VACUUM PUMP

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a vacuum pump, and more particularly to a vacuum pump that can reduce an amount of deposit (or, a "depo") produced when gas in a vacuum pump solidifies and accumulates in a gap.

2. Description of the Related Art

[0002] In recent years, in a process of forming a semiconductor device from a wafer, which is a substrate to be processed, a technique has been adopted that processes the wafer in a processing chamber of a semiconductor manufacturing apparatus in which a high vacuum is maintained to produce semiconductor devices as products. For a semiconductor manufacturing apparatus that processes wafers in a vacuum chamber, a vacuum pump is used that includes a turbomolecular pump portion, a thread groove pump portion, and the like to achieve and maintain a high degree of vacuum.

[0003] The turbomolecular pump portion has, in a casing thereof, thin rotor blades, which are rotatable and made of metal, and stator blades fixed to the casing. The rotor blades are operated at a high speed of several hundred meters per second, for example, and process gas entering from an inlet port after being used for processing is compressed in the pump and exhausted from an outlet port.

[0004] The process gas molecules taken in through the inlet port of the vacuum pump immediately after passing through the inlet port are hot, and then cooled in a compression process occurring while the process gas is moved toward the outlet port by rotation of the rotor blades in the vacuum pump. The process gas is solidified when cooled, and solidified by-products may adhere and accumulate as deposit on the stator blades, an inner surface of an outer cylinder (casing), and the like. These by-products are typically chlorine-based or fluorine-sulfide-based gas. In such gas, a lower degree of vacuum and a higher pressure increase sublimation temperature, facilitating solidification and accumulation in the vacuum pump. Reaction products accumulating in the vacuum pump may narrow a flow passage for the reaction products and thus reduce compression performance and exhaust performance of the vacuum pump. At the same time, when a gas transfer portion including the rotor blades and stator blades of aluminum, stainless steel, or the like is heated to an excessively high temperature, the strength of the rotor blades and the stator blades may be lowered. This may cause breakage during operation. Also, the electrical components and the electric motor for

rotating a rotor in the vacuum pump may fail to elicit desired performance when the temperature is high. As such, the vacuum pump requires temperature control so as to maintain a predetermined temperature.

[0005] In this respect, as a vacuum pump that limits the deposition of reaction products, a structure is known that controls a temperature in the gas flow passage by providing a cooling device or a heating device around a stator and allows the gas in the gas flow passage to be transferred without solidifying (see PTL 1, for example).

[0006] However, the gas taken into the vacuum pump has a characteristic by which a higher degree of vacuum and a higher pressure increase a sublimation temperature of the gas and thus increase a possibility of the gas solidifying and accumulating in the vacuum pump. Meanwhile, when the gas transfer portion including the rotor blades and stator blades is heated to an excessively high temperature, problems may arise where the strength decreases and the performances of the electrical components and the electric motor in the vacuum pump are adversely affected. As such, temperature control is desirable that limits the solidification of gas in the vacuum pump while maintaining normal operation of the vacuum pump and without adversely affecting the performance of the electrical components and the electric motor in the vacuum pump or lowering the strength of the gas transfer portion.

[0007] To this end, a vacuum pump 10 shown in FIGS. 9 and 10 is divided into an upper stage group gas transfer portion 11, which includes a cooling-side stator 17A placed in a cooling area that requires cooling, and a lower stage group gas transfer portion 12, which includes a heating-side stator 17B placed in a heating area that requires heating. A gap 15 is formed between the cooling-side stator 17A and the heating-side stator 17B to allow the cooling-side stator 17A and the heating-side stator 17B to be independent of each other so that a temperature of the upper stage group gas transfer portion 11 and a temperature of the lower stage group gas transfer portion 12 do not affect each other. Stator blade spacers 14 are held by bolts 19 to position the cooling-side stator 17A and the heating-side stator 17B.

[Citation List]

[Patent Literature]

[0008]

[PTL 1] Japanese Patent Application Publication No. H10-205486

SUMMARY OF THE INVENTION

[0009] In the structure in which the cooling-side stator 17A and the heating-side stator 17B are held and positioned by the bolts 19, the size of the gap 15 between the cooling-side stator

17A and the heating-side stator 17B (the dimension in the axial direction) varies depending on the magnitude of tightening force of the bolts 19, a deformation amount of O-rings 18 due to tightening, the type of the stator blade spacers 14, or the like. When the gap 15 is positioned in a state of facing the circumferential surface of a rotor blade 16 in a radial direction, molecules of the process gas transferred in the direction of tangent and the downstream direction tend to move toward the gap 15 by the rotating rotor blade 16 (the number of gas molecules increases). The gas entering the gap 15 is cooled by the cooling-side stator 17A, and solidified in the gap 15, and moreover deposited as a by-product. This deposit narrows the width of the gap 15, reduces the thermal insulating effect, and changes the temperature distribution in the pump. As such, it is necessary to periodically perform maintenance work such as disassembling the vacuum pump 10 to remove deposit accumulating in the gap 15. This maintenance work causes the problem of poor productivity.

[0010] In view of the foregoing, it is an object of the present invention to solve technical problems that need to be solved and provide a vacuum pump that improves productivity by reducing the flow of gas (the number of gas molecules) flowing to a gap provided for thermal insulation, and reducing the amount of by-products accumulating in the gap, and moreover extending intervals at which maintenance work is required.

[0011] The present invention has been proposed to achieve the above object. The invention according to claim 1 provides a vacuum pump including: a casing having an inlet port and an outlet port; a rotor shaft rotationally supported inside the casing; rotor blades in multiple stages, the rotor blades being rotatable together with the rotor shaft; stator blades in multiple stages, the stator blades being fixed to the casing and located respectively between the rotor blades in multiple stages; and a cooling-side stator and a heating-side stator that hold the stator blades in multiple stages at predetermined intervals, wherein an opening of a gap of a predetermined width configured to provide thermal insulation between the cooling-side stator and the heating-side stator is located at a position where the opening does not face outer circumference surfaces of the rotor blades in an axial direction of the rotor shaft.

[0012] According to this configuration, the opening of the gap of a predetermined width configured to provide thermal insulation between the cooling-side stator and the heating-side stator is located at a position in the axial direction of the rotor shaft where the opening does not face outer circumference surfaces of the rotor blades. As such, even if part of gas is blown toward the inner circumference surfaces of the stators by the centrifugal force created by the rotation of the rotor blades, the amount of process gas entering the opening of the gap is significantly small because the opening of the gap is at an offset position where the opening

does not face the outer circumference surfaces of the rotor blades. As a result, the amount of deposit accumulating in the gap is reduced. As a result, the intervals at which maintenance work is required can be extended, thereby improving productivity.

[0013] The invention according to claim 2 provides the vacuum pump according to claim 1, wherein a shape of the gap includes a first gap section extending horizontally outward in a radial direction perpendicular to the axial direction and a second gap section extending further outward in the radial direction from an outer end of the first gap section and toward a downstream side in the axial direction.

[0014] According to this configuration, the process gas entering the first gap section through the opening collides with the wall of the next second gap section once when moving further inward. As such, the wall provides resistance to the flow of process gas moving into the gap. This reduces the amount of the process gas entering the gap through the opening, further reducing the amount of deposit produced from the process gas.

[0015] The invention according to claim 3 provides the vacuum pump according to claim 1 or 2, wherein the shape of the gap includes a third gap section extending toward a downstream side in the axial direction.

[0016] In this configuration, any process gas entering the gap through the opening directly faces and collides with the wall of the third gap section, which extends downward, immediately after entering through the opening. The wall therefore provides resistance to the flow of process gas moving into the gap. This reduces the amount of the process gas entering the gap through the opening, further reducing the amount of deposit produced from the process gas.

[0017] The invention according to claim 4 provides the vacuum pump according to any one of claims 1 to 3, wherein the shape of the gap includes a fourth gap section extending outward in a radial direction perpendicular to the axial direction and toward an upstream side in the axial direction.

[0018] According to this configuration, the shape of a vertical cross-section of the gap includes the fourth gap section extending outward in the radial direction perpendicular to the axial direction and toward the upstream side in the axial direction. Thus, the process gas entering the gap through the opening collides with the fourth gap section once. This provides the resistance to the flow of process gas moving into the gap. Thus, the amount of the process gas entering the gap through the opening is reduced, further reducing the amount of deposit produced from the process gas.

[0019] The invention according to claim 5 provides the vacuum pump according to any one of claims 1 to 4, wherein the shape of the gap includes an overhang portion that is located above the opening and protrudes further inward of the casing than the opening.

[0020] In this configuration, as viewed in a vertical cross-section of the casing in the axial direction, the shape of a vertical cross-section of the gap includes the overhang portion that is located above the opening of the gap formed in the inner circumference surface of the casing and protrudes further inward of the casing than the opening. The overhang portion regulates the flow of process gas from the upstream side such that the process gas moves to the downstream side away from the opening of the gap instead of moving toward the opening. This reduces the amount of the process gas entering the gap through the opening, further reducing the amount of deposit produced from by the process gas.

[0021] This invention reduces the amount of the process gas entering the gap provided for thermal insulation and thus reduces the amount of deposit produced from the process gas and accumulating in the gap. As a result, the intervals at which maintenance work for removing deposit in the gap is required can be extended, thereby improving productivity.

Furthermore, the thermal insulation effect of the gap is also improved, and it is also possible to finely control the temperature within the range that does not adversely affect the performance of the electrical components and the electric motor for rotating the rotor in the vacuum pump, or lower the strength of the rotor or the stator.

Moreover, normal operation of the vacuum pump can be performed while controlling the solidification of the process gas.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] FIG. 1 is a vertical cross-sectional view of a turbomolecular pump as an example of a vacuum pump according to an embodiment of the present invention;

FIG. 2 is a diagram showing an example of an amplifier circuit in the turbomolecular pump;

FIG. 3 is a time chart showing an example of control performed when a current command value detected by the amplifier circuit in the turbomolecular pump is greater than a detected value;

FIG. 4 is a time chart showing an example of control performed when a current command value detected by the amplifier circuit in the turbomolecular pump is less than a detected value;

FIG. 5A is a partially enlarged cross-sectional view of Section A of the turbomolecular pump in FIG. 1, and FIG. 5B is a further enlarged cross-sectional view of a section illustrating the shape of a gap;

FIG. 6A is a partially enlarged view of a section corresponding to Section A in FIG. 1 of a modification of the present invention, and FIG. 6B is a further enlarged cross-sectional view of a section in FIG. 6A illustrating the shape of a gap;

FIG. 7A is a partially enlarged view of a section corresponding to Section A in FIG. 1 of another modification of the present invention, and FIG. 7B is a further enlarged cross-sectional view of a section in FIG. 7A illustrating the shape of a gap;

FIG. 8A is a partially enlarged view of a section corresponding to Section A in FIG. 1 of yet another modification of the present invention, and FIG. 8B is a further enlarged cross-sectional view of a section of FIG. 8A illustrating the shape of a gap;

FIG. 9 is a vertical cross-sectional view of a turbomolecular pump as an example of a conventional vacuum pump; and

FIG. 10 is a partially enlarged view corresponding to Section B in FIG. 9.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0023] To achieve the object of providing a vacuum pump that improves productivity by reducing the flow of gas (the number of gas molecules) flowing to a gap formed for thermal insulation, reducing the amount of by-products accumulating in the gap, and extending the intervals at which maintenance work is required, the present invention is directed to a vacuum pump including: a casing having an inlet port and an outlet port; a rotor shaft rotationally supported inside the casing; rotor blades in multiple stages that are rotatable together with the rotor shaft; stator blades in multiple stages that are fixed to the casing and located between the rotor blades in multiple stages; and a heating-side stator and a cooling-side stator that hold the stator blades in multiple stages at predetermined intervals, wherein an opening of a gap of a predetermined width configured to provide thermal insulation between the heating-side stator and the cooling-side stator is located at a position in an axial direction of the rotor shaft where the opening does not face outer circumference surfaces of the rotor blades.

Examples

[0024] Referring to the accompanying drawings, examples according to embodiments of the present invention are described in detail. In the following examples, when reference is made to the number, numerical value, amount, range, or the like of components, it is not

limited to the specific number, and may be greater than or less than the specific number, unless specified otherwise or clearly limited to the specific number in principle.

[0025] Also, when reference is made to the shape and positional relationship of components and the like, those that are substantially analogous or similar to the shape and the like are included unless specified otherwise or the content clearly dictates otherwise in principle.

[0026] In the drawings, characteristic parts may be enlarged or otherwise exaggerated to improve understanding of the characteristics, and components are not necessarily drawn to scale. In cross-sectional views, hatch patterns of some components may be omitted to improve understanding of the cross-sectional structure of the components.

[0027] In the following description, the expressions indicating directions, such as up, down, left, and right, are not absolute and are appropriate when the portions of the turbomolecular pump of the present invention are in the orientation shown in the drawing, and should be interpreted with a change according to any change in the orientation. Additionally, the same elements are designated by the same reference numerals throughout the description of the examples.

[0028] FIG. 1 is a vertical cross-sectional view showing an example of a turbomolecular pump 100 as a vacuum pump according to the present invention.

[0029] As shown in FIG. 1, the turbomolecular pump 100 has a circular outer cylinder 127 as a housing having an inlet port 101 at its upper end. A rotating body 103 in the outer cylinder 127 includes a plurality of rotor blades 102 (102a, 102b, 102c, …), which are turbine blades for gas suction and exhaustion, in its outer circumference section. The rotor blades 102 extend radially in multiple stages. The rotating body 103 has a rotor shaft 113 in its center. The rotor shaft 113 is suspended in the air and position-controlled by a magnetic bearing of 5-axis control, for example.

[0030] Upper radial electromagnets 104 include four electromagnets arranged in pairs on an X-axis and a Y-axis. Four upper radial sensors 107 are provided in close proximity to the upper radial electromagnets 104 and associated with the respective upper radial electromagnets 104. Each upper radial sensor 107 may be an inductance sensor or an eddy current sensor having a conduction winding, for example, and detects the position of the rotor shaft 113 based on a change in the inductance of the conduction winding, which changes according to the position of the rotor shaft 113. The upper radial sensors 107 are configured to detect a radial displacement of the rotor shaft 113, that is, the rotating body 103 fixed to the rotor shaft 113, and send it to the controller (not illustrated).

[0031] In the controller, for example, a compensation circuit having a PID adjustment function generates an excitation control command signal for the upper radial electromagnets 104 based on a position signal detected by the upper radial sensors 107. Based on this excitation control command signal, an amplifier circuit 150 (described below) shown in FIG. 2 controls and excites the upper radial electromagnets 104 to adjust a radial position of an upper part of the rotor shaft 113.

[0032] The rotor shaft 113 may be made of a high magnetic permeability material (such as iron and stainless steel) and is configured to be attracted by magnetic forces of the upper radial electromagnets 104. The adjustment is performed independently in the X-axis direction and the Y-axis direction. Lower radial electromagnets 105 and lower radial sensors 108 are arranged in a similar manner as the upper radial electromagnets 104 and the upper radial sensors 107 to adjust the radial position of the lower part of the rotor shaft 113 in a similar manner as the radial position of the upper part.

[0033] Additionally, axial electromagnets 106A and 106B are arranged so as to vertically sandwich a metal disc 111, which has a shape of a circular disc and is provided in the lower part of the rotor shaft 113. The metal disc 111 is made of a high magnetic permeability material such as iron. An axial sensor 109 is provided to detect an axial displacement of the rotor shaft 113 and send an axial position signal to the controller.

[0034] In the controller, the compensation circuit having the PID adjustment function may generate an excitation control command signal for each of the axial electromagnets 106A and 106B based on the signal on the axial position detected by the axial sensor 109. Based on these excitation control command signals, the amplifier circuit 150 controls and excites the axial electromagnets 106A and 106B separately so that the axial electromagnet 106A magnetically attracts the metal disc 111 upward and the axial electromagnet 106B attracts the metal disc 111 downward. The axial position of the rotor shaft 113 is thus adjusted.

[0035] As described above, the controller appropriately adjusts the magnetic forces exerted by the axial electromagnets 106A and 106B on the metal disc 111, magnetically levitates the rotor shaft 113 in the axial direction, and suspends the rotor shaft 113 in the air in a non-contact manner. The amplifier circuit 150, which controls and excites the upper radial electromagnets 104, the lower radial electromagnets 105, and the axial electromagnets 106A and 106B, is described below.

[0036] The motor 121 includes a plurality of magnetic poles circumferentially arranged to surround the rotor shaft 113. Each magnetic pole is controlled by the controller so as to drive and rotate the rotor shaft 113 via an electromagnetic force acting between the magnetic

pole and the rotor shaft 113. The motor 121 also includes a rotational speed sensor (not shown), such as a Hall element, a resolver, or an encoder, and the rotational speed of the rotor shaft 113 is detected based on a detection signal of the rotational speed sensor.

[0037] Furthermore, a phase sensor (not shown) is attached adjacent to the lower radial sensors 108 to detect the phase of rotation of the rotor shaft 113. The controller detects the position of the magnetic poles using both detection signals of the phase sensor and the rotational speed sensor.

[0038] A plurality of stator blades 123 (123a, 123b, 123c, ...) are arranged slightly spaced apart from the rotor blades 102 (102a, 102b, 102c, ...). Each rotor blade 102 is inclined by a predetermined angle from a plane perpendicular to the axis of the rotor shaft 113 in order to transfer exhaust gas molecules downward through collision.

[0039] The stator blades 123 are also inclined by a predetermined angle from a plane perpendicular to the axis of the rotor shaft 113. The stator blades 123 extend inward of the outer cylinder 127 and alternate with the stages of the rotor blades 102. The outer circumference ends of the stator blades 123 are inserted between and thus supported by a plurality of layered stator blade spacers 125 (125a, 125b, 125c, ...).

[0040] The stator blade spacers 125 are ring-shaped members made of a metal, such as aluminum, iron, stainless steel, or copper, or an alloy containing these metals as components, for example. The outer cylinder 127 is fixed to the outer circumferences of the stator blade spacers 125 with a slight gap. A base portion 129 is located at the base of the outer cylinder 127. The base portion 129 has an outlet port 133 providing communication to the outside. The exhaust gas transferred to the base portion 129 through the inlet port 101 from the chamber is then sent to the outlet port 133.

[0041] According to the application of the turbomolecular pump, a threaded spacer 131 may be provided between the lower part of the stator blade spacer 125 and the base portion 129. The threaded spacer 131 is a cylindrical member made of a metal such as aluminum, copper, stainless steel, or iron, or an alloy containing these metals as components. The threaded spacer 131 has a plurality of helical thread grooves 131a in its inner circumference surface. When exhaust gas molecules move in the rotation direction of the rotating body 103, these molecules are transferred toward the outlet port 133 in the direction of the helix of the thread grooves 131a. In the lowermost section of the rotating body 103 below the rotor blades 102 (102a, 102b, 102c, ...), a cylindrical portion 102E extends downward. The outer circumference surface of the cylindrical portion 102E is cylindrical and projects toward the inner circumference surface of the threaded spacer 131. The outer circumference surface is

adjacent to but separated from the inner circumference surface of the threaded spacer 131 by a predetermined gap. The exhaust gas transferred to the thread grooves 131a by the rotor blades 102 and the stator blades 123 is guided by the thread grooves 131a to the base portion 129.

[0042] The base portion 129 is a disc-shaped member forming the base section of the turbomolecular pump 100, and is generally made of a metal such as iron, aluminum, or stainless steel. The base portion 129 physically holds the turbomolecular pump 100 and also serves as a heat conduction path. As such, the base portion 129 is preferably made of rigid metal with high thermal conductivity, such as iron, aluminum, or copper.

[0043] In this configuration, when the motor 121 drives and rotates the rotor blades 102 together with the rotor shaft 113, the interaction between the rotor blades 102 and the stator blades 123 causes the suction of exhaust gas from the chamber through the inlet port 101. The exhaust gas taken through the inlet port 101 moves between the rotor blades 102 and the stator blades 123 and is transferred to the base portion 129. At this time, factors such as the friction heat generated when the exhaust gas comes into contact with the rotor blades 102 and the conduction of heat generated by the motor 121 increase the temperature of the rotor blades 102. This heat is conducted to the stator blades 123 through radiation or conduction via gas molecules of the exhaust gas, for example.

[0044] The stator blade spacers 125 are joined to each other at the outer circumference portion and conduct the heat received by the stator blades 123 from the rotor blades 102, the friction heat generated when the exhaust gas comes into contact with the stator blades 123, and the like to the outside.

[0045] In the above description, the threaded spacer 131 is provided at the outer circumference of the cylindrical portion 102E of the rotating body 103, and the thread grooves 131a are engraved in the inner circumference surface of the threaded spacer 131. However, this may be inversed in some cases, and a thread groove may be engraved in the outer circumference surface of the cylindrical portion 102E, while a spacer having a cylindrical inner circumference surface may be arranged around the outer circumference surface.

[0046] According to the application of the turbomolecular pump 100, to prevent the gas drawn through the inlet port 101 from entering an electrical portion, which includes the upper radial electromagnets 104, the upper radial sensors 107, the motor 121, the lower radial electromagnets 105, the lower radial sensors 108, the axial electromagnets 106A, 106B, and

the axial sensor 109, the electrical portion may be surrounded by a stator column 122. The inside of the stator column 122 may be maintained at a predetermined pressure by purge gas.

[0047] In this case, the base portion 129 has a pipe (not shown) through which the purge gas is introduced. The introduced purge gas is sent to the outlet port 133 through gaps between a protective bearing 120 and the rotor shaft 113, between the rotor and the stator of the motor 121, and between the stator column 122 and the inner circumference cylindrical portion of the rotor blade 102.

[0048] The turbomolecular pump 100 requires the identification of the model and control based on individually adjusted unique parameters (for example, various characteristics associated with the model). To store these control parameters, the turbomolecular pump 100 includes an electronic circuit portion 141 in its main body. The electronic circuit portion 141 may include a semiconductor memory, such as an EEPROM, electronic components such as semiconductor elements for accessing the semiconductor memory, and a substrate 143 for mounting these components. The electronic circuit portion 141 is housed under a rotational speed sensor (not shown) near the center, for example, of the base portion 129, which forms the lower part of the turbomolecular pump 100, and is closed by an airtight bottom lid 145.

[0049] Some process gas introduced into the chamber in the manufacturing process of semiconductors has the property of becoming solid when its pressure becomes higher than a predetermined value or its temperature becomes lower than a predetermined value. In the turbomolecular pump 100, the pressure of the exhaust gas is lowest at the inlet port 101 and highest at the outlet port 133. When the pressure of the process gas increases beyond a predetermined value or its temperature decreases below a predetermined value while the process gas is being transferred from the inlet port 101 to the outlet port 133, the process gas is solidified and adheres and accumulates on the inner side of the turbomolecular pump 100A.

[0050] For example, when $SiCl_4$ is used as the process gas in an Al etching apparatus, according to the vapor pressure curve, a solid product (for example, $AlCl_3$) is deposited at a low vacuum (760 [torr] to 10-2 [torr]) and a low temperature (about 20 [°C]) and adheres and accumulates on the inner side of the turbomolecular pump 100. When the deposit of the process gas accumulates in the turbomolecular pump 100A, the accumulation may narrow the pump flow passage and degrade the performance of the turbomolecular pump 100. The above-mentioned product tends to solidify and adhere in areas with higher pressures, such as the vicinity of the outlet port and the vicinity of the threaded spacer 131.

[0051] To solve this problem, conventionally, a heater or annular water-cooled tube 149 (not shown) is wound around the outer circumference of the base portion 129, and a

temperature sensor (e.g., a thermistor, not shown) is embedded in the base portion 129, for example. The signal of this temperature sensor is used to perform control to maintain the temperature of the base portion 129 at a constant high temperature (preset temperature) by heating with the heater or cooling with the water-cooled tube 149 (hereinafter referred to as TMS (temperature management system)).

[0052] The amplifier circuit 150 is now described that controls and excites the upper radial electromagnets 104, the lower radial electromagnets 105, and the axial electromagnets 106A and 106B of the turbomolecular pump 100 configured as described above. FIG. 2 is a circuit diagram of the amplifier circuit 150.

[0053] In FIG. 2, one end of an electromagnet winding 151 forming an upper radial electromagnet 104 or the like is connected to a positive electrode 171a of a power supply 171 via a transistor 161, and the other end is connected to a negative electrode 171b of the power supply 171 via a current detection circuit 181 and a transistor 162. Each transistor 161, 162 is a power MOSFET and has a structure in which a diode is connected between the source and the drain thereof.

[0054] In the transistor 161, a cathode terminal 161a of its diode is connected to the positive electrode 171a, and an anode terminal 161b is connected to one end of the electromagnet winding 151. In the transistor 162, a cathode terminal 162a of its diode is connected to a current detection circuit 181, and an anode terminal 162b is connected to the negative electrode 171b.

[0055] A diode 165 for current regeneration has a cathode terminal 165a connected to one end of the electromagnet winding 151 and an anode terminal 165b connected to the negative electrode 171b. Similarly, a diode 166 for current regeneration has a cathode terminal 166a connected to the positive electrode 171a and an anode terminal 166b connected to the other end of the electromagnet winding 151 via the current detection circuit 181. The current detection circuit 181 may include a Hall current sensor or an electric resistance element, for example.

[0056] The amplifier circuit 150 configured as described above corresponds to one electromagnet. Accordingly, when the magnetic bearing uses 5-axis control and has ten electromagnets 104, 105, 106A, and 106B in total, an identical amplifier circuit 150 is configured for each of the electromagnets. These ten amplifier circuits 150 are connected to the power supply 171 in parallel.

[0057] An amplifier control circuit 191 may be formed by a digital signal processor portion (not shown, hereinafter referred to as a DSP portion) of the controller. The amplifier control circuit 191 switches the transistors 161 and 162 between on and off.

[0058] The amplifier control circuit 191 is configured to compare a current value detected by the current detection circuit 181 (a signal reflecting this current value is referred to as a current detection signal 191c) with a predetermined current command value. The result of this comparison is used to determine the magnitude of the pulse width (pulse width time Tp1, Tp2) generated in a control cycle Ts, which is one cycle in PWM control. As a result, gate drive signals 191a and 191b having this pulse width are output from the amplifier control circuit 191 to gate terminals of the transistors 161 and 162.

[0059] Under certain circumstances such as when the rotational speed of the rotating body 103 reaches a resonance point during acceleration, or when a disturbance occurs during a constant speed operation, the rotating body 103 may require positional control at high speed and with a strong force. For this purpose, a high voltage of about 50 V, for example, is used for the power supply 171 to enable a rapid increase (or decrease) in the current flowing through the electromagnet winding 151. Additionally, a capacitor is generally connected between the positive electrode 171a and the negative electrode 171b of the power supply 171 to stabilize the power supply 171 (not shown).

[0060] In this configuration, when both transistors 161 and 162 are turned on, the current flowing through the electromagnet winding 151 (hereinafter referred to as an electromagnet current iL) increases, and when both are turned off, the electromagnet current iL decreases.

[0061] Also, when one of the transistors 161 and 162 is turned on and the other is turned off, a freewheeling current is maintained. Passing the freewheeling current through the amplifier circuit 150 in this manner reduces the hysteresis loss in the amplifier circuit 150, thereby limiting the power consumption of the entire circuit to a low level. Moreover, by controlling the transistors 161 and 162 as described above, high frequency noise, such as harmonics, generated in the turbomolecular pump 100 can be reduced. Furthermore, by measuring this freewheeling current with the current detection circuit 181, the electromagnet current iL flowing through the electromagnet winding 151 can be detected.

[0062] That is, when the detected current value is smaller than the current command value, as shown in FIG. 3, the transistors 161 and 162 are simultaneously on only once in the control cycle Ts (for example, 100 μs) for the time corresponding to the pulse width time Tp1. During this time, the electromagnet current iL increases accordingly toward the current value

iLmax (not shown) that can be passed from the positive electrode 171a to the negative electrode 171b via the transistors 161 and 162.

[0063] When the detected current value is larger than the current command value, as shown in FIG. 4, the transistors 161 and 162 are simultaneously off only once in the control cycle Ts for the time corresponding to the pulse width time Tp2. During this time, the electromagnet current iL decreases accordingly toward the current value iLmin (not shown) that can be regenerated from the negative electrode 171b to the positive electrode 171a via the diodes 165 and 166.

[0064] In either case, after the pulse width time Tp1, Tp2 has elapsed, one of the transistors 161 and 162 is on. During this period, the freewheeling current is thus maintained in the amplifier circuit 150.

[0065] The outer cylinder 127 as a casing encloses an upper stage group gas transfer portion, which includes a cooling-side stator 110A (stator blades 123a to 123f) and cooling-side rotor blades 102A (rotor blades 102a to 102g) located in a cooling area that requires cooling, and a lower stage group gas transfer portion, which includes a heating-side stator 110B (stator blades 123h to 123j) and heating-side rotor blades 102B (rotor blades 102h to 102k) located in a heating area that requires heating. O-rings 112 are provided between the cooling-side stator 110A and the heating-side stator 110B, and the cooling-side stator 110A is separated from the heating-side stator 110B by a predetermined amount to form a gap 114. Accordingly, the cooling-side stator 110A and the heating-side stator 110B are independent of each other so that the temperature of the cooling-side stator 110A and the temperature of the heating-side stator 110B do not influence each other. The stator blade spacers 125 are held by bolts 115 to position the cooling-side stator 110A and the heating-side stator 110B. In FIG. 1, reference numeral 152 denotes a temperature sensor that detects the temperature of the cooling-side stator 110A, reference numeral 153 denotes a temperature sensor that detects the temperature of the heating-side stator 110B, reference numeral 154 denotes a heater for heating the heating-side stator 110B, and reference numeral 155 denotes a cooling pipe for cooling the cooling-side stator 110A.

[0066] A gap of a distance S is formed between the rotor blade 102g of the upper stage group gas transfer portion on the cooling side and the rotor blade 102h of the lower stage group gas transfer portion on the heating side. The rotor blades 102g and 102h are adjacent to an opening 114A of the gap 114 between the cooling-side stator 110A and the heating-side stator 110B. The positions of the rotor blades 102g and 102h are offset from the opening 114A in an axial direction, that is, in an up-down direction such that neither the outer

circumference surface of the cooling-side rotor blade 102g nor the outer circumference surface of the heating-side rotor blade 102h directly faces the opening 114A of the gap 114. The distance S is preferably long enough so that these outer circumference surfaces do not directly face the opening 114A of the gap 114 even if one or both of the cooling-side stator 110A and the heating-side stator 110B move in the axial direction when the cooling-side stator 110A and the heating-side stator 110B are held and positioned by the bolts 115.

Considering the movement of the process gas molecules caused by the rotor blades 102g and 102h, a preferable position of the opening 114A is substantially the center of the distance between the rotor blades 102g and 102h in the axial direction. However, the position of the opening 114A is not limited to the substantial center, and may be on the downstream side of the substantial central position, focusing more on the movement of process gas molecules caused by the rotor blade 102g, for example.

[0067] Also, the size of width (dimension in the axial direction) of the opening 114A of the gap 114 is set to a predetermined width that minimizes the entry of molecules, taking into account the average free path, which is the average value of the distances process gas molecules can travel without colliding with other molecules and changing course, the thermal insulating effect, and the like. For example, the size of the gap 114 and the opening 114A may be 0.1 mm to 2.0 mm, and more preferably 0.5 mm to 1.0 mm.

[0068] In the structure of this example, as shown in the enlarged views in FIGS. 5A and 5B of Section A in FIG. 1, the shape of a vertical cross-section of the gap 114 in a vertical cross-section of the outer cylinder 127 as the casing taken in the axial direction has a horizontal gap section 114a and an inclined gap section 114b, which are integral. The horizontal gap section 114a is a first gap section extending horizontally from the opening 114A outward in a radial direction perpendicular to the axial direction. The inclined gap section 114b is a second gap section extending obliquely further outward in the radial direction from the outer end of the horizontal gap section 114a and downward toward the downstream side in the axial direction. Accordingly, the gap 114 is configured to have a portion extending from the opening 114A in an inverted L shape. In the following description, the upstream side in the axial direction is the side where the inlet port 101 is located, and the downstream side in the axial direction is the side where the outlet port 133 is located. Also, the axial direction is a direction of the axis of the rotor shaft 113, and the radial direction is a direction perpendicular to the axis, that is, the radial direction of the outer cylinder 127.

[0069] In the vacuum pump 10 configured as in this example, the opening 114A of the gap 114, which has a predetermined width and provides thermal insulation between the

cooling-side stator 110A and the heating-side stator 110B, is positioned so as not to directly face the outer circumference surfaces of the rotor blades 102 (the rotor blades 102g and 102h), that is, offset from these circumference surfaces in the axial direction of the rotating body 103. As a result, even if part of the process gas is blown toward the inner circumference surfaces of the cooling-side stator 110A and the heating-side stator 110B of the cylindrical portion 102E by the centrifugal force created by the rotation of the rotor blades 102, the amount of process gas entering the opening 114A of the gap 114 is significantly small, thereby reducing the amount of deposit accumulating in the gap 114. This extends the intervals at which maintenance work for removing deposit in the gap 114 is required, thereby improving productivity.

[0070] In the example shown in FIGS. 1, 5A, and 5B, the shape of a vertical cross-section of the gap 114 in a cross-section of the outer cylinder 127 as the casing taken in the axial direction has the horizontal gap section 114a, which extends horizontally outward from the opening 114A, and the inclined gap section 114b, which extends obliquely further outward in the radial direction from the outer end of the horizontal gap section 114a and toward the downstream side in the axial direction. The horizontal gap section 114a and the inclined gap section 114b are formed integrally. Accordingly, the gap 114 is configured to have a portion extending in an inverted L shape.

[0071] In the structure shown in FIGS. 1, 5A, and 5B, the horizontal gap section 114a extends from the opening 114A, and the gap 114 is then bent to form the inclined gap section 114b extending obliquely downward and outward from the outer end of the horizontal gap section 114a. Thus, when process gas enters the horizontal gap section 114a through the opening 114A and then flows into the inclined gap section 114b, the inclined gap section 114b serves as a wall against which the process gas collides, providing the resistance to the flow of process gas further moving inward. This reduces the amount of the process gas entering the gap 114 through the opening 114A, further reducing the amount of deposit produced from by the process gas.

[0072] The structure of the gap 114 is not limited to the structures shown in FIGS. 1, 5A, and 5B, and may be the structures shown in FIGS. 6A and 6B to 8A and 8B, for example. Also, the inclined gap section 114b may extend obliquely further outward in the radial direction from the outer end of the horizontal gap section 114a and upward to the upstream side in the axial direction.

[0073] In the structure of a gap 114 shown in FIGS. 6A and 6B, the shape of a vertical cross-section of the gap 114 in a cross-section of the outer cylinder 127 as the casing taken in

the axial direction has a vertical gap section 114c and a horizontal gap section 114a, which are integrally formed. The vertical gap section 114c is a third gap section extending to the downstream side in the axial direction immediately after the opening 114A. The horizontal gap section 114a extends horizontally outward in the radial direction from the lower end of the vertical gap section 114c. Accordingly, the gap 114 is configured to have a portion extending from the opening 114A substantially in the shape of letter I.

[0074] In the structure shown in FIGS. 6A and 6B, the gap 114 is formed to have a substantially I-shaped cross-section. Accordingly, any process gas entering the gap 114 through the opening 114A directly faces the wall of the vertical gap section 114c, which extends to the downstream side in the axial direction, immediately after entering through the opening 114A. This wall provides the resistance to the flow of process gas moving inward. This reduces the amount of the process gas entering the gap 114 through the opening 114A and also further reduces the amount of deposit. The vertical gap section 114c is structured so as to extend to the downstream side in the axial direction immediately after the opening 114A. Conversely, the vertical gap section 114c may be structured so as to extend to the upstream side in the axial direction immediately after the opening 114A.

[0075] In the structure of a gap 114 shown in FIGS. 7A and 7B, the shape of a vertical cross-section of the gap 114 in a cross-section of the outer cylinder 127 as the casing taken in the axial direction has an inclined gap section 114d and an inclined gap section 114e, which are formed integrally. The inclined gap section 114d is a fourth gap section extending obliquely immediately from the opening 114A outward in a radial direction perpendicular to the axial direction and toward the upstream side in the axial direction. The inclined gap section 114e is a fifth gap section extending obliquely from the outer end of the inclined gap section 114d toward the downstream side in the axial direction. Accordingly, the gap 114 is configured to have a portion extending from the opening 114A substantially in an inverted V shape.

[0076] In the structure of FIGS. 7A and 7B, the inclined gap section 114d extends immediately from the opening 114A obliquely upward and outward. Thus, the process gas entering the inclined gap section 114d through the opening 114A collides with the wall of the inclined gap section 114d extending obliquely upward and outward. This wall provides resistance to the flow of process gas moving inward. This reduces the amount of the process gas entering the gap 114 through the opening 114A, further reducing the amount of deposit produced from the process gas.

[0077] In the configuration of FIGS. 7A and 7B, the inclined gap section 114d, which extends obliquely from the opening 114A outward in a radial direction perpendicular to the axial direction and toward the upstream side in the axial direction, and the inclined gap section 114e, which extends obliquely from the outer end of the inclined gap section 114d toward the downstream side of in the axial direction, are formed integrally, so that the gap 114 is configured to have a portion extending from the opening 114A substantially in an inverted V shape. However, a structure may be used that includes one of the inclined gap section 114d extending obliquely to the upstream side from the opening 114A or the inclined gap section 114e extending obliquely to the downstream side from the opening 114A.

[0078] In the structure of a gap 114 shown in FIGS. 8A and 8B, as viewed in a cross-section of the outer cylinder 127 as the casing taken in the axial direction, an overhang portion 116 is located above the opening 114A of the gap 114 formed in the inner circumference surface of the outer cylinder 127. The overhang portion 116 protrudes further inward of the outer cylinder 127 than the opening 114A. That is, the overhang portion 116 forms a step with the opening 114A, thereby regulating the flow of process gas such that the process gas flowing from the upstream side moves directly to the downstream side instead of moving toward the opening 114A. The gap 114 includes a vertical gap section 114c, which is the third gap section extending to the downstream side immediately from the opening 114A, and a horizontal gap section 114a, which extends horizontally outward in a radial direction perpendicular to the axial direction from the lower end of the vertical gap section 114c. The vertical gap section 114c and the horizontal gap section 114a are formed integrally. Accordingly, the gap 114 is configured to have a portion extending from the opening 114A substantially in the shape of letter I.

[0079] In the structure shown in FIGS. 8A and 8B, the gap 114 is formed to have a substantially I-shaped cross-section. Accordingly, any process gas entering the gap 114 through the opening 114A directly faces the wall of the vertical gap section 114c, which extends downward, immediately after entering through the opening 114A. Thus, the process gas collides with the wall, and the wall therefore provides resistance to the flow of process gas moving inward. This reduces the amount of the process gas entering the gap 114 through the opening 114A, further reducing the amount of deposit produced from the process gas. A lower surface edge section (lower surface of the overhang) 116a of the overhang portion 116 and a lower edge section 114g of the opening 114A are rounded. These portions are rounded so that part of the process gas colliding with the lower surface edge section 116a or the lower edge section 114g after colliding with and bouncing off a rotor blade 102 in the

outer cylinder 127 is directed away from the opening 114A and toward the rotor shaft 113. This limits entry of such process gas into the opening 114A.

[0080] The invention is amenable to various modifications without departing from the spirit of the invention. The invention is intended to cover all modifications.

REFERENCE SIGNS LIST

[0081]

100	Turbomolecular pump
101	Inlet port
102	Rotor blade
102A	Cooling-side rotor blade
102B	Cooling-side rotor blade
102E	Cylindrical portion
102a	Rotor blade
102b	Rotor blade
102c	Rotor blade
102d	Rotor blade
102e	Rotor blade
102f	Rotor blade
102g	Rotor blade
103	Rotating body
104	Upper radial electromagnet
105	Lower radial electromagnet
106A	Axial electromagnet
106B	Axial electromagnet
107	Upper radial sensor
108	Lower radial sensor
109	Axial sensor
110A	Cooling-side stator (upper stage group gas transfer portion)
110B	Heating-side stator (lower stage group gas transfer portion)
111	Metal disc
112	O-ring
113	Rotor shaft
114	Gap

114A	Opening
114a	Horizontal gap section (first gap section)
114b	Inclined gap section (second gap section)
114c	Vertical gap section (third gap section)
114d	Inclined gap section (fourth gap section)
114e	Inclined gap section (fifth gap section)
114g	Lower edge section
115	Bolt
116	Overhang portion
116a	Lower surface edge section
120	Protective bearing
121	Motor
122	Stator column
123	Stator blade
123a	Stator blade
123b	Stator blade
123c	Stator blade
123d	Stator blade
123e	Stator blade
123f	Stator blade
123g	Stator blade
123h	Stator blade
123i	Stator blade
125	Stator blade spacer
127	Outer cylinder
129	Base portion
131	Threaded spacer
131a	Thread groove
133	Outlet port
141	Electronic circuit portion
143	Substrate
145	Bottom lid
149	Water cooling tube
150	Amplifier circuit

151	Electromagnet winding
152	Temperature sensor
153	Temperature sensor
154	Electromagnet winding
155	Water cooling tube
161	Heater
161a	Cathode terminal
161b	Anode terminal
162	Transistor
162a	Cathode terminal
162b	Anode terminal
165	Diode
165a	Cathode terminal
165b	Anode terminal
166	Diode
166a	Cathode terminal
166b	Anode terminal
171	Power supply
171a	Positive electrode
171b	Negative electrode
181	Current detection circuit
191	Amplifier control circuit
191a	Gate drive signal
191b	Gate drive signal
191c	Current detection signal
S	Distance
Tp1	Pulse width time
Tp2	Pulse width time
Ts	Control cycle
iL	Electromagnet current
iLmax	Current value
iLmin	Current value