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Atom Probe Tomography of Al-Cu Precipitation in an Al-5 at.%Cu Thin Film

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Al-Cu alloy thin films have found a variety of uses in microelectronics because of their simple processing and good electrical conductivity. In particular, the Cu additions have shown to reduce electromigration effects that occur at high current densities in Al interconnections. The reduction of electromigration is associated with the segregation of Cu to grain boundaries within the Al matrix and the precipitation of Al-Cu intermetallic phase(s) [1]. Recently, Choi *et al*. [2] reported atom probe studies of an Al-2at.%Cu film. In this work, Cu segregation to grain boundaries was clearly evident and they did not observe the formation of any metastable intermetallic phases commonly observed in bulk Al-Cu for similar compositions. In the present work, we have investigated richer Cu concentrations and the interaction of different underlayers on the precipitation in an Al-Cu thin film.

A series of ~20 nm thick Al-5at.%Cu films were co-continuously sputter deposited from two elemental targets with a working gas of UHP Ar at 2.5 mTorr. Prior to sputtering, the base chamber was $<10^{-7}$ Torr. The films were sputter deposited onto pre-fabricated Si tips that were either bare Si (with native surface oxide) or had a Pt or NiFe film on the surface of the tip which served as an underlayer for the Al-Cu film. Once the Al-Cu film was deposited, the specimen was annealed at 240°C for 4 hours under a flowing Ar+5%H_2 environment to facilitate precipitation of the Θ-phase (Al_2Cu). Post-annealing, the coated tips were placed in a Local Electrode Atom Probe (LEAP) [3]. The needle was cryogenically cooled to 115K and field evaporated at 200 kHz at a 1% field evaporation rate.

As can be seen in Fig. 1, we clearly see the depletion of Cu within the Al matrix and the formation of two Al_2Cu Θ-phase precipitates. The precipitates exhibited a disk shape morphology that expands laterally within the film and grew up towards the free surface and substrate interface. Choi *et al*. [2] reported that for their lower concentrations of Cu, the second phase formation or segregation of Cu was not present at these surfaces. At these annealing temperatures, the native oxide at the Si substrate appears sufficient to impede any Si interdiffusion within the Al-Cu matrix. Similarly, it was found that a chemically abrupt interface was present between the annealed Al-Cu film and the NiFe underlayer. This materials' interface is critical in providing potential leads to magnetic related sensors. Unlike these two films, the Pt underlayer significantly interdiffused into the Al-Cu film upon annealing, as shown in Fig. 2. Interestingly, the Cu concentration increases and the Pt concentration decreases near the surface of the film even though Pt and Cu have complete solid solubility (at elevated temperatures). In contrast, Al and Pt only exhibit solid solubility at concentrations greater than ~90at.% Pt. Surprisingly, this level of either Pt or Cu is well within the supersaturation for the formation of Al-based intermetallic(s). There was no evidence of phase

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separation or clustering of these elements in the Al matrix. Although this anneal was able to promote thermally activated diffusion of Pt into the matrix, the kinetics of any secondary phase formation must be significantly high and/or hindered. Consequently, this system, at the annealing temperatures investigated, is unable to achieve a favored phase. The role of Pt in kinetically limiting phase separation in Al-Cu films will be addressed in this presentation.

References:
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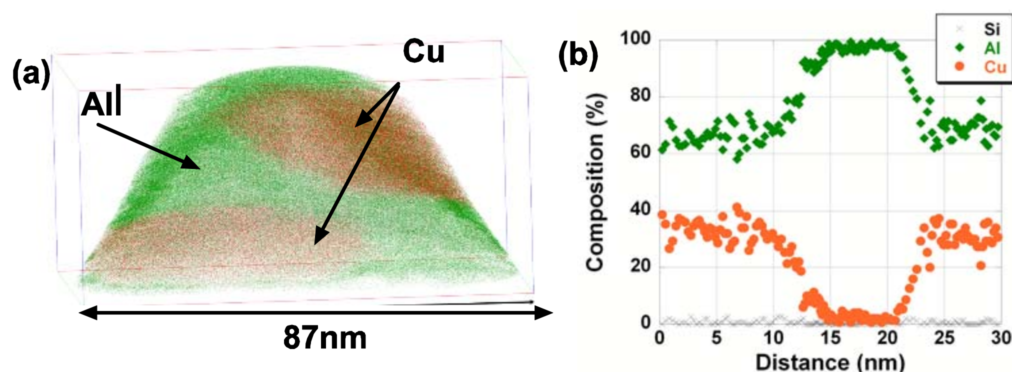

Fig.1: (a) Atom map reconstruction of the Al and Al_2Cu phases within the film (b) Composition profile through the two precipitates

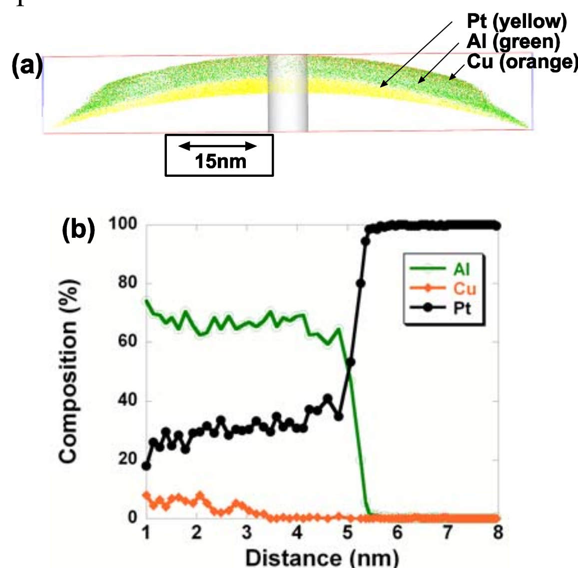

Fig.2: (a) Atom map reconstruction of the interdiffused Pt underlayer within the Al-Cu film. Note the lack of phase separation (b) Compositional profile through the film and underlayer.

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