Impact of Native Oxide Removal Using Fluorine-Based Plasmas Before Silicon Atomic Layer Etching

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Abstract: This study investigates the effects of plasma pretreatments (CF_4, CHF_3, CH_3F, SF_6, NF_3) on silicon atomic layer etching (ALE). CF_4 showed the highest etch per cycle (13.1 Å/cycle), while CH_3F and SF_6 decreased EPC. The results emphasize the need to optimize plasma pretreatment conditions for improved ALE performance in semiconductor manufacturing.

1. Introduction

Atomic layer etching (ALE) has better controllability and selectivity than reactive ion etching (RIE) but suffers from low throughput. To address this, ALE is selectively applied to critical layers after RIE, though RIE-induced damage can affect initial ALE cycles. Fluorocarbon plasma pretreatment is commonly used to mitigate these damage layers. Since pretreatment significantly influences surface composition changes, its role is crucial. However, research on ALE pretreatment remains limited despite its importance.

2. Methods

The experiment was conducted using a 300mm inductively coupled plasma (ICP) chamber powered by a 13.56 MHz source and bias power. The experimental procedure followed an Atomic Layer Etching (ALE) concept, which was divided into three distinct steps: Pretreatment, absorption, and desorption. In this study, the conditions for absorption and desorption were maintained constant, while the gas composition used in the Pretreatment step was varied, including CF_4, CHF_3, CH_3F, NF_3, and SF_6, in order to evaluate the effects of different gases.

3. Results and Discussion

Figure 1 presents the etch per cycle (EPC) values, calculated by dividing the etched Si thickness after 15 cycles of ALE by the number of cycles, following pretreatment etching with various gases (CF_4, CHF_3, CH_3F, NF_3, and SF_6). Among these gases, CF_4 exhibited the highest EPC of 13.1 Å/cycle. In contrast, CH_3F showed a reduced EPC of 12.1 Å/cycle, attributed to the formation of a carbon polymer layer on the surface. Furthermore, CH_3F resulted in a more significant accumulation of carbon polymer, leading to the complete suppression of Si etching, with an EPC of 0 Å/cycle. Following NF_3 pretreatment, the EPC was measured at 5.1 Å/cycle, while SF_6 pretreatment yielded an EPC of 4.3 Å/cycle. The observed reduction in EPC after NF_3 and SF_6 pretreatments is attributed to the formation of surface nitride and sulfur species, which inhibited the etching process.

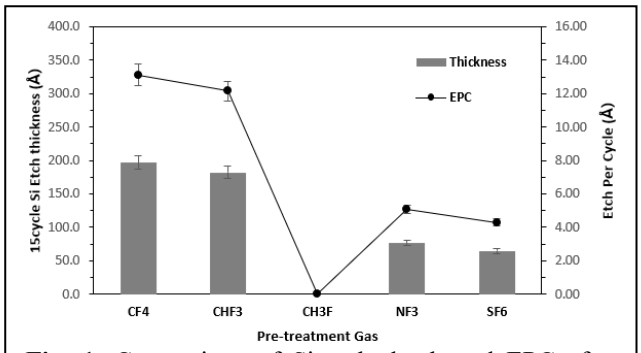

Fig. 1. Comparison of Si etch depth and EPC after pretreatment etching with CF_4, CHF_3, CH_3F, NF_3, and SF_6 gases.

4. Conclusion

The EPC in ALE was found to vary depending on the type of pretreatment gas employed. A reduction in EPC was observed when using CHx gases containing hydrogen. Furthermore, the decrease in EPC was more pronounced in the presence of nitride and sulfur compared to carbon. These findings suggest that, considering the limited throughput of ALE, CF_4 is the most effective pretreatment gas for the removal of Si negative oxide.

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References

[1] K.J Kanarik et al., J. Vac.Sci.Technol. A33, 020802 (2015).
[2] C. T. Carver et al., Solid State Sci. Technol. 4, N5005 (2015).
[3] K. J. Kanarik et al., J. Phys. Chem. Lett. 9, 4814 (2018).
[4] K. Koh et al. J. Vac. Sci. Technol. A, 36(1), 10B106 (2017)