Stress Evolution During Growth of Metal Thin Films

R. Moenig, J. Leib, A.R. Takahashi, C.V. Thompson
Sponsorship: NSF

Mechanical stress strongly influences the reliability and performance of highly miniaturized devices, therefore control of stresses in deposited structures and films is of general interest. Obtaining this control requires an understanding of the physical processes involved, as well as a quantitative knowledge of their contributions to total stress of a system. Our work focuses on the stresses that evolve during e-beam evaporative growth of high mobility metals on different amorphous substrates. Figure 1 shows a typical stress curve obtained by measuring substrate bending with a capacitive displacement sensor during film deposition. During early stages, islands nucleate and grow on a surface, causing a compressive stress thought to be related to the surface state of the growing islands [1,2]. As deposition continues, islands begin to coalesce and form a continuous layer. During this process, the stress becomes increasingly tensile while surface energy of the islands is transferred into grain boundary and elastic energy. After the film becomes continuous, the stress reverses and approaches a constant compressive value (again, thought to be related to the state of the film surface during deposition). One possible method of modifying the observed stress thickness behavior is to vary the size of islands using growth interrupts before island coalescence. Figure 2 shows the coarsening of islands during an interrupt which occurs on timescales corresponding to the mobility of an atom on the substrate. Upon resumption of growth the resulting larger islands coalesce at greater thicknesses and therefore lead the tensile peak in Figure 1 to shift towards higher thickness values. Flash depositions of Ta on the surface of deposited films allow for atomic force microscopy imaging of “frozen” films as shown in Figure 2 and provide a method for correlating the island size after a given length of interrupt with corresponding changes in measured stress curves. The ability to lock in a surface state at any stage of deposition or to interrupt growth also provides the means for exploring several other fundamental film stress generators, including the relaxation of stress due to coarsening of grains and islands and due to surface roughness.

Figure 1: Stress measurement during deposition of Au on borosilicate glass. Deposition occurred at 1 Å/s, substrate was held at RT.

Figure 2: Atomic force microscope phase images of 40 Å Cu films deposited on SiO2. (a) Ta deposition immediately after Cu growth, mean particle diameter 15 nm. (b) Ta deposition 15 min after Cu growth, mean particle diameter 21 nm.

REFERENCES: