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Epitaxial Ni films, e-beam nano-patterning and BMR

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Abstract

We have attempted to clarify possible domain-wall processes present in the recently reported large ballistic magnetoresistance effects in nano-contacts. To that effect we have used e-beam lithography applied to epitaxial Ni films to fabricate nano-bridges in more controlled geometry than electrochemical deposition. Our preliminary results indicate that magnetic domains do play a role in the magneto-resistance of these nano-bridges but the order of magnitude of the observed effect is considerably smaller than the reported observations in electrochemically prepared nano-contacts.

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The latest results on ballistic magneto-resistance (BMR) research have shown surprising BMR effects with values over 3000% in Ni nano-contacts at room temperature [1]. It has been postulated that the BMR effect arises from non-adiabatic spin scattering across very narrow (atomic scale) magnetic domain walls trapped at nano-sized constrictions [2]. The reported BMR effect has been observed at room temperature and low magnetic field in Ni nano-contacts electrodeposited between polycrystalline Ni wires. Much of the published data so far, is still poorly understood. In an attempt to clarify some of the possible processes present in the observed phenomena we have used e-beam lithography applied to epitaxial (0 0 1) Ni films grown on MgO substrates to fabricate nano-bridges in more controlled geometry than those prepared with electrochemical deposition. The idea behind this scheme is that epitaxial ferromagnetic thin films may favor ballistic regime provided that the nano-contact is small enough [3].

Prior to the aforementioned BMR articles, other researchers have reported on domain-wall (DW) scattering effects on the magneto-resistance (MR) in magnetic thin films [4,5]. In particular, Kent et al. [5] have worked with epitaxial films and have observed enhancement in MR (0.3% at low T and low field) due to DW scattering in chemically ordered $L1_o$FePt films, which exhibit the highest known magnetic anisotropy. To our knowledge no one has reported BMR studies on epitaxial Ni films.

Epitaxial thin films exhibit higher anisotropy than polycrystalline films. Thus narrower DWs are expected for epitaxial Ni films than those in polycrystalline wires. In addition, the MR effect at both sides of the DW in a nano-contact depends on the ratio $\boldsymbol{r} = \boldsymbol{D}_{up}/\boldsymbol{D}_{down}$, where $\boldsymbol{D}_{up}$ and $\boldsymbol{D}_{down}$ are the density of states of majority and minority spins at Fermi level. This ratio has been calculated to be 12 for Ni, 10 for Co and 3 for Fe [6]. Thus we expect nano-contacts patterned on epitaxial Ni films should favour BMR.

To test these assumptions we deposited epitaxial Ni films on MgO substrates using two deposition techniques: molecular beam epitaxy (MBE) and sputtering. High-resolution X-ray diffraction used to obtain structural information for both types of films, indicated epitaxial cube on cube growth, with no significant

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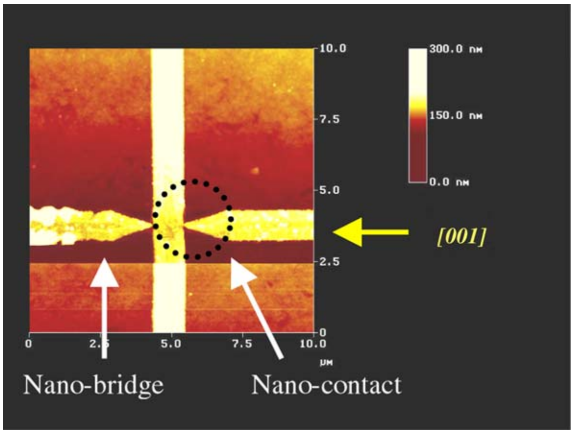

Fig. 1. Atomic force microscopy image of a typical nano-bridge patterned with e-beam lithography on (0 0 1) Ni films.

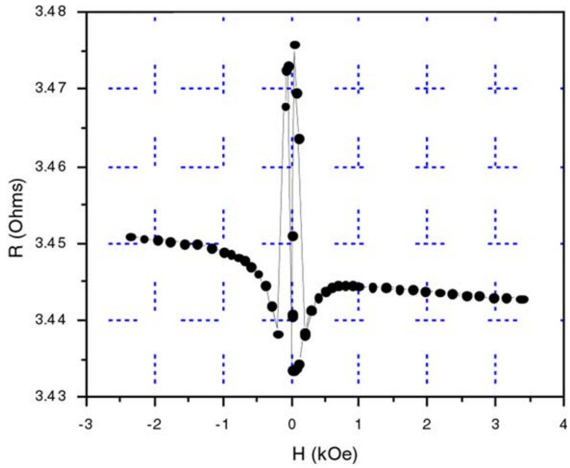

Fig. 2. Magnetoresistance at RT for a 300 nm wide nano-contact. The Ni film was 30 nm thick. We notice peaks in MR at low field coincident with the coercivity of the film.

difference between the films [7]. The thickness of the films was in the 20–30 nm range. The films were characterized magnetically using longitudinal magneto-optic Kerr effect (MOKE). Studies on the azimuthal dependence of the coercive field have provided insight on the effect of structure and surface morphology on the magnetic anisotropy of the films.

We have observed that (0 0 1)-oriented films exhibit 'spikes' in coercivity along the magnetization hard axes, indicative of higher density of domain-wall nucleation during reversal along these particular directions. Thus we have used e-beam lithography to pattern 'T'-shaped nano-bridges where the segments of the 'T' are along the magnetization hard axes. The idea behind this scheme is that the combination of magnetocrystalline and shape anisotropies will provide two 'knobs' to tune the magnetization state at both sides of the nano-contact. Fig. 1 shows an atomic force microscopy (AFM) image of a typical nano-bridge.

The typical width of the nano-contact in our preliminary bridges was 200–500 nm. MR measurements were obtained using a four-point probe technique. Due to our 'T' geometry, the measured resistance included contributions from the resistance due to the nano-contact (R_c) and to the nano-bridge (R_b), which is not negligible in our case.

Typically we observed MR effects ranging from a few tenths of a percent to a few percent (Fig. 2). When the contact width was larger than 2 μm the low-field peaks in MR were absent, and the only MR effect observed in these larger contacts was the typical background anisotropy MR.

One sample exhibited a peculiar "relaxation" mechanism as described by Muñoz et al. [8], where the saturation resistance slightly drifted after subsequent cycles of the applied field. Interestingly, the MR effect in this sample was considerably larger (~35%) than in our typical samples.

In conclusion, in our preliminary work we observed low-field peaks in MR in our nano-contacts only when the width was smaller than 0.5 μm. The onset of the peaks coincided with the coercivity of the films. The absence of such peaks in larger contacts allows us to conclude that the MR effect is due to domain-wall formation at the nano-contact. We still need to establish if the observed effect is due to BMR or diffusive DW scattering. Progressive reduction of the nano-contact width led to increased resistance of the MR peaks R_c, but this reduction was in general achieved by also reducing the size of the nano-bridge. This in turn, led to higher R_b and therefore total higher resistance in most cases and therefore a smaller relative MR effect.

We are currently working in different geometries to maximize the effect of the nano-contact in MR.

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