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(54) **APPARATUS AND METHOD FOR PROVIDING FLUID FOR IMMERSION LITHOGRAPHY**

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(57) **ABSTRACT**

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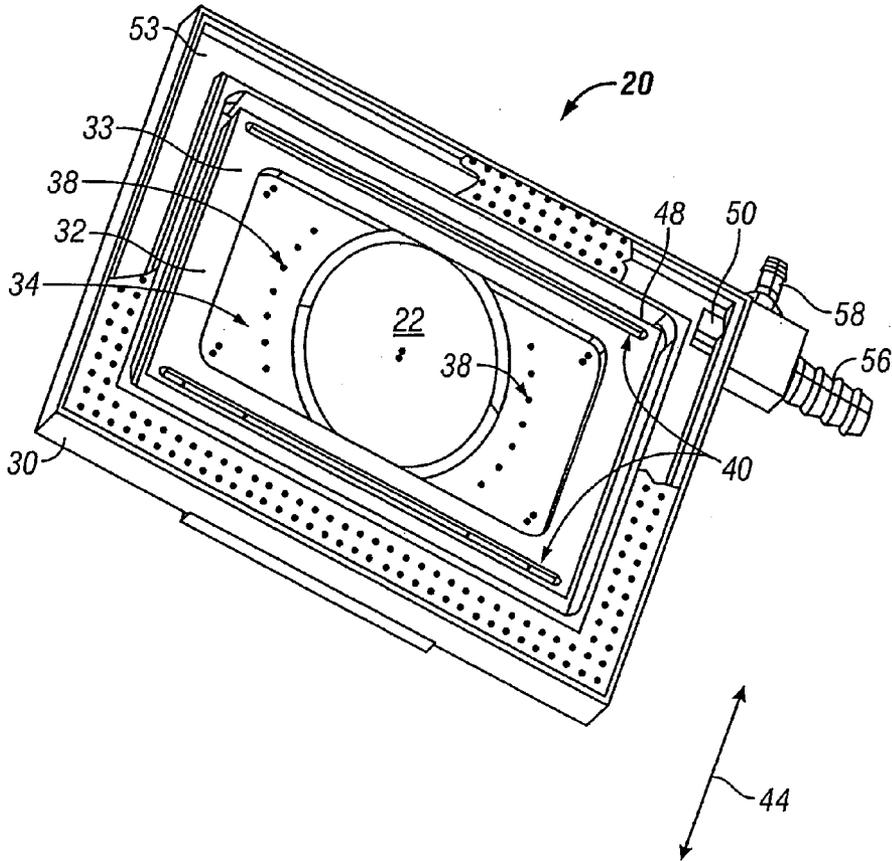
A lithographic projection apparatus projects a pattern from a patterning device onto a substrate using a projection system. The apparatus has a liquid supply system to supply a liquid to a space between the projection system and the substrate. The apparatus also has a fluid removal system including a chamber to hold liquid and having an open end adjacent to a volume in which fluid will be present. The open end removes, through a pressure differential across the open end when liquid is present in the chamber, substantially only liquid from the volume when liquid in the volume is adjacent to the open end but not gas from the volume when gas in the volume is adjacent to the open end.

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Related U.S. Application Data

(60) Division of application No. 11/362,833, filed on Feb. 28, 2006, which is a continuation of application No. PCT/US04/22915, filed on Jul. 16, 2004.



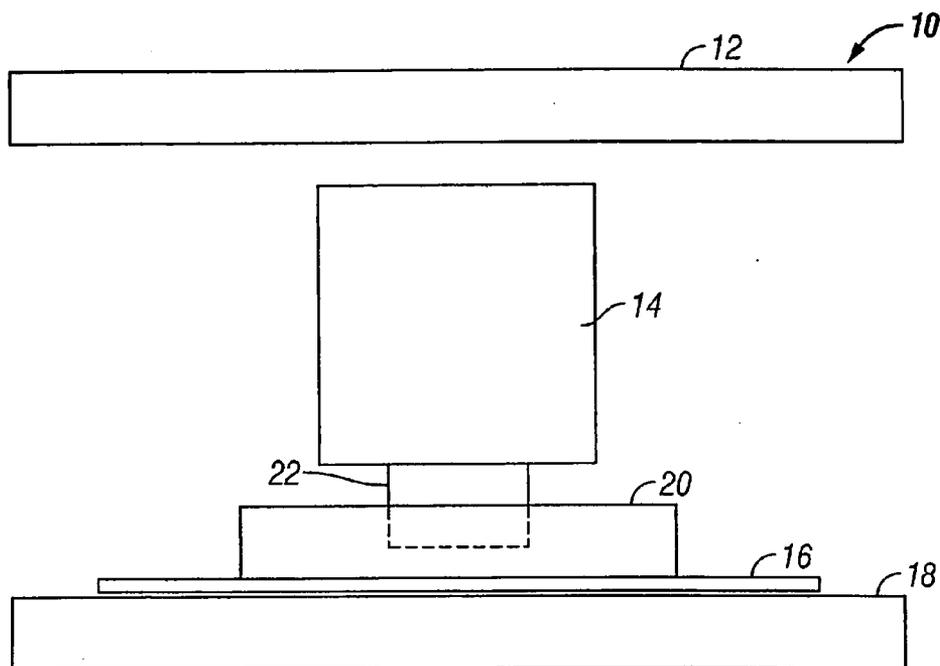


FIG. 1

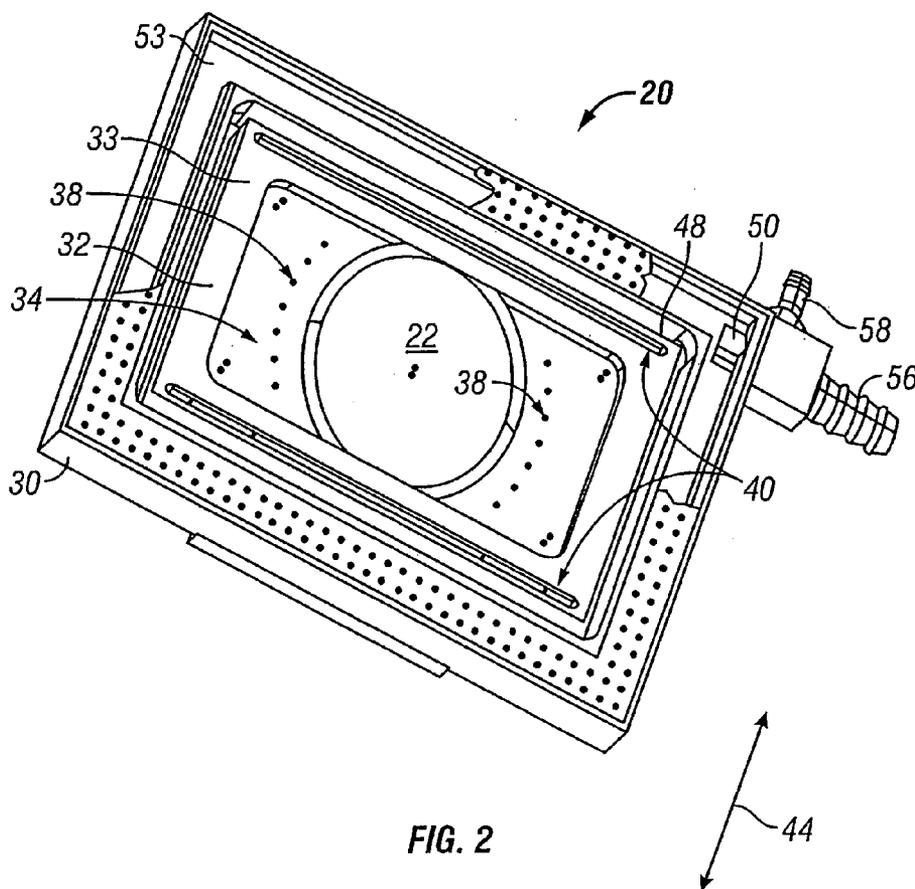


FIG. 2

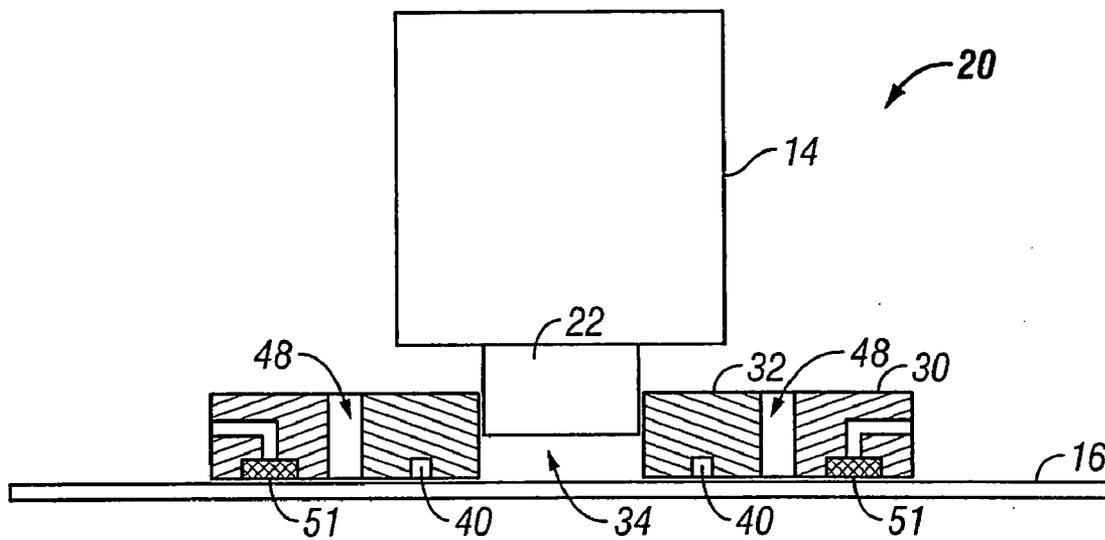


FIG. 3

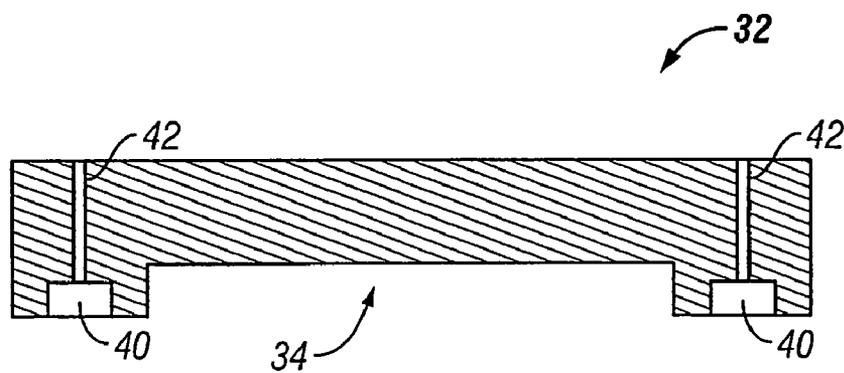


FIG. 4

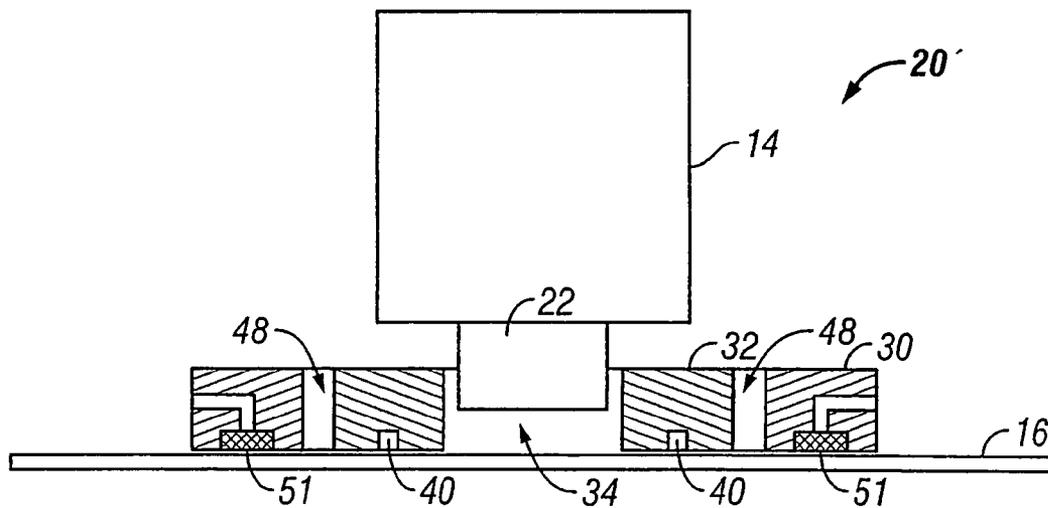


FIG. 5

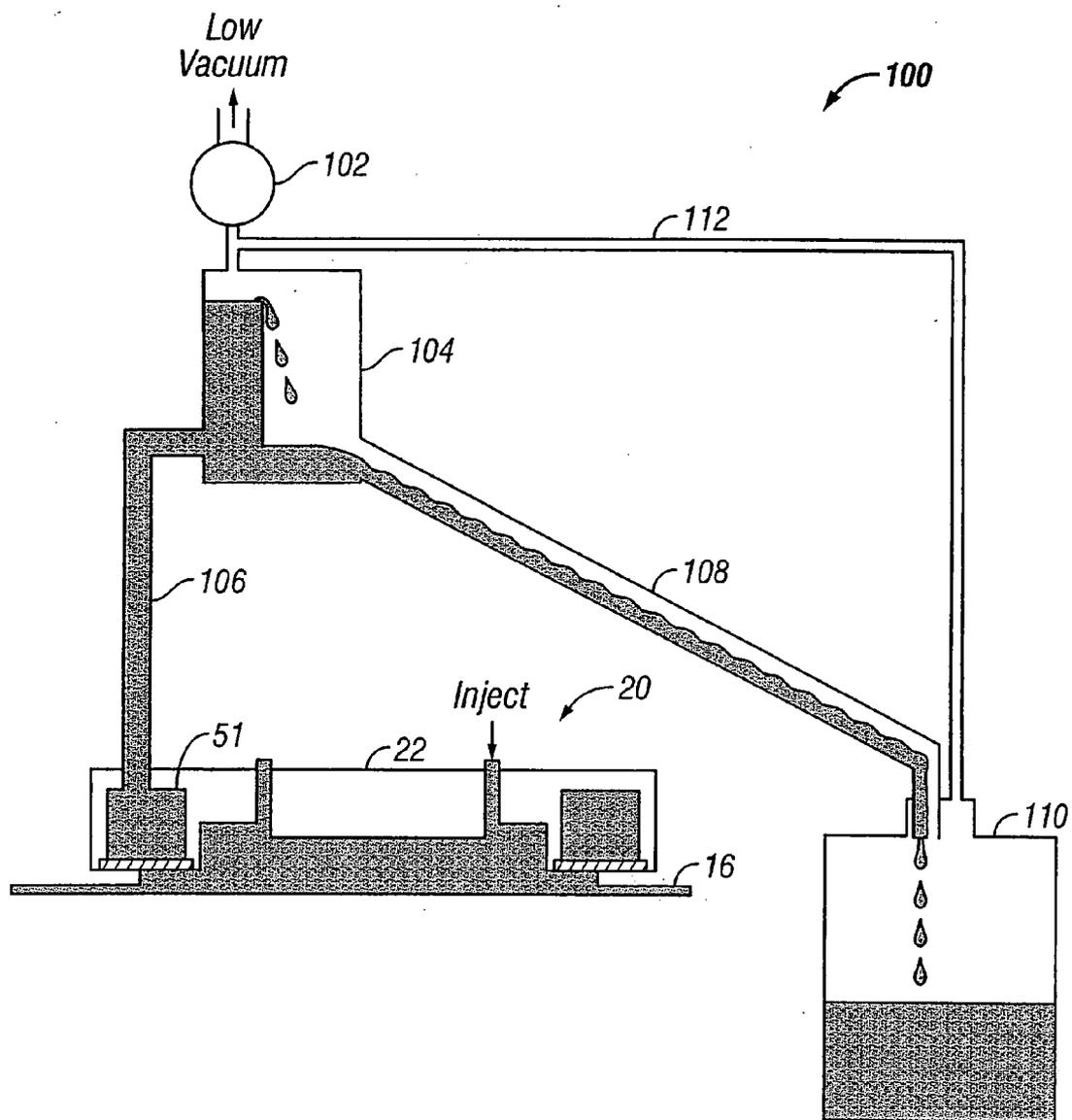


FIG. 6

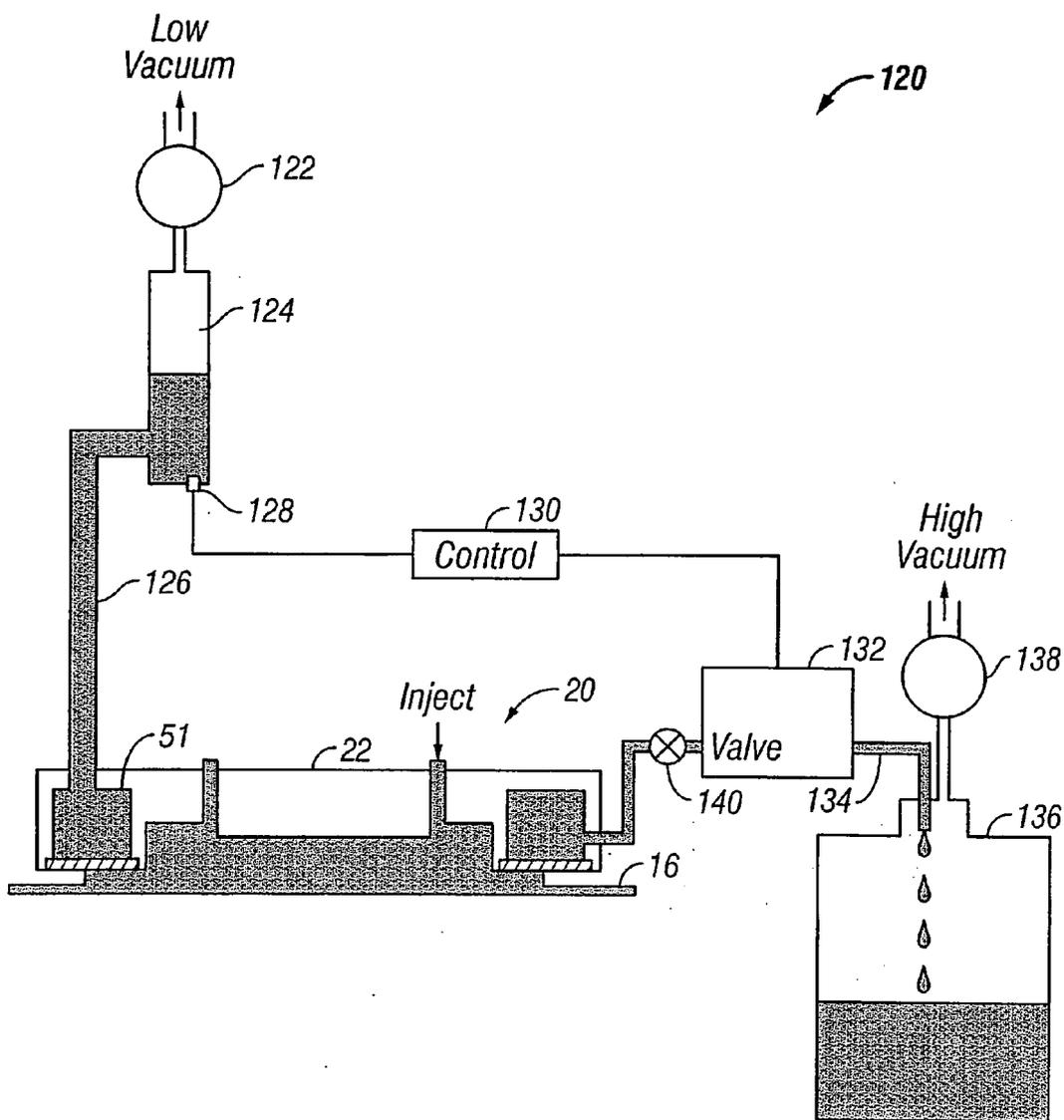


FIG. 7

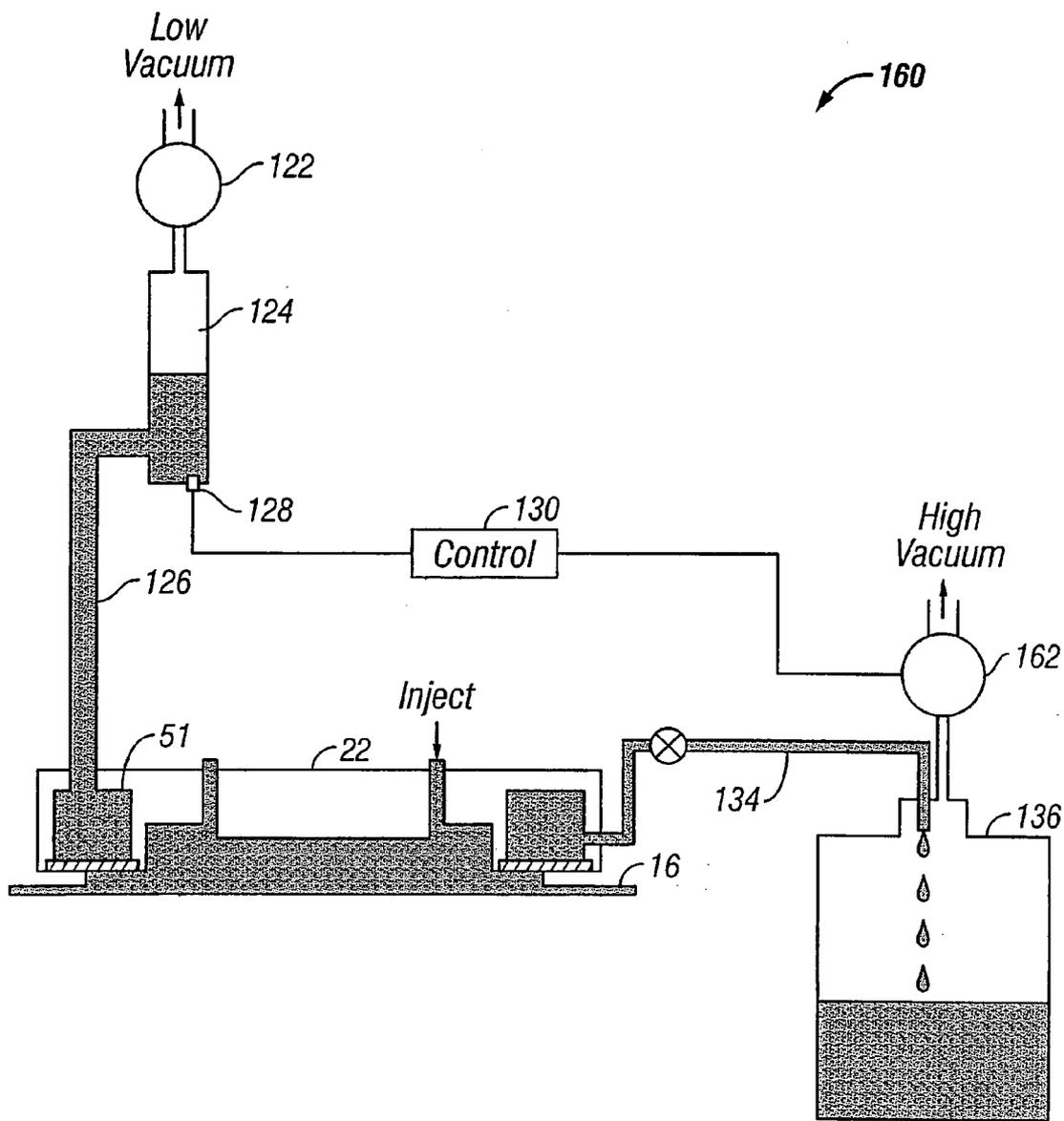


FIG. 8

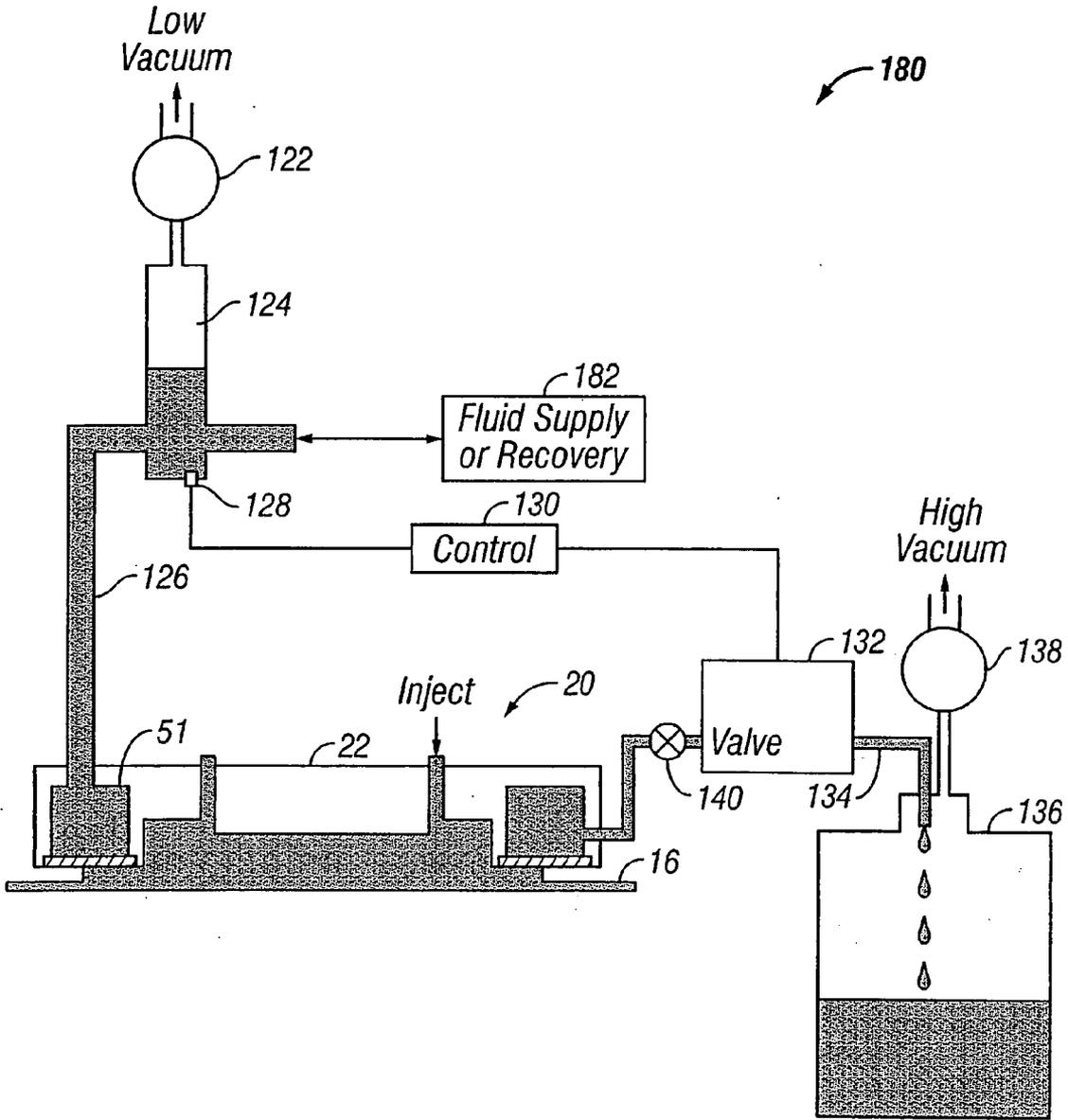


FIG. 9

APPARATUS AND METHOD FOR PROVIDING FLUID FOR IMMERSION LITHOGRAPHY

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This is a divisional of U.S. patent application Ser. No. 11/362,833 filed Feb. 28, 2006, which in turn is a continuation of International Application No. PCT/US2004/022915 filed Jul. 16, 2004, which claims the benefit of U.S. Provisional Patent Application No. 60/500,312 filed Sep. 3, 2003, and U.S. Provisional Patent Application No. 60/541,329 filed Feb. 2, 2004. The disclosures of these applications are incorporated herein by reference in their entireties.

BACKGROUND

[0002] The invention relates generally to systems and methods for providing fluid for immersion lithography and, more particularly, for controlling the fluid flow and pressure to provide stable conditions for immersion lithography.

[0003] An exposure apparatus is one type of precision assembly that is commonly used to transfer images from a reticle onto a semiconductor wafer during semiconductor processing. A typical exposure apparatus includes an illumination source, a reticle stage assembly that retains a reticle, an optical assembly, a wafer stage assembly that retains a semiconductor wafer, a measurement system, and a control system. The resist coated wafer is placed in the path of the radiation emanating from a patterned mask and exposed by the radiation. When the resist is developed, the mask pattern is transferred onto the wafer. In microscopy, extreme ultraviolet (EUV) radiation is transmitted through a thin specimen to a resist covered plate. When the resist is developed, a topographic shape relating to the specimen structure is left.

[0004] Immersion lithography is a technique that can enhance the resolution of projection lithography by permitting exposures with a numerical aperture (NA) greater than one, which is the theoretical maximum for conventional "dry" systems. By filling the space between the final optical element and the resist-coated target (i.e., wafer), immersion lithography permits exposure with light that would otherwise be totally internally reflected at an optic-air interface. Numerical apertures as high as the index of the immersion liquid (or of the resist or lens material, whichever is least) are possible. Liquid immersion also increases the wafer depth of focus, i.e., the tolerable error in the vertical position of the wafer, by the index of the immersion liquid compared to a dry system with the same numerical aperture. Immersion lithography thus has the potential to provide resolution enhancement equivalent to the shift from 248 to 193 nm. Unlike a shift in the exposure wavelength, however, the adoption of immersion would not require the development of new light sources, optical materials, or coatings, and should allow the use of the same or similar resists as conventional lithography at the same wavelength. In an immersion system where only the final optical element and its housing and the wafer (and perhaps the stage as well) are in contact with the immersion fluid, much of the technology and design developed for conventional tools in areas such as contamination control, carry over directly to immersion lithography.

[0005] One of the challenges of immersion lithography is to design a system for delivery and recovery of a fluid, such

as water, between the final optical element and the wafer, so as to provide a stable condition for immersion lithography.

SUMMARY

[0006] Embodiments of the invention are directed to systems and methods of controlling the fluid flow and pressure to provide stable conditions for immersion lithography. A fluid is provided in a space between the lens and the substrate during the immersion lithography process. Fluid is supplied to the space and is recovered from the space through a porous member in fluidic communication with the space. Maintaining the pressure in the porous member under the bubble point of the porous member can eliminate noise created by mixing air with the fluid during fluid recovery. The bubble point is a characteristic of the porous member that depends on the size of the holes in the porous member (the largest hole) and the contact angle that the fluid forms with the porous member (as a parameter based on the property of the porous material and the property of the fluid). Because the bubble point is typically a very low pressure, the control of this low pressure becomes an important issue.

[0007] An aspect of the invention is directed to a method of recovering a fluid from a space between a lens and a substrate in an immersion lithography system. The method includes drawing the fluid from the space via a recovery flow line through a porous member and maintaining a pressure of the fluid in the porous member below a bubble point of the porous member during drawing of the fluid from the space.

[0008] In some embodiments, maintaining the pressure is accomplished by providing an overflow container kept at a preset pressure and directing the fluid drawn from the space through the porous member via the recovery flow line to the overflow container. Maintaining the pressure can further include siphoning the fluid from the overflow container to a collection tank. The fluid is siphoned down by gravity to the collection tank disposed below the overflow container. In other embodiments, maintaining the pressure includes providing a fluid level buffer, drawing the fluid from the space via a buffer flow line through the porous member to the fluid level buffer, sensing a pressure or a fluid level at the fluid level buffer, and controlling the fluid flow drawn from the space via the recovery flow line through the porous member based on the sensed pressure or fluid level at the fluid level buffer. Controlling the fluid flow can include controlling a variable valve disposed in the recovery flow line downstream of the porous member. In still other embodiments, maintaining the pressure includes providing a fluid level buffer, drawing the fluid from the space via a buffer flow line through the porous member to the fluid level buffer, sensing a pressure or a fluid level at the fluid level buffer, and controlling a vacuum pressure at an outlet of the recovery flow line through the porous member based on the sensed pressure or fluid level at the fluid level buffer. Controlling the vacuum pressure can include controlling a vacuum regulator in a collection tank at the outlet of the recovery flow line.

[0009] In accordance with another aspect of the invention, an apparatus for recovering a fluid from a space between a lens and a substrate in an immersion lithography system includes an inner part that includes a lens opening to accommodate a portion of the lens and to position the lens apart from the substrate separated by the space to receive a

fluid in the space between the lens and the substrate. An outer part is disposed around the inner part, and includes a porous member fluidically coupled with the space and with a fluid recovery outlet to draw fluid from the space via the porous member to the fluid recovery outlet. A pressure control system is fluidically coupled with the porous member to maintain a pressure at the surface of the porous member below a bubble point of the porous member during drawing of the fluid from the space via the porous member.

[0010] In some embodiments, the pressure control system includes an overflow container fluidically coupled with the porous member and a vacuum regulator that regulates a pressure in the overflow container. A collection tank is fluidically coupled to and disposed below the overflow container. In other embodiments, the pressure control system includes a fluid level buffer fluidically coupled with the porous member, a sensor that senses a pressure or a fluid level at the fluid level buffer and a controller that adjusts a flow rate of the fluid drawn from the space through the fluid recovery outlet, based on a sensor signal output from the sensor, to maintain a pressure at the surface of the porous member below a bubble point of the porous member during drawing of the fluid from the space via the porous member. The pressure control system can include a valve disposed downstream of the fluid recovery outlet, and the controller controls the valve to adjust the flow rate of the fluid drawn from the space through the fluid recovery outlet. In still other embodiments, the pressure control system includes a collection tank fluidically coupled to the fluid recovery outlet and a controllable vacuum regulator that regulates a pressure in the collection tank. The controller controls the controllable vacuum regulator to adjust the flow rate of the fluid drawn from the space through the fluid recovery outlet to the collection tank by controlling the pressure in the collection tank.

[0011] In specific embodiments, the inner part is spaced from the outer part by an intermediate spacing. The inner part includes an inner cavity forming a part of the spacing between the lens and the substrate, and the inner part includes apertures disposed above the inner cavity for at least one of introducing fluid into and drawing fluid from the inner cavity. The inner part includes apertures disposed on opposite sides of the lens opening for introducing fluid into the inner cavity. The inner part includes a pair of buffer slots disposed on opposite sides of the lens opening in a direction of scan of the immersion lithography system. The inner part includes purge holes and each of the pair of buffer slots is fluidically coupled to at least one of the purge holes. The porous member is selected from the group consisting of a mesh, a porous material, and a member having etched holes therein.

[0012] In accordance with another aspect of the invention, an apparatus includes an optical projection system having a last optical element and that projects an image onto a workpiece, and a stage that supports the workpiece adjacent to the optical projection system when the image is being projected onto the workpiece. A gap is provided between the last optical element and the workpiece and is filled with an immersion fluid. A porous material is positioned adjacent to the gap and recovers fluid exiting the gap. A control system maintains a pressure on the porous material. The pressure is at or below the bubble point of the porous material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The invention will be described in conjunction with the accompanying drawings of exemplary embodiments in which like reference numerals designate like elements and in which:

[0014] FIG. 1 is a simplified elevational view schematically illustrating an immersion lithography system according to an embodiment of the invention;

[0015] FIG. 2 is a perspective view of a nozzle for fluid delivery and recovery for immersion lithography according to one embodiment of the invention;

[0016] FIG. 3 is a simplified cross-sectional view of the nozzle of FIG. 2;

[0017] FIG. 4 is a cross-sectional view of the inner part of the nozzle of FIG. 2;

[0018] FIG. 5 is a simplified cross-sectional view of the nozzle according to another embodiment;

[0019] FIG. 6 is a simplified view schematically illustrating a pressure control system for fluid recovery in an immersion lithography system according to one embodiment of the invention;

[0020] FIG. 7 is a simplified view schematically illustrating a pressure control system for fluid recovery in an immersion lithography system according to another embodiment of the invention;

[0021] FIG. 8 is a simplified view schematically illustrating a pressure control system for fluid recovery in an immersion lithography system according to another embodiment of the invention; and

[0022] FIG. 9 is a simplified view schematically illustrating a pressure control system for fluid recovery in an immersion lithography system with water stagnation prevention according to another embodiment of the invention.

DETAILED DESCRIPTION OF EMBODIMENTS

[0023] FIG. 1 shows an immersion lithography system 10 including a reticle stage 12 on which a reticle is supported, a projection lens 14, and a wafer 16 supported on a wafer stage 18. An immersion apparatus 20, which is sometimes referred to herein as a showerhead or a nozzle, is disposed around the final optical element 22 of the projection lens 14 to provide and recover a fluid, which may be a liquid such as water or a gas, between the final optical element 22 and the wafer 16. In the present embodiment, the immersion lithography system 10 is a scanning lithography system in which the reticle and the wafer 16 are moved synchronously in respective scanning directions during a scanning exposure.

[0024] FIGS. 2 and 3 show the apparatus or nozzle 20 for delivery and recovery of the fluid between the final optical element 22 and the wafer 16 for immersion lithography. FIG. 2 shows the bottom perspective view of the nozzle 20, which includes an outer part 30 and an inner part 32. The inner part 32 defines an inner cavity 34 to receive the fluid between the final optical element 22 and the wafer 16. The inner part 32 includes apertures 38 for fluid flow into and out of the inner cavity 34. As seen in FIG. 2, there are apertures 38 disposed on both sides of the final optical element 22. The inner part

32 has a flat portion **33** surrounding the inner cavity **34**. The flat portion **33** is substantially parallel to the wafer **16**. The distance **D1** between the end surface of the final optical element **22** and the wafer **16** is greater than the distance **D2** between the flat portion **33** and the wafer **16**. The distance **D1** could be 1.0-5.0 mm, and the distance **D2** could be 0.5-2.0 mm. In another embodiment, the distance **D1** is substantially equal to the distance **D2**. The inner part **32** further includes a pair of buffers or buffer slots **40** with purge holes **42** (see FIG. 4). The buffers **40** are arranged at or near the flat portion **33**. The buffers **40** are disposed on opposite sides of the final optical element **22**. A cross-sectional view of the inner part **32** in the direction of scan **44** is illustrated in FIG. 4.

[0025] The outer part **30** is spaced from the inner part **32** by an intermediate spacing or groove **48**, which may be referred to as an atmospheric groove. The outer part **30** includes one or more fluid recovery openings **50** disposed on opposite sides of the final optical element **22**. A porous member **51** is disposed in a slot or outer cavity **53** that extends around the inner part **32** and fluidically communicates with the pair of fluid recovery openings **50**. The porous member **51** may be a mesh or may be formed of a porous material having holes typically in the size range of about 50-200 microns. For example, the porous member **51** may be a wire mesh including woven pieces or layers of material made of metal, plastic, or the like, a porous metal, a porous glass, a porous plastic, a porous ceramic, or a sheet of material having chemically etched holes (e.g., by photo-etching). The outer part **30** further includes a fluid buffer outlet **56** and a fluid recovery outlet **58**. In another embodiment of the nozzle **20'** as seen in FIG. 5, the inner part **32** does not contact or form a seal with the final optical element **22**, but is spaced from the final optical element **22**. The gap prevents nozzle vibrations from being transmitted to the final optical element **22**. However, the gap may allow the fluid to be exposed to air.

[0026] One feature of the nozzle **20** is that it is made in two pieces, namely, the outer part **30** and the inner part **32**. The inner part **32** keeps the fluid between the lens and the wafer surface, and the outer part **30** is mainly provided for fluid recovery. Vibration might be introduced during fluid recovery from the outer part **30** through the porous member **51** to the other components of the lithography system, including the inner part **32** which may be used to direct an autofocus beam to the wafer **16**. A damping material can be mounted between the outer part **30** and the mounting piece to which the outer part **30** is mounted to minimize the transmission of vibration from the outer part **30**. In addition, the outer part **30** that includes the porous member may be prone to contamination and thus needs to be replaced for maintenance. Making the outer part **30** as a separate part facilitates easier maintenance. It can also minimize readjustment and recalibration time after replacement of the outer part as opposed to replacing the entire nozzle **20**. Manufacturability of the nozzle **20** can also be improved if the nozzle **20** is made in two separate parts. It is understood that the nozzle **20** may be made of a single piece in alternative embodiments.

[0027] Another feature of the nozzle **20** is the atmospheric groove **48** between the inner part **32** and the outer part **30**. This atmospheric groove **48** functions as a breaking edge to prevent fluid in the inner part **32** from being drawn out by

the porous member **51** on the outer part **30** if the fluid recovery rate is faster than the fluid supply rate. In the situation when there is no breaking edge, a balance between the fluid recovery rate and the fluid supply rate has to be maintained so that fluid can be kept within the inner part **32** at all times during scanning. Having the atmospheric groove **48** allows the recovery rate to be set at a maximum to minimize fluid leakage out of the outer part **30** during scanning. The atmospheric groove **48** also acts as a buffer for fluid to go in and out during scanning, minimizing water supply and recovery requirements.

[0028] In the process of immersion lithography, a fluid is to be filled between the projection lens **14** and the wafer **16** from a dry state and, at other times, the fluid is to be recovered. For example, in the beginning of exposure of a new wafer, the fluid is to completely fill the inner cavity **34** of the inner part **32** before starting exposure. During this process, ideally no air bubbles can exist between the projection lens **14** and wafer **16** or other optical paths such as the auto focus beam. The fluid supply in the inner cavity of the inner part **32** is designed to be at the highest point in the cavity (via apertures **38**) so that the fluid is filled from top down, allowing air bubbles to be pushed out of the inner cavity during the filling process. The fluid desirably is initially supplied from one side in this embodiment (the set of apertures **38** on one side), so that the fluid is filled from one side to the other, again allowing air bubbles to be pushed out to avoid trapping air therein. Other arrangements are also possible, as long as the fluid is being filled from the inside out.

[0029] On occasion, the fluid has to be fully recovered from the inner cavity of the inner part **32**. In FIG. 4, there are small holes **42** in each of the buffers **40** in the inner cavity. These holes **42** are provided for fast fluid recovery or fluid purge when the fluid has to be fully recovered. Sucking the fluid out from these holes **42** using high vacuum with the combination of some movement in the wafer stage **18** allows all the fluid to be recovered within a reasonable time.

[0030] The inner part **32** has two groups or rows of holes **38** for supplying or recovering the fluid. Each row can be independently controlled to either supply or recover the fluid. In the case where both rows are chosen for fluid supply, all the fluid is recovered through the porous member **51** in the outer part **30**. Because both rows are supplying fluid, a pressure can build up in the inner cavity causing deformation of the final optical element **22** of the projection lens **14** or the wafer **16** or both. The fluid flow across the final optical element **22** may also be limited, and thus the temperature of the fluid between the final optical element **22** and the wafer **16** may eventually rise, causing adverse effects. On the other hand, if one row is chosen for supply and the other for recovery, a fluid flow will be driven across the final optical element **22**, minimizing temperature rise. It can also reduce the pressure otherwise created by supplying fluid from both rows. In this case, less fluid needs to be recovered through the porous member **51**, lowering the fluid recovery requirement in the porous member. In other nozzle configurations, multiple fluid supplies and recoveries may be provided so as to optimize the performance.

[0031] During scanning motion of the wafer stage **18** (in the direction of scan **44** in FIG. 2), the fluid may be dragged in and out of the inner cavity of the inner part **32**. When the

fluid is dragged out, it is recovered through the porous member 51 in the outer part 30. When the wafer stage 18 is moved in the opposite direction, air may be dragged into the inner cavity of the inner part 32. During this time, the fluid in the buffers 40, as well as the fluid supplied from within the inner cavity, helps to refill the fluid that is dragged along the scanning direction, preventing air from getting into the inner cavity. The buffers 40 and the porous member 51 work together to minimize fluid leaking out from the outer part 30, and air dragging into the inner cavity of the inner part 32 during scanning motion of the wafer stage 18.

[0032] Recovering fluid through the porous member 51 by maintaining the pressure in the porous member 51 under the bubble point can eliminate noise created by mixing air with the fluid during fluid recovery. The bubble point is a characteristic of the porous member 51 that depends on the size of the holes in the porous member 51 (the largest hole) and the contact angle that the fluid forms with the porous member 51 (as a parameter based on the property of the porous material and the property of the fluid). Due to the fact that the bubble point is typically a very low pressure (e.g., about 1000 pascal), the control of this low pressure becomes an important issue. FIGS. 6-7 illustrate three specific ways of maintaining the pressure below the bubble point during fluid recovery.

[0033] In the pressure control system 100 of FIG. 6, a pressure under bubble point is maintained at the surface of the porous member 51 using a vacuum regulator 102 with the assistance of an overflow container or tank 104 fluidically coupled to the porous member 51 by a recovery flow line 106 (which is connected to the fluid buffer outlet 56). The pressure at the surface of the porous member 51 is equal to the pressure maintained by the vacuum regulator 102 subtracting the pressure created by the height of the fluid above the porous member 51. Maintaining a constant height of fluid above the porous member 51 using the overflow tank 104 allows easy control of the pressure at the surface of the porous member 51. The fluid that is recovered through the porous member 51 will overflow and be siphoned down along a siphon line 108 to a collection tank 110, which is disposed below the overflow tank 104. An optional flow path 112 is connected between the overflow tank 104 and the collection tank 110 to assist in equalizing the pressure between the overflow tank 104 and the collection tank 110 and facilitate flow along the siphon line 108. One feature of this pressure control system 100 is that it is a passive system without the necessity of control.

[0034] In the pressure control system 120 of FIG. 7, the pressure at the surface of the porous member 51 is maintained below the bubble point using a vacuum regulator 122 at a fluid level buffer 124 which is fluidically coupled with the porous member 51 by a buffer flow line 126 (which is connected to the fluid buffer outlet 56). A pressure transducer or a water level sensor 128 is used to measure the pressure or fluid level at the fluid level buffer 124. The sensor signal is then used for feedback control 130 to a valve 132 that is disposed in a recovery flow line 134 (which is connected to the fluid recovery outlet 58) connected between the porous member 51 and a collection tank 136. The valve 132 may be any suitable valve, such as a proportional or variable valve. The variable valve 132 is adjusted to control the fluid flow through the fluid recovery line 134 to the collection tank 136 to maintain the pressure or fluid level of

the fluid level buffer 124 at a preset value. The collection tank 136 is under a relatively higher vacuum controlled by a high vacuum regulator 138 for fluid recovery. In this fluid control system 120, no overflow tank is needed and the collection tank 136 can be placed anywhere in the system and need not be disposed below an overflow tank. An on/off valve 140 is desirably provided in the fluid recovery line 134 and is switched off when fluid recovery is not required.

[0035] In FIG. 8, the pressure control system 160 is similar to the system 120 of FIG. 7, and like reference characters are used for like parts. Instead of using the valve 132 for the feedback control of fluid recovery, this system 160 employs a controllable vacuum regulator 162 for the feedback control of fluid recovery. The vacuum regulator 162 is typically electronically controllable to adjust the vacuum pressure in the collection tank 136 based on the sensor signal from the pressure transducer or a water level sensor 128. The vacuum regulator 162 is adjusted to control the fluid flow through the fluid recovery line 134 to the collection tank 136 to maintain the pressure or fluid level of the fluid level buffer 124 at a preset value. The on/off valve 140 in the fluid recovery line 134 is switched off when fluid recovery is not required.

[0036] FIG. 9 shows a pressure control system for fluid recovery in an immersion lithography system with water stagnation prevention according to another embodiment of the invention. The pressure control system 180 is similar to the system 120 of FIG. 7 having the same components with the same reference characters. In addition, the fluid level buffer 124 is fluidically coupled with a fluid supply or fluid recovery 182 to supply fluid to or recover fluid from the fluid level buffer 124 to prevent stagnation. An optional pump or a similar moving part may be used to induce flow between the fluid level buffer 124 and the fluid supply or fluid recovery 182. There is a possibility of bacteria/fungus growth in stagnated water or fluid over time. Under normal operation, the water at the fluid level buffer 124 is stagnated because water recovered from the mesh 51 will go through the small tube at the mesh level to the collection tank 136. By inducing flow into or out of the fluid level buffer 124 during normal operation, the bacteria/fungus growth problem can be prevented.

[0037] It is to be understood that the above description is intended to be illustrative and not restrictive. Many embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the invention should not be limited to the above description.

[0038] Also, the present invention could be applied to Twin-Stage-Type Lithography Systems. Twin-Stage-Type Lithography Systems, for example, are disclosed in U.S. Pat. No. 6,262,796 and U.S. Pat. No. 6,341,007, the disclosures of which are incorporated herein by reference in their entireties.

What is claimed is:

1. A lithographic projection apparatus arranged to project a pattern from a patterning device onto a substrate using a projection system and having a liquid supply system arranged to supply a liquid to a space between the projection system and the substrate, comprising a fluid removal system including a chamber configured to hold liquid and having an open end adjacent a volume in which fluid will be present, the open end configured to remove, through a pressure

differential across-the open end when liquid is present in the chamber, substantially only liquid from the volume when liquid in the volume is adjacent the open end but not gas from the volume when gas in the volume is adjacent the open end.

2. The apparatus according to claim 1, wherein the fluid removal system is arranged to remove liquid from a volume adjacent the space.

3. The apparatus according to claim 2, further comprising a member at least partially surrounding the space and comprising the open end in a surface of the member facing the substrate.

4. The apparatus according to claim 3, wherein the member further comprises a gas supply device having an outlet in a surface of the member facing the substrate so as to form a gas knife to remove residual liquid from a surface of the substrate, the gas knife being located radially outwardly of the open end.

5. The apparatus according to claim 1, wherein the open end comprises a porous member comprising a plurality of apertures.

6. The apparatus according to claim 1, wherein the open end comprises a capillary conduit having a hydrophilic wall.

7. The apparatus according to claim 1, wherein the capillary conduit has a width of about 0.05 mm and the fluid removal system is configured to provide an underpressure of about -20 mbar to create the pressure differential, when the liquid is water and the gas is air.

8. The apparatus according to claim 1, wherein the fluid removal system comprises a liquid/gas separation manifold thermally isolated from its surroundings and the chamber comprises a pipe extending into a lower part of the manifold.

9. The apparatus according to claim 1, wherein the liquid supply system comprises, in series before outlet to the space, a pressure regulator with an external tap, a variable restriction, and a constant restriction, the external tap connected downstream of the variable restriction and configured so that an input of the constant restriction is at a substantially constant pressure.

10. The apparatus according to claim 1, wherein the liquid supply system comprises, in series before outlet to the space, a forward pressure regulator with an external tap connected downstream of it, a variable restriction, and a second pressure regulator with an external tap connected upstream of it, the external tap of the forward pressure regulator connected upstream of an input of the variable restriction and the external tap of the backward pressure regulator connected downstream of an output of the variable restriction, the forward and backward pressure regulators configured to maintain substantially constant pressures at the inlet and outlet of the variable restriction.

11. A lithographic projection apparatus arranged to project a pattern from a patterning device onto a substrate using a projection system and having a liquid supply system arranged to supply a liquid to a space between the projection system and the substrate, comprising a fluid removal system including a chamber configured to hold gas and having an open end adjacent a volume in which fluid will be present, the open end configured to remove, through a pressure differential across the open end when gas is present in the chamber, substantially only gas from the volume when gas in the volume is adjacent the open end but not liquid from the volume when liquid in the volume is adjacent the open end.

12. The apparatus according to claim 11, wherein the open end comprises a capillary conduit having a hydrophobic wall.

13. The apparatus according to claim 11, wherein the open end comprises a porous member comprising a plurality of apertures.

14. The apparatus according to claim 11, wherein the chamber configured to hold gas is a first chamber and its open end is a first open end and further comprising a second chamber configured to hold liquid and having a second open end adjacent the volume, the second open end configured to remove, through a pressure differential across the second open end when liquid is present in the second chamber, substantially only liquid from the volume when liquid in the volume is adjacent the second open end but not gas from the volume when gas in the volume is adjacent the second open end.

15. The apparatus according to claim 14, further comprising a substrate table configured to hold the substrate and comprising the first open end and the second open end in a surface of the substrate table adjacent an edge of the substrate, when the substrate is held on the substrate table.

16. The apparatus according to claim 14, wherein the first open end comprises a capillary conduit having a hydrophobic wall and the second open end comprises a capillary conduit having a hydrophilic wall.

17. A lithographic projection apparatus arranged to project a pattern from a patterning device onto a substrate using a projection system and having a liquid supply system arranged to supply a liquid to a space between the projection system and the substrate, comprising a fluid removal system including a capillary conduit having an open end adjacent a volume in which fluid will be present, the capillary conduit configured to remove, through a pressure differential across the capillary conduit, substantially only liquid from the volume or to remove, through a pressure differential across the capillary conduit, substantially only gas from the volume.

18. The apparatus according to claim 17, wherein the fluid removal system is arranged to remove liquid from a volume adjacent the space.

19. The apparatus according to claim 18, further comprising a member at least partially surrounding the space and comprising the capillary conduit with the open end in a surface of the member facing the substrate.

20. The apparatus according to claim 17, further comprising a substrate table configured to hold the substrate and comprising the open end in a surface of the substrate table adjacent an edge of the substrate, when the substrate is held on the substrate table.

21. The apparatus according to claim 17, wherein the capillary conduit has a width of about 0.05 mm and the fluid removal system is configured to provide an underpressure of about -20 mbar to create the pressure differential, when the liquid is water and the gas is air.

22. The apparatus according to claim 17, wherein the capillary conduit has a hydrophobic wall when configured to remove substantially only gas or a hydrophilic wall when configured to remove substantially only liquid.