Integrated Modeling Investigation of Plasma Dielectric Etching Processes

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The trend in the microelectronics industry towards fabricating smaller and smaller features on larger wafers with more layers of metal in the back-end is increasing the time and cost pressure on traditional empirical process development for plasma etching. This has triggered active exploration of dry etch mechanisms to correlate general plasma and surface characteristics with process conditions. A phenomenological understanding of etch processes has improved significantly over the last decade. Integrated equipment-feature modeling of plasma etching processes has evolved to the point that a "knob-to-feature" description of the etch process can be effected given the right model inputs. With calibration from initial experiments, an integrated model can efficiently link etching results to process knobs, and provide predictive suggestions for process and equipment optimization. The development of an integrated plasma equipment-feature modeling infrastructure with incorporated surface reaction mechanisms, and its application to a photoresist/dielectric etching system, are the focuses of this work.

The simulation hierarchy developed here includes coupled equipment and feature scale models. Discharge equipment modeling is based on the 2-dimensional Hybrid Plasma Equipment Model (HPEM), which has been developed at the University of Illinois.[1] The plasma is approximated as a fluid in the HPEM. Electromagnetic fields, electron energy distribution, species source functions, densities, and fluxes are calculated by sequential modules in an iterative fashion. The HPEM results on species fluxes and electromagnetic fields are post-processed in a Monte-Carlo sheath model to generate energy and angle distributions of fluxes incident to the wafer. The fluxes and their distributions are inputs to the feature scale model, which computes the time evolution of profiles using a Monte-Carlo technique.

We investigated etching of stacked photoresist/SiO_2 films in inductively coupled fluorocarbon (c-C_4F_8/CF_4 based) discharges. The gas phase chemistry is based on a validated set of electron impact cross section data.[1] The etch mechanism for SiO_2 includes neutral passivation, CF_x polymerization, and ion assisted removal of volatile products, which are generally believed to be the dominant processes.[2, 3] The mechanisms developed here for photoresist etching consist of ion sputtering, ion activation, polymer deposition, and atomic F etching of activated sites. Ion-surface interactions are energy and incident angle dependent in the model. Modeling results on etch rates for SiO_2 and photoresist were validated by comparing with experiments at various bias powers.[Fig. 1] Profile simulation was also validated by comparing modeling and experimental results.[Fig. 2] The model quantitatively captured the nature of the evolution of the photoresist corner facet, which was attributed to the angular dependent sputter yield. The validated SiO_2/photoresist etch model was then applied to investigate the performance of a representative inductive plasma reactor with 300 mm wafer. The impact of various process/equipment parameters (gas chemistry, power supply, gas inlet, etc.) on the plasma properties (fluxes, ion energy, etc.), and their influences on etch results (rate, selectivity, profile, etc.), were investigated.

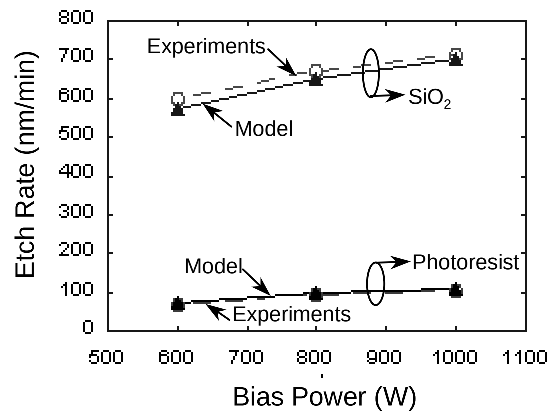

Fig. 1. Comparison of experimental and simulated etch rates for SiO_2 and photoresist at various bias powers. Results were obtained from Ar/c-C_4F_8 plasma etching conducted in a commercial inductive discharge tool.

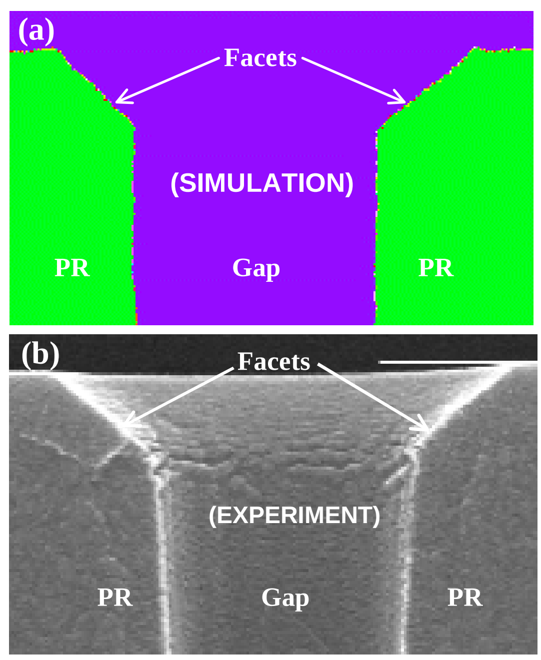

Fig. 2. Etched photoresist profiles from (a) simulation, and (b) experiment. Results were obtained from Ar/c-C_4F_8 plasma etching conducted in a commercial inductive discharge tool.

[1] S. Rauf and P. L. G. Ventzek, to be published in J. Vac. Sci. Technol. A 20, (2002).

[2] M. Scharpkens, T. E. F. M. Standaert, N. R. Rueger, P. G. M. Sebel, G. S. Oehrlein, and J. M. Cook, J. Vac. Sci. Technol. A 17, 26 (1999).

[3] M. Matsui, T. Tatsumi, and M. Sekine, J. Vac. Sci. Technol. A 19, 1282 (2001).