Temperature dependent transition in MnAs : EMCD and electron holography in-situ studies

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The control of a magnetic state by thermal or electrical activation is essential for the development of new magnetic devices, such as those envisaged for thermally activated or electrically assisted recording. Compounds such as FeRh or MnAs, which exhibit magnetic transitions close to ambient temperature from a ferromagnetic state to a zero global magnetization state (antiferromagnetic or paramagnetic), are anticipated for such applications. However, the mechanisms involved in these transitions are still very controversial and are studied only on the surface without visualization of the magnetic order in volume.

MnAs presents a remarkable magnetostructural phase transition from the ferromagnetic (FM) hexagonal Φ#177; phase (NiAs type symmetry, $B8_1$) to non-ferromagnetic (N-FM) orthorhombic β phase (MnP type symmetry, $B3_1$) around 40°C with temperature rising. Most interestingly, the parameters of this first order transition are different in MnAs thin films grown on GaAs substrate compared to bulk MnAs. The temperature range where Φ#177; and β domains coexist broadens and varies with the film thickness, orientation and deposition conditions. The constrained lateral size and constant mean lattice spacing in the MnAs layer explain the phase coexistence. The thermal dilatation and crystalline transformation give rise to elastic strain that can be relaxed through the coexistence of Φ#177; and β domains.

Prior to domain formation observation as a function of temperature, EMCD experiments have been performed on MnAs thin films to follow the magnetostructural transition as a function of temperature and investigate the magnetic moments as a function of the crystallographic directions. The anisotropy of the EMCD has been measured and compared to DFT calculations of the magnetic moments [X. Fu et al., Physical Review B 93, 104410 (2016)]

MnAs thin film were also observed in cross section by in situ electronic holography associated with temperature control to map the Φ#177; and β domain coexistence [C. Gatel et al., Nano Letters 17, 2460 (2017)]. The magnetic induction of these alloys could thus be quantitatively mapped with a spatial resolution close to the nanometer during magnetic transitions. This approach revealed an inhomogeneous spatial distribution of the magnetic transition temperature along the axis of growth but also a variation of the temperature range necessary to achieve the complete transition of the layers. These results highlight the effects of the surface of the films but also of their interface with the substrate. For MnAs, the existence of two types of ferromagnetic domains during the transition was revealed, each with their own magnetic anisotropy and spatial extension. One of these domain families plays a particularly important role in the stabilization of magnetic walls.

Beyond these results on the fundamental transition mechanisms, our work brings a new illustration of the interest of the development of EMCD and electronic holography experiments under stress, here by the control of the temperature.