A method of cleaning process residues formed on surfaces in a chamber during processing of a substrate in the chamber includes first and second steps. In a first cleaning step, a first energized cleaning gas having a first chlorine-containing gas and oxygen is provided in the chamber and then exhausted. In a second cleaning step, a second energized cleaning gas having a second chlorine-containing gas and oxygen is provided in the chamber and then exhausted.
METHOD AND APPARATUS FOR CLEANING A SUBSTRATE PROCESSING CHAMBER

BACKGROUND

[0001] The present invention relates to the cleaning of a substrate processing chamber.

[0002] When an energized gas is used to etch or deposit material on a substrate in a chamber, process residues are often formed on the surfaces of walls and components that are in the chamber. These process residues are undesirable, as they can corrode the wall and component surfaces, requiring their replacement and thereby increasing chamber downtime. Accumulated process residues can also flake off from chamber surfaces and fall upon and contaminate the substrate while it is being processed in the chamber. Residue build-up can also result in variability of wafer processing characteristics such as the critical dimension of features etched in the substrate (CD shift). The accumulated process residues formed during one process, can also interact with the process gases of another process, thereby preventing different processes from being run in the same chamber for mixed application productions.

[0003] Conventional chamber cleaning processes are periodically performed to clean the process residues from the chamber surfaces. However, such cleaning processes often fail to properly clean the residues off the chamber walls in a consistent and reproducible manner. In wet cleaning processes, an operator manually scrubs down surfaces in the chamber with a residue dissolving solvent to clean the chamber. However, the operator can often affect the quality and reproducibility of such a cleaning procedure. In dry or plasma clean processes, a cleaning gas is introduced into the chamber and energized by coupling RF or microwave energy to the gas to clean the residues formed on the surfaces in the chamber. For example, metal-containing etchant residues formed in the etching of a metal-containing layer on a substrate, may be cleaned with an energized cleaning gas comprising an oxidizing gas and a chlorine-containing gas, such as Cl₂, Cl₃, or HCl. However, the dry cleaning processes often fail to properly clean residues having different chemical compositions or thickness that are formed in the chamber.

[0004] Thus, it is desirable to have a cleaning process capable of cleaning different types of process residues, such as metal-containing and other etchant residues, from surfaces in the chamber. It is also desirable to clean the residues in a consistent and reproducible manner.

SUMMARY

[0005] An embodiment of a method of cleaning process residues formed on surfaces in a chamber during processing of a substrate in the chamber comprises first and second cleaning steps. The first cleaning step comprises providing a first energized cleaning gas comprising a first chlorine-containing gas and oxygen in the chamber, and exhausting the first cleaning gas. The second cleaning step comprises providing a second energized cleaning gas comprising a second chlorine-containing gas and oxygen in the chamber, and exhausting the second cleaning gas.

[0006] An embodiment of a substrate processing apparatus comprises a chamber having a substrate support, a gas supply, a gas energizer, a gas exhaust, and a controller. The controller comprises substrate processing program code to operate the substrate support, gas supply, gas energizer and gas exhaust to process a substrate in the chamber by introducing an etchant gas into the chamber, energizing the etchant gas to etch the substrate, and exhausting the etchant gas. The controller also comprises chamber cleaning program code to operate the substrate support, gas supply, gas energizer and gas exhaust to clean surfaces in the chamber by, in a first cleaning step, providing a first energized cleaning gas comprising a first chlorine-containing gas and oxygen in the chamber, and exhausting the first cleaning gas, and in a second cleaning step, providing a second energized cleaning gas comprising a second chlorine-containing gas and oxygen in the chamber, and exhausting the second cleaning gas.

[0007] Another embodiment of a method of cleaning process residues formed on surfaces in a chamber during processing of a substrate in the chamber comprises a first cleaning step comprising introducing a first cleaning gas comprising Cl₂ and O₂ into the chamber, coupling RF energy to the first cleaning gas in the chamber to energize the first cleaning gas, and exhausting the first cleaning gas. The method further comprises a second cleaning step comprising introducing a second cleaning gas comprising HCl and O₂ into the chamber, coupling RF energy to the second cleaning gas in the chamber to energize the second cleaning gas, and exhausting the second cleaning gas.

[0008] Another embodiment of a substrate processing apparatus comprises a chamber having a substrate support, a gas supply, a gas energizer, a gas exhaust, and a controller. The controller comprises substrate processing program code to operate the substrate support, gas supply, gas energizer and gas exhaust to process a substrate in the chamber by introducing an etchant gas into the chamber, energizing the etchant gas to etch the substrate, and exhausting the etchant gas. The controller further comprises chamber cleaning program code to operate the substrate support, gas supply, gas energizer and gas exhaust to clean surfaces in the chamber by, in a first cleaning step, introducing a first cleaning gas comprising Cl₂ and O₂ into the chamber, coupling RF energy to the first cleaning gas in the chamber to energize the first cleaning gas, and exhausting the first cleaning gas, and in a second cleaning step, introducing a second cleaning gas comprising HCl and O₂ into the chamber, coupling RF energy to the second cleaning gas in the chamber to energize the second cleaning gas, and exhausting the second cleaning gas.

[0009] In another embodiment of a method of cleaning process residues formed on surfaces in a chamber during processing of a substrate in the chamber, an energized cleaning gas comprising H₂, chlorine species and oxygen species is provided in the chamber and then exhausted from the chamber.

[0010] In yet another embodiment of a substrate processing apparatus, the apparatus comprises a chamber having a substrate support, a gas supply, a gas energizer, a gas exhaust, and a controller. The controller comprises substrate processing program code to operate the substrate support, gas supply, gas energizer and gas exhaust to process a substrate in the chamber by introducing an etchant gas into the chamber, energizing the etchant gas to etch the substrate,
and exhausting the etchant gas. The controller also comprises chamber cleaning program code to operate the substrate support, gas supply, gas energizer and gas exhaust to clean surfaces in the chamber by providing an energized cleaning gas in the chamber, the energized cleaning gas comprising H₂, chlorine species and oxygen species, and exhausting the cleaning gas.

**DRAWINGS**

[0011] These and other features, aspects, and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings which illustrate examples of the invention, where:

[0012] FIG. 1 is a partial sectional schematic side view of an embodiment of a chamber;

[0013] FIG. 2 is a partial sectional view of a substrate having etched features in a metal-containing layer; and

[0014] FIG. 3 is an illustrative block diagram of a controller comprising a computer readable program.

**DESCRIPTION**

[0015] During processing of a substrate 104 in a process chamber 106, process residues are generated by the interaction of a process gas with the substrate 104. For example, in an etching process to form features 52 in a metal-containing layer 53, such as a metal-containing layer comprising one or more of aluminum, titanium and copper, metal-containing etchant residues can be generated by the interaction of an energized etchant gas with the metal-containing layer 53, as shown in FIG. 2. These metal-containing etchant residues formed by the reaction of energized etchant gas with the metal-containing layer 53 can often comprise residues that are difficult to clean, such as metal-containing salts. Etching of the metal-containing layer 53 on the substrate 104 can also generate other residues, such as carbon-containing residues formed by the interactions of the etchant gas with a patterned layer of photore sist 55 on the substrate 104. The etchant residues deposit on surfaces 113 in the chamber 106, such as surfaces 113 of one or more of the chamber wall 107, the substrate support 110, gas supply 130, gas energizer 154 or gas exhaust 144, and can adversely affect subsequent processes in the chamber.

[0016] To clean the metal-containing etchant residues, a cleaning process is performed in the chamber 106. The cleaning process comprises providing an energized cleaning gas comprising chlorine-containing gas and oxygen (O₂) into the chamber 106. The energized cleaning gas cleans the etchant residues by reacting with the residues on the surfaces 113 in the chamber 106 and forming volatile compounds and species, which are exhausted from the chamber 106. For example, reactive chlorine-containing species can react with metal-containing etchant residues comprising aluminum, titanium and titanium nitride to form volatile products such as AlCl₃ and TiCl₄, that are exhausted from the chamber 106. Reactive oxygen-containing species can remove etchant residues comprising carbon-containing compounds by reacting with the carbon-containing compounds to form gaseous carbon monoxide and carbon dioxide species. Examples of chlorine-containing gases suitable for cleaning the etchant residues can comprise one or more of Cl₂, HCl and CCl₄.

[0017] However, it has been discovered that cleaning with the energized cleaning gas comprising chlorine-containing gas and oxygen can often fail to satisfactorily clean the residues from surfaces 113 in the chamber 106, and may even generate other types or compositions of cleaning residues that deposit on surfaces 113 in the chamber 106. For example, a cleaning step with a cleaning gas comprising Cl₂ and O₂ may leave cleaning residues such as metal and/or chlorine-containing salts and oxides on surfaces 113 in the chamber 106. These cleaning residues can be detrimental to subsequent processes performed in the chamber 106.

[0018] Thus, in one aspect of the invention, the cleaning of etchant residues in the chamber 106 is improved by providing a first cleaning gas comprising a first chlorine-containing gas and oxygen in a first cleaning step, and then changing the composition to provide a second cleaning gas comprising a second chlorine-containing gas and oxygen in a second cleaning step. By changing the composition, the first and second cleaning gas steps are optimized to enhance cleaning of the chamber surfaces 113. For example, in a first cleaning step, the first cleaning gas can comprise a first chlorine-containing gas that is selected to aggressively clean etchant residues, and in the second cleaning step, the second cleaning gas can comprise a second chlorine-containing gas that is selected to clean any remaining etchant residues, as well as to remove any cleaning residues generated by the first cleaning gas during the first cleaning step. In this manner, the cleaning process can be optimized to not only clean process residue generated in previous substrate processing steps, but also to clean any cleaning residues that might be generated during the cleaning process itself. The first and second cleaning steps may be sequentially repeated a desired number of times to provide the desired level of cleaning in the chamber 106.

[0019] It has been discovered that good cleaning of the etchant residues is provided by performing a cleaning process comprising, in the first cleaning step, providing an energized first cleaning gas comprising a first chlorine-containing gas comprising Cl₂ and oxygen, and in the second cleaning step, providing a second energized cleaning gas comprising a second chlorine-containing gas comprising HCl and oxygen. These first and second cleaning gas compositions have been found to provide effective and synergistic cleaning of the residues in the chamber 106. In the first cleaning step, the chlorine species from Cl₂ provide good cleaning of metal containing residues, while the oxygen species from the oxygen gas clean carbon-containing residues. In the second step, chlorine species from the HCl also react with and remove the metal-containing species and, in addition, energized hydrogen species from HCl and oxygen species interact to form reactive OH species that react with metal-containing species such as metal-containing salts and oxides, to form metal hydroxides that can be exhausted from the chamber 106. The second cleaning gas composition comprising HCl and oxygen is also very effective at cleaning residues left by the first cleaning gas composition, such as chlorine salts generated by the first cleaning gas comprising Cl₂ and O₂. Thus, the first and second cleaning gases provide beneficial and cooperative cleaning of the etchant residues.

[0020] Yet another benefit of the second cleaning gas composition comprising HCl and O₂ is that it may allow more beneficial “sticky” carbon-containing residue to remain in the chamber 106, while also providing for the
removal of undesirable “flaky” metal-containing residue. Unlike “flaky” types of residue, the “sticky” carbon-containing residue adheres well to surfaces 113 in the chamber 106, and also captures residues formed during subsequent processes, keeping them from re-depositing on the substrate 104. The second cleaning gas comprising HCl and O₂ provides preferential removal of the “flaky” residue over the carbon-containing residue because the formation of OH species from the interaction of the oxygen and HCl gases resides in relatively less free oxygen available for the removal of the “sticky” carbon-containing residues. Thus, by providing the first cleaning gas comprising Cl₂ and O₂ and the second cleaning gas comprising HCl and O₂, the composition of the remaining process residues can be tailored to provide beneficial effects in subsequent substrate processes.

[0021] The cleaning of process residues is further improved by providing a first energized cleaning gas comprising a first volumetric flow ratio of chlorine-containing gas to oxygen in the first cleaning step, and providing a second energized cleaning gas comprising a second volumetric flow ratio of chlorine-containing gas to oxygen in the second cleaning step. The first and second volumetric flow ratios allow for improved cleaning because the flow ratios can be tailored to clean a particular type of etchant residue formed in the chamber 106 during each cleaning step. For example, a first or second cleaning gas comprising a lower ratio of chlorine-containing gas to oxygen, and thus more oxygen species, may be more effective at cleaning etchant residues containing large amounts of carbon-containing residues, and a first or second cleaning gas comprising a higher ratio of chlorine-containing gas to oxygen, and thus more chlorine-containing species, may be more effective at cleaning etchant residues that have a higher content of metal species, such as aluminum species. A suitable first volumetric flow ratio of chlorine-containing gas to oxygen in a first cleaning gas comprising Cl₂ to O₂ is, for example, from about 0.1:1 to about 1:1, and even from about 0.2:1 to about 0.8:1. A suitable second volumetric flow ratio of chlorine-containing gas to oxygen in a second cleaning gas comprising HCl and O₂ has been discovered to be a ratio of at least about 3:7, such as from about 6:13 to about 1:1. Maintaining this second volumetric flow ratio at a level of at least about 3:7 is important, as providing a ratio that is too low can have detrimental effects. For example, providing a lower flow ratio of HCl to O₂ can yield an excessive amount of O₂, resulting in the excessive removal of beneficial process residues from the surfaces 113, such as carbon-containing or other “sticky” residues. Providing too little HCl also results in less formation of the reactive OH species, thereby decreasing the metal-containing residue cleaning efficiency of the second cleaning gas. Thus, providing the first and second volumetric flow ratios of chlorine-containing gas to oxygen gas, and maintaining the second volumetric flow ratio of HCl to O₂ in the second cleaning gas at a level of at least about 3:7 provides optimum cleaning of etchant and/or cleaning residues, and provides a desirable composition of process residues remaining in the chamber 106 that is beneficial for subsequent substrate processes.

[0022] The first and second cleaning gases are energized to clean the etchant residues by coupling RF power to the cleaning gas in the process zone 108. RF power is coupled to the cleaning gas at a power level that is suitable to provide sufficiently energized cleaning gas comprising energized species that rapidly and efficiently remove undesirable process residues without overcleaning of the process residues. RF power can be coupled to the cleaning gas by applying a current to an inductor antenna 175 about the chamber 106 at a power level per unit area of from about 2×10⁶ to about 7×10⁶ Watts/cm², and even from about 2.5×10⁶ to about 5.1×10⁶ Watts/cm². Also, a bias RF power level per unit area of from about 0 to about 5×10⁻⁶ Watts/cm², and even from about 1.5×10⁻⁶ to about 3.2×10⁻⁶ Watts/cm² can be coupled by applying a current to one or more electrodes 139, 141 in the chamber 106.

[0023] The volumetric flow rate and pressure of the first and second cleaning gases are maintained at levels that allow for cleaning of the undesirable process residues without overcleaning and damaging of the surfaces 113 in the chamber 106. A suitable volumetric flow rate per unit chamber volume of a first cleaning gas comprising Cl₂ and O₂ may be from about 5.9×10⁻⁵ sccm/cc to about 3.9×10⁻² sccm/cc, and even from about 8.9×10⁻³ sccm/cc to about 3.4×10⁻¹ sccm/cc. A suitable pressure of the first cleaning gas in the chamber 106 may be from about 10 mTorr to about 60 mTorr, and even from about 15 mTorr to about 50 mTorr. A suitable volumetric flow rate per unit chamber volume of a second cleaning gas comprising HCl and O₂ may be from about 1×10⁻⁵ sccm/cc to about 4×10⁻² sccm/cc and even from about 7.3×10⁻³ sccm/cc to about 2×10⁻² sccm/cc. A suitable pressure of the second cleaning gas comprising HCl and O₂ in the chamber 106 may be from about 5 mTorr to about 50 mTorr.

[0024] Cleaning of surfaces 113 in the chamber 106 may be further improved by performing a purge stage before or after the cleaning stage to purge unwanted gases and residues from the chamber 106. The purge stage generally comprises introducing a purge gas, such as for example, Ar, into the chamber 106 at a flow rate of for example from about 100 to about 200 sccm, while maintaining an exhaust throttle valve 150 fully opened to allow the purging gas to effectively remove residual chlorine and other gaseous species from the chamber 106. As a result of the opened throttle state, the pressure in the chamber 106 during the purge step may be less than about 10 mTorr and may even be about 4 mTorr. In one version, a first purge stage performed prior to the first and second cleaning steps is performed for less than about 10 seconds, such as for about 5 seconds. A second purge stage performed after the first and second cleaning steps may be performed for less than about 5 seconds, such as for about 2 seconds.

[0025] In one version, a plasma is formed from the purge gas and sustained to further neutralize contaminants and charged species on the surfaces 113 in the chamber 106. For example, when the purge stage is performed before the cleaning steps, a plasma can be formed from the purge gas to neutralize charge on the substrate 104 to aid in de-chucking of the substrate 104. The plasma can be formed by maintaining a source power level of about 500 Watts and a bias power of less than about 100 Watts. Thus, the purge stage enhances cleaning of the chamber 106 by removing gaseous species and other contaminants from the chamber 106.

[0026] The second cleaning gas comprising HCl and O₂ provides a combination of chlorine species, oxygen species
and hydrogen species that allows for the removal of different types of residue to provide good cleaning of the surfaces 113 of the chamber 106. Other cleaning gas compositions comprising a combination of chlorine species, oxygen species and hydrogen species can also be provided to clean the chamber 106. For example, the cleaning gas can comprise a chlorine-containing gas such as one or more of Cl₂ and HCl, and can further comprise one or more of (i) an oxygen-containing gas comprising oxygen species, such as one or more of O₂, H₂O and HO₂, and (ii) a hydrogen-containing gas comprising hydrogen species, such as one or more of H₂, H₂O and HO₂. In one version, the cleaning gas comprises a H₂ in combination with a chlorine-containing gas and an oxygen-containing gas, for example in the following compositions: (i) Cl₂/O₂/H₂, (ii) Cl₂/H₂O/H₂O₂, (iii) Cl₂/H₂/ H₂O₂, (iv) HCl/H₂O, (v) HCl/H₂O and (vi) HCl/H₂O₂. Other suitable cleaning gas compositions comprising chlorine species, oxygen species and hydrogen species can comprise, for example, (i) Cl₂/O₂/H₂O, (ii) Cl₂/O₂/H₂O₂, (iii) Cl₂/HClO₂, (iv) HCl/H₂O, (v) HCl/H₂O, (vi) Cl₂/ H₂O₂. The energized cleaning gas comprising chlorine species, oxygen species and hydrogen species can be provided as a part of multi-step cleaning process, for example in combination with a separate cleaning step that provides Cl₂ and O₂, or can be provided in a single step cleaning process.

[0027] An embodiment of the apparatus 102 suitable for processing a substrate 104 comprises a process chamber 106, such as a decoupled plasma source (DPS) chamber, schematically illustrated in FIG. 1, and commercially available from Applied Materials Inc., Santa Clara, Calif. The particular embodiment of the apparatus 102 shown herein is suitable for processing substrates 104, such as semiconductor wafers, and may be adapted by those of ordinary skill to process other substrates 104, such as flat panel displays, polymer panels, or other electrical circuit receiving structures. The apparatus 102 is provided only to illustrate the invention, and should not be used to limit the scope of the invention or its equivalents to the exemplary embodiments provided herein. The apparatus 102 may be attached to a mainframe unit that contains and provides electrical, plumbing, and other support functions for the apparatus 102. Exemplary mainframe units compatible with the illustrative embodiment of the apparatus 102 are currently commercially available as the Precision 5000™ systems from Applied Materials, Inc., of Santa Clara, Calif.

[0028] Generally, the apparatus 102 comprises a chamber 106 having walls typically fabricated from metal or ceramic materials. In the embodiment shown, the chamber 106 comprises a wall, which may comprise sidewalls 114, a bottom wall 116, and a ceiling 118. The ceiling 118 may comprise a substantially arcuate shape, or in other versions, the ceiling 118 may comprise a dome, substantially flat, or multi-radius shaped portion. The chamber 106 typically comprises a volume of at least about 5,000 cm³, and more preferably from about 10,000 to about 50,000 cm³. In operation, process gas is introduced into the chamber 106 through a gas supply 130 that includes a process gas source 138, conduits 136 having flow control valves 134, and gas outlets 142 around a periphery of the substrate 104, which may be held on a support 110. Alternatively to the configuration shown in FIG. 1, the process gas may be introduced through a showerhead (not shown) mounted on the ceiling 118 of the chamber 106. Spent process gas and etchant byproducts are exhausted from the chamber 106 through an exhaust 144, which includes a pumping channel 146 that receives spent process gas, a throttle valve 150 to control the pressure of process gas in the chamber 106, and one or more exhaust pumps 152. The exhaust 144 may also contain a system for abating undesirable gases from the exhaust.

[0029] The process gas is energized to process the substrate 104 by a gas energizer 154 that couples energy to the process gas in the process zone 108 of the chamber 106 (as shown) or in a remote zone upstream from the chamber 106 (not shown). In one version, the gas energizer 154 comprises an antenna 156 comprising one or more inductor coils 158, which may have a circular symmetry about the center of the chamber 106. Typically, the antenna 156 comprises solenoids having from about 1 to about 20 turns. A suitable arrangement of solenoids is selected to provide a strong inductive flux linkage and coupling to the process gas. When the antenna 156 is positioned near the ceiling 118 of the chamber 106, the adjacent portion of the ceiling may be made from a dielectric material, such as silicon dioxide, which is transparent to RF or electromagnetic fields. An antenna power supply 155 provides, for example, RF power to the antenna 156 at a frequency of typically about 50 kHz to about 60 MHz, and more typically about 13.56 MHz; and at a power level of from about 100 to about 5000 Watts. An RF match network (not shown) may also be provided. Alternatively or additionally, the gas energizer 154 may comprise a microwave or remote gas activator (not shown).

[0030] In one version, the gas energizer 154 may also or alternatively comprise process electrodes (not shown) that may be used to energize or further energize the process gas. Typically, the process electrodes include one electrode (not shown) in a wall, such as a sidewall 114 or ceiling 118 of the chamber 106 that may be capacitively coupled to another electrode, such as an electrode in the support 110 below the substrate 104. The electrode may comprise a dielectric ceiling 118 that serves as an induction field transmitting window that provides a low impedance to an RF induction field transmitted by the antenna 156 above the ceiling 118. Suitable dielectric materials that can be employed include materials such as aluminum oxide or silicon dioxide. Generally, the electrodes may be electrically biased relative to one another by an electrode voltage supply (not shown) that includes an AC voltage supply for providing an RF bias voltage. The RF bias voltage may comprise frequencies of about 50 kHz to about 60 MHz, and is preferably about 13.56 MHz, and the power level of the RF bias current is typically from about 50 to about 3000 Watts.

[0031] The support 110 may comprise an electrostatic chuck 170 comprising a dielectric body 174 that at least partially covers an electrode 178 and that may include a substrate receiving surface 180. The electrode 178 may also serve as one of the process electrodes discussed above. The electrode 178 may be capable of generating an electrostatic charge for electrostatically holding the substrate 104 to the support 110 or electrostatic chuck 170. A power supply 182 provides the chucking voltage to the electrode 178.

[0032] The processes may be performed in the chamber 106 by operating the chamber components with a controller 300 as shown in FIG. 3. The controller 300 may comprise a computer 302 having a central processor unit (CPU) 306, such as for example a 68040 microprocessor, commercially available from Synergy Microsystems, California, or a Pen-
tium Processor commercially available from Intel Corporation, Santa Clara, Calif., that is coupled to a hardware interface 304, memory 308 and peripheral computer components, as shown in FIG. 3. Preferably, the memory 308 may include a removable storage media 310, such as for example a CD or floppy drive, a non-removable storage media 312, such as for example a hard drive and random access memory 314. The controller 300 may further comprise a plurality of interface cards including, for example, analog and digital input and output boards, interface boards, and motor controller boards. The interface between an operator and the controller 300 can be, for example, via a display 316 and a light pen 318. The light pen 318 detects light emitted by the monitor display 316 with a light sensor in the tip of the light pen 318. To select a particular screen or function, the operator touches a designated area of a screen on the monitor 316 and pushes the button on the light pen 318. Typically, the area touched changes color, or a new menu is displayed, confirming communication between the user and the controller 300.

[0033] The data signals received by and/or evaluated by the controller 300 may be sent to a factory automation host computer 338. The factory automation host computer 338 may comprise a host software program 340 that evaluates data from several systems, platforms or chambers 106, and for batches of substrates 104 or over an extended period of time, to identify statistical process control parameters of (i) the processes conducted on the substrates 104, (ii) a property that may vary in a statistical relationship across a single substrate 104, or (iii) a property that may vary in a statistical relationship across a batch of substrates 104. The host software program 340 may also use the data for ongoing in-situ process evaluations or for the control of other process parameters. A suitable host software program comprises a WORKSTREAM™ software program available from aforementioned Applied Materials. The factory automation host computer 338 may be further adapted to provide instruction signals to (i) remove particular substrates 104 from the processing sequence, for example, if a substrate property is inadequate or does not fall within a statistically determined range of values, or if a process parameter deviates from an acceptable range; (ii) end processing in a particular chamber 106, or (iii) adjust process conditions upon a determination of an unsuitable property of the substrate 104 or process parameter. The factory automation host computer 338 may also provide the instruction signal at the beginning or end of processing of the substrate 104 in response to evaluation of the data by the host software program 340.

[0034] In one version the controller 300 comprises a computer-readable program 320 may be stored in the memory 308, for example on the non-removable storage media 312 or on the removable storage media 310. The computer readable program 320 generally comprises process control software comprising program code to operate the chamber 106 and its components, process monitoring software to monitor the processes being performed in the chamber 106, safety systems software, and other control software, as for example, illustrated in FIG. 3. The computer-readable program 320 may be written in any conventional computer-readable programming language, such as for example, assembly language, C++, Pascal, or Fortran. Suitable program code is entered into a single file, or multiple files, using a conventional text editor and stored or embodied in computer usable medium of the memory 308.

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 library routines. To execute the linked, compiled object code, the user invokes the object code, causing the CPU 306 to read and execute the code to perform the tasks identified in the program.

[0035] An illustrative block diagram of a hierarchical control structure of a specific embodiment of a computer readable program 320 is also shown in FIG. 3. Using a light pen interface, a user enters a process set and chamber number into the computer readable program 320 in response to menus or screens displayed on the CRT terminal. The computer readable program includes process selector program code 321 to control the substrate position, gas flow, gas pressure, temperature, RF power levels, and other parameters of a particular process, as well as code to monitor the chamber process. The process sets are predetermined groups of process parameters necessary to carry out specified processes. The process parameters are process conditions, including without limitations, gas composition, gas flow rates, temperature, pressure, and gas energizer settings such as RF or microwave power levels.

[0036] The process sequencer instruction set 322 comprises program code to accept a chamber type and set of process parameters from the process selector 321 and to control its operation. The sequencer program 322 initiates execution of the process set by passing the particular process parameters to a chamber manager instruction set 324 that controls multiple processing tasks in the process chamber 106. Typically, the process chamber instruction set 324 includes a substrate positioning instruction set 326, a gas flow control instruction set 328, a gas pressure control instruction set 330, a temperature control instruction set 332, a gas energizer control instruction set 334, and a process monitoring instruction set 336. Typically, the substrate positioning instruction set 326 comprises program code for controlling chamber components that are used to load the substrate 104 onto the support 110 and optionally, to lift the substrate 104 to a desired height in the chamber 106. The gas flow control instruction set 328 comprises program code for controlling the flow rates of different constituents of the process gas. The gas flow control instruction set 328 regulates the opening size of the gas flow control valves 134 to obtain the desired gas flow rate into the chamber 106. The gas pressure control instruction set 330 comprises program code for controlling the pressure in the chamber 106 by regulating open/close position of the throttle valve 150. The temperature control instruction set 332 comprises program code to control temperatures in the chamber 106, such as for example the temperature of a wall 107 in the chamber 106 or the temperature of the substrate 104.

[0037] The gas energizer control instruction set 334 comprises program code for setting, for example, the RF power level applied to the antenna 156 by the antenna power supply 155. The process monitoring instruction set may comprise program code for monitoring a process in the chamber 106, such as an etching or cleaning process, and determining a process endpoint.

[0038] In one version, the chamber manager instruction set 324 may set process conditions in the chamber 106 to etch one or more substrates 104, such as one or substrates comprising a metal-containing layer 53, and perform one or
more cleaning steps, such as the first and second cleaning steps. For example, in a substrate etching stage, the substrate positioning instruction set 326 may position a substrate 104 to be etched in the chamber 106 and the gas flow instruction set 328 may regulate the flow of etchant gas into the chamber 106 while the gas energizer sets the RF power levels for energizing the etchant gas. In a chamber cleaning stage, the gas flow instruction set 328 may regulate the flow of cleaning gases into the chamber 106, for example by setting a volumetric flow ratio of gases in the cleaning gas, while the gas energizer control instruction set 334 sets the RF power levels for energizing the cleaning gas. For example, in a first cleaning step, the gas flow instruction set 328 may regulate the flow of a first cleaning gas comprising Cl\textsubscript{2} and O\textsubscript{2}, by setting a volumetric flow ratio of Cl\textsubscript{2} to O\textsubscript{2}, and the gas energizer control instruction set 334 may set the RF power level to energize the first cleaning gas. In a second cleaning step, the gas flow instruction set 328 may regulate the flow of a second cleaning gas comprising HCl and O\textsubscript{2}, by setting a volumetric flow ratio of HCl to O\textsubscript{2} of at least about 3:7, and the gas energizer control instruction set 334 may set the RF power level to energize the second cleaning gas. As another example, the gas flow instruction set 328 may regulate the flow of a purge gas comprising Ar in a purge stage, and the gas energizer control instruction set 334 may set an RF power level to energize the purge gas. The gas pressure control instruction set 330 may regulate the pressure in each process. For example, in the purge stage, the gas pressure control instruction set 330 may maintain the throttle valve 150 in the fully opened stage.

The data signals received by and/or evaluated by the controller 300 may also be sent to a factory automation host computer 338. The factory automation host computer 338 may comprise a host software program 340 that evaluates data from several systems, platforms or chambers 106, and for batches of substrates 104 or over an extended period of time, to identify statistical process control parameters of (i) the processes conducted on the substrates 104, (ii) a property that may vary in a statistical relationship across a single substrate 104, or (iii) a property that may vary in a statistical relationship across a batch of substrates 104. The host software program 340 may also use the data for ongoing in-situ process evaluations or for the control of other process parameters. A suitable host software program comprises a WORKSTREAM™ software program available from aforementioned Applied Materials. The factory automation host computer 338 may be further adapted to provide instruction signals to (i) remove particular substrates 104 from the processing sequence, for example, if a substrate property is inadequate or does not fall within a statistically determined range of values, or if a process parameter deviates from an acceptable range; (ii) end processing in a particular chamber 106, or (iii) adjust process conditions upon a determination of an unsuitable property of the substrate 104 or process parameter. The factory automation host computer 338 may also provide the instruction signal at the beginning or end of processing of the substrate 104 in response to evaluation of the data by the host software program 340.

[0040] Although exemplary embodiments of the present invention are shown and described, those of ordinary skill in the art may devise other embodiments which incorporate the present invention, and which are also within the scope of the present invention. For example, other substrate etching processes may be performed without deviating from the scope of the present invention. Also, cleaning gas compositions other than those specifically mentioned may be used, as would be apparent to those of ordinary skill in the art. Furthermore, the terms below, above, bottom, top, up, down, first and second and other relative or positional terms are shown with respect to the exemplary embodiments in the figures and are interchangeable. Therefore, the appended claims should not be limited to the descriptions of the preferred versions, materials, or spatial arrangements described herein to illustrate the invention.

What is claimed is:
1. A method of cleaning process residues formed on surfaces in a chamber during processing of a substrate in the chamber, the method comprising:
   (a) a first cleaning step comprising:
      providing a first energized cleaning gas in the chamber, the first energized cleaning gas comprising a first chlorine-containing gas and oxygen; and
      exhausting the first cleaning gas;
   (b) a second cleaning step comprising:
      providing a second energized cleaning gas in the chamber, the second energized cleaning gas comprising a second chlorine-containing gas and oxygen; and
      exhausting the second cleaning gas.
2. A method according to claim 1 wherein the second energized cleaning gas is selected to remove residues that are formed during the first cleaning step.
3. A method according to claim 1 wherein in the first chlorine-containing gas comprises only chlorine, and wherein the second chlorine-containing gas comprises chlorine and hydrogen.
4. A method according to claim 1 wherein the second chlorine-containing gas comprises HCl.
5. A method according to claim 4 wherein the second energized cleaning gas comprises HCl and O\textsubscript{2} in a volumetric flow ratio of at least about 3:7.
6. A method according to claim 1 wherein at least one of the first and second cleaning gases comprises one or more of H\textsubscript{2}, H\textsubscript{2}O and H\textsubscript{2}O\textsubscript{2}.
7. A substrate processing apparatus comprising:
   a chamber having a substrate support;
   a gas supply;
   a gas energizer;
   a gas exhaust, and
   a controller comprising:
   (a) substrate processing program code to operate the substrate support, gas supply, gas energizer and gas exhaust to process a substrate in the chamber by introducing an etchant gas into the chamber, energizing the etchant gas to etch the substrate, and exhausting the etchant gas; and
   (b) chamber cleaning program code to operate the substrate support, gas supply, gas energizer and gas exhaust to clean surfaces in the chamber by,
   (i) in a first cleaning step:
providing a first energized cleaning gas in the chamber, the first energized cleaning gas comprising a first chlorine-containing gas and oxygen; and

exhausting the first cleaning gas; and

(ii) in a second cleaning step:

providing a second energized cleaning gas in the chamber, the second energized cleaning gas comprising a second chlorine-containing gas and oxygen; and

exhausting the second cleaning gas.

8. An apparatus according to claim 7 wherein the controller comprises chamber cleaning program code to operate the gas supply to provide a second energized cleaning gas that is selected to remove residues that are formed during the first cleaning step.

9. An apparatus according to claim 7 wherein the controller comprises chamber cleaning program code to operate the gas supply to provide a first chlorine-containing gas comprising only chlorine in the first cleaning step, and a second chlorine-containing gas comprising chlorine and hydrogen in the second cleaning step.

10. An apparatus according to claim 7 wherein the controller comprises chamber cleaning program code to operate the gas supply to provide a second chlorine-containing gas comprising HCl.

11. An apparatus according to claim 10 wherein the controller comprises chamber cleaning program code to operate the gas supply to provide a second energized cleaning gas comprising HCl and O₂ in a volumetric flow ratio of at least about 3:7.

12. An apparatus according to claim 7 wherein the controller comprises chamber cleaning program code to operate the gas supply to provide at least one of a first and second cleaning gas comprising one or more of H₂, H₂O and H₂O₂.

13. A method of cleaning process residues formed on surfaces in a chamber during processing of a substrate in the chamber, the method comprising:

(a) a first cleaning step comprising:

introducing a first cleaning gas into the chamber, the first cleaning gas comprising Cl₂ and O₂;

coupling RF energy to the first cleaning gas in the chamber to energize the first cleaning gas; and

exhausting the first cleaning gas; and

(b) a second cleaning step comprising:

introducing a second cleaning gas into the chamber, the second cleaning gas comprising HCl and O₂;

coupling RF energy to the second cleaning gas in the chamber to energize the second cleaning gas; and

exhausting the second cleaning gas.

14. A method according to claim 13 wherein the second cleaning gas comprises HCl and O₂ in a volumetric flow ratio of at least about 3:7.

15. A method according to claim 13 further comprising, before (a) or (b), introducing a purging gas into the chamber, sustaining a plasma of the purging gas, and exhausting the purging gas.

16. A substrate processing apparatus comprising:

a chamber having a substrate support;

a gas supply;

a gas energizer;

a gas exhaust; and

a controller comprising:

(a) substrate processing program code to operate the substrate support, gas supply, gas energizer and gas exhaust to process a substrate in the chamber by introducing an etchant gas into the chamber, energizing the etchant gas to etch the substrate, and exhausting the etchant gas; and

(b) chamber cleaning program code to operate the substrate support, gas supply, gas energizer and gas exhaust to clean surfaces in the chamber by,

(i) in a first cleaning step:

introducing a first cleaning gas into the chamber, the first cleaning gas comprising Cl₂ and O₂;

coupling RF energy to the first cleaning gas in the chamber to energize the first cleaning gas; and

exhausting the first cleaning gas; and

(ii) in a second cleaning step:

introducing a second cleaning gas into the chamber, the second cleaning gas comprising HCl and O₂;

coupling RF energy to the second cleaning gas in the chamber to energize the second cleaning gas; and

exhausting the second cleaning gas.

17. An apparatus according to claim 16 wherein the controller further comprises chamber purging program code to operate the substrate support, gas supply, gas energizer and gas exhaust to purge the chamber by introducing a purging gas into the chamber, sustaining a plasma of the purging gas, and exhausting the purging gas.

18. An apparatus according to claim 17 wherein the controller comprises chamber purging program code to operate the gas supply to introduce the purging gas before and after the first and second cleaning steps.

19. An apparatus according to claim 16 wherein the controller comprises chamber purging program code to operate the gas supply to introduce a second cleaning gas comprising HCl and O₂ in a volumetric flow ratio of at least about 3:7.

20. A method of cleaning process residues formed on surfaces in a chamber during processing of a substrate in the chamber, the method comprising:

(a) providing an energized cleaning gas in the chamber, the energized cleaning gas comprising H₂, chlorine species and oxygen species; and

(b) exhausting the cleaning gas.

21. A method according to claim 20 wherein the cleaning gas comprises one or more of HCl and Cl₂.
22. A method according to claim 20 wherein the cleaning gas comprises one or more of O₂, H₂O and H₂O₂.

23. A method according to claim 20 further comprising:

(c) providing a second energized cleaning gas in the chamber, the second energized cleaning gas comprising Cl₂ and O₂ and

(i) exhausting the second cleaning gas.

24. A substrate processing apparatus comprising:

(a) a chamber having a substrate support;

(b) a gas supply;

(c) a gas energizer;

(d) a gas exhaust; and

(e) a controller comprising:

(i) providing an energized cleaning gas in the chamber, the first energized cleaning gas comprising H₂, chlorine species and oxygen species; and

(ii) exhausting the cleaning gas.

25. An apparatus according to claim 24 wherein the controller comprises chamber cleaning program code to operate the gas supply to provide one or more of HCl and Cl₂.

26. An apparatus according to claim 24 wherein the controller comprises chamber cleaning program code to operate the gas supply to provide one or more of O₂, H₂O and H₂O₂.

27. An apparatus according to claim 24 wherein the controller comprises chamber cleaning program code to operate the substrate support, gas supply, gas energizer and gas exhaust to clean surfaces in the chamber by, in a second cleaning step:

(iii) providing a second energized cleaning gas in the chamber, the second energized cleaning gas comprising Cl₂ and O₂; and

(iv) exhausting the second cleaning gas.

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