Modeling Investigation of Plasma Clean Processes

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In microelectronic fabrication, a wafer surface clean process before metal deposition (known as a “pre-clean” process) is essential for the removal of contamination from previous processing steps (e.g., plasma etching) and to ensure good adhesion between the deposited metal and underlying materials. There are two common cleaning processes: sputter preclean (SPC) and reactive preclean (RPC). SPC uses an inert gas (e.g., Ar) discharge.[1] In this process high energy ions are generated to physically sputter the surface of the wafer. Advantages of SPC include its assured cleaning ability, ease of implementation, and free-of-chemical-consequence nature. These process merits retain it as a mainstream application in state of the art semiconductor fabrication. A drawback is that corner faceting occurs at feature openings in SPC, leading to critical dimension (CD) loss. The gradually maturing RPC process employs a chemically reactive plasma (e.g., hydrogen based plasma) to drive chemical reactions at the surface for removing contamination. This approach is advantageous under conditions where retaining the initial profile is a stringent requirement as is the case in the sub quarter micron regime. Given the time cost associated with processing experiments and the benefit of looking into these processes at early stages of process integration, modeling and simulation of preclean processes is of high potential benefit. As such simulation of preclean processes is the topic of this work.

The modeling hierarchy consists of equipment and feature scale simulations. The bulk plasma model is based on the 2-dimensional Hybrid Plasma Equipment Model (HPEM) developed at the University of Illinois,[2] which has been well described in the literature. Sequential modules operate iteratively to calculate electromagnetic fields, electron energy distribution functions, species source functions, densities, fluxes and the like. For studying SPC, a Surface Kinetics Model (SKM) incorporating a site balance algorithm is coupled within HPEM to compute location dependent processing rates.[2] In SPC profile simulation, HPEM generated species fluxes and spatial-temporal characteristics of the sheath and pre-sheath are post-processed in a Monte-Carlo sheath model which generate energy and angle dependent distribution functions characterizing fluxes incident to the wafer. The fluxes and their characteristic distribution functions are inputs to the feature scale model, which computes the time evolution of profiles using a Monte-Carlo technique.

The model has been applied to the study of SPC processing. Material parameters for new process developments (sputter yield, threshold energy, sputter angular dependency), mostly unavailable in the literature, were obtained through calibration with a limited number of experimental data points. The calibrated model was then applied to study the impact of process parameters in a large process window consisting of coil power, bias power, and pressure. Predicted clean rates matched well with experimental results and were a test of the model extendibility (Figure 1). Simulations attribute feature faceting to the angular dependence of ion sputtering yield, which drives sputtering in a preferential direction. The model depicts that feature facet size evolves with increasing field sputter depth (Figure 2). As a contrast to SPC, an equipment model has been used to study RPC process. Here, plasma chemistry effects are critical to process metrics and will be reviewed in this work.

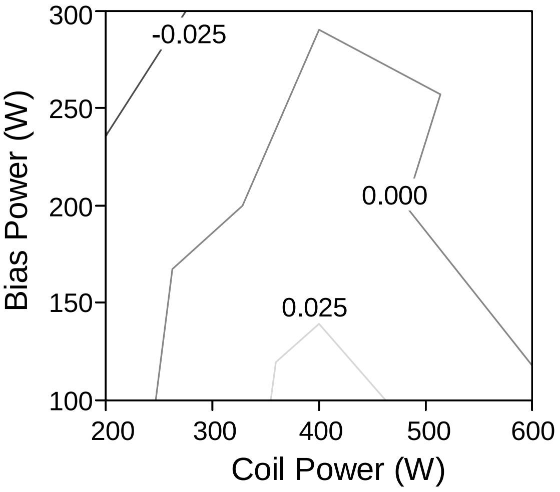

Fig. 1. Contour of relative differences in etch rates from simulation and experiments as a function of coil power and bias power.

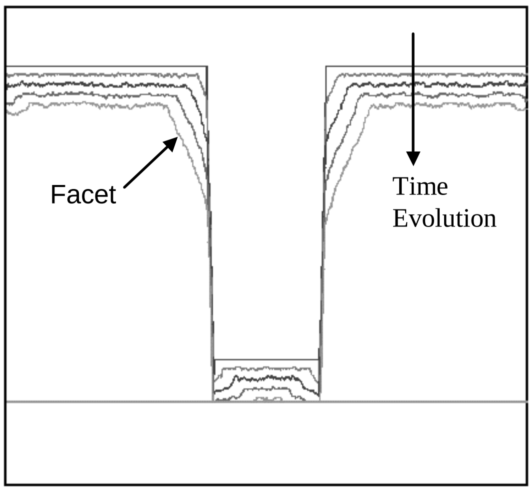

Fig. 2. Feature profile evolution in a SPC process.

[1] P. J. Matsuo, T. E. F. M. Standaert, S. D. Allen, G. S. Oehrlein, and T. J. Dalton, J. Vac. Sci. Technol. B 17, 1435 (1999).

[2] D. Zhang and M. J. Kushner, J. Vac. Sci. Technol. A 19, 524 (2001).

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