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### Matched tcr joule heater designs for electrostatic chucks

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#### Abstract

A method of forming a substrate support in a substrate processing system includes forming at least one ceramic layer and arranging a plurality of thermal elements adjacent to the ceramic layer in one or more thermal zones. Each of the thermal zones includes at least one of the thermal elements and each of the thermal elements includes a first resistive material having a positive thermal coefficient of resistance (TCR) and a second resistive material having a negative TCR. The second resistive material is electrically connected to the first resistive material. At least one of the first resistive material and the second resistive material of each of the thermal elements is electrically connected to a power supply to receive power and each of the thermal elements heats a respective one of the thermal zones based on the received power.

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## Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) The present disclosure is a divisional of U.S. patent application Ser. No. 15/292,688, filed on Oct. 13, 2016, which claims the benefit of U.S. Provisional Application No. 62/258,825, filed on Nov. 23, 2015. The entire disclosures of the applications referenced above are incorporated herein by reference.

### FIELD

(1) The present disclosure relates to substrate processing systems, and more particularly to systems and methods for controlling the temperature of a substrate support in a substrate processing system.

### BACKGROUND

(2) The background description provided here is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

(3) Substrate processing systems may be used to treat substrates such as semiconductor wafers. Example processes that may be performed on a substrate include, but are not limited to, a chemical vapor deposition (CVD), atomic layer deposition (ALD), and/or other etch, deposition, or cleaning processes. A substrate may be arranged on a substrate support, such as a pedestal, an electrostatic chuck (ESC), etc. in a processing chamber of the substrate processing system. During etching, gas mixtures including one or more precursors may be introduced into the processing chamber and plasma may be used to initiate chemical reactions.

(4) During process steps, temperatures of various components of the system, and the substrate itself, may vary. These temperature variations may have undesirable effects on the resulting substrates (such as defects or non-uniform critical dimensions). Accordingly, substrate processing

systems may attempt to control temperatures of various components and the substrates during processing.

## SUMMARY

(5) A substrate support for supporting a substrate in a substrate processing system includes a plurality of thermal elements. The thermal elements are arranged in one or more thermal zones, and each of the thermal zones includes at least one of the thermal elements. Each of the thermal elements includes a first resistive material having a positive thermal coefficient of resistance and a second resistive material having a negative thermal coefficient of resistance. The second resistive material is electrically connected to the first material. At least one of the first resistive material and the second resistive material of each of the thermal elements is electrically connected to a power supply to receive power, and each of the thermal elements heats a respective one of the thermal zones based on the received power. At least one ceramic layer is arranged adjacent to the thermal elements.

(6) A method of forming a substrate support in a substrate processing system includes forming at least one ceramic layer and arranging a plurality of thermal elements adjacent to the ceramic layer. The thermal elements are arranged to correspond to one or more thermal zones, and each of the thermal zones includes at least one of the thermal elements. Each of the thermal elements includes a first resistive material having a positive thermal coefficient of resistance and a second resistive material having a negative thermal coefficient of resistance. The second resistive material is electrically connected to the first material. At least one of the first resistive material and the second resistive material of each of the thermal elements is electrically connected to a power supply to receive power. Each of the thermal elements heats a respective one of the thermal zones based on the received power.

(7) Further areas of applicability of the present disclosure will become apparent from the detailed description, the claims and the drawings. The detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

(1) The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

(2) FIG. 1 is a functional block diagram of an example substrate processing system including a substrate support according to the principles of the present disclosure;

(3) FIGS. 2A and 2B show an example heating plate including a plurality of heating elements in a side view and a top plan view, respectively, according to the principles of the present disclosure;

(4) FIG. 3 illustrates example wiring of a plurality of heating elements according to the principles of the present disclosure;

(5) FIG. 4 illustrates another example wiring of a plurality of heating elements according to the principles of the present disclosure;

(6) FIGS. 5A, 5B, and 5C show example arrangements of heating layers including a first material having a first temperature coefficient of resistance (TCR) and a second material having a second TCR according to the principles of the present disclosure; and

(7) FIGS. 6A, 6B, 6C, and 6D show configurations of a single heating layer including both a first heating material and a second heating material according to the principles of the present disclosure.

(8) In the drawings, reference numbers may be reused to identify similar and/or identical elements.

### DETAILED DESCRIPTION

(9) In a substrate processing system, temperatures of a substrate support, such as an electrostatic chuck (ESC), may be controlled during process steps. For example, different processes and

respective steps may require that a substrate is maintained at the same or different temperatures. A contact surface temperature of the substrate support may be controlled to maintain the substrate at desired temperatures. For example only, the substrate support may include a heating plate (e.g., a ceramic heating plate). The substrate may be arranged on the heating plate. Accordingly, the temperature of the heating plate is controlled to achieve the desired temperatures of the substrate. (10) The temperature of the heating plate may be controlled by selectively providing current to a plurality of heating elements, which may be implemented using resistive materials embedded within the heating plate. In other words, the heating plate implements resistive (i.e., joule) heating. The heating elements may be arranged within a plurality of zones of the substrate support (e.g., a multi-zone substrate support). For example only, the substrate support may include 2, 3, 4, or 100 or more zones. Each zone may include one or more heating elements.

(11) Resistive materials may have an associated temperature coefficient of resistance (TCR), which corresponds to an increased resistance (for positive TCR materials) or a decreased resistance (for negative TCR materials) as temperature increases. Accordingly, the power provided to the heating elements to control the temperature of the substrate support varies with temperature, causing variations in power output, temperature control efficiency and accuracy, etc. For example only, a material having a TCR of 0.3% per ° C. experiences a 60% change in resistance at from 0° C. to 200° C.

(12) Systems and methods according to the present disclosure implement pairs of matched resistive heating elements having complementary positive and negative TCRs. For example, each heating element includes a first material having a positive TCR and a second material having a negative TCR. For example only, materials having a positive TCR include, but are not limited to, highly-doped platinum, tungsten ruthenium in oxides, etc. and materials having a negative TCR include, but are not limited to, semiconductors, low percent doped metals in oxides, etc. Accordingly, as the temperature of the respective zone of the substrate support varies, the resistance of the heating element including the matched positive and negative TCR materials remains substantially constant and/or changes at lower rates. In some examples, the first material and the second material are connected in series. In other examples, the first material and the second material are connected in parallel. The first material and the second material may be aligned vertically in different planes of the heating plate. In some examples, the first and second materials are spaced apart in different layers and another layer (e.g., a dielectric layer, a bus layer, etc.) is arranged between the first and second materials. In other examples, the first material and the second material may be coplanar (e.g., interwoven in a same plane of the heating plate).

(13) Referring now to FIG. 1, an example substrate processing system **100** for performing etching using RF plasma is shown. The substrate processing system **100** includes a processing chamber **102** that encloses other components of the substrate processing system **100** and contains the RF plasma. The substrate processing system **100** includes an upper electrode **104** and a substrate support **106**, such as an electrostatic chuck (ESC). During operation, a substrate **108** is arranged on the substrate support **106**.

(14) For example only, the upper electrode **104** may include a showerhead **109** that introduces and distributes process gases. The showerhead **109** may include a stem portion including one end connected to a top surface of the processing chamber. A base portion is generally cylindrical and extends radially outwardly from an opposite end of the stem portion at a location that is spaced from the top surface of the processing chamber. A substrate-facing surface or faceplate of the base portion of the showerhead includes a plurality of holes through which process gas or purge gas flows. Alternately, the upper electrode **104** may include a conducting plate and the process gases may be introduced in another manner.

(15) The substrate support **106** includes a conductive baseplate **110** that acts as a lower electrode. The baseplate **110** supports a heating plate **112**, which may correspond to a ceramic multi-zone heating plate. A thermal resistance layer **114** may be arranged between the heating plate **112** and the

baseplate **110**. The baseplate **110** may include one or more coolant channels **116** for flowing coolant through the baseplate **110**.

(16) An RF generating system **120** generates and outputs an RF voltage to one of the upper electrode **104** and the lower electrode (e.g., the baseplate **110** of the substrate support **106**). The other one of the upper electrode **104** and the baseplate **110** may be DC grounded, AC grounded or floating. For example only, the RF generating system **120** may include an RF voltage generator **122** that generates the RF voltage that is fed by a matching and distribution network **124** to the upper electrode **104** or the baseplate **110**. In other examples, the plasma may be generated inductively or remotely. Although, as shown for example purposes, the RF generating system **120** corresponds to a capacitively coupled plasma (CCP) system, the principles of the present disclosure may also be implemented in other suitable systems, such as, for example only transformer coupled plasma (TCP) systems, CCP cathode systems, etc.

(17) A gas delivery system **130** includes one or more gas sources **132-1**, **132-2**, . . . , and **132-N** (collectively gas sources **132**), where N is an integer greater than zero. The gas sources supply one or more precursors and mixtures thereof. The gas sources may also supply purge gas. Vaporized precursor may also be used. The gas sources **132** are connected by valves **134-1**, **134-2**, . . . , and **134-N** (collectively valves **134**) and mass flow controllers **136-1**, **136-2**, . . . , and **136-N** (collectively mass flow controllers **136**) to a manifold **140**. An output of the manifold **140** is fed to the processing chamber **102**. For example only, the output of the manifold **140** is fed to the showerhead **109**.

(18) A temperature controller **142** may be connected to a plurality of heating elements (e.g., thermal control elements, or TCEs) **144** arranged in the heating plate **112**. For example, the heating elements **144** may include, but are not limited to, macro heating elements corresponding to respective zones in a multi-zone heating plate and/or an array of micro heating elements disposed across multiple zones of a multi-zone heating plate. The temperature controller **142** may be used to control the plurality of heating elements **144** to control a temperature of the substrate support **106** and the substrate **108**. Each of the heating elements **144** according to the principles of the present disclosure includes a first material having a positive TCR and a second material having a negative TCR as described below in more detail.

(19) The temperature controller **142** may communicate with a coolant assembly **146** to control coolant flow through the channels **116**. For example, the coolant assembly **146** may include a coolant pump and reservoir. The temperature controller **142** operates the coolant assembly **146** to selectively flow the coolant through the channels **116** to cool the substrate support **106**.

(20) A valve **150** and pump **152** may be used to evacuate reactants from the processing chamber **102**. A system controller **160** may be used to control components of the substrate processing system **100**. A robot **170** may be used to deliver substrates onto, and remove substrates from, the substrate support **106**. For example, the robot **170** may transfer substrates between the substrate support **106** and a load lock **172**. Although shown as separate controllers, the temperature controller **142** may be implemented within the system controller **160**.

(21) Referring now to FIGS. 2A and 2B, an example heating plate **200** (e.g., a ceramic heating plate) including a plurality of heating elements **204** is shown in a side cross-sectional view and a top plan view, respectively. Each of the heating elements **204** includes a first material **208** and a second material **212**. The first material **208** may have a positive TCR while the second material **212** may have a negative TCR, or vice versa. Respective absolute values of the TCRs of the plurality of heating elements **204** may be the same or different. In other words, the first material **208** of one of the heating elements **204** may have a first positive TCR while the first material **208** of another one of the heating elements **204** may have the same first positive TCR or a second, different positive TCR. The first material **208** and the second material **212** may be spaced apart as shown, with a layer arranged therebetween. In some examples, a dielectric layer, a bus layer, etc. is arranged therebetween as described in more detail below. The heating elements **204** may be completely or

partially encapsulated by one or more ceramic layers of the heating plate **200**.

(22) Although the heating elements **204** are described herein as being arranged within ceramic layers, in some embodiments the heating elements **204** may be formed in a metallized layer that is deposited on a bottom surface of a ceramic layer (e.g., either prior to or subsequent to the respective ceramic layer being fired). For example only, the metallized layer may comprise tungsten, palladium, silver, etc. to act as a heating layer. In some examples, the metallized layer may be deposited via PVD, electroless deposition, electroplating, etc. prior to the firing of the ceramic layer. In other examples, the metallized layer may be deposited via screen-printing prior to the firing of the ceramic layer.

(23) Although as shown the first material **208** is arranged directly above the second material **212** in a vertical direction, this illustration is for example only and other arrangements may be used as described below in more detail. For example, the first material **208** and the second material **212** may be offset in a lateral direction such that the first material **208** only partially overlaps the second material **212**, partially overlaps the second material **212** of another heating element, etc. In some examples, the first material **208** may be completely offset from the second material **212** in a lateral direction (i.e., the first material **208** does not overlap the second material **212** of the same heating element), and the first material **208** and the second material **212** may be coplanar.

(24) Each of the heating elements **204** may correspond to a different zone of the heating plate **200**, or multiple heating elements **204** may correspond to a single zone. Although shown arranged in a rectangular grid, in other examples the heating elements **204** may be arranged in other configurations such as concentric rings, a hexagonal grid, etc.

(25) Each of the heating elements **204** is connected to power supply lines **216** and/or power return lines **220** as shown schematically. The connections of the power supply lines **216** and the power return lines **220** are shown for example only, and other arrangements may be used. For example, a bus layer **224** may be arranged below the heating elements **204** including the power supply lines **216** and the power return lines **220**. Connections between the bus layer **224** and the heating elements **204** are provided using respective vias **228**. In the present example, no two heating elements **204** share a same pair of the power supply lines **216** and the power return lines **220**.

Accordingly, by selectively switching respective power supply lines **216** and power return lines **220**, each of the heating elements **204** can be individually provided with power independently of others of the heating elements **204**. In some implementations, to prevent crosstalk between different heating elements **204**, a rectifier (e.g. a diode, FIG. 3) may be serially connected between each of the heating elements **204** and the power supply lines **216**, or between each of the heating elements **204** and the power return lines **220**. The rectifier can be arranged within the heating plate (e.g., in the bus layer **224**) or any suitable location. In other implementations, other current blocking elements (e.g., solid state switches) may be used to prevent crosstalk.

(26) In examples, the first material **208** and the second material **212** may each include composites of various insulators and conductors. For example only, the first material **208** may include Al.sub.2O.sub.3, SiO.sub.2, Si.sub.3N.sub.4, AlN, Al, Cu, Mo, W, Au, Ag, Pt, Pd, C, MoSi.sub.2, WC, SiC, and mixtures thereof resulting in a positive TCR. Conversely, the second material **212** may include Si or Ge (e.g., applied in powder form as a screen-printed ink), metal oxides including, but not limited to, spinel phase manganates, cobalt oxides, nickel oxides, and mixtures thereof (e.g., Fe.sub.2O.sub.3 and Ti, NiO and Li, etc.), Rh, Ru, Pt, W, and other known low-temperature semiconducting metal oxides. Other materials that may be suitable in some implementations include C, Ni, Cr, and Co. The materials **208** and **212** may be formed by combining powders (for example only, having particle sizes from 0.2 to 10 microns) of an insulator and a conductor with a suitable liquid (e.g. methanol, ethanol, acetone, isopropyl alcohol, water, mineral oil, or a mixture thereof) into a slurry, and sintering the slurry.

(27) The heating plate **200** may be formed from ceramic using various methods. For example, a mixture of ceramic powder, binder and liquid may be pressed into ceramic layer sheets (which may

be referred to as “green sheets”). The green sheets are dried and holes are punched in the green sheets to form vias (e.g., corresponding to the vias **228**). The vias are filled with conductive material (e.g., a slurry of conducting powder). The power supply lines **216** and the power return lines **220** corresponding to a first bus or routing layer are formed on the green sheets. For example only, the power supply lines **216** and the power return lines **220** are formed on the ceramic green sheets by screen printing a slurry of conducting powder (e.g. W, WC, doped SiC, MoSi.sub.2, etc.), pressing a precut metal foil, spraying a slurry of conducting powder, and/or other suitable techniques.

(28) The heating elements **204** are then formed on the ceramic green sheets. For example only, the heating elements **204** may be formed by screen printing or spraying a slurry of insulator and conductor powders in one or more heating layer green sheets (e.g., first heating layer green sheets corresponding to a first material and second heating layer green sheets corresponding to a second material). For example, the first heating layer green sheets may be deposited on the ceramic green sheets, an intermediate layer (e.g., another ceramic green sheet layer, a dielectric layer, and/or a second bus layer) may be formed on the first heating layer green sheets. Additional vias may be formed through the first heating layer green sheets to connect the first bus layer and/or the first heating layer green sheets to the second bus layer. The second heating layer green sheets are then formed on the intermediate layer.

(29) The ceramic green sheets and the heating layer green sheets are aligned and then bonded together by sintering. For example, in one example, the ceramic green sheets and the first heating layer green sheets may be aligned and bonded together prior to forming the intermediate layer. The intermediate layer is then formed, aligned, and bonded to the first heating layer, and the second heating layer green sheets are formed, aligned, and bonded to the intermediate layer. In other examples, the ceramic green sheets, the first heating layer green sheets, the intermediate layer, and the second heating layer green sheets are aligned and bonded together in a same process step. Other ceramic green sheets may be formed on the heating layer green sheets as described above to form a substantially contiguous ceramic layer completely encapsulating the first and second heating materials of the heating layer.

(30) Referring now to FIG. 3, example wiring of a plurality of heating elements **300** is shown schematically. In this example, a first material TCR1 (e.g., having a positive TCR) and a second material TCR2 (e.g., having a negative TCR) are connected in series. For example, a first end of the first material TCR1 is connected to a power supply bus **304** and a second end of the first material TCR1 is connected to a first end of the second material TCR2. A second end of the second material TCR2 is connected to a power return bus **308**. In some embodiments, a diode **312** (e.g., functioning as a rectifier as described above in FIGS. 2A and 2B) may be serially connected between each of the heating elements **300** and the power supply bus **304**. As shown in FIG. 3, nodes **316** indicate a connection between intersecting wires, and intersecting wires that do not include the node **316** are not connected together.

(31) Referring now to FIG. 4, another example wiring of a plurality of heating elements **400** is shown schematically. In this example, a first material TCR.sub.1 (e.g., having a positive TCR) and a second material TCR.sub.2 (e.g., having a negative TCR) are connected in parallel. For example, respective first ends of the first material TCR.sub.1 and the second material TCR.sub.2 are connected to a power supply bus **404** and respective second ends of the first material TCR.sub.1 and the second material TCR.sub.2 are connected to a power return bus **408**. In some embodiments, a diode **412** may be serially connected between each of the heating elements **400** and the power supply bus **404**. As shown in FIG. 4, nodes **416** indicate a connection between intersecting wires, and intersecting wires that do not include the node **416** are not connected together.

(32) FIGS. 5A, 5B, and 5C show example arrangements of heating layers corresponding to a first material having a first (e.g., positive) TCR and a second material having a second (e.g., negative) TCR. As shown in an example in FIG. 5A, a layer **500** corresponds to a first ceramic layer of green



sheets, which may include a bus layer **504** formed thereon. Vias **508** are formed in the layer **500** to connect the bus layer **504** to a power supply and a power return. Green sheets including a first heating layer **512** and a second heating layer **516** are formed on the layer **500**. A dielectric layer **520** may be formed between the first heating layer **512** and the second heating layer **516**. A layer **524** corresponding to a second ceramic layer of green sheets may be formed on the first heating layer **512**. A plurality of vias **528** formed through the second heating layer **516**, the dielectric layer **520**, and/or the first heating layer **512** connect the bus layer **504** to the first heating layer **512** and the second heating layer **516** according to a desired configuration (e.g., whether the first heating layer **512** and the second heating layer **516** in respective heating elements are connected in series, in parallel, etc.).

(33) As shown in another example in FIG. 5B, a layer **532** corresponds to a first ceramic layer of green sheets, which may include a bus layer **536** formed thereon. Vias **540** are formed in the layer **532** to connect the bus layer **536** to a power supply and a power return. Green sheets including a first heating layer **544** and a second heating layer **548** are formed on a layer **552** and the layer **532**. The layer **552** corresponds to a second ceramic layer of green sheets, which may include a bus layer **556** formed thereon. A layer **560** corresponding to a third ceramic layer of green sheets may be formed on the first heating layer **544**. A plurality of vias **564** formed through the second heating layer **548**, the layer **552**, and/or the first heating layer **544** connect the bus layer **536** to the first heating layer **544**, the second heating layer **548**, and the bus layer **556** according to a desired configuration (e.g., whether the first heating layer **544** and the second heating layer **548** in respective heating elements are connected in series, in parallel, etc.).

(34) As shown in an example in FIG. 5C, a layer **568** corresponds to a first ceramic layer of green sheets, which may include a bus layer **572** formed thereon. Vias **576** are formed in the layer **568** to connect the bus layer **572** to a power supply and a power return. Green sheets including a first heating layer **580** with both a first heating material and a second heating material are formed on the layer **568**. In other words, the same heating layer **580** includes both a positive TCR material and a negative TCR material (i.e., the first heating material and the second heating material are substantially coplanar) in contrast to arranging the first heating material and the second heating material in different layers as shown in FIGS. 5B and 5C. A layer **584** corresponding to a second ceramic layer of green sheets may be formed on the first heating layer heating layer **580**.

(35) Referring now to FIGS. 6A, 6B, 6C, and 6D show example configurations of a single heating layer **600** including both a first heating material **604** and a second heating material **608** as described in FIG. 5C. The first heating material **604** and the second heating material **608** are interwoven in the same heating layer **600** (e.g., in the same plane). In FIG. 6A, the first heating material **604** and the second heating material **608** are interwoven in an “S”-shape. In FIG. 6B, the first heating material **604** and the second heating material **608** include interlocking alternating fingers. In FIG. 6C, the first heating material **604** and the second heating material **608** are interwoven in a “U”-shape. In FIG. 6D, the first heating material **604** and the second heating material **608** are interwoven in a spiral shape.

(36) As shown in each of FIGS. 6A, 6B, 6C, and 6D, the first heating material **604** and the second heating material **608** are connected together in a serial configuration. However, in other examples, the first heating material **604** and the second heating material **608** may be connected together in a parallel configuration. Power is provided to a first end of the first heating material **604** using a via **612**. A second end of the first heating material **604** is connected to a first end of the second heating material **608** using respective vias **616** and **620**. A second end of the second heating material **608** is connected to a power return using via **624**.

(37) The foregoing description is merely illustrative in nature and is in no way intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of

the drawings, the specification, and the following claims. It should be understood that one or more steps within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure. Further, although each of the embodiments is described above as having certain features, any one or more of those features described with respect to any embodiment of the disclosure can be implemented in and/or combined with features of any of the other embodiments, even if that combination is not explicitly described. In other words, the described embodiments are not mutually exclusive, and permutations of one or more embodiments with one another remain within the scope of this disclosure.

(38) Spatial and functional relationships between elements (for example, between modules, circuit elements, semiconductor layers, etc.) are described using various terms, including “connected,” “engaged,” “coupled,” “adjacent,” “next to,” “on top of,” “above,” “below,” and “disposed.” Unless explicitly described as being “direct,” when a relationship between first and second elements is described in the above disclosure, that relationship can be a direct relationship where no other intervening elements are present between the first and second elements, but can also be an indirect relationship where one or more intervening elements are present (either spatially or functionally) between the first and second elements. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A OR B OR C), using a non-exclusive logical OR, and should not be construed to mean “at least one of A, at least one of B, and at least one of C.”

(39) In some implementations, a controller is part of a system, which may be part of the above-described examples. Such systems can comprise semiconductor processing equipment, including a processing tool or tools, chamber or chambers, a platform or platforms for processing, and/or specific processing components (a wafer pedestal, a gas flow system, etc.). These systems may be integrated with electronics for controlling their operation before, during, and after processing of a semiconductor wafer or substrate. The electronics may be referred to as the “controller,” which may control various components or subparts of the system or systems. The controller, depending on the processing requirements and/or the type of system, may be programmed to control any of the processes disclosed herein, including the delivery of processing gases, temperature settings (e.g., heating and/or cooling), pressure settings, vacuum settings, power settings, radio frequency (RF) generator settings, RF matching circuit settings, frequency settings, flow rate settings, fluid delivery settings, positional and operation settings, wafer transfers into and out of a tool and other transfer tools and/or load locks connected to or interfaced with a specific system.

(40) Broadly speaking, the controller may be defined as electronics having various integrated circuits, logic, memory, and/or software that receive instructions, issue instructions, control operation, enable cleaning operations, enable endpoint measurements, and the like. The integrated circuits may include chips in the form of firmware that store program instructions, digital signal processors (DSPs), chips defined as application specific integrated circuits (ASICs), and/or one or more microprocessors, or microcontrollers that execute program instructions (e.g., software). Program instructions may be instructions communicated to the controller in the form of various individual settings (or program files), defining operational parameters for carrying out a particular process on or for a semiconductor wafer or to a system. The operational parameters may, in some embodiments, be part of a recipe defined by process engineers to accomplish one or more processing steps during the fabrication of one or more layers, materials, metals, oxides, silicon, silicon dioxide, surfaces, circuits, and/or dies of a wafer.

(41) The controller, in some implementations, may be a part of or coupled to a computer that is integrated with the system, coupled to the system, otherwise networked to the system, or a combination thereof. For example, the controller may be in the “cloud” or all or a part of a fab host computer system, which can allow for remote access of the wafer processing. The computer may enable remote access to the system to monitor current progress of fabrication operations, examine a history of past fabrication operations, examine trends or performance metrics from a plurality of fabrication operations, to change parameters of current processing, to set processing steps to follow

a current processing, or to start a new process. In some examples, a remote computer (e.g. a server) can provide process recipes to a system over a network, which may include a local network or the Internet. The remote computer may include a user interface that enables entry or programming of parameters and/or settings, which are then communicated to the system from the remote computer. In some examples, the controller receives instructions in the form of data, which specify parameters for each of the processing steps to be performed during one or more operations. It should be understood that the parameters may be specific to the type of process to be performed and the type of tool that the controller is configured to interface with or control. Thus as described above, the controller may be distributed, such as by comprising one or more discrete controllers that are networked together and working towards a common purpose, such as the processes and controls described herein. An example of a distributed controller for such purposes would be one or more integrated circuits on a chamber in communication with one or more integrated circuits located remotely (such as at the platform level or as part of a remote computer) that combine to control a process on the chamber.

(42) Without limitation, example systems may include a plasma etch chamber or module, a deposition chamber or module, a spin-rinse chamber or module, a metal plating chamber or module, a clean chamber or module, a bevel edge etch chamber or module, a physical vapor deposition (PVD) chamber or module, a chemical vapor deposition (CVD) chamber or module, an atomic layer deposition (ALD) chamber or module, an atomic layer etch (ALE) chamber or module, an ion implantation chamber or module, a track chamber or module, and any other semiconductor processing systems that may be associated or used in the fabrication and/or manufacturing of semiconductor wafers.

(43) As noted above, depending on the process step or steps to be performed by the tool, the controller might communicate with one or more of other tool circuits or modules, other tool components, cluster tools, other tool interfaces, adjacent tools, neighboring tools, tools located throughout a factory, a main computer, another controller, or tools used in material transport that bring containers of wafers to and from tool locations and/or load ports in a semiconductor manufacturing factory.

## Claims

1. A method of forming a substrate support in a substrate processing system, the method comprising: forming a first ceramic layer of green sheets; forming a bus layer on the first ceramic layer, and forming first vias in the first ceramic layer to connect the bus layer to power supply and power return lines; arranging a plurality of thermal elements on the first ceramic layer in one or more thermal zones, wherein each of the one or more thermal zones includes at least one of the plurality of thermal elements, wherein each of the plurality of thermal elements includes a first resistive material having a positive thermal coefficient of resistance (TCR), and a second resistive material having a negative TCR, wherein the second resistive material is electrically connected to the first resistive material, and a dielectric layer is formed between the first resistive material and the second resistive material; and forming a second ceramic layer of green sheets on the plurality of thermal elements, wherein a plurality of second vias are formed through the second resistive material and the dielectric layer to connect the bus layer to the first resistive material, wherein at least one of the first resistive material and the second resistive material of each of the plurality of thermal elements is electrically connected to a power supply via an independent pair of the power supply and power return lines, to selectively receive power from the power supply independent of other ones of the plurality of thermal elements, wherein, for each of the plurality of thermal elements, a corresponding one of multiple diodes is serially connected between the power supply line corresponding to the thermal element and the at least one of the first resistive material and the second resistive material, and wherein each of the plurality of thermal elements heats a respective

one of the one or more thermal zones based on the received power.

2. The method of claim 1, wherein forming a heating layer including the plurality of thermal elements includes depositing a metallized layer on a surface of the first ceramic layer.
  3. The method of claim 1, wherein respective absolute values of the positive TCR and the negative TCR are equal.
  4. The method claim 1, wherein a sum of the positive TCR and the negative TCR is zero.
  5. The method of claim 1, further comprising connecting the first resistive material and the second resistive material in series.
  6. The method of claim 1, further comprising connecting the first resistive material and the second resistive material in parallel.
  7. The method of claim 1, further comprising arranging the first resistive material above the second resistive material.
  8. The method of claim 7, further comprising arranging the first resistive material directly above the second resistive material.
  9. The method of claim 7, further comprising laterally offsetting the first resistive material from the second resistive material.
  10. The method claim 1, further comprising arranging the first resistive material to be coplanar with the second resistive material.
  11. The method of claim 10, further comprising interweaving the first resistive material and the second resistive material.
  12. The method of claim 11, wherein the first resistive material and the second resistive material are interwoven to form at least one of an “S”-shape, a spiral shape, and a “U”-shape.
  13. The method of claim 11, wherein the first resistive material and the second resistive material include alternately interlocking fingers.
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