Dendrimer-mediated Growth of Thin Metal Films: An X-ray Study

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

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

Motivation
• G8 PAMAM dendrimer monolayer can act as a “glue-like” layer to improve adhesion between evaporated Au films and SiO2/Si substrates.
• Can similar effect be found in sputtered metal films?
• How can we study the buried interface separating the metal film and dendrimer layer? Interfacial reactions? Any influence on film formation process?

Experimental procedure
• Au and Cu films were deposited via magnetron sputtering.
• G8 PAMAM dendrimer monolayer was used.
• Grazing incidence x-ray scattering (GIXS) studies were performed (XRR + GIXRD).

GIXS Background
• For hard x-rays, the refractive index of matter is: 
  \[ n = 1 - \delta - i\beta \]
• \( \delta \sim 10^{-5} \) dispersion term: \( \beta \sim 10^{-7} \) absorption term.
• The critical angle (\( \alpha_c \)) is:
  \[ \alpha_c = \sqrt{\frac{\delta}{\beta}} \]
• The depth at which the intensity drops by a factor of \( 1/e \) is a function of incidence (\( \alpha_c \)) and \( n \):
  \[ D_{1/e} = \frac{1}{4\pi} \sqrt{\alpha_c^2 - 2\delta + 4\beta^2} \sim 1/2 \]

Profile fitting analysis
• G8 PAMAM dendrimer monolayer can act as a “glue-like” layer to improve adhesion between evaporated Au films and SiO2/Si substrates.
• Can similar effect be found in sputtered metal films?
• How can we study the buried interface separating the metal film and dendrimer layer? Interfacial reactions? Any influence on film formation process?

XRR patterns for a G8 Dendrimer Monolayer
• The Parratt scheme was used to calculate the reactivity. Roughness was incorporated by the Nevot-Croce method.
• The thickness (\( t \)), roughness (\( \sigma \)), and density (\( \rho \)) of each layer can be obtained by fitting.

GIXRD patterns for Cu and Au films (~50 nm)
• Au films are not homogeneous. A distinct mixed layer between dendrimer and Au cannot be identified.
• Both Cu and Au films are polycrystalline and without strong texture.

Implications from grain refinement
• The grain size \( D \) is related to the nucleation rate \( N \) by
  \[ D \propto \frac{1}{N} \propto \exp\left(\frac{G_c}{kT}\right) \]
• A smaller \( D \) requires a smaller formation energy \( G_c \), which hints at a smaller contact angle \( \theta \).
• The thermodynamic work of adhesion is: \( W_{ad} = \gamma_d (1 + \cos \theta) \)
• Hence, promotion of grain refinement means higher \( W_{ad} \).
• Higher \( W_{ad} \) does not necessarily leads to higher practical work of adhesion in that the latter includes mechanical contributions (from inelastic deformation of the film and substrate).

Conclusions
• There is no distinct mixed layered formed in sputtered deposited Au and Cu films on D8/SiO2/Si.
• ~33% grain refinement was found in Cu films.