SELECTIVE ETCH FOR SILICON FILMS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a PCT application of U.S. Patent Application No. 13/088,930 by Jingchun Zhang et al., filed April 18, 2011, titled "SELECTIVE ETCH FOR SILICON FILMS," and is related to and claims the benefit of U.S. Provisional Patent Application No. 61/348,920 by Jingchun Zhang et al., filed May 27, 2010, entitled "OXIDE DESELECTIVE ETCH," the entire disclosures of which are incorporated herein by reference for all purposes.

BACKGROUND OF THE INVENTION

Integrated circuits are made possible by processes which produce intricately patterned material layers on substrate surfaces. Producing patterned material on a substrate requires controlled methods for removal of exposed material. Chemical etching is used for a variety of purposes including transferring a pattern in photoresist into underlying layers, thinning layers or thinning lateral dimensions of features already present on the surface. Often it is desirable to have an etch process which etches one material faster than another helping e.g. a pattern transfer process proceed. Such an etch process is said to be selective to the first material. As a result of the diversity of materials, circuits and processes, etch processes have been developed with a selectivity towards a variety of materials.

A Siconi^{TM} etch is a remote plasma assisted dry etch process which involves the simultaneous exposure of a substrate to H_2, NF_3 and NH_3 plasma by-products. Remote plasma excitation of the hydrogen and fluorine species allows plasma-damage-free substrate processing. The Siconi^{TM} etch is largely conformal and selective towards silicon oxide layers but does not readily etch silicon regardless of whether the silicon is amorphous, crystalline or polycrystalline. The selectivity provides advantages for applications such as shallow trench isolation (STI) and inter-layer dielectric (ILD) recess formation. The Siconi^{TM} process produces solid by-products which grow on the surface of the substrate as substrate material is removed. The solid by-products are subsequently removed via sublimation when the temperature of the substrate is raised.

To date, remote plasma etches (such as Siconi™) have been limited to selectivity towards silicon oxide. Methods are needed to expand the range of possible selectivities for remote plasma etch processes.

BRIEF SUMMARY OF THE INVENTION

A method of etching patterned heterogeneous silicon-containing structures is described and includes a remote plasma etch with inverted selectivity compared to existing remote plasma etches. The methods may be used to conformally trim polysilicon while removing little or no silicon oxide. More generally, silicon-containing films containing less oxygen are removed more rapidly than silicon-containing films which contain more oxygen. Other exemplary applications include trimming silicon carbon nitride films while essentially retaining silicon oxycarbide. Applications such as these are enabled by the methods presented herein and enable new process flows. These process flows are expected to become desirable for a variety of finer linewidth structures. Methods contained herein may also be used to etch silicon-containing films faster than nitrogen-and-silicon containing films having a greater concentration of nitrogen.

Embodiments of the invention include methods of etching patterned substrate in a substrate processing region of a substrate processing chamber. The patterned substrate has an exposed oxygen-and-silicon-containing region and an exposed silicon-containing region which contains less oxygen than the oxygen-and-silicon-containing region. The method includes flowing a fluorine-containing precursor into a remote plasma region fluidly coupled to the substrate processing region while forming a plasma in the first plasma region to produce plasma effluents. The method further includes etching the silicon-containing region faster than the oxygen-and-silicon-containing region by flowing the plasma effluents into the substrate processing region.

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 disclosed embodiments. The features and advantages of the disclosed embodiments 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 disclosed embodiments may be realized by reference to the remaining portions of the specification and the drawings.

FIG. 1 is a flow chart of a silicon selective etch process according to disclosed embodiments.

FIGS. 2A-2B are schematics before and after a silicon selective etch process according to disclosed embodiments.

FIG. 3 is a plot indicating etch rates of silicon oxide, silicon nitride and polysilicon during a silicon selective etch according to disclosed embodiments.

FIG. 4 is a flow chart of a selective etch process according to disclosed embodiments.

FIGS. 5A-5B are schematics before and after a selective etch process according to disclosed embodiments.

FIG. 6 is a plot indicating etch rates of silicon oxycarbide and silicon carbon nitride during a selective etch according to disclosed embodiments.

FIG. 7 is a cross-sectional view of a processing chamber for performing etch processes according to disclosed embodiments.

FIG. 8 is a processing system for performing etch processes according to disclosed embodiments.

In the appended figures, similar components and/or features may have the same reference label. Further, various components of the same type may be distinguished by following the reference label by a dash and a second label that distinguishes among the similar components. If only the first reference label is used in the specification, the description is applicable to any one of the similar components having the same first reference label irrespective of the second reference label.

DETAILED DESCRIPTION OF THE INVENTION

A method of etching patterned heterogeneous silicon-containing structures is described and includes a remote plasma etch with inverted selectivity compared to existing remote plasma etches. The methods may be used to conformally trim polysilicon while removing little or no silicon oxide. More generally, silicon-containing films containing less oxygen are removed more rapidly than silicon-containing films which contain more oxygen. Other exemplary applications include trimming silicon carbon nitride films while essentially retaining silicon oxycarbide. Applications such as these are enabled by the methods presented herein and enable new process flows. These process flows are expected to become desirable for a

variety of finer linewidth structures. Methods contained herein may also be used to etch silicon-containing films faster than nitrogen-and-silicon containing films having a greater concentration of nitrogen.

Siconi™ etch processes have used a hydrogen source of ammonia (NH_3) and a fluorine source of nitrogen trifluoride (NF_3) which together flow through a remote plasma system (RPS) and into a reaction region. The flow rates of ammonia and nitrogen trifluoride are typically chosen such that the atomic flow rate of hydrogen is roughly twice that of fluorine in order to efficiently utilize the constituents of the two process gases. The presence of hydrogen and fluorine allows the formation of solid byproducts of $(NH_4)_2SiF_6$ at relatively low substrate temperatures. The solid byproducts are removed by raising the temperature of the substrate above the sublimation temperature. Siconi™ etch processes remove oxide films more rapidly than films devoid of oxygen. The inventors have discovered that the selectivity can be inverted by reducing (or eliminating) the supply of hydrogen while retaining the flow of nitrogen trifluoride.

In order to better understand and appreciate the invention, reference is now made to FIGS. 1 and 2 which are a flow chart of a oxide deselective etch process and a shallow trench isolation (STI) structure according to disclosed embodiments. Prior to the first operation, a gap is formed in a polysilicon adlayer 220-1 and an underlying silicon substrate 210. The gap is filled with silicon oxide 230 to electrically isolate devices (not shown). The silicon oxide is polished such that the surface is roughly coplanar with the top of the polysilicon and the silicon oxide is trimmed back below the polysilicon to achieve the structure shown in FIG 2. The process of FIG. 1 begins when the substrate is transferred into a processing chamber (operation 110). Note that regions of silicon oxide 230 and polysilicon 220 are exposed on the surface of the substrate.

A flow of nitrogen trifluoride is initiated into a plasma region separate from the processing region (operation 120). Other sources of fluorine may be used to augment or replace the nitrogen trifluoride. In embodiments, the fluorine-containing precursor comprises at least one precursor selected from the group consisting of nitrogen trifluoride, diatomic fluorine, monatomic fluorine and fluorine-substituted hydrocarbons. The separate plasma region may be referred to as a remote plasma region herein and may be within a distinct module from the processing chamber or a compartment within the processing chamber. A flow of ammonia may or may not be present into the remote plasma region during this operation. When

included, the hydrogen-containing precursor comprises at least one precursor selected from the group consisting of atomic hydrogen, molecular hydrogen, ammonia, a hydrocarbon and an incompletely halogen-substituted hydrocarbon. The flows of nitrogen trifluoride and optional ammonia may be selected such that the fluorine-to-hydrogen atomic flow ratio is greater than one of 2:1, 5:1 or 10:1. Products from the remote plasma (plasma effluents) are flowed into the processing region and allowed to interact with the patterned substrate surface (operation 125). The patterned layer is selectively etched (operation 130) such that the polysilicon adlayer is conformally trimmed while the silicon oxide gapfill 230 is etched more slowly in disclosed embodiments. The etch rate of the polysilicon may be greater than five or ten times the etch rate of the silicon oxide gapfill depending on the ratio of the flow of fluorine to the flow of hydrogen. The flows of the gases are then stopped (operation 135) and the substrate is removed from the processing region (operation 145). The polysilicon may be trimmed by between 1 nm and 15 nm in disclosed embodiments. Including a significant flow of oxygen into the remote plasma region (and therefore in the plasma effluent flow) is not recommended since the silicon may be oxidized thwarting the desirable etch selectivity towards silicon. The plasma region and substrate processing region are devoid or essentially devoid of oxygen during the etch process, according to embodiments of the invention.

FIG. 3 is a plot of etch quantities after a timed etch such as that used to trim the polysilicon adlayer 220 of FIG. 2. Note that a Siconi^{TM}, having about twice the atomic concentration of hydrogen as compared with fluorine, results in silicon oxide removal at a significantly greater rate than polysilicon. The selectivity inverts as the ratio of hydrogen to fluorine is reduced. Polysilicon and silicon oxide are removed at roughly the same rate when equal parts of hydrogen and fluorine are delivered to the remote plasma region. Below a ratio of 1:1 hydrogen:fluorine, the etch rate of polysilicon exceeds that of silicon oxide. Essentially no hydrogen is flowed to the remote plasma region, in embodiments, which results in an etch selectivity greater than 10:1 polysilicon:silicon oxide. The technique may also be applied to a gap in a silicon substrate without a polysilicon adlayer, in embodiments, and the oxide deselective etch would remove silicon at a greater rate than the silicon oxide gapfill.

The selective etch represented by FIGS. 1-3 was described in conjunction with a shallow-trench isolation application. A variety of other applications will benefit from this silicon-selective etch. For example, this selective etch may be used to trim the fin of a finFET structure without removing a detrimental quantity of exposed oxygen-containing material such as silicon oxide. A finFET contains a vertical protrusion of single crystalline silicon

whose thickness impacts device performance. Single crystalline silicon etches at a similar rate to polysilicon when processed with the remote plasma selective etch described herein. A wide variety of alternative geometries to the device structures described herein are expected to emerge and will benefit from the oxide deselective etch.

The utility of the remote plasma etch described herein is not limited to systems including patterned silicon and silicon oxide. FIG. 4 is a flow chart of a selective etch which removes silicon carbon nitride (SiCN) faster than silicon oxy-carbide (SiOC). In embodiments the SiCN consists essentially of silicon, carbon and nitrogen. Similarly, the SiOC may consist essentially of silicon, carbon and oxygen. FIGS. 5A-5B are schematics of an exemplary application before and after the selective etch. The exemplary application involves formation of an inter-metal dielectric layer. An underlying copper layer 550 has a silicon carbon nitride (SiCN) 560-1 formed above it to prevent the diffusion of contaminants from overlying low-K film 570. A suitable SiCN film 560-1 is Blok^{TM} and a suitable low-K film 570 is Black Diamond, each of which is available from Applied Materials, Santa Clara, California. The low-K film 570 is formed above the layer of SiCN 560-1 and patterned with an oxide selective etch to form the trench shown in FIG. 5A. The trench will later be filled with metal to form a conducting link between different metal layers. Before an ohmic contact can be made, however, the dielectric SiCN must first be removed.

The process of FIG. 4 begins when the patterned substrate is transferred into a processing chamber (operation 410). A flow of nitrogen trifluoride is initiated into the remote plasma region (operation 420). The remote plasma region may be essentially devoid of hydrogen or have lesser flows of hydrogen as described previously with reference to FIGS. 1-2. Hydrogen is impossible to completely eliminate from a vacuum system and "essentially devoid" of hydrogen is used to accommodate reasonable tolerances. Plasma effluents are flowed into the processing region and allowed to interact with the patterned substrate surface (operation 425). The patterned layer is selectively etched (operation 430) such that the silicon carbon nitride layer is preferentially removed relative to the silicon oxy-carbide. The selective etch continues until the portion of the SiCN is removed from the bottom of the trench to allow a subsequent layer of metal to contact the newly exposed carbon surface. The flows of the precursors are stopped (operation 435) and the substrate is removed from the processing region (operation 445). The SiCN film 560-2 following the selective etch is shown in FIG. 5B.

FIG. 6 is a plot indicating etch rates of silicon oxycarbide and silicon carbon nitride during an oxide deselective etch according to disclosed embodiments. The curves show the dependence of etch rate on the partial pressure of nitrogen trifluoride in the substrate processing region. In addition to being dependent on the hydrogen:fluorine atomic flow ratio as indicated previously, the selectivity is further dependent on the concentration of nitrogen trifluoride in the vicinity of the patterned substrate. Lower partial pressures enable an increase in the selectivity of SiCN over SiOC which is preferred in the exemplary application. Below about 50 mTorr partial pressure nitrogen trifluoride, the etch rate of both SiCN and SiOC reduce as the partial pressure is reduced. The rate of reduction is faster for the SiOC which allows the selectivity toward etching SiCN to be increased. The partial pressure of nitrogen trifluoride is below 50 mTorr, 30 mTorr or 20 mTorr in different embodiments.

The oxide deselective etch described herein etches materials which are essentially devoid of oxygen faster than oxygen-and-silicon containing films. It is noteworthy that a small amount of oxygen is often present in SiCN and polysilicon even when inclusion of oxygen is not intended. Furthermore, common measurement techniques used to determine elemental composition may over-report the presence of oxygen due to atmospheric contamination during sample preparation and measurement. Describing a material as "essentially devoid of oxygen" or "oxygen-free" accommodates these as acceptable tolerances. Even more generally, a silicon-containing film having less oxygen will etch more rapidly than a silicon-containing film having more oxygen. In embodiments, the silicon-containing film may consist essentially of silicon either in amorphous, crystalline or polycrystalline form. Similarly, the oxygen-and-silicon-containing film may consist essentially of SiO_2. The oxide deselective etch may still have utility as long as both films have exposed surfaces since each will etch at a different rate. The etch rate of an exposed silicon-containing region may be greater than an etch rate of an exposed oxygen-and-silicon-containing region by a multiplicative factor greater than five in embodiments of the invention. .

Oxide deselective etches have been described thus far. The methods described herein may be used to selectively etch silicon faster than silicon nitride as shown in FIG. 3. The selectivity is not as pronounced as is the case for silicon etch selectivity over silicon oxide. The difference can still be helpful in a variety of process flows. These etch processes may be referred to herein as nitride deselective etches and have the same process parameter embodiments described with reference to oxide deselective etches. Analogously, the remote

plasma region and the substrate processing region may each be devoid or essentially devoid of nitrogen during these etch processes, according to embodiments of the invention. Generally speaking, silicon-containing materials may be etched selectively compared to a nitrogen-and-silicon-containing material having a greater nitrogen concentration than the silicon-containing materials. The etch rate of an exposed silicon-containing region may be greater than an etch rate of an exposed nitrogen-and-silicon-containing material by a multiplicative factor greater than 1.5 in embodiments of the invention. Silicon-containing films, such as silicon, may also be etched faster than nitrogen-oxygen-and-silicon-containing films.

Additional oxide deselective etch process parameters are disclosed in the course of describing an exemplary processing system.

Exemplary Processing System

FIG. 7 is a partial cross sectional view showing an illustrative processing chamber 700, in which, embodiments of the invention may be carried out. Generally, a hydrogen-containing precursor and a fluorine-containing precursor may be introduced through one or more apertures 751 into remote plasma region(s) 761-763 and excited by plasma power source 746.

In one embodiment, the processing chamber 700 includes a chamber body 712, a lid assembly 702, and a support assembly 710. The lid assembly 702 is disposed at an upper end of the chamber body 712, and the support assembly 710 is at least partially disposed within the chamber body 712. The processing chamber 700 and the associated hardware are preferably formed from one or more process-compatible materials (e.g. aluminum, stainless steel, etc.).

The chamber body 712 includes a slit valve opening 760 formed in a sidewall thereof to provide access to the interior of the processing chamber 700. The slit valve opening 760 is selectively opened and closed to allow access to the interior of the chamber body 712 by a wafer handling robot (not shown). In one embodiment, a wafer can be transported in and out of the processing chamber 700 through the slit valve opening 760 to an adjacent transfer chamber and/or load-lock chamber, or another chamber within a cluster tool. An exemplary cluster tool which may include processing chamber 700 is shown in FIG. 8.

In one or more embodiments, chamber body 712 includes a chamber body channel 713 for flowing a heat transfer fluid through chamber body 712. The heat transfer fluid can be a heating fluid or a coolant and is used to control the temperature of chamber body 712 during

processing and substrate transfer. Heating the chamber body 712 may help to prevent unwanted condensation of the gas or byproducts on the chamber walls. Exemplary heat transfer fluids include water, ethylene glycol, or a mixture thereof. An exemplary heat transfer fluid may also include nitrogen gas. Support assembly 710 may have a support assembly channel 704 for flowing a heat transfer fluid through support assembly 710 thereby affecting the substrate temperature.

The chamber body 712 can further include a liner 733 that surrounds the support assembly 710. The liner 733 is preferably removable for servicing and cleaning. The liner 733 can be made of a metal such as aluminum, or a ceramic material. However, the liner 733 can be any process compatible material. The liner 733 can be bead blasted to increase the adhesion of any material deposited thereon, thereby preventing flaking of material which results in contamination of the processing chamber 700. In one or more embodiments, the liner 733 includes one or more apertures 735 and a pumping channel 729 formed therein that is in fluid communication with a vacuum system. The apertures 735 provide a flow path for gases into the pumping channel 729, which provides an egress for the gases within the processing chamber 700.

The vacuum system can include a vacuum pump 725 and a throttle valve 727 to regulate flow of gases through the processing chamber 700. The vacuum pump 725 is coupled to a vacuum port 731 disposed on the chamber body 712 and therefore, in fluid communication with the pumping channel 729 formed within the liner 733. The terms "gas" and "gases" are used interchangeably, unless otherwise noted, and refer to one or more reactants, catalysts, carrier, purge, cleaning, combinations thereof, as well as any other fluid introduced into the chamber body 712. The term “precursor” is used to refer to any process gas which takes part in a reaction to either remove or deposit material from a surface.

Apertures 735 allow the pumping channel 729 to be in fluid communication with a processing region 740 within the chamber body 712. The processing region 740 is defined by a lower surface of the lid assembly 702 and an upper surface of the support assembly 710, and is surrounded by the liner 733. The apertures 735 may be uniformly sized and evenly spaced about the liner 733. However, any number, position, size or shape of apertures may be used, and each of those design parameters can vary depending on the desired flow pattern of gas across the substrate receiving surface as is discussed in more detail below. In addition, the size, number and position of the apertures 735 are configured to achieve uniform flow of

gases exiting the processing chamber 700. Further, the aperture size and location may be configured to provide rapid or high capacity pumping to facilitate a rapid exhaust of gas from the chamber 700. For example, the number and size of apertures 735 in close proximity to the vacuum port 731 may be smaller than the size of apertures 735 positioned farther away from the vacuum port 731.

A gas supply panel (not shown) is typically used to provide process gas(es) to the processing chamber 700 through one or more apertures 751. The particular gas or gases that are used depend upon the process or processes to be performed within the chamber 700. Illustrative gases can include, but are not limited to one or more precursors, reductants, catalysts, carriers, purge, cleaning, or any mixture or combination thereof. Typically, the one or more gases introduced to the processing chamber 700 flow into plasma volume 761 through aperture(s) 751 in top plate 750. Alternatively or in combination, processing gases may be introduced more directly through aperture(s) 752 into processing region 740. Aperture(s) 752 bypass the remote plasma excitation and are useful for processes involving gases that do not require plasma excitation or processes which do not benefit from additional excitation of the gases. Electronically operated valves and/or flow control mechanisms (not shown) may be used to control the flow of gas from the gas supply into the processing chamber 700. Depending on the process, any number of gases can be delivered to the processing chamber 700, and can be mixed either in the processing chamber 700 or before the gases are delivered to the processing chamber 700.

The lid assembly 702 can further include an electrode 745 to generate a plasma of reactive species within the lid assembly 702. In one embodiment, the electrode 745 is supported by top plate 750 and is electrically isolated therefrom by inserting electrically isolating ring(s) 747 made from aluminum oxide or any other insulating and process compatible material. In one or more embodiments, the electrode 745 is coupled to a power source 746 while the rest of lid assembly 702 is connected to ground. Accordingly, a plasma of one or more process gases can be generated in remote plasma region composed of volumes 761, 762 and/or 763 between electrode 745 and annular mounting flange 722. In embodiments, annular mounting flange comprises or supports gas delivery plate 720. For example, the plasma may be initiated and maintained between electrode 745 and one or both blocker plates of blocker assembly 730. Alternatively, the plasma can be struck and contained between the electrode 745 and gas delivery plate 720, in the absence of blocker assembly 730. In either embodiment, the plasma is well confined or contained within the lid assembly 702.

Accordingly, the plasma is a "remote plasma" since no active plasma is in direct contact with the substrate disposed within the chamber body 712. As a result, plasma damage to the substrate may be avoided since the plasma is separated from the substrate surface.

A wide variety of power sources 746 are capable of activating the nitrogen-containing precursor (nitrogen trifluoride). For example, radio frequency (RF), direct current (DC), or microwave (MW) based power discharge techniques may be used. The activation may also be generated by a thermally based technique, a gas breakdown technique, a high intensity light source (e.g., UV energy), or exposure to an x-ray source. Alternatively, a remote activation source may be used, such as a remote plasma generator, to generate a plasma of reactive species which are then delivered into the chamber 700. Exemplary remote plasma generators are available from vendors such as MKS Instruments, Inc. and Advanced Energy Industries, Inc. In the exemplary processing system an RF power supply is coupled to electrode 745. A higher-power microwave power source 746 is beneficial in the event that reactive oxygen will also be produced using power source 746.

The temperatures of the process chamber body 712 and the substrate may each be controlled by flowing a heat transfer medium through chamber body channel 713 and support assembly channel 704, respectively. Support assembly channel 704 may be formed within support assembly 710 to facilitate the transfer of thermal energy. Chamber body 712 and support assembly 710 may be cooled or heated independently. For example, a heating fluid may be flown through one while a cooling fluid is flown through the other.

Other methods may be used to control the substrate temperature. The substrate may be heated by heating the support assembly 710 (or a portion thereof, such as a pedestal) with a resistive heater or by some other means. In another configuration, gas delivery plate 720 may be maintained at a temperature higher than the substrate and the substrate can be elevated in order to raise the substrate temperature. In this case the substrate is heated radiatively or by using a gas to conduct heat from gas delivery plate 720 to the substrate. The substrate may be elevated by raising support assembly 710 or by employing lift pins.

During the etch processes described herein, chamber body 712 may be maintained within an approximate temperature range of between 50°C and 80°C, between 55°C and 75°C or between 60°C and 70°C in different embodiments. During exposure to plasma effluents and/or oxidizing agents, the substrate may be maintained below about 100°C, below about 65°C, between about 15°C and about 50°C or between about 22°C and about 40°C in

different embodiments. The substrate may also be held at elevated temperatures during the etch since the oxide deselective etch does not rely as heavily if at all on a sublimation step. The substrate may be maintained above 70°C, above 100°C or above 130°C in disclosed embodiments.

Plasma effluents include a variety of molecules, molecular fragments and ionized species. During oxide deselective etching, plasma effluents include fluorine radicals which react readily with exposed silicon-containing material which lacks oxygen or possesses a small amount of oxygen. Plasma effluents may react with a oxygen-free silicon-containing layer to form SiF and H_2O vapor products which are removed from processing region 740 by vacuum pump 725.

In embodiments, little or no hydrogen is introduced into the remote plasma region. Under such conditions, little or no solid residue is produced on the substrate surface and a sublimation step may be omitted. When a source of hydrogen is included, the substrate may be heated to sublimate solid residue etch by-products formed upon exposing the substrate to the plasma effluents. In embodiments, the gas delivery plate 720 is heatable by incorporating heating element 770 within or near gas delivery plate 720. The substrate may be heated by reducing the distance between the substrate and the heated gas delivery plate. The gas delivery plate 720 may be heated to between about 100°C and 150°C, between about 110°C and 140°C or between about 120°C and 130°C in different embodiments. By reducing the separation between the substrate and the heated gas delivery plate, the substrate may be heated to above about 75°C, above about 90°C, above about 100°C or between about 115°C and about 150°C in different embodiments. When a hydrogen source is flowed along with a fluorine source, the heat radiated from gas delivery plate 720 to the substrate should be made sufficient to dissociate or sublimate solid $(NH_4)_2SiF_6$ from the oxide portions of the substrate into volatile SiF_4, NH_3 and HF products which may be pumped away from processing region 740.

Nitrogen trifluoride (or another fluorine-containing precursor) may be flowed into remote plasma volume 761 at rates between about 25 sccm and about 200 sccm, between about 50 sccm and about 150 sccm or between about 75 sccm and about 125 sccm in different embodiments. Ammonia (or hydrogen-containing precursors in general) may be flowed into remote plasma volume 761 at rates below or about 20 sccm , below or about 15 sccm, below or about 10 sccm, below or about 5 sccm or below or about 2 sccm in different embodiments.

Combined flow rates of hydrogen-containing and fluorine-containing precursors into the remote plasma region may account for 0.05% to about 20% by volume of the overall gas mixture; the remainder being a carrier gas. In one embodiment, a purge or carrier gas is first initiated into the remote plasma region before those of the reactive gases to stabilize the pressure within the remote plasma region.

Production of the plasma effluents occurs within volumes 761, 762 and/or 763 by applying plasma power to electrode 745 relative to the rest of lid assembly 702. Plasma power can be a variety of frequencies or a combination of multiple frequencies. In the exemplary processing system the plasma is provided by RF power delivered to electrode 745. The RF power may be between about 1 W and about 1000 W, between about 5 W and about 600 W, between about 10 W and about 300 W or between about 20 W and about 100 W in different embodiments. The RF frequency applied in the exemplary processing system may be less than about 200 kHz, less than about 150 kHz, less than about 120 kHz or between about 50 kHz and about 90 kHz in different embodiments.

Processing region 740 can be maintained at a variety of pressures during the flow of plasma effluents into processing region 740. The pressure may be maintained between about 500 mTorr and about 30 Torr, between about 1 Torr and about 10 Torr or between about 3 Torr and about 6 Torr in different embodiments. Lower pressures may also be used within processing region 740. The pressure may be maintained below or about 500 mTorr, below or about 250 mTorr, below or about 100 mTorr, below or about 50 mTorr or below or about 20 mTorr in different embodiments.

The selectivity of the etch process may be enhanced by neutralizing charged species generated in volumes 761-763 prior to flowing plasma effluents into the substrate processing region. Neutral reactive radicals (molecular fragments) are still passed into the substrate processing region and react with the substrate to perform the selective etch process. To this end, the holes in the showerhead may be narrowed to increase the neutralizing collisions as effluents migrate toward the substrate processing region. A separate showerhead may also be included in the path of the plasma effluents to suppress the flow of ions into the substrate processing region. The separate showerhead may be referred to as an ion suppressor (not shown). These neutral (uncharged) species may still include highly reactive species that are transported with less reactive carrier gas through the holes. The flow of ionized effluents into the substrate processing region may be reduced to below the flow of neutral species on a per

molecular fragment basis. The flow may also be below 10% of the neutral species or may be essentially eliminated, in disclosed embodiments. Controlling the amount of ionic species passing into the substrate processing region provides increased control over the gas mixture brought into contact with the underlying wafer substrate, increasing control of the selectivity of the etch process.

A plurality of holes in the ion suppressor and/or the showerhead may be configured to control the passage of the activated gas (i.e., the ionic, radical, and/or neutral species) into the substrate processing region. For example, the aspect 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 into the substrate processing region is reduced. The holes may include a tapered portion that faces the remote plasma region (volumes 761, 762 and/or 763). The taper may serve to allow a substantial number of effluents into the hole but force a large percentage of the effluents to undergo neutralizing collisions prior to entering the substrate processing region. An adjustable electrical bias may also be applied to the ion suppressor and/or showerhead as an additional means to control the flow of ionic species through the suppressor.

In one or more embodiments, the processing chamber 700 can be integrated into a variety of multi-processing platforms, including the Producer™ GT, Centura™ AP and Endura™ platforms available from Applied Materials, Inc. located in Santa Clara, Calif. Such a processing platform is capable of performing several processing operations without breaking vacuum.

FIG. 8 is a schematic top-view diagram of an illustrative multi-chamber processing system 800. The system 800 can include one or more load lock chambers 802, 804 for transferring of substrates into and out of the system 800. Typically, since the system 800 is under vacuum, the load lock chambers 802, 804 may "pump down" the substrates introduced into the system 800. A first robot 810 may transfer the substrates between the load lock chambers 802, 804, and a first set of one or more substrate processing chambers 812, 814, 816, 818 (four are shown). Each processing chamber 812, 814, 816, 818, can be outfitted to perform a number of substrate processing operations including the dry etch processes described herein in addition to cyclical layer deposition (CLD), atomic layer deposition (ALD), chemical vapor deposition (CVD), physical vapor deposition (PVD), etch, pre-clean, degas, orientation and other substrate processes.

The first robot 810 can also transfer substrates to/from one or more transfer chambers 822, 824. The transfer chambers 822, 824 can be used to maintain ultrahigh vacuum conditions while allowing substrates to be transferred within the system 800. A second robot 830 can transfer the substrates between the transfer chambers 822, 824 and a second set of one or more processing chambers 832, 834, 836, 838. Similar to processing chambers 812, 814, 816, 818, the processing chambers 832, 834, 836, 838 can be outfitted to perform a variety of substrate processing operations including the dry etch processes described herein in addition to cyclical layer deposition (CLD), atomic layer deposition (ALD), chemical vapor deposition (CVD), physical vapor deposition (PVD), etch, pre-clean, degas, and orientation, for example. Any of the substrate processing chambers 812, 814, 816, 818, 832, 834, 836, 838 may be removed from the system 800 if not necessary for a particular process to be performed by the system 800.

System controller 857 is used to control motors, valves, flow controllers, power supplies and other functions required to carry out process recipes described herein. System controller 857 may rely on feedback from optical sensors to determine and adjust the position of movable mechanical assemblies. Mechanical assemblies may include the robot, throttle valves and susceptors which are moved by motors under the control of system controller 857.

In an exemplary embodiment, system controller 857 includes a hard disk drive (memory), USB ports, a floppy disk drive and a processor. System controller 857 includes analog and digital input/output boards, interface boards and stepper motor controller boards. Various parts of multi-chamber processing system 800 which contains processing chamber 800 are controlled by system controller 857. The system controller executes system control software in the form of a computer program stored on computer-readable medium such as a hard disk, a floppy disk or a flash memory thumb drive. Other types of memory can also be used. The computer program includes sets of instructions that dictate the timing, mixture of gases, chamber pressure, chamber temperature, RF power levels, susceptor position, and other parameters of a particular process.

A process for etching, depositing or otherwise processing a film on a substrate or a process for cleaning chamber can be implemented using a computer program product that is executed by the controller. The computer program code can be written in any conventional computer readable programming language: for example, 68000 assembly language, C, C++, Pascal, Fortran or others. Suitable program code is entered into a single file, or multiple files, using a

conventional text editor, and stored or embodied in a computer usable medium, such as a memory system of the computer. If the entered code text is in a high level language, the code is compiled, and the resultant compiler code is then linked with an object code of precompiled Microsoft Windows® library routines. To execute the linked, compiled object code the system user invokes the object code, causing the computer system to load the code in memory. The CPU then reads and executes the code to perform the tasks identified in the program.

The interface between a user and the controller may be via a touch-sensitive monitor and may also include a mouse and keyboard. In one embodiment two monitors are used, one mounted in the clean room wall for the operators and the other behind the wall for the service technicians. The two monitors may simultaneously display the same information, in which case only one is configured to accept input at a time. To select a particular screen or function, the operator touches a designated area on the display screen with a finger or the mouse. The touched area changes its highlighted color, or a new menu or screen is displayed, confirming the operator's selection.

As used herein "substrate" may be a support substrate with or without layers formed thereon. The support substrate may be an insulator or a semiconductor of a variety of doping concentrations and profiles and may, for example, be a semiconductor substrate of the type used in the manufacture of integrated circuits. A gas in an "excited state" describes a gas wherein at least some of the gas molecules are in vibrationally-excited, dissociated and/or ionized states. A gas may be a combination of two or more gases. "Silicon oxide" is predominantly SiO_2 but may include concentrations of other elemental constituents such as nitrogen, hydrogen, carbon and the like. The terms "gap" and "trench" are used throughout with no implication that the etched geometry has a large horizontal aspect ratio. Viewed from above the surface, these structures may appear circular, oval, polygonal, rectangular, or a variety of other shapes. As used herein, a conformal etch process refers to a generally uniform removal of material on a surface in the same shape as the surface, i.e., the surface of the etched layer and the pre-etch surface are generally parallel. A person having ordinary skill in the art will recognize that the etched interface likely cannot be 100% conformal and thus the term "generally" allows for acceptable tolerances.

Having disclosed 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 disclosed embodiments. 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.

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.

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 dielectric material" includes reference to one or more dielectric materials and equivalents thereof known to those skilled in the art, and so forth.

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 method of etching patterned substrate in a substrate processing region of a substrate processing chamber, wherein the patterned substrate has an exposed oxygen-and-silicon-containing region and an exposed silicon-containing region which contains less oxygen than the oxygen-and-silicon-containing region, the method comprising:

flowing a fluorine-containing precursor into a remote plasma region fluidly coupled to the substrate processing region while forming a plasma in the first plasma region to produce plasma effluents; and

etching the silicon-containing region faster than the oxygen-and-silicon-containing region by flowing the plasma effluents into the substrate processing region.

2. The method of claim 1 wherein an etch rate of the exposed silicon-containing region is greater than an etch rate of the exposed oxygen-and-silicon-containing region by a multiplicative factor greater than 5.

3. The method of claim 1 wherein the exposed silicon-containing region is essentially devoid of oxygen.

4. The method of claim 1 wherein the exposed silicon-containing region consists essentially of silicon.

5. The method of claim 1 wherein the exposed oxygen-and-silicon-containing region consists essentially of SiO_2.

6. The method of claim 1 wherein the exposed silicon-containing region is polysilicon, the exposed oxygen-and-silicon-containing region is SiO_2 and the polysilicon is trimmed by between 1 nm and 15 nm.

7. The method of claim 1 wherein the exposed silicon-containing region consists essentially of silicon, carbon and nitrogen.

8. The method of claim 1 wherein the exposed oxygen-and-silicon-containing region consists essentially of silicon, carbon and oxygen.

9. The method of claim 1 wherein the exposed silicon-containing region is SiCN, the exposed oxygen-and-silicon-containing region is SiOC and the SiCN is removed from the base of a trench formed in the SiOC.

10. The method of claim 1 wherein the fluorine-containing precursor comprises at least one precursor selected from the group consisting of nitrogen trifluoride, diatomic fluorine, monatomic fluorine and fluorine-substituted hydrocarbons.

11. The method of claim 1 wherein the plasma effluents possess an atomic ratio of fluorine-to-hydrogen which is greater than 5:1.

12. The method of claim 1 wherein essentially no ionized species are present in the plasma effluents within the substrate processing region to increase the etch selectivity of the silicon-containing region.

13. A method of etching patterned substrate in a substrate processing region of a substrate processing chamber, wherein the patterned substrate has an exposed nitrogen-and-silicon-containing region and an exposed silicon-containing region which contains less nitrogen than the nitrogen-and-silicon-containing region, the method comprising:

flowing a fluorine-containing precursor into a remote plasma region fluidly coupled to the substrate processing region while forming a plasma in the first plasma region to produce plasma effluents; and

etching the silicon-containing region faster than the nitrogen-and-silicon-containing region by flowing the plasma effluents into the substrate processing region.

14. The method of claim 13 wherein an etch rate of the exposed silicon-containing region is greater than an etch rate of the exposed nitrogen-and-silicon-containing region by a multiplicative factor greater than 1.5.

15. The method of claim 13 wherein the exposed silicon-containing region is essentially devoid of nitrogen.

16. The method of claim 13 wherein the exposed silicon-containing region consists essentially of silicon.

17. The method of claim 13 wherein the exposed nitrogen-and-silicon-containing region consists essentially of silicon nitride.

18. The method of claim 13 wherein the fluorine-containing precursor comprises at least one precursor selected from the group consisting of nitrogen trifluoride, diatomic fluorine, monatomic fluorine and fluorine-substituted hydrocarbons.

19. The method of claim 13 wherein the fluorine-containing precursor and the plasma effluents are essentially devoid of hydrogen.

20. The method of claim 13 wherein the plasma effluents possess an atomic ratio of fluorine-to-hydrogen which is greater than 5:1.