US 20170200587A1

(19) **United States**

(12) **Patent Application Publication**

GODET et al.

(10) **Pub. No.: US 2017/0200587 A1**

(43) **Pub. Date: Jul. 13, 2017**

(54) **ATOMIC LAYER ETCHING SYSTEM WITH REMOTE PLASMA SOURCE AND DC ELECTRODE**

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(21) Appl. No.: **15/399,084**

(22) Filed: **Jan. 5, 2017**

Related U.S. Application Data

(60) Provisional application No. 62/276,098, filed on Jan. 7, 2016.

Publication Classification

(51) **Int. Cl.**

H01J 37/32 (2006.01)

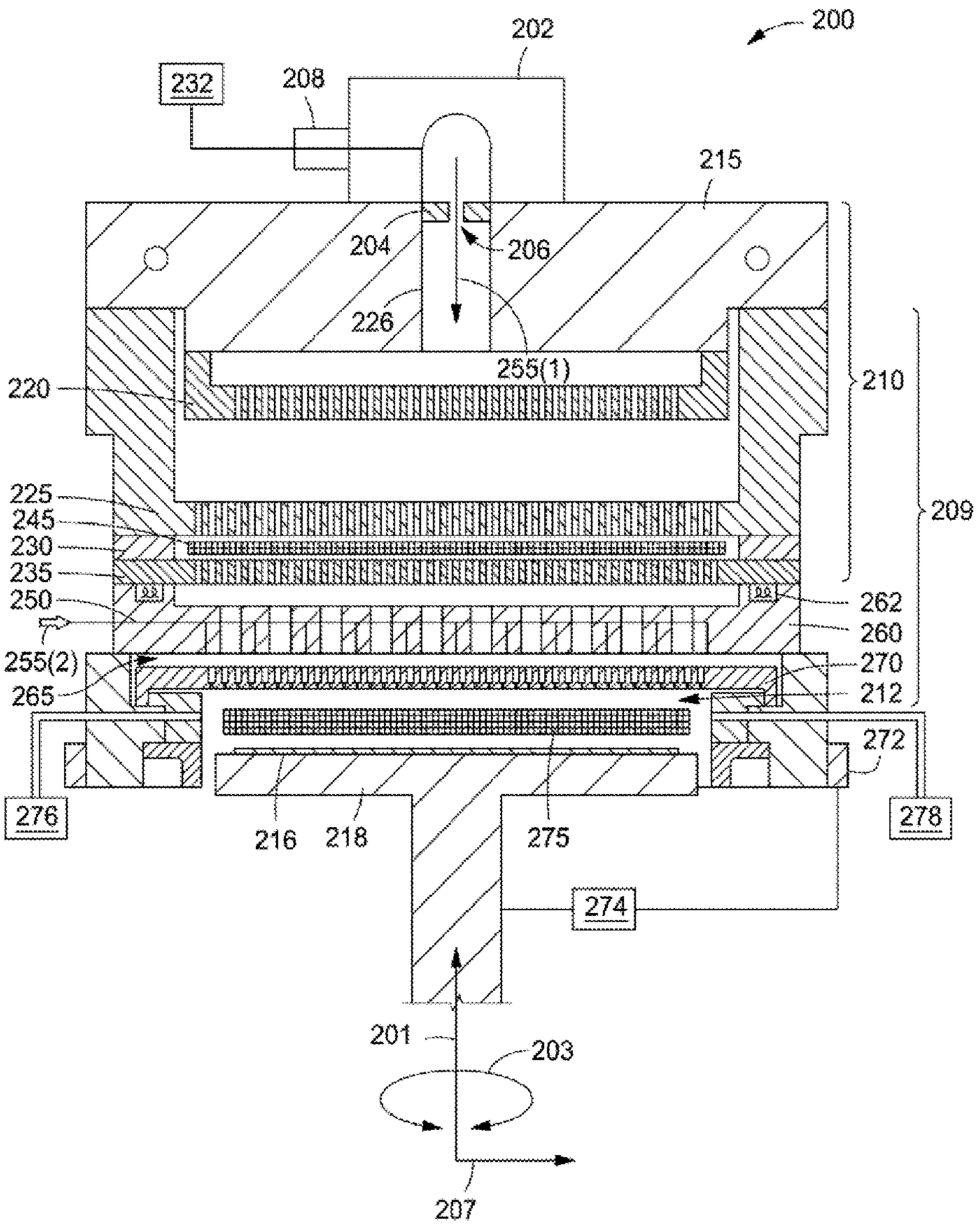
H01L 21/3065 (2006.01)

(52) **U.S. Cl.**

CPC .. ***H01J 37/32082*** (2013.01); ***H01J 37/32532*** (2013.01); ***H01J 37/3244*** (2013.01); ***H01L 21/3065*** (2013.01); *H01J 2237/334* (2013.01)

(57) **ABSTRACT**

Implementations described herein relate to apparatus and methods for performing atomic layer etching (ALE). Pulsed plasma generation and subsequent bias application to plasma afterglow may provide for improved ALE characteristics. Apparatus described herein provide for plasma generation from one or more plasma sources and biasing of plasma afterglow to facilitate material removal from a substrate.



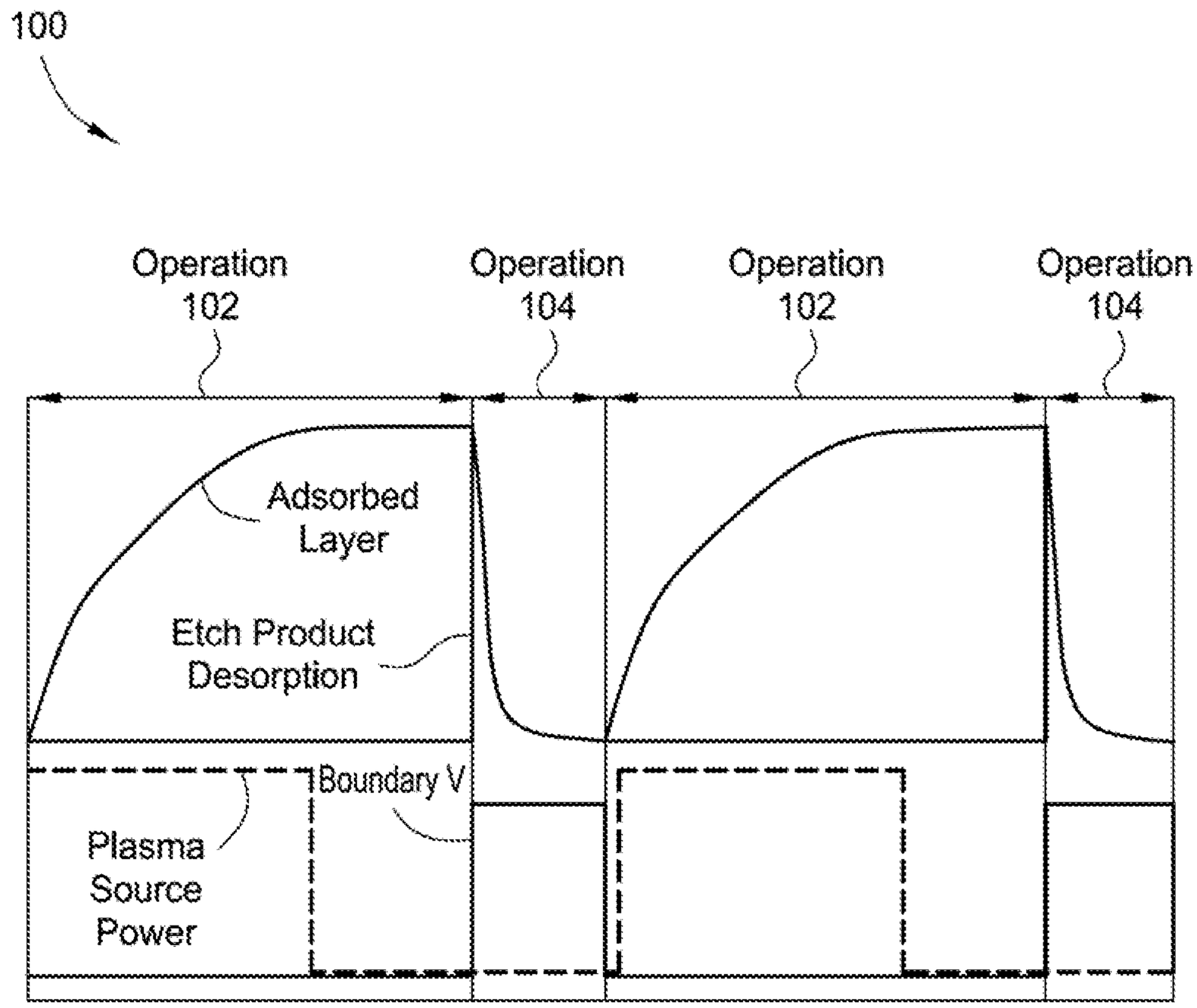

100
Operation 102
Operation 104
Operation 102
Operation 104
Adsorbed Layer
Etch Product Desorption
Boundary V
Plasma Source Power

FIG. 1

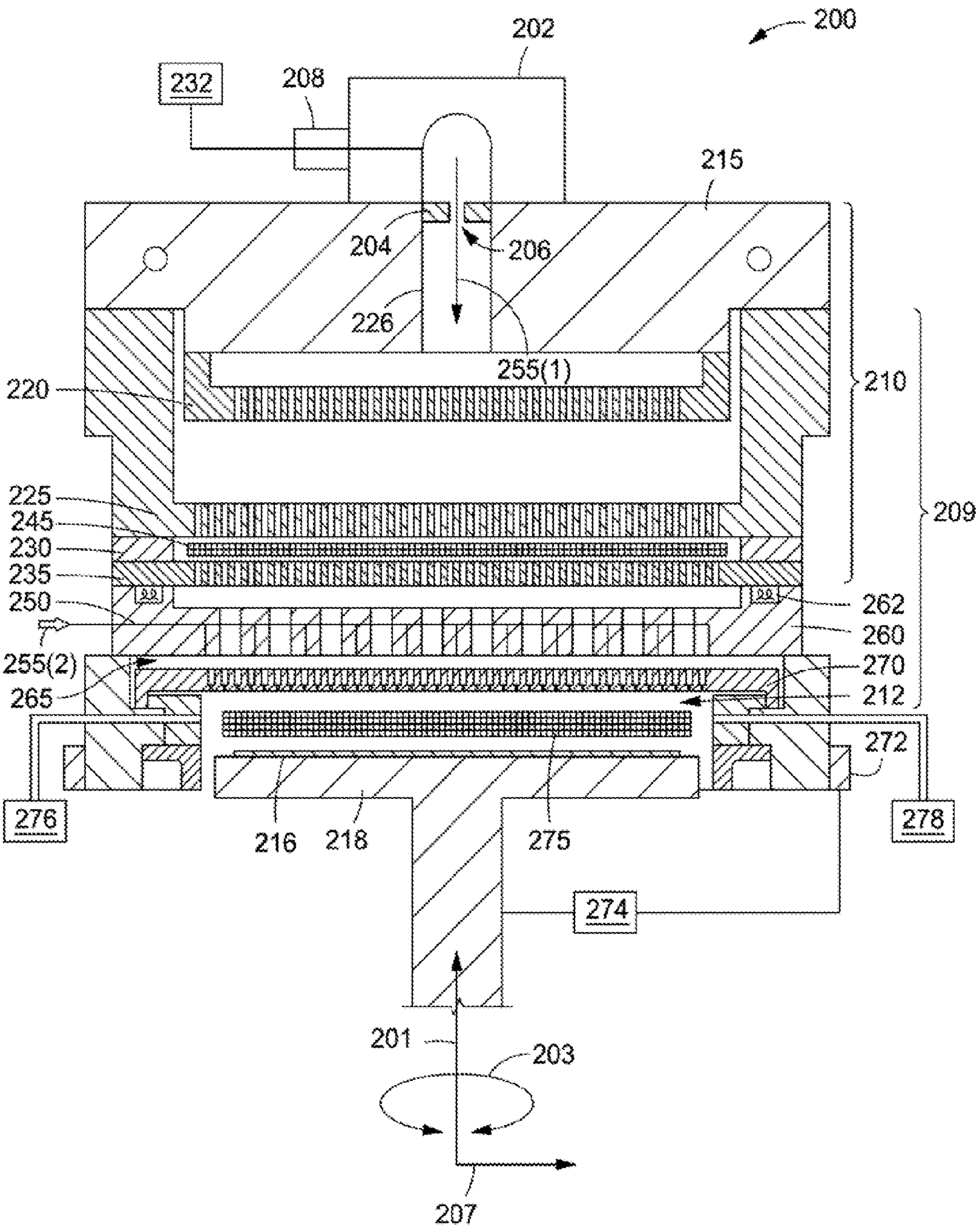

200
202
232
208
215
204
206
226
255(1)
220
210
209
225
245
230
235
250
262
260
255(2)
270
265
212
272
276
278
216
218
275
274
201
203
207

FIG. 2

ATOMIC LAYER ETCHING SYSTEM WITH REMOTE PLASMA SOURCE AND DC ELECTRODE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims benefit of U.S. Provisional Patent Application No. 62/276,098, filed Jan. 7, 2016, the entirety of which is herein incorporated by reference.

BACKGROUND

[0002] Field

[0003] Implementations of the present disclosure generally relate to an atomic layer etching apparatus.

[0004] Description of the Related Art

[0005] Moore's law and the continued development of semiconductors predict that devices in future integrated circuits will be as small as one atomic layer thick and less than several atomic layers wide. Present plasma etching processes are generally unable to achieve precise pattern transfer for advanced technology nodes. These current etching techniques may also damage underlying layers of a substrate. In particular, traditional plasma etching techniques lack the level of control that is needed for precise patterning of sub-20 nm structure and current atomic layer etching with pulsed gases is too slow to be practical for large volume manufacturing of integrated circuits.

[0006] Atomic layer etching (ALE) has been developed as a promising etch technology for advanced technology nodes. ALE generally includes four operations. First, a chemisorption operation, including clean substrate exposure to a reactant gas to facilitate the adsorption of the reactant gas onto the substrate surface. Second, excess Cl_2 gas is purged with an inert gas flow to avoid etching by a gas-phase reactant in the subsequent step. Third, the reaction step, such as chemical sputtering, is affected between the adsorbed gas and the underlying solid reaction, often via inert gas plasma. This process may also be self-limiting in that ions react only with substrate atoms bonded to the chemisorbed gas.

[0007] Once the chlorinated layer is removed, further etching by physical sputtering of the substrate is significantly reduced or eliminated. Finally, evacuation of a reaction chamber is utilized to exhausts the etching byproducts. If the periods of chemisorption in the first operation and the etching third operation are for sufficiently extended durations, the etching rate approaches one atomic layer per cycle, where the atomic layer thickness is that of the chlorinated layer, but not necessarily one monolayer of the substrate. Additionally, if the substrate surface remains nearly-atomically smooth during the ALE cycling, it is possible to achieve ideal removal conditions of substantially one monolayer of the substrate per cycle.

[0008] Recent developments to ALE have further improved etching performance. For example, constant gas flows and the like have improved the etch rate to achieve potentially commercially viable ALE etching processes. However, problems still exist even with new ALE advancements. For example, photo-assisted etching (PAE) is a phenomenon in which undesirable additional etching of the substrate or degradation of a photoresist occurs as a result of photons emitted from the plasma being utilized to perform the ALE process. As such, undesirable microtrenches may be formed upon exposure to the photons which may reduce device yield or contribute to device failure at advanced technology nodes.

[0009] Accordingly, what is needed in the art are improved apparatus for ALE processes.

SUMMARY

[0010] In one implementation, a processing chamber apparatus is provided. The apparatus includes a plate stack configured to generate a first plasma, a substrate support assembly disposed opposite the plate stack, and a process region defined between the plate stack and the substrate support assembly. The process region may be configured to maintain generation of a second plasma and a remote plasma source may also be fluidly coupled to the process region.

[0011] In another implementation, a processing chamber apparatus is provided. The apparatus includes a plate stack configured to generate a first plasma and the plate stack includes a first diffuser, a faceplate, a ceramic ring, a second diffuser, a gas distribution device, and a plasma blocking screen. A substrate support assembly is disposed opposite the plate stack and a process region defined between the plate stack and the substrate support assembly is configured to maintain generation of a second plasma. A remote plasma source is also fluidly coupled to the process region.

[0012] In yet another implementation, a processing chamber apparatus is provided. The apparatus includes a plate stack configured to generate a first plasma and the plate stack includes a first diffuser, a faceplate, a ceramic ring, a second diffuser, a gas distribution device, and a plasma blocking screen. An RF electrode is electrically coupled to the first diffuser and the faceplate and the first plasma is a remote plasma generated between the faceplate and the second diffuser. A substrate support assembly is disposed opposite the plate stack and a process region, configured to maintain generation of a second plasma, is defined between the plate stack and the substrate support assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to implementations, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only exemplary implementations and are therefore not to be considered limiting of its scope, may admit to other equally effective implementations.

[0014] FIG. **1** illustrates a method of performing an atomic layer etching process, according to implementations described herein.

[0015] FIG. **2** illustrates a schematic, cross-sectional view of a processing chamber, according to implementations described herein.

[0016] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements and features of one implementation may be beneficially incorporated in other implementations without further recitation.

DETAILED DESCRIPTION

[0017] Implementations described herein relate to apparatus and methods for performing atomic layer etching (ALE). Pulsed plasma generation and subsequent bias application to plasma afterglow may provide for improved ALE characteristics. Apparatus described herein provide for plasma generation from one or more plasma sources and biasing of plasma afterglow to facilitate material removal from a substrate.

[0018] FIG. **1** illustrates an atomic layer etching (ALE) process **100** according to an implementation of the present disclosure. The top portion of the FIG. **1** illustrates the ALE process **100**, whereas the bottom portion of the FIG. **1** illustrates the process parameter. The ALE process **100** includes two operations: an adsorption operation **102** and an etching operation **104**. During the adsorption operation **102**, a substrate may be exposed to adsorbate such that the adsorbate may adsorb onto the surface of the substrate. In some implementations, the adsorbate may be a reactant. For example, the adsorbate may include dissociated reactant atoms or dissociated reactant molecules having unpaired electrons or dangling bonds. The reactant may include, without limitation, halogens, such as fluorine (F), chlorine (Cl), bromine (Br), or iodine (I). Non-halogen materials, such as hydrogen (H_2) and oxygen (O_2) may also be utilized in certain implementations. In one implementation, the reactant may be disassociated chlorine (CI) atoms that are derived from chlorine reactant gas (Cl_2). It is contemplated that other halogens, halogenated species, or other reactants may also be used in the adsorbate. In alternate implementations, the intact or un-dissociated reactant may also be used as the adsorbate on the substrate. Suitable adsorbate precursors include, without limitation, CF_4, CHF_3, BlO_3, Bl_3, BCl_3, H_2, and O_2, among others. As utilized herein, the term "gas" includes vapor generated from a substance in solid or liquid state at room temperature or at standard temperature and pressure, without limitation.

[0019] The adsorbate may be obtained by generating plasma containing the reactants. In one implementation, inert gas may be ionized along with the reactant. Without limitation, the resulting plasma may contain reactants, reactant gas ions, and inert gas ions. In one implementation, argon (Ar) is utilized as the inert gas. It is contemplated that any noble gas species or other inert gas species may also be utilized.

[0020] In certain implementations, if the reactant is ionized with the inert gas, the concentration of the reactant gas, may be between about 0.01% and about 20% by volume; alternatively, the reactant gas concentration may be between about 0.01% and about 15%; and in certain implementations, the reactant gas concentration may be between about 0.01% and about 10% by volume of the combined gas. In one implementation, the reactant gas may include a concentration of less than about 1% by volume. Without limitation, the plasma generated may include Ar species and a small portion of CI reactant gas species.

[0021] In certain implementations, a plasma source is used to generate the reactant. Non-limiting exemplary plasma sources may include, inductively coupled plasma (ICP) sources, capacitively coupled plasma (CCP) sources, helicon sources, microwave sources, and remote plasma sources (RPS). In certain implementations, the plasma source is a remote plasma source. In operation, the remote plasma source may RF powered during the adsorption operation **102**. Suitable apparatus for performing the method **100** is described in greater detail with regard to FIG. **2**.

[0022] In certain implementations, the plasma source is not powered through the entire adsorption operation **102**. For example, the RF power applied to the plasma source may be lowered during the latter portion of the adsorption stage **102**. In non-limiting examples, the plasma source may be RF powered during the beginning portion of the adsorption operation **102**. During the latter portion of the operation **102**, lower power may be applied to the plasma source, or the plasma source may be turned OFF to provide afterglow. Alternatively, the plasma source may be powered continuously throughout the entire adsorption operation **102**.

[0023] Without intending to be bound by theory, the adsorption process may occur as described herein. A substrate comprising a clean surface, without a passivating layer may include unpaired electron or dangling bonds. Reactants from the plasma near the substrate surface may then bond with the dangling bonds of the surface, such as through chemisorption, to form a product layer. For example, the product layer may comprise a monolayer of the reactants and a monolayer of the substrate atoms that are associated. More specifically, the Cl reactants are adsorbed onto the surface of an exemplary silicon (Si) substrate to form a product layer comprising $SiCl_x$, where x is between 1 and 4 and the product layer may include known products and ionic species. Further, in certain instances, the product layer may comprise a monolayer of reactant species CI atoms and a monolayer of Si atoms. Adsorption may continue until the substrate surface is saturated with the reactants. Without limitation, saturation is achieved when substantially all available substrate surface-sites, such as unpaired electrons or dangling bonds, are occupied or associated with the reactants. In certain instances a portion of the substrate surface is not covered with the reactants. For example, a portion of the substrate surface may contain a passivating layer, such as but not limited to an oxide layer. In non-limiting examples, the passivating layer may not contain available sites, available unpaired electrons or dangling bonds, and as such is not covered with the reactants. In certain implementations, the substrate surface is at least partially covered with chemisorbed reactants in the product layer and at least partially covered with a passivating layer.

[0024] In certain implementations, during the adsorption operation **102**, the reactant gas ions and/or inert gas ions may be present in the plasma, such that the substrate surface comprising a product layer is exposed to the ions. The energy of the ions (i.e. plasma potential) bombarding the substrate may be selectively controlled to avoid or minimize undesired etching, physical, or chemical sputtering. For example, the energy required by Cl ions to etch Si may be less than about 25 eV, whereas the energy required by Ar ions to cause sputtering may be between about 30 eV and about 60 eV. In certain implementations, the energy of the ions bombarding the substrate during the adsorption operation **102** may be controlled to be about 15 eV or less. The ion energy may be controlled by, for example, providing an electrostatic shielding (e.g. Faraday shield) of the plasma source and/or performing the process under relatively high pressure, for example, less than about 50 mTorr, in order to minimize undesired etching, physical, or chemical sputtering.

[0025] After completion of the adsorption operation **102**, the etching operation **104** may be performed. During the

etching operation **104**, ions may bombard the substrate to remove the product layer. In certain implementations, the ions include positively charged ions or negatively charged ions. In one implementation, positively charged ions are used to remove the product layer. It is contemplated that the energy of the ions bombarding the substrate during the etching operation **104** may preferably be above the threshold for chemically-assisted sputtering but below the threshold for physical sputtering. The ions with selected energy may be directed toward the substrate by controlling the potential difference between the plasma and the substrate. To direct positive ions toward the substrate, the potential difference between may be increased by increasing the plasma potential relative to the substrate potential, decreasing the substrate potential relative to the plasma, or both. To direct negative ions, the potential difference between may be increased by decreasing the plasma potential relative to the substrate potential, increasing the substrate potential relative to the plasma, or both. Positive or negative, DC or RF bias may be applied to the plasma and/or the substrate during the etching operation **104**. In addition, continuous bias may be provided to the plasma and/or the substrate. Alternatively, a series of pulsed bias may also be utilized. In pulsed bias implementations, DC bias may be applied for an amount of time between about 10 μs (10 microseconds) and about 500 μs.

[0026] In certain implementations, the plasma source may be RF powered during the etching operation **104**. For example, the plasma source may be provided with pulsed RF power, where each RF power pulse is provided between the bias pulses noted above. In certain implementations, the RF power pulse may be applied for an amount of time between about 50 μs and about 200 μs. As such, a series of pulsed RF power may be applied to the plasma source during the etching operation **104** and a series of pulsed DC or RF bias may be applied to the plasma and/or the substrate. Each bias pulse may be provided between the RF power pulses. The bias pulse may be delayed for an amount of time between about 20 μs and about 200 μs after ceasing of the RF power pulse. In other words, the bias pulse may be delayed and then initiated during the plasma afterglow.

[0027] By selectively increasing the potential difference between the plasma and the substrate, the product layer, which includes the chlorinated product layer in the certain implementation described here, may be removed. In the process, the monolayer of the substrate atoms associated with the product may be removed from the substrate concurrently. Additionally, the adsorption operation **102** and the etching operation **104** may be repeated to remove additional layers of the substrate atoms one layer at a time.

[0028] FIG. **2** illustrates a schematic, cross-sectional view of a processing chamber **200** according to implementations described herein. The processing chamber **200** includes a first plasma source **210** and a process region **212** that may also generate or contain a remotely generated plasma during various processing operations, as discussed below. In the orientation of FIG. **2**, a general direction of gas and/or plasma product flow is downwards (i.e. towards a substrate support assembly **218**), and this direction may be referred to as "downstream" herein, while an opposing direction upwards in the orientation of FIG. **2**, may be referred to as "upstream." Gas and/or plasma products which flow along a radial direction **207** may be referred to as "cross-flow" herein. Also, significant portions of the apparatus shown in FIG. **2** may be cylindrically symmetric about a central axis **201**, with associated directions being defined as the radial direction **207** and an azimuthal direction **203**. This convention of directions may be used herein, although one skilled in the art will understand that many of the principles described herein are not limited to cylindrically symmetric systems.

[0029] As shown in FIG. **2**, the first plasma source **210** may introduce gases, and/or gases that are ionized by an upstream remote plasma source, as plasma source gases **255**(**1**), through an RF electrode **215**. In certain implementations, the plasma source gases **255**(**1**) may be any of the inert gases described above with regard to FIG. **1**. A gas manifold **202** may be coupled to and/or disposed adjacent the RF electrode **215**. Process gasses may be provided to the gas manifold **202** from a gas first source **232**. The process gases from the first gas source **232** may enter the gas manifold **202** through a feed-through member **208**. In one implementation, the feed-through member **208** may be formed from a polymeric material, such as polytetrafluoroethylene. A flow centering insert **204** may be disposed within a gas inlet tube **226** adjacent the gas manifold **202**. The flow centering insert **204** may be a ring like apparatus with an opening **206** formed therein. The opening **206** may be formed through the center of the insert **204** and the opening **206** may be a single aperture or may be multiple apertures. In the single aperture implementation, a diameter of the opening **206** may be about 0.125 inches. The flow centering insert **204** may improve concentric flow distribution of process gases within the processing chamber **200**.

[0030] The RF electrode **215** may be electrically coupled to a first gas diffuser **220** and a face plate **225** that serve to redirect flow of the source gases so that gas flow is uniform across the first plasma source **210** (uniform from left to right in the view of FIG. **2**). It should be noted that all of the diffusers or screens described hereinafter may be characterized as electrodes, as any such diffusers or screens may be tied to a particular electrical potential. An insulator **230** electrically insulates the RF electrode **215**, including the face plate **225**, from a second diffuser **235** that is held at electrical ground. The second diffuser **235** serves as a second electrode counterfacing the face plate **225** of the RF electrode **215**.

[0031] Surfaces of the face plate **225**, the second diffuser **235** and the insulator **230** define a first plasma generation cavity where a first plasma **245** (i.e. first remote plasma) may be created when the plasma source gases are present and RF energy is provided at the face plate **225** through the RF electrode **215**. The RF electrode **215**, the face plate **225**, and the second diffuser **235** may be formed of any conductor, and in implementations are formed of aluminum (or an aluminum alloy, such as the known "6061" alloy type).

[0032] Surfaces of the face plate **225** and the second diffuser **235** that face the first plasma **245** directly may be coated with ceramic layers of, for example, yttria (Y_2O_3) or alumina (Al_2O_3) for resistance to bombardment by energetic plasma products generated in the plasma **245**. The ceramic coating may be formed by an electron beam coating process, an anodization process, and/or a non-pore anodization process. Other suitable coatings include nickel plated coatings and surface oxidation processes, for example, by exposure to a concentrated HNO_3 solution. Other surfaces of the face plate **225** and the second diffuser **235** that are not necessarily exposed directly to plasma, but are exposed to reactive gases

and/or radicals generated by plasmas, may be coated either with ceramic layers (e.g., yttria, alumina) or with a suitable passivating layer (e.g., an anodized layer, or a chemically generated alumina layer) for chemical resistance. The insulator **230** may be any insulator, and in certain implementations, is formed from a ceramic material.

[0033] Plasma products generated in the first plasma **245** pass through the second diffuser **235** that again helps to promote the uniform distribution of plasma products, and may assist in electron temperature control. Upon passing through the second diffuser **235**, the plasma products pass through a gas distribution device **260** that promotes uniformity. The gas distribution device **260** is also held at electrical ground. Apertures that pass completely through the gas distribution device **260** are generally of a diameter at least three times a diameter of apertures within the second diffuser **235**. Also, the gas distribution device **260** includes further gas channels **250** that may be used to introduce one or more gases **255**(**2**) to the plasma products as they enter the process region **212** (that is, gases **255**(**2**) emerge only from a side of gas distribution device **260** that is distal to second diffuser **235**). The gases **255**(**2**) may be provided from a second gas source (not shown). In certain implementations, the gases **255**(**2**) may be adsorbate or reactant gases as described with regard to FIG. **1**. The gas distribution device **260** may also be made of aluminum or aluminum alloy, and like the face plate **225** and the second diffuser **235** discussed above, may be at least coated with a passivating layer for chemical resistance, or may be coated with a ceramic layer.

[0034] A heating element **262** may also be disposed in the processing chamber **200**. The heating element **262** may be a spiral shaped heater, such as a resistive heater or the like. The heating element **262** may be disposed in a groove formed in the gas distribution device **260** as illustrated, or may be disposed in groove formed in the second diffuser **235**. Alternatively, the heating element **262** may be disposed in a groove formed in the gas distribution device **260** facing a plasma blocking screen **270**. In another implementation, the heating element **262** may be disposed in a groove formed in the plasma blocking screen **270** facing the gas distribution device **260**. The heating element **262** may be configured to improve symmetric thermal distribution across the processing chamber **200** and facilitate maintenance of the first plasma **245** and/or plasma products (i.e. radicals). In general, each of the plates, diffusers, and/or showerheads **220**, **225**, **230**, **235**, **260**, **270** may be collectively referred to as a plate stack **209**. The plate stack **209** is generally disposed within the processing chamber **200** between the RF electrode **215** and opposite the substrate support assembly **218**.

[0035] The gases **255**(**1**), **255**(**2**) and/or plasma products from the first plasma **245** enter a plenum cavity **265**, then pass through the plasma blocking screen **270** to the process region **212**. The plasma blocking screen **270** may have a thickness in the range of between about 0.01 inches and about 1.0 inch, and many small apertures that are configured to allow gases and plasma products from upstream sources pass through into the process region **212** may be formed therein. The apertures of the plasma blocking screen **270** are generally high aspect ratio holes and a hole diameter of the apertures may be between about 0.01 inches and about 0.25 inches. The plasma blocking screen **270** substantially blocks downstream plasmas and plasma products from upstream components, as discussed in detail below. In implementations, the plasma blocking screen **270** may advantageously form at least ten apertures per square inch in a central region thereof, and in certain implementations may form thirty or more apertures per square inch. In one implementation, the plasma blocking screen may be disposed a distance of between about 0.5 cm and about 4 cm from the substrate support assembly **218** when the substrate support assembly **218** is disposed in a processing position. The relatively small distance between the plasma blocking screen **270** and the substrate support assembly **218** reduces the volume of the process region **212**. By reducing the volume of the process region **212**, processes performed in the processing chamber **200** may be performed more economically and processing conditions of the process regions **212** may be changed more efficiently and quickly.

[0036] Like the gas distribution device **260**, the plasma blocking screen **270** is also held at electrical ground. Like the face plate **225** and the second diffuser **235** discussed above, surfaces of the plasma blocking screen **270** that are exposed directly to plasma are advantageously coated with ceramic (e.g., alumina or yttria) while surfaces that are not exposed directly to plasma may also be coated with ceramic, and are advantageously at least coated with a passivating layer for chemical resistance to reactive gases and activated species. In one implementation, a detachable coating containing a silicon material may be disposed on the plasma blocking screen **270** to reduce defectivity and enable efficient replacement of the coating if the coating becomes damaged or operates with reduced efficiency.

[0037] All of the gases and/or plasma products, generated as described above, interact with a substrate **216** which may be disposed within the process region **212**, and a second plasma **275** (i.e. direct plasma) may be generated within the process region **212**. When a plasma is desired within process region **212**, because the second diffuser **235** is held at electrical ground, RF power to create the second plasma **275** is applied to the substrate support assembly **218**. Depending on the flow of gases, adsorbate/reactant or inert gas plasmas may be generated as the second plasma **275**. It is contemplated that alternating the flow of adsorbate/reactant gases and inert gases, and subsequent plasma generation may enable the method **100**. In one implementation, the first plasma **245** may comprise an inert gas plasma and the second plasma **275** may comprise an adsorbate/reactant gas plasma.

[0038] A DC bias may also be applied to the substrate support assembly **218** to steer ions generated in the first or second plasmas **245**, **275** to facilitate directional (anisotropic) ALE of the substrate **216**. The substrate support assembly **218** may also include an electrostatic chuck to secure the substrate **216** thereon during processing. In another implementation, a bias ring **272** may be coupled to the processing chamber **200** adjacent the substrate support assembly **218**. The bias ring **272** may made from any material in any geometric shape which provides biasing of a plasma or plasma afterglow towards the substrate **216** disposed in the process region **212**. The substrate support assembly **218** and/or bias ring **272** may be switchably connected with an RF and/or DC bias source **274**, so as to generate a plasma and/or bias potential within process region **212** at selected times and not at other times. The substrate support assembly **218** may be connected with the same RF power supply as is used to create the first plasma **245** between the face plate **225** and the second diffuser **235**, or may be connected with a different RF power supply.

[0039] In certain implementations, a remote plasma source **276** may be fluidly coupled with the process region **212**. Although not illustrated, the remote plasma source **276** may be coupled to a third gas source (or the second gas source depending upon the desired type of plasma to be generated). In this implementation, a third plasma may be generated remotely from the process region **212** and delivered to the process region **212**. For purposes of illustration, the third plasma (generated in the remote plasma source **276**) may occupy the same area as the second plasma **275**. However, the third plasma may be cross-flowed along the radial direction **207** through the process region **212** to an exhaust which is fluidly coupled to the process region **212**. In one implementation, the exhaust **278** may be coupled to the process region **212** opposite the remote plasma source **276**. In one implementation, adsorbate/reactant gases may be remotely generated into the third plasma and delivered to the process region **212**. In one implementation, both the second plasma **275** and the third plasma generated by the remote plasma source **276** may be utilized to generate the adsorbate/reactant plasma or plasma products. Alternatively, one of the second plasma **275** or the third plasma generated by the remote plasma source **276** may be utilized to generate the adsorbate/reactant plasma or plasma products.

[0040] In operation, the substrate support assembly **218** may be rotated during exposure of the substrate **216** to the third plasma/plasma products to improve exposure uniformity and substrate surface active site reactions with the adsorbate/reactant plasma and/or plasma products. It is believed that by generating the adsorbate/reactant plasma or plasma products remotely from the process region **212**, undesirable photo assisted etching (PAE) may be reduced or eliminated. It is contemplated that remote plasma generation may reduce or eliminate the presence of photons present in the third plasma or plasma products "seen" by the substrate **216** in the process region **212**. Accordingly, ALE processes may be enabled without the deleterious effects of PAE.

[0041] While the foregoing is directed to implementations of the present disclosure, other and further implementations of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

1. A processing chamber apparatus, comprising:
a plate stack configured to generate a first plasma;
a substrate support assembly disposed opposite the plate stack;
a process region defined between the plate stack and the substrate support assembly, wherein the process region is configured to maintain generation of a second plasma; and
a remote plasma source fluidly coupled to the process region to provide a cross-flow of plasma products through the process region.

2. The apparatus of claim **1**, further comprising:
an RF electrode;
a gas source;
a gas manifold; and
a gas inlet tube.

3. The apparatus of claim **2**, wherein a flow centering insert is disposed within the gas inlet tube adjacent the gas manifold.

4. The apparatus of claim **2**, wherein the gas source is configured to deliver an inert gas to the plate stack.

5. The apparatus of claim **1**, wherein the plate stack comprises:
a first diffuser;
a faceplate;
a ceramic ring;
a second diffuser;
a gas distribution device; and
a plasma blocking screen.

6. The apparatus of claim **5**, wherein the faceplate and the second diffuser define a remote plasma region.

7. The apparatus of claim **5**, wherein each of the first diffuser, the faceplate, the ceramic ring, the second diffuse, the gas distribution device, and the plasma blocking screen are coated with a ceramic coating comprising yttria or alumina.

8. The apparatus of claim **5**, wherein the plasma blocking screen is disposed a distance of between 0.5 cm and 4.0 cm from the substrate support assembly when the substrate support assembly is disposed in a processing position.

9. The apparatus of claim **5**, wherein the plasma blocking screen has a thickness of between 0.01 inches and 1.0 inch.

10. The apparatus of claim **9**, wherein the plasma blocking screen comprises apertures, the apertures having a diameter of between 0.01 inches and 0.25 inches.

11. The apparatus of claim **1**, further comprising:
an exhaust fluidly coupled to the process region.

12. The apparatus of claim **11**, wherein the exhaust is coupled to the process region opposite the remote plasma source.

13. A processing chamber apparatus, comprising:
a plate stack configured to generate a first plasma, the plate stack comprising:
a first diffuser;
a faceplate;
a ceramic ring;
a second diffuser;
a gas distribution device; and
a plasma blocking screen;
a substrate support assembly disposed opposite the plate stack;
a process region defined between the plate stack and the substrate support assembly, wherein the process region is configured to maintain generation of a second plasma; and
a remote plasma source fluidly coupled to the process region to provide a cross-flow of plasma products through the process region.

14. The apparatus of claim **13**, wherein the faceplate and the second diffuser define a remote plasma region.

15. The apparatus of claim **13**, wherein each of the first diffuser, the faceplate, the ceramic ring, the second diffuse, the gas distribution device, and the plasma blocking screen are coated with a ceramic coating comprising yttria or alumina.

16. The apparatus of claim **13**, wherein the plasma blocking screen is disposed a distance of between 0.5 cm and 4.0 cm from the substrate support assembly when the substrate support assembly is disposed in a processing position.

17. The apparatus of claim **13**, wherein the plasma blocking screen has a thickness of between 0.01 inches and 1.0 inch.

18. A processing chamber apparatus, comprising:
a plate stack configured to generate a first plasma, the plate stack comprising:

a first diffuser;
a faceplate;
a ceramic ring;
a second diffuser;
a gas distribution device; and
a plasma blocking screen;
an RF electrode electrically coupled to the first diffuser and the faceplate, wherein the first plasma is a remote plasma generated between the faceplate and the second diffuser;
a substrate support assembly disposed opposite the plate stack;
a process region defined between the plate stack and the substrate support assembly, wherein the process region is configured to maintain generation of a second plasma; and
a remote plasma source fluidly coupled to the process region to provide a cross-flow of plasma products through the process region.

19. The apparatus of claim **18**, wherein each of the first diffuser, the faceplate, the ceramic ring, the second diffuse, the gas distribution device, and the plasma blocking screen are coated with a ceramic coating comprising yttria or alumina.

20. The apparatus of claim **18**, wherein the plasma blocking screen is disposed a distance of between 0.5 cm and 4.0 cm from the substrate support assembly when the substrate support assembly is disposed in a processing position.

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