ESRF	**Experiment title:** Interface Structure in Permalloy-Copper Multilayers	**Experiment number:** SI-506
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Report:

The poor thermal stability of permalloy/copper multilayers has been a significant problem in their application in spin valves. It is known however, that doping of cobalt at the interfaces not only increases the giant magnetoresistance (GMR) but also improves the thermal stability. The increased GMR on doping has been interpreted as critical evidence for interface scattering determining the magnitude of the GMR. We have used scattering of synchrotron radiation to study the structural changes associated with annealing of multilayers of nominal composition [Cu(Å) $Ni_{0.8}Fe_{0.2}$(Å)]$_{50}$ and [Co(Å)Cu(Å)Co(Å)$Ni_{0.8}Fe_{0.2}$(Å)]$_{50}$ grown by magnetron sputtering on (001) Si substrates.

In-situ measurements of the grazing incidence x-ray reflectivity and diffuse scatter were performed in a vacuum of better than 10^{-6} Torr in the Bühler HDK 2.4/DP furnace on beamline BM16. Despite some difficulties in retaining sample alignment at the very low incidence and exit angles due to sample movement as the furnace warmed up and the sample holder expanded, excellent data sets were recorded. The furnace temperature was carefully calibrated by replacing the sample with NIST silicon powder standard SRM640b and measuring the lattice parameter as a function of the furnace thermocouple temperature. From the tabulated thermal expansion coefficient of silicon, a true measure of the sample temperature was obtained.

High resolution powder diffraction measurements showed no change in symmetry on annealing but a small contraction by 0.22% of the average lattice parameter of the multilayer. Superlattice satellites, visible only on the 111 Bragg peak in the Co doped multilayer, increased in separation, indicating a reduction in the period of the multilayer. No change in the texture was observed in any sample on annealing.

Undoped multilayers exhibited GMR of up to nearly 20% at room temperature but with a sharp triangular shape and slow approach to saturation indicative of biquadratic coupling between layers. Co doped layers showed a room temperature GMR of up to 50% and a more parabolic variation with field, indicative of strong bilinear antiferromagnetic coupling. No change was measured in the GMR after annealing at 175°C for 1 hour in argon but for both doped and undoped material, the GMR fell dramatically on annealing at 275°C.

At annealing temperatures up to 203°C, there was little change in the grazing incidence x-ray diffuse scatter for either type of sample. (In some experiments there was evidence of roughening of the top surface, probably due to oxidation.) On raising the annealing temperature to 243°C, a broad peak of strong diffuse scatter was observed at the scattering angle corresponding to the first order multilayer Bragg peak in the undoped samples (Fig 1). From the width of the peak in reciprocal space, we deduce that the scatter arises from a roughness of in-plane correlation length 1200±200Å. An equivalent peak is observed in the cobalt-doped samples, but this does not begin to appear until 263°C and develops strongly only at 283°C. The associated in-plane length scale is 1600±200Å. The peak is not present when an equivalent scan of the specimen angle is made with the detector away from the multilayer Bragg peak, showing that the long length-scale roughness is conformal through the multilayer and associated with the copper/permalloy interfaces [2].

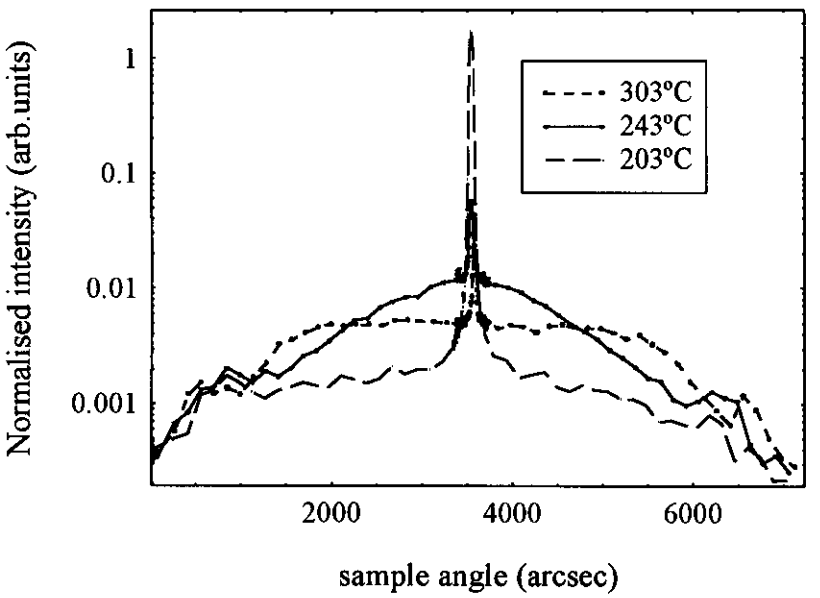

Fig. 1. Change in grazing incidence diffuse scatter during in situ annealing of an undoped multilayer. The scan is of the sample only, at fixed detector angle. Note the fall in intensity of the sharp specular peak as the annealing temperature increases. Wavelength 1Å.

On increasing the temperature to 303° the diffuse scatter becomes more uniformly distributed as a function of angle, a feature associated with a shortening of the in-plane correlation length of the roughness. There is a fall in the integrated diffuse scatter but this may only reflect the change in correlation length, not a change in the amplitude of the roughness [1]. There is a fall in the Bragg peak in the specular reflectivity profile but the peak remained still visible at 303°C. We thus conclude that only a limited amount of interdiffusion has taken place and distinct interfaces remain present in the multilayer.

[1] I. Pape, B. K. Tanner and M. Wormington, J. Non-Crystalline Solids **248** (1999) 75

[2] B.D.Fulthorpe, T.P.A.Hase, B.K.Tanner, C.H.Marrows, B.J.Hickey, submitted to J. Magn. Mag. Mater