

DETAILED DESCRIPTION

[0009] In a NAND flash memory, for example, as described above, when a W film is etched back, an other film may be exposed at a portion where the W film is not embedded. Examples of the other film may include a silicon film (Si film), a silicon oxide film (SiO film), a silicon nitride film (SiN film), and an aluminum oxide film (AlO film). There are also portions, which are exposed from the beginning, such as the back surface of the substrate and the like. For example, in the case of a silicon (Si) substrate, Si is exposed at the back surface thereof. In the case of the Si substrate, silicon 601 corresponds to the Si substrate. For example, as shown in FIG. 1, an aluminum oxide film 603 and a titanium nitride film 602 may form on silicon 601, and tungsten 604 may be embedded therein.

[0010] For example, when Si is exposed, Si may be shaved off by reacting with an etching gas, or etched W may react with Si such that W penetrates into Si. For example, when AlO is exposed, it may react with an element contained in the etching gas to form a foreign substance, and the foreign substance may remain in AlO. When a halogen-based etching gas is used as the etching gas, the foreign substance mainly contains Al and a halogen element. For example, when a nitrogen trifluoride (NF₃) gas, which is a fluorine-containing gas, is used as the etching gas, Al and F react to form AlF. AlF has a low vapor pressure and may possibly remain in AlO as a solid.

[0011] Thus, the present inventors have conducted intensive research and have conceived to allow an oxygen-containing gas to flow together with an etching gas during etching-back. For example, by allowing an oxygen-containing gas to flow, Si and O react with each other to form SiO at a portion where Si is exposed. This makes it possible to suppress reaction of Si with the etching gas and to suppress shaving-off of Si. In addition, it is possible to suppress the reaction between etched W and Si and to suppress entry of W into Si. This is because Si reacts with W to form a tungsten silicon film (tungsten silicide or WSi), but SiO does not react with W. In addition, it is possible to suppress reaction of AlO with the etching gas and to suppress formation of a foreign substance due to the reaction of AlO with the element contained in the etching gas.

at which a first metal film (e.g., a TiN film) is formed at an opening part (hole) in which a second metal film (e.g., a W film) is embedded; and

a removal step of removing the O₂ gas and the NF₃ gas.

[0042] When the term "wafer" is used herein, it may refer to "a wafer itself" or "a laminated body (aggregation) of a wafer and a predetermined layer or film formed on the surface of the wafer" (i.e., a wafer including a predetermined layer or film formed on the surface thereof). In addition, when the term "wafer surface" is used herein, it may refer to "a surface (exposed surface) of a wafer itself" or "a surface of a predetermined layer or a film formed on a wafer, i.e., an outermost surface of a wafer as a laminated body." In addition, when the term "substrate" is used herein, it may be synonymous with the word "wafer."

(Wafer Loading)

[0043] When a plurality of wafers 200 having a surface with a pattern hole in which an AlO film and a titanium nitride film (TiN film) are sequentially formed is charged into a boat 217 (wafer charging), as shown in FIG. 1, the boat 217 supporting the plurality of wafers 200 is lifted by the boat elevator 115 and loaded into the process chamber 201 (boat loading). In this state, the seal cap 219 closes the lower end opening of the outer tube 203 via the O-ring 220.

(Pressure Regulation and Temperature Adjustment)

[0044] The inside of the process chamber 201 is evacuated by the vacuum pump 246 so as to have a desired pressure (degree of vacuum). At this time, the pressure in the process chamber 201 is measured by the pressure sensor 245, and the APC valve 243 is feedback-controlled based on the measured pressure information (pressure regulation). The vacuum pump 246 keeps operating at least until the processing to the wafers 200 is completed. Furthermore, the inside of the process chamber 201 is heated by the heater 207 so as to reach a desired temperature. At this time, the amount of supplying electric power to the heater 207 is feedback-controlled based on the temperature information detected by the temperature sensor 263 so that the inside of the process chamber 201 has a desired temperature distribution (temperature adjustment). The

heating of the inside of the process chamber 201 by the heater 207 is continuously performed at least until the processing to the wafers 200 is completed.

[W Film Formation Step (W Deposition)]

[0045] A step of forming a W film is performed.

(WF₆ Gas and H₂ Gas Supply)

[0046] The valves 314 and 324 are opened to allow a WF₆ gas and a H₂ gas to flow through the gas supply pipes 310 and 320, respectively. The flow rates of the WF₆ gas and the H₂ gas are adjusted by the MFCs 312 and 322, respectively. The WF₆ gas and the H₂ gas are supplied to the process chamber 201 from the gas supply holes 410a and 420a of the nozzles 410 and 420, respectively, and are exhausted from the exhaust pipe 231. At this time, the WF₆ gas and the H₂ gas are supplied to the wafers 200. At the same time, the valves 514 and 524 may be opened to allow an inert gas such as a N₂ gas or the like to flow through the gas supply pipes 510 and 520. The flow rates of the N₂ gas flowing through the gas supply pipes 510 and 520 are adjusted by the MFCs 512 and 522. The N₂ gas is supplied to the process chamber 201 together with the WF₆ gas and the H₂ gas, and is exhausted from the exhaust pipe 231. At this time, in order to prevent the WF₆ gas and the H₂ gas from entering the nozzle 430, the valve 534 is opened to allow the N₂ gas to flow into the gas supply pipe 530. The N₂ gas is supplied to the process chamber 201 through the gas supply pipe 330 and the nozzle 430, and is exhausted from the exhaust pipe 231.

[0047] At this time, the APC valve 243 is controlled to set the pressure in the process chamber 201 to a pressure falling within a range of, for example, 10 to 6630 Pa. The supply flow rate of the WF₆ gas controlled by the MFC 312 is set to a flow rate falling within a range of, for example, 0.01 to 5 slm, and the supply flow rate of the H₂ gas controlled by the MFC 322 is set to a flow rate falling within a range of, for example, 0.1 to 50 slm. However, the supply flow rate of the WF₆ gas and the supply flow rate of the H₂ gas may be determined according to a desired film thickness. The time for supplying the WF₆ gas and the H₂ gas to the wafers 200,

chamber 201 during the supply of the NF_3 gas is set to a pressure falling within a range of, for example, 1 to 3990 Pa. The supply flow rate of the NF_3 gas controlled by the MFCs 612, 622, and 632 is set to a flow rate falling within a range of, for example, 0.1 to 10 slm. The time for supplying the NF_3 gas to the wafers 200, i.e., the gas supply time (irradiation time), is set such that one pulse is maintained for a time falling within a range of, for example, 0.1 to 60 seconds. The cumulative irradiation time (total irradiation time) of the NF_3 gas is set to a time falling within a range of, for example, 0.1 to 3600 seconds. At this time, the temperature of the heater 207 is set to be equal to the temperature in the O_2 supply step.

[0055] When the etching-back to a predetermined film thickness is completed, the valves 614, 624, and 634 are closed to stop the supply of the NF_3 gas. Finally, the above-described O_2 supply step is performed.

(After-Purging and Atmospheric Pressure Return)

[0056] A N_2 gas is supplied into the process chamber 201 from each of the gas supply pipes 510, 520, and 530, and is exhausted from the exhaust pipe 231. The N_2 gas acts as a purge gas, whereby the inside of the process chamber 201 is purged with the inert gas, and the gases and by-products remaining in the process chamber 201 are removed from the inside of the process chamber 201 (after-purging). Thereafter, the atmosphere in the process chamber 201 is replaced with the inert gas (inert gas replacement), and the pressure in the process chamber 201 is returned to the atmospheric pressure (atmospheric pressure return).

(Wafer Unloading)

[0057] Thereafter, the seal cap 219 is lowered by the boat elevator 115, and the lower end of the outer tube 203 is opened. Then, the boat 217 is unloaded from the lower end of the outer tube 203 to the outside of the outer tube 203 while the processed wafers 200 are supported by the boat 217. Thereafter, the processed wafers 200 are taken out from the boat 217 (wafer discharging).

[0058] The results of evaluation will be described with reference to FIGS. 6 and 7. As shown

removed in each cycle by the same procedure as the residual gas removal step of the W film formation step. That is, the O₂ gas is allowed to flow in a state in which the NF₃ gas is not flowing into the process chamber 201. The supply of the NF₃ gas is started after a predetermined time has elapsed. After a predetermined time has elapsed, the supply of the NF₃ gas and the supply of the O₂ gas are stopped at the same timing. After removing the residual gas in the process chamber 201, the O₂ gas is started to flow again in a state in which the NF₃ gas is not flowing in the process chamber 201. The time for supplying the NF₃ gas is shorter than the time for supplying the O₂ gas.

[0070] According to this modification, one or more of the effects of the above-described embodiments may be obtained, and the following effect may be further obtained.

(m) It is possible to efficiently discharge WF_x (WF₆ or the like) generated by the reaction with the etching gas.

<Modification 6>

[0071] In modification 6 of the above-described embodiments, as shown in FIG. 8F, the O₂ gas supply (continuous supply) step of the above-described etching-back step is performed, and the NF₃ gas is continuously supplied. That is, the NF₃ gas and the O₂ gas are started to flow into the process chamber 201 at the same timing. After a predetermined time has elapsed, the supply of the NF₃ gas and the supply of the O₂ gas are stopped at the same timing. The time for supplying the NF₃ gas and the time for supplying the O₂ gas have the same length of time. According to this modification, one or more of the effects of the above-described embodiments may be obtained.

[0072] In the above-described embodiments, there has been described the example in which the W film is etched back. However, the present disclosure is not limited thereto. The present disclosure may also be applied to the etching of a TiN film, a tantalum nitride film (TaN film), a cobalt film (Co film), and other films containing a metal element, such as a metal film, a metal nitride film, a metal carbide film, and the like.

[0073] In the above-described embodiments, there has been described the example in which the