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Surface spin slips in thin dysprosium films

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Abstract – We present a discussion of the surface nucleation of spin slip phases of thin dysprosium films. The surface region contribution is a relevant fraction of the energy per unit area leading to states not found in the bulk magnetic phase diagram. The reduced exchange energy of surface atoms allows the nucleation of large magnetic moment helical states which are strongly affected by anisotropy and external fields. Near the Curie temperature the helimagnetic phase is distorted by the hexagonal anisotropy, displaying surface spin slips, which evolve to spin flop-like helical states at moderate temperatures.

Considerable research effort has been dedicated to investigate the impact of confinement and surface effects on the equilibrium phases of magnetic systems with size comparable to fundamental magnetic lengths. Particularly interesting are magnetic systems in which the bulk magnetic phases consist of a periodical repetition of units containing a finite number of spins. This is the case of the helical structure of rare earth metals, and the helix period is a valuable length scale to evaluate confinement effects.

Recent reports include a strong thickness dependence of the Neel temperature of Ho thin films, indicating that the helical state does not form below ten atomic layers [1]; large thermal hysteresis of Dy thin films, induced by an alternate chirality helical phase associated to the locking of surface spins to the external field direction [2] and a giant magneto-caloric effect of Dy ultra-thin films, due to the absence of the helical phase and the abrupt drop of the thermal average value of the magnetization at the Neel point [3].

We presently report on new surface magnetic phases of thin dysprosium films, with thicknesses ranging from below to a few helix periods. Surface effects originate in the break of the exchange energy balance near the surface. The modification of the local exchange field in the near surface atomic planes favors an almost ferromagnetic arrangement of near surface spins. At low temperatures the surface spins align more easily with the easy axis of the hexagonal anisotropy than spins from inner atomic planes, thus forming surface spin slips. For a 26 angstroms dysprosium film, with thickness smaller than the helix period (around 31 angstroms), the surface spin slip states have an average turn angle smaller than the bulk helical value (Fig.1(a)). At the expense of the overall exchange energy, the near surface spins align at small angles with the easy directions of the hexagonal anisotropy, posing a constraint on the magnetic structure of inner planes.

At temperatures above 105 K, the hexagonal anisotropy is small allowing a larger alignment of spins with the local exchange field at each atomic plane, and a spin flop – like phase is formed (Fig.1(b)), with an increase in the turn angle. The magnetic moment per surface area is much larger than the corresponding bulk values (Fig.2), even though the external field strength (below 1 kOe) is much smaller than the constitutive (exchange) fields. This might be a feature of interest for applications requiring large changes of magnetization, such as the use of nano-structured magnetic materials for adiabatic demagnetization devices.

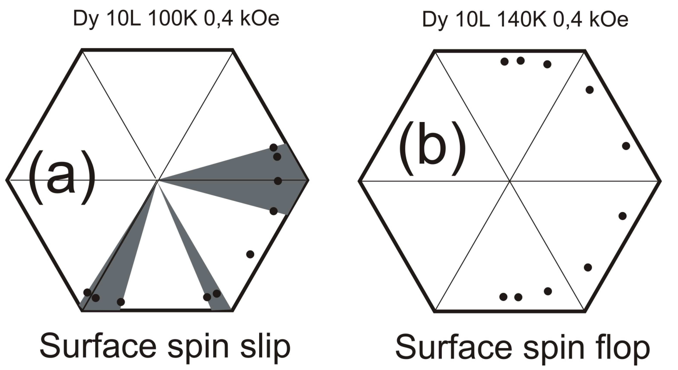

Figure 1: Schematic representation of (a) the low temperature surface induced spin slip phase and (b) the surface spin flop helical state for T=140 K of a 26 A thick dysprosium film .

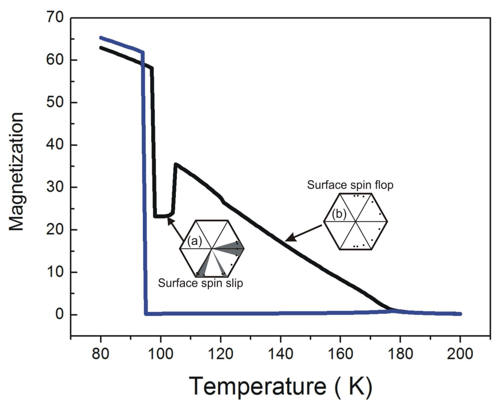

Figure 2: Isofield magnetization curves for a 26 A thick dysprosium film, for external field H=400 Oe (black line) and the corresponding curve for bulk dysprosium (blue line).

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