Investigation of Ion Control in Ar Plasma with Discharge Voltage Amplitude Modulation: COMSOL Simulation

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Abstract: We investigated behavior of incident ions in the AR30 trench under few-Torr pressure conditions using amplitude modulation (AM) discharge with COMSOL Multiphysics. AM discharge plasma enables more ions with high kinetic energy to reach high-aspect-ratio trench sidewalls compared to continuous waveform (CW) plasma, which potentially improve SiO_2 film quality on trench sidewall.

1. Introduction

With the growing demand for semiconductor devices, plasma enhanced chemical vapor deposition (PECVD) has become one of the important processes in semiconductor manufacturing. Silicon dioxide (SiO_2), commonly deposited by TEOS-based PECVD at Torr-order conditions, is widely used as a dielectric and barrier/seed layer. However, SiO_2 films deposited by TEOS-PECVD often suffer from poor step coverage and quality on sidewalls, leading to voids due to non-uniform ion bombardment. To address this, precise control of both ion energy distribution function (IEDF) and ion angular distribution function (IADF) is essential.

In our previous research[1-2], we used sinusoidal amplitude-modulated (AM) discharge on capacitively coupled plasma (CCP) at 10 mTorr, and through PIC-MCC simulations, we confirmed that ion and energy flux to the trench sidewalls increases with changes in voltage amplitude, along with variations in plasma parameters such as electron density, IEDF, and IADF. However, PIC-MCC simulations at higher pressures, which are important for industrial processes, are computationally challenging [3]. Therefore, in this study, we employ COMSOL Multiphysics for fluid simulations to investigate the effects of AM discharge at few-Torr.

2. Methods

We employed COMSOL Multiphysics to analyse the capacitively coupled Ar plasma at a pressure of 2 Torr. The discharge is sustained between two parallel plate electrodes with a distance of 10 mm. The lower electrode is grounded, and the radio frequency (RF) voltage for both sinusoidal AM discharge [4] and continuous waveform (CW) discharge is applied to the upper electrode. The trench geometry used in the calculation had a height of 3000 nm and a width of 100 nm (AR = 30).

3. Results and Discussion

We confirmed using COMSOL Multiphysics that plasma parameters such as IEDF and IADF vary over time in response to changes in voltage amplitude even at 2 Torr. Figure 1 shows the dependence of (a) the ratio of the normalized number of ions incident on the sidewall and (b) the ratio of the total ion energy in the parallel direction on the depth in AM and CW discharges, where the total ion energy is defined as the normalized number of ions multiplied by the energy per ion. These results suggest that AM discharge can contribute to improving step coverage and film quality on trench sidewalls even at 2 Torr.

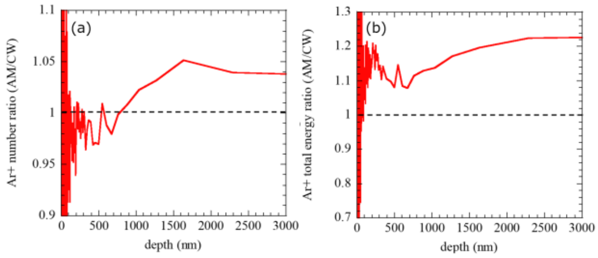

Fig. 1. (a) The ratio of the normalized number of ions incident on the sidewall and (b) the ratio of the total ion energy in the parallel direction to the depth in AM and CW discharges.

4. Conclusion

Using COMSOL Multiphysics, we investigated the effects of sinusoidal AM discharge on the IEDF and IADF for the sidewalls of AR30 trench structures in capacitively coupled plasma at 2 Torr. The results revealed that AM discharge allows a greater number of ions with higher energy to reach the sidewalls of high-aspect-ratio trenches compared to CW discharge. Consequently, AM discharge promotes more uniform ion bombardment, leading to improved step coverage and enhanced film quality. A comprehensive discussion, including comparisons with PIC simulations at 10 mTorr, will be presented in the conference.

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