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XMCD study of the anisotropy of nanometric Co clusters in insulating and metallic matrices ☆

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Abstract

The orbital to spin magnetic moment ratio of Co clusters homogeneously dispersed in Al_2O_3 is found to be much larger than in bulk Co and inversely proportional to the cluster diameter. For the same size, covering the clusters with a Cu layer increases m_L/m_S. An enhancement on m_L/m_S in the surface atoms is one order of magnitude more effective as a source of anisotropy than in the bulk.

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Keywords: Magnetic nanoparticles; Magnetic anisotropy; XMCD; Orbital moment

The anisotropy of nanometer-sized magnetic particles usually exceeds that of the bulk material and depends on the shape and especially on the fraction of atoms that are located at the surface of the clusters. To investigate if the anisotropy can be also modified by embedding the particles in a suitable metallic matrix and to compare the properties of clusters in insulating and metallic matrices, we prepared $Al_2O_3/Co/Al_2O_3$ and $Al_2O_3/Co/Cu$ (1.5 nm)$/Al_2O_3$ trilayers (which will be referred as "Co/Al_2O_3" and "$Co/Cu/Al_2O_3$" samples, respectively). This preparation process gives rise to the formation of nearly spherical Co clusters homogeneously dispersed in Al_2O_3 or Cu/Al_2O_3 matrices [1]. By fitting the equilibrium magnetization and AC susceptibility measured above the blocking temperatures, we have independently determined the distribution of cluster sizes present in all samples. The particle size distribution is in good agreement with what was directly determined from TEM pictures [2]. Furthermore, it is found to be almost independent of the matrix in which the clusters grow. $\langle D \rangle$ increases from about 1.4 to 3 nm as the nominal thickness of the Co layer varies from 0.2 to 0.7 nm.

An effective anisotropy constant K_{eff} has been obtained using a scaling method of the out-of-phase susceptibility measured near the superparamagnetic blocking temperature, which, as shown in Ref. [1], provides direct information on the distribution of activation barriers. We have found that K_{eff} , dominated by the local surface anisotropy due to the symmetry breaking, is much larger than the anisotropy of bulk fcc Co and approximately proportional to $1/\langle D \rangle$. Moreover, we have found that for the same size, clusters covered by a metallic (Cu) layer show a higher blocking temperature, and therefore a larger anisotropy (from 15% to 25%) than those embedded only in alumina [3].

To further investigate the origin of the effects that size and environment have on the anisotropy, we have

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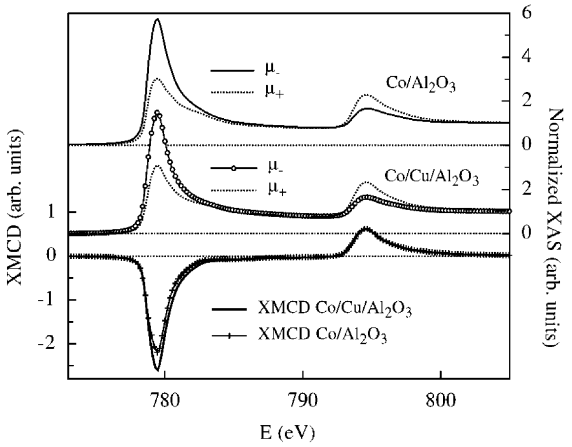

Fig. 1. $L_{2,3}$ XAS spectra of Co in Co/Al_2O_3 (upper panel) and $Co/Cu/Al_2O_3$ (middle panel) samples with $\langle D\rangle = 2.8$ nm recorded at $T = 2$ K, $H = 2$ T. Lower panel: the corresponding XMCD spectra. The Co/Al_2O_3 XMCD spectrum has been scaled by a factor $= 0.93$. See the text for details.

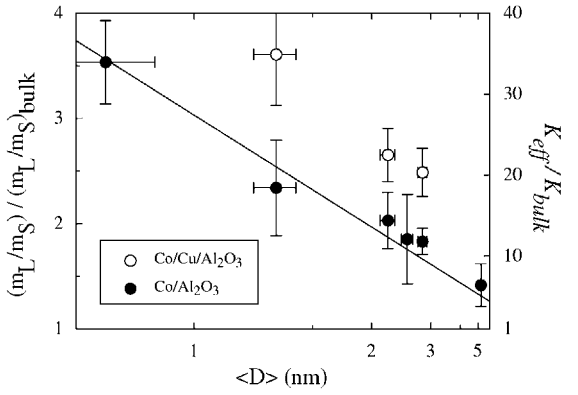

Fig. 2. Left axis: $(m_L/m_S)/(m_L/m_S)_{bulk}$ of the Co/Al_2O_3 (•) and $Co/Cu/Al_2O_3$ (◦) series. Right axis: linear fit to the effective anisotropy K_{eff}–K_{bulk} of the Co/Al_2O_3 series from Ref. [1] (full line).

performed a soft X-ray magnetic circular dichroism (XMCD) study at the $L_{2,3}$ Co edges on the cited samples. The XMCD experiments were performed at the ID8 beamline of the ESRF in Grenoble. Both total fluorescence and electron yields were recorded. Fig. 1 shows circularly polarized X-ray absorption scans at the $L_{2,3}$ Co edges on the Co/Al_2O_3 (upper panel) and $Co/Cu/Al_2O_3$ (middle panel) samples with $\langle D\rangle =$ 2.8 nm. μ_- (μ_+) is the normalized absorption when magnetization and photon helicity are kept parallel (antiparallel).

The lower panel shows XMCD for both samples, obtained as $\mu_- - \mu_+$. XMCD sum rules [4] have been used to determine the ratio of the orbital to spin magnetic moment, within the $\langle T_z\rangle = 0$ approximation, as usual for metallic 3d systems [5,6]. We limit ourselves to use the orbital-to-spin ratio (m_L/m_S), which is independent of the effective number of 3*d* holes. The XMCD curve obtained for the Co/Al_2O_3 sample (crossed line) has been scaled by a factor = 0.93 in such a way that the L_2 feature ($E \approx 793$ eV) is identical to that of the $Co/Cu/Al_2O_3$ one (full line). The area of the L_3 XMCD feature ($E \approx 778$ eV) relative to the L_2 one is definitely larger for the clusters covered by a copper layer than for those only in contact with alumina, and hence it is m_L/m_S, as it is derived from the XMCD sum rules [4].

The m_L/m_S ratio normalized to the m_L/m_S value for bulk Co obtained on a thick layer is shown in Fig. 2 for every studied sample, both of the Co/Al_2O_3 (•) and the $Co/Cu/Al_2O_3$ series (◦). We obtained $(m_L/m_S)_{bulk} =$ 0.091(1) in agreement with previous results [6].

Fig. 2 shows that m_L/m_S ratio is much larger in the cluster arrays than in the bulk, the difference being proportional to $1/\langle D\rangle$. Furthermore, clusters of the same average size but in contact with a metallic (Cu) matrix, have a larger m_L/m_S than those dispersed in alumina [3].

To relate the cluster size dependence of m_L/m_S with the effective anisotropy, Fig. 2 show the linear fit to K_{eff} as obtained in the Co/Al_2O_3 series in Ref. [1], normalized to the bulk K_{bulk} value. It has been shown [1] that the $1/\langle D\rangle$ dependence implies that K_{eff} is dominated by the pinning of the magnetic moments located at the surface, due to the symmetry breaking. Therefore, the $1/\langle D\rangle$ enhancement of m_L/m_S must also be linked to the surface atoms.

Our results show that the effect of an increase on m_L/m_S is one order of magnitude more effective as source of anisotropy in the surface than in the bulk. Due to the large surface-to-volume ratio of nano-objects, this result may lead to important basic and applied developments by modifying not only the geometry but also the electronic environment, as exemplified by the enhanced m_L/m_S ratio and anisotropy of the $Co/Cu/Al_2O_3$ samples.

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