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Influence of Co Underlayer Thickness on Mass Resolving Power in Field Evaporated Cu/Co Bilayer

K. Tippey, B.C. Hornbuckle, B. Fu, and G.B. Thompson

University of Alabama, Department of Metallurgical & Materials Engineering, Tuscaloosa, AL 35487-0202, USA

A critical aspect of atom probe tomography is the ability to correctly range the time of flight mass spectrum. If the field evaporation is not optimized where atoms field evaporate at times not at the peak field conditions, the mass spectrum will yield long tails. These mass-to-charge tails are concerning in that they can lead to peak overlaps between different species as well as incorrect compositional determination if not all the ions are ranged and counted correctly.

In the current study, the influence of a Co underlayer on the mass resolving power of Cu is studied. Co/Cu based multilayers have received interest because of their use in giant magnetoresistance devices. The bilayer studied in this work was sputter-deposited on a n-doped Si pillar with a 5 nm Cr layer to improve the adhesion of the bilayer to the substrate. A 200 nm Cu film, with no Co, was deposited to serve as a base line comparison to a 80 nm Co/200 nm Cu and a 160 nm Co/200 nm Cu bilayer. The Si post was a 2 x 2 μm flat surface requiring annular ion milling using a focus ion beam to yield the correct needle-shape geometry required field evaporation. An *in situ* 2 μm Pt coating was deposited over the film to provide a protective surface during the shaping of the needle. Ideally, the milling was ceased at the Pt/Cu interface. Particular care was done to ensure that the taper angle and radius of curvature was equivalent between each specimen. A representative tip is shown in figure 1. Since experimental variation will occur, three specimens for each Co thickness - 0, 80, and 160 nm - were made. The time-of-flight mass spectrums were averaged to eliminate small variations that could be present between tip geometry as well as in laser focus point fluctuations on the tips during field evaporation. Evaporation was continued from the Cu until it penetrated ~50 nm into either the Co layer or Si substrate (if no Co underlayer was not present).

Each film was run in a Cameca Local Electrode Atom Probe (LEAP) 3000XSi. The tips were held at a base temperature of 30 K, laser pulsed with a λ = 532 nm and at an energy density of 33 pJ/mm^2 at 250 kHz (one experiment was done at 10 kHz). Targeted evaporation was set a 0.5%. During field evaporation, the standing voltage ranged from ~ 2 keV to ~5 keV as the tip evolved.

As the Co thickness increased, the full width half maximum (FWHM) increased with increasing Co thickness, as seen in figures 2 and plotted in figure 3. The thermal conductivities for Cu and Co is ~75 W/m*K and 10 W/m*K, respectively. The lower thermal conductivity of Co can cause a retention of heat within the specimen tip which is manifested by the uncontrolled field evaporation of Cu after the pulse ceases. Interestingly, in prior work of atom probe tomography in Cu/Co multilayers [1], this mass resolving degradation was not noted. This maybe a result that these previous studies involved smaller volumes as a consequence of an individual films being one to a few nanometers thick.

The mechanism of field evaporation, wither an electro-optical or thermal effect, by pulsed laser has been a matter of discussion [2]. To determine if the degradation of Cu's FWHM is dominated by electro-optical or thermal effects, the pulse frequency of the laser was reduced from 250 kHz to 10 kHz keeping all other atom probe run conditions equivalent for a 160 nm Co/200 nm Cu bilayer. As can be seen in figure 3, a significant improvement was achieved. By reducing the pulse frequency, the specimen tip was provided adequate time for the heat to be extracted from the Co layer prior to the next pulse. If it was dominated by an electro-optical mechanism, wither pulsed at 250 kHz or 10 kHz, the mechanism would be the same and the mass spectrums would be equivalent. Based on the improved FWHM with decreasing laser pulse frequency, the dominate mechanism for field evaporation appears to be primarily or solely a thermal assisted effect.

References:

[1] A.K. Petford-Long *et al*. *Microscopy and Microanalysis* **10**(3), pp. 366-372 (2004)

[2] B. Gault *et al. Ultramicroscopy* **107**(9), pp. 713-719 (2007)

[3] This work was funded under NSF-DMR-1207220

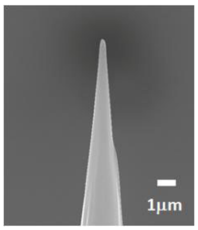

Figure 1: SEM micrograph showing a representative ion milled atom probe tip with the bilayer.

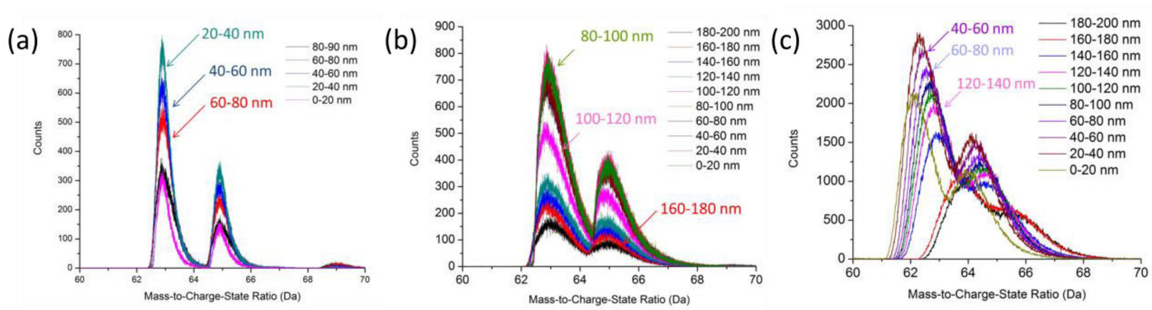

Figure 2: Cu's mass spectrums for the following Co underlayer thicknesses: **(a)** 0 nm **(b)** 80 nm and **(c)** 160 nm. The sub-sectioned 20 thicknesses represent the data volumes used for the FWHM analysis referenced to the distance from either the Si-Cu interface for (a) or from the Co-Cu interface for (b) and (c).

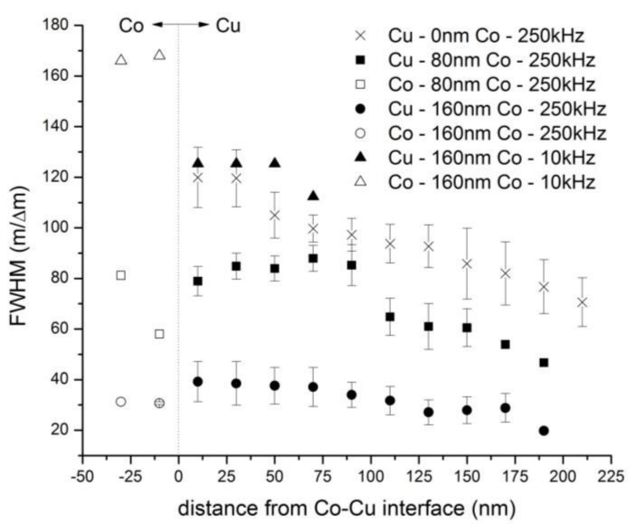

Figure 3: Plot of FWHM vs. distance from the Co-Cu interface.

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