SEMICONDUCTOR PROCESSING SYSTEM AND METHODS USING CAPACITIVELY COUPLED PLASMA

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ABSTRACT

Substrate processing systems are described that have a capacitively coupled plasma (CCP) unit positioned inside a process chamber. The CCP unit may include a plasma excitation region formed between a first electrode and a second electrode. The first electrode may include a first plurality of openings to permit a first gas to enter the plasma excitation region, and the second electrode may include a second plurality of openings to permit an activated gas to exit the plasma excitation region. The system may further include a gas inlet for supplying the first gas to the first electrode of the CCP unit, and a pedestal that is operable to support a substrate. The pedestal is positioned below a gas reaction region into which the activated gas travels from the CCP unit.
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BACKGROUND OF THE INVENTION

Plasma deposition and etching processes for fabricating semiconductor integrated circuits have been in wide use for decades. These processes typically involve the formation of a plasma from plasma-generating gases that are exposed to electric fields of sufficient power inside the processing chamber to cause the gases to ionize. The temperatures needed to form these gases into plasmas can be much lower than needed to thermally ionize the same gases. Thus, plasma generation processes can be used to generate reactive radicals and ion species from the starting gases at significantly lower chamber processing temperatures than is possible by simply heating the gases. This allows the plasma to deposit and/or etch materials from substrate surfaces without raising the substrate temperature above a threshold that will melt, decompose, or otherwise damage materials on the substrate.

Exemplary plasma deposition processes include plasma-enhanced chemical vapor deposition (PECVD) of dielectric materials such as silicon oxide on exposed surfaces of a substrate wafer. Conventional PECVD involves the mixing together of gases and/or deposition precursors in the processing chamber and striking a plasma from the gases to generate reactive species that react and deposit material on the substrate. The plasma is typically positioned close to the exposed surface of the substrate to facilitate the efficient deposition of the reaction products.

Similarly, plasma etching processes include exposing selected parts of the substrate to plasma activated etching species that chemically react and/or physically sputter materials from the substrate. The removal rates, selectivity, and direction for the plasma etched materials can be controlled with adjustments to the etchant gases, plasma excitation energy, and electrical bias between the substrate and charged plasma species, among other parameters. Some plasma techniques, such as high-density plasma chemical vapor deposition (HDP-CVD), rely on simultaneous plasma etching and deposition to create features on the substrate.

While plasma environments are generally less destructive to substrates than high-temperature deposition environments, they still create fabrication challenges. Etching precision can be a problem with energetic plasmas that over-etch shallow trenches and gaps. Energetic species in the plasmas, especially ionized species, can create unwanted reactions in a deposited material that adversely affect the material’s performance. Thus, there is a need for systems and methods to provide more precise control over the plasma components that make contact with a substrate wafer during fabrication.

BRIEF SUMMARY OF THE INVENTION

Systems and methods are described for improved control of the environment between a plasma and the surfaces of a substrate wafer that are exposed to plasma and/or its effluents. The improved control may be realized at least in part by an ion suppression element positioned between the plasma and the substrate that reduces or eliminates the number of ionically-charged species that reach the substrate. Adjusting the concentration of ion species that reach the substrate surface allows more precise control of the etch rate, etch selectivity, and deposition chemistry (among other parameters) during a plasma assisted etch and/or deposition on the substrate.

In some examples, the ion suppression element may be part of the gas/precursor delivery equipment of a substrate processing chamber. For example, a showerhead positioned inside the chamber between a plasma region and the substrate may act as both a distribution component for gases and precursors as well as an ion suppressor that reduces the amount of ionized species traveling through the showerhead from the plasma region to the substrate. In additional examples, the ion suppression element may be a partition between the plasma region and the substrate that has one or more openings through which plasma effluents may pass from the plasma region to the substrate. The size, position geometry of the openings, the distance between the partition and the substrate, and the electrical bias on the partition, among other characteristics, may be selected to control the amounts of charged species reaching the substrate. In some instances the partition may also act as an electrode that helps generate and define the plasma region in the processing chamber.

Embodiments of the invention include a substrate processing system that has a capacitive coupled plasma (CCP) unit positioned inside the process chamber. The CCP unit may include a plasma excitation region formed between a first electrode and a second electrode. The first electrode may include a first plurality of openings to permit a first gas to enter the plasma excitation region, and the second electrode may include a second plurality of openings to permit an activated gas to exit the plasma excitation region. The system may further include a gas inlet for supplying the first gas to the first electrode of the CCP unit, and a pedestal that is operable to support a substrate. The pedestal is positioned below a gas reaction region into which the activated gas travels from the CCP unit.

Embodiments of the invention further include additional substrate processing systems. These systems may include a gas inlet for supplying a first gas to a processing chamber, an electrode comprising a plurality of openings, and a showerhead. The showerhead may include a first plurality of channels that permit the passage of an activated gas to a gas reaction region in the processing chamber, and a second plurality of channels that permit passage of a second gas to the gas reaction region. The activated gas is formed in a plasma excitation region between the electrode and the showerhead, which also acts as a second electrode. The systems may further include a pedestal positioned below the gas reaction region that is operable to support a substrate.

Embodiments of the invention still further include substrate processing systems having an ion suppressor.
systems may include a gas inlet for supplying a first gas to a processing chamber, an electrode with a first plurality of openings, and the ion suppressor. The ion suppressor may include an electrically conductive plate having a second plurality of openings that permit the passage of an activated gas to a gas reaction region in the processing chamber. The activated gas is formed in a plasma excitation region between the electrode and the ion suppressor. These systems may further include a pedestal, positioned below the gas reaction region, that is operable to support a substrate.

Additional embodiments and features are set forth in part in the description that follows, and in part will become apparent to those skilled in the art upon examination of the specification or may be learned by the practice of the invention. The features and advantages of the invention may be realized and attained by means of the instrumentalities, combinations, and methods described in the specification.

BRIEF DESCRIPTION OF THE DRAWINGS

A further understanding of the nature and advantages of the present invention may be realized by reference to the remaining portions of the specification and the drawings wherein like reference numerals are used throughout the several drawings to refer to similar components. In some instances, a sublabel is associated with a reference numeral and follows a hyphen to denote one of multiple similar components. When reference is made to a reference numeral without specification to an existing sublabel, it is intended to refer to all such multiple similar components.

FIG. 1 shows a simplified cross-sectional view of a processing system that includes a processing chamber having CCP unit and showerhead according to embodiments of the invention;

FIG. 2 shows a simplified perspective view of a processing system that includes a processing chamber having a CCP unit and showerhead according to embodiments of the invention;

FIG. 3 shows a simplified schematic of the gas flow paths of a pair of gas mixtures through a processing system according to embodiments of the invention;

FIG. 4 shows a simplified cross-sectional view of a processing system that includes a processing chamber having a showerhead that also acts as an ion suppression element;

FIG. 5 shows a simplified cross-sectional view of a processing system that includes a processing chamber with an ion suppression plate partitioning a plasma region from gas reaction region according to embodiments of the invention;

FIG. 6A shows a simplified perspective view of an ion-suppression element according to embodiments of the invention;

FIG. 6B shows a simplified perspective view of a showerhead that also act as an ion-suppression element according to embodiments of the invention;

FIG. 7A shows some exemplary hole geometries for the openings in an ion-suppression element according to embodiments of the invention;

FIG. 7B shows a schematic of a hole geometry opening according to embodiments of the invention; and

FIG. 8 shows an exemplary configuration of opposing openings in a pair of electrodes that help define a plasma region in a processing chamber according to embodiments of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Systems and methods are described for the generation and control of a plasma inside a semiconductor processing chamber. The plasma may originate inside the processing chamber, outside the processing chamber in a remote plasma unit, or both. Inside the chamber, the plasma is contained and separated from the substrate wafer with the help of an ion suppression element that is positioned between the plasma and the substrate wafer. In some instances, this ion suppression element may also function as part of a plasma generation unit (e.g., an electrode), a gas/precursor distribution system (e.g., a showerhead), and/or another component of the process system. In additional instances, the ion suppression element may function primarily to define a partition between a plasma generation region and a gas reaction region that etches and/or deposits material on exposed surfaces of the substrate wafer.

The ion suppression element functions to reduce or eliminate the amount of ionically charged species traveling from the plasma generation region to the substrate. Uncharged neutral and radical species may still pass through the openings in the ion suppressor to react with substrate. It should be noted that the complete elimination of ionically charged species in the reaction region surrounding the substrate is not always the desired goal. In many instances, ionic species are required to reach the substrate in order to perform the etch and/or deposition process. In these instances, the ion suppressor helps control the concentration of ionic species in the reaction region at a level that assists the process.

Exemplary Processing System Configurations

Exemplary processing system configurations include an ion suppressor positioned inside a processing chamber to control the type and quantity of plasma excited species that reach the substrate. In some embodiments the ion suppressor unit may be a perforated plate that may also act as an electrode of the plasma generating unit. In additional embodiments the ion suppressor may be the showerhead that distributes gases and excited species to a reaction region in contact with the substrate. In still more embodiments ion suppression may be realized by a perforated plate ion suppressor and a showerhead, both of which plasma excited species pass through to reach the reaction region.

FIGS. 1 and 2 show simplified cross-sectional and perspective views, respectively, of a processing system that includes both an ion suppressor 110 as part of a capacitively coupled plasma (CCP) unit 102 and a showerhead 104 that may also contribute to ion suppression. The processing system may also optionally include components located outside the processing chamber 100, such as fluid supply system 114. The processing chamber 100 may hold an internal pressure different than the surrounding pressure. For example, the pressure inside the processing chamber may be about 10 mTorr to about 20 Torr.

The CCP unit 102 may function to generate a plasma inside the processing chamber 100. The components of the CCP unit 102 may include a lid or hot electrode 106 and an ion suppression element 110 (also referred to herein as an ion suppressor). In some embodiments, the lid 106 and ion suppressor 110 are electrically conductive electrodes that can be electrically biased with respect to each other to generate an electric field strong enough to ionize gases between the electrodes into a plasma. An electrical insulator 108, may separate the lid 106 and the ion suppressor 110 electrodes to prevent them from short circuiting when a plasma is generated. The plasma exposed surfaces of the lid 106, insulator 108, and ion suppressor 110 may define a plasma excitation region 112 in the CCP unit 102.
Plasma generating gases may travel from a gas supply system through a gas inlet into the plasma excitation region. The plasma generating gases may be used to strike a plasma in the excitation region, or may maintain a plasma that has already been formed. In some embodiments, the plasma generating gases may have already been at least partially converted into plasma excited species in a remote plasma system (not shown) positioned outside the processing chamber before traveling downstream through the inlet to the CCP unit. When the plasma excited species reach the plasma excitation region, they may be further excited in the CCP unit, or pass through the plasma excitation region without further excitation. In some operations, the degree of added excitation provided by the CCP unit may change over time depending on the substrate processing sequence and/or conditions.

The plasma generating gases and/or plasma excited species may pass through a plurality of holes (not shown) in the fid for a more uniform delivery into the plasma excitation region. Exemplary configurations include having the inlet open into a gas supply region partitioned from the plasma excitation region by lid so that the gases/species flow through the holes in the lid into the plasma excitation region. Structural and operational features may be selected to prevent significant backflow of plasma from the plasma excitation region back into the supply region, and fluid supply system. The structural features may include the selection of dimensions and cross-sectional geometry of the holes in the lid that deactivates backstreaming plasma, as described below in FIGS. 7A and 7B. The operational features may include maintaining a pressure difference between the gas supply region and plasma excitation region that maintains a unidirectional flow of plasma through the ion suppressor.

As noted above, the lid and the ion suppressor may function as a first electrode and second electrode, respectively, so that the lid and/or ion suppressor receive an electric charge. In these configurations, electrical power (e.g., RF power) may be applied to the lid, ion suppressor, or both. For example, electrical power may be applied to the lid while the ion suppressor is grounded. The substrate processing system may include a RF generator that provides electrical power to the lid and/or ion suppressor. The electrically charged lid may facilitate a uniform distribution of plasma (e.g., reduce localized plasma) within the plasma excitation region. To enable the formation of a plasma in the plasma excitation region, the insulator may electrically insulate the lid and suppressor. Insulator 108 may be made from a ceramic and may have a high breakdown voltage to avoid sparking. The CCP unit may further include a cooling unit that includes one or more cooling fluid channels to cool surfaces exposed to the plasma with a circulating coolant (e.g., water).

The ion suppressor may include a plurality of holes that suppress the migration of ionically-charged species out of the plasma excitation region while allowing uncharged neutral or radical species to pass through the ion suppressor into an activated gas delivery region. These uncharged species may include highly reactive species that are transported with less reactive carrier gas through the holes. As noted above, the migration of ions through the holes may be reduced, and in some instances completely suppressed. Controlling the amount of ionic species passing through the ion suppressor provides increased control over the gas mixture brought into contact with the underlying wafer substrate, which in turn increases control of the deposition and/or etch characteristics of the gas mixture. For example, adjustments in the ion concentration of the gas mixture can significantly alter its etch selectivity (e.g., SiOx:SiNx etch ratios, Poly-Si:SiOx etch ratios, etc.). It can also shift the balance of conformal-to-flowable of a deposited dielectric material.

The plurality of holes may be configured to control the passage of the activated gas (i.e., the ionic, radical, and/or neutral species) through the ion suppressor. For example, the ionic ratio of the holes (i.e., the hole diameter to length) and/or the geometry of the holes may be controlled so that the flow of ionically-charged species in the activated gas passing through the ion suppressor is reduced. The holes in the ion suppressor may include a tapered portion that faces the plasma excitation region, and a cylindrical portion that faces the showerhead. An adjustable electrical bias may also be applied to the ion suppressor as an additional means to control the flow of ionic species through the suppressor.

The showerhead is positioned between the ion suppressor and a gas reaction region. The gas reaction region that makes contact with a substrate that is mounted on a pedestal. The gases and plasma excited species may pass through the ion suppressor into an activated gas delivery region that is defined between the ion suppressor and the showerhead. A portion of these gases and species may further pass thorough the showerhead into a gas reaction region that makes contact with the substrate.

The showerhead may have a dual-zone showerhead that has a first set of channels to permit the passage of plasma excited species, and a second set of channels that deliver a second gas/precursor mixture into the gas reaction region. The two sets of channels prevent the plasma excited species and second gas/precursor mixture from combining until they reach the gas reaction region. In some embodiments, one or more of the holes in the ion suppressor may be aligned with one or more of the channels in the showerhead to allow at least some of the plasma excited species to pass through a hole and a channel without altering their direction of flight. In additional embodiments, the second set of channels may have an annular shape at the opening facing the gas reaction region, and these annular openings may be concentrically aligned around the circular openings of the first set of channels.

The second set of channels in the showerhead may be fluidly coupled to a source gas/precursor mixture that is selected for the process to be performed. For example, when the processing system is configured to perform a deposition of a dielectric material such as silicon dioxide (SiOx) the gas/precursor mixture may include a silicon-containing gas or precursor such as silane, disilane, TFA, DSA, TEOS, OMCTS, TMDSO, among other silicon-containing materials. This mixture may react in gas reaction region with an oxidizing gas mixture that may include plasma excited species such as plasma generated radical oxygen (O), activated molecular oxygen (O2) and ozone (O3), among other species. Excessive ions in the plasma excited
species may be reduced as the species move through the holes 122 in the ion suppressor 110, and reduced further as the species move through the channels 126 in the showerhead 104. In another example, when the processing system is configured to perform an etch on the substrate surface, the source gas/precursor mixture may include etchants such as oxidants, halogens, water vapor and/or carrier gases that mix in the gas reaction region 130 with plasma excited species distributed from the first set of channels in the showerhead 104.

[0037] The processing system may further include a power supply 140 electrically coupled to the CCP unit 102 to provide electric power to the lid 106 and/or ion suppressor 110 to generate a plasma in the plasma excitation region 112. The power supply may be configured to deliver an adjustable amount of power to the CCP unit 102 depending on the process performed. In deposition processes for example, the power delivered to the CCP unit 102 may be adjusted to set the conformity of the deposited layer. Deposited dielectric films are typically more flowable at lower plasma powers and shift from flowable to conformal when the plasma power is increased. For example, an argon containing plasma maintained in the plasma excitation region 112 may produce a more flowable silicon oxide layer as the plasma power is decreased from about 1000 Watts to about 100 Watts or lower (e.g., about 900, 800, 700, 600, or 500 Watts or less), and a more conformal layer as the plasma power is increased from about 1000 Watts or more (e.g., about 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700 Watts or more). As the plasma power increases from low to high, the transition from a flowable to conformal deposited film may be relatively smooth and continuous or progress through relatively discrete thresholds. The plasma power (either alone or in addition to other deposition parameters) may be adjusted to select a balance between the conformal and flowable properties of the deposited film.

[0038] The processing system may still further include a pedestal 150 that is operable to support and move the substrate (e.g., a wafer substrate). The distance between the pedestal 150 and the showerhead 104 help define the gas reaction region 130. The pedestal may be vertically or axially adjustable within the processing chamber 100 to increase or decrease the gas reaction region 130 and effect the deposition or etching of the wafer substrate by repositioning the wafer substrate with respect to the gases passed through the showerhead 104. The pedestal 150 may have a heat exchange channel through which a heat exchange fluid flows to control the temperature of the wafer substrate. Circulation of the heat exchange fluid allows the substrate temperature to be maintained at relatively low temperatures (e.g., about −20 °C. to about 90 °C.). Exemplary heat exchange fluids include ethylene glycol and water.

[0039] The pedestal 150 may also be configured with a heating element (such as a resistive heating element) to maintain the substrate at heating temperatures (e.g., about 90 °C. to about 1100 °C.). Exemplary heating elements may include a single-loop heater element embedded in the substrate support platter that makes two or more full turns in the form of parallel concentric circles. An outer portion of the heater element may run adjacent to a perimeter of the support platter, while an inner portion may run on the path of a concentric circle having a smaller radius. The wiring to the heater element may pass through the stem of the pedestal.

[0040] FIG. 3 shows a simplified schematic 300 of the gas flow paths of a pair of gas mixtures through a processing system that includes both an ion suppressor plate and a showerhead. At block 305, a first gas, such as a plasma generating gas mixture, is supplied to the processing chamber via a gas inlet. The first gas may include one or more of the following gases: CF₄, NH₃, NF₃, Ar, He, H₂O, H₂, O₂, etc. Inside the processing chamber, the first gas may be excited through a plasma discharge to form one or more plasma effluents at block 310. Alternatively (or in addition to the in-situ plasma generation) a remote plasma system (RPS) coupled to the processing chamber may be used generate an ex-situ plasma whose plasma excitation products are introduced into the process chamber. The RPS plasma excitation products may include ionically-charged plasma species as well as neutral and radical species.

[0041] Whether the plasma effluents are generated by an in-situ plasma unit, an RPS unit, or both, they may be passed through an ion suppressor in the processing chamber at block 315. The ion suppressor may block and/or control the passage of ionic species while allowing the passage of radical and/or neutral species as the plasma activated first gas travels to the gas reaction region in the processing chamber. At block 320, a second gas may be introduced into the processing chamber. As noted above, the contents of the second gas depend on the process performed. For example, the second gas may include deposition compounds (e.g., Si-containing compounds) for deposition processes and etchants for etch processes. Contact and reaction between the first and second gases may be prevented until the gases arrive at the gas reaction region of the process chamber.

[0042] One way to prevent the first and second gases from interacting before the gas reaction region is to have them flow through separate channels in a dual-zone showerhead. Block 330 shows the activated first gas and second gas passing through a DZSH that has a first plurality of channels that permit the activated first gas to pass through the showerhead without interacting with the second gas that passes through a second plurality of channels. After exiting the DZSH, the first and second gases may mix together in the gas reaction region of the processing chamber at block 335. Depending on the process performed, the combined gases may react to deposit a material on the exposed surfaces of the substrate, etch materials from the substrate, or both.

[0043] Referring now to FIG. 4, a simplified cross-sectional view of a processing system 400 having a showerhead 402 that also acts as an ion suppression element is shown. In the configuration shown, a first gas source for plasma generation 402 is fluidly coupled to an optional RPS unit 404 where a first plasma may be generated and the plasma effluents transported into the processing chamber 406 through gas inlet 408. Inside the processing chamber 406, the gases may pass through holes 410 in a gas distribution plate 412 into a gas region 414 defined between the plate 412 and showerhead 402. In some embodiments, this region 414 may be a plasma excitation/activation region where the gas distribution plate 412 and showerhead 402 act as first and second electrodes to further excite the gas and/or generate the first plasma. The holes 410 in the gas distribution plate 412 may be dimensionally or geometrically structured to deactivate backstreaming plasma. The plate 412 and showerhead 402 may be coupled with a RF power generator 422 that supplies a charge to the plate 412 and showerhead 402 to excite the gases and/or
generate a plasma. In one embodiment, the showerhead 402 is grounded while a charge is applied to plate 412.  

In one embodiment, the showerhead 402 may pass through showerhead 402 into a gas reaction region 416 and pass through the substrate’s surface. The showerhead 402 may also allow a second gas (i.e., precursor gas/mixture) to flow from an external source (not shown) into the gas reaction region 416 via a second gas inlet (not shown). The DZSH may prevent the activated/excited gas from mixing with the second gas until the gases flow into the gas reaction region 416.  

The excited gas may flow through a plurality of holes 424 in the DZSH, which may be dimensionally and/or geometrically structured to control or prevent the passage of excited species while allowing the passage of activated/excited gases (i.e., reactive radical or uncharged neutral species). FIG. 7A provides exemplary embodiments of hole configurations that may be used in the DZSH. In addition to the holes 424, the DZSH may include a plurality of channels 426 through which the second gas flows. The second gas or precursor gas may exit the showerhead 402 through one or more apertures (not shown) that are positioned adjacent holes 424. The DZSH may act as a second gas delivery system and an ion suppression element.  

As described above, the mixed gases may deposit a material and/or etch the surface of the substrate 418, which may be positioned on a plate 420. The plate 420 may be vertically movable within the processing chamber 406. The processing of the substrate 418 within the processing chamber 406 may be affected by the configurations of the holes 424, the pressure within the gas region 414, and/or the position of the substrate 418 within the processing chamber. Further, the configuration of the holes 424 and/or pressure within the gas region 414 may control the amount of ion species (plasma) allowed to pass into the gas reaction region 416. The ionic concentration of the gas mixture can shift the balance of conformal-to-etchable of a deposited dielectric material in addition to altering the etch selectivity.  

Referring now to FIG. 5, a simplified cross-sectional view of another processing system 500 having a plate 512 (i.e., ion suppressor plate) that acts as an ion suppression element is shown. In the configuration shown, a first gas source 502 is fluidly coupled to an RPS unit 504 where a first plasma may be generated and the plasma effluents transported into the processing chamber 506 through gas inlet 508. The plasma effluents may be transported to a gas region 514 defined between the ion suppressor plate 512 and the gas inlet 508. Inside the gas region 514, the plasma may pass through holes 510 in the ion suppressor plate 512 into a gas reaction/activation region 516 defined between the ion suppressor plate 512 and a substrate 528. The substrate 518 may be supported on a plate 520 as described above so that the substrate is movable within the processing chamber 506.  

Also as described above, the holes 510 may be dimensionally and/or geometrically structured so that the passage of ionically charged species (i.e., plasma) is prevented and/or controlled while the passage of uncharged neutral or radical species (i.e., activated gas) is permitted. The passage of ionic species may be controllable by varying the pressure of the plasma within gas region 514. The pressure in gas region 514 may be controlled by controlling the amount of gas delivered through gas inlet 508. The precursor gas (i.e., second gas) may be introduced into the processing chamber 506 at one or more second gas inlets 522 positioned vertically below or parallel with ion suppressor 512. The second gas inlet 522 may include one or more apertures, tubes, etc. (not shown) in the processing chamber 506 walls and may further include one or more gas distribution channels (not shown) to deliver the precursor gas to the apertures, tubes, etc. In one embodiment, the ion suppressor 512 includes one or more second gas inlets, through which the precursor gas flows. The second gas inlets of the ion suppressor 512 may deliver the precursor gas into the gas reaction region 516. In such an embodiment, the ion suppressor 512 functions as both an ion suppressor and a dual zone showerhead as described previously. The activated gas that passes through the holes 510 and the precursor gas introduced in the processing chamber 506 may be mixed in the gas reaction chamber 516 for etching and/or deposition processes.  

Having now described exemplary embodiments of processing chambers, attention is now directed to exemplary embodiments of ion suppressors, such as ion suppressor plates 412 and 512 and showerhead 402.  

Exemplary Ion Suppressors  

FIG. 6A shows a simplified perspective view of an ion-suppression element 600 (ion suppressor) according to embodiments of the invention. The ion suppression element 600 may correspond with the ion suppressor plates of FIGS. 4 and/or 5. The perspective view shows the top of the ion suppression element or plate 600. The ion suppression plate 600 may be generally circular shaped and may include a plurality of plasma effluent passageways 602, where each of the passageways 602 includes one or more through holes that allow passage of the plasma effluents from a first region (e.g., plasma region) to a second region (e.g., gas reaction region or showerhead). In one embodiment, the through holes of the passageway 602 may be arranged to form one or more circular patterns, although other configurations are possible. As described previously, the through holes may be geometrically or dimensionally configured to control or prevent the passage of ion species while allowing the passage of uncharged neutral or radical species. The through holes may have a larger inner diameter toward the top surface of the ion suppression plate 600 and a smaller inner diameter toward the bottom surface of the ion suppression plate. Further, the through holes may be generally cylindrical, conical, or any combination thereof. Exemplary embodiments of the configurations of the through holes are provided in FIGS. 7A-B.  

The plurality of passageways may be distributed substantially evenly over the surface of the ion suppression plate 600, which may provide even passage of neutral or radical species through the ion suppression plate 600 into the second region. In some embodiments, such as the embodiment of FIG. 5, the processing chamber may only include an ion suppression plate 600, while in other embodiments, the processing chamber may include both an ion suppression plate 600 and a showerhead, such as the showerhead of FIG. 6B, or the processing chamber may include a single plate that acts as both a dual zone showerhead and an ion suppression plate.  

FIG. 6B shows a simplified bottom view perspective of a showerhead 620 according to embodiments of the invention. The showerhead 620 may correspond with the showerhead illustrated in FIG. 4. As described previously, the showerhead 620 may be positioned vertically adjacent to and
above a gas reaction region. Similar to ion suppression plate 600, the showerhead 620 may be generally circular shaped and may include a plurality of first holes 622 and a plurality of second holes 624. The plurality of first holes 622 may allow plasma effluents to pass through the showerhead 620 into a gas reaction region, while the plurality of second holes 624 allows a precursor gas, such as a silicon precursor, etchants etc., to pass into the gas reaction region.

[0054] The plurality of first holes 622 may be through holes that extend from the top surface of the showerhead 620 through the showerhead. In one embodiment, each of the plurality of first holes 622 may have a smaller inner diameter (ID) toward the top surface of the showerhead 620 and a larger ID toward the bottom surface. In addition, the bottom edge of the plurality of first holes 622 may be chamfered 626 to help evenly distribute the plasma effluents in the gas reaction region as the plasma effluents exit the showerhead and thereby promote even mixing of the plasma effluents and precursor gases. The smaller ID of the first holes 622 may be between about 0.5 mm and about 20 mm. In one embodiment, the smaller ID may be between about 1 mm and 6 mm. The cross sectional shape of the first holes 622 may be generally cylindrical, conical, or any combination thereof. Further, the first holes 622 may be concentrically aligned with the through holes of passageways 602, when both and ion suppression element 600 and a showerhead 620 are used in a processing chamber. The concentric alignment may facilitate passage of an activated gas through both the ion suppression element 600 and the showerhead 620 in the processing chamber.

[0055] In another embodiment, the plurality of first holes may 622 be through holes that extend from the top surface of the showerhead 620 through the showerhead, where each of the first holes 622 have a larger ID toward the top surface of the showerhead and a smaller ID toward the bottom surface of the showerhead. Further, the first holes 622 may include a taper region that transition between the larger and smaller IDs. Such a configuration may prevent or regulate the passage of a plasma through the through holes while permitting the passage of an activated gas. Such embodiments may be used in place or in addition to ion suppression element 600. Example embodiments of such through holes are provided in FIG. 7A.

[0056] The number of the plurality of first holes 622 may be between about 60 and about 2000. The plurality of first holes 622 may have a variety of shapes, but are generally round. In embodiments where the processing chamber includes both a ion suppression plate 600 and a showerhead 620, the plurality of first holes 622 may be substantially aligned with the passageways 602 to facilitate passage of the plasma effluents through the ion suppression plate and showerhead.

[0057] The plurality of second holes 624 may extend partially through the showerhead from the bottom surface of the showerhead 620 partially through the showerhead. The plurality of second holes may be coupled with or connected to a plurality of channels (not shown) that deliver the precursor gas (e.g., deposition compounds, etchants, etc.) to the second holes 624 from an external gas source (not shown). The second holes may include a smaller ID at the bottom surface of the showerhead 620 and a larger ID in the interior of the showerhead. The number of second holes 624 may be between about 100 and about 5000 or between about 500 and about 2000 in different embodiments. The diameter of the second hole’s smaller ID (i.e., the diameter of the hole at the bottom surface) may be between about 0.1 mm and about 2 mm. The second holes 624 are generally round and may likewise be cylindrical, conical, or any combination thereof. Both the first and second holes may be evenly distributed over the bottom surface of the showerhead 620 to promote even mixing of the plasma effluents and precursor gases.

[0058] With reference to FIG. 7A, exemplary embodiments of the configurations of the through holes are shown. The through holes depicted generally include a large inner diameter (ID) region toward an upper end of the hole and a smaller ID region toward the bottom or lower end of the hole. The smaller ID may be between about 0.2 mm and about 5 mm. Further the aspect ratio of the holes (i.e., the smaller ID to hole length) may be approximately 1 to 20. Such configurations may substantially block and/or control passage of ion species of the plasma effluent while allowing the passage of radical or neutral species. For example, varying the aspect ratio may regulate the amount of plasma that is allowed to pass through the through holes. Plasma passage may further be regulated by varying the pressure of the plasma within a region directly above the through holes.

[0059] Referring now to specific configurations, through hole 702 may include a large ID region 704 at an upper end of the hole and a small ID region 706 at a lower end of the hole with a stepped edge between the large and small IDs. Through hole 710 may include a large ID region 712 on an upper end and a large ID region 716 on a lower end of the hole with a small ID region 714 therebetween. The transition between the large and small ID regions may be stepped or blunt to provide an abrupt transition between the regions.

[0060] Through hole 720 may include a large ID region 722 at the upper end of the hole and small ID region 726 at a lower end of the hole with a tapered region 724 that transitions at an angle θ between the large and small regions. The height 728 of the small ID region 726 may depend on the overall height 727 of the hole, the angle θ of tapered region 724, the large ID, and the small ID. In one embodiment, the tapered region 724 comprises an angle of between about 15° and about 30°, preferably about 22°; the overall height 727 is between about 4 mm and about 8 mm, and preferably about 6.35 mm; the large ID is between about 1 mm and about 4 mm, and preferably about 2.54 mm; the small ID is between about 0.2 mm and 1.2 mm, and preferably about 0.89 mm, so that the height 728 of the small ID region 726 is between about 1 mm and about 3 mm, and preferably about 2.1 mm.

[0061] Through hole 730 may include a first ID region 732 at the upper end of the hole, a second ID region 734 concentrically aligned and positioned vertically below first ID region 732, and a third ID region 736 concentrically aligned with and positioned vertically below second ID region 734. First ID region 732 may comprise a large ID, second ID region 734 may comprise a small ID, and third ID region 736 may comprise a slightly larger ID than second ID region 734. Third ID region 736 may extend to the lower end of the hole or may be outwardly tapered to an exit ID 737. The taper between the third ID region 736 and the exit ID 737 may taper at an angle θ, which may be between about 15° and about 30°, and preferably about 22°.

[0062] The second ID region 734 may include a chamfered edge that transitions from the first ID region 732 at an angle θ, which may be between about 110° and about 140°. Similarly, the second ID region 734 may include a chamfered edge that transitions into the third ID region 736 at an angle θ, which may also be between about 110° and about 140°.
embodiment, the large ID of first region 732 may be between about 2.5 mm and about 7 mm, and preferably about 3.8 mm; the small ID of second ID region 734 may be between about 0.2 mm and about 5 mm, and preferably about 0.04 mm; the slightly larger ID of third ID region 736 may be between about 0.75 mm and about 2 mm, and preferably about 1.1 mm; and the exit ID may be between about 2.5 mm and about 5 mm, and preferably about 3.8 mm.

[0063] The transition (blunt, stepped, tapered, etc.) between the large ID regions and small ID regions may substantially block the passage of ion species from passing through the holes while allowing the passage of radical or neutral species. For example, referring now to FIG. 7B, shown is an enlarged illustration of through hole 720 that includes the transition region 724 between the large ID region 722 and the small ID region 726. The tapered region 724 may substantially prevent plasma 725 from penetrating through the through hole 720. For example, as the plasma 725 penetrates into the through hole 720, the ion species may deactivate or ground out by contacting the walls of the tapered region 724, thereby limiting the passage of the plasma through the hole and containing the plasma within the region above the through hole 720. The radical or neutral species, however, may pass through the through hole 720. Thus, the through hole 720 may filter the plasma 720 to prevent or control the passage of unwanted species. In an exemplary embodiment, the small ID region 726 of the through holes comprises an ID of 1 mm or smaller. To maintain a significant concentration of radical and/or neutral species penetrating through the through holes, the length of the small ID region and/or the taper angle may be controlled.

[0064] In addition to preventing the passage of plasma, the through holes described herein may be used to regulate the passage of plasma so that a desired level of plasma is allowed to pass through the through hole. Regulating the flow of plasma through the through holes may include increasing the pressure of the plasma in the gas region above the ion suppressor plate so that a desired fraction of the plasma is able to pass through the ion suppressor without deactivating or grounding out.

[0065] Referring now to FIG. 8, a simplified illustration of a capacitively coupled plasma (CCP) unit 800 is shown. Specifically, the CCP unit 800 shown includes a top plate 802 and a bottom plate 804 that define a plasma generation region 810 in which a plasma is contained. As previously described, the plasma may be generated by an RPS (not shown) and delivered to the plasma generation region 810 via through hole 806. Alternatively or additionally, the plasma may be generated in the CCP unit 800, for example, by utilizing top plate 802 and bottom plate 804 as first and second electrodes coupled to a power generation unit (not shown).

[0066] The top plate 802 may include a through hole 806 that allows process gas and/or plasma to be delivered into the plasma generation region 810 while preventing backstreaming of plasma through the top plate 802. The through hole 806 may be configured similar to through hole 730 having first, second, and third ID regions (820, 822, and 824 respectively), with a chamfered edge between adjacent regions (828 and 829) and a tapered region 826 transitioning between third ID region 824 and an exit ID. The tapered region 826 between third ID region 824 and the exit ID and/or the chamfered edge between second and third ID regions (822 and 824 respectively) may prevent backstreaming of plasma by deactivating or grounding ion species as the plasma penetrates into the through hole 806.

[0067] Similarly, the bottom plate 804 may include a through hole 808 that allows the radical or neutral species to pass through the through hole while preventing or controlling the passage of ion species. The through hole 808 may be configured similar to through hole 720 having a large ID region 830, a small ID region 832, and a tapered region 834 that transitions between the large ID region 830 and the small ID region 832. The tapered region 834 may prevent the flow of plasma through the through hole 808 by deactivating or grounding ion species as previously explained while allowing radical or neutral species to pass therethrough.

[0068] To further prevent passage of the plasma through the through holes, 802 and/or 804, the top plate 802 and/or bottom plate 804 may receive a charge to electrically bias the plasma and contain the plasma within plasma generation region 810 and/or adjust an ion concentration in the activated gas that passes through the bottom plate. Using top plate 802 and bottom plate 804 in CCP unit 800, the plasma may be substantially generated and/or maintained in the plasma generation region 810, while radical and neutral species are delivered to a gas reaction region to be mixed with one or more precursor gases to etch material from or deposit material on a substrate surface.

[0069] Having described several embodiments, it will be recognized by those of skill in the art that various modifications, alternative constructions, and equivalents may be used without departing from the spirit of the invention. Additionally, a number of well-known processes and elements have not been described in order to avoid unnecessarily obscuring the present invention. Accordingly, the above description should not be taken as limiting the scope of the invention.

[0070] Where a range of values is provided, it is understood that each intervening value, to the tenth of the unit of the lower limit unless the context clearly dictates otherwise, between the upper and lower limits of that range is also specifically disclosed. Each smaller range between any stated value or intervening value in a stated range and any other stated or intervening value in that stated range is encompassed. The upper and lower limits of these smaller ranges may independently be included or excluded in the range, and each range where either, neither or both limits are included in the smaller ranges is also encompassed within the invention, subject to any specifically excluded limit in the stated range. Where the stated range includes one or both of the limits, ranges excluding either or both of those included limits are also included.

[0071] As used herein and in the appended claims, the singular forms “a”, “an”, and “the” include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to “a process” includes a plurality of such processes and reference to “the electrode opening” includes reference to one or more electrode openings and equivalents thereof known to those skilled in the art, and so forth.

[0072] Also, the words “comprise,” “comprising,” “include,” “including,” and “includes” when used in this specification and in the following claims are intended to specify the presence of stated features, integers, components, or steps, but they do not preclude the presence or addition of one or more other features, integers, components, steps, acts, or groups.
What is claimed is:

1. A substrate processing system comprising:
   a capacitively coupled plasma (CCP) unit positioned inside a process chamber, wherein the CCP unit comprises a plasma excitation region formed between a first electrode and a second electrode, and wherein the first electrode comprises a first plurality of openings to permit a first gas to enter the plasma excitation region, and the second electrode comprises a second plurality of openings to permit an activated gas to exit the plasma excitation region;
   a gas inlet for supplying the first gas to the first electrode of the CCP unit; and
   a pedestal that is operable to support a substrate, wherein the pedestal is positioned below a gas reaction region into which the activated gas travels from the CCP unit.

2. The system of claim 1, wherein the system further comprises a showerhead positioned between the second electrode of the CCP unit and the gas reaction region above the pedestal, wherein the showerhead comprises a first plurality of showerhead channels that permit passage of the activated gas to the gas reaction region, and a second plurality of channels that permit passage of a second gas to the gas reaction region.

3. The system of claim 2, wherein the second plurality of openings in the second electrode are concentrically aligned with the first plurality of showerhead channels.

4. The system of claim 1, wherein the system further comprises one or more second gas inlets positioned between the second electrode and the pedestal, wherein the second gas inlets supply a second gas to the gas reaction region.

5. The system of claim 1, wherein the system further comprises a remote plasma system coupled to the gas inlet and operable to excite the first gas entering the process chamber through the gas inlet.

6. The system of claim 1, wherein the activated gas comprises at least one reactive radical.

7. A substrate processing system comprising:
   a gas inlet for supplying a first gas to a processing chamber; an electrode comprising a plurality of openings; a showerhead comprising a first plurality of channels that permit the passage of an activated gas to a gas reaction region in the processing chamber, and a second plurality of channels that permit passage of a second gas to the gas reaction region, wherein the activated gas is formed in a plasma excitation region between the electrode and the showerhead, which also acts as a second electrode; and a pedestal that is operable to support a substrate, wherein the pedestal is positioned below the gas reaction region.

8. The system of claim 7, wherein the first plurality of channels in the showerhead suppresses plasma in the plasma excitation region from entering the gas reaction region, while permitting the activated gas to pass through the showerhead.

9. The system of claim 7, wherein the system further comprises a one or more second gas inlets positioned between the showerhead and the pedestal, wherein the second gas inlets supply a second gas to the gas reaction region.

10. The system of claim 7, wherein the system further comprises a remote plasma system coupled to the gas inlet and operable to excite the first gas entering the process chamber through the gas inlet.

11. A substrate processing system comprising:
   a gas inlet for supplying a first gas to a processing chamber; an electrode comprising a plurality of openings; an ion suppressor comprising an electrically conductive plate having a second plurality of openings that permit the passage of an activated gas to a gas reaction region in the processing chamber, wherein the activated gas is formed in a plasma excitation region between the electrode and the ion suppressor; and a pedestal that is operable to support a substrate, wherein the pedestal is positioned below the gas reaction region.

12. The system of claim 11, wherein the system further comprises a showerhead positioned between the ion suppressor and the pedestal.

13. The system of claim 11, wherein the system further comprises a remote plasma system coupled to the gas inlet and operable to excite the first gas entering the process chamber through the gas inlet.

14. The system of claim 11, wherein the system comprises an electrical power supply coupled to the electrode and the ion suppressor, wherein the power supply is operable to create an adjustable bias voltage in the ion suppressor to adjust an ion concentration in the activated gas passing from the plasma excitation region to the gas reaction region.