Mechanism for Plasma Etching of SiO_2 Using Low Global Warming Potential Materials

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Abstract: - Perfluoro carbon (PFC) plasmas, which are mainly used for plasma etching of SiO_2 contact holes, have high global warming potentials (GWPs). As an alternative to PFCs, heptafluoroisopropyl methyl ether (HFE-347mmy) was used for SiO_2 etching. HFE-347mmy have a significantly lower GWP (~ 350) than those of the conventional PFCs. In this study, SiO_2 was etched in a HFE-347mmy/Ar plasma, and its etch characteristics was investigated. The etching characteristics of SiO_2 in the HFE-347mmy/Ar plasma were studied in terms of the angular dependence of etch rates. The angular dependence of the SiO_2 etch rates was obtained using the specially designed Faraday cage system. The normalized etch yield (NEY) curves showed maxima at angles between 50 and 70°, indicating that physical sputtering was the main contributor to the etching of SiO_2 in HFE-347mmy/Ar plasmas. This work revealed the feasibility of using HFE-347mmy/Ar plasmas in SiO_2 etching as an alternative to PFC plasmas.

Key-Words: - Angular dependence, Etch rate, Etch yield, Fluorinated ether plasma, Perfluoro carbon plasma, Faraday cage

1 Introduction

As the minimum feature size keeps shrinking, etching of high aspect-ratio SiO_2 contact holes is one of the key processes in the fabrication of ultra large scale integrated devices. Plasma etching is exclusively used to pattern SiO_2 contact holes because of its anisotropic etch characteristics. The discharge gases mainly used for the plasma etching of SiO_2 contact holes are perfluoro carbons (PFCs) such as CF_4 and C_4F_8 [1-3]. Theses PFCs are problematic from an environmental viewpoint because of their high global warming potentials (GWPs) [4-6].

General approaches to reduce PFC emission include process optimization, abatement, recycling (or recovery), and alternative chemicals. As part of efforts for PFC emission reduction, the use of alternative chemicals is being investigated [4-8].

Several classes of chemistries have been evaluated as alternatives to PFCs. Among them, hydrofluoroethers draw attractions because of their much lower GWPs compared to those of PFCs [9,10]. Previous studies show that hydrofluoroethers have low GWPs because the hydrogen atom in the hydrofluoroethers play roles in increasing the reactivity of the molecule toward hydroxyl radicals in the troposphere, which is the major destruction mechanism [11]

In this study, SiO_2 was etched in heptafluoisoropropyl methyl ether (HFE-347mmy)/Ar plasmas, and its etching characteristics were investigated. HFE-347mmy is hydrofluoroether and its GWP is ~350 which is significantly lower than those of PFCs. The etching characteristics of SiO_2 in HFE-347mmy/Ar plasmas were studied by varying the ion-incident angles. A Faraday cage system was used to control the angle of ions incident on the substrate. Etch mechanism for SiO_2 etching was discussed based on the angular dependence of etch rates.

2 Experimental

Figure 1 shows an inductively coupled plasma system used in this study. Two separate 13.56–MHz radio–frequency (rf) power generators were used independently to apply power to the induction coil (source power) and the electrode (bias power), respectively. The source power controlled plasma density while the bias power controlled ion energy.

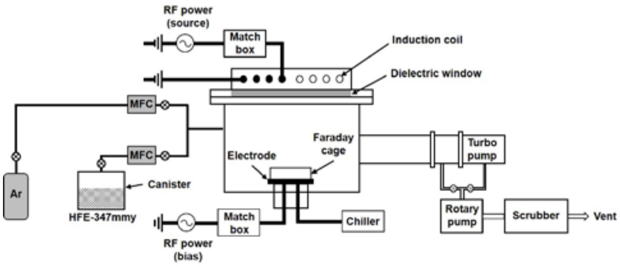

Fig. 1. Schematic diagram of an inductively coupled plasma system.

Heptafluoroisopropyl methyl ether (HFE-347mmy) was contained in a canister. The canister was maintained at 75°C to vaporize HFE-347mmy whose boiling point was 29°C. The vaporized HFE-347mcc3 was introduced to the chamber. HFE-347mmy was mixed with Ar because HFE-347mmy alone did not etch SiO_2. The pressure in the chamber was 10 mTorr, and the substrate temperature was 15°C. The source power was 250 W. The bias voltage was changed from –400 to –1200 V for the measurement of the angular dependence of the etch rates. The flow rates of HFE-347mmy and Ar were 10 and 20 sccm, respectively.

A Faraday cage was used to measure the etch rates of SiO_2 at various ion-incident angles. Figure 2 shows a schematic diagram of the Faraday cage and the arrangement of the samples. The ion-incident angle (θ) was defined as the angle between the ion-incident direction and the surface normal to the sample. The angle of the sample holder was varied between 0 and 90°. The substrates were 500-nm-thick SiO_2 films thermally grown on a p-type Si wafer. Each substrate was cut into a 10 × 5 mm^2 rectangle and placed on the sample holder.

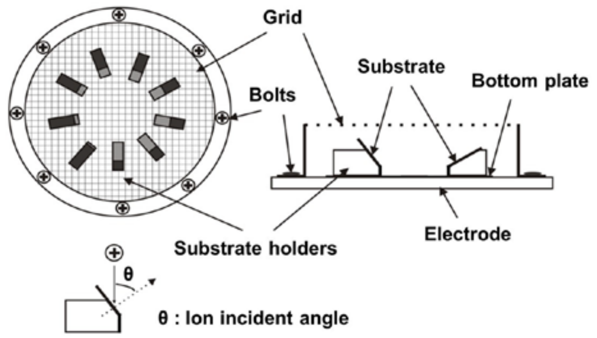

Fig. 2. Schematic diagrams of a Faraday cage and the substrate arrangement in the cage.

3 Results and Discussion

Figure 3 shows the change in the etch rate of SiO_2 with ion-incident angle at various bias voltages in HFE-347mmy/Ar plasmas. The etch rates increased with bias voltage at all ion-incident angles. It was also observed that the etch rates gradually decreased with increasing ion-incident angle for the bias voltages used in this study. When the ion-incident angle was 90°, the etch rates were negative, indicating that a net deposition rather than etching occured at this angle.

Figure 4 shows the angular dependence of the normalized etch rate (NER) of SiO_2 at various bias voltages in HFE-347mmy/Ar plasmas. The NER was defined as the etch rate at the specific angle with respect to the etch rate on the horizontal surface: i.e., etch rate (θ) / etch rate (0°). The line in the NER plot represents a cosine curve corresponding to the change in the flux of ions incident on the surface of the substrate. The NERs fell virtually on a single curve for the bias voltages higher than –800 V. On the other hand, the NERs at bias voltages between –400 and –600 V were lower than those at other bias voltages (–800 ~ –1200 V), and they decreased with decreasing bias voltage.

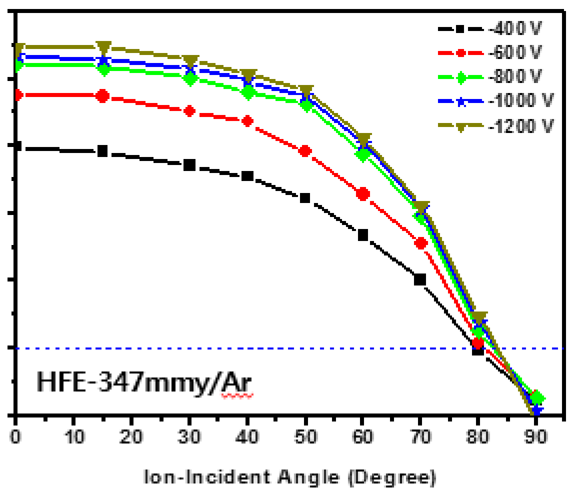

Fig. 3. Angular dependence of etch rates of SiO_2 in HFE-347mmy/Ar plasma at various bias voltages.

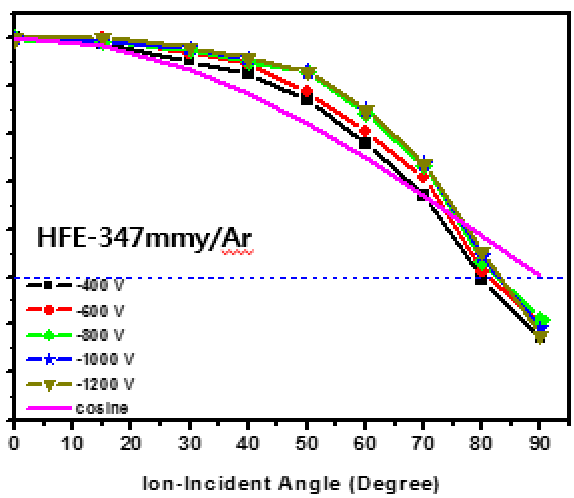

Fig. 4. Angular dependence of normalized etch rates of SiO_2 in HFE-347mmy/Ar plasma at various bias voltages.

Figure 5 shows the angular dependence of the normalized etch yield (NEY) of SiO_2 as a function of ion-incident angle at various bias voltages in HFE-347mmy/Ar plasmas. The NEY was defined as the etch yield at a specific angle normalized with respect to one on a horizontal surface. Thus, the NEY was equal to NER/cosθ. The use of NEY is relevant to investigate the ion-surface interaction because the ion flux variation with ion-incident angle is excluded. The NEYs of a HFE-347mmy/Ar plasma showed maxima at angles between 50 and 70°. At bias voltages higher than –800 V, the NEY curves were nearly identical.

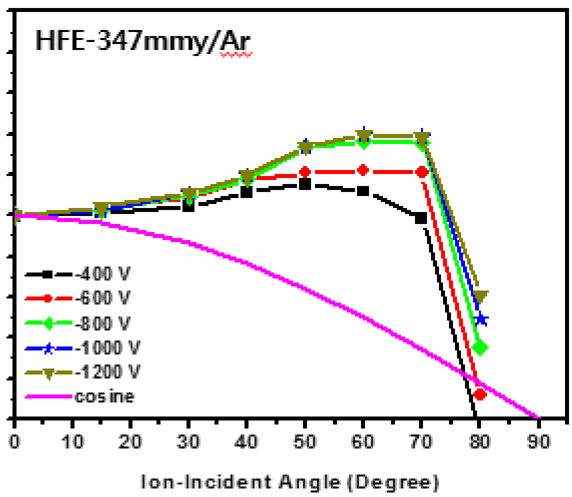

Fig. 5 Angular dependence of normalized etch yields of SiO_2 in HFE-347mmy/Ar plasma at various bias voltages

The angular dependence of the etch yield can be used to determine the major etch mechanism. When physical sputtering is the main etch mechanism, the etch yield has a maximum at angles between 40 and 70°. On the other hand, when ion-enhanced chemical etching is the main etch mechanism, the etch yield decreases monotonically with ion-incident angle, following the cosine curve.

The shapes of the NEY curves in Figure 5 suggest that physical sputtering is a major contributor to SiO_2 etching in HFE-347mmy/Ar plasmas. The physical-sputtering-dominated etch mechanism can also be found in the etching of SiO_2 using PFC-containing plasmas [1,2]

4 Conclusion

Plasma etching of SiO_2 was conducted in a plasma containing heptafluoroisopropyl methyl ether (HFE-347mmy), which had significantly low global warming potential than the conventional perfluoro carbon gases. The change in the etch rates with ion-incident angle was successfully measured in HFE-347mmy/Ar plasmas using the specially-designed Faraday cage system. The normalized etch yield (NEY), which excluded the effect of ion-flux variation with ion-incident angle, was also obtained from the measured angular dependence of the SiO_2 etch rates. The NEYs of HFE-347mmy/Ar plasmas showed maxima at angles between 50 and 70°, implying that physical sputtering was the main contributor to SiO_2 etching in HFE-347mmy/Ar plasma. The NEY curves were nearly identical at bias voltages higher than –800 V.

This suggests that the use of a HFE-347mmy plasma would offer a wider process window. Since this work revealed the feasibility of using HFE-347mmy plasmas in SiO_2 etching as an alternative to PFC plasmas, future work is to compare the SiO_2 etch profiles obtained with HFE-347mmy and PFC plasmas, respectively.

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