Etching of High Aspect Ratio Structures in Silicon

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Plasma etching of high aspect ratio features (depth-to-width) such as deep holes and trenches in Si is an important step in the manufacture of capacitors in memory devices and integrated components of microelectromechanical (MEMS) systems [1]. In these applications, the goal is to etch deep features anisotropically with high etch rates and high selectivity to the mask while maintaining good uniformity across the wafer. We have studied the etching of deep sub-micron diameter high aspect ratio holes (>10) in Si using SF_6/O_2 plasma [2]. We combine etching experiments and plasma diagnostics with feature scale modeling to gain a fundamental understanding of the etching kinetics necessary to develop and scale up processes.

Etching experiments were conducted in a low pressure, high density, inductively coupled plasma etching reactor with a planar coil [2]. The substrate electrode is biased with a separate rf power supply to achieve independent control of the ion flux and ion energy. Specifically, we have studied the effects of pressure, rf-bias voltage and SF_6-to-O_2 gas ratio on the etch rate, selectivity and feature profile using Si wafers patterned with 0.35 μm diameter holes in a SiO_2 mask. Visualization of the profiles using scanning electron microscopy (SEM) is complimented by plasma diagnostics such as mass spectrometry and optical emission spectroscopy in conjunction with actinometry. The positive ion flux impinging on the wafer surface was measured using a small piece of heavily doped silicon mounted in the center of a 200-mm diameter heavily doped Si wafer with a Kapton tape placed in between itself and the wafer. The probe was negatively biased (-75 V) with respect to the wafer using a floating power supply and the probe current was determined from the potential drop across a precision resistor, measured using a battery-operated voltmeter.

Simultaneous with the experiments, we have developed a semi-empirical feature scale model of the etching process. This model is used to quantify etching kinetics and identify the important kinetic parameters that affect profile evolution. Information from plasma diagnostics and previously published data are used to reduce the degrees of freedom in the model by estimating the F, O, and ion fluxes as well as the ion energy and angle distributions. We have designed experiments to directly measure parameters such as the chemical etch rate constant and the dependence of the etch yield on the ion angle. Experimentally inaccessible parameters such as the sticking coefficients, ion-enhanced etch yield and ion scattering parameters are determined by matching simulated profiles with those experimentally observed under different plasma etching conditions.

The F-to-ion flux ratio and F-to-O flux ratio are found to be the important plasma parameters that determine the etch rate and anisotropy. Plasma diagnostics provide quantitative information about the location of the ion and neutral-limited regimes in the operating parameter space. The SF_6-to-O_2 gas ratio determines the balance between etching and sidewall passivation, which controls the feature profile shape. We show that profile evolution simulations with kinetic parameters obtained from a few well-designed experiments can be predictive over a wide range of process parameter space (Figure 1).

Most recently, we have extended our experiments and the simulations to more complex mixtures to study HBr and Cl_2 addition to SF_6/O_2 plasmas. This combination of gases is an alternative to the well-known Bosch process for deep feature etching. Upon adding HBr to an SF_6/O_2 plasma reduces undercut and increases the sidewall taper angle. On the other hand, adding Cl_2 to an SF_6/O_2 increases mask undercut.

References

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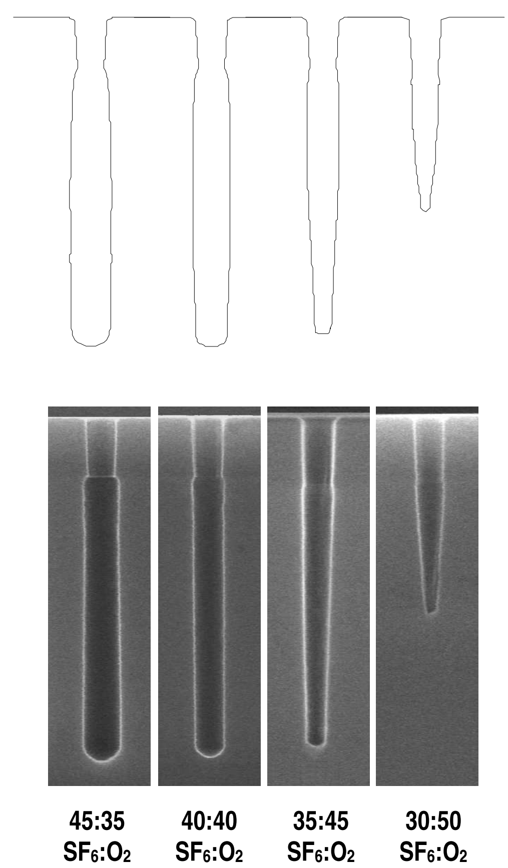

Figure 1. Comparison of etched (bottom) and simulated profiles (top) as a function of SF_6-toO_2 ratio in an SF_6/O_2 plasma. The flow rates of SF_6 and O_2 are ratios are given at the bottom of each profile