GAS DISTRIBUTION SYSTEM HAVING FAST GAS SWITCHING CAPABILITIES

BACKGROUND

Semiconductor structures are processed in plasma processing apparatuses including a plasma processing chamber, a gas source that supplies process gas into the chamber, and an energy source that produces plasma from the process gas. Semiconductor structures are processed in such apparatuses by techniques including dry etching processes, deposition processes, such as chemical vapor deposition (CVD), physical vapor deposition, or plasma-enhanced chemical vapor deposition (PECVD) of metal, dielectric and semiconductor materials and resist stripping processes. Different process gases are used for these processing techniques, as well as processing different materials of semiconductor structures.

SUMMARY

A gas distribution system which is operable to supply selected gases to a vacuum chamber, such as a plasma processing chamber, is provided. The gases can be etching gas compositions and/or deposition gas compositions. Preferred embodiments of the gas distribution system can provide fast gas switching capabilities, which allow the system to change over between different gases supplied to the vacuum chamber within a short period of time, preferably without the occurrence of undesirable pressure surges or flow instabilities of either gas. Some preferred embodiments of the gas distribution system can provide selected gas flows, including different gas chemistries and/or flow rates, to different zones of the interior of the vacuum chamber.

A preferred embodiment of a gas distribution system comprises a first gas passage and a second gas passage adapted to be in fluid communication with a first gas line, and a third gas passage and a fourth gas passage adapted to be in fluid communication with a second gas line. The first and third gas passages are adapted to supply gas to an interior of a vacuum chamber, and the second and fourth gas passages are adapted to supply gas to a by-pass line. First, second, third and fourth fast switching valves are arranged along the respective first, second, third and fourth gas passages. The first and fourth fast switching valves are adapted to receive

signals to open while the second and third fast switching valves are closed to supply the first gas to the vacuum chamber via the first gas line and the first and third gas passages while the second gas is supplied to the by-pass line via the second gas line and the second and fourth gas passages. The second and third fast switching valves are adapted to receive signals to open while the first and fourth fast switching valves are closed to supply the second gas to the vacuum chamber via the second gas line and the third gas passage while the first gas is supplied to the by-pass line via the first gas line and the second gas passage.

Another preferred embodiment of a gas distribution system for supplying gas to a plasma processing chamber including a gas distribution member having inner and outer zones which are flow insulated from each other is provided, which comprises a first gas passage adapted to be in fluid communication with a first process gas source, the inner zone and a by-pass line; a second gas passage adapted to be in fluid communication with the first process gas source, the outer zone and the by-pass line; a third gas passage adapted to be in fluid communication with a second process gas source, the inner zone and the by-pass line; and a fourth gas passage adapted to be in fluid communication with a second process gas source, the outer zone and the by-pass line. The gas distribution system comprises fast switching valves which are adapted to receive signals to open and close so as to (i) supply the first process gas to the inner and outer zones via the first and second gas passages, while the second process gas is supplied to the by-pass line via the third and fourth gas passages, and (ii) to change the flows of the first and second process gases to supply the second process gas to the inner and outer zones via the third and fourth gas passages, while the first process gas is supplied to the by-pass line via the first and second gas passage.

A further preferred embodiment of a gas distribution system for supplying gas to a plasma processing chamber including a gas distribution member having inner and outer zones which are flow insulated from each other is provided, which comprises a gas switching section including a plurality of first gas passages, each of which is adapted to be (i) in fluid communication with at least one first gas passage and/or at least one second gas passage, and (ii) in fluid communication with at least one of the inner zone of the gas distribution member, the outer zone of the gas

distribution member, and a by-pass line. The gas switching section also comprises a fast switching valve arrangement adapted to receive signals to (iii) open a first group of fast switching valves and close a second group of fast switching valves to supply a first process gas to the inner and outer zones while a second process gas is diverted to the bypass line via a first group of the first gas passages, and (iv) to close the first group of fast switching valves and open the second group of fast switching valves to switch the first and second process gas flows to supply the second process gas to the inner and outer zones while the first process gas is diverted to the bypass line via a second group of the first gas passages.

A preferred embodiment of a method of processing a semiconductor structure in a plasma processing chamber is provided, which comprises a) supplying a first process gas into the plasma processing chamber while diverting a second process gas to a bypass-line, the plasma processing chamber containing a semiconductor substrate including at least one layer and a patterned resist mask overlying the layer; b) energizing the first process gas to produce a first plasma and (i) etching at least one feature in the layer or (ii) forming a polymer deposit on the mask; c) switching the flows of the first and second process gases so that the second process gas is supplied into the plasma processing chamber while diverting the first process gas to the by-pass line, the first process gas being substantially replaced in a plasma confinement zone of the plasma processing chamber by the second process gas within a period of less than about 1 s, or less than about 200 ms; d) energizing the second process gas to produce a second plasma and (iii) etching the at least one feature in the layer or (iv) forming a deposit on the layer and the mask; e) switching the flows of the first and second process gases so that the first process gas is supplied into the plasma processing chamber while diverting the second process gas to the by-pass line, the second process gas being substantially replaced in the plasma confinement zone of the plasma processing chamber by the first process gas within a period of less than about 1 s, or less than about 200 ms; and f) repeating a)-e) a plurality of times with the substrate.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

FIG. 1 is a sectional view of an exemplary embodiment of a plasma processing apparatus that preferred embodiments of the gas distribution system can be used with.

FIG. 2 illustrates a preferred embodiment of the gas distribution system.

FIG. 3 depicts a preferred embodiment of a gas supply section of the gas distribution system.

FIG. 4 depicts a preferred embodiment of a flow control section of the gas distribution system.

FIG. 5 depicts a first preferred embodiment of a gas switching section of the gas distribution system.

FIG. 6 depicts a second preferred embodiment of the gas switching section of the gas distribution system.

FIG. 7 depicts a third preferred embodiment of the gas switching section of the gas distribution system.

DETAILED DESCRIPTION

Plasma processing apparatuses for processing semiconductor materials, such as semiconductor devices formed on semiconductor substrates, e.g., silicon wafers, include a plasma processing chamber and a gas distribution system that supplies process gas into the plasma processing chamber. The gas distribution system can distribute gas to a single zone or multiple zones across the surface of a substrate during plasma processing. The gas distribution system can include flow controllers to control the flow ratio of the same or different process gas, or gas mixture, to the zones, thereby allowing in-process adjustment of across-substrate uniformity of gas flow and gas composition.

Although multiple-zone gas distribution systems can provide improved flow control as compared to a single-zone system, it may be desirable to provide such systems with an arrangement that allows substrate processing operations in which the gas composition and/or the gas flow can be changed within a short period of time.

A gas distribution system is provided for supplying different gas compositions and/or flow ratios to a chamber. In a preferred embodiment, the gas distribution system is adapted to be in fluid communication with an interior of a vacuum chamber, such as a plasma processing chamber of a plasma processing apparatus, and provide the capability of supplying different gas chemistries and/or gas flow rates to the vacuum chamber during processing operations. The plasma processing apparatus can be a low-density, medium-density or high-density plasma reactor including an energy source that uses RF energy, microwave energy, magnetic fields, or the like to produce plasma. For example, the high-density plasma can be produced in a transformer coupled plasma (TCP™) reactor, also known as an inductively coupled plasma reactor, an electron-cyclotron resonance (ECR) plasma reactor, a capacitive-type discharge, or the like. Exemplary plasma reactors that preferred embodiments of the gas distribution system can be used with include Exelan™ plasma reactors, such as the 2300 Excelan™ plasma reactor, available from Lam Research Corporation, located in Fremont, California. During plasma etching processes, multiple frequencies can be applied to a substrate support incorporating an electrode and an electrostatic chuck. Alternatively, in dual-frequency plasma reactors, different frequencies can be applied to the substrate support and an electrode, such as a showerhead electrode, spaced from the substrate.

A preferred embodiment of the gas distribution system can supply a first gas into the interior of a vacuum chamber, such as a plasma processing chamber, via a single zone or multiple zones, preferably at least an inner zone and an outer zone of a gas distribution member adjacent to an exposed surface of a substrate to be processed. The inner and outer zones are radially spaced, and preferably flow insulated, from each other in the plasma processing chamber. The gas distribution system can simultaneously divert a second gas that is different from the first gas to a vacuum chamber by-pass line. The by-pass line can be in fluid communication with a vacuum pump, or the like. In a preferred embodiment, the first gas is a first process gas and the second gas is a different process gas. For example, the first gas can be a first etch gas chemistry or deposition gas chemistry, and the second gas can be a different etch gas chemistry or deposition gas chemistry. The gas distribution system can simultaneously provide different controlled flow rates of the first gas to

the inner zone and the outer zone, respectively, while the second gas is diverted to the by-pass line, and vice versa. By diverting one of the gases to the by-pass line, change over of the gas supplied to the vacuum chamber can be achieved within a short period of time.

The gas distribution system includes switching devices that allow gas switching, or gas change over, in a short period of time between first and second gases supplied to an interior of a vacuum chamber that includes a single zone or includes multiple zones. For multiple-zone systems, the gas distribution system can supply the first gas to the inner zone and outer zone while the second gas is diverted to the by-pass line, and then switch the gas distributions within a short period of time so that the second gas is supplied to the inner zone and outer zone while the first gas is diverted to the by-pass line. The gas distribution system can alternately supply the first and second gases into the interior of the vacuum chamber, each for a desired period of time to allow quick change over between different processing operations that use different gas chemistries, e.g., alternating steps of a method of processing a semiconductor device. In a preferred embodiment, the method steps can be different etch steps, e.g., a faster etch step, such as a main etch, and a relatively slower etch step, such as an over etch step; an etch step and a material deposition step; or different material deposition steps that deposit different materials onto a substrate.

In a preferred embodiment of the gas distribution system, a volume of a gas composition in a confined region within a vacuum chamber, preferably a plasma confinement zone, can be replaced (i.e., flushed out) by another gas composition introduced into the vacuum chamber within a short period of time. Such gas replacement preferably can be achieved in less than about 1 s, more preferably within less than about 200 ms, by providing valves having a fast switching capability in the gas distribution system. The plasma confinement zone can have a gas volume of about ½ liter to about 4 liters for a plasma processing chamber for processing 200 mm or 300 mm wafers. The plasma confinement zone can be defined by a stack of confinement rings, such as disclosed in commonly-owned U.S. Patent No. 5,534,751, which is hereby incorporated by reference in its entirety.

FIG. 1 depicts an exemplary semiconductor material plasma processing apparatus 10 that embodiments of the gas distribution system 100 can be used with. The apparatus 10 comprises a vacuum chamber or plasma processing chamber 12 having an interior containing a substrate support 14 on which a substrate 16 is supported during plasma processing. The substrate support 14 includes a clamping device, preferably an electrostatic chuck 18, which is operable to clamp the substrate 16 on the substrate support 14 during processing. The substrate can be surrounded by focus rings and/or edge rings, ground extensions or other parts, such as parts disclosed in commonly-owned U.S. Patent Application Publication No. US 2003/0029567, which is incorporated herein by reference in its entirety.

In a preferred embodiment, the plasma processing chamber 12 includes a plasma confinement zone having a volume of about ½ liter to about 4 liters, preferably about 1 liter to about 3 liters. For example, the plasma processing chamber 12 can include a confinement ring arrangement, such as disclosed in commonly-owned U.S. Patent No. 5,534,751, which is incorporated herein by reference in its entirety, to define the plasma confinement zone. The gas distribution system can replace such a volume of gas in the plasma confinement zone with another gas within a period of less than about 1 s, preferably in less than about 200 ms, without substantial back diffusion. The confinement mechanism can limit the fluid communication from the plasma volume to portions of the interior of the plasma processing chamber 12 that are outside of the plasma volume.

The substrate 16 may include a base material, such as a silicon wafer; an intermediate layer of a material that is to be processed, e.g., etched, over the base material; and a masking layer over the intermediate layer. The intermediate layer may be of a conductive, dielectric or semiconductive material. The masking layer can be patterned photoresist material having an opening pattern for etching desired features, e.g., holes, vias and/or trenches, in the intermediate layer and/or one or more other layers. The substrate can include additional layers of conductive, dielectric or semiconductive materials between the base layer and the masking layer, depending on the type of semiconductor device formed on the base material.

Exemplary dielectric materials that can be processed are, for example, doped silicon oxide, such as fluorinated silicon oxide; un-doped silicon oxide, such as

silicon dioxide; spin-on glass; silicate glasses; doped or un-doped thermal silicon oxide; and doped or un-doped TEOS deposited silicon oxide. Such dielectric materials can overlie a conductive or semiconductive layer, such as polycrystalline silicon; metals, such as aluminum, copper, titanium, tungsten, molybdenum and their alloys; nitrides, such as titanium nitride; and metal silicides, such as titanium silicide, tungsten silicide and molybdenum silicide.

The exemplary plasma processing apparatus 10 shown in FIG. 1 includes a showerhead electrode assembly having a support plate 20 forming a wall of the plasma chamber, and a showerhead 22 attached to the support plate. A baffle assembly is located between the showerhead 22 and the support plate 20 to uniformly distribute process gas to a backside 28 of the showerhead. The baffle assembly can include one or more baffle plates. In the embodiment, the baffle assembly includes baffle plates 30A, 30B and 30C. Open plenums 48A, 48B and 48C are defined between the baffle plates 30A, 30B and 30C; and between the baffle plate 30C and showerhead 22. The baffle plates 30A, 30B and 30C and showerhead 22 include through passages for flowing process gas into the interior of plasma processing chamber 12.

In the embodiment, the plenum between the plate 20 and the baffle plate 30A and the plenums 48A, 48B and 48C between the baffle plates 30A, 30B and 30C are divided into an inner zone 42 and an outer zone 46 by seals 38a, 38b, 38c and 38d, such as O-rings. The inner zone 42 and outer zone 46 can be supplied process gas having different respective gas chemistries and/or flow rates by the gas distribution system 100, preferably under control of a controller 500. Gas is supplied from an inner zone gas supply 40 into the inner zone 42, and gas is supplied from an outer zone gas supply 44 into an annular channel 44a and then into the outer zone 46. The process gas flows through the passages in the baffle plates 30A, 30B and 30C and the showerhead 22 and into the interior of the plasma processing chamber 12. The process gas is energized into the plasma state in the plasma processing chamber 12 by a power source, such as an RF source driving electrode 22, or a power source driving an electrode in the substrate support 14. The RF power applied to the electrode 22 can be varied when different gas compositions are supplied into the

plasma processing chamber 12, preferably within a time period of less than about 1 s, more preferably less than about 200 ms.

In other preferred embodiments, the plasma processing apparatus 10 can include a gas injector system for injecting process gas into the plasma processing chamber. For example, the gas injector system can have a configuration as disclosed in commonly-owned U.S. Patent Application No. 09/788,365, U.S. Patent Application No. 10/024,208, U.S. Patent No. 6,013,155, or U.S. Patent No. 6,270,862, each of which is incorporated herein by reference in its entirety.

FIG. 2 shows a preferred embodiment in which the gas distribution system 100 includes a gas supply section 200, a flow control section 300, and a gas switching section 400 in fluid communication with each other. The gas distribution system 100 preferably also includes a controller 500 (FIG. 1), which is connected in control communication to control operation of the gas supply section 200, flow control section 300 and gas switching section 400.

In the gas distribution system 100, the gas supply section 200 can supply different gases, such as first and second process gases, to the flow control section 300 via respective first and second gas lines 235, 245. The first and second gases can have different compositions and/or gas flow rates from each other.

The flow control section 300 is operable to control the flow rate, and optionally also to adjust the composition, of different gases that can be supplied to the switching section 400. The flow control section 300 can provide different flow rates and/or chemistries of the first and second gases to the switching section 400 via gas passages 324, 326 and 364, 366, respectively. In addition, the flow rate and/or chemistry of the first gas and/or second gas that is supplied to the plasma processing chamber 12 (while the other gas is diverted to by-pass line 50, which can be in fluid communication with a vacuum pumping system, such as between a turbo pump and a roughing pump) can be different for the inner zone 42 and the outer zone 46. Accordingly, the flow control section 300 can provide desired gas flows and/or gas chemistries across the substrate 16, thereby enhancing substrate processing uniformity.

In the gas distribution system 100, the switching section 400 is operable to switch from the first gas to the second gas within a short period of time to allow the

first gas to be replaced by the second gas in a single zone or multiple zones, e.g., the inner zone 42 and the outer zone 46, while simultaneously diverting the first gas to the by-pass line, or vice versa. The gas switching section 400 preferably can switch between the first and second gases without the occurrence of undesirable pressure surges and flow instabilities in the flow of either gas. If desired, the gas distribution system 100 can maintain a substantially constant sequential volumetric flow rate of the first and second gases through the plasma processing chamber 12.

FIG. 3 shows a preferred embodiment of the gas supply section 200 of the gas distribution system 100. The gas supply section 200 is preferably connected to the controller 500 to control operation of flow control components, such as valves and flow controllers, to allow control of the composition of two or more gases that can be supplied by the gas supply section 200. In the embodiment, the gas supply section 200 includes multiple gas sources 202, 204, 206, 208, 210, 212, 214 and 216, each being in fluid communication with the first gas line 235 and the second gas line 245. As such, the gas supply section 200 can supply many different desired gas mixtures to the plasma processing chamber 12. The number of gas sources included in the gas distribution system 100 is not limited to any particular number of gas sources, but preferably includes at least two different gas sources. For example, the gas supply section 200 can include more than or less than the eight gas sources included in the embodiment shown in FIG. 3. For example, the gas supply section 200 can include two, three, four, five, ten, twelve, sixteen, or more gas sources. The different gases that can be provided by the respective gas sources include individual gases, such as O_2, Ar, H_2, Cl_2, N_2 and the like, as well as gaseous fluorocarbon and/or fluorohydrocarbon compounds, such as CF_4, CH_3F and the like. In one preferred embodiment, the plasma processing chamber is an etch chamber and the gas sources 202-216 can supply Ar, O_2, N_2, Cl_2, CH_3, CF_4, C_4F_8 and CH_3F or CHF_3 (in any suitable order thereof). The particular gases supplied by the respective gas sources 202-216 can be selected based on the desired process that is to be performed in the plasma processing chamber 12, e.g., particular dry etching and/or material deposition processes. The gas supply section 200 can provide broad versatility regarding the choice of gases that can be supplied for performing etching processes and/or material deposition processes.

The gas supply section 200 preferably also includes at least one tuning gas source to adjust the gas composition. The tuning gas can be, e.g., O_2, an inert gas, such as argon, or a reactive gas, such as a fluorocarbon or fluorohydrocarbon gas, e.g., C_4F_8. In the embodiment shown in FIG. 3, the gas supply section 200 includes a first tuning gas source 218 and a second tuning gas source 219. As described below, the first tuning gas source 218 and second tuning gas source 219 can supply tuning gas to adjust the composition of the first and/or second gas supplied to the gas switching section 400.

In the embodiment of the gas supply section 200 shown in FIG. 3, a flow control device 240 preferably is disposed in each of the gas passages 222, 224, 226, 228, 230, 232, 234 and 236 in fluid communication with the gas sources 202, 204, 206, 208, 210, 212, 214 and 216, respectively, and also in the gas passages 242, 244 in fluid communication with the first tuning gas source 218 and the second tuning gas source 219, respectively. The flow control devices 240 are operable to control the flow of the gas supplied by the associated gas sources 202-216 and 218, 219. The flow control devices 240 preferably are mass flow controllers (MFCs).

In the embodiment shown in FIG. 3, valves 250, 252 are located along the gas passages downstream of each of the gas sources 202-216. The valves 250, 252 can be selectively opened or closed, preferably under control of the controller 500, to allow different gas mixtures to be flowed to the first gas line 235 and/or the second gas line 245. For example, by opening the valves 252 associated with one or more of the gas sources 202-216 (while the remaining valves 252 associated with the other ones of the gas sources 202-216 are closed), a first gas mixture can be supplied to the first gas line 235. Likewise, by opening the valves 250 associated with one or more of the other gas sources 202-216 (while the remaining valves 250 associated with the other ones of the gas sources 202-216 are closed), a second gas mixture can be supplied to the second gas line 245. Accordingly, various mixtures and mass flow rates of the first and second gases can be provided to the first gas line 235 and the second gas line 245 by controlled operation of the gas supply section 200.

In a preferred embodiment, the gas supply section 200 is operable to provide a continuous flow of the first and second gases via the first gas line 235 and the second gas line 245, respectively. The first gas or the second gas is flowed to the

plasma processing chamber 12 while the other gas is diverted to the by-pass line. The by-pass line can be connected to a vacuum pump, or the like. By continuously flowing both of the first and second gases, the gas distribution system 100 can achieve rapid change over of the gas flow.

FIG. 4 shows a preferred embodiment of the flow control section 300 of the gas distribution system 100. The flow control section 300 includes a first flow control section 305 in fluid communication with the first gas line 235 from the gas supply section 200, and a second flow control section 315 in fluid communication with the second gas line 245 from the gas supply section 200. The flow control section 300 is operable to control the ratio of the first gas supplied to the inner zone 42 and outer zone 46, respectively, while the second gas is diverted to the by-pass line, and to control the ratio of the second gas supplied to the inner zone 42 and outer zone 46, respectively, while the first gas is diverted to the by-pass line. The first flow control section 305 divides the flow of the first gas introduced at the first gas line 235 into two separate outlet flows of the first gas, and the second flow control section 315 divides the flow of the second gas introduced at the second gas line 245 into two separate outlet flows of the second gas. The first flow control section 305 includes first and second gas passages 324, 326 in fluid communication with the inner zone 42 and outer zone 46, respectively, via the switching system 400, and the second flow control section 315 includes first and second gas passages 364, 366 in fluid communication with the inner zone 42 and outer zone 46, respectively, via the switching system 400.

In a preferred arrangement, the first flow control section 305 and the second flow control section 315 each include at least two flow restrictors. Each flow restrictor preferably has a fixed restriction size for gas flow through it. The flow restrictors are preferably orifices. The flow restrictors restrict gas flow and maintain an approximately constant gas pressure in a region of the gas passages upstream of and proximate the orifices. Each of the first flow control section 305 and the second flow control section 315 preferably includes a network of orifices, e.g., two, three, four, five or more orifices, each preferably having a different cross-sectional restriction size, e.g., a different diameter or a different cross-sectional area. The restriction sizes of the orifices are smaller than the cross-sectional areas of the other

portions of the gas flow path of the gas distribution system 100. The orifices are preferably sonic orifices. The gas flows are preferably operated at the critical flow regime in the flow control section 300 so that the flow conductance of a given orifice is determined solely by its restriction size and upstream pressure. As the flow conductance of an orifice increases, the pressure drop across the orifice to achieve a given flow rate through the orifice decreases.

In the embodiment shown in FIG. 4, the first and second flow control sections 305, 315 each include five orifices 330, 332, 334, 336 and 338. For example, the orifices 330, 332, 334, 336 and 338 can have relative restriction sizes, e.g., diameters, of one, two, four, eight and sixteen, respectively. Accordingly, when gas flow occurs through all five orifices 330-338, the four orifices 330-336 have approximately the same total conductance as that of the single orifice 338. Alternatively, up to three of the four orifices 330-336 can be opened to provide different ratios of the total conductance of the orifices 330-336 as compared to the conductance of the orifice 338, in order to supply different ratios of the first gas flow and the second gas flow to the inner zone 42 and the outer zone 46.

Another embodiment can include a different number of orifices, e.g., a total of two orifices; including the orifice 338 and a second orifice that replaces the multiple orifices 330-336. The second orifice preferably has the same restriction size as the orifice 338. In such embodiment, the flow ratio of the first gas and/or second gas supplied to the inner zone 42 and the outer zone 46 is approximately 1:1.

Valves 320 preferably are located upstream of each of the respective orifices 330-338 to control the flow of the first and second gases to the orifices. For example, in the first flow control section 305 and/or the second flow control section 315, one or more of the valves 320 can be opened to allow flow of the first gas and/or second gas to one or more of the associated orifice(s) 330-336, while the other valve 320 is opened to allow flow of the first gas and/or the second gas to the orifice(s) 338.

In the first flow control section 305, the orifices 330-336 are in fluid communication with the gas passage 322. The gas passage 322 is divided into the first and second gas passages 324, 326, which are in fluid communication with the gas switching section. A pair of valves 320 is located in the first and second gas

passages 324, 326 to control flow of the first gas flowed through one or more of the orifices 330-336 of the first flow control section 305 to the inner zone 42 and/or the outer zone 46. In an alternative embodiment, the pair of valves 320 located along the gas passages 324, 326 can be replaced by a single, four-way valve.

In the first flow control section 305, the orifice 338 is arranged along the gas passage 319. The gas passage 319 is divided into gas passages 331, 333, which are in fluid communication with the first and second gas passages 324, 326, respectively. A pair of valves 320 is located in the gas passages 331, 333 to control flow of the first gas flowed through the orifice 338 to the first and second gas passages 324, 326. In an alternative embodiment, the pair of valves 320 located along the gas passages 331, 333 can be replaced by a single, four-way valve.

In the second flow control section 315, a pair of valves 320 is located along the first and second gas passages 364, 366 to control flow of the second gas flowed through one or more of the orifices 330-336 to the inner zone 42 and the outer zone 46 of the plasma processing chamber. In an alternative embodiment, the pair of valves 320 located along the gas passages 364, 366 can be replaced by a single, four-way valve.

In the second flow control section 315, the orifice 338 is arranged along the gas passage 359. The gas passage 359 is divided into gas passages 372, 374, which are in fluid communication with the first and second gas passages 364, 366, respectively. A pair of valves 320 is located in the gas passages 372, 374 to control flow of the second gas flowed through the orifice 338 to the first and/or second gas passages 364, 366. In an alternative embodiment, the pair of valves 320 located along the gas passages 372, 374 can be replaced by a single four-way valve.

The orifices 330-338 are included in the flow control section 300 to prevent pressure surges and flow instabilities in the gas flow when the gas distribution system 100 changes the gas flowed into the plasma processing chamber 12 from the first gas to the second gas, and vice versa.

In the embodiment shown in FIG. 4, the gas passage 242 of the first tuning gas source 218 (FIG. 3) is arranged to supply the first tuning gas to the first gas passage 324 and/or second gas passage 326 of the first flow control section 305 to adjust the first gas composition. The gas passage 244 of the second tuning gas

source 219 (FIG. 3) is arranged to supply the second tuning gas to the first gas passage 364 and/or second gas passage 366 of the second flow control section 315 to adjust the second gas composition. The first and second tuning gases can be the same tuning gas or different tuning gases.

A flow control device 340, preferably an MFC, is arranged along the gas passage 242. Valves 320 are located along the gas passages 337, 339 to control flow of the first tuning gas into the gas passage 326, 324, respectively. In an alternative embodiment, the pair of valves 320 located along the gas passages 337, 339 can be replaced by a single, four-way valve.

A flow control device 340, preferably an MFC, is arranged along the gas passage 244. Valves 320 are located along the gas passages 376, 378 to control flow of the second tuning gas into the gas passages 366, 364, respectively. In an alternative embodiment, the pair of valves 320 located along the gas passages 376, 378 can be replaced by a single, four-way valve.

In the embodiment of the flow control section 300 shown in FIG. 4, the first flow control section 305 and the second flow control section 315 include the same components arranged in the same configuration. However, in other preferred embodiments of the gas distribution system 100, the first and second flow control sections 305, 315 can have different components and/or different configurations from each other. For example, the first and second flow control sections 305, 315 can include different numbers of orifices and/or orifices with different restriction sizes from each other.

In the gas distribution system 100, the gas switching system 400 is in fluid communication with the flow control section 300, and with the interior of the vacuum chamber and the by-pass line to which the first and second gases are flowed. A first preferred embodiment of the gas switching system 400 is depicted in FIG. 5. The gas switching system 400 can alternately supply first and second gases to both the inner zone 42 and the outer zone 46 of the plasma processing chamber 12. The gas switching system 400 is in fluid communication with the first gas passage 324 and the second gas passage 326 of the first flow control section 305, and with the first gas passage 364 and the second gas passage 366 of the second flow control section 315. An orifice 430 is arranged along each of the gas passages 324, 326, 364

and 366 to prevent undesirable pressure surges during change over of the first and second gases.

The first gas passage 324 of the first flow control section 305 is divided into gas passages 448, 450; the second gas passage 326 of the first flow control section 305 is divided into gas passages 442, 444; the first gas passage 364 of the second flow control section 315 is divided into gas passages 452, 454; and the second gas passage 366 of the second flow control section 315 is divided into gas passages 456, 458. In the embodiment, the gas passage 442 is in fluid communication with the outer zone 46 of the plasma chamber 12, the gas passage 448 is in fluid communication with the inner zone 42 of the plasma processing chamber 12, and the gas passage 444 provides a by-pass line. The gas passage 456 is in fluid communication with the gas passage 442 to the outer zone 46. The gas passage 452 is in fluid communication with the gas passage 448 to the inner zone 42. The gas passages 450, 454 and 458 are in fluid communication with the gas passage 444 to the by-pass line.

A valve 440 is arranged along each of the gas passages 442, 444, 448, 450, 452, 454, 456 and 458. In an alternative embodiment, each of the pairs of valves 440 located along the gas passages 442, 444; 448, 450; 452, 454; and 456, 458 can be replaced by a single, four-way valve. The valves 440 can be selectively opened and closed, preferably under control of the controller 500, to supply the first or second gas to the chamber, while simultaneously diverting the other gas to the by-pass line.

For example, to supply the first gas to the inner zone 42 and the outer zone 46 of the plasma processing chamber 12 and divert the second gas to the by-pass line, the valves 440 along the gas passages 442, 448 and 454, 458 are opened, while the valves 440 along the gas passages 444, 450 and 452, 456 are closed. To switch the gas flow so that the second gas is supplied to the inner zone 42 and the outer zone 46 of the plasma processing chamber 12, while the first gas is diverted to the by-pass line, the valves 440 along the gas passages 444, 450 and 452, 456 are opened, while the valves 440 along the gas passages 442, 448 and 454, 458 are closed. In other words, a first group of valves 440 is opened and a second group of valves 440 is closed to supply the first gas to the plasma processing chamber 12, and

then the same first group of valves is closed and the same second group of valves 440 is opened to change the gas flow to supply the second gas to the plasma processing chamber.

In the gas switching system 400, the valves 440 are fast-switching valves. As used herein, the term "fast-switching valve" means a valve that can be opened or closed within a short period of time, preferably less than about 100 ms, more preferably less than about 50 ms, after receiving a signal from the controller 500 to open or close. The valves 440 are preferably electronically controlled and actuated by receiving a signal from the controller 500 to open or close. A suitable "fast-switching valve" that can be used in the gas switching system 400 is valve model number FSR-SD-71-6.35, available from Fujikin of America, located in Santa Clara, California.

Accordingly, the gas switching system 400 can supply the first gas, e.g., to the interior of the vacuum chamber while diverting the second gas to the by-pass line, and then, preferably under control of the controller 500, quickly switch these gas flows and supply the second gas to the vacuum chamber while diverting the first gas to the by-pass line. The amount of time that the first gas or second gas is supplied to the vacuum chamber before the gases are switched can be controlled by the controller 500. The volume of the gas passages 324, 326, 364 and 366 between the associated orifices 430 and the valves 440 preferably is less than about 10 cm^3. As explained above, the gas distribution system can be used with a plasma processing chamber including a plasma confinement zone to replace a gas volume of about ½ liter to about 4 liters within a period of less than about 1 s, more preferably less than about 200 ms, to thereby stabilize the system.

A gas switching system 1400 according to a second preferred embodiment is depicted in FIG. 6. In the gas switching system 1400, a valve 440 and a orifice 430, which is located downstream of the valve 440 are arranged along each of the gas passages 442-458. Otherwise, the gas switching system 1400 can have the same configuration as the gas switching system 400. The orifices 430 prevent undesirable pressure surges during switching of gases. In an alternative embodiment, each of the pairs of valves 440 located along the gas passages 442, 444; 448, 450; 452, 454; and 456, 458 can be replaced by a single, four-way valve.

A gas switching system 2400 according to a third preferred embodiment is depicted in FIG. 7. In this embodiment, the gas switching system 2400 is in fluid communication with a first gas passage 405 and a second gas passage 415. The first and second gas passages 405, 415 can be, e.g., a first gas outlet and a second gas outlet, respectively, of a flow control section that, unlike the flow control section 300 shown in FIG. 4, does not include both inner and outer zone gas outlets. An orifice 430 is located along each of the first gas passage 405 and second gas passage 415. The first gas passage 405 is divided into gas passages 422, 424, and the second gas passage 445 is divided into gas passages 426, 428. The gas passages 422 and 426 are in fluid communication with an interior of a vacuum chamber, and the gas passages 424 and 428 are in fluid communication with a by-pass line. A valve 440 is located along each of the gas passages 422, 424 and 426, 428. In an alternative embodiment, each of the pairs of valves 440 located along the gas passages 422, 424; and 426, 428 can be replaced by a single, four-way valve.

For example, to supply the first gas to the vacuum chamber and simultaneously route the second gas to the by-pass line, the valves 440 along the fluid passages 422 and 428 are opened and the valves 440 along the gas passages 424 and 426 are closed. To switch the gas flows so that the second gas is supplied to the vacuum chamber and the first gas is diverted to the by-pass line, the valves 440 along the fluid passages 424 and 426 are opened and the valves 440 along the fluid passages 422 and 428 are closed.

In another preferred embodiment of the gas switching system, the embodiment shown in FIG. 7 can be modified by removing the orifices 430 arranged in the first gas passage 405 and second gas passage 415 upstream of the valves 440, and instead arranging a orifice in each of the gas passages 422, 424, 426 and 428 downstream of the associated valves 440.

Preferred embodiments of the gas distribution system 100 can be used to supply different gas chemistries and/or flow rates to the plasma processing chamber 12 to perform various etching and/or deposition processes. For example, the gas distribution system 100 can supply process gases to a plasma processing chamber to etch features in a silicon oxide, such as an SiO_2 layer protected by an overlying mask, such as a UV resist mask. The SiO_2 layer can be formed on a semiconductor

wafer, such as a silicon wafer, having a diameter of 200 mm or 300 mm. The features can be, e.g., vias and/or trenches. During such etching processes, it is desirable to deposit a polymer on portions of the mask to repair striations, e.g., cracks or fissures, in the mask (i.e., to fill the striations) so that features etched in the SiO_2 have their desired shape, e.g., vias have a round cross-section. If striations are not repaired, they can eventually reach the layer underlying the mask and in effect be transferred to that layer during etching. Also, a polymer can be deposited on the sidewalls of the features.

It has been determined, however, that the thickness of the polymer deposited on the sidewalls and the base of etched features affects the etch rate. In anisotropic etching processes, polymer deposited on the bottom of the feature is substantially removed during etching. However, if the polymer becomes too thick on the sidewalls and/or on the base, the etch rate of SiO_2 is decreased, and may be stopped completely. Polymer may also flake off of surfaces if it becomes too thick. Accordingly, the amount of time that the gas mixture for forming the polymer deposit on the mask and features is supplied into the plasma processing chamber is preferably controlled to thereby control the thickness of the polymer deposit formed on the SiO_2 layer, while also providing sufficient repair and protection of the mask. During etching of the SiO_2 layer, polymer is periodically removed from the mask. Accordingly, the polymer is preferably deposited on the mask between periods of etching of the SiO_2 layer to ensure that sufficient repair and protection of the mask is achieved.

The gas distribution system 100 can be used to supply process gas into a plasma processing chamber to etch SiO_2 protected by an overlying mask, e.g., a UV resist mask, with control of the thickness of polymer deposited on the features, and with repair and protection of the mask. The gas switching system of the gas distribution system 100 is operable to allow a first process gas used to etch the SiO_2 to be supplied into the plasma processing chamber for a first period of time while a second gas mixture used to form the polymer deposit is diverted to a bypass line, and then to quickly switch the gas flows so that the second gas mixture is supplied into the plasma processing chamber to form the polymer deposit while the first gas mixture is supplied to the by-pass line. Preferably, the first gas mixture supplied to

a plasma confinement zone of the plasma processing chamber is at least substantially replaced with the second gas mixture within a period of less than about 1 s, more preferably less than about 200 ms. The plasma confinement zone preferably has a volume of about ½ liter to about 4 liters.

The first gas mixture used to etch SiO_2 can contain, e.g., a fluorocarbon species, such as C_4F_8, O_2 and argon. The flow ratio of C_4F_8/O_2/argon can be, e.g., 20/10/500 sccm. The second gas mixture used to form a polymer deposit can contain, e.g., a fluorohydrocarbon species, such as CH_3F, and argon. The flow ratio of CH_3F/argon can be, e.g., 15/500 sccm. The second gas mixture can optionally also include O_2. For a capacitive-coupled plasma etch reactor for processing 200 mm or 300 mm wafers, the chamber pressure can be, e.g., 70-90 mTorr. The first gas mixture is preferably flowed into the plasma processing chamber for about 5 seconds to about 20 seconds each time it is introduced into the chamber (while the second gas is diverted to the by-pass line), and the second gas mixture is preferably flowed into the plasma processing chamber for about 1 second to about 3 seconds each time it is introduced into the chamber (while the first gas is diverted to the by-pass line). During etching of SiO_2 on a substrate, the length of the etching period and/or the polymer deposition period can be increased or decreased within the preferred time periods. The polymer deposit preferably reaches a maximum thickness of less than about 100 angstroms during the etching process, which typically lasts up to about 3 minutes. During etching, polymer can be deposited on the mask to repair striations and provide mask protection. Accordingly, the shape of the openings in the mask preferably can be maintained during the etching process.

The present invention has been described with reference to preferred embodiments. However, it will be readily apparent to those skilled in the art that it is possible to embody the invention in specific forms other than as described above without departing from the spirit of the invention. The preferred embodiments are illustrative and should not be considered restrictive in any way. The scope of the invention is given by the appended claims, rather than the preceding description, and all variations and equivalents which fall within the range of the claims are intended to be embraced therein.

WHAT IS CLAIMED IS:

1. A gas distribution system for supplying gas to a vacuum chamber, comprising:

a first gas passage and a second gas passage adapted to be in fluid communication with a first gas line;

a third gas passage and a fourth gas passage adapted to be in fluid communication with a second gas line, the first and third gas passages being adapted to supply gas to the vacuum chamber, and the second and fourth gas passages being adapted to supply gas to a by-pass line;

a first fast switching valve arranged along the first gas passage;

a second fast switching valve arranged along the second gas passage;

a third fast switching valve arranged along the third gas passage;

a fourth fast switching valve arranged along the fourth gas passage;

the first and fourth fast switching valves being adapted to receive signals to open while the second and third fast switching valves are closed so that the first gas is supplied to the vacuum chamber via the first gas line and the first and third gas passages while the second gas is supplied to the by-pass line via the second gas line and the second and fourth gas passages; and

the second and third fast switching valves being adapted to receive signals to open while the first and fourth fast switching valves are closed so that the second gas is supplied to the vacuum chamber via the second gas line and the third gas passage while the first gas is supplied to the by-pass line via the first gas line and the second gas passage.

2. The gas distribution system of Claim 1, further comprising:

a first flow restrictor adapted to be arranged along the first gas line upstream of the first and second fast switching valves; and

a second flow restrictor adapted to be arranged along the second gas line upstream of the third and fourth fast switching valves;

wherein the first and second flow restrictors are adapted to maintain an approximately constant gas pressure in a region of the first and second gas lines upstream of and proximate the first and second flow restrictors.

3. The gas distribution system of Claim 2, wherein the first gas line has a volume between the first flow restrictor and the first and second fast switching valves of less than about 10 cm^3, and the second gas line has a volume between the second flow restrictor and the third and fourth fast switching valves of less than about 10 cm^3.

4. The gas distribution system of Claim 1, further comprising:

a third flow restrictor adapted to be arranged along the first gas passage downstream of the first fast switching valve;

a fourth flow restrictor adapted to be arranged along the second gas passage downstream of the second fast switching valve;

a fifth flow restrictor adapted to be arranged along the third gas passage downstream of the third fast switching valve; and

a sixth flow restrictor adapted to be arranged along the fourth gas passage downstream of the fourth fast switching valve;

wherein the third, fourth, fifth and sixth flow restrictors are adapted to maintain an approximately constant gas pressure in a region of the first, second, third and fourth gas passages upstream of and proximate the respective first, second, third, fourth, fifth and sixth flow restrictors.

5. The gas distribution system of Claim 1, further comprising a controller which is operable to control the opening and closing of the first, second, third and fourth fast switching valves.

6. The gas distribution system of Claim 1, wherein the first, second, third and fourth fast switching valves can be opened and/or closed within a period of less than about 100 ms, or less than about 50 ms, after receiving a signal.

7. A plasma processing apparatus, comprising:

a plasma processing chamber including a showerhead electrode assembly and having a plasma confinement zone with a volume of about ½ liter to about 4 liters; and

the gas distribution system according to Claim 1 in fluid communication with the plasma processing chamber;

wherein the gas distribution system can substantially replace the first gas or the second gas in the plasma zone with the other of the first gas or the second gas within a period of less than about 1 s, or less than about 200 ms.

8. A gas distribution system for supplying gas to a plasma processing chamber including a gas distribution member having inner and outer zones which are flow insulated from each other, the gas distribution system comprising:

a first gas passage adapted to be in fluid communication with a first process gas source, the inner zone of the gas distribution member of the plasma processing chamber and a bypass line;

a second gas passage adapted to be in fluid communication with the first process gas process source, the outer zone of the gas distribution member of the plasma processing chamber and the bypass line;

a third gas passage adapted to be in fluid communication with a second process gas source, the inner zone and the by-pass line;

a fourth gas passage adapted to be in fluid communication with the second process gas source, the outer zone and the by-pass line; and

a plurality of fast switching valves adapted to receive signals to open or close so that (i) the first process gas is supplied to the inner and outer zones via the first and second gas passages, while the second process gas is supplied to the by-pass line via the third and fourth gas passages, and (ii) to change the flows of the first and second process gases so that the second process gas is supplied to the inner and outer zones via the third and fourth gas passages, while the first process gas is supplied to the by-pass line via the first and second gas passages.

9. The gas distribution system of Claim 8, further comprising at least one flow restrictor arranged along each of the first, second, third and fourth process gas passages, the flow restrictors being adapted to maintain an approximately constant gas pressure in a region of the first, second, third and fourth gas passages upstream of and proximate the flow restrictors.

10. The gas distribution system of Claim 8, wherein the fast switching valves can be opened and/or closed within a period of less than about 100 ms, or less than 50 ms, after receiving a signal.

11. A plasma processing apparatus, comprising:

a plasma processing chamber including a showerhead electrode assembly having the inner and outer zones and an interior volume of about ½ liter to 4 liters; and

the gas distribution system according to Claim 8 in fluid communication with the inner and outer zones of the showerhead electrode assembly;

wherein the gas distribution system being operable to substantially replace the first process gas or the second process gas in the plasma confinement zone with the other of the first process gas or the second process gas within a period of less than about 1 s, or less than about 200 ms.

12. A gas distribution system for supplying process gas to a plasma processing chamber including a gas distribution member having inner and outer zones which are flow insulated from each other, the gas distribution system comprising a gas switching section, including:

a plurality of first gas passages each (i) adapted to be in fluid communication with at least one first gas passage and/or at least one second gas passage, and (ii) adapted to be in fluid communication with at least one of the inner zone of the gas distribution member of the plasma processing chamber, the outer zone of the gas distribution member of the plasma processing chamber, and a by-pass line; and

a fast switching valve arrangement adapted to receive signals to (iii) open a first group of fast switching valves and close a second group of fast switching valves

to supply a first process gas to the inner and outer zones while a second process gas is diverted to the bypass line, via a first group of the first gas passages, and (iv) to close the first group of fast switching valves and open the second group of fast switching valves to change the first and second process gas flows so as to supply the second process gas to the inner and outer zones while the first process gas is diverted to the bypass line, via a second group of the first gas passages.

13. The gas distribution system of Claim 12, further comprising a controller operable to control the opening and closing of the first and second groups of fast switching valves.

14. The gas distribution system of Claim 12, further comprising a flow control section, comprising:

at least one second gas passage adapted to be fluid communication with a first gas line which is in fluid communication with at least one first process gas source;

at least one first valve operable to allow the first process gas to be supplied from the first gas line to at least one second gas passage;

at least one third gas passage adapted to be fluid communication with a second gas line which is in fluid communication with at least one second process gas source; and

at least one second valve operable to allow the second process gas to be supplied from the second gas line to at least one third gas passage.

15. The gas distribution system of Claim 14, further comprising a gas supply section including:

the first gas line adapted to be in fluid communication with a plurality of the first process gas sources;

the second gas line adapted to be in fluid communication with a plurality of the second process gas sources;

at least one third valve operable to allow supply of the first process gas to at least one of the first and second gas lines; and

at least one fourth valve operable to allow supply of the second process gas to at least one of the first and second gas lines.

16. The gas distribution system of Claim 14, wherein the flow control section includes at least one first flow restrictor and at least one second flow restrictor in fluid communication with the respective second and third gas passages, the first and second flow restrictors being adapted to maintain an approximately constant gas pressure in a region upstream and proximate of the first and second flow restrictors.

17. The gas distribution system of Claim 16, wherein the at least one first flow restrictor includes at least two first flow restrictors, the at least one second flow restrictor includes one second flow restrictor, and at least one first flow restrictor has a different flow conductance than the second flow restrictor.

18. The gas distribution system of Claim 17, wherein the first flow restrictors have a total flow conductance which is approximately equal to the flow conductance of the second flow restrictor.

19. The gas distribution system of Claim 14, wherein the second and third gas passages are adapted to be in fluid communication with at least one tuning gas source which is operable to supply a tuning gas to at least one of the second and third gas passages.

20. The gas distribution system of Claim 12, wherein the gas switching section comprises a flow restrictor arranged along each of the first gas passages upstream of a respective fast switching valve, the flow restrictors being adapted to maintain an approximately constant gas pressure in a region of an associated first gas passage upstream of and proximate the flow restrictor.

21. The gas distribution system of Claim 12, wherein the fast switching valves can be opened and/or closed within a period of less than about 100 ms, or less than about 50 ms, after receiving a signal.

22. A plasma processing apparatus, comprising:

a plasma processing chamber including a showerhead electrode assembly and having an interior volume of about ½ liter to about 4 liters; and

the gas distribution system according to Claim 12 in fluid communication with the plasma processing chamber;

wherein the gas distribution system is operable to substantially replace the first process gas or the second process gas in the plasma confinement zone with the other of the first process gas or second process gas within a period of less than about 1 s, or less than about 200 ms.

23. A method of processing a semiconductor structure in a plasma processing chamber, comprising:

a) supplying a first process gas into the plasma processing chamber while diverting a second process gas to a bypass-line, the plasma processing chamber containing a semiconductor substrate including at least one layer and a patterned resist mask overlying the layer;

b) energizing the first process gas to produce a first plasma and (i) etching at least one feature in the layer or (ii) forming a polymer deposit on the mask;

c) switching the flows of the first and second process gases so that the second process gas is supplied into the plasma processing chamber while diverting the first process gas to the by-pass line, the first process gas being substantially replaced in a plasma confinement zone of the plasma processing chamber by the second process gas within a period of less than about 1 s, or less than about 200 ms;

d) energizing the second process gas to produce a second plasma and (iii) etching the at least one feature in the layer or (iv) forming a polymer deposit on the layer and the mask;

e) switching the flows of the first and second process gases so that the first process gas is supplied into the plasma processing chamber while diverting the second process gas to the by-pass line, the second process gas being substantially replaced in the plasma confinement zone of the plasma processing chamber by the first process gas within a period of less than about 1 s, or less than about 200 ms; and

f) repeating a)-e) a plurality of times with the substrate.

24. The method of Claim 23, wherein the polymer deposit is formed to a maximum thickness of less than about 100 angstroms after repeating a)-e) a plurality of times with the substrate.

25. The method of Claim 23, wherein the first plasma etches the at least one feature in the layer, and the second plasma forms the deposit on the layer and the mask, the deposit repairing striations in the mask.

26. The method of Claim 23, wherein the plasma confinement zone has a volume of about ½ liter to about 4 liters.

27. The method of Claim 23, wherein:

the first layer is of SiO_2;

the mask is a UV-resist mask;

the first process gas comprises a mixture of C_4F_8, O_2 and argon and the first plasma etches the layer; and

the second process gas comprises a mixture of CH_3F, argon and optionally O_2 and the second plasma forms the polymer deposit on the feature and the mask.

28. The method of Claim 27, wherein the first process gas is supplied into the plasma processing chamber for a period of about 5 seconds to about 20 seconds, and the second process gas is supplied into the plasma processing chamber for a period of about 1 second to about 3 seconds, each time that the first and second process gases, respectively, are supplied into the plasma processing chamber.

29. The method of Claim 23, wherein the plasma processing chamber comprises a showerhead electrode assembly including an inner zone and an outer zone, the first process gas being supplied to the inner zone and the outer zone while the second process gas is diverted to the by-pass line, and the second process gas being supplied to the inner zone and the outer zone while the first process gas is diverted to the by-pass line.

30. The method of Claim 29, wherein the first process gas and/or the second process gas is/are supplied to the inner zone and the outer zone at different flow rates.