

DESCRIPTION

PRESSURE REDUCTION SYSTEM AND VACUUM TREATMENT DEVICE

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TECHNICAL FIELD

The present invention relates to a depressurization system including a plurality of depressurization devices, such as a cryopump or a cryotrap, and a compression device, which supplies compressed coolant to the plurality of depressurization devices, and a vacuum processing device using the same.

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BACKGROUND ART

In the prior art, as devices that form ultrahigh vacuum, depressurization devices that condense and collect gas on a cryogenic surface are known. For example, patent document 1 describes a cryopump and patent document 2 describes a cryotrap. A compression device that supplies compressed coolant to the depressurization device is essential for such type of depressurization device in which the cryogenic surface is formed by absorbing heat when the coolant expands. A depressurization device cooperates with such a compression device to obtain an ultrahigh vacuum.

A manufacturing apparatus that manufactures a display device such as a liquid crystal display, a semiconductor device such as a CPU or a memory, and the like uses a charge unit including the above-described depressurization device and compression device as a charge system for a vacuum chamber of the same. In the case of a cluster type manufacturing apparatus in which one

manufacturing apparatus is formed by a plurality of vacuum chambers, the number of depressurization devices is required to be the same as the number of vacuum chambers. To reduce the space occupied by the manufacturing apparatus, the
5 depressurization system is formed with the plurality of depressurization devices sharing a single compression device.

PRIOR ART DOCUMENTS

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Patent Document 1: Japanese Laid-Open Patent Publication No. 2002-70737

Patent Document 2: Japanese Laid-Open Patent Publication No. 2009-19500

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SUMMARY OF THE INVENTION

Nowadays, from the standpoint of conserving the global environment, it is strongly desired that the manufacturing
20 apparatus described above consume less power. In the depressurization system in which the discharge capability of the plurality of depressurization devices is obtained from the single compression device, the space occupied by the manufacturing apparatus is reduced. However, each of the
25 plurality of depressurization devices is supplied with the same amount of coolant compressed by the compression device. In the cluster type manufacturing apparatus including a plurality of vacuum chambers that operate in different states, each of the plurality of depressurization devices
30 normally requires a different discharge capability. Thus, when each depressurization device is supplied with the same amount of coolant, unnecessary coolant may be supplied to a depressurization device. Thus, in a depressurization system

in which the discharge capability of the plurality of depressurization devices is obtained with a single compression device, unnecessary coolant is sent under pressure from the compression device. Such a mechanism
5 significantly inhibits reduction in power consumption of the compression device. This further inhibits reduction in energy consumption of the depressurization system.

Accordingly, it is an object of the present invention to
10 provide a depressurization system and a vacuum processing device, in which the discharge capability of a plurality of depressurization devices is obtained with a single compression device, so that the depressurization system and vacuum processing device can reduce power consumption.

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MEANS FOR SOLVING THE PROBLEM

One aspect of the present invention is a depressurization system. The depressurization system
20 includes a plurality of depressurization devices, each of which includes a cooling unit that receives a compressed coolant and is capable of supplementing gas when adiabatically expanding the compressed coolant. A compression device includes a compression unit provided with
25 an AC electric motor. The compression device supplies the compressed coolant to the cooling unit of each of the plurality of depressurization devices from the compression unit at a flow rate corresponding to a rotation speed of the AC electric motor. A temperature detection unit detects a
30 temperature of the cooling unit of each depressurization device. An inverter device is capable of changing frequency of AC power supplied to the AC electric motor. A frequency controller controls an output frequency of the inverter

device. The frequency controller relatively raises the output frequency of the inverter device when the temperature of the cooling unit of at least one of the plurality of depressurization devices is greater than or equal to a first threshold value, and relatively lowers the output frequency of the inverter device when the temperature of the cooling unit of all of the plurality of depressurization devices decreases to less than the first threshold value.

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BRIEF DESCRIPTIC

DRAWINGS

Fig. 1 is a schematic diagram showing a manufacturing apparatus for a semiconductor device serving as a vacuum processing device according to the present invention;

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Fig. 2(a) is a schematic diagram showing the structure of a vacuum discharge unit in the vacuum processing device of Fig. 1, and Fig. 2(b) is a schematic diagram showing the structure of a high vacuum discharge unit in the vacuum processing device of Fig. 1;

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Fig. 3 is a pipe diagram showing the flow of coolant in a depressurization system of a first processing section shown in Fig. 1;

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Fig. 4 is a schematic block diagram showing the electrical structure related to a compression device in the depressurization system of the first processing section shown in Fig. 1;

Fig. 5 is a flowchart showing the control of the output frequency of an inverter device performed by a frequency controller of Fig. 4; and

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Fig. 6 is a timing chart showing temperature changes of a cooling unit in each chamber of the first processing section shown in Fig. 1 and an output frequency of the inverter device.

EMBODIMENTS OF THE INVENTION

One embodiment of a depressurization system according to the present invention and a vacuum processing device using the same will now be described with reference to Figs. 1 to 6. Fig. 1 is a schematic diagram showing a manufacturing apparatus 10 for a semiconductor device serving as a vacuum processing device, Fig. 2(a) is a schematic diagram showing the structure of a vacuum discharge unit, and Fig. 2(b) is a schematic diagram showing the structure of a high vacuum discharge unit.

As shown in Fig. 1, the manufacturing apparatus 10 for a semiconductor device forms a film made from a predetermined metal on a substrate W. The manufacturing apparatus 10 includes a first processing section 11, which includes a plurality of chambers for performing, for example, a sputtering process, and a second processing section 12, which includes a plurality of chambers for performing, for example, heat processing on the substrate W, and a buffer chamber 13, which connects the first and second processing sections 11 and 12.

The first processing section 11 includes a transportation chamber 15 having a polygonal cross-section. Two load lock chambers 16a and 16b, four chambers 17, 18, 19, and 20, and one buffer chamber 13 are each connected by a gate valve 21 to the transportation chamber 15. Each chamber is in communication with the transportation chamber 15 when the corresponding gate valve 21 opens and is disconnected from the transportation chamber 15 when the corresponding gate valve 21 closes. The substrate W is

transferred into the manufacturing apparatus 10 through the load lock chamber 16a, and the substrate W is transferred out of the manufacturing apparatus 10 through the load lock chamber 16b. The four chambers 17, 18, 19, and 20 perform various types of processes on the substrate W under a vacuum atmosphere. For example, the chambers 17 and 20 form a metal film of aluminum on the substrate W by performing sputtering, and the chambers 18 and 19 form a metal film of aluminum on the substrate W by performing long-slow sputtering. A transportation robot 22 for transporting the substrate W is arranged in the transportation chamber 15. The transportation robot 22 transports the substrate W from the transportation chamber 15 to the load lock chambers 16a, 16b, the chambers 17, 18, 19, and 20, and the buffer chamber 13 (and in the reverse direction).

In the same manner as the first processing section 11, the second processing section 12 includes a transportation chamber 25 having a polygonal cross-section. The buffer chamber 13 is connected to the transportation chamber 25 in a state of communication. Chambers 26, 27, 28, 29, 30, and 31 are each connected by a gate valve 21 to the transportation chamber 25. Each chamber is in communication with the transportation chamber 15 when the corresponding gate valve 21 opens and is disconnected from the transportation chamber 15 when the corresponding gate valve 21 closes. In the chamber 26 of the second processing section 12, a cooling process is performed on the substrate W, the temperature of which has become high after undergoing various processes. Each of the three chambers 27, 30, and 31 is a chamber that executes various types of processes on the substrate W under a vacuum atmosphere. For example, each chamber executes a film forming process that deposits

sputtering grains on the substrate W while applying a bias voltage to the substrate W to form a metal film or a metal nitride film. Each of the chambers 28 and 29 also executes various types of processes on the substrate W under a vacuum atmosphere. For example, the chamber 28 executes heat processing on the substrate W under a reducing gas atmosphere of hydrogen gas or the like, and the chamber 29 executes a degassing process to remove gas particles from the surface of the substrate W. A transportation robot 32 is also arranged in the transportation chamber 25 to transport the substrate W. The transportation robot 32 transports the substrate W from the transportation chamber 25 to the buffer chamber 13 and the chambers 26, 27, 28, 29, 30, and 31 (and in the reverse direction).

The manufacturing apparatus 10 of the semiconductor device described above is a so-called cluster type device in which a plurality of chambers is mounted to each of the transportation chamber 15 and the transportation chamber 25, which are coupled with the buffer chamber 13 arranged in between. The substrate W moves between the transportation chamber 15 and the transportation chamber 25, each of which are vacuum chambers, through the buffer chamber 13. The substrate W transferred into the load lock chamber 16a is sequentially transported to the chambers, which are vacuum chambers, by the transporting operation of the transportation robots 22 and 32, and undergo various types of processes under the vacuum atmosphere in the chamber to which the substrate W is transported.

Each process such as the sputtering process performed on the substrate W is performed in a chamber under a vacuum atmosphere. Thus, each chamber is connected to a vacuum

discharge unit 34, which forms a vacuum state in the chamber, or a high vacuum discharge unit 35, which forms a high vacuum state having a higher degree of vacuum than the vacuum state in the chamber. More specifically, among the
5 chambers of the manufacturing apparatus 10, the vacuum discharge unit 34 is coupled to chambers that do not require a high degree of vacuum, and the high vacuum discharge unit 35 is coupled to chambers that require a high degree of vacuum. As shown in Fig. 1, for example, the vacuum
10 discharge unit 34 is coupled to the load lock chambers 16a and 16b of the first processing section 11, and the chambers 26, 28, 29 of the second processing section 12. The high vacuum discharge unit 35 is coupled to the transportation chamber 15, the chambers 17, 18, 19, and 20 of the first
15 processing section 11, the transportation chamber 25, and the chambers 27, 30, and 31 of the second processing section 12.

As shown in Fig. 2(a), the vacuum discharge unit 34
20 includes a roughing pump 36, which roughly discharges air from a chamber, a turbo-molecular pump 37, which forms a vacuum state by further discharging air from the chamber that has undergone rough air discharging, a roughing pump 38, which roughly discharges air from a back pressure side
25 of the turbo-molecular pump 37 to guarantee the discharge capability of the turbo-molecular pump 37, and a plurality of valves 39, which open and close the passages between such elements and the chamber. When forming a vacuum state in a chamber, the roughing pump 36 and the roughing pump 38 are
30 first driven so that air is roughly drawn out from the chamber and the back pressure side of the turbo-molecular pump 37. The valve 39 between the roughing pump 36 and the chamber is then closed and the valve 39 between the turbo-

molecular pump 37 and the chamber is opened to draw out air from the chamber with the turbo-molecular pump 37.

As shown in Fig. 2(b), the high vacuum discharge unit 35 includes a cryotrap 40, which serves as a depressurization device forming a depressurization system at the intake side of the turbo-molecular pump 37 in addition to the structure of the high vacuum unit 34 described above to form a high vacuum state in the connected chamber. The cryotrap 40 includes a cooling unit 41 (see Fig. 3), which is formed by a cooling machine and a cooling panel cooled by the cooling machine. The cooling unit 41 supplies compressed helium gas (coolant) to the cooling machine and is connected to a compression device 42 (see Fig. 3) forming the depressurization system.

The cryotrap 40 is a device for condensing and collecting gas such as water vapor, which remains in a chamber without being discharged by the roughing pump 36 and the turbo-molecular pump 37 of the high vacuum discharge unit 35, on the cryogenic surface of the cooling panel. The high pressure helium gas compressed by the compression device 42 is supplied to the cooling machine of the cooling unit 41, and the cooling panel is cooled to 123 K by the absorption of heat when the high pressure helium gas adiabatically expands. This obtains a cryogenic surface on the cooling panel. The cooling panel includes a temperature sensor 50 (see Fig. 4) serving as a temperature detection unit for detecting the temperature of the cooling panel. Hereafter, the temperature of the cooling unit 41 refers to the temperature of the cooling panel.

The depressurization system applied to the manufacturing

apparatus 10 for a semiconductor device will now be described with reference to Figs. 3 to 6. The manufacturing apparatus 10 for a semiconductor device includes a depressurization system corresponding to the high vacuum discharge unit 35 of the first processing section 11, and a depressurization system corresponding to the high vacuum discharge unit 35 of the second processing section 12. The basic structure of the depressurization systems is the same other than that the number of cooling units 41 is different, and thus the depressurization system in the first processing section 11 will be described. The description on the depressurization system in the second processing section 12 will be omitted. Fig. 3 is a system diagram of the piping showing the flow of the coolant in the depressurization system of the first processing section 11, and Fig. 4 is a block diagram showing an electrical schematic structure related to the compression device 42 configuring the depressurization system of the first processing section 11.

As shown in Fig. 3, the compression device 42 forming the depressurization system includes a compression unit 44, which receives drive force from an AC electric motor 43 to compress helium gas serving as the coolant. The helium gas compressed by the compression unit 44 to a high pressure is temporarily accumulated in the accumulator 45 and then supplied to the cooling machine of each cooling unit 41. Thus, the single compression device 42 supplies the compressed high pressure helium gas to each cooling unit 41 of the five high vacuum discharge units 35 in the first processing section 11. The high pressure helium gas supplied to each cooling unit 41 is adiabatically expanded in the cooling machine of each cooling unit 41 to a low pressure, temporarily accumulated in a low pressure gas accumulating

unit 46, and then returned again to the compression unit 44 of the compression device 42.

As shown in Fig. 4, the compression device 42 includes a frequency controller 51, an inverter device 52, and the AC electric motor 43. The temperature sensor 50 arranged in each cooling unit 41 of the first processing section 11 is electrically connected to the frequency controller 51 and outputs a detection signal, which indicates the present temperature of the cooling unit 41, to the frequency controller 51. The frequency controller 51 generates or stores in advance various types of reference voltages such as a voltage level corresponding to a target value for temperature of cooling unit 41, a voltage level corresponding to a first threshold value for the temperature of cooling unit 41, and a voltage level corresponding to a second threshold value, which is a temperature higher than the first threshold value. Then, the frequency controller 51 compares a voltage level corresponding to the detection result of each temperature sensor 50 and the reference voltages.

The target value for the temperature of the cooling unit 41 is the temperature of the cooling unit 41 when the cooling panel can sufficiently obtain the cooling capability in a stable manner, and is set to, for example, 123 K. The first threshold value is the temperature at which further efficient cooling is required at the cooling panel, i.e., the cooling target, and is set to, for example, 128 K. The second threshold value is the temperature at which the temperature of the cooling panel, i.e., the cooling target is forcibly and rapidly cooled, and is set to, for example, 138 K.

The frequency controller 51 acquires the detection signal from each temperature sensor 50 in a predetermined detection cycle (five minutes in the present embodiment) immediately after the compression device 42 starts to operate. Then, the frequency controller 51 outputs to the inverter device 52 a control command value having the frequency of the AC power supplied from the inverter device 52 to the AC electric motor 43. The predetermined detection cycle is a time that is sufficient for each cooling unit 41 to be influenced by changes in the output frequency of the inverter device 52.

The inverter device 52 temporarily converts the AC power supplied from an external power supply 53 (AC 200V, 50 Hz in the present embodiment) to direct current and then converts the direct current back to alternating current to change the frequency of the AC power supplied to the AC electric motor 43. The inverter device 52 is capable of changing the frequency of the AC power from the external power supply 53 between 30 Hz, which is the lower limit value, and 50 Hz, which is the upper limit value. Further, the inverter device 52 receives a control command value from the frequency controller 51 and supplies the AC electric motor 43 with AC power having a frequency that is based on the control command value. The upper limit value of the output frequency of the inverter device 52 is the frequency at which the temperature of each cooling unit 41 is forcibly cooled to the target value of 123 K or lower.

The AC electric motor 43 receives AC power from the inverter device 52 and produces rotation at a rotation speed corresponding to the frequency of the AC power and supplies

each cooling unit 41 with helium gas at an amount corresponding to the rotation speed. More specifically, when the frequency of the AC power supplied from the inverter device 52 becomes high, the rotation speed of the AC electric motor 43 becomes high, and the amount of the helium gas supplied to each cooling unit 41 increases. When the supply amount of the helium gas increases in such a manner, the cooling capability is improved in all of the cooling units 41, which are connected to one another via the accumulator 45. In contrast, when the frequency of the AC power supplied from the inverter device 52 becomes low, the rotation speed of the AC electric motor 43 becomes low, and the amount of the helium gas supplied to each cooling unit 41 decreases. When the supply amount of the helium gas is decreased in such a manner, the cooling capability decreases in all of the cooling units 41, which are connected to one another via the accumulator 45. In this manner, in the depressurization system described above, the frequency of the AC power supplied from the inverter device 52 to the AC electric motor 43 is controlled by the frequency controller 51, and the temperature of each cooling unit 41 is controlled in accordance with the frequency of the AC power.

The control of the output frequency of the inverter device 52 executed by the frequency controller 51 will now be described with reference to Fig. 5. Fig. 5 is a flowchart showing control of the output frequency of the inverter device 52 executed by the frequency controller 51. The series of processes are executed in predetermined detection cycles, that is, whenever the frequency controller 51 acquires the temperature of the cooling unit 41, and are implemented by dedicated logical circuits arranged in the frequency controller 51. However, the series of processes do

not have to be implemented in such a manner and may be implemented by a program or the like loaded to a versatile computer.

5 As shown in Fig. 5, the frequency controller 51 acquires the temperature of each cooling unit 41 based on the detection signal from each temperature sensor 50 (step S101). The frequency controller 51 then determines whether or not the temperature in at least one of the cooling units
10 41 is greater than or equal to 38 K, which is the second threshold value, that is, whether or not there is a cooling unit 41 that needs to be forcibly cooled (step S102). When the frequency controller 51 determines that the temperature in at least one of the cooling units 41 is greater than or
15 equal to the second threshold value (step S102: YES), the frequency controller 51 outputs to the inverter device 52 a control command value instructing to set the output frequency of the inverter device 52 to 50 Hz, which is the upper limit value (step S103). The frequency controller 51
20 performs forcible cooling on all the cooling units 41 with the AC electric motor 43 and ends the series of processes.

 In this case, when the forcible cooling command is output from the frequency controller 51 to the inverter
25 device 52, the output frequency of the AC power supplied to the AC electric motor 43 is set to 50 Hz, which is the upper limit value of the output frequency. When the AC power is supplied at the output frequency of the upper limit value, the rotation speed reaches maximum in the AC electric motor
30 43 and the amount of the helium gas supplied to each cooling unit 41 reaches maximum in the compression device 42. In other words, when the temperature in at least one of the cooling units 41 becomes greater than or equal to the second

threshold value, the cooling unit 41 of which temperature is greater than or equal to the second threshold value is given priority for cooling and rapidly cooled.

5 When the frequency controller 51 determines that the temperature in each of the cooling units 41 is less than the second threshold value, that is, forcible cooling on the cooling unit 41 is unnecessary (step S102: NO), the frequency controller 51 determines whether or not the
10 temperature in at least one of the cooling units 41 is greater than or equal to 128 °C which is the first threshold value (step S104). If the frequency controller 51 determines that the temperature in at least one of the cooling units 41 is greater than or equal to the first threshold value (step
15 S104: YES), the frequency controller 51 determines whether or not the present frequency of the AC power supply is 50 Hz, which is the upper limit value, that is, whether or not the frequency of the AC power supply can be further increased (step S105). If the present frequency of the AC
20 power supply is the upper limit value of 50 Hz (step S105: YES), the frequency controller 51 determines that it is not possible to increase the frequency of the AC power supply, outputs to the inverter device 52 the control command value for maintaining the frequency of the AC power at the upper
25 limit value of 50 Hz, and ends the series of processes. If the present frequency of the AC power supply is not 50 Hz or the upper limit value (step S105: NO), a control command value for raising the frequency of the AC power by 5 Hz from the present value is output to the inverter device 52 (step
30 S106). This ends the series of processes.

In this case, when the control command value to raise the present output frequency by 5 Hz is output from the

frequency controller 51 to the inverter device 52, the frequency of the AC power supplied to the AC electric motor 43 becomes higher by 5 Hz from the present value, and the rotation speed is enhanced by the raised frequency in the AC electric motor 43. When the rotation speed becomes higher in the AC electric motor 43, the amount of the helium gas supplied from the compression device 42 to each cooling unit 41 also increases, and thus further cooling can be performed on the cooling unit 41.

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If the frequency controller 51 determines that the temperature in all the cooling units 41 is lower than 128K or the first threshold value (step S104: NO), the frequency controller 51 determines whether or not the present frequency of the AC power supply is 30 Hz or the lower limit value of the inverter device 52, that is, whether or not the frequency of the AC power supply can be further reduced (step S107). If the present frequency of the AC power supply is 30 Hz, which is the upper limit value (step S107: YES), the frequency controller 51 determines that it is not possible to reduce the frequency of the AC power supply, and outputs to the inverter device 52 the control command value for maintaining the frequency of the AC power supply at 30 Hz. This ends the series of processes. If the present frequency of the AC power supply is not the upper limit value of 30 Hz (step S107: NO), the control command value for reducing the frequency of the AC power supply by 5 Hz from the present value is output to the inverter device 52 (step S108). This ends the series of processes.

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In this case, when the control command value for reducing the present output frequency by 5 Hz is output from the frequency controller 51 to the inverter device 52, the

frequency of the AC power supplied to the AC electric motor 43 becomes lower by 5 Hz from the present value, and the rotation speed is lowered by the reduced frequency in the AC electric motor 43. When the rotation speed of the AC electric motor 43 becomes lower, the amount of the helium gas supplied from the compression device 42 to each cooling unit 41 also decreases. Thus, the power consumed by the compression device 42 can be reduced if further cooling is not necessary in the cooling units 41.

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In the depressurization as described above, the output frequency of the inverter device 52 is raised by 5 Hz by the frequency controller 51 when further cooling is necessary in at least one of the cooling units 41. The helium gas supplied to all the cooling units 41 is then increased by an amount corresponding to + 5 Hz, and the cooling capability in all the cooling units 41 is increased accordingly. If further cooling is not necessary in all the cooling units 41, the output frequency of the inverter device 52 is lowered by 5 Hz by the frequency controller 51. The helium gas supplied to all the cooling units 41 is then reduced by an amount corresponding to 5 Hz, and the cooling capability in all the cooling units 41 is decreased accordingly. Thus, the power consumption in the compression device 42 is reduced while performing efficient cooling in correspondence with the present temperature in all of the cooling units 41.

One example of control of the output frequency of the inverter device 52 executed by the frequency controller 51 will now be described with reference to a timing chart. Fig. 6 is a timing chart showing changes in the temperature of the cooling unit 41 in each chamber of the first processing

section 11. The timing chart also shows an output frequency of the inverter device 52 set based on the changes in temperature. Timing t1 to t10 in Fig. 6 indicates the timing for each detection cycle that detects the temperature of each cooling unit 41 and shows the timing from an idle state in which all the chambers are waiting to perform processing (timing t0) to the timing in a state in which processing is continued in each chamber (timing t10). In the idle state (timing t0) in which each chamber does not particularly require a large discharge capability, the frequency of the AC power supplied to the AC electric motor 43 is always set to the lower limit value of 30 Hz by the frequency controller 51.

As shown in Fig. 6, in the idle state at timing t0 and when the detection cycle from timing t0 elapses at timing t1, the temperature in all the cooling units 41 is lower than the second threshold value (138 K) and further than the first threshold value (128K). At timing t0 and timing t1 at which a large discharge capability is not particularly required in each chamber, the AC power supply of 30 Hz, which is the lower limit value, is supplied to the AC electric motor 43. Thus, at timing t0 and timing t1, the output frequency of the inverter device 52 continues to be maintained at the lower limit value of 30 Hz.

A large discharge capability is then required in the chamber 17, and the temperature of the cooling unit 41 corresponding to the chamber 17 becomes greater than or equal to the first threshold value. As a result, the frequency controller 51 determines that the temperature of at least one of the cooling units 41 is greater than or equal to the first threshold value at timing t2. In

addition, the frequency controller 51 determines that the present output frequency in the inverter device 52 is the lower limit value of 30 Hz. Thus, a control command value for raising the output frequency by 5 Hz from the present
5 frequency (30 Hz) is input from the frequency controller 51 to the inverter device 52. As a result, the AC power in which the frequency is 35 Hz is supplied to the AC electric motor 43 and the output frequency is raised by 5 Hz. Thus, the rotation speed of the AC electric motor 43 increases,
10 the amount of the helium gas supplied to each cooling unit 41 increases, and the cooling capability in all the cooling units 41 increases.

Subsequently, a large discharge capability is
15 continuously required in the chamber 17, and the temperature of the cooling unit 41 of the chamber 17 remains to be greater than or equal to the first threshold value in the successive detection cycles. As a result, the frequency controller 51 determines that the temperature of at least
20 one of the cooling units 41 is continuously greater than or equal to the first threshold value at timing t3. In addition, the frequency controller 51 determines that the present output frequency (35 Hz) in the inverter device 52 is less than the upper limit value of 50 Hz, and the control
25 command value for raising the output frequency by 5 Hz from the present frequency (35 Hz) is input from the frequency controller 51 to the inverter device 52. As a result, the AC power of which the frequency is 40 Hz is supplied to the AC electric motor 43. Thus, the rotation speed of the AC
30 electric motor 43 further increases and the cooling capability in all the cooling units 41 further increases.

From this state, if a large discharge capability is

separately required in the chamber 20 although sufficient discharge capability is ensured in the chamber 17, the temperature of the cooling unit 41 in the chamber 17 becomes less than the first threshold value but the temperature of the cooling unit 41 in the other chamber 20 becomes greater than or equal to the first threshold value, as shown in Fig. 6. Thus, at timing t4, the frequency controller 51 continues to make the same determination that the temperature of at least one of the cooling units 41 is greater than or equal to the first threshold value in the successive detection cycles. In addition, the frequency controller 51 determines that the present output frequency (40 Hz) in the inverter device 52 is less than the upper limit value of 50 Hz. Thus, the control command value for raising the output frequency by 5 Hz from the present frequency (40 Hz) is input from the frequency controller 51 to the inverter device 52. As a result, the AC power supply in which the frequency is 45 Hz is supplied to the AC electric motor 43. Thus, the rotation speed of the AC electric motor 43 further increases in accordance with the processing content of the chamber 20, and the cooling capability in each cooling unit 41 increases significantly.

Then, a large discharge capability is continuously required in the chamber 20, and the temperature of the cooling unit 41 of the chamber 20 remains to be greater than or equal to the first threshold value in the successive detection cycles. As a result, at timing t5, the frequency controller 51 determines that the temperature of at least one of the cooling units 41 is continuously greater than or equal to the first threshold value. In addition, the frequency controller 51 determines that the present output frequency (45 Hz) in the inverter device 52 is less than 50

Hz or the upper limit value. Thus, the control command value for raising the output frequency by 5 Hz from the present frequency (45 Hz) is input from the frequency controller 51 to the inverter device 52. As a result, the AC power supply in which the frequency is the upper limit value of 50 Hz is supplied to the AC electric motor 43, and the cooling capability in each cooling unit 41 reaches maximum.

In this manner, at timing t2 to t5, it is determined that the temperature of at least one of the cooling units 41 is greater than or equal to the first threshold value. Thus, the control command value for raising the output frequency by 5 Hz is continuously input to the inverter device 52 at each timing t2 to t5. In the cooling unit 41 cooled using the compressed helium gas, the temperature does not immediately change when the supply amount of the helium gas increases or decreases.

For example, when a long time is required for the adiabatic expansion cycle of the coolant or when a long time is required for heat conduction in the adiabatic expansion cycle, a considerable length of time is required until an increase or decrease in the supply amount of the coolant is reflected on the temperature of the cooling unit. Thus, when rapidly raising the temperature of the cooling unit 41, it is preferable that the supply amount of the coolant be drastically increased. When gradually raising the temperature of the cooling unit 41, it is preferable that the supply amount of the coolant be slightly increased or not increased.

As described above, in the present embodiment, when at least one of the cooling units 41 is continuously greater

than or equal to the first threshold value, that is, when further cooling is required for one of the cooling units 41, the frequency of the AC power supplied to the AC electric motor 43 is raised in a stepped manner. Accordingly, the output frequency is further raised in view of the temperature change of each cooling unit 41 resulting from the previous increase in the output frequency. In such a control method, an excessive increase in the output frequency of the inverter device 52 can be avoided, and the power consumed in the compression device 42 can be reduced since an excessive increase in the frequency is avoided.

Then, at timing t6, sufficient discharge capability is ensured in each chamber, and the temperature of all the cooling units 41 becomes less than the first threshold value of 128 K. Thus, at timing t6, the frequency controller 51 determines that there are no cooling units 41 in which the temperature is greater than or equal to the first threshold value. In addition, the frequency controller 51 determines that the present output frequency (50 Hz) in the inverter device 52 is greater than the lower limit value (30 Hz). The control command value for reducing the output frequency by 5 Hz from the present frequency is then input from the frequency controller 51 to the inverter device 52. As a result, the rotation speed of the AC electric motor 43 becomes lower, and redundant cooling capability is less likely to be obtained in all the cooling units 41.

Subsequently, in the same manner, at timing t7 to t9 during which sufficient discharge capability is ensured in each chamber and the temperature of all the cooling units 41 is less than the first threshold value of 128 K in successive detection cycles, the control command value for

reducing the output frequency by 5 Hz from the present frequency is input from the frequency controller 51 to the inverter device 52 at each timing. When the frequency of the AC power output by the inverter device 52 reaches the lower limit value (30 Hz) at timing t9, the frequency of the AC power supplied to the AC electric motor 43 is maintained at the lower limit value of 30 Hz after timing t10.

In this manner, at timing t6 to t10, it is continuously determined that the temperature of each cooling unit 41 is less than the first threshold value. Thus, the control command value for reducing the present frequency by 5 Hz is input to the inverter device 52 at each of timings t6 to 10. As described above, in a cooling unit 41 cooled using the compressed helium gas, the temperature does not immediately change when the supply amount of the helium gas increases or decreases. Thus, the frequency of the AC power supplied to the AC electric motor 43 is reduced in a stepped manner when the temperature of each cooling unit 41 is continuously less than the first threshold value, that is, when further cooling is not required on the cooling units 41. Accordingly, the output frequency is further reduced in view of the temperature change of each cooling unit 41 resulting from the previous decrease in the output frequency. The output frequency of the inverter device 52 can thus be reduced in accordance with the present temperature of the cooling unit 41, and the power consumed in the compression device 42 can be reduced by the reduction of the output frequency. In the manufacturing apparatus 10 that includes such depressurization system, the power consumption in the manufacturing apparatus 10 can be reduced by the reduced amount of power consumption in the depressurization system.

If it is determined that the temperature of at least one cooling unit 41 is greater than or equal to the first threshold value at timing t6, the frequency of the AC power supplied to the AC electric motor 43 continues to be maintained at the upper limit value of 50 Hz. If, for example, it is determined that the temperature of at least one of the cooling units 41 is greater than or equal to the first threshold value at timing t8, the control command for raising the present frequency (40 Hz) by 5 Hz is input to the inverter device 52 from the frequency controller 51 to the inverter device 52. Further, for example, if it is determined that the temperature of at least one cooling unit 41 is greater than or equal to the second threshold value of 138 K, the control command value for forcibly setting the output frequency to the upper limit value of 50 Hz is input to the inverter device 52 to the inverter device 52 in any one of timings t0 to t10.

As described above, the depressurization system according to the present embodiment and the manufacturing apparatus 10 using the same has the advantages described below.

(1) The output frequency of the inverter device 52 is raised by the frequency controller 51 when the temperature of at least one of the cooling units 41 is greater than or equal to the first threshold value, and the output frequency of the inverter device 52 is lowered by the frequency controller 51 when the temperature of each cooling unit 41 is less than the first threshold value. In such control method of the output frequency, the amount of the helium gas supplied to each cooling unit 41 is increased if further cooling is necessary in the cooling unit 41. This increases

the cooling capability of each cooling unit 41. When further cooling is not necessary in the cooling unit 41, the amount of the helium gas supplied to each cooling unit 41 is reduced. This attenuates the cooling capability of each cooling unit 41. Thus, the power consumed by the compression device 42 is reduced when the output frequency is lowered while efficiently cooling each cooling unit 41 according to the present temperature.

(2) The frequency controller 51 acquires the temperature of each cooling unit 41 for each predetermined detection cycle and raises the output frequency to the inverter device 52 towards the upper limit value in a stepped manner for each detection cycle when the temperature of at least one of the cooling units 41 is greater than or equal to the first threshold value. In other words, the output frequency is further raised in view of the temperature change of each cooling unit 41 resulting from the previous increase in the output frequency. In such a structure, an excessive rise in the output frequency of the inverter device 52 is avoided, and the power consumed in the compression device 42 is reduced since an excessive rise in the frequency is avoided.

(3) The frequency controller 51 acquires the temperature of each cooling unit 41 for each predetermined detection cycle and reduces the output frequency of the inverter device 52 towards the lower limit value in a stepped manner for each predetermined detection cycle when the temperature of each cooling unit 41 is less than the first threshold value. Thus, the output frequency is further reduced in view of the temperature change of each cooling unit 41 resulting from the previous decrease in the output frequency. As a result, the output frequency of the inverter device 52 is

reduced according to the present temperature of the cooling unit 41, and the power consumed in the compression device 42 is reduced by the decrease in the output frequency.

5 (4) The frequency controller 51 sets the output frequency of the inverter device 52 to the upper limit value of 50 Hz when the temperature of at least one of the cooling units 41 is greater than or equal to the second threshold value. In such a structure, the cooling capability of the
10 cooling machine is maximized and the cooling unit 41 is rapidly cooled when the cooling of a cooling unit 41 needs to be performed with top priority.

15 The above embodiment may be modified as described below.

 In the embodiment described above, the depressurization system is applied to the manufacturing apparatus 10 of the semiconductor device serving as the vacuum processing device but is not limited in such a manner, and the present
20 invention may be applied to other devices as long as the device uses the depressurization device and the compression device.

 The frequency controller 51 of the embodiment described
25 above sets the output frequency of the inverter device 52 to the upper limit value at which the inverter device can output when the temperature of at least one of the cooling units 41 is greater than or equal to the second threshold value. However, the control based on the second threshold
30 value may be eliminated. In the embodiment described above, when the temperature of at least one of the cooling units 41 is greater than or equal to the first threshold value, further cooling is performed in the cooling unit 41.

Accordingly, the present invention obtains at least advantages (1) to (3) even when the control based on the second threshold value is eliminated.

5 The frequency controller 51 of the embodiment described above controls the output frequency to lower the output frequency of the inverter device 52 towards the lower limit value in a stepped manner for each detection cycle when the temperature of all the cooling units 41 is decreased to less
10 than the first threshold value based on the temperature of each cooling unit 41. Instead of such a control method, the frequency controller 51 may set the output frequency of the inverter device 52 to the lower limit value when the temperature of all the cooling units 41 is decreased to less
15 than the first threshold value. With such a structure, the present invention can obtain at least advantages (1) and (2).

 The frequency controller 51 of the embodiment described
20 above controls the output frequency to raise the output frequency of the inverter device 52 towards the upper limit value in a stepped manner for each detection cycle when the temperature of at least one of the cooling units 41 is greater than or equal to the first threshold value based on
25 the temperature of each cooling unit 41. Instead of such a control method, the frequency controller 51 may control the output frequency of the inverter device 52 with two values, the lower limit value and the upper limit value, as another method for further cooling the cooling unit 41. In this
30 case, the frequency controller 51 improves the cooling effect by setting the output frequency of the inverter device 52 to the upper limit value when the temperature of at least one cooling unit 41 is greater than or equal to the

first threshold value.

The frequency controller 51 of the embodiment described above acquires the temperature of each cooling unit 41 for each predetermined detection cycle and controls the output frequency of the inverter device 52 based on the acquired temperature. However, the present invention is not limited in such a manner, and the frequency controller 51 may continuously acquire the temperature of the cooling unit 41 to control the output frequency of the inverter device 52.

The frequency controller 51 of the embodiment described above may set the output frequency of the inverter device 52 to be the frequency corresponding to the temperature of the cooling unit 41 instead of raising the output frequency of the inverter device 52 in a stepped manner when at least one temperature of the cooling unit 41 is greater than or equal to the first threshold value. In this case, if there are a plurality of cooling units 41 having a temperature greater than or equal to the first threshold value, the frequency controller 51 may set the output frequency of the inverter device 52 so as to be the frequency corresponding to the highest temperature of such cooling units 41.

In the embodiment described above, the number of the cooling units 41 or the supply target of the compression device 42 is not particularly limited as long as it is two or more in accordance with the pumping capability of the compression device 42.

In the depressurization system of the embodiment described above, the cryotrap 40 is used as the depressurization device. However, a cryopump may be used as

the depressurization device. When using the cryopump as the depressurization device, it is preferable that the first threshold value and the second threshold value be changed accordingly.

5

In Fig. 5, step S105 (comparison with the upper limit value of 50 Hz) and step S107 (comparison with lower limit value of 30 Hz) may be eliminated. In other words, the output frequency may be relatively increased (e.g., 5 Hz) as soon as the temperature of a first one cooling unit 41 becomes greater than or equal to the first threshold value (128K), and the frequency may be relatively decreased (e.g., 5 Hz) as soon as the temperature of all the cooling units 41 becomes less than the first threshold value (128 K).

10

CLAIMS

1. A depressurization system comprising:

a plurality of depressurization devices, each of which
5 includes a cooling unit that receives a compressed coolant
and is capable of supplementing gas when adiabatically
expanding the compressed coolant;

a compression device including a compression unit
provided with an AC electric motor, wherein the compression
10 device supplies the compressed coolant to the cooling unit
of each of the plurality of depressurization devices from
the compression unit at a flow rate corresponding to a
rotation speed of the AC electric motor;

a temperature detection unit that detects a temperature
15 of the cooling unit of each depressurization device;

an inverter device capable of changing a frequency of AC
power supplied to the AC electric motor; and

a frequency controller that controls an output frequency
of the inverter device,

20 wherein the frequency controller relatively raises the
output frequency of the inverter device when the temperature
of the cooling unit of at least one of the plurality of
depressurization devices is greater than or equal to a first
threshold value, and relatively lowers the output frequency
25 of the inverter device when the temperature of the cooling
unit of all of the plurality of depressurization devices
decreases to less than the first threshold value.

2. The depressurization system according to claim 1,
30 wherein the frequency controller

acquires the temperature of the cooling unit of each
depressurization device in each predetermined detection
cycle, and

determines whether or not the temperature of the cooling unit of at least one depressurization device is greater than or equal to the first threshold value in each detection cycle and raises the output frequency of the inverter device.

3. The depressurization system according to claim 2, wherein the frequency controller further determines whether the output frequency of the inverter device has been raised to an upper limit value when the temperature of the cooling unit of at least one depressurization device is greater than or equal to the first threshold value and raises the output frequency if not.

4. The depressurization system according to any one of claims 1 to 3, wherein the frequency controller

acquires the temperature of the cooling unit of each depressurization device for each predetermined detection cycle, and

determines whether or not the temperature of the cooling unit of all of the plurality of depressurization devices is less than the first threshold value for each detection cycle and lowers the output frequency of the inverter device.

5. The depressurization system according to claim 4, wherein the frequency controller further determines whether the output frequency of the inverter device has been lowered to a lower limit value when the temperature of the cooling unit of at least one depressurization device is less than the first threshold value and lowers the output frequency if not.

6. The depressurization system according to claim 1 or

2, wherein the frequency controller sets the output frequency of the inverter device to an upper limit value when the temperature of the cooling unit of at least one depressurization device is greater than or equal to a second
5 threshold value, which is greater than the first threshold value.

7. A vacuum processing device comprising:
a plurality of vacuum chambers; and
10 the depressurization system according to any one of claims 1 to 3, wherein each of the plurality of vacuum chambers is connected to one of the plurality of depressurization devices.