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Method and device for substrate processing

Abstract

There is provided a method for processing a substrate, comprising: preparing a substrate processing device including a rotatable stage on which a substrate is placed, a frozen heat transfer body fixed on a backside of the stage with a gap interposed therebetween and cooled to an extremely low temperature, a gas supply mechanism configured to supply to the gap a cooling gas for transferring a cold heat of the frozen heat transfer body to the stage, a rotation mechanism configured to rotate the stage, and a processing mechanism configured to process the substrate; preheating the stage such that a temperature of the stage reaches a steady cooling temperature within a fixed range; and after preheating, continuously processing a plurality of substrates by the processing mechanism while rotating the stage that has reached the steady cooling temperature in a state where a substrate having a specific temperature higher than or equal to room temperature is placed on the stage.

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Background/Summary

TECHNICAL FIELD

(1) The present disclosure relates to a method and device for substrate processing.

BACKGROUND

(2) A processing apparatus for a substrate such as a semiconductor substrate or the like, e.g., a film forming apparatus, performs processing that requires an extremely low temperature. For example, a technique for forming a magnetic film in an ultra-high vacuum and ultra-low temperature environment is required to obtain a magnetoresistive element having a high magnetoresistive ratio.

(3) As a technique for uniformly cooling a substrate at an extremely low temperature in an ultra-high vacuum environment, there is known one in which a stage on which a substrate is placed is rotatably provided, and a frozen heat transfer body is disposed at a center of a back surface of a stage with a gap interposed therebetween (see, e.g., Patent Document 1). Such technique uniformly cools the substrate to an extremely low temperature by supplying cold heat of a chiller to the stage via the frozen heat transfer body while supplying a cooling gas to the gap between the rotating stage and the frozen heat transfer body.

PRIOR ART DOCUMENTS

Patent Documents

(4) Patent Document 1: Japanese Patent Application Publication No. 2019-016771

SUMMARY

Problems to Be Resolved by the Invention

(5) The present disclosure provides a method and device for processing a substrate, capable of shortening a time required until a temperature of a substrate reaches a steady cooling temperature in the case of rotating and processing the substrate in a state where the substrate is cooled to an extremely low temperature.

Means of Solving the Problems

(6) A method according to an aspect of the present disclosure is a method for processing a substrate, and comprises: preparing a substrate processing device including a rotatable stage on which a substrate is placed, a frozen heat transfer body fixed on a backside of the stage with a gap interposed therebetween and cooled to an extremely low temperature, a gas supply mechanism configured to supply to the gap a cooling gas for transferring a cold heat of the frozen heat transfer body to the stage, a rotation mechanism configured to rotate the stage, and a processing mechanism configured to process the substrate; preheating the stage such that a temperature of the stage reaches a steady cooling temperature within a fixed range; and after preheating, continuously processing a plurality of substrates by the processing mechanism while rotating the stage that has reached the steady cooling temperature in a state where a substrate having a specific temperature higher than or equal to room temperature is placed on the stage.

Effect of the Invention

(7) In accordance with the present disclosure, there are provided a method and device for processing a substrate, capable of shortening a time required until a temperature of a substrate reaches a steady cooling temperature in the case of rotating and processing the substrate in a state where the substrate is cooled to an extremely low temperature.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. **1** is a schematic cross-sectional view showing an example of a substrate processing device capable of performing a substrate processing method according to an embodiment.

(2) FIG. **2** is a cross-sectional view schematically showing a state in which a stage temperature is measured by a temperature measuring mechanism in the substrate processing device of FIG. **1**.

(3) FIG. **3** schematically shows another example of a shape of a comb teeth portion in a stage device of the substrate processing device of FIG. **1**.

(4) FIG. **4** shows a change in a stage temperature depending on the number of processed wafers in the case of processing a wafer that is a substrate by a conventional method in the substrate processing device of FIG. **1**.

(5) FIG. **5** is a flowchart showing a substrate processing method according to an embodiment.

(6) FIG. **6** explains an example of a preheating step of the substrate processing method according to the embodiment.

(7) FIG. **7** shows changes in a stage temperature depending on the number of processed wafers in the case of processing a wafer that is a substrate by the substrate processing method according to an embodiment and the conventional method in the substrate processing device of FIG. **1**.

(8) FIG. **8** explains another example of the preheating step.

(9) FIG. **9** explains still another example of the preheating step.

DETAILED DESCRIPTION

(10) Hereinafter, an embodiment will be described in detail with reference to the accompanying drawings.

(11) <Processing Device>

(12) First, an example of a substrate processing device capable of performing a substrate processing method according to an embodiment will be described. FIG. **1** is a schematic cross-sectional view showing an example of the substrate processing device.

(13) As shown in FIG. **1**, a substrate processing device **1** includes a processing chamber **10** that can be maintained in a vacuum state, a target **30**, a stage device **50**, and a controller **100**. The substrate processing device **1** is configured as a film forming device capable of performing sputtering film formation of a magnetic film on a semiconductor wafer (hereinafter, simply referred to as “wafer”) W that is a substrate in an ultra-high vacuum and ultra-low temperature environment in the processing chamber **10**. The magnetic film is used for, e.g., a tunneling magneto resistance (TMR) element.

(14) The processing chamber **10** processes the wafer W that is a substrate to be processed. An exhaust device (not shown) such as a vacuum pump capable of decreasing a pressure to an ultra-high vacuum level is connected to the processing chamber **10**, so that the inside of the processing chamber **10** can be depressurized to an ultra-high vacuum state (e.g., 10.sup.−5 Pa or less). A gas supply line (not shown) from the outside is connected to the processing chamber **10** to supply a sputtering gas (e.g., noble gas such as argon (Ar) gas, krypton (Kr) gas, neon (Ne) gas, or nitrogen gas) required for sputtering film formation. Further, a loading/unloading port (not shown) for the wafer W is formed on a sidewall of the processing chamber **10**, and can be opened and closed by a gate valve (not shown).

(15) At an inner upper portion of the processing chamber **10**, the target **30** is disposed above the wafer W held by the stage device **50** to face the wafer W. An AC voltage or a DC voltage is applied from a plasma generation power source (not shown) to the target **30**. When an AC voltage or a DC voltage is applied from the plasma generation power source to the target **30** in a state where the sputtering gas is introduced into the processing chamber **10**, plasma of the sputtering gas is produced in the processing chamber **10**, and the target **30** is sputtered by ions in the plasma. Atoms or molecules of the sputtered target material are deposited on the surface of the wafer W held by the stage device **50**. Although the number of targets **30** is not particularly limited, from the viewpoint that different films made of different materials can be formed by one substrate processing device **100**, it is preferable that a plurality of targets are present. For example, in the case of depositing a magnetic film (film containing a ferromagnetic material such as Ni, Fe, Co, or the like), CoFe, FeNi, and NiFeCo can be used as the material of the target **30**. Further, those materials containing another element can also be used as the material of the target **30**.
(16) As will be described later, the stage device **50** holds the wafer W on the stage **56**, and cools the wafer W to an extremely low temperature via the stage **56** while rotating the stage **56** together with the wafer W. Further, as will be described later, the stage device **50** has an elevating mechanism **74** for raising and lowering the stage **56** and a temperature measuring mechanism **90** for measuring a temperature of the stage.
(17) The controller **100** is a computer, and includes a main controller including a central processing unit (CPU) for controlling individual components of the substrate processing device, an input device, an output device, a display device, and a storage device. The main controller controls a voltage applied to the target **30** during sputtering, introduction of a sputtering gas, raising/lowering and rotation of the stage **56** to be described later, loading/unloading of the wafer W, introduction of a cooling gas to be described later, an operation of a chiller **52** to be described later, or the like. Further, the main controller executes an operation set in the substrate processing device **1** based on a processing recipe called from the storage medium of the storage device.
(18) Next, the stage device **50** will be described in detail.
(19) As shown in FIG. **1**, the stage device **50** includes the stage **56**, the elevating mechanism **74**, and the temperature measuring mechanism **90**. The stage device **50** further includes the chiller **52**, a frozen heat transfer body **54**, a stage support **58**, a seal rotation mechanism **62**, and a driving mechanism **68**.
(20) The elevating mechanism **74** is configured to move the wafer W among a transfer position for transferring the wafer W to the stage **56**, a processing position for forming a film on the wafer W placed on the stage **56**, and a temperature measurement position for measuring a temperature of the stage using a substrate transfer device. The transfer position is set to be lower than the processing position and the temperature measurement position, and the temperature measurement position is set to be lower than the processing position. Further, the elevating mechanism **74** can control the distance between the target **30** and the wafer W.
(21) The temperature measuring mechanism **90** includes a temperature detection contact portion **91** disposed at a portion of the stage **56** that does not interfere with the placement of the wafer W, and a temperature detector **92** attached to a bottom portion of the processing chamber **10** under the stage **56**. The temperature detector **92** has a temperature sensor and is separated from the temperature detection contact portion except during temperature measurement. When the temperature detector **92** is in contact with the temperature detection contact portion **91**, the temperature of the stage **56** can be measured. The temperature detection contact portion **91** can be brought into contact with and separated from the temperature detector **92** by raising and lowering the stage **56** using the elevating mechanism **74**. As shown in FIG. **2**, the positions of the temperature detection contact portion **91** and the temperature detector **92** are made to correspond to each other by rotating the stage **56**, and the temperature of the stage **56** is measured by bringing the temperature detection contact portion **91** into contact with the temperature detector **92** by lowering

the stage **56** to the temperature measurement position. Such temperature measurement is performed without rotating the stage **56** immediately before the wafer W is processed while rotating the stage **56**, for example.

(22) The chiller **52** holds the frozen heat transfer body **54** and cools an upper surface of the frozen heat transfer body **54** to an extremely low temperature. The chiller **52** has a cold head portion **52***a* at an upper portion thereof, and cold heat is transferred from the cold head portion **52***a* to the frozen heat transfer body **54**. The chiller **52** preferably uses a Gifford-McMahon (GM) cycle in view of cooling performance. In the case of forming a magnetic film used for a TMR element, a cooling temperature of the frozen transfer body **54** by the chiller **52** is within a range of, e.g., 250K to 50K (−23° C. to −223° C.)

(23) The frozen heat transfer body **54** is fixed on the chiller **52**, and is formed in a substantially cylindrical shape and made of a material having high thermal conductivity such as pure copper (Cu) or the like. An upper portion of the frozen heat transfer body **54** is disposed in the processing chamber **10**.

(24) The frozen heat transfer body **54** is disposed below the stage **56** such that the center thereof coincides with a central axis C of the stage **56**. A first cooling gas supply line **54***a* through which a first cooling gas can flow is formed along the central axis C inside the frozen heat transfer body **54**, and a gas supply mechanism **59** is connected to the first cooling gas supply line **54***a*. The first cooling gas is supplied from the gas supply mechanism **59** to the first cooling gas supply line **54***a*. It is preferable to use helium (He) gas having high thermal conductivity as the first cooling gas.

(25) The stage **56** is separated from the upper surface of the frozen heat transfer body **54** by a gap G (e.g., 2 mm or less). The stage **56** is made of a material having high thermal conductivity such as pure copper (Cu) or the like. The gap G communicates with the first cooling gas supply line **54***a* formed inside the frozen heat transfer body **54**. Therefore, the extremely low temperature first cooling gas cooled by the frozen heat transfer body **54** is supplied from the gas supply mechanism **59** to the gap G through the first cooling gas supply line **54***a*. Accordingly, the cold heat of the chiller **52** is transferred to the stage **56** via the first cooling gas supplied to the frozen heat transfer body **54** and the gap G, thereby cooling the stage **56** to an extremely low temperature. The gas supply mechanism **59** can perform the removal of the first cooling gas from the gap G as well as the supply of the first cooling gas to the gap G.

(26) The stage **56** includes an electrostatic chuck **56***a*. The electrostatic chuck **56***a* is formed of a dielectric film, and a chuck electrode **56***b* is embedded therein. A predetermined DC voltage is applied to the chuck electrode **56***b* through a wiring L. Accordingly, the wafer W can be attracted and fixed by an electrostatic attractive force.

(27) The stage **56** has a first heat transfer portion **56***c* under the electrostatic chuck **56***a*, and convex portions **56***d* protruding toward the frozen heat transfer body **54** are formed on a bottom surface of the first heat transfer portion **56***c*. In the illustrated example, the convex portions **56***d* are formed as two annular portions surrounding the central axis C of the stage **56**. The height of each convex portion **56***d* may be, e.g., 40 mm to 50 mm. The width of each convex portion **56***d* may be, e.g., 6 mm to 7 mm. Although the shape and number of the convex portions **56***d* are not particularly limited, it is preferable to set the shape and number thereof such that a sufficient heat exchangeable surface area can be obtained in order to increase the heat transfer efficiency with the frozen heat transfer body **54**.

(28) The frozen heat transfer body **54** has a second heat transfer portion **54***b* on an upper surface of the main body, i.e., on the surface facing the first heat transfer portion **56***c*. The second heat transfer portion **54***b* has concave portions **54***c* to be fitted into the convex portions **56***d* with the gap G interposed therebetween. In the illustrated example, the concave portions **54***c* are formed as two annular portions surrounding the central axis C of the stage **56**. The height of each concave portion **54***c* may be the same as the height of each convex portion **56***d*, and may be, e.g., 40 mm to 50 mm. The width of each concave portion **54***c* may be slightly greater than the width of each convex

portion **56***d*, and is preferably, e.g., 7 mm to 9 mm. The shape and number of the concave portions **54***c* are determined to correspond to those of the convex portions **56***d*.
(29) The convex portions **56***d* of the first heat transfer portion **56***c* and the concave portions **54***c* of the second heat transfer portion **54***b* are fitted to each other via the gap G, thereby forming a comb teeth portion. Due to the presence of the comb teeth portion, the gap G is saw-toothed, so that the heat transfer efficiency of the first cooling gas between the first heat transfer portion **56***c* of the stage **56** and the second heat transfer portion **54***b* of the frozen heat transfer body **54** can be increased.
(30) As shown in FIG. **3**, the convex portions **56***d* and the concave portions **54***c* may have corresponding wave shapes. Further, it is preferable that the surfaces of the convex portions **56***d* and the concave portions **54***c* are subjected to uneven processing by blasting or the like. Accordingly, the surface area for heat transfer can be increased to further improve the heat transfer efficiency.
(31) Alternatively, the concave portions may be formed at the first heat transfer portion **56***c*, and the convex portions corresponding to the concave portions may be formed at the second heat transfer portion **54***b*.
(32) The electrostatic chuck **56***a* and the first heat transfer portion **56***c* in the stage **56** may be integrally formed, or may be separately formed and joined. Further, the main body of the frozen heat transfer body **54** and the second heat transfer portion **54***b* may be integrally formed, or may be separately formed and joined.
(33) The stage **56** has a through-hole **56***e* penetrating therethrough vertically. A second cooling gas supply line **57** is connected to the through-hole **56***e*, and a second cooling gas for heat transfer is supplied from the second cooling gas supply line **57** to the backside of the wafer W through the through-hole **56***e*. Similarly to the first cooling gas, He gas having high thermal conductivity is preferably used as the second cooling gas. By supplying the second cooling gas to the backside of the wafer W, i.e., to the gap between the wafer W and the electrostatic chuck **56***a*, the cold heat of the stage **56** can be efficiently transferred to the wafer W via the second cooling gas. Although one through-hole **56***e* may be formed, it is preferable to form a plurality of through-holes **56***e* in order to particularly efficiently transfer the cold heat of the frozen heat transfer body **54** to the wafer W.
(34) By separating the flow path of the second cooling gas supplied to the backside of the wafer W from the flow path of the first cooling gas supplied to the gap G, the cooling gas can be supplied at a desired pressure and a desired flow rate to the backside of the wafer W regardless of the supply of the first cooling gas. At the same time, the cooling gas in a high pressure and extremely low temperature state can be continuously supplied to the gap G without being limited by the pressure, the flow rate, and the supply timing of the gas supplied to the backside.
(35) Further, the stage **56** may have a through-hole connected from the gap G, so that a part of the first cooling gas may be supplied as the cooling gas to the backside of the wafer W.
(36) The stage support **58** is disposed at an outer side of the frozen heat transfer body **54** and rotatably supports the stage **56**. The stage support **58** has a substantially cylindrical main body **58***a* and a flange portion **58***b* extending outward on a bottom surface of the main body **58***a*. The main body **58***a* is disposed to cover the gap G and an upper outer peripheral surface of the frozen heat transfer body **54**. Accordingly, the stage support **58** also has a function of shielding the gap G that is a connection portion between the frozen heat transfer body **54** and the stage **56**.
(37) The seal rotation mechanism **62** is disposed below a heat insulating member **60**. The seal rotation mechanism **62** has a rotating portion **62***a*, an inner fixing portion **62***b*, an outer fixing portion **62***c*, and a heating device **62***d*.
(38) The rotating portion **62***a* has a substantially cylindrical shape extending downward coaxially with the heat insulating member **60**, and is rotated by the driving device **68** while being hermetically sealed with a magnetic fluid with respect to the inner fixing portion **62***b* and the outer fixing portion **62***c*. Since the rotating portion **62***a* is connected to the stage support **58** via the heat

insulating member **60**, the transfer of the cold heat from the stage support **58** to the rotating portion **62***a* is blocked by the heat insulating member **60**. Therefore, it is possible to suppress deterioration of the sealing performance or occurrence of condensation caused by a decrease in the temperature of the magnetic fluid of the seal rotation mechanism **62**.

(39) The inner fixing portion **62***b* has a substantially cylindrical shape having an inner diameter greater than an outer diameter of the frozen heat transfer body **54** and having an outer diameter is smaller than the inner diameter of the rotating portion **62***a*. The inner fixing portion **62***b* is disposed between the frozen heat transfer body **54** and the rotating portion **62***a* via a magnetic fluid.

(40) The outer fixing portion **62***c* has a substantially cylindrical shape having an inner diameter greater than an outer diameter of the rotating portion **62***a*, and is disposed at an outer side of the rotating portion **62***a* via a magnetic fluid.

(41) The heating device **62***d* is embedded in the inner fixing portion **62***b* and heats the entire seal rotation mechanism **62**. Accordingly, it is possible to suppress the deterioration of the sealing performance or the occurrence of condensation caused by a decrease in the temperature of the magnetic fluid of the seal rotation mechanism **62**.

(42) With such a configuration, the seal rotation mechanism **62** can rotate the stage support **58** in a state where a region communicating with the processing chamber **10** is hermetically sealed with a magnetic fluid and held in a vacuum state.

(43) A bellows **64** is disposed between an upper surface of the outer fixing portion **62***c* and a bottom surface of the processing chamber **10**. The bellows **64** is a metal bellows structure that can be extended and contracted vertically. The bellows **64** surrounds the frozen heat transfer body **54**, the stage support **58**, and the heat insulating member **60**, and separates the space in the processing chamber **10** and the space communicating therewith and held in a vacuum state from a space in an atmospheric atmosphere.

(44) A slip ring **66** is disposed below the seal rotation mechanism **62**. The slip ring **66** has a rotating body **66***a* including a metal ring, and a fixed body **66***b* including a brush. The rotating body **66***a* is fixed to a bottom surface of the rotating portion **62***a* of the seal rotating mechanism **62**, and has a substantially cylindrical shape extending downward coaxially with the rotating portion **62***a*. The fixed body **66***b* has a substantially cylindrical shape having an inner diameter slightly greater than an outer diameter of the rotating body **66***a*.

(45) The slip ring **66** is electrically connected to a DC power supply (not shown), and a voltage supplied from the DC power supply is transmitted to the wiring L via the brush of the fixed body **66***b* and the metal ring of the rotating body **66***a*. Accordingly, a voltage can be applied from the DC power supply to the chuck electrode without causing torsion or the like in the wiring L. The rotating body **66***a* of the slip ring **66** is configured to rotate via the driving mechanism **68**.

(46) The driving mechanism **68** is a direct drive motor having a rotor **68***a* and a stator **68***b*. The rotor **68***a* has a substantially cylindrical shape extending coaxially with the rotating body **66***a* of the slip ring **66**, and is fixed to the rotating body **66***a*. The stator **68***b* is formed in a substantially cylindrical shape having an inner diameter greater than an outer diameter of the rotor **68***a*. When the driving mechanism **68** is driven, the rotor **68***a* rotates, and the rotation of the rotor **68***a* is transmitted to the stage **56** via the rotating body **66***a*, the rotating portion **62***a*, and the stage support **58**. Then, the stage **56** and the wafer W thereon are rotated with respect to the frozen heat transfer body **54**. In FIG. **1**, for convenience, the rotating members are hatched with dots.

(47) Although the direct drive motor is illustrated as an example of the driving mechanism **68**, the driving mechanism **68** may be driven via a belt or the like.

(48) A first insulation structure **70** that is a vacuum insulation structure (vacuum double tube structure) formed in a cylindrical shape of a double tube structure and having an inner space maintained in a vacuum state is disposed to cover the cold head portion **52***a* of the chiller **52** and the lower portion of the frozen heat transfer body **54**. The first heat insulation structure **70** can suppress the deterioration of the cooling performance caused by heat input from the outside such as

the driving mechanism **68** or the like into the cold head portion **52***a* and the lower portion of the frozen heat transfer body **54** that are important for cooling the stage **56** and the wafer W.
(49) Further, a second insulation structure **71** that is a cylindrical vacuum double tube structure having an inner space maintained in a vacuum state is disposed to cover substantially the entire frozen heat transfer body **54** and to overlap the inner side of the first heat insulation structure **70**. The second insulation structure **71** can suppress the deterioration of the cooling performance caused by heat input from the outside such as the magnetic fluid seal, the first cooling gas leaking to the space S, or the like into the frozen heat transfer body **54**. Since the first heat insulation structure **70** and the second heat insulation structure **71** overlap at the lower portion of the frozen heat transfer body **54**, a non-insulated portion of the frozen heat transfer body **54** can be eliminated, and the insulation at the cold head portion **52***a* and its vicinity can be enhanced.
(50) Further, the first heat insulation structure **70** and the second heat insulation structure **71** can suppress the transfer of cold heat of the chiller **52** and the frozen heat transfer body **54** to the outside.
(51) A sealing member **81** is disposed between the main body **58***a* of the stage support **58** and the second heat insulation structure **71**. A space S sealed with a sealing member **81** is formed by the main body **58***a* of the stage support **58**, the second heat transfer portion **54***b* of the frozen heat transfer body **54**, and the upper portion of and the second heat insulation structure **71**. The first cooling gas leaking from the gap G flows into the space S. A gas flow path **72** is connected to the space S while penetrating through the sealing member **81**. The gas flow path **72** extends downward from the space S. A space between an upper surface of the second heat insulation structure **71** and the second heat transfer portion **54***b* of the frozen heat transfer body **54** is sealed with a sealing member **82**. The sealing member **82** suppresses the supply of the first cooling gas leaking into the space S to the main body of the frozen heat transfer body **54**.
(52) The gas flow path **72** may allow the gas in the space S to be discharged, or may allow the cooling gas to be supplied to the space S. In both cases where the gas is discharged through the gas flow path **72** and where the cooling gas is supplied through the gas flow path **73**, it is possible to prevent deterioration of the sealing performance caused by a decrease in the temperature of the magnetic fluid due to the inflow of the first cooling gas from into the seal rotation mechanism **62**. When the gas flow path **72** has the cooling gas supply function, the third cooling gas is supplied to function as a counterflow to the first cooling gas leaking from the gap G. It is preferable that a supply pressure of the third cooling gas is substantially the same as or slightly higher than a supply pressure of the first cooling gas in order to enhance the function as the counterflow. The condensation can be prevented by using a gas having thermal conductivity lower than that of the first cooling gas, such as argon (Ar) gas or neon (Ne) gas, as the third cooling gas.
(53) <Substrate Processing Method>
(54) Next, a substrate processing method performed in the substrate processing device **1** will be described.
(55) In the case of processing the wafer W in a normal state, the processing chamber **10** is evacuated, and the chiller **52** of the stage device **50** operates. At the same time, the first cooling gas is supplied to the gap G through the first cooling gas flow path **54***a*. Accordingly, the cold heat transferred from the chiller **52** maintained at an extremely low temperature to the frozen heat transfer body is transferred to the stage **56** via the first cooling gas supplied to the gap G, and the rotatable stage **56** is maintained at a steady cooling temperature within a fixed range.
(56) Then, the elevating mechanism **74** moves (lowers) the stage device **50** such that the stage **56** is located at the transfer position. Thus, the wafer maintained at a specific temperature (e.g., 75° C.) higher than room temperature is transferred from a vacuum transfer chamber (not shown) into the processing chamber **10** and placed on the stage **56** by a substrate transfer device (not shown). Next, a pressure in the processing chamber **10** is adjusted to an ultra-high vacuum (e.g., 10.sup.−5 Pa or less) that is a processing pressure, and a DC voltage is applied to the chuck electrode **56***b* to

electrostatically attract the wafer W on the electrostatic chuck **56***a*. The second cooling gas is supplied to the backside of the wafer W, and the wafer W is maintained at the same temperature as that of the stage **56**. In that case, since the stage **56** is separated from the fixed frozen heat transfer body **54**, the wafer W can be rotated by the driving mechanism **68** via the stage support **58** while cooling the stage **56** and the wafer W.

(57) In a state where the wafer W is rotated, a sputtering gas is introduced into the processing chamber **10**, and a voltage is applied from a plasma generation power source (not shown) to the target **30**. Accordingly, plasma of the sputtering gas is generated, and the target **30** is sputtered by ions in the plasma. Atoms or molecules of the sputtered target material are deposited on the surface of the wafer W held in an extremely low temperature state by the stage device **50**, thereby forming a desired film, e.g., a magnetic film for use in a TMR element having a high magnetoresistance ratio. The temperature of the stage **56** can be monitored by the temperature measuring mechanism **90** when the stage **56** is not rotating.

(58) Such a series of processes are continuously performed on a plurality of wafers W. However, it was found that in the process of continuously processing the wafers W at the time of starting processing, the stage temperature is gradually increased and saturated at a steady cooling temperature within a fixed range.

(59) This may be because indirect cooling in which a cooling gas is supplied to a space between the frozen heat transfer body **54** and the rotating stage **56** to rotate and cool the wafer W to an extremely low temperature is employed and also because the temperature measuring mechanism **90** cannot monitor a temperature during the rotation of the stage **56**. In other words, in the case of performing indirect cooling using a cooling gas, if the wafers W maintained at room temperature or higher are continuously processed at the time of starting processing, the phenomenon that the temperature of the stage **56** is gradually increased due to heat received from the wafers W occurs. During the rotation of the stage **56**, the temperature cannot be monitored and, thus, the temperature cannot be controlled. Accordingly, it is difficult to correct such phenomenon. The temperature of the stage **56** is saturated at a steady cooling temperature within a fixed range because the heat received from the substrate and the cold heat supplied to the stage **56** via the cooling gas are balanced. In this case, the temperature continues to increase to the steady cooling temperature until several to several tens of wafers W are processed after the start of processing, which makes the temperature management of the wafer W difficult. Such phenomenon is remarkable particularly when the cooling temperature of the wafer W is about 120 K (−153° C.) or less. Specifically, as shown in FIG. **4**, for example, the stage temperature is managed by the frozen heat transfer body **54** within a range of the center temperature ±1K and reaches the steady cooling temperature. However, the stage temperature is lower than the steady cooling temperature by about 3° C. to 4° C. at the time of starting processing, and is saturated at the steady cooling temperature when about ten wafers W are processed. FIG. **4** plots the average value of the stage (electrostatic chuck) temperature during processing that is measured by a thermocouple when the control temperature of the frozen heat transfer body **54** is 95K (−178° C.) and the wafer temperature is 75° C.

(60) Conventionally, there is a problem that about ten wafers W whose temperatures are not controlled are processed from the start of processing. Therefore, a processing method capable of shortening a time required until the temperature reaches the steady cooling temperature (steady cooling temperature arrival time) is required.

(61) Therefore, in one embodiment, as shown in FIG. **5**, before the processing of the wafer W that is a substrate is started, first, preheating is performed to increase the temperature of the stage **56** to the steady cooling temperature (step **1**) and, then, multiple wafers W are continuously processed on the stage **56** that has reached the steady cooling temperature (step **2**).

(62) Such a processing sequence is executed based on a processing recipe preset in the controller **100**. In other words, a preheating time required until the temperature reaches the steady cooling temperature or the like is obtained in advance, and the processing recipe is stored in the storage

device of the controller **100** based on the preheating time or the like. Then, the processing is performed based on the processing recipe.
(63) By performing the preheating process of step **1**, the temperature of the stage **56** can be rapidly increased to the steady cooling temperature.
(64) In the preheating of step **1**, as shown in FIG. **6**, the first cooling gas is removed from the gap G between the stage **56** and the frozen heat transfer body **54**, and a dummy wafer DW heated to the same temperature as that of an actual device wafer is placed on the stage **56** and processed. The dummy wafer DW can be transferred by the same substrate transfer mechanism as that used for the wafer W.
(65) By removing the first cooling gas from the gap G, the cooling of the stage **56** is blocked, and the stage **56** is heated by heat received from the dummy wafer having the same temperature as that of the actual device wafer. By processing about one to three dummy wafers, the temperature of the stage **56** can be stabilized at the steady cooling temperature, which makes it possible to considerably shorten the time required until the temperature of the stage **56** reaches the steady cooling temperature compared to the conventional case.
(66) When the stage temperature reaches the steady cooling temperature by performing preheating, the first cooling gas is introduced into the gap G to start cooling of the stage **56**, and the processing of the actual device wafer (wafer W) in step **2** is continuously performed on a plurality of wafers W. The processing performed in this case is the same as that described above. In the case of continuously processing the actual device wafers in a state where the stage temperature has reached the steady cooling temperature, the variation in the stage temperature can be maintained within a range of ±1K, for example, as described above.
(67) The dummy wafer used for preheating preferably has the same temperature as that of the actual device wafer subjected to dummy processing under the same conditions as those applied to the actual device wafer. Further, it is preferable that the dummy processing of the dummy wafer in the substrate processing device **1** is performed under the same conditions as those applied to the actual device wafer.
(68) In the case of performing preheating using the dummy wafer whose temperature is the same as that of the actual device wafer, the dummy wafer can be processed during the preheating under the same conditions as those of other actual processing except that the first cooling gas is removed from the gap G. Therefore, it is highly compatible with the actual processing.
(69) Next, a result of monitoring a change in the stage temperature in the case of performing preheating and then continuously processing the actual device wafers will be described. Here, the preheating of the stage was performed by continuously processing two dummy wafers heated to 75° C. equal to the temperature of the actual device wafer in a state where the first cooling gas was removed from the gap G and, then, the first cooling gas was supplied to continuously process the actual device wafers. FIG. **7** shows a relationship between the number of processed wafers and the stage temperature in that case. FIG. **7** also shows, for comparison, a result of processing using a conventional method in which the dummy wafer shown in FIG. **4** is not used. Similarly to FIG. **4**, FIG. **7** plots the average value of the temperature of the stage (the electrostatic chuck) during processing that is measured by a thermocouple when the control temperature of the frozen heat transfer body **54** is 95 K (−178° C.) and the wafer temperature is 75° C.
(70) As shown in FIG. **7**, it was found that by processing two dummy wafers in a state where the first cooling gas is removed, the processing is performed within a management temperature range (steady cooling temperature) in subsequent processing of the actual device wafer. Since the processing time of one wafer is predetermined, the time required to reach the steady cooling temperature is considerably shortened compared to when the dummy wafer is not processed. Specifically, when the dummy wafer is not used, it is necessary to process about 10 wafers until the temperature reaches the steady cooling temperature. Therefore, the time required to reach the steady cooling temperature is shortened to about ¼ to ⅕ by the present method.

(71) The preheating process of step **1** is not necessarily performed by the technique using the dummy wafer having the same temperature as that of the actual device wafer as long as the stage **56** can be preheated to the steady cooling temperature, and may be performed by various techniques.
(72) For example, the dummy processing may be performed using a dummy wafer having a temperature higher than that of the actual device wafer. Further, the stage may be heated by a heater. Accordingly, the preheating can be performed with an enhanced heating effect. In such cases, the effect of shortening the steady cooling temperature arrival time can be obtained without removing the first cooling gas from the gap G. Also in such cases, the steady cooling temperature arrival time can be further shortened by removing the first cooling gas from the gap G.
(73) As a technique for heating the stage **56** using a heater, there may be used a technique for performing heating by providing a lamp heater **120** at a movable shutter **110** for shielding sputtered particles from the target **30**, which is generally used in a sputtering device, as shown in FIG. **8**. Further, as shown in FIG. **9**, a technique for performing heating by providing a resistance heater **130** at the stage **56** may also be used.
OTHER APPLICATIONS
(74) While the embodiments of the present disclosure have been described, the embodiments of the present disclosure are illustrative in all respects and are not restrictive. The above-described embodiments may be omitted, replaced, or changed in various forms without departing from the scope of the appended claims and the gist thereof.
(75) For example, in the above embodiment, sputtering film formation of a magnetic film for use in a TMR element has been described as an example of substrate processing. However, the present disclosure is not limited to the above embodiment as long as the substrate is rotated and processed while indirectly cooling the stage holding the substrate using a cooling gas.
(76) Further, although an example in which a semiconductor wafer is used as a substrate has been described in the above embodiment, the substrate is not limited to the semiconductor wafer and may be another substrate such as a flat panel display (FPD) substrate, a ceramic substrate, or the like.
DESCRIPTION OF REFERENCE NUMERALS
(77) **1**: substrate processing device **10**: processing chamber **30**: target **50**: stage device **52**: chiller **54**: frozen heat transfer body **54***a*: first cooling gas supply line **56**: stage **74**: elevating mechanism **90**: temperature measuring mechanism **100**: controller **110**: shutter G: gap W: wafer (substrate)

Claims

1. A method for processing a substrate, comprising: preparing a substrate processing device including a rotatable stage on which a substrate is placed, a frozen heat transfer body fixed on a backside of the stage with a gap interposed therebetween and cooled to an extremely low temperature, a gas supply mechanism configured to supply to the gap a cooling gas for transferring a cold heat of the frozen heat transfer body to the stage, a rotation mechanism configured to rotate the stage, and a processing mechanism configured to process the substrate; and controlling the substrate processing device by a controller, wherein the controller is configured to: cool the stage to an extremely low temperature by supplying the cooling gas to the gap between the stage and the frozen heat transfer body without the substrate being disposed on the stage, after the stage is cooled to the extremely low temperature and before the the substrate is placed on the stage, preheat the stage to increase a temperature of the stage from the extremely low temperature to a steady cooling temperature within a fixed range that is greater than the extremely low temperature; and after the stage is preheated to the steady cooling temperature, continuously process each of a plurality of substrates by the processing mechanism while rotating the stage that has reached the steady cooling temperature in a state where the substrate on the stage has a specific temperature higher than or

equal to room temperature is placed on the stage.
2. The method of claim 1, wherein preheating comprises placing a dummy substrate having the same temperature as a temperature of the substrate on the stage thereby increasing the temperature of the stage, removing the cooling as from the gap, and performing dummy processing after the cooling gas is removed from the gap.
3. The method of claim 2, wherein preheating comprises performing dummy processing on one to three dummy substrates.
4. The method of claim 2, wherein the dummy processing is performed under the same conditions as conditions of actual processing of the substrate.
5. The method of claim 1, wherein preheating comprises placing a dummy substrate having a temperature higher than a temperature of the substrate on the stage thereby increasing the temperature of the stage and performing dummy processing.
6. The method of claim 5, wherein preheating comprises removing the cooling gas from the gap.
7. The method of claim 1, wherein preheating comprises heating the stage using a heater.
8. The method of claim 7, wherein the heater is a lamp heater disposed above the stage or a resistance heater disposed at the stage.
9. The method of claim 7, wherein preheating comprises removing the cooling gas from the gap.
10. The method of claim 1, wherein the substrate processing is sputtering film formation in which sputtered particles from a target disposed above the stage in a vacuum chamber are deposited on the substrate in a vacuum state.
11. A device for processing a substrate, comprising: a rotatable stage on which a substrate is placed; a frozen heat transfer body fixed on a backside of the stage with a gap interposed therebetween and cooled to an extremely low temperature; a gas supply mechanism configured to supply to the gap a cooling gas for transferring cold heat of the frozen heat transfer body to the stage; a rotation mechanism configured to rotate the stage; a processing mechanism configured to process the substrate; and a controller, wherein the controller is configured to: cool the stage to an extremely low temperature by supplying the cooling gas to the gap between the stage and the frozen heat transfer body without the substrate being disposed on the stage, after the stage is cooled to the extremely low temperature and before the the substrate is placed on the stage, preheat the stage to increase a temperature of the stage from the extremely low temperature to a steady cooling temperature within a fixed range that is greater than the extremely low temperature; and after the stage is preheated to the steady cooling temperature, continuously process each of a plurality of substrates by the processing mechanism while rotating the stage that has reached the steady cooling temperature in a state where the substrate on the stage has a specific temperature higher than or equal to room temperature is placed on the stage.
12. The device of claim 11, wherein the controller controls the device such that the preheating is performed by placing a dummy substrate having the same temperature as a temperature of the substrate on the stage thereby increasing the temperature of the stage, the cooling gas is removed from the gap, and dummy processing is performed after the cooling gas is removed from the gap.
13. The device of claim 12, wherein the controller controls the device such that the preheating is performed by performing dummy processing on one to three dummy substrates.
14. The device of claim 12, wherein the controller controls the device such that the dummy processing is performed under the same conditions as conditions of actual processing of the substrate.
15. The device of claim 11, wherein the controller controls the device such that the preheating is performed by placing a dummy substrate having a temperature higher than a temperature of the substrate on the stage and performing dummy processing thereby increasing the temperature of the stage.
16. The device of claim 15, wherein the controller controls the device such that the preheating is performed after the cooling gas is removed from the gap.

17. The device of claim 11, wherein the controller controls the device such that the preheating is performed by heating the stage using a heater.
18. The device of claim 17, wherein the heater is a lamp heater disposed above the stage or a resistance heater disposed at the stage.
19. The device of claim 17, wherein the controller controls the device such that the preheating is performed in a state where the cooling gas is removed from the gap.
20. The device of claim 11, wherein the processing mechanism has a vacuum chamber accommodating the stage and a target accommodated in the vacuum chamber, and performs sputtering film formation in which sputtered particles from the target are deposited on the substrate in a vacuum state.