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Effects of N_2 addition on chemical etching of silicon nitride layers in $F_2/Ar/N_2$ remote plasma processing

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Abstract

In this study, chemical dry characteristics of silicon nitride layers were investigated in the $F_2/N_2/Ar$ remote plasma. A toroidal-type remote plasma source was used for the generation of remote plasmas. The effects of additive N_2 gas on the etch rates of various silicon nitride layers deposited using different deposition techniques and precursors were investigated by varying the various process parameters, such as the F_2 flow rate, the addition N_2 flow rate and the substrate temperature. The etch rates of the various silicon nitride layers at the room temperature were initially increased and then decreased with the N_2 flow increased, which indicates an existence of the maximum etch rates. The etch rates of the silicon oxide layers were also significantly increased with the substrate temperature increased. In the present experiments the F_2 gas flow, addition N_2 flow rate and the substrate temperature were found to be the critical parameters in determining the etch rate of the silicon nitride layers

1. Introduction

Remote plasma cleaning processes of silicon dioxide and PE-nitride(silicon nitride deposited by PECVD) layers using perfluorocompounds(PFCs) such as C_2F_6, C_3F_8, C_4F_8, and NF_3 have been studied and used in the industry [1-7]. Re-emitted PFCs during chamber cleaning are known to cause serious global warming effect in the atmosphere [1-5]. Various ways to reduce the emission of PFCs have been investigated in the semiconductor industry by the use of alternative process chemicals, process optimization and new abatement technologies including destruction destruction and recovery [2]. Therefore, remote plasma cleaning process using less expensive alternative gases such as F_2 can be very effective in the cleaning of SiO_2 and Si_3N_4 thin films because F_2gas can be generated on-site at lower price than NF3. But the problems of F_2 gas cleaning process are its high toxicity and reactivity [4]. Successful F_2 line passivation methods and F_2handing measures have been developed for safety during the use of F_2 gas [5-6]. CVD chamber cleaning process using F_2 for silicon oxide and silicon nitride has been rarely reported. Therefore, development of remote F_2 plasma cleaning process of silicon nitride or oxide is needed.

2. Experiments

Fig.1 show a schematic diagram of the PECVD system used in the present experiment equipped with a toroidal-type remote plasma source (New Power Plasma Co.) with the power of 10kW and the AC frequency of 400kHz and the gas sampling system [3-7].The silicon nitride PECVD chamber has a load-lock chamber and a pressure controller with a throttle valve. Before the cleaning experiments, in order to prevent the corrosion and explosive reaction of metal surfaces, fluorine passivation process of metal surfaces inside the gas lines of the remote plasma source, gas cabinet system, and F_2 deliver lines was performed by using a diluted F_2gas flow [5-6]. For delivery of F_2gas from the gas bottle to the remote plasma source, a double tubing system was adopted. In this experiment, a bottled F_2 with a purity of 98% was used.

3. Results and discussion

In order to see the effect of F_2 concentration in the input gas, the effect of $N_2/(F_2+Ar)$ flow ratio on the cleaning rate was investigated. The cleaning rates as a function of the $N_2/(F_2+Ar)$ gas flow ratio while keeping the total (F_2+Ar) gas flow at 3000 sccm was shown in Fig. 2. Increasing the $F_2/(F_2+Ar)$ gas flow ratio from 16.7% to 83.4% enhanced the cleaning rate from 113 to 185 nm/min. The cleaning rate was increased by a factor of 1.64 in this experiment.

Fig. 3 shows the cleaning rates of PE-nitride layers as a function of the cleaning temperature. Total gas flow was fixed at 3000sccm and the substrate temperature was varied from 25 to 350 ℃. Cleaning rate of PE-nitride layers by 29% F_2 remote plasma was increased from considerably 57.5 to 5916 nm/min as the substrate temperature was varied from 25 to 350℃. The cleaning rate of PE-nitride layer was also increased as the F_2 concentration increases from 29% to 68% at the same cleaning temperature.

Fig. 4shows the FT-IR spectra obtained under the conditions of F_2 gas flow with plasma-on state. The spectra in Fig. 4were obtained at the exhaust line under the condition of working pressure of 2Torr, remote plasma source power of 1204 W and F_2 (500 sccm)/Ar(500 sccm) gas flow ratio. The FT-IR spectra during the remote F_2plasma cleaning PE-nitride layer show the main emitted species of CF_4, SiF_4, HF, H_2O and CO_2. The new peaks of SiF_4 and CF_4 are observed during the cleaning of silicon nitride layer.

4. Summary

We have successfully carried out gas line passivation using diluted F_2 gas before cleaning experiments. It was found that F_2remote plasma generated by a toroidal-type remote plasma source is very effective in obtaining the high cleaning rate of PE-nitride layers. Cleaning rates of PE-nitride layers were increased with increasing the F_2flow rate and $F_2/(F_2+Ar)$ flow ratio. The cleaning rate of PE-nitride layers was also considerably increased as cleaning temperature varies 25 to 350℃. Monitoring of emitted gases during remote plasma cleaning an the condition of F_2 (500sccm)/Ar(500sccm) shows the main cleaning reaction products of CF_4, F_2, and SiF_4.

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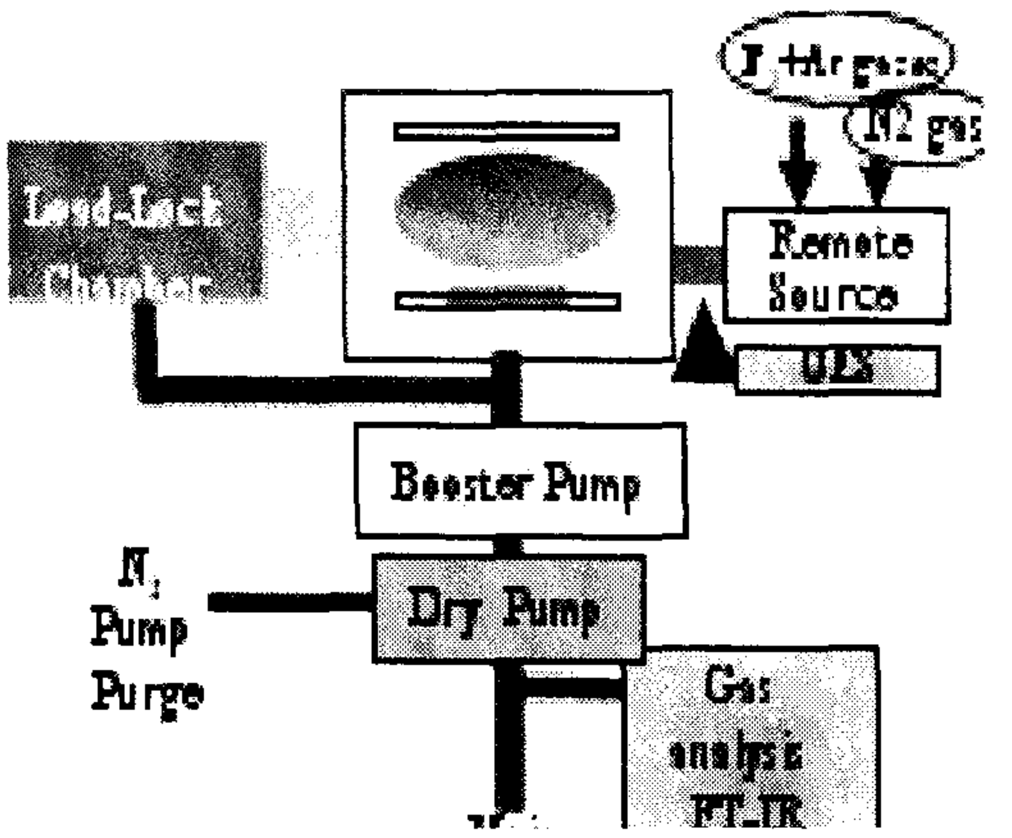

Fig.1. Schematic of the PECVD system equipped with the remote plasma source used for F_2 chamber cleaning.

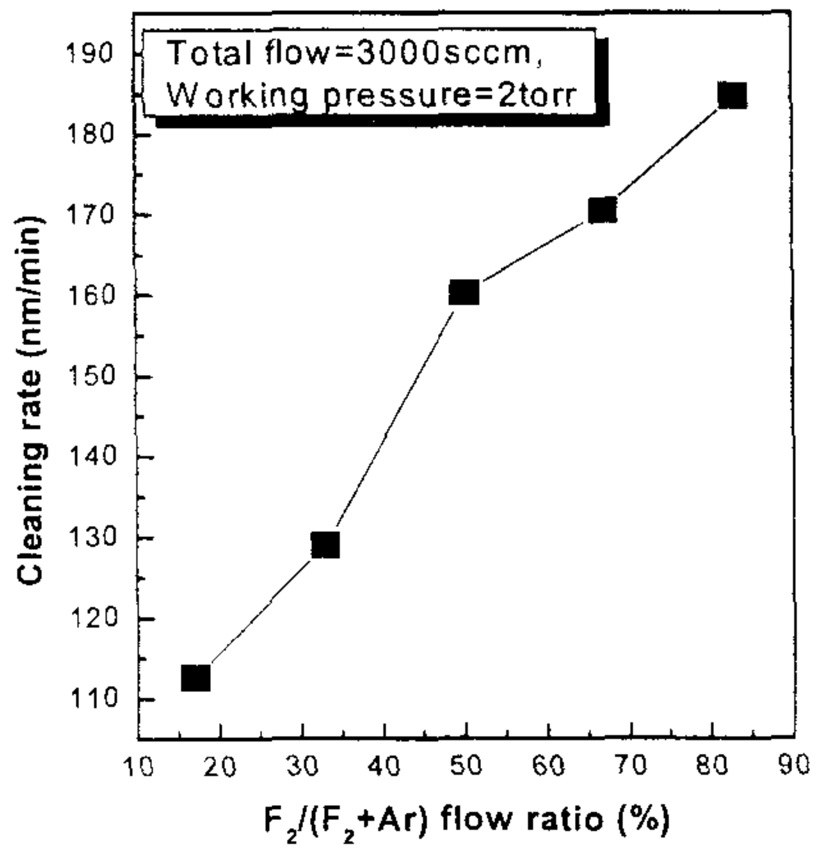

Fig.2. Cleaning rate of the PE-nitride layer as afunction of F2/(F2+Ar) flow rate.

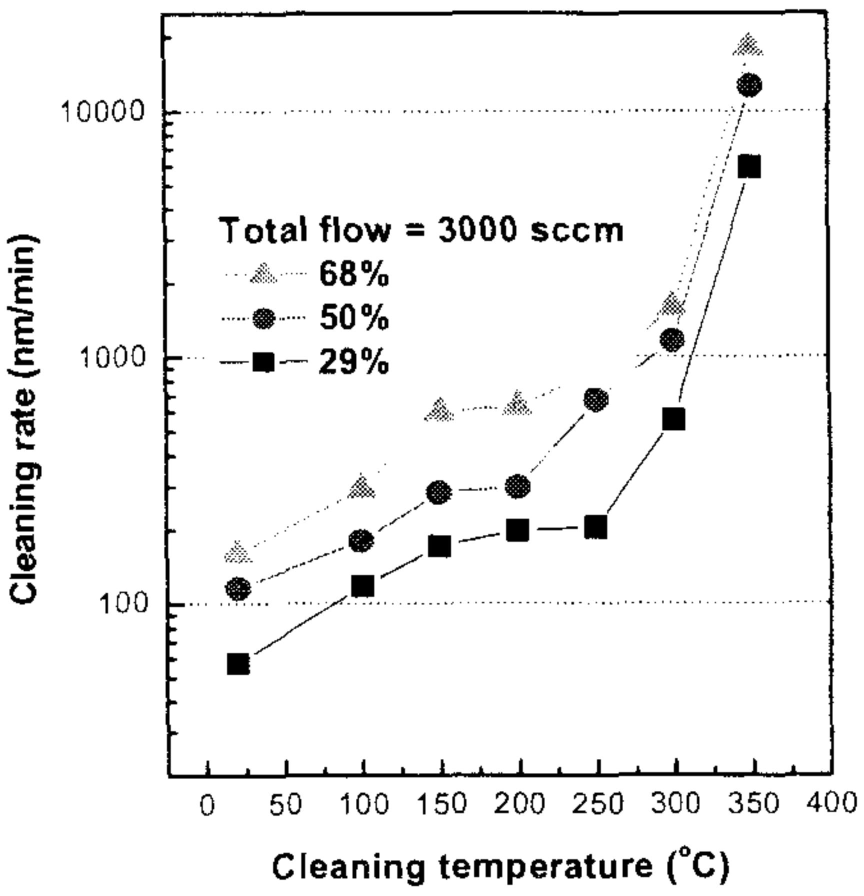

Fig.3. Cleaning rate of the sili con nitride layer as a function of cleaning temperature.

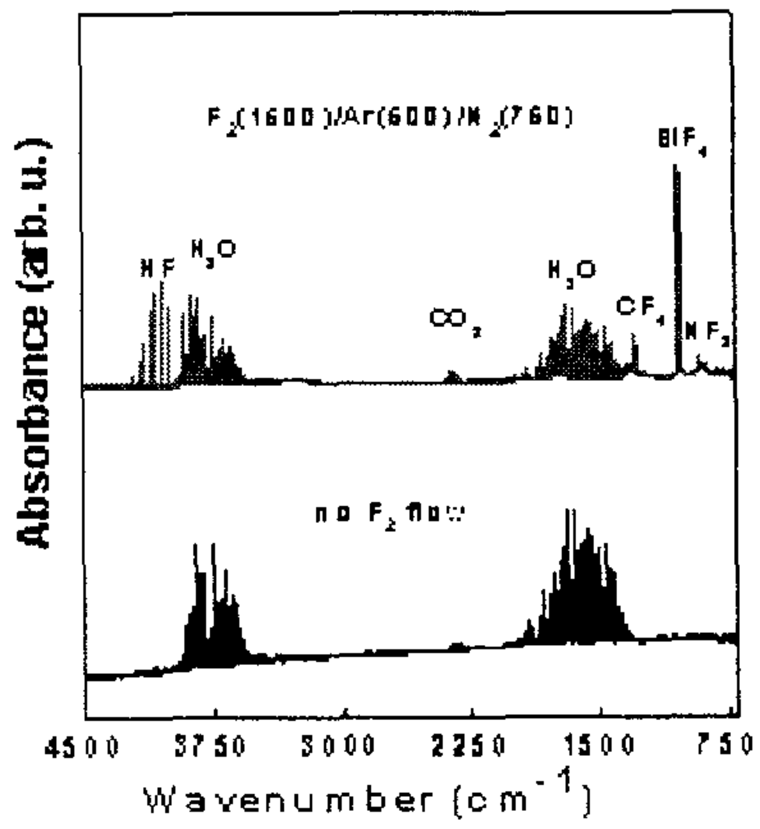

Fig.4. FT-IR spectra from the gas exhaust line with no F2(plasma-off),F2(1500scm)/Ar(500scm)/N2(750sccm) plasma.