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Effects of Chamber Wall Conditions on Plasma Etching Processes

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Wafer-to-wafer process reproducibility is one of the major concerns in plasma etching of thin films. One of the sources of plasma process irreproducibility and process drift is the condition of the chamber walls. Plasma chamber walls can play a crucial role in determining the discharge properties such as ion density, electron temperature, and species concentration. Despite the importance of plasma-wall interactions, reactions occurring on surfaces in contact with the plasma are poorly understood and wall conditions are typically uncontrolled during etching. Situation is becoming even more complicated as more stringent demands are placed on plasma etching processes. For example, often, a stack of thin films of different materials must be etched sequentially in the same reactor using different gases. Complex multi-layered films are deposited on the chamber walls during the etching of the stack and interaction between successive etching steps through the changing wall conditions may have deleterious effects. Chemicals used and/or produced during the etching of one film may adsorb or deposit on the walls of the reactor and alter the chemical reactivity of the walls. The changing wall conditions cause variations in the discharge properties and directly affect etching reproducibility. This problem of process sensitivity to the wall conditions has been known for a long time but its management has remained an art. Thus, it is critical to monitor the wall conditions and the nature of the films and adsorbates that are deposited on the walls.

In order to investigate the effect of the wall conditions on the plasma properties, a novel diagnostic probe based on multiple total internal reflection Fourier transform infrared (MTIR-FTIR) spectroscopy was developed and used to study the nature of the species depositing and adsorbing on the chamber walls [1,2]. Briefly, the probe consists of an infrared transparent, trapezoidal crystal placed flush with the reactor wall. The crystal is exposed to the plasma and essentially experiences the same effects of the discharge as the chamber walls. Infrared radiation from an FTIR spectrometer is focused onto one of the beveled edges of the crystal and undergoes multiple total internal reflections until it emerges from the opposite beveled edge. Infrared radiation exiting the crystal is collected and focused onto a HgCdTe detector using reflective optics. During its traversal of the crystal, the infrared radiation is absorbed by the species depositing on the surface of the crystal exposed to the plasma.

Using this technique we studied the shallow trench isolation etching of Si where a photoresist patterned stack of anti-reflection coating, Si_3N_4, SiO_2 and Si is etched sequentially using gases as varied as fluorocarbons, Cl_2, HBr, and O_2. During the fluorocarbon etching of Si_3N_4 and SiO_2, fluorocarbon films deposit on the chamber walls. During the subsequent etching of Si by Cl_2/O_2, etch products such as $SiCl_x$ fragments react with the O in the plasma and deposit a silicon oxychloride layer on the reactor walls on top of the fluorocarbon layer. In order to maintain etching reproducibility, these multi-layered films must be cleaned before the next wafer is etched in the chamber. Reactions occurring on the wall surfaces and strategies to remove these complex multi-layered films to maintain reproducibility of wall conditions and etching processes will be discussed [1-5].

The effect of reactor wall conditions on Cl concentration and polysilicon etch rate uniformity was also studied in a high-density inductively coupled plasma reactor [6]. Experimental measurements of etch rate, wall conditions, and two dimensional ion flux distributions on the wafer are combined with a simple transport and reaction model for Cl atoms in the plasma to elucidate the effect of reactor wall conditions on the etch rate uniformity. Specifically, we focus on the effects of wafer-to-wafer drifts in the wall conditions and effects of such drifts in the uniformity of etching. The spatially averaged etch rate across the wafer surface increases with time as etch products reacting with residual oxygen in the chamber and coat the reactor walls with a thin layer of silicon oxychloride film. Etch rate is highest at the center of the wafer when the anodized aluminum reactor walls are maintained in a “clean” state, free of silicon oxychloride deposits. In contrast, the etch rate peaks at the edges of the wafer when the reactor walls are coated with the silicon oxychloride film. The spatially averaged ion flux increases slightly while ion flux uniformity does not change as the reactor walls are covered with silicon oxychloride film indicating that the drift in etch rate and etch uniformity is primarily due to the drift in atomic chlorine concentration and its spatial distribution. The increase in Cl concentration is due to its lower recombination probability on the silicon oxychloride film surface as compared to the “clean” anodized aluminum wall. As the reactor walls are coated with a silicon oxychloride film the etch rate distribution changes from a center-fast profile to a edge-fast profile due to a change in the dominant atomic chlorine depletion mechanism from wall recombination to recombination on the wafer surface.

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