Exchange Bias Effects in Co nanoparticles dispersed in a Mn matrix

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Recently it has been recognized that gas-phase clusters can be deposited on to surfaces to produce high-performance magnetic films [1]. If this is done in conjunction with an atomic vapour from a conventional MBE-type source the nanoparticles become embedded in a matrix of choice. This method has been labelled the Low Energy Cluster Beam deposition (LECBD) technique [2]. We study Co nanoparticles of 1.8 nm diameter dispersed in a magnetically disordered spin glass-like Mn matrix produced by the LECDB technique. In these systems there is significant alloying between the ferromagnetic cluster material (Co) and the antiferromagnetic matrix (Mn), which introduces new possibilities and different interface exchange coupling effects [3].

We model the behaviour of the Co@Mn assemblies and we compare it with the experimental findings. We consider N identical magnetic particles (grains), with spherical shape and diameter D placed at random on the nodes of a hexagonal lattice. In order to take into account the core/shell structure of these nanoparticles and the contribution of the interface in the magnetic behaviour of the assembly, we consider that each nanoparticle consists of four regions. A ferromagnetic Co core with uniaxial anisotropy, a ferromagnetic Co rich Co/Mn alloy interface with uniaxial anisotropy, an antiferomagnetic Mn rich Co/Mn alloy interface and an antiferromagnetic Mn spin glass like shell with random anisotropy. The Co cores interact via long-range dipolar forces.

Results for the hysteresis loop are given at the Fig. 1 for Co volume fraction 5% after applying a cooling field $H=0.4(J/g\mu_B)$. At the same figure we have plotted for comparison the hysteresis loop for the Co nanoparticles in an Ag matrix at the same volume fraction. In this case for the description of the randomly placed Co nanoparticles in the Ag matrix we have used the single spin Stoner Wohlfath type model, which we have described elsewhere [4].

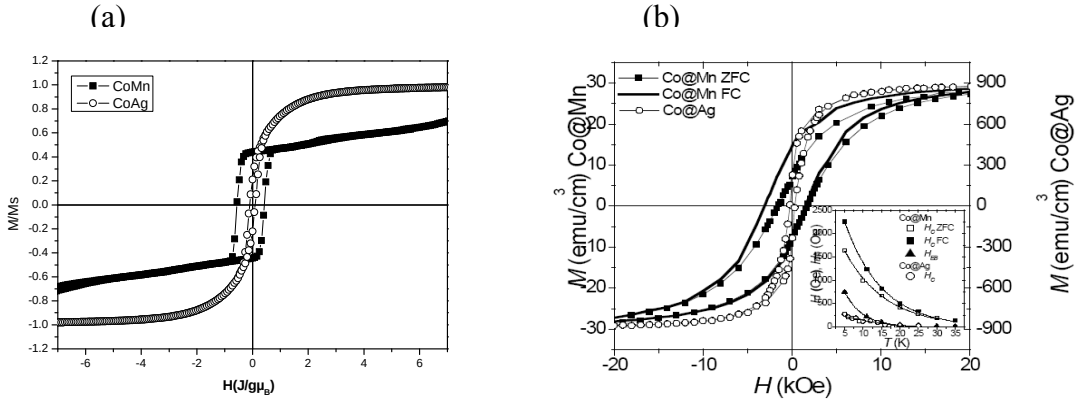

Fig. 1 Hysteresis loops of (a) Monte Carlo simulations and (b) of experiment at 5 K [3] for Co/Mn and Co/Ag nanoparticle assemblies.

We observe that the hysteresis loop is shifted for the Co@Mn nanoparticle assemblies in contrast to the hysteresis loop for Co@Ag assemblies which is symmetric. The Co@Mn nanoparticle assemblies have much higher coercive field (Hc= 0.495 $J/g\mu_B$) from the Co@Ag nanoparticle assemblies (Hc= 0.096 $J/g\mu_B$) and an exchange bias field Hex=0.08 $J/g\mu_B$. Fig.1(a) describes the data of Fig.1(b) reasonably well confirming the description of the Co nanoparticles in the Mn matrix by taking into account the Co-Mn alloying that is responsible for the low Co moments.

In Fig. 2 we have plotted the ZFC curve for Co@Mn and Co@Ag nanoparticle assemblies. We observe that the Tmax is much higher in the case of the Co@Mn assemblies in agreement with experimental findings that give a Tmax of Co@Mn almost three times bigger than Tmax for Co@Ag.

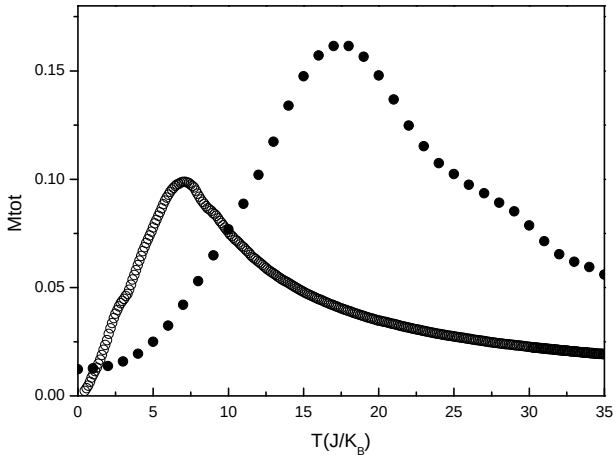

Fig. 2 ZFC curves for Co@Mn(full circles) and Co@Ag (open circles) nanoparticle assemblies.

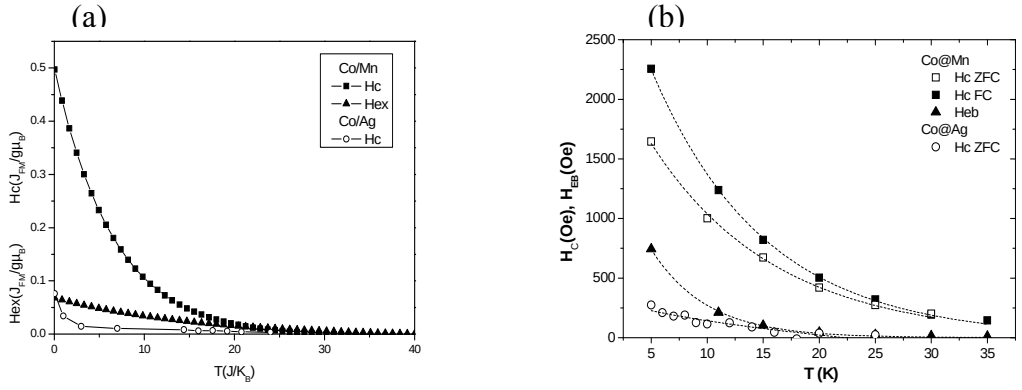

Fig. 3 Temperature dependence of the coercive and the exchange bias field of (a) Monte Carlo simulations and (b) experimental results for Co@Mn and Co@Ag nanoparticles assemblies (the solid lines are the exponential decay fitting) and of Hc for the Co@Ag nanoparticle assemblies (the solid line is the power low Ho(1-a^t) fitting).

We observe that indeed the Hex and Hc exhibit an exponential decay with the temperature in agreement with the experimental findings. In the case of Co@Ag nanoparticle assemblies the solid line gives a power low fitting Ho(1-a^t), with the exponent t differing from the -1/2 power of the Kneller and Luborsky [5] thermal decay of Hc.

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