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Hysteresis loops shifts in magnetite nanoparticles

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Abstract – By using a Monte Carlo simulation approach we study magnetite nanoparticles taking into account surface anisotropy effects, hysteretic properties and the circumstances yielding both horizontal and vertical shifts in the hysteresis loops; thermal and particle size effects are also considered in our analysis (Figs. 1, 2).

Since the exchange bias was discovered in 1956 by Meiklejohn and Bean [1], most of the reported work on literature has been devoted to the study of layered antiferromagnetic (AFM)-ferromagnetic (FM) systems, including mainly, thin films and small particles [2]. Exchange bias has also been observed in interfaces involving the presence of a ferrimagnet (ferri) like AFM-ferri and FM-ferri systems. However, despite the fact fine particles were the first type of system where exchange bias was observed, most of the related work on particles deals with those consisting of a ferromagnetic core surrounded by its respective antiferromagnetic or ferrimagnetic native oxide, and some very few studies on pure systems exhibiting exchange bias, e.g. pure ferri or AFM nanoparticles, have been carried out. In this study we address the role of surface anisotropy on the hysteretic properties of magnetite Fe_3O_4 nanoparticles and the circumstances yielding both horizontal and vertical shifts in the hysteresis loops. Our analysis involves temperature dependence and particle size effects. Different particle sizes ranging from 2 nm up to 7 nm were considered. Our theoretical framework is based on a three-dimensional classical Heisenberg model with nearest magnetic neighbor interactions involving tetrahedral (*A*) and octahedral (*B*) irons. Cubic magnetocrystalline anisotropy for core spins, single-ion site anisotropy for surface spins, and interaction with a uniform external magnetic field, were considered [3]. Our results revealed the onset of low temperature exchange bias field, which can be positive or negative, at high enough values of the surface anisotropy constant (K_S). Susceptibility data, computed separately for the core and the surface, suggest differences in the hard-soft magnetic character at the core-surface interface. Such differences are K_S-driven and depend on the system size. Such a hard-soft interplay, via the surface anisotropy, is the proposed mechanism for explaining the observed exchange bias phenomenology. Our results indicate also that the strongly pinned spins at high enough surface anisotropy values are responsible for both the horizontal and vertical shifts of the hysteresis loops. The dependences of the switching and exchange bias fields with the surface anisotropy and temperature are finally discussed.

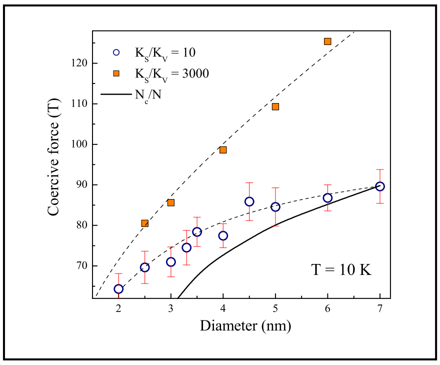

Figure 1: Low temperature coercive force as a function of the particle diameter for two different K_S/K_V ratios.

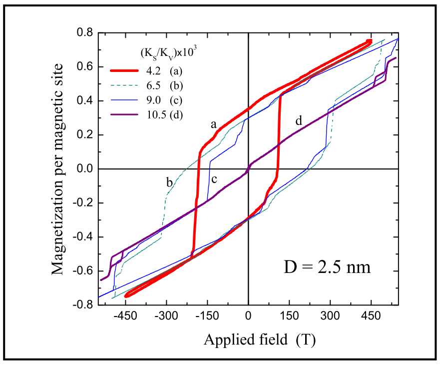

Figure 2: Hysteresis loops for D=2.5 nm, T=10 K and several K_S/K_V ratios. Positive remanence tends to decrease as the surface anisotropy increases.

References

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