Magnetotransport and magnetic properties of Co/Cu multilayers under the influence of In surfactant

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Since the discovery of giant magnetoresistance effect (GMR) and exchange coupling in multilayers [1], consisting of ferromagnetic layers separated by a nonmagnetic spacer, many multilayer systems have been intensively studied, mostly due to their potential technical applications. Among other systems Co/Cu superlattices are an example of particular interest because of their very large magnetoresistance even at room temperature [2]. The magnetotransport properties of thin multilayered systems and spin dependent scattering depend on surface and interface morphology [3]. One possible way to improve the chemical interface is to use a small addition of surfactants/interfactants [4], which allow the change of growth mode from island formation to layer-by-layer growth, leading to the smoothening of interfaces. Typically, low-surface-energy elements are used as surfactants. They act by continuous segregation to the surface during deposition (surfactant) or remain at the interface between metal films (interfactant). The aim of this work is to investigate the GMR properties of the Co/Cu multilayers modified by In surfactant.

The $[Co(10Å)/Cu(20Å)/In(0.6Å)]_N$ multilayers (N=5,10,20) were thermally evaporated at very low deposition rates (between 0.03Å/s and 0.3 Å/s) on (100) Si substrates. The thickness of the Cu spacer layer corresponds to the second peak of the oscillations of antiferromagnetic coupling between adjacent Co layers [5]. Two sets of multilayers were prepared with the In introduced either at each bilayer interface ($[CoCuIn]_N$) or at every second bilayer interface ($[CoCuInCoCu]_N$). Structural characterization of samples was performed by X-ray reflectometry (XRR). Using *ex situ* Scanning Force Microscope (SFM) we have measured the topography of the top surface of the multilayered structure. Magnetoresistance measurements were carried out using a standard four-probe dc method with current in the plane of the sample parallel with field respect to the current. Perpendicular and transverse geometry were also checked. Magnetic hysteresis loops were measured with a SQUID magnetometer with magnetic fields parallel to the sample plane. All measurements were carried out at room temperature.

Low-angle X-ray reflectivity spectra (Fig. 1) show well-defined Kiessig fringes, and a similar intensity fall-off with increasing angle for Co/Cu multilayers with In. This indicates that the roughness of the samples is low, and of similar magnitude. Well-determined Bragg peaks demonstrate that the bilayer period is conserved through the whole sample. We have found that In addition leads to well ordered structures with small roughness (a few Å) and smoother interfaces than in case of pure Co/Cu samples.

The surface topography measured with SFM was determined with the auto-correlation and the height-height correlation functions [6]. The rms roughness and the lateral correlation length, corresponding to the island size, were determined by averaging the roughness over different window sizes. The results obtained for the top layer of all samples revealed that the rms roughness increased smoothly with bilayer index N, reaching values of 6 Å and 10 Å, for

$[CoCuIn]_{20}$ and $[CoCu]_{20}$, respectively. The average size of the islands observed on the surface was about 20 nm for $[CoCuIn]_N$ multilayers, and about 30 nm for pure Co/Cu system. On large length scales the films are very smooth. The roughness values obtained from SFM image analysis were in very good agreement with the values obtained from XRR measurements. We did not observe any significant difference between the topography of samples of [CoCuIn] and [CoCuInCoCu] type.

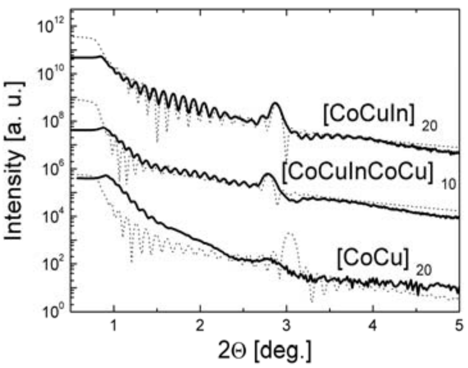

Fig. 1. Low-angle X-ray reflectivity data for the $[CoCuIn]_{20}$ and $[CoCuInCoCu]_{10}$ multilayers in comparison with $[CoCu]_{20}$. Sequential curves have been offset for clarity. The dashed lines are simulated fits to the data.

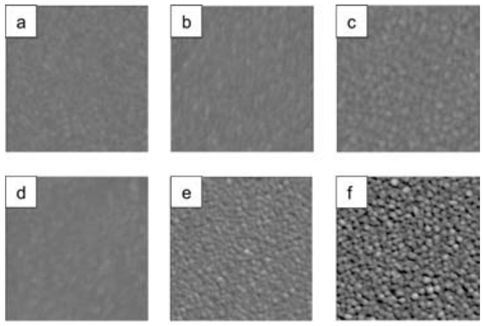

Fig. 2. SFM images of $[Co(10Å)/Cu(20Å)/In(0.6Å)]_N$ multilayers for N=5(a), 10(b) and 20(c). Images d,e,f show the corresponding $[Co(10Å)/ Cu(20Å))]_N$ multilayers. The scan size is 0.5 μm x 0.5μm.

Figure 3 shows a typical MR curve as a function of the magnetic field together with magnetic hysteresis loop for $[CoCuIn]_{20}$ sample.

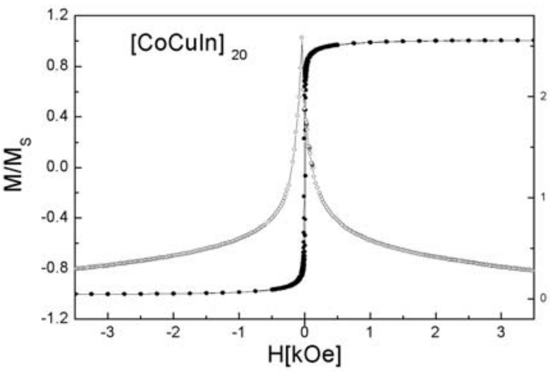

Fig. 3. Magnetic hysteresis loop and GMR ratio $\Delta R/R=(R(H)-R(H_{max}))/R(H)_{max}$ for $[CoCuIn]_{20}$ multilayer.

We observed the increase of magnetoresistance values from 1.5% for CoCu mulilayers to about 4% for samples with inserted In. This result demonstrates a clear dependence between magnetoresistance and structural imperfections of investigated samples. However, the magnetization hysteresis loops in all cases demonstrated the very small fraction of antiferromagnetic coupling. The possible explanation could be that the magnetic boundary does not follow the chemical boundary, and in consequence not all atoms of magnetic material follow the applied field. This result indicates that the role of chemical roughness is not predominant in the studied system and is not equivalent to the role of magnetic roughness.

The authors thank Prof. K. Tomala and Dr. M. Rams for helpful cooperation in SQUID measurements.

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