are located either side of the radiation beam B' in the scanning direction (i.e. in the Y-direction). The cooling elements 22, 24 are positioned above the substrate W and adjacent the projection path of the patterned EUV radiation beam B'. The cooling elements 22, 24 are adjacent to an exposure area E (i.e. an area upon which the radiation beam B is incident). In this context the term "adjacent" may be interpreted as meaning less than 1 cm from an edge of the exposure area E. The cooling elements 22, 24 may be less than 0.5 cm from an edge of the exposure area E, and may be around 0.1 cm from an edge of the exposure area E. Each cooling element 22, 24 may be configured to cool an area which lies within 3 cm or less from a line which bisects the exposure area E. Each cooling element 22, 24 may be configured to cool an area which lies within 2 cm or less from an edge of the exposure area. In some examples, the first and second cooling elements 22, 24 may have the same overall construction.

[00038] The cooling elements 22, 24 provide localised cooling of the substrate W in areas which lie beneath the cooling elements 22, 24. Thus, during a scanning exposure of the substrate W in which the substrate W is moving in the positive Y-direction (from left to right in Figure 2) the first cooling element 22 cools part of the substrate that is about to be exposed by the radiation beam B and the second cooling element 24 cools part of the substrate W that has just been exposed by the radiation beam B'. If the scanning exposure moves the substrate W in the negative Y-direction (from right to left in Figure 2) then the second cooling element 24 provides cooling of part of the substrate that is about to be exposed by the radiation beam B' and the first cooling element 22 provides cooling of part of the substrate W that has just been exposed by the radiation beam B'.

[00039] Each cooling element 22, 24 is configured to receive heat from the substrate W and to transfer that heat to some other location, for example using a cooling fluid (e.g. water). In this context the term "cooling fluid" is not intended to imply that the fluid must have a particular temperature but instead indicates that the fluid transports heat away from the cooling element 22, 24. The cooling fluid is passed through cooling conduits 25A, 25B, 25C, 25D in the cooling elements 22, 24. The cooling elements 22, 24 may be kept at a relatively very low temperature, e.g. a temperature of -70 degrees Celsius.

[00040] The cooling apparatus 20 may counteract the high heating dose on the substrate W caused by the EUV radiation being incident on the exposure area E of the substrate W

[00041] Each cooling element 22, 24 comprises a body 26, 27 and a finger 28, 29 which extend from their respective body 26, 27 towards the substrate W. The fingers 28, 29 define a slit 30. More generally, the cooling apparatus 20 has a slit 30 which passes through the cooling apparatus 20. The slit 30 is arranged such that the projection path of the patterned EUV radiation beam B' passes through the slit 30. In other examples, the cooling elements may not comprise fingers and in this case the slit may be defined by the bodies of the cooling elements.

[00042] The cooling apparatus 20 comprises a membrane system, which in this example is a single membrane 32, located in the slit 30. The membrane 32 is positioned in the projection path of the patterned EUV radiation beam B'. The slit 30 provides the only path for contaminants and/or gas etc to pass from the region 18 to the projection system PS. The membrane 32 being in position in the slit 30 physically closes the slit 30. Therefore, the membrane 32 physically separates the projection system PS from the region 18. The cooling apparatus 20 with the membrane 32 may be considered to isolate the region 18 from the projection system PS and vice versa. The cooling apparatus with the membrane system may be referred to as a cooling mask. In other examples, the membrane system may have more than one membrane, e.g. as shown in Figure 5.

[00043] The lithographic apparatus LA comprises a barrier 34, which may also be referred to as a tray, which is located at or around the outer periphery of the cooling apparatus 20. The barrier 34 extends outwardly and/or upwardly (e.g. vertically or at an angle) from the cooling apparatus 20. The barrier 34 may extend to other walls or components of the lithographic apparatus LA, e.g. the projection optics box (POB), which houses the projection system PS. The barrier 34 may be rigidly connected to these walls or other components of the lithographic apparatus. The barrier 34 is connected to the cooling apparatus 20 such that no contaminants and/or gas etc may pass from the region 18 to the projection system PS between cooling apparatus 20 and the barrier 34. Thus, the barrier 34 and the cooling apparatus 20 with the membrane 32 together isolate the region 18 from the projection system PS. In other examples, the barrier 34 may be integral with the cooling apparatus 20 such that no contaminants and/or gas may pass from the region 18 to the projection system PS. The barrier and the cooling apparatus with the membrane system may be referred to as a cooling mask. In other examples, the barrier may only be located partially at or around the outer periphery of the cooling apparatus. In other examples, there may be no separate barrier and the cooling apparatus alone may isolate the region from the projection system.

[00044] The cooling apparatus 20 with the barrier 34 functions as a fixed assembly unlike cooling apparatus in other systems that may have to shift up/down due to dose change or wafer surface variation. In other systems, the cooling elements may be held by a support which includes a mechanism that moves the cooling elements to a desired height above the substrate table WT. However, in the lithographic apparatus LA with the cooling apparatus 20 as described, the problem of dose change or wafer surface variation is solved by flow variation. The fly height (i.e. the distance between the cooling elements 22, 24 and the wafer W) may be larger and so the movement due to the wafer surface variations is not required. Therefore, there will be no gaps between the barrier 34 and the cooling apparatus 20 and the cooling mask (the cooling apparatus 20 and the barrier 34) may be considered to be one body attached (e.g. bolted or welded) to the projection optics box (POB).

[00045] Figure 3 shows a cross sectional view of the cooling apparatus 20 in position with the barrier 34, which is shown in more detail. The substrate W is shown in Figure 3 but it will be understood that they would be located in the region 18 (also not shown) below the cooling apparatus 20.

[00046] The lithographic apparatus LA includes a funnel 36. The funnel 36 has an approximate truncated cone shape with a larger diameter hole 36A at the top and smaller diameter hole 36B at the bottom (the bottom being the end closest to the cooling apparatus 20). The funnel 36 includes a rim 36C which extends outwards from the larger diameter hole 36A. The projection path of the patterned EUV radiation beam B' is through the larger diameter hole 36A and the smaller diameter hole 36B. That is, the patterned EUV radiation beam B' passes through the funnel 36 before being incident upon the membrane 32 in the cooling apparatus 20. The barrier 34 is attached to the rim 36C of the funnel 36.

[00047] In Figure 3, the funnel 36 is shown with gas delivery conduits 37 which in other systems may be used for supplying a gas flow towards the substrate. However, in embodiments, the funnel 36 does not supply gas through the gas delivery conduits 37. Furthermore, in some embodiments, the funnel 36 may not have gas delivery conduits. It will be appreciated that in other examples, the funnel may have a different size and shape as long as it provides the function of allowing EUV radiation through a portion of the funnel.

[00048] In embodiments, the funnel 36 may provide a similar function as the barrier 34, either instead of, or in addition, to the barrier 34. That is, providing a shield (or barrier) to separate the region 18 from the projection system PS. More particularly, the arrangement may be such that the only path for gas and/or the contaminants to travel from the region 18 to the projection system PS may be through the funnel 36. In other embodiments, the funnel 36 may not be present and the isolation of the region 18 from the projection system PS may be by other means, such as the barrier 34 or the cooling apparatus 20. The barrier 34 being connected to the cooling apparatus 20 and to the rim 36C of the funnel 36 means that the projection system PS is isolated from the region 18.

[00049] The location of the membrane 32 is shown in Figure 3 located between the fingers 28, 29 of the cooling elements 22, 24. It can be seen that the slit 30 is an aperture located within the cooling apparatus 20 to allow the patterned radiation beam B' to pass through the cooling apparatus 20 to be incident on the substrate W below the cooling apparatus 20.

[00050] The use of the membrane 32 in the cooling apparatus 20 means that contaminants cannot reach the projection system PS. This means that a relatively high flow of gas towards the substrate W to stop contaminants, which in other systems may be provided through the gas delivery conduits 37 in the funnel 36 (also known as a Dynamic Gas Lock – DGL for short), is not required. In other systems the high gas flow from the DGL was required to suppress the contaminants from reaching the projection system PS. In high NA (Numerical Aperture) lithographic apparatus LA systems, the DGL gas flow may need to be increased to maintain the same suppression of contaminants as in lower NA systems. The use of the membrane 32 results in the removal of parasitic heat loads which may have occurred due to the DGL (there was heating on the substrate due to high DGL flow). In addition, the need for related heat shields and conditioning solutions (e.g. active and passive cooling) is avoided which in other

systems may have been required to thermally control the redirected DGL flow. These may have been required for e.g. avoiding excessive mirror heating or cooling.

[00051] Furthermore, use of the membrane 32 means that there is a reduction in pumping power when compared to other systems having a DGL as the high gas flow previously required by the DGL is not required or, in some embodiments, substantially reduced for the present gas flow systems. This can save on cost as well as reducing heat build up in other components. For example, more than 30% of the pumping capacity may be removed. This also introduces significant design volume in the lithographic apparatus LA that may be able to be utilised e.g. for other components.

[00052] Combining the functionality of the DGL and cooling apparatus of other systems into a single component (i.e. the cooling apparatus 20) may result in better serviceability and higher availability of the system. This is because, although in other systems the DGL and cooling apparatus are separate modules, their serviceability is entangled resulting in longer recovery time which may result in double the machine time to recover.

[00053] The membrane 32 may also provide the function of suppressing some of the undesired EUV or IR radiation that may be reflected from the pellicle and/or reticle and thus may stop at least some of this unwanted radiation from being incident on the substrate W. In other systems, this functionality could be provided by a membrane located elsewhere in the lithographic apparatus, e.g. in the DGL funnel. However, locating the membrane 32 in the slit in the cooling apparatus provides an advantage of a reduced surface area of the membrane. This means the membrane 32 is more robust and less likely to be damaged or break due to e.g. pressure differences between the region 18 and the projection system PS. EUV radiation is highly absorbed by materials and therefore the membrane must be made thin enough so that the desired amount of EUV radiation can pass through the membrane. However, the strength of the membrane will decrease with decreasing thickness. A more robust membrane can be achieved due to the smaller surface area of the membrane 32 in position in the cooling apparatus 20 as the strength of the membrane will increase with decreasing surface area. In addition a higher pressure difference over the membrane 32 may be allowed due to the increased strength of the membrane 32.

[00054] The cooling apparatus 20 further comprises gas delivery conduits (not shown) which are configured to deliver gas to below the membrane 32. The gas delivery conduits may be provided in the cooling elements 22, 24. A gas flow system (not shown) is configured to provide the flow of gas below the membrane 32. The gas delivery conduits are at least partially provided in the fingers 28, 29 of the cooling elements 22, 24 such that the gas flow is provided from the fingers 28, 29 into the region 18. The fingers 28, 29 have the advantage of providing better distribution of the cooling flow below the membrane 32 for cleaning purposes to be able to leave the gap as shown in FIG 4.a between the fingers 28, 29 and the wafer W.

[00055] As depicted by arrows in Figure 2, gas delivered by the gas delivery conduits flows at least partially across the membrane 32 and downwards from the membrane 32. The gas flow may also be directly downwards from the fingers 28, 29 towards the substrate W as shown by the arrows.

[00056] Figure 4a shows the cooling apparatus 20 and the substrate W from above. As depicted in Figure 4a by arrows, gas can also flow outwards from between the fingers 28, 29 (i.e. from the slit 30) in a substantially horizontal direction (i.e. the x direction). This may be because there may be less resistance to movement of the gas in these directions.

5 [00057] Figure 4b also shows the cooling apparatus 20 and the substrate W from above. Figure 4b shows the gas flow from the fingers 28, 29 which first hit the substrate W and then go across the substrate W. The gas flow system is configured to provide the flow of the gas onto the exposure area E on the substrate W. In general, gas may be considered to travel outwardly and exit from beneath the cooling element bodies 26, 27 to the surrounding environment.

10 [00058] Thus, it can be seen that the gas flow system provides a flow of gas between the cooling elements 22, 24 and the substrate W. This flow of gas increases heat transfer (transport) from the substrate W to the cooling elements 22, 24. This has an advantage of providing more efficient cooling of the substrate W.

[00059] The gas flow from the cooling apparatus 20 provides increased cooling of the substrate W. 15 The gas flow also provides an advantage of more central cooling (i.e. over the exposure area E of the substrate W) when compared to other systems which do not have the gas flow coming from the cooling apparatus 20. This provides more efficient cooling when compared to other systems with just cooling elements covering the area around the EUV exposure area E of the substrate W.

[00060] As mentioned previously, the gas flow also flows at least partially across the membrane 32. 20 Thus, the gas flow also provides an advantage of cooling the membrane 32 which may have been heated by absorbing some of the EUV radiation from the patterned beam B', or EUV or IR radiation reflected from the pellicle or reticle. When the membrane is heated then some of the heat is re-radiated towards the substrate W and some of the heat may be conducted by any gas below the membrane. The membrane heating up may in turn heat up the substrate W and/or the cooling apparatus. Thus, cooling of the 25 membrane 32 by the gas flow provides advantages of helping to avoid additional radiation and heating being transferred to the substrate W and/or the cooling apparatus 20.

[00061] The gas flow across the membrane 32 may also clean the membrane 32, e.g. removing any particles etc that may have been deposited there. A problem of contamination at the membrane 32 may be solved by the gas flow below and around the membrane 32 which can flow away through a gap or 30 gaps perpendicular to the fingers 28, 29.

[00062] Plasma cleaning may be used below the membrane 32 which linearly depends on the EUV radiation power and the gas pressure. The cleaning rate also depends on type of resist, membrane material and the cooling gas used.

[00063] Having a smaller separation between the bottom of the cooling apparatus 20 (i.e. the bottom 35 of the fingers 28, 29) and the substrate W (also known as the fly height) in order to achieve a desired Heat Transfer Coefficient (HTC) at the fingers may result in a collision between the fingers and the

substrate W. Due to the introduction of the cooling gas below the membrane 32, the fly height may be increased to avoid this issue.

[00064] In this example, the gas is nitrogen (N_2). Having the membrane 32 in place in the slit 30 isolates the region 18 from the projection system PS, where hydrogen (H_2) may be present. It is desirable to keep the hydrogen separated from the nitrogen to avoid the problems caused by mixing hydrogen and nitrogen in the EUV radiation beam path. CAR (chemically amplified resists) resists relating to the substrate W may have acids that are essential for proper function of this resist. If (basic) amines N_xH_y components (potentially ionized) reacts/neutralizes with the acids then this has a negative effect on the resist functionality. Since these effects will only take place in the top of resist we will have different photo-chemistry in the top and rest of the resist, giving potential rise to topping effects in the resist. By separating the nitrogen and hydrogen using the membrane 32 the acid neutralizing amines will not be produced and the risk of issues relating to the reactive molecules NH_2^+ that could be produced may be mitigated.

[00065] The use of the membrane 32 thus allows nitrogen to be used as the cooling gas for cooling the substrate W. Nitrogen is 5 times more stable than hydrogen with respect to the thermal accommodation coefficient (TAC) for different surface materials. The TAC determines the extent to which a heat load is transferred from a gas to a material (the TAC may be considered to be the fraction of excess energy that is transferred from the gas to the material). The more stable TAC provided by using the nitrogen leads to more accurate cooling of the substrate W. This may directly affect the calibration procedure and may result in less overlay penalty. Alternatively, any other suitable gas may be used (e.g. another inert gas such as hydrogen or helium). Hydrogen may be used, for example, for cleaning the bottom of the membrane 32 by cleaning radicals and ions formed by the passage of the EUV radiation.

[00066] The gas is delivered at a pressure which is sufficiently high to transport a significant amount of heat from the substrate W to the cooling element bodies 26, 27. The pressure of the gas may be kept sufficiently low that the gas does not cause damage to the substrate W. Furthermore, the pressure of the gas may be kept sufficiently low that it does not generate tangential forces sufficiently strong to cause the substrate W to slip over burls on the substrate table WT (e.g. does not generate tangential forces greater than around 10mN). The pressure of the gas may be kept sufficiently low that significant deformation of the substrate W does not occur at locations where the substrate is supported by burls of the substrate table WT. The substrate may have an outer edge of for example 1-3mm which is not supported by burls of the substrate table WT. The pressure of the gas may be sufficiently low that downward deformation of the substrate at the outer edge is limited to an amount which can be compensated for by the lithographic apparatus (e.g. deformation of less than 10nm). The pressure of the gas in the region 18 may for example be greater than 100 Pascals. The pressure of the gas in the region 18 may for example be greater than 200 Pascals. The pressure of gas in the region 18 may for example be up to around 1000 Pascals, may be up to around 2000 Pascals, and may be up to around

5000 Pascals. The pressure of gas in the region 18 may for example be 100 kPa or more. The pressure of gas in the region 18 may for example be around 500 kPa or more.

[00067] The pressure of the gas in the region 18 will be affected by the gap between the lowermost surface of the cooling element body 26, 27 and the substrate W (increasing the gap will make it more difficult to maintain a high pressure). The separation may for example be around 20 microns or more, and may be around 50 microns or more. The separation may be around 200 microns or less.

[00068] In addition to facilitating transport (transfer) of heat from the substrate W to the cooling element bodies 26, 27 the gas may also act as a cushion which prevents or inhibits contact occurring between the cooling element bodies 26, 27 and the substrate W. In an embodiment, a separation between a lowermost surface of the cooling element bodies 26, 27 and the substrate W may be greater than 20 microns, and may for example be 50 microns or more. If the separation is too small then there will be a significant risk of a cooling element body 26, 27 coming into contact with a substrate W. This is undesirable because it may cause damage to the lithographic apparatus. A separation of 20 microns may be sufficient to reduce the risk of contact to a reasonable level. A separation of 50 microns may be sufficient to substantially eliminate the risk of contact. The separation may for example be up to 100 microns, and may for example be up to 200 microns. A separation greater than 200 microns may be undesirable because it may allow too much gas to leak out from underneath the cooling element bodies 26, 27.

[00069] Further details of aspects of a cooling apparatus and cooling elements that may be used are described in, for example, published application WO2018/041599A1, which is herein incorporated by reference.

[00070] In some embodiments, there may be provided an additional gas flow system (not shown) which provides a flow of additional gas above the membrane 32. The additional gas flow system comprises gas delivery conduits (not shown) in the cooling apparatus 20. The gas delivery conduits may be provided in the cooling elements 22, 24. In some examples, the additional gas flow may be provided through the funnel 36 but in this case a large flow rate may be required which may not be beneficial. In some examples, the additional gas flow system may be part of the gas flow system previously described or may be a separate gas flow system. In some examples, the gas delivery conduits of the additional gas flow system may be at least be partially shared with the gas delivery conduits of the gas flow system.

[00071] The additional gas flow above the membrane 32 may provide a pressure balance with the gas flow below the membrane 32. This additional gas flow above the membrane 32 may at least partially protect the projection system PS from contaminants etc in case the membrane 32 is damaged or breaks. The additional gas flow above the membrane 32 may prevent falling particles etc from hitting the membrane 32 (the membrane may break if the particle is large enough. The falling particles may be loose particles generated or received upstream (light path) of the projection system PS. The

additional gas flow above the membrane 32 may cool the membrane 32 that heats up owing to absorption of EUV and IR radiation.

[00072] The additional gas may be hydrogen. Alternatively, any other suitable gas may be used (e.g. another inert gas such as helium).

5 [00073] Figure 5 shows an embodiment of an alternative membrane system which comprises two membranes. The membrane system comprises a first membrane, which is substantially the same as the membrane 32 and will be referred to as such, and a second membrane which will be referred to as a further membrane 38. The arrangement of Figure 5 is the same or similar to Figure 2 and the same numerals will be used for the same or similar parts. The barrier 34 in Figure 5 provides the same
10 function as the barrier 34 in Figure 2. Some reference numerals have been omitted for clarity but it will be appreciated that the cooling apparatus 20 of Figure 5 may have the same or similar components as the cooling apparatus of Figure 2.

[00074] The further membrane 38 is located above the membrane 32, the membrane 32 being located in the same position as in Figure 2. The membrane 32 and the further membrane 38 both
15 physically close the slit 30 such that containments and/or gas etc cannot pass from the region 18 to the projection system PS.

[00075] It will be appreciated that, in other examples, the membrane 32 and the further membrane 38 may not be in the precise locations shown in Figure 5 and may be located at different vertical locations between the fingers 28, 29, whilst still physically closing the slit 30. In other examples, there
20 may not be fingers and the membrane 32 and the further membrane 38 may be located between parts of the cooling bodies 26, 27.

[00076] The cooling apparatus 20, the membrane 32 and the further membrane 38 define a volume 40. A further gas flow system (not shown) is configured to provide a flow of a further gas through the volume 40 as shown by the arrow in the volume 40. The volume 40 is isolated, e.g. the further gas
25 cannot escape into the region 18. The further gas flow system may be part of or separate to the gas flow system and/or the additional gas flow system.

[00077] The flow of the further gas is above the membrane 32 and below the membrane 38 (i.e. between the two membranes).

[00078] The further gas is relatively cold to help reduce the temperature of the membranes 32, 38.
30 The further gas may be at a temperature that cools the membranes 32, 38. The further gas may be hydrogen. Hydrogen may be preferred as it may provide better transmission of EUV radiation than other gases. Alternatively, any other suitable gas may be used (e.g. another inert gas such as helium).

[00079] Figure 6 is a cross section view taken along the line A-A' shown in Figure 5. Figure 6 shows the cooling apparatus 20 including further gas delivery conduits, an inlet gas delivery conduit 42 to supply the further gas to the volume 40 and an outlet gas delivery conduit 44 to return the further gas
35 from the volume 40. Arrows in the further gas delivery conduits 42, 44 show the flow direction of the further gas. There are two manifolds 46 to help distribute the further gas substantially evenly into the

volume 40 over the membranes 32, 38 and out of the volume 40 respectively. Each cooling element 22, 24 may comprise further gas delivery conduits.

[00080] The further gas flow between the membranes 32, 38 provides improved cooling of the membranes 32, 38. Furthermore, having a second membrane (further membrane 38) also physically closing the slit 30 means that even if the first membrane (membrane 32) was damaged and was to allow some contaminants through the slit 30 then the second membrane 38 would protect the projection system PS by stopping these contaminants. In other examples, the membrane system may comprise more than two membranes.

[00081] Although specific reference may be made in this text to the use of lithographic apparatus in the manufacture of ICs, it should be understood that the lithographic apparatus described herein may have other applications. 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.

[00082] 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. Such a lithographic tool may use vacuum conditions or ambient (non-vacuum) conditions.

[00083] 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 and may be used in other applications, for example imprint lithography.

[00084] 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 as 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.

[00085] 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 clauses set out below. Other aspects of the invention are set-out as in the following numbered clauses.

1. A lithographic apparatus comprising:

a projection system configured to project a patterned radiation beam via a projection path onto an exposure area at a substrate held on a substrate table that is moveable in a region underneath the projection system; and

a cooling apparatus configured to cool the substrate via heat transfer from the substrate to a cooling element positioned above the substrate and adjacent the projection path;

wherein the cooling apparatus comprises a membrane system positioned in the projection path so as to physically separate the projection system from the region.

2. The lithographic apparatus of clause 1, comprising a gas flow system configured to provide a flow of a gas below the membrane system.

3. The lithographic apparatus of clause 2, wherein the gas flow system is configured to provide the flow of the gas between the cooling element and the substrate, the flow being configured to increase heat transfer from the substrate to the cooling element.

4. The lithographic apparatus of clause 3, wherein the gas flow system is configured to provide the flow of the gas onto the exposure area on the substrate.

5. The lithographic apparatus of clause 2-4, wherein the gas flow system comprises a gas delivery conduit in the cooling apparatus.

6. The lithographic apparatus of clause 2-5, wherein the gas comprises nitrogen.

7. The lithographic apparatus of any preceding clause, further comprising an additional gas flow system configured to provide a flow of an additional gas above the membrane system.

8. The lithographic apparatus of any preceding clause, wherein the membrane system comprises a single membrane.

9. The lithographic apparatus of clauses 1-7, wherein the membrane system comprises a first membrane and a second membrane.

10. The lithographic apparatus of clause 9, further comprising a further gas flow system configured to provide a flow of a further gas through a volume defined by the cooling apparatus, the first membrane and the second membrane.

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11. The lithographic apparatus of any preceding clause, further comprising a barrier positioned at an outer periphery of the cooling apparatus and extending outwards and/or upwards from the cooling apparatus.

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12. The lithographic apparatus of clause 11, wherein the barrier is connected to the cooling apparatus.

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13. The lithographic apparatus of any preceding clause, wherein the cooling apparatus comprises a slit which is configured such that the projection path passes through the slit, wherein the membrane system physically closes the slit.

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14. The lithographic apparatus of any preceding clause, wherein the cooling element comprises fingers extending away from a body of the cooling element towards the substrate, wherein the membrane system is positioned between the fingers.

15. The lithographic apparatus of clause 14, wherein the gas flow system is configured to provide the flow of gas out from the fingers.

25

16. A cooling apparatus configured for use in the lithographic apparatus of any of clauses 1-15.

17. A lithographic method comprising:

projecting a patterned radiation beam through a projection system via a projection path to form an exposure area on a substrate held on a substrate table, and

30

using a cooling apparatus to cool the substrate via a cooling element positioned above the substrate and adjacent the projection path, the cooling element acting to remove heat from the substrate,

wherein the cooling apparatus comprises a membrane system positioned in the projection path so as to physically separate the projection system from the region.

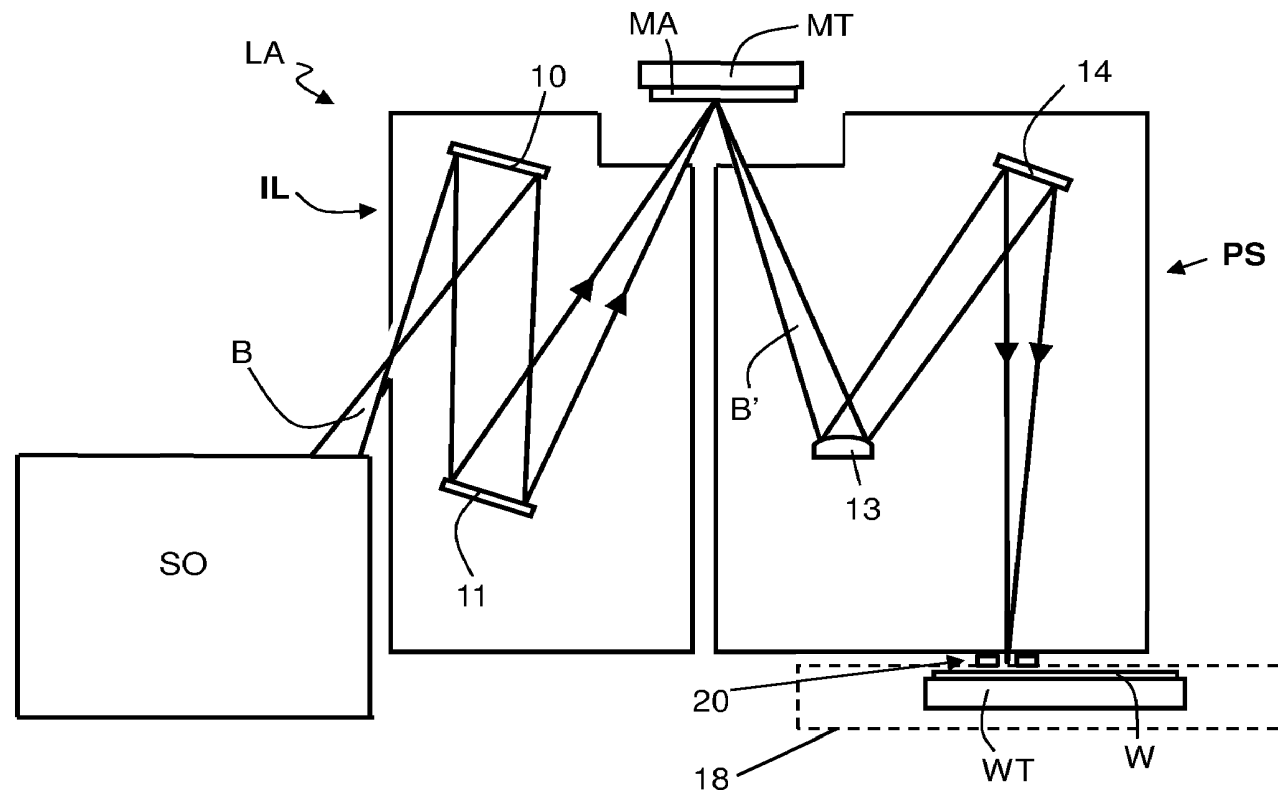
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18. The lithographic method of clause 17, further comprising providing a flow of gas below the membrane system from a gas flow system.

19. The lithographic method of clause 17 or 18, further comprising providing the flow of gas between the cooling element and the substrate, the flow being configured to increase heat transfer from the substrate to the cooling element.
- 5 20. The lithographic method of clause 17-19, further comprising providing a flow of a further gas from a further gas system through a volume defined by the cooling apparatus, a first membrane and a second membrane of the membrane system.

CONCLUSIE

1. Een inrichting ingericht voor het belichten van een substraat.

**FIG. 1**

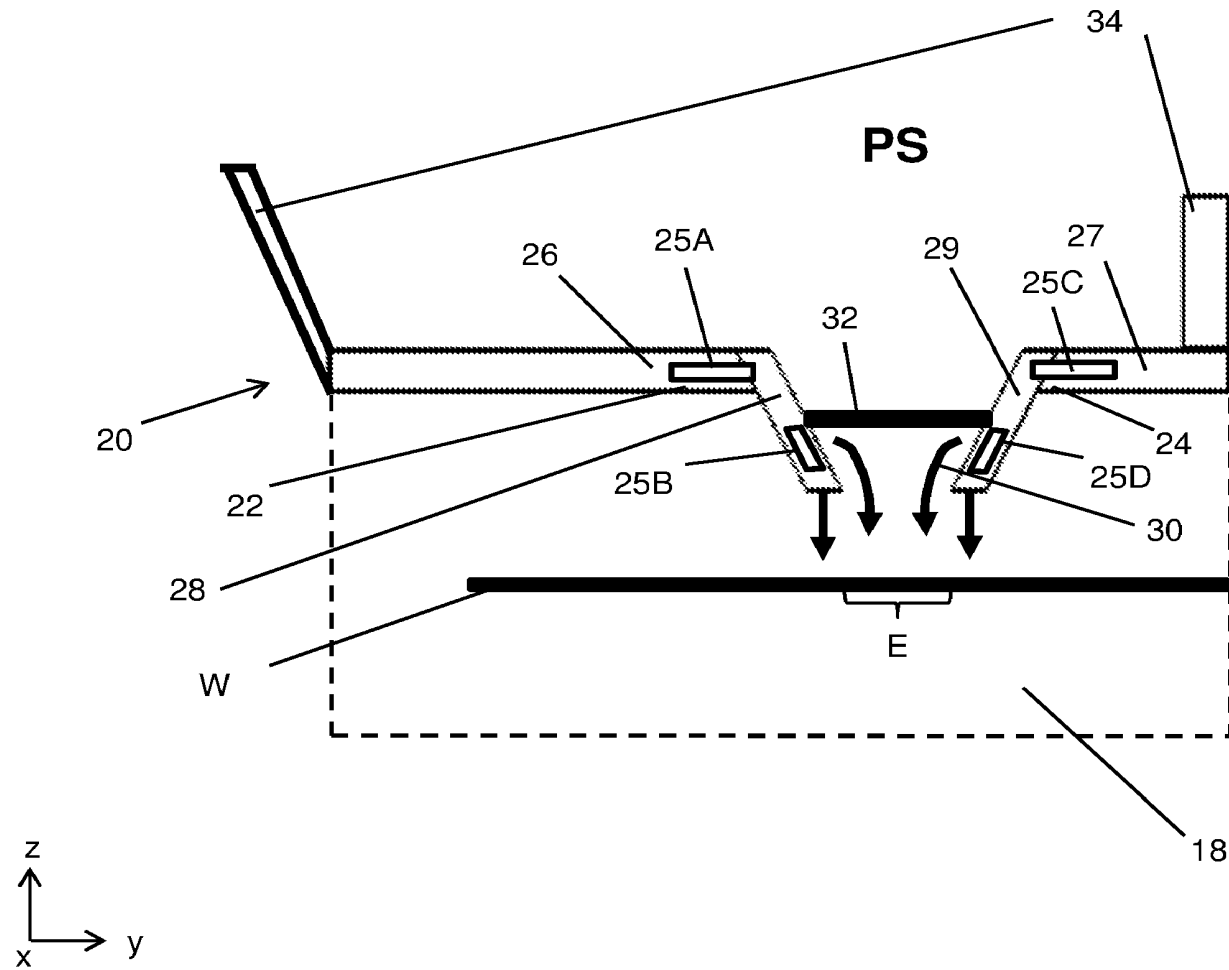
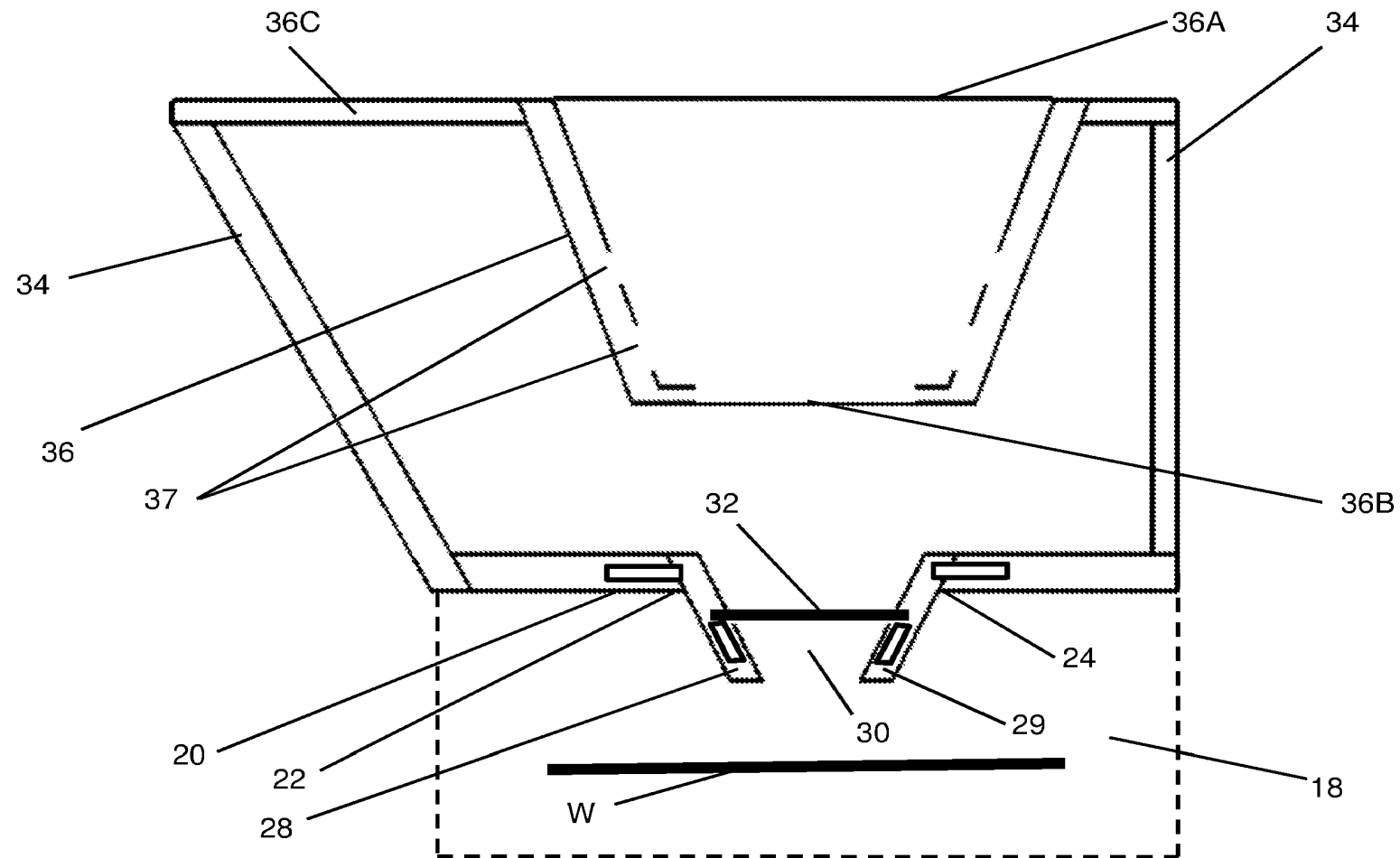


FIG. 2

**FIG. 3**

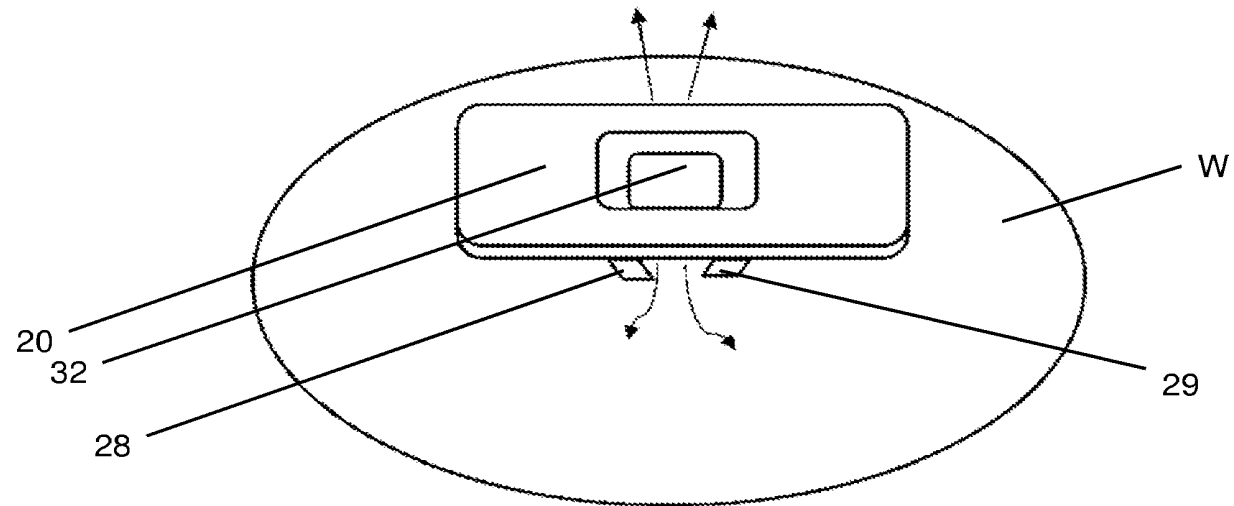


FIG. 4a

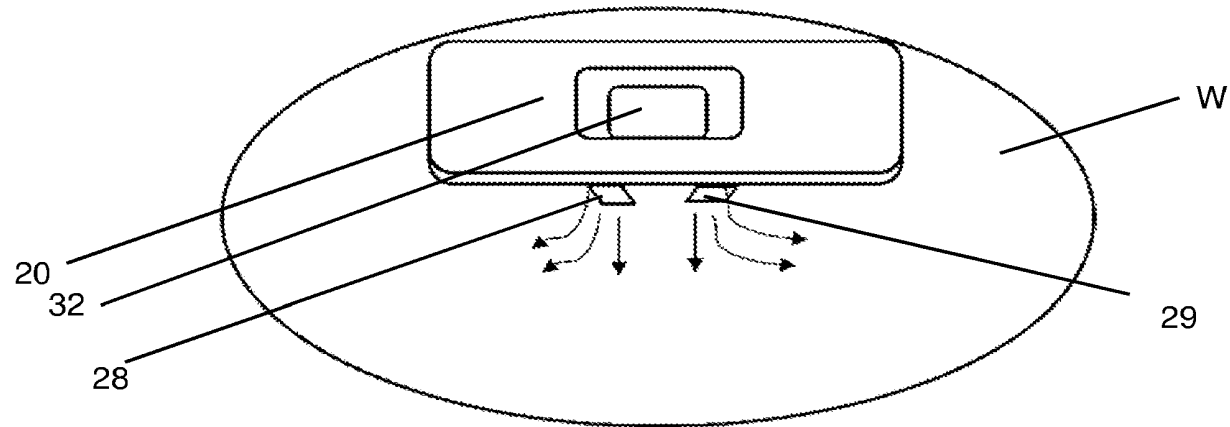
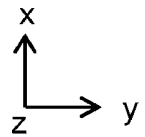
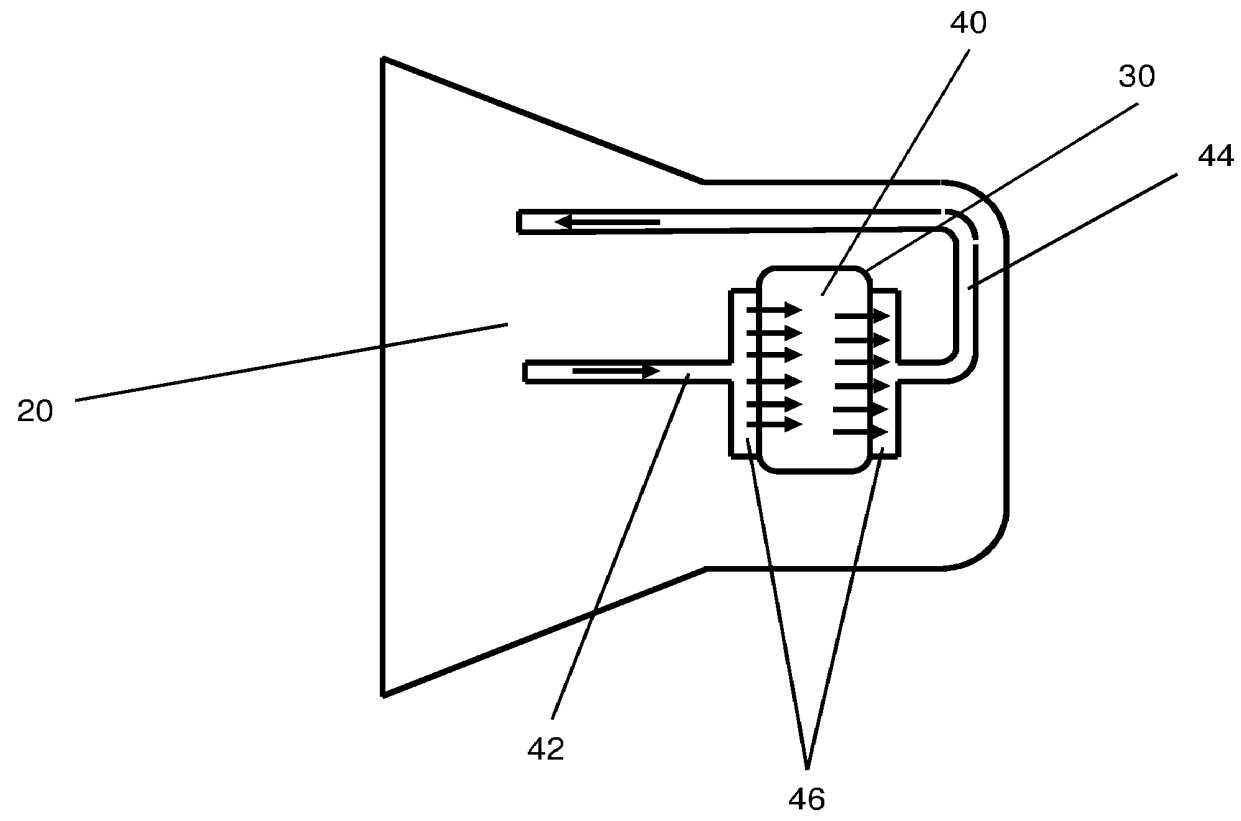


FIG. 4b



**FIG. 6**

ABSTRACT

A lithographic apparatus comprising: a projection system configured to project a patterned radiation beam via a projection path onto an exposure area at a substrate held on a substrate table that is moveable in a region underneath the projection system; and a cooling apparatus configured to cool the substrate via heat transfer from the substrate to a cooling element positioned above the substrate and adjacent the projection path; wherein the cooling apparatus comprises a membrane system positioned in the projection path so as to physically separate the projection system from the region.