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(54) APPARATUS AND METHODS FOR IMPROVING TREATMENT UNIFORMITY IN A PLASMA PROCESS

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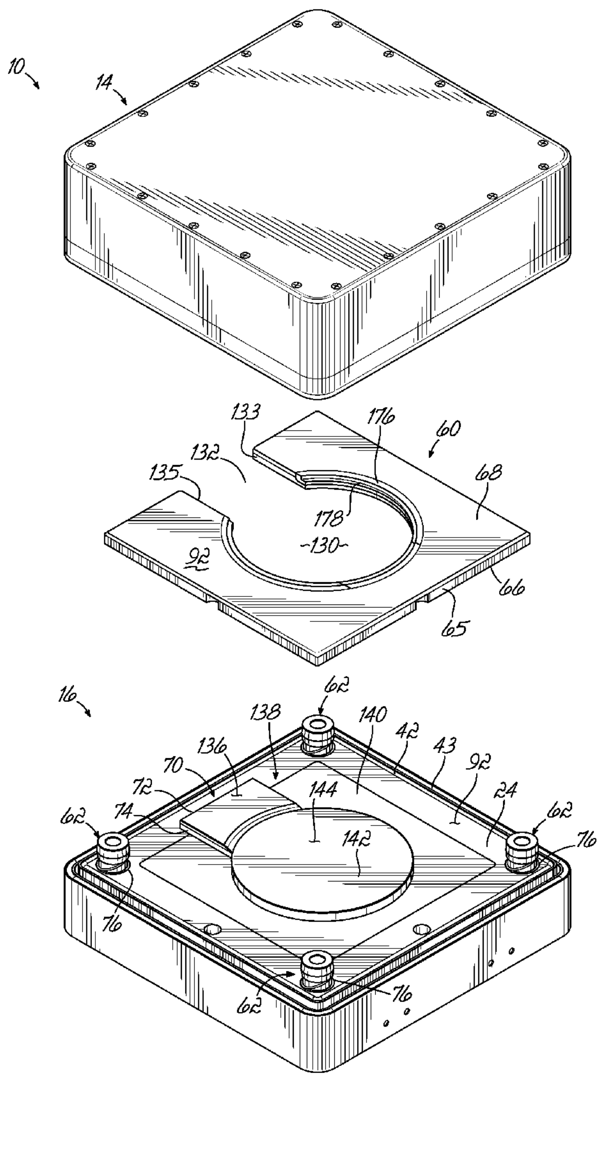
(57) ABSTRACT

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.



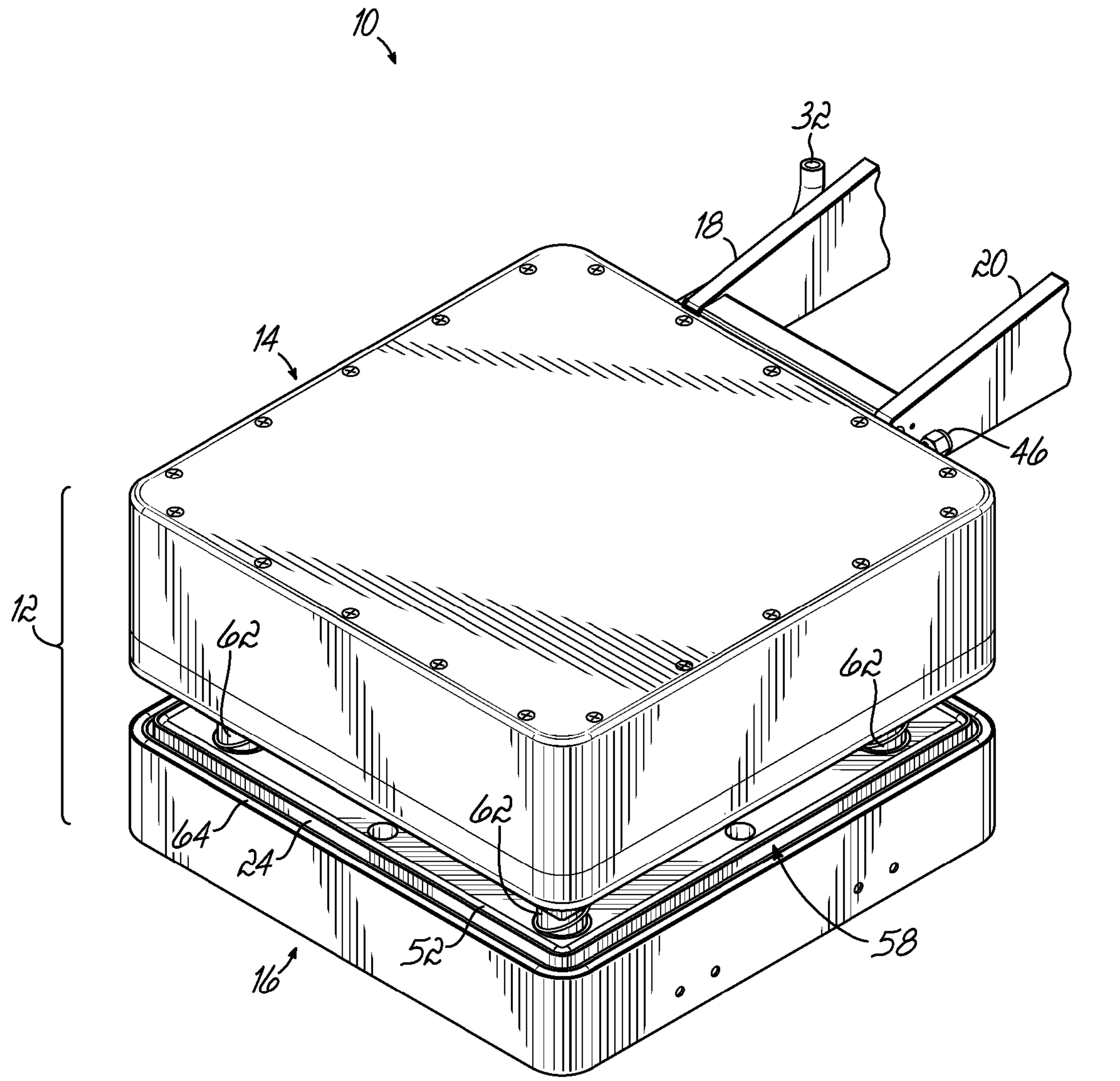
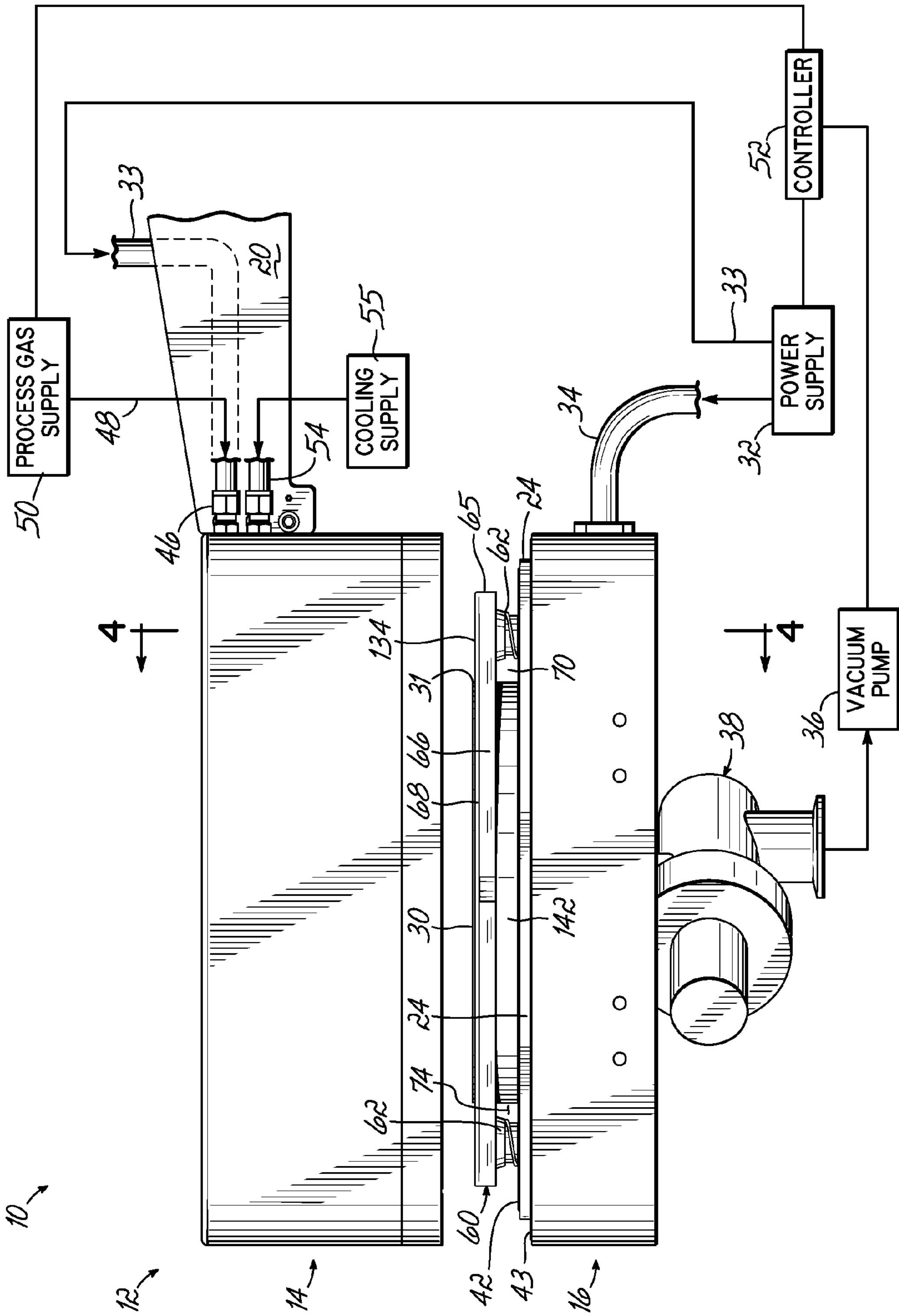



FIG. 1


PROCESS GAS SUPPLY
COOLING SUPPLY
CONTROLLER
POWER SUPPLY
VACUUM PUMP
4
4
10
12
14
16
20
24
30
31
32
33
34
36
38
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48
50
52
54
55
60
62
65
66
68
70
74
134
142

FIG. 2

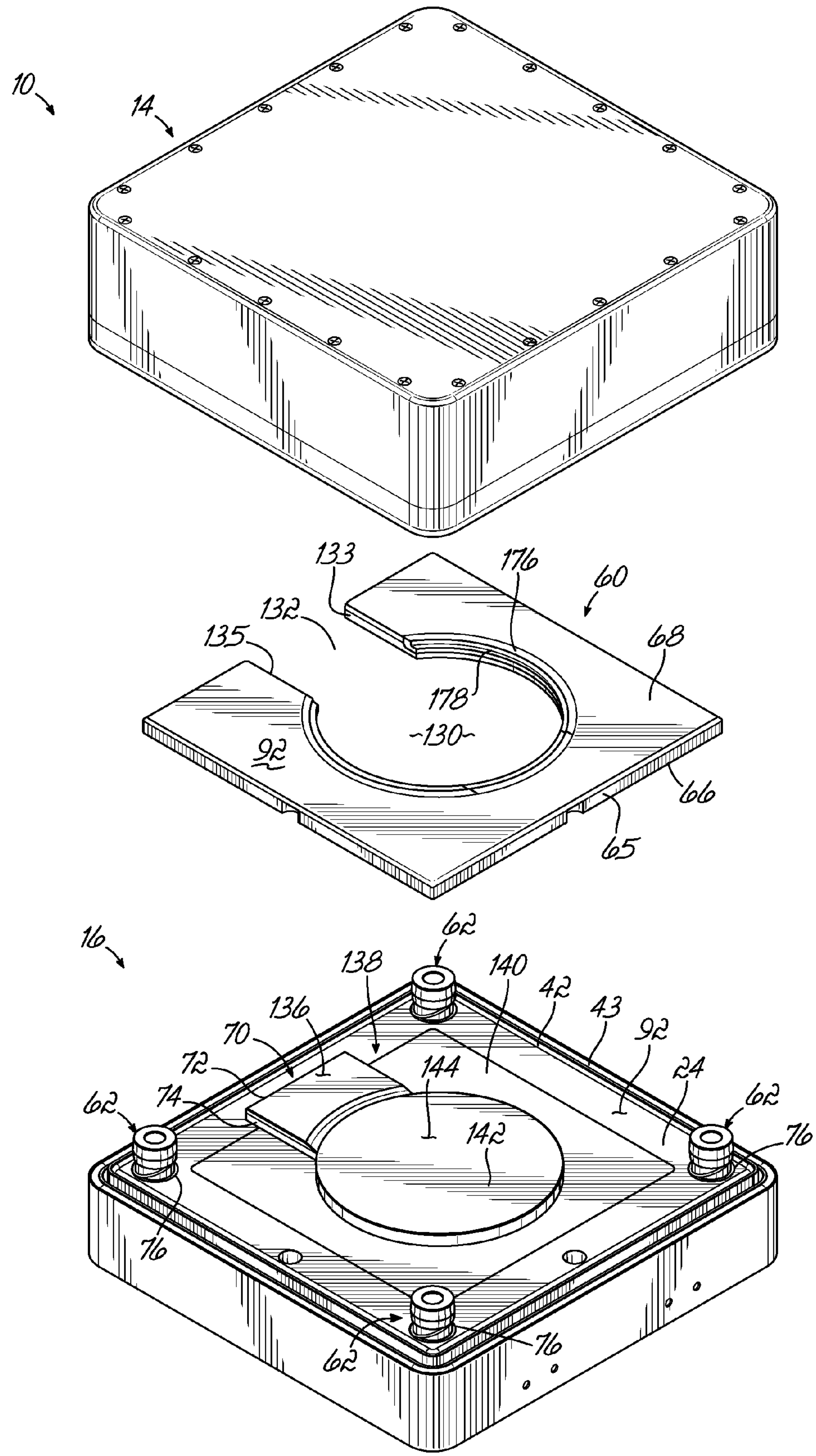

10
14
133
176
60
132
135
68
178
~130~
92
66
65
16
62
138
140
42
43
136
70
92
72
144
24
74
62
62
142
76
76
76
62

FIG. 3

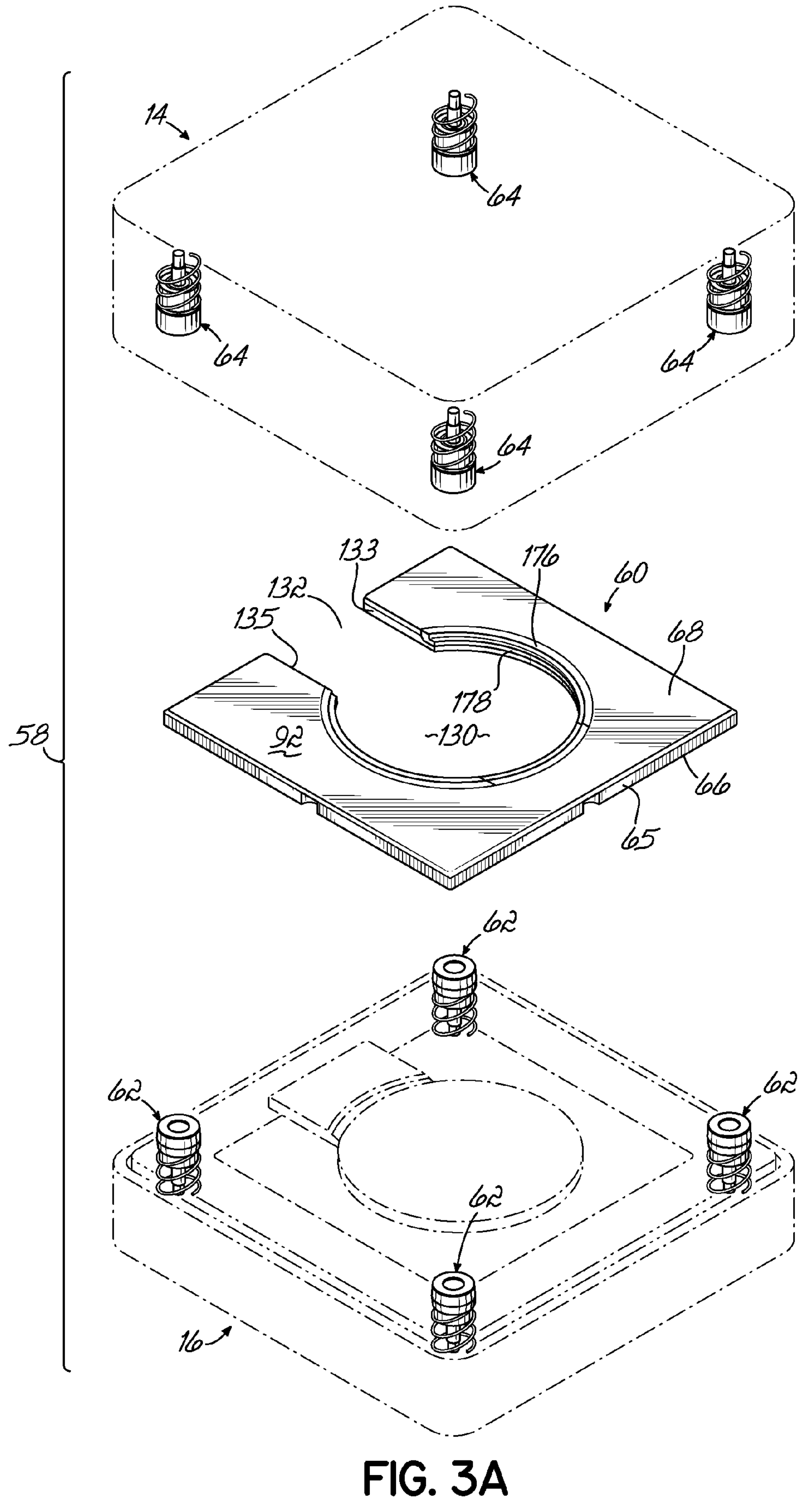

14
64
64
64
64
133
176
60
132
135
68
178
92
~130~
58
66
65
62
62
62
62
16

FIG. 3A

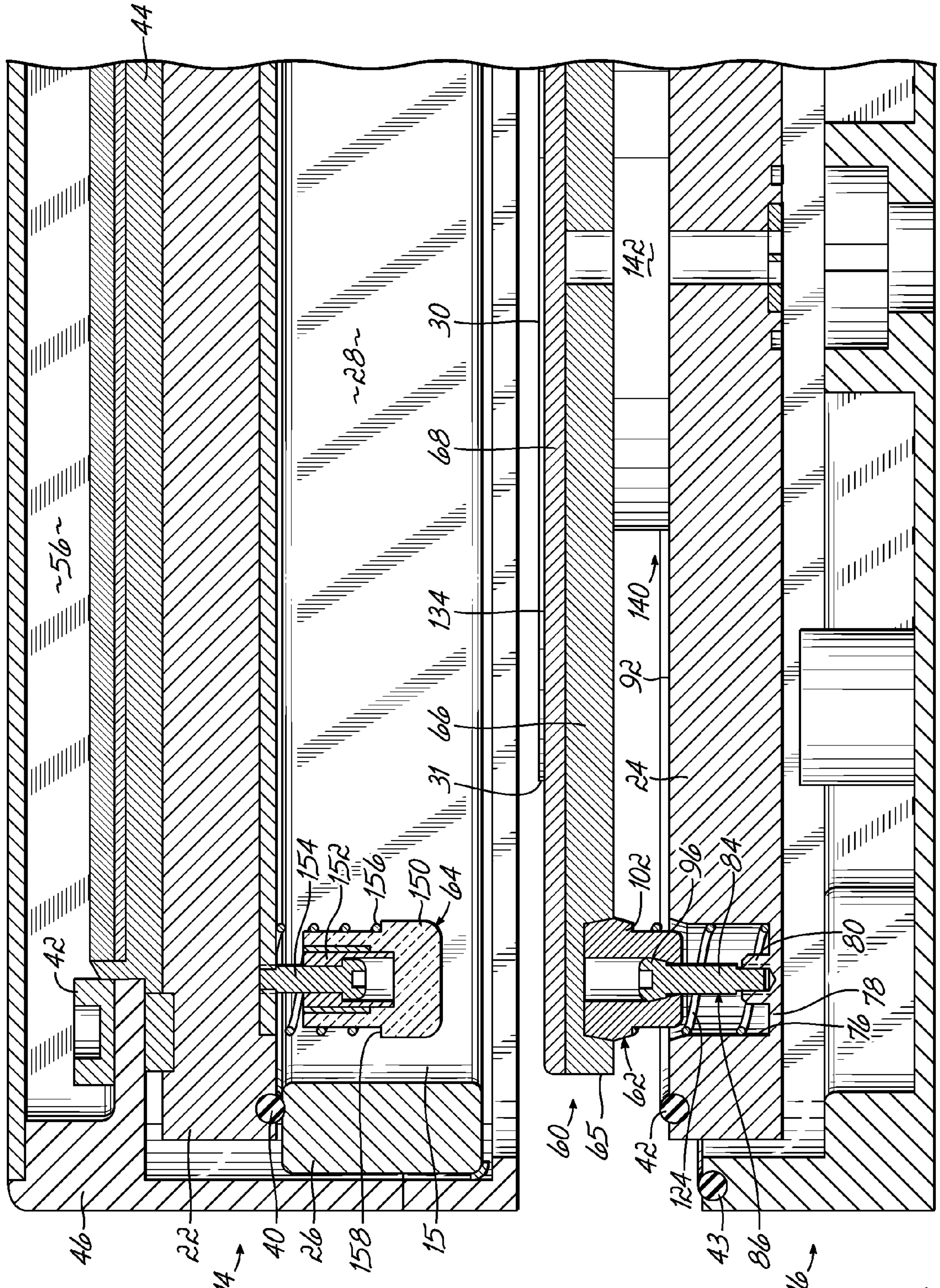
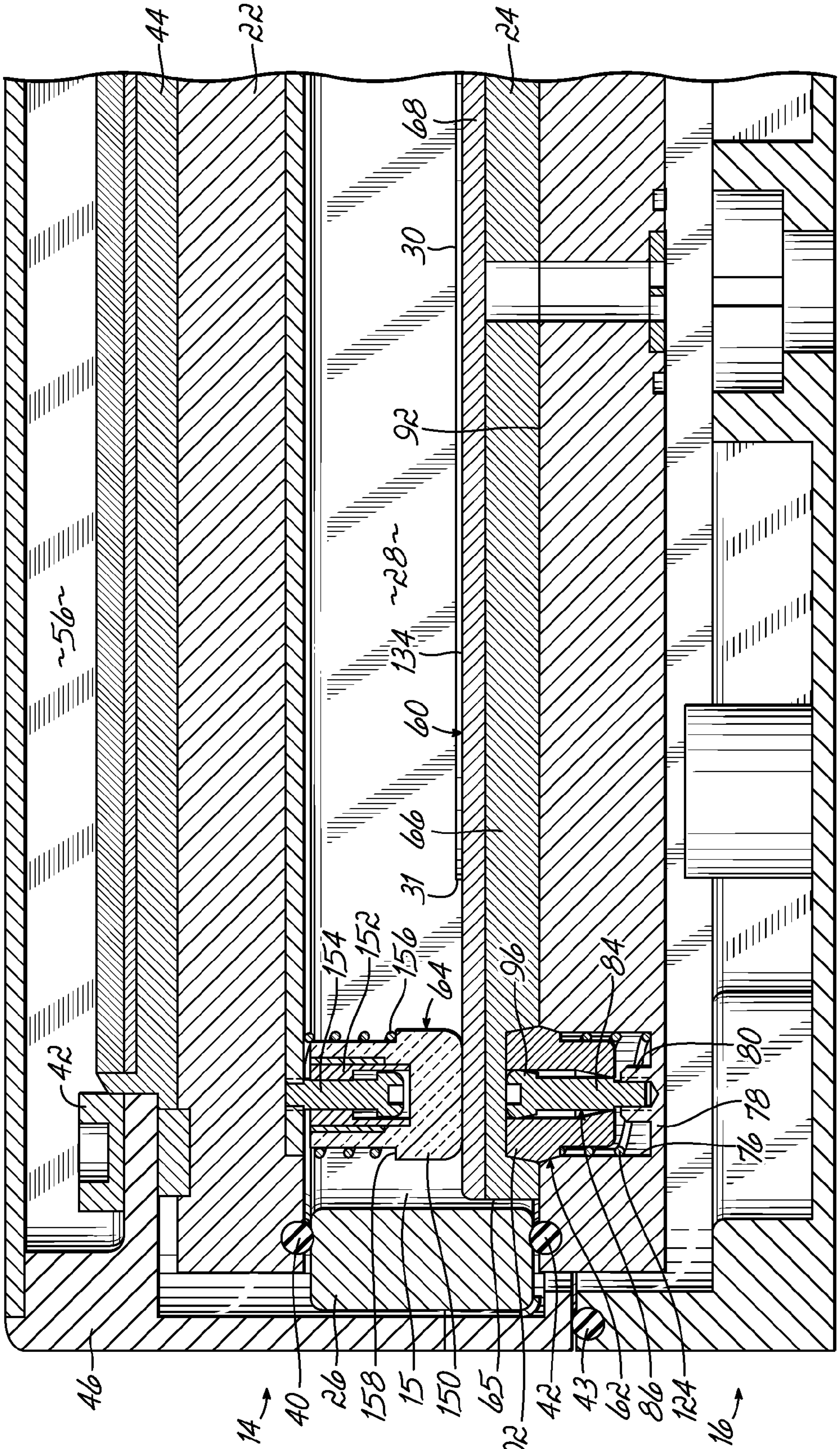

44
~56~
~28~
30
68
134
66
31
154
152
156
150
64
142
140
92
24
102
96
84
80
78
76
42
46
22
14
40
26
158
15
60
65
62
42
124
43
86
16

FIG. 4


44
22
24
68
30
92
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134
60
66
31
154
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64
96
84
80
78
76
~56~
42
46
14
40
26
158
15
150
65
102
42
43
62
86
124
16

FIG. 5

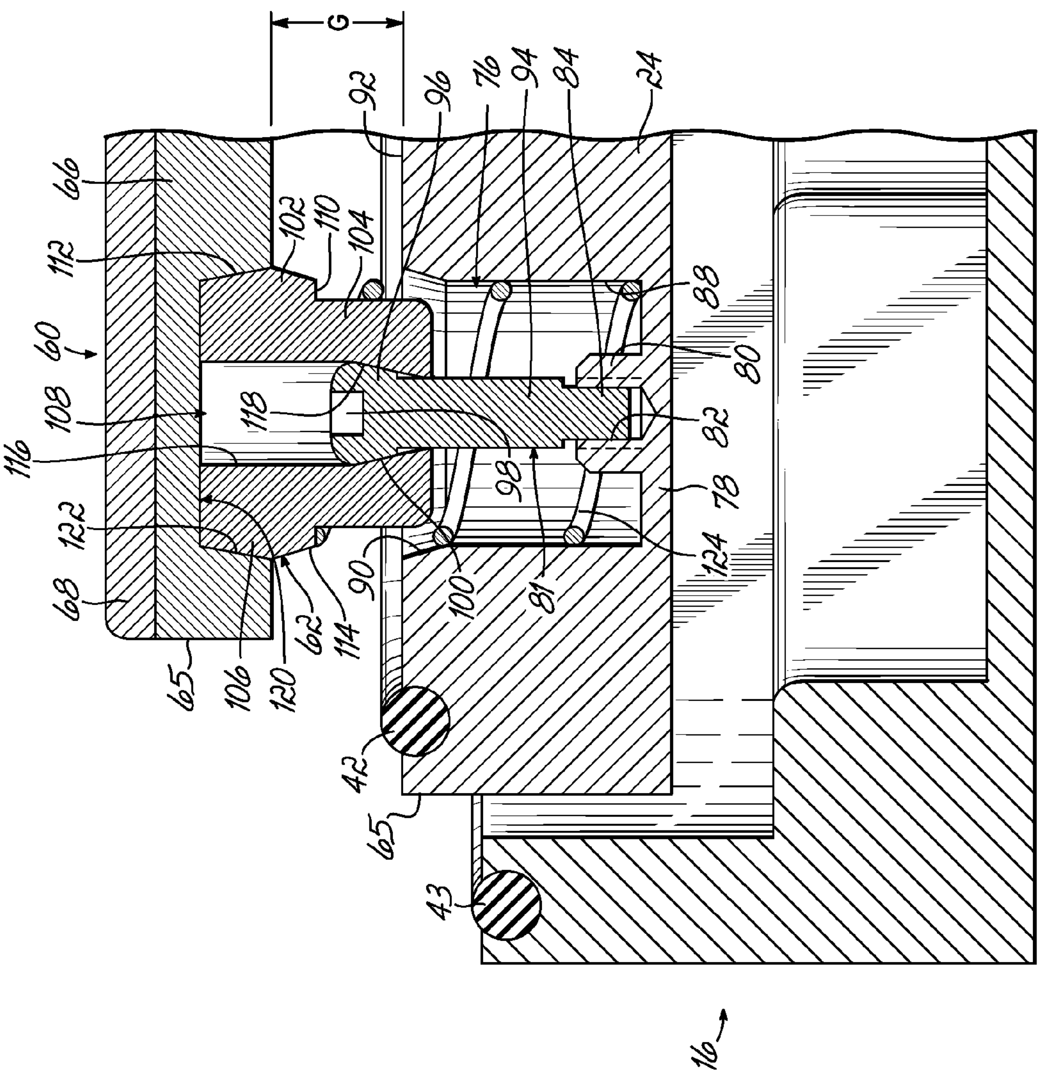
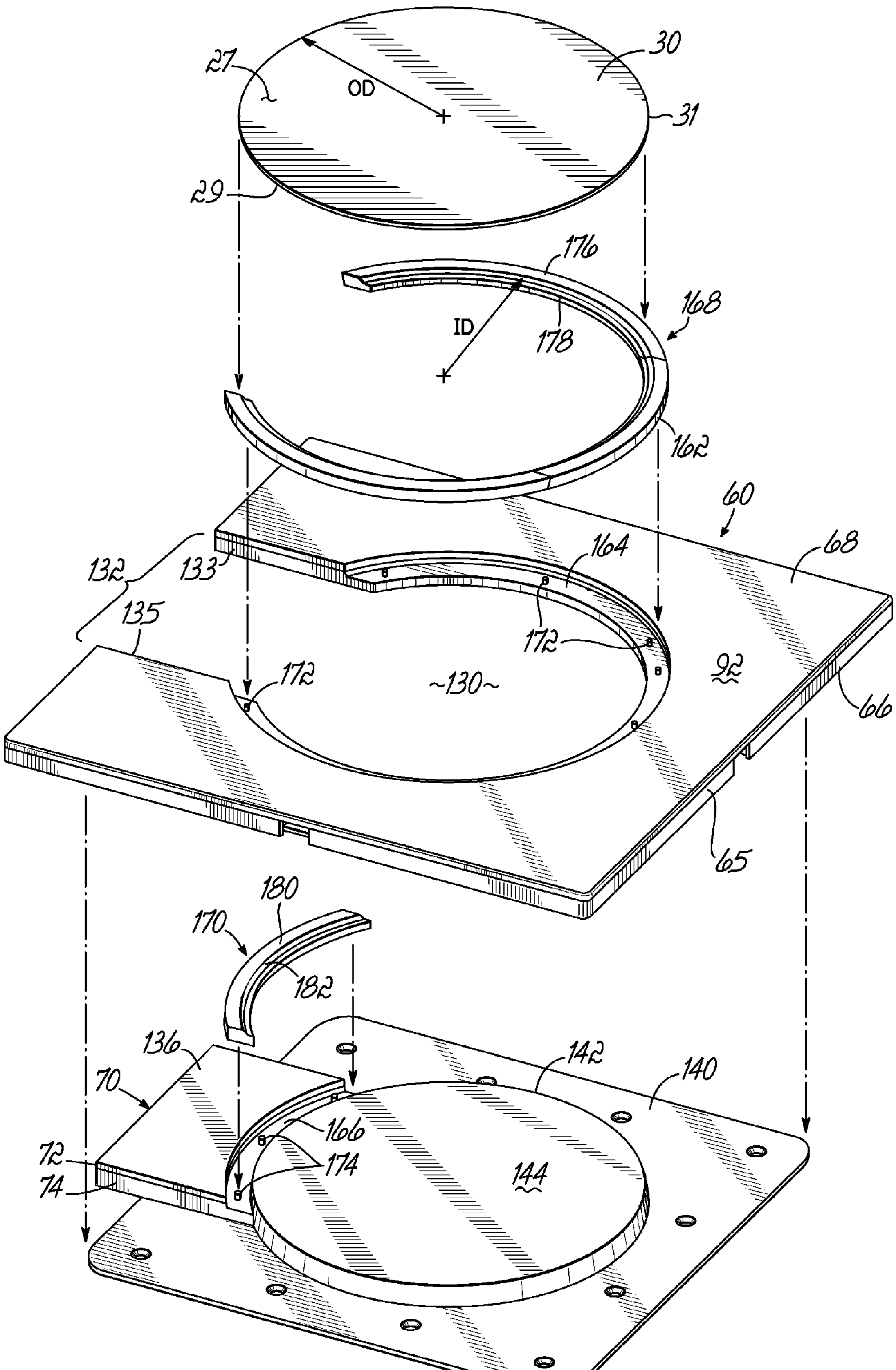

G
92
96
76
94
84
24
66
112
102
110
104
88
60
80
108
118
82
116
98
78
122
68
90
100
81
124
65
106
120
62
114
42
65
43
16

FIG. 6



27
OD
30
31
29
176
ID
168
178
162
60
68
132
133
164
135
172
172
~130~
92
66
65
180
170
182
136
142
140
70
166
72
174
74
144


FIG. 7

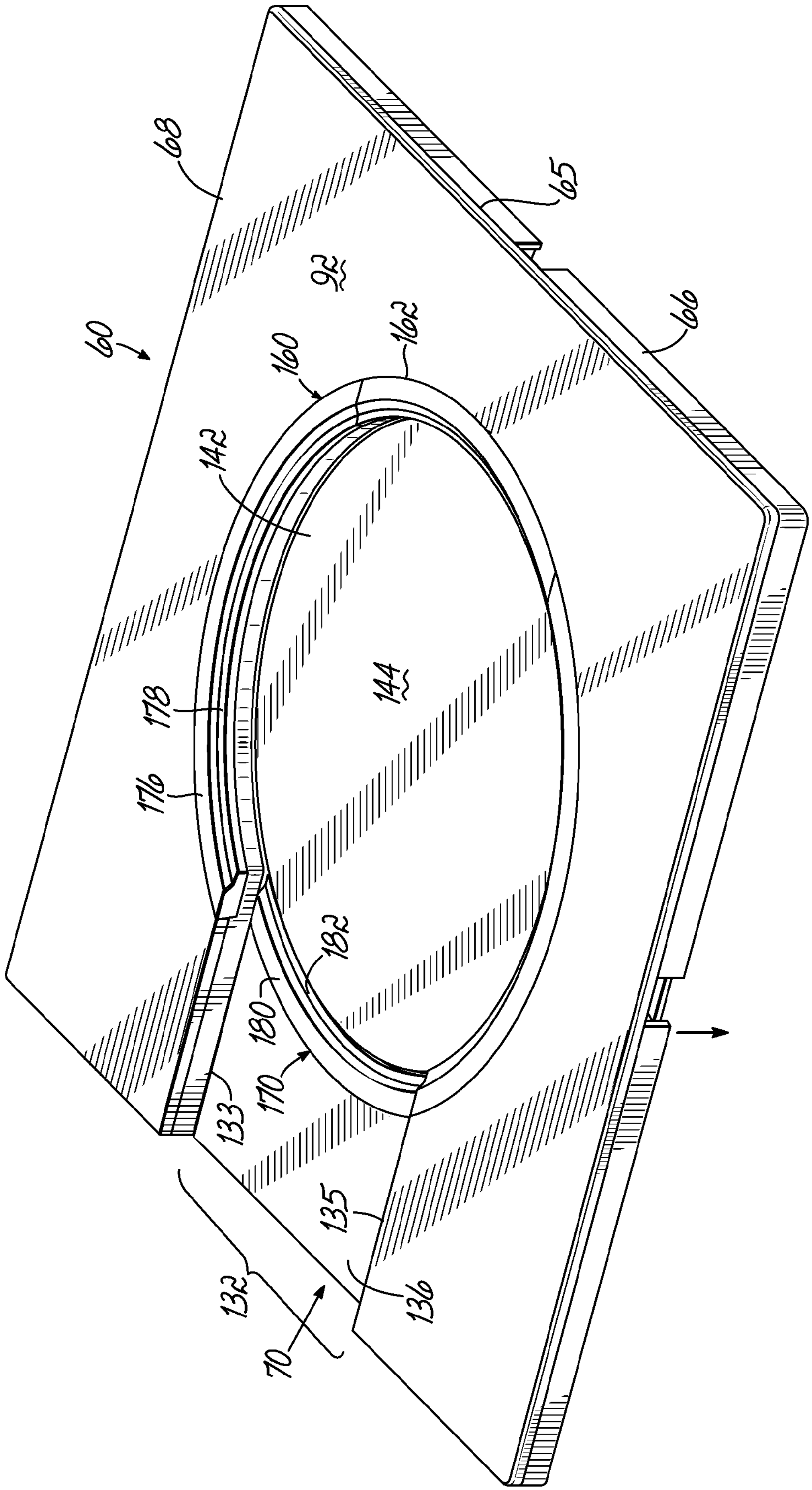

60
68
65
92
66
160
162
142
144
178
176
182
180
170
133
135
136
132
70

FIG. 8A

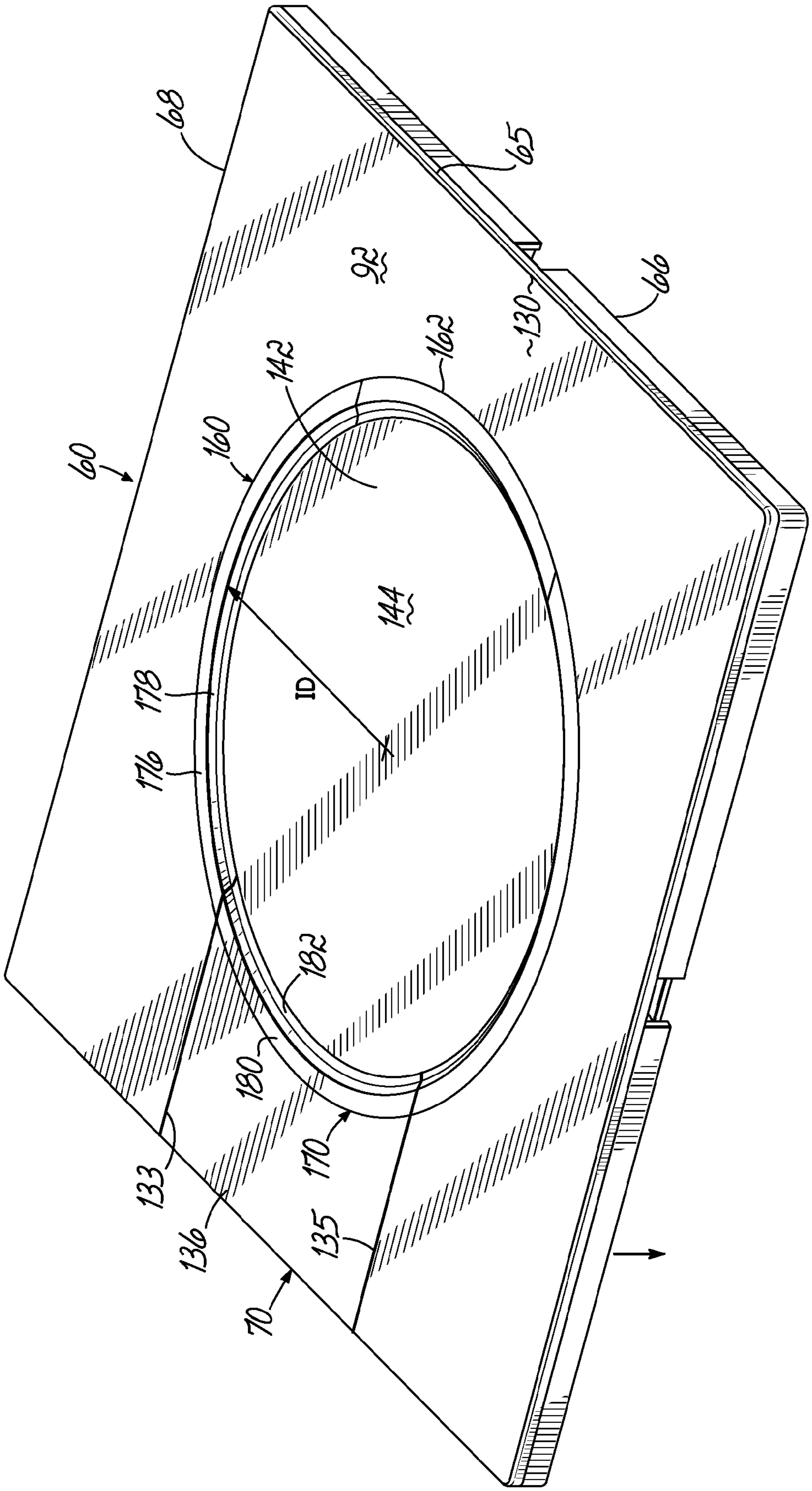

68
65
92
130
66
60
160
162
142
144
ID
178
176
182
180
170
133
136
135
70

FIG. 8B

# 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 about 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. **3**A 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 placed 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. **8**A 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. **8**B is a perspective view similar to FIG. **8**A depicting the wafer lift mechanism in a raised condition.

## DETAILED DESCRIPTION

**[0020]** With reference to FIGS. **1**-**4**, a plasma processing system **10** generally includes a vacuum vessel or enclosure **12** having a lid **14** and a base **16** upon which the lid **14** rests, a pair of support arms **18**, **20** connected to the lid **14**, an upper electrode **22**, and a lower electrode **24**. The processing system **10** further includes a separating member or ring **26** positioned between the upper and lower electrodes **22**, **24** and contacting confronting faces about the perimeter of the upper and lower electrodes **22**, **24**. The confronting faces of the electrodes **22**, **24** are generally planar and parallel plates and have approximately identical surface areas.

**[0021]** The support arms **18**, **20** mechanically couple the lid **14** with a lifting device **28** (not shown) is capable of vertically lifting and lowering the lid **14** relative to the base **16** 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 coaxial 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 effecting 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 impendence 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 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 configured 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 removability 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 **3**A, 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 round in the representative embodiment. However, the central opening **130** may have other shapes, such as rectangular.

**[0045]** The gap **132** is defined between confronting sidewalls **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. **3**A 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 overlying 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 bolt 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 rims **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**, **3**A, **7**, **8**A, and **8**B in which like reference numerals 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. **8**B, 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. **8**A with the workpiece fixture **60** is its elevated condition and in FIG. **8**B 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), polyimide, 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 wishing to be 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 during plasma processes as the preferential edge effect 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 retrofit, 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 polyetheretherketone (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.

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