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Chemical dry etching of silicon nitride in F_2/Ar remote plasmas

J.Y. Hwang [a], D.J. Kim [a], N.-E. Lee [a,*], Y.C. Jang [a,b], G.H. Bae [a,b]

[a] *School of Materials Science and Engineering and Center for Advanced Plasma Surface Technology, Sungkyunkwan University, Suwon, Kyunggi-do 440-746, South Korea*
[b] *Atto, 2DA-302, Shihwa Indus. Com. , Jungwang, Shiheung-City, Kyunggi-do 429-849, South Korea*

Abstract

In this work, chemical dry etching process of the silicon nitride layers using the F_2/Ar remote plasmas generated by a toroidal-type remote plasma source was investigated by varying the total (F_2+Ar) gas flow, the F_2/(F_2+Ar) flow ratio, the etching temperature and the working pressure. Under the current experimental condition, the chemical etching rates of the silicon nitride were significantly enhanced with increasing the F_2 gas flow rate and F_2/(F_2+Ar) flow ratio. Observed tendency in the etch rate was consistent with the variations of the optical emission intensity of the F radicals in the afterglow region of the remote plasma source and of the concentration of the emitted SiF_4 reaction by-product molecules. The substrate temperature was the most influential process parameter in determining the etching rates. The etching rates of the silicon nitride layers were increased by a factor of ≅50, 109, and 114 for the F_2 gas flow ratios of 29, 50, and 68%, respectively, as the substrate temperature increases from 25 to 350 °C.

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1. Introduction

Chemical dry etching of thin films in microelectronic fabrication has been widely used for removing the layers while minimizing the ion-induced damage of the adjacent active layers and the erosion of the chamber materials [1–7]. Chemical dry etching processes of silicon [1–4], silicon nitride [1,2,5–7], and silicon oxide layers [6,7] have been investigated in downstream remote plasmas containing perfluorocarbon (PFC) [1–3,5,6] or nitrogen trifluoride (NF_3) gas [4,7].

Remote plasmas containing the PFCs (C_2F_6, C_3F_8, C_4F_8) or NF_3 gas are also being widely used in the silicon semiconductor and thin film transistor liquid crystal displays (TFT-LCDs) industry to clean the chemical vapor deposition (CVD) or plasma-enhanced chemical vapor deposition (PECVD) reactors in which the silicon oxide and nitride films are deposited [8–23]. The PFCs that are re-emitted during chamber cleaning, however, are known to have a serious global warming effect in the atmosphere [8–12,17–23]. The use of alternative process gases is one of the ultimate solutions for reduction in the re-emission of those gases.

In particular, NF_3 remote plasma etching or cleaning process has been developed in order to minimize the erosion and damage of chamber parts during etching as well as to decrease global warming effect and currently used widely in the current TFT-LCD and Si wafer processing facilities [10]. Remote plasma etching or cleaning using NF_3/Ar chemistry, however, has some issues related to the high cost of producing NF_3 gas and the erosion of the exhaust lines [11]. Therefore, remote plasma etching process using the less expensive alternative gases such as F_2 can be cost-effective in the etching or cleaning of SiO_2 and Si_3N_4 thin films because F_2 gas should be able to be generated on-site near the factory at a lower price than NF_3. Potential problems in applying the F_2 etching or cleaning process in the production lines, however, are its high toxicity and reactivity [13]. Successful F_2 line passivation methods and F_2 handing measures have been developed in order to ensure the safety of the personnel involved in the use of F_2 gas [15,16]. Only few experimental works on F_2 remote plasma etching processes have been reported in the literature [24–26], but no detailed experimental works on the chemical dry etching of the silicon nitride layers using F_2 remote plasmas have been reported. In

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* Corresponding author. Tel.: +82 31 290 7398; fax: +82 31 290 7410.
E-mail address: nelee@skku.edu (N.-E. Lee).

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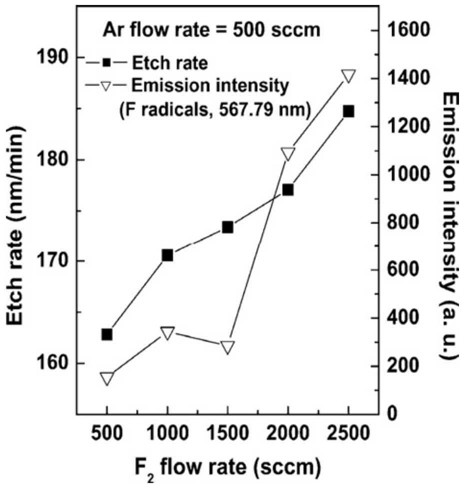

Fig. 1. Etching rates during the remote F_2/Ar plasma etching of the PE-nitride as a function of the F_2 gas flow rate.

this study, we carried out the F_2/Ar remote plasma etching experiments of the PE-nitride (silicon nitride layers deposited by PECVD using SiH_4 and NH_3) in a commercial 8-inch plasma reactor.

2. Experimemts

The schematic diagram of the experimental system used in the present experiment equipped with a toroidal-type remote plasma source and the gas sampling systems was described elsewhere [11,17,26]. Before conducting the etching experiments, various safety precautions were taken concerning the gas cabinet, gas delivery lines, remote plasma source, exhaust lines and scrubber systems [26]. Square-shaped (1×1 cm^2) substrates with the silicon nitride layers deposited on Si (001) were used as the samples for etching experiments. In the present experiment, 200-nm-thick silicon nitride layer (PE-nitride) deposited by PECVD using SiH_4 and NH_3 was used for etching. The samples were transported through the load-lock chamber and located at the substrate holder without heating and biasing. During etching experiment, silicon nitride (200 nm)/Si(001) and Si(001) samples were loaded together and etching rate of silicon nitride was determined from the etch rates of the two samples. The plasma was ignited at the Ar flow rate of 500 sccm. In this etching experiment, a bottled F_2 with a purity of 98% was used.

The etching rate of the silicon nitride layers was measured using an α-step profilometer (Tencor, AS-500). A multi-channel optical emission spectrometer (Ocean Optics) with the spectral range of 270–970 nm was used for an analysis of the optical emission from the afterglow region of the remote plasma source in order to understand any correlation between the generated F radical intensity and the etch rate. The gas analysis tools used in order to understand the production of the by-products during etching processes were a Fourier transform-infrared spectroscopy (FT-IR; MIDAC I2000) and residual gas analyzer (RGA; Hiden Analytical Inc.) that are connected to the exhaust line. In particular, the F_2 gas was monitored by RGA because it cannot be detected by FT-IR measurements.

3. Results and discussion

As can be seen from the Fig. 1, the increase of F_2 gas flow rate from 500 to 2500 sccm increased the room-temperature etching rate of silicon nitride layers slightly from ≅163 to 185 nm/min. The optical emission intensity of the F radicals at the wavelength of 567.79 nm was gradually increased with increasing the F_2 flow rate. Increasing the F_2 flow rate presumably enhances the F radical density delivered to the PECVD chamber resulting in an enhancement of the etching rate. The tendency in the optical emission intensity of the F radicals in Fig. 1 is well correlated with the F_2 flow rate variation. The results indicate that the F radical density in the remote plasma source is a determining factor of the etch rate.

The species emitted during the F_2/Ar remote plasma etching of the PE-nitride layer at a selected condition from the experimental conditions in Fig. 1 were monitored by FT-IR and RGA in order to understand the etch reaction of the silicon nitride layers. The spectra obtained with no F_2 flow (not shown here) indicated the significant amounts of H_2O and CO_2 in the

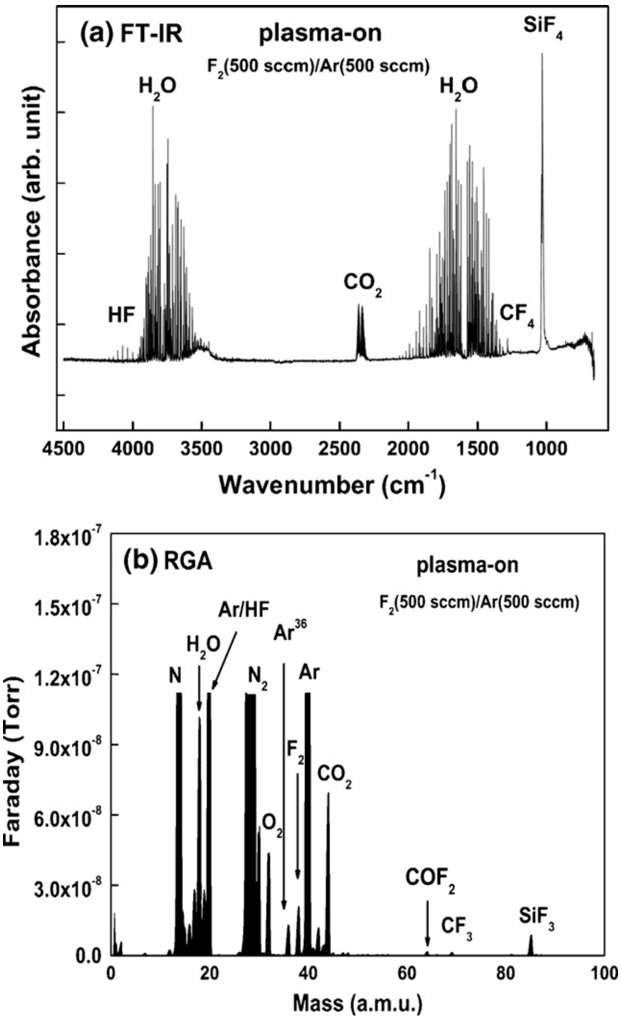

Fig. 2. (a) FT-IR spectra and (b) RGA spectra during remote plasma etching of the PE-nitride layers at a flow ratio of F_2(500 sccm)/Ar(500 sccm), an input power of 1024 W and working pressure of 2 Torr.