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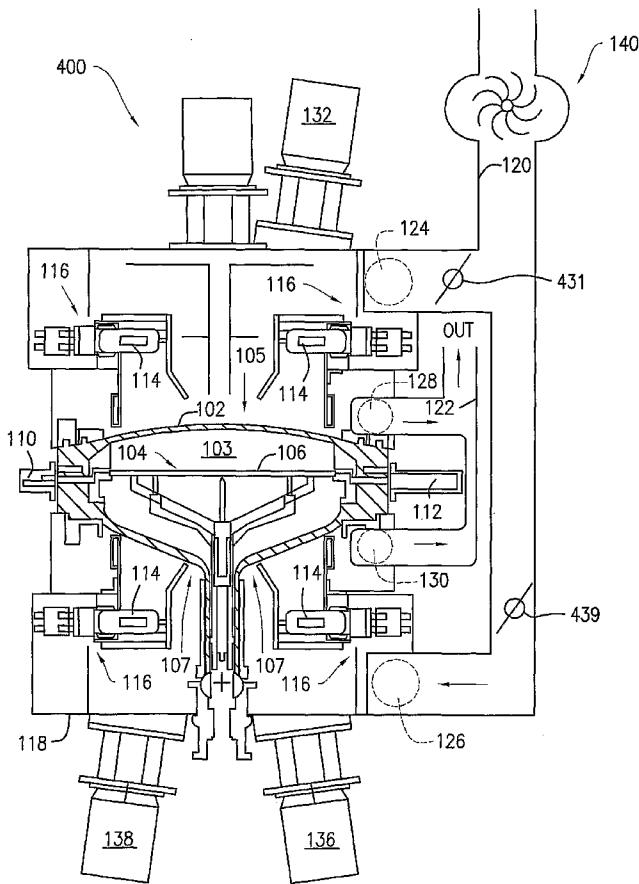
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(54) Title: METHOD AND APPARATUS TO CONTROL SEMICONDUCTOR FILM DEPOSITION CHARACTERISTICS



(57) Abstract: Methods, systems and apparatus are disclosed for adjusting the temperature of at least a portion of the surface of a reaction chamber during a film formation process to control film properties. More than one portion of the chamber surface may be temperature-modulated.

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METHOD AND APPARATUS TO CONTROL SEMICONDUCTOR FILM DEPOSITION
CHARACTERISTICS

TECHNICAL FIELD

5 Embodiments of the present invention pertain to the formation of films on a substrate. These films, including but not limited to Si, SiGe, SiC and SiGeC, in both their doped and undoped forms, are used in the manufacture of advanced electronic components.

10 BACKGROUND ART

Such films exhibit various properties, such as morphology and doping concentrations, which must be controlled to within certain tolerances. The advances exhibited in electronics over the past few decades are the direct result of the ability of 15 semiconductor foundries to increase circuit pattern densities. As these pattern densities increase, the tolerances for the thin films required to make the circuits become increasingly strict. Therefore, careful control of the formation of thin films, and the resultant properties of such films, is essential for 20 continued advances in electronics. These aforementioned films are typically made in an apparatus of the type shown and described in United States Patent No. 6,083,323.

A substrate typically has a top face upon which a film can be formed and a bottom face. To grow the film, the 25 substrate is placed into a reaction chamber. The top face of the substrate faces a top surface of the reaction chamber; similarly, the bottom face of the substrate faces a bottom surface of the reaction chamber. During the film formation process, the substrate is heated according to process 30 parameters.

As noted above, it would be desirable to provide methods and apparatus for providing improved control of film characteristics, including but not limited to growth rate,

morphology, faceting, doping distributions, etc. It is also desirable to provide methods and systems that provide a high level of process repeatability.

5 DISCLOSURE OF THE INVENTION

Aspects of the present invention provide methods, apparatus and systems, for forming thin films on a substrate. During the film formation process, the substrate is heated according to process parameters. Also, during the formation process, the temperature of at least a portion of the surface of the reaction chamber is modulated so that the temperature of this surface varies with the process time in a predetermined manner. This temperature-modulated portion of the reaction chamber surface may be the top surface, the bottom surface, adjacent surfaces or the entire chamber surface. In one embodiment, the temperatures of a plurality of surfaces in the reaction chamber are individually modulated. In one embodiment, the top surface is modulated according to a first temperature parameter, and the bottom surface is modulated according to a second temperature parameter.

In one embodiment, a system or apparatus for forming films includes a cooling system that can be controlled during the film formation period to regulate the temperature of at least a portion of the reaction chamber surface. In one embodiment, the cooling system utilizes one or more setpoints to set the level of cooling power employed by the cooling system to adjust the temperature modulated portion of the reaction chamber surface during the film formation process. In another embodiment, the cooling system employs a temperature feedback loop to adjust the power employed by the cooling system so that the temperature of the cooled surface follows a predetermined,

time-dependent trajectory across the film formation processing period.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a cross-sectional view of a first embodiment 5 of a thermal reaction chamber;

FIG. 2 is a diagram of control logic that can be used in accordance with one or more embodiments;

FIG. 3 is a graph illustrating a hypothetical temperature trajectory;

FIG. 4 is a diagram of control logic that can be used according to one or more embodiments;

FIG. 5 shows a cross-sectional view of a second embodiment of a thermal reaction chamber;

FIG. 6 is a diagram of control logic that can be used 15 according to one or more embodiments;

FIG. 7 is a graph illustrating hypothetical first and second temperature trajectories for the embodiment shown in FIGS. 5 and 6;

FIG. 8 shows a cross-sectional view of a third embodiment 20 of a thermal reaction chamber; and

FIG. 9 shows a cross-sectional view of a fourth embodiment of a thermal reaction chamber.

MODES FOR CARRYING OUT THE INVENTION

Before describing several exemplary embodiments of the 25 invention, it is to be understood that the invention is not limited to the details of construction or process steps set forth in the following description. The invention is capable of other embodiments and of being practiced or being carried out in various ways.

Novel apparatus and techniques in chamber wall 30 temperature regulation to improve the manufacturing of advanced electronics, such as transistor applications in the 65nm and

45nm technology nodes are disclosed. Improvements in growth rate and reduced faceting have been observed, and based upon these observations, improvements in yield, film quality and process repeatability are expected to be obtained. Improvements 5 are particularly expected in low temperature film formation processes where the process temperatures are less than 850 °C, or where films are formed on patterned wafers, or where high dopant concentration films (in the range of 1%) are formed. These improvements can be achieved without affecting other 10 important film parameters and morphology, and which may be practiced in any device adapted for the growth or deposition of films, such as the Epi Centura® 300 mm CVD system of Applied Materials, Inc., providing an additional control parameter for controlling growth kinetics.

15 For purposes of the following disclosure, a film formation process spans the entire period of time, termed the processing period, between the insertion of a substrate into a processing chamber, and the extraction of the substrate from the processing chamber. A single process may incorporate one or 20 more steps; for example, a process may include a pre-clean/surface conditioning step, a film deposition step, and a cool-down step. The invention may be applied, for example, to epitaxial and polycrystalline or amorphous film deposition processes, such as Si, SiGe, SiC (carbon doped silicon), SiGeC 25 (in doped or undoped forms), silicon nitride and other compound semiconductor films (which may include III-V or II-IV materials), and may be broadly applied to other processes.

30 FIG. 1 shows a cross-sectional view of a thermal reaction chamber 103 used in a first embodiment chemical film formation system 100. The chamber 103 has chamber walls 102 that define the inner volume of the chamber 103 in which reactive film formation processes are accomplished, such as suitable

deposition processes, including but not limited to CVD. A housing 118 envelopes and supports the chamber walls 102. A substrate support structure 104 is used to support a substrate 106 within the chamber 103 during CVD processing. The substrate 5 106 has a top face upon which a film is to be deposited or grown, and this top face typically faces away from the substrate support structure 104, although this is not a requirement. Hence, the bottom face of the substrate 106 typically faces, and contacts, the substrate support structure 104.

10 During processing, gases enter the chamber 103 through an entry port 110 and are removed through an exhaust port 112. Also during processing, heat is provided by infrared radiation bulbs 114. The infrared radiation bulbs 114 are mounted proximate the chamber walls 102, on a support assembly 116 15 connected to the housing 118. The chamber walls 102 of the chamber 103 are transparent, typically made of quartz, and allow infrared radiation from the radiation bulbs 114 to freely enter the reaction chamber 103 to heat the substrate 106. The chamber walls 102 have a top surface 105 that faces the top face of the 20 substrate 106, and a bottom surface 107 that faces the bottom face of the substrate 106 and the substrate support structure 104.

25 A more complete description of thermal reactors and their operation is disclosed in commonly assigned U.S. Pat. No. 5,258,824 entitled "In-Situ Measurement Of A Thin Film Deposited On A Wafer" and U.S. Pat. No. 5,108,792 entitled "Double-dome Reactor for Semiconductor Processing", the entire contents of each of which is incorporated herein by reference.

30 During processing, the chamber walls 102, although substantially transparent, still become heated. A coolant flow for cooling the chamber walls 102 is supplied to the housing 118 from a blower 140 via inlet conduit 120, directed past the chamber

walls 102 and exhausted through outlet conduit 122. More specifically, the coolant flow is supplied via conduit 120 to housing 118 through upper inlet port 124 and lower inlet port 126. The coolant flow exits the housing 118 through upper 5 exhaust port 128 and lower exhaust port 130. Coolant entering through upper inlet port 124 passes across the top surface 105 of the chamber walls 102 and exits through upper exhaust port 128. Similarly, coolant entering through lower inlet port 126 passes across the bottom surface 107 of the chamber walls 102 10 and exits through lower exhaust port 130. The housing 118 forms a shroud that channels the coolant past the chamber walls 102. This constant flow of coolant along the chamber walls 102 cools the chamber walls 102 of the reaction chamber 103. Typically, the coolant is air.

15 Alternate ways of controlling the temperature of the chamber walls 102 may also include water cooling surfaces in contact with the chamber walls 102, or the use of nitrogen, helium, argon or other inert gases flowing across the chamber walls 102. A coolant regulator 131, such as an air vane or 20 other coolant flow control device, located in the inlet conduit 120, controls the amount of coolant flow to the housing 118 and, in turn, controls the temperature of the chamber walls 102. Alternatively, other devices for controlling the coolant flow may be used, such as an adjustable iris, a valve, blower speed 25 control circuitry for the blower 140 and the like. Together, the blower 140 and coolant regulator 131, or other suitable ways as outlined above, provide a cooling system for cooling the chamber walls 102, in which the cooling power provided by the cooling system for the chamber walls 102 is controllable, i.e., 30 the rate of heat removal from the chamber walls 102 may be controlled by the cooling system so as to regulate the temperature of chamber walls 102 in a controlled manner.

The temperature of the chamber walls 102 may be monitored using conventional temperature measuring devices familiar to those in the art, such as optical pyrometers, thermocouples or the like. For example, the temperature of the top surface 105 of the chamber walls 102 may be monitored using optical pyrometer 132; optical pyrometer 134 may be used to measure the temperature of the substrate 106; optical pyrometer 136 may be used to measure the temperature of the substrate support structure 104, and optical pyrometer 138 may be used to monitor the temperature of the bottom surface 107 of the chamber walls 102.

A first signal, encoding the measured temperature of the top surface 105, is output from the top surface temperature measuring device 132 and received for processing by control logic 200, an embodiment of which is represented in Fig. 2. Similarly, a second signal, encoding the measured temperature of the bottom surface 107, is output from the bottom surface temperature measuring device 138 and received for processing by the control logic 200. The control logic 200 utilizes the first signal, the second signal or a function of the two to control the cooling power of the cooling system so as to modulate the temperature of the chamber walls 102 over the processing period according to a predetermined temperature trajectory.

In one embodiment, the control logic 200 comprises a processor 210 in electrical communications with a memory 220. The memory 220 comprises control code 221, which is executed by the processor 210 and which controls the operations of the processor 210; the control code 221 serves as the operating system for the control logic 200. In the following, when the processor 210 is described as performing an act, it should be understood that it is the control code 221 that causes the processor 210 to perform the act described; providing the

control code 221 program should be well within the means of one reasonably skilled in the art.

In the embodiment disclosed in Fig. 2, the processor 210 obtains the temperature of the top surface 105 via a top surface temperature input 231 that receives the first signal from the top surface temperature measuring device 132. Similarly, the processor 210 obtains the temperature of the bottom surface 107 via a bottom surface temperature input 232 that receives the second signal from the bottom surface temperature measuring device 138. The control logic 200 is used, amongst other things, to control the cooling system used to cool the chamber walls 102 so as to modulate the chamber wall 102 temperature over the process period in a predetermined manner, thereby providing an independent parameter for controlling the kinetics of the film formation process. It should be clear, however, that the control logic 200 may contain many other additional inputs that are not indicated in Fig. 2, such as inputs for measuring gas flow rates, substrate 106 and substrate support structure 104 temperatures, etc., as known in the art.

The control logic 200 may be provided a display 238 to present process-relevant information to a user, and an input device 239 to permit the user to enter information into the control logic 200. The processor 210 can control the display 238 to present, for example, the temperatures of the top surface 105, bottom surface 107, substrate 106 and substrate support structure 104, the current process step, the current process time, gas flow rates, etc. Likewise, the processor 210 may change parameters stored within the memory 220 according to data received from the input device 239, with such changes potentially resulting in changes to the process steps executed by the processor 210, and hence changes in the way the processor 210 controls the CVD system 100. The display 238, input device

239, control code 221 and processor 210 together form a user input/output (I/O) interface, in a manner familiar to those in the art, which permits the user to both monitor and control the CVD system 100.

5 In the embodiment shown, the memory 220 of the control logic 200 also contains a temperature parameter 222 that is used to control and modulate the temperature of at least a portion of the chamber wall 102 over the processing period. The temperature parameter 222 comprises at least one setpoint 223, 10 and typically will have two or more setpoints 223. Each setpoint 223 contains a respective time value 224 and temperature value 225. The time value 224 indicates a time within the processing period, and may be in any format suitable to encode such information, such as a 24-hour time, a process- 15 relative time (i.e., the amount of time elapsed since the beginning of the process, or to the end of the process), a step-relative time (i.e., the amount of time elapsed since the beginning of a current step within the process, or to the end of the step) or the like. The temperature value 225 indicates a 20 temperature that is desired for the temperature-modulated portion of the chamber wall 102 at the related time value 224 in the setpoint 223, and may be in any form suitable to indicate such temperature information; examples include an absolute temperature, as in degrees Celsius or Kelvin, or a relative 25 temperature, as in an offset from a process temperature.

Together, the setpoints 223 provide temperature trajectory information for the temperature-modulated portion of the chamber wall 102 over the processing period. At predetermined intervals during the processing period, such as 30 0.01 second intervals, the control logic 200 obtains chamber wall 102 temperature information from the temperature inputs 231, 232, and utilizes this information to generate a current

measured temperature 229. Any method may be used to generate the current measured temperature 229, such as by averaging, weighted averaging, using only one of the temperature inputs 231, 232, etc. This may be selectable by the user via the user 5 I/O interface. The processor 210 then uses the current time (as obtained from timer 240) and the time values 224 to index into the temperature parameter information 222 to find the closest setpoints 223 between which the current time lies.

Still referring to FIG. 2, next, the processor 210 10 performs linear interpolation (or any other suitable interpolation), using the associated temperature values 225 of the closest setpoints 223, to determine the current target temperature 228 of the temperature-modulated portion of the chamber wall 102. Typically two setpoints 223 (or one setpoint 15 if before or beyond the minimum and maximum time values 224) are used as the closest setpoints 223, but three or more may be used depending upon the type of interpolation performed. The processor 210 utilizes the current measured temperature 229 and current target temperature 228 as inputs into a standard feed-20 back loop to control the power level of the cooling system for the temperature-modulated portion of the chamber walls 102 so that the current measured temperature 229 reaches the current target temperature 228. By way of continuous feedback, the current measured temperature 229 as a function of time should 25 substantially track the temperature parameter 222, within measurement errors and the mechanical limitations of the cooling system.

In the embodiments depicted in Figs. 1 and 2, for example, the processor 210 sends signals to a cooling power 30 control output 233 to control the coolant regulator 131 based upon the measured and target temperatures 229 and 228. If the difference between the current measured temperature 229 and the

current target temperature 228 is positive (i.e., the temperature-modulated portion of the chamber wall 102 is currently hotter than desired), then the processor 210 sends a signal to the cooling power control output 233 to open the 5 coolant regulator 131 more to increase the rate of coolant flowing over the chamber walls 102, i.e., to increase the cooling power of the cooling system. Conversely, if the difference is negative, the processor 210 would instruct the coolant regulator 131 to further restrict the flow of coolant, 10 so as to decrease the cooling power of the cooling system. The processor 210 may utilize the magnitude of the difference between the current measured and target temperatures 229, 228 to determine how restrictive or permissive of air flow the coolant regulator 131 should be, i.e., by how much the cooling power 15 should be increased or decreased.

By way of example, Fig. 3 illustrates a hypothetical desired temperature trajectory of the average temperature of the chamber walls 102 over a portion of the processing period. The graph in Fig. 3 is normalized to show temperature differentials 20 with respect to a predefined process temperature, which may be the starting temperature of the film formation step. The user may desire that the chamber walls 102 cool down to the process temperature from a pre-bake step, spend about ten seconds at the process temperature to stabilize, and then, upon the start of 25 the film formation step, begin an asymptotic-like slope down to a temperature that is about 65 °C below the process temperature at the completion of the film formation step. This steadily decreasing temperature of the chamber walls 102 over the film formation step helps to reduce faceting. The user may decide to 30 use six points 252-257 to approximate an asymptotic curve 260, and two points 251, 252 to provide for the ten second

temperature stabilization period prior to the film formation step.

If the film formation step begins at a process time of 1340 seconds, the I/O system of the control logic 200 may then 5 be utilized to enter seven corresponding setpoints 223 for the temperature parameter 222: a first setpoint 223 with a time 224 of 1330 and a temperature 225 of 0 °C for a first point 251; a second setpoint 223 with a time 224 of 1340 and a temperature 225 of 0 °C for a second point 252; a third setpoint 223 with a 10 time 224 of 1370 and a temperature 225 of -25 °C for a third point 253; a fourth setpoint 223 with a time 224 of 1405 and a temperature 225 of -35 °C for a fourth point 254; a fifth setpoint 223 with a time 224 of 1440 and a temperature 225 of - 45 °C for a fifth point 255; a sixth setpoint 223 with a time 15 224 of 1510 and a temperature 225 of -60 °C for a sixth point 256, and finally a seventh setpoint 223 with a time 224 of 1560 and a temperature 225 of -65 °C for a seventh point 257. The I/O system might then be utilized to instruct the control logic 200 to use an average value obtained from the top surface 20 temperature input 231 and the bottom surface temperature input 232 to generate the current measured temperature 229. During the film formation process, the control logic 200 would then use the seven setpoints 223 of the temperature parameter 222 to control the coolant regulator 131 so that the current measured 25 temperature 229 tracks the current target temperature 228. Of course, it should be clear that the target temperature 228 in this case is not an actual temperature, but a temperature differential based upon a predefined process temperature. That is, when generating the current measured temperature 229, the 30 control logic 200 may subtract the known, constant process temperature to yield a temperature differential for the current measured temperature 229. For example, at a process time of

1470, as shown in Fig. 3, the control logic 200 would extrapolate between the fifth and sixth setpoints 223 for the fifth point 255 and sixth point 256 to find a current target temperature 228 of 53 °C below the process temperature. The 5 control logic 200 would then send signals to the cooling power control output 233, based upon the current target temperature 228 of -53 °C and the value of the current measured temperature 229, to regulate the cooling system so that the average temperature of the chamber walls 102 tracks the temperature 10 trajectory defined by the setpoints 223. The coolant regulator 131 could also be manually adjusted to control the temperature trajectory of the chamber walls 102.

In the above exemplary embodiment, the setpoints 223 utilize a temperature value 225 to construct the temperature 15 parameter 222 that defines a desired temperature trajectory of the modulated surface of the chamber walls 102 over the processing period. However, with reference to Fig. 4, because there is a tight correlation between the power of the cooling system (i.e., the speed of the blower 140 and/or the setting of 20 the coolant regulator 131) and the radiance of the heating elements 114, as another embodiment it is equally possible to define the temperature parameter 322 as having one or more setpoints 323, each with an associated time value 324 and cooling power level value 325. In this case, the processor 310 25 of the second embodiment control logic 300 generates a current target cooling power level 328 in a manner analogous to that used above to find the current target temperature 228, and then sends signals to the cooling power control output 333 to set the power of the cooling system (i.e., blower 140 and/or coolant 30 regulator 131) to match the current target cooling power level 328.

Because of the inherent consistency and reproducibility of processing runs, the temperature parameter 322 defined as a series of cooling power levels 325 at respective time values 324 is functionally similar to the temperature parameter 222 of the 5 above embodiment. However, variations between the desired and actual temperatures of the modulated region of the chamber walls 102 may be greater than in the first embodiment.

Embodiments of the present invention provide for controlled modulation of the entire chamber wall 102, or a 10 portion of the chamber wall 102, over the processing period. In particular, as indicated in Fig. 3, the controlled modulation of the chamber wall 102 within individual steps of the film formation process can be achieved. For example, a higher overall growth rate with reduced faceting can be achieved by 15 providing a temperature parameter 222, 322 that initially increases the temperature of the top surface 105, and then slowly decreases the top surface 105 temperature as the deposition or growth of the film on the substrate progresses. Selection of the temperature parameter 222, 322 will depend on 20 the property that is to be optimized. For example, increasing the wall 102 temperature causes gas to crack or decompose better, thereby enhancing the growth rate. Film composition can be varied through this mechanism as well, since some dopant species absorb or incorporate better when decomposed. All of 25 this may be done within a process step, as the film formation procedure goes through various stages. It will thus be understood that the skilled artisan can empirically determine and select the temperature parameter 222, 322 to achieve the desired film properties.

30 With reference to Fig. 5 and Fig. 6, a third embodiment system 400 provides additional independent parameters for the film deposition process by allowing independent control of the

temperatures of multiple portions of the chamber wall 102. For ease of presentation, components in Fig. 5 that are essentially identical to those in the prior embodiments have been provided the same reference numbers. As indicated in the discussion of 5 Fig. 1, coolant entering inlet port 124 passes across the top surface 105 of the chamber walls 102, thus cooling the top surface 105. Similarly, coolant entering the bottom inlet port 126 cools the bottom surface 107. Hence, by independently controlling the amount of coolant entering the top inlet port 10 124 and the bottom inlet port 126 it is possible to respectively independently control the temperature of the top surface 105 and the bottom surface 107 of the chamber walls 102. To effectuate this, this embodiment provides a first coolant regulator 431 for controlling the rate of coolant flow into the upper inlet port 15 124, and a second coolant regulator 439 for controlling the rate of coolant flow into the lower inlet port 126.

The coolant regulators 431, 439 may be air vanes, adjustable irises, valves, liquid-cooled surfaces in contact with their respective chamber wall 102 surfaces, or the like. 20 Alternatively, one of the coolant regulators 431, 439 may be an air vane, adjustable iris, valve, cooled surface or the like, and the other may utilize blower speed control circuitry to control the speed of the blower 140.

Control logic 500 for the embodiment shown in FIG. 5 is 25 analogous to that of the previous embodiments, but provides for independent control of the first coolant regulator 431 and the second coolant regulator 439 according to a first temperature parameter 560 and a second temperature parameter 570, respectively, stored in the memory 520. The first temperature 30 parameter 560 defines a desired temperature trajectory of the top surface 105 over the processing period. The second

temperature parameter 570 defines a desired temperature trajectory of the bottom surface 107 over the processing period. For example, with reference to Fig. 7, the first temperature parameter 560 may have fifteen setpoints 563 defining a first 5 temperature trajectory 601, analogous to that depicted in Fig. 3, for the top surface 105 relative to the process temperature. For example, seven points 611-617 may comprise a pre-bake temperature trajectory 610 for the top surface 105. Four points 621-624 may comprise a film deposition temperature trajectory 10 620 for the top surface 105 that increases during the film deposition step. This increase may be substantially asymptotic from the process temperature to a higher target temperature over the time period of the film deposition step. Such an increase 15 in temperature of the top surface 105 during the film deposition step yields higher deposition rates. Four points 631-634 may comprise a cool-down temperature trajectory 630 for the top surface 105.

The second temperature parameter 570 may also have, for example, eight setpoints 573 defining a second temperature 20 trajectory 602 for the bottom surface 107 across the entire film formation process. The processor 510 may utilize the first temperature parameter 560 to generate a first current target temperature 523, and utilize the second temperature parameter 570 to generate a second current target temperature 524. 25 Monitoring of inputs, such as the top surface temperature input 531, which receives first signals from the top surface temperature measuring device 132, enables the processor 510 to generate a current top surface temperature 521. Similarly, by monitoring the bottom surface temperature input 532, which 30 receives second signals from the bottom surface temperature measuring device 138, the processor 510 may generate a current bottom surface temperature 522. Of course, the current top

surface temperature 521, as well as the current bottom surface temperature 522, may be a function of a plurality of inputs, as desired by the user.

Analogous to the previous embodiments, the processor 510 utilizes the first current target temperature 523 and the current top surface temperature 521 to send signals to the first cooling power control output 533 to control the first coolant regulator 431, and hence to modulate the top surface 105 temperature according to the first temperature parameter 560. 5 Similarly, the processor 510 utilizes the second current target temperature 524 and the current bottom surface temperature 522 to send signals to the second cooling power control output 534 to control the second coolant regulator 439, and hence to modulate the bottom surface 107 temperature according to the 10 first temperature parameter 560. 15 Of course, the first temperature parameter 560 and the second temperature parameter 570 may be defined by respective cooling power levels rather than temperatures, as is done in the second embodiment, in which case it may not be necessary to monitor the current top surface 20 temperature 521 or the current bottom surface temperature 522 to control the first coolant regulator 431 and the second coolant regulator 439.

As shown in Fig. 8, it is possible to use a first variable speed blower 701, and a second variable speed blower 25 702, to respectively control the temperature of the top surface 105 and bottom surface 107 of the chamber walls 102. With further reference to Fig. 6, the control logic 500 is equally suited to control the embodiment depicted in Fig. 8. First 30 cooling power control output 533 may control the speed of first blower 701, while second cooling power control output 534 may control the speed of second blower 702.

With reference to Fig. 9, it is possible to independently control the temperature of the top surface 105 and the bottom surface 107 by changing the irradiancy bias between top lamps 802 and bottom lamps 804. The top lamps 802 are disposed above 5 the top surface 105 of the chamber walls 102, and thus heat the top surface 105 while heating the substrate 106. The bottom lamps 804 are disposed below the bottom surface 107 of the chamber walls 102, and thus heat the bottom surface 107 while heating the substrate 106. The combined irradiancy of the top 10 lamps 802 and bottom lamps 804 determines the final temperature of the substrate 106. If the irradiancy of the top lamps 802 is increased while the irradiancy of the bottom lamps 804 is decreased, it is possible to increase the temperature of the top surface 105 and decrease the temperature of the bottom surface 15 107, while keeping the substrate 106 at the same temperature. Reversing this irradiancy bias will lead to heating of the bottom surface 107 and cooling of the top surface 105, while maintaining the temperature of the substrate 106. The irradiancy of the top lamps 802 may therefore be controlled 20 independent of the irradiancy of the bottom lamps 804. With reference to Fig. 6, independent control of the top lamps 802 and bottom lamps 804 permits the control circuit 500 to control the irradiancy bias between the top lamps 802 and bottom lamps 804. First cooling power control output 533 may thus be used to 25 control the speed of variable speed blower 140, while second cooling power control output 534 may be used to control the irradiancy bias between the top lamps 802 and the bottom lamps 804. It will be appreciated that second cooling power control output 534 may actually be two independent outputs that 30 respectively control the irradiancy of the top lamps 802 and the bottom lamps 804, and the difference between these two irradiancy outputs yields the irradiancy bias that

preferentially heats and cools one of the surfaces 105, 107 over the other surface 107, 105.

For example, to cool the bottom surface 107, the processor 510 may control the second cooling power control 5 output 534 so that the irradiancy of the top lamps 802 increases, while the irradiancy of the bottom lamps 804 decreases. From the temperature perspective of the substrate 106, little has changed. However, from the point of view of the bottom surface 107, as less radiant energy impinges upon the 10 bottom surface 107, the bottom surface 107 will begin to cool. It will be appreciated that, since more radiant energy will impinge upon the top surface 105, the top surface 105 may begin to heat beyond its first temperature parameter 560. In response to this, the processor 510 may control the first cooling power 15 control output 533 to increase the speed of the variable speed blower 140 to cool the top surface 105, which will incidentally lead to even more cooling of the bottom surface 107. Similarly, reversing the bias can lead to heating of the bottom surface 107. Hence, by using the second cooling power control output 20 534 to modulate the irradiancy bias between the lamps 802, 804, the processor can selectively raise or lower the temperature of the bottom surface 107 with respect to the top surface 105.

It is possible not only to temperature-modulate the top and bottom surfaces 105, 107 of the chamber walls 102, but also 25 to modulate side portions of the chamber walls 102. For example, with reference to Fig. 1, with suitable control of inlet and outlet ducting, it is possible to control the respective temperatures of left adjacent top surface 151 and right adjacent top surface 152. The adjacent top surface 151, 30 152 are adjacent to the top surface 105, and hence adjacent to the top surface of the substrate 106. Similarly, it is possible to temperature-modulate left adjacent bottom surface 153 and

right adjacent bottom surface 154, which are adjacent to the bottom surface 107, and hence adjacent to the bottom surface of the substrate 106. The control logic may be easily expanded to accommodate as many temperature parameters as there are 5 individual chamber wall surface portions to temperature-modulate, and the method of doing so should be clear in light of this disclosure.

Although the invention herein has been described with reference to particular embodiments, it is to be understood that 10 these embodiments are merely illustrative of the principles and applications of the present invention. It will be apparent to those skilled in the art that various modifications and variations can be made to the method of the present invention without departing from the spirit and scope of the invention. 15 Thus, it is intended that the present invention include modifications and variations that are within the scope of the appended claims and their equivalents.

CLAIMS

1. A method for forming a film on a substrate comprising:
5 placing a substrate in a reaction chamber surrounded by a plurality of walls to perform a film formation process; and
modulating at a non-constant value the temperature of at least a first wall during the film formation process.
2. The method of claim 1, wherein the first wall is actively
10 kept at a temperature above the temperature of a second wall during the film formation process.
3. The method of claim 2 wherein an irradiancy bias between a first lamp heating the first wall and a second lamp heating the
15 second wall is controlled to raise the temperature of the first wall with respect to the second wall.
4. The method of claim 1, wherein the temperature is modulated to a first value higher than a second value, the first value
20 occurring before the second value during a film formation step within the film formation process.
5. The method of claim 1, wherein coolant is flowed adjacent at least one of the plurality of walls at a controlled, variable
25 rate.
6. The method of claim 5, wherein the coolant is flowed using a variable speed blower.

7. A method for forming a film on a substrate, the method comprising:

5 selecting a first temperature parameter, the first temperature parameter being a non-constant value over a processing period;

disposing the substrate within chamber walls of a processing chamber;

10 forming the film on the substrate during the processing period; and

controlling the temperature of a first portion of the chamber walls during the processing period so that the temperature of the first portion of the chamber walls substantially conforms with the first temperature parameter.

15

8. The method of claim 7 wherein the first temperature parameter is selected according to a desired property of the film that is to be formed.

20 9. The method of claim 7 wherein the first temperature parameter is a non-constant value over a step within the processing period.

25 10. The method of claim 9 wherein the step is a film formation step.

11. The method of claim 10 wherein the first temperature parameter defines a function that is adapted to minimize faceting during the film formation step.

30

12. The method of claim 11 wherein the function adapted to minimize faceting during the film formation step starts at a

first temperature and changes over the film formation step to a second temperature that is less than the first temperature.

13. The method of claim 10 wherein the first temperature
5 parameter defines a function that is adapted to increase a deposition rate during the film formation step.

14. The method of claim 13 wherein the function adapted to increase the deposition rate during the film formation step
10 starts at a first temperature and changes over the film formation step to a second temperature that is greater than the first temperature.

15. The method of claim 7 wherein the first portion of the
15 chamber walls is above a top face of the substrate.

16. The method of claim 7 further comprising:

selecting a second temperature parameter, the second temperature parameter being a non-constant value over the
20 processing period; and

controlling the temperature of a second portion of the chamber walls so that the temperature of the second portion of the chamber walls substantially conforms with the second temperature parameter during the processing period.

25

17. The method of claim 16 wherein the second temperature parameter is selected according to a desired property of the film that is to be formed.

30 18. The method of claim 16 wherein the first portion of the chamber walls is above a top face of the substrate, and the

second portion of the chamber walls is below a bottom face of the substrate.

19. The method of claim 16 wherein the second temperature 5 parameter is a non-constant value over a step within the processing period.

20. The method of claim 19 wherein the step is a film formation step.

10

21. The method of claim 16 wherein the second portion of the chamber walls is adjacent to the substrate.

22. A film formation system comprising:

15 a chamber wall adapted to accept a substrate on which a film is to be formed;

a first cooling system for cooling a first portion of the chamber wall;

20 a first regulator for controlling the cooling power of the first cooling system; and

control logic for controlling the first regulator, the control logic comprising: a memory for holding a first temperature parameter defining a desired temperature trajectory of the first portion of the chamber wall over a processing 25 period; a user input/output system for entering the first temperature parameter; a first output for controlling the first regulator; and a processing circuit for sending first signals to the first output over the processing period according to the first temperature parameter.

30

23. The system of claim 22 wherein the first temperature parameter comprises a plurality of setpoints, each setpoint comprising a respective time within the processing period.

5 24. The system of claim 23 wherein each setpoint further comprises a respective temperature.

25. The system of claim 23 wherein each setpoint further comprises a respective cooling power level.

10

26. The system of claim 22 further comprising:

a second cooling system for cooling a second portion of the chamber wall; and

15 a second regulator for controlling the cooling power of the second cooling system, wherein the control logic further comprises a second output for controlling the second regulator, wherein the processing circuit is capable of sending second signals to the second output during the processing period according to a second temperature parameter stored in the
20 memory.

27. The system of claim 22 further comprising a first lamp capable of heating the first portion of the chamber walls and a second lamp capable of heating a second portion of the chamber walls, the control logic capable of controlling an irradiancy bias between the first lamp and the second lamp to selectively heat the first wall over the second wall.

28. The system of claim 27 wherein the first lamp and the second lamp collectively heat the substrate.

30

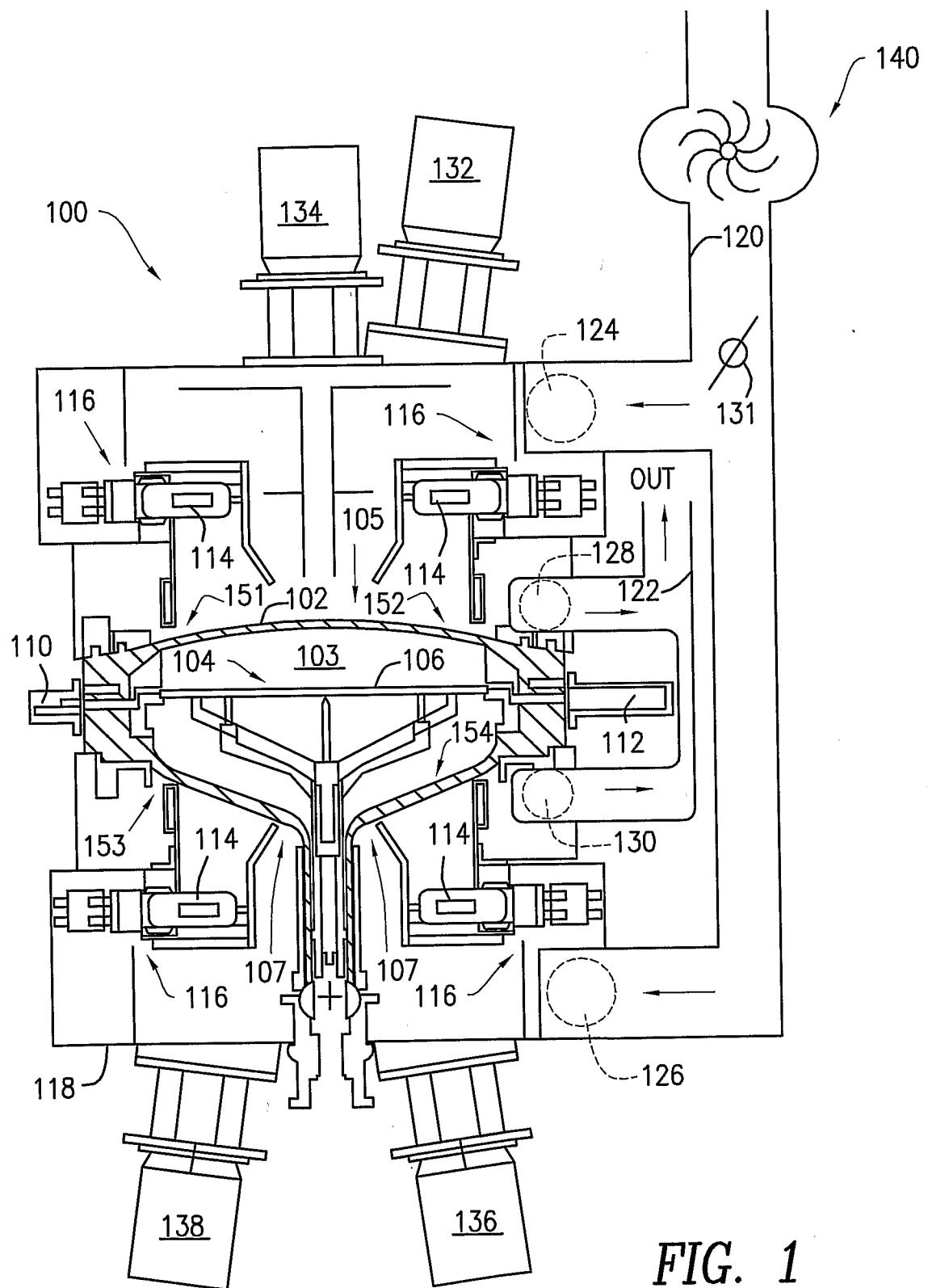


FIG. 1

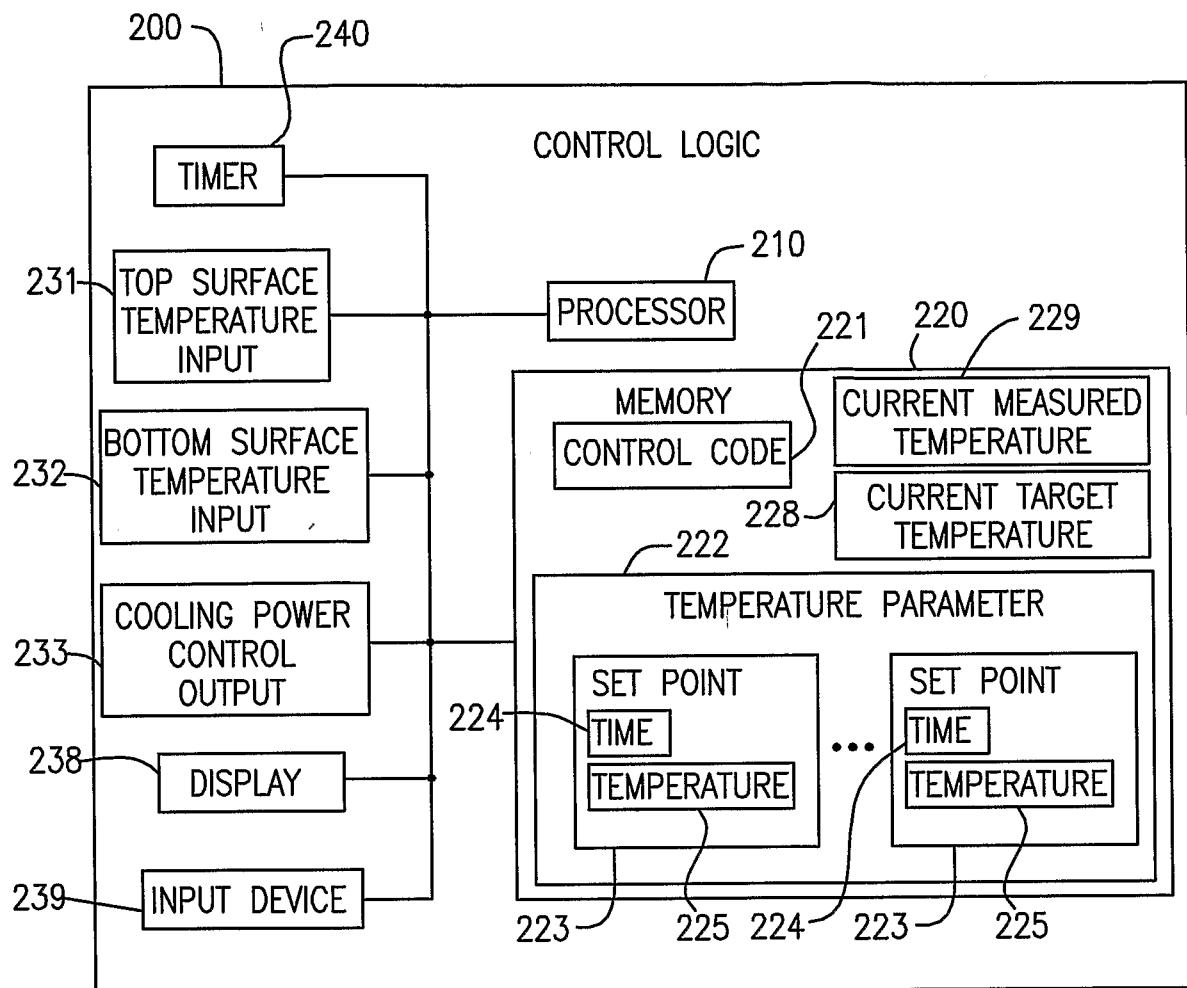


FIG. 2

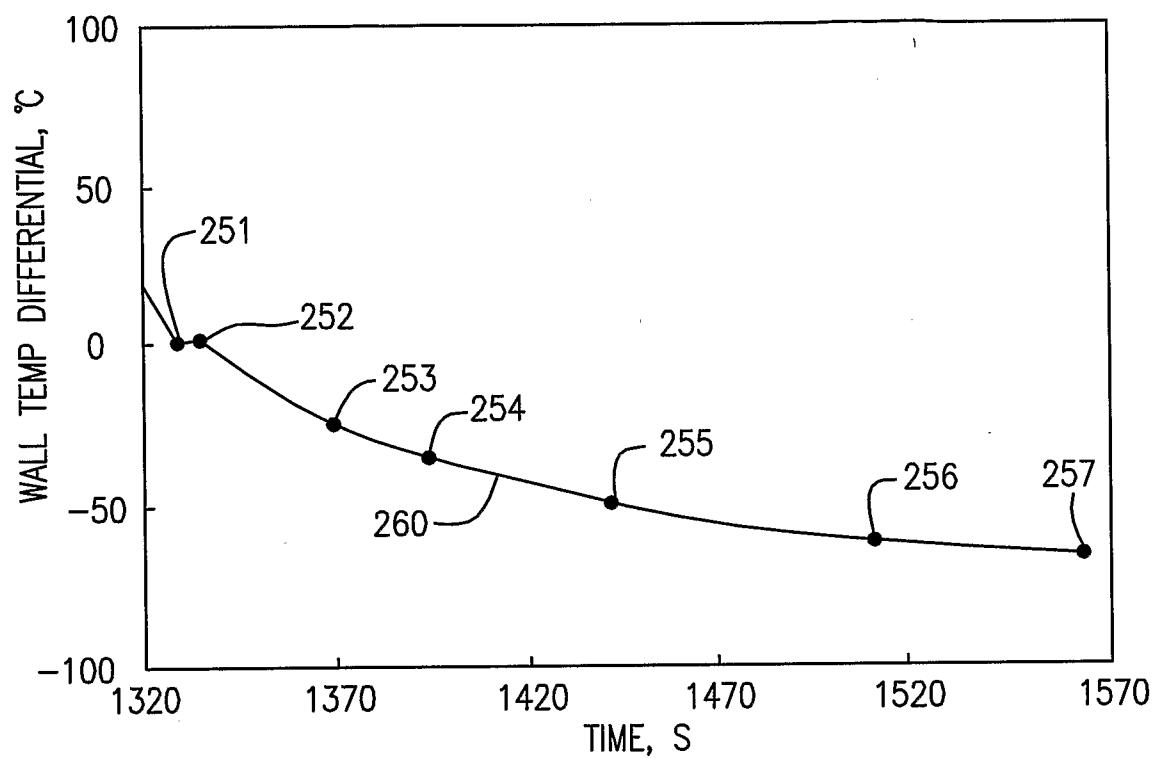


FIG. 3

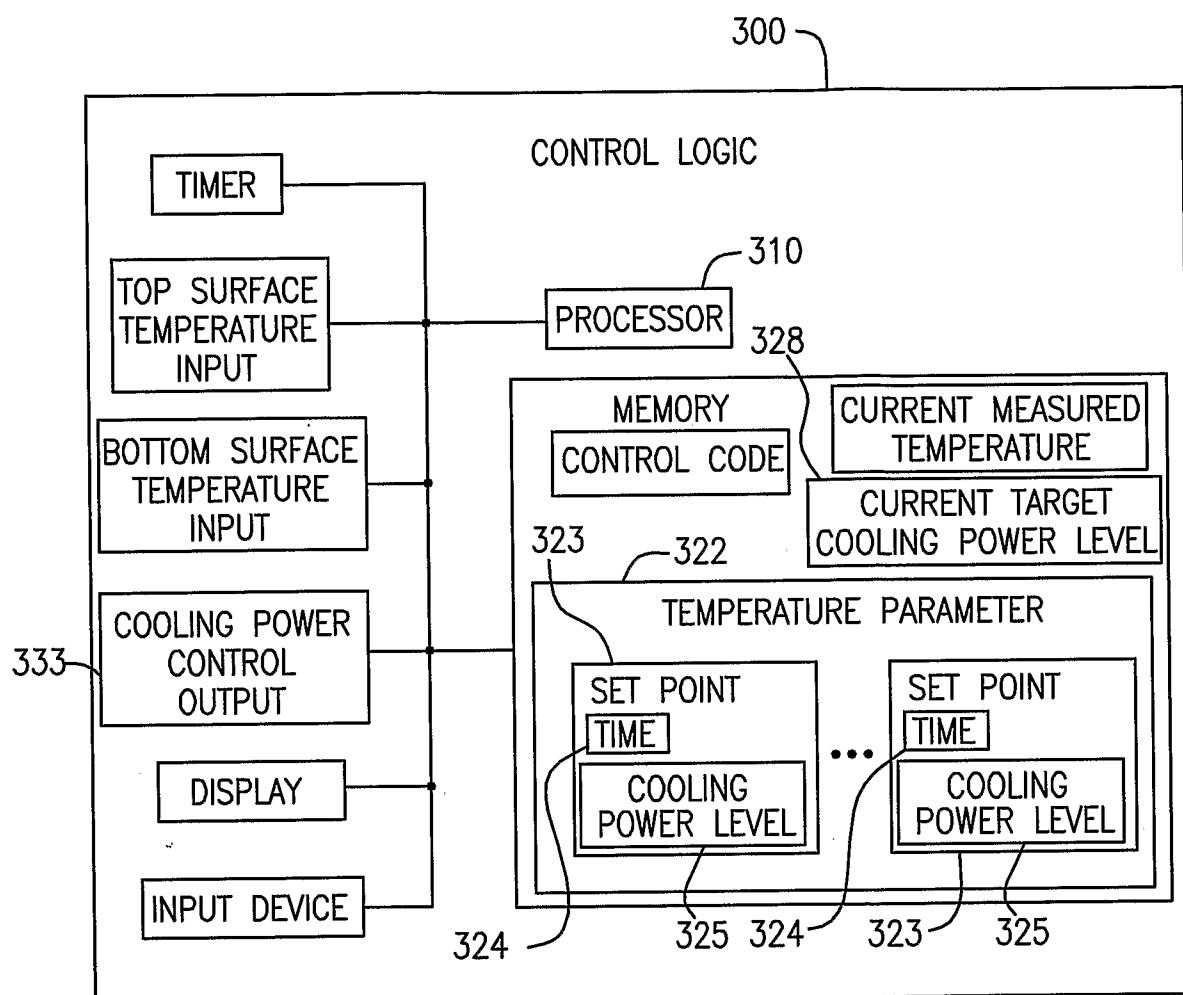
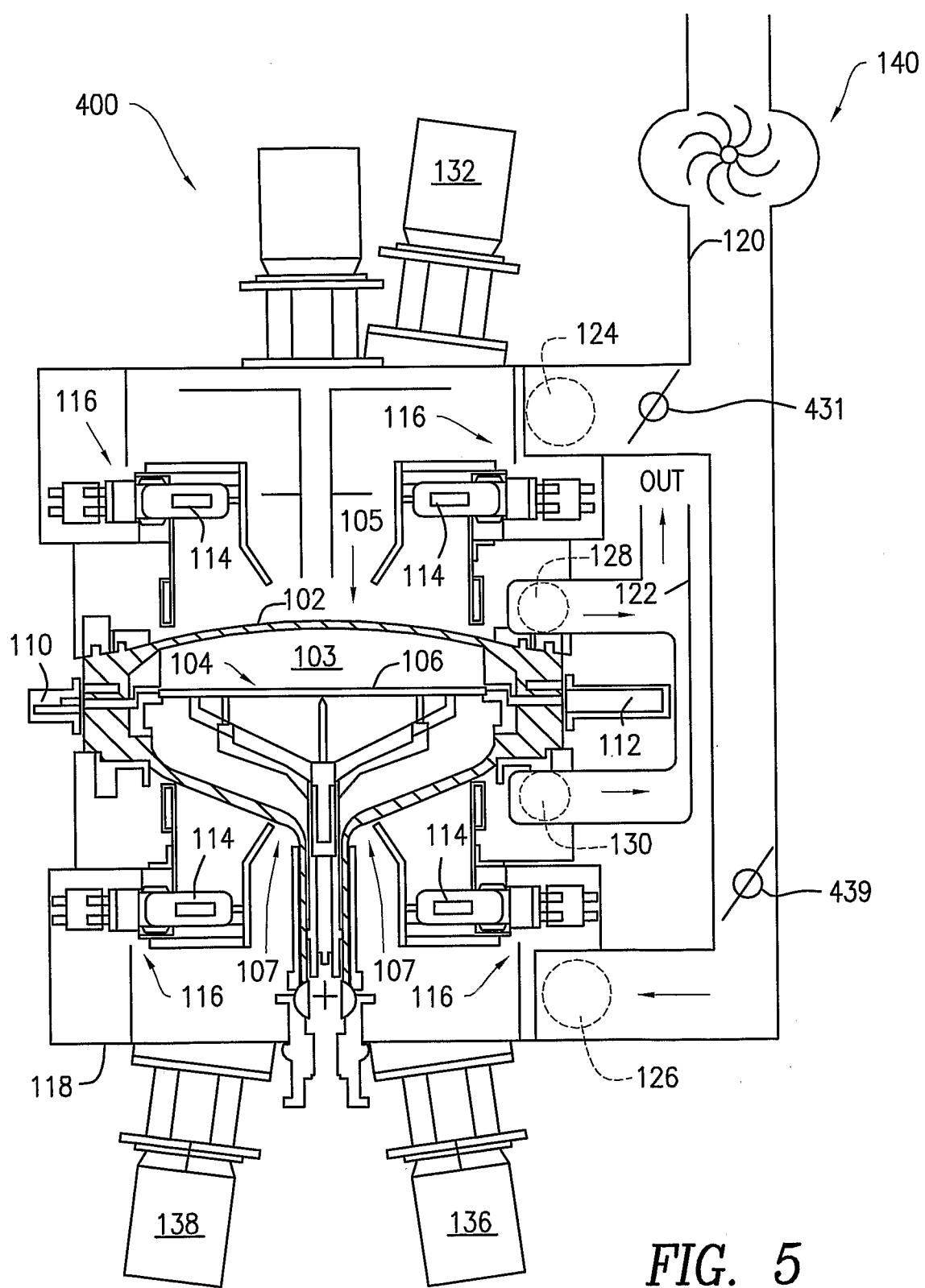


FIG. 4



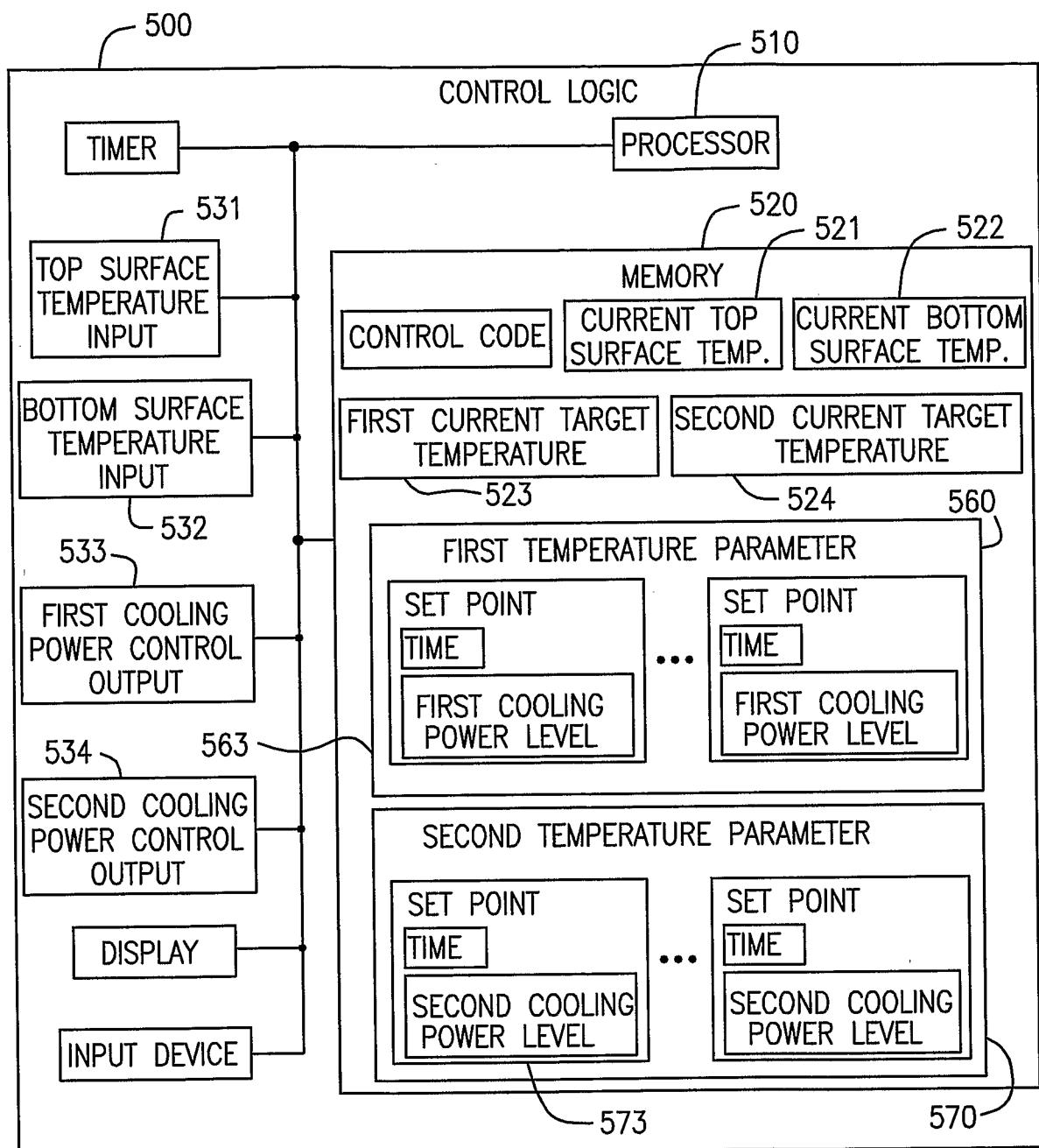


FIG. 6

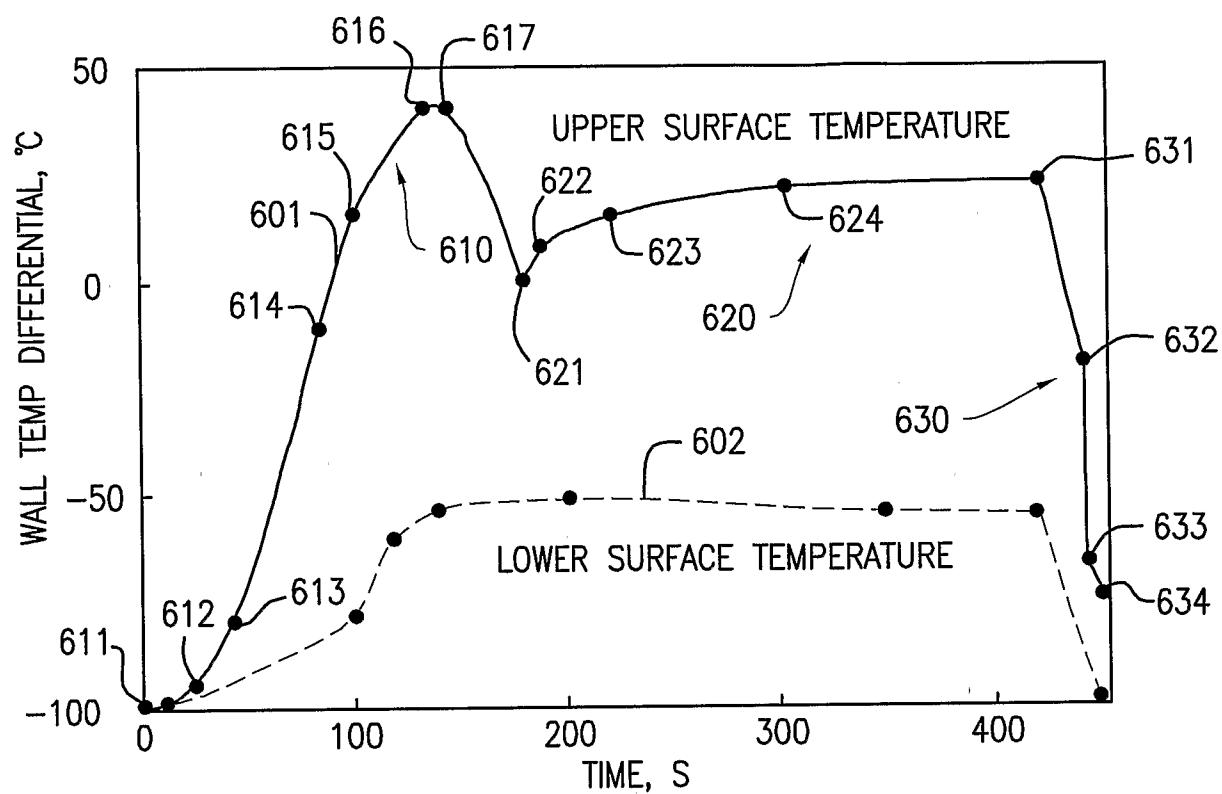


FIG. 7

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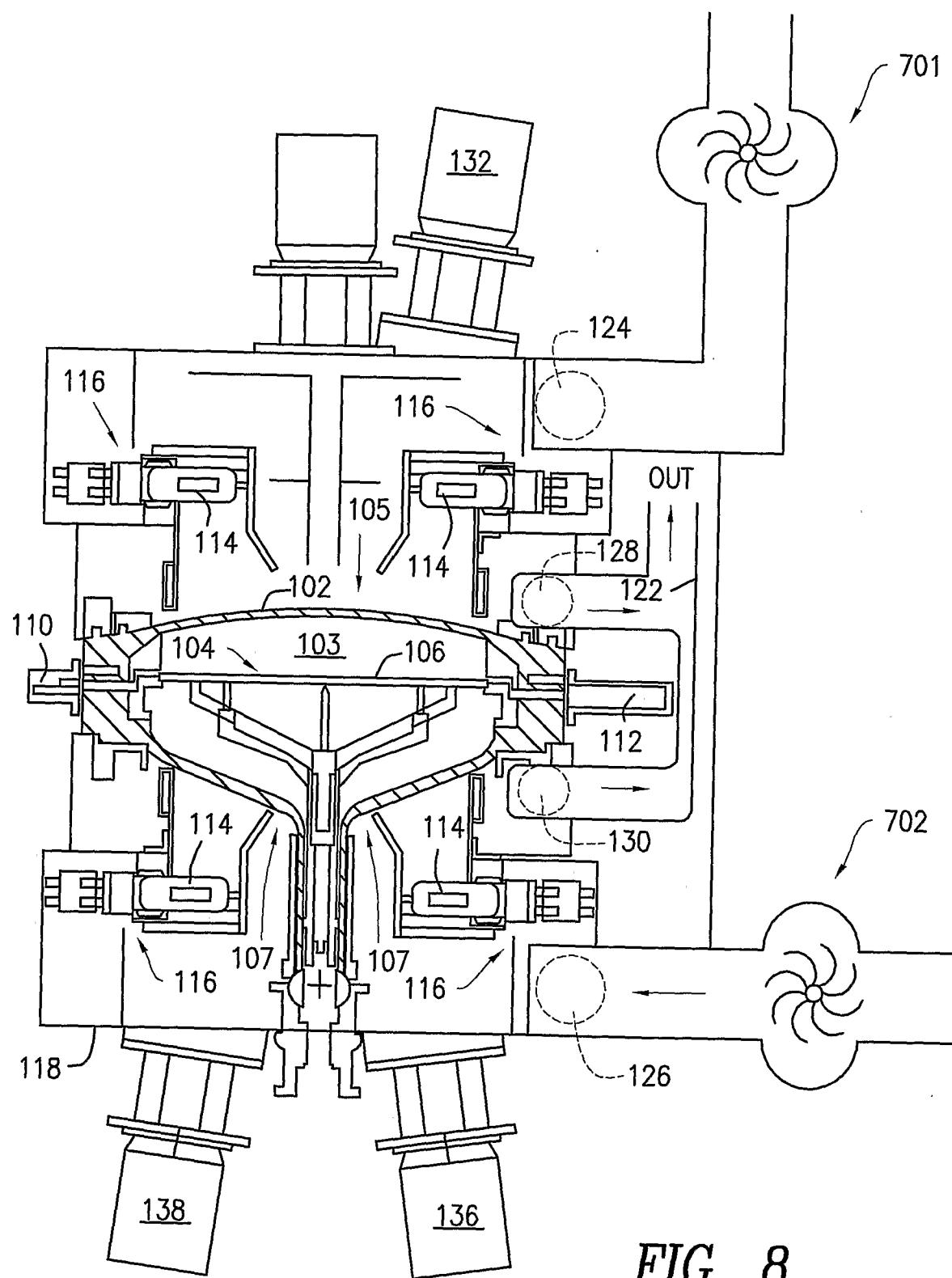


FIG. 8

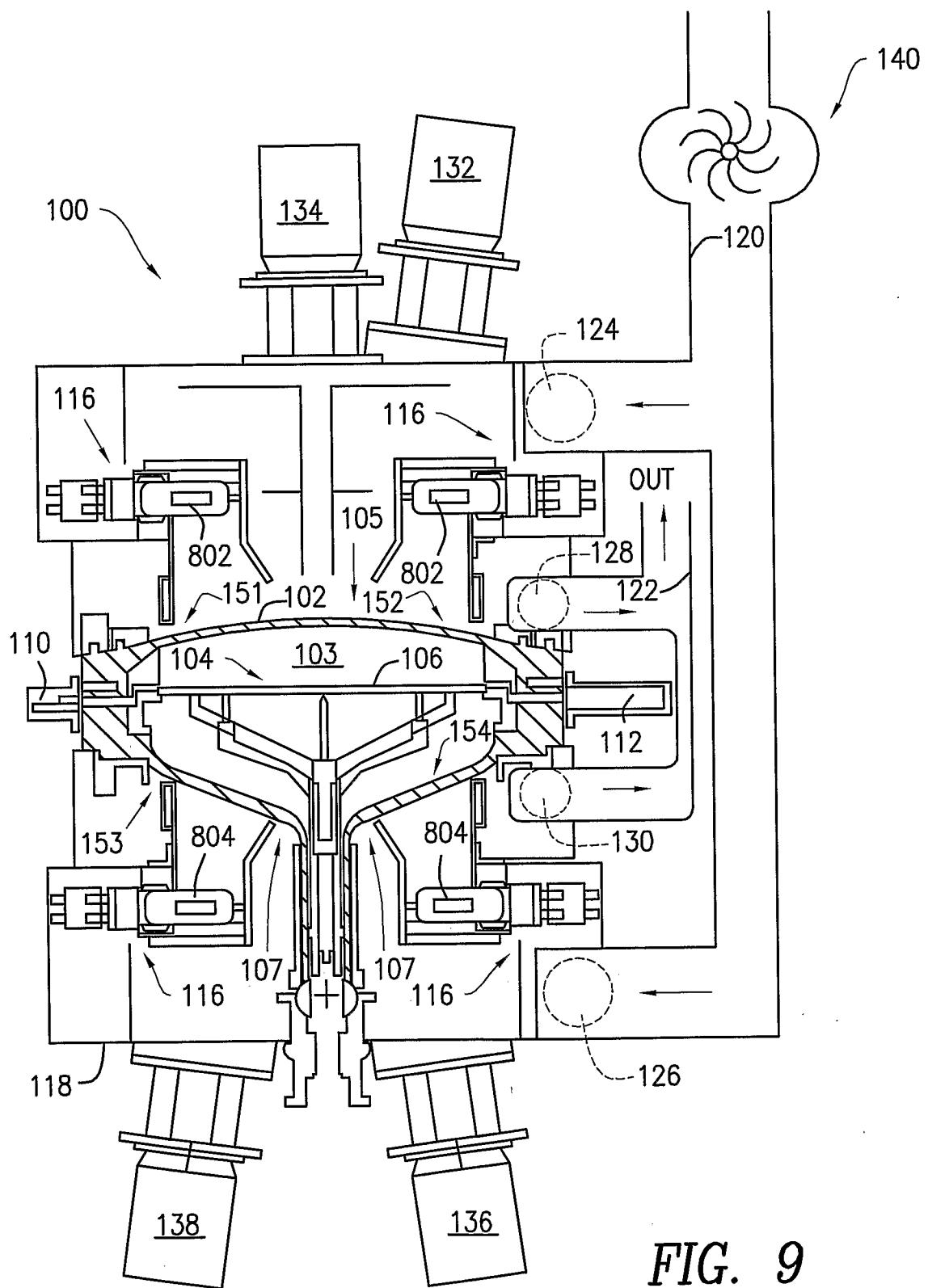


FIG. 9