

## NOVEL METHODS FOR CLEANING ION IMPLANTER COMPONENTS

### **FIELD OF THE INVENTION**

[0001] The present invention relates to a method and apparatus for cleaning the vacuum chamber and beamline of an ion implantation system used in the fabrication of a microelectronic device. In addition, the present invention relates to a method for the *in situ* cleaning of cryogenic pumps to remove purge resistant effluent material.

### **DESCRIPTION OF THE RELATED ART**

[0002] Ion implantation is used in integrated circuit fabrication to accurately introduce controlled amounts of dopant impurities into semiconductor wafers and is a crucial process in microelectronic/semiconductor manufacturing. In such implantation systems, an ion source ionizes a desired dopant element gas and the ions are extracted from the source in the form of an ion beam of desired energy. Extraction is achieved by applying a high voltage across suitably shaped extraction electrodes, which incorporate apertures for passage of the extracted beam. The ion beam is then directed at the surface of the workpiece, such as a semiconductor wafer, in order to implant the workpiece with the dopant element. The ions of the beam penetrate the surface of the workpiece to form a region of desired conductivity.

[0003] Several types of ion sources are commonly used in commercial ion implantation systems, including the Freeman and Bernas types using thermoelectrodes and powered by an electric arc, a microwave type using a magnetron, indirectly heated cathode sources, and RF plasma sources, all of which typically operate in a vacuum. The ion source generates ions by introducing electrons into a vacuum chamber filled with the dopant gas (commonly referred to as the "feedstock gas"). Collisions of the electrons with

dopant atoms and molecules in the gas results in the creation of an ionized plasma consisting of positive and negative dopant ions. An extraction electrode with a negative or positive bias will respectively allow the positive or negative ions to pass through the aperture and out of the ion source as a collimated ion beam, which is accelerated towards the workpiece. Feedstock gases include, but are not limited to,  $\text{BF}_3$ ,  $\text{B}_{10}\text{H}_{14}$ ,  $\text{B}_{12}\text{H}_{22}$ ,  $\text{PH}_3$ ,  $\text{AsH}_3$ ,  $\text{PF}_5$ ,  $\text{AsF}_5$ ,  $\text{H}_2\text{Se}$ ,  $\text{N}_2$ ,  $\text{Ar}$ ,  $\text{GeF}_4$ ,  $\text{SiF}_4$ ,  $\text{O}_2$ ,  $\text{H}_2$ , and  $\text{GeH}_4$ .

[0004] Presently, there are upwards of 10-15 implantation steps in the fabrication of state of the art devices. Increasing wafer sizes, decreasing critical dimensions, and growing circuit complexity are placing greater demands on ion implant tools, with respect to better process control, the deliverance of high beam currents at low energies, and a decrease in the mean time between failures (MTBF).

[0005] The parts of the ion implanter tool that require the most maintenance include: the ion source, which must be serviced after approximately 100 hours of operation, depending on its operating conditions; the extraction electrodes and the high voltage insulator, which usually require cleaning after a few hundred hours of operation; and the cryogenic pump

[0006] In the ideal case, all feedstock molecules would be ionized and extracted, but in reality a certain amount of feedstock decomposition occurs, which results in the deposition on and contamination of the vacuum chamber and beamline. For example, boron residue readily deposits on surfaces in the ion source region. The residue can form on low voltage insulators in the ion source, causing electrical short circuits, which can interrupt the arc required to produce thermionic electrons. This phenomenon is generally known as "source glitching," and it is a major contributor to ion beam instability, and may eventually cause premature failure of the source. The residue also forms on the high voltage components of the ion implanter, such as the source insulator or the surfaces of the

extraction electrodes, causing energetic high voltage sparking. Such sparks are another contributor to beam instability, and the energy released by these sparks can damage sensitive electronic components, leading to increased equipment failures and poor MTBF. While the ion source life expectancy for ion implantation systems using non halide-containing source materials is generally around 168 hours, with halide-containing materials such as  $\text{GeF}_4$ , the ion source life can be as low as 10 hours due to the detrimental effects of residue deposition on source operation.

[0007] Presently, vacuum chambers are cleaned using gases such as  $\text{NF}_3$  and other nitrogen-containing gases as well as oxidizing species. For example, U.S. Patent No. 6,135,128 in the name of Graf et al. relates to the cleaning of an ion source using  $\text{NF}_3$  gas. However,  $\text{NF}_3$  cleaning gas requires an energetic source to release atomic fluorine, which upon release tends to be too aggressive, attacking every component in the ion source region. In addition, the required energetic source, e.g., plasma, increases the cost of ownership (COO). U.S. Patent No. 6,355,933 in the name of Tripsas et al. relates to the introduction of oxygenated gases to the ion source for reacting with deposit forming species. Although oxidizing gases prove useful for the removal of carbonaceous species, it is disadvantageous if any component of the vacuum chamber or beamline is fabricated from carbon/graphitic material. Moreover, the introduction of an oxidizing species to the vacuum chamber may promote the formation of a surface oxide layer, or "rust," on most metallic components, said oxide layer potentially resulting in particle formation, entrapment of gas molecules, shorts and premature filament failure.

[0008] Cryogenic vacuum pumps (cryopumps) are widely used in high vacuum applications. Cryopumps are based on the principle of removing gases from a vacuum chamber by cryocondensing and/or cryosorbing the gases on cold surfaces inside the cryopump. In cryocondensation, gas molecules are condensed on previously condensed

gas molecules, and thick layers of condensation can be formed, thereby, pumping large quantities of gas. Cryosorption is commonly used to pump gases that are difficult to condense at the normal operating temperatures of the cryopump. In this case, a sorbent material, such as activated charcoal, is attached to the coldest surface in the cryopump, typically a second stage of a cryoarray. Because the binding energy between a gas particle and the adsorbing surface is greater than the binding energy between the gas particles themselves, the gas particles that cannot be condensed are removed from the vacuum system by adhering to the sorbent material.

[0009] Presently, ion implant cryopumps use inert gas, e.g., N<sub>2</sub>, to purge away the cryogenically captured gas molecules and process residues accumulated during the process cycle. The inert gas purge assists in bringing the cryopump to ambient temperature, and adequately purges the evolving, previously cryosorbed gas molecules, including water vapor, hydrogen and organic compounds. The inert gas purge, however does not remove all the process effluents, hereinafter referred to as accumulated process effluents, some of which underwent reaction to form non-volatile species during the warm-up of the cryopump and/or adhered to the metallic components of the pump. Presently, the only method of removing the accumulated process effluents is through cryopump maintenance.

[0010] There are two types of cryopump maintenance evolutions, a vacuum side rebuild, and displacer side rebuild. Both forms of maintenance involve removal of the cryopump from the implanter. The vacuum side rebuild requires the pump be disassembled, cleaned, reassembled, and functionally tested and is recommended by the OEM on an annual basis. The displacer side maintenance involves disassembly, cleaning, reassembly, and functional testing of the displacer (gas flow cooling, actuating mechanism) of the cryopump and is recommended by the OEM on a tri-annual basis.

[0011] In addition to the operational difficulties caused by residues in the ion implanter and the cryopump, there are also significant personnel safety issues due to the emission of toxic or corrosive vapors when components are removed for cleaning. The safety issues arise wherever residues are present, but are of particular concern in the ion source region of the vacuum chamber because the ion source is the most frequently maintained component of the ion implanter. To minimize down time, contaminated ion sources are often removed from the implanter at temperatures significantly above room temperature, which increases the emission of vapors and exacerbates the safety issue.

[0012] It would therefore be a significant advance in the art of ion implantation to provide an *in situ* cleaning process for the effective, selective removal of unwanted residues deposited throughout the implanter, particularly in the ion source region of the vacuum chamber, during implantation. Such *in situ* cleaning would enhance personnel safety and contribute to stable, uninterrupted operation of the implantation equipment.

[0013] An alternative to *in situ* cleaning is to provide a separate cleaning station whereby contaminated components that have been removed from the implanter can be cleaned safely without any mechanical abrasion which might damage delicate components such as graphite electrodes. It would therefore also be a significant advance in the art of ion implantation to provide an off-line cleaning station that could be used to selectively and non-destructively clean components following removal from the implant system.

[0014] In addition, it would be a significant advance in the art to provide an *in situ* cleaning process for the removal of accumulated process effluents from the cryopump thereby reducing or eliminating the frequency of cryopump maintenance.

#### **SUMMARY OF THE INVENTION**

[0015] The present invention relates generally to a method and apparatus for cleaning internal components of an ion implantation tool. Specifically, the present invention relates to the *in situ* removal of residue from the vacuum chamber and components contained therein by contacting the vacuum chamber and/or components with a gas-phase reactive halide composition, e.g.,  $\text{XeF}_2$ , for sufficient time and under sufficient conditions to at least partially remove the residue from the components, and to do so in such a manner that residue is removed selectively with respect to the materials from which the components of the ion implanter are constructed.

[0016] In one aspect, the invention relates to a method of cleaning a vacuum chamber of a semiconductor manufacturing tool, at least one component, or combination thereof, said method comprising:

- (a) introducing an etchant gas from an etchant container into the vacuum chamber;
- (b) terminating introduction of the etchant gas into the vacuum chamber upon attainment of a predetermined pressure in the vacuum chamber; and
- (c) reacting the etchant gas with a residue in the vacuum chamber for a sufficient time to at least partially remove the residue from the interior of the vacuum chamber, at least one component contained therein, or combination thereof;

wherein the etchant gas is chosen to react selectively with the residue in the vacuum chamber, the residue on the components contained therein, or combination thereof, while being essentially non-reactive with the interior of the vacuum chamber, the components contained therein, or combination thereof. Preferably, the etchant gas comprises a gas selected from the group consisting of  $\text{XeF}_2$ ,  $\text{XeF}_6$ ,  $\text{XeF}_4$ ,  $\text{IF}_5$ ,  $\text{IF}_7$ ,  $\text{SF}_6$ ,  $\text{C}_2\text{F}_6$  and  $\text{F}_2$ .

[0017] In another aspect, the present invention relates to a method of cleaning a vacuum chamber of a semiconductor manufacturing tool, at least one internal component, or combination thereof, said method comprising:

- (a) introducing an etchant material from an etchant container into the vacuum chamber;
- (b) terminating introduction of the etchant gas into the vacuum chamber upon attainment of a predetermined pressure;
- (c) dissociating the etchant material into a reactive halide species in the vacuum chamber using a plasma source positioned in said vacuum chamber; and
- (d) reacting the reactive halide species with a residue in the vacuum chamber for a sufficient time to at least partially remove the residue from the vacuum chamber and/or the at least one internal component.

Preferably, an inert gas from an inert gas source is introduced into the vacuum chamber prior to dissociating the etchant material.

[0018] In yet another aspect, the present invention relates to an apparatus for cleaning a vacuum chamber of a semiconductor manufacturing tool, at least one internal component, or combination thereof, said apparatus comprising:

- (a) an etchant material source having an etchant material disposed therein, wherein the etchant material source is communicatively connected to, and is situated upstream of, the vacuum chamber; and
- (b) a valve between the etchant material source and the vacuum chamber;

wherein said apparatus is further characterized by comprising at least one of the following components (I) and (II):

- (I) a heater for heating the etchant material source; and
- (II) an inert gas source having an inert gas disposed therein, wherein the inert gas source is communicatively connected to, and is situated upstream of, the etchant material source.

Preferably, the etchant material comprises a gas selected from the group consisting of XeF<sub>2</sub>, XeF<sub>6</sub>, XeF<sub>4</sub>, IF<sub>5</sub>, IF<sub>7</sub>, SF<sub>6</sub>, C<sub>2</sub>F<sub>6</sub> and F<sub>2</sub>.

[0019] In a further aspect, the present invention relates to a method of cleaning a vacuum chamber of a semiconductor manufacturing tool, at least one component, or combination thereof, said method comprising:

- (a) introducing an etchant gas from an etchant container into the vacuum chamber;
- (b) withdrawing a plurality of gas species from the vacuum chamber using a vacuum pump to effectuate a continuous flow of the etchant gas therethrough; and
- (c) flowing the etchant gas through the vacuum chamber for a sufficient time to react the etchant gas with the residue to at least partially remove the residue from the vacuum chamber, at least one component contained therein, or combination thereof,

wherein the etchant gas comprises a gas selected from the group consisting of XeF<sub>2</sub>, XeF<sub>6</sub>, XeF<sub>4</sub>, IF<sub>5</sub>, IF<sub>7</sub>, SF<sub>6</sub>, C<sub>2</sub>F<sub>6</sub> and F<sub>2</sub>. Preferably, the etchant gas is chosen to react selectively with the residue in the vacuum chamber, while being essentially non-reactive with the interior of the vacuum chamber or the components contained therein.

[0020] In yet another aspect, the invention relates to a method of cleaning accumulated process effluent from the interior of a cryopump, said method comprising purging the cryopump with at least two purge gases, said purge gases including nitrogen and at least one reactive gas selected from the group consisting of oxygen, ozone, nitrogen oxides, species that generate oxygen radicals *in situ*, and combinations thereof, wherein said method is characterized by at least one of the following purge process sequences (I), (II), and (III):

- (I) (a) purging with essentially pure nitrogen for time x; and  
(b) purging with the at least one reactive gas for time y, wherein the at least one reactive gas is essentially pure;
- (II) (a) purging with essentially pure nitrogen at time zero;  
(b) blending the essentially pure nitrogen with the at least one reactive gas, wherein the nitrogen and the at least one reactive gas are no longer essentially pure;
- (III) (a) purging with a mixture of nitrogen and at least one reactive gas,

wherein the accumulated process effluent is substantially removed from the interior of the cryopump.

[0021] A further aspect of the present invention relates to a method of *ex situ* cleaning at least one component of a semiconductor manufacturing tool, said method comprising:

- (a) positioning the component in an *ex situ* vacuum chamber;
- (b) introducing an etchant gas from an etchant container into the *ex situ* vacuum chamber;
- (c) terminating introduction of the etchant gas into the vacuum chamber upon attainment of a predetermined pressure in the vacuum chamber; and
- (d) reacting the etchant gas with a residue in the vacuum chamber for a sufficient time to at least partially remove the residue from the at least one component contained therein;

wherein the etchant gas is chosen to react selectively with the residue on the at least one component, while being essentially non-reactive with the interior of the vacuum chamber.

[0022] Yet another aspect of the invention relates to improved methods of manufacturing microelectronic devices such as semiconductors using the inventive methods and systems described herein.

[0023] Other aspects, features and embodiments of the invention will be more fully apparent from the ensuing disclosure and appended claims.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0024] Figure 1 is a schematic of an indirectly heated cathode ion source, illustrating three optional placements for the etchant material.

[0025] Figure 2 is a schematic of the direct dissociative plasma configuration described herein.

[0026] Figure 3 is a schematic diagram of a 300 amu residual gas analyzer, used to monitor by-products of the residue removal reactions.

[0027] Figure 4 is an RGA trace as a function of time showing the efficacy of  $\text{XeF}_2$  in removing boron residue from an aluminum base layer.

[0028] Figure 5 is an RGA trace as a function of time illustrating that  $\text{XeF}_2$  does not react with a tungsten layer.

### **DETAILED DESCRIPTION OF THE INVENTION AND PREFERRED EMBODIMENTS THEREOF**

[0029] The present invention relates to a method and apparatus for cleaning the vacuum chamber and/or beamline of an ion implantation system used in the fabrication of a microelectronic device. Specifically, the present invention relates to the *in situ* removal of residue from a vacuum chamber of the ion implanter and components contained therein by contacting the vacuum chamber and/or components with a gas-phase reactive halide composition, e.g.,  $\text{XeF}_2$ ,  $\text{NF}_3$ ,  $\text{F}_2$ ,  $\text{XeF}_6$ ,  $\text{XeF}_4$ ,  $\text{SF}_6$ ,  $\text{C}_2\text{F}_6$ ,  $\text{IF}_5$  or  $\text{IF}_7$ , for sufficient time and

under sufficient conditions to at least partially remove the residue from the components, and to do so in such a manner that residue is removed selectively with respect to the materials from which the components of the ion implanter are constructed.

[0030] As used herein, “vacuum chamber” includes the source vacuum chamber, and the ion source region including the source arc chamber, the source insulators, the extraction electrodes, the suppression electrodes, the high voltage insulators, source bushing and the source turbomolecular pump.

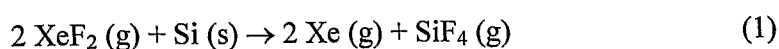
[0031] As used herein, “beamline” includes the ion source region and other components inside the vacuum system, including the beamline vacuum chamber, the accelerator column, interior ion optical components such as electrostatic steerers and lenses, the beamline turbomolecular pumps and the vacuum exhaust lines.

[0032] As used herein, “microelectronic device” corresponds to semiconductor substrates, flat panel displays, and microelectromechanical systems (MEMS), manufactured for use in microelectronic, integrated circuit, or computer chip applications. It is to be understood that the term “microelectronic device” is not meant to be limiting in any way and includes any substrate that will eventually become a microelectronic device or microelectronic assembly.

[0033] As used herein, “residue” corresponds to the unused portion of the implant gas (e.g., some portion of  $\text{BF}_3$ ,  $\text{PH}_3$ ,  $\text{AsH}_3$ ,  $\text{GeF}_4$ , etc.), carrier gas residue (e.g., fluorine, chlorine, oxygen, nitrogen, argon, etc.), as well as chamber material that is sputtered/deposited (e.g., tungsten, molybdenum and/or aluminum-containing species). For example, the residue may include metals such as B, As, P, Ge, W, Mo and/or Al, compounds between the B, As, P and/or Ge species and the W, Mo and/or Al species, as well as permutations of the materials of construction. The residue may be conducting or

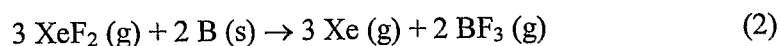
non-conducting. Preferably, the residue is devoid of non-dopant components of the implant gas.

[0034] The reactive halide gas may for example include a XeF<sub>2</sub> vapor. XeF<sub>2</sub> will sublime at room temperature, but may be heated using a heater to increase the rate of sublimation. XeF<sub>2</sub> is known to be an effective silicon etchant and has been used as a silicon selective etchant in Micro Electro Mechanical System (MEMS) device processing because it is extremely selective to SiO<sub>2</sub> and other dielectric materials. Specifically, XeF<sub>2</sub> reacts with silicon according to the following reaction.

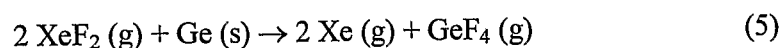
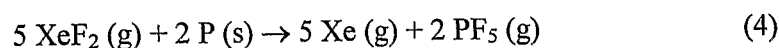
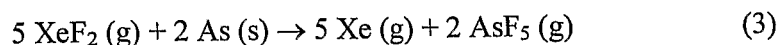


Importantly, the silicon/XeF<sub>2</sub> reaction can occur without activation, i.e., plasma or thermal heating.

[0035] In this application, the use of XeF<sub>2</sub> as an etchant for metallic boron is disclosed. Although not wishing to be bound by theory, it is thought that the boron is etched according to the following reaction.



The use of XeF<sub>2</sub> as an etchant for arsenic, phosphorus and germanium has not been reported to the best of our knowledge; however, XeF<sub>2</sub> may prove to be an effective etchant for these materials as well according to the following reactions (3) - (5).



Similar to the silicon/XeF<sub>2</sub> reaction, the reactions disclosed herein may occur with or without energetic activation.

[0036] Importantly, the method and apparatus taught herein is used to at least partially remove the residue from the components of the ion implanter, and to do so in such a

manner that residue is removed selectively with respect to the materials from which the components of the ion implanter are constructed, e.g., aluminum, tungsten, molybdenum, etc.. As used herein, the term "at least partially remove" is defined as the removal of at least about 25 wt. %, more preferably at least about 50 wt. %, more preferably at least 75 wt. %, and most preferably at least about 90 wt. % of the residue to be removed. The extent of residue removal and/or ion implanter component removal may be determined using analytical techniques well known in the art including, but not limited to, temperature-programmed infrared spectroscopy (TPIR), Fourier Transform Infrared Spectroscopy (FTIR), electron paramagnetic spectroscopy (EPM), residual gas analysis (RGA), mass spectrometry, and combinations thereof.

[0037] Several novel ways to deliver the gas-phase reactive halide composition, e.g., a composition including  $\text{XeF}_2$ , to the vacuum chamber and the beamline for *in situ* cleaning therein are proposed, including a stagnant mode, a continuous mode, and a direct introduction mode. Although reference is made hereinafter to a  $\text{XeF}_2$  composition, other reactive halide compositions may be used including, but not limited to,  $\text{XeF}_6$ ,  $\text{XeF}_4$ ,  $\text{SF}_6$ ,  $\text{C}_2\text{F}_6$ ,  $\text{IF}_5$  or  $\text{IF}_7$ . It is further noted that the  $\text{XeF}_2$  or alternative reactive halide compositions may comprise, consist essentially of or consist of  $\text{XeF}_2$  or alternative reactive halides. Preferably, the gas-phase reactive halide composition is devoid of or substantially free of an oxidizing species and a nitrogen-containing species, wherein the nitrogen-containing species comprises at least one additional element selected from the group consisting of O, F, and Br, unless indicated otherwise. Alternatively, the gas-phase reactive halide composition may include reducing species such as hydrogen and/or carbon monoxide.

[0038] In addition, it is noted that the apparatuses described herein may include improved low-pressure dopant gas supply arrangements which permit dopant gases to be

delivered to the ion source unit at ground potential, as described in U.S. Provisional Patent Application No. 60/712,648 in the name of Robert Kaim et al. and entitled "Delivery of Low Pressure Dopant Gas to a High Voltage Ion Source," which is hereby incorporated by reference herein in the entirety.

[0039] In the stagnant mode, an etchant container with the  $\text{XeF}_2$  composition disposed therein is communicatively attached to the chamber of the ion implanter to be cleaned, wherein the etchant container and the chamber to be cleaned have a valve disposed therebetween. During cleaning, the valve may be manually or remotely opened whereby the  $\text{XeF}_2$  vapor is permitted to fill the chamber to be cleaned until a pre-determined pressure is attained. The etchant container may be moderately heated to increase the sublimation rate and/or the sublimation pressure.

[0040] In a more preferred embodiment, the cleaning apparatus includes a separate holding chamber of sufficient volume positioned between the etchant container and vacuum chamber. The  $\text{XeF}_2$  may be flowed first into the holding chamber and stored therein until a pre-determined pressure threshold is reached. Such holding chamber serves to allow immediate gas flow to the vacuum chamber on demand and to shorten the "waiting-period" associated with sublimation. The walls of the holding chamber may be heated to permit higher pressure storage while avoiding condensation of  $\text{XeF}_2$  on interior surfaces of the chamber. The holding chamber may further comprise flow-regulating devices, such as a mass flow controller, to achieve reproducible delivery of  $\text{XeF}_2$  into the vacuum chamber.

[0041] Once the desired pressure in the vacuum chamber has been attained, the vacuum chamber is sealed and the  $\text{XeF}_2$  permitted to react for sufficient time and under sufficient conditions to at least partially remove the residue from the vacuum chamber and the components contained therein. The vacuum chamber can then be evacuated and the

cleaning process repeated as needed. The evacuated gas mixture may be further directed to abatement units including, but not limited to, chemical and/or physical adsorption beds, incinerators, wet scrubbers, or a combination thereof.

[0042] The internal pressure, time, and number of repeat cleanings may be readily determined by those of ordinary skill in the art. The nature and extent of the cleaning of the residue may be empirically determined while varying the time and/or contacting conditions (such as temperature, pressure, concentration and partial pressure) of the  $\text{XeF}_2$  composition to identify the process conditions producing a desired residue removal result. For example, the pressure of the  $\text{XeF}_2$  composition in the vacuum chamber may be about 0.3 Torr to about 4.0 Torr, preferably about 0.3 Torr to about 0.7 Torr, and the length of cleaning about 1 to about 4 minutes, which may be repeated about two (2) to about ten (10) times. Preferably, the pressure of the  $\text{XeF}_2$  is about 0.35 Torr and the length of cleaning about 1 minute. Importantly, the pressure in the vacuum chamber during cleaning should be carefully monitored as the pressure will gradually increase as the cleaning reaction proceeds and should plateau when the reaction has run its course.

[0043] A residual gas analyzer may be used to measure the concentration of  $\text{XeF}_2$  and other reaction byproducts, which may also be useful for monitoring the progress of the cleaning process. A residual gas analyzer (RGA), as shown schematically in Fig. 3, may be attached to the vacuum chamber and used to monitor the by-products of the residue removal reactions. The RGA may be a 200 amu or 300 amu analyzer, most preferably a 300 amu analyzer.

[0044] Preferably, the  $\text{XeF}_2$  gas is generated without energetic activation, although activation is contemplated herein. Thus, effective cleaning can be performed at room temperature, although cleaning is contemplated at temperature in a range of about  $0^\circ\text{C}$  to

about 1000°C depending on the circumstances. Preferably, in the stagnant mode, the temperature is in a range from about 0°C to about 50°C.

[0045] Importantly, the process parameters are chosen to ensure that the reactive halide gas is essentially non-reactive with the vacuum chamber and the beamline components material of construction. As used herein, “essentially non-reactive” corresponds to less than about 5 % of the total reactive halide gas reacts with the components of the vacuum chamber and the beamline, preferably less than about 2 %, most preferably less than about 1%.

[0046] An example of the stagnant mode for cleaning an ion source region 10 is shown in Figure 1, which includes a vacuum chamber 100, an arc chamber 16, the acceleration electrode 14, the deceleration electrode 12, the cathode 18, the anticathode 20 and the gate valve 110. The etchant container 80 holding the  $\text{XeF}_2$  may be communicatively connected to the arc chamber 16 by the dedicated vapor feed line 90 (as shown) or alternatively, although not shown in Fig. 1, the etchant container 80 may be communicatively connected to the vacuum chamber 100 (i.e., positioned outside of the vacuum chamber 100). To introduce the  $\text{XeF}_2$  gas into the arc chamber 16, valve 84 is manually or automatically opened to permit the  $\text{XeF}_2$  to flow from the etchant container 80 to the arc chamber 16. Alternatively, although not shown in Fig. 1, the  $\text{XeF}_2$  from an etchant container such as 80, may be introduced into the arc chamber via a reactive gas inlet line (e.g., component 22) instead of a dedicated  $\text{XeF}_2$  inlet line. Sublimation of the  $\text{XeF}_2$  source may be assisted by heating the etchant container 80 using a heater including, but not limited to, heater wires 88, conformal heating blankets, jackets or shrouds, electrical heating tape, heated fluids and/or gases, or an oven. In addition, temperature measurement device may be used including, but not limited to, a thermocouple 86. The entire etchant container housing 82 may be water cooled. Although not illustrated in Fig.

1, a holding chamber may be situated between the etchant container and the vacuum (i.e., if the etchant container 80 is positioned outside of the vacuum chamber 100) or arc chamber. Following at least partial removal of the residue from the interior of the chamber to be cleaned, valve 92 is opened and the gases are evacuated using pump 96 via outlet line 94. In another embodiment of the stagnant mode, the residue is devoid of tungsten species.

[0047] In the continuous mode, an etchant container with the cleaning gas composition disposed therein is directly or indirectly communicatively attached to the vacuum chamber or to the arc chamber, and a vacuum pump is withdrawing the cleaning gas and reaction products so that there is a continuous flow of gases through the vacuum chamber or the arc chamber. An inert carrier gas may be arranged to flow continuously over the  $\text{XeF}_2$  composition in the etchant container to deliver a steady stream of  $\text{XeF}_2$  to the chamber to be cleaned. The flow rate of the carrier gas, temperature of the etchant container, and cleaning time are experimental parameters readily determined by those skilled in the art. Similar to the stagnant mode, a holding chamber may be situated between the etchant container and the chamber to be cleaned.

[0048] An example of the continuous mode, wherein the etchant container is communicatively connected to the arc chamber, is shown in Figure 1. The etchant container 40 holding the  $\text{XeF}_2$  composition is communicatively connected to the arc chamber 16 via the valve 42. Alternatively,  $\text{XeF}_2$  vapor may be introduced together with other reactive gases, dopant gases or inert gases via the general purpose gas inlet line 22. Outlet valve 92, pump 96 and outlet line 94 are positioned to withdraw gases from the vacuum chamber 100, thereby effectuating the continuous flow mode. When inert gas container 44, valve 46, valve 42 and valve 92 are open, and pump 96 is operating, inert gas flows continuously over the  $\text{XeF}_2$  composition in the etchant container 40 and the mixture

is introduced into the arc chamber 16. The gases egress out of the chamber via outlet line 94. Inert gases contemplated herein include, but are not limited to, argon, nitrogen, xenon, and helium. A further alternative includes sublimation assistance by heating the etchant container 40 using a heater, as described previously with regards to the stagnant mode. In removal use thereof, cleaning may be effectuated by flowing the XeF<sub>2</sub> mixture (or the pure XeF<sub>2</sub>) continuously through the arc chamber while the ion source is on (i.e., a plasma is generated in the arc chamber) or off. An alternative plasma-generating source for placement in the arc chamber or directly upstream of the arc chamber is also contemplated herein. Preferably, the ion source is on during the continuous mode cleaning process.

[0049] In addition, Fig. 1 illustrates the introduction of the XeF<sub>2</sub> composition into the vacuum chamber 100. In this embodiment, XeF<sub>2</sub> from etchant container 60 is communicatively connected to the vacuum chamber 100 via a dedicated inlet line. When inert gas container 64, valve 66, valve 62 and valve 92 are open, and pump 96 is operating, inert gas flows continuously over the XeF<sub>2</sub> composition in the etchant container 60 and the mixture is introduced into the vacuum chamber 100 via the dedicated inlet line.

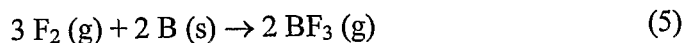
[0050] In yet another embodiment of the continuous mode, the etchant gas and the dopant gas are introduced simultaneously to the arc chamber permitting a continuous ion-implantation and cleaning process. The amount of cleaning gas and the process conditions must be tailored to insure the desired dopant species are not compromised, as readily determined by one skilled in the art.

[0051] In a still further embodiment of the continuous mode, cleaning may be effectuated by alternating the continuous flow of the dopant gas (i.e., BF<sub>3</sub> or other dopant gases during ion implantation) and the continuous flow of the cleaning gas to the vacuum chamber or the arc chamber, with or without an intermediate evacuation step. The dopant gas and the cleaning gas may be alternating between one and five times, as readily

determined by one skilled in the art. This alternating dopant gas/cleaning gas methodology is advantageous relative to the current industry practice of alternating dopant species, because the cleaning schedule may be decoupled from and interleaved with the processing schedule, and more frequent cleaning may occur.

[0052] In the direct introduction mode, an etchant container with pre-measured amounts of XeF<sub>2</sub> composition, e.g., in the form of pellets, is introduced into the sealed vacuum chamber 100. The XeF<sub>2</sub> completely sublimates in the vacuum chamber and the XeF<sub>2</sub> is permitted to react for sufficient time and under sufficient conditions to at least partially remove the residue from the ion source region components. The amount of etchant and the time required for cleaning are readily determined by those skilled in the art. Methods for mechanical dispensing, i.e., etchant containers, are readily engineered by those skilled in the art. Following at least partial removal of the residue from the interior of the chamber to be cleaned, valve 92 is opened and the gases are evacuated using pump 96 via outlet line 94. Direct introduction cleaning may be repeated as necessary.

[0053] In another embodiment of the invention, the reactive halide gas may for example comprise a nitrogen trifluoride (NF<sub>3</sub>) vapor. NF<sub>3</sub> is used in the semiconductor industry as a fluorine source for plasma etching, e.g., *in situ* chamber cleaning of CVD reactors. Additional applications include etching of polysilicon, silicon nitride, tungsten silicide and tungsten films. Specifically, NF<sub>3</sub> dissociates into reactive halide species in the plasma, such as fluorine radicals and/or fluoride ions, said reactive halide species subsequently reacting with the residue to be removed. For example, if the residue includes boron, cleaning occurs according to the following reaction.



[0054] Several novel ways to deliver the NF<sub>3</sub> compound to the ion source region for *in situ* cleaning therein are proposed, including a direct dissociative plasma configuration.

[0055] In the direct dissociative plasma configuration, a  $\text{NF}_3$  source 222 is communicatively connected to the arc chamber 210, with a valve situated therebetween 220 (see Figure 2). As seen in Figure 2, the  $\text{NF}_3$  source is communicatively connected with the reactive gas, e.g.,  $\text{BF}_3$ , inlet tube 218, allowing introduction of  $\text{NF}_3$  simultaneously with other ion source dopant materials. However, other means of introducing  $\text{NF}_3$  into the arc chamber are contemplated, for example via a dedicated  $\text{NF}_3$  inlet line. During cleaning,  $\text{NF}_3$  enters the arc chamber 210 and the fluoride ions are generated using the existing plasma equipment (e.g., the filament 212, cathode 214 and the anticathode 216) or some additional electronics arranged within the arc chamber 210. Inert, diluent gases are preferably added to the arc chamber to dilute the highly reactive fluoride ions. Parameters such as  $\text{NF}_3$  flow rate into the arc chamber, amount of diluent gas, chamber pressure and time required for cleaning are readily determined by those skilled in the art. Multiple pressures and flow rates are also contemplated, wherein the different pressures and flow rates are used sequentially to effect different plasma shapes and consequently different concentration profiles. Different profiles may be useful for cleaning different areas of the arc chamber, i.e., outer corners, etc. Following at least partial removal of the residue from the interior of the chamber, the gases are evacuated via an outlet line and optionally abated.

[0056] Additional cleaning gases contemplated for introduction using the direct dissociative plasma introduction mode, in addition to  $\text{NF}_3$ , include  $\text{XeF}_2$ ,  $\text{XeF}_6$ ,  $\text{XeF}_4$ ,  $\text{IF}_5$ ,  $\text{IF}_7$ ,  $\text{SF}_6$  and  $\text{C}_2\text{F}_6$ .

[0057] In another embodiment of the invention, the reactive halide gas is fluorine, for example as delivered from Advanced Technology Materials VAC cylinder (Danbury, Connecticut, USA). Fluorine is an extremely corrosive gas and can be used with or without thermal or electrical activation. Without activation, the fluorine gas can be

admitted directly to the vacuum chamber, wherein the gas is permitted to spontaneously react for sufficient time and under sufficient conditions to at least partially remove the residue. If additional activation is required, components may be heated or left at an elevated temperature and the gas permitted to react for sufficient time to at least partially remove the residue. In the alternative, a plasma may be generated within the arc chamber (as described previously) to further induce fluorine activation.

[0058] The embodiments described herein may be added directly to newly manufactured ion implantation tools or in the alternative, implanters already in use may be easily retrofitted with the cleaning systems described herein.

[0059] In a further embodiment, the etchant gas may be blended with the implanting species, e.g., boron trifluoride, so that etching and implanting may occur simultaneously, which is cost effective in terms of minimization of down time and elimination of additional expensive delivery systems. Thus, another embodiment of the invention relates to a method of implanting an implant species while simultaneously etching or cleaning the vacuum chamber and/or beamline, preferably using a blend of implanting species and an etchant gas.

[0060] The advantages of the present invention include, but are not limited to, selective cleaning of unwanted residue in the vacuum chamber and beamline of an ion implantation system, the ability to clean the residue without using plasma-induced radicals thereby minimizing damage to the components of the vacuum chamber and beamline, and effective cleaning at room temperature. Residue removal from the vacuum chamber and beamline using the methods introduced herein reduces source glitching and extraction arcing, thereby contributing to more stable operation of the ion implanter. Further, the ion source lifetime and MTBF are increased, with a concomitant decrease in preventative maintenance costs and time.

[0061] *In situ* cleaning of the vacuum chamber and beamline should be performed about 1 to 2 times per week, although the number of cleanings may be more or less often depending on how often the ion implanter is used. Typically, the length of the entire cleaning operation is about 1 hour, although the cleaning time may be more or less.

[0062] To perform any of the cleaning operations described herein, the ion source is left on or turned off (as indicated in the foregoing processes) and the source isolation valve is closed (for stagnant or continuous processes) or open (for continuous processes) prior to introduction of the etchant gas (or the etchant container in the direct introduction mode). Following residue removal, normal ion implanter operations may be resumed.

[0063] In yet another embodiment of the invention, off-line (*ex situ*) cleaning of the components of the ion source region using a vapor phase is disclosed. In this embodiment, components from any part of the ion implanter which are delicate (e.g., graphite-containing components) may be cleaned off-line thereby eliminating exposure to conventional off-line cleaners, such as harsh abrasives or liquids. Off-line cleaning using a vapor phase material is an advance in the art because abrasives can damage the delicate components and liquids which enter the pores of the delicate components during cleaning must be pumped out of the pores during pump down of the vacuum chamber.

[0064] In this embodiment, the ion source or any other power supplies are turned off, relevant isolation valves are closed, and the ion source or other vacuum chamber is vented to atmospheric pressure. Preferably, the ion source region is allowed to cool to room temperature before disengagement of the components to be cleaned from the ion source region. The components are removed from the implanter and positioned in a separate, off-line vacuum chamber with a simple pumping system and valves. Alternatively, the components may be positioned in some other high pressure vessel such as a supercritical fluid vessel altered for said *ex situ* cleaning. Etchant gas, for example XeF<sub>2</sub>, is introduced

into the off-line vacuum chamber according to the teachings herein, for sufficient time and under sufficient conditions to at least partially remove the residue from the components. Following each cleaning phase, the toxic by-products are pumped away, optionally to abatement units, as previously described, to properly dispose of the toxic vapors. Preferably, the off-line vacuum chamber is a stand alone unit that is able to service numerous ion implanters, e.g., upwards of 10-12, in the fab.

[0065] In yet another embodiment, the present invention relates to the *in situ* cleaning of the cryogenic pump.

[0066] As used herein, “accumulated process effluents” correspond to those species that are not removable during the conventional cryopump purge process using nitrogen as the purge gas. For example, the accumulated process effluents may be species that underwent a chemical change while the cryopump was warmed to ambient temperature. Alternatively, the accumulated process effluents may correspond to species that have adhered to the metallic parts of the cryopump.

[0067] Nitrogen is the conventional gas of choice during the cryopump purging process whereby the temperature of the cryopump is raised from 10-14K to ambient temperature and the previously cryosorbed species are carried away within the purge gas to the exhaust system. In the present invention, a portion of the nitrogen purge gas may be replaced by a reactive gas to remove or inhibit accumulated process effluent buildup in the cryopump. Reactive gases contemplated herein include, but are not limited to, oxygen, ozone, nitrogen oxides, other species that generate oxygen radicals, and combinations thereof.

[0068] The purge gas(es) may be delivered to the cryopump using a process selected from the group consisting of: (i) 100 % (“essentially pure”) nitrogen for x minutes followed by 100 % (“essentially pure”) reactive gas for y minutes repeated n times,

wherein  $n$  may be any integer between 1 and 10 and  $[n \times (x + y)]$  equals the cumulative length of this purging process; (ii) 100 % (“essentially pure”) nitrogen at time zero and 100 % (“essentially pure”) reactive gas at the end of this cryopump purging process, whereby the percentage of nitrogen decreases and the percentage of reactive gas increases continuously or in steps (equal or non-equal in dimension) temporally from time zero to the end of this cycle purge; (iii) 100 % (“essentially pure”) nitrogen at time zero and less than 100 % reactive gas at the end of this cryopump purging process, whereby the percentage of nitrogen decreases and the percentage of reactive gas increases continuously or in steps (equal or non-equal in dimension) temporally from time zero to the end of this cycle purge; (iv)  $(100 - z)$  % nitrogen and  $z$  % reactive gas continuously throughout the purging process; and (v) variations and combinations thereof. Preferably, “ $x$ ” is in a range from about 10 minutes to about 120 minutes, preferably about 10 minutes to about 20 minutes, “ $y$ ” is in a range from about 10 minutes to about 120 minutes, preferably about 10 minutes to about 20 minutes, and “ $z$ ” is in a range from about 0.01% to about 99.99%.

[0069] As defined herein, “essentially pure” corresponds a gas containing less than 5 vol. % contaminating species, preferably less than 2 vol. %, more preferably less than 1 vol. %, and most preferably less than 0.5 vol. %. It is to be understood by one skilled in the art that a contaminating species may include reactive as well as non-reactive gas species.

[0070] The foregoing purge gas(es) delivery options ((i) - (v)) may be applied during warm-up of the cryopump to ambient temperature, following achievement of ambient temperature (i.e., the cryopump temperature was increased using 100% (“essentially pure”) nitrogen followed by the application of one or more of the foregoing purge gas delivery options) or a combination of both. Accordingly, for purposes of the present

invention, time zero corresponds to the moment the pump is no longer cryogenically cooled, or the moment when the pump achieves ambient temperature, or some other moment when the accumulated process effluent can be most efficiently removed, as readily determined by one skilled in the art for the desired *in situ* cleaning.

[0071] Importantly, substitution of a reactive purge gas for at least a portion of the nitrogen purge gas will reduce buildup of the accumulated process effluent in the cryopump, which has the advantage of reducing or eliminating the frequency of cryopump maintenance and concomitantly decreases the tool downtime and the cost of ownership. In addition, the acidity level in the cold head of the cryopump may be decreased as a result of the use of the reactive gas(es).

[0072] The features and advantages of the invention are more fully shown by the illustrative examples discussed below.

### Example 1

[0073] Test samples were prepared using electron beam deposition of aluminum, boron, tungsten and silicon on glass microscope slides. The aluminum was used as a bottom layer barrier on the glass slide. Some samples were capped with a protective silicon layer while others were left uncapped and allowed to oxidize. The test samples were sequentially placed into an *ex situ* XeF<sub>2</sub> reactor and etched for 16 one-minute pulse-etch cycles at a pressure of 300-400 mTorr at room temperature.

[0074] Figure 4 illustrates the removal, as determined by RGA, of boron from a glass slide having a base layer of 500 nm of aluminum with 500 nm of boron deposited thereon. There was no silicon capping layer therefore the boron could have potentially formed an oxide layer prior to etching. The XeF<sub>2</sub> etch process removed most of the boron in about 4 cycles with a concomitant increase in unreacted XeF<sub>2</sub>, indicating that boron removal was

decreasing or had ceased altogether. Importantly, Fig. 4 illustrates that the boron layer was readily removed using the  $\text{XeF}_2$  system and method taught herein, even if an oxide layer had formed thereon prior to etching.

[0075] Figure 5 illustrates the removal, as determined by RGA, of tungsten from a glass slide having a base layer of 500 nm of aluminum with 150 nm of tungsten deposited thereon. There was no silicon capping layer therefore the tungsten could have potentially formed an oxide layer prior to etching. No tungsten compounds were observed by RGA however, the presence of  $\text{XeF}_2$  was significant, indicating that no tungsten removal was occurring. Importantly, Figs. 4 and 5 illustrate that the system and method taught herein selectively removes ion implantation residue, e.g., boron, while being essentially non-reactive with the materials of construction of the ion implanter, e.g., tungsten and aluminum.

[0076] While the invention has been described herein with reference to various specific embodiments, it will be appreciated that the invention is not thus limited, and extends to and encompasses various other modifications and embodiments, as will be appreciated by those ordinarily skilled in the art. Accordingly, the invention is intended to be broadly construed and interpreted, in accordance with the ensuing claims.

## **THE CLAIMS**

### **What is claimed is:**

1. A method of cleaning a vacuum chamber of a semiconductor manufacturing tool, at least one component, or combination thereof, said method comprising:
  - (a) introducing an etchant gas from an etchant container into the vacuum chamber;
  - (b) terminating introduction of the etchant gas into the vacuum chamber upon attainment of a predetermined pressure in the vacuum chamber; and
  - (c) reacting the etchant gas with a residue in the vacuum chamber for a sufficient time to at least partially remove the residue from the interior of the vacuum chamber, at least one component contained therein, or combination thereof;wherein the etchant gas is chosen to react selectively with the residue in the vacuum chamber, the residue on the components contained therein, or combination thereof, while being essentially non-reactive with the interior of the vacuum chamber, the components contained therein, or combination thereof.
2. The method of claim 1, wherein the semiconductor manufacturing tool is an ion implanter.
3. The method of claim 2, wherein the at least one component is an ion source region component of the ion implanter.

4. The method of claim 2, wherein the at least one component is a beamline component of the ion implanter.
5. The method of claim 2, wherein the at least one component is a turbomolecular pump situated in communication with the vacuum chamber, and used for pumping the vacuum chamber.
6. The method of claim 1, wherein the etchant gas comprises a gas selected from the group consisting of  $\text{XeF}_2$ ,  $\text{XeF}_6$ ,  $\text{XeF}_4$ ,  $\text{IF}_5$ ,  $\text{IF}_7$ ,  $\text{SF}_6$ ,  $\text{C}_2\text{F}_6$  and  $\text{F}_2$ .
7. The method of claim 1, wherein the etchant gas comprises  $\text{XeF}_2$ .
8. The method of claim 1, wherein the residue comprises an element selected from the group consisting of boron, phosphorus, germanium, molybdenum, tungsten, aluminum, and arsenic.
9. The method of claim 1, wherein the predetermined pressure is subatmospheric.
10. The method of claim 7, wherein the predetermined pressure is from about 0.3 Torr to about 4.0 Torr.
11. The method of claim 3, wherein an ion source in the ion source region comprises a source selected from the group consisting of an indirectly heated cathode source, a Freeman source and a Bernas source.
12. The method of claim 1, wherein said time is from about 0.5 minute to about 5 minutes.

13. The method of claim 1, further comprising (d) evacuating the vacuum chamber following completion of said reacting.
14. The method of claim 13, further comprising repeating (a) through (d) at least once.
15. The method of claim 1, wherein the etchant container contains an etchant material, and wherein the etchant container is heated by a heater to increase the rate of physical conversion of the etchant material into the etchant gas.
16. The method of claim 15, wherein the heater is selected from the group consisting of an oven, a conformal heating blanket, electrical heating tape, heated fluids and/or gases, and heater wires.
17. The method of claim 1, wherein an inert gas is introduced into the etchant container to transport the etchant gas to the vacuum chamber.
18. The method of claim 17, wherein the inert gas comprises a gas selected from the group consisting of argon, nitrogen, xenon and helium.
19. The method of claim 1, wherein the etchant container is positioned in the vacuum chamber or positioned upstream of the vacuum chamber.
20. The method of claim 19, wherein the etchant container contains a pre-measured amount of an etchant material for generation of the etchant gas in the vacuum chamber.
21. The method of claim 20, wherein the etchant material is a solid or a liquid.

22. The method of claim 20, wherein the etchant material is pelletized  $\text{XeF}_2$ .
23. The method of claim 1, wherein the reaction of the etchant gas with the residue is effectuated without energetic activation.
24. The method of claim 8, wherein a concentration of the elements in the residue is determined by an analytical technique selected from the group consisting of temperature-programmed infrared spectroscopy (TPIR), Fourier Transform Infrared Spectroscopy (FTIR), electron paramagnetic spectroscopy (EPM), residual gas analysis (RGA), mass spectrometry, and combinations thereof.
25. The method of claim 1, wherein the etchant gas is devoid of an oxidizing species and a nitrogen-containing species, wherein the nitrogen-containing species comprises at least one additional element selected from the group consisting of O, F, and Br.
26. A method of cleaning a vacuum chamber of a semiconductor manufacturing tool, at least one internal component, or combination thereof, said method comprising:
  - (a) introducing an etchant material from an etchant container into the vacuum chamber;
  - (b) terminating introduction of the etchant gas into the vacuum chamber upon attainment of a predetermined pressure;
  - (c) dissociating the etchant material into a reactive halide species in the vacuum chamber using a plasma source positioned in said vacuum chamber; and

(d) reacting the reactive halide species with a residue in the vacuum chamber for a sufficient time to at least partially remove the residue from the vacuum chamber, the at least one internal component, or combination thereof.

27. The method of claim 26, wherein the etchant material comprises a material selected from the group consisting of  $\text{XeF}_2$ ,  $\text{XeF}_6$ ,  $\text{XeF}_4$ ,  $\text{NF}_3$ ,  $\text{IF}_5$ ,  $\text{IF}_7$ ,  $\text{SF}_6$ ,  $\text{C}_2\text{F}_6$  and  $\text{F}_2$ .
28. The method of claim 26, further comprising introducing an inert gas from an inert gas source into the vacuum chamber prior to dissociating the etchant material.
29. An apparatus for cleaning a vacuum chamber of a semiconductor manufacturing tool, at least one internal component, or combination thereof, said apparatus comprising:
- (a) an etchant material source having an etchant material disposed therein, wherein the etchant material source is communicatively connected to, and is situated upstream of, the vacuum chamber; and
  - (b) a valve between the etchant material source and the vacuum chamber;
- wherein said apparatus is further characterized by comprising at least one of the following components (I) and (II):
- (I) a heater for heating the etchant material source; and

(II) an inert gas source having an inert gas disposed therein, wherein the inert gas source is communicatively connected to, and is situated upstream of, the etchant material source.

30. The apparatus of claim 29, wherein the etchant material comprises a compound selected from the group consisting of  $\text{XeF}_2$ ,  $\text{XeF}_6$ ,  $\text{XeF}_4$ ,  $\text{IF}_5$ ,  $\text{IF}_7$ ,  $\text{SF}_6$ ,  $\text{C}_2\text{F}_6$  and  $\text{F}_2$ .
31. The apparatus of claim 29, wherein the at least one component is an ion source of an ion implanter, said ion source selected from the group consisting of an indirectly heated cathode source, a Freeman source and a Bernas source.
32. The apparatus of claim 29, wherein the heater is selected from the group consisting of an oven, a conformal heating blanket, electrical heating tape, heated fluids and/or gases, and heater wires.
33. The apparatus of claim 29, wherein the inert gas comprises nitrogen, argon, xenon, or helium.
34. The apparatus of claim 29, wherein the at least one component is a beamline component of an ion implanter.
35. The apparatus of claim 29, wherein the at least one component is a turbomolecular pump situated in communication with the vacuum chamber, and used for pumping the vacuum chamber.
36. The apparatus of claim 29, wherein the etchant material is devoid of an oxidizing species and a nitrogen-containing species, wherein the nitrogen-containing species

comprises at least one additional element selected from the group consisting of O, F, and Br.

37. A method of *ex situ* cleaning at least one component of a semiconductor manufacturing tool, said method comprising:
- (a) positioning the component in an *ex situ* vacuum chamber;
  - (b) introducing an etchant gas from an etchant container into the *ex situ* vacuum chamber;
  - (c) terminating introduction of the etchant gas into the vacuum chamber upon attainment of a predetermined pressure in the vacuum chamber; and
  - (d) reacting the etchant gas with a residue in the vacuum chamber for a sufficient time to at least partially remove the residue from the at least one component contained therein;
- wherein the etchant gas is chosen to react selectively with the residue on the at least one component, while being essentially non-reactive with the interior of the vacuum chamber and the component material itself.
38. The method of claim 37, wherein the semiconductor manufacturing tool is an ion implanter.
39. The method of claim 37, wherein the at least one component comes from an ion source region.

40. The method of claim 38, wherein the at least one component comes from the beamline of the ion implanter.
41. The method of claim 37, wherein the etchant gas comprises a gas selected from the group consisting of  $\text{XeF}_2$ ,  $\text{XeF}_6$ ,  $\text{XeF}_4$ ,  $\text{NF}_3$ ,  $\text{IF}_5$ ,  $\text{IF}_7$ ,  $\text{SF}_6$ ,  $\text{C}_2\text{F}_6$  and  $\text{F}_2$ .
42. The method of claim 37, wherein the etchant gas comprises  $\text{XeF}_2$ .
43. The method of claim 37, wherein the residue comprises an element selected from the group consisting of boron, phosphorus, germanium, molybdenum, tungsten, aluminum, and arsenic.
44. The method of claim 37, wherein the predetermined pressure is subatmospheric.
45. The method of claim 44, wherein the predetermined pressure is from about 0.3 Torr to about 4.0 Torr.
46. The method of claim 37, wherein the at least one component comprises an ion source selected from the group consisting of an indirectly heated cathode source, a Freeman source and a Bernas source.
47. The method of claim 37, wherein said time is from about 0.5 minute to about 5 minutes.
48. The method of claim 37, further comprising (e) evacuating the vacuum chamber following completion of said reacting.
49. The method of claim 48, further comprising repeating (b) through (e) at least once.

50. A method of cleaning a vacuum chamber of a semiconductor manufacturing tool, at least one component, or combination thereof of the vacuum chamber, said method comprising:

- (a) introducing an etchant gas from an etchant container into the vacuum chamber;
- (b) withdrawing a plurality of gas species from the vacuum chamber using a vacuum pump to effectuate a continuous flow of the etchant gas therethrough; and
- (c) flowing the etchant gas through the vacuum chamber for a sufficient time to react the etchant gas with the residue to at least partially remove the residue from the vacuum chamber and/or at least one component contained therein,

wherein the etchant gas comprises a gas selected from the group consisting of  $\text{XeF}_2$ ,  $\text{XeF}_6$ ,  $\text{XeF}_4$ ,  $\text{IF}_5$ ,  $\text{IF}_7$ ,  $\text{SF}_6$ ,  $\text{C}_2\text{F}_6$  and  $\text{F}_2$ , and wherein the etchant gas is chosen to react selectively with the residue in the vacuum chamber, while being essentially non-reactive with the interior of the vacuum chamber or the components contained therein.

51. The method of claim 50, wherein the semiconductor manufacturing tool is an ion implanter.

52. The method of claim 50, wherein the vacuum chamber comprises an ion source region.

53. The method of claim 50, wherein the vacuum chamber comprises a beamline vacuum chamber.
54. The method of claim 50, further comprising flowing a dopant gas from a dopant source into the vacuum chamber to effectuate ion implantation therein.
55. The method of claim 54, further comprising repeating (a) through (d) at least once.
56. The method of claim 50, further comprising dissociating the etchant gas into a reactive halide species in the vacuum chamber using an energetic source.
57. The method of claim 50, wherein the reactive halide species reacts with the residue to at least partially remove the residue from the vacuum chamber.
58. The method of claim 50, wherein the residue comprises an element selected from the group consisting of boron, phosphorus, germanium, molybdenum, tungsten, aluminum, and arsenic.
59. The method of claim 56, wherein the energetic source comprises a plasma generator.
60. The method of claim 59, wherein the plasma generator comprises an ion source selected from the group consisting of an indirectly heated cathode source, a Freeman source and a Bernas source.
61. The method of claim 56, wherein the energetic source is positioned within or immediately upstream of said vacuum chamber.

62. The method of claim 50, wherein the reaction of the etchant gas with the residue is effectuated without energetic activation.
63. The method of claim 50, wherein the etchant gas further comprises an inert species selected from the group consisting of argon, nitrogen, xenon and helium.
64. The method of claim 50, wherein the etchant gas comprises  $\text{XeF}_2$ .
65. The method of claim 50, wherein a concentration of the elements in the residue is determined by an analytical technique selected from the group consisting of temperature-programmed infrared spectroscopy (TPIR), Fourier Transform Infrared Spectroscopy (FTIR), electron paramagnetic spectroscopy (EPM), residual gas analysis (RGA), mass spectrometry, and combinations thereof.
66. The method of claim 50, wherein the etchant gas is devoid of an oxidizing species and a nitrogen-containing species, wherein the nitrogen-containing species comprises at least one additional element selected from the group consisting of O, F, and Br.
67. A method of cleaning accumulated process effluent from the interior of a cryopump, said method comprising purging the cryopump with at least two purge gases, said purge gases including nitrogen and at least one reactive gas selected from the group consisting of oxygen, ozone, nitrogen oxides, species that generate oxygen radicals *in situ*, and combinations thereof, wherein said method is characterized by at least one of the following purge process sequences (I), (II), and (III):
  - (I) (a) purging with essentially pure nitrogen for time x; and

(b) purging with the at least one reactive gas for time y, wherein the at least one reactive gas is essentially pure;

(II) (a) purging with essentially pure nitrogen at time zero;

(b) blending the essentially pure nitrogen with the at least one reactive gas, wherein the nitrogen and the at least one reactive gas are no longer essentially pure;

(III) (a) purging with a mixture of nitrogen and at least one reactive gas,

wherein the accumulated process effluent is substantially removed from the interior of the cryopump.

68. The method of claim 67, wherein the reactive gas comprises oxygen.

69. The method of claim 67, wherein the cryopump is purged during cryopump warm-up.

70. The method of claim 67, wherein the cryopump is purged at ambient temperature.

71. The method of claim 67, wherein the accumulated process effluent comprises non-volatile species that were produced during cryopump warm-up.

72. The method of claim 67, comprising Sequence (I), further comprising repeating (a) and (b) at least once.

73. The method of claim 67, comprising Sequence (II), wherein the blending comprises a process selected from the group consisting of continuous, equivalent steps, and non-equivalent steps.
74. The method of claim 67, comprising Sequence (II), wherein the amount of nitrogen is less than the amount of at least one reactive gas.