

Influence of the interfaces on the anisotropic magnetoresistance of Ni/Co multilayers

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Anisotropic magnetoresistance in Ni is found to increase abruptly when Co impurity layers are inserted. Some experiments carried out in different Ni/Co multilayers indicate that interfaces are responsible for the magnetoresistance enhancement. © 1996 American Institute of Physics. [S0003-6951(96)00243-4]

All materials exhibit magnetoresistance (MR), that is, a change in resistance when a magnetic field is applied. This property is stronger in magnetic than in nonmagnetic materials. Magnetoresistance is a phenomenon of great interest due to its technological applications.¹ Among the different types of MR observed in magnetic materials, the following three should be remarked: anisotropic magnetoresistance (AMR), giant magnetoresistance (GMR), and colossal magnetoresistance (CMR).

AMR,² which appears in traditional 3D magnetic materials is anisotropic with respect to field direction. MR is positive (i.e., resistance grows with the applied magnetic field) when the applied magnetic field is parallel to the current, and negative when perpendicular. On the other hand, GMR and CMR, which have been discovered more recently in multiphase systems and perovskite oxides, respectively,³ are characterized by large MR factors and by their isotropy with respect to the field direction (both are always negative). Systems which exhibit GMR or CMR would seem to be the most promising for applications, as they show MR factors one or two orders of magnitude above those which solely display AMR, but in general, with high applied magnetic field and low temperature. Moreover, in AMR materials, a special configuration of the contacts makes use of the anisotropy of MR to extraordinarily enhance the change in the output signal at low field and room temperature, as recently published by the authors.⁴

AMR in Ni/Co multilayers^{4,5} is much larger than that of pure bulk Ni or Co, and similar in magnitude to that displayed in the best homogeneous materials (alloys of Ni and Co).⁶ Furthermore, Ni/Co multilayers for a wide range of thickness have low saturation field and high sensitivity; the required characteristics for applications.

The very different macroscopic transport properties of AMR and GMR materials are a consequence of the different underlying microscopic physics. The intrinsic origin of AMR is the spin-orbit coupling,⁶ this changes the shape of the electron cloud and creates a local anisotropy in each domain, whereas GMR is due to spin-dependent scattering of electrons.⁷⁻¹⁰

Interfaces also play a key role in the magnetotransport properties of magnetic multilayers (for GMR see for instance Ref. 11). In order to study this effect in AMR, a Ni sample

with periodically inserted Co impurity layers was prepared. This consisted of iterating a pattern of Ni depositions of several atomic layers with Co deposition insufficient to fill one atomic layer. Its magnetoresistance is studied and compared with that of a Ni/Co multilayer, a pure Ni sample, and a Ni/Co bulk sample.

Samples are grown by rf planar magnetron sputtering on water cooled intrinsic Si(111) substrates. The discharge gas was Ar at a pressure of 5×10^{-3} mbar, the base pressure being, at least, lower than 10^{-6} mbar. The deposition rates were 0.8 Å/s for Co and 0.9 Å/s for Ni. For more details see Ref. 4.

The first sample was a $(\text{Ni}_{25}/\text{Co}_{50})_{40}$ multilayer. $(\text{Ni}_x/\text{Co}_y)_z$ stands for a two layers pattern (a Ni layer x Å thick and a Co y Å thick) repeated z times. The multilayer structure, obtained by alternating Co and Ni deposition, was checked by low angle x-ray diffraction.⁴ The thickness deposited per unit of time was calibrated by scanning electron microscopy (obtaining images of the edge of calibration films), and the thickness of the layers mean a proportional deposition time.

A film $(\text{Ni}_{25}/\text{Co}_1)_{40}$ was also deposited. The 1 Å of Co does not mean a uniform layer thickness, but a deposition time proportional to 1 Å. This time is insufficient to deposit a complete 1-atom-thick layer, hence giving rise to an impurity layer.

In order to compare these films with bulk samples, a 1500 Å thick film of Ni $(\text{Ni}_{1000}/\text{Co}_0)_1$ and a sample with 1000 Å of Ni and 2000 Å of Co $(\text{Ni}_{1000}/\text{Co}_{2000})_1$ were grown.

MR measurements were carried out with the four lead technique, using a Fluke 8842a multimeter and pressure contacts, at room temperature, and the square-shaped configuration of leads shown in Fig. 1. Two different quantities were measured: $(V/I)_L$, the ratio between the output voltage and the applied current parallel to the field [Fig. 1(a)]; and $(V/I)_T$, a similar measurement but with the current applied perpendicularly to the field [Fig. 1(b)]. Both magnitudes are directly related with the longitudinal and transversal resistivities through expressions in Ref. 4. The same well-defined geometry has been kept in all the samples for the sake of compatibility with previous results,⁴ and in order to measure both configurations simultaneously.

MR measurements of the multilayer $(\text{Ni}_{25}/\text{Co}_{50})_{40}$ carried out with the square-shaped lead arrangement, are plotted

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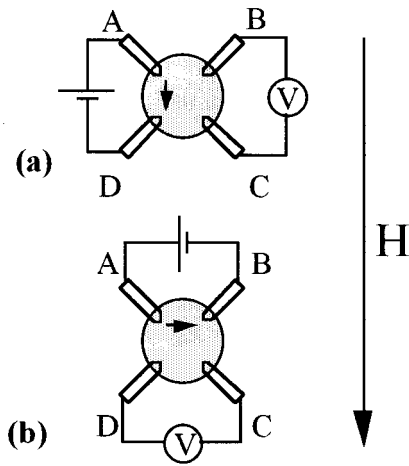


FIG. 1. Four lead configurations for magnetoresistance measurements. (a) Measured voltage and current parallel to the field, *longitudinal* configuration. (b) Measured voltage and current perpendicular to the field, *transversal* configuration.

in Fig. 2. Data, as percentages with change respect to the value at maximum field, are negative for $(V/I)_L$ and positive for $(V/I)_T$.

Figure 3 shows MR loop of the $(\text{Ni}_{1000}/\text{Co}_{2000})_1$ sample. Notice, that although the total Co and Ni thickness is the same as in the sample of Fig. 2, MR is smaller than that corresponding to the multilayer $(\text{Ni}_{25}/\text{Co}_{50})_{40}$.

Similar comparison may be done between MR of pure Ni film (Fig. 4) and that of the sample $(\text{Ni}_{25}/\text{Co}_{1})_{40}$ (Fig. 5). It is to be noticed that after inserting impurity layers, MR of Ni is enlarged by a factor of two. This fact points out that since MR increases by 100% with respect to the total MR in the Ni sample, the scattering in the bulk Ni must be of the same order of magnitude as that of the scattering in the Co impurities. In order to check the reproducibility, several

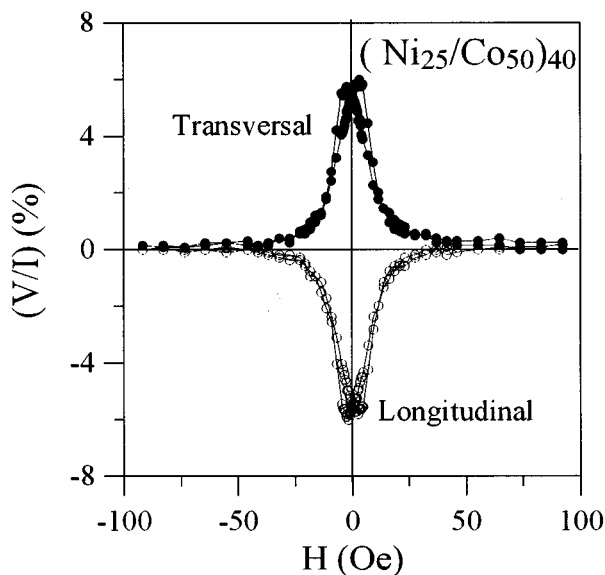


FIG. 2. Magnetoresistance of $(\text{Ni}_{25}/\text{Co}_{50})_{40}$. The values are percentages of change with respect to the maximum field value. Full dots correspond to the longitudinal configuration [Fig. 1(a)], and open dots to the transversal configuration [Fig. 1(b)].

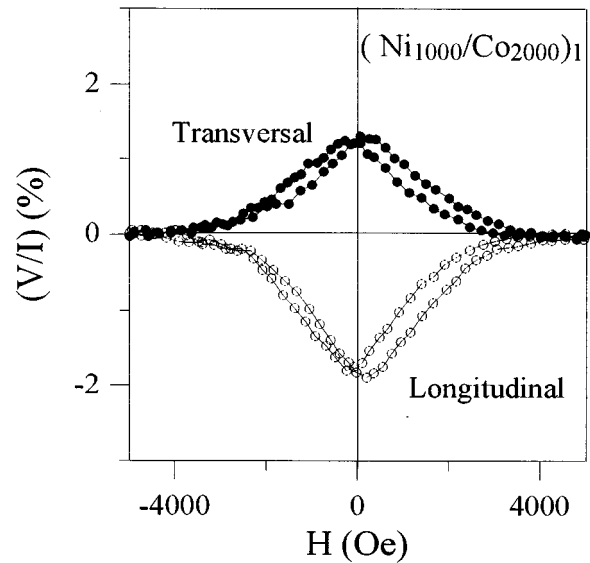


FIG. 3. Magnetoresistance of a bilayer with 1000 Å of Ni and 2000 Å of Co.

nominally identical samples have been measured, being the standard deviations in the MR well below the observed effect.

On the other hand, MR in $(\text{Ni}_{25}/\text{Co}_{1})_{40}$ is similar to that in $(\text{Ni}_{25}/\text{Co}_{50})_{40}$. Thus, the change in MR of $(\text{Ni}_{25}/\text{Co}_{50})_{40}$ with respect to the “bulk” bilayer $(\text{Ni}_{1000}/\text{Co}_{2000})_1$ should be exclusively attributed to the interface scattering.

Once the contribution of interfaces to the AMR in Ni/Co multilayers has been established, one would expect the electron mean free path, MFP, with respect to the layer thickness, to be the critical value to control the AMR effect. If the layer thickness is much shorter than the MFP, electrons are scattered by the interface, but in the case of layer thicknesses larger than MFP many electrons are scattered without having arrived at the interface.

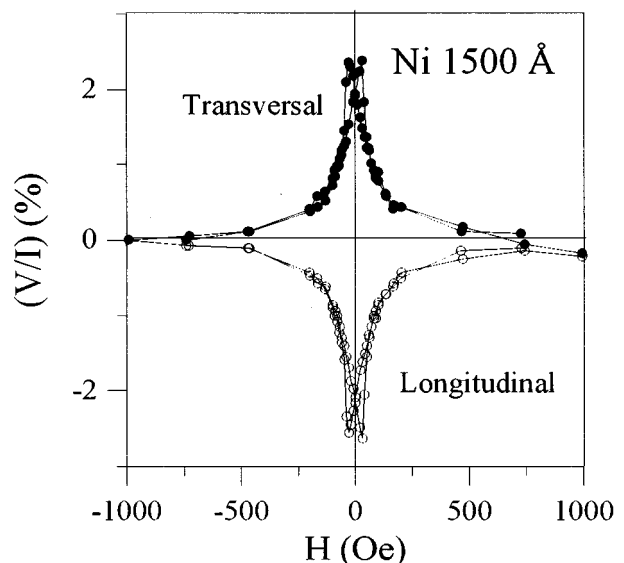


FIG. 4. Magnetoresistance of a deposit of Ni 1500 Å thick.

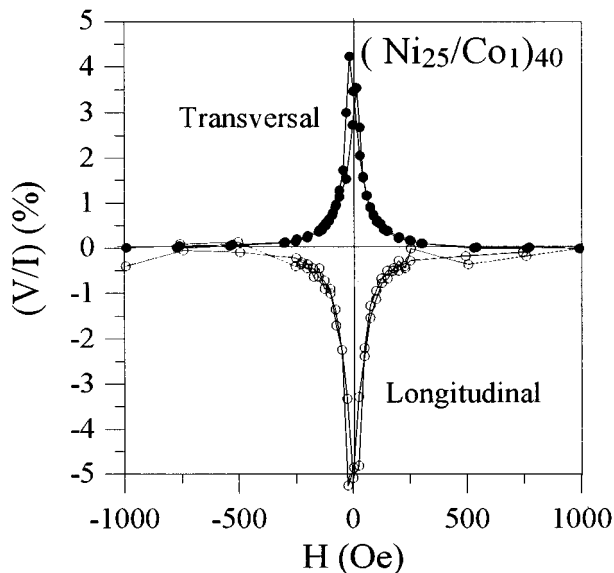


FIG. 5. Magnetoresistance of $(\text{Ni}_{25}/\text{Co}_1)_{40}$.

Finally, we can summarize the results achieved in this work as follows: (i) some Ni/Co multilayers have a MR factor very much larger than that of a bulk material with Ni and Co phases of the same composition. (ii) Similar results are obtained when the Co layer is reduced to impurities inserted

in Ni. As a consequence, we conclude that the scattering of electrons at the interfaces, plays a significant role in the total scattering of electrons in highly magnetoresistive Ni/Co multilayers. This conclusion suggests that surface magnetic anisotropy at the interfaces¹² may be the origin of the AMR enhancement observed in Ni/Co multilayers.^{4,5}

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