Edge Ring with Conductive Contact Interface

BACKGROUND OF THE INVENTION

[0001] Substrate processing systems perform treatments on substrates such as semiconductor wafers. Examples of substrate treatments include deposition, ashing, etching, cleaning, and/or other processes. Process gas mixtures may be supplied to the processing chamber to treat the substrate. Plasma may be used to ignite the gases to enhance chemical reactions.

[0002] The substrate is arranged on a substrate support during treatment. An edge ring that includes an annular body is arranged around and adjacent to a radially outer edge of the substrate. The edge ring may be used to shape or focus the plasma onto the substrate.

SUMMARY OF THE INVENTION

[0003] Embodiments of the disclosure are drawn to apparatus, systems, and methods for an edge ring with a conductive contact interface.

[0004] In some embodiments, an edge ring system for use in a process chamber is provided, including: a middle ring including an outer ring portion and an inner ring portion, and a plurality of bridges connecting the inner ring portion to the outer ring portion, such that a plurality of gaps are defined between the plurality of bridges; an edge ring configured to be supported on the middle ring between the outer ring portion and the inner ring portion during transfer of the middle ring and the edge ring into or out of the process chamber; a moving ring configured to be raised and lowered relative to the middle ring, wherein the moving ring is configured to form a conductive contact with a lower surface of the edge ring through the plurality of gaps.

[0005] In some embodiments, the conductive contact between the moving ring and the lower surface of the edge ring enables the moving ring and the edge ring to be substantially equipotential during processing of a substrate in the process chamber.

[0006] In some embodiments, the edge ring is defined from a substantially conductive material.

[0007] In some embodiments, the lower surface of the edge ring is defined by a coating of a substantially conductive material.

[0008] In some embodiments, the moving ring is defined from a substantially conductive material.

[0009] In some embodiments, an upper surface of the moving ring is defined by a coating of a substantially conductive material.

[0010] In some embodiments, the moving ring includes a plurality of conductive pins embedded therein, the conductive pins are configured to form said conductive contact with the lower surface of the edge ring.

[0011] In some embodiments, upper portions of the conductive pins are configured to protrude from an upper surface of the moving ring.

[0012] In some embodiments, raising and lowering the moving ring is configured to selectively raise and lower the edge ring, respectively.

[0013] In some embodiments, the moving ring includes raised portions that extend upward through the plurality of gaps to form the conductive contact with the lower surface of the edge ring.

[0014] In some embodiments, the conductive contact is configured to have an impedance of less than about 1 Ohm.

[0015] In some embodiments, the conductive contact enables coupling of RF power to an edge region of the process chamber, reducing non-vertical tilting of ions during plasma processing in the process chamber.

[0016] In some embodiments, an edge ring system for use in a process chamber is provided, including: a middle ring including an outer ring portion and an inner ring portion, and a plurality of bridges connecting the inner ring portion to the outer ring portion, such that a plurality of gaps are defined between the plurality of bridges; an edge ring configured to be supported on the middle ring between the outer ring portion and the inner ring portion during transfer of the middle ring and the edge ring into or out of the process chamber, wherein the edge ring is defined from a substantially conductive material; a moving ring configured to be raised and lowered relative to the middle ring, wherein the moving ring is configured to form a conductive contact with a lower surface of the edge ring through the plurality of gaps, wherein an upper surface of the moving ring is defined by a coating of a substantially conductive material.

[0017] In some embodiments, an edge ring system for use in a process chamber is provided, including: a middle ring including an outer ring portion and an inner ring portion, and a plurality of bridges connecting the inner ring portion to the outer ring portion, such that a plurality of gaps are defined between the plurality of bridges; an edge ring configured to be supported on the middle ring between the outer ring portion and the inner ring portion during transfer of the middle ring and the edge ring into or out of the process chamber, wherein the edge ring is defined from a substantially conductive material; a moving ring configured to be raised and lowered relative to the middle ring, wherein the moving ring is configured to form a conductive contact with a lower

surface of the edge ring through the plurality of gaps, wherein the moving ring includes a plurality of conductive pins embedded therein, the conductive pins are configured to form said conductive contact with the lower surface of the edge ring.

[0018] 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.

BRIEF DESCRIPTION OF DRAWINGS

[0019] FIG. 1 is a functional block diagram of an example substrate processing system including a self-centering edge ring according to the present disclosure.

[0020] FIGS. 2A and 2B are cross-sectional views of an example edge ring system with an edge ring and a middle ring in a raised position according to the present disclosure.

[0021] FIG. 2C is a cross-sectional view of the edge ring system of FIGS. 2A and 2B with the edge ring in a raised position and the middle ring in a lowered position according to the present disclosure.

[0022] FIG. 2D is an isometric view of the middle ring of FIGS. 2A, 2B, and 2C.

[0023] FIG. 2E is a plan view of the middle ring of FIGS. 2A, 2B, 2C, and 2D.

[0024] FIG. 2F is a plan view of the moving ring of FIGS. 2A, 2B, and 2C.

[0025] FIG. 3A provides cross-sections of a capacitive contact interface between the edge ring and moving ring, in accordance with an existing embodiment for edge tilt correction.

[0026] FIG. 3B is a cross-section of an embodiment of the moving ring and the edge ring having a conductive contact, in accordance with embodiments of the disclosure.

[0027] FIG. 4A is a cross-section of a top edge ring and moving ring defined from low resistance bulk materials, in accordance with embodiments of the disclosure.

[0028] FIG. 4B is a cross-section of a top edge ring and moving ring having conductive coatings to form a low-resistive contact, in accordance with embodiments of the disclosure.

[0029] FIG. 4C is a cross-section of a moving ring and edge ring having conductive coatings, in accordance with embodiments of the disclosure.

[0030] FIG. 4D is a view of a surface of a ring having a plurality of contact pads disposed thereon, in accordance with embodiments of the disclosure.

[0031] FIG. 5A is a cross-section of an edge ring and moving ring, with the moving ring having a conductive pin, in accordance with embodiments of the disclosure.

[0032] FIG. 5B is a cross-section of a moving ring and edge ring, in accordance with embodiments of the disclosure.

[0033] FIG. 5C is a cross-section of a moving ring and edge ring, in accordance with embodiments of the disclosure.

[0034] FIG. 6 is a cross-section of a moving ring having a contact structure defined therein, in accordance with embodiments of the disclosure.

[0035] FIG. 7A is a cross-section of an edge ring and moving ring with an engineered contact using a drop-down pin, in accordance with embodiments of the disclosure.

[0036] FIG. 7B is a cross-section of an edge ring and moving ring with an engineered contact using a drop-down pin, in accordance with embodiments of the disclosure.

[0037] FIG. 8A is a cross-section of a top portion of a moving ring having a hyperstatic conductive structure, in accordance with embodiments of the disclosure.

[0038] FIG. 8B illustrates a tubular conductive structure used to effect direct coupling electrical contact between a moving ring and edge ring, in accordance with embodiments of the disclosure.

DETAILED DESCRIPTION OF THE INVENTION

[0039] In the manufacture of modern semiconductor devices such as 3D NAND memory, high aspect ratio structures such as tubes/holes and channels are etched in a substrate (e.g. wafer) in a plasma process chamber. However, non-uniformity of the plasma sheath from the center to the edge of the process region causes ions at the edge to be driven at a non-vertical angle, resulting in tilting of the etched structures at the edge region of the substrate. This ultimately reduces the yield of a given substrate, as the structures at the edge may become unusable.

[0040] To counteract this, an existing system of adjustable RF-coupled rings can be implemented as described herein. More specifically, an edge ring surrounding the chuck can be positioned and configured to couple RF power at the edge so as to offset the sheath nonuniformity, effecting flattening of the sheath at the edge and reducing non-vertical tilting of etched structures at the edge. However, the existing capacitively coupled design suffers from significant part-to-part variability, as contact impedance variability between a moving ring and top edge ring cause variability when changing from one edge ring to another. Even with moving ring compensation, results from different chambers are not consistent.

[0041] During substrate processing, a substrate is arranged on a pedestal such as an electrostatic chuck (ESC), process gases are supplied, and plasma is struck in the processing chamber. In some examples, an edge ring is arranged around a radially outer edge of the substrate to shape the plasma. During operation, the substrate and an exposed surface of the edge ring are etched by the

plasma. As a result, the edge ring wears and the effect of the edge ring on the plasma changes, which may adversely affect uniformity. For example, due to wear, the exposed surface of the edge ring may have a different height relative to the substrate. Therefore, in some substrate processing systems, the worn edge ring is replaced periodically.

[0042] In some embodiments, the edge ring may correspond to a top edge ring in an edge ring system or assembly that further includes a bottom ring and/or a middle ring. For example, the edge ring may be supported on a middle ring or bottom ring. In some embodiments, the edge ring is configured to be transferred into and out of the processing chamber through a same opening (e.g., a slot valve) as substrates. This approach reduces chamber down time by eliminating vacuum break and potential sources of contamination. In systems that include a middle ring, the edge ring may be transferred (e.g., under vacuum, using a transfer robot) together with the middle ring and/or placed onto the middle ring within the processing chamber.

[0043] Referring now to FIG. 1, an example of a substrate processing system 100 that performs plasma processing and that includes a replaceable edge ring system according to certain embodiments of the present disclosure is shown. The substrate processing system 100 includes a coil driving circuit 104. In some examples, the coil driving circuit 104 includes an RF source 108, a pulsing circuit 112, and a tuning circuit 114. The pulsing circuit 112 controls a TCP envelope of the RF signal and varies a duty cycle of the TCP envelope (e.g., between 1% and 99%) during operation. As can be appreciated, the pulsing circuit 112 and the RF source 108 can be combined or separate.

[0044] The tuning circuit 114 may be directly connected to one or more inductive coils 116. The tuning circuit 114 tunes an output of the RF source 108 to a desired frequency and/or a desired phase, matches an impedance of the inductive coils 116 and/or splits power between the inductive coils 116. While examples including multiple coils are shown, a single coil including a single conductor or multiple conductors can be used.

[0045] A dielectric window 120 is arranged along one side of a processing chamber 122. The processing chamber 122 further comprises a substrate support (or pedestal) 124 to support a substrate 128. The substrate support 124 may include an electrostatic chuck (ESC), a mechanical chuck or other type of chuck. Process gas is supplied to the processing chamber 122 and plasma 132 is generated inside of the processing chamber 122. An RF bias drive circuit 136 may be used to supply an RF bias to the substrate support 124 during operation to control ion energy. The RF bias drive circuit 136 may include an RF source and an impedance matching circuit (not shown).

[0046] In some embodiments, a plenum 140 is arranged adjacent to (e.g., above, as shown) the dielectric window 120. A gas delivery system 144 may be used to deliver gas from a gas source 146

via a valve 148 to the plenum 140. The gas may include cooling gas (air) that is used to cool the inductive coils 116 and the dielectric window 120.

[0047] A gas delivery system 156 may be used to supply a process gas mixture to the processing chamber 122. The gas delivery system 156 may include gas sources 158 (e.g., precursor, vapor, one or more other gases, inert gases), a gas metering system 160 such as valves and mass flow controllers, and a manifold 162. A gas injector (not shown) may be arranged at a center of the dielectric window 120 (or other location) and is used to inject gas mixtures from the gas delivery system 156 into the processing chamber 122.

[0048] A heater/cooler 164 may be used to heat/cool the substrate support 124 to a predetermined temperature. An exhaust system 166 includes a valve 168 and pump 170 to control pressure in the processing chamber 122 and/or to remove reactants from the processing chamber 122 by purging or evacuation.

[0049] A system controller 172 may be used to control the process. The system controller 172 monitors system parameters and controls delivery of the gas mixtures, striking, maintaining and extinguishing the plasma, removal of reactants, supply of cooling gas, etc.

[0050] The substrate support 124 may include an edge ring assembly or system including a top edge ring 174. As shown, the top edge ring 174 is arranged above a middle ring 176 and a bottom ring 178. As described below in more detail, an outer diameter of a lower surface of the top edge ring 174 may have a chamfer that contacts the middle ring 176 during transfer. Correspondingly, an upper surface on the middle ring may have a chamfer that contacts the chamfer of the edge ring during transfer. The chamfered surfaces maintain the concentricity of the top edge ring 174 relative to the middle ring 176 during transfer and placement.

[0051] For example, the system controller 172 controls a robot 180 to deliver substrates and/or edge rings to the processing chamber 122. The system controller 172 also controls one or more actuators 182 that move lift pins (not shown in FIG. 1) to selectively raise and lower the top edge ring 174 and/or the middle ring 176 to facilitate transfer of the top edge ring 174 to and from the substrate support 124. When the top edge ring 174 and middle ring 176 are lowered onto the substrate support 124, the top edge ring 174 may be supported on the bottom ring 178 and does not contact the middle ring 176. In other words, lowering the top edge ring 174 and the middle ring 176 causes the bottom ring 178 to contact the top edge ring 174 and separate the top edge ring 174 from the middle ring 176. Although shown as a single ring, in some embodiments the bottom ring 178 may include two or more concentric rings, such as an outer bottom ring (e.g., a static ring

configured to support the middle ring 176) and an inner ring (e.g., a moving or lifter ring configured to raise and lower the top edge ring 174).

[0052] The system controller 172 may also receive outputs from one or more sensors 184 that are used to sense a height of the edge rings. Non-limiting examples of sensors include optical sensors, physical sensors, piezo sensors, ultrasonic sensors, etc.

[0053] An edge ring system 200 including an edge ring 204 and a middle ring 208 is shown in cross-section in FIGS. 2A, 2B, and 2C and an isometric view of the middle ring 208 is shown in FIG. 2D. A plan view of the middle ring 208 is shown in FIG. 2E. A plan view of a moving ring 232 is shown in FIG. 2F. As shown in FIGS. 2A and 2B, the edge ring 204 is supported on the middle ring 208 during transfer (i.e., during transfer to the substrate support 124 and prior to placement on a bottom ring 212).

[0054] An outer diameter of a lower surface 216 of the edge ring 204 has a chamfer 218 (i.e., a downward and outward facing chamfered surface) that contacts and is supported on the middle ring 208 during transfer. In other words, the lower surface 216 of the edge ring 204 is conical. An inner diameter of an outer ring portion 220 of the middle ring 208 may have a complementary chamfer 222 (i.e., an upward and inward facing chamfered surface) that contacts the chamfer 218 of the edge ring 204 (i.e., at least a portion of the upper surface of the middle ring 208 may be conical). In other words, the inner diameter of the outer ring portion 220 has a chamfered corner (or a sloped surface) positioned between a top surface of the bridge 228 and the inner diameter surface of the outer ring portion 220. In some embodiments, the chamfer 222 may be larger than a corner such that the slope surface may extend from a top surface of the bridge 228 to a top surface of the outer ring portion 220. The chamfers 218 and 222 maintain the concentricity of the edge ring 204 relative to the middle ring 208 during transfer and placement.

[0055] As shown in FIGS. 2D and 2E, the middle ring 208 includes the outer ring portion 220 and an inner ring portion 224. The inner ring portion 224 is coupled to the outer ring portion 220 via a two or more bridges 228. FIG. 2A is a cross-sectional view taken at a location of one of the bridges 228. Conversely, FIG. 2B is a cross-sectional view taken at a location of one of a plurality of gaps 230 between the bridges 228. As shown, the edge ring 204 does not contact the bridges 228 during transfer.

[0056] While only two of the bridges 228 are visible in FIG. 2D, the middle ring 208 may include any number of bridges. In some embodiments, the middle ring 208 has six or more bridges 228. In some embodiments, each bridge has a width of about 8-12 mm. The width of the bridges 228 may vary with the number of bridges. As the number of bridges 228 increases, the widths of the bridges

228 may decrease and vice versa. In this manner, an overall area of the gaps 230 may be maintained at desired value. For example, during processing, the edge ring 204 is raised by and supported on a moving ring 232. In some embodiments, all of the bridges 228 have the same width (or substantially the same width). In some embodiments, a subset of bridges 228 has a different width than another subset of bridges 228. A subset of bridges may include one or more bridges.

[0057] A plan view of the moving ring 232 is shown in FIG. 2F. Raised portions 234 of the moving ring 232 extend through the gaps 230 to contact the edge ring 204. For example, an upper surface of the moving ring 232 includes a plurality of the raised portions 234 alternating with slots or grooves 236. Since FIGS. 2A-2C are cross-section views taken at a location of one of the raised portions 234 with the moving ring in a lowered position (in FIGS. 2A and 2B) and a raised position (FIG. 2C), the grooves 236 are not visible in FIGS. 2A-2C.

[0058] Accordingly, the edge ring 204 is in contact with the moving ring 232. Since the size of the gaps 230 determine a contact surface area between the edge ring 204 and the moving ring 232, the widths of the bridges 228 and the corresponding sizes of the gaps 230 can be selected to maximize contact between the edge ring 204 and the moving ring 232. In other words, as an overall area of the bridges 228 increases, an overall area of the raised portions 234 decreases and an overall contact surface area between the raised portions 234 and a bottom surface of the edge ring 204 decreases.

[0059] Conversely, as an overall area of the bridges 228 decreases, an overall area of the raised portions 234 increases and an overall contact surface area between the raised portions 234 and a bottom surface of the edge ring 204 increases. However, as an overall area (and respective widths) of the bridges 228 decreases, mechanical stability, strength, etc. of the bridges 228 decreases. Accordingly, the overall area and respective widths of the bridges 228 can be selected to maximize contact between the moving ring 232 and the edge ring 204 while also maintaining mechanical strength of the bridges 228 over a lifetime of the edge ring system 200.

[0060] In some embodiments, a contact area of the moving ring 232 (i.e., an overall area of the raised portions 234) contacts about 72-76% of the bottom surface of the edge ring 204. In some embodiments, the contact area is about 74-75% of the bottom surface of the edge ring 204. Conversely, a portion of the bottom surface of the edge ring 204 that does not contact the raised portions 234 overlaps the bridges 228. In some embodiments, about 24-28% of the edge ring 204 overlaps the bridges 228. In some embodiments, the surface area of the edge ring 204 that overlaps the bridges is about 25-26%. In these embodiments, the range ratio of the contact/overlapping area

allows sufficient bridge surface area for stable robotic transfer while maximizing the surface contact area of the bottom surface of the edge ring 204.

[0061] In some embodiments, a robot transfer module is configured to contact a portion of the bridge 228 when transferring the edge ring assembly (including the edge ring 204 and the middle ring 208). In some embodiments, the middle ring is configured with fewer bridges (less than 6 as shown in Fig. 2E, but greater than 2 bridges), so that the contact surface percentage of the moving ring 232 and the bottom surface of the edge ring 204 would increase beyond 76%. However, regardless of the number of the bridges, the bridges are designed to be mechanically stable and support the inner and outer parts of the middle ring at the end of life.

[0062] In an embodiment, one or more tabs or bump-outs 238 may extend radially outward from an outer perimeter of the moving ring 232. The bump-outs 238 are aligned with corresponding lift pins (not shown in FIGS. 2A-2F) that extend upward outside of the outer perimeter of the moving ring 232. In this manner, the lift pins raise and lower the moving ring 232, which in turn raises and lowers the edge ring 204.

[0063] As shown in FIGS. 2A-2C, the inner ring portion 224 has a generally "L"-shaped cross-section. For example, the inner ring portion 224 has a ledge 240 that extends radially outward toward the outer ring portion 220. Conversely, an inner diameter of the lower surface 216 of the edge ring 204 has a rim 242 that extends downward toward the ledge 240. During transfer, the rim 242 may contact the ledge 240. In other words, the edge ring 204 may be at least partially supported on the inner ring portion 224 during transfer. The edge ring 204 as shown is supported entirely within an inner diameter and an outer diameter of the middle ring 208. In embodiments, the edge ring 204 is partially supported on the ledge 240, the middle ring 208 (e.g., on the chamfer 222), or both the ledge 240 and the middle ring 208. In an embodiment, the edge ring 204 is supported only on the ledge 240.

[0064] In some embodiments, one or both of the chamfers 218 and 222 may be omitted. For example, the inner ring portion 224 and the rim 242 may be configured to provide centering functionality. In other words, as shown, engagement between the inner ring portion 224 and the rim 242 prevents lateral movement of the edge ring 204 relative to the middle ring 208. Further, in the raised position shown in FIG. 2C, the rim 242 extends downward below a plane defined by an upper end of the inner ring portion 224. In other words, an interface 244 between the edge ring 204 and the inner ring portion 224, the bridges 228, and the moving ring 232 defines a serpentine path. Accordingly, direct line-of-sight between a plasma volume above the edge ring system 200 and a lower surface of the rim 242, the ledge 240, the bridges 228, and an inner diameter of the

moving ring 232 is interrupted, protecting portions of the middle ring 208 and the moving ring 232 from direct exposure to the processing environment.

[0065] In embodiments, a thickness or height H1 of the edge ring 204 at an inner diameter (i.e., at a location corresponding to the rim 242) is 3.0 to 4.0 mm. In one embodiment, the height H1 is about (e.g., within +/- 5% of) 3.5 mm. A thickness or height H2 of the edge ring 204 at a location radially outward of the rim 242 is 2.0 to 2.5 mm. In one embodiment, the height H2 is about (e.g., within +/- 5% of) 2.2 mm. In one embodiment, H2 is about (e.g., within +/- 5% of) 62% of H1. A maximum thickness or height H3 of the middle ring is between 7.0 and 8.0 mm. In one embodiment, the height H3 is about (e.g., within +/- 5% of) 7.5 mm and is greater than twice H1. In one embodiment, the height H3 is about (e.g., within+/- 5% of) 210% of H1.

[0066] In some embodiments, the middle ring 208 and/or the bottom ring 212 includes one or more centering or alignment features. As shown, an annular groove 250 is defined in a lower surface of the middle ring 208 and an annular rim 252 extends upward from an upper surface of the bottom ring 212. The annular groove 250 is configured to receive the annular rim 252 when the middle ring 208 is lowered onto the bottom ring 212. The annular groove 250 and the annular rim 252 create a serpentine path between the middle ring 208 and the bottom ring 212 to interrupt direct line-of- sight. In this manner, plasma and other process materials are prevented from penetrating between the middle ring 208 and the bottom ring 212.

[0067] In some embodiments, an outer diameter of the middle ring 208 includes a projection 254 that extends radially outward from the middle ring 208. The projection 254 is configured to extend above one or more other structures of the processing chamber (e.g., an upper end of a chamber liner, not shown) to protect the structures from erosion caused by exposure to plasma.

[0068] In an embodiment, the bottom ring 212 is configured to encircle the moving ring 232, which in turn encircles an ESC (e.g., the substrate support 124). The moving ring 232 may be supported on the substrate support 124. In an embodiment, the raised portions 234 on an upper surface of the moving ring 232 are aligned with the gaps 230 between the bridges 228 of the middle ring 208. Conversely, the grooves 236 between the raised portions 234 are aligned with the bridges 228. Accordingly, when the moving ring 232 is raised, the raised portions 234 pass through the gaps 230 to contact the edge ring 204. In this manner, when centered, the edge ring 204 is supported within an inner diameter and an outer diameter of the middle ring 208 while still being moveable (i.e., configured to be raised and lowered) by the moving ring 232 located below the middle ring 208.

[0069] Further, when the edge ring 204 is in a raised position during processing (as shown in FIG. 2C), the edge ring 204 may be periodically (e.g., between processes or processing steps) re-

centered by lowering the moving ring portion 232-1 to cause the chamfer 218 to contact the chamfer 222. In some embodiments, the middle ring 208 can instead be raised to cause the chamfer 222 to contact the chamfer 218. In either example, contact between the chamfers 218 and 222 (and/or between the ledge 240 and the rim 242) force the edge ring 204 into a centered concentric position relative to the middle ring 208.

[0070] In existing systems, the moving ring has an insulating coating, such as aluminum oxide, which is resilient under plasma operating conditions in the chamber. This configuration relies upon a capacitive coupling between the moving ring and the (top) edge ring in order to couple RF power to the edge. However, there is a high degree of variability in the capacitive coupling due to the inherent variances in manufacture of the moving ring and edge ring. For example, such parts come with differences in terms of the flatness of surfaces, thicknesses of layers/coatings, tolerances, etc. As a result of the variability of the capacitive coupling, there is a high amount of variability in the edge tilt correction that is provided by the moving ring and a given edge ring in combination, both azimuthally for a given edge ring, and from one edge ring to another, and from one chamber (e.g. moving ring) to another.

[0071] In order to compensate for such variability in the existing setup, extensive calibration is required each time the edge ring is changed, and/or the moving ring is changed. In the case where the chamber is designed to be opened in order to change rings, then capacitance measurements can be taken while the chamber is open. But this necessitates downtime associated with opening and closing the chamber. In the case where the chamber is designed to remain closed when changing rings, the chamber environmental integrity can be maintained, but then it is not possible to perform direct capacitance measurements. And this then necessitates performing other tests such as performing etch tests and measuring etch rates in order to calibrate the edge ring, which is time consuming and therefore requires significant downtime. In either case, the edge tilt adjustment afforded by the edge ring and the moving ring in combination is not predictable from one ring set to another, and this results in significant downtime when changing rings due to the need to perform extensive calibration in order to determine and set the initial height of the edge ring that gives zero tilt in etched structures at the edge.

[0072] Thus, for a given edge ring and moving ring, it is possible to perform tuning experiments to determine initial height settings for the edge ring and/or moving ring, by determining precisely what height is needed to achieve zero tilt at the edge. But then when a new set of rings is introduced, the predetermined zero tilt position is no longer valid because of significant capacitance and contact impedance variability between the top edge ring and moving ring.

[0073] To address the above-mentioned problems, embodiments of the present disclosure disclose moving rings and edge rings with substantially the same voltage, so that after tuning a first set of rings for a given chamber, then when a new set of rings is brought in, it is possible to tune the new set of rings to substantially the same value. The result can be achieved using basic geometric calibration without making further adjustments. And further, a secondary benefit is that between chambers, the matching will improve.

[0074] More specifically, when initially installing a new edge ring, first the height is fine-tuned and calibrated so that the top ring is flat. Also, the center of the top edge ring is calibrated so as to enable proper placement of the wafer so that it is centered relative to the top edge ring. These two calibrations are generally performed in any new edge ring installation. However in the existing (capacitively coupled) setup, a third step of performing either a capacitance measurement with the chamber open (if possible), or determining etch rate testing with the chamber closed, is necessary in order to fine tune the ring height to achieve zero tilt at the edge. This third step is to compensate for the variability inherent in the capacitively coupled design, which can be on the order of greater than approximately 30 Ohm contact impedance variation from one edge ring to another, as the capacitance changes when the edge ring (or moving ring) is changed. This level of variation can equate to an approximate height tuning variance of plus or minus 0.2 millimeters (mm), which is quite significant and necessitates compensatory tuning as described.

[0075] However, embodiments of the present disclosure provide for a conductive coupling between the moving ring and the edge ring, which enables the moving ring and the edge ring to be substantially equipotential during operation. With this design, the impedance variability between the moving ring and the edge ring, e.g. when replacing the edge ring with a new edge ring, is on the order of about 1 Ohm or less. This level of variability obviates the need for additional tuning of the edge ring beyond the initial flatness and centering calibrations. Whereas with the capacitively coupled design it is necessary to compensate for the impedance variation when changing edge rings, this compensation is no longer necessary in the conductively coupled design of the present disclosure, as the expected tilt correction can be obtained without it. This provides a significant throughput improvement, as the additional tuning is not needed, while still maintaining the improved edge tilt performance afforded by the edge ring which improves wafer yield.

[0076] As noted above, the capacitive coupling of the top edge ring to the moving ring has a significant contact variability which results in large tilt variability of etched structures when changing rings in the chamber. This is due to significant variation in the contact gap between the contacting surfaces of the edge ring and the moving ring in the existing design.

[0077] FIG. 3A illustrates cross-sections of a capacitive contact interface between the edge ring and moving ring, in accordance with an existing configuration.

[0078] In the cross-section 300, the edge ring 204 is composed of a material such as silicon carbide (SiC); the moving ring 232 consists of an inner layer 302 of silicon (Si), and a dielectric layer 304. It will be appreciated that the dielectric layer is insulating and therefore enables a capacitive interface between the moving ring 232 and the edge ring 204. However, as shown in the magnified conceptual cross-section 310 showing the interface between the moving ring and the edge ring, the reality of the contact between the moving ring and the edge ring is that it is highly variable and unpredictable, as the imperfect flatness of the lower surface 216 of the edge ring 204 and the top surface 312 of moving ring 232 results in portions that make physical contact and other portions that form air gaps. The resulting effective air gap introduces an additional dielectric effect that must be addressed through additional tuning on an individual basis. Due to surface variations, the additional dielectric effect is unpredictable from one ring to another and thereby requires adjustment with each ring change. In fact, the extreme edge tilt angle variability performance is essentially limited by the ability to control these gaps.

[0079] It will be appreciated that this existing configuration can produce a contact impedance in the range of about 150 Ohm with a variance of plus or minus about 30 Ohm. This can result in a tilt angle variance of greater than about 300 milli-degrees, e.g. when changing edge rings.

[0080] In contrast to the capacitive contact interface, by engineering a conductive contact between the moving ring and the edge ring, then the variability resulting from this interface is greatly reduced. One of the advantages is that the time required to tune/adjust each new ring is reduced because the conductive contact can minimize the impact of unpredictable dielectric effect.

[0081] FIG. 3B is a cross-section of an embodiment of the moving ring and the edge ring having a conductive contact, in accordance with embodiments of the present disclosure.

[0082] In the illustrated embodiment, the edge ring 204 is composed of a low resistance material, such as a doped silicon carbide material. In some embodiments, the bottom surface of the edge ring 204 is coated with a protective and/or dielectric coating (e.g. a fluorinated or oxide coating). In some embodiments, an engineered conductive contact 320 is implemented to provide a direct electrical coupling between the moving ring 232 and edge ring 204. The conductive contact 320 will form a resistive contact interface between the moving ring and edge ring, so that the contact impedance is in the range of about 0.5 to 1 Ohm, or to about 0.7 Ohm in some embodiments, with a variance in the range of less than about 0.5 Ohm in some embodiments, or a variance of about 0.35 Ohm in some embodiments. The resulting tilt angle variance with such a design can be less

than about 4 milli-degrees. It will be appreciated that this represents an improvement in the extreme edge tilt angle variability performance of more than one order of magnitude with the resistive contact design as compared to that of the capacitive contact interface design previously described.

[0083] It will be appreciated that while the vast majority of power is directly coupled through the conductive contact(s) in the presently described embodiments, this does not preclude the additional capacitive coupling of some power along interfaced regions between the moving ring and edge ring that do not possess a conductive contact. However, this additional capacitive coupling of power is estimated to be much less than the power that is coupled directly through the conductive contact(s) (in some instances, could be one thousandth of the power coupled directly through the conductive contact(s)).

[0084] Several embodiments are contemplated for making the engineered conductive contact 320 between the edge ring and moving ring, as further described below.

[0085] FIG. 4A is a cross-section of a top edge ring and moving ring defined from low resistance bulk materials, in accordance with embodiments of the disclosure.

[0086] In some embodiments, in order to achieve a low-resistive contact between the edge ring 204 and the moving ring 232, the bulk material of both rings is defined from low resistance materials. For example, the edge ring 204 can be defined from a material having low resistivity and high erosion resistance in a plasma environment, such as doped SiC (e.g. nitrogen-doped), gallium nitride (GaN), silicon (Si), etc. In some embodiments, the bulk material of the edge ring 204 is chosen to have a resistivity of less than about 0.01 ohm-cm.

[0087] In some embodiments, the bulk material of the moving ring 232 is also chosen from a conductive yet plasma erosion resistant material, such as an aluminum (Al) alloy, Hastelloy, Elgiloy, poly-Si, etc. In some embodiments, the bulk material of the moving ring 324 is chosen to have a resistivity of less than about 0.01 ohm-cm.

[0088] By defining the bulk materials of the edge ring 204 and the moving ring 232 as described, a low resistance (low impedance) current path is established between the edge ring and moving ring, and lower contact impedance variability is achieved.

[0089] FIG. 4B is a cross-section of a top edge ring and moving ring having conductive coatings to form a low-resistive contact, in accordance with embodiments of the disclosure.

[0090] In the illustrated embodiment, the edge ring 204 and the moving ring 232 can have bulk materials defined as described above. Furthermore, low-resistance contact between the rings is further enhanced by providing coatings of conductive materials along the interfacing portions of

the rings. As shown, the lower surface of the edge ring 204 has a conductive coating 400, and the upper surface of the moving ring 232 has a conductive coating 402. The conductive coatings 400 and 402 contact each other when the rings are in use for plasma processing in the chamber. In some embodiments, one or both of the conductive coatings 400/402 is defined from a conductive material such as aluminum, aluminum alloy, Hastelloy, Hastelloy with a titanium interlayer, a low-resistance ceramic (e.g. zirconium nitride), etc. In some embodiments, the conductive coatings are deposited using a deposition process such as a physical vapor deposition (PVD) process or an atomic layer deposition (ALD) process. In some embodiments, one or both of the conductive coatings 400/402 has a thickness in the range of about 10 to 100μm (microns).

[0091] In some embodiments, the conductive coating 400 and the conductive coating 402 consist of the same material. For example, in some embodiments, both the conductive coating 400 and the conductive coating 402 are Hastelloy coatings. In this case, contact is made between two Hastelloy surfaces. In other embodiments the conductive coating 400 and the conductive coating 402 consist of different materials.

[0092] In some embodiments, the moving ring 232 includes the conductive coating 402, whereas the edge ring 204 does not include the conductive coating 400, but the edge ring 204 consists of a low-resistance bulk material. For example, in some embodiments, the moving ring 232 includes the conductive coating 402 defined from a Hastelloy material, whereas the edge ring 204 does not include the conductive coating 400 but is defined from a bulk material consisting of a low-resistance SiC. In this case, contact is made between the Hastelloy coating on the moving ring and the low-resistance SiC of the edge ring. In other embodiments, the edge ring 204 includes the conductive coating 400, whereas the moving ring 232 does not include the conductive coating 402, but is defined from a low-resistance bulk material.

[0093] It will be appreciated that the coefficient of thermal expansion (CTE) of the conductive coating materials should be chosen to sufficiently match that of the respective bulk materials of the rings, so as to prevent delamination of the coatings after repeated thermal cycling. For example, if the edge ring 204 has bulk material of a low-resistance (doped) SiC, then the conductive coating 400 can be defined from a material having a CTE similar to that of the low-resistance SiC (e.g. less than about 100% difference in CTE in some embodiments).

[0094] In some embodiments, the conductive coatings are configured to handle >400C plasma processing temperature and a 1000 RF hour lifetime specification.

[0095] In some embodiments, to provide improved surface structure for contact, the surfaces of the of the rings are polished prior to deposition of the conductive coatings. That is, a surface

polishing process is performed on the lower surface of the bulk material of the edge ring 204 prior to deposition of the conductive coating 400. And a surface polishing process is performed on the upper surface of the bulk material of the moving ring 232 prior to deposition of the conductive coating 402. In this manner, the surface structure of the conductive coatings 400/402 have lower roughness for improved contact.

[0096] In some embodiments, the cross-sectional shape of the edge ring 204 has an inverted "U"-shape, so as to include an inner annular projection 410 and an outer annular projection 412 that extend downward from the main body of the edge ring 204. In some embodiments, the conductive coating 400 extends along the inward facing surface of the outer annular projection 412 as shown. In some embodiments, the conductive coating 400 extends along the outward facing surface of the inner annular projection 410 as shown.

[0097] In accordance with embodiments presently described, a low resistive (low impedance) current path is established between the top edge ring and moving ring using conductive coatings, as compared to the existing capacitively coupled ring contacts. And with lower contact surface roughness, contact impedance variability is further reduced.

[0098] FIG. 4C is a cross-section of a moving ring and edge ring having conductive coatings, in accordance with embodiments of the disclosure.

[0099] The illustrated embodiment of FIG. 4C is similar to the embodiment of FIG. 4A, except that the region occupied by the conductive coating 402 along the upper surface of the moving ring 232 spans less than the radial width of the upper surface. In some embodiments, the radial width of the conductive coating 402 is in the range of about 5 to 95% of the radial width of the upper surface of the moving ring 232.

[0100] In some embodiments, by having a radial width of the conductive coating that is less than the radial width of the upper surface, then variability in the contact between the moving ring and edge ring is improved. That is, differences in the horizontal level of the contacting surfaces of the moving ring and edge ring (e.g. due to manufacturing variability) may be less likely to have as great an impact on contact impedance variation when the contacting surface area is lower. Put more simply, it can be challenging to manufacture two large surfaces to be perfectly flat and contact each other consistently, which can lead to a higher degree of variation in the contact. Therefore, in some embodiments, more consistent contact may be achieved when one of the contacting surfaces is smaller, in this case the conductive coating 402 on the moving ring 232.

[0101] FIG. 4D is a view of a surface of a ring having a plurality of contact pads disposed thereon, in accordance with embodiments of the disclosure.

[0102] In various embodiments, the surface 420 can be the lower surface of the edge ring 204 or the upper surface of the moving ring 232. In some embodiments, the surface 420 includes three contact pads 422a, 422b, and 422c, which are equally spaced apart at 120 degrees from each other. In some embodiments, the surface 420 further includes contact pads 424a, 424b, and 424c, for a total of six contact pads that are equally spaced at 60 degree intervals. In some embodiments, the surface 420 includes three or more contact pads spaced apart at equivalent intervals. Each of the contact pads can be defined by a coating of conductive material, such as that described above, at the specified locations, so as to define specific points of conductive contact at equidistant intervals around the ring.

[0103] In some embodiments, the surface 420 is the top surface of the moving ring 232, with the contact pads defined thereon, whereas the edge ring 204 is defined from a low-resistance bulk material and/or the lower surface of the edge ring includes the conductive coating 400 throughout its azimuthal extent. In this setup, the edge ring 204 does not need to be rotationally aligned relative to the moving ring 232.

[0104] In other embodiments, the surface 420 is the lower surface of the edge ring 204, with the contact pads defined thereon, whereas the moving ring 232 is defined from a low-resistance bulk material and/or the upper surface of the moving ring includes the conductive coating 402 throughout its azimuthal extent. In this setup, the edge ring 204 may need to be rotationally aligned relative to the moving ring 232 so as to avoid placement of the contact pads at the grooves 236 between the raised portions 234 of the moving ring 232.

[0105] In further embodiments, the moving ring 232 is configured to include additional structures configured to form at least three points of conductive contact with the edge ring 204.

[0106] FIG. 5A is a cross-section of an edge ring and moving ring, with the moving ring having a conductive pin, in accordance with embodiments of the disclosure.

[0107] In the illustrated embodiment, the moving ring 232 includes at least three contact structures. A given contact structure as shown is defined by a conductive pin 502 disposed in a tube 501 formed in the main body 500 of the moving ring 232. In some embodiments, the main body 500 of the moving ring consists of a conductive core with a highly plasma erosion resistive insulating coating (e.g. Si core with aluminum oxide coating).

[0108] In some embodiments, the conductive pins 502 consist of conductive yet plasma erosion resistive materials (e.g. low-resistance SiC, Aluminum, Hastelloy, stainless steel, etc.). In some embodiments, the top surface 504 of the conductive pin 502 is coated with a coating of a

conductive and plasma resistant material, such as those of the conductive coatings previously described.

[0109] A gasket seal 506 consists of an electrically insulating material that is sufficiently pliable to form a seal between the conductive pin 502 and the wall of the tube 501, blocking process gases from entering the tube 501 in which the conductive pin 502 is disposed. In some embodiments, the gasket seal 506 is in the form factor of an O-ring type structure. In some embodiments, the gasket seal 506 consists of, or is fabricated from, a material such as Hastelloy, Titanium, etc.

[0110] It will be appreciated that the top surface 504 of the conductive pin is configured to contact the lower surface of the edge ring 204, and thereby form a direct coupling low-resistive contact with the edge ring 204. In some embodiments, there are specifically three points of contact that are configured, and therefore three contact structures as presently described defined in the moving ring 232, equally positioned around the moving ring at 120 degree intervals from each other. In other embodiments, there are more than three points of contact, and consequently more than three contact structures defined in the moving ring 232. Accordingly, through the establishment of the low resistive (low impedance) current path between edge and moving rings, lower contact impedance variability is achieved.

[0111] In some embodiments, the area of the top surface 504 that forms the contact is in the range of about 0.5 to 300 square cm.

[0112] In some embodiments, the conductive pin 502 has a substantially cylindrical shape. In some embodiments, the conductive pin 502 may include one or more substantially cylindrical or conical segments having various diameters. In some embodiments, the top surface 504 of the conductive pin 502 has a substantially circular shape, having a diameter in the range of about 1 to 7.5 mm.

[0113] In various embodiments, the edge ring 204 can be defined as described elsewhere herein.

[0114] FIG. 5B is a cross-section of a moving ring and edge ring, in accordance with embodiments of the disclosure.

[0115] The illustrated embodiment of FIG. 5B is similar to that of FIG. 5A, except that the top surface 510 of the conductive pin 502 is configured to have a convex or dome-shaped structure, and the lower surface of the edge ring 204 is configured to have a corresponding recess 512 with a matching concave shape. The contact between the top surface 510 and recess 512 results in formation of a low-resistive contact having a curved contact profile at the (three or more) points of contact that constrains or prevents ring-to-ring lateral movements.

[0116] FIG. 5C is a cross-section of a moving ring and edge ring, in accordance with embodiments of the disclosure.

[0117] The illustrated embodiment of FIG. 5C is similar to that of FIG. 5B, except that the conductive pin 502 is in the form of a pogo pin having a spring-loaded upper portion that is depressed under the load of the edge ring 204. In some embodiments, the conductive pin 502 is in the form of a pogo pin 530, including a spring 532, and an upper portion 534. The spring constant of the spring 532 is configured so that the weight of the edge ring 204 is adequate to compress the spring and form a reliable and repeatable contact impedance. In some embodiments, the weight of the edge ring is in the range of about 200 to 300 grams, and so with three points of contact, each pogo pin is configured to be compressible under a weight of about 60 to 100 grams. In some embodiments, the weight of the edge ring is about 200 grams, and with three points of contact, each pogo pin is configured to be compressible under a weight of about 60 to 70 grams.

[0118] In some embodiments, the top surface 520 of the conductive pin 502 has a substantially (convex) conical shape, and the edge ring 204 has a corresponding recess 522 having a substantially (concave) conical shape, wherein the contact between the top surface 520 and the recess 522 forms a low-resistance (low impedance) current path between the edge ring 204 and the moving ring 232.

[0119] FIG. 6 is a cross-section of a moving ring having a contact structure defined therein, in accordance with embodiments of the disclosure.

[0120] In the illustrated embodiment, the moving ring 232 includes a tube 501 that extends vertically throughout the moving ring 232, forming a vertical through-hole in the moving ring 232. A two-part conductive pin is disposed in the tube 501 in the form of an upper conductive pin portion 600 that connects to a lower conductive pin portion 602. In some embodiments, as shown, the top of the lower conductive pin portion 602 is defined by a screw segment that screws into a corresponding screwhole defined at the bottom of the upper conductive pin portion 600. In other embodiments, the configuration of the screw segment and corresponding screwhole are reversed.

[0121] In some embodiments, the upper conductive pin portion 600 includes a head portion 604 having a top surface that extends or protrudes above the level of the top surface 612 of the main body 500 of the moving ring 232. In some embodiments, the height of the top surface of the head portion 604 is higher than the height of the top surface 612 of the moving ring by about 100 microns to 1 mm. The protrusion of the conductive pin above the moving ring's top surface ensures that the edge ring rests on and contacts only the conductive pins with the full weight of the edge ring acting to promote optimal electrical contact with the conductive pins.

[0122] In some embodiments, the top of the head portion 604 is configured to have a flanged portion 614 having a diameter greater than the diameter of the upper portion 616 of the tube 501.

The flanged portion 614 limits the extent to which the upper conductive pin portion 600 can be inserted downward into the tube 501, ensuring that the top surface of the head portion 604 is at a height above that of the top surface 612 of the moving ring 232. Additionally, the flanged portion 614 further provides a tortuous path to resist the intrusion of process gases into the tube 501. In some embodiments, the head portion 604 is in the form of a screw head (e.g. a socket screw head, etc.). It will be appreciated that the top surface of the head portion 604 is configured to contact the lower surface of the edge ring 204, and thereby form a low-resistance contact.

[0123] In some embodiments, the lower conductive pin portion 602 includes a head portion 606 whose bottom surface does not extend below the level of the bottom surface of the moving ring 232.

[0124] In some embodiments, the upper conductive pin portion 600 is in the form of a binding post or binding barrel (in some embodiments, having a hex socket head). In some embodiments, the lower conductive pin portion 602 is in the form of a shoulder screw (in some embodiments, having a hex socket head). It will be appreciated that during assembly of the contact structure, the upper conductive pin portion 600 is inserted through the top of the tube 501, and the lower conductive pin portion 602 is inserted through the bottom of the tube 501, and the portions are connected to each other, e.g. via a screw mechanism as described.

[0125] In some embodiments, an O-ring 608 is fitted around the upper conductive pin portion 600 and configured to prevent diffusion of process gases through the top of the tube 501. In some embodiments, an O-ring 610 is fitted around the lower conductive pin portion 602 and configured to prevent diffusion of process gases through the bottom of the tube 501.

[0126] FIG. 7A is a cross-section of an edge ring and moving ring with an engineered contact using a drop-down pin, in accordance with embodiments of the disclosure.

[0127] In the illustrated embodiment, the edge ring 204 includes a drop-down pin 700 that inserts into an opening 701 defined in the moving ring 232 when the edge ring 204 is engaged by the moving ring 232. In some embodiments, the drop-down pin 700 is secured to the main body 702 of the edge ring 204 by a screw mounting. For example, in some embodiments, the upper portion of the drop-down pin 700 is threaded so as to screw into a screw hole defined along the lower surface of the edge ring's main body.

[0128] In some embodiments, the drop-down pin 700 is composed of a conductive metal having a CTE that is similar to that of the material of the main body 702 of the edge ring 204. For example, in some embodiments, the main body 702 of the edge ring 204 is composed of a low-resistance SiC material, and the drop-down pin is composed of a metal having a CTE similar to the CTE of the low-

resistance SiC material. In some embodiments, the metal is one of aluminum, Hastelloy C22, stainless steel, etc.

[0129] In some embodiments, a gasket 704 (e.g. fingerstock gasket shown at ref. 706) is disposed in the hole 701, at an elevation such that when the drop-down pin 700 is inserted into the hole 701, contact is made with the gasket 704. The gasket 704 provides a designed lateral clamping force that provides a reliable and repeatable electrical contact with the drop-down pin 700. In this manner, a conductive contact between the edge ring and moving ring is made.

[0130] In some embodiments, an O-ring 703 is provided to block the diffusion path of process gases into the opening 701.

[0131] It will be appreciated that with the laterally clamping provided in accordance with the present embodiment, that lateral alignment and centering of the edge ring is easily achieved and lateral movement of the edge ring is prevented once engaged by the moving ring.

[0132] FIG. 7B is a cross-section of an edge ring and moving ring with an engineered contact using a drop-down pin, in accordance with embodiments of the disclosure.

[0133] In the illustrated embodiment, the edge ring 204 includes a drop-down pin 700 as previously described. Further, a gasket 710 is provided in an opening that engages the drop-down pin with lateral clamping force when the drop-down pin is inserted through the gasket 710. However, unlike the gasket 704 previously described, gasket 710 is not necessarily electrically conductive, but is made from a low friction material (e.g. PTFE, etc.) of suitable compliance to provide guidance and lateral clamping of the drop-down pin 700 when inserted into the opening in the moving ring 232 and through the gasket 710. In some embodiments, the coefficient of friction of the material is in the range of about 0.05 to 0.1 on polished steel.

[0134] In the illustrated embodiment, electrical contact is made by a receiving gasket 712 that is contacted by the bottom surface of the drop-down pin 700 when seated in the opening in the moving ring 232. In some embodiments, the receiving gasket 710 is defined as a structured soft metal pad. In some embodiments, the structured soft metal pad is defined having a sponge-like porous structure, or a 3D-printed truss structure.

[0135] FIG. 8A is a cross-section of a top portion of a moving ring having a hyperstatic conductive structure, in accordance with embodiments of the disclosure.

[0136] In the illustrated embodiment, a top portion 800 of a moving ring is shown, which includes a channel or cavity 802 in which a metal sheet 804 is disposed. The metal sheet consists of a material having suitable compliance, and at a suitable thickness, so as to be configured to enable the metal sheet to buckle as shown, forming a series of ridges and troughs. When the edge ring 204

is supported by the moving ring, then at least some of the ridges contact the lower surface of the edge ring 204, thereby forming multiple points of electrical contact between the moving ring and edge ring. Furthermore, the ridges can be compressed under the load of the edge ring 204 to an extent that the edge ring is also supported by the top surface 805 of the moving ring, thereby closing off the cavity 802 and limiting or blocking penetration of process gases into the cavity 802.

[0137] In some embodiments, the metal sheet 804 consists of a conductive metal/alloy such as Al-6061, Hastelloy, etc. In some embodiments, the thickness of the metal sheet 804 is in the range of about 0.1 to 0.3 mm.

[0138] FIG. 8B illustrates a tubular conductive structure used to effect direct coupling electrical contact between a moving ring and edge ring, in accordance with embodiments of the disclosure.

[0139] In some embodiments, a tubular conductive structure 810 is utilized to form electrical contact between a moving ring and edge ring. Shown at ref. 809 is a side profile view of a length of an exemplary tubular conductive structure 810, in a form factor of a spiraled strip of a conductive material. In some embodiments, the conductive material is a low-resistance material having sufficient compliance (which may in part be achieved through a suitable thickness) to enable compression under the load presented by the edge ring, and consequent formation of a high surface area contact.

[0140] In the embodiment presented at ref. 811, a cross-section of a portion 812 of a moving ring is illustrated. The portion 812 is structured having a dovetail groove 814 in which the tubular conductive structure 810 is disposed. In an alternative embodiment presented at ref. 813, a cross-section of a portion 816 of a moving ring is illustrated, the portion 816 being structured having a standard (rectangular shaped) groove 818 in which the tubular conductive structure 810 is disposed. It will be appreciated that in a given moving ring, several such grooves and tubular conductive structures can extend azimuthally along the top of the moving ring 232, such as along the top of the raised portions 234, providing a large contact area through which to form a low-resistance contact between the edge ring and moving ring. Furthermore, it will be appreciated that the tubular conductive structures can be compressed under the load of the edge ring 204 to an extent that the edge ring is also supported by the top surface of the moving ring, thereby closing off the groove openings and limiting or blocking penetration of process gases into the grooves.

[0141] While certain examples of compliant conductive structures have been described, it will be appreciated that other types of structurally-compliant conductive materials can be used to form a low-resistance contact between an edge ring and moving ring, such as a metal helix, metal strip, fuzz button, etc. In various embodiments, one or more compliant conductive structures are

disposed in one or more cavities (or recesses or grooves) that are defined along the top of the moving ring. In some embodiments, the compliant conductive structures are configured to be compressed by the weight of the edge ring, and thereby close or seal off the cavities. It will be appreciated that in various embodiments, the structural stiffness in the vertical direction of the compliant conductive structures can be controlled by the manufactured dimensions, such as by controlling the thickness of material used, total length or area of the compliant conductive structure utilized, controlling the extent to which compliant conductive structure extends above the top surface of the moving ring's main body (when unloaded), etc.

[0142] By utilizing compliant conductive structures as presently described, many points of conductive contact can be formed at the interface between the moving ring and edge ring. The true area of contact can be quite large in such embodiments, providing significantly lower contact impedance and lower contact impedance variability.

[0143] In the above-described embodiments, engineered conductive contacts between the moving ring and edge ring have been described. In some embodiments, the surface contact area of the conductive contact(s) can be less than about 5 percent of the top surface area of the moving ring; in some embodiments, less than about 1 percent. It will further be appreciated that actual contact between surface structures can be imperfect due to surface structure variation, and accordingly in some embodiments, the actual electrical contact path of a given conductive contact structure can be, for example, less than 5 percent of the available contact surface area of a given conductive contact structure.

[0144] 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.

[0145] 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."

[0146] In some embodiments, 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.

[0147] 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.

[0148] The controller, in some embodiments, 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.

[0149] 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 (ALO) 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.

[0150] 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. An edge ring system for use in a process chamber, comprising:

an edge ring with a lower contact surface, the edge ring is configured to be vertically raised and lowered;

a moving ring configured to raise and lower the edge ring, wherein the moving ring is configured to form a conductive contact with the lower contact surface of the edge ring;

wherein the conductive contact enables a direct coupling of RF power to the edge ring which reduces non-vertical tilting of ions during plasma processing in the process chamber.

2. The edge ring system of claim 1, wherein the conductive contact between the moving ring and the lower contact surface of the edge ring enables the moving ring and the edge ring to be substantially equipotential during processing of a substrate in the process chamber.

3. The edge ring system of claim 1, wherein the edge ring is defined from a substantially conductive material.

4. The edge ring system of claim 1, wherein the lower contact surface of the edge ring is defined by a coating of a substantially conductive material.

5. The edge ring system of claim 1, wherein the moving ring is defined from a substantially conductive material.

6. The edge ring system of claim 1, wherein an upper surface of the moving ring is defined by a coating of a substantially conductive material.

7. The edge ring system of claim 1, wherein the moving ring includes a plurality of conductive pins embedded therein, the conductive pins are configured to form said conductive contact with the lower surface of the edge ring.

8. The edge ring system of claim 7, wherein upper portions of the conductive pins are configured to protrude from an upper surface of the moving ring.

9. The edge ring system of claim 1, wherein raising and lowering the moving ring is configured to selectively raise and lower the edge ring, respectively.

10. The edge ring system of claim 1, further comprising:

a middle ring including an outer ring portion and an inner ring portion, and a plurality of bridges connecting the inner ring portion to the outer ring portion, such that a plurality of gaps are defined between the plurality of bridges;

wherein the edge ring is configured to be supported on the middle ring between the outer ring portion and the inner ring portion during transfer of the middle ring and the edge ring into or out of the process chamber;

wherein the moving ring includes raised portions that extend upward through the plurality of gaps to form the conductive contact with the lower contact surface of the edge ring.

11. The edge ring system of claim 1, wherein the conductive contact between the moving ring and the lower contact surface of the edge ring is configured to have an impedance of less than about 1 Ohm.

12. The edge ring system of claim 1, wherein the conductive contact enables coupling of RF power to an edge region of the process chamber, reducing non-vertical tilting of ions during plasma processing in the process chamber.

13. An edge ring system for use in a process chamber, comprising:

an edge ring defined from a substantially conductive material and having a lower contact surface, the edge ring configured to be vertically raised and lowered;

a moving ring configured to vertically raise and lower the edge ring, wherein the moving ring is configured to form a conductive contact with the lower contact surface of the edge ring, wherein an upper surface of the moving ring is defined by a coating of a substantially conductive material.

14. The edge ring system of claim 13, wherein the conductive contact between the moving ring and the lower contact surface of the edge ring enables the moving ring and the edge ring to be substantially equipotential during processing of a substrate in the process chamber.

15. The edge ring system of claim 13, wherein the lower contact surface of the edge ring is defined by a coating of a substantially conductive material.

16. The edge ring system of claim 13, wherein the moving ring is defined from a substantially conductive material.

17. An edge ring system for use in a process chamber, comprising:

an edge ring defined from a substantially conductive material and having a lower contact surface, the edge ring configured to be vertically raised and lowered;

a moving ring configured to be raised and lowered relative to the middle ring, wherein the moving ring is configured to form a conductive contact with the lower contact surface of the edge ring, wherein the moving ring includes a plurality of conductive pins embedded therein, the conductive pins are configured to form said conductive contact with the lower contact surface of the edge ring.

18. The edge ring system of claim 17, wherein the conductive contact between the moving ring and the lower contact surface of the edge ring enables the moving ring and the edge ring to be substantially equipotential during processing of a substrate in the process chamber.

19. The edge ring system of claim 17, wherein the lower contact surface of the edge ring is defined by a coating of a substantially conductive material.

20. The edge ring system of claim 17, wherein upper portions of the conductive pins are configured to protrude from an upper surface of the moving ring.