Apparatus and methods for improving treatment uniformity in a plasma process.

Inventors: Jiangang Zhao, Concord, CA (US); James D. Getty, Vacaville, CA (US)

Assignee: NORDSON CORPORATION, Westlake, OH (US)

Abstract:
Apparatus and methods for improving treatment uniformity in a plasma process. The sacrificial body, which is extends about an outer peripheral edge of the workpiece during plasma processing, is composed of a plasma-removable material. The sacrificial body may include multiple sections that are arranged to define a circular geometrical shape. The sacrificial body functions to increase the effective outer diameter of the workpiece, which operates to alleviate detrimental edge effects intrinsic to plasma processing by effectively reducing the etch rate near the outer peripheral edge of the workpiece.
APPARATUS AND METHODS FOR IMPROVING TREATMENT UNIFORMITY IN A PLASMA PROCESS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 60/941,518, filed Jun. 1, 2007. The disclosure of this provisional application is hereby incorporated by reference herein in its entirety.

TECHNICAL FIELD

[0002] The invention generally relates to apparatus and methods for processing workpieces with a plasma and, more particularly, to apparatus and methods for improving plasma treatment uniformity in a plasma processing system.

BACKGROUND

[0003] Uniform plasma treatment for wafer level applications is a concern for the semiconductor manufacturing industry. One problem that plagues conventional etch processes and plasma processing equipment is non-uniformity in the etch rate across a workpiece, such as a wafer. Workpiece edge effects represent a common source of these etch rate non-uniformities. The uniformity of the etch rate can be determined from the quotient of a difference between the maximum and minimum lateral etch rate on the treated surface to the product of two times the average etch rate across the workpiece. Typically, the maximum etch rate occurs near the peripheral edge of the workpiece and the minimum etch rate is observed near the workpiece center.

[0004] Conventional methods have been used in the effort to improve the uniformity of the etch rate across the surface area of the workpiece. For example, a magnetron may be employed to generate the plasma. However, such solutions significantly increase the cost of the plasma processing equipment.

[0005] A cost-effective solution is desired that addresses workpiece edge effects that occur in conventional processing systems and that adversely impact the uniformity of the plasma treatment across the surface area of the workpiece, as well as other artifacts of the plasma treatment that have a negative influence on treatment uniformity.

SUMMARY

[0006] In one embodiment, an apparatus is provided for use in plasma processing a workpiece. The apparatus includes a sacrificial ring composed of a plasma-removable material. The sacrificial ring is adapted to be arranged around an outer peripheral edge of the workpiece so that an outer diameter of the workpiece is effectively increased.

[0007] In another embodiment, an apparatus is provided for use in plasma processing a workpiece. The apparatus includes a vacuum enclosure configured to contain a plasma. The vacuum enclosure includes a support pedestal adapted to contact and support a second surface of the workpiece when processing a first surface of the workpiece with the plasma. The apparatus further includes a sacrificial ring composed of a plasma-removable material, the sacrificial ring extending about the outer peripheral edge of the workpiece supported on the pedestal so that an outer diameter of the workpiece is effectively increased.

[0008] In yet another embodiment, a method is provided for plasma processing a workpiece having a first surface, a second surface, and an outer peripheral edge connecting the first and second surfaces. The method includes arranging a sacrificial ring composed of a plasma-removable material about the outer peripheral edge of the workpiece and exposing the first surface of the workpiece and the sacrificial ring to a plasma. The method further includes shifting a maximum etch rate from a location on the first surface of the workpiece to a different location on the sacrificial ring.

BRIEF DESCRIPTION OF THE FIGURES

[0009] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with a general description of the invention given above, and the detailed description given below, serve to explain the principles of the embodiments of the invention.

[0010] FIG. 1 is a perspective view of a plasma processing system including a vacuum enclosure and a wafer lift mechanism disposed inside the vacuum enclosure.

[0011] FIG. 2 is a front view of the plasma processing system of FIG. 1.

[0012] FIG. 3 is an exploded view of the enclosure and wafer lift mechanism of the plasma processing system of FIGS. 1 and 2.

[0013] FIG. 3A is another exploded view of the workpiece vertical lift mechanism of the plasma processing system of FIGS. 1, 2, and 3.

[0014] FIG. 4 is a cross-sectional view taken generally along line 4-4 in FIG. 2 in which the wafer lift mechanism is raised in a raised position with the lid of the vacuum enclosure opened relative to the base of the vacuum enclosure.

[0015] FIG. 5 is a cross-sectional view similar to FIG. 4 in which the lid of the vacuum enclosure is in contact with the base of the vacuum enclosure and the wafer lift mechanism is thereby placed in a lowered position.

[0016] FIG. 6 is an enlarged view of a portion of FIG. 4.

[0017] FIG. 7 is an exploded view of a portion of the wafer lift mechanism of FIGS. 1-6.

[0018] FIG. 8A is a perspective view depicting the wafer lift mechanism in a raised condition in which only a portion of the wafer lift mechanism is illustrated for clarity of illustration.

[0019] FIG. 8B is a perspective view similar to FIG. 8A depicting the wafer lift mechanism in a raised condition.

DETAILED DESCRIPTION

[0020] With reference to FIGS. 1-4, a plasma processing system generally includes a vacuum vessel or enclosure having a lid and a base upon which the lid rests, a pair of support arms connected to the lid, an upper electrode, and a lower electrode. The processing system further includes a support pedestal adapted to contact and support a second surface of the workpiece when processing a first surface of the workpiece with the plasma. The apparatus further includes a sacrificial ring composed of a plasma-removable material, the sacrificial ring extending about the outer peripheral edge of the workpiece supported on the pedestal so that an outer diameter of the workpiece is effectively increased.

[0021] The support arms mechanically couple the lid with a lifting device capable of vertically lifting and lowering the lid relative to the base between a raised position (FIG. 1) and a lowered position (FIG. 5).
When the lid 14 and base 16 are in a contacting relationship, a processing region 28 is defined as the space bounded vertically between the inwardly-facing horizontal surfaces of the electrodes 22, 24 and bounded laterally inside the inwardly-facing vertical surface of the sidewall defined by the separating ring 26. In the raised position, the processing region 28 is accessible for inserting unprocessed workpieces 30 and removing processed workpieces 30. In the lowered position (FIG. 5), an environment may be established in the processing region 28 that is suitable for plasma processing each successive workpiece 30 positioned in the processing region 28. The upper electrode 22 moves along with the lid 14 when the lid 14 is moved by the lifting device between the raised and lowered positions relative to the base 16.

[0022] A power supply 32 (FIG. 2), which is coupled with the electrodes 22, 24 by shielded coxial cables or transmission lines 33, 34, respectively, controls the power level and frequency of operation of the electrodes 22, 24. The power supply 32 may be an alternating current power supply operating at an extremely low frequency, such as 50 Hz and 60 Hz, at a high radio frequency, such as 40 kHz and 13.56 MHz, at a medium radio frequency, such as 1 kHz, or at a microwave frequency, such as 2.4 GHz. The power supply 32 may also operate at dual frequencies superimposed upon one another. Alternatively, the power supply 32 may be a direct current (DC) power supply in which the plasma is non-oscillating. In other alternative embodiments, power supply 32 may supply a radio frequency (RF) power component that provides dense plasma and a DC power component that independently increases ion energy without affecting the plasma density.

[0023] The power supply 32 may be operated at one or more radio frequencies and include an impedance matching network (not shown) that measures reflected power from the load represented by the electrodes 22, 24 and plasma confined therebetween back to the power supply 32. The impedance matching network adjusts the frequency of operation of power supply 32 to minimize the reflected power. The construction of such matching networks is understood by a person of ordinary skill in the art. For example, the impedance matching network may tune the matching network by changing the capacitance of variable capacitors within the matching network to match the impedance of the power supply 32 to the impedance of the load as the load changes. The power and voltage levels and operating frequency(ies) may vary of course, depending upon the particular application.

[0024] A vacuum pump 36 continuously pumps byproduct generated by the plasma process and non-reacted source gas from the processing region 28, when the plasma processing system 10 is operating, through a vacuum manifold 38. The vacuum pump 36 is operative to maintain the total pressure in the processing region 28 at a sub-atmospheric level low enough to facilitate plasma creation. Typical pressures suitable for plasma formation range from about twenty (20) millitorr to greater than about fifty (50) torr. The pressure within the processing region 28 is controlled in accordance with a particular desired plasma process and primarily consists of partial pressure contributions from the source gas, which may comprise one or more individual gas species, supplied to the evacuated processing region 28.

[0025] With continued reference to FIGS. 1-4, a sealing member 40 is compressed between the separating ring 26 and the upper electrode 22. When the lid 14 is lowered into contact with the base 16 as shown in FIG. 5, another sealing member 42 is compressed between the separating ring 26 and a perimeter of the lower electrode 24. The sealing members 40, 42 are illustrated as conventional elastomeric O-rings, although the invention is not so limited. When the lid 14 is in its lowered position, a conducting member 43 is captured between the respective perimeters of the lid 14 and base 16, which are metallic. The conducting member 43 supplies a good electrical contact between the lid 14 and base 16.

[0026] A gas inlet plate 44 (FIG. 4) is fastened to an upper horizontal surface of the upper electrode 22. The gas inlet plate 44 is coupled by a gas port 46 and a delivery line 48 with a source gas supply 50. A mass flow controller and a flow measurement device (not shown) may be provided that cooperate to regulate the flow of each process gas from the source gas supply 50 to the gas port 46. The gas inlet plate 44 includes distribution passages (not shown) and the upper electrode 22 includes passages (not shown) coupled with the distribution passages of the gas inlet plate 44. The passages in the upper electrode 22 communicate with the processing region 28 for injecting process gas into the process chamber.

[0027] The plasma processing system 10 includes a microprocessor-based controller 52 (FIG. 2) that is programmed to control the operation of, among other components, the power supply 32, the vacuum pump 36, and the source gas supply 50. For example, the controller regulates the power levels, voltages, currents and frequencies of the power supply 32 and orchestrates the provision of source gas from source gas supply 50 and the pumping rate of vacuum pump 36 to define a suitable pressure in the processing region 28 in accordance with the particular plasma process and application.

[0028] During processing of workpiece 30, the power applied between the electrodes 22, 24 by power supply 32 produces an electromagnetic field in the processing region 28, which is defined between the two electrodes 22, 24 when the lid 14 and base 16 are contacting and an environment suitable for plasma processing is present in the processing region. The electromagnetic field excites the atoms or molecules of source gas present in the processing region to a plasma state, which is sustained by the application of power from power supply 32 for the duration of the plasma treatment.

[0029] Transmission line 34, which is electrically coupled in a known manner with the lower electrode 24, is routed to the lower electrode 24. Transmission line 33 is electrically coupled in a known manner with one or both of the electrodes 22, 24. A forced flow of a cooling fluid may be routed through the air gaps 56 between the electrodes 22, 24 and enclosure 12 for cooling the processing system 10 and, in particular, for cooling the electrodes 22, 24. To that end, a fitting 54 (FIG. 2) may be provided in the lid 14 to define a coolant port for coupling a coolant supply 55 (FIG. 2) with these air gaps 56.

[0030] The electrodes 22, 24 are formed from an electrically-conductive material, such as aluminum. The separating ring 26 is formed from a non-conducting dielectric material and is constructed to be able to withstand the plasma environment inside the processing region 28 without unduly contaminating the processed workpiece 30. Generally, this implies that the material forming the separating ring 26 should be substantially resistant to etching by the plasma present in the processing region 28. The separating ring 26 defines a vertical sidewall of non-conductive material, in addition to providing the vacuum seal between the electrodes 22, 24.

[0031] Constituent species from the plasma contact and interact with exposed material on the workpiece 30 to perform the desired surface modification. The plasma is config-
ured to perform the desired surface modification of the workpiece 30 by selecting parameters such as the chemistry of the source gas, the pressure inside the processing region 28, and the amount of power and/or frequency applied to the electrodes 22, 24. The processing system 10 may include an end point recognition system (not shown) that automatically recognizes when a plasma process (e.g., an etching process) has reached a predetermined end point or, alternatively, plasma processes may be timed based upon an empirically-determined time of a process recipe.

[0032] With reference to FIGS. 3, 3A, 4, 5, and 6 in which like reference numerals refer to like features in FIGS. 1 and 2, the plasma processing system 10 further includes a vertical lift mechanism 58 located inside the vacuum enclosure 12. The vertical lift mechanism 58 receives each workpiece 30 in a lifted condition relative to the lower electrode 24. The workpiece fixture 60 is automatically moveable in conjunction with opening and closing the lid 14 and without operator intervention between a raised position, when the lid 14 is opened, as best shown in FIG. 4, and a lowered position when the lid 14 is in a closed position relative to the base 16, as best shown in FIG. 5. In other words, the workpiece fixture 60 moves toward the lowered position as the upper electrode 22 is moved by the lid 14 toward the lower electrode 24 to seal the processing region 28 and moves toward the raised position as the upper electrode 22 is moved by the lid 14 away from the lower electrode 24. When the lid 14 is placed in the lowered position contacting the base 16 to seal the processing region 28 from the ambient environment, the vertical lift mechanism 58 automatically places the workpiece 30 in a treatment position.

[0033] The vertical lift mechanism 58 generally includes a workpiece fixture 60, a set of resiliently-biased supports 62 mechanically coupling the workpiece fixture 60 with the lower electrode 24, a set of resiliently-biased push devices 64 projecting from the upper electrode 22 toward the lower electrode 24 and the workpiece fixture 60, a lift plate 66, and a workpiece ring 68. An outer peripheral edge or perimeter 65 of the workpiece fixture 60, which is positioned between the upper and lower electrodes 22, 24, is encircled by the separating ring 26.

[0034] As best shown in FIGS. 3 and 3A, the lift plate 66 and workpiece ring 68 are joined, for example, by a pin-in-socket type engagement in which one of the lift plate 66 or workpiece ring 68 carries a set of projecting pins (not shown) and the other of the lift plate 66 or workpiece ring 68 carries a set of sockets (not shown) that register and mate with the pins. A cover plate 70, which is disposed on the lower electrode 24, includes a cap 72 and a support 74 that underlies the cap 72. The cap 72 may also be joined with the support 74 by a pin-in-socket type engagement or, alternatively, the cap 72 and support 74 may constitute an integral, one-piece component. The cover plate 70 has a good electrical contact with the lower electrode 24, as does the workpiece ring 68 and lift plate 66, when the lid 14 is lowered. As a consequence, the workpiece fixture 60, the workpiece 30, and the lower electrode 24 are at approximately equivalent electrical potentials when the plasma processing system 10 is operating to generate plasma inside the processing region 28 and to process workpieces 30 inside the processing region 28 with the plasma.

[0035] A recess 76 is located near each of the corners of the lower electrode 24. Each recess 76 has a base 78 that represents a relatively thin wall of the material of lower electrode 24 remaining after the respective recess 76 is formed or machined in the lower electrode 24. Projecting from the base 78 of each of the recesses 76 is a mounting post 80 with an internally threaded opening 82. Each mounting post 80 may be positioned to be substantially coaxial with the respective one of the recesses 76. In the assembly forming the support 62, a threaded tip 84 of a guide pin 86 is mated with the internally threaded opening 82 of each mounting post 80. The internally threaded opening 82 of each mounting post 80 is oriented such that the respective guide pin 86 projects in a direction toward the lift plate 66.

[0036] Each of the recesses 76 is also bounded peripherally by a substantially cylindrical sidewall 88 extending to the base 78 and a beveled or flared rim 90 disposed between sidewall 88 and a top surface 92 of the lower electrode 24. The diameter of the flared rim 90, which intersects the top surface 92, is greater than the diameter of the sidewall 88 of each recess 76 and diverges with increasing diameter in a direction toward the top surface.

[0037] Each guide pin 86 includes a substantially cylindrical, non-threaded shank 94 extending from the threaded tip 84 toward a head 96. The head 96 may include a recessed feature 98 that receives the tip of a tool (not shown) used to generate the mated engagement between the threaded tip 84 of guide pin 86 and the internally-threaded opening 82. The head 96 of each guide pin 86, which projects at least partially above the nearby top surface 92 of the lower electrode 24, carries a flared surface 100 located near the non-threaded shank 94. The non-threaded shank 94 of each guide pin 86 and the sidewall 88 of the respective recess 76 have a substantially coaxial arrangement.

[0038] Each of the supports 62 includes a stop block 102 coupled by a respective one of the guide pins 86 with the lift plate 66 of the workpiece fixture 60. Each stop block 102 includes a body 104 with an enlarged head 106 and a central bore or passageway 108 extending the length of the body 104. The radially outward projection of enlarged head 106 relative to the body 104 defines an edge or lip 110, which extends circumferentially about the body 104. The enlarged head 106 of each stop block 102 further includes a first beveled or tapered exterior sidewall 112 that decreases in diameter with increasing distance from the lip 110 and a second beveled or tapered exterior sidewall 114 that increases in diameter with increasing distance from the lip 110. The exterior sidewall 114 is disposed between the lip 110 and the tapered exterior sidewall 112. The passageway 108 includes a substantially cylindrical surface 116 and a beveled or tapered surface 118 that narrows a portion of the substantially cylindrical surface 116.

[0039] A flared recess 120 is defined near each of the peripheral corners of the lift plate 66. The tapered exterior sidewall 112 of each stop block 102 is engaged with a respective one of the flared recesses 120. The depth of each flared recess 120 is selected such that a respective inclined surface 122 of the flared recess 120 and tapered exterior sidewall 112 of each stop block 102 are contacting when the lift plate 66 is secured with the stop blocks 102. The inclination angles of each flared recess 120 and the corresponding tapered exterior sidewall 112 of its stop block 102 are matched to assist in securing the stop blocks 102 with the lift plate 66, yet permit ready removable of the lift plate 66 by a vertical force of sufficient magnitude.

[0040] When mounted to the lift plate 66, the tapered surface 118 of passageway 108 in stop block 102 is located
generally between one of the recesses 76 in the lower electrode 24 and the workpiece fixture 60. Disposed in each of the recesses 76 is a spring element 124, which may have the form of a compression spring formed from a helical coil of wire. Each spring element 124 is confined within the respective recess 76 and is captured between the base 78 and the lip 110 on the respective stop block 102.

[0041] As best shown in FIG. 6, the spring elements 124 are extended when the workpiece fixture 60 is in the raised position. As a result, the lift plate 66 and workpiece ring 68 of the workpiece fixture 60 are supported in a resiliently floating manner atop the supports 62. Under the load supplied by the lift plate 66 and workpiece ring 68, the spring elements 124 collectively have a spring force sufficient to suspend or elevate the lift plate 66 above the top surface 92 of lower electrode 24.

[0042] The tapered surface 118 contacts the flared surface 100 on the head 96 of guide pin 86 to provide a positive stop for vertical motion when the workpiece fixture 60 is in the raised position. The inclination angles of the flared surface 100 and the tapered surface 118 are matched so that each stop block 102 is self-centered on the respective guide pin 86 when the workpiece fixture 60 is in the raised position. This permits the workpiece fixture 60 to return to a reproducible spatial location when residing in the raised position. In turn, this provides a reproducible location within plasma processing system 10 for the workpiece 30 carried by the workpiece fixture 60.

[0043] As explained in detail below, movement of the lid 14 toward a lowered position (FIG. 5) moves the workpiece fixture 60 toward a lowered position and, thereby, compresses the spring elements 124. As the workpiece fixture 60 is lowered, the head 96 of each of the guide pins 86 moves in its respective passageway 108 toward the lift plate 66.

[0044] As best shown in FIGS. 3 and 3A, the workpiece fixture 60 includes a central opening 130 extending entirely through the lift plate 66 and workpiece ring 68, and a gap 132 that extends radially from the central opening 130 to the outer perimeter 65 of the workpiece fixture 60. The cover plate 70 is dimensioned with a width substantially identical to the width of the gap 132. When the workpiece fixture 60 is lowered to a process position, the cover plate 70 fills the gap 132 so that the central opening 130 is surrounded by a substantially planar surface defined collectively by a top surface 134 of the workpiece ring 68 and a top surface 136 of the cover plate 70. To promote the requisite coplanar arrangement, the respective thicknesses of the cover plate 70 and workpiece fixture 60 are selected to be approximately equal, which permits the top surfaces 134, 136 to be approximately flush when the workpiece fixture 60 is in its lowered position. The central opening 130 is rounded in the representative embodiment. However, the central opening 130 may have other shapes, such as rectangular.

[0045] The gap 132 is defined between confronting side walls 133, 135 extending through the thickness of the workpiece ring 68. The width of the gap 132 in the workpiece fixture 60 is selected such that an end effector can pass through the gap 132 and access the central opening 130 for transferring unprocessed workpieces 30 to the workpiece fixture 60 and removing processed workpieces 30 from the workpiece fixture 60. The end effector is operatively coupled with a robot, such as a selective compliant articulated/assembly robot arm (SCARA) robot, as understood by a person having ordinary skill in the art.

[0046] The lower electrode 24 further comprises a removable electrode section 138, which includes a mounting flange 140 situated in a recess defined in the lower electrode 24 and a pedestal portion 142. The pedestal portion 142, which defines a representative workpiece support, projects from the mounting flange 140 toward the upper electrode 22. The electrode section 138 is secured with conventional fasteners to the underlying and surrounding remainder of the lower electrode 24. The top surface 92 of lower electrode 24 and the top surface 92 of the mounting flange 140 are approximately flush. The surface area of a top surface 144 of the pedestal portion 142, which is elevated above the surrounding mounting flange 140, is approximately equal to the open cross-sectional area radially inside the central opening 130. The diameter of the pedestal portion 142 is approximately equal to the diameter of the central opening 130 of workpiece ring 68. The electrode section 138 has a good electrical contact with the remainder of the lower electrode 24 so that the pedestal portion 142 and support 74 are at substantially the same potential as the lower electrode 24 when the plasma processing system 10 is operating and a plasma is present in the processing region 28.

[0047] The cover plate 70 comprises another raised region of the electrode section 138 that projects above the plane of the mounting flange 140. The cover plate 70 and pedestal portion 142 may comprise a single or unitary raised region projecting from the mounting flange 140. Alternatively, the cover plate 70 may comprise a separate component that is mounted to the electrode section 138 and, in this instance, may include locating pins (not shown) or the like used to automatically position the cover plate 70 relative to the central opening 130 in the workpiece fixture 60.

[0048] When the workpiece fixture 60 is lowered to a process position, contact between the workpiece 30 and the top surface 144 of pedestal portion 142 transfers the workpiece 30 from the workpiece ring 68 to the pedestal portion 142. The transfer of the workpiece 30 is accomplished without any structure on the pedestal portion 142, the lower electrode 24, or the base 16 of the enclosure 12 guiding the workpiece 30 onto the pedestal portion 142. In the lowered process position of the workpiece fixture 60, the top surface 134 of workpiece ring 68 is recessed slightly below the top surface 144 of the pedestal portion 142. During plasma treatment, the workpiece 30 rests on the top surface 144 of the pedestal portion 142.

[0049] The electrode section 138 and the lift plate 66 are constructed from an electrical conductor, such as aluminum. The cap 72 on the cover plate 70 and the workpiece ring 68 are constructed from an electrical insulator or dielectric, such as alumina or high-purity alumina. Alternatively, the cap 72 on the cover plate 70 and the workpiece ring 68 may also be constructed from an electrical conductor, such as aluminum. The selection of a constituent material for the cap 72 of the cover plate 70 and the workpiece ring 68 is dictated by the type of plasma performance required in the plasma processing system 10 for a particular plasma process on workpiece 30.

[0050] With reference to FIGS. 3A and 4, one of the push devices 64 is located spatially near each inside corner 15 of separating ring 26 and, as apparent, near each corresponding outside corner (not shown) of the upper electrode 22. Each of the push devices 64 includes a pusher block 150, which is secured with the upper electrode 22 by the cooperation between an insert 152 and a shoulder bolt 154, and a spring
element 156. Each of the pusher blocks 150 has a substantially overlapping relationship with a respective one of the stop blocks 102. One end of the spring element 156, which may have the form of a compression spring formed from a helical coil of wire, is captured between an enlarged head 158 of the pusher block 150 and the upper electrode 22. The pusher block 150 is constructed from an insulating or dielectric material, such as a ceramic, and the insert 152 and shoulder bolt 154 may be formed from a metal, such as a stainless steel. The shoulder bolt 154 has a threaded tip that is fastened in a threaded bore hole in the upper electrode 22. The pusher block 150 of each push device 64 is movable relative to the shoulder bolt 154 between a first position (FIG. 4) in which the spring element 156 is extended and a second position (FIG. 5) in which the spring element 156 is compressed. The spring element 156 supplies a preloaded bias to each pusher block 150 in the first position.

[0051] As the lid 14 is moved toward the base 16, the pusher block 150 of each of the push devices 64 contacts the top surface 134 of workpiece ring 68 and the spring elements 156 begin to compress. As the lid 14 approaches the base 16, the spring elements 156 are further compressed, which applies an increasing force to the workpiece ring 68 that causes the workpiece fixture 60 to move toward the top surface 144 of the pedestal portion 142 and toward the lower electrode 24. When the workpiece fixture 60 is in the fully lowered position, the tapered exterior sidewall 114 on each stop block 102 contacts the flared rim 90 of recess 76 and each pusher block 150 is moved to its second position.

[0052] The inclination angles of the flared rim 90 and tapered exterior sidewall 114 are approximately equal or matched. When the workpiece fixture 60 is in the lowered position, each of the flared rings 90 is in contact with the respective one of the exterior sidewalls 114. The contact automatically self-centers each stop block 102 within its respective recess 76. Consequently, each time that the lid 14 is lowered, the workpiece fixture 60 returns to a reproducible spatial location relative to the lower electrode 24 and removable electrode section 138 when the lid 14 moves the workpiece fixture 60 to the lowered position. In turn, this provides a reproducible location for successive workpieces 30 on the pedestal portion 142 during each sequential plasma treatments.

[0053] With reference to FIGS. 3, 3A, 7, 8A, and 8B in which like reference numbers refer to like features and in accordance with an embodiment of the invention, the plasma processing system 10 further includes a sacrificial ring, which is generally indicated by reference numeral 160. When the bottom surface 29 of workpiece 30 is supported on the top surface 144 of the pedestal portion 142, the sacrificial ring 160 extends circumferentially about an outer peripheral edge 31 encircling the perimeter of the workpiece 30 in a concentric relationship with the workpiece 30.

[0054] The sacrificial ring 160 includes a body 161 consisting of a first section 168 that is mounted to a curved shoulder 164 of the lift plate 66 of workpiece ring 68 and a second section 170 that is mounted to a shoulder 166 of the support 74 of cover plate 70. The first section 168 comprises an arc of greater arc length than the arc presented by the second section 170. The curved shoulder 164, which is defined in the lift plate 66 of the workpiece ring 68, coaxially encircles the central opening 130 and terminates at an intersection with sidewalls 133, 135 that flank the gap 132. The curved shoulder 164, which opens onto the central opening 130, is recessed relative to the top surface 92 of the workpiece ring 68. The curved shoulder 166, which is defined in the support 74 of the cover plate 70, is juxtaposed with the shoulder 164 when workpiece fixture 60 is in the lowered position to geometrically close a complete circular object. Shoulder 166, which also opens onto the central opening 130, is recessed relative to the top surface 136 of the cover plate 70. The sections 168, 170 of the sacrificial ring 160 may be secured with the lift plate 66 and support 74 by a pin-in-socket type engagement using pins 172, 174, respectively.

[0055] The first section 168 of the sacrificial ring 160 includes a ridge 176 and a shoulder or rim 178 that is disposed radially inside of the ridge 176. The ridge 176 of the first section 168 projects above the rim 178 so that the peripheral edge 31 of workpiece 30, which connects the top and bottom surfaces 27, 29 of workpiece 30, overlies the rim 178 and is disposed radially inside of ridge 176. Likewise, the second section 170 of the sacrificial ring 160 includes a ridge 180 and a shoulder or rim 182 that is disposed radially inside of the ridge 180. The ridge 180 of the second section 170 projects above the rim 182 so that the peripheral edge 31 of workpiece 30 overlies the rim 182 and is disposed radially inside of rim 182. The sections 168, 170 may each be formed from multiple segments of material (i.e., a narrow segment having an inner edge with a larger radius of curvature on a wide segment with an inner edge of smaller radius of curvature) or, alternatively, may be machined or molded from a single, integral piece of material.

[0056] The radial dimension or width of the rim 178 is selected such that only a thin annular surface area on the bottom surface 29 and extending about the peripheral edge 31 of the workpiece 30 is contacted by the rim 178. In one embodiment, the contacted width may be an annulus extending approximately equal to 3 millimeters radially inward from the peripheral edge 31 of workpiece 30. The diameter of the central opening 130 in the lift plate 66 is approximately equal to the diameter of the workpiece 30 less the radial dimension of the rims 178, 182.

[0057] As best shown in FIG. 8B, the ridges 176, 180 are aligned with each other, as are the rims 178, 182, in a substantially continuous, annular geometrical shape when the workpiece fixture 60 is in the lowered process position. The relationship between the sections 168, 170 is shown in FIG. 8A with the workpiece fixture 60 in its elevated condition and in FIG. 8B with the workpiece fixture 60 in its lowered condition with the lid 14 closed and ready to process the workpiece 30. The alignment of the ridges 176, 180, when the workpiece fixture 60 is lowered, defines a substantially continuous ring of material with a radial dimension that effectively shifts the location of the outer peripheral edge of the workpiece 30 radially outward toward the outer diameter of the sacrificial ring 160. The top surface of the ridges 176, 180 are substantially co-planar with the adjacent top surface of the workpiece 30. The sacrificial ring 160 has a non-contacting relationship with the workpiece 30 when the workpiece fixture 60 is in its lowered position.

[0058] The sacrificial ring 160, which in one embodiment may be about 10 millimeters wide, is formed from a consumable material that etches when exposed to the plasma. The consumable material may be composed of an organic polymer or another material (i.e., silicon) similar in composition to the material of the workpiece 30 to be plasma etched. Suitable organic polymers may include, but are not limited to, polyetheretherketone (PEEK), polynide, and polyamide or...
nylon. The sacrificial ring 160 may be fabricated from these types of materials by techniques familiar to a person having ordinary skill in the art.

[0059] Organic polymers may be particular suitable materials for the composition of the sacrificial ring 160 if, for example, the plasma of the plasma treatment system 10 is being used to strip a layer of photoresist from the workpiece 30. In this instance, the material composing the sacrificial ring 160 is similar to the composition of the material being removed by plasma etching from the workpiece. When eroded by plasma etching, the material of the sacrificial ring 160 may form etch byproducts that are relatively volatile and, as a result, that are readily evacuated from the processing region 28 by vacuum pump 36. Accordingly, the contamination or residue on the sidewalls 13 of vacuum enclosure 12 and the components therein, including the workpiece 30 itself, from the etching of the sacrificial ring 160 may be negligible.

[0060] The radial dimension of the ridges 176, 180 is selected to optimize the shift in the effective location of the peripheral edge of the workpiece 30. In other words, the workpiece 30 presents a larger effective diameter to the plasma so that the intrinsic zone of relatively high etch rate, which originates from workpiece edge effects, etches the sacrificial ring 160, rather than the workpiece 30 at its peripheral rim. The uniformity of plasma treatment across the workpiece 30 is improved because this higher etch rate is shifted radially outwardly and off the workpiece 30. The ridges 176, 180 are exposed to the plasma in the processing region 28 when the system 10 is used to generate plasma and treat the top surface 27 of the workpiece 30. Generally, the sacrificial ring 160 has an annular geometrical shape characterized by an inner diameter, ID, approximately equal to an outer diameter of the outer peripheral edge 31 of the workpiece 30. The difference in the inner diameter, ID, and the outer diameter of the sacrificial ring 160 defines its effective radial dimension.

[0061] The sacrificial ring 160 can be used to shift the edge effect inherent in plasma treatment from the outer peripheral edge 31 of the workpiece 30 to a perimeter 162 of the sacrificial ring 160. By this mechanism and although not being limited by theory, the sacrificial ring 160 is believed to operate to alleviate or mitigate the workpiece edge effect at the periphery by sacrificing its own treatment uniformity due to preferential etching that increases the etch rate mainly over the consumable material of the sacrificial ring 160. Consequently, the etch rate is more uniform across the workpiece 30 as less variation in etch rate occurs between central and peripheral edge regions of workpiece 30.

[0062] The lifetime of the sacrificial ring 160 for maintaining its effectiveness in effectively shifting the location of the outer peripheral edge of the workpiece 30 may be contingent upon its constituent material and the specifics of the plasma process. The sacrificial ring 160 may be replaced, as necessary, as it is a consumable component.

[0063] The sacrificial ring 160 represents a simple and effective technique for improving the across-wafer uniformity of a plasma treatment in a wafer level application, such as plasma etching, photoresist stripping or descumming, surface cleaning, surface activation, and thin film deposition. The sacrificial ring 160 can be implemented without significantly increasing the capital cost of the plasma treatment system 10. Furthermore, the sacrificial ring 160 can be used to improve the uniformity of plasma treatment across the workpiece without requiring time-consuming or expensive etch processes or etch equipment. Plasma treatment systems can be retrofitted, in a simple and inexpensive manner, with the sacrificial ring 160 to address the etch uniformity problems arising from edge effects.

[0064] References herein to terms such as “vertical”, “horizontal”, etc. are made by way of example, and not by way of limitation, to establish a three-dimensional frame of reference. The term “horizontal” as used herein is defined as a plane substantially parallel to a plane containing one of the confronting surfaces of the electrodes 22, 24, regardless of orientation. The term “vertical” refers to a direction perpendicular to the horizontal, as just defined. Terms, such as “upper”, “lower”, “on”, “above”, “below”, “side” (as in “sidewall”), “higher”, “lower”, “over”, “beneath” and “under”, are defined with respect to the horizontal plane. It is understood various other frames of reference may be employed without departing from the spirit and scope of the invention as a person of ordinary skill will appreciate that the defined frame of reference is relative as opposed to absolute.

[0065] While the invention has been illustrated by a description of various embodiments and while these embodiments have been described in considerable detail, it is not the intention of the applicants to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. The invention in its broader aspects is therefore not limited to the specific details, representative apparatus and methods, and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the spirit or scope of applicant’s general inventive concept. The scope of the invention itself should only be defined by the appended claims.

What is claimed is:

1. An apparatus for use in plasma processing a workpiece having an outer peripheral edge, the apparatus comprising:
   a sacrificial body composed of a plasma-removable material, said sacrificial body adapted to be arranged about the outer peripheral edge of the workpiece so that an outer diameter of the workpiece is effectively increased.

2. The apparatus of claim 1 wherein said sacrificial body includes a plurality of sections arranged to have an annular geometrical shape when placed in a juxtaposed relationship, said plurality of sections configured to be arranged concentrically with the workpiece.

3. The apparatus of claim 1 wherein said sacrificial body is composed of an organic polymer.

4. The apparatus of claim 3 wherein said organic polymer is polyethyetherketone (PEEK), polyimide, or polyamide.

5. The apparatus of claim 1 wherein said sacrificial body is composed of a material similar in composition to a material constituting a portion of the workpiece exposed to the plasma.

6. The apparatus of claim 1 wherein said sacrificial body has an annular geometrical shape and an inner diameter approximately equal to an outer diameter of the outer peripheral edge of the workpiece.

7. An apparatus for plasma processing a workpiece having an outer peripheral edge, a first surface, and a second surface connected by the outer peripheral edge, the apparatus comprising:
   a vacuum enclosure configured to contain a plasma, said vacuum enclosure including a support pedestal adapted
to contact and support the second surface of the workpiece when the first surface of the workpiece is exposed to the plasma; and

a sacrificial body composed of a plasma-removable material, said sacrificial body extending about the outer peripheral edge of the workpiece supported on said pedestal so that an outer diameter of the workpiece is effectively increased.

8. The apparatus of claim 7 wherein said sacrificial body includes a plurality of sections arranged to have an annular geometrical shape when placed in a juxtaposed relationship, said plurality of sections configured to be arranged concentrically with the workpiece.

9. The apparatus of claim 8 further comprising:

a wafer lift mechanism disposed inside said vacuum enclosure, said wafer lift mechanism including a wafer fixture movable between a first position in which said wafer fixture holds the workpiece in a non-contacting relationship with said support pedestal and a second position in which said wafer fixture places the second surface of the workpiece in a contacting relationship with said support pedestal, and said first section of said sacrificial body is carried by said wafer fixture.

10. The apparatus of claim 9 wherein said second section is mounted adjacent to said support pedestal, and said second section is stationary when said wafer fixture is moved between the first and second positions.

11. The apparatus of claim 7 wherein said sacrificial body is composed of an organic polymer.

12. The apparatus of claim 11 wherein said organic polymer is polyetheretherketone (PEEK), polyimide, or polyamide.

13. The apparatus of claim 7 wherein said sacrificial body is composed of a material similar in composition to a material constituting a portion of the workpiece exposed to the plasma.

14. The apparatus of claim 7 wherein said sacrificial body has an annular geometrical shape and an inner diameter approximately equal to an outer diameter of the outer peripheral edge of the workpiece.

15. A method for plasma etching a workpiece having a first surface, a second surface, and an outer peripheral edge connecting the first and second surfaces, the method comprising:

arranging a sacrificial body composed of a plasma-removable material about the outer peripheral edge of the workpiece;

exposing the first surface of the workpiece and the sacrificial body to a plasma; and

shifting a maximum etch rate from a location on the first surface of the workpiece to a different location on the sacrificial body.

16. The method of claim 15 further comprising:

supporting the first surface of the workpiece on a support pedestal positioned inside a vacuum enclosure confining the plasma during the etching process.

17. The method of claim 15 wherein the sacrificial body is divided into a plurality of sections that, when aligned, define an annular geometrical shape, and further comprising:

temporarily supporting the workpiece on a wafer lift mechanism disposed inside the vacuum enclosure;

moving the wafer lift mechanism to transfer the workpiece from the wafer lift mechanism to the support pedestal; and

when the workpiece is transferred, aligning at least one of the sections of the sacrificial body with at least another of the sections of the sacrificial body to define a substantially continuous annular geometrical shape.

18. The method of claim 17 further comprising:

supporting the workpiece on the support pedestal while the first surface of the workpiece is etched.

19. The method of claim 15 further comprising:

eroding the material of the sacrificial body with the exposure to the plasma; and

replacing the sacrificial body with another sacrificial body after sufficient erosion of the sacrificial body occurs.