REAL-TIME SOLUTION TEMPERATURE CONTROL SYSTEM AND METHOD

TECHNICAL FIELD

The present application relates to the technical field of semiconductor processing, and in particular to a real-time solution temperature control system and method.

BACKGROUND

In wet processes, such as wafer cleaning process, or process development, it is often necessary to change the temperature of a cleaning solution to meet different process requirements or R&D testing requirements. Existing temperature control methods for a cleaning solution during a process and the existing defects of the methods are as follows:

1. Cleaning-solution blending-tank blending method

(a) Process flow: The cleaning solution is blended in a cleaning-solution blending tank, heated or cooled to the target temperature, and then supplied to a process chamber;

(b) Process defects:

(1) Cost and footprint: One solution supply system can only provide a cleaning solution at one temperature at a certain time, and when a customer needs a single tool capable of providing cleaning solutions at multiple temperatures simultaneously, a plurality of cleaning-solution supply systems are required, which increases the cost of the tool and increases the footprint of the tool;

(2) Inflexible temperature switching: To change the temperature of the cleaning solution, it is necessary to manually replace the solution or change the temperature setting conditions, wherein a heater or a cooling device heats or cools the cleaning solution, and the cleaning solution requires an extended heating or cooling period before the cleaning solution reaches the required operating temperature, which results in a long switching time and reduces the productivity of the tool; moreover, switching often requires manual operation, which is not suitable for automation;

(3) Poor temperature control accuracy: The temperature of the cleaning solution when the cleaning solution reaches the process chamber is subject to seasonal variation, pipeline length, and pipeline location, resulting in poor temperature control accuracy.

2. In-line solution blending method

(a) Process flow: In existing in-line solution blending methods, such as high-temperature SC1, only the temperature of hot water is controlled, while the ammonia solution and hydrogen peroxide, which account for a relatively small proportion, are directly used at room temperature; to change the temperature of the cleaning solution, the temperature of hot water needs to be changed;

(b) Process defects:

(1) Cost and footprint: One solution supply system can only provide a cleaning solution at one temperature at a certain time, and when a customer needs a single tool capable of providing cleaning solutions at multiple temperatures simultaneously, a plurality of cleaning-solution supply systems are required, which increases the cost of the tool and increases the footprint of the tool;

(2) Inflexible temperature switching: To change the temperature, it is necessary to change temperature setting conditions and control the output power of a hot-water heater, and the process can only be carried out when the high-temperature hot water reaches the required operating temperature, which results in a long switching time and reduces the productivity of the tool;

(3) Poor temperature control accuracy: The temperature of the cleaning solution when the cleaning solution reaches a process chamber is subject to seasonal variation, pipeline length, and pipeline location, resulting in poor temperature control accuracy.

Amid the gradual refinement of semiconductor manufacturing processes and the continuous reduction of process nodes, the requirements for the temperature control of a cleaning solution in wet cleaning are becoming increasingly high. There is a need to develop a more accurate temperature control method that is not subject to seasonal variation, different chamber pipeline lengths, and different pipeline locations. Therefore, a real-time solution temperature control system and method are required to

enhance process flexibility and save temperature control time, thereby accommodating a wider range of application scenarios.

SUMMARY

In order to better cope with the more refined temperature control of chemical solutions in semiconductor manufacturing processes, improve process accuracy, and enhance process flexibility, the present invention proposes a real-time solution temperature control system and method.

In a first aspect, the present application proposes a real-time solution temperature control system, comprising:

a solution supply module, configured to supply solutions at different temperatures to a solution blending module;

a solution blending module, configured to receive and uniformly blend the solutions at different temperatures supplied by the solution supply module;

a temperature sensing module, configured to measure the temperature of the uniformly blended solution in the solution blending module;

a control module, configured to adjust the flow rates of the solutions at different temperatures delivered by the solution supply module to the solution blending module according to the temperature of the uniformly blended solution measured by the temperature sensing module, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature.

According to a specific embodiment of the present application, the solution supply module includes a solution storage unit and a delivery unit; the solution storage unit is in communication with the solution blending module through the delivery unit;

the solution storage unit includes:

a room-temperature deionized water storage unit, configured to store room-temperature deionized water to be supplied to the solution blending module;

a high-temperature deionized water storage unit, configured to store high-temperature deionized water to be supplied to the solution blending module;

a chemical solution storage unit, configured to store chemical solution to be supplied to the solution blending module.

According to a specific embodiment of the present application, the solution storage unit includes at least one chemical solution storage unit. When the number of chemical solution storage units is greater than one, the chemical solution stored in each chemical solution storage unit is different.

According to a specific embodiment of the present application, the control module is preconfigured with the relationship data between different processes and corresponding temperatures, and a database that stores, for each temperature, the volume ratio of each component of the solution;

the control module is further configured to:

determine the target temperature of the uniformly blended solution;

control the flow rates of the solutions at different temperatures delivered by the solution supply module to the solution blending module according to the volume ratio of each component of the solution corresponding to the target temperature;

acquire the temperature measurement result of the temperature sensing module in real time;

when the temperature measurement result deviates from the target temperature for a preset duration, maintain the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module constant, calculate the required flow rate change of room-temperature deionized water and the required flow rate change of high-temperature deionized water in real time according to the temperature measurement result, and deliver the room-temperature deionized water and high-temperature deionized water at the corresponding flow rate to the solution blending module, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature.

According to a specific embodiment of the present application, the real-time calculation of the required flow rate change of room-temperature deionized water and the required flow rate change of high-temperature deionized water by the control module according to the temperature measurement result includes:

calculating the required flow rate change of room-temperature deionized water ΔL_{D1} and the required flow rate change of high-temperature deionized water ΔL_{D2} using the system of equations consisting of equation 1 and equation 2 given below:

$$\Delta L_{D1} + \Delta L_{D2} = 0 \qquad \text{Equation 1}$$

$$\Delta Q_{D1} + \Delta Q_{D2} + \sum_{i=1}^{n} \Delta Q_i = 0 \qquad \text{Equation 2}$$

wherein, equation 1 is obtained based on the conditions that the total solution supply flow rate is constant and the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module are constant, where the sum of the flow rate change of room-temperature deionized water supplied from the room-temperature deionized water storage unit to the solution blending module and the flow rate change of high-temperature deionized water supplied from the high-temperature deionized water storage unit to the solution blending module is 0; equation 2 is obtained based on the law of conservation of thermal energy;

wherein, the solution storage unit includes n chemical solution storage unit(s), ΔQ_i is the heat change of the chemical solution in the i-th chemical solution storage unit, n and i are positive integers greater than or equal to 1, ΔQ_{D1} and ΔQ_{D2} are the heat changes of room-temperature deionized water and high-temperature deionized water, respectively, the unit of heat change is joule (J), and ΔQ_{D1} and ΔQ_{D2} are obtained according to the heat calculation formula $Q = cm\Delta t$ and the mass–density–volume formula $m = \rho v = \rho * L * t$,

wherein, c is the specific heat capacity, with the unit being J/(kg·°C);

m is the mass, with the unit being kg;

Δt is the increase or decrease in temperature, with the unit being °C;

ρ is the density, with the unit being kg/dm³;

L is the flow rate, with the unit being liter/minute;

t is the unit time, with the unit being minute.

According to a specific embodiment of the present application, the control module is configured to:

determine the target temperature of the uniformly blended solution;

acquire the temperature measurement result of the temperature sensing module in real time;

when the temperature measurement result deviates from the target temperature for a preset duration, maintain the temperature and flow rate of the solution supplied from a high-flow solution storage unit to the solution blending module constant; adjust the flow rate changes of the solutions supplied from other solution storage units to the solution blending module in real time according to the temperature measurement result, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature, wherein, the high-flow solution storage unit refers to the solution storage unit in the solution supply module that delivers the maximum flow rate to the solution blending module.

According to a specific embodiment of the present application, when the chemical solution storage units include two solution supply pipelines, the control module is further configured to maintain the temperature and flow rate of the solution supplied from the high-flow solution storage unit to the solution blending module constant; the real-time adjustment of the flow rate changes of the solutions supplied from other solution storage units to the solution blending module by the control module according to the temperature measurement result includes:

calculating the flow rate change of chemical solution 1 ΔL_1, the flow rate change of chemical solution 2 ΔL_2, and the flow rate change of room-temperature deionized water ΔL_{D1} using the system of equations consisting of equation 3, equation 4, equation 5, equation 6, and equation 7 given below:

$$r_1 = \frac{L_1}{L_{D1}+L_{D2}}$$ Equation 3

$$r_2 = \frac{L_2}{L_{D1}+L_{D2}}$$ Equation 4

$$\Delta Q_1 + \Delta Q_{D1}+\Delta Q_{D2}=0$$ Equation 5

$$(L_1 + \Delta L_1)/(L_{D1} + L_{D2} + \Delta L_{D1}) = r_1$$ Equation 6

$$(L_2 + \Delta L_2)/(L_{D1} + L_{D2} + \Delta L_{D2}) = r_2$$ Equation 7

wherein, equation 3 and equation 4 represent the volume ratios of the two chemical solutions in the chemical solution storage units; equation 5 is obtained based on the law of conservation of thermal energy; equation 6 and equation 7 represent the volume ratios of the two chemical solutions in the solution storage unit under the condition that the volume ratios of the chemical solutions remain constant after the flow rates change;

wherein, r_1 and r_2 are the set volume ratios of the two chemical solutions in the solution, respectively; L_1 and L_2 are the flow rates of the two chemical solutions, respectively, with the unit being liter/minute; ΔL_1 is the flow rate change of the chemical solution whose flow rate needs to be changed, with the unit being liter/minute; L_{D1} and L_{D2} are the flow rates of room-temperature deionized water and high-temperature deionized water, respectively, with the unit being liter/minute; ΔL_{D1} and ΔL_{D2} are the flow rate changes of room-temperature deionized water and high-temperature deionized water, respectively, with the unit being liter/minute; ΔQ_1 is the heat change of the chemical solution whose flow rate needs to be changed, with the unit being J; ΔQ_{D1} is the heat change of room-temperature deionized water, with the unit being J; ΔQ_{D2} is the heat change of high-temperature deionized water, with the unit being J.

In a second aspect, the present application proposes a real-time solution temperature control system, comprising:

a solution supply module, configured to supply solutions at different temperatures to a solution blending module;

a solution blending module, configured to receive and uniformly blend the solutions at different temperatures supplied by the solution supply module;

a temperature sensing module, including a first temperature sensing unit, configured to measure the temperature of each component of the solution before the solution is uniformly blended, and generate first temperature measurement results;

a control module, configured to determine the target temperature of the uniformly blended solution; adjust the flow rates of the solutions at different temperatures delivered by the solution supply module to the solution blending module according to the first temperature measurement results, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature.

According to a specific embodiment of the present application, the solution supply module includes:

a room-temperature deionized water storage unit, configured to store room-temperature deionized water to be supplied to the solution blending module;

a high-temperature deionized water storage unit, configured to store high-temperature deionized water to be supplied to the solution blending module;

a chemical solution storage unit, configured to store chemical solution to be supplied to the solution blending module.

According to a specific embodiment of the present application, the solution supply module includes at least one chemical solution storage unit. When the number of chemical solution storage units is greater than one, the chemical solution stored in each chemical solution storage unit is different.

According to a specific embodiment of the present application, the control module adjusting the flow rates of the solutions at different temperatures delivered by the solution supply module to the solution blending module according to the first temperature measurement results includes:

maintaining the total solution supply flow rate, and the temperature and flow rate

of the chemical solution supplied from the chemical solution storage unit to the solution blending module constant, calculating the required flow rate of room-temperature deionized water and the required flow rate of high-temperature deionized water in real time according to the first temperature measurement results, and delivering the room-temperature deionized water and high-temperature deionized water at the corresponding flow rate to the solution blending module, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature.

According to a specific embodiment of the present application, the control module calculating the required flow rate of room-temperature deionized water and the required flow rate of high-temperature deionized water in real time according to the first temperature measurement results includes:

calculating the required flow rate of room-temperature deionized water L_{D1} and the required flow rate of high-temperature deionized water L_{D2} using the system of equations consisting of equation 8 and equation 2 given below:

$$L_D = L_{D1} + L_{D2} \qquad \text{Equation 8}$$

$$\Delta Q_{D1} + \Delta Q_{D2} + \sum_{i=1}^{n} \Delta Q_i = 0 \qquad \text{Equation 2}$$

wherein, equation 8 is obtained based on the conditions that the total supply flow rate is constant and the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module are constant, where the sum of the amount of room-temperature deionized water and the amount of high-temperature deionized water supplied to the solution blending module is L_D; equation 2 is obtained based on the law of conservation of thermal energy;

wherein, L_{D1} is the required flow rate of room-temperature deionized water, L_{D2} is required flow rate of high-temperature deionized water, the solution supply module includes n chemical solution storage unit(s), ΔQ_i is the heat change of the chemical solution in the i-th chemical solution storage unit, n and i are positive integers greater than or equal to 1, ΔQ_{D1} and ΔQ_{D2} are the heat changes of room-temperature deionized water and high-temperature deionized water, respectively, the unit of heat

change is J, and ΔQ_{D1} and ΔQ_{D2} are obtained according to the heat calculation formula $Q = cm\Delta t$ and the mass–density–volume formula $m = \rho v = \rho * L * t$,

wherein, c is the specific heat capacity, with the unit being J/(kg·°C);

m is the mass, with the unit being kg;

Δt is the increase or decrease in temperature, with the unit being °C;

ρ is the density, with the unit being kg/dm³;

L is the flow rate, with the unit being liter/minute;

t is the unit time, with the unit being minute.

According to a specific embodiment of the present application, the temperature sensing module further includes a second temperature sensing unit configured to measure the temperature of the uniformly blended solution in the solution blending module and generate a second temperature measurement result;

the control module is further configured to:

acquire the second temperature measurement result of the second temperature sensing unit in real time;

when the second temperature measurement result deviates from the target temperature within a preset duration, maintain the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module constant, calculate the required flow rate change of room-temperature deionized water and the required flow rate change of high-temperature deionized water in real time according to the second temperature measurement result, and deliver the room-temperature deionized water and high-temperature deionized water at the corresponding flow rate to the solution blending module, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature.

In a third aspect, the present application proposes a real-time solution temperature

control method, including the following steps:

using a solution supply module to supply solutions at different temperatures to a solution blending module;

uniformly blending the solutions at different temperatures in the solution blending module, and measuring the temperature of the uniformly blended solution in real time using a temperature sensing module and feeding the temperature back to a control module;

the control module adjusting the flow rates of the solutions at different temperatures delivered by the solution supply module to the solution blending module according to the temperature of the uniformly blended solution measured by the temperature sensing module, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature.

According to a specific embodiment of the present application, the solution includes at least two of the following: chemical solution, room-temperature deionized water, and high-temperature deionized water.

According to a specific embodiment of the present application, when the solution includes chemical solution, the chemical solution consists of one or more components.

According to a specific embodiment of the present application, the method further includes:

preconfiguring the relationship data between different processes and corresponding temperatures, and the volume ratio of each component of the solution for each temperature in the control module;

the control module determining the target temperature of the uniformly blended solution according to the process, and controlling the uniform blending of the solutions at different temperatures according to the volume ratio of each component of the solution corresponding to the target temperature;

the temperature sensing module acquiring the actual temperature of the uniformly

blended solution in real time; when the actual temperature is measured to deviate from the target temperature for a preset duration, maintaining the temperature and flow rate of the chemical solution supplied from a chemical solution storage unit to the solution blending module constant, calculating the required flow rate change of room-temperature deionized water and the required flow rate change of high-temperature deionized water in real time according to the actual temperature measurement result, and delivering the room-temperature deionized water and high-temperature deionized water at the corresponding flow rate to the solution blending module, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature.

According to a specific embodiment of the present application, the control module calculating the required flow rate change of room-temperature deionized water and the required flow rate change of high-temperature deionized water in real time according to the actual temperature measurement result includes:

calculating the required flow rate change of room-temperature deionized water ΔL_{D1} and the required flow rate change of high-temperature deionized water ΔL_{D2} using the system of equations consisting of equation 1 and equation 2 given below:

$$\Delta L_{D1} + \Delta L_{D2} = 0 \qquad \text{Equation 1}$$

$$\Delta Q_{D1} + \Delta Q_{D2} + \sum_{i=1}^{n} \Delta Q_i = 0 \qquad \text{Equation 2}$$

wherein, equation 1 is obtained based on the conditions that the total solution supply flow rate is constant and the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module are constant, where the sum of the flow rate change of room-temperature deionized water supplied from a room-temperature deionized water storage unit to the solution blending module and the flow rate change of high-temperature deionized water supplied from a high-temperature deionized water storage unit to the solution blending module is 0; equation 2 is obtained based on the law of conservation of thermal energy;

wherein, the solution supply module includes n chemical solution storage unit(s), ΔQ_i is the heat change of the chemical solution in the i-th chemical solution storage

unit, n and i are positive integers greater than or equal to 1, ΔQ_{D1} and ΔQ_{D2} are the heat changes of room-temperature deionized water and high-temperature deionized water, respectively, the unit of heat change is J, and ΔQ_{D1} and ΔQ_{D2} are obtained according to the heat calculation formula $Q = cm\Delta t$ and the mass–density–volume formula $m = \rho v = \rho * L * t$,

wherein, c is the specific heat capacity, with the unit being J/(kg·°C);

m is the mass, with the unit being kg;

Δt is the increase or decrease in temperature, with the unit being °C;

ρ is the density, with the unit being kg/dm³;

L is the flow rate, with the unit being liter/minute;

t is the unit time, with the unit being minute.

According to a specific embodiment of the present application, the method further includes:

the control module determining the target temperature of the solution according to the process, and acquiring the temperature measurement result of the temperature sensing module in real time; when the temperature measurement result deviates from the target temperature for a preset duration, maintaining the temperature and flow rate of the solution supplied from a high-flow solution storage unit to the solution blending module constant; adjusting the flow rate changes of the solutions from other solution storage units to the solution blending module in real time according to the temperature measurement result, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature, wherein, the high-flow solution storage unit refers to the solution storage unit in the solution supply module that delivers the maximum flow rate to the solution blending module.

According to a specific embodiment of the present application, when the number of chemical solution storage units is 2, the control module is further configured to maintain the temperature and flow rate of the solution supplied from the high-flow

solution storage unit to the solution blending module constant; the control module adjusting the flow rate changes of the solutions from other solution storage units to the solution blending module in real time according to the temperature measurement result includes:

calculating the flow rate change of chemical solution 1 ΔL_1, the flow rate change of chemical solution 2 ΔL_2, and the flow rate change of room-temperature deionized water ΔL_{D1} using the system of equations consisting of equation 3, equation 4, equation 5, equation 6, and equation 7 given below:

$$r_1 = \frac{L_1}{L_{D1}+L_{D2}} \quad \text{Equation 3}$$

$$r_2 = \frac{L_2}{L_{D1}+L_{D2}} \quad \text{Equation 4}$$

$$\Delta Q_1 + \Delta Q_{D1} + \Delta Q_{D2} = 0 \quad \text{Equation 5}$$

$$(L_1 + \Delta L_1)/(L_{D1} + L_{D2} + \Delta L_{D1}) = r_1 \quad \text{Equation 6}$$

$$(L_2 + \Delta L_2)/(L_{D1} + L_{D2} + \Delta L_{D2}) = r_2 \quad \text{Equation 7}$$

wherein, equation 3 and equation 4 represent the volume ratios of the two chemical solutions supplied through two solution delivery pipelines of the chemical solution storage units; equation 5 is obtained based on the law of conservation of thermal energy; equation 6 and equation 7 represent the volume ratios of the two chemical solutions supplied through two solution delivery pipelines of the chemical solution storage units under the condition that the volume ratios of the chemical solutions remain constant after the flow rates change;

wherein, r_1 and r_2 are the set volume ratios of the two chemical solutions in the solution, respectively; L_1 and L_2 are the flow rates of the two chemical solutions, respectively, with the unit being liter/minute; ΔL_1 is the flow rate change of the chemical solution whose flow rate needs to be changed, with the unit being liter/minute; L_{D1} and L_{D2} are the flow rates of room-temperature deionized water and high-temperature deionized water, respectively, with the unit being liter/minute; ΔL_{D1} and ΔL_{D2} are the flow rate changes of room-temperature deionized water and high-

temperature deionized water, respectively, with the unit being liter/minute; ΔQ_1 is the heat change of the chemical solution whose flow rate needs to be changed, with the unit being J; ΔQ_{D1} is the heat change of room-temperature deionized water, with the unit being J; ΔQ_{D2} is the heat change of high-temperature deionized water, with the unit being J.

In a fourth aspect, the present application proposes a real-time solution temperature control method, including the following steps:

a control module acquiring the target temperature of the blended solution;

using a solution supply module to supply solutions at different temperatures to a solution blending module;

uniformly blending the solutions at different temperatures in the solution blending module, measuring the supply temperature of each component of the solution in the solution blending module in real time using a first temperature sensing unit, generating first temperature measurement results, and feeding the first temperature measurement results back to the control module;

the control module adjusting the flow rates of the solutions at different temperatures delivered by the solution supply module to the solution blending module according to the first temperature measurement results, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature.

According to a specific embodiment of the present application, the solution includes at least two of the following: chemical solution, room-temperature deionized water, and high-temperature deionized water.

According to a specific embodiment of the present application, when the solution includes chemical solution, the chemical solution consists of one or more components.

According to a specific embodiment of the present application, the control module adjusting the flow rates of the solutions at different temperatures delivered by the solution supply module to the solution blending module according to the first

temperature measurement results includes:

maintaining the total solution supply flow rate, and the temperature and flow rate of the chemical solution supplied from a chemical solution storage unit to the solution blending module constant, calculating the required flow rate of room-temperature deionized water and the required flow rate of high-temperature deionized water in real time according to the first temperature measurement results, and delivering the room-temperature deionized water and high-temperature deionized water at the corresponding flow rate to the solution blending module, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature.

According to a specific embodiment of the present application, the control module calculating the required flow rate of room-temperature deionized water and the required flow rate of high-temperature deionized water in real time according to the first temperature measurement results includes:

calculating the required flow rate of room-temperature deionized water L_{D1} and the required flow rate of high-temperature deionized water L_{D2} using the system of equations consisting of equation 8 and equation 2 given below:

$$L_D = L_{D1} + L_{D2} \qquad \text{Equation 8}$$

$$\Delta Q_{D1} + \Delta Q_{D2} + \sum_{i=1}^{n} \Delta Q_i = 0 \qquad \text{Equation 2}$$

wherein, equation 8 is obtained based on the conditions that the total solution supply flow rate is constant and the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module are constant, where the sum of the amount of room-temperature deionized water supplied from a room-temperature deionized water storage unit to the solution blending module and the amount of high-temperature deionized water supplied from a high-temperature deionized water storage unit to the solution blending module is L_D; equation 2 is obtained based on the law of conservation of thermal energy;

wherein, L_{D1} is the required flow rate of room-temperature deionized water; L_{D2} is the required flow rate of high-temperature deionized water; the solution supply

module includes n chemical solution storage unit(s), ΔQ_i is the heat change of the chemical solution in the i-th chemical solution storage unit, n and i are positive integers greater than or equal to 1, ΔQ_{D1} and ΔQ_{D2} are the heat changes of room-temperature deionized water and high-temperature deionized water, respectively, the unit of heat change is J, and ΔQ_{D1} and ΔQ_{D2} are obtained according to the heat calculation formula $Q = cm\Delta t$ and the mass–density–volume formula $m = \rho v = \rho * L * t$,

wherein, c is the specific heat capacity, with the unit being J/(kg·°C);

m is the mass, with the unit being kg;

Δt is the increase or decrease in temperature, with the unit being °C;

ρ is the density, with the unit being kg/dm³;

L is the flow rate, with the unit being liter/minute;

t is the unit time, with the unit being minute.

According to a specific embodiment of the present application, the method further includes:

using a second temperature sensing unit to measure the temperature of the uniformly blended solution in the solution blending module and generating a second temperature measurement result;

a control module acquiring the temperature measurement result of the second temperature sensing unit in real time;

when the second temperature measurement result deviates from the target temperature within a preset duration, maintaining the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module constant, calculating the required flow rate change of room-temperature deionized water and the required flow rate change of high-temperature deionized water in real time according to the second temperature measurement result, and delivering the room-temperature deionized water and high-temperature deionized

water at the corresponding flow rate to the solution blending module, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature.

The real-time solution temperature control system and method of the present invention achieve the purpose of adjusting the temperature of the blended solution in real time by adjusting the flow rate of each component of the supplied solution in real time in an in-line solution blending manner. At the same time, when a tool needs blended solutions at multiple temperatures for configuration, only one set of solution supply system is required, which reduces the cost and the footprint of the tool. Secondly, the temperature of the blended solution can be flexibly controlled through in-line controlling of the flow rate of each component of the blended solution, which eliminates the need for waiting during temperature switching, and achieves independent control of the temperature of each process chamber, thereby improving the utilization rate of the tool. In addition, the temperature control is more accurate, which avoids the temperature difference of the blended solutions in different process chambers caused by factors such as ambient temperature or pipeline length, thereby improving the process effect, enhancing the process flexibility, saving the temperature control time, and meeting the demands of more application scenarios. Other features and advantages of the present invention will be described in the subsequent specification, and some of the features and advantages will become obvious from the specification or be understood by implementing the present invention. The objective and other advantages of the present invention can be achieved and obtained through the structures specified in the specification, claims, and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The features and performance of the present invention are further described with reference to the following embodiments and the accompanying drawings of the embodiments.

FIG. 1 shows a schematic structural diagram of a real-time solution temperature control system according to an embodiment of the present invention;

FIG. 2 shows a schematic structural diagram of a real-time solution temperature

control system according to an embodiment of the present invention when a solution supply module of the real-time solution temperature control system supplies a multi-component solution;

FIG. 3 shows a schematic structural diagram of a real-time solution temperature control system according to an embodiment of the present invention when two types of chemical solutions are supplied;

FIG. 4 shows a schematic structural diagram of a real-time solution temperature control system according to another embodiment of the present invention;

FIG. 5 shows a schematic structural diagram of a real-time solution temperature control system according to another embodiment of the present invention when a solution supply module of the real-time solution temperature control system supplies a multi-component solution;

FIG. 6 shows a schematic flow chart of a real-time solution temperature control method according to an embodiment of the present invention;

FIG. 7 shows a schematic flow chart of a real-time solution temperature control method according to another embodiment of the present invention.

PREFERRED EMBODIMENTS OF THE APPLICATION

In order to further clarify the objective, technical solutions, and advantages of the embodiments of the present invention, the technical solutions in the embodiments of the present invention will be clearly and completely described below with reference to the accompanying drawings in the embodiments of the present invention. Obviously, the described embodiments are part of the embodiments of the present invention, rather than all the embodiments. Based on the embodiments of the present invention, all other embodiments obtained by those of ordinary skill in the art without making creative efforts shall fall within the protection scope of the present invention.

In the wafer cleaning process or process development, it is often necessary to change the temperature of the cleaning solution to meet different process requirements or R&D testing requirements. To solve the problems of high cost, inflexible

temperature switching, and poor temperature control accuracy of the cleaning-solution blending-tank blending method and in-line solution blending method in the prior art, the inventor has conducted targeted research and proposed a real-time solution temperature control system and method to achieve more refined temperature control of a solution in semiconductor manufacturing processes, improve the process accuracy, and enhance the process flexibility.

Next, the real-time solution temperature control system and method provided by the present invention will be described in detail.

Please refer to FIG. 1, which shows a schematic structural diagram of a real-time solution temperature control system according to an embodiment of the present invention. As shown in FIG. 1, the real-time solution temperature control system comprises a solution supply module 100, a solution blending module 200, a temperature sensing module 300, and a control module 400. Wherein, the solution supply module 100 is configured to supply cleaning solutions at different temperatures to the solution blending module 200; the solution supply module 100 includes solution storage units 101 and delivery units 102, and the solution storage units 101 are in communication with the solution blending module 200 through the delivery units 102; the solution blending module 200 is configured to receive and uniformly blend the cleaning solutions at different temperatures supplied by the solution supply module 100, and then deliver the blended solution to a cleaning chamber of a cleaning apparatus through a solution delivery unit 500 to perform the cleaning process; the temperature sensing module 300 is configured to measure the temperature of the uniformly blended cleaning solution in the solution blending module 200, and is generally arranged on the solution blending module 200; the control module 400 is configured to adjust the flow rates of the cleaning solutions at different temperatures delivered by the solution supply module 100 to the solution blending module 200 according to the temperature of the uniformly blended cleaning solution measured by the temperature sensing module 300, enabling the temperature of the uniformly blended cleaning solution in the solution blending module 200 to reach the target temperature. The present invention achieves the purpose of more refined temperature control of the uniformly blended cleaning solution in semiconductor manufacturing processes by monitoring the temperature of the blended cleaning solution and adjusting the flow rates of the cleaning solutions at different temperatures in real time, thereby

improving the process accuracy and flexibility.

Furthermore, during actual processes, the solution blending module 200 can be a blending valve as the blending space for the cleaning solutions at different temperatures, or a blending tank as the blending space for the cleaning solutions at different temperatures. The specific selection can be made according to actual needs. The embodiments of the present invention place no restriction on the spatial structure of the solution blending module 200, and any structure that can uniformly blend the cleaning solutions falls within the protection scope of the present invention. It should be noted that when the solution blending module 200 is a blending valve, considering that the volume of the blending valve is small and it is inconvenient to set the temperature sensing module 300 on the blending valve, the temperature sensing module 300 can be arranged on the solution delivery unit 500 to measure the temperature of the cleaning solutions at different temperatures after blending.

Furthermore, the control module 400 includes a control unit 401 and flow adjustment units 402. The flow adjustment units 402 are arranged on the delivery units 102 and are used to control the flow rates of the solutions flowing through the delivery units 102. The control unit 401 receives the temperature of the blended cleaning solution sent by the temperature sensing module 300 and controls the flow adjustment units 402 to adjust the flow rates of the cleaning solutions at different temperatures supplied by the solution supply module 100 to the solution blending module 200.

Please continue to refer to FIG. 1. In the design of a wafer cleaning apparatus, solution storage tank or solution storage cylinder is generally used as the solution storage units 101 of the solution supply module 100; the delivery units 102 are generally solution delivery pipelines; the temperature sensing module 300 is generally a temperature sensor; the control unit 401 of the control module 400 is generally the control system of the cleaning apparatus; the flow adjustment units 402 of the control module 400 are generally flow control valves. During processes, the cleaning solutions at different temperatures are delivered from the solution storage units 101 to the solution blending module 200 through the delivery units 102. After the cleaning solutions at different temperatures are uniformly blended in the solution blending module 200, the blended solution is delivered to a wafer in a cleaning chamber through the solution delivery unit 500 to perform the cleaning process on the wafer. The

temperature sensing module 300 measures the temperature of the cleaning solution in the solution blending module 200 and sends the measured data to the control unit 401 of the control module 400. The control unit 401 controls the flow adjustment units 402 to adjust the flow rates of the cleaning solutions at different temperatures supplied by the solution supply module 100 to the solution blending module 200 according to the received data, enabling the temperature of the uniformly blended cleaning solution in the solution blending module 200 to reach the target temperature.

Wherein, the solution supply module 100 determines the number of solution storage units 101 and delivery units 102 according to the components contained in the cleaning solution in the solution blending module 200. Each solution storage unit 101 is in communication with the solution blending module 200 through one delivery unit 102 to deliver one component of the cleaning solution to the solution blending module 200. It should be understood that in this embodiment, cleaning solutions of the same chemical composition at different temperatures are also regarded as different components; cleaning solutions of different chemical compositions at the same temperature are also regarded as different components. For example, when the cleaning solution includes room-temperature deionized water and high-temperature deionized water, even room-temperature deionized water and high-temperature deionized water have the same chemical composition, room-temperature deionized water and high-temperature deionized water are still regarded as cleaning solutions of different components, and two solution storage units 101 are required for separate storage by default; when the cleaning solution includes hydrogen peroxide and room-temperature deionized water, even hydrogen peroxide and room-temperature deionized water are at the same temperature, hydrogen peroxide and room-temperature deionized water are also regarded as different components, and two solution storage units 101 are required for separate storage by default. For example, please refer to FIG. 2, which shows a schematic structural diagram of a real-time solution temperature control system according to an embodiment of the present invention when the solution supply module of the real-time solution temperature control system supplies cleaning solutions at different temperatures. When the cleaning solution consists of three components (room-temperature deionized water, high-temperature deionized water, and chemical solution), as shown in FIG. 2, the solution supply module 100 in the embodiments of the present invention includes: a room-temperature deionized water storage unit 101a

configured to store room-temperature deionized water to be supplied to the solution blending module 200; a high-temperature deionized water storage unit 101b configured to store high-temperature deionized water to be supplied to the solution blending module 200; a chemical solution storage unit 101c configured to store chemical solution to be supplied to the solution blending module 200.

Please continue to refer to FIG. 2. In order to facilitate the accurate control of the temperature of the cleaning solution in the solution blending module 200, the relationship data between different processes and corresponding temperatures and the volume ratio of each component of the cleaning solution for each temperature can be collected and processed to generate a database, which is stored in the control unit 401 of the control module 400. When the wafer in the cleaning chamber needs to be cleaned, the control module 400 can first determine the target temperature of the uniformly blended cleaning solution based on the upcoming process; control the flow rate of each component of the cleaning solution delivered by the solution supply module 100 to the solution blending module 200 according to the volume ratio of each component of the cleaning solution corresponding to the target temperature; at the same time, the control unit 401 acquires the temperature measurement result of the uniformly blended cleaning solution measured by the temperature sensing module 300 in real time. When the temperature measurement result deviates from the target temperature for a preset duration, maintain the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit 101c to the solution blending module 200 constant. The required flow rate changes of room-temperature deionized water and high-temperature deionized water are calculated in real time according to the temperature measurement result, and the room-temperature deionized water and high-temperature deionized water at the corresponding flow rate are delivered to the solution blending module 200, enabling the temperature of the uniformly blended cleaning solution in the solution blending module 200 to reach the target temperature. Considering that the properties of the chemical solution may change due to temperature change, and to facilitate the accurate control of the temperature of the cleaning solution, in this embodiment, the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit 101c to the solution blending module 200 are maintained constant, and the flow rates of the room-temperature deionized water supplied from the room-temperature deionized water storage unit 101a and the high-

temperature deionized water supplied from the high-temperature deionized water storage unit 101b to the solution blending module 200 are adjusted. In this embodiment, the chemical solution storage unit 101c supplies chemical solution, the room-temperature deionized water storage unit 101a supplies room-temperature deionized water, and the high-temperature deionized water storage unit 101b supplies high-temperature deionized water. For example, the temperature of the high-temperature deionized water can be 35 °C, 50 °C, 60 °C, 65 °C, or 70 °C, and the temperature can also be set to other temperatures higher than room temperature. The specific setting can be made according to process requirements.

According to process requirements, the type of chemical solution can be one or more. It should be understood that the way of understanding the type of chemical solution here is the same as the way of understanding the above-mentioned components, and will not be repeated herein. When more than one type of chemical solution is supplied, different chemical solutions need to be stored in different chemical solution storage units, and each chemical solution storage unit is equipped with a separate delivery unit. Therefore, the solution storage unit includes at least one chemical solution storage unit. When the number of chemical solution storage units is greater than one, the type of chemical solution stored in each chemical solution storage unit is different, and the chemical solutions stored in different chemical solution storage units are delivered to the solution blending module through the delivery unit connected to the chemical solution storage units, respectively. For example, when the cleaning solution is SC1, the components of the cleaning solution are room-temperature deionized water, high-temperature deionized water, ammonia solution, and hydrogen peroxide. The chemical solutions in the SC1 cleaning solution include two types, namely ammonia solution and hydrogen peroxide. When the cleaning solution is SC2, the components of the cleaning solution are room-temperature deionized water, high-temperature deionized water, hydrochloric acid, and hydrogen peroxide. The chemical solutions in the SC2 cleaning solution also include two types, namely hydrochloric acid and hydrogen peroxide. Please refer to FIG. 3, which shows a real-time solution temperature control system according to an embodiment of the present invention when two types of chemical solutions are supplied. As shown in FIG. 3, the chemical solution storage units in the figure include a chemical solution storage unit 101c and a chemical solution storage unit 101d, which are used to supply ammonia

solution and hydrogen peroxide or hydrochloric acid and hydrogen peroxide, respectively.

The real-time calculation of the required flow rate change of room-temperature deionized water ΔL_{D1} and the required flow rate change of high-temperature deionized water ΔL_{D2} by the control module 400 according to the temperature measurement result of the temperature sensing module 300 includes:

calculating the required flow rate change of room-temperature deionized water ΔL_{D1} and the required flow rate change of high-temperature deionized water ΔL_{D2} using the system of equations consisting of equation 1 and equation 2 given below:

$$\Delta L_{D1} + \Delta L_{D2} = 0 \qquad \text{Equation 1}$$

wherein, ΔL_{D1} is the required flow rate change of room-temperature deionized water; ΔL_{D2} is the required flow rate change of high-temperature deionized water.

$$\Delta Q_{D1} + \Delta Q_{D2} + \sum_{i=1}^{n} \Delta Q_i = 0 \qquad \text{Equation 2}$$

wherein, equation 1 is obtained based on the conditions that the total solution supply flow rate is constant and the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module are constant, where the sum of the flow rate change of room-temperature deionized water supplied from the room-temperature deionized water storage unit to the solution blending module and the flow rate change of high-temperature deionized water supplied from the high-temperature deionized water storage unit to the solution blending module is 0; equation 2 is obtained based on the law of conservation of thermal energy;

wherein, the solution storage unit 101 includes n chemical solution storage unit(s), ΔQ_i is the heat change of the chemical solution in the i-th chemical solution storage unit, n and i are positive integers greater than or equal to 1, ΔQ_{D1} and ΔQ_{D2} are the heat changes of room-temperature deionized water and high-temperature deionized water, respectively, the unit of heat change is J, and ΔQ_{D1} and ΔQ_{D2} are obtained according to the heat calculation formula $Q = cm\Delta t$ and the mass–density–volume formula $m = \rho v = \rho * L * t$,

wherein, c is the specific heat capacity, with the unit being J/(kg·°C);

m is the mass, with the unit being kg;

Δt is the increase (or decrease) in temperature, with the unit being °C;

ρ is the density, with the unit being kg/dm³;

L is the flow rate, with the unit being liter/minute;

t is the unit time, with the unit being minute.

In this embodiment, n is equal to 2. The information of each component of the cleaning solution supplied by the solution supply module is as follows (the flow rates of different components are calculated according to the required volume ratios of the chemical solutions and the total flow rate):

chemical solution 1: supply temperature T_1, density ρ_1, specific heat capacity C_1, flow rate L_1;

chemical solution 2: supply temperature T_2, density ρ_2, specific heat capacity C_2, flow rate L_2;

room-temperature deionized water: temperature T_{D1}, density ρ_{D1}, specific heat capacity C_D, flow rate L_{D1}, and the required flow rate change is set to ΔL_{D1};

high-temperature deionized water: temperature T_{D2} density ρ_{D2}, specific heat capacity C_D, flow rate L_{D2}, and the required flow rate change is set to ΔL_{D2};

the target temperature after blending is T;

then, the mass of each component and the change of the mass within the unit time t are:

mass of chemical solution 1: $m_1 = L_1 * t * \rho_1$;

mass of chemical solution 2: $m_2 = L_2 * t * \rho_2$;

mass of room-temperature deionized water: $m_{D1} = L_{D1} * t * \rho_{D1}$;

mass of high-temperature deionized water: $m_{D2} = L_{D2} * t * \rho_{D2}$;

mass change of room-temperature deionized water: $\Delta m_{D1} = \Delta L_{D1} * t * \rho_{D1}$;

mass change of high-temperature deionized water: $\Delta m_{D2} = \Delta L_{D2} * t * \rho_{D2}$;

during the process where the temperature of the blended solution changes from the actually measured temperature T_S to the target temperature T, the heat changes are:

1. chemical solution 1: $\Delta Q_1 = c_1 * m_1 * (T - T_s)$;

2. chemical solution 2: $\Delta Q_2 = c_2 * m_2 * (T - T_s)$;

3. room-temperature deionized water: $\Delta Q_{D1} = c_D * m_{D1} * (T - T_S) + c_D * \Delta m_{D1} * (T - T_{D1})$;

4. high-temperature deionized water: $\Delta Q_{D2} = c_D * m_{D2} * (T - T_S) + c_D * \Delta m_{D2} * (T - T_{D2})$;

neglecting the slight heat of dilution, according to the law of conservation of thermal energy, the following formulas can be derived from the above equation 1 and equation 2:

$$\Delta L_{D1} = c_1 * L_1 * \rho_1 * (T - T_S) + c_2 * L_2 * \rho_2 * (T - T_S) + c_D * L_{D1} * \rho_{D1} * (T - T_S) + c_D * L_{D2} * \rho_{D2} * (T - T_S)/(c_D * \rho_{D2} * (T - T_{D2}) - c_D * \rho_{D1} * (T - T_{D1}))$$

$$\Delta L_{D2} = -(c_1 * L_1 * \rho_1 * (T - T_S) + c_2 * L_2 * \rho_2 * (T - T_S) + c_D * L_{D1} * \rho_{D1} * (T - T_S) + c_D * L_{D2} * \rho_{D2} * (T - T_S))/(c_D * \rho_{D2} * (T - T_{D2}) - c_D * \rho_{D1} * (T - T_{D1}))$$

It should be noted that the calculation in this embodiment is treated as an approximation, which specifically includes: neglecting the influence of the change in the specific heat capacity of water at different temperatures; neglecting the influence of the heat of dilution and the slight heat of chemical reaction.

Different from the above calculation method, when the total supply flow rate is variable, in order to ensure the cleaning effect of the cleaning solution, the volume ratio of each component of the cleaning solution is required to remain constant. At this time, the control module 400 is configured to: determine the target temperature of the cleaning solution. In the embodiments of the present invention, the control module 400 can select the upcoming process to determine the target temperature of the cleaning solution based on the data pre-stored in the database, or staff can manually input the target temperature data, which is not limited in this embodiment; at the same time, the control module acquires the temperature measurement result of the uniformly blended cleaning solution measured by the temperature sensing module 300 in real time; when the temperature measurement result deviates from the target temperature for a preset duration, the control module maintains the temperature and flow rate of the solution supplied from a high-flow solution storage unit to the solution blending module constant; adjusts the flow rate changes of the solutions from other solution storage units to the solution blending module in real time according to the temperature measurement result, enabling the temperature of the uniformly blended cleaning solution in the solution blending module to reach the target temperature. Wherein, the high-flow solution storage unit refers to the solution storage unit in the solution supply module that delivers the maximum flow rate to the solution blending module. For example, please refer to FIG. 2. In the embodiments of the present invention, the flow rate of high-temperature deionized water supplied from the high-temperature deionized water storage unit 101b to the solution blending module is greater than the flow rates of the solutions supplied from the room-temperature deionized water storage unit 101a and the chemical solution storage unit 101c to the solution blending module. Then, the temperature and flow rate of the high-temperature deionized water supplied from the high-temperature deionized water storage unit 101b to the solution blending module remain constant, and the flow rates of the solutions supplied from the room-temperature deionized water storage unit 101a and the chemical solution storage unit 101c to the solution blending module are adjusted to adjust the temperature of the blended cleaning solution to the target temperature. It should be noted that this method is suitable for cases where the temperature requirement accuracy is high and the measured temperature of the blended solution has a small deviation from the target temperature.

When the number of chemical solution storage units is greater than one, the chemical solution component stored in each chemical solution storage unit is different. For example, please refer to FIG. 3. When the solution storage unit includes 2 chemical solution storage units, the chemical solution storage unit 101c stores chemical solution 1 to be supplied to the solution blending module; the chemical solution storage unit 101d stores chemical solution 2 to be supplied to the solution blending module. The control module 400 maintains the temperature and flow rate of the solution supplied from the high-flow solution storage unit, i.e., the high-temperature deionized water storage unit 101b, to the solution blending module constant; the control module 400 adjusts the flow rate changes of the solutions from other solution storage units to the solution blending module in real time according to the temperature measurement result. For example, in this example, the adjustment of the flow rate changes of the room-temperature deionized water storage unit 101a, the chemical solution storage unit 101c, and the chemical solution storage unit 101d includes:

calculating the flow rate change of chemical solution 1 ΔL_1, the flow rate change of chemical solution 2 ΔL_2, and the flow rate change of room-temperature deionized water ΔL_{D1} using the system of equations consisting of equation 3, equation 4, equation 5, equation 6, and equation 7 given below:

$$r_1 = \frac{L_1}{L_{D1}+L_{D2}} \quad \text{Equation 3}$$

$$r_2 = \frac{L_2}{L_{D1}+L_{D2}} \quad \text{Equation 4}$$

$$\Delta Q_1 + \Delta Q_{D1}+\Delta Q_{D2}=0 \quad \text{Equation 5}$$

$$(L_1 + \Delta L_1)/(L_{D1} + L_{D2} + \Delta L_{D1}) = r_1 \quad \text{Equation 6}$$

$$(L_2 + \Delta L_2)/(L_{D1} + L_{D2} + \Delta L_{D2}) = r_2 \quad \text{Equation 7}$$

wherein, equation 3 and equation 4 represent the volume ratios of the two chemical solutions supplied by the chemical solution storage units; equation 5 is obtained based on the law of conservation of thermal energy; equation 6 and equation 7 represent the volume ratios of the two chemical solutions supplied by the solution storage unit under the condition that the volume ratios of the chemical solutions remain

constant after the flow rates change;

wherein, r_1 and r_2 are the set volume ratios of the two chemical solutions in the cleaning solution, respectively; L_1 and L_2 are the flow rates of the two chemical solutions, respectively, with the unit being liter/minute; ΔL_1 is the flow rate change of the chemical solution whose flow rate needs to be changed, with the unit being liter/minute; L_{D1} and L_{D2} are the flow rates of room-temperature deionized water and high-temperature deionized water, respectively, with the unit being liter/minute; ΔL_{D1} and ΔL_{D2} are the flow rate changes of room-temperature deionized water and high-temperature deionized water, respectively, with the unit being liter/minute; ΔQ_1 is the heat change of the chemical solution whose flow rate needs to be changed, with the unit being J; ΔQ_{D1} is the heat change of room-temperature deionized water, with the unit being J; ΔQ_{D2} is the heat change of high-temperature deionized water, with the unit being J.

The information of each component of the cleaning solution supplied by the solution supply module is the same as the description given above. The following formulas can be calculated and obtained based on the system of equations consisting of equation 3, equation 4, equation 5, equation 6, and equation 7:

flow rate change of room-temperature deionized water $\Delta L_{D1} = [c_1 * L_1 * \rho_1 * (T - T_1) + c_2 * L_2 * \rho_2 * (T - T_2) - c_1 * L_1 * \rho_1 * (T - T_s) - c_2 * L_2 * \rho_2 * (T - T_s) - c_D * L_{D1} * \rho_{D1} * (T - T_S) - c_D * L_{D2} * \rho_{D2} * (T - T_S) - （L_{D1} + L_{D2}） * c_1 * L_1 * \rho_1 * (T - T_1)/（L_{D1} + L_{D2}） - （L_{D1} + L_{D2}） * c_2 * L_2 * \rho_2 * (T - T_2)/（L_{D1} + L_{D2}）]/[c_1 * L_1 * \rho_1 * (T - T_1)/（L_{D1} + L_{D2}） + c_2 * L_2 * \rho_2 * (T - T_2)/（L_{D1} + L_{D2}） + c_D * \rho_{D1} * (T - T_{D1})]$

flow rate change of chemical solution 1 $\Delta L_1 = (L_{D1} + L_{D2} + \Delta L_{D1}) * L_1 / (L_{D1} + L_{D2}) - L_1$; the ΔL_{D1} obtained from the above formula is substituted to obtain ΔL_1;

flow rate change of chemical solution 2 $\Delta L_{D2} = (L_{D1} + L_{D2} + \Delta L_{D1}) *$

$L_2 / (L_{D1} + L_{D2}) - L_2$; the ΔL_{D1} obtained from the above formula is substituted to obtain ΔL_2.

In another embodiment, please refer to FIG. 4, which shows a schematic structural diagram of a real-time solution temperature control system according to another embodiment of the present invention. As shown in FIG. 4, first temperature sensing units 301 are arranged on the delivery units 102 of the solution supply module 100 to measure the supply temperature of each component of the cleaning solution and generate first temperature measurement results. The control module 400 is configured to determine the target temperature of the uniformly blended cleaning solution; adjust the flow rates of the cleaning solutions at different temperatures delivered by the solution supply module 100 to the solution blending module 200 according to the first temperature measurement results, enabling the temperature of the uniformly blended cleaning solution in the solution blending module 200 to reach the target temperature.

Specifically, the control module 400 first determines the target temperature of the uniformly blended cleaning solution. In the embodiments of the present invention, the control module 400 can select the upcoming process to determine the target temperature of the cleaning solution based on the data pre-stored in the database, or staff can manually input the target temperature data, which is not limited in this embodiment; at the same time, the control module 400 acquires the temperature of each component of the cleaning solution before blending measured by the first temperature sensing units 301 in real time. Then, calculation is performed based on the first temperature measurement results of the first temperature sensing units 301. The total supply flow rate, and the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module are maintained constant, the required flow rate of room-temperature deionized water and the required flow rate of high-temperature deionized water are calculated in real time according to the first temperature measurement results, and the room-temperature deionized water and high-temperature deionized water at the corresponding flow rate are delivered to the solution blending module 200, enabling the temperature of the uniformly blended cleaning solution in the solution blending module 200 to reach the target temperature.

For example, please refer to FIG. 5. When the solution storage units 101 include

a room-temperature deionized water storage unit 101a, a high-temperature deionized water storage unit 101b, and a chemical solution storage unit 101c, the real-time calculation of the required flow rates of room-temperature deionized water and high-temperature deionized water by the control module 400 according to the first temperature measurement results includes:

based on the conditions that the total supply flow rate, and the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module are constant, the sum of the supply amount of room-temperature deionized water and the supply amount of high-temperature deionized water being L_D; calculating the required flow rate of room-temperature deionized water L_{D1} and the required flow rate of high-temperature deionized water L_{D2} using the system of equations consisting of equation 8 given below and the equation 2 given above:

$$L_D = L_{D1} + L_{D2} \qquad \text{Equation 8}$$

The information of each component of the cleaning solution supplied by the solution supply module 100 is the same as the description given above, then:

required flow rate of room-temperature deionized water $L_{D1} = (c_D * L_D * \rho_{D2} * (T_{D2} - T) - c_1 * L_1 * \rho_1 * (T - T_1) - c_2 * L_2 * \rho_2 * (T - T_2))/(c_D * \rho_{D2} * (T_{D2} - T) + c_D * \rho_{D1} * (T - T_{D1}))$

required flow rate of high-temperature deionized water $L_{D2} = (c_1 * L_1 * \rho_1 * (T - T_1) + c_2 * L_2 * \rho_2 * (T - T_2) + c_D * L_D * \rho_{D1} * (T - T_{D1}))/(c_D * \rho_{D2} * (T_{D2} - T) + c_D * \rho_{D1} * (T - T_{D1}))$

The control system of the present application further comprises a second temperature sensing unit 302 arranged on the solution blending module 200, and the second temperature sensing unit 302 is configured to measure the temperature of the uniformly blended cleaning solution in the solution blending module 200 and generate a second temperature measurement result; when the second temperature measurement result deviates from the target temperature within a preset duration, the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit

101c to the solution blending module are maintained constant, the required flow rate change of room-temperature deionized water and the required flow rate change of high-temperature deionized water are calculated in real time according to the second temperature measurement result, and the room-temperature deionized water and high-temperature deionized water at the corresponding flow rate are delivered to the solution blending module 200, enabling the temperature of the uniformly blended cleaning solution in the solution blending module 200 to reach the target temperature. The specific calculation process is: calculating the required flow rate change of room-temperature deionized water ΔL_{D1} and the required flow rate change of high-temperature deionized water ΔL_{D2} based on equation 1 and equation 2. On the basis of arranging the second temperature sensing unit 302 on the solution blending module 200, the first temperature sensing units 301 are arranged on the delivery units 102 at the same time to measure the temperatures of the supplied solutions and the temperature of the uniformly blended solution. The combined monitoring of the two temperatures can further ensure the accuracy of solution flow rate control.

The present invention further provides a control method matching the above-mentioned real-time solution temperature control system. Please refer to FIG. 6, which shows a schematic flow chart of a real-time solution temperature control method according to an embodiment of the present invention. As shown in FIG. 6, the method includes the following steps:

step S200: Use the solution supply module to supply cleaning solutions at different temperatures to the solution blending module;

step S300: The cleaning solutions at different temperatures are uniformly blended in the solution blending module, and the temperature sensing module is used to measure the temperature of the uniformly blended cleaning solution in real time and feed the temperature back to the control module;

step S400: The control module adjusts the flow rates of the cleaning solutions at different temperatures delivered by the solution supply module to the solution blending module according to the temperature of the uniformly blended cleaning solution measured by the temperature sensing module, enabling the temperature of the uniformly blended cleaning solution in the solution blending module to reach the target

temperature.

Furthermore, the cleaning solution includes at least two of the following: chemical solution, room-temperature deionized water, and high-temperature deionized water.

Furthermore, when the cleaning solution includes chemical solution, the chemical solution consists of one or more components.

Furthermore, before using the solution supply module to supply the cleaning solutions at different temperatures to the solution blending module, the method further includes:

step S100: Preconfigure the relationship data between different processes and corresponding temperatures and the volume ratio data of each component of the cleaning solution for each temperature in the control module.

In a specific process, the control module first determines the target temperature of the cleaning solution according to the process, and then controls the cleaning solutions at different temperatures to be delivered to the solution blending module for uniform blending according to the volume ratio data of each component of the cleaning solution corresponding to the target temperature;

the temperature sensing module acquires the actual temperature of the uniformly blended cleaning solution in real time, and when the actual temperature is measured to deviate from the target temperature for a preset duration, the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module are maintained unchanged, the required flow rate change of room-temperature deionized water and the required flow rate change of high-temperature deionized water are calculated in real time according to the temperature measurement result, and the room-temperature deionized water and high-temperature deionized water at the corresponding flow rate are delivered to the solution blending module, enabling the temperature of the uniformly blended cleaning solution in the solution blending module to reach the target temperature.

Furthermore, the step of calculating the required flow rate change of room-

temperature deionized water and the required flow rate change of high-temperature deionized water in real time according to the temperature measurement result includes:

calculating the required flow rate change of room-temperature deionized water ΔL_{D1} and the required flow rate change of high-temperature deionized water ΔL_{D2} using the system of equations consisting of equation 1 and equation 2.

In another embodiment, the method further includes:

the control module determining the target temperature of the cleaning solution according to the process, and acquiring the temperature measurement result of the temperature sensing module in real time; when the temperature measurement result deviates from the target temperature for a preset duration, the temperature and flow rate of the solution supplied from a high-flow solution storage unit to the solution blending module being maintained constant; the flow rate changes of the solutions from other solution storage units to the solution blending module being adjusted in real time according to the temperature measurement result, enabling the temperature of the uniformly blended cleaning solution in the solution blending module to reach the target temperature, wherein, the high-flow solution storage unit refers to the solution storage unit in the solution supply module that delivers the maximum flow rate to the solution blending module.

Furthermore, when the number of chemical solution storage units is 2, the control module is further configured to maintain the temperature and flow rate of the solution supplied from the high-flow solution storage unit to the solution blending module constant; the step of adjusting the flow rate changes of the solutions from other solution storage units to the solution blending module in real time by the control module according to the temperature measurement result includes:

calculating the flow rate change of chemical solution 1 ΔL_1, the flow rate change of chemical solution 2 ΔL_2, and the flow rate change of room-temperature deionized water ΔL_{D1} using the system of equations consisting of equation 3, equation 4, equation 5, equation 6, and equation 7.

The present invention further provides another control method matching the

above-mentioned real-time solution temperature control system. Please refer to FIG. 7, which shows a schematic flow chart of a real-time solution temperature control method according to another embodiment of the present invention. As shown in FIG. 7, the method includes the following steps:

step S1100: The control module acquires the target temperature of the cleaning solution, wherein, the control module can select the upcoming process to determine the target temperature of the cleaning solution based on the data pre-stored in the database, or staff can manually input the target temperature data, which is not limited in this embodiment;

step S1200: Use the solution supply module to supply cleaning solutions at different temperatures to the solution blending module;

step S1300: The cleaning solutions at different temperatures are uniformly blended in the solution blending module, and a first temperature sensing unit arranged on the delivery unit connecting the solution supply module and the solution blending module is used to measure the supply temperature of each component of the cleaning solution in real time, generate first temperature measurement results, and feed the first temperature measurement results back to the control module;

step S1400: The control module adjusts the flow rates of the cleaning solutions at different temperatures delivered by the solution supply module to the solution blending module according to the first temperature measurement results, enabling the temperature of the uniformly blended cleaning solution in the solution blending module to reach the target temperature.

Furthermore, the cleaning solution includes at least two of the following: chemical solution, room-temperature deionized water, and high-temperature deionized water.

Furthermore, when the cleaning solution includes chemical solution, the chemical solution consists of one or more components.

Furthermore, the adjustment of the flow rates of the cleaning solutions at different temperatures delivered by the solution supply module to the solution blending module

according to the first temperature measurement results includes:

maintaining the total supply flow rate, and the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module constant, calculating the required flow rate of room-temperature deionized water and the required flow rate of high-temperature deionized water in real time according to the first temperature measurement results, and delivering the room-temperature deionized water and high-temperature deionized water at the corresponding flow rate to the solution blending module, enabling the temperature of the uniformly blended cleaning solution in the solution blending module to reach the target temperature.

Furthermore, the real-time calculation of the required flow rate of room-temperature deionized water and the required flow rate of high-temperature deionized water according to the first temperature measurement results includes:

calculating the required flow rate of room-temperature deionized water L_{D1} and the required flow rate of high-temperature deionized water L_{D2} using the system of equations consisting of equation 8 and equation 2.

Furthermore, a second temperature sensing unit arranged on the solution blending module is used to measure the temperature of the uniformly blended cleaning solution in the solution blending module and generate a second temperature measurement result;

the control module acquires the second temperature measurement result of the second temperature sensing unit in real time;

when the second temperature measurement result deviates from the target temperature within a preset duration, the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module are maintained constant, the required flow rate change of room-temperature deionized water and the required flow rate change of high-temperature deionized water are calculated in real time according to the second temperature measurement result, and the room-temperature deionized water and high-temperature deionized water at the corresponding flow rate are delivered to the solution blending module, enabling the

temperature of the uniformly blended cleaning solution in the solution blending module to reach the target temperature, wherein, the specific calculation process is: calculating the required flow rate change of room-temperature deionized water ΔL_{D1} and the required flow rate change of high-temperature deionized water ΔL_{D2} based on equation 1 and equation 2.

The in-line solution blending temperature control method proposed by the present invention is applicable to chemical solutions that can be blended in-line. The temperature control range of the chemical solution is between the temperatures of high-temperature deionized water and room-temperature deionized water. At the same time, it should be understood that the real-time solution temperature control method provided by the present invention is applicable to both semiconductor cleaning process and other wet processes in the field of semiconductor processing technology. In fact, the method is applicable to any situation where solutions at different temperatures need to be blended to reach a target temperature, and the target temperature is within the temperature range of each component of the solution. For example, finished acid can also achieve automatic temperature control using this method. For example, if the temperature of a finished acid needs to be controlled between room temperature and temperature T_A, the finished acid can be supplied in two parts: one part of the solution is controlled at room temperature, and the other part is controlled at temperature T_A. The temperature of the blended solution can be flexibly controlled between room temperature and T_A by adjusting the flow rates of the two parts of the solution.

It should be understood that, in the calculation processing used in the present invention to adjust the flow rate of each component of the cleaning solution, an approximate approach is used: the variation of the specific heat capacity of water with temperature, heat of dilution, and slight heat of chemical reaction are all neglected. If higher accuracy is required, these influences may be taken into account.

Although the present invention has been described in detail with reference to the foregoing embodiments, those of ordinary skill in the art should understand that modifications may still be made to the technical solutions recorded in each of the foregoing embodiments, or that some technical features in the technical solutions may be equivalently substituted; such modifications 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 invention.

What is claimed is:

1. A real-time solution temperature control system, comprising:

a solution supply module, configured to supply solutions at different temperatures to a solution blending module;

a solution blending module, configured to receive and uniformly blend the solutions at different temperatures supplied by the solution supply module;

a temperature sensing module, configured to measure the temperature of the uniformly blended solution in the solution blending module;

a control module, configured to adjust the flow rates of the solutions at different temperatures delivered by the solution supply module to the solution blending module according to the temperature of the uniformly blended solution measured by the temperature sensing module, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature.

2. The control system according to claim 1, wherein the solution supply module includes a solution storage unit and a delivery unit; the solution storage unit is in communication with the solution blending module through the delivery unit; the solution storage unit includes: a room-temperature deionized water storage unit, configured to store room-temperature deionized water to be supplied to the solution blending module; a high-temperature deionized water storage unit, configured to store high-temperature deionized water to be supplied to the solution blending module; a chemical solution storage unit, configured to store chemical solution to be supplied to the solution blending module.

3. The control system according to claim 2, wherein the solution storage unit includes at least one chemical solution storage unit, and when the number of chemical solution storage units is greater than one, the chemical solution stored in each chemical solution storage unit is different.

4. The control system according to claim 3, wherein the control module is preconfigured with the relationship data between different processes and

corresponding temperatures, and a database that stores, for each temperature, the volume ratio of each component of the solution;

the control module is further configured to:

determine the target temperature of the uniformly blended solution;

control the flow rates of the solutions at different temperatures delivered by the solution supply module to the solution blending module according to the volume ratio of each component of the solution corresponding to the target temperature;

acquire the temperature measurement result of the temperature sensing module in real time;

when the temperature measurement result deviates from the target temperature for a preset duration, maintain the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module constant, calculate the required flow rate change of room-temperature deionized water and the required flow rate change of high-temperature deionized water in real time according to the temperature measurement result, and deliver the room-temperature deionized water and high-temperature deionized water at the corresponding flow rate to the solution blending module, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature.

5. The control system according to claim 4, wherein the control module calculating the required flow rate change of room-temperature deionized water and the required flow rate change of high-temperature deionized water in real time according to the temperature measurement result includes:

calculating the required flow rate change of room-temperature deionized water $\Delta \mathrm{L}_{\mathrm{D1}}$ and the required flow rate change of high-temperature deionized water $\Delta \mathrm{L}_{\mathrm{D2}}$ using the system of equations consisting of equation 1 and equation 2 given below:

$$\Delta \mathrm{L}_{\mathrm{D1}} + \Delta \mathrm{L}_{\mathrm{D2}} = 0 \qquad \text{Equation 1}$$

$$\Delta Q_{D1} + \Delta Q_{D2} + \sum_{i=1}^{n} \Delta Q_i = 0 \qquad \text{Equation 2}$$

wherein, equation 1 is obtained based on the conditions that the total solution supply flow rate is constant and the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module are constant, where the sum of the flow rate change of room-temperature deionized water supplied from the room-temperature deionized water storage unit to the solution blending module and the flow rate change of high-temperature deionized water supplied from the high-temperature deionized water storage unit to the solution blending module is 0; equation 2 is obtained based on the law of conservation of thermal energy;

wherein, the solution storage unit includes n chemical solution storage unit(s), ΔQ_i is the heat change of the chemical solution in the i-th chemical solution storage unit, n and i are positive integers greater than or equal to 1, ΔQ_{D1} and ΔQ_{D2} are the heat changes of room-temperature deionized water and high-temperature deionized water, respectively, the unit of heat change is J, and ΔQ_{D1} and ΔQ_{D2} are obtained according to the heat calculation formula $Q = cm\Delta t$ and the mass–density–volume formula $m = \rho v = \rho * L * t$,

wherein, c is the specific heat capacity, with the unit being J/(kg·°C);

m is the mass, with the unit being kg;

Δt is the increase or decrease in temperature, with the unit being °C;

ρ is the density, with the unit being kg/dm³;

L is the flow rate, with the unit being liter/minute;

t is the unit time, with the unit being minute.

6. The control system according to claim 3, wherein the control module is configured to:

determine the target temperature of the uniformly blended solution;

acquire the temperature measurement result of the temperature sensing module in

real time;

when the temperature measurement result deviates from the target temperature for a preset duration, maintain the temperature and flow rate of the solution supplied from a high-flow solution storage unit to the solution blending module constant; adjust the flow rate changes of the solutions supplied from other solution storage units to the solution blending module in real time according to the temperature measurement result, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature, and the high-flow solution storage unit refers to the solution storage unit in the solution supply module that delivers the maximum flow rate to the solution blending module.

7. The control system according to claim 6, wherein when the chemical solution storage units include two solution supply pipelines, the control module is further configured to maintain the temperature and flow rate of the solution supplied from the high-flow solution storage unit to the solution blending module constant; the control module adjusting the flow rate changes of the solutions supplied from other solution storage units to the solution blending module in real time according to the temperature measurement result includes:

calculating the flow rate change of chemical solution 1 ΔL_1, the flow rate change of chemical solution 2 ΔL_2, and the flow rate change of room-temperature deionized water ΔL_{D1} supplied to the solution blending module using the system of equations consisting of equation 3, equation 4, equation 5, equation 6, and equation 7 given below:

$$r_1 = \frac{L_1}{L_{D1}+L_{D2}} \quad \text{Equation 3}$$

$$r_2 = \frac{L_2}{L_{D1}+L_{D2}} \quad \text{Equation 4}$$

$$\Delta Q_1 + \Delta Q_{D1}+\Delta Q_{D2}=0 \quad \text{Equation 5}$$

$$(L_1 + \Delta L_1)/(L_{D1} + L_{D2} + \Delta L_{D1}) = r_1 \quad \text{Equation 6}$$

$$(L_2 + \Delta L_2)/(L_{D1} + L_{D2} + \Delta L_{D2}) = r_2 \quad \text{Equation 7}$$

wherein, equation 3 and equation 4 represent the volume ratios of the two chemical solutions in the chemical solution storage units; equation 5 is obtained based on the law of conservation of thermal energy; equation 6 and equation 7 represent the volume ratios of the two chemical solutions in the solution storage unit under the condition that the volume ratios of the chemical solutions remain constant after the flow rates change;

wherein, r_1 and r_2 are the set volume ratios of the two chemical solutions in the solution, respectively; L_1 and L_2 are the flow rates of the two chemical solutions, respectively, with the unit being liter/minute; ΔL_1 is the flow rate change of the chemical solution whose flow rate needs to be changed, with the unit being liter/minute; L_{D1} and L_{D2} are the flow rates of room-temperature deionized water and high-temperature deionized water, respectively, with the unit being liter/minute; ΔL_{D1} and ΔL_{D2} are the flow rate changes of room-temperature deionized water and high-temperature deionized water, respectively, with the unit being liter/minute; ΔQ_1 is the heat change of the chemical solution whose flow rate needs to be changed, with the unit being J; ΔQ_{D1} is the heat change of room-temperature deionized water, with the unit being J; ΔQ_{D2} is the heat change of high-temperature deionized water, with the unit being J.

8. A real-time solution temperature control system, comprising:

a solution supply module, configured to supply solutions at different temperatures to a solution blending module;

a solution blending module, configured to receive and uniformly blend the solutions at different temperatures supplied by the solution supply module;

a temperature sensing module, including a first temperature sensing unit, configured to measure the temperature of each component of the solution before the solution is uniformly blended, and generate first temperature measurement results;

a control module, configured to determine the target temperature of the uniformly blended solution; adjusting the flow rates of the solutions at different temperatures delivered by the solution supply module to the solution blending module according to

the first temperature measurement results, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature.

9. The control system according to claim 8, wherein the solution supply module includes:

a room-temperature deionized water storage unit, configured to store room-temperature deionized water to be supplied to the solution blending module;

a high-temperature deionized water storage unit, configured to store high-temperature deionized water to be supplied to the solution blending module;

a chemical solution storage unit, configured to store chemical solution to be supplied to the solution blending module.

10. The control system according to claim 9, wherein the solution supply module includes at least one chemical solution storage unit, and when the number of chemical solution storage units is greater than one, the chemical solution stored in each chemical solution storage unit is different.

11. The control system according to claim 10, wherein the control module adjusting the flow rates of the solutions at different temperatures delivered by the solution supply module to the solution blending module according to the first temperature measurement results includes:

maintaining the total solution supply flow rate, and the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module constant, calculating the required flow rate of room-temperature deionized water and the required flow rate of high-temperature deionized water in real time according to the first temperature measurement results, and delivering the room-temperature deionized water and high-temperature deionized water at the corresponding flow rate to the solution blending module, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature.

12. The control system according to claim 11, wherein the control module

calculating the required flow rate of room-temperature deionized water and the required flow rate of high-temperature deionized water in real time according to the first temperature measurement results includes:

calculating the required flow rate of room-temperature deionized water L_{D1} and the required flow rate of high-temperature deionized water L_{D2} using the system of equations consisting of equation 8 and equation 2 given below:

$$L_D = L_{D1} + L_{D2} \quad \text{Equation 8}$$

$$\Delta Q_{D1} + \Delta Q_{D2} + \sum_{i=1}^{n} \Delta Q_i = 0 \quad \text{Equation 2}$$

wherein, equation 8 is obtained based on the conditions that the total supply flow rate is constant and the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module are constant, where the sum of the amount of room-temperature deionized water and the amount of high-temperature deionized water supplied to the solution blending module is L_D; equation 2 is obtained based on the law of conservation of thermal energy;

wherein, L_{D1} is the required flow rate of room-temperature deionized water, L_{D2} is required flow rate of high-temperature deionized water, the solution supply module includes n chemical solution storage unit(s), ΔQ_i is the heat change of the chemical solution in the i-th chemical solution storage unit, n and i are positive integers greater than or equal to 1, ΔQ_{D1} and ΔQ_{D2} are the heat changes of room-temperature deionized water and high-temperature deionized water, respectively, the unit of heat change is J, and ΔQ_{D1} and ΔQ_{D2} are obtained according to the heat calculation formula $Q = cm\Delta t$ and the mass–density–volume formula $m = \rho v = \rho * L * t$,

wherein, c is the specific heat capacity, with the unit being J/(kg·°C);

m is the mass, with the unit being kg;

Δt is the increase or decrease in temperature, with the unit being °C;

ρ is the density, with the unit being kg/dm³;

L is the flow rate, with the unit being liter/minute;

t is the unit time, with the unit being minute.

13. The control system according to claim 10, wherein the temperature sensing module further includes a second temperature sensing unit configured to measure the temperature of the uniformly blended solution in the solution blending module and generate a second temperature measurement result;

the control module is further configured to:

acquire the second temperature measurement result of the second temperature sensing unit in real time;

when the second temperature measurement result deviates from the target temperature within a preset duration, maintain the temperature and flow rate of the chemical solution supplied from the chemical solution storage unit to the solution blending module constant, calculate the required flow rate change of room-temperature deionized water and the required flow rate change of high-temperature deionized water in real time according to the second temperature measurement result, and deliver the room-temperature deionized water and high-temperature deionized water at the corresponding flow rate to the solution blending module, enabling the temperature of the uniformly blended solution in the solution blending module to reach the target temperature.