Eco-Friendly Dry-Cleaning of Silicon Dioxide Deposition Chambers using a Cylinder-Type Remote Plasma Source with NF_3/N_2 Mixtures

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Silicon dioxide (SiO_2) chamber cleaning is critical in semiconductor manufacturing, but traditional methods using perfluorocarbon gases like NF_3 raise environmental concerns due to their high global warming potential. This study presents a novel, eco-friendly approach utilizing a cylinder-type inductively coupled plasma remote plasma source (ICP RPS) with NF_3/N_2 gas mixtures for enhanced SiO_2 removal. The addition of a small amount of N_2 to NF_3 (1:9 ratio) was found to significantly improve cleaning efficiency and uniformity. Comprehensive plasma diagnostics, including quadrupole mass spectrometry (QMS), optical emission spectroscopy (OES), and Langmuir probe measurements, revealed that N_2 addition increases electron density and temperature, leading to enhanced generation and consumption of highly reactive fluorine radicals responsible for SiO_2 etching.This innovative process offers a promising pathway to reduce NF_3 consumption in SiO_2 chamber cleaning, mitigating environmental impact while maintaining high cleaning performance. The results of this study contribute valuable insights into the optimization of plasma-based cleaning processes for the semiconductor industry.

1. Introduction

Nitrogen Trifluoride (NF_3) is a commonly used chamber cleaning agent known for its strong greenhouse gas effects, possessing a global warming potential (GWP) 740 times that of CO_2. However, developing alternative gases and new cleaning processes requires an extended development time and validation. So eco-friendly cleaning processes and diagnostic methods using existing gases are needed before alternative gases are develpoed.

This paper proposes an eco-friendly chamber cleaning process that can reduce the use of NF_3 gas. The proposed process aims to reduce the environmental load associated with the use of highly reactive fluorine-based gases such as NF_3. To achieve this goal, the effect of the N_2/NF_3 ratios on the etching characteristics of SiO_2 was investigated by using a cylinder-type remote plasma source (RPS). The cleaning mechanism and uniformity are suggested through plasma characterization and film surface analysis.

2. Experiment

In this study, the experiments were conducted using an ICP-type 4th generation display plasma processing chamber (dimensions: 730 mm x 920 mm). Figure 1 shows an internal linear ICP-type 4th generation display processing chamber installed with a remote plasma source (RPS) composed of a 13.56 MHz cylindrical-ICP type RPS system. SiO_2 thin film samples were located on the substrate and the chamber wall to investigate the cleaning rate and cleaning uniformity with the RPS.

NF_3 and N_2 were are used as cleaning gases, and SiO_2 deposited by PECVD (plasma enhanced chemical vapor deposition) was used as the cleaning samples. The cleaning process with the PRS was processed at 780 mTorr (1.5 slm), 2 kW of RPS, and room temperature.

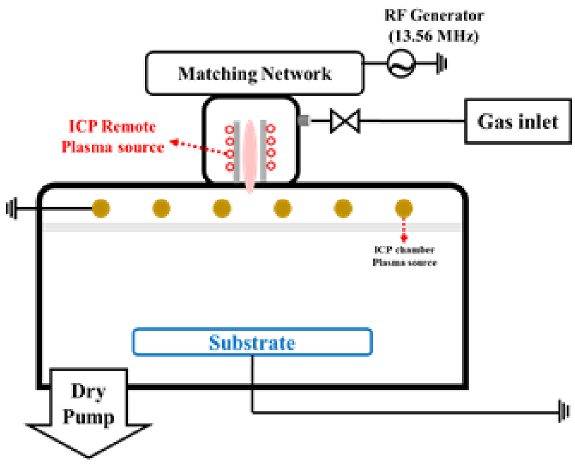

Figure 1. Schematic drawing of a remote ICP-type RPS installed in an internal linear ICP-type plasma processing system used in the experiment.

The etched amount of films was measured with a spectroscopic ellipsometer, and to analyze the N_2/NF_3 species in the plasma, an optical emission spectrometer (OES) was used. The surfaces of cleaned SiO_2 on Si were observed by field emission scanning electron microscopy (FE-SEM). Also, a quadrupole mass spectrometer (QMS) was used by identifying most of the chemical species in plasma process. Electron temperature was measured using a Langmuir probe.

3. Results and Discussion

The etch rates of SiO_2/Si for cleaning condition were investigated by varying the ratio of N_2 species to NF_3 species in N_2/NF_3 remote plasmas. First, dissociated species were observed using OES while changing the ratio of N_2/NF_3 from 0 to 20 %, and the OES data were collected during the SiO_2 chamber cleaning process using NF_3 plasma, confirming the presence of various chemical species; F peaks (703.7 nm, 712.8 nm) and N_2 peak (FPS between 550 and 700 nm, SPS between 300 and 400 nm) were observed.

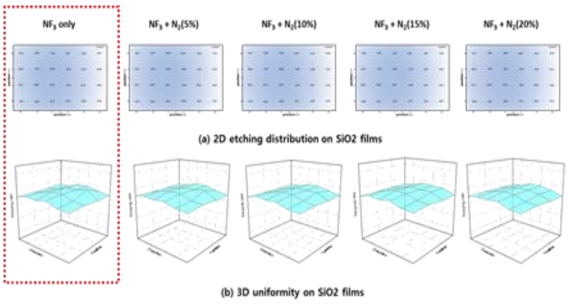

Figure 2. (a) 2D and (b) 3D cleaning distribution of SiO_2 films for 0~20 % N_2/NF_3 ratios.

SiO_2 etching data were collected at 24 points (6 x 4 square points) on the substrate surface with increasing N_2 ratios from 0 to 20%, maintaining a total flow of 1.5 slm and a power of 2 kW. Figure 2(a) illustrates the etching rate distribution, demonstrating a decreasing trend with increasing N_2 ratio. Figure 2(b) depicts the 3D etching uniformity across the substrate surface, revealing an improvement in uniformity as the N_2 ratio increases.

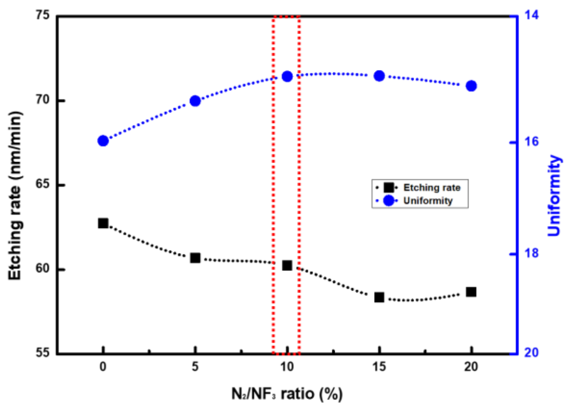

Figure 3. SiO_2 cleaning rate and uniformity as a function of N_2/NF_3 ratio.

Figure 3 shows the summary of SiO_2 cleaning rate and cleaning uniformity with the RPS as a function of a N_2/NF_3 ratio. Results indicate that adding a small amount of N_2 to NF_3 enhances cleaning efficiency by increasing electron density and temperature (not shown), thereby promoting the production and consumption of highly reactive fluorine radicals.

4. Conclusion

This study proposed an environmentally friendly SiO_2 chamber cleaning method to mitigate the contribution of global warming by minimizing the use of NF_3 gas. When NF_3 and N_2 gas were mixed at a ratio of 9:1, it was confirmed that the cleaning rate decrease 3.93% of that achieved with NF_3 alone. However, uniformity was improved and the amount of NF_3 usage was decreased when the same thickness of SiO_2 was cleaned. Accordingly, in addition to the replacement with low GWP gases for SiO_2 chamber cleaning, this type of approach can enable the implementation of an eco-friendly cleaning process that can mitigate the impact of global warming.

References

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