HEATED SUBSTRATE SUPPORT ASSEMBLY AND METHOD

A substrate support assembly 30 comprises a support 38 with a substrate supporting surface 55 and a collar 130 comprising an electrical connector, whereby a voltage may be supplied to the collar 130 through the electrical connector. The collar 130 may pass a current therethrough to resistively heat the collar to a predetermined temperature before substrate processing. In another version, the temperature of the collar 130 may be controlled during and/or before substrate processing.
HEATED SUBSTRATE SUPPORT ASSEMBLY
AND METHOD

BACKGROUND

The invention relates to the supporting of a substrate.

In the manufacture of integrated circuits, a substrate may be processed by an energized gas in a chamber. The substrate is typically supported in the chamber by a support, a portion of which may comprise a dielectric material covering an electrode. The electrode may be charged to electrostatically hold the substrate, to energize the process gas in the chamber, or to do both. In addition, the support may comprise a heater to heat the substrate, or a heat exchanger, such as for example, channels through which heat transfer fluid may be circulated to heat or cool the substrate. In addition, a heat transfer gas, such as helium, may be introduced below the substrate to enhance heat transfer rates to and from the substrate. Also within or on the support, an annular ring or collar may serve as a focus ring preferentially directing the energized gas species toward the substrate, focusing energy onto the substrate, or may serve as a barrier ring to reduce exposure of the support to the erosive environment, or for other substrate processing purposes.

One problem with conventional chambers arises when parts of the chamber, such as components in or on the support of the chamber, vary in temperatures during the processing of a set of substrates. For example, substrate processing is often performed at elevated temperatures that may exceed 100°C and in processes that may have 50°C fluctuations during different process stages. The substrates may be processed inconsistently when the temperatures of the chamber components vary during processing. In addition, when the temperature of a component varies across the component, a substrate may not be consistently processed across its entire surface. Substrate performance and process throughput may be adversely affected by these inconsistencies.
Therefore, it is desirable to maintain consistent processing temperatures from substrate to substrate. It is further desirable to be able to control the temperature of a component in the processing chamber.

**SUMMARY**

The present invention satisfies these needs. In one aspect of the invention, a substrate support assembly comprises a support comprising a surface adapted to support the substrate and a collar comprising an electrical connector, whereby a voltage may be applied to the collar through the electrical connector.

In another aspect of the invention, a substrate processing chamber comprises a substrate support assembly comprising a support and a collar, the support comprising a surface adapted to support the substrate, a gas distributor, a gas energizer, a gas exhaust, and a voltage supply adapted to supply a voltage to the collar, whereby a substrate on the support may be processed by gas introduced through the gas distributor, energized by the gas energizer and exhausted by the gas exhaust.

In another aspect of the invention, a substrate support heater comprises a collar and a voltage supply adapted to supply a voltage to the collar to heat the collar.

In another aspect of the invention, a method of supporting a substrate in a process chamber and processing the substrate in the process chamber comprises supporting the substrate on a support in the process chamber, supplying a voltage to a component in the process chamber to heat the component, and providing an energized process gas in the process chamber.

In another aspect of the invention, a method of supporting a substrate in a process chamber and processing the substrate in the process chamber comprising providing a support and a collar, heating the collar, after heating the collar, supporting a substrate on the support, and introducing an energized process gas into the process chamber.
In another aspect of the invention, a method of fabricating a substrate support comprises forming a collar at least partially around a substrate support and forming an electrical connector within or in contact with the collar.

**DRAWINGS**

These features, aspects, and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings which illustrate exemplary features of the invention. However, it is to be understood that each of the features can be used in the invention in general, not merely in the context of the particular drawings, and the invention includes any combination of these features, where:

- Figure 1 is a schematic side view of a chamber and support according to the present invention;
- Figure 2a is a schematic view of a version of a collar and voltage supply according to the present invention;
- Figure 2b is a simplified electrical circuit diagram of the collar and voltage supply of Figure 2a;
- Figure 3a is a schematic view of another version of a collar and voltage supply according to the present invention;
- Figure 3b is a simplified electrical circuit diagram of the collar and voltage supply of Figure 3a;
- Figure 4 is a partial schematic sectional side view of a version of a support assembly according to the present invention;
- Figure 5 is a partial schematic sectional side view of another version of a support assembly according to the present invention;
Figure 6 is a schematic view of a collar and a control and monitoring system according to the present invention; and

Figure 7 is a schematic view of another version of a collar and a control and monitoring system according to the present invention.

DESCRIPTION

The present invention relates to a support with a heated collar ring for supporting a substrate in a process chamber and a method of supporting a substrate on a support. The description and accompanying drawings represent illustrative embodiments of the invention and are not intended to limit the invention.

A substrate 15 may be processed in an apparatus 20 comprising a process chamber 25, such as for example, an MxP, MxP Super e, or an MxP eMax etching chamber, which may be commercially available from Applied Materials Inc., Santa Clara, California, and are generally described in commonly assigned U.S. Patent Nos. 4,842,683 and 5,215,619 to Cheng et al; and U.S. Patent No. 4,868,338 to Maydan et al, all of which are incorporated herein by reference in their entireties. An exemplary apparatus 20, as schematically illustrated in Figure 1, may be used in a multi-chamber integrated system for processing semiconductor substrates -- as for example, described in U.S. Patent No. 4,951,601 to Maydan et al, which is also incorporated herein by reference in its entirety -- and that provides control, electrical, plumbing and other support functions for the chamber 25. However, the present invention may be also used to fabricate other substrates 15, such as dielectric materials, for example, flat panel displays, and can also be used for manufacturing processes other than semiconductor fabrication.

Generally, the chamber 25 comprises a support assembly 30 to receive the substrate 15 in the process zone 35 in which the substrate 15 may be processed. The support assembly 30 comprises a support 38 on which the substrate 15 may be held. The support 38 may comprise, for example, an electrostatic chuck 40 comprising a dielectric 45 at least partially covering an electrode 50, the dielectric 45
having a surface 55 adapted to receive the substrate 15 and with gas outlets 60 through which a heat transfer gas, such as helium, may be passed from a heat transfer gas source 65 and via gas conduits 70, to control the temperature of the substrate 15 (as shown in Figure 1), or the support 38 may comprise a support member which may be made of metal, such as aluminum. Alternatively, the support 38 may be a vacuum or mechanical chuck or any other support as is known in the art. The electrode 50 below the dielectric comprises a single conductor (as shown) or a plurality of conductors (not shown), which may be electrically biased by an electrode voltage supply 75 to electrostatically hold the substrate 15. A base 80 below the electrostatic chuck 40 may optionally contain a heat exchanger, such as channels through which a heat transfer fluid may be circulated.

Process gas is introduced into the chamber 25 through a gas supply 85 that includes a gas source 90 and one or more gas nozzles 95 terminating in the chamber 25. The gas nozzles 95 may be located around the periphery of the substrate 15 (as shown) or in a showerhead mounted on the ceiling of the chamber (not shown), and a gas flow controller 100 may be used to control the flow rate of the process gas. Spent process gas and etchant byproducts are exhausted from the chamber 25 through an exhaust system 105. The exhaust system 105 typically comprises an exhaust conduit leading to a plurality of pumps, such as roughing or high vacuum pumps, that evacuate the gas in the chamber 25. A throttle valve 110 is provided in the exhaust conduit to control the pressure of the gas in the chamber 25.

An energized gas, such as for example a gaseous plasma, is generated from the process gas by a gas energizer 75 that couples electromagnetic energy, such as RF or microwave energy, to the process gas in the process zone 35 of the chamber 25. For example, the gas energizer may comprise a first process electrode 115 such as an electrically grounded sidewall or ceiling of the chamber 25 and a second electrode which may be electrode 50 in dielectric 45 (as shown) or another conductive element in the support assembly 30. The first and second electrodes 115, 50 are electrically biased relative to one another by an RF voltage provided by an electrode voltage supply 75. The frequency of the RF voltage applied to the electrodes 115, 50 is typically from about 50 KHz to about 60 MHz. In other
versions, the gas energizer may also or alternatively include an inductor antenna (not shown) comprising one or more coils to inductively couple RF energy to the chamber 25. The capacitively generated plasma may be enhanced by electron cyclotron resonance in a magnetically enhanced reactor in which a magnetic field generator 120, such as a permanent magnet or electromagnetic coils, provides a magnetic field in the chamber 25. Preferably, the magnetic field comprises a rotating magnetic field having an axis that rotates parallel to the plane of the substrate 15, as for example, described in aforementioned U.S. Patent No. 4,842,683.

The chamber 25 may also comprise a process monitoring system (not shown) to monitor a process being performed on the substrate 15. A typical process monitoring system comprises an interferometric system that measures an intensity of light reflected from a layer being processed on the substrate 15, or a plasma emission analysis system that measures a change in light emission intensity of a gas species in the chamber 25 (not shown). The process monitoring system is useful to detect an endpoint of a process being performed on the substrate 15.

The support assembly 30 shown in Figure 1 may be formed by covering, or embedding, the electrode 50 in the dielectric 45 which may comprise a dielectric material that prevents electrical shorting with the plasma formed in the chamber 25. The dielectric 45 comprises a relatively low RF electrical field absorption that allows an RF electric field emanating from the electrode 50 to be capacitively coupled through the dielectric 45. The dielectric 45 may be made from a dielectric material that is permeable to the RF energy supplied to the electrode 50 to allow capacitive coupling through the cover layer to the plasma and the process electrode 115. For example, the dielectric 45 may also comprise a semiconductor material with a low level of conductivity. The dielectric 45 may have a smooth receiving surface, that directly contacts and supports the substrate 15.

The dielectric 45 may comprise a unitary and discrete structure containing the electrode 50 and may be fabricated as a monolithic structure from thermally fused ceramic or polymer. Monolith ceramics typically have low porosity, good electrical properties, and may entirely enclose the electrode 50. The high dielectric breakdown strength of the dense ceramic structure also allows application
of higher RF power to the electrode 50. The dielectric 45 may be fabricated from a ceramic having a low porosity of less than about 20%, and preferably less than about 10%. Suitable ceramic materials include one or more of aluminum oxide, aluminum nitride, boron carbide, boron nitride, silicon oxide, silicon carbide, silicon nitride, titanium oxide, titanium carbide, yttrium oxide, and zirconium oxide. The dielectric 45 may also comprise a semiconductor material such as undoped or doped ceramic materials. Alternatively, the dielectric 45 can comprise a laminate of polyimide or aramid layers covering the electrode 50 and typically fabricated by an autoclave pressure forming process. The electrode 50 embedded in the dielectric may be fabricated from a conductive metal which allows heat treatment or thermal sintering of the dielectric with the embedded electrode. The dielectric 45 with the embedded electrode 50 can be fabricated by isostatic pressing, hot pressing, mold casting, or tape casting, from a mixture of ceramic powders and a low concentration of organic binder material.

The electrode 50 at least partially covered by the dielectric 45 may be adapted to be electrically charged to electrostatically hold the substrate 15 to the receiving surface 55, adapted to energize the gas in the chamber 25, or adapted to do both. For electrostatic clamping, the electrode 50 may be a monopolar or bipolar electrode. The electrode 50 is made from an electrically conducting material, such as a metal, for example, aluminum, copper, molybdenum or mixtures thereof. Molybdenum has a good thermal conductivity and resistance in corrosion in non-oxidizing environments, such as when the electrode 50 is embedded in the dielectric 45. The electrode 50 may comprise a generally planar shape conformal to the shape of the substrate 15. For example, the electrode 50 may be a mesh of electrically conducting wire (not shown) extending below substantially the entire substrate 15.

In one version, the support assembly 30 comprises a collar 130 around or near the support 38, such as the electrostatic chuck 40 in the version of Figure 1. The collar 130, for example, may protect the support 38 or electrostatic chuck 40 from erosion or corrosion, as described in U.S. Patent No. 5,636,098 to Salfelder et al, which is incorporated herein by reference in its entirety, by serving as a guard which reduces contact between erosive gases in the chamber 25 and the dielectric 45.
or other component. In this version, the collar may comprise a surface that is coupleable with a surface of the dielectric 45 to reduce a gas flow between the dielectric 45 and the collar 130. The collar 130 may be formed of the same or different material as the dielectric 45. For example, in this version, the collar 130 may comprise one or more of silicon, polyethylene, polyurethane, polycarbonate, polystyrene, nylon, polypropylene, polyvinylchloride, polyethylene terephthalate, fluoroethylene polypropylene copolymers, polytetrafluoroethylene, acrylate, butyl, chlorosulfonated polyethylene, epichlorohydrin, fluorinated rubber, natural rubber, neoprene, nitrile, polybutadiene, polyisoprene, and polysulfide.

Alternatively or in addition to being used as a guard, the collar 130 may have other uses in the support assembly 30. For example, in one version the collar 130 may be a dielectric or semiconducting material that serves to channel energy through the chuck 40 to focus the energy on the substrate 15, as described in U.S. Patent No. 5,748,434 to Rossman et al, which is incorporated herein by reference in its entirety. In another version, the collar 130 may serve to preferentially direct an energized gas toward the substrate 15. The collar 130 may include a portion (not shown) that extends above the dielectric 45 to form an inner recess to support the substrate 15. In yet another version, the collar 130 comprises a dielectric material positioned adjacent or near the chuck 40 to allow RF power to be capacitively coupled from a conductor below the collar 130 though the collar 130 to the plasma 35. It is believed this results in an extended plasma sheath that provides a uniform plasma for processing of the substrate 15. It is also believed that the capacitive coupling through the collar 130 allows a plasma self bias to build up and clean process deposits from the collar 130. These process deposits are generated, for example, by polymerizing species in the plasma and may generally be composed of fluorine and carbon compounds. The arrangement may also serve to strip off the DC component of the RF/DC electrode by allowing only RF-coupling to the conductor. Suitable dielectric ceramic materials for fabricating the collar 130 include aluminum oxide, aluminum nitride, boron carbide, boron nitride, diamond, silicon oxide, silicon nitride, titanium oxide, titanium carbide, zirconium boride, zirconium carbide, and equivalents or mixtures thereof. Suitable polymeric materials for forming the collar 130 include polyimide, polyketone, polyetherketone, polysulfone, polycarbonate,
polystyrene, polyvinylchloride, polypropylene, polyethersulfone, polyethylene, nylon, silicone, and rubber.

During processing, the substrate 15 is transferred by a robot arm (not shown) from a load-lock transfer chamber (not shown) through a slit valve and into the process zone 35 of the process chamber 25. The substrate 15 is placed on the support 38 where it may be held by the electrostatic chuck 40. Optionally, a heat transfer gas is supplied through holes 60 in the surface of the electrostatic chuck 40 to control the temperature of the substrate 15. Optionally, cooling fluid may be circulated through the base 80 to control the temperature of the base 80 and/or the support 38. Thereafter, the process conditions in the process chamber 25 are set to process a particular layer or layers on the substrate 15 or to perform other chamber processes, the process conditions comprising one or more of process gas composition and flow rates, power levels of gas energizers 75, gas pressure, and substrate temperature. The process can also be performed in multiple stages, for example, each stage having different process conditions. For example, in an etching process, one or more compositions of an energized process gas comprising etchant gas for etching the substrate 15 are provided in the process chamber 25. Suitable etchant gases for etching layers on the substrate 30, include for example, HCl, BCl3, HBr, Br2, Cl2, CCl4, SiCl4, SF6, F2, NF3, HF, CF3, CF4, CH3F, CHF3, C2H2F2, C2H6F8, C2F6, C3F8, C4F8, C2HF8, C4F10, CF2Cl2, CFCl3, O2, N2, He, and mixtures thereof. The process chamber 25 is typically maintained at a pressure ranging from about 0.1 to about 400 mTorr. The etchant gas composition is selected to provide high etch rates and/or high etching selectivity ratios for etching the overlayer relative to the underlayer. When multiple layers are being sequentially etched, first, second and third etchant gas compositions can be sequentially introduced into the process chamber 25 to etch each particular layer. Alternatively or in addition, other processes, such as plasma enhanced chemical vapor deposition (CVD), ion implantation, substrate cleaning, chamber cleaning or the like may be performed in the process chamber 25.

The process gas may be energized and maintained at first process conditions suitable for etching, for example, the substrate 15. Referring to Figure 1, an energized process gas is provided in the process zone 35 by capacitively and/or inductively coupling energy into the process zone 35 using the gas energizer 75, or by
applying microwaves to an etchant gas in a remote zone or in the chamber. By energized process gas, it is meant that the process gas is activated or energized so that one or more of dissociated species, non-dissociated species, ionic species, and/or neutral species are excited to higher energy states in which they are more chemically reactive. In one version, the process gas is energized by applying an RF bias voltage to the process electrodes or by applying an RF source current to an inductor antenna encircling the process chamber 25. The process gas ionizes in the applied electric field to form ions and neutral species that process the substrate 15 and form volatile gaseous species that are exhausted from the process chamber 25.

During the processing of a substrate 15, temperature variations in components of the support assembly 30 or the process chamber 25 can lead to inconsistently processed substrates 15. For example, it has been discovered that process drift problems can be associated with temperature variations. A process drift is related to processing rate differences from one substrate to another or across the surface of a substrate. The temperatures of components in the process chamber may vary during a process by 50°C to 100°C. However, due to material, geometric and location differences, the temperature variation between two or more components is typically not identical. It is desirable for these temperature variations of components to be consistent from one substrate to the next substrate in a set of substrates to provide substantially consistently processed substrates. Also due to processing conditions and chamber configurations, temperatures across a component during the processing of a substrate 15 may vary. This variation can lead to process rate differences across a substrate 15 which may lead to a damaged or insufficiently processed substrate 15.

One process drift problem may occur when processing a set of substrates 15 in a process chamber 25 comprising a temperature controlled support 38 and a collar 130 that is not temperature controlled. The temperature of the non-controlled collar 130 is dependent on the process conditions and its initial temperature. Since the initial temperature of the support 38 is controlled but the initial temperature of the collar is not, the temperature variations between the different components may not be consistent from one substrate 15 to the next. Such initial temperature variations can result in process drift. During a typical process, due
to the ion bombardment from the energized gas or from other sources, the
temperature of the collar 130 may rise more than 100°C, and in some cases more
than 300°C or 400°C. Before the first substrate 15 in a set of substrates is
processed, the collar 130 rests at an initial temperature, \( T_i \). As the first substrate 15
is processed, the collar’s temperature is elevated to a first processing temperature
\( T_{p\text{li}} \), which may vary with time. After the process is completed, the first substrate is
removed from the chamber and a second substrate is provided. During the transfer
period, the collar 130 temperature drops to a second substrate initial temperature, \( T_{i\text{r}} \),
which is between the first substrate initial temperature, \( T_i \), and the first substrate
processing temperature, \( T_{p\text{li}} \). As the second substrate is processed, the collar
temperature again rises, but this time to a second processing temperature, \( T_{p\text{lii}} \), which
is higher than the first processing temperature, \( T_{p\text{li}} \). As each subsequent substrate 15
is processed, the cycle continues until a steady state initial temperature, \( T_{ssr} \), is
reached. After a certain number of substrates 15 have been processed, the collar
temperature at the beginning of processing will be the steady state temperature, \( T_{ssr} \),
and the process temperature for each substrate 15 will be approximately a steady
state processing temperature, \( T_{\text{pssr}} \). The substrates 15 processed before the steady
state temperature, \( T_{ssr} \), is reached may be inconsistently processed and of unsuitable
quality.

It has been discovered that by controlling the temperature of a typically
non-controlled component, such as a collar 130, the problem of process drift can be
reduced or even eliminated. For example, in one version of the invention, the collar
130 is heated to the steady state temperature, \( T_{ssr} \), before the first substrate 15 is
processed. In this manner, the temperature transitional period during which the initial
collar temperature previously was raised by sacrificially processing substrates is
reduced or eliminated, thereby increasing the number of suitably processed substrates
15.

Accordingly, in one version of the invention, the process chamber 25
may be provided with a heating system 135 capable of heating the collar 130 or other
component in the process chamber 25. In the version shown in Figure 1, the heating
system 135 comprises an AC or DC voltage supply 140 adapted to supply an AC or
DC voltage to the collar 130 via an electrical connector 142. The collar 130 is
adapted to pass a current therethrough when a voltage is applied to the collar. Thus, the collar 130 comprises a resistance that is sufficiently low to allow a current to pass therethrough from the application of the voltage. In one version, the collar comprises a resistance of less than about 10 kΩ. In addition, the collar 130 comprises a resistance that is sufficiently high that the current passing therethrough raises the temperature of the collar. In one version, the the collar 130 comprises a resistance of at least about 2 Ω.

The electrical connector 142 may comprise one or more electrical leads 145, 150 extending from the voltage supply 140. The leads 145, 150 may be embedded within the collar 130 or otherwise electrically in contact with the collar 130, or the leads 145, 150 may contact an electrical contact 152 on or within the collar 130. In one version, the electrical connection is provided through the electrical contact 152, such as a banana clip type connector. Alternatively, the leads 145, 150 may be either permanently or releaseably connected directly to or within the collar 130. The collar 130 forms a resistive element in a circuit comprising the voltage supply 140, the leads 145, 150 and the collar 130. Due to the resistivity of the collar 130, electrical energy is converted to thermal energy in the current carrying medium of the collar 130.

The collar 130, in one version, may comprise semiconducting material having intrinsic resistance and conductive properties suitable for heating the collar 130. Suitable semiconducting ceramic materials for fabricating the collar 130 include for example, doped ceramic materials, such as mixtures of the ceramic materials described herein, such as aluminum oxide and titanium oxide, or aluminum nitride and other conduction additives, as well as silicon, silicon carbide and silicon nitride. Typically, the conduction enhancing additives form interstitial or grain boundary conducting species in the crystal structure of the ceramic that provide enhanced conduction. The semiconducting material may be a material having chemical compatibility in an energized gas environment. For example, the collar 130 may comprise a material, such as silicon, which produces similar species of gaseous byproducts in the energized gas environment as a silicon substrate and thereby may limit or reduce contamination of the substrate. Alternatively or additionally, the collar 130 may comprise a material, such as silicon carbide, which is relatively non-reactive
in an energized gas environment. The collar ring may, in one version, comprise semiconducting material comprising a resistivity of about $10^{-3} \Omega \text{ cm}$ to about $10^3 \Omega \text{ cm}$, and more preferably from about $10^2 \Omega \text{ cm}$ to about $10^2 \Omega \text{ cm}$. For example, a collar 130 comprising one or more of silicon, silicon carbide, boron carbide, or the like, has been shown to be resistively heatable with a relatively low voltage being supplied thereto. The semiconducting material may have a resistance of from about 2 $\Omega$ to about 10 k$\Omega$, more preferably from about 50 $\Omega$ to about 100 $\Omega$, and most preferably about 100 $\Omega$ to about 200 $\Omega$. By supplying a voltage from the power supply 140, which may be for example from about 24 volts to about 1000 volts, the collar 130 can be heated to a desired temperature, or the temperature may be otherwise controlled as discussed below.

In one version, the collar may be heated to a desired temperature, such as the steady state temperature, $T_{ss}$, prior to processing a substrate 15 or a set of substrates. In the process chamber 25 shown in Figure 1, it has been determined that a suitable steady state temperature, $T_{ss}$, when etching, for example, a dielectric layer on a substrate 15 is at least about 80°C, more preferably from about 100°C to about 300°C, and most preferably about 200°C. The leads 145, 150 may be oppositely situated in or on the collar 130 as shown in Figure 2a to provide a parallel resistor 155 arrangement as diagrammatically shown in Figure 2b. With this configuration, the voltage supply 140 may provide a voltage of about 200 volts to a collar having a resistance of about 150 $\Omega$ for a period of about 300 seconds to heat the collar 130 from room temperature to the steady state temperature, $T_{ss}$.

Alternatively, as shown in Figures 3a and 3b, the collar 130 may comprise one or more resistors which effectively form a series resistor 160 by electrically separating the leads 145, 150, for example by providing a slot 165 in the collar 130. Any other circuit arrangement that allows for resistive heating of the collar 130 may alternatively be provided.

By preheating the collar 130, a set of substrates can be processed without the need to sacrificeilly process initial substrates, thereby adding as many as 25 substrates 15 to the throughput of the processing of the set. This amounts to a significant savings in time and materials. In addition, the preheating eliminates a step of determining at what point acceptable processing conditions have been reached,
further improving process throughput and lowering operational costs. Additionally, resistive heating has several advantages over radiant or other types of heating. For example, the desired component can be heated without significantly affecting the temperature of surrounding components, which minimizes the impact on the processing of a substrate.

In one version, the slot 165 shown in Figure 3a, may also serve to compensate for relative thermal expansion between the collar 130 and the support 38 or other component in the chamber 25. Due to differences in material and/or geometries, the heating of the support assembly 30 can result in varying thermal expansions of components in the support assembly 30. In addition to varying relative thermal expansions, the components can be heated to different temperatures. The effect of temperature on the support assembly 30 may cause erosion of the support and inconsistent generation of electrostatic chucking forces. For example, when the collar 130 is used as a guard preventing erosive gas from penetrating to the support 38, the collar 130 may relatively expand more or less than the support 38, for example more or less than the dielectric 45, thereby creating or widening gaps through which erosive gases may pass. To reduce or compensate for the effects of thermal expansion on the performance of the support assembly 30, the collar 130 may comprise a thermal expansion compensation slot 165. The slot 165 provides a gap for expansion of the collar 130 when it is heated. The slot 165 allows the collar to thermally expand into the gap, and thereby reducing radial and height expansion of the collar 130 by taking in or absorbing thermally induced dimensional change into the gap. Thus, the thermal expansion slot 165 may comprise a gap that is sized larger than a net dimensional change that would occur when the collar 130 is increased from a low temperature to a substrate processing temperature or vice versa. Thus, when the collar 130 expands at a higher rate than the dielectric 45, there is little or no creation or enlargening of gaps. As a result, the collar 130 may serve to protect the dielectric 45 throughout high temperature or varying temperature processes. In addition, when the collar 130 expands at a lower rate than the dielectric 45 the slot 165 reduces the internal stresses in the collar 130 by allowing the opposing sides of the slot 165 to spread apart when forced apart by an expanding member within the collar 130. The slot 165 may, of course, take different forms than the one shown in
Figure 3a. For example, the slot 165 may be angled or tilted, or a plurality of slots 165, or partial slots, may be provided.

The collar 130, in one version, may comprise a collar ring 200 in combination with other rings or members, as shown in Figure 4, such as a second ring 210. The collar 130, in this version, may serve as a shield often termed a "process kit." The process kit surrounds the chuck 40 and is generally comprised of dielectric material. The shield may also serve to channel energy through the chuck 40 to focus the energy on the substrate 15, to preferentially direct a plasma 35 toward the substrate 15, to allow RF power to be capacitively coupled therethrough to a plasma 35 to present an extended plasma sheath to the substrate 15, or may serve other purposes in the support assembly 30 as discussed above. In one version, the collar ring 200 may comprise one or more semiconducting materials and the leads 145, 150 may be attached thereto. Alternatively, one of the other components, such as second ring 210 may be heated, or a plurality of components may be heated.

In another version, as shown in Figure 5, the collar 130 at least partially rests on a shoulder 215 of the dielectric 45. In the version shown, the collar ring 200 is positioned on or near the shoulder 215. This version may provide an improved seal for protecting the dielectric 45. In this version, the collar 130 comprises a collar ring 200, for example a silicon ring, a second ring 220, for example a quartz ring, and a third ring 230, for example a quartz or silicon ring. The second ring may be a shadow ring which serves as a dielectric between an RF energized support 38 and a plasma. The third ring 230 may be a cover ring which serves to enhance the process and/or to reduce the erosion of an underlying ring, such as shadow ring 220. A voltage may be supplied to any one or more of the rings in the collar 130. In the version shown in Figure 5, the voltage is applied to the cover ring 230, such as a silicon cover ring, which often has a thermal mass larger than that of the collar ring 200. The support may further comprise a bulkhead 240, one or more quartz pipes 245, and centering bumpers 247.

In the versions shown in Figure 4 and 5, any one or more of the components of the collar 130 may be provided with a slot 165 as discussed above. In one version, the collar ring 200 comprises one or more slots 165 and serves as a
clamping ring. The slot 165 in collar ring 200 provides thermal expansion compensation sufficient to allow the collar ring 200 to be fit into the shoulder 215 to very close height tolerances, thereby further improving the protecting ability of the collar 130.

In one version, the collar 130 may comprise one or more materials having coefficients of thermal expansion (CTE) within about ±20% of the CTE of that of the electrostatic chuck 40. For example, when the dielectric 45 comprises a ceramic, such as aluminum oxide or aluminum nitride, the collar 130 may comprise a material having a coefficient of thermal expansion of from about 8 to about 9 ppm/°C, such as boron carbide, to provide a suitable level of CTE matching between the collar 130 and the chuck 40.

The heating system 135 may heat the collar 130 to the steady state temperature, $T_{ss}$, and then be shut off, or the heating system may be used to control the temperature of the collar 130 throughout or during a portion of the processing of a set of substrates. A version of a control system that may be used to control and/or monitor the temperature of the collar 130 during the initial preheat and/or during processing is shown in Figure 6. In this version, the heating system 135 comprises a control and monitoring system 250 including a controller 260 operable to control the heating of the collar 130 for example by adjusting the voltage applied to the collar 130 by the voltage supply 140. In addition, one or more thermometers, 270, may be positioned in, near, or in communication with the collar 130. In the version shown in Figure 6, the thermometer 270 is positioned substantially at the midpoint between the leads 145, 150 so as to approximate the average temperature of the collar 130. A signal in relation to the temperature of the collar 130 is supplied to a temperature monitor 280, which may be within the controller 260. The temperature monitor supplies the temperature information to the controller 260 which then may generate a control signal in response to the temperature information. The control signal may be used to drive or control the voltage supply 140, for example. Thus, the controller 260 may control and adjust the operation of the heating system 135 in accordance with the monitored data. The thermometer 270 may be a conventional thermistor positioned within or near the collar 130 or a similar temperature measuring probe. Alternatively, the thermometer may be an optical pyrometer or a fluoro-optical probe.
The controller 260 may comprise a computer readable medium having computer readable program code embodied therein that monitors the output signal(s) from the temperature monitor 280 and performs at least one of the following steps: (i) terminates the heating process once a predetermined temperature, such as the steady state temperature, $T_{ss}$, has been reached; (ii) adjusts the voltage supplied to the collar 130; (iii) controls the temperature of the collar 130 by causing a secondary source (not shown) to heat or cool the collar 130; (iv) adjusts process conditions in the process chamber 25; (v) terminates a process in the process chamber 25; (vi) provides an alarm signal to notify an operator of undesired collar temperatures; or (vii) maintain an application of a voltage to the collar 130. The controller 260 may control the operation of the voltage supply 140 or may also operate the process chamber 25. The controller 260 may comprise a computer program code product that controls a computer comprising one or more central processor units (CPUs) interconnected to a memory system with peripheral control components, such as for example, a PENTIUM microprocessor, commercially available from Intel Corporation, Santa Clara, California. The CPUs of the controller 260 can also comprise ASIC (application specific integrated circuits) that operate a particular component of the chamber 25. An interface between an operator and the controller 260 may be provided and may be, for example, a CRT monitor and a light with a light sensor in the tip of the pen (not shown). To select a particular screen or function, the operator touches a designated area of the CRT monitor and pushes a button on the pen. The area touched changes its color or a new menu or screen is displayed to confirm the communication between the light pen and the CRT monitor. Other devices, such as a keyboard, mouse or pointing communication device can also be used to communicate with the controller 260.

The computer program code operating the CPU(s) and other devices of the computer can be written in any conventional computer readable programming language, such as for example, assembly language, C, C++, or Pascal. Suitable program code is entered into a single file, or multiple files, using a conventional text editor and stored or embodied in a computer-usable medium, such as a memory system of the computer. If the entered code text is in a high level language, the code is compiled to a compiler code which is linked with an object code of precompiled library routines. To execute the linked and compiled object code, the system user
invokes the object code, causing the computer to load the code in memory to perform the tasks identified in the computer program. Any suitable computer operating system may be provided, such as for example, Windows (TM) operating system by Microsoft Corporation or Linux operating systems.

In one version, the control and monitoring system 250 may monitor the temperature of the collar 130 and provide an output signal, or a control signal, that is triggered when the temperature exceeds or falls below a predetermined level. For example, when the temperature of the collar 130 falls below a preset and operator input range of acceptable temperatures, the controller 260 can generate a signal that causes the voltage supply 140 to increase the voltage supplied to the collar 130 to raise the temperature of the collar 130. Conversely, when the temperature exceeds the acceptable range of temperatures, the controller 260 can cause the voltage supply 140 to lower the applied voltage supplied to the collar 130. The control and monitoring system can continuously or periodically sample the temperature of the collar 130 and continuously or periodically adjust the applied voltage correspondingly.

In one exemplary version for controlling operation of the support 38, an acceptable range of temperatures is from about 100°C to about 350°C, and more preferably from about 200°C to about 250°C. The voltage supply initially provides about 208 volts and is adjusted in increments of about 5 volts. The controller 260 may compare monitored data to a "look-up" table in a continuous feedback loop. In one version, the control and monitoring system 250 may be used throughout the processing of a substrate 15 or a set of substrates. In another version, the control and monitoring system 250 may be engaged when each substrate 15 from a set is placed on the support 38 in the chamber 25 to assure that the collar 130 is at the steady state temperature, $T_{ss}$, at the beginning of processing of each substrate 15.

In another version, such as the version shown in Figure 7, a plurality of thermometers 270 may be provided to determine the temperature of the collar 130 at spaced locations thereabout. In the version shown, four thermometers are provided to monitor the temperature at 90 degree intervals around the collar 130, although other configurations and/or more or fewer thermometers may be provided. In one version, the temperature monitor 280 averages the temperatures from the thermometers 270 and supplies the average temperature information to the controller.
260 which uses the temperature information to control the heating system 135 as discussed above.

In another version, the signals from the thermometers 270 are individually analyzed by the temperature monitor 280 or the controller 260. By separately analyzing the signals, it can be determined if a significant temperature variation exists across the collar 130. A large temperature variation can result in lack of substrate processing uniformity across the surface of the substrate 15. When one portion of the collar 130 is determined to differ more than a predetermined amount, for example about 10°C, from any other portion, the controller 260 may generate a control signal in response thereto. For example, the controller 260 may perform at least one of the following steps: (i) terminate the processing of the substrate, (ii) provide a alarm signal to notify an operator that an undesirable condition exists; (iii) adjust the temperature of the appropriate portions of the collar 130 through a secondary source (not shown); (iv) adjust the voltage supplied to the collar 130; or (v) adjust process conditions in the process chamber 25. In one version, an alarm signal is initiated when a significant temperature variation is detected indicating to an operator that inspection of the processed substrate 15 or set of substrates may be desirable. In another version, separate heating systems 135 may be provided to heat different portions of the collar 130 under the control of controller 260. When the detected temperatures are within a predetermined range relative to one another, the controller 260 may generate a control signal causing the voltage supply to continue providing substantially the same voltage to the collar 130.

In one version, the collar 130 may comprise a polymer hardening precursor piece, as disclosed in U.S. Patent 5,990,017 to Collins et al, which is incorporated herein by reference in its entirety. In this version, it is desirable to heat the collar 130 above a polymerization temperature to achieve a desired increase in oxide-to-silicon etch selectivity. The heating system 135 and/or the control and monitoring system 250 is effective in heating or controlling the temperature of the collar 130 to provide high oxide-to-silicon etch selectivity during the processing of a substrate and consistently processed substrates. The collar 130 serving as a polymer hardening precursor may be heated to an initial temperature and/or the temperature may be controlled throughout processing. In one version, a silicon collar 130 is
maintained at a temperature of from about 180°C to about 220°C. However, the temperature range varies greatly with the processing conditions.

The heating system 135 may alternatively or additionally be used to heat or control the temperature of other components in the process chamber 25. For example, a component within the support, a gas distributor 95 or a chamber wall that is in thermal proximity of a substrate 15 may affect the processing of the substrate 15 when it is not temperature controlled. Thus, it may be desirable to provide a heating system 135 and/or a control and monitoring system 250 with any component in a support 38 or with a gas distributor 95 or chamber wall, for example.

While the present invention has been described in considerable detail with reference to certain preferred versions, many other versions should be apparent to those of ordinary skill in the art. For example, the support, collar or other component may be used in other process chambers. It is to be further understood that the collar or other component may be any suitable shape or size and in not necessarily of a circular cross-section as shown in the drawings. For example, the collar member can be oval, square, rectangular, polygonal or any other shape. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained herein.
What is claimed is:

1. A substrate support assembly comprising:
   a support comprising a surface adapted to support a substrate
   and
   a collar comprising an electrical connector,
   whereby a voltage may be applied to the collar through the electrical connector.

2. A support assembly according to claim 1 wherein the collar comprises a resistance that is sufficiently low to allow a current to pass therethrough from the application of the voltage.

3. A support assembly according to claim 2 wherein the collar comprises a resistance of less than about 10 kΩ.

4. A support assembly according to claim 2 wherein the collar comprises a resistance that is sufficiently high that the current passing therethrough raises the temperature of the collar.

5. A support assembly according to claim 4 wherein the collar comprises a resistance of at least about 2 Ω.

6. A support assembly according to claim 1 further comprising a voltage supply adapted to provide a voltage to the collar.

7. A support assembly according to claim 1 wherein the electrical connector comprises one or more of (i) a lead extending from the collar, and (ii) an electrical contact that may be connected to the collar.

8. A support assembly according to claim 1 wherein the collar comprises a semiconducting material.
9. A support assembly according to claim 8 wherein the collar comprises one or more of silicon, silicon carbide, and boron carbide.

10. A support assembly according to claim 8 wherein the collar comprises a dopant.

11. A support assembly according to claim 1 wherein the support comprises an electrode at least partially covered by a dielectric.

12. A support assembly according to claim 1 wherein the collar comprises a dielectric material.

13. A support assembly according to claim 12 wherein the dielectric material comprises a ceramic.

14. A support assembly according to claim 1 wherein the collar comprises a circular portion.

15. A support assembly according to claim 1 comprising a slot in the collar.

16. A support assembly according to claim 1 wherein the collar comprises a surface that is adapted to couple with the support to reduce a gas flow therebetween.

17. A support assembly according to claim 1 wherein the collar is adapted to direct energized gas toward the substrate on the support.

18. A support assembly according to claim 1 wherein the collar comprises a material capable of providing species that can form passivating deposits on a substrate on the support.
19. A substrate processing chamber comprising:
   a support adapted to support a substrate;
   a gas distributor;
   a gas energizer;
   a gas exhaust;
   a semiconducting component; and
   a voltage supply adapted to supply a voltage to the
   semiconducting component,
   whereby a substrate on the support may be processed by gas introduced
   through the gas distributor, energized by the gas energizer and exhausted by the gas
   exhaust.
20. A substrate processing chamber according to claim 19 wherein
   the support comprises an electrode and a dielectric at least partially covering the
   electrode.
21. A substrate processing chamber according to claim 19 wherein
   the semiconducting component is adapted to pass a current therethrough and wherein
   the resistance of the semiconducting component is sufficiently high to heat the
   semiconducting component as the current passes therethrough.
22. A substrate processing chamber according to claim 19 wherein
   the semiconducting component is adapted to pass a current therethrough and wherein
   the voltage supply is adapted to supply a voltage sufficiently high to heat the
   semiconducting component to a predetermined temperature.
23. A substrate processing chamber according to claim 19 wherein
   the semiconducting component is a collar about the support.
24. A substrate processing chamber according to claim 19 further
   comprising one or more temperature detectors adapted to detect a temperature of the
   semiconducting component.
25. A substrate processing chamber according to claim 24 further comprising a controller responsive to the detected temperature.

26. A substrate processing chamber according to claim 25 wherein the controller is adapted generate a control signal to perform at least one of the following steps: (i) terminate the application of a voltage to the semiconducting component once a predetermined temperature has been reached; (ii) adjust the voltage supplied to the semiconducting component; (iii) control the temperature of the semiconducting component; (iv) adjust process conditions in the processing chamber, (v) terminate a process in the processing chamber; (vi) provide an alarm signal; or (vii) maintain an application of a voltage to the semiconducting component.

27. A substrate processing chamber according to claim 19 further comprising a plurality of temperature detectors adapted to detect temperatures at different portions of the semiconducting component and a controller responsive to the detected temperatures.

28. A substrate processing chamber according to claim 27 further comprising a controller responsive to the detected temperatures.

29. A substrate processing chamber according to claim 28 wherein the controller is adapted generate a control signal to perform at least one of the following steps: (i) terminate a process in the processing chamber, (ii) provide a alarm signal; (iii) adjust the temperature of portions of the semiconducting component; (iv) adjust the voltage supplied to the semiconducting component; (v) adjust process conditions in the processing chamber; or (vi) maintain an application of a voltage to the semiconducting component.

30. A substrate support heater comprising:
   a collar and
   a voltage supply adapted to supply a voltage to the collar to heat the collar.
31. A substrate support heater according to claim 30 wherein the collar is adapted to pass a current therethrough and wherein the resistance of the collar is sufficiently high to heat the collar as the current passes therethrough.

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32. A substrate support heater according to claim 30 wherein the collar comprises a resistance of from about 2 Ω to about 10 kΩ.

33. A substrate support heater according to claim 32 wherein the collar comprises a semiconducting material.

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34. A substrate support heater according to claim 33 wherein the collar comprises one or more of silicon, silicon carbide and boron carbide.

35. A substrate support heater according to claim 30 further comprising one or more temperature detectors adapted to detect a temperature of the collar.

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36. A substrate support heater according to claim 35 further comprising a controller adapted to control the voltage supplied to the collar in response to the detected temperature.

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37. A method of supporting a substrate in a process chamber and processing the substrate in the process chamber, the method comprising:

supporting the substrate on a support in the process chamber;

supplying a voltage to a collar about the support; and

providing an energized process gas in the process chamber.

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38. A method according to claim 37 wherein the collar comprises semiconducting material.

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39. A method according to claim 37 further comprising controlling the temperature of the collar.
40. A method according to claim 37 further comprising detecting a temperature of the collar.

41. A method according to claim 40 further comprising controlling the temperature of the collar in response to the detected temperature.

42. A method of supporting a substrate in a process chamber and processing the substrate in the process chamber, the method comprising:
supporting the substrate on a support in the process chamber;
supplying a voltage to a semiconducting component in the process chamber to heat the component; and
providing an energized process gas in the process chamber.

43. A method according to claim 42 comprising providing a collar at least partially around the support and wherein the voltage is supplied to the collar.

44. A method according to claim 42 further comprising controlling the temperature of the component.

45. A method according to claim 42 further comprising detecting a temperature of the component.

46. A method according to claim 45 further comprising controlling the temperature of the component in response to the detected temperature.

47. A method of supporting a substrate in a process chamber and processing the substrate in the process chamber, the method comprising:
providing a support and a collar;
heating the collar;
and
introducing an energized process gas into the process chamber.
48. A method according to claim 47 comprising supplying a voltage to the collar to heat the collar.

49. A method according to claim 47 comprising heating the collar to a temperature of at least about 80°C.

50. A method according to claim 47 further comprising detecting a temperature of the collar.

51. A method according to claim 50 comprising terminating heating of the collar when a predetermined temperature has been reached.

52. A method according to claim 47 further comprising heating the collar after supporting the substrate on the support.

53. A method according to claim 52 further comprising maintaining the temperature of the collar within a predetermined temperature range during the processing of the substrate.

54. A method according to claim 53 wherein the temperature range is from about 100°C to about 350°C.

55. A method of fabricating a substrate support, the method comprising:

forming a collar at least partially around a substrate support and forming an electrical connector within or in contact with the collar.

56. A method according to claim 55 further comprising providing a voltage supply in electrical contact with the electrical connector.