

HEAT PIPE WITH TEMPERATURE CONTROL

BACKGROUND OF THE INVENTION

1. Field of Invention

The present invention relates generally to semiconductor processing equipment.

- 5 More particularly, the present invention relates to a heat pipe with an internal temperature that may be readily controlled by changing the pressure within the heat pipe.

2. Description of the Related Art

- For precision instruments such as photolithography machines which are used in semiconductor processing, factors which affect the performance, *e.g.*, accuracy, of the precision instrument generally must be dealt with and, insofar as possible, eliminated.
- 10 When the performance of a precision instrument is adversely affected, as for example by disturbance forces or by excessive heat, products formed using the precision instrument may be improperly formed and, hence, defective. For instance, a photolithography machine which is subjected to disturbance forces may cause an image projected by the
- 15 photolithography machine to move, and, as a result, be aligned incorrectly on a projection surface such as a semiconductor wafer surface.

- Scanning stages such as wafer scanning stages and reticle scanning stages are often used in semiconductor fabrication processes, and may be included in various photolithography and exposure apparatuses. Wafer scanning stages are generally used to
- 20 position a semiconductor wafer such that portions of the wafer may be exposed as appropriate for masking or etching. Reticle scanning stages are generally used to accurately position a reticle or reticles for exposure over the semiconductor wafer. Patterns are generally resident on a reticle, which effectively serves as a mask or a negative for a wafer. When a reticle is positioned over a wafer as desired, a beam of light
- 25 or a relatively broad beam of electrons may be collimated through a reduction lens, and provided to the reticle on which a thin metal pattern is placed. Portions of a light beam, for example, may be absorbed by the reticle while other portions pass through the reticle and are focused onto the wafer.

- A stage such as a wafer scanning stage or a reticle scanning stage is typically
- 30 supported by a base structure such that the stage may move in a linear direction. The base structure often includes or houses various sensors and actuators which serve to control the motion of the stage and a table, *e.g.*, a wafer table, which is a part of an overall stage

apparatus. Such actuators are often arranged to control a coarse stage of an overall wafer stage, and include coils which generate heat. The heat generated by the coils may be relatively significant, *e.g.*, significant enough to affect an exposure process performed using the overall wafer stage. The heat generated may be, for example, in the range of approximately 10 degrees Celsius to approximately 20 degrees Celsius higher than a desired ambient temperature. Since the heat generated by the coils may adversely affect the performance of the overall wafer stage by, for example, interfering with the operation of sensors such as interferometers, the generated heat is generally carried away or otherwise removed from the vicinity of relatively critical components of the overall wafer stage. Carrying heat away from relatively critical components, as for example a wafer, reduces the effect of excessive heat on the critical components.

One device that may be used to carry heat away from relatively critical components is a heat pipe. For example, a heat source such as a linear motor within a stage device may be substantially in contact with a heat pipe which is arranged to remove heat from the heat source and to transfer the heat to a heat sink. Fig. 1 is a diagrammatic representation of a conventional heat pipe. A heat pipe 100 includes an evaporator end 102 and a condenser end 104. Heat pipe 100 may generally be configured as a hollow cylindrical tube that is substantially lined with wicking material 112, *e.g.*, a cotton sleeve. When heat is generated by a heat source 106, a fluid in liquid form that is contained within heat pipe 100 may be heated to its boiling point by heat source 106 at evaporator end 102. The fluid is typically a fluid which takes on a gaseous or vapor state when heated, and a liquid state when cooled. When heated at evaporator end 102, the fluid may be conducted towards a heat sink 107 positioned near condenser end 104, as indicated by arrows 108. It should be understood that heat sink 107 may be the environment around heat pipe 100, and may not necessarily be a physical component.

Heat sink 107 is arranged to remove the heat from the fluid and, as a result, allows the fluid to be cooled. That is, fluid at condenser end 104 condenses and transfers its latent heat of vaporization to heat sink 107. Cooled fluid may be returned through heat pipe 100 to heat source 102 when the condensed fluid enters wicking material 112 which is located within heat pipe 100. Capillary action then forces the condensed fluid through wicking material 112 back to evaporator end 102, as indicated by arrows 110.

In some cases, the ability to control the boiling temperature of fluid within a heat pipe may be needed such that the temperature of a heat source such as heat source 106 of Fig. 1 may be controlled. Controlling the temperature of a heat source may be critical, as many systems may require that the temperature of a heat source, *e.g.*, the surface

temperature of a coil of a linear motor, be maintained as close to an ambient temperature such as room temperature as possible. To control the temperature of a heat source, the boiling temperature associated with a fluid contained within a heat pipe may be controlled. For example, a heat pipe may be "charged" to alter the boiling temperature of fluid contained within the heat pipe to lower it to a level which enables the surface temperature of a coil of a linear motor to be maintained at a desired level. Charging a heat pipe generally includes adding a fluid such as water inside a heat pipe, or removing a fluid from a heat pipe, to alter the boiling temperature of the heat pipe. As shown in Fig. 2, additional fluid 230 may be added to an evaporator end 202 of a heat pipe 200 when it is desired for the boiling temperature associated with heat pipe 200 to be altered. Although a process of charging heat pipe 200 may be effective in altering the boiling temperature associated with heat pipe 200 and, hence the temperature associated with evaporator end 202, it is generally difficult to charge heat pipe 200 except at one time during the manufacturing process. Thus, the boiling temperature remains effectively constant during the use of heat pipe 200.

Some heat pipes have been designed to enable temperatures associated with the heat pipes to be substantially controlled, even if boiling temperatures associated with the heat pipes are essentially not controlled. A gas-loaded, variable conductance heat pipe, for example, may be used in some cases to enable the temperature within a heat pipe to remain fairly constant. Allowing the temperature within a heat pipe to remain fairly constant may allow a heat pipe to operate more efficiently, although the temperature at an evaporator end of such a heat pipe is generally not changeable. Figs. 3a and 3b are diagrammatic representations of a gas-loaded, variable conductance heat pipe. A heat pipe 300, which has an evaporator end 302 and a condenser end 304, includes a gas reservoir 340 at condenser end 304. Gas contained within reservoir 340 has a gas front 342 which moves depending upon the temperature of vapor contained within heat pipe 300. As gas front 342 moves, the surface area of condenser end 304 varies. For instance, as shown in Fig. 3b, when gas front 342 moves into condenser end 304, the surface area of condenser end 304 is decreased from the surface area of condenser end 304 as shown in Fig. 3a.

Since the surface area of condenser end 304 varies as gas front 342 moves, the thermal conductance of heat pipe 300 also varies as a function of the position of gas front 342. When the surface area of condenser end 304 increases, thermal conductance increases, and when the surface area of condenser end 304 decreases, thermal conductance decreases. As a result, a temperature drop across evaporator end 302 and

condenser end 304 is effectively controllable by moving gas front 342. While the temperature drop within heat pipe 300 may be controlled such that the temperature within heat pipe 300 may be maintained at a substantially constant temperature, the use of heat pipe 300 generally does not enable the temperature at evaporator end 302 to be
5 controlled.

While the use of a heat pipe to transfer heat away from critical components of an overall wafer stage system is typically effective, heat pipes generally are not able to be used to readily and efficiently allow the temperatures of heat sources to be controlled. As discussed above, although charging a heat pipe may enable a desired boiling temperature
10 to be obtained within the heat pipe, it is typically difficult to charge heat pipes except at one time during a manufacturing process. Hence, the boiling temperature within a heat pipe generally remains substantially constant during the use of the heat pipe. As a result, the boiling temperature achieved within a heat pipe may not be sufficient to maintain a surface of a heat source at a desired temperature, since the boiling temperature of the fluid
15 in the heat pipe effectively determines the constant temperature at which the evaporator end of the heat pipe which typically contacts the heat source may be held.

Therefore, what is needed is a method and an apparatus for enabling the temperature at which fluid in a heat pipe boils to be controlled. More specifically, what is desired is a method and an apparatus for controlling the temperature of an evaporator end
20 of a heat pipe such that the temperature of a heat source may effectively be controlled.

SUMMARY OF THE INVENTION

The present invention relates to a heat pipe within which the boiling temperature of a fluid may be adjusted. According to one aspect of the present invention, a method for controlling a temperature associated with a heat pipe that contains a fluid and has an
25 evaporator end includes measuring the temperature associated with the heat pipe and determining when the temperature associated with the heat pipe is at a desired level. The method also includes changing a pressure within the heat pipe when it is determined that the temperature associated with the heat pipe is not at a desired level. Changing the pressure within the heat pipe causes the temperature associated with the heat pipe to
30 change.

In one embodiment, the heat pipe includes a pressure control mechanism, and changing the pressure within the heat pipe includes operating the pressure control mechanism. In such an embodiment, the pressure control mechanism may include a

piston assembly, and changing the pressure within the heat pipe may include applying a controlled pressure using the piston assembly.

Controlling the temperature within a heat pipe effectively allows the temperature at which heat is removed from a heat source that is cooled by the heat pipe to be controlled. Specifically, the temperature of the fluid may be controlled by substantially controlling the pressure within the heat pipe. When the boiling temperature of the fluid within the heat pipe is controlled, the temperature of the evaporator end of the heat pipe is essentially controlled. Hence, the temperature at which heat is removed from a heat source, *e.g.*, a coil of a linear motor, may be substantially controlled by adjusting the pressure within the heat pipe. Controlling the temperature at which heat is removed from the heat source enables the surface temperature of the heat source to be more readily maintained at a constant level, which enhances the performance of an overall system, *e.g.*, a stage apparatus, which includes the heat source.

According to another aspect of the present invention, a heat pipe includes an evaporator end, a fluid, and a pressure control mechanism. The pressure control mechanism is arranged to change a pressure within the heat pipe such that a boiling temperature of the fluid is changed. In one embodiment, the pressure control mechanism is arranged to change the pressure by increasing the pressure such that the boiling temperature of the fluid is increased. In another embodiment, the pressure control mechanism includes a piston arrangement that applies a control pressure to change the pressure within the heat pipe.

According to yet another aspect of the present invention, a method for controlling a temperature of an actuator within a stage apparatus that is in communication with an evaporator end of a heat pipe includes determining a desired temperature for the actuator, determining a corresponding desired temperature for the evaporator end using the desired temperature for the actuator, and adjusting a mechanism within the heat pipe to achieve the desired temperature for the evaporator end. Adjusting the pressure causes a boiling temperature of a fluid within the heat pipe to be adjusted such that a temperature of the evaporator end is adjusted.

In one embodiment, adjusting the pressure within the heat pipe includes applying a control force of a first amount to a piston arrangement of the heat pipe. The control force of the first amount is arranged to cause the piston arrangement to change the pressure within the heat pipe. In such an embodiment, the method may also include determining when the temperature of the evaporator end is the desired temperature for the evaporator end. When the temperature of the evaporator end is the desired temperature

for the evaporator end, the control force is maintained at the first amount. Alternatively, when the temperature of the evaporator end is not the desired temperature for the evaporator end, the pressure within the heat pipe may be adjusted to achieve the desired temperature for the evaporator end by applying a control force of a second amount to the
5 piston arrangement.

According to still another aspect of the present invention, a heat transfer apparatus includes a flow passage and at least one heat receiving section where heat is transferred from a heat source. The heat receiving section is disposed on the way of the flow passage. A heat transfer medium filled within the flow passage is circulated within the
10 flow passage, and a temperature setting device connected to the flow passage changes a state-shift temperature of the heat transfer medium. In one embodiment, the temperature setting device changes a boiling temperature of the heat transfer medium. In another embodiment, the temperature setting device changes a pressure within the flow passage.

In accordance with a further aspect of the present invention, a heat transfer
15 apparatus includes a flow passage, at least one heat receiving section where heat is transferred from a heat source, and a heat transfer medium filled within the flow passage. The heat receiving section is disposed on the way of the flow passage and the heat source is disposed within the flow passage. The heat transfer medium is circulated within the flow passage.

According to another aspect of the present invention, a method for controlling a temperature associated with a heat transfer apparatus includes circulating a heat transfer medium within a flow passage that includes at least one heat receiving section where heat is transferred from a heat source, and changing a state-shift temperature of the heat transfer medium circulating within the flow passage. In one embodiment, changing a
20 state-shift temperature includes changing a boiling temperature of the heat transfer medium. In another embodiment, changing a state-shift temperature includes changing a pressure within the flow passage.

In accordance with yet another aspect of the present invention, a method for controlling a temperature associated with a heat transfer apparatus includes filling a heat
30 transfer medium within a flow passage and circulating the heat transfer medium within the flow passage. The flow passage includes a heat source.

These and other advantages of the present invention will become apparent upon reading the following detailed descriptions and studying the various figures of the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may best be understood by reference to the following description taken in conjunction with the accompanying drawings in which:

Fig. 1 is a diagrammatic representation of a conventional heat pipe.

5 Fig. 2 is a diagrammatic representation of a conventional heat pipe which is chargeable.

Fig. 3a is a diagrammatic representation of a gas-loaded, variable conductance heat pipe.

10 Fig. 3b is a diagrammatic representation of a gas-loaded, variable conductance heat pipe, *e.g.*, heat pipe 300 of Fig. 3a, with gas from a reservoir present in a condenser section.

Fig. 4 is a diagrammatic representation of a heat pipe within which pressure may be controlled in accordance with an embodiment of the present invention.

15 Fig. 5 is a diagrammatic representation of a heat pipe within which pressure may be controlled using a piston arrangement in accordance with an embodiment of the present invention.

Fig. 6 is a block diagram representation of actions which occur when a piston of a heat pipe assembly is moved in accordance with an embodiment of the present invention.

20 Fig. 7 is a diagrammatic representation of a heat pipe with a piston which serves as a pressure controller and an internal temperature sensor in accordance with an embodiment of the present invention.

Fig. 8 is a diagrammatic representation of a control loop which may be used to control the temperature within a heat pipe in accordance with an embodiment of the present invention.

25 Fig. 9 is a process flow diagram which illustrates one method of controlling the temperature in a heat pipe by adjusting the pressure in the heat pipe in accordance with an embodiment of the present invention.

Fig. 10a is a diagrammatic representation of a piston which is actuated by a voice coil motor in accordance with an embodiment of the present invention.

30 Fig. 10b is a diagrammatic representation of a piston which is actuated by an air bellows in accordance with an embodiment of the present invention.

Fig. 11 is a diagrammatic representation of a photolithography apparatus in accordance with an embodiment of the present invention.

Fig. 12 is a process flow diagram which illustrates the steps associated with fabricating a semiconductor device in accordance with an embodiment of the present invention.

Fig. 13 is a process flow diagram which illustrates the steps associated with processing a wafer, *i.e.*, step 1304 of Fig. 12, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

When the ambient temperature around an overall precision stage device, *e.g.*, an overall wafer stage device, is raised during a wafer exposure process, the performance of the stage device may be compromised. As a result, errors or inconsistencies may arise during a wafer exposure process that is performed using the stage device when the ambient temperature is raised, as for example from a desired temperature in the range of approximately 20 to approximately 25 degrees Celsius to a temperature in the range of approximately 30 to approximately 40 degrees Celsius. Often, heat which is generated by actuators associated with a stage device causes the ambient temperature to be raised. The actuators as above comprise a first part (heat source) that has a coil (conductor) and generates heat and a second part that cooperates with the first part to generate force. In order to reduce the amount by which the ambient temperature is raised by actuators such as linear motors or motors with electromagnetic coils, heat pipes (a heat transfer apparatus) may be used to carry heat away from the actuators to heat sinks that absorb the heat.

Typically, heat pipes (a heat transfer apparatus) are used to enable the surface temperature of a coil, *e.g.*, a coil of a linear motor, to be maintained at a particular temperature such as room temperature. Although a heat pipe is generally effective in carrying heat away from the coil, when the temperature at which a heat pipe operates to transfer heat away from the coil is too high, the coil may not be cooled sufficiently, and convection in the air surrounding the coil may cause the air to be heated up and, hence, interfere with the measurements made by sensors such as interferometers.

By controlling the temperature of a heat transfer medium, *e.g.*, a fluid, within a heat pipe (heat transfer apparatuses), the temperature at which heat is removed from a heat source such as an actuator may be controlled. In one embodiment, the temperature of the heat transfer medium, particularly at an evaporator end of a heat pipe, may be controlled by substantially controlling the pressure within the heat pipe. Controlling the pressure within the heat pipe enables the boiling temperature of fluid within the heat pipe

to be controlled, which effectively enables the temperature of the evaporator end of the heat pipe to be controlled. As a result, the temperature at which heat is removed from a heat source, *e.g.*, a coil of a linear motor, may be substantially controlled by adjusting the pressure within the heat pipe. Controlling the temperature at which heat is removed from the heat source enables the surface temperature of the heat source to be more readily maintained at a constant level. The structure of a heat transfer apparatus such as a heat pipe disclosed in the embodiments is varied. The apparatus may be used in an arrangement such as described in U.S. Patent No. 3,605,878 and U.S. Patent No. 6,684,941. The disclosures in the above U.S. Patents are incorporated herein by reference as long as the national laws in designated states or elected states, to which this international application is applied, permit.

Fig. 4 is a diagrammatic representation of a heat pipe within which pressure may be controlled in accordance with an embodiment of the present invention. A heat pipe 404 may be arranged between a heat source 416, *e.g.*, heat generating coils of an actuator, and a heat sink 420, *e.g.*, the environment surrounding heat pipe 404. Specifically, heat source 416 is positioned at an evaporator end 408 of heat pipe 404, while heat sink 420 is positioned at a condenser end 412 of heat pipe 404. A pressure control mechanism 424, which is effectively a part of heat pipe 404, is arranged to enable the pressure within heat pipe 404 to be varied. Pressure control mechanism 424 may generally be positioned substantially anywhere with respect to heat pipe 404. In one embodiment, pressure control mechanism 424 may be a piston which is subjected to a control force, as will be described below with respect to Fig. 5. It should be appreciated, however, that pressure control mechanism 424 may generally be substantially any mechanism which enables the pressure within heat pipe 404 to be varied. Further, heat source 416 may be positioned within heat pipe (heat transfer apparatus) 404. Alternately, heat source 416 may be positioned out of heat pipe (heat transfer apparatus) 404.

Typically, by increasing the pressure within heat pipe 404, the boiling temperature of a fluid which is either in a liquid state or a gas-liquid state may be increased. On the other hand, by decreasing the pressure within heat pipe 404, the boiling temperature of the fluid which is either in a liquid state or a gas-liquid state may be lowered. When the boiling point or temperature of the fluid within heat pipe 404 changes, then the temperature at evaporator end 408, which generally contains the fluid in a liquid state, changes. As such, changing the boiling temperature of the fluid changes the temperature of evaporator end 408 and, hence, the temperature at which heat source 416 may be maintained may effectively be changed, since heat source 416 is generally in

communication with evaporator end 408. By way of example, when the pressure within heat pipe 404 increases and the boiling temperature of the fluid within heat pipe 404 increases, then heat generated by heat source 416 may be substantially dissipated by heat pipe 404 at a higher temperature. Hence, allowing the boiling temperature of fluid within heat pipe 404 to be substantially controlled using pressure control mechanism 424 allows the temperature associated with evaporator end 408 and the temperature of heat source 416 to be controlled.

As mentioned above, one suitable pressure control mechanism 424 is a piston mechanism. Referring next to Fig. 5, one embodiment of a heat pipe within which pressure may be controlled using a piston will be described in accordance with an embodiment of the present invention. A heat pipe 504 which includes an evaporator end 508 and a condenser end 512 is positioned between a heat source 516 and a heat sink 520 such that heat source 516 is located at evaporator end 508 and heat sink 520 is located at condenser end 512. A piston 514 is positioned with respect to heat pipe 504 such that when a control force 530, which may be applied through an actuator that is controlled by a control mechanism, is applied to piston 514, piston 514 may cause a pressure within heat pipe 504, *i.e.*, an internal pressure of heat pipe 504, to change. Piston 514 may cause the pressure within heat pipe 504 to change by effectively applying a control pressure within heat pipe 504. In order to prevent fluid from escaping from heat pipe 504, a diaphragm (not shown) may be used in one embodiment to effectively create a seal that prevents fluid from leaking out from heat pipe 504 through any gaps which are present between piston 514 and heat pipe 504. It should be appreciated that applying a control pressure within heat pipe 504 may also cause at least a slight volume change within heat pipe 504.

Piston 514 generally has an associated surface area which effectively comes into contact with an interior of heat pipe 504. As such, the control pressure applied by piston 514 may be expressed as a function of control force 530 and the contact area of piston 514. Hence, by increasing control force 530, the control pressure applied by piston 514 may be increased, and the pressure within heat pipe 504 may rise. Generally, when control force 530 is applied in a negative y-direction 540, piston 514 moves in negative y-direction 540 and causes the pressure within heat pipe 504 to increase. Alternatively, when control force 530 is applied in a positive y-direction 540, piston moves in positive y-direction 540 and typically causes the pressure within heat pipe 504 to decrease.

With reference to Fig. 6, the actions which occur when a piston of a heat pipe assembly is moved will be discussed in accordance with an embodiment of the present

invention. When the force applied to a piston of a heat pipe, *e.g.*, piston 514 of Fig. 5, is adjusted in action 610, the pressure within the heat pipe changes in action 614. By way of example, when the force applied to the piston is increased, the pressure within the heat pipe may increase. A change in pressure within the heat pipe causes the boiling
5 temperature of the fluid in the heat pipe to change in action 618. At a given pressure, when the fluid in the heat pipe is in a gas-liquid state, changing the pressure within the heat pipe changes the boiling temperature of the fluid, as will be appreciated by those skilled in the art. For an embodiment in which the pressure within the heat pipe is increased, the boiling temperature of the fluid in the heat pipe typically increases.

10 Once the boiling temperature of the fluid in the heat pipe changes, the temperature at the evaporator end of the heat pipe changes in action 622. Since the evaporator end of the heat pipe is generally in the vicinity of a heat source, by changing the temperature at the evaporator end of the heat pipe, the temperature at which heat is removed from the heat source is also changed.

15 To monitor the temperature of the fluid in the heat pipe or, more particularly, the evaporator end of a heat pipe, in order to ascertain whether the boiling temperature of fluid within the heat pipe is at a desired level or needs to be changed to reach the desired level, a temperature sensor may be positioned within the heat pipe. Fig. 7 is a diagrammatic representation of a heat pipe with a piston which serves as a pressure
20 controller and an internal temperature sensor in accordance with an embodiment of the present invention. A heat pipe 602 includes a piston 614 which is controlled by a force 618. To determine an appropriate amount of force 618 to apply to piston 614 to achieve a desired boiling temperature within heat pipe 602, a temperature sensor 640 may be positioned at an evaporator end 606 of heat pipe 602. Temperature sensor 640 may
25 generally be used to measure a temperature of fluid within heat pipe 602, and may be substantially any suitable temperature sensor 640. Suitable temperature sensors or transducers may include, but are not limited to, thermometers such as thermocouple thermometers, and thermistor thermometers, as well as thermoelectric sensors and resistive temperature sensors.

30 Output from temperature sensor 640 may be provided to a controller which provides force 618 such that the magnitude of force 618 may be adjusted as appropriate to create a pressure within heat pipe 602 which is suitable for causing a temperature within heat pipe 602 to be raised or lowered. As shown in Fig. 8, which is a diagrammatic block diagram representation of one suitable control loop which may be used to control the
35 temperature within a heat pipe such as heat pipe 602, a desired temperature 802 for an

evaporator end of a heat pipe is provided as a control input in a control loop 800. The desired temperature 802 is provided to a controller 806, *e.g.*, by a user who specifies desired parameters of the heat pipe, which controls an actuator 808 that provides a control force to a piston of the heat pipe. In one embodiment, actuator 808 may be a voice coil
5 motor, a linear motor, or substantially any electromagnetic actuator.

A measured temperature 810, which may be provided by a temperature sensor within the heat pipe, is also provided as an input to controller 806. Using desired temperature 802 and measured temperature 810, controller 806 may determine an appropriate amount, or level, of force to be exerted by actuator 808 on a piston of the heat
10 pipe to enable measured temperature 810 to be approximately the same as desired temperature 802. It should be appreciated that controller 806 may substantially continuously adjust actuator 808 as necessary and, hence, the pressure within the heat pipe, as needed to effectively maintain measured temperature 810 at a level that is approximately the same as desired temperature 802.

Referring next to Fig. 9, one method of controlling the temperature in a heat pipe by adjusting the pressure in the heat pipe will be described in accordance with an embodiment of the present invention. A process 900 of controlling the temperature in a heat pipe begins at step 902 in which a determination is made regarding what the desired temperature for the evaporator end of the heat pipe is. Determining what the desired
20 temperature is may include obtaining a desired temperature from a user of the heat pipe, or determining a desired temperature based upon the requirements of an overall stage apparatus which uses the heat pipe. For example, a desired surface temperature for an actuator which is being cooled using the heat pipe may be used to determine a corresponding desired temperature for the evaporator end of the heat pipe. It should be
25 appreciated that although the desired temperature for the evaporator end of the heat pipe may be the same as the desired temperature for the actuator, the two desired temperatures may also vary.

After the desired temperature is determined, the temperature at an evaporator end of the heat pipe may be measured in step 906. Although the temperature is typically
30 measured within the heat pipe at an evaporator end to enable a desired temperature to be maintained at the evaporator end, it should be appreciated that the temperature within the heat pipe may be measured substantially anywhere within the heat pipe. Alternatively, the temperature of the actuator, some other temperature, or a performance parameter related to the temperature of the actuator, *e.g.*, air turbulence or sensor noise, may be
35 measured. Once the temperature within the heat pipe is measured, it is determined in step

908 whether the temperature at the evaporator end of the heat pipe is as desired. If it is determined that the temperature at the evaporator end of the heat pipe is as desired, then the indication is that the pressure within the heat pipe is sufficient for maintaining the boiling point of liquid within the heat pipe at a desired temperature. Accordingly, in step 5 912, the current control force applied to the piston of the heat pipe is maintained at its current level. That is, the actuator which causes the control force to be applied to the piston effectively does not change the amount of control force that is applied to the piston. From step 912, process flow returns to step 906 in which the temperature at the evaporator end of the heat pipe is measured.

10 Returning to step 908, if it is determined that the temperature at the evaporator end of the heat pipe is not as desired, then the implication may be that the pressure within the heat pipe is either too high or too low for the desired temperature to be achieved. For example, if the temperature at the evaporator end of the heat pipe is too high, then the pressure in the heat pipe is likely to be too high to enable the desired temperature at the 15 evaporator end to be achieved. As such, from step 908, process flow moves to step 910 in which the control force applied to the piston of the heat pipe, *e.g.*, using an actuator, is adjusted to adjust the pressure within the heat pipe. Typically, the adjustment made to the control force is arranged to be sufficient to alter the pressure within the heat by an amount that is sufficient to achieve the desired temperature at the evaporator end of the heat pipe. 20 Once the control force is adjusted, process flow returns to step 906 in which the temperature at the evaporator end of the heat pipe is measured.

 In general, an actuator used to vary the force applied to a piston of a heat pipe may be substantially any suitable actuator that may be controlled, as for example by a controller which sends signals to the actuator to alter the force generated by the actuator. 25 By way of example, an actuator which is coupled to the piston of the heat pipe may be a motor such as a voice coil motor (VCM). Fig. 10a is a diagrammatic representation of a piston which is actuated by a VCM in accordance with an embodiment of the present invention. A heat pipe 950 includes a piston 944 which is coupled to a VCM 930. As shown, a body 934 of VCM 930 is coupled to piston 944 such that magnets 936 in 30 cooperation with a coil 932 cause body 934 to move and create a force on piston 944. Often, forces on piston 944 created by VCM 930 may either cause piston 944 to be moved in a positive y-direction 948, or in a negative y-direction 948. A diaphragm 940 or similar mechanism may be arranged to prevent fluid contained in an interior 954 of heat pipe 950 from leaking around piston 944 and out of heat pipe 950. As piston 944

moves, the pressure within interior 954 may change as a function of the force applied by VCM 930 on piston 944 and the area of piston 944.

Another actuator which may be used to apply force to a piston of a heat pipe is an air bellows. Fig. 10b is a diagrammatic representation of a piston which is actuated by an air bellows in accordance with an embodiment of the present invention. A heat pipe 980 includes a piston 974 which may be sealed using a diaphragm 970 to prevent leakage of fluid contained in an interior 984 of heat pipe 980. Piston 974 may be coupled to an air bellows 960 which may be used to alter a control force applied to piston 974 and, hence, the pressure within interior 984. Typically, the amount of force applied by air bellows 960 onto piston 974 may be varied by altering the air pressure within bellows 960. As a result, movement of piston 974 in a y-direction 968 may be controlled by controlling the air pressure within bellows 960.

A heat pipe with a controllable internal temperature may generally be incorporated as part of an apparatus such as a photolithography apparatus. By way of example, a heat pipe (a heat transfer apparatus) with temperature control may be applied to a coil of an electromagnetic actuator in a photolithography apparatus, or a heat pipe (a heat transfer apparatus) with temperature control may be connected to a linear motor within the photolithography apparatus. With reference to Fig. 11, a photolithography apparatus which may include a heat pipe with temperature control will be described in accordance with an embodiment of the present invention. A photolithography apparatus (exposure apparatus) 40 includes a wafer positioning stage 52 that may be driven by a planar motor (not shown), as well as a wafer table 51 that is magnetically coupled to wafer positioning stage 52 by utilizing an EI-core actuator. The planar motor which drives wafer positioning stage 52 generally uses an electromagnetic force generated by magnets and corresponding armature coils arranged in two dimensions. A wafer 64 is held in place on a wafer holder or chuck 74 which is coupled to wafer table 51. Wafer positioning stage 52 is arranged to move in multiple degrees of freedom, *e.g.*, between three to six degrees of freedom, under the control of a control unit 60 and a system controller 62. The movement of wafer positioning stage 52 allows wafer 64 to be positioned at a desired position and orientation relative to a projection optical system 46. Heat generated during the movement of wafer positioning stage 52 may be stored by a heat pipe (not shown) that is coupled to wafer positioning stage 52.

Wafer table 51 may be levitated in a z-direction 10b by any number of voice coil motors (not shown), *e.g.*, three voice coil motors. In the described embodiment, at least three magnetic bearings (not shown) couple and move wafer table 51 along a y-axis 10a.

The motor array of wafer positioning stage 52 is typically supported by a base 70. Base 70 is supported to a ground via isolators 54. Reaction forces generated by motion of wafer stage 52 may be mechanically released to a ground surface through a frame 66. One suitable frame 66 is described in JP Hei 8-166475 and U.S. Patent No. 5,528,118, which are each herein incorporated by reference in their entireties.

An illumination system 42 is supported by a frame 72. Frame 72 is supported to the ground via isolators 54. Illumination system 42 includes an illumination source, and is arranged to project a radiant energy, *e.g.*, light, through a mask pattern on a reticle 68 that is supported by and scanned using a reticle stage which includes a coarse stage and a fine stage. The radiant energy is focused through projection optical system 46, which is supported on a projection optics frame 50 and may be supported the ground through isolators 54. Suitable isolators 54 include those described in JP Hei 8-330224 and U.S. Patent No. 5,874,820, which are each incorporated herein by reference in their entireties.

A first interferometer 56 is supported on projection optics frame 50, and functions to detect the position of wafer table 51. Interferometer 56 outputs information on the position of wafer table 51 to system controller 62. In one embodiment, wafer table 51 has a force damper which reduces vibrations associated with wafer table 51 such that interferometer 56 may accurately detect the position of wafer table 51. A second interferometer 58 is supported on projection optical system 46, and detects the position of reticle stage 44 which supports a reticle 68. Interferometer 58 also outputs position information to system controller 62.

It should be appreciated that there are a number of different types of photolithographic apparatuses or devices. For example, photolithography apparatus 40, or an exposure apparatus, may be used as a scanning type photolithography system which exposes the pattern from reticle 68 onto wafer 64 with reticle 68 and wafer 64 moving substantially synchronously. In a scanning type lithographic device, reticle 68 is moved perpendicularly with respect to an optical axis of a lens assembly (projection optical system 46) or illumination system 42 by reticle stage 44. Wafer 64 is moved perpendicularly to the optical axis of projection optical system 46 by a wafer stage 52. Scanning of reticle 68 and wafer 64 generally occurs while reticle 68 and wafer 64 are moving substantially synchronously.

Alternatively, photolithography apparatus or exposure apparatus 40 may be a step-and-repeat type photolithography system that exposes reticle 68 while reticle 68 and wafer 64 are stationary. In one step and repeat process, wafer 64 is in a substantially constant position relative to reticle 68 and projection optical system 46 during the

exposure of an individual field. Subsequently, between consecutive exposure steps, wafer 64 is consecutively moved by wafer positioning stage 52 perpendicularly to the optical axis of projection optical system 46 and reticle 68 for exposure. Following this process, the images on reticle 68 may be sequentially exposed onto the fields of wafer 64 so that the next field of semiconductor wafer 64 is brought into position relative to illumination system 42, reticle 68, and projection optical system 46.

It should be understood that the use of photolithography apparatus or exposure apparatus 40, as described above, is not limited to being used in a photolithography system for semiconductor manufacturing. For example, photolithography apparatus 40 may be used as a part of a liquid crystal display (LCD) photolithography system that exposes an LCD device pattern onto a rectangular glass plate or a photolithography system for manufacturing a thin film magnetic head.

The illumination source of illumination system 42 may be g-line (436 nanometers (nm)), i-line (365 nm), a KrF excimer laser (248 nm), an ArF excimer laser (193 nm), and an F₂-type laser (157 nm). Alternatively, illumination system 42 may also use charged particle beams such as x-ray and electron beams. For instance, in the case where an electron beam is used, thermionic emission type lanthanum hexaboride (LaB₆) or tantalum (Ta) may be used as an electron gun. Furthermore, in the case where an electron beam is used, the structure may be such that either a mask is used or a pattern may be directly formed on a substrate without the use of a mask.

With respect to projection optical system 46, when far ultra-violet rays such as an excimer laser is used, glass materials such as quartz and fluorite that transmit far ultra-violet rays is preferably used. When either an F₂-type laser or an x-ray is used, projection optical system 46 may be either catadioptric or refractive (a reticle may be of a corresponding reflective type), and when an electron beam is used, electron optics may comprise electron lenses and deflectors. As will be appreciated by those skilled in the art, the optical path for the electron beams is generally in a vacuum.

In addition, with an exposure device that employs vacuum ultra-violet (VUV) radiation of a wavelength that is approximately 200 nm or lower, use of a catadioptric type optical system may be considered. Examples of a catadioptric type of optical system include, but are not limited to, those described in Japan Patent Application Disclosure No. 8-171054 published in the Official gazette for Laid-Open Patent Applications and its counterpart U.S. Patent No. 5,668,672, as well as in Japan Patent Application Disclosure No. 10-20195 and its counterpart U.S. Patent No. 5,835,275, which are all incorporated herein by reference in their entireties. In these examples, the reflecting optical device

may be a catadioptric optical system incorporating a beam splitter and a concave mirror. Japan Patent Application Disclosure (Hei) No. 8-334695 published in the Official gazette for Laid-Open Patent Applications and its counterpart U.S. Patent No. 5,689,377, as well as Japan Patent Application Disclosure No. 10-3039 and its counterpart U.S. Patent No.

5 5,892,117, which are all incorporated herein by reference in their entireties. These examples describe a reflecting-refracting type of optical system that incorporates a concave mirror, but without a beam splitter, and may also be suitable for use with the present invention.

Further, in photolithography systems, when linear motors (see U.S. Patent Nos. 10 5,623,853 or 5,528,118, which are each incorporated herein by reference in their entireties) are used in a wafer stage or a reticle stage, the linear motors may be either an air levitation type that employs air bearings or a magnetic levitation type that uses Lorentz forces or reactance forces. Additionally, the stage may also move along a guide, or may be a guideless type stage which uses no guide.

15 Alternatively, a wafer stage or a reticle stage may be driven by a planar motor which drives a stage through the use of electromagnetic forces generated by a magnet unit that has magnets arranged in two dimensions and an armature coil unit that has coil in facing positions in two dimensions. With this type of drive system, one of the magnet unit or the armature coil unit is connected to the stage, while the other is mounted on the 20 moving plane side of the stage.

Movement of the stages as described above generates reaction forces which may affect performance of an overall photolithography system. Reaction forces generated by the wafer (substrate) stage motion may be mechanically released to the floor or ground by use of a frame member as described above, as well as in U.S. Patent No. 5,528,118 and 25 published Japanese Patent Application Disclosure No. 8-166475. Additionally, reaction forces generated by the reticle (mask) stage motion may be mechanically released to the floor (ground) by use of a frame member as described in U.S. Patent No. 5,874,820 and published Japanese Patent Application Disclosure No. 8-330224, which are each incorporated herein by reference in their entireties.

30 Isolators such as isolators 54 may generally be associated with an active vibration isolation system (AVIS). An AVIS generally controls vibrations associated with forces 112, *i.e.*, vibrational forces, which are experienced by a stage assembly or, more generally, by a photolithography machine such as photolithography apparatus 40 which includes a stage assembly.

A photolithography system according to the above-described embodiments, *e.g.*, a photolithography apparatus which may include one or more heat pipes (heat transfer apparatuses), may be built by assembling various subsystems in such a manner that prescribed mechanical accuracy, electrical accuracy, and optical accuracy are maintained.

5 In order to maintain the various accuracies, prior to and following assembly, substantially every optical system may be adjusted to achieve its optical accuracy. Similarly, substantially every mechanical system and substantially every electrical system may be adjusted to achieve their respective desired mechanical and electrical accuracies. The process of assembling each subsystem into a photolithography system includes, but is not

10 limited to, developing mechanical interfaces, electrical circuit wiring connections, and air pressure plumbing connections between each subsystem. There is also a process where each subsystem is assembled prior to assembling a photolithography system from the various subsystems. Once a photolithography system is assembled using the various subsystems, an overall adjustment is generally performed to ensure that substantially

15 every desired accuracy is maintained within the overall photolithography system. Additionally, it may be desirable to manufacture an exposure system in a clean room where the temperature and humidity are controlled.

Further, semiconductor devices may be fabricated using systems described above, as will be discussed with reference to Fig. 12. The process begins at step 1301 in which

20 the function and performance characteristics of a semiconductor device are designed or otherwise determined. Next, in step 1302, a reticle (mask) in which has a pattern is designed based upon the design of the semiconductor device. It should be appreciated that in a parallel step 1303, a wafer is made from a silicon material. The mask pattern designed in step 1302 is exposed onto the wafer fabricated in step 1303 in step 1304 by a

25 photolithography system. One process of exposing a mask pattern onto a wafer will be described below with respect to Fig. 13. In step 1305, the semiconductor device is assembled. The assembly of the semiconductor device generally includes, but is not limited to, wafer dicing processes, bonding processes, and packaging processes. Finally, the completed device is inspected in step 1306.

30 Fig. 13 is a process flow diagram which illustrates the steps associated with wafer processing in the case of fabricating semiconductor devices in accordance with an embodiment of the present invention. In step 1311, the surface of a wafer is oxidized. Then, in step 1312 which is a chemical vapor deposition (CVD) step, an insulation film may be formed on the wafer surface. Once the insulation film is formed, in step 1313,

35 electrodes are formed on the wafer by vapor deposition. Then, ions may be implanted in

the wafer using substantially any suitable method in step 1314. As will be appreciated by those skilled in the art, steps 1311-1314 are generally considered to be preprocessing steps for wafers during wafer processing. Further, it should be understood that selections made in each step, *e.g.*, the concentration of various chemicals to use in forming an insulation film in step 1312, may be made based upon processing requirements.

At each stage of wafer processing, when preprocessing steps have been completed, post-processing steps may be implemented. During post-processing, initially, in step 1315, photoresist is applied to a wafer. Then, in step 1316, an exposure device may be used to transfer the circuit pattern of a reticle to a wafer. Transferring the circuit pattern of the reticle of the wafer generally includes scanning a reticle scanning stage which may, in one embodiment, include a force damper to dampen vibrations.

After the circuit pattern on a reticle is transferred to a wafer, the exposed wafer is developed in step 1317. Once the exposed wafer is developed, parts other than residual photoresist, *e.g.*, the exposed material surface, may be removed by etching. Finally, in step 1319, any unnecessary photoresist that remains after etching may be removed. As will be appreciated by those skilled in the art, multiple circuit patterns may be formed through the repetition of the preprocessing and post-processing steps.

Although only a few embodiments of the present invention have been described, it should be understood that the present invention may be embodied in many other specific forms without departing from the spirit or the scope of the present invention. By way of example, although a heat pipe (heat transfer apparatus) has been described as including a pressure controller which is a piston, a pressure controller may be substantially any mechanism which enables pressure within the heat pipe to be controlled. In other words, a pressure controller on a heat pipe (heat transfer apparatus) may not necessarily be a piston.

A heat pipe with an internal temperature which may be controlled by controlling the pressure within the heat pipe may be used for a variety of different application. For instance, as described above, a heat pipe (heat transfer apparatus) with an internal temperature which is controllable may be used within a photolithography apparatus to cool linear motors, voice coil motors, or substantially any other electromagnetic actuator. It should be appreciated, however, that such a heat pipe (heat transfer apparatus) may generally be used to cool substantially any mechanism or device which would benefit from being cooled.

While a pressure control mechanism such as a piston has been shown as being positioned near a condenser end of a heat pipe (heat transfer apparatus), a pressure control

mechanism may generally be positioned substantially anywhere with respect to the heat pipe. Positioning the pressure control mechanism closer to a condenser end of the heat pipe, which contains mostly gas or vapors, may enable the pressure control mechanism to be more readily actuated. However, the pressure control mechanism may instead be
5 located near a middle portion of a heat pipe, or closer to an evaporator end of the heat pipe in some embodiments.

Changing the pressure within a heat pipe (heat transfer apparatus) may, in some cases, cause an appreciable change in the interior volume of the heat pipe. Conversely, changing the interior volume of a heat pipe may lead to a change in pressure within the
10 heat pipe. As such, it should be appreciated that the internal volume of the heat pipe may effectively be changed, *e.g.*, by displacing a piston of the heat pipe, to cause a change in pressure within the heat pipe that leads to a change in the boiling temperature of fluid in the heat pipe.

In general, the steps associated with the methods of the present invention may
15 vary widely. Steps may be added, removed, altered, and reordered without departing from the spirit or the scope of the present invention. For example, a process of controlling the temperature within a heat pipe (heat transfer apparatus) may include at least periodically determining a desired temperature within the heat pipe. Periodically determining a desired temperature within the heat pipe (heat transfer apparatus) enables
20 changes to requirements associated with an overall stage apparatus to be accounted for, as the control force applied to a piston of a heat pipe (heat transfer apparatus) may be adjusted to compensate for any change to a desired temperature. Therefore, the present examples are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein, but may be modified within the scope of the
25 appended claims.

WHAT IS CLAIMED IS:

1. A method for controlling a temperature associated with a heat pipe, the heat pipe being arranged to contain a fluid, the heat pipe having an evaporator end, the evaporator end being arranged to be in the vicinity of a heat source, the method
5 comprising:
 - measuring the temperature associated with the heat pipe;
 - determining when the temperature associated with the heat pipe is at a desired level; and
 - changing a pressure within the heat pipe when it is determined that the
10 temperature associated with the heat pipe is not at a desired level, wherein changing the pressure within the heat pipe causes the temperature associated with the heat pipe to change.
2. The method of claim 1 wherein changing the pressure within the
15 heat pipe includes increasing the pressure within the heat pipe to cause the temperature associated with the heat pipe to be raised.
3. The method of claim 1 wherein the heat pipe includes a pressure control mechanism, and changing the pressure within the heat pipe includes operating the
20 pressure control mechanism.
4. The method of claim 3 wherein the pressure control mechanism includes a piston assembly, and changing the pressure within the heat pipe includes applying a controlled pressure using the piston assembly.
25
5. The method of claim 4 wherein the piston assembly is actuated by an electromagnetic actuator, and changing the pressure within the heat pipe includes applying a controlled force to the piston assembly using the electromagnetic actuator.
6. The method of claim 4 wherein the piston assembly is actuated by
30 an air bellows, and changing the pressure within the heat pipe includes applying a controlled force to the piston assembly using the air bellows.

7. The method of claim 1 wherein measuring the temperature associated with the heat pipe includes measuring the temperature at the evaporator end.

8. The method of claim 7 wherein the temperature measured at the evaporator end is a boiling temperature of the fluid.

9. A method for operating an exposure apparatus comprising the method for controlling the temperature of claim 1.

10. A method for making an object including at least a photolithography process, wherein the photolithography process utilizes the method of operating an exposure apparatus of claim 9.

11. A method for making a wafer utilizing the method of operating an exposure apparatus of claim 9.

12. A heat pipe comprising:
an evaporator end;
a fluid; and
a pressure control mechanism, wherein the pressure control mechanism is arranged to change a pressure within the heat pipe such that a boiling temperature of the fluid is changed.

13. The heat pipe of claim 12 wherein the pressure control mechanism is arranged to change the pressure by increasing the pressure such that the boiling temperature of the fluid is increased.

14. The heat pipe of claim 12 wherein the pressure control mechanism includes a piston arrangement, the piston arrangement being arranged to apply a control pressure to change the pressure within the heat pipe.

15. The heat pipe of claim 14 wherein the pressure control mechanism further includes an actuator, the actuator being arranged to apply a control force to the piston arrangement such that the piston arrangement applies the control pressure to change the pressure within the heat pipe.

16. The heat pipe of claim 14 wherein the pressure control mechanism further includes an air bellows, the air bellows being arranged to cause the piston arrangement to apply the control pressure to change the pressure within the heat pipe.
- 5
17. The heat pipe of claim 14 further including:
a temperature sensor, the temperature sensor being arranged to measure the boiling temperature of the fluid.
- 10
18. The heat pipe of claim 17 wherein the measured boiling temperature is provided to the pressure control mechanism, the pressure control mechanism being arranged to change the pressure by an amount determined using the measured boiling temperature.
- 15
19. The heat pipe of claim 17 wherein the temperature sensor is arranged at the evaporator end.
- 20
20. The heat pipe of claim 12 further including:
a condenser end, wherein the pressure control mechanism is positioned near the condenser end of the heat pipe.
21. The heat pipe of claim 12 wherein the evaporator end is arranged to be positioned near an external heat source.
- 25
22. The heat pipe of claim 21 wherein the external heat source is a coil of a linear motor within a stage apparatus.
23. An exposure apparatus comprising the stage apparatus of claim 22.
- 30
24. A device manufactured with the exposure apparatus of claim 23.
25. A wafer on which an image has been formed by the exposure apparatus of claim 23.

26. A method for controlling a temperature of an actuator within a stage apparatus, the stage apparatus being in communication with an evaporator end of a heat pipe, the method comprising:

- 5 determining a desired temperature for the actuator; and
 adjusting a mechanism within the heat pipe to achieve a corresponding desired temperature for a section of the heat pipe, wherein adjusting the mechanism causes a boiling temperature of a fluid within the heat pipe to be adjusted such that a temperature of the section is adjusted.

- 10 27. The method of claim 26 further including:
 determining the corresponding desired temperature for the section using the desired temperature for the actuator.

- 15 28. The method of claim 26 wherein adjusting the pressure within the heat pipe includes applying a control force of a first amount to a piston arrangement of the heat pipe, wherein the control force of the first amount is arranged to cause the piston arrangement to change the pressure within the heat pipe.

- 20 29. The method of claim 28 further including:
 determining when the temperature of the section is the desired temperature for the section, wherein when it is determined that the temperature of the section is the desired temperature for the section, the control force is maintained at the first amount.

- 25 30. The method of claim 29 wherein when it is determined that the temperature of the section is not the desired temperature for the section, adjusting the pressure within the heat pipe to achieve the desired temperature for the section further includes applying a control force of a second amount to the piston arrangement, wherein the control force of the second amount is arranged to cause the piston arrangement to change the pressure within the heat pipe, the second amount being different from the first
30 amount.

31. The method of claim 26 wherein the section is the evaporator end.

- 35 32. A method for operating an exposure apparatus comprising the method for controlling the temperature of claim 26.

33. A method for making an object including at least a photolithography process, wherein the photolithography process utilizes the method of operating an exposure apparatus of claim 32.
- 5 34. A method for making a wafer utilizing the method of operating an exposure apparatus of claim 32.
35. A method for controlling a temperature of an actuator within a stage apparatus, the stage apparatus being in communication with an evaporator end of a heat pipe, the heat pipe including a piston arrangement, the method comprising:
determining a desired temperature for the actuator; and
adjusting the piston arrangement to achieve the desired temperature for a section of the heat pipe, wherein adjusting the piston arrangement causes a boiling
15 temperature of a fluid within the heat pipe to be changed such that a temperature of the section is changed.
36. The method of claim 35 further including:
determining a corresponding desired temperature for the section using the
20 desired temperature for the actuator.
37. The method of claim 35 wherein adjusting the piston arrangement includes adjusting an internal pressure of the heat pipe to change the temperature of the section.
- 25 38. The method of claim 35 wherein adjusting the piston arrangement includes adjusting an internal volume of the heat pipe to change the temperature of the section.
- 30 39. The method of claim 35 wherein adjusting the piston arrangement includes applying a control force to the piston arrangement.
40. The method of claim 39 wherein applying the control force to the piston arrangement causes a control pressure to be applied using the piston arrangement,

the control pressure being arranged to cause the boiling temperature of the fluid to be changed.

5 41. The method of claim 35 wherein the section is the evaporator end.

42. A method for operating an exposure apparatus comprising the method for controlling the temperature of claim 35.

10 43. A method for making an object including at least a photolithography process, wherein the photolithography process utilizes the method of operating an exposure apparatus of claim 42.

44. A method for making a wafer utilizing the method of operating an exposure apparatus of claim 42.

15 45. A cooling device comprising:
a heat pipe having an end portion that is arranged to be in vicinity of a heat source;
a fluid that is contained in the heat pipe; and
a pressure control mechanism connected to the heat pipe, the pressure
20 control mechanism being arranged to change a pressure within the heat pipe such that a boiling temperature of the fluid is changed.

25 46. The cooling device of claim 45, wherein the heat pipe has an evaporator end and a condenser end, and the evaporator end is located on the end portion.

47. A heat transfer apparatus comprising:
a flow passage;
at least one heat receiving section where heat is transferred from a heat source, the at least one heat receiving section being disposed on the way of the flow
30 passage;
a heat transfer medium filled within said flow passage, the heat transfer medium being circulated within the flow passage; and
a temperature setting device connected to the flow passage, the temperature setting device changing a state-shift temperature of the heat transfer medium.
35

48. The heat transfer apparatus of claim 47, wherein the temperature setting device changes a boiling temperature of the heat transfer medium.

49. The heat transfer apparatus of claim 47, wherein the temperature
5 setting device changes a pressure within the flow passage.

50. The heat transfer apparatus of claim 47, wherein the heat source is a part of an actuator within a stage apparatus.

10 51. An exposure apparatus comprising the stage apparatus of claim 50.

52. A heat transfer apparatus comprising:
a flow passage;
at least one heat receiving section where heat is transferred from a heat
15 source, the at least one heat receiving section being disposed on the way of the flow passage and the heat source being disposed within the flow passage; and
a heat transfer medium filled within said flow passage, the heat transfer medium being circulated within the flow passage.

20 53. The heat transfer apparatus of claim 52, further comprising a temperature setting device connected to the flow passage, the temperature setting device changing a state-shift temperature of the heat transfer medium.

54. The heat transfer apparatus of claim 52, wherein the temperature
25 setting device changes a boiling temperature of the heat transfer medium.

55. The heat transfer apparatus of claim 52, wherein the temperature setting device changes a pressure within the flow passage.

30 56. The heat transfer apparatus of claim 55, wherein the heat source is a part of an actuator within a stage apparatus.

57. An exposure apparatus comprising the stage apparatus of claim 56.

58. A method for controlling a temperature associated with a heat transfer apparatus, the method comprising:

circulating a heat transfer medium within a flow passage, the flow passage including at least one heat receiving section where heat is transferred from a heat source;

5 and

changing a state-shift temperature of the heat transfer medium circulating within the flow passage.

59. The method of claim 58, wherein changing a state-shift
10 temperature includes changing a boiling temperature of the heat transfer medium.

60. The method of claim 58, wherein changing a state-shift temperature includes changing a pressure within the flow passage.

61. A method for operating a stage device comprising the method for
15 controlling the temperature of claim 58.

62. A method for operating an exposure apparatus comprising the
method for controlling the temperature of claim 58.

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63. A method for making an object including at least a photolithography process, wherein the photolithography process utilizes the method of operating an exposure apparatus of claim 62.

64. A method for making a wafer utilizing a method for operating an
25 exposure apparatus of claim 62.

65. A method for controlling a temperature associated with a heat transfer apparatus, the method comprising:

30 filling a heat transfer medium within a flow passage, the flow passage including a heat source; and

circulating the heat transfer medium within the flow passage.

66. The method of claim 65 further comprising changing a state-shift
35 temperature of the heat transfer medium circulating within the flow passage.

67. The method of claim 66, wherein changing a state-shift temperature includes changing a boiling temperature of the heat transfer medium.

5 68. The method of claim 66, wherein changing a state-shift temperature includes changing a pressure within the flow passage.

69. A method for operating a stage device comprising the method for controlling the temperature of claim 65.

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70. A method for operating an exposure apparatus comprising the method for controlling the temperature of claim 69.

71. A method for making an object including at least a
15 photolithography process, wherein the photolithography process utilizes the method of operating an exposure apparatus of claim 70.

72. A method for making a wafer utilizing a method for operating an exposure apparatus of claim 70.

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