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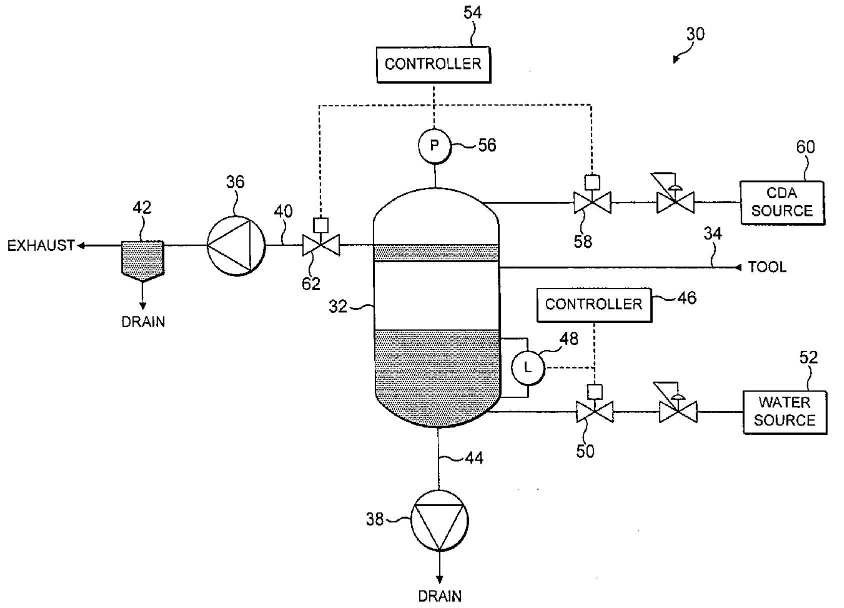
(54) Title: VACUUM SYSTEM FOR IMMERSION PHOTOLITHOGRAPHY



(57) Abstract: A vacuum system for extracting a stream of a multi-phase fluid from a photolithography tool comprises a pumping arrangement for drawing the fluid from the tool, and an extraction tank (32) located upstream from the pumping arrangement for separating the fluid drawn from the tool into gas and liquid phases. The pumping arrangement comprises a first pump (36) for extracting gas from the tank, and a second pump (38) for extracting liquid from the tank (32). In order to minimise any pressure fluctuations transmitted from the vacuum system back to the fluid (32) within the tool, a pressure control system maintains a substantially constant pressure in the tank (32) by regulating the amounts of liquid and gas within the tank (32).

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VACUUM SYSTEM FOR IMMERSION PHOTOLITHOGRAPHY

This invention relates to a vacuum system for extracting a multi-phase fluid from an immersion photolithography exposure tool.

Photolithography is an important process step in semiconductor device fabrication. In overview, in photolithography a circuit design is transferred to a wafer through a pattern imaged on to a photoresist layer deposited on the wafer surface. The wafer then undergoes various etch and deposition processes before a new design is transferred to the wafer surface. This cyclical process continues, building up the multiple layers of the semiconductor device.

The minimum feature that may be printed using photolithography is determined by the resolution limit *W*, which is defined by the Rayleigh equation as:

$$W = \frac{k_1 \lambda}{NA} \qquad (1)$$

where k_1 is the resolution factor, λ is the wavelength of the exposing radiation and *NA* is the numerical aperture. In lithographic processes used in the manufacture of semiconductor devices, it is therefore advantageous to use radiation of very short wavelength, in order to improve optical resolution, so that very small features in the device may be accurately reproduced. In the prior art, monochromatic visible light of various wavelengths have been used, and more recently radiation in the deep ultra violet (DUV) range has been used, including radiation at 193 nm as generated using an ArF excimer laser.

The value of *NA* is determined by the acceptance angle (α) of the lens and the index of refraction (*n*) of the medium surrounding the lens, and is given by

$$NA = n\sin\alpha \qquad (2)$$

For clean dry air (CDA), the value of n is 1, and so the physical limit to NA for a lithographic technique using CDA as a medium between the lens and the wafer is 1, with the practical limit being currently around 0.9.

Immersion photolithography is a known technique for improving optical resolution by increasing the value of *NA*, as well as increasing the depth of focus (DOF) or vertical process latitude. With reference to Figure 1, in this technique a liquid 10 having a refractive index $n > 1$ is placed between the lower surface of the objective lens 12 of a projection device 14 and the upper surface of a wafer 16 located on a moveable wafer stage 18. The liquid placed between lens 12 and wafer 16 should, ideally, have a low optical absorption at 193nm, be compatible with the lens material and the photoresist deposited on the wafer surface, and have good uniformity. These criteria are met by ultra-pure, degassed water, which has a refractive index $n \approx 1.44$ for light at 193 nm. The increased value of *n*, in comparison to a technique where the medium between lens and wafer is CDA, increases the value of *NA*, which in turn decreases the resolution limit *W*, enabling smaller features to be reproduced.

Due to outgassing from the photoresist layer , generation of particulates during photolithography, and maintaining a uniform wafer temperature, it is desirable to maintain a steady flow of water between the lens 12 and the wafer 16. For example, as described in US 2004/0075895 the lens and wafer could be immersed in a bath of water supported by the wafer stage, with a pump used to recirculate the water within the bath. However, due to the weight of the water bath acting on the wafer stage, this technique is generally considered undesirable.

An alternative technique, as shown in Figure 1, is to use a nozzle or showerhead device 20 connected to a water source and a vacuum system, shown generally at 22, to produce a localised stream of ultra-pure, degassed water between the lens 12 and the wafer 16. To prevent the ingress of water into other parts of the tool, for example, the mechanism used to move the wafer stage 18, one or more differential air seals 24 are used. As a result, the vacuum system 22 extracts from the tool a multi-phase mixture of water and CDA. However, the extraction of such a multi-phase mixture from the tool using a single vacuum pump, especially in slug or churn regime flows, can generate undesirable pressure and flow fluctuations upstream of the pump, which could be transmitted back to the tool. This could lead to errors in the photolithography process, for example, through variations in the refractive index of the medium located between the lens and the wafer, or through the transmission of mechanical vibrations to the tool.

It is an aim of at least the preferred embodiment of the present invention to provide a vacuum system for extracting a stream of a multi-phase fluid from a photolithography tool and which can minimise any pressure fluctuations imparted thereby to fluid within the tool.

In a first aspect, the present invention provides a system for extracting a stream of multi-phase fluid from a photo-lithography tool, the system comprising a pumping arrangement for drawing the fluid from the tool, separating means, for example, an extraction tank, located upstream from the pumping arrangement for separating the fluid drawn from the tool into gas and liquid phases, the pumping arrangement comprising a first pumping unit for extracting gas from the tank and a second pumping unit for extracting liquid from the tank, and a pressure control system for controlling the pressure within the tank by regulating the amounts of gas and liquid therewithin.

In order to minimise any pressure fluctuations transmitted from the system back to the fluid within the tool, the pressure control system can maintain a substantially constant pressure in the tank by regulating the amounts of liquid and gas within the tank.

In order to control the amount of gas within the tank, the pressure control system preferably comprises means for supplying gas to the tank from a source thereof, and control means for controlling the flow of gas to the tank. For example, where there is a variation in the flow of fluid into the tank, and/or a variation in the flow of gas from the tank, gas can be introduced into the tank from the external source to compensate for such variations. In the preferred embodiment the pressure control system comprises a variable flow control device, such as a butterfly or other control valve, through which gas is supplied to the tank, with the control means being configured to vary the conductance of the valve to control the pressure within the tank. For example, a controller may be configured to receive a signal indicative of the pressure within the tank, and to control the conductance of the valve in dependence on the received signal. This signal may be received from a pressure sensor, capacitance manometer or other form of sensor of sufficient sensitivity to achieve the required level of pressure control.

As well as, or as an alternative to, controlling the supply of gas to the tank, the controller is preferably configured to control the flow of gas from the tank in dependence on the received signal. For example, another variable flow control device may be provided, through which gas is extracted from the tank by the first pumping unit, with the controller being configured to control the conductance of this variable flow control device.

In order to control the amount of liquid in the tank, the pressure control system preferably comprises means for supplying liquid to the tank from a source thereof, and control means for controlling the flow of liquid to the tank. For example, in order to minimise pressure variations due to the extraction of liquid from the tank by the second pumping unit, the control means is preferably configured to maintain a substantially constant level of liquid within the tank. In the preferred embodiment, the liquid supply means comprises a variable flow control device such as a butterfly or other control valve, through which liquid is supplied to the tank, with the control means being configured to vary the conductance of the valve to control the level of liquid within the tank. For example, a controller may be configured to receive a signal indicative of the level of liquid within the tank, and to control the conductance of the valve in dependence on the received signal. This signal may be received from a level meter, float detector, or other form of sensor of sufficient sensitivity to allow a substantially constant level of liquid to be maintained within the tank. One or more flexible tubes are preferably used to convey fluid (single and/or multi-phase) between the components of the system. For example, a flexible tube may be used to convey the multi-phase fluid to the extraction tank. Further flexible tubes may also be used to convey the single phase streams from the tank to respective pumping units. This can minimise the transmission of vibrations generated during use of the system back to the fluid within the tool.

In a second aspect, the present invention provides a method of extracting a stream of multi-phase fluid from a photo-lithography tool, the method comprising the steps of: connecting a pumping arrangement to the tool via an extraction tank; operating the pumping arrangement to draw the fluid from the tool; separating the fluid drawn from the tool into gas and liquid phases within the extraction tank, the pumping arrangement extracting separately gas and liquid from the extraction tank; and controlling the pressure within the extraction tank by regulating the amounts of gas and liquid therewithin.

Features described above in relation to system aspects of the invention are equally applicable to method aspects, and vice versa.

By way of example, an embodiment of the invention will now be further described with reference to the following figures in which:

Figure 1 illustrates schematically a known system for immersion photolithography; and

Figure 2 illustrates schematically an embodiment of a vacuum system for extracting a multi-phase fluid from an immersion photolithography tool.

With reference to Figure 2, a system 30 for extracting a multi-phase fluid from an immersion photolithography tool comprises an extraction tank 32 for receiving the multi-stream fluid drawn from the tool by a pumping arrangement located downstream from the tank 32. The tank 32 is connected to the tool by flexible tubing 34 so as to minimise the amount of mechanical coupling between the system 30 and the tool, and thereby minimise the transmission of vibrations generated during use of the system 30 back to the tool.

The tank 32 is configured to separate the liquid and gas phases within the fluid received from the tool. In this example, the fluid received from the tool comprises a mixture of clean dry air (CDA) and ultra-pure water, and so the tank 32 contains any suitable material and/or structure for affecting the separation of the CDA from the water. However, the tank 32 may be configured to separate a different liquid-gas mixture received from the tool. For example, the liquid may comprise an aqueous or non-aqueous solution, and the gas may be other than CDA.

The pumping arrangement comprises a first pumping unit 36 for extracting gas from the tank 32, and a second pumping unit 38 for extracting liquid from the tank 32.

The first pumping unit 36 may comprise any suitable pump for extracting the gas from the tank 32, and is preferably chosen for compatibility with the gas extracted from the tank 32, which is likely to be saturated with liquid vapour, for minimum transmission of pressure fluctuations back to the gas contained in the tank 32, and for relatively long maintenance periods. In this embodiment, the first pumping unit 36 may conveniently comprise an air-powered ejector pump or a water-based liquid ring pump for extracting CDA from the tank 32. In order to inhibit the transfer of vibrations to the tank 32 during use, the first pumping unit 36 is connected to the tank using flexible tubing 40. As the gas exhaust from the first pumping unit 36 may be saturated or supersaturated with liquid vapour, in this embodiment water vapour, a separator vessel 42 may be connected to the exhaust of the first pumping unit 36, the vessel 42 containing any suitable material and/or structure for affecting the separation of water vapour from the CDA. The water extracted from the CDA is exhaust to a drain, and the CDA is vented to the atmosphere.

The second pumping unit 38 may comprise any suitable pump for extracting the liquid from the tank 32, and is preferably chosen for compatibility with the liquid extracted from the tank 32 and for relatively long maintenance periods. In this embodiment where the liquid is water, the second pumping unit 38 may conveniently comprise a water-powered ejector pump or a diaphragm pump for extracting water from the tank 32. In order to inhibit the transfer of vibrations to the tank 32 during use, the second pumping unit 38 is connected to the tank using flexible tubing 44. The internal diameter of the flexible tubing 44 may be chosen to restrict the flow rate of liquid from the tank 32 to the second pumping unit 38. Alternatively, or in addition, a fixed or variable flow restrictor may be located between the tank 32 and the second pumping unit 38.

In order to minimise any pressure fluctuations transmitted from the system 30 back to the fluid within the tool, the system 30 includes a pressure control system for maintain a substantially constant pressure in the tank 32. In this embodiment, this is achieved by regulating the amounts of liquid and gas within the tank 32.

The amount of liquid contained in the tank 32 is maintained at a substantially constant level by a controller 46, thereby maintaining a substantially constant volume of gas in the tank 32. The controller 46 is connected to a sensor 48 for detecting the level of liquid with the tank 32. The sensor 48 may comprise, for example, a level meter, float meter or other form of suitable sensor. The sensor 48 outputs a signal to the controller 46 indicative of the level of the liquid within the tank 32. In response to this signal, the controller 46 outputs to a variable flow control device 50 located between the tank 32 and a pressurised external liquid source 52 connected to the tank 32 a signal which causes the device 50 to vary the flow of liquid, in this embodiment water, to the tank 32. For example, the device 50 may be a butterfly or other control valve having a conductance that can be varied in dependence on, preferably in proportion to, the signal received from the controller 46. By varying the flow rate of the water to the tank from the external source 52, the controller 46 can compensate for any variation in the flow rate of fluid to the tank 32 from the tool and/or any variation in the rate of extraction of liquid from the tank 32 by the second pumping unit 38, and thus maintain the liquid in the tank 32 at a substantially constant level. The controller 46 may be arranged to process the signal received from the sensor 48 to compensate for any ripples generated in the surface of the liquid during use.

With the gas occupying a substantially constant volume within the tank 32, any variations in the amount of gas contained in the multi-phase fluid received from the tank, and/or any in the rate of extraction of gas from the tank 32 by the first pumping unit 36, and any temperature fluctuations within the tank 32, could vary the pressure of the gas within the tank 32, and impart pressure and flow fluctuations to the fluid in the tool. The pressure control system is therefore configured to maintain a substantially constant pressure within the tank 32 by also regulating the amount of gas within the tank 32.

To achieve this, the pressure control system comprises a controller 54 connected to a sensor 56 for detecting the gas pressure with the tank 32. The sensor 56 may comprise, for example, a pressure sensor, a capacitance manometer or other form of sensor of sufficient sensitivity to achieve the required level of pressure control. The sensor 56 outputs a signal to the controller 54 indicative of the gas pressure within the tank 32. In response to this signal, the controller 54 outputs to a variable flow control device 58 located between the tank 32 and a pressurised external gas source 60 connected to the tank 32 a signal which causes the device 58 to vary the flow of gas, in this embodiment CDA, to the tank 32. A further variable flow control device 62 may be located between the tank 32 and the first pumping unit 36 and configured to receive a signal from the controller 54 to vary the flow of gas from the tank 32. For example, the devices 58, 62 may also be butterfly or other control valves having a conductance that can be varied in dependence on, preferably in proportion to, the signal received from the controller 54. By controlling the flow of gas into and out from the tank 32, the controller 54 can maintain a substantially constant gas pressure within the tank 32.

The system 30 can thus provide a system capable of extracting a multi-phase fluid from the immersion lithography tool whilst minimising any pressure fluctuations imparted thereby to the fluid within the tool.

CLAIMS

1. A system for extracting a stream of multi-phase fluid from a photolithography tool, the system comprising a pumping arrangement for drawing the fluid from the tool, separating means located upstream from the pumping arrangement for separating the fluid drawn from the tool into gas and liquid phases, the pumping arrangement comprising a first pumping unit for extracting gas from the separating means and a second pumping unit for extracting liquid from the separating means, and a pressure control system for controlling the pressure within the separating means by regulating the amounts of gas and liquid therewithin.

2. A system according to Claim 1, wherein the pressure control system comprises gas supply means for supplying gas to the separating means from a source thereof, and control means for controlling the flow of gas to the separating means.

3. A system according to Claim 2, wherein the gas supply means comprises a variable flow control device through which gas is supplied to the separating means, the control means being configured to vary the conductance of the variable flow control device to control the pressure within the separating means.

4. A system according to Claim 3, wherein the control means comprises a controller configured to receive a signal indicative of the pressure within the separating means, and to control the conductance of the variable flow control device in dependence on the received signal.

5. A system according to Claim 4, wherein the controller is further configured to control the flow of gas from the separating means in dependence on the received signal.

6. A system according to Claim 5, wherein the pressure control system comprises a further variable flow control device through which gas is extracted from the separating means by the first pumping unit, the controller being configured to control the conductance of the further variable flow control device in dependence on the received signal.

7. A system according to any preceding claim, wherein the pressure control system comprises control means for controlling the flow of gas from the separating means.

8. A system according to Claim 7, wherein the pressure control system comprises a variable flow control device through which gas is extracted from the separating means by the first pumping unit, the control means being configured to control the conductance of the variable flow control device to control the pressure within the separating means.

9. A system according to Claim 8, wherein the control means comprises a controller configured to receive a signal indicative of the pressure within the separating means, and to control the conductance of the variable flow control device in dependence on the received signal.

10. A system according to any preceding claim, wherein the pressure control system comprises liquid supply means for supplying liquid to the separating means from a source thereof, and control means for controlling the flow of liquid to the separating means.

11. A system according to Claim 10, wherein the control means is configured to control the level of liquid within the separating means.

12. A system according to Claim 11, wherein the liquid supply means comprises a variable flow control device through which liquid is supplied to the separating means, the control means being configured

to vary the conductance of the variable flow control device to control the level of liquid within the separating means.

13. A system according to Claim 12, wherein the control means comprises a controller configured to receive a signal indicative of the level of liquid within the separating means, and to control the conductance of the variable flow control device in dependence on the received signal.

14. A system according to any preceding claim, wherein the separation means comprises an extraction tank.

15. A system according to any preceding claim, comprising a flexible tube for conveying gas from the separating means to the first pumping unit.

16. A system according to any preceding claim, comprising a flexible tube for conveying liquid from the separating means to the second pumping unit.

17. A system according to any preceding claim, comprising a flexible tube for conveying liquid from the photolithography tool to the separating means.

18. A method of extracting a stream of multi-phase fluid from a photolithography tool, the method comprising the steps of: connecting a pumping arrangement to the tool via an extraction tank; operating the pumping arrangement to draw the fluid from the tool; separating the fluid drawn from the tool into gas and liquid phases within the extraction tank, the pumping arrangement extracting separately gas and liquid from the extraction tank; and controlling the pressure within the extraction tank by regulating the amounts of gas and liquid therewithin.

19. A method according to Claim 18, wherein the pressure within the extraction tank is controlled by supplying gas to the extraction tank from a source thereof, and controlling the flow of gas to the extraction tank.

20. A method according to Claim 19, wherein the flow of gas to the extraction tank is controlled in dependence on the pressure therewithin.

21. A method according to Claim 20, wherein the flow of gas from the extraction tank is controlled in dependence on the pressure therewithin.

22. A method according to any of Claims 18 to 21, wherein the pressure within the extraction tank is controlled by supplying liquid to the extraction tank from a source thereof, and controlling the flow of liquid to the extraction tank.

23. A method according to Claim 22, wherein the pressure within the extraction tank is controlled by controlling the level of liquid within the extraction tank.

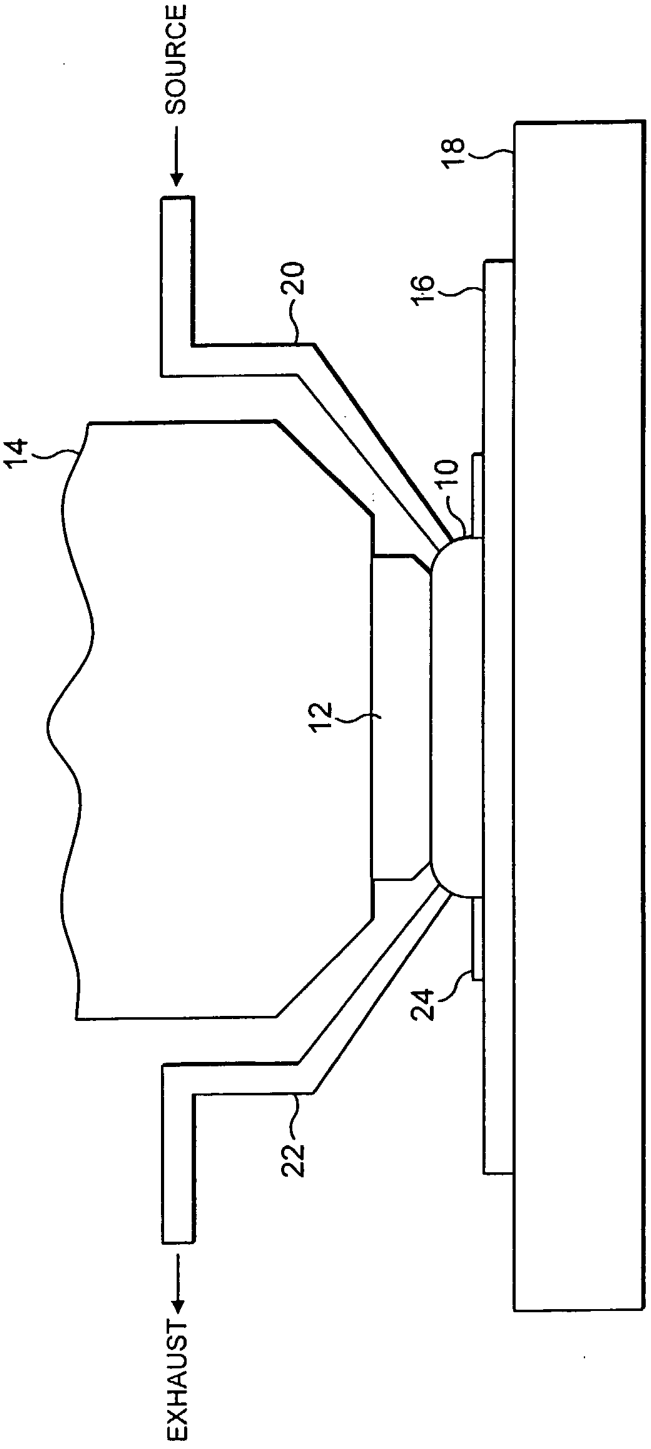

FIG. 1
(PRIOR ART)

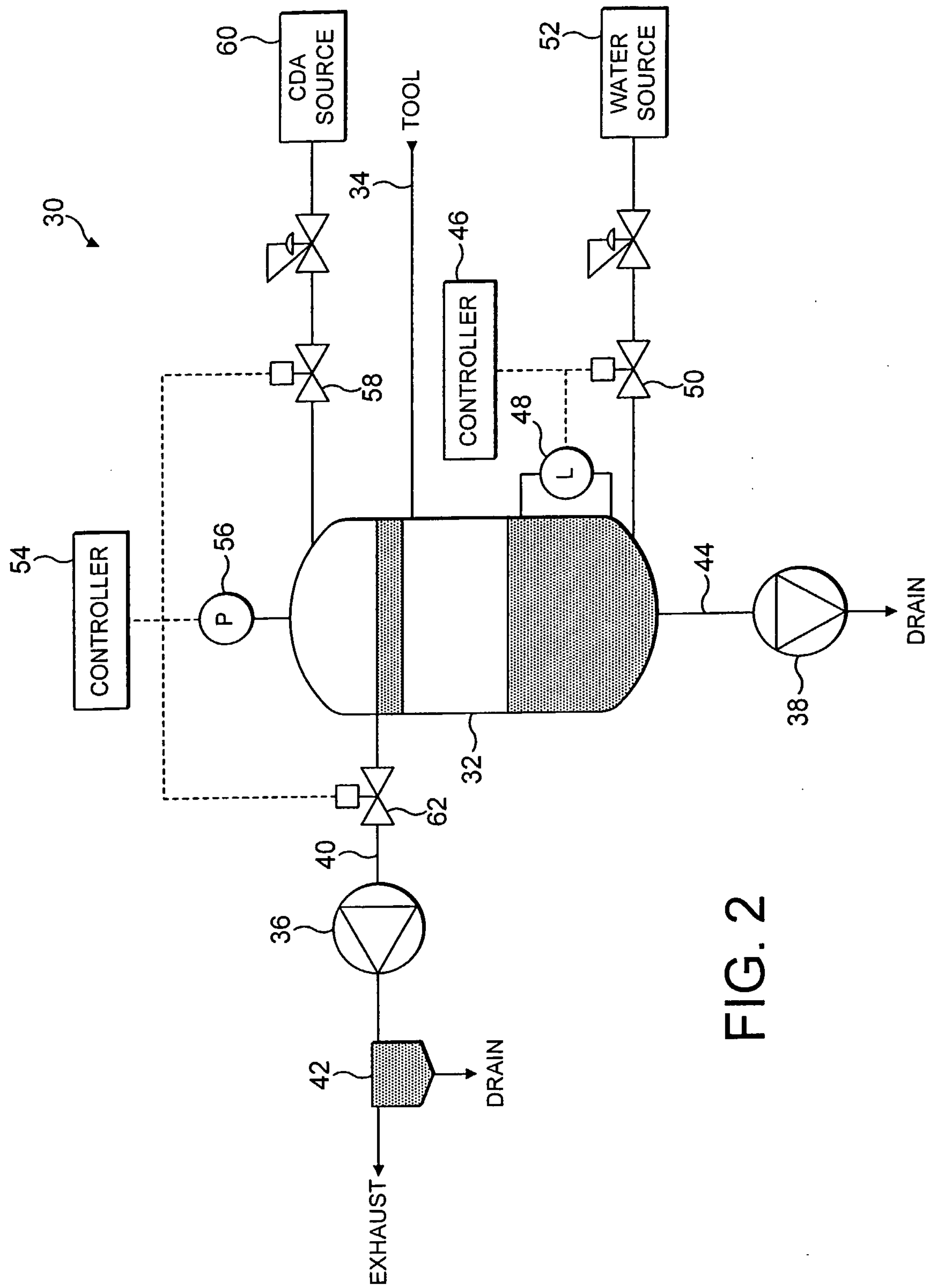
30
60
CDA SOURCE
TOOL
34
52
WATER SOURCE
46
CONTROLLER
58
50
48
L
54
CONTROLLER
56
P
44
DRAIN
38
32
62
40
36
42
DRAIN
EXHAUST

FIG. 2