Magnetic transition in temperature: inhomogeneities revealed by electron holography at the nanometer scale

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The control of a magnetic state by thermal or electrical activation is essential for the development of new magnetic devices, for instance in heat or electrically-assisted magnetic recording or room-temperature memory resistor[1,3]. Compounds such as FeRh or MnAs, which undergoes a magnetic transition from a ferromagnetic state to a state of zero magnetization (antiferromagnetic or paramagnetic) close to room temperature are expected for such applications. However, the mechanisms involved in these transitions are still under debate as they were mainly studied with surface investigation techniques without visualization of the magnetic reorganization in volume. For the first time, the use of *in situ* electronic holography on thin films demonstrates the effects of discontinuities and defects on the magnetic transition at the nanometer scale.[4,5]

The FeRh alloy presents an unusual magnetic transition from a low temperature antiferromagnetic state to a high temperature ferromagnetic state close to 370K accompanied by a 1% volume expansion.[1 - 5] The transition is obtained for a narrow composition range $0.48<x<0.56$ in the B2-ordered a' crystal phase of $Fe_{1-x}Rh_x$. MnAs presents a remarkable magnetostructural phase transition from the ferromagnetic hexagonal α phase (NiAs type symmetry, B_{81}) to non-ferromagnetic (N-FM) orthorhombic β phase (MnP type symmetry, B_{31}) 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 α 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.

In situ heating / cooling electron holography was used to quantitatively map the magnetization of FeRh and MnAs thin films from the cross-section view through the magnetic transition at the nanoscale. We demonstrate the possibility of measuring very locally a magnetization vs temperature loop. This approach reveals for both alloys an inhomogeneous spatial distribution of the transition temperature but also a variation of the temperature range required to complete this transition in the whole layers (Figure 1). These results show the effects of the surface and the interface with the substrate. For FeRh alloy, we evidenced an unexpected transition mechanism with first the appearance of a periodic spacing of nucleated ferromagnetic domains followed by a spatial extension during transition monitoring.[4] For MnAs thin films, we demonstrate the appearance of the types of ferromagnetic domains during the transition with different magnetic anisotropy and spatial extension.[5] Such ferromagnetic domains play an important role in the stabilization of the magnetic walls (Figure 2).

Beyond these results on the fundamental transition mechanisms, our work brings a new illustration of the development of experiments of electronic holography under solicitation, here by the control of the temperature. The study under an electric field would also provide information on the magnetoelectric coupling in multiferroic compounds.

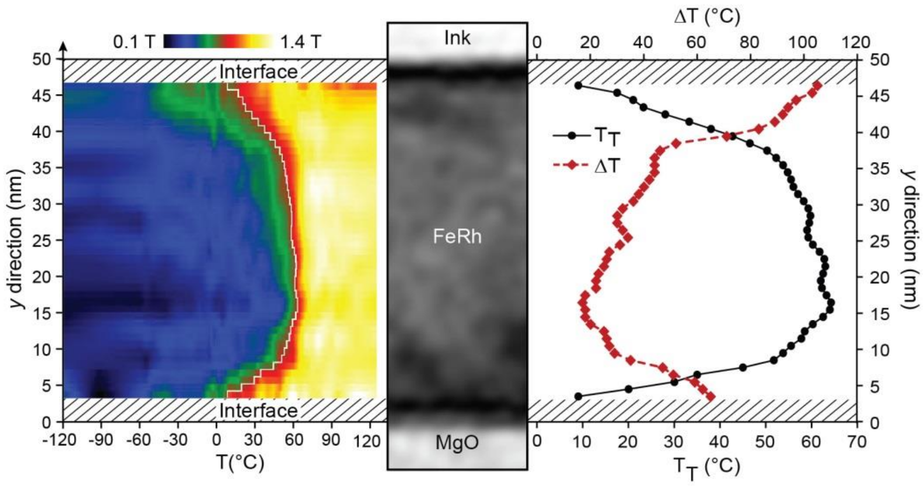

Figure1. Evolution of the AFM/FM transition along the growth direction. (a) Map of the magnetization as a function the temperature and the position in the layer depth. The color scale corresponds to the magnitude of the magnetization and the transition temperature is displayed by the white profile corresponding to magnetization of 0.75 T. (b) Amplitude image of the part of the FeRh layer used for the calculation. (c) Profiles of the transition temperature T_T and the transition width ΔT as a function of the position within the FeRh layer.

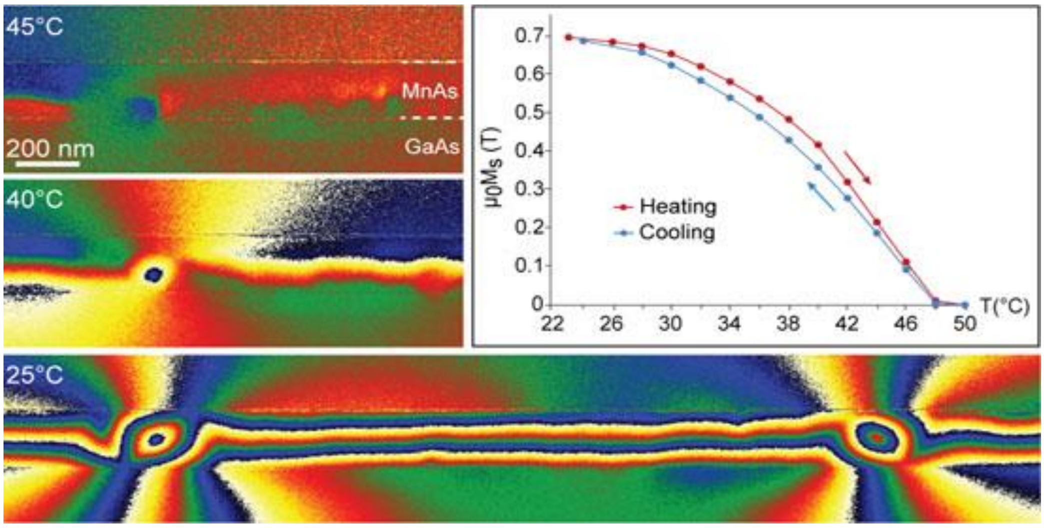

Figure 2. Magnetic phase shift maps obtained at 25°C, 40°C and 45°C. The graph corresponds to the evolution of the horizontal component of the magnetization measured by electron holography as a function of temperature T for both the heating (red) and cooling (blue) processes.

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