

METHODS AND APPARATUS FOR OPTIMAL TEMPERATURE CONTROL IN A PLASMA PROCESSING SYSTEM

BACKGROUND

[0001] The present invention relates to fabrication of semiconductor integrated circuits and, more particularly, to temperature control of plasma processing systems.

[0002] In the fabrication of semiconductor-based devices, e.g., integrated circuits or flat panel displays, layers of materials may alternately be deposited onto and etched from a substrate surface. During the fabrication process, various layers of material, e.g., borophosphosilicate glass (BPSG), polysilicon, metal, etc. are deposited on the substrate. The deposited layers may be patterned with known techniques, e.g., a photoresist process. Thereafter, portions of the deposited layers can be etched away to form various features, e.g., interconnect lines, vias, trenches, and etc.

[0003] As can be appreciated by those skilled in the art, in the case of semiconductor processing such as etch processes, a number of parameters within the processing chamber must be tightly controlled to maintain high quality results. Temperature is one such parameter. Because etch quality (and resulting semiconductor-based device performance) may be highly sensitive to temperature fluctuations of components in a plasma processing system, accurate control therefore is required. Moreover, as feature sizes continue to get smaller, there is an ever increasing need to provide plasma processing apparatus with better temperature control in order to provide consistent and precise fabrication of semiconductor devices.

[0004] FIG. 1A is an illustrative representation of a prior art plasma processing chamber that incorporates a top piece and a bottom piece. The top piece (upper chamber) normally houses such elements as the RF coil, quartz window, and gas inlet. The bottom piece (lower chamber), on the other hand, commonly houses such elements as the electrostatic chuck, substrate, and gas removal system.

[0005] In particular, FIG. 1A is an example embodiment described in U.S. Patent No. 6,104,966 to Bailey, III et al., which is hereby incorporated by reference. FIG. 1A is a prior art cross-sectional diagram of a plasma processing apparatus 100. The plasma processing apparatus 100 includes a heating and cooling plate 104 that is thermally coupled to a plasma processing chamber 132. The plasma processing chamber 132 has a substrate holding mechanism 126 to support a substrate 122 during fabrication.

[0006] As an example, a substrate holding mechanism 126 can be an electrostatic chuck (ESC). The surface of a substrate 122 is etched by an appropriate plasma processing source gas that is released into a processing chamber 132. Plasma source gases may be released by a variety of mechanisms, including a showerhead or a gas distribution plate. A vacuum plate 116 maintains a sealed contact with chamber walls 118 of plasma processing chamber 132. Coils 134 provided on the vacuum plate 116 may be coupled to a radio frequency (RF) power source (not shown) and used to create plasma from plasma source gases released into plasma processing chamber 132. A substrate holding mechanism 126 is also often RF powered during the etch processes using a RF power supply (not shown). A pump 130 is also included to draw process gases and gaseous products from plasma processing chamber 132 through a duct 136.

[0007] A combination heating and cooling plate 104 placed on the top of the apparatus operates to control the temperature of vacuum plate 116 of the plasma processing apparatus 100 such that an inner surface of a vacuum plate 116, which is exposed to plasma during operation, may be maintained at a controlled temperature. Heating and cooling plate 104 may be constructed using several physical layers comprising in providing both heating and cooling operation. More particularly, heating and cooling plate 104 includes a thermal gasket 138 that thermally couples heating and cooling plate 104 with vacuum plate 116.

[0008] Thermal gasket 138 may be configured to provide a conformal thermal interface between vacuum plate 116 and a heating and cooling plate 104. Heating and cooling plate 104 also includes a heater block 112. Heater block 112 includes resistive elements that output thermal energy to heater block 112 when elements are supplied with electrical current. A thermal break 140 may be provided between heater block 112 and cooling block 108. Thermal break 140 may provide a thermal separation zone between a hot surface created by heater block 112 and a cold surface created by cooling block 108. A cooling block 108 includes a plurality of cooling elements in thermal communication with cooling block 108. Accordingly, a heating and cooling plate 104 can be viewed as a sandwich structure including thermal gasket 138, heater block 112, thermal break 140, and cooling block 108. Accordingly, temperature of the vacuum plate 116 may be controlled through activation of either heater elements of heater block 112 or cooling elements of cooling block 108.

[0009] Most top piece designs, however, are optimized for operational performance within the chamber itself, and not for other considerations such as general thermal

performance. Historically, since the manufacturing cost of the top piece was just a relatively small portion of the overall system cost, there has been no incentive to re-design with smaller amount of material, hence a smaller thermal mass. Subsequently, the larger thermal mass of the top piece tends to resist rapid temperature adjustment, often creating substantially long wait intervals in order to bring the system to the desired temperature – in some cases as long as 15 minutes or more. In addition, thermal excursions, once detected, cannot generally be quickly stabilized due to the thermal inertia of the mass.

[0010] A common plasma chamber design incorporates aluminum, which exhibits high thermal conductivity. FIG. 1B is an illustrative representation of a portion of a prior art plasma processing apparatus 150 having an upper chamber 176 having a large thermal mass. Plasma processing apparatus 150 includes a heating or cooling element 158 thermally coupled to a large thermal mass 162 which is, in turn, thermally coupled to the upper chamber 176. A vacuum plate 154 seals upper chamber 176. A skirt or flexible barrier 172 separates upper chamber 176 from lower chamber 180. A large thermal mass 162 presents an advantage of leveling temperature perturbations during substrate processing due, in part, to its mass.

[0011] In addition, since many temperature control systems often incorporate the heating and cooling elements, comprising plastic and stainless steel materials, directly into the chamber structure itself, preventive maintenance may be an issue. The presence of plastic and stainless steel often limits the types of available cleaning techniques, and hence the effectiveness of preventive maintenance. That is, although a particular cleaning chemical may effectively clean the residue from the chamber walls, the same chemical may also substantially damage the plastic materials or stainless steel.

[0012] In view of foregoing, there is a need for methods and apparatus for optimal temperature control in plasma processing systems.

SUMMARY OF THE INVENTION

[0013] The invention relates, in one embodiment, in a plasma processing system, to a temperature control device for controlling temperature of an upper chamber of a plasma processing apparatus. The temperature control device includes a thermally conductive body having an inner surface and an outer surface removably connected with and in thermal communication with the upper chamber of the plasma processing apparatus. The temperature control device also includes a plurality of thermal interface layers in thermal communication

with the thermally conductive body wherein at least one layer is a heating element; and a cooling element connected with the banded thermally conductive body and thermally coupled with the upper chamber of the plasma processing apparatus wherein the cooling element is configured to conduct a fluidic medium. The temperature control device further includes at least one temperature sensor for sensing temperature of the upper chamber of the plasma processing apparatus; a temperature control unit for controlling the heating element and the cooling element; and a latching mechanism for securing the temperature control device to the upper chamber.

[0014] The invention relates, in another embodiment, in a plasma processing system, to a method of using a temperature control device, including a latching mechanism, for controlling the temperature of an upper chamber of a plasma processing apparatus comprising. The method includes providing a combination heating and cooling band wherein the cooling portion of the band is configured to conduct fluidic flow having a constant temperature. The method also includes adjusting the volume of the fluidic flow in response to temperature variation within the upper chamber; and adjusting the heat output of the heating element in response to temperature variation within the upper chamber.

[0015] These and other features of the present invention will be described in more detail below in the detailed description of the invention and in conjunction with the following figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The present invention is illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings and in which like reference numerals refer to similar elements and in which:

[0017] FIGS. 1A-1B are illustrative representations of prior art plasma processing chambers;

[0018] FIG. 2 is a graphical representation of sample data representing temperature over time of an example plasma processing chamber;

[0019] FIGS. 3A-3C are illustrative cross-sectional representations of an embodiment of the present invention;

[0020] FIG. 4 is an illustrative top view representation of an embodiment of the present invention;

[0021] FIG. 5 is an example process flow chart for utilizing an embodiment the present invention; and

[0022] FIGS. 6A-6C are example process flow charts for controlling temperature in a plasma processing chamber utilizing various embodiments the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0023] The present invention will now be described in detail with reference to a few preferred embodiments thereof as illustrated in the accompanying drawings. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent, however, to one skilled in the art, that the present invention may be practiced without some or all of these specific details. In other instances, well known process steps and/or structures have not been described in detail in order to not unnecessarily obscure the present invention.

[0024] While not wishing to be bound by theory, it is believed by the inventor herein that an agile temperature management system may achieve substantially accurate temperature control in a plasma processing system.

[0025] In one embodiment, a temperature management system and method may operate to achieve optimal temperature control of an upper chamber of a plasma processing apparatus during fabrication of semiconductor devices. An optimal temperature control system, as contemplated by the present invention, provides greater process control for plasma processing apparatuses which is becoming more and more important as feature size continues to shrink. Furthermore, in a non-obvious way, the present invention provides for rapid response temperature control of a plasma processing system.

[0026] In another embodiment, the temperature control system includes a heating and cooling unit that is coupled to an outer surface of an upper chamber of a plasma processing apparatus to be temperature controlled. A heating and cooling unit serves to transport heat into or away from the surface(s) being controlled through the same thermal interface.

[0027] In another embodiment, the temperature control system includes a heating and cooling unit that is coupled via a latching mechanism to an outer surface of an upper chamber of a plasma processing apparatus to be temperature controlled.

[0028] In another embodiment, the latching mechanism is a clamp assembly.

[0029] In another embodiment, the clamp assembly is integrated directly into the heating and cooling unit.

[0030] Additional embodiments of the invention are discussed below. However, those skilled in the art will readily appreciate that the detailed description given herein with respect to these figures is for explanatory purposes as the invention extends beyond these limited embodiments. Furthermore, those skilled in the art will readily understand that the illustrations are not necessarily scale drawings, but are intended to assist in describing the embodiments herein.

[0031] FIG. 2 is a graphical representation 200 of sample data representing temperature over time of an example plasma processing chamber. In this example, temperatures for an operating plasma process chamber utilizing neither a heating element nor a cooling element are graphically produced. The curve depicted demonstrates an upward trend in temperature over time. Although the graph shown terminates at a temperature less than 90° C, it is expected that the temperature would continue to rise over time until mechanical failure due to excessive heat occurred. Temperature spikes (e.g., 204) during plasma processing cycles are depicted along with temperature dips (e.g., 208).

[0032] Temperature spikes generally represent points at which plasma is extinguished. That is, because plasma releases heat energy, temperature rises until plasma is extinguished. One skilled in the art will appreciate that temperature may continue to rise for period of time after plasma is extinguished due to heat buildup in a process chamber and due to use of large thermal masses in constructing process chambers. When plasma is extinguished, temperature continues to fall as heat is dissipated into the atmosphere. Temperature dips represent points at which plasma is ignited. As noted above, a lag time may occur in some systems due, in part, to thermal mass. A dramatic drop in temperature illustrated at 210, where time is approximately equal to 70 minutes, is representative of temperature drop occurring during an idle state of the plasma processing chamber.

[0033] FIGS. 3A-3C are illustrative cross-sectional representations of an embodiment of the present invention. In particular, FIG. 3A is a simplified graphical representation of a cross-section of an upper chamber 300 of a plasma processing apparatus in one embodiment of the present invention. An upper chamber 300 is sealed from atmosphere by a vacuum tight lid or plate 304. Lid 304 may be removably attached with upper chamber sidewall(s) 312 to create a vacuum tight seal. One skilled in the art will appreciate that the selection of the

materials for constructing the sidewall(s) 312 is based on many factors including for example, thermal conductivity, reactivity, rigidity, and cost.

[0034] Typically, sidewall(s) may be constructed using aluminum. Sidewall(s) may be constructed as a single planar surface having a circular profile, or may be constructed as multiple planar surfaces having 2 or more planar surfaces. A temperature control device 308 is attached with and in thermal communication with sidewall(s) 312. Temperature control device 308 is described in further detail below for FIGS. 3B-3C. A protective skirt 316 provides some protection for upper chamber 300 from process chamber 324 below. Any of a variety of protective skirts may be utilized as can be appreciated by one skilled in the art. Finally, upper chamber 300 is supported by process chamber sidewalls 320.

[0035] FIG. 3B is a magnified and simplified view of a portion of the example apparatus as illustrated in FIG. 3A. As noted above, a temperature control device 308 may be attached with and in thermal communication with upper chamber sidewall(s) 312. A thermally conductive body 334 in thermal communication with upper chamber sidewall(s) 312 is configured to support components of temperature control device 308. A cooling channel 338 is formed in thermally conductive body 334 to house cooling conduit 326. Cooling channel 338 is a single circuitous channel having a path that doubles back on itself in order to average thermal loads over thermal body 334. In this manner, warping of thermally conductive body 334 may be reduced. Cooling conduit 326 carries a fluidic medium selected to efficiently conduct thermal energy away from upper chamber 300. Any number of cooling fluids may be utilized in accordance with the present invention. In one embodiment, water is used as the fluidic medium. Cooling conduit 326 may be attached with thermally conductive body 334 in any of a number of manners known in the art. In some embodiments, where more efficient cooling is required, cooling conduit 326 may be secured in the cooling channel 338 with a thermally conductive material such as a polymer resin for example. A plurality of thermal interface layers indicated by 330 is further illustrated in FIG. 3C.

[0036] FIG. 3C is a magnified cross-sectional representation of a portion of the example apparatus illustrated in FIG. 3B. In particular, FIG. 3C illustrates an example of the thermal interface layers 330 (FIG. 3B) in close detail. In one embodiment of the present invention, a thermally conductive material 344 comprises a thermal interface layer. Thermally conductive material 344 may be used to improve the metal to metal contact between surfaces – in this example, between the upper chamber sidewall 312 and dissipation band 348. As can be

appreciated by one skilled in the art, the quality of the thermal conductivity between two parts depends at least in part upon the mechanical bond between the parts.

[0037] In many cases, defects in the mechanical bond due to material aberrations, manufacturing defects, or physical deformity due to warping or mishandling, for example, may be present. Thus, the need for an interface material that can account for these differences ensuring efficient thermal conductivity. In this manner, thermal loads may be effectively conducted in a vector perpendicular to the interface layer. In one embodiment, thermally conductive material 344 is a thermal pad. In other embodiments, thermally conductive material 344 is thermal grease. A dissipation band 348 comprises another of the plurality of physical interface layers. Without being bound by theory, it is believed that the dissipation band 348 functions to distribute thermal loads evenly over the surface of thermally conductive body 334. The dissipation of thermal loads by a dissipation band differs from conduction of thermal loads by a thermally conductive material in that dissipation is substantially radial with respect to interface layer surfaces whereas conduction is substantially perpendicular with respect to interface layer surfaces. Dissipation band material may be chosen from any of a number of suitable thermally dissipative materials well-known in the art. In one embodiment, dissipation band 348 is series 6000 aluminum.

[0038] A heater layer 350 comprises another of the plurality of thermal interface layers. In one embodiment, heater layer 350 is a kapton etched foil heater. The capacity of the heater is selected based upon the process demand parameters. Referring briefly back to FIG. 2, a temperature down spike (e.g., 208) and a machine idle state (e.g., 210) are both the result of the plasma (a heat generating process) being extinguished. In order to maintain thermal stability, a heater layer 350 is utilized, thus making up whatever thermal load was created while the plasma was ignited. In some embodiments, heater layer 350 may also be utilized to bring the upper plasma chamber 300 up to operating temperature prior to processing. In other words, a heater may be used to initialize and stabilize the chamber before actual process begins. In every case, the capacity of the heater may be selected based upon the desired temperature range being maintained.

[0039] A thermal barrier layer 352 comprises another of the plurality of thermal interface layers. Without being bound by theory, thermal barrier layer 354 may function as a heat sink selected to make fluidic medium less efficient. In any thermal system, one skilled in the art will appreciate that balanced thermal loading is desirable. In one embodiment, where

fluidic medium is provided at an uncontrolled flow rate, the efficiency of the fluidic medium may exceed the thermal output of the process. In this example, an apparatus configured in this manner might never reach a desired operating temperature or might only reach sub-optimal operating temperature only upon input of excess energy from a heater layer (e.g., heater layer 350) resulting in a coordinate increase in production costs. In other examples, the flow of fluid may experience perturbations such as temperature differences or flow rate differences during processing. Thermal barrier layer 352, in those examples, may diminish perturbation effects on process temperatures by acting as a thermal cushion to those effects. In one embodiment the thermal barrier is Mylar Polycarbonate available from various manufacturers.

[0040] A final layer (not shown) may be bonded to an outer surface of the thermally conductive body 334. This final layer, in some embodiments, is a thermal arrestor. A thermal arrestor may insulate a thermal control device from ambient temperature changes thus resulting in better process control of the device. Each of the layers discussed may be bonded to each other using any thermally conductive adhesive well known in the art. In some embodiments, double sided thermal adhesive tape such as THERMATTACH® T412 from Chomerics may be used. Those skilled in the art will recognize that the layers illustrated are not scale representations of actual embodiments. Rather, the layers are for illustrative purposes only. Material selection and design constraints will dictate layer sizing.

[0041] Referring to FIG. 4, an illustrative top view representation of temperature control device 308 is shown, according to one embodiment of the present invention. This embodiment of the present invention is characterized by its circular cross section. It may be understood that this invention may also encompass other cross-sectional profiles without limitation. Mounting blocks 432 may be attached with each end of thermally conductive body 334. Mounting blocks 432 may serve multiple functions. First, mounting blocks 432 may serve as attachment points for a clamping system 428 to secure temperature control device 308 to an upper chamber of a plasma processing apparatus. Clamping may be accomplished in any manner commonly known in the art.

[0042] In one embodiment, the clamp assembly may be integrated with the temperature control device; such that a screwdriver, socket, or nut driver may be used to rotate a screw coupled to a band having serrations, in order to secure the temperature control device to the plasma processing chamber. As the screw is rotated, the screw threads advance the serrations causing a reduction in the inside diameter of the band.

[0043] In another embodiment, the removable clamp may be integrated with the temperature control device, such that a pair of pliers or a special tool may be employed to secure the temperature control device to the plasma processing chamber. Generally made from an elastically deformable material, when a compressive force is applied to tabs extending from the clamp, the inside diameter of the clamp is increased. Removal of the compressive force causes the inside diameter of the clamp to decrease, thereby applying a compressive force to a hose inserted therein

[0044] In another embodiment, the clamp assembly may be integrated with the temperature control device, such that an upper clamp half, a lower clamp half, a hinge pin connecting the halves, and a fastener are employed secure the temperature control device to the plasma processing chamber. The fastener may comprise a bolt carried by a rotatable pivot pin mounted in the lower clamp half. Slots may be provided in the upper clamp half and the lower clamp half so that the bolt can swing in and out of engagement with the clamp halves to permit the assembly to be opened for mounting the tubular, and then closed and locked by tightening the bolt to retain the tubular in the clamp assembly.

[0045] Tension imparted on the device must be sufficient to maintain the position of temperature control device 308, but not excessive so as to damage or distort temperature control device 308 and its associated structures. In selecting a clamping method, uniform and repeatable contact pressure when temperature control device 308 is mounted is desirable.

[0046] Second, mounting blocks 432 may serve as attachment points for cooling conduit 420/424. At least one inlet 420 and one outlet 424 may be mounted on either of mounting blocks 432. Any number of suitable fittings well known in the art may be utilized as attachment points for the cooling conduit.

[0047] Handles 416 are provided to assist in the handling of temperature control device 308. Handles 416 may be thermally isolated from temperature control device 308 so as to reduce or eliminate thermal noise in the system. Additional handles may be added as required without departing from the present invention. A temperature sensing device is shown at 404. Temperature sensing device 404 may be used to interlock a plasma control system in the event of an over-temperature condition. In one embodiment, a resistance temperature detector (RTD) may be used to sense temperature. A heater attachment point 408 is connected with thermally conductive body 334. Heater attachment point 408 provides stress relief for heater layer 350 (FIG. 3C) and convenient access to the heater embedded in temperature control

device 308. Ideally, heater attachment point 408 is thermally isolated from temperature control device 308 so as not to introduce thermal noise into the system.

[0048] FIG. 5 is a simplified example process flow chart for utilizing an embodiment the present invention. At a first step 502, a plasma chamber is initialized. That is, a plasma chamber is prepared for processing having been cleaned and otherwise readied. The chamber is then stabilized to desired operational parameters at step 504. As can be appreciated, any number of operational parameters may be established according to a particular production recipe or requirement. After the chamber is stabilized at a step 504, a substrate is placed in the chamber at step 506 and the chamber is optionally stabilized to the desired operational parameters at step 508. Once the chamber is stabilized at step 508, the substrate is processed at step 512. Processing substrates may include any of a number of plasma operations. That is, plasma may be ignited and extinguished in a cyclic manner until the desired processing has occurred, including, for example, etching and deposition. Concurrent with processing step 510, is regulation of thermal loads in an upper chamber at step 512. This step is discussed in further detail below for FIGS. 6A-6C. Once a substrate has been processed, the method determines whether another substrate is ready for processing at step 514. In the event that another substrate is ready, the process continues to step 506. When all substrates are completed, the method ends.

[0049] FIGS. 6A-6C are example process flow diagram for controlling temperature in a plasma processing chamber utilizing embodiments the present invention. As noted above, at least three different methods of temperature control are contemplated by the disclosed invention. These different methods will be discussed in order.

Temperature Control: Constant Fluidic Flow/Variable Heat

[0050] FIG. 6A is an example process flow diagram of one embodiment of the present invention. In particular, FIG. 6A diagrams a method of controlling a temperature control device where fluidic medium flow is constant and heat is variable. More particularly, FIG. 6A describes in further detail step 510 of FIG. 5. At a first step 602, temperature of the upper chamber is detected. Temperature may be detected using any of a number of temperature sensing devices known in the art. Once the temperature has been read, it is compared against a desired operating parameter selected by a user whereupon a query of whether the temperature is too low is made at step 604. If temperature is too low (e.g., temperature is lower than a

desired set point), a heating element is activated at step 606. Generally speaking, a heating element is either on or off. That is, heat output for a heating element is constant.

[0051] In some embodiments, heat output may be regulated by a power limiting circuit (not shown). The method proceeds to query whether the process is complete at step 614. If the process is complete, the method continues at step 514 (FIG. 5). If the process is not complete, the method continues to read upper chamber temperature at step 602 and continues cycling until the process is complete.

[0052] If the method determines, at a step 604, that temperature is not too low (e.g., temperature is higher than set point), the method queries whether a heating element is on at step 608. If the heating element is on and temperature is above a desired set point, then the query of step 608 is answered in the affirmative and the heating element is turned off at step 610. The method proceeds to query whether the process is complete at step 614. If the process is complete, the method continues at step 514 (FIG. 5). If the process is not complete, the method then returns to read upper chamber temperature at step 602 and continues cycling until the process is complete.

[0053] If the query of step 608 is answered in the negative, the method then queries whether an over-temperature condition exists at step 612. If the answer to step 612 is no (i.e., no over-temperature condition), then the method proceeds to query whether the process is complete at step 614. If the process is complete, the method terminates. If the process is not complete, the method continues to step 602 and continues cycling until the process is complete. If an over-temperature condition exists at step 612, then the method stops. Notably, each cycle requires a query to determine whether the process is complete as illustrated by step 614.

Temperature Control: Variable Fluidic Flow/Constant Heat

[0054] FIG. 6B is an example process flow diagram of one embodiment of the present invention. In particular, FIG. 6B diagrams a method of controlling a temperature control device where the fluidic medium flow is variable and heat output is constant. More particularly, FIG. 6B describes in further detail step 510 of FIG. 5. At a first step 622, temperature of an upper chamber is detected. Temperature may be detected using any of a number of temperature sensing devices known in the art. Once temperature has been read at step 622, it is compared against a desired operating parameter selected by a user whereupon a query of whether the read temperature is too low is made at step 624. If the read temperature is too low (e.g., temperature is lower than a desired set point), fluidic medium flow to a

temperature control device may be decreased at step 626. The method proceeds to query whether the process is complete at step 632. If the process is complete, the method continues at step 514 (FIG. 5). If the process is not complete, the method returns to read upper chamber temperature at step 622 and continues cycling until the process is complete.

[0055] If the method determines, at step 624, that temperature is not too low, the method queries whether an over-temperature condition exists at step 628. If an over-temperature condition does not exist, then fluidic medium flow may be increased at step 630. The method proceeds to query whether the process is complete at step 632. If the process is complete, the method continues at step 514 (FIG. 5). If the process is not complete, the method returns to read upper chamber temperature at step 622 and continues cycling until the process is complete. If an over-temperature condition exists at step 628, the method terminates. Notably, each cycle requires a query to determine whether the process is complete as illustrated by step 632.

Temperature Control: Variable Fluidic Flow/Variable Heat

[0056] FIG. 6C is an example process flow diagram of one embodiment of the present invention. In particular, FIG. 6C diagrams a method of controlling a temperature control device where fluidic medium flow is variable and heat output is variable. More particularly, FIG. 6C describes in further detail step 510 of FIG. 5. At a first step 642, temperature of an upper chamber is detected. Temperature may be detected using any of a number of temperature sensing devices known in the art. Once the temperature has been read, it is compared against a desired operating parameter selected by a user whereupon a query of whether temperature is too low is made at step 644. If the read temperature of the upper chamber is found to be too low, then one of three actions may be initiated at step 646: a) a heating element is activated; b) fluidic medium flow is decreased; or c) a heating element is activated and fluidic medium flow is decreased.

[0057] The determination of which element is activated in response to a low temperature condition is user determinable and may depend on a variety of conditions for example, implementation cost, resource availability, or desired speed of reaction (i.e. system agility). Thus, a user may select a heating element response where additional fluidic flow is not available or cost effective. In like manner, a user may select to decrease fluidic medium flow response where additional energy for activating a heat element is not available or cost effective. In contrast, where maximum system agility is desirable and both availability and

cost are not limited, both elements (e.g., heating element activated, fluidic medium flow decreased) may be activated. The method proceeds to query whether the process is complete at step 652. If the process is complete, the method continues at step 514 (FIG. 5). If the process is not complete, the method returns to read upper chamber temperature at step 642 and continues cycling until the process is complete.

[0058] If the method determines, at step 644, that the temperature is not too low, then the method queries whether an over-temperature condition exists at step 648. If an over-temperature condition does not exist, the method proceeds to step 650 where one of three conditions are activated: a) a heating element is deactivated; b) fluidic medium flow is increased; or c) a heating element is deactivated and fluidic flow is increased. As noted above, the determination of which element is activated in response to a high temperature condition is user determinable and may depend on a variety of conditions including, for example, implementation cost, resource availability, or desired speed of reaction (i.e. system agility). Thus, a user may select a heating element response where increased fluidic flow is not practical or cost effective.

[0059] In like manner, a user may select increasing fluidic medium flow response where selecting a heating element response is not practical or cost effective. In contrast, where maximum system agility is desirable and both availability and cost are not limited, both elements (e.g., heating element OFF, increase fluidic flow) may be activated. The method proceeds to query whether the process is complete at step 652. If the process is complete, the method continues at step 514 (FIG. 5). If the process is not complete, the method returns to read the temperature at step 642 and continues cycling until the process is complete. If, at step 648, an over-temperature condition is detected, the method terminates.

[0060] As presented herein, the present invention provides agile temperature control for plasma processing systems. In addition, the present invention provides ergonomic benefits due in part to its efficient design.

[0061] While his invention has been described in terms of several preferred embodiments, there are alterations, permutations, modifications and various substitute equivalents, which fall within the scope of this invention. For example, the TCP 2300 plasma processing type system manufactured by Lam Research Corporation of Fremont, CA may be used to practice the present invention.

[0062] It should also be noted that there remain many alternative ways of implementing the methods and apparatuses of the present invention. It is therefore intended that the following appended claims be interpreted as including all such alterations, permutations, modifications, and various substitute equivalents as fall within the true spirit and scope of the present invention.

CLAIMS

What is claimed is:

1. A temperature control device for controlling temperature of an upper chamber of a plasma processing apparatus comprising:
 - a thermally conductive body having an inner surface and an outer surface removably connected with and in thermal communication with the upper chamber of the plasma processing apparatus;
 - a plurality of thermal interface layers in thermal communication with the thermally conductive body wherein at least one layer is a heating element;
 - a cooling element connected with the banded thermally conductive body and thermally coupled with the upper chamber of the plasma processing apparatus wherein the cooling element is configured to conduct a fluidic medium;
 - at least one temperature sensor for sensing temperature of the upper chamber of the plasma processing apparatus;
 - a temperature control unit for controlling the heating element and the cooling element;
 - and
 - a latching mechanism for securing the temperature control device to the upper chamber.
2. The temperature control device of claim 1 wherein the thermally conductive body is aluminum.
3. The temperature control device of claim 1 wherein the heating element is a kapton etched foil heater.
4. The temperature control device of claim 1 wherein the inner most layer of the plurality of thermal interface layers is a thermal contact material such that heat transfer is enhanced.
5. The temperature control device of claim 1 wherein at least one layer of the plurality of thermal interface layers is a diffuser such that heat is radially diffused.

6. The temperature control device of claim 1 wherein at least one layer of the plurality of thermal interface layers is a thermal barrier.
7. The temperature control device of claim 1 further comprising a thermal arrestor such that the temperature control device is protected from ambient conditions.
8. The temperature control device of claim 1 wherein the cooling element is configured to receive a constant volumetric flow of fluidic media and wherein the heating element is configured to operate in response to temperature variation within the upper chamber.
9. The temperature control device of claim 1 wherein the cooling element is configured to allow adjustment to the volumetric flow of fluidic media in response to temperature variation within the upper chamber and wherein the heating element is configured for constant heat output.
10. The temperature control device of claim 1 wherein the cooling element is configured to allow adjustment to the volumetric flow of fluidic media in response to temperature variation within the upper chamber and wherein the heating element is configured to operate in response to temperature variation within the upper chamber.
11. A temperature agile upper chamber of a plasma apparatus comprising:
 - a continuous sidewall;
 - a combination heating and cooling band in thermal communication with the continuous sidewall, the heating and cooling comprising a heating element and a cooling element wherein the cooling element of the band is configured to conduct a fluidic medium;
 - at least one temperature sensor thermally coupled with the upper chamber of the plasma processing apparatus; and
 - a thermal regulating control unit for controlling the heating element and the cooling element.
12. The thermally agile upper chamber of a plasma apparatus of claim 11 wherein the combination heating and cooling band further comprises a plurality of thermal interface layers.

13. The thermally agile upper chamber of a plasma apparatus of claim 12 wherein at least one of the plurality of thermal interface layers is a heating element.
14. The thermally agile upper chamber of a plasma apparatus of claim 13 wherein the heating element is a kapton etched foil heater.
15. The thermally agile upper chamber of a plasma apparatus of claim 14 wherein the cooling element is configured to receive a constant volumetric flow of fluidic media and wherein the heating element is configured to operate in response to temperature variation within the upper chamber.
16. The thermally agile upper chamber of a plasma apparatus of claim 11 wherein the cooling element is configured to allow adjustment to the volumetric flow of fluidic media in response to temperature variation within the upper chamber and wherein the heating element is configured for constant heat output.
17. The thermally agile upper chamber of a plasma apparatus of claim 11 wherein the cooling element is configured to allow adjustment to the volumetric flow of fluidic media in response to temperature variation within the upper chamber and wherein the heating element is configured to operate in response to temperature variation within the upper chamber.
18. The thermally agile upper chamber of a plasma apparatus of claim 15 wherein the fluidic media is water.
19. A method of using a temperature control device, including a latching mechanism, for controlling the temperature of an upper chamber of a plasma processing apparatus comprising:
 - providing a combination heating and cooling band wherein the cooling portion of the band is configured to conduct fluidic flow having a constant temperature;
 - adjusting the volume of the fluidic flow in response to temperature variation within the upper chamber; and

adjusting the heat output of the heating element in response to temperature variation within the upper chamber.

20. A method of using a temperature control device of claim 19 wherein the volume of the fluidic flow is constant.

21. A method of using a temperature control device of claim 19 wherein the heat output is constant.