Micro/Nano Mechanical and Tribological Behavior of Metallic Thin Films

X. Li, M. Curry, F. Huang, S. C. Street, and M. L. Weaver

MINT Center, Department of Metallurgical and Materials Engineering and Department of Chemistry
The University of Alabama

This project was funded by grant NSF-CMS 0324601 & shared equipment from NSF-DMR 0213985.

Abstract

Previously it was demonstrated that increased adhesion could be achieved between evaporated Au films and Si substrates through inserting a dendrimer (D) monolayer between [1,2]. Concomitant with this improved adhesion was an increase in nanindentation hardness. In this present investigation, nanoindentation and nanoscratch tests have been conducted on dendrimer-mediated and dendrimer-free Au and Cu thin films to explore the manner in which dendrimer underlayers influence their mechanical and tribological properties, and to yield valuable information that will lead to the development of hybrid dendrimer-mediated films.

Experimental procedure

Metal films were deposited via magnetron sputtering (SP) and thermal evaporation (EV). Generation 8 (G8) PAMAM dendrimer was used. Film hardness was determined via the Oliver and Pharr (O&P) method. Indentation impressions and scratch tracks were imaged by AFM and SEM.

Composite nanohardness

- For a 12.5 nm film thickness EV Au/D/Si exhibits a higher hardness than EV Au/Si. The hardness did not change in SP Au films.
- Both EV and SP Cu/D/Si films show lower hardness than corresponding Cu/Si films. Similar results were obtained for Ti, Cr, and Al films (not shown here).
- Hardness values obtained using the O&P method, i.e., H(O&P), were erroneously high. The O&P model was thus modified to account for pile-up around the indenter. The corrected hardness (Hc) showed the same trend as H(O&P).

Scratch profiles and SEM images following nanoscratch tests of 15 nm Au films

- Critical loads (CL) for 15 nm Au films:
  - EV Au/D/Si: ~4.5±0.3 mN; EV Au/Si ~1.5±0.3 mN; SP Au films ~1 mN.
  - The measured hardness and scratch CL are influenced by the intrinsic film hardness and interfacial adhesion. In Au films, grain refinement was observed which may account for the hardness increase observed in EV/Au/D/Si films.
  - For all Au films scratch tracks exhibited cutting after the CL which suggests that interface debonding dominates scratch failure. Prior to the CL, long range plowing was observed in the EV Au films, which infers good interfacial adhesion.
- CL for 15 nm Cu films:
  - No significant difference between EV and SP Au films.
  - Cu/D/Si: ~10.1±1.8 mN; Cu/Si: ~11.6±0.8 mN.
  - Plowing occurred in the Cu/D/Si prior to scratch failure. Jagged scratch tracks were also observed.

Conclusion

- Evaporated Au/D/Si films have higher hardness and scratch critical loads than other Au films.
- The main reason is assumed to be that interfacial adhesion is enhanced by the presence of a dendrimer that restrains delamination at interface and blocks the film deformation.
- Enhanced adhesion was observed in EV Au films, but not in SP Au films. The adhesion enhancement is due directly to the poor native bonding between Au and SiO2. The underlying mechanisms are under investigation.
- The composite hardness of Cu/D/Si films is comparable to Cu/Si films, and the scratch critical loads are nearly equal. The better native bonding between Cu/SiO2, than Au/SiO2, tempers the adhesive enhancement.

References

2. Street et al., Chem. Mater., 13 (2001), 3669-3677