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 \(\geq 1\) 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-stepetch- and-clean process. The sequence begins with the etching of an 8 : 1 aspect-ratio trench in porous SiCOH using an Ar/C\(_2\)F\(_6\) 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 MCFPM 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 \(\geq 1\) eV as HF and fluoroxyhydrocarbons. Hot H, H\(^+\), 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\(_2\)F\(_6\)/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 \(5 \times 10^{10}\) cm\(^{-3}\), whereas the H atom density has a maximum value of \(2 \times 10^{10}\) 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 \(< 15\)\(^\circ\). The H\(^+\) atom fluxes (total H flux of \(8 \times 10^{17}\) 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
cleaning extends and removes polymers from deep in the trench without significant damage.

REFERENCES

