

SEMICONDUCTOR HEAT TREATMENT EQUIPMENT AND TEMPERATURE CONTROL METHOD THEREFOR

TECHNICAL FIELD

[0001] The present disclosure relates to the field of semiconductor technology, and in particular, to a semiconductor heat treatment equipment and a temperature control method therefor.

BACKGROUND

[0002] Epitaxial growth refers to growing a specific epitaxial thin film on the basis of a wafer by an epitaxial process, and the wafer and the epitaxial thin film are collectively referred to as an epitaxial wafer. At present, growth of an epitaxial layer of silicon carbide is mainly performed with a Chemical Vapor Deposition (CVD) method, and a specific chemical reaction is that SiH_4 and C_3H_8 (or C_2H_4) undergo a cracking reaction at a high temperature (above 1600°C) under a reduced pressure (about 100 mbar) to generate Si atoms and C atoms, and then the Si atoms and the C atoms are recombined on a surface of the wafer to generate SiC. A thermochemical distillation method is widely applied to epitaxial layer growth, in which a temperature is an important influencing factor and has great significance to doping uniformity and film thickness uniformity of the epitaxial layer. If the temperature deviates from a set process temperature, process parameters may be subjected to serious adverse effects.

[0003] However, related semiconductor equipments cannot ensure that the wafer is at a position with a highest temperature in a chamber during a process, and thus temperature uniformity of the wafer cannot be ensured.

SUMMARY

[0004] In view of the above, the present disclosure aims to provide a semiconductor heat treatment equipment and a temperature control method therefor, which can ensure that a

center of a wafer coincides with a center of a coil during a process, so that the wafer is always kept at a point of highest temperature, and temperature uniformity of the wafer is ensured.

[0005] In order to achieve the above objective, the following technical solutions are provided in embodiments of the present disclosure.

[0006] In a first aspect, an embodiment of the present disclosure provides a semiconductor heat treatment equipment, including: a coil, a chamber, a first temperature sensor, a second temperature sensor, and a temperature controller; the chamber is used for placement of a wafer to be processed, the coil surrounds the chamber and provides a thermal field for the chamber, and the chamber is provided with a first temperature measurement hole and a second temperature measurement hole, which are distributed in a central region of the chamber; the first temperature sensor is configured to detect a temperature of the chamber through the first temperature measurement hole, and record the temperature as a first temperature; the second temperature sensor is configured to detect the temperature of the chamber through the second temperature measurement hole, and record the temperature as a second temperature; and the temperature controller is configured to acquire the first temperature and the second temperature, determine, when the temperature of the chamber reaches a steady state, whether a center position of the coil deviates from a center point of the chamber based on the first temperature and/or the second temperature, and control the coil to translate along a central axis based on the first temperature and/or the second temperature in response to the center position of the coil deviating from the center point of the chamber until the center position of the coil reaches the center point of the chamber.

[0007] Further, the temperature controller is further configured to determine whether the first temperature is equal to the second temperature, and determine that the center position of the coil deviates from the center point of the chamber in response to the first temperature being not equal to the second temperature; and control the coil to translate along the central axis based on the first temperature and the second temperature until the first temperature is equal to the second temperature, and determine that the center position of the coil reaches the center point of the chamber.

[0008] Further, the chamber includes a plurality of regions, and a number of turns of the coil in each region is the same, a temperature gradient distribution curve when the temperature of the chamber reaches the steady state is stored in the temperature controller, and the temperature gradient distribution curve illustrates a chamber temperature

corresponding to each region; the temperature controller is further configured to acquire a region of the chamber where the first temperature measurement hole is located, and record the region as a first setting region; determine a chamber temperature at the temperature gradient distribution curve which corresponds to the first setting region, and record the chamber temperature as a first target temperature; determine whether the first temperature is equal to the first target temperature, and determine that the center position of the coil deviates from the center point of the chamber in response to the first temperature being not equal to the first target temperature; and/or

the temperature controller is further configured to acquire a region of the chamber where the second temperature measurement hole is located, and record the region as a second setting region; determine a chamber temperature at the temperature gradient distribution curve which corresponds to the second setting region, and record the chamber temperature as a second target temperature; determine whether the second temperature is equal to the second target temperature, and determine that the center position of the coil deviates from the center point of the chamber in response to the second temperature being not equal to the second target temperature.

[0009] Further, the semiconductor heat treatment equipment further includes: a drive component, which is connected to the coil, and is configured to drive the coil to translate;

the temperature controller is further configured to calculate a translation amount and a translation direction of the coil based on the first target temperature and the first temperature, and control, based on the translation amount and the translation direction, the drive component to drive the coil to translate until a center point of the coil coincides with the center point of the chamber; and/or

the temperature controller is further configured to calculate a translation amount and a translation direction of the coil based on the second target temperature and the second temperature, and control, based on the translation amount and the translation direction, the drive component to drive the coil to translate until the center point of the coil coincides with the center point of the chamber.

[0010] Further, the temperature controller is a programmable logic controller, which is respectively communicatively connected to the first temperature sensor, the second temperature sensor, and an induction power supply of the coil.

[0011] In a second aspect, an embodiment of the present disclosure provides a temperature control method for a semiconductor heat treatment equipment, which is applied to the

semiconductor heat treatment equipment described in the first aspect, and the temperature control method includes:

acquiring the first temperature detected by the first temperature sensor, and acquiring the second temperature detected by the second temperature sensor;

when the temperature of the chamber reaches the steady state, determining whether the center position of the coil deviates from the center point of the chamber based on the first temperature and/or the second temperature; and

in response to the center position of the coil deviating from the center point of the chamber, controlling the coil to translate along the central axis based on the first temperature and/or the second temperature until the center position of the coil reaches the center point of the chamber.

[0012] Further, determining whether the center position of the coil deviates from the center point of the chamber based on the first temperature and/or the second temperature includes:

determine whether the first temperature is equal to the second temperature, and in response to the first temperature being not equal to the second temperature, determining that the center position of the coil deviates from the center point of the chamber; and/or

controlling the coil to translate along the central axis based on the first temperature and/or the second temperature until the center position of the coil reaches the center point of the chamber includes:

in a case where the first temperature is higher than the second temperature, controlling the coil to translate in a first direction until the first temperature is equal to the second temperature; wherein the first direction is a direction in which the second temperature measurement hole is located; and

in a case where the first temperature is lower than the second temperature, controlling the coil to translate in a second direction until the first temperature is equal to the second temperature; wherein the second direction is a direction in which the first temperature measurement hole is located.

[0013] Further, the temperature control method includes:

calculating a skin depth of the chamber at a preset process temperature, acquiring an alternating current value of the coil, dividing the chamber into a plurality of regions based on a number of turns of the coil, and calculating a heat source intensity of each region of the chamber based on the skin depth and the alternating current value; wherein a number of turns of the coil in each region is the same; and

acquiring ambient temperatures at two ends of the chamber when the temperature of the chamber reaches the steady state, and calculating a chamber temperature of each region based on the ambient temperatures and the heat source intensity of each region to obtain a temperature gradient distribution curve of the chamber.

[0014] Further, calculating the chamber temperature of each region based on the ambient temperatures and the heat source intensity of each region includes:

starting from a first region at either end of the chamber, calculating, based on the heat source intensity of the first region and the ambient temperatures, the chamber temperature of the first region when a process reaches a steady state;

taking the chamber temperature of the first region as an ambient temperature of a next adjacent region, calculating, based on the ambient temperature of the next region and the heat source intensity of the next region, the chamber temperature of the next region when the process reaches the steady state, and so on until the chamber temperature of a region where the center point of the chamber is located is obtained by calculation; and

based on symmetry of the chamber temperatures from the first region to the region where the center point of the chamber is located, obtaining chamber temperatures of regions from the region where the center point of the chamber is located to the other end of the chamber.

[0015] Further, a calculation formula for the chamber temperature is as follows:

$$T_{i1} = \sqrt[4]{\frac{F_i * V_i}{\sigma * \varepsilon * A} + T_{i2}^4}$$

where T_{i1} is the chamber temperature of an i^{th} region, F_i is the heat source intensity of the i^{th} region, σ is a Stokes constant, ε is a surface thermal emissivity of the chamber, A is an area of an inner surface of the chamber, T_{i2} is an ambient temperature corresponding to the i^{th} region, and V_i is a volume of the i^{th} region.

[0016] Further, determining whether the center position of the coil deviates from the center point of the chamber based on the first temperature and/or the second temperature includes:

acquiring a region of the chamber where the first temperature measurement hole is located, and recording the region as a first setting region; determining a chamber temperature at the temperature gradient distribution curve which corresponds to the first setting region, and recording the temperature as a first target temperature; and determining whether the first temperature is equal to the first target temperature, and determining that the center position of the coil deviates from the center point of the chamber in response to the first temperature being not equal to the first target temperature; and/or

acquiring a region of the chamber where the second temperature measurement hole is located, and recording the region as a second setting region; determining a chamber temperature at the temperature gradient distribution curve which corresponds to the second setting region, and recording the temperature as a second target temperature; and determining whether the second temperature is equal to the second target temperature, and determining that the center position of the coil deviates from the center point of the chamber in response to the second temperature being not equal to the second target temperature.

[0017] Further, the semiconductor heat treatment equipment includes a drive component, which is connected to the coil, and is configured to drive the coil to translate; and controlling the coil to translate along the central axis based on the first temperature and/or the second temperature until the center position of the coil reaches the center point of the chamber includes:

calculating a translation amount and a translation direction of the coil based on the first target temperature and the first temperature; and controlling, based on the translation amount and the translation direction, the drive component to rotate, so as to drive the coil to translate until the center point of the coil coincides with the center point of the chamber; and/or

calculating a translation amount and a translation direction of the coil based on the second target temperature and the second temperature; and controlling, based on the translation amount and the translation direction, the drive component to rotate, so as to drive the coil to translate until the center point of the coil coincides with the center point of the chamber.

[0018] The embodiments of the present disclosure provide the semiconductor heat treatment equipment and the temperature control method therefor. The semiconductor heat treatment equipment includes: the coil, the chamber, the first temperature sensor, the second temperature sensor, and the temperature controller; the chamber is used for placement of the wafer to be processed, the coil surrounds the chamber and provides the thermal field for the chamber, and the chamber is provided with the first temperature measurement hole and the second temperature measurement hole, which are distributed in the central region of the chamber; the first temperature sensor is configured to detect the temperature of the chamber through the first temperature measurement hole, and record the temperature as the first temperature; the second temperature sensor is configured to detect the temperature of the chamber through the second temperature measurement hole, and

record the temperature as the second temperature; and the temperature controller is configured to acquire the first temperature and the second temperature, determine, when the temperature of the chamber reaches the steady state, whether the center position of the coil deviates from the center point of the chamber based on the first temperature and/or the second temperature, and control the coil to translate along the central axis based on the first temperature and/or the second temperature in response to the center position of the coil deviating from the center point of the chamber until the center position of the coil reaches the center point of the chamber. According to the present disclosure, by disposing the two temperature sensors in the chamber and determining, when the temperature of the chamber reaches the steady state, whether the center position of the coil deviates from the center point of the chamber based on the first temperature detected by the first temperature sensor and/or the second temperature detected by the second temperature sensor, it can be determined whether a center point of the wafer is at a point of highest temperature; and by moving the coil when the center point of the wafer deviates from the center position of the coil to enable the center position of the coil to reach the center point of the chamber, it can be ensured that a center of the wafer coincides with a center of the coil during a process, so that the wafer is always kept at the point of highest temperature, and temperature uniformity of the wafer is ensured..

[0019] Other technical features and advantages of embodiments of the present disclosure will be described in the following description, or part of the technical features and advantages can be derived or undoubtedly determined from the description or be understood by implementing the above technical solutions provided in the embodiments of the present disclosure.

[0020] In order to make the above objectives, technical features, and advantages of the present disclosure more obvious and understandable, exemplary embodiments of the present disclosure are listed and described in detail below with reference to the drawings.

BRIEF DESCRIPTION OF DRAWINGS

[0021] In order to describe the technical solutions in the implementations or the background part of the present disclosure more clearly, the drawings for the description of the implementations or the background part will be briefly described below. Apparently, the drawings described below are just for some implementations of the present disclosure,

and other drawings can be derived by those of ordinary skill in the art from the drawings provided herein without any inventive work.

[0022] FIG. 1 is a schematic structural diagram of a chamber in a related semiconductor heat treatment equipment;

[0023] FIG. 2a is a structural front view of a chamber according to an embodiment of the present disclosure;

[0024] FIG. 2b is a structural side view of a chamber according to an embodiment of the present disclosure;

[0025] FIG. 3 is a chamber temperature distribution curve graph of regions in a chamber according to an embodiment of the present disclosure;

[0026] FIG. 4 is a flowchart illustrating a temperature control method for a semiconductor heat treatment equipment according to an embodiment of the present disclosure; and

[0027] FIG. 5 is a schematic diagram illustrating distribution of heat source intensity of regions in a chamber according to an embodiment of the present disclosure.

DETAIL DESCRIPTION OF EMBODIMENTS

[0028] In order to make the objectives, technical solutions and advantages of the present disclosure clearer, the technical solutions in the present disclosure will be described below with reference to the drawings. Apparently, the embodiments described herein are only part of the embodiments of the present disclosure, but are not all the embodiments.

[0029] In the related wafer heating technology, induction heating is generally adopted as a main heating method for SiC epitaxy, and the method has the advantages of high heating speed, high heating efficiency, quick start, and energy saving, and is widely applied in the semiconductor industry. During a SiC epitaxial process, strict requirements are proposed on uniformity of a temperature near a substrate and temperature accuracy. As a medium for generating a magnetic field, a coil has a direct impact on distribution of a temperature field in a heating process.

[0030] Alternating current is introduced into the coil to generate a corresponding magnetic field and magnetic flux, and a chamber (such as a graphite piece with a hollow barrel-shaped structure) placed within the coil generates induced electromotive force, so that eddy current flows through the chamber, with a center position of the chamber reserved as a wafer position. Reaction gases flow through the chamber along a horizontal direction

from one end of the coil, and are pumped away from the other end of the coil. Thus, an ambient temperature in the chamber close to a peripheral region in the horizontal direction is lower. When the chamber is in a low-pressure vacuum state, temperatures at two sides of the coil are lower based on the heat radiation principle; when the wafer is located at a center position of the coil, a highest point in the temperature field coincides with a center of the wafer. However, since the chamber is not mounted within the coil in a completely fixed manner, the wafer may deviate from the center of the coil in a case of manual mounting and lack of reliable fixation. Therefore, the related semiconductor equipments cannot ensure that the wafer is at a position with a highest temperature in the chamber during a process, and thus cannot ensure temperature uniformity of the wafer.

[0031] Referring to a schematic structural diagram of a chamber in a related semiconductor heat treatment equipment shown in FIG. 1, the chamber is a graphite piece, the graphite chamber has a hollow cylindrical structure, two semicircular split bodies are spliced to form a complete cylinder, and a wafer placement position is reserved at a center of a center line of the graphite piece. Since a conventional parallel-flow silicon carbide epitaxial equipment cannot directly measure a temperature of a wafer, an infrared thermometer is used to indirectly measure a chamber temperature through a temperature measurement hole shown in FIG. 1, and the temperature measurement hole is generally located right above the wafer placement position, such as the position of the temperature measurement point shown in FIG. 1. The coil surrounds the graphite piece, and has a fixed number of turns and fixed turn spacing, alternating current is introduced into the coil to generate a corresponding magnetic field and magnetic flux, and the graphite piece within the coil generates induced electromotive force, so that eddy current flows through the graphite piece. When the current flows through the graphite piece, an opposite force is generated due to resistance, and causes energy to pass through the graphite piece in the form of heat, so that the graphite piece and the wafer in the graphite piece are heated. The related semiconductor heat treatment equipment has the following disadvantages.

[0032] First disadvantage: since the reaction gases flow through the graphite piece along the horizontal direction from the right side of the coil shown in FIG. 1 and are pumped away from the left side of the coil, ambient temperatures at the left side and the right side of the graphite piece are lower; when the chamber is in a low-pressure vacuum state, temperatures at the two sides of the coil are lower based on the thermal radiation principle. The magnitude of a flow rate of each reaction gas, the magnitude of a pressure in the

chamber, and a pumping force of a pump can all affect temperature uniformity of a center position of the graphite piece. Since a position of the coil cannot be adjusted and the turn spacing and the number of turns of the coil are fixed, a temperature at the center position of the graphite piece can be adjusted only by adjusting the magnitude of the alternating current passing through the coil, which causes high power consumption and prolongs temperature adjustment time.

[0033] Second disadvantage: since the chamber is not mounted within the coil in a completely fixed manner, a center point of the graphite piece may deviate from the center position of the coil due to the lack of reliable fixation. Under the condition that the position of the coil cannot be adjusted, the temperature uniformity of the center position of the graphite piece is affected.

[0034] Third disadvantage: since the parallel-flow silicon carbide epitaxial equipment cannot directly measure the temperature of the wafer, a temperature of the graphite piece right above the wafer is measured for indirect temperature measurement on the wafer, the measured temperature of the graphite piece may change along with a change of the temperature field, and reliability of the temperature measurement cannot be ensured by measuring the temperature of the graphite piece through the single temperature measurement hole.

[0035] In order to solve at least one of the above problems, an embodiment provides a semiconductor heat treatment equipment, including: a coil, a chamber, a first temperature sensor, a second temperature sensor, and a temperature controller;

[0036] The chamber is used for placement of a wafer to be processed, and the coil surrounds the chamber and provides a thermal field for the chamber. Referring to a structural front view of a chamber in FIG. 2a and a structural side view of a chamber in FIG. 2b, the chamber is provided with a first temperature measurement hole 21 and a second temperature measurement hole 22, which are distributed in a central region of the chamber; and a position of the wafer 20 to be processed is such arranged that a center point of the wafer 20 to be processed coincides with a center point of the chamber, that is, the center point of the chamber and the center point of the wafer are the same point.

[0037] The first temperature sensor is configured to detect a temperature of the chamber through the first temperature measurement hole 21, and record the temperature as a first temperature.

[0038] The second temperature sensor is configured to detect the temperature of the chamber through the second temperature measurement hole 22, and record the temperature as a second temperature.

[0039] The temperature controller is configured to acquire the first temperature and the second temperature, determine, when the temperature of the chamber reaches a steady state, whether a center position of the coil deviates from the center point of the chamber based on the first temperature and/or the second temperature, and control the coil to translate along a central axis based on the first temperature and/or the second temperature if the center position of the coil deviates from the center point of the chamber until the center position of the coil reaches the center point of the chamber. It should be understood that the central axis of the coil coincides with a central axis of the chamber.

[0040] After a process is started, a current is introduced into the coil to heat the chamber at constant power, the temperature of the chamber reaches a required process temperature after the chamber is heated for a certain period of time (e.g., 30 min), it is determined whether a fluctuation amplitude of the temperature of the chamber within a preset duration is less than a set amplitude, and it is determined that the temperature of the chamber reaches the steady state if the fluctuation amplitude of the temperature of the chamber within the preset duration is less than the set amplitude. In an implementation, the temperature of the chamber may be detected in real time based on the first temperature sensor and/or the second temperature sensor, and it is determined that the temperature of the chamber reaches the steady state when the temperature of the chamber reaches a set process temperature and the fluctuation amplitude within 1 min is less than 0.2°C. The temperature of the chamber (i.e., an inner wall temperature of the chamber) is monitored based on the first temperature sensor and the second temperature sensor.

[0041] It is found by research that when the temperature of the chamber reaches the steady state, a point of highest temperature is at a center point of the coil or is distributed in the central region of the chamber, the central region is a region which takes the center point of the chamber as a center and has an edge keeping a certain distance (e.g., 5 mm) from the center, and each temperature in the central region may be regarded as a point of highest temperature, that is, a difference between each temperature in the central region and an actual point of highest temperature is within an allowable deviation range. When the first temperature sensor and the second temperature sensor are distributed in the central region of the chamber, if the center point of the chamber coincides with the center point of the coil,

that is, when the center point of the wafer coincides with the center point of the coil, temperature values detected by the first temperature sensor and the second temperature sensor are equal, or a difference between the detected temperature values is within an allowable deviation range.

[0042] In an implementation, it may be determined whether the center position of the coil deviates from the center point of the chamber or a distance by which the center position of the coil deviates from the center point of the chamber exceeds an allowable deviation range by determining whether the first temperature and the second temperature detected by the first temperature sensor and the second temperature sensor are equal or a difference between the first temperature and the second temperature is within the allowable deviation range, and then it may be determined whether the center point of the wafer deviates from the center position of the coil.

[0043] In some embodiments, the first temperature measurement hole 21 and the second temperature measurement hole 22 are distributed on two sides of a center of the chamber. In an embodiment, the first temperature measurement hole 21 and the second temperature measurement hole 22 are symmetrically distributed with respect to the center of the chamber, so that the first temperature sensor and the second temperature sensor may be equidistantly distributed in a central region of the wafer and distributed in central symmetry. When the center point of the chamber coincides with the center point of the coil, that is, when the center point of the wafer coincides with the center point of the coil, the temperature values detected by the first temperature sensor and the second temperature sensor are equal; and it may be determined whether the center position of the coil deviates from the center point of the chamber by determining whether the first temperature and the second temperature detected by the first temperature sensor and the second temperature sensor are equal, and then it may be determined whether the center point of the wafer deviates from the center position of the coil.

[0044] It should be noted that one first temperature measurement hole 21 and one second temperature measurement hole 22 are provided in the present embodiment, but the embodiments of the present disclosure are not limited thereto. In practical applications, a number of each of the first temperature measurement hole 21 and the second temperature measurement hole 22 may be more than one, the first temperature measurement hole 21 and the second temperature measurement hole 22 are disposed in pair, and each pair of the first temperature measurement hole 21 and the second temperature measurement hole 22 are

distributed in the central region of the chamber. Based on the above, the first temperature sensor and the second temperature sensor are disposed in pair, and each pair of the first temperature sensor and the second temperature sensor are in one-to-one correspondence with each pair of the first temperature measurement hole 21 and the second temperature measurement hole 22.

[0045] In another implementation, a chamber temperature distribution curve graph when the temperature of the chamber reaches the steady state may be obtained, it may be determined whether the center position of the coil deviates from the center point of the chamber or the distance by which the center position of the coil deviates from the center point of the chamber exceeds the allowable deviation range by determining, based on the chamber temperature distribution curve graph, whether the first temperature detected by the first temperature sensor or the second temperature detected by the second temperature sensor is reasonable (for example, whether the first temperature or the second temperature corresponds to and is equal to a temperature in the chamber temperature distribution curve graph), and then it may be determined whether the center point of the wafer deviates from the center position of the coil.

[0046] According to the semiconductor heat treatment equipment provided in the present embodiment, by disposing the two temperature measurement holes in the chamber and determining, when the temperature of the chamber reaches the steady state, whether the center position of the coil deviates from the center point of the chamber or the distance by which the center position of the coil deviates from the center point of the chamber exceeds the allowable deviation range based on the first temperature detected by the first temperature sensor and/or the second temperature detected by the second temperature sensor, it can be determined whether the center point of the wafer is at the point of highest temperature; and by moving the coil when the center point of the wafer deviates from the center position of the coil to enable the center position of the coil to reach the center point of the chamber, it can be ensured that a center of the wafer coincides with a center of the coil during the process, so that the wafer is always kept at the point of highest temperature, and temperature uniformity of the wafer is ensured.

[0047] In an embodiment, the temperature controller provided in the present embodiment is further configured to determine whether the first temperature is equal to the second temperature or the difference between the first temperature and the second temperature is within the allowable deviation range, and determine that the center position of the coil

deviates from the center point of the chamber if the first temperature is not equal to the second temperature or the difference between the first temperature and the second temperature exceeds the allowable deviation range; control the coil to translate along the central axis based on the first temperature and the second temperature until the first temperature is equal to the second temperature or the difference between the first temperature and the second temperature is within the allowable deviation range, and determine that the center position of the coil reaches the center point of the chamber.

[0048] When the temperature values detected by the first temperature sensor and the second temperature sensor are not equal or the difference between the detected temperature values exceeds the allowable deviation range, it is indicated that the center point of the chamber does not coincide with the center point of the coil, that is, the center point of the wafer deviates from the center position of the coil or a distance by which the center point of the wafer deviates from the center position of the coil exceeds an allowable deviation range. Therefore, the coil is controlled to translate along the central axis (that is, the coil surrounding the chamber is translated along the central axis of the chamber, and a distance between the coil and an outer wall of the chamber is kept unchanged in the translation process, for example, the central axis of the coil is kept coincident with the central axis of the chamber) to translate the center position of the coil until the temperature values detected by the first temperature sensor and the second temperature sensor are equal or the difference between the detected temperature values is within the allowable deviation range, it is determined that the center position of the coil reaches the center point of the chamber, that is, the center position of the coil reaches the center point of the wafer, and the wafer reaches the point of highest temperature.

[0049] In another embodiment, the chamber provided in the present embodiment includes a plurality of regions, and the number of turns of the coil in each region is the same, a temperature gradient distribution curve when the temperature of the chamber reaches the steady state is stored in the temperature controller, and the temperature gradient distribution curve illustrates a chamber temperature corresponding to each region; and the chamber is evenly divided into the plurality of regions based on the number of turns of the coil outside the chamber, for example, when a total number of turns of the coil is 10, the chamber within the coil may be divided into 10 regions, with the number of turns of the coil in each region being 1. Referring to a chamber temperature distribution curve graph of regions in a chamber shown in FIG. 3 where the horizontal axis represents a region number and the

vertical axis represents a chamber temperature (in units of k), as can be seen from FIG. 3, the chamber temperatures after the chamber reaches the steady state are in axisymmetric nonlinear distribution, and the point of highest temperature is at the center point of the coil, i.e., the center points of the chamber and the wafer. Therefore, when distributing two temperature measurement points in the central region of the chamber, optionally, the two temperature measurement points are equidistantly distributed in the central region of the chamber and distributed in central symmetry; if the center point of the coil coincides with the center point of the chamber, temperatures measured at the two temperature measurement points are equal or a difference between the measured temperatures is within an allowable deviation range, a position of the coil may be adjusted based on the temperature difference between the two temperature measurement points, then the point of highest temperature in the temperature field may coincide with the center of the wafer.

[0050] In some embodiments, the temperature controller is further configured to acquire a region of the chamber where the first temperature measurement hole is located, and record the region as a first setting region; determine a chamber temperature at the temperature gradient distribution curve which corresponds to the first setting region, and record the chamber temperature as a first target temperature; determine whether the first temperature is equal to the first target temperature or a difference between the first temperature and the first target temperature is within an allowable deviation range, and determine that the center position of the coil deviates from the center point of the chamber if the first temperature is not equal to the first target temperature or the difference between the first temperature and the first target temperature exceeds the allowable deviation range. The first target temperature is a temperature expected to be detected by the first temperature sensor when the center point of the chamber coincides with the center point of the coil.

[0051] In some embodiments, the temperature controller is further configured to acquire a region of the chamber where the second temperature measurement hole is located, and record the region as a second setting region; determine a chamber temperature at the temperature gradient distribution curve which corresponds to the second setting region, and record the chamber temperature as a second target temperature; determine whether the second temperature is equal to the second target temperature or a difference between the second temperature and the second target temperature is within an allowable deviation range, and determine that the center position of the coil deviates from the center point of the chamber if the second temperature is not equal to the second target temperature or the

difference between the second temperature and the second target temperature exceeds the allowable deviation range. The second target temperature is a temperature expected to be detected by the second temperature sensor when the center point of the chamber coincides with the center point of the coil.

[0052] It should be noted that the temperature controller can acquire the first setting region, determine the chamber temperature at the temperature gradient distribution curve which corresponds to the first setting region, and determine that the center position of the coil deviates from the center point of the chamber if the first temperature is not equal to the first target temperature or the difference between the first temperature and the first target temperature exceeds the allowable deviation range. Alternatively, the temperature controller can acquire the second setting region, determine the chamber temperature at the temperature gradient distribution curve which corresponds to the second setting region, and determine that the center position of the coil deviates from the center point of the chamber if the second temperature is not equal to the second target temperature or the difference between the second temperature and the second target temperature exceeds the allowable deviation range. Alternatively, the temperature controller can acquire the first setting region and the second setting region, determine the respective chamber temperatures at the temperature gradient distribution curve which correspond to the first setting region and the second setting region, and determine that the center position of the coil deviates from the center point of the chamber if the first temperature is not equal to the first target temperature or the difference between the first temperature and the first target temperature exceeds the allowable deviation range, and/or if the second temperature is not equal to the second target temperature or the difference between the second temperature and the second target temperature exceeds the allowable deviation range. If the first temperature is equal to the first target temperature or the difference between the first temperature and the first target temperature is within the allowable deviation range, and if the second temperature is equal to the second target temperature or the difference between the second temperature and the second target temperature is within the allowable deviation range, it is indicated that the center point of the chamber coincides with the center point of the coil, and the position of the coil does not deviate.

[0053] Taking the chamber temperature distribution curve graph shown in FIG. 3 as an example, assuming that the first setting region of the first temperature measurement hole is Region 8 and the second setting region of the second temperature measurement hole is

Region 2, it can be seen from the chamber temperature distribution curve graph that when the center point of the chamber coincides with the center point of the coil, the first target temperature at the temperature gradient distribution curve which corresponds to the first setting region (i.e., Region 8) of the first temperature measurement hole is 1550°C, and the second target temperature at the temperature gradient distribution curve which corresponds to the second setting region (i.e., Region 2) of the second temperature measurement hole is 1550°C. Based on the above, when the temperature of the chamber reaches the steady state, it is determined whether the first temperature detected by the first temperature sensor is equal to the first target temperature, and it is indicated that the position of the coil deviates and the center point of the chamber does not coincide with the center point of the coil if the first temperature is not equal to the first target temperature; and it is determined whether the second temperature detected by the second temperature sensor is equal to the second target temperature, and it is indicated the position of the coil deviates and the center point of the chamber does not coincide with the center point of the coil if the second temperature is not equal to the second target temperature. If the first temperature detected by the first temperature sensor and the second temperature detected by the second temperature sensor are equal and are both 1550°C, it is indicated that the center point of the chamber coincides with the center point of the coil, and the position of the coil does not deviate.

[0054] In an embodiment, the semiconductor heat treatment equipment provided in the present embodiment further includes: a drive component, which is connected to the coil, and is configured to drive the coil to translate. The drive component includes, for example, a motor.

[0055] In an implementation, the temperature controller is further configured to calculate a translation amount and a translation direction of the coil based on the first target temperature and the first temperature, and control, based on the translation amount and the translation direction, the drive component to drive the coil to translate until the center point of the coil coincides with the center point of the chamber.

[0056] When the first temperature currently detected by the first temperature sensor is higher than the first target temperature, it is indicated that the center point of the coil is closer to the first temperature measurement hole, such that the temperature detected by the first temperature sensor is higher than the first target temperature expected to be detected in a case of no deviation of the center of the coil. Therefore, the coil is controlled to translate toward the second temperature measurement hole (i.e., in a direction from the center point

of the chamber to the second temperature measurement hole), and the translation amount is related to the difference between the first temperature and the first target temperature: the greater the difference, the larger the translation amount. Conversely, if the first temperature is lower than the first target temperature, it is indicated that the center point of the coil is closer to the second temperature measurement hole, such that the temperature detected by the first temperature sensor is lower than the first target temperature expected to be detected in a case of no deviation of the center of the coil. Therefore, the coil is controlled to translate toward the first temperature measurement hole (i.e., in a direction from the center point of the chamber to the first temperature measurement hole), and the translation amount is related to the difference between the first target temperature and the first temperature: the greater the difference, the larger the translation amount.

[0057] Illustratively, taking the chamber temperature distribution curve graph shown in FIG. 3 as an example, assuming that the first temperature measurement hole is disposed in Region 8, when the center point of the chamber coincides with the center point of the coil, the first target temperature expected to be detected by the first temperature sensor is 1550°C as shown in FIG. 3. If the first temperature detected by the first temperature sensor is 1600°C when the temperature of the chamber reaches the steady state, it is indicated that the curve in FIG. 3 translates toward the first temperature measurement hole (i.e., in a direction from Region 2 to Region 8) by one region, that is, the chamber translates toward the second temperature measurement hole by one region, and the center of the coil is closer to the first temperature measurement hole. Therefore, the coil is controlled to translate toward the second temperature measurement hole (i.e., in a direction from Region 8 to Region 2) by one region length (such as by 30 mm), so as to restore both the first temperature and the second temperature to 1550°C.

[0058] In some embodiments, taking the drive component including a rotating motor and a transmission structure as an example, the translation direction of the coil is controlled by controlling the drive component to rotate forward or reversely, converting power supplied by the rotating motor into linear power with the transmission structure, and transmitting the linear power to the coil. Certainly, the drive component may further include a linear motor in practical applications.

[0059] In another implementation, the temperature controller is further configured to calculate a translation amount and a translation direction of the coil based on the second target temperature and the second temperature, and control, based on the translation amount

and the translation direction, the motor to rotate to drive the coil to translate until the center point of the coil coincides with the center point of the chamber.

[0060] When the second temperature currently detected by the second temperature sensor is higher than the second target temperature, it is indicated that the center point of the coil is closer to the second temperature measurement hole than to the first temperature measurement hole, such that the second temperature detected by the second temperature sensor is higher than the second target temperature expected to be detected in a case of no deviation of the center of the coil. Therefore, the coil is controlled to translate toward the first temperature measurement hole, and the translation amount is related to the difference between the second temperature and the second target temperature: the greater the difference, the larger the translation amount. Conversely, if the second temperature is lower than the second target temperature, it is indicated that the center point of the coil is closer to the first temperature measurement hole than to the second temperature measurement hole, such that the second temperature detected by the second temperature sensor is lower than the second target temperature expected to be detected in a case of no deviation of the center of the coil. Therefore, the coil is controlled to translate toward the second temperature measurement hole, and the translation amount is related to the difference between the second target temperature and the second temperature: the greater the difference, the larger the translation amount.

[0061] Illustratively, taking the chamber temperature distribution curve graph shown in FIG. 3 as an example, assuming that the second temperature measurement hole is disposed in Region 2, when the center of the chamber coincides with the center of the coil, the second target temperature expected to be detected by the second temperature sensor is 1550°C as shown in FIG. 3. If the second temperature detected by the second temperature sensor is 1500°C when the temperature of the chamber reaches the steady state, it is indicated that the curve in FIG. 3 translates toward the first temperature measurement hole (i.e., in a direction from Region 2 to Region 8) by one region, that is, the chamber translates toward the second temperature measurement hole by one region, and the center of the coil is closer to the first temperature measurement hole than to the second temperature measurement hole. Therefore, the coil is controlled to translate toward the second temperature measurement hole (i.e., in a direction from Region 8 to Region 2) by one region length (such as by 30 mm), so as to restore both the first temperature and the second temperature to 1550°C.

[0062] In an embodiment, the temperature controller provided in the present embodiment is a programmable logic controller; and the programmable logic controller is respectively communicatively connected to the first temperature sensor, the second temperature sensor, and an induction power supply of the coil, so that the programmable logic controller is capable of acquiring the first temperature detected by the first temperature sensor, the second temperature detected by the second temperature sensor, an alternating current I passing through the coil, and a current frequency f .

[0063] According to the semiconductor heat treatment equipment provided in the present embodiment, the coil can be adjusted and translated based on the temperature distribution curve of the chamber and the temperatures detected by the two temperature sensors, so that the point of highest temperature at the center point of the coil can be ensured to coincide with the center point of the wafer, and temperature uniformity of the wafer during growth can be ensured; the temperature of the chamber can be easily controlled and fast calculated, and temperature adjustment efficiency is improved; and by using the two temperature sensors to detect the temperature in the chamber, temperature measurement can be performed effectively and reliably, positions of the two temperature measurement holes can be used as judgment conditions for the adjustment of the position of the coil, and the temperature uniformity of the wafer can be ensured.

[0064] Corresponding to the semiconductor heat treatment equipment provided in the above embodiments, an embodiment provides a temperature control method for a semiconductor heat treatment equipment, which is applied to the semiconductor heat treatment equipment provided in the above embodiments. Referring to a flowchart illustrating a temperature control method for a semiconductor heat treatment equipment shown in FIG. 4, the method mainly includes the following steps.

[0065] At step S402, the first temperature detected by the first temperature sensor is acquired, and the second temperature detected by the second temperature sensor is acquired.

[0066] The temperature controller is respectively communicatively connected to the first temperature sensor and the second temperature sensor, and acquires the first temperature detected by the first temperature sensor and the second temperature detected by the second temperature sensor in real time.

[0067] At step S404, when the temperature of the chamber reaches the steady state, it is determined whether the center position of the coil deviates from the center point of the chamber based on the first temperature and/or the second temperature.

[0068] After a process is started, a current is introduced into the coil to heat the chamber at constant power, the temperature of the chamber reaches a required process temperature after the chamber is heated for a certain period of time (e.g., 30 min), it is determined whether a fluctuation amplitude of the temperature of the chamber within a preset duration is less than a set amplitude, and it is determined that the temperature of the chamber reaches the steady state if the fluctuation amplitude of the temperature of the chamber within the preset duration is less than the set amplitude.

[0069] When the temperature of the chamber reaches the steady state, in a case where the center point of the chamber coincides with a center point of the coil, temperature values detected by the first temperature sensor and the second temperature sensor are equal. In an implementation, it may be determined whether the center position of the coil deviates from the center point of the chamber by determining whether the first temperature and the second temperature detected by the first temperature sensor and the second temperature sensor are equal or a difference between the first temperature and the second temperature is within an allowable deviation range, and then it may be determined whether a center point of the wafer deviates from the center position of the coil.

[0070] In another implementation, it may be determined whether the center position of the coil deviates from the center point of the chamber by determining, based on a chamber temperature distribution curve graph, whether the first temperature detected by the first temperature sensor or the second temperature detected by the second temperature sensor is reasonable (for example, whether the first temperature or the second temperature corresponds to and is equal to a temperature in the chamber temperature distribution curve graph), and then it may be determined whether the center point of the wafer deviates from the center position of the coil.

[0071] At step S406, if the center position of the coil deviates from the center point of the chamber, the coil is controlled to translate along a central axis based on the first temperature and/or the second temperature until the center position of the coil reaches the center point of the chamber.

[0072] In an implementation, the coil is controlled to translate along the central axis based on the first temperature and the second temperature until the first temperature is equal to

the second temperature or the difference between the first temperature and the second temperature is within the allowable deviation range, and it is determined that the center position of the coil reaches the center point of the chamber. In another implementation, the chamber temperature distribution curve graph when the temperature of the chamber reaches the steady state may be obtained, the coil is controlled to translate along the central axis based on the first temperature or the second temperature, and it is determined that the center position of the coil reaches the center point of the chamber when the first temperature or the second temperature corresponds to and is equal to a temperature in the chamber temperature distribution curve graph.

[0073] In the temperature control method for a semiconductor heat treatment equipment provided in the present embodiment, by disposing two temperature measurement holes in the chamber and determining, when the temperature of the chamber reaches the steady state, whether the center position of the coil deviates from the center point of the chamber based on the first temperature detected by the first temperature sensor and/or the second temperature detected by the second temperature sensor, it can be determined whether the center point of the wafer is at a point of highest temperature; and by moving the coil when the center point of the wafer deviates from the center position of the coil to enable the center position of the coil to reach the center point of the chamber, it can be ensured that a center of the wafer coincides with a center of the coil during the process, so that the wafer is always kept at the point of highest temperature, and temperature uniformity of the wafer is ensured.

[0074] An embodiment provides an implementation of determining whether the center position of the coil deviates from the center point of the chamber based on the first temperature and the second temperature: determining whether the first temperature is equal to the second temperature or the difference between the first temperature and the second temperature is within the allowable deviation range, and determining that the center position of the coil deviates from the center point of the chamber if the first temperature is not equal to the second temperature or the difference between the first temperature and the second temperature exceeds the allowable deviation range.

[0075] An embodiment provides an implementation of controlling the coil to translate along the central axis based on the first temperature and the second temperature until the center position of the coil reaches the center point of the chamber, which may be performed by referring to the following steps.

[0076] Step (1): in a case where the first temperature is higher than the second temperature, the coil is controlled to translate in a first direction until the first temperature is equal to the second temperature, with the first direction being a direction in which the second temperature measurement hole is located.

[0077] If the first temperature is higher than the second temperature, it is indicated that the temperature detected by the first temperature sensor is higher, the center point of the coil deviates in a direction in which the first temperature measurement hole is located. Therefore, the coil is controlled to translate in the direction in which the second temperature measurement hole is located (i.e., a direction from a region where the first temperature measurement hole is located to a region where the second temperature measurement hole is located), so as to make the first temperature equal to the second temperature.

[0078] Taking the chamber shown in FIG. 2b as an example, when the first temperature is higher than the second temperature, it is indicated that the center point of the coil is closer to the first temperature measurement hole 21 and is on the right side of the center point of the chamber. Therefore, the coil is controlled to translate in the direction in which the second temperature measurement hole is located, that is, the coil is controlled to translate to the left until the first temperature is equal to the second temperature, then the center point of the wafer coincides with the center point of the coil.

[0079] Step (2): in a case where the first temperature is lower than the second temperature, the coil is controlled to translate in a second direction until the first temperature is equal to the second temperature, with the second direction being a direction in which the first temperature measurement hole is located.

[0080] If the first temperature is lower than the second temperature, it is indicated that the temperature detected by the second temperature sensor is higher, and the center point of the coil is closer to the second temperature sensor. Therefore, the coil is controlled to translate in the direction in which the first temperature measurement hole is located, so as to make the first temperature equal to the second temperature.

[0081] Taking the chamber shown in FIG. 2b as an example, when the first temperature is lower than the second temperature, it is indicated that the center point of the coil is closer to the second temperature measurement hole 22 and is on the left side of the center point of the chamber. Therefore, the coil is controlled to translate in the direction in which the first temperature measurement hole 21 is located, that is, the coil is controlled to translate to the

right until the first temperature is equal to the second temperature, then the center point of the wafer coincides with the center point of the coil.

[0082] In an embodiment, in order to prove that the point of highest temperature is at the center position of the coil, the method provided in the present embodiment further includes the following steps.

[0083] At step 1), a skin depth of the chamber at a preset process temperature is calculated, an alternating current value of the coil is acquired, the chamber is divided into a plurality of regions based on the number of turns of the coil, and a heat source intensity of each region of the chamber is calculated based on the skin depth and the alternating current value, with the number of turns of the coil in each region being the same.

[0084] A temperature field of the coil is analyzed to determine a location of highest temperature in the chamber. Firstly, an analysis of a magnetic field intensity of the chamber is carried out, and a calculation formula for an intensity of a magnetic field acting on the chamber is as follows:

$$H_{m0} = \sqrt{2} * \left(\frac{n}{Z_0} \right) \quad (\text{Formula One})$$

where n is the number of turns of the coil, and Z_0 is a winding length of the coil. A calculation formula for a density of an eddy current acting on an inner surface of the chamber is as follows:

$$\delta_{m0} = \sqrt{2} * \frac{H_{m0}}{\Delta} = 2 * \frac{I}{\Delta} * \left(e^{\frac{r-r_0}{\Delta}} \right) \quad (\text{Formula Two})$$

where δ_{m0} is the density of the eddy current acting on the surface of the chamber, Δ is the skin depth, H_{m0} is the intensity of the magnetic field, r is a radius of a measured point, and r_0 is a cylinder radius of the chamber.

[0085] A calculation formula for the skin depth is as follows:

$$\Delta = \sqrt{\frac{2}{\omega * \mu * \gamma}} \quad (\text{Formula Three})$$

where ω is angular frequency ($\omega=2\pi f$ (rad/s), and frequency $f=4900$ Hz), μ is magnetic permeability ($\mu=4\pi*10^7$), and γ is electrical conductivity (e.g., 83333S/m).

[0086] Along with a change of the radius, a calculation formula for an eddy current density at the measured point is as follows:

$$\delta_{mr} = \delta_{m0} * e^{\frac{r-r_0}{\Delta}} \quad (\text{Formula Four})$$

[0087] When small area ds on the radius r is considered, a calculation formula for an eddy current passing through the small area is as follows:

$$dI_r = \delta_{mr} * dS \quad (\text{Formula Five})$$

[0088] A calculation formula for a power at which the eddy current is generated is as follows:

$$dP = (dI_r)^2 * dR * \frac{1}{J} \quad (\text{Formula Six})$$

where dR is effective resistance of a material of the eddy current passing through the small area, and J is a conversion parameter ($J=4.18 \text{ cal/w}$).

[0089] The heat source intensity may be calculated by the Formula Five and the Formula Six, the chamber is evenly divided into a plurality of regions based on the number of turns of the coil, and the number of turns of the coil in each region is the same. For example, in a case where the number of turns of the coil is 30, if the chamber is divided into 10 regions, the number of turns of the coil in each region is 3; in a case where the number of turns of the coil is 10, if the chamber is divided into 10 regions, the number of turns of the coil in each region $n_i=1$, and the winding length of the coil in each region $Z_i=30 \text{ mm}$, then a calculation formula for the heat source intensity of an i^{th} region of the chamber is as follows:

$$F_i = \frac{dP}{dV} = \frac{4 * \rho * I^2}{\Delta^2 * J * e^{\frac{2 * r_0}{\Delta}}} * \left(\frac{n_i}{Z_i} \right) * e^{\frac{2 * r}{\Delta}} \quad (\text{Formula Seven})$$

where ρ is a resistivity of a chamber material, I is the alternating current introduced into the coil, and F_i is the heat source intensity of the i^{th} region.

[0090] Since the number of turns of the coil in each region is the same and the length of the coil is fixed, it can be found by simulation calculation that the heat source intensity of each region is the same. Assuming that a chamber thickness is 15 mm, and the radius r of the measured point meets $r=0.085 \text{ m}$, referring to a schematic diagram illustrating distribution of heat source intensity of the regions in the chamber shown in FIG. 5, it may be obtained by calculation that $F_1=F_2=F_3=\dots=F_{10}=3.9511 * 10^4 \text{ W/m}^3$, that is, the heat source intensity of each region in the chamber is the same.

[0091] At step 2), ambient temperatures at two ends of the chamber when the temperature of the chamber reaches the steady state are acquired, and a chamber temperature of each region is calculated based on the ambient temperatures and the heat source intensity of each region to obtain a temperature gradient distribution curve of the chamber.

[0092] A heat quantity of each region is calculated based on the heat source intensity of each region by the following formula:

$$Q_i = F * V_i * t \quad (\text{Formula Eight})$$

where Q_i is a heat quantity of the i^{th} region, V_i is a volume of the i^{th} region, and t is heating time.

[0093] Without any external interference, under the condition that the heat source intensity in the chamber is stable, energy in the chamber is uniform and consistent, an influence of the ambient temperature on the temperature field in the chamber needs to be considered, and a heat loss may be calculated and simulated by the following Formula Nine for an influence of a chamber environment on the chamber. Under the condition of considering that the ambient temperature and the temperature in the chamber are in a stable state, the ambient temperature at the front of the chamber and the ambient temperature at the back of the chamber are stable and same, and heat generated by the chamber is equal to heat absorbed by the environment around the chamber.

$$Q = \sigma * \varepsilon * A * (T_1^4 - T_2^4) \quad (\text{Formula Nine})$$

where Q is variation of environmental heat of the chamber caused by heat radiation, σ is a Stokes constant, ε is a surface thermal emissivity of the chamber, A is an area of the inner surface of the chamber, T_2 is the ambient temperature, and T_1 is a chamber temperature after the temperature of the chamber reaches the steady state (i.e., a temperature of the inner surface of the chamber).

[0094] If the heating time $t=1s$, a calculation formula for the chamber temperature is as follows:

$$T_1 = \sqrt[4]{\frac{F * V}{\sigma * \varepsilon * A}} + T_2^4 \quad (\text{Formula Ten})$$

[0095] The present embodiment provides an implementation of calculating the chamber temperature of each region based on the ambient temperatures and the heat source intensity of each region, which may be performed by referring to the following steps.

[0096] At step 1, starting from a first region at either end of the chamber, the chamber temperature of the first region when a process reaches a steady state is calculated based on the heat source intensity of the first region and the ambient temperatures.

[0097] Starting from the first region at either end of the chamber, taking the chamber in FIG. 2b as an example, for example, the chamber may be divided into 10 regions in a case

where the number of turns of the coil is 10, starting from a first region at the left end of the chamber in FIG. 2b, a calculation formula for the chamber temperature of the first region is as follows:

$$T_{11} = \sqrt[4]{\frac{F_1 * V_1}{\sigma * \epsilon * A}} + T_{12}^4$$

where T_{11} is the chamber temperature of the first region, F_1 is the heat source intensity of the first region, σ is the Stokes constant, ϵ is the surface thermal emissivity of the chamber, A is the area of the inner surface of the chamber, T_{12} is the ambient temperature corresponding to the first region (i.e., the ambient temperatures at the two ends of the chamber, which may be obtained by detection with a thermometer), and V_1 is the volume of the first region.

[0098] At step 2, the chamber temperature of the first region is taken as the ambient temperature of a next adjacent region, the chamber temperature of the next region when the process reaches the steady state is calculated based on the ambient temperature of the next region and the heat source intensity of the next region, and so on until the chamber temperature of a region where the center point of the chamber is located is obtained by calculation.

[0099] Taking the chamber temperature of the first region as the ambient temperature of the next adjacent region, i.e., $T_{22} = T_{11}$, a calculation formula for the chamber temperature of the next region (i.e., a second region) is as follows:

$$T_{21} = \sqrt[4]{\frac{F_2 * V_2}{\sigma * \epsilon * A}} + T_{22}^4$$

where T_{21} is the chamber temperature of the second region, F_2 is the heat source intensity of the second region, T_{22} is the ambient temperature corresponding to the second region (that is, the chamber temperature of the first region, which is taken as the ambient temperature of the adjacent second region), and V_2 is the volume of the second region.

[0100] The chamber temperature of the second region is taken as the ambient temperature of an adjacent third region, and so on. Thus, the chamber temperature of the first region to the chamber temperature of the region where the center point of the chamber is located are sequentially calculated.

$$T_{i1} = \sqrt[4]{\frac{F_i * V_i}{\sigma * \epsilon * A}} + T_{i2}^4$$

where T_{i1} is the chamber temperature of the i^{th} region, F_i is the heat source intensity of the i^{th} region, σ is the Stokes constant, ε is the surface thermal emissivity of the chamber, A is the area of the inner surface of the chamber, T_{i2} is the ambient temperature corresponding to the i^{th} region, and V_i is the volume of the i^{th} region.

[0101] At step 3, based on symmetry of the chamber temperatures from the first region at one end of the chamber to the region where the center point of the chamber is located, chamber temperatures of regions from the region where the center point of the chamber is located to the other end of the chamber are obtained.

[0102] Due to the symmetry of the chamber temperatures, a chamber temperature curve graph of the regions at the other half of the chamber may be derived from a chamber temperature curve graph of the first region to the region where the center point of the chamber is located, with the two chamber temperature curve graphs symmetric to each other.

[0103] When the chamber reaches the steady state, referring to the chamber temperature distribution curve graph of the regions in the chamber shown in FIG. 3 where the horizontal axis represents the region number and the vertical axis represents the chamber temperature (in units of k), as can be seen from FIG. 3, a temperature model after the chamber reaches the steady state presents axisymmetric nonlinear distribution, and the point of highest temperature is at the center point of the coil, i.e., the center points of the chamber and the wafer. Therefore, when the two temperature measurement holes are equidistantly distributed in the central region of the chamber and distributed in central symmetry, the temperatures detected by the two temperature sensors are equal when the center point of the coil coincides with the center point of the chamber.

[0104] In an embodiment, the present embodiment provides two implementations of determining whether the center position of the coil deviates from the center point of the chamber based on the first temperature and/or the second temperature.

[0105] In an implementation, a region of the chamber where the first temperature measurement hole is located is acquired and recorded as a first setting region; a chamber temperature at the temperature gradient distribution curve which corresponds to the first setting region is determined and recorded as a first target temperature; and it is determined whether the first temperature is equal to the first target temperature, and it is determined that the center position of the coil deviates from the center point of the chamber if the first temperature is not equal to the first target temperature.

[0106] The setting position of the temperature measurement hole on the chamber is generally unchanged, the region where the first temperature measurement hole is located is acquired and recorded as the first setting region, and the chamber temperature at the temperature gradient distribution curve which corresponds to the first setting region is determined and recorded as the first target temperature, i.e., a temperature theoretically expected to be detected by the first temperature sensor when the temperature of the chamber reaches the steady state and the center point of the coil coincides with the center point of the chamber. If the first temperature is equal to the first target temperature, it is determined that the center position of the coil does not deviate from the center point of the chamber, and the wafer is at the point of highest temperature.

[0107] In another embodiment, a region of the chamber where the second temperature measurement hole is located is acquired and recorded as a second setting region; a chamber temperature at the temperature gradient distribution curve which corresponds to the second setting region is determined and recorded as a second target temperature; and it is determined whether the second temperature is equal to the second target temperature, and it is determined that the center position of the coil deviates from the center point of the chamber if the second temperature is not equal to the second target temperature.

[0108] The region where the second temperature measurement hole is located is acquired and recorded as the second setting region, and the chamber temperature at the temperature gradient distribution curve which corresponds to the second setting region is determined and recorded as the second target temperature, i.e., a temperature theoretically expected to be detected by the second temperature sensor when the temperature of the chamber reaches the steady state and the center point of the coil coincides with the center point of the chamber. If the second temperature is equal to the second target temperature, it is determined that the center position of the coil does not deviate from the center point of the chamber, and the wafer is at the point of highest temperature.

[0109] In an embodiment, the semiconductor heat treatment equipment provided in the present embodiment further includes a drive component, which is connected to the coil, and is configured to drive the coil to translate. The present embodiment provides two implementations of controlling the coil to translate along the central axis based on the first temperature and/or the second temperature until the center position of the coil reaches the center point of the chamber, which may be performed with reference to the following first implementation and second implementation.

First Implementation

[0110] A translation amount and a translation direction of the coil are calculated based on the first target temperature and the first temperature; and the drive component is controlled to rotate based on the translation amount and the translation direction, so as to drive the coil to translate until the center point of the coil coincides with the center point of the chamber.

[0111] When the first temperature currently detected by the first temperature sensor is higher than the first target temperature, it is indicated that the center point of the coil is closer to the first temperature measurement hole, such that the temperature detected by the first temperature sensor is higher than the first target temperature expected to be detected in a case of no deviation of the center of the coil. Therefore, the coil is controlled to translate toward the second temperature measurement hole (i.e., in a direction from the center point of the chamber to the second temperature measurement hole), and the translation amount is related to a difference between the first temperature and the first target temperature: the greater the difference, the larger the translation amount. Conversely, if the first temperature is lower than the first target temperature, it is indicated that the center point of the coil is closer to the second temperature measurement hole, such that the temperature detected by the first temperature sensor is lower than the first target temperature expected to be detected in a case of no deviation of the center of the coil. Therefore, the coil is controlled to translate toward the first temperature measurement hole (i.e., in a direction from the center point of the chamber to the first temperature measurement hole), and the translation amount is related to the difference between the first target temperature and the first temperature: the greater the difference, the larger the translation amount.

Second Implementation

[0112] A translation amount and a translation direction of the coil are calculated based on the second target temperature and the second temperature; and the drive component is controlled to rotate based on the translation amount and the translation direction, so as to drive the coil to translate until the center point of the coil coincides with the center point of the chamber.

[0113] When the second temperature currently detected by the second temperature sensor is higher than the second target temperature, it is indicated that the center point of the coil is closer to the second temperature measurement hole than to the first temperature measurement hole, such that the second temperature detected by the second temperature sensor is higher than the second target temperature expected to be detected in a case of no

deviation of the center of the coil. Therefore, the coil is controlled to translate toward the first temperature measurement hole, and the translation amount is related to a difference between the second temperature and the second target temperature: the greater the difference, the larger the translation amount. Conversely, if the second temperature is lower than the second target temperature, it is indicated that the center point of the coil is closer to the first temperature measurement hole than to the second temperature measurement hole, such that the second temperature detected by the second temperature sensor is lower than the second target temperature expected to be detected in a case of no deviation of the center of the coil. Therefore, the coil is controlled to translate toward the second temperature measurement hole, and the translation amount is related to the difference between the second target temperature and the second temperature: the greater the difference, the larger the translation amount.

[0114] According to the temperature control method for a semiconductor heat treatment equipment provided in the present embodiment, the coil can be adjusted and translated based on the temperature distribution curve of the chamber and the temperatures detected by the two temperature sensors, so that the point of highest temperature at the center point of the coil can be ensured to coincide with the center point of the wafer, and temperature uniformity of the wafer during growth can be ensured; the temperature of the chamber can be easily controlled and fast calculated, and temperature adjustment efficiency is improved; and by using the two temperature sensors to detect the temperature in the chamber, temperature measurement can be performed effectively and reliably, positions of the two temperature measurement holes can be used as judgment conditions for the adjustment of a position of the coil, and the temperature uniformity of the wafer can be ensured.

[0115] The implementation principle and technical effects of the method provided in the present embodiment are the same as those of the above embodiments. For brief description, reference may be made to the corresponding contents in the above equipment embodiments for which is not stated in the method embodiments.

[0116] An embodiment of the present disclosure provides a computer readable medium, which stores computer-executable instructions which, when called and executed by a processor, cause the processor to implement the method described in the above embodiments.

[0117] Those of ordinary skill in the art can clearly understand that, for convenience and simplicity of description, reference may be made to a corresponding process in the above

embodiments for a specific operating process of a system described above, and thus the specific operating process of the system will not be described here.

[0118] A computer program product of the temperature control method for a semiconductor heat treatment equipment provided in the embodiments of the present disclosure includes a computer-readable storage medium storing program codes, instructions included in the program codes may be used to implement the method described in the above method embodiments, reference may be made to the method embodiments for a specific implementation, and thus the specific implementation will not be described here.

[0119] In addition, in the description of the embodiments of the present disclosure, unless expressly stated and limited otherwise, the terms “mount”, “couple”, and “connect” should be understood broadly, for example, the terms may refer to fixed connection, detachable connection, or integration; the terms may refer to mechanic connection or electrical connection; and the terms may refer to direct connection, indirect connection through an intermediate medium, or communication between interiors of two elements. The specific meanings of the above terms in the present disclosure can be understood by those of ordinary skill in the art according to specific cases.

[0120] If implemented in the form of a software functional unit and sold or used as an independent product, the functions may be stored in a computer-readable storage medium. Based on such understanding, the essence of the technical solutions of the present disclosure or the part of the technical solutions of the present disclosure contributing to the existing technology or part of the technical solutions of the present disclosure may be implemented in the form of a software product, which is stored in a storage medium and includes several instructions to enable a computer device (which may be a personal computer, a server, or a network device) to perform all or part of the steps in the method described in each embodiment of the present disclosure. The above storage medium includes: a Universal Serial Bus Flash Disk (a USB flash disk), a mobile hard disk, a Read-Only Memory (ROM), a Random Access Memory (RAM), a magnetic disk, an optical disc, or various media capable of storing program codes.

[0121] In the description of the present disclosure, it should be understood that the orientations or positional relationships indicated by the terms “center”, “above”, “below”, “left”, “right”, “vertical”, “horizontal”, “inner”, “outer” and the like are the orientations or positional relationships based on the drawings, and those terms are used simply for conveniently describing the present disclosure and simplifying the description, rather than

indicating or implying that the device or element referred to must have a particular orientation or must be constructed and operated in a particular orientation, and therefore, those terms should not be considered as limitation to the present disclosure. In addition, the terms “first”, “second”, and “third” are used only for the purpose of description, and should not be interpreted as indicating or implying relative importance.

[0122] Finally, it should be noted that the above embodiments are just the specific implementations of the present disclosure, and are used to describe but not to limit the technical solutions of the present disclosure, and the scope of the present disclosure is not limited to the above embodiments. Although the present disclosure is described in detail with reference to the above embodiments, it should be understood by those of ordinary skill in the art that those of ordinary skill in the art can still make modifications to the technical solutions described in the above embodiments, or can readily envisage changes of the technical solutions described in the above embodiments, or make equivalent substitutions to part of the technical features within the technical scope disclosed in the present disclosure; and those modifications, changes or substitutions do not cause the essence of the corresponding technical solutions to depart from the spirit and scope of the technical solutions of the embodiments of the present disclosure, and should all fall within the scope of the present disclosure. Therefore, the scope of the present disclosure shall be subject to the scope of the claims.

What is claimed is:

1. A semiconductor heat treatment equipment, comprising: a coil, a chamber, a first temperature sensor, a second temperature sensor, and a temperature controller;

the chamber is used for placement of a wafer to be processed, the coil surrounds the chamber and provides a thermal field for the chamber, and the chamber is provided with a first temperature measurement hole and a second temperature measurement hole, which are distributed in a central region of the chamber;

the first temperature sensor is configured to detect a temperature of the chamber through the first temperature measurement hole, and record the temperature as a first temperature;

the second temperature sensor is configured to detect the temperature of the chamber through the second temperature measurement hole, and record the temperature as a second temperature; and

the temperature controller is configured to acquire the first temperature and the second temperature, determine, when the temperature of the chamber reaches a steady state, whether a center position of the coil deviates from a center point of the chamber based on the first temperature and/or the second temperature, and control the coil to translate along a central axis based on the first temperature and/or the second temperature in response to the center position of the coil deviating from the center point of the chamber until the center position of the coil reaches the center point of the chamber.

2. The semiconductor heat treatment equipment of claim 1, wherein the temperature controller is further configured to determine whether the first temperature is equal to the second temperature, and determine that the center position of the coil deviates from the center point of the chamber in response to the first temperature being not equal to the second temperature; and

control the coil to translate along the central axis based on the first temperature and the second temperature until the first temperature is equal to the second temperature, and determine that the center position of the coil reaches the center point of the chamber.

3. The semiconductor heat treatment equipment of claim 1, wherein the chamber comprises a plurality of regions, and a number of turns of the coil in each region is the same, a temperature gradient distribution curve when the temperature of the chamber reaches the steady state is stored in the temperature controller, and the temperature gradient distribution curve illustrates a chamber temperature corresponding to each region;

the temperature controller is further configured to acquire a region of the chamber where the first temperature measurement hole is located, and record the region as a first setting region; determine a chamber temperature at the temperature gradient distribution curve which corresponds to the first setting region, and record the chamber temperature as a first target temperature; determine whether the first temperature is equal to the first target temperature, and determine that the center position of the coil deviates from the center point of the chamber in response to the first temperature being not equal to the first target temperature; and/or

the temperature controller is further configured to acquire a region of the chamber where the second temperature measurement hole is located, and record the region as a second setting region; determine a chamber temperature at the temperature gradient distribution curve which corresponds to the second setting region, and record the chamber temperature as a second target temperature; determine whether the second temperature is equal to the second target temperature, and determine that the center position of the coil deviates from the center point of the chamber in response to the second temperature being not equal to the second target temperature.

4. The semiconductor heat treatment equipment of claim 3, further comprising: a drive component, which is connected to the coil, and is configured to drive the coil to translate;

the temperature controller is further configured to calculate a translation amount and a translation direction of the coil based on the first target temperature and the first temperature, and control, based on the translation amount and the translation direction, the drive component to drive the coil to translate until a center point of the coil coincides with the center point of the chamber; and/or

the temperature controller is further configured to calculate a translation amount and a translation direction of the coil based on the second target temperature and the

second temperature, and control, based on the translation amount and the translation direction, the drive component to drive the coil to translate until the center point of the coil coincides with the center point of the chamber.

5. The semiconductor heat treatment equipment of claim 1, wherein the temperature controller is a programmable logic controller, which is respectively communicatively connected to the first temperature sensor, the second temperature sensor, and an induction power supply of the coil.

6. A temperature control method for a semiconductor heat treatment equipment, which is applied to the semiconductor heat treatment equipment of any one of claims 1 to 5, comprising:

acquiring the first temperature detected by the first temperature sensor, and acquiring the second temperature detected by the second temperature sensor;

when the temperature of the chamber reaches the steady state, determining whether the center position of the coil deviates from the center point of the chamber based on the first temperature and/or the second temperature; and

in response to the center position of the coil deviating from the center point of the chamber, controlling the coil to translate along the central axis based on the first temperature and/or the second temperature until the center position of the coil reaches the center point of the chamber.

7. The method of claim 6, wherein determining whether the center position of the coil deviates from the center point of the chamber based on the first temperature and/or the second temperature comprises:

determine whether the first temperature is equal to the second temperature, and in response to the first temperature being not equal to the second temperature, determining that the center position of the coil deviates from the center point of the chamber; and/or

controlling the coil to translate along the central axis based on the first temperature and/or the second temperature until the center position of the coil reaches the center point of the chamber comprises:

in a case where the first temperature is higher than the second temperature, controlling the coil to translate in a first direction until the first temperature is equal to

the second temperature; wherein the first direction is a direction in which the second temperature measurement hole is located; and

in a case where the first temperature is lower than the second temperature, controlling the coil to translate in a second direction until the first temperature is equal to the second temperature; wherein the second direction is a direction in which the first temperature measurement hole is located.

8. The method of claim 6, further comprising:

calculating a skin depth of the chamber at a preset process temperature, acquiring an alternating current value of the coil, dividing the chamber into a plurality of regions based on a number of turns of the coil, and calculating a heat source intensity of each region of the chamber based on the skin depth and the alternating current value; wherein a number of turns of the coil in each region is the same; and

acquiring ambient temperatures at two ends of the chamber when the temperature of the chamber reaches the steady state, and calculating a chamber temperature of each region based on the ambient temperatures and the heat source intensity of each region to obtain a temperature gradient distribution curve of the chamber.

9. The method of claim 8, wherein calculating the chamber temperature of each region based on the ambient temperatures and the heat source intensity of each region comprises:

starting from a first region at either end of the chamber, calculating, based on the heat source intensity of the first region and the ambient temperatures, the chamber temperature of the first region when a process reaches a steady state;

taking the chamber temperature of the first region as an ambient temperature of a next adjacent region, calculating, based on the ambient temperature of the next region and the heat source intensity of the next region, the chamber temperature of the next region when the process reaches the steady state, and so on until the chamber temperature of a region where the center point of the chamber is located is obtained by calculation; and

based on symmetry of the chamber temperatures from the first region to the region where the center point of the chamber is located, obtaining chamber temperatures

of regions from the region where the center point of the chamber is located to the other end of the chamber.

10. The method of claim 9, wherein a calculation formula for the chamber temperature is as follows:

$$T_{i1} = \sqrt[4]{\frac{F_i * V_i}{\sigma * \varepsilon * A} + T_{i2}^4}$$

where T_{i1} is the chamber temperature of an i^{th} region, F_i is the heat source intensity of the i^{th} region, σ is a Stokes constant, ε is a surface thermal emissivity of the chamber, A is an area of an inner surface of the chamber, T_{i2} is an ambient temperature corresponding to the i^{th} region, and V_i is a volume of the i^{th} region.

11. The method of claim 8, wherein determining whether the center position of the coil deviates from the center point of the chamber based on the first temperature and/or the second temperature comprises:

acquiring a region of the chamber where the first temperature measurement hole is located, and recording the region as a first setting region; determining a chamber temperature at the temperature gradient distribution curve which corresponds to the first setting region, and recording the temperature as a first target temperature; and determining whether the first temperature is equal to the first target temperature, and determining that the center position of the coil deviates from the center point of the chamber in response to the first temperature being not equal to the first target temperature; and/or

acquiring a region of the chamber where the second temperature measurement hole is located, and recording the region as a second setting region; determining a chamber temperature at the temperature gradient distribution curve which corresponds to the second setting region, and recording the temperature as a second target temperature; and determining whether the second temperature is equal to the second target temperature, and determining that the center position of the coil deviates from the center point of the chamber in response to the second temperature being not equal to the second target temperature.

12. The method of claim 11, wherein the semiconductor heat treatment equipment further comprises a drive component, which is connected to the coil, and is configured to drive the coil to translate; and controlling the coil to translate along the central axis based on the first temperature and/or the second temperature until the center position of the coil reaches the center point of the chamber comprises:

calculating a translation amount and a translation direction of the coil based on the first target temperature and the first temperature; and controlling, based on the translation amount and the translation direction, the drive component to drive the coil to translate until the center point of the coil coincides with the center point of the chamber; and/or

calculating a translation amount and a translation direction of the coil based on the second target temperature and the second temperature; and controlling, based on the translation amount and the translation direction, the drive component to drive the coil to translate until the center point of the coil coincides with the center point of the chamber.