Task ID: 425.019
Task Title: Low Environmental Impact Processing of sub-50 nm Interconnect Structures
Deliverable: Report on the characterization of thermal and mechanical properties of sacrificial layer material for incorporation into interconnect.

Summary Abstract:

This project evaluates the performance of gas, liquid, and supercritical fluid processes to clean sub-50 nm structures, fabricate multilevel air gaps, and planarize surfaces without contact. These tasks were chosen because of the potential to reduce resource use and waste production by understanding process limitations. The primary objective of this project is to develop a set of principles to guide the choice of materials and processing fluids to fabricate sub-50 nm structures with the lowest cost of ownership.

The thermal and mechanical properties of initiated chemical vapor deposition (iCVD) films were investigated with respect to the properties require for sacrificial layers for fabrication of prototype air gap structures for high performance interconnect designs. The iCVD method synthesizes polymers in situ on surfaces without using solvents. Both the cleanliness of decomposition and the thermal stability are important characteristics of a sacrificial polymer. While it is required to decompose cleanly leaving behind negligible residue, the sacrificial layer also must be stable up to a certain temperature to prevent premature deposition. This requirement is necessary because subsequent microfabrication steps may be required to operate at high temperatures.

Technical Results and Data:

Thin films of iCVD sacrificial polymers were synthesized using a methacrylate monofunctional monomer (M) and a difunctional monomer, ethylene glycol dimethacrylate, (X) as the cross-linker All films used in the analyses had initial thicknesses of over 1.3 µm as measured with using variable-angle spectroscopic ellipsometry (VASE). VASE was performed on a J. A. Woollam M-2000 spectroscopic ellipsometer with a xenon light source. Data were acquired at three angles (65°, 70°, and 75°) and 225 wavelengths, and the Cauchy-Urbach model was used to fit the data.

Thermal properties were measured using the interferometry for thermal stability (ITS). The change in film thickness was monitored by noting the reflectance of a 633-nm HeNe laser beam off the substrate. The onset temperature of decomposition was taken as the temperature at which the laser signal started to fluctuate. The samples were kept under a nitrogen atmosphere throughout the annealing. They were heated to 150 °C from room temperature in 10 min. and kept at 150 °C for 30 min. The temperature was then raised to 240 °C in 30 min. and kept constant for another 30 min. Finally, the temperature was raised to 430 °C over the course of 60 min. The samples were then kept at this temperature for 90 min. before being cooled to room temperature. Prior to the end of the 90-min. period, the laser signal of each of the films had become steady indicating no further thickness change. This ramp-and-soak temperature profile was to facilitate equilibration of temperature within the apparatus. VASE was performed before and after annealing for evaluating of thickness losses.

Figure 1 shows the percent thickness removal decreases and the onset temperature of decomposition as a function of increasing crosslink density. It is interesting to note the high degree of cleanliness of the decomposition even for the most crosslinked film. In fact, all the films had residue thicknesses of less than 0.01 µm. The non-crosslinked film had a 99.82% thickness loss.

Figure 2 shows the loading and unloading profiles used for measuring mechanical properties by nanoindentation. During the creeping portion, the viscoelasticity in the polymer films relaxes. Films deposited at the highest percentage of crosslink fraction have Young's modulus values of 5.15 ± 0.12 GPa.and Hardness values of 0.70 ± 0.02 GPa. These measurements represents a significant increase in mechanical robustness over the film deposited with lowest fraction of crosslinker which had a Young's modulus of 4.27 ± 0.19 GPa and a Hardness of 0.44± 0.19 GPa.

Conclusions:

The iCVD films have onset temperatures of decomposition in the range of 270 to 302 °C. They also decompose cleanly during thermal annealing, leaving behind negligible residue when raised to 430 °C under a nitrogen atmosphere. Crosslinking does not cause an appreciable increase in the amount of residue but enhances the mechanical properties of the films.

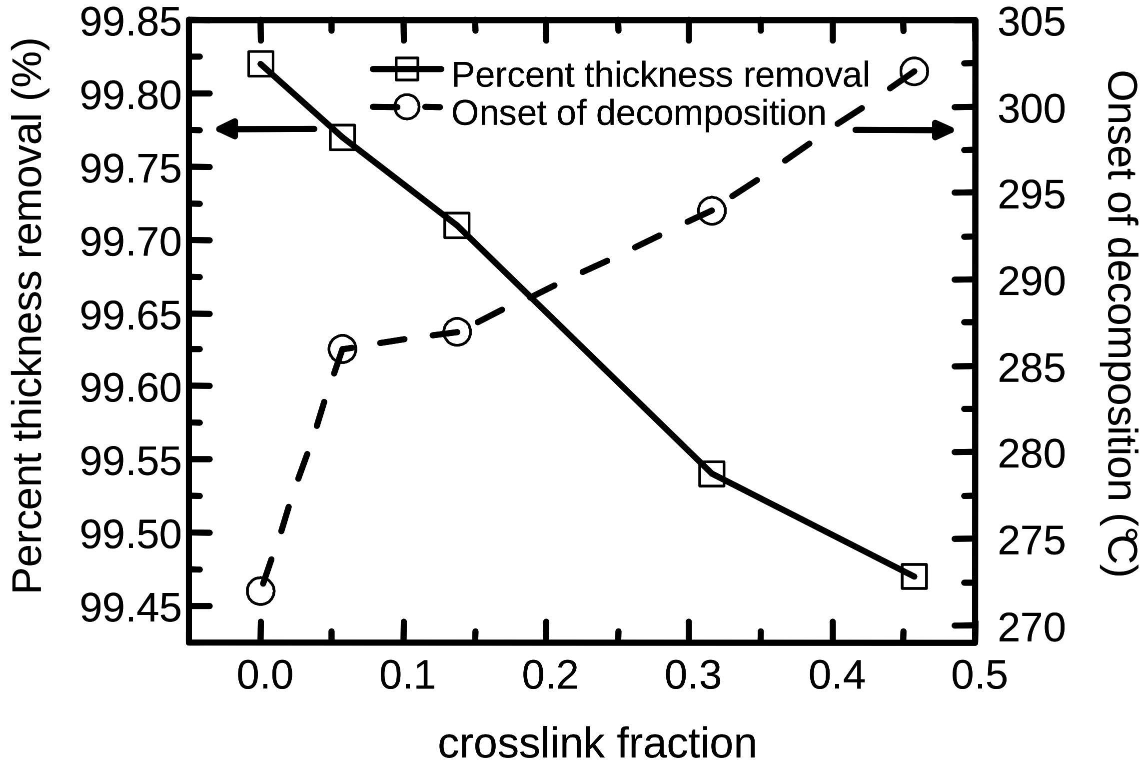

Figure 1. Thermal properties of iCVD films as a function of the crosslink density of the films. Left side axis corresponds to percentage of the sacrificial material remaining after annealing. The right side axis displays the temperature at which decompositions begins, representing the highest temperature which could be used from subsequent processing steps for integration of the sacrificial layer into an air gap structure.

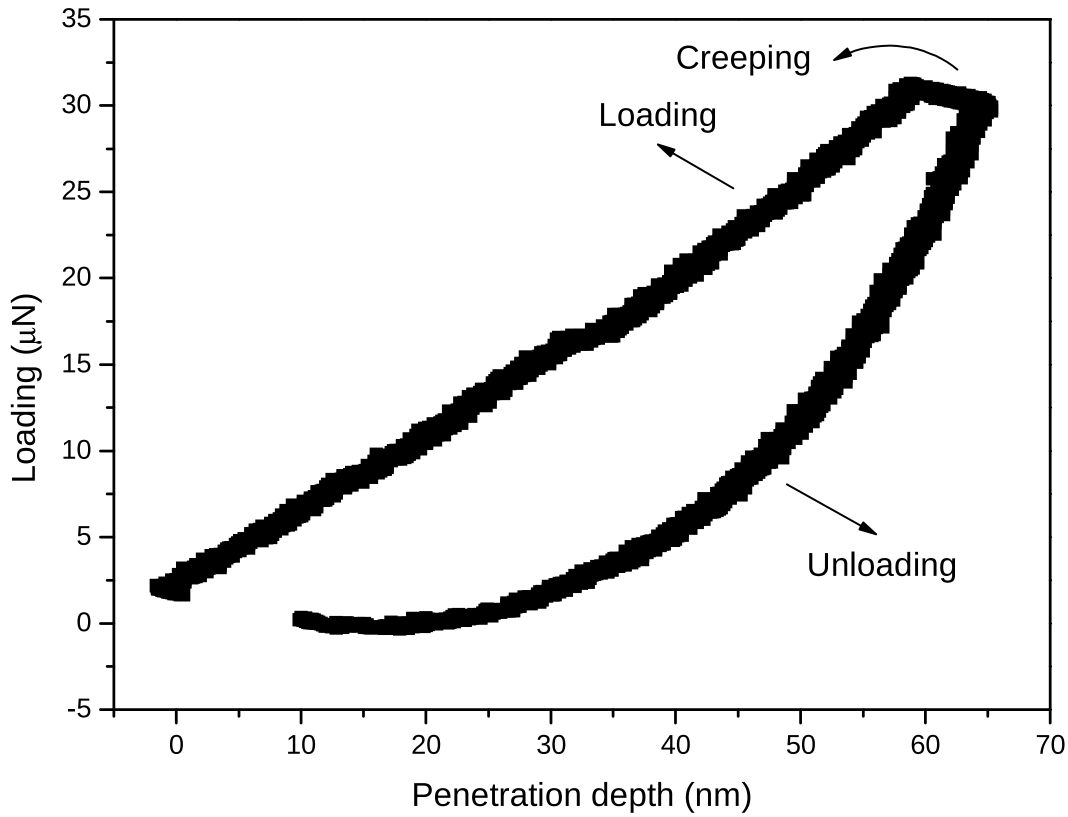

Figure 2. The loading and unloading profile used for nanoindentation measurement on the sacrificial layers which allows for the relaxation of viscoelastic effects in the polymeric materials.