GIANT MAGNETORESISTANCE OF A SINGLE INTERFACE

Magnetoresistance of Ag/Fe/Ag trilayers

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Ag/Fe/Ag trilayers and multilayers (30-120 bilayers) were prepared by vacuum evaporation (with 10^{-7} Pa base pressure) on an Si single crystal substrate at room temperature. The layer thickness of the Ag/Fe/Ag trilayers (d_{Fe} = 25 nm with d_{Ag} = 4 and 8 nm) and the multilayers (d_{Fe} = 0.2 nm with d_{Ag} = 2.6 and 5.5 nm, d_{Fe} = 0.7 nm with d_{Ag} = 1, 2, 3, 4 and 8 nm and d_{Fe} = 1.4 nm with d_{Ag} = 2 and 4 nm) were controlled by a quartz oscillator. The multilayer structure and the magnetic properties were investigated by X-ray reflectometry, X-ray diffraction, Mössbauer spectroscopy and SQUID magnetization measurements. The magnetoresistance was measured by a four contact method at 4.2 and 300 K up to a magnetic field of 12 T with current in plane (CIP) for parallel ($H \| I$) and transversal ($H \perp I$) geometries.

The multilayer structure was observed by X-ray reflectometry in case of $d_{Fe} \geq 1.4$ nm. However, when $d_{Fe} \leq 0.7$ nm the layers are not continuous and the samples can be regarded as granular materials. (Below, the samples will be characterized by the nominal layer thickness.) X-ray diffraction and Mössbauer spectroscopy results [1] indicate non-equilibrium mixing of Fe and Ag both in the multilayers with d_{Fe} = 1.4 nm and in the granular samples. Concentration distribution along the growth direction is suggested [1].

The magnetoresistance is defined as $\Delta R/R = [R(B) - R(0)]/R(0)$. For all the samples qualitatively similar magnetoresistance is observed:

(i) the resistance decreases with increasing field,

V. Chandrasekhar et al. (eds.),
Kondo Effect and Dephasing in Low-Dimensional Metallic Systems, 181–184.

(ii) the changes are equal in parallel and the transversal geometry,
(iii) no saturation occurs up to 12 T,
(iv) $\Delta R/R$(12 T) is larger at 4.2 K than at 293 K.

Representative magnetoresistance curves at 4.2 K are shown in Fig. 1 for the Ag(8 nm)/Fe(25 nm)/Ag(8 nm) trilayer sample. The insert shows the low field part on a magnified scale. In case of the trilayer samples an anisotropic component can be observed which can be attributed to the anisotropic magnetoresistance of the iron layer. This component is not present in the other samples. After subtracting the anisotropic contributions the parallel and the transversal magnetoresistance are equal for the trilayers, as well as for the other samples.

The magnitude of $\Delta R/R_o$(12 T) depends both on the Ag and the Fe layer thickness. Though there are differences in the zero field resistivity values (R_o), the dominant factor in the thickness dependence of $\Delta R/R_o$(12 T) is the variance of ΔR. The magnitude of the giant magnetoresistance (GMR) and the thickness dependence is consistent with the results measured on sputter deposited Fe-Ag multilayers [2,3].

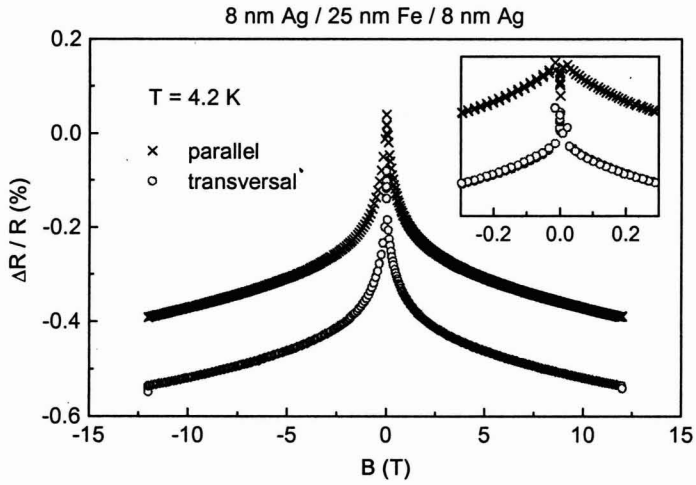

Figure 1. Magnetoresistance of a Ag/Fe/Ag trilayer. The insert shows the low field part on a magnified scale.

The largest GMR effect (≈ 30%) is observed in case of granular samples with $d_{Fe} = 0.2$ nm. The temperature dependence of the low field magnetic susceptibility of these samples [4] shows characteristics of superpara-magnetic particles (or spin glasses). There is a cusp around 40 K in the zero field cooled (ZFC) curve and below this temperature the field cooled susceptibility progressively deviates from the ZFC. The absence of

saturation in the magnetoresistance can be attributed to scattering on these superparamagnetic entities. In superparamagnetic systems [5] $\Delta R/R_o$ is supposed to be proportional to $(M/M_s)^2$, where M and M_s are the instantaneous and the saturation magnetization, respectively. This plot is shown in Fig. 2. for the $Fe_{0.05}Ag_{0.95}$ sample using magnetization data measured up to 5 T magnetic field. The proportionality is clearly not fulfilled, the bulk magnetization saturates at lower field than the magnetoresistance. The magnetic behavior is dominated by the large volume particles, while the resistance is influenced by the number of the scattering centers and therefore it is more sensitive to small volume particles. This difference in the sensitivity of the two methods is even more pronounced in case of $d_{Fe} \geq 0.7$ nm. The main features of the GMR effect do not change, although at 4.2 K all the $d_{Fe} \geq 0.7$ nm samples are ferromagnetic and according to Mössbauer spectroscopy results [1] the superparamagnetic fraction, if it at all exists, is certainly below 1-2%. Impurity Fe atoms in the Ag matrix might also give a contribution to the observed magnetoresistance.

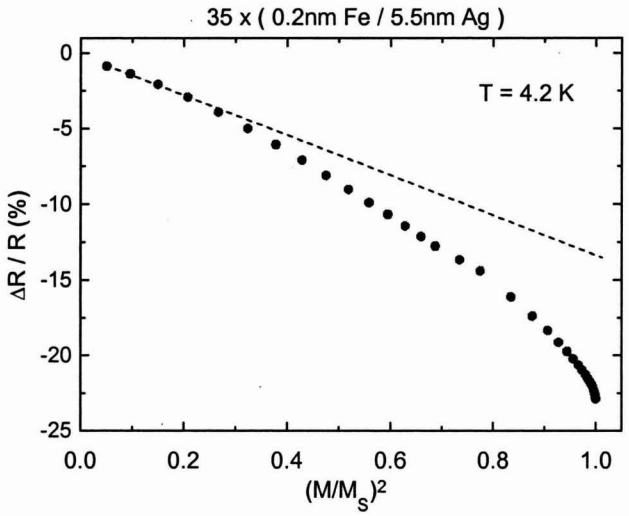

Figure 2. Magnetoresistance as a function of the squared reduced magnetisation. Linear variation is shown by the dotted line.

On the basis of the above results the magnetoresistance measured on a single thick Fe layer covered by silver (trilayer samples) is explained by the granular nature and/or alloying of the interface layers. The magnitude of the resistance change slightly depends on the Ag thickness. Since Ag and Fe are not soluble in equilibrium, heat treating the sample results in decomposition while the layer structure can be preserved in case of thick layers. Preliminary results show that after annealing at $T = 500$ °C for 1 hour in a high vacuum

(10^{-6} Pa) furnace, the Ag(8 nm)/Fe(25 nm)/Ag(8 nm) sample the GMR-like magnetoresistance disappears and ordinary positive magnetoresistance ($\Delta R/R \sim B^2$) characteristic of the pure metals [6] is observed between 0.2 and 12 T.

In conclusion, Ag/Fe/Ag trilayers show magnetotransport behavior similar to multilayers and granular alloys. The magnetoresistance decreases with increasing magnetic field and does not saturate up to $B = 12$ T. The parallel and the transversal megnetoresistance curves coincide, except a low field anisotropic magnetoresistance component characteristic of a single Fe layer. These results are explained by atomic scale mixing and by the granular nature of the interfaces. Restoring the conventional magneto-resistance behavior by heat treatment further supports this picture.

Acknowledgements

This work was supported by the Hungarian Research Funds T026327, T030753 and AKP 98-25 2,2. One of the authors (D.K.) is grateful for the support from the Bolyai Research Grant.

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