



(19) **United States**

(12) **Patent Application Publication**
Holland et al.

(10) **Pub. No.: US 2007/0102118 A1**

(43) **Pub. Date: May 10, 2007**

(54) **METHOD AND APPARATUS FOR CONTROLLING TEMPERATURE OF A SUBSTRATE**

Publication Classification

- (51) **Int. Cl.**
C23F 1/00 (2006.01)
C23C 16/00 (2006.01)
- (52) **U.S. Cl.** **156/345.27**; 118/725; 118/728;
156/345.52; 156/345.53; 156/914;
118/724

(76) Inventors: **John Holland**, San Jose, CA (US);
Theodoros Panagopoulos, Cupertino, CA (US)

Correspondence Address:
PATTERSON & SHERIDAN, LLP
APPLIED MATERIALS INC
595 SHREWSBURY AVE
SUITE 100
SHREWSBURY, NJ 07702 (US)

(57) **ABSTRACT**

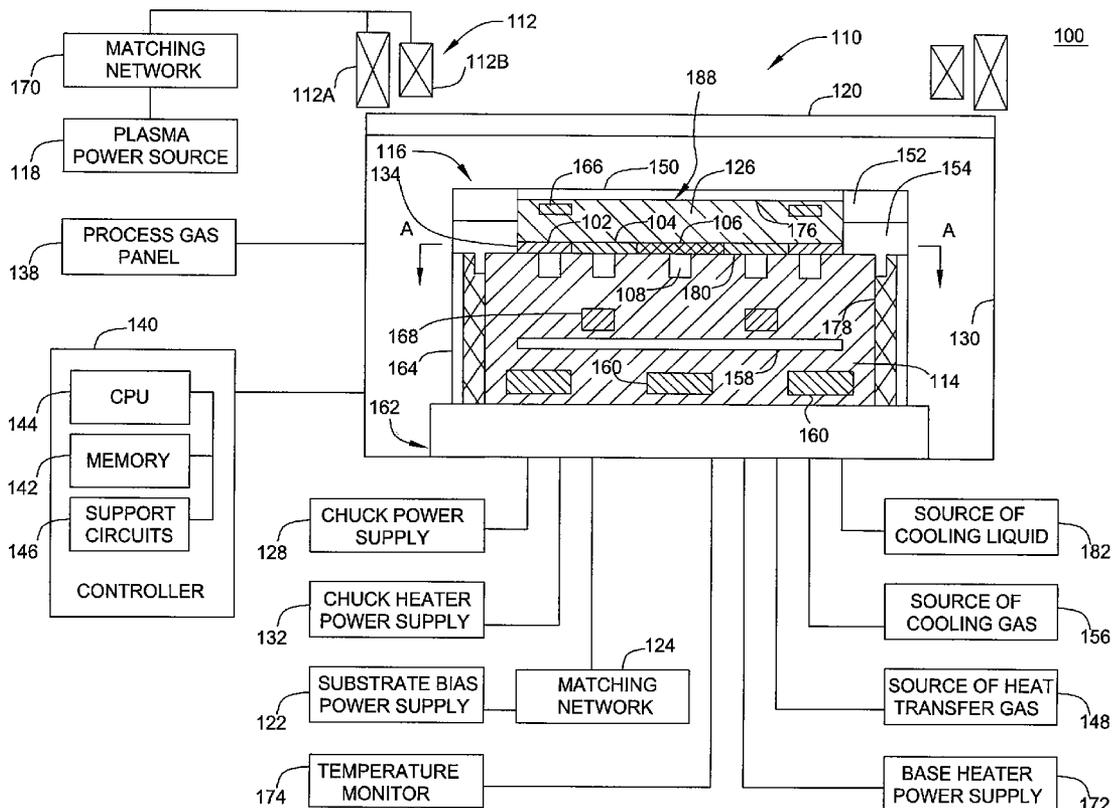
A pedestal assembly and method for controlling temperature of a substrate during processing is provided. In one embodiment, the pedestal assembly includes a support member that is coupled to a base by a material layer. The material layer has at least two regions having different coefficients of thermal conductivity. In another embodiment, the support member is an electrostatic chuck. In further embodiments, a pedestal assembly has channels formed between the base and support member for providing cooling gas in proximity to the material layer to further control heat transfer between the support member and the base, thereby controlling the temperature profile of a substrate disposed on the support member.

(21) Appl. No.: **11/563,272**

(22) Filed: **Nov. 27, 2006**

Related U.S. Application Data

(62) Division of application No. 10/960,874, filed on Oct. 7, 2004.



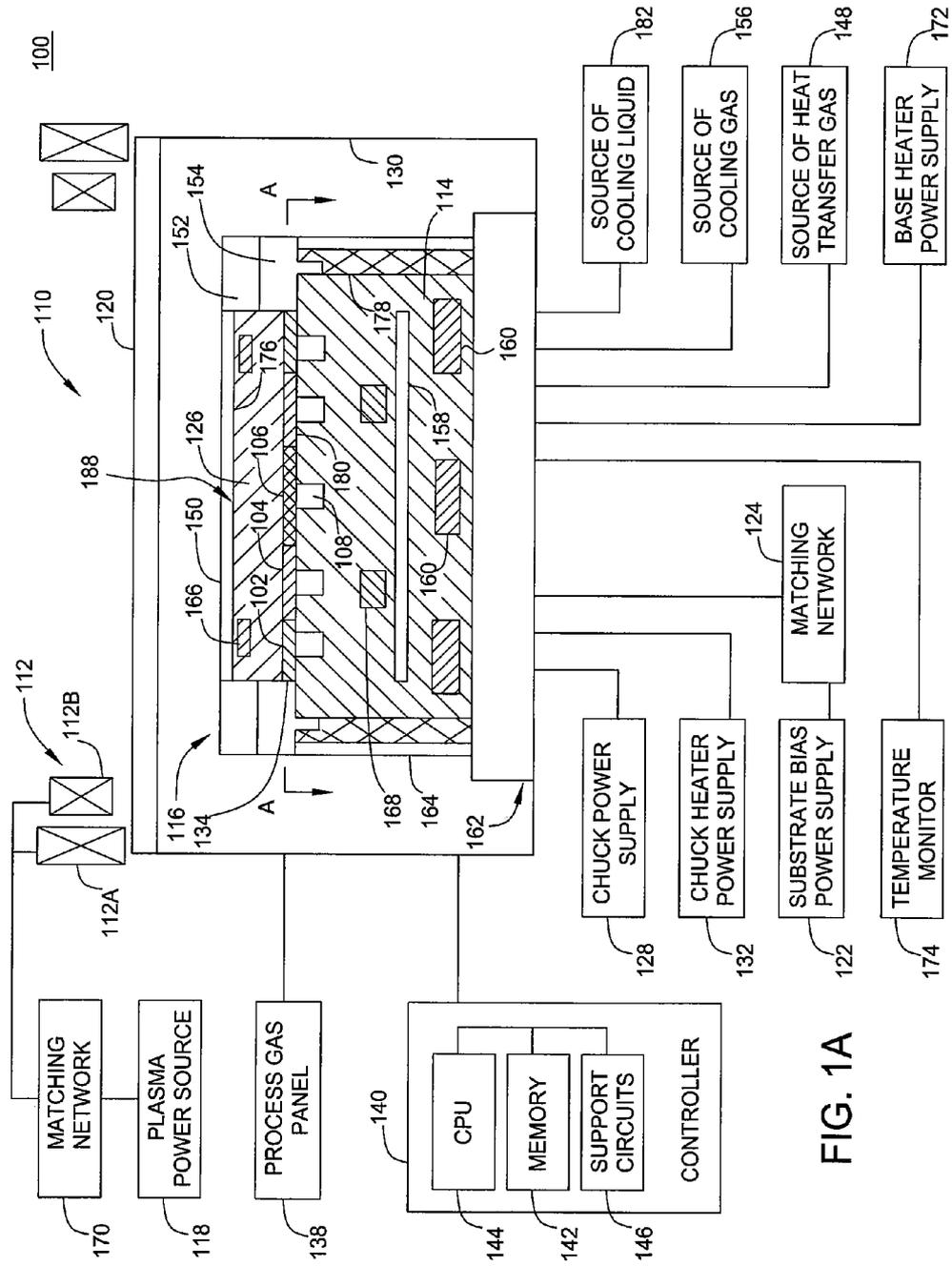


FIG. 1A

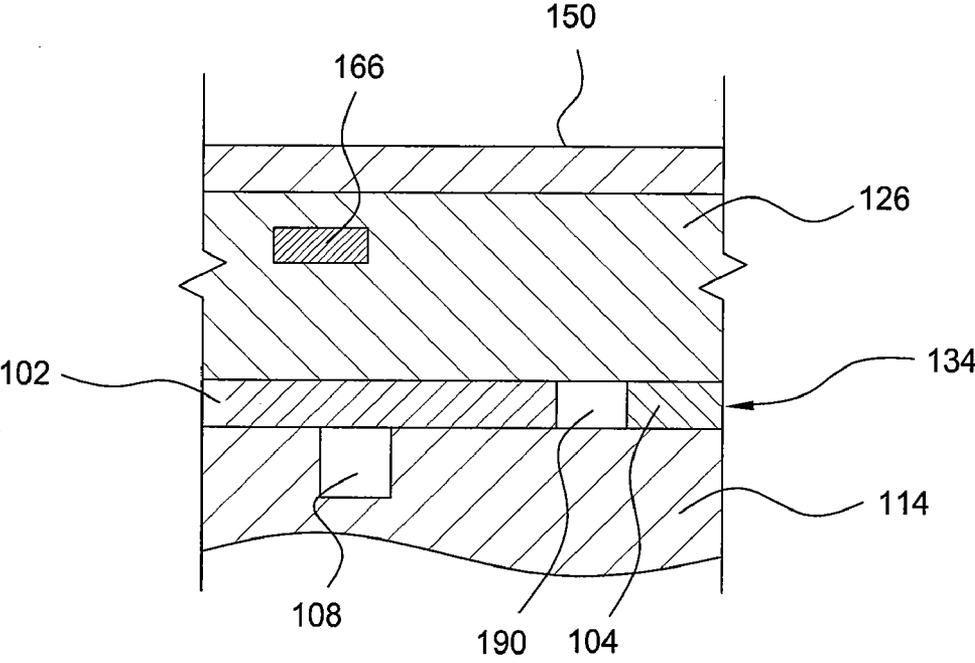


FIG. 1B

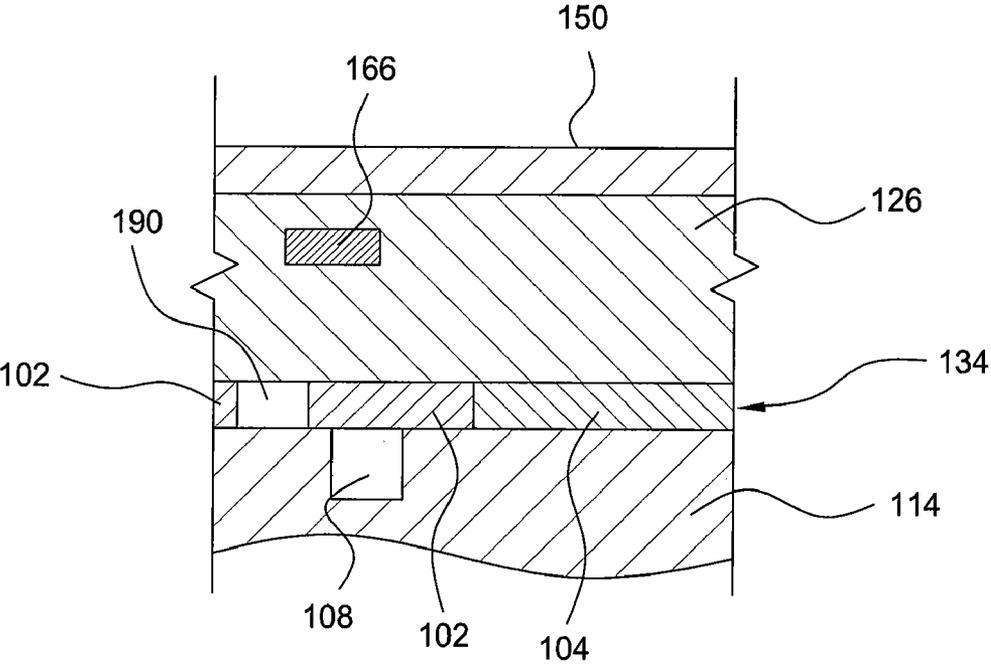


FIG. 1C

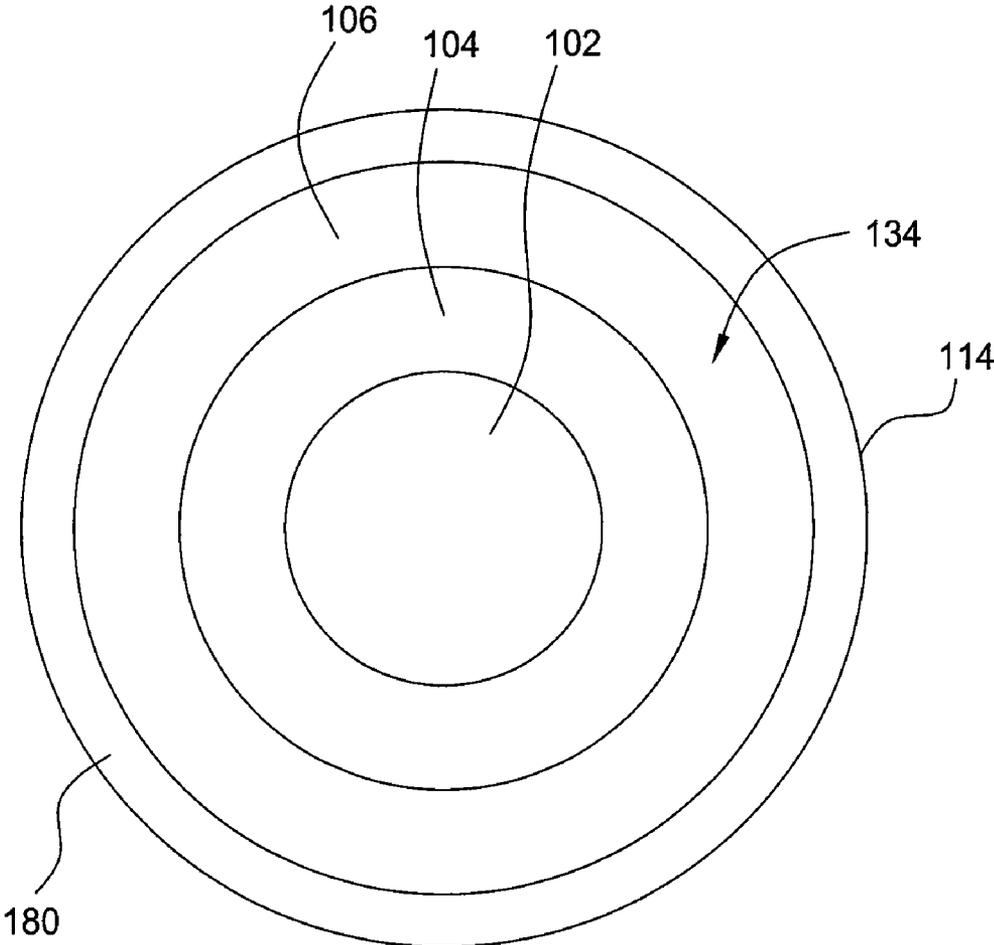


FIG. 2

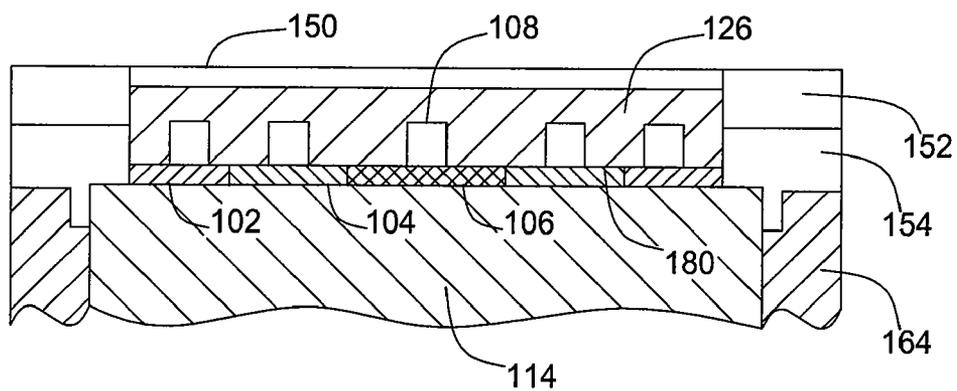


FIG. 3

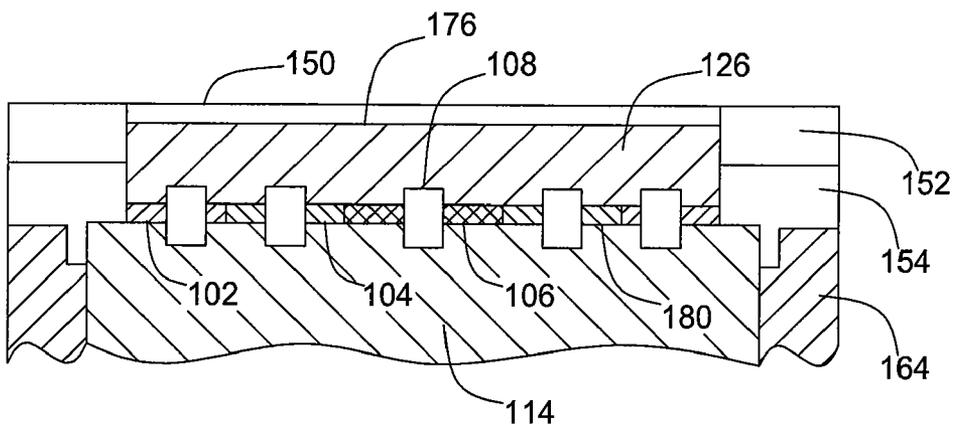


FIG. 4

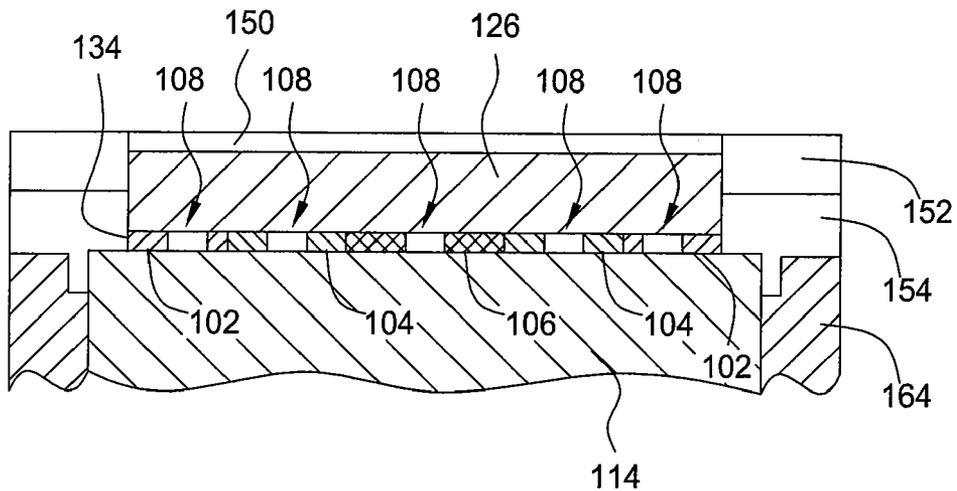


FIG. 5

600

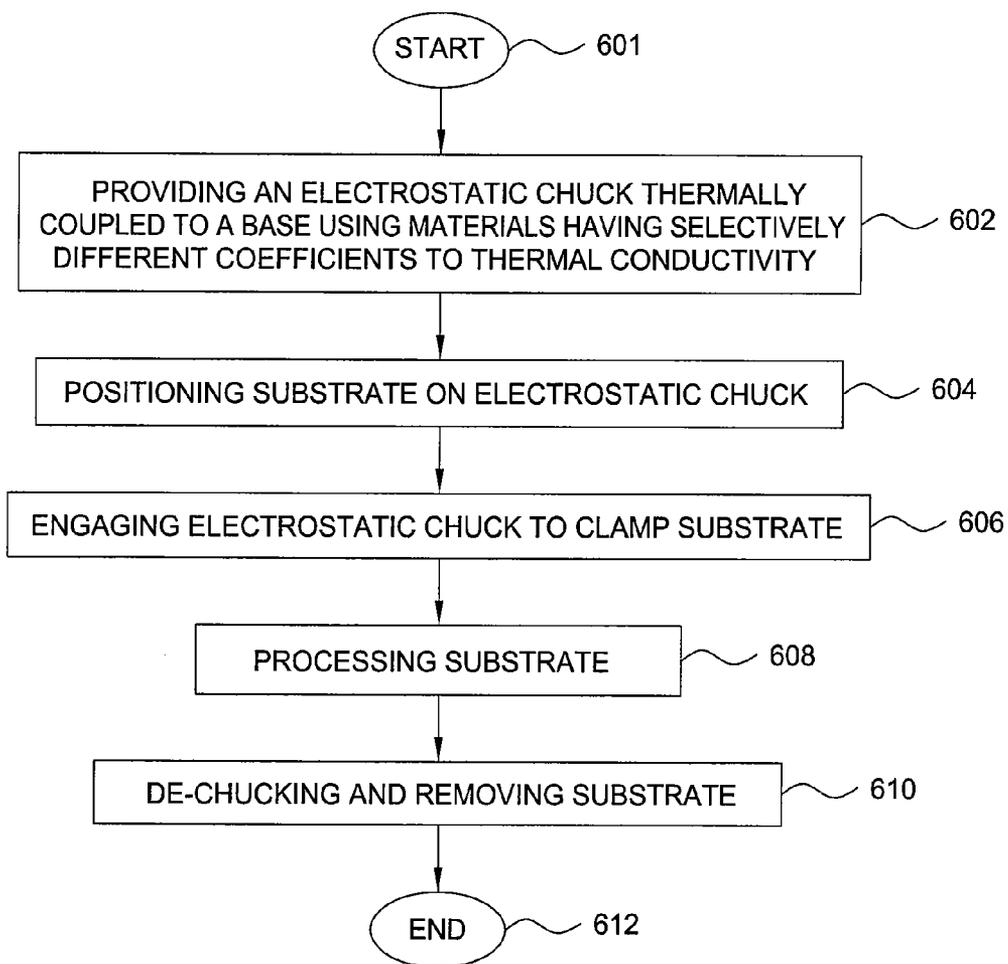


FIG. 6

METHOD AND APPARATUS FOR CONTROLLING TEMPERATURE OF A SUBSTRATE

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a divisional of U.S. patent application Ser. No. 10/960,874, filed Oct. 7, 2004, which is incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] Embodiments of the present invention generally relate to semiconductor substrate processing systems. More specifically, the invention relates to a method and apparatus for controlling temperature of a substrate in a semiconductor substrate processing system.

[0004] 2. Description of the Related Art

[0005] In manufacture of integrated circuits, precise control of various process parameters is required for achieving consistent results within a substrate, as well as the results that are reproducible from substrate to substrate. During processing, changes in the temperature and temperature gradients across the substrate may be detrimental to material deposition, etch rate, step coverage, feature taper angles, and other parameters of semiconductor devices. As such, generation of the pre-determined pattern of temperature distribution across the substrate is one of critical requirements for achieving high yield.

[0006] In some processing applications, a substrate is retained to a substrate pedestal by an electrostatic chuck during processing. The electrostatic chuck is coupled to a base of the pedestal by clamps, adhesive or fasteners. The chuck may be provided with an embedded electric heater, as well as be fluidly coupled to a source of backside heat transfer gas for controlling substrate temperature during processing. However, conventional substrate pedestals have insufficient means for controlling substrate temperature distribution across the diameter of the substrate. The inability to control substrate temperature uniformity has an adverse effect on process uniformity both within a single substrate and between substrates, device yield and overall quality of processed substrates.

[0007] Therefore, there is a need in the art for an improved method and apparatus for controlling temperature of a substrate during processing the substrate in a semiconductor substrate processing apparatus.

SUMMARY OF THE INVENTION

[0008] The present invention generally is a method and apparatus for controlling temperature of a substrate during processing the substrate in a semiconductor substrate processing apparatus. The method and apparatus enhances temperature control across the diameter of a substrate, and may be utilized in etch, deposition, implant, and thermal processing systems, among other applications where the control of the temperature profile of a workpiece is desirable.

[0009] In one embodiment of the invention, a substrate pedestal assembly is provided. The pedestal assembly includes a support member that is coupled to a base using a

material layer. The material layer has at least two regions having different coefficients of thermal conductivity. In another embodiment, the support member is an electrostatic chuck. In further embodiments, a pedestal assembly has channels formed between the base and support member for providing cooling gas in proximity to the material layer to further control heat transfer between the support member and the base, thereby facilitating control of the temperature profile of a substrate disposed on the support member.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0011] FIG. 1A is a schematic diagram of an exemplary semiconductor substrate processing apparatus comprising a substrate pedestal in accordance with one embodiment of the invention;

[0012] FIGS. 1B-1C are partial cross-sectional views of embodiments of a substrate pedestal having gaps formed in different locations in a material layer of the substrate pedestal.

[0013] FIG. 2 is a schematic cross-sectional view of the substrate pedestal taken along a line 2-2 of FIG. 1A;

[0014] FIG. 3 is a schematic partial cross-sectional view of another embodiment of the invention;

[0015] FIG. 4 is a schematic partial cross-sectional view of another embodiment of the invention; and

[0016] FIG. 5 is a schematic partial cross-sectional view of yet another embodiment of the invention; and

[0017] FIG. 6 is a flow diagram of one embodiment of a method for controlling temperature of a substrate disposed on a substrate pedestal.

[0018] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures.

DETAILED DESCRIPTION

[0019] The present invention generally is a method and apparatus for controlling temperature of a substrate during processing. Although invention is illustratively described in a semiconductor substrate processing apparatus, such as, e.g., a processing reactor (or module) of a CENTURA® integrated semiconductor wafer processing system, available from Applied Materials, Inc. of Santa Clara, Calif., the invention may be utilized in other processing systems, including etch, deposition, implant and thermal processing, or in other application where control of the temperature profile of a substrate or other workpiece is desirable.

[0020] FIG. 1 depicts a schematic diagram of an exemplary etch reactor 100 having one embodiment of a substrate pedestal assembly 116 that may illustratively be used to practice the invention. The particular embodiment of the

etch reactor **100** shown herein is provided for illustrative purposes and should not be used to limit the scope of the invention.

[0021] Etch reactor **100** generally includes a process chamber **110**, a gas panel **138** and a controller **140**. The process chamber **110** includes a conductive body (wall) **130** and a ceiling **120** that enclose a process volume. Process gasses are provided to the process volume of the chamber **110** from the gas panel **138**.

[0022] The controller **140** includes a central processing unit (CPU) **144**, a memory **142**, and support circuits **146**. The controller **140** is coupled to and controls components of the etch reactor **100**, processes performed in the chamber **110**, as well as may facilitate an optional data exchange with databases of an integrated circuit fab.

[0023] In the depicted embodiment, the ceiling **120** is a substantially flat dielectric member. Other embodiments of the process chamber **110** may have other types of ceilings, e.g., a dome-shaped ceiling. Above the ceiling **120** is disposed an antenna **112** comprising one or more inductive coil elements (two co-axial coil elements **112A** and **112B** are illustratively shown). The antenna **112** is coupled, through a first matching network **170**, to a radio-frequency (RF) plasma power source **118**.

[0024] In one embodiment, the substrate pedestal assembly **116** includes a support member **126**, a thermoconductive layer **134**, a base **114**, a collar ring **152**, a joint ring **154**, a spacer **178**, a ground sleeve **164** and a mount assembly **162**. The mounting assembly **162** couples the base **114** to the process chamber **110**. The base **114** is generally formed from ceramic or similar dielectric material. In the depicted embodiment, the base **114** further comprises at least one optional embedded heater **158** (one heater **158** is illustratively shown), at least one optional embedded insert **168** (one annular insert **168** is illustratively shown), and a plurality of optional conduits **160** fluidly coupled to a source **182** of a heating or cooling liquid. In this embodiment, the base **114** is further thermally separated from the ground sleeve **164** using an optional spacer **178**.

[0025] The conduits **160** and heater **158** may be utilized to control the temperature of the base **114**, thereby heating or cooling the support member **126**, thereby controlling, in part, the temperature of a substrate **150** disposed on the support member **126** during processing.

[0026] The insert **168** is formed from a material having a different coefficient of thermal conductivity than the material of the adjacent regions of the base **114**. Typically, the inserts **168** has a smaller coefficient of thermal conductivity than the base **114**. In a further embodiment, the inserts **168** may be formed from a material having an anisotropic (i.e. direction-dependent coefficient of thermal conductivity). The insert **168** functions to locally change the rate of heat transfer between the support member **126** through the base **114** to the conduits **160** relative to the rate of heat transfer though neighboring portions of the base **114** not having an insert **168** in the heat transfer path. Thus, by controlling the number, shape, size, position and coefficient of heat transfer of the inserts, the temperature profile of the support member **126**, and the substrate **150** seated thereon, may be controlled. Although the insert **168** is depicted in FIG. 1 shaped as an annular ring, the shape of the insert **168** may take any number of forms.

[0027] The thermoconductive layer **134** is disposed on a chuck supporting surface **180** of the base **114** and facilitates thermal coupling (i.e., heat exchange) between the support member **126** and the base **114**. In one exemplary embodiment, the thermoconductive layer **134** is an adhesive layer that mechanically bonds the support member **126** to member supporting surface **180**. Alternatively (not shown), the substrate pedestal assembly **116** may include a hardware (e.g., clamps, screws, and the like) adapted for fastening the support member **126** to the base **114**. Temperature of the support member **126** and the base **114** is monitored using a plurality of sensors (not shown), such as, thermocouples and the like, that are coupled to a temperature monitor **174**.

[0028] The support member **126** is disposed on the base **114** and is circumscribed by the rings **152**, **154**. The support member **126** may be fabricated from aluminum, ceramic or other materials suitable for supporting the substrate **150** during processing. The substrate **150** may rest upon the support member **126** by gravity, or alternatively be secured thereto by vacuum, electrostatic force, mechanical clamps and the like. The embodiment depicted in FIG. 1, the support member **126** is an electrostatic chuck **188**.

[0029] The electrostatic chuck **188** is generally formed from ceramic or similar dielectric material and comprises at least one clamping electrode (not shown) controlled using a power supply **128**. In a further embodiment, the electrostatic chuck **188** may comprise at least one RF electrode (not shown) coupled, through a second matching network **124**, to a power source **122** of substrate bias, and may also include at least one embedded heater (not shown) controlled using a power supply **132**.

[0030] The electrostatic chuck **188** may further comprise a plurality of gas passages (not shown), such as grooves, that are formed in a substrate supporting surface **176** of the chuck and fluidly coupled to a source **148** of a heat transfer (or backside) gas. In operation, the backside gas (e.g., helium (He)) is provided at controlled pressure into the gas passages to enhance the heat transfer between the electrostatic chuck **188** and the substrate **150**. Conventionally, at least the substrate supporting surface **176** of the electrostatic chuck is provided with a coating resistant to the chemistries and temperatures used during processing the substrates.

[0031] In one embodiment, the support member **126** comprises at least one embedded insert **166** (one annular insert **166** is illustratively shown) formed from at least one material having a different coefficient of thermal conductivity than the material(s) of adjacent regions of the support member **126**. Typically, the inserts **166** are formed from materials having a smaller coefficient of thermal conductivity than the material(s) of the adjacent regions. In a further embodiment, the inserts **166** may be formed from materials having an anisotropic coefficient of thermal conductivity. In an alternate embodiment (not shown), at least one insert **166** may be disposed coplanar with the substrate supporting surface **176**.

[0032] As with the inserts **168** of the base **114**, the thermal conductivity, as well as the shape, dimensions, location, and number of inserts **166** in the support member **126** may be selectively chosen to control the heat transfer through the pedestal assembly **116** to achieve, in operation, a predetermined pattern of the temperature distribution on the substrate supporting surface **176** of the support member **126** and, as such, across the diameter of the substrate **150**.

[0033] The thermoconductive layer 134 comprises a plurality of material regions (two annular regions 102, 104 and circular region 106 are illustratively shown), at least two of which having different coefficients of thermal conductivity. Each region 102, 104, 108 may be formed from at least one material having a different coefficient of thermal conductivity than the material(s) of adjacent regions of the thermoconductive layer 134. In a further embodiment, one or more of the materials comprising the regions 102, 104, 106 may have an anisotropic coefficient of thermal conductivity. For example, coefficients of thermal conductivity of materials in the layer 134 in the directions orthogonal or parallel to the member supporting surface 180 may differ from the coefficients in at least one other direction. The coefficient of thermal conductivity between the regions 102, 104, 106 of the layer 134 may be selected to promote laterally different rates of heat transfer between the chuck 126 and base 114, thereby controlling the temperature distribution across the diameter of the substrate 150.

[0034] In yet further embodiment, gaps 190 (as shown in FIG. 2A) maybe provided between at least two adjacent regions of the thermoconductive layer 134. In the layer 134, such gaps 190 may form either gas-filled or vacuumed volumes having pre-determined form factors. A gap 190 may alternatively be formed within a region of the layer 134 (as shown in FIG. 1C).

[0035] FIG. 2 depicts a schematic cross-sectional view of the substrate pedestal taken along a line 2-2 in FIG. 1A. In the depicted embodiment, the thermoconductive layer 134 illustratively comprises the annular regions 102, 104 and the circular region 106. In alternate embodiments, the layer 134 may comprise either more or less than three regions, as well as regions having different form factors, for example, the regions may be arranged as grids, radially oriented shapes, and polar arrays among others. The regions of the thermoconductive layer 134 may be composed from materials (e.g., adhesive materials) applied in a form of a paste that is further developed into a hard adhesive compound, as well as in a form of an adhesive tape or an adhesive foil. Thermal conductivity of the materials in the thermoconductive layer 134 may be selected in a range from 0.01 to 200 W/mK and, in one exemplary embodiment, in a range from 0.1 to 10 W/mK. In yet another embodiment, the adjacent regions have a difference in thermal conductivities in the range of about 0.1 to 10 W/mK, and may have a difference in conductivity between an inner most and out most regions of the layer 134 of about 0.1 to about 10 W/mK. Examples of suitable adhesive materials include, but not limited to, pastes and tapes comprising acrylic and silicon based compounds. The adhesive materials may additionally include at least one thermally conductive ceramic filler, e.g., aluminum oxide (Al_2O_3), aluminum nitride (AlN), and titanium diboride (TiB_2), and the like. One example of an adhesive tape suitable for the conductive layer 134 is sold under the tradename THERMATTACH®, available from Chomerics, a division of Parker Hannifin Corporation, located in Wolburn, Mass.

[0036] In the thermoconductive layer 134, the thermal conductivity, as well as the form factor, dimensions, and a number of regions having the pre-determined coefficients of thermal conductivity may be selectively chosen to control the heat transfer between the electrostatic chuck 126 and the base 114 to achieve, in operation, a pre-determined pattern

of the temperature distribution on the substrate supporting surface 176 of the chuck and, as such, in the substrate 150. To further control the heat transfer through the conductive layer 134 between the base 114 and support member 126, one or more channels 108 are provided to flow a heat transfer medium therethrough. The channels 108 are coupled through the base 114 to a source 150 of heat transfer medium, such as a cooling gas. Some examples of suitable cooling gases include helium and nitrogen, among others. As the cooling gas disposed in the channels 108 is part of the heat transfer path between the chuck 126 and base 114, the position of the channels 108, and the pressure, flow rate, temperature, density and composition of the heat transfer medium of cooling gas provided, provides enhanced control of the heat transfer profile through the pedestal assembly 116. Moreover, as the density and flow rate of gas in the channel 108 may be controlled in-situ during processing of substrate 150, the temperature control of the substrate 150 may be changed during processing to further enhance processing performance. Although a single source 156 of cooling gas is shown, it is contemplated that one or more sources of cooling gas may be coupled to the channels 108 in a manner such that the types, pressures and/or flow rate of cooling gases within individual channels 108 may be independently controller, thereby facilitating an even greater level of temperature control.

[0037] In the embodiment depicted in FIG. 1A, the channels 108 are depicted as formed in the member supporting surface 180. However, it is contemplated that the channels 108 may be formed at least partially in the member supporting surface 180, at least partially in the bottom surface of the support member 126, or at least partially in the thermally conductive layer 134, along with combinations thereof. In one embodiment, between about 2 to 10 channels 108 are disposed in the pedestal assembly 116 and provide with the selectivity maintained at a pressure between about 760 Torr (atmospheric pressure) to about 10 Torr. For example, at least one of the channels 108 may be partially or entirely formed in the electrostatic chuck 126, as illustrated in FIGS. 3-4. More specifically, FIG. 3 depicts a schematic diagram of a portion of the substrate pedestal assembly 116 where the channels 108 are formed entirely in the electrostatic chuck 126. FIG. 4 depicts a schematic diagram of a portion of the substrate pedestal assembly 116 where the channels 108 are partially formed in the base 114 and, partially, in the electrostatic chuck 126. FIG. 5 depicts a schematic diagram of a portion of the substrate pedestal assembly 116 where the channels 108 are formed in the thermoconductive layer 134. Although in FIG. 5 the channels are shown disposed between different regions 102, 104, 106 of the thermoconductive layer 134, the one or more of the channels may be formed through one or more of the regions 102, 104, 106.

[0038] Returning to FIG. 1A, at least one of the location, shape, dimensions, and number of the channels 108 and inserts 166, 168 as well as the thermal conductivity of the inserts 166, 168 and gas disposed in the channels 108, may be selectively chosen to control the heat transfer between the support member 126 to the base 114 to achieve, in operation, a pre-determined pattern of the temperature distribution on the substrate supporting surface 176 of the chuck 126 and, as such, control the temperature profile of the substrate 150. In further embodiments, the pressure of the cooling gas in at least one channel 108, as well as the flow of the cooling

liquid in at least one conduit **156** may also be selectively controlled to achieve and/or enhance temperature control of the substrate. The heat transfer rate may also be controlled by individually controlling the type of gas, pressure and/or flow rate between respective channels **108**.

[0039] In yet further embodiments, the pre-determined pattern of the temperature distribution in the substrate **150** may be achieved using individual or combinations of the described control means, e.g., the thermoconductive layer **134**, the inserts **166**, **168**, channels **108**, conduits **160**, the pressure of cooling gas in the channels **108**, and the flow of the cooling liquid in the conduits **160**. Furthermore, in the discussed above embodiments, pre-determined patterns of the temperature distribution on the substrate supporting surface **176** and in the substrate **150** may additionally be selectively controlled to compensate for non-uniformity of the heat fluxes originated, during processing the substrate **150**, by a plasma of the process gas and/or substrate bias.

[0040] FIG. 6 depicts a flow diagram of one embodiment of an inventive method for controlling temperature of a substrate processed in a semiconductor substrate processing apparatus as a process **600**. The process **600** illustratively includes the processing steps performed upon the substrate **150** during processing in the reactor **100** described in the embodiments above. It is contemplated that the process **600** may be performed in other processing systems.

[0041] The process **600** starts at step **601** and proceeds to step **602**. At step **602**, the substrate **150** is transferred to the pedestal assembly **116** disposed in the process chamber **110**. At step **604**, the substrate **150** is positioned (e.g., using a substrate robot, not shown) on the substrate supporting surface **176** of the electrostatic chuck **188**. At step **606**, the power supply **132** engages the electrostatic chuck **188** to clamp the substrate **150** to the supporting surface **176** of the chuck **188**. At step **608**, the substrate **150** is processed (e.g., etched) in the process chamber **110** in accordance with a process recipe executed as directed by the controller **140**. During step **608**, the substrate pedestal assembly **116** facilitates a pre-determined pattern of temperature distribution in the substrate **150**, utilizing one or more of the temperature control attributes of the pedestal assembly **116** discussed in reference to FIGS. 1-5 above. Optionally, the rate and/or profile of heat transferred through the chuck **114** during step **608** may be adjusted in-situ by changing one or more of the characteristics of the gas present in one or more of the channels **108**. Upon completion of processing, at step **610**, the power supply **132** disengages the electrostatic chuck **188** and, as such, de-chucks the substrate **150** that is further removed from the process chamber **110**. At step **612**, the process **600** ends.

[0042] While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. A substrate pedestal assembly comprising:
 - a substrate support member;
 - a base having a first surface; and

a material layer disposed between and contacting the first surface and the support member, wherein the material layer comprises a plurality of material regions, at least two of the material regions having different coefficients of thermal conductivity.

2. The substrate pedestal assembly of claim 1, wherein at least one region of the plurality of material regions has an anisotropic coefficient of thermal conductivity.

3. The substrate pedestal assembly of claim 1, wherein at least one region of the plurality of material regions is separated by a gap from an adjacent material region.

4. The substrate pedestal assembly of claim 1, wherein the material layer couples the support member to the first surface of the base.

5. The substrate pedestal assembly of claim 4, wherein at least one region of the material layer is thermally conductive adhesive material.

6. The substrate pedestal assembly of claim 4, wherein at least one region of the material layer comprises at least one thermally conductive adhesive tape.

7. The substrate pedestal assembly of claim 4, wherein the material layer is at least one of an acrylic based compound and silicon based compound.

8. The substrate support pedestal assembly of claim 1, wherein the material layer further comprises a ceramic filler selected from the group consisting of aluminum oxide (Al_2O_3), aluminum nitride (AlN), titanium diboride (TiB_2), and combinations thereof.

9. The substrate pedestal assembly of claim 1, wherein the regions of the material layer have coefficients of thermal conductivity in a range from 0.01 to 200 W/mK.

10. The substrate pedestal assembly of claim 1 further comprising at least one channel adapted to provide a heat transfer medium between the base and support member.

11. The substrate pedestal assembly of claim 10, wherein the at least one channel is at least partially formed in the base.

12. The substrate pedestal assembly of claim 10, wherein the at least one is at least partially formed in the support member.

13. The substrate pedestal assembly of claim 10, wherein the pressure of the heat transfer medium in the at least one channel may be selectively controlled in a range from about 760 to about 10 Torr.

14. The substrate pedestal assembly of claim 10, wherein the heat transfer medium is He.

15. The substrate pedestal assembly of claim 10, wherein the at least one channel is formed in the material layer.

16. The substrate pedestal assembly of claim 1, wherein the base comprises at least one conduit fluidly coupled to a heat transfer liquid source.

17. The substrate pedestal assembly of claim 10, wherein the channel is formed between material regions having different coefficients of thermal expansion.

18. The substrate pedestal assembly of claim 1, wherein the base comprises at least one embedded heater electrically coupled to a controlled power supply.

19. The substrate pedestal assembly of claim 1, wherein the base comprises at least one embedded insert formed from a material having a different coefficient of thermal conductivity than a material of an adjacent region of the base.

20. The substrate pedestal assembly of claim 19, wherein the material of the at least one embedded insert has a lower coefficient of thermal conductivity than the material of the adjacent region of the base.

21. The substrate pedestal assembly of claim 19, wherein the material of the at least one embedded insert has an anisotropic coefficient of thermal conductivity.

22. The substrate pedestal assembly of claim 1, wherein the support member comprises at least one embedded insert formed from a material having a different coefficient of thermal conductivity than a material of an adjacent region of the support member.

23. The substrate pedestal assembly of claim 22, wherein the material of the at least one embedded insert has a lower coefficient of thermal conductivity than the material of the adjacent region of the support member.

24. The substrate pedestal assembly of claim 22, wherein the material of the at least one embedded insert has an anisotropic coefficient of thermal conductivity.

25. The substrate pedestal assembly of claim 1, wherein a support member is an electrostatic chuck.

* * * * *