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The influence of roughness on the Curie temperature and magnetisation in multilayers

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A system of three magnetic (M) layers divided by nonmagnetic (N) spacers is considered. The existence of roughness on the interfaces, described by the model proposed by Bruno and Chappert, leads to a modification of interlayer exchange coupling (IEC). The Curie temperature and magnetisation are calculated using the Green function formalism for the system of layers with Fe standing for M and Cu or Au standing for N. The parameters characterising this system are taken into account for the GaAs substrate. The results obtained show a decreasing Curie temperature with the increasing roughness parameter as compared to the Curie temperature of the sample with an ideal interface. The magnetisation curves are shifted as a result of roughness in the interface region.

Key words: *multilayer; Curie temperature; magnetisation*

1. Introduction

Since the discovery of interlayer exchange coupling (IEC) between magnetic layers separated by nonmagnetic metallic spacers, great interest has been paid to the magnetic properties of exchange-coupled multilayers [1, 2]. The properties of systems such as Fe/Cu/Fe, Fe/Au/Fe, and Co/Cu/Co have been extensively investigated [3–6]. The number of papers in which the problem of magnetic characteristics such as magnetisation and Curie temperature are discussed [7, 8], is however, much smaller than the number of papers devoted to other properties of multilayers [9–11].

We consider a system consisting of three magnetic (M) layers divided by nonmagnetic (N) spacers, described by a Heisenberg-type Hamiltonian with a nearest-neighbour interaction of the form [12]:

$$H = -\frac{1}{2}\sum_{\nu j,\nu' j'} J_{\nu j,\nu' j'}\vec{S}_{\nu j}\vec{S}_{\nu' j'} - g\mu_B H_{\text{eff}}\sum S^z_{\nu j} - \frac{1}{2}\sum_{\nu\nu j,\nu' j'} A_{\nu j,\nu' j'}S^z_{\nu j}S^z_{\nu' j'} \tag{1}$$

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where ν denotes the number of monatomic planes and j the position of a lattice point on the plane, respectively. The parameter $J_{\nu j,\nu' j'}$ is taken as J for the homogenous medium of internal layers, and as J_{12} for the interaction between spins belonging to interfaces. $A_{\nu j,\nu' j'}$ is the anisotropy parameter, consisting of a uniaxial volume anisotropy along the z-axis as the preferred axis and a surface and interfacial anisotropy, H_{eff} is the sum of the external field oriented perpendicular to the surface and the demagnetising field.

In our considerations, we take into account a generalisation of the Ruderman–Kittel theory for oscillatory interlayer exchange coupling [13]. The roughness of the interface, represented by the parameter r, changing from 0 (a flat interface) to 0.25 (a rough interface), was introduced by a model proposed by Bruno and Chappert, leading to the modification of the IEC [14, 15]. The parameter r has the meaning of the probability of appearing of monolayer step up or down interfaces.

2. Results

Applying the standard Green function formalism to the considered system, we calculate the Curie temperature and magnetisation [12]. In this section, we discuss numerical results obtained on the basis of this model. All the characteristics presented have been obtained for the thickness of 5 magnetic layers (MLs). An example of the dependence of Curie temperature on the roughness parameter is shown in Fig. 1a, for the system Fe/Cu/Fe/Cu/Fe/GaAs with spacers of the same thickness and the surface anisotropy parameter taken from [4]. One can see that the Curie temperature decreases with increasing roughness and is smaller for larger spacer thickness.

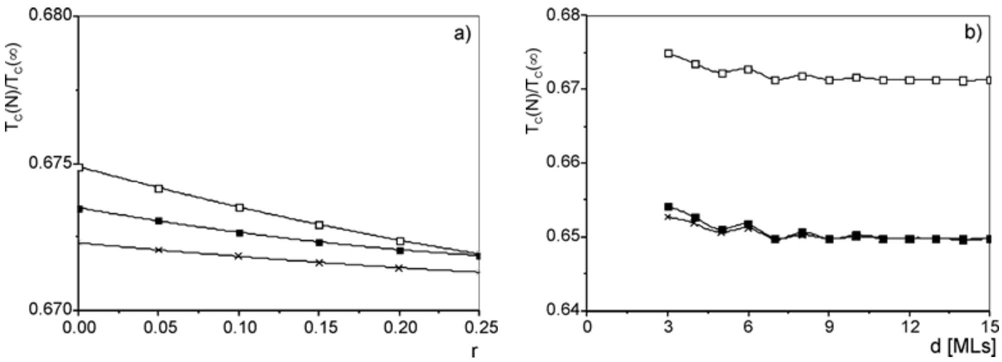

Fig. 1. The Curie temperature as function of a) the roughness parameter r for a constant spacer thickness of 3 MLs (open squares), 4 MLs (full squares), 5 MLs (crosses), b) spacer thickness for different roughness parameters: $r = 0$ for one of the spacer interfaces, and $r = 0$ (open squares), $r = 0.15$ (full squares), and $r = 0.25$ (crosses) for the others. The results are obtained for the system Fe/Cu/Fe/Cu/Fe/GaAs, where the orientation of the spacer is (111). The thickness is 5 MLs and $T_C(\infty)$ denotes the Curie temperature for the bulk magnetic materials

Figure 1b presents the Curie temperature as a function of the spacer thickness for various roughness parameters. The upper curve in Fig. 1b is obtained for interfaces with the same level of roughness. As one can expect, the Curie temperature is an oscillating function of the spacer thickness and decreases with the increasing roughness parameter. The period of oscillation is equal to half of the period of oscillation of IEC. A similar behaviour of T_C can be observed for the systems Fe/Au/Fe/Au /Fe/GaAs, Fe/Au/Fe/Au/Fe/InAs and Co/Cu/Co/Cu/Co.

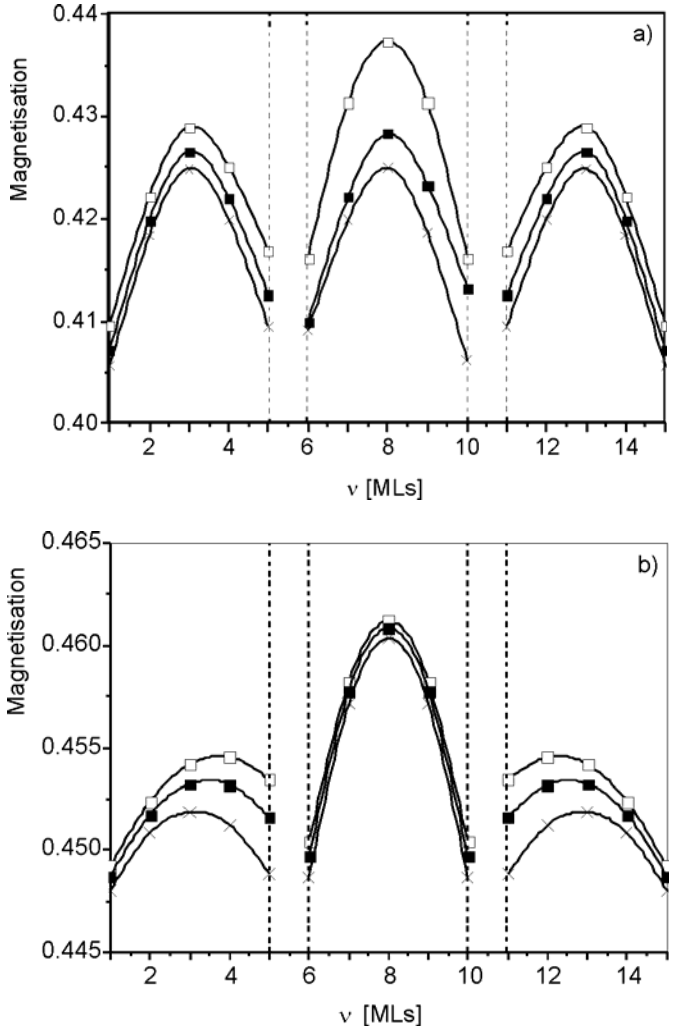

Fig. 2. Magnetisation profiles as a function of the number of layers for: a) the roughness of one respective interface equal to $r = 0$, and of the other equal to 0 (open squares), 0.15 (full squares), and 0.25 (crosses); the spacer thickness 3 MLs, b) for the same spacer thickness of 3 MLs (open squares), 5 MLs (full squares), and 7 MLs (crosses) in the structure Fe/Cu/Fe/Cu/Fe/GaAs. The width of the "gap" between the magnetic layers is not related to the spacer thickness

In view of the fact that the presence of roughness results in a change in the magnitude and phase of IEC, one can expect that the roughness influences the magnetisation distribution across magnetic layers.

The influence of roughness on magnetisation distribution is very weak for Cu(111) and Au(111), and a little stronger for other orientations of the spacer. More significant are the shifts in the profiles induced by the difference parameters describing both spacers. The profiles have been obtained for the temperature of 300 K (Figs. 2a, b). In addition, different values of the roughness parameter of the interfaces are the reason for the asymmetric magnetisation profiles visible in Fig. 2a.

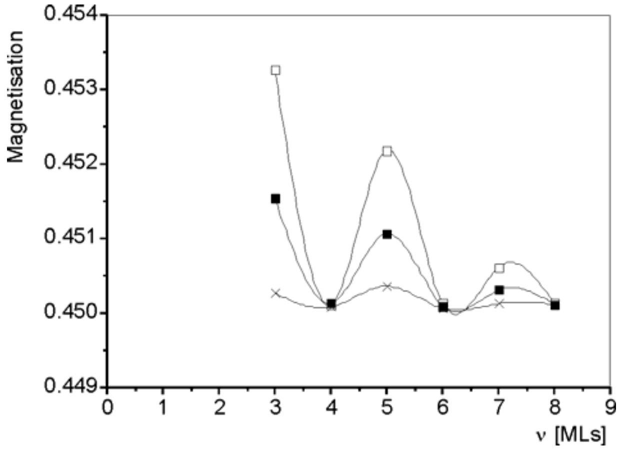

Fig. 3. The magnetisation profile for one of the chosen numbers of layers and for $T = 300$K in the system Fe/Cu/Fe/Cu/Fe/GaAs as a function of spacer thickness and for different roughness parameters

It is interesting to see the cross-section of the magnetisation profile for one chosen magnetic layer. Figure 3 presents the magnetisation as a function of the spacer thickness for the central layer of the system. Roughness is the reason for decreasing magnetisation but the period of oscillation is the same as for the oscillation of Curie temperature, and twice smaller than for IEC.

3. Conclusions

Although the presented results are obtained in the framework of a very simple model and have rather a qualitative character, it seems that some information is important from the experimental point of view. In order to apply multilayers, it is necessary to work out methods for obtaining layered structures with well-defined layer thicknesses and surfaces that are as flat as possible. Small differences between spacers or roughness parameters caused magnetisation and the Curie temperature to change in the coupled systems.

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