Polymer Cleaning From Porous Low-k Dielectrics in He/H_2 Plasmas

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***Abstract*—Porous dielectrics such as SiCOH are used as the insulator in interconnect wiring in microelectronics devices to lower the dielectric constant and therefore decrease the resistive–capacitive delay. After etching a trench in low-k dielectrics in fluorocarbon plasmas, a CF_x polymer remains on the sidewalls, which must be removed in a manner that does not damage the low-k material. This can be accomplished using He/H_2 plasmas, which produce hot H atoms (i.e., energy > 1 eV). We present images of the distributions of hot H atoms and H^+ ions from an inductively coupled plasma and their resulting cleaning of a trench etched in SiCOH.**

***Index Terms*—Plasma cleaning, plasma etching, porous dielectrics.**

POROUS dielectrics having a low dielectric constant (low-k) are being used to lower interconnect-wiring capacitance to limit the resistive–capacitive time delay in integrated circuits. [1] SiCOH, i.e., silicon dioxide with CH_x groups lining the pores, is one commonly used material, having porosities as large as 50% with pore diameters of up to a few nanometers. Such dielectrics are typically etched in fluorocarbon plasmas in which there is deposition of a CF_x polymer. The polymer is then removed by a subsequent plasma clean to enable the deposition of diffusion barriers of metals such as Ti and Ta [1]. During the removal process, the photoresist (PR) is also typically removed. O_2 plasmas are generally used for such removal; however, these plasmas are often damaging to SiCOH. He/H_2 plasmas are being investigated for polymer and PR removal to reduce the potential damage to SiOCH [2].

In this paper, results from a computational investigation of polymer cleaning from porous low-k SiCOH in He/H_2 plasmas will be discussed. We modeled an integrated two-step etch-and-clean process. The sequence begins with the etching of an 8 : 1 aspect-ratio trench in porous SiCOH using an Ar/C_4F_8/O_2 capacitively coupled plasma (CCP). Residual CF_x polymers on the sidewalls of SiCOH were then removed using a He/H_2 inductively coupled plasma (ICP). The Hybrid Plasma Equipment Module was employed to obtain the energy and angular distributions for charged- and neutral-species incidents onto the surface [2]. The etch and cleaning reaction mechanisms were implemented in the Monte Carlo Feature Profile Module (MCFPM) with which the evolution of the low-k surfaces properties is predicted [3]. The MCPFM resolves the porous material with an approximately atomic resolution.

Polymer and PR removal in He/H_2 ICPs are accomplished by a synergy between hot H atoms, H^{**}, and ion bombardment. H^{**}, having a translational energy of up to many electronvolts, is generated by the dissociative excitation of dominantly vibrationally excited H_2 and by charge-exchange reactions. CF_x-polymer cleaning reactions by thermal H atoms are endothermic ($\Delta H = 0.1 \sim 0.9$ eV). Although included in the model, their endothermic nature produces few reactions. We found that CF_x polymers can be efficiently removed by H atoms with energy values > 1 eV as HF and fluorohydrocarbons. Hot H, He^+, and vacuum-ultraviolet photons remove H from CH_3 groups lining the pores to create the active sites which are useful in a subsequent sealing step. In addition, some removal of CH_3 groups occurs by H^{**} atoms as CH_4. The PR is dominantly removed by an ion-activated process.

Plasma properties (H^{**} and total ion densities and flux distributions to the wafer) and SiCOH feature properties are shown in Fig. 1. The etch step was performed using a CCP sustained in Ar/C_4F_8/O_2 $= 80/15/5$ at 40 mTorr and powered at 10 MHz.The cleaning was performed by an ICP reactor sustained in a 10-mTorr He/$H_2 = 75/25$ mixture powered at 13.56 MHz with a bias of 10 MHz on the substrate. The H atom and the total ion density in the reactor is shown in Fig. 1. The total ion density has a maximum value of 5×10^{10} cm^{-3}, whereas the H atom density has a maximum value of 2×10^{13} cm^{-3}, which is depleted in the center of the reactor due to gas heating (up to 800 K). The same mechanisms responsible for producing the H^{**} also generally heat the gas. The energy and angular distributions of H^{**} and ions are shown in Fig. 1. The ion fluxes (10^{16} cm^{-2}s^{-1}) largely responsible for the PR removal have an average energy near 25 eV and an angular spread from the vertical of $< 15°$. The H^{**} atom fluxes (total H flux of 8×10^{17} cm^{-2}s^{-1}) have a nearly isotropic angular distribution and a peak at the maximum value at < 1000 K. However, the tail of the energy distribution extends to above 10 eV. These hot isotropic atoms are able to both penetrate into the trench and treat the entire sidewall. The before- and after-cleaning profiles show that the vast majority of the CF_x polymer and the PR mask can be removed without a significant degradation of SiOCH by the removal of CH_3 lining the inside of the pores. Some damage does occur, as shown by the inset, where a pore has been "opened up" by the removal of CH_3. The entire surface is also activated in preparation for subsequent pore sealing.

In conclusion, we have shown the images of the plasma and porous SiOCH feature properties for the He/H_2 cleaning of a trench following etching in a fluorocarbon gas mixture. The

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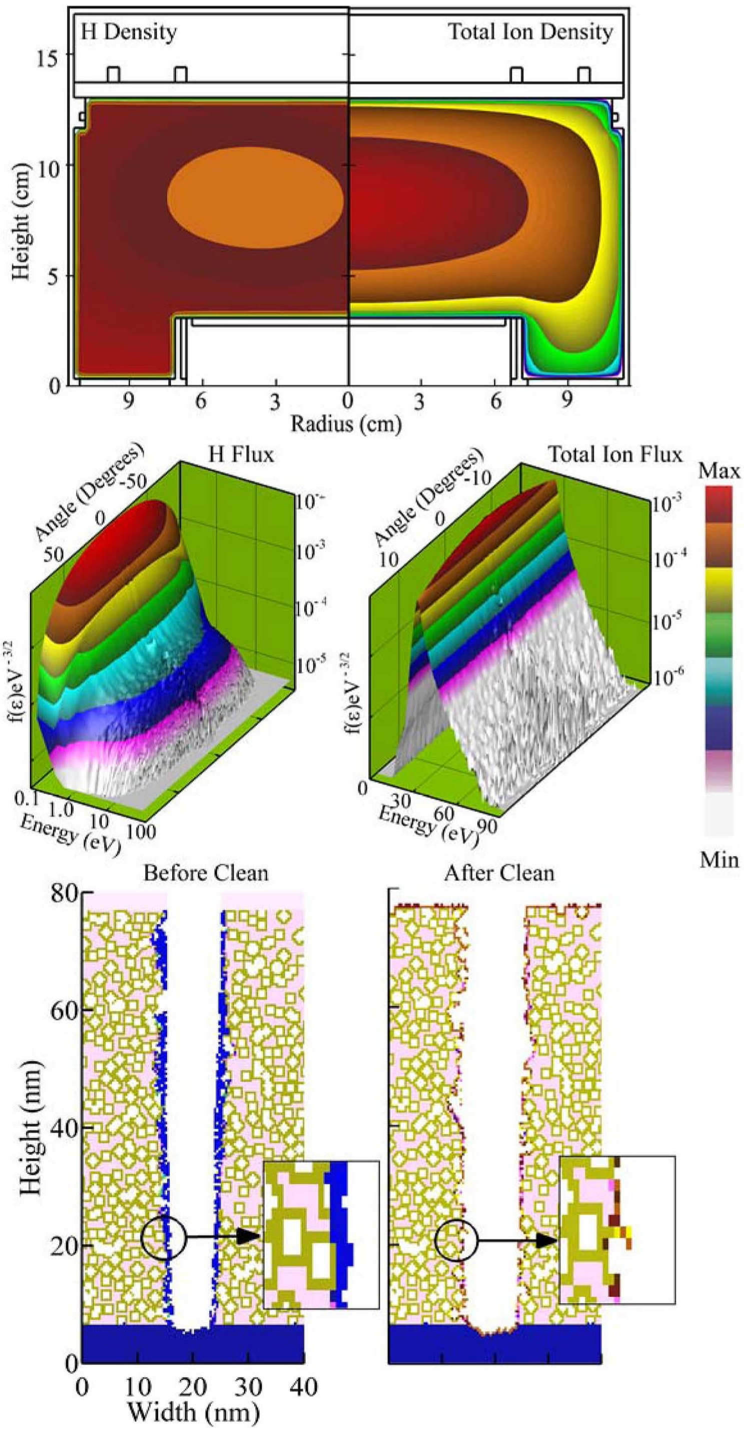

Fig. 1. Properties of the plasma and feature during the cleaning of polymers from a trench etched in porous SiOCH by a He/H_2 ICP. (top) Densities of H atoms and ions in the ICP reactor. (middle) Fluxes of H atoms and ions to the substrate. (bottom) Trench before and after cleaning. The blue cells on the sidewalls denote polymers, the olive green is CH_3 lining the pores in SiO_2, and the red/yellow cells are activated sites. The insets show how some damage may occur during the polymer removal.

cleaning extends and removes polymers from deep in the trench without significant damage.

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