Microstructural and micromagnetic characterization of thin film magnetic tunnel junctions

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Magnetic thin films and multilayers are of increasing technological importance. There is particular interest in the behavior of magnetic tunnel junctions (MTJs) which consist of ferromagnet-insulator-ferromagnet combinations. The conductance of such systems depends strongly on the relative alignment of the magnetization in the two ferromagnets.[1] This effect lends itself to the development of sensitive magnetic field sensors and provides the basis for enhanced information storage capabilities (MRAM - magnetic random access memory). Much relevant microstructural and micromagnetic detail about MTJs can be provided by characterization in the electron microscope using plan-view and cross-sectional geometries. We describe here our studies of thin film tunnel junctions comprised of CoPtCr alloy ("hard") underlayers, Al_2O_3 insulating barriers and Co, CoPt or NiFe alloy ("soft") free layers. These MTJs were prepared using magnetron sputter deposition onto thermally oxidized Si substrates at ambient temperatures with metal contact masks. Additional samples were prepared for plan-view observation by deposition onto thin (~55nm) silicon nitride membranes. High-resolution studies utilized a JEM-4000EX, and a Philips CM-200 FEG-TEM equipped with an auxiliary (Lorentz) minilens[2] allowed micromagnetic observations under close to field-free conditions with the objective lens switched off, or else it was slightly excited to allow magnetization processes to be followed *in situ* by tilting the sample.

An important issue in the integration of magnetic tunnel junctions with Si processing technology is the effect of moderate annealing on the tunnel barrier. Figure 1 shows a cross-sectional image of a CoPtCr/Al_2O_3/CoPt MTJ after it had been annealed at 350°C. The crystallinity of the ferromagnetic layers is apparent, and it is also clear that the integrity of the barrier has been maintained. Comprehensive measurements were made of the mean thickness of the alumina barrier layers in a series of MTJs as a function of annealing temperature. As shown in Fig.2, very little variation in the layer width relative to the thickness at room temperature was observed for annealing at temperatures of 250°C, 300°C and 350°C. No significant changes in the overall short-range and long-range roughness of the ferromagnet-insulator interfaces due to annealing was noted. A further requirement of an MTJ intended for memory applications is that the reference ("hard") layer should be stable over many (preferably 10^6 or more) magnetization reversals of the free layer. We have utilized Lorentz microscopy to study domain wall formation and movement of plan-view samples during complete magnetization cycles. Prior calibration of the objective lens magnetic field provided knowledge of the in-plane component of the field as the orientation of the sample was cycled. Figure 3 shows the typical domain structure and magnetization ripple visible in Lorentz micrographs of a) Co, and b) NiFe, soft layers at close to their respective coercive fields. The arrows indicate the direction of the applied field and the magnetization of the hard layer. Careful study revealed that most of each soft layer reversed by rotation of the magnetization direction, although narrow bands often remained pinned, apparently by features of the underlying hard layer, and only reversed close to the coercive field. Electron holography of patterned samples is planned to provide further insight into the field reversal mechanism.[3]

References

1 Julliere, M., Phys Lett. A54 (1975) 225
2 Chapman, J N *et al*, IEEE Trans Magn 30 (1994) 4479
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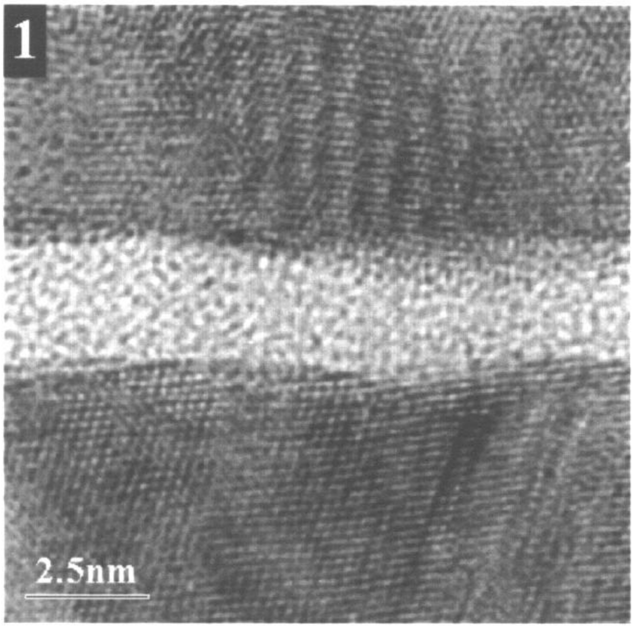

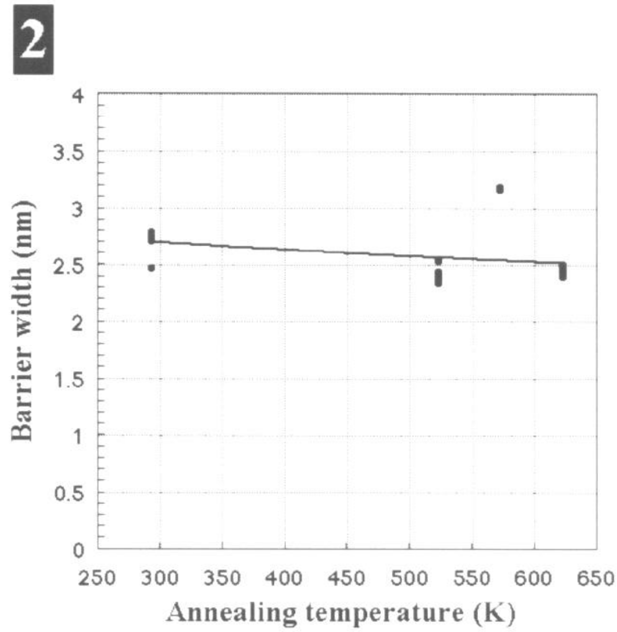

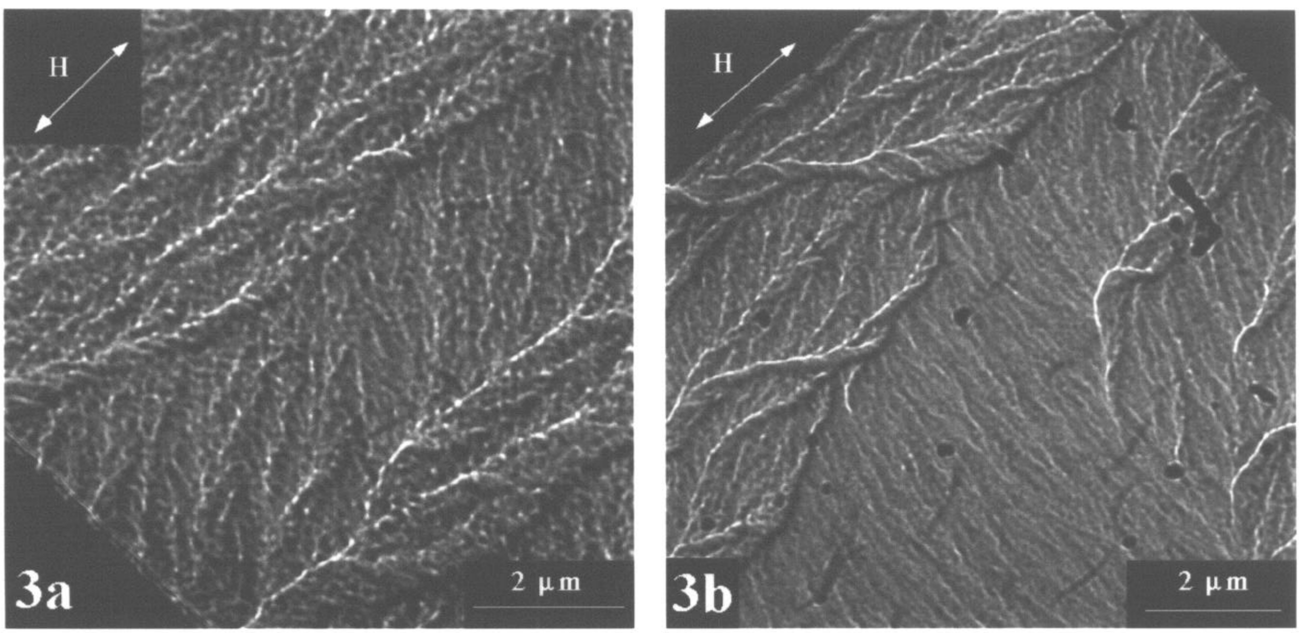

Fig. 1. High-resolution electron micrograph showing cross-section of CoPtCr/Al_2O_3/CoPt MTJ after annealing at 350°C.

Fig. 2. Mean width of alumina barrier layer in MTJ as function of annealing temperature.

Fig. 3. Lorentz micrographs showing comparison of domain structure and ripple contrast of: a) Co; and b) NiFe, soft layers for MTJ grown on silicon nitride membranes. Arrows indicate direction of applied field and hard layer magnetization.