Apparatus and Method for Reducing Contamination on Thermally Processed Semiconductor Substrates

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the field of thermal processing of semiconductor substrates, and, more particularly, to reducing metal contamination, such as aluminum iron and copper contamination, on the surface of thermally processed semiconductor substrates.

2. Background of the Invention

In the manufacture of devices on semiconductor substrates, such as semiconductor wafers, multiple levels of conductive layers are applied to the substrate. In order to fabricate features, circuits, vias and devices on the substrate, various techniques are used to deposit and etch materials on the substrate. Deposition techniques include processes such as physical vapor deposition (PVD), chemical vapor deposition (CVD), sputtering, and immersion of the substrate into an electrolyte solution. Following such deposition, the semiconductor substrates may be heated to elevated temperatures in ovens or rapid thermal processing (RTP) chambers to anneal the structures formed thereon.

A large number of semiconductor substrates are formed from silicon. Typically, heat-treating or thermal processing of silicon wafers takes place in an RTP chamber. Each wafer is individually placed within an RTP reaction chamber formed primarily of quartz, and certain components of the chamber may be formed from stainless steel, aluminum or other generally non-corrosive material. Flanges and tubing for introducing and exhausting thermal processing gases, such as, *e.g.* , steam, oxygen, hydrogen, nitrogen, NH_3, N_2O, NO, chlorine containing gas, oxygen containing gas, nitrogen containing gas, ozone, hydrocarbon compounds, metal-organic compounds, radicals or a combination of such gases, and inert gases, such as nitrogen (for silicon processing with temperatures below 1150°C) or argon, are elements associated with the RTP chamber that may be formed from stainless steel and/or aluminum.

Untreated stainless steel surfaces generally contain some free iron (Fe) and iron oxide (FeO) in thousands of minute inclusions, cracks and crannies within the surfaces. Other possible heavy metal surface contaminants, such as free nickel, may also be present. As steam or other corrosive processing gases or fluids contact the stainless steel surfaces of the reaction chamber or its associated elements, some of the embedded Fe, FeO and other contaminant particles tend to separate from the stainless steel surfaces and be carried away with the processing fluids. These dislodged particles carried by processing fluids may contact and contaminate the semiconductor substrate (wafer) surfaces during thermal processing within the reaction chamber.

Semiconductor fabricators seek to produce semiconductor substrates of the highest possible purity. For example, the industry presently strives to limit iron (Fe) and iron oxide (FeO) levels to at or below 1 E10/cm^3, or 10 billion Fe atoms per cubic centimeter of silicon semiconductor substrate (10 milliard is the European equivalent).

Five approaches have been adopted to try to limit corrosion of stainless steel used to form components of semiconductor substrate processing chambers:

First, naturally passivated stainless steels may be used. Stainless steel surfaces eventually passivate when exposed to oxygen. A clean steel surface exposed to oxygen will form a CrO layer, called the passivated layer. The passivated layer retards heavy metal particles, such as Fe, from separating from the steel surface. However, natural passivation produces a thin and non-uniform CrO layer. This natural passivation can be enhanced by electropolishing followed by passivation under controlled conditions.

Second, electropolished steel may be used. During electropolishing, the exposed steel surface is immersed in a heated electrolytic bath that contains metal plates connected to a cathode (negative terminal). An anode is connected to the steel surface. When a direct current is applied, the electrical reaction causes an ionic conduction that removes particles of metal from the steel surface. The unwanted Fe scales, protrusions, nooks and crannies are normally first to be removed in the electrolytic reaction. The end result is less free Fe on the steel surfaces.

Third, the stainless steel may be coated with Teflon or a solid polymer material. The coating holds contaminant heavy metal particles onto the steel surface. Unfortunately, such coatings cannot withstand temperatures over about 300°C, and RTP processes may exceed 1000°C, in which case the temperatures of associated elements of the reaction chamber often exceeds 300°C.

As a fourth approach, an electropolished stainless steel surface may be passivated by being immersed in an acid (such as citric or nitric acid), as recommended by standards, such as ASTM 380-99. In the acid bath, the free iron is removed and the steel surface undergoes an oxidation in which the Cr, Ni and Mo are oxidized very quickly to form an extra protective coating. The protective layer of CrO is much thicker and more effective against corrosion than the CrO layer formed with natural passivation. Still, the steel surface may not always be sealed uniformly and completely enough to protect the reaction chamber components and associated elements formed from such steel against corrosion and subsequent release of metallic elements that contaminate thermally processed semiconductor substrates.

Fifth, the stainless steel itself may be specially fabricated to resist corrosion. A special process called vacuum induction melting-vacuum arc remelting (VIM-VAR) produces stainless steel with lower levels of residual Fe and FeO and other surface contaminants (such as sodium or potassium). It is used to produce a special 316L-SCQ (super clean quality for semiconductor applications) stainless steel with a lower sulfur content (0.005 to 0.015% versus 0.03% for a standard 316L stainless), and generally lower surface contaminants. In addition, other stainless steel alloys, such as 317LM with higher percentages of Cr, Ni and Mo, are also available. Such special steels are significantly more expensive than standard stainless, such as 316L. Moreover, where the semiconductor industry has imposed such exacting requirements to limit semiconductor surface contamination by Fe and other heavy metals and deposits, even these special stainless steels cannot be used without further treatment if they liberate excessive contaminants when exposed to corrosive thermal processing gases and fluids.

Therefore, the industry seeks a reaction chamber for thermally processing semiconductor substrates formed from stainless steel or aluminum components, or having stainless steel or aluminum elements associated therewith, which does not have the heavy metal contamination drawbacks associated with the prior art.

SUMMARY OF THE INVENTION

An apparatus for thermal processing a semiconductor substrate, such as a silicon semiconductor wafer, with reactive gases, such as *e.g.* steam, oxygen, hydrogen, nitrogen, NH_3, N_2O, NO, chlorine containing gas, oxygen containing gas, nitrogen containing gas, ozone, hydrocarbon compounds, metal-organic compounds, radicals or a combination of such gases, has a reaction chamber for processing the substrate with the reactive gas when the substrate is held within the chamber. At least one element forming a part of or associated with the reaction chamber and adapted for contacting the reactive gas introduced into the chamber is formed of a metal coated with a layer comprising silicon or a silica-containing compound. Preferably, the base metal that is coated with the silicon or silica-containing compound is selected from stainless steel, 316L stainless steel, 316L-SCQ stainless steel, 317LM stainless steel or aluminum or an aluminum alloy. Other stainless steels with similar compositions to those of 316L, 317LM and 316L-SCQ could be used. For example, less expensive stainless steels, such as 304, and steels more commonly found outside the United States, such as 4404, X2CrNiMo18-14-3, Z3CND17-12-03, Z3CND18-14-03, 316S11, 316S13, 316S14, 316S31, LW22, LWC22, LWCF22, X2CrNiMo17-13, SUS 316L, 2353, 2375 and 2367, could be used. If aluminum or an aluminum alloy is used as the base metal, then the silicon or silica-containing layer preferably is SiO_2 or Si_3N_4.

A method for reducing metal contamination on surfaces of a semiconductor substrate when said substrates are thermal processed according to this invention, includes the steps of: (a) providing a reaction chamber with at least one element constructed of a metal forming a part of or associated with said chamber and adapted for contacting a reactive gas introduced into the

chamber, wherein at least a portion of said element that is adapted for contacting the reactive gas is coated with a silicon or silica-containing layer;

(b) inserting the semiconductor substrate into the chamber;

(c) introducing reactive gases into the chamber; and

(d) heating the semiconductor substrate as it is held within the chamber.

Preferably, the at least one element constructed of metal is constructed of stainless steel, 316L stainless steel, 316L-SCQ stainless steel or 317LM stainless steel or any of the steels mentioned above. The metal also can be aluminum or an aluminum alloy. After applying a silicon or silica-containing coating on a stainless steel element adapted for contacting the reactive gas, the iron contamination (Fe) can be reduced to levels approaching 1 E10/cm^3 and below. Depending on the coating conditions, the coating thickness, the surface finish (especially the surface roughness or physical condition before the coating and the chemical composition of the surface before the coating, for example, potassium and sodium concentration), and the coating layer, the level of iron contamination can be further reduced to levels below 1 E10/cm^3. Nickel, zinc, copper, magnesium and other heavy metal surface contaminants are reduced to applicable acceptable levels as well.

A further advantage of the method in which metal elements are coated with a silicon or silica-containing layer is that the corrosion rate of that metal is reduced when steam or chlorine-containing reactive gases are used in the thermal processing.

The advantages of the invention are best obtained when all metal elements of the reaction chamber and associated with the reaction chamber that come into contact with steam or other reactive gases are coated with a silicon or silica-containing layer. One such element associated with the reaction chamber is a flange that is attached to the reaction chamber at the inlet for reactive gases. The flange preferably is constructed of a metal, such as stainless steel, and at least the portion of the flange adapted for contacting the reactive gas is coated with a silicon or silica-containing layer. Another such element associated with the reaction chamber is a flange that is attached to the chamber at the outlet for reactive gases. The flange preferably is

constructed of a metal, such as stainless steel, and at least the portion of the flange adapted for contacting the reactive gas is coated with a silicon or silica-containing layer. Other flanges, such as, *e.g.*, a nitrogen curtain flange, that may come into contact with the reactive gases preferably are also constructed of a silica or silicon-coated metal. In addition, various tubes associated with the inlet and/or outlet to the reaction chamber may be constructed of a metal, and have at least the portion of the tubes adapted for contacting the reactive gases coated with a silicon or silica-containing layer.

The silicon or silica-containing layer is applied to the metal (preferably stainless steel or aluminum) to a coating thickness greater than about 1000□, and preferably in the range of about 1200 Å to about 4800 Å. Good results have been achieved when the silica-containing layer is applied to the stainless steel parts with a chemical vapor deposition (CVD) process using silica in a vacuum at a temperature in the range of 300°C to 400°C. In the most preferred embodiment, the silicon or silica-containing layer is applied to all stainless steel surfaces of parts of the reaction chamber or associated with the reaction chamber that may come into contact with the reactive gases. For aluminum parts, the silica-containing layer is preferably applied with a chemical vapor deposition (CVD) process using silica in a vacuum at a temperature in the range of 200°C to 600°C.

The present invention focuses on coating metal elements of or associated with a reaction chamber for a thermal processing system, especially a rapid thermal processing (RTP) system, in which reactive gases are used for thermal processing of semiconductor substrates, such as silicon semiconductor wafers. The metal elements that come into contact with the reactive gases are at least partly coated with a silicon or silica-containing layer to reduce contamination on the semiconductor substrate that might otherwise be caused by the metal and/or impurities or alloy elements contained in the metal elements liberated therefrom by reaction with the reactive gases. The coating layer also may have an advantage in reducing the corrosion rate of the metal elements if the thermal processing is conducted with reactive gases that may cause corrosion of

unprotected metal. The coating layer protects the semiconductor substrate (*i.e.*, a silicon wafer) from contaminants that otherwise would be emitted when the metal elements corrode.

In general, other compositions for the coating layer may be chosen, depending upon the composition of the semiconductor substrate being processed in the reaction chamber. Preferably, the coating layer composition is chosen to complement the composition of the semiconductor substrate. For example, if the semiconductor substrates to be processed are III-V, II-VI or IV-IV semiconductor wafers, the coating layer for the metal elements of the reaction chamber and associated with the reaction chamber comprise at least one element of the compound semiconductor wafer – silicon or silica-containing if the compound semiconductor wafer is silicon carbide (SiC) and/or silicon, SiC, SiO_2 or Si_3N_4.

DESCRIPTION OF THE FIGURES

FIG. 1 is a schematic cross-sectional view in side elevation of a stainless steel reaction chamber, nitrogen supply, steam generator and semiconductor substrate transport device;

FIG. 2 is a schematic cross-sectional view taken along line 2-2 in FIG. 1;

FIG. 3 is a schematic cross-sectional view taken along line 3-3 in FIG. 1; and

FIG. 4 is a schematic cross-sectional view taken along line 4-4 in FIG 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Figure 1, there is shown a schematic of a cross section in side elevation of the components of an example stainless steel RTP processing chamber **100**. The reaction chamber **20** houses a quartz sleeve **22**. The quartz sleeve **22** defines an envelope into which a semiconductor substrate, such as a semiconductor wafer **30**, is inserted and from which said substrate is extracted. The quartz sleeve has an inlet **23**. The semiconductor wafer **30** is held upon supports **28** while positioned within the quartz sleeve **22** inside the cavity of the reaction chamber **20** (See also FIG. 3). In contrast, an aluminum RTP processing chamber typically does

not incorporate a quartz sleeve and the steam and process gases introduced into the chamber will contact the chamber surfaces.

A robot **14**, shown only in schematic in Figure 1, transfers the semiconductor wafer **30** into and out of the sleeve **22** in the reaction chamber **20**. The robot **14** is provided with an arm **16** that selectively reciprocates back and forth in the directions as indicated by arrow **17**. Various robotic transfer systems are known to persons skilled in the art of thermal processing of semiconductor substrates.

Above and below the quartz sleeve **22** within the reaction chamber **20** are arrays of heat lamps **32** and **32'**, shown in Figures 1 and 2. The top array has a series of fourteen heat lamps **32** disposed substantially parallel to one another. The bottom array has a series of fourteen heat lamps **32'** disposed substantially parallel to one another and substantially perpendicularly to the lamps **32** in the top array. The heat lamps are activated to heat a semiconductor substrate and reactive gases held within the quartz sleeve envelope **22**. When the lamps **32, 32'** are activated, the quartz walls of the sleeve **22** remain cooler than the semiconductor substrate **30**.

Typical RTP treatments, such as, for example, described in prior U.S. Patent Nos. 4,331,485, 4,356,384 and 4,680,451, involve heating the semiconductor substrate from room temperature to a prescribed elevated process temperature, such as from 200°C to 1700°C in a matter of 1 to 300 seconds. The semiconductor substrate **30** is held at that elevated temperature for only a short time, such as 30 to 60 seconds. The temperature and time selected depend upon the processing or treatment intended for the semiconductor substrate and the type of semiconductor material. For silicon semiconductor wafers, there are mainly two types of heat treatment applications: first, an implant annealing or film annealing or restructuring process; and second, a film growing process, such as the formation of an SiO_2 layer of a certain thickness on the semiconductor substrate. Most processing for silicon semiconductor wafers uses temperatures below 1250°C and process times between 1 and 180 seconds. Higher temperatures are applied when implant annealing SiC (IV-IV diamond) semiconductors. For such wafers, temperatures of about 1700°C for several seconds up to 60 seconds are used.

The quartz sleeve **22** of the reaction chamber **20** is held between a rear gas flange **46** and a process exhaust flange **7**. A front nitrogen curtain flange **24** preferably is also provided adjacent the exhaust flange **7**. Nitrogen gas flows into the quartz sleeve **22** from the nitrogen supply **12** through an inlet **26** into the nitrogen curtain flange **24**, then into the reaction chamber **20** and all the way into the flange **6** to prevent air or other atmospheric contaminants from entering the sleeve **22** when the chamber door (not shown) is opened. The chamber door is opened to permit a semiconductor wafer **30** to be inserted into or extracted from the chamber **20** and sleeve **22**. The door remains closed when the semiconductor wafer is thermally processed within the chamber.

The nitrogen curtain flange **24**, shown in Figures 1 and 4, is formed from stainless steel and is connected to a series of tubes **45**, also formed of stainless steel. The nitrogen curtain flange **24**, including its inlet passageway **26** and inner cavity **27** and all openings through which reactive gases may contact, is coated with a silicon or silica-containing layer to a coating thickness of about from 1200 and 4800Å.

The steam and process gas inlet flange **18**, shown in Figures 1 and 3, is formed from stainless steel and is connected to a series of tubes **50** through which the reactive gas, such as steam or water vapor in the preferred embodiment, passes. The steam and process gas inlet flange **18** further defines an inner cavity **42** that communicates with the interior **23** of the quartz envelope **22** and through which the robotic transfer system **14** inserts and extracts the semiconductor wafer **30** into and out of the quartz envelope **22**. The steam and process gas inlet flange **18**, including its inlet passageway **44** and inner cavity **42** and all openings through which reactive gases may contact, is coated with a silicon or silica-containing layer to a coating thickness of about 1200 to 4800Å.

Associated with the reaction chamber **20** and adjacent to the quartz sleeve **22**, and preferably adjacent to the nitrogen curtain flange **24**, is a process gas exhaust flange **7**, shown in Figures 1 and 4. The exhaust flange **7** selectively exhausts reactive gases that come from the gas inlet flange **18** and through the reaction chamber quartz sleeve **22**. The exhaust flange **7** defines

an inner cavity **23** that communicates with the interior of the quartz sleeve **22** envelope. The inner cavity **23** communicates with an outlet **45** for the exhaust. The exhaust flange **7** preferably also serves as a means for conducting oxygen sampling for the gaseous contents held within the chamber **20**. The exhaust flange **7** is formed from stainless steel and is coated with a silicon or silica-containing layer to a coating thickness of about 1200 to 4800Å.

The rear flange **6** defines a central cavity **40** and an outlet **38** for leaking nitrogen. During thermal processing, leaking nitrogen preferably is exhausted from the central cavity **40** outside the O-rings (not shown) in flange **6**. The rear flange **6** is formed of stainless steel. The central cavity **40** and all passageways through which gases may flow in the nitrogen curtain flange **6** are coated with a silicon or silica-containing layer to a uniform thickness of about 1200 to 4800Å.

Preferably, any stainless steel tubing assemblies through which reactive gases may pass are also coated with a silicon or silica-containing layer. For example, the stainless steel tubing **50** that connects the gas supply (steam generator **10** in the preferred embodiment) to the gas inlet flange **18** is also coated with silicon at a coating thickness of about 1200 to 4800Å. Similarly, the stainless steel tubing **48** that connects the nitrogen supply **12** to the nitrogen curtain flange **24** and the stainless steel tubing **52** used for exhaust are coated with a protective silicon or silica-containing layer.

Preferably, the silicon or silica-containing layer is applied to the stainless steel using a chemical vapor deposition (CVD) process, in which the stainless steel parts are placed in a closed chamber. A vacuum is drawn in this chamber, and silica is deposited on the metal surfaces at a temperature in the range of 300°C to 400°C. The silica-containing coating is applied to a thickness of from 1200Å to 4800Å. Such silica-containing coated stainless steel is stable to temperatures over 600°C. Thicker coatings may be more apt to shed particles, and thinner coatings may not sufficiently protect the steel surface from corrosion or particle emission.

Restek Corporation of Bellefonte, Pennsylvania USA uses such a CVD process to apply inert silica coatings to stainless steel, which Restek calls the SILICOSTEEL® process. With the SILICOSTEEL process, a layer of inert silica is permanently bonded to the base metal to improve corrosion resistance by shielding the base metal from mineral acids and alcohols. When stainless steel flanges and tubing coated with silicon/silica using the SILICOSTEEL process were incorporated into a RTP thermal processing apparatus of the preferred embodiment, the semiconductor substrates processed in the RTP apparatus had lower iron contamination than those processed in an apparatus without silicon coated parts.

In the embodiment of the invention in which the process chamber or parts associated therewith are formed from aluminum or an aluminum alloy, the silicon or silica-containing layer preferably is applied using a CVD process conducted at temperatures in the range of about 200°C to 600°C. The silica-containing coating is applied to the aluminum to a thickness of at least about 1000Å (100nm). The corrosion resistivity to steam or thermal process gases may be improved by more than a factor of 10 when an SiO_2-coating is applied.

Tests were conducted to investigate whether and to what extent a silicon or silica-containing coating on stainless steel would reduce corrosion etching weight loss, and thus the likely contamination of semiconductor substrates. Stainless steel coupons of various grades, 316L, 317LM and 316L-SCQ, were prepared. Table I shows the typical compositions for these grades of stainless steel.

Table II shows the results of experiments to study the corrosion rate as a function of the substrate material, silicon coating thickness, treatments and steel surface finish. Several samples of 316L stainless steel were electropolished. Two of these samples were also passivated for expected increased corrosion resistance. All of the stainless steel samples were immersed in an 18% hydrochloric acid solution for 24 hours to determine the corrosion rates with and without a silica-containing coating applied. The coated samples were then immersed in the hydrochloric acid solution for 24 hours to determine the corrosion rates. Additional details and the results of the tests are set forth in Table II below.

As can be seen from Table II, silica-coated 316L stainless steel samples exhibit improved corrosion resistance by a factor of 5 to 6 over uncoated steel of equivalent grade, whether electropolished only or also passivated. The corrosion rate, expressed in 100 times grams per hour per square centimeter of sample surface area, was assessed by measuring weight loss after the sample was immersed 24 hours in the 18% hydrochloric acid solution.

Table I: Percent (%) composition of typical austenitic stainless steels (the balance is Fe)

Type	C	Mn	P	S	Si	Cr	Ni	Mo
316L	‹0.003	‹2.0	‹0.045	‹0.03	‹1.0	16.0-18.0	10.0-14.0	2.0-3.0
316L-SCQ	‹0.003	‹2.0	‹0.045	0.005-0.015	‹1.0	16.0-18.0	10.0-14.0	2.0-3.0
317LM	‹0.003	‹2.0	‹0.045	‹0.03	‹1.0	18.0-20.0	12.0-16.0	4.0-4.5

Table II: Comparing Corrosion Rate as a Function of Substrate, Silicon Coating Thickness, Treatments and Surface Finish

	Electropolished	Electropolished	Electropolished	Not Electropolished	Not Electropolished	Not Electropolished	Not Electropolished
	Passivated C#2	Passivated N#5	Not Passivated	Not Passivated	Not Passivated	Not Passivated	Not Passivated
Base Metal	316L	316L	316L	316L-SCQ	317LM	316L	316L	316L
Surface Finish in micro-inch	16μ"	16μ"	16μ"	16μ	16μ"	16μ"	63μ"	16μ"
Corrosion Rate A w/o silicon coating	0.2136	0.2056	0.2106	0.2222	0.0061	0.2252	0.1149	0.2252
Silicon coating thickness	2400Å	2400Å	2400Å	2400Å	2400Å	2400Å	2400Å	4800Å
Corrosion Rate B (Coating applied at 400°C)	0.0837	0.1708	NA	0.0006	0.0021	0.1745	0.1921	0.1553
Corrosion Rate C (Coating applied at 345°C)	0.0402	0.0401	0.0353	0.0004	0.0011	NA	0.1149	NA
Improvement Rate (A/C)	5.3	5.1	6.0	517	5.6	–	1.0	–
Improvement C/C-316L-SCQ	93	93	82	1	2.5	–	2.7	–

From Table II, it is seen that in these corrosion tests the improvement between the coated and uncoated stainless steel samples is significant, and that corrosion resistance can be improved by more than a factor of 100. The results also show that the surface finish significantly influences the corrosion resistance. For RTP applications, the surface finish before coating should be better than about 60 micro-inch, preferably better than 25 micro-inch, and most preferably in the range between 1 and 20 micro-inch. Taking into account the costs for preparing a high quality surface finish, sufficiently good results are achieved with 16 micro-inch. However, if the requirements of Fe or FeO contamination levels become more exacting in the future, a higher surface finish quality may become necessary.

Further, if the reactive gas for processing the semiconductor substrate comprises chlorine, then the test results show that preferably steel with a higher Mo concentration, like 317LM, may be selected for forming the metal elements to be coated. A non-coated 317LM stainless steel had the best corrosion resistivity of all non-coated steels, with the non-coated 316L-SCQ stainless steel having a rate similar to that of ordinary 316L stainless steel. However, because the 316L-SCQ surface has lower surface contaminants, after coating, it had a higher corrosion resistivity against corrosion by HCl than the other samples. The silicon or silica-containing coating is influenced by surface impurities such as Na and K, which are lower for the 316L-SCQ due to its VIM-VAR processing. Special steel with a higher Mo concentration (such as above 3% like 317LM), may also undergo the VIM-VAR processing, and this may additionally increase the corrosion resistivity against HCl.

In addition, it was demonstrated that a 2400Å coating offers as good or better corrosion resistance as does a 4800Å coating, and applying the coating at 345AC shows some improvement over 400AC, although both coating thicknesses and both application temperatures have successfully reduced corrosion.

An additional experiment was conducted to compare the corrosion-resistant effectiveness of the stainless steel surface with and without a silicon or silica-containing coating layer (at 400°C). Stainless steel test coupons were submerged in hot (95°C) deionized (DI) water and

held in the water for from 450 to 500 hours. Then, the amount of iron leached into the water was measured using a microsample x-ray analysis (MXA). The measured parts per billion of iron (Fe) in the water were:

316L without treatment:	5.1 PPB
316L with silica-coating	4.0 PPB
316L-SCQ with silica-coating	0.9 PPB

Thus, the coated samples resisted emitting Fe particles and demonstrated greater corrosion resistance than the uncoated samples.

While the invention has been described by way of examples and in terms of several preferred embodiments, the invention should not be limited to the disclosed embodiments. On the contrary, applicants intend to cover various modifications and similar arrangements, including modifications resulting from combinations of the features described above, all within the spirit and scope of their invention as claimed in the following claims.

WE CLAIM:

1. An apparatus for thermal processing a semiconductor substrate, comprising:

a reaction chamber for processing the substrate with a reactive gas when the substrate is held within the chamber, with at least one element constructed of a metal forming at least a part of or associated with said chamber and adapted for contacting the reactive gas introduced into the chamber, wherein at least a portion of said element that is adapted for contacting the reactive gas is coated with a silicon or silica-containing layer.

2. The apparatus of claim 1, wherein the at least one element constructed of metal is constructed of stainless steel, aluminum or aluminum alloy.

3. The apparatus of claim 1, wherein the reaction chamber has an inlet adapted for introducing reactive gas into the chamber, and wherein the at least one element is a flange that is attached to said chamber at said inlet, and said flange is constructed of a metal, and at least the portion of said flange adapted for contacting the reactive gas is coated with the silicon or silica-containing layer.

4. The apparatus of claim 1, wherein the reaction chamber has an outlet adapted for exhausting reactive gas from the chamber, and wherein the at least one element is a flange that is attached to said chamber at said outlet, and said flange is constructed of a metal, and at least the portion of said flange adapted for contacting the reactive gas is coated with the silicon or silica-containing layer.

5. The apparatus of claim 1, wherein the reaction chamber has an inlet adapted for introducing reactive gas into the chamber and an outlet adapted for exhausting reactive gas from the chamber, and wherein the at least one element is a nitrogen curtain flange that is attached to said chamber at said inlet or said outlet, and said nitrogen curtain flange is constructed of a metal, and at least the portion of said flange adapted for contacting the reactive gas is coated with the silicon or silica-containing layer.

6. The apparatus of claim 1, wherein the reaction chamber has an inlet adapted for introducing reactive gas into the chamber and an outlet adapted for exhausting reactive gas from

the chamber, and wherein one or more tubes are associated with the inlet, and wherein said tubes are constructed of a metal, and at least the portion of said tubes adapted for contacting the reactive gases is coated with the silicon or silica-containing layer.

7. The apparatus of claim 3 wherein the flange is constructed of stainless steel.

8. The apparatus of claim 4, wherein the flange is constructed of stainless steel.

9. The apparatus of claim 5, wherein the nitrogen curtain flange is constructed of stainless steel.

10. The apparatus of claim 6, wherein the one or more tubes are constructed of stainless steel.

11. The apparatus of claim 2, wherein the silicon or silica-containing layer is applied to the stainless steel to a coating thickness in the range of about 1200 Å to about 4800 Å.

12. The apparatus of claim 11, wherein the silicon or silica-containing layer is applied to the stainless steel with a chemical vapor deposition (CVD) process at a temperature in the range of 300°C to 400°C.

13. The apparatus of claim 2, wherein the silicon or silica-containing layer is applied to the aluminum with a chemical vapor deposition (CVD) process at a temperature in the range of 200□C to 600□C.

14. The apparatus of claim 1, wherein the reactive gas comprises a single gas or a mixture of gases selected from the group consisting of oxygen, hydrogen, nitrogen, NH_3, N_2O, NO, argon, chlorine containing gases, oxygen containing gases, nitrogen containing gases, hydrocarbon compounds, metal-organic compounds, radicals, water vapor and steam.

15. The apparatus of claim 1, wherein the at least one element constructed of a metal forming a part of or associated with said chamber has surfaces adapted for contacting the reactive gas introduced into the chamber, and all of said surfaces are coated with a silicon or silica-containing layer

16. A method for reducing metal contamination on surfaces of a semiconductor substrate when said substrates are thermal processed, comprising the steps of:

providing a reaction chamber with at least one element constructed of a metal forming at least a part of or associated with said chamber and adapted for contacting a reactive gas introduced into the chamber, wherein at least a portion of said element that is adapted for contacting the reactive gas is coated with a silicon or silica-containing layer;

inserting the semiconductor substrate into the chamber;

introducing reactive gases into the chamber; and

heating the semiconductor substrate as it is held within the chamber.

17. The method of claim 16, wherein the at least one element constructed of metal is constructed of stainless steel, aluminum or an aluminum alloy.

18. The method of claim 16, wherein the reaction chamber has an inlet adapted for introducing reactive gas into the chamber, and wherein the at least one element is a flange that is attached to said chamber at said inlet, and said flange is constructed of a metal, and at least the portion of said flange adapted for contacting the reactive gas is coated with the silicon or silica-containing layer.

19. The method of claim 16, wherein the reaction chamber has an outlet adapted for exhausting reactive gas from the chamber, and wherein the at least one element is a flange that is attached to said chamber at said outlet, and said flange is constructed of a metal, and at least the portion of said flange adapted for contacting the reactive gas is coated with the silicon or silica-containing layer.

20. The method of claim 16, wherein the reaction chamber has an inlet adapted for introducing reactive gas into the chamber and an outlet adapted for exhausting reactive gas from the chamber, and wherein the at least one element is a nitrogen curtain flange that is attached to said chamber at said inlet or said outlet, and said nitrogen curtain flange is constructed of a metal, and at least the portion of said flange adapted for contacting the reactive gas is coated with the silicon or silica-containing layer.

21. The method of claim 16, wherein the reaction chamber has an inlet adapted for introducing reactive gas into the chamber and an outlet adapted for exhausting reactive gas from

the chamber, and wherein one or more tubes are associated with the inlet, and wherein said tubes are constructed of a metal, and at least the portion of said tubes adapted for contacting the reactive gases is coated with the silicon or silica-containing layer.

22. The method of claim 18 wherein the flange is constructed of stainless steel.

23. The method of claim 19, wherein the flange is constructed of stainless steel.

24. The method of claim 20, wherein the nitrogen curtain flange is constructed of stainless steel.

25. The method of claim 21, wherein the one or more tubes are constructed of stainless steel.

26. The method of claim 17, wherein the silicon or silica-containing layer is applied to the stainless steel to a coating thickness in the range of about 1200 Å to about 4800 Å.

27. The method of claim 17, wherein the silicon or silica-containing layer is applied to the stainless steel with a chemical vapor deposition (CVD) process at a temperature in the range of 300°C to 400°C.

28. The method of claim 17, wherein the silicon or silica-containing layer is applied to the aluminum with a chemical vapor deposition (CVD) process at a temperature in the range of 200°C to 600°C.

29. The method of claim 16, wherein the reactive gas comprises a single gas or a mixture of gases selected from the group consisting of oxygen, hydrogen, nitrogen, NH_3, N_2O, NO, chlorine containing gases, oxygen containing gases, nitrogen containing gases, hydrocarbon compounds, metal-organic compounds, radicals, water vapor and steam.

30. The method of claim 16, wherein the at least one element constructed of a metal forming a part of or associated with said chamber has surfaces that are adapted for contacting the reactive gas, and all of said surfaces are coated with a silicon or silica-containing layer