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(54) **CONDENSIBLE GAS COOLING SYSTEM**

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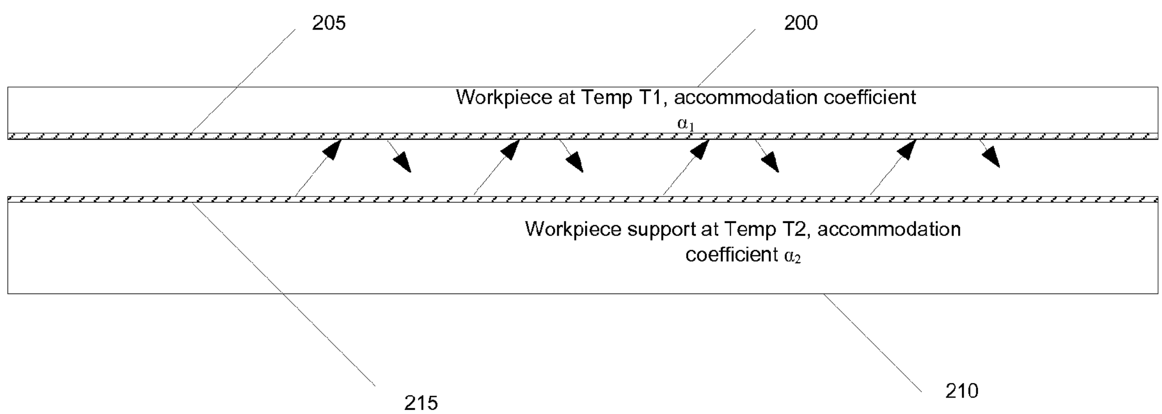
(57) **ABSTRACT**

A workpiece cooling system and method are disclosed. Transferring heat away from a workpiece, such as a semiconductor wafer during ion implantation, is essential. Typically this heat is transferred to the workpiece support, or platen. In one embodiment, the desired operating temperature is determined. Based on this, a gas having a vapor pressure within a desired range, such as 10-50 torr, is selected. This range is required to be sufficiently low so as to be less than the clamping force. This condensible gas is used to fill the volume between the workpiece and the workpiece support. Heat transfer occurs based on adsorption and desorption, thereby offering improved transfer properties than traditionally employed gases, such as helium, hydrogen, nitrogen, argon and air.



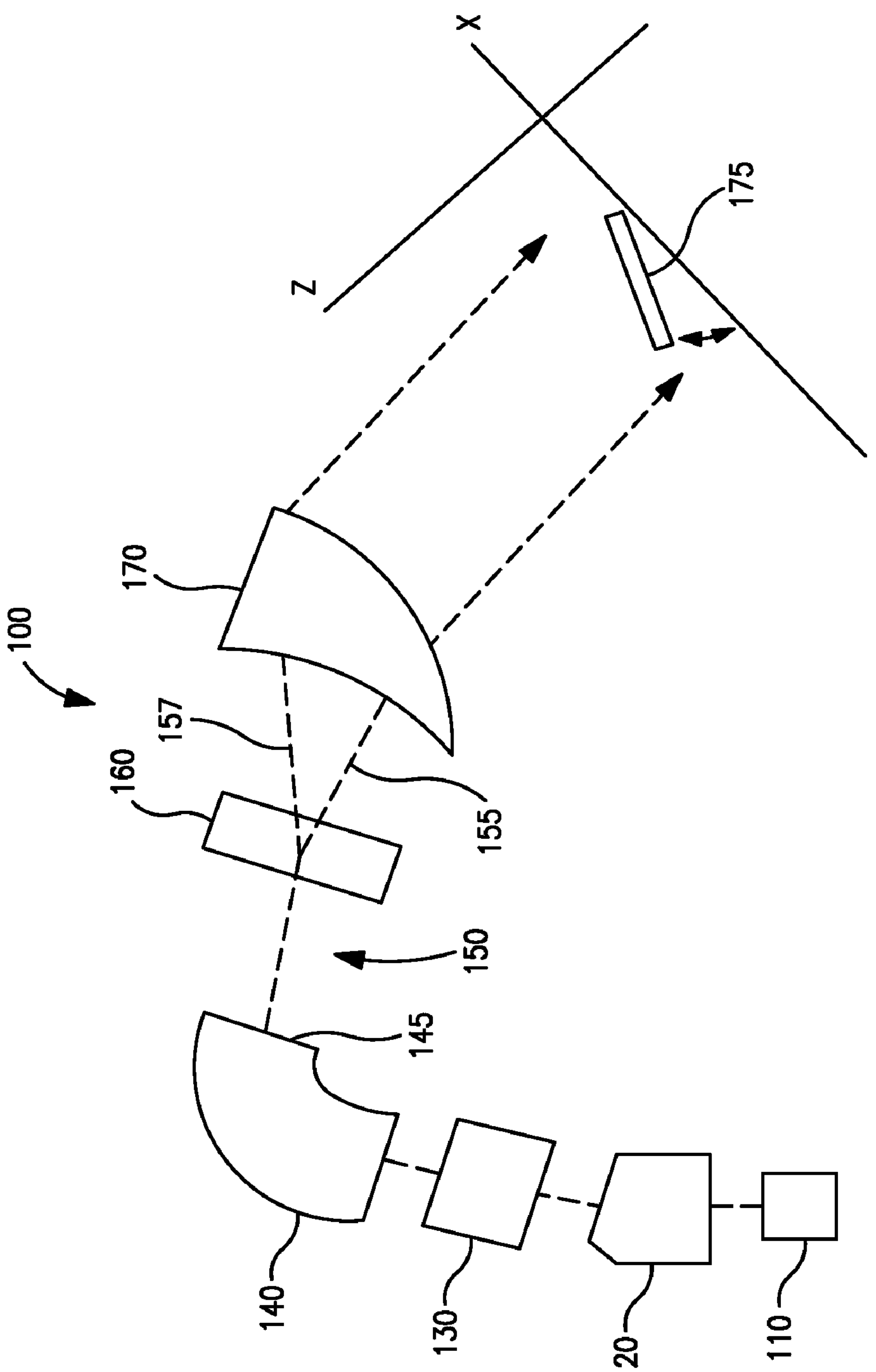


FIG. 1

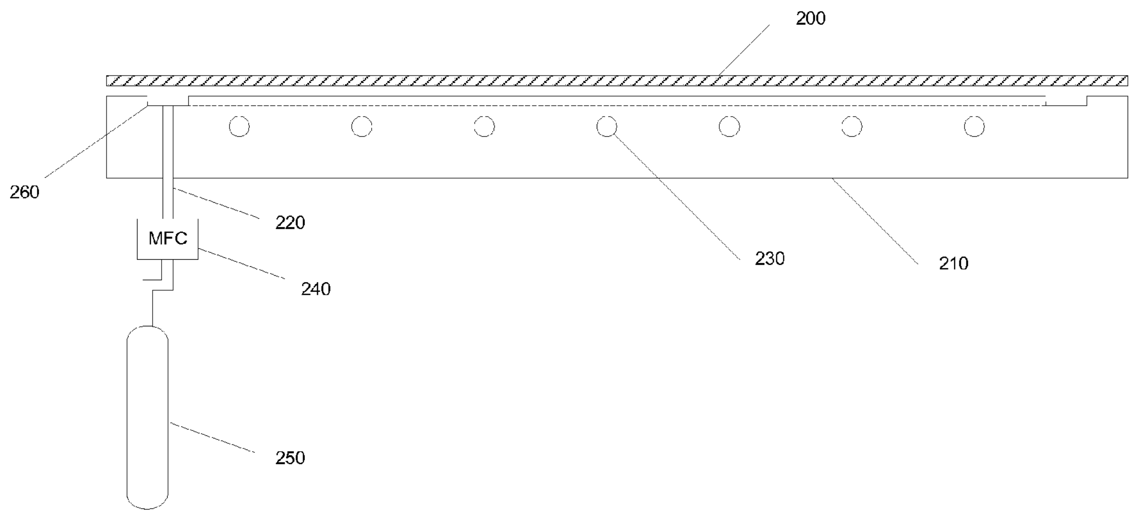


FIG. 2

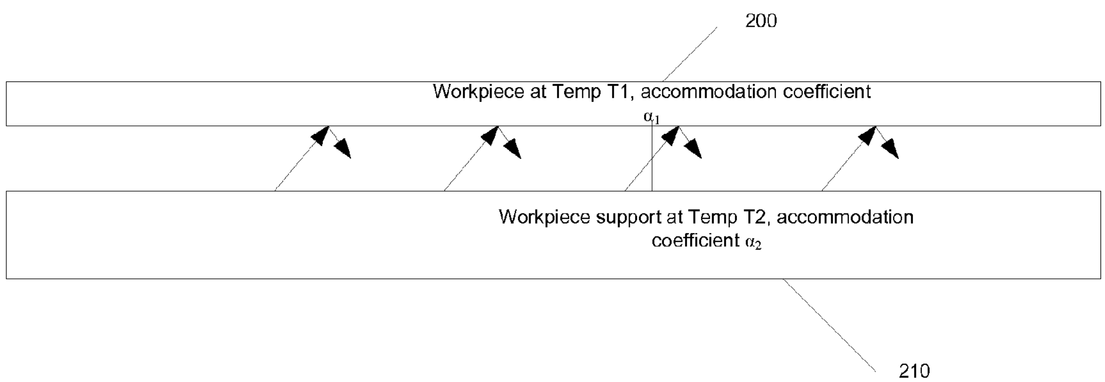

200
Workpiece at Temp T1, accommodation coefficient
α1
Workpiece support at Temp T2, accommodation
coefficient α2
210

FIG. 3

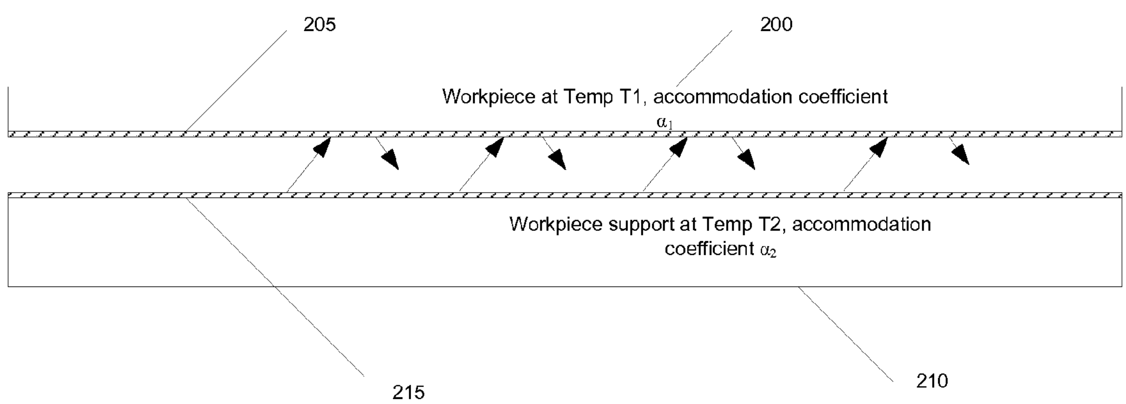

205
200
Workpiece at Temp T1, accommodation coefficient α_1
Workpiece support at Temp T2, accommodation coefficient α_2
215
210

FIG. 4

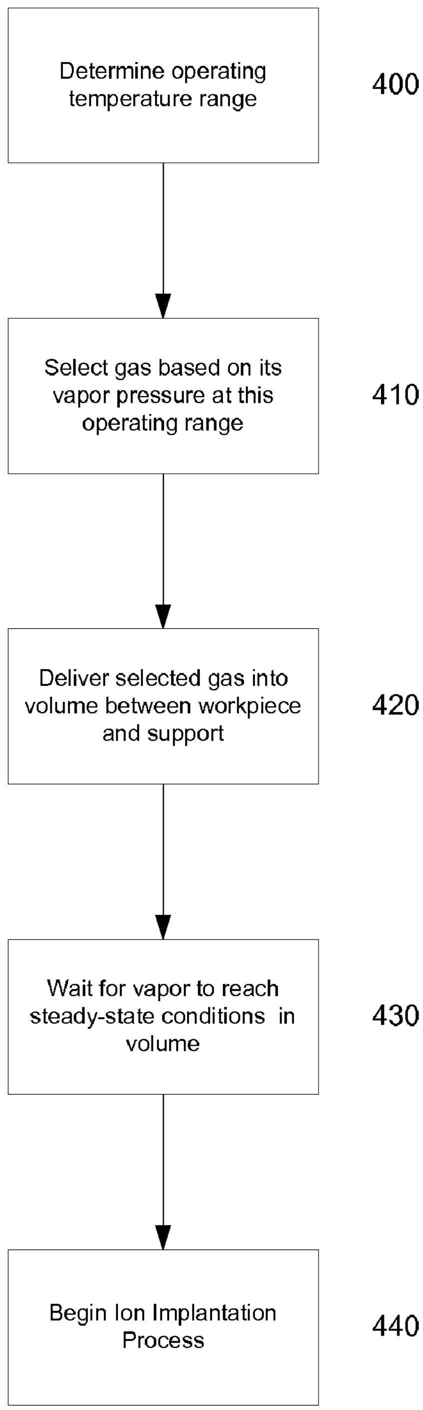

Determine operating temperature range
400
Select gas based on its vapor pressure at this operating range
410
Deliver selected gas into volume between workpiece and support
420
Wait for vapor to reach steady-state conditions in volume
430
Begin Ion Implantation Process
440

FIG. 5

CONDENSIBLE GAS COOLING SYSTEM

BACKGROUND OF THE INVENTION

[0001] Ion implanters are commonly used in the production of semiconductor wafers. An ion source is used to create an ion beam, which is then directed toward the wafer. As the ions strike the wafer, they dope a particular region of the wafer. The configuration of doped regions defines their functionality, and through the use of conductive interconnects, these wafers can be transformed into complex circuits.

[0002] A block diagram of a representative ion implanter **100** is shown in FIG. **1**. An ion source **110** generates ions of a desired species. In some embodiments, these species are atomic ions, which may be best suited for high implant energies. In other embodiments, these species are molecular ions, which may be better suited for low implant energies. These ions are formed into a beam, which then passes through a source filter **120**. The source filter is preferably located near the ion source. The ions within the beam are accelerated/decelerated in column **130** to the desired energy level. A mass analyzer magnet **140**, having an aperture **145**, is used to remove unwanted components from the ion beam, resulting in an ion beam **150** having the desired energy and mass characteristics passing through resolving aperture **145**.

[0003] In certain embodiments, the ion beam **150** is a spot beam. In this scenario, the ion beam passes through a scanner **160**, which can be either an electrostatic or magnetic scanner, which deflects the ion beam **150** to produce a scanned beam **155-157**. In certain embodiments, the scanner **160** comprises separated scan plates in communication with a scan generator. The scan generator creates a scan voltage waveform, such as a sine, sawtooth or triangle waveform having amplitude and frequency components, which is applied to the scan plates. In a preferred embodiment, the scanning waveform is typically very close to being a triangle wave (constant slope), so as to leave the scanned beam at every position for nearly the same amount of time. Deviations from the triangle are used to make the beam uniform. The resultant electric field causes the ion beam to diverge as shown in FIG. **1**.

[0004] In an alternate embodiment, the ion beam **150** is a ribbon beam. In such an embodiment, there is no need for a scanner, so the ribbon beam is already properly shaped.

[0005] An angle corrector **170** is adapted to deflect the divergent ion beamlets **155-157** into a set of beamlets having substantially parallel trajectories. Preferably, the angle corrector **170** comprises a magnet coil and magnetic pole pieces that are spaced apart to form a gap, through which the ion beamlets pass. The coil is energized so as to create a magnetic field within the gap, which deflects the ion beamlets in accordance with the strength and direction of the applied magnetic field. The magnetic field is adjusted by varying the current through the magnet coil. Alternatively, other structures, such as parallelizing lenses, can also be utilized to perform this function.

[0006] Following the angle corrector **170**, the scanned beam is targeted toward the workpiece **175**. The workpiece is attached to a workpiece support. The workpiece support provides a variety of degrees of movement.

[0007] The workpiece support is used to both hold the wafer in position, and to orient the wafer so as to be properly implanted by the ion beam. To effectively hold the wafer in place, most workpiece supports typically use a circular surface on which the workpiece rests, known as a platen. Often, the platen uses electrostatic force to hold the workpiece in position. By creating a strong electrostatic force on the platen, also known as the electrostatic chuck, the workpiece or wafer can be held in place without any mechanical fastening devices. This minimizes contamination and also improves cycle time, since the wafer does not need to be unfastened after it has been implanted. These chucks typically use one of two types of force to hold the wafer in place: coulombic or Johnson-Rahbeck force.

[0008] The workpiece support typically is capable of moving the workpiece in one or more directions. For example, in ion implantation, the ion beam is typically a scanned or ribbon beam, having a width much greater than its height. Assume that the width of the beam is defined as the x axis, the height of the beam is defined as the y axis, and the path of travel of the beam is defined as the z axis. The width of the beam is typically wider than the workpiece, such that the workpiece does not have to be moved in the x direction. However, it is common to move the workpiece along the y axis to expose the entire workpiece to the beam.

[0009] Another important function of the workpiece support is to provide a heat sink for the workpiece. For example, during ion implantation, a significant amount of energy, in the form of heat, is imparted to the workpiece. This heat, left unregulated, could affect the properties of the workpiece that is being implanted. Therefore, this heat is preferably transferred away from the workpiece and to the workpiece support. The workpiece support then dissipates the heat. In certain embodiments, fluid is passed through conduits within the workpiece support, which allows the heat to be transferred to the fluid and away from the workpiece support. Other methods of cooling the workpiece support are also well known in the art.

[0010] In certain embodiments, the heat is transferred from the workpiece to the workpiece support, simply through the physical contact between the two components. However, tests have shown that even though the workpiece and the support appear to be in physical contact; at a microscopic level, there is relatively little actual contact between the two components, due to imperfections and the roughness of the adjacent surfaces.

[0011] The ion implantation system described above is preferably housed in an environment that is near vacuum conditions. In fact, the pressure within this environment is typically less than 10^{-5} Torr. Since the surrounding environment is nearly an absolute vacuum, there are no other mediums through which the heat can be transferred. Consequently, heat transfer is far less efficient than desired.

[0012] One technique to improve the transfer of heat from the workpiece to the support is the use of "back side gas". FIG. **2** shows a simplified illustration of this technique. Briefly, the workpiece **200** is clamped to the support, using mechanical or electrostatic means. Then, conduits **220** in the workpiece support **210** transfer gas **250** to the volume between the workpiece **200** and the support **210**, also known as the wafer/platen interface.

[0013] A simple figure showing this heat transfer mechanism is presented in FIG. **3**. Heat transfer occurs when a gas molecule collides with the workpiece **200**, absorbing heat from the workpiece **200**. This gas molecule later collides with the workpiece support **210**, imparting the transferred heat to the support. The workpiece support serves as a heat sink and maintains an acceptable temperature. In some embodiments, the workpiece support is cooled by passing fluid through internal cooling conduits **230**. The flow of back side gas may be controlled by a mass flow controller **250**.

[0014] Since it is these gas molecules that transfer the heat, an increase in the number of molecules, such as by an increase in pressure, results in improved heat transfer. However, the pressure of the back side gas has an upper limit; as the pressure of the back side gas increases, it begins to overcome the clamping forces, thereby pushing the workpiece away from the support. This reduces the actual physical contact between the two surfaces and significantly lowers the heat transfer. This reduction occurs at very low pressure, such as less than 50 Torr in an ion implantation environment. Excessive pressure may also cause damage to the workpiece. Furthermore, a large increase in the number of molecules serves to increase collisions between molecules, and therefore reduces the heat transferred between the solids.

[0015] As described above, back side gas aids in the heat transfer as gas molecules receive heat from the workpiece and transfer that heat to the workpiece support. As is well known, at gas-solid interfaces, there is an efficiency at which this heat transfer occurs, which is dependent on both the type of gas molecule and the type of solid. This efficiency is described by the accommodation coefficient, which has a value between 0 (no heat transfer) and 1 (perfect heat transfer). The accommodation coefficient (α) is typically defined as:

$$\alpha=(T_r-T_i)/(T_s-T_i),$$

[0016] where T_r is the temperature of the reflected molecules (i.e. gas molecules after they reflect off the solid surface);

[0017] T_i is the temperature of the incident molecules (i.e. gas molecules before they hit the solid surface; and

[0018] T_s is the temperature of the solid surface.

[0019] Lighter gases, such as helium and hydrogen, typically have lower accommodation coefficients then heavier gasses, such as nitrogen, argon and air. In addition, the solid surface contributes to the accommodation coefficient, as some solids provide better heat transfer than others. Returning to FIG. **3**, assume that the accommodation coefficient between the gas molecule and the workpiece **200** is α_1 and the accommodation coefficient between the gas and the workpiece support **210** is α_2. As molecules collide with the workpiece, these molecules absorb heat from the workpiece, in proportion to the accommodation coefficient α_1. These molecules later collide with the support **210**, imparting their heat in proportion to the accommodation coefficient α_2. Thus, the actual heat transfer between the workpiece and the workpiece support is proportional to $\alpha_1*\alpha_2$. For example, if the accommodation coefficient at one surface with a specific gas is 0.9 and the coefficient at the other surface with that gas is 0.7, then the heat transfer between the two surfaces is only 63% efficient. Heavier gases can increase these coefficients, however, lighter gas molecules move more rapidly and thus transfer heat more quickly. This may favor their use over heavier species, despite the difference in accommodation coefficient.

[0020] In many environments, it is important to keep the workpiece within a predetermined temperature range. Thus, efficient heat transfer from the workpiece to the workpiece support is essential. Therefore, it would be beneficial to develop a system and method for improving the cooling of workpieces, especially semiconductor wafers in an ion implantation system.

SUMMARY OF THE INVENTION

[0021] The problems of the prior art are overcome by the workpiece cooling system and method described in the present disclosure. Typically this heat is transferred to the workpiece support, or platen. In one embodiment, the desired operating temperature is determined. Based on this, a gas having a vapor pressure within a desired range, such as 10-50 torr, is selected. This range is required to be sufficiently low so as to be less than the clamping force. This condensible gas is used to fill the volume between the workpiece and the workpiece support. Heat transfer occurs based on adsorption and desorption, thereby offering improved transfer properties than traditionally employed gases, such as helium, hydrogen, nitrogen, argon and air.

BRIEF DESCRIPTION OF FIGURES

[0022] FIG. **1** represents a traditional ion implanter;

[0023] FIG. **2** represents a cross-section of a workpiece and support according to one embodiment;

[0024] FIG. **3** represents a simplified illustration showing the heat transfer mechanisms of the prior art;

[0025] FIG. **4** represents a simplified illustration showing the heat transfer mechanism described the present disclosure; and

[0026] FIG. **5** represents a flow chart illustrating process steps used in accordance with one embodiment.

DETAILED DESCRIPTION OF THE INVENTION

[0027] As described above, maintaining the temperature of a workpiece, such as a semiconductor wafer in an ion implantation process, is essential. Current techniques for maintaining the temperature of a workpiece rely on the transfer of heat from the workpiece to the workpiece support, such as the platen, which is physically contacting the workpiece. Some embodiments augment this heat transfer mechanism by delivering "back side gas" in the volume between the workpiece and the support. These gas molecules act to transfer the heat (or a portion of it) from the workpiece to the support. However, as described above, this heat transfer mechanism is not as efficient as desired.

[0028] Returning to FIG. **2**, a cross section of a workpiece support **210**, with an attached workpiece **200** is shown. The workpiece support may have two types of conduits. Conduit **220** brings gas **250** to the back side of the workpiece, in the volume between the workpiece and the support. The gas **250** is stored preferably in a central reservoir, such as a tank, and may pass through a mass flow controller or pressure regulator **240** to regulate its flow through conduit **220**. In certain embodiments, the small trench **260** is provided in the upper surface of the support **210** to allow an unobstructed path for the gas **250** to enter the volume. The MFC or pressure regulator **240** controls the flow of gas to achieve the desired gas pressure. As noted above, the pressure is preferably carefully controlled, as excessive pressure may serve to lift the workpiece away from the support, or may damage the workpiece.

[0029] In some embodiments, a second conduit **230** is used to circulate a fluid which is used to cool the workpiece support. For example, water, air or a suitable coolant may be circulated through the internal conduit **230** of the workpiece so as to conduct heat away from the platen.

[0030] Each ion implantation process has a preferred operating temperature range. For example, many ion implantations are performed within a temperature range of 0° C. to 50° C., and more commonly at room temperature (15-30° C.). Others are performed at cryogenic temperatures, such as less than −50° C. Other implants are performed at elevated temperatures, such as greater than 100° C. Once the desired operating range is determined, an appropriate gas is selected. The gas should be one that has a sufficiently low vapor pressure at the desired operating temperature. For example, at room temperature, water has a vapor pressure of about 20 Torr. For a cryogenic implant at −100° C., propane has a similar vapor pressure. Ammonia (NH_3) would also be suitable for low temperature implants. Its vapor pressure at −80° C. is approximately 30 Torr. For higher temperature implants, substances such as glycerine can be used, as its vapor pressure is approximately 40 Torr at 200° C.

[0031] As stated above, the vapor pressure of the gas in the working region must be less than the clamping force exerted on the workpiece, such that the workpiece remains undamaged and in contact with the workpiece support. In other words, the pressure exerted by the gas, multiplied by the area of the workpiece, determines the force being exerted on the workpiece in the direction away from the workpiece support. In opposition to this force is the clamping force. In order for the workpiece to remain in contact with the support, the clamping force must be greater than the gas pressure, multiplied by the area of the workpiece. Since the area of the workpiece is fixed, the gas pressure must be controlled to insure that this condition is satisfied.

[0032] In many embodiments, the desired vapor pressure is between 1 and 50 Torr, although other ranges are possible and within the scope of the disclosure. The selected gas is delivered through conduit **220**. For example, as noted above, at room temperature, water has a vapor pressure between 10 and 20 Torr. For an ion implantation occurring at room temperature, water vapor is delivered to the volume between the workpiece and the support. This can be done using the conduit **220** shown in FIG. **2**. The water vapor is pressurized using MFC or pressure regulator **240** such that the vapor phase and liquid phase are in equilibrium. When this happens, a thin film **205** of water vapor adsorbs on the back surface of the wafer **200**. A thin film **215** also adsorbs on the top surface of workpiece support **210**. By creating a film of gas vapor on each surface, the heat transfer mechanism is changed.

[0033] FIG. **4** shows a simplified representation of the heat transfer mechanism. In this scenario, gas vapor molecules adsorb to the film **205** on the surface of the workpiece. A different water vapor molecule, already at the elevated temperature, is displaced and desorbs from the film **205**. This displaced molecule is then adsorbed into the film **215** on the top surface of the support **210**. Again, a different molecule is then displaced, which is at the reduced temperature of the support. Since the molecule being desorbed is at or nearly at the temperature of the solid, (i.e. T_r is roughly equal to T_s), an accommodation coefficient of nearly 1 can be realized.

[0034] FIG. **5** represents a flowchart of the process steps previously described. As stated above, first a desired operating temperature is determined, as shown in Box **400**. Then, a suitable gas is selected, based on this operating temperature, as shown in Box **410**. Again, the vapor pressure of this gas at the desired temperature is preferably sufficiently low so as not to damage the workpiece or overcome the clamping force. As noted above, if necessary, the MFC or a pressure regulator **240** can be used to reduce the working pressure below the vapor pressure of the working fluid. The selected gas is then delivered into the volume between the workpiece and the support, as shown in Box **420**. Preferably, sufficient time is allowed to permit the gas to reach steady-state conditions in this volume, as shown in Box **430**. Steady-state conditions are met when the gas pressure is equal to the vapor pressure. This allows the gas to adsorb on the back side of the workpiece and the top surface of the support. Once steady-state conditions have been reached, the ion implantation process can begin, as shown in Box **440**.

[0035] As shown in Box **430**, it is preferably to allow the vapor to reach steady-state conditions before beginning the ion implantation process. This can be accomplished in a number of ways. In one embodiment, the process cycle time is slowed to allow steady-state conditions to be reached. In other words, once a new workpiece or wafer has been placed on the platen, the flow of vapor is started. Ample time elapsed before the ion implantation process begins. This time permits the vapor pressure and adsorbed film to reach a steady state value. This method is straightforward, but may impact throughput, depending on the time required for equilibrium to be reached.

[0036] Other methods can be used to reduce the amount of time required for the vapor to reach steady-state conditions. For example, the adsorbed vapor film on the workpiece support may be maintained during wafer exchange by reducing the temperature of the support. The colder temperature will liquefy or perhaps freeze the film. Alternatively, the vapor may be introduced through a porous medium that is part of the workpiece support. Finally, coating the workpiece with the selected gas, liquid, or material before it is placed on the support can reduce the required time. For example, a workpiece may be exposed to water vapor prior to being placed on the workpiece support, and then chilled to retain the water until placed on the support. In one embodiment, the wafer orient station is used to simultaneously apply the water vapor and chill the wafer (during the orient). After this is completed, the wafer will be placed on the workpiece support and a steady state vapor pressure established as the wafer and support temperature equalizes.

[0037] While the disclosure describes ion implantation, the disclosure is not limited to this embodiment. The method and system described herein can be used in any application utilizing a workpiece and a workpiece support, especially in a vacuum environment.

What is claimed is:

1. A method for transferring heat from workpiece while said workpiece is being processed, said workpiece mounted on a workpiece support, comprising:

a. Determining an operating temperature range for said processing;
b. Selecting a gas, said gas having a vapor pressure within a desired range at said operating temperature range;
c. Delivering said gas in the volume between the back side of said workpiece and the top surface of said workpiece support; and
d. Processing said workpiece.

2. The method of claim **1**, further comprising the step of waiting for said gas to reach equilibrium in said volume before said workpiece is processed.

3. The method of claim **2**, wherein a film of liquid is produced on said back side of said workpiece and said top surface of said workpiece support.

4. The method of claim **1**, wherein a force is applied to hold said workpiece on said workpiece support, and said desired range of said vapor pressure produces an opposing force that is less than said force holding said workpiece.

5. The method of claim **1**, wherein said gas is delivered at a pressure equal to said vapor pressure.

6. The method of claim **1**, further comprising the step of cooling said support before said processed workpiece is removed.

7. The method of claim **1**, wherein said operating temperature range is between 0 and 50° C., and said selected gas comprises water vapor.

8. The method of claim **7**, wherein said vapor pressure is between 10 and 50 torr.

9. The method of claim **1**, wherein said operating temperature range is less than −50° C., and said selected gas comprises ammonia.

10. The method of claim **1**, wherein said operating temperature range is greater than 100° C., and said selected gas comprises glycerin.

11. The method of claim **1**, wherein said process comprises ion implantation.

12. A system for transferring heat away from a workpiece, while said workpiece is being processed at a predetermined operating temperature range, comprising:

a. a workpiece support upon which said workpiece is placed, such that the top surface of said support contacts the back side of said workpiece;

b. means for holding said workpiece on said workpiece support, said means exerting a force on said workpiece;

c. a conduit for providing gas to the volume defined by the back side of said workpiece and said top surface of said workpiece support;

d. and a reservoir for holding said gas, wherein said gas has a vapor pressure at said operating temperature range, wherein said vapor pressure which produces an opposing force on the workpiece that is lower than said force exerted by said means to hold said workpiece.

13. The system of claim **12**, wherein said operating temperature range is between 0 and 50° C., and said gas comprises water vapor.

14. The system of claim **12**, wherein said operating temperature range is less than −50° C., and said gas comprises ammonia.

15. The system of claim **12**, wherein said operating temperature range is greater than 100° C., and said gas comprises glycerin.

16. The system of claim **12**, wherein said conduit is located within said workpiece support, and said gas passes through said workpiece support to reach said volume.

17. The system of claim **12**, further comprising a mass flow controller or pressure regulator located between said reservoir and said volume.

18. The system of claim **17**, wherein said mass flow controller delivers said gas at a pressure equal to said vapor pressure.

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