Report on experiment HE-1515, Beamline BM 28
Date: 12/03/2003 to 18/03/2003

Bulk Eu is known to undergo a helimagnetic transition around 90 K, the wave vectors of the helices lying along the <100> directions of the bcc lattice. This magnetic transition is accompanied by a tetragonal lattice distortion inducing the formation of three cristallo-magnetic domains. The purpose of the HE-1515 project was the study of the magnetic behaviour of Eu epitaxial films in relation with the strains occurring in these films supposed to be able to modify the bulk properties. This project completes two previous experiments, namely HE-937 (February 2001) and HS-1624 (November 2001), which were devoted to a 970 nm (110)Eu film presenting three structural domains rotated by 60° in the plane of growth (HE-937), and a 375 nm single crystal Eu(110) film (HS-1624). From these experiments it was shown that :

1. The three helimagnetic domains form inside the epitaxial films as in the bulk case.
2. As in the bulk Eu case, the wave vector lying in the sample plane is along the [001] axis, at variance with the two other out-of-plane wave vectors which show a tilt angle relative to the [100] and [010] cubic axis, with the tendency to get closer to the [110] axis. This tilt angle increases as the temperature decreases.
3. The three domains show a hysteresis behaviour as a function of temperature. In particular the HS-1624 experiment revealed that the [001] domain disappears at the benefit of the two others near 40 K with decreasing temperature and reappears around 70 K with increasing temperature.
4. Strains occurring in the sample used for the HS-1624 experiment are located in the plane of growth, the deformation being in a major part along the <1-12> directions above the Néel temperature.

The aim of the HE-1515 experiment was an attempt to understand these observations by two ways : first, by studying other samples orientations like Eu(100) thin films. Unfortunately, up to now, we failed to find a growing process able to produce such samples. Second, by varying the thickness of (110)Eu films and by exploring the previous observations as a function of this parameter. This has been done for a set of samples with thickness ranging from 75 nm to 750 nm.

From these measurements, the temperature for which the [001] magnetic domains disappear has been explored as a function of the film thickness (figure 1) as well as the populations of each magnetic domain vs temperature. The tilt angle (β on figure 2) as been measured at 10 K, showing a huge variation at small thickness.

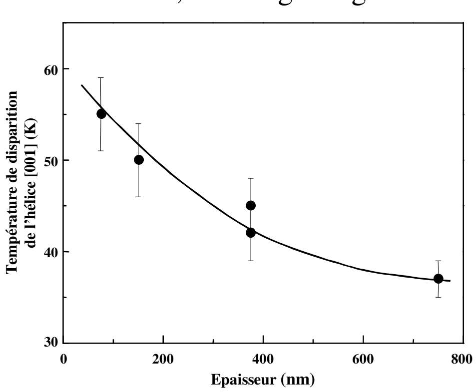

Figure 1: Evolution of the temperature for which [001] cristallo-magnetic domains disappear as a function of sample thickness. Ligne is a guide for the eyes

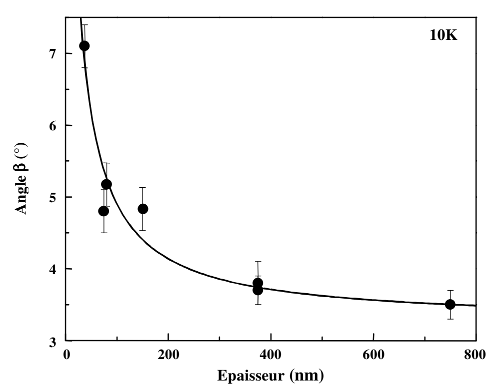

Figure 2: Evolution of the tilt angle at 10K as a function of the sample thickness. Ligne is a guide for the eyes.

We also confirmed that the strains in the samples are essentially localised along the <1-12> directions above the Néel temperature. But in order to link the previous observations with strains, it is necessary to estimate these strains below the Néel temperature inside each magnetic domain vs temperature for various thickness. This has been partly done for one sample by measuring the positions of the two X-ray magnetic satellites associated to each domain for a particular node of the mean reciprocal lattice of the samle. The middle of the line between the two satellites gives then the position of the Bragg peak associated to the corresponding domain. This is shown on figure 3, where the thermal variation of the reticular distance d(121) is reported for each domain (H is for [100], K is for [010], and L is for [001] ; the continuous curve is for bulk Eu). It is seen that the amplitude of the magneto-elastic distortion is more pronounced as compared to the bulk one and persists at low temperature at variance with the results for bulk Eu. This point remains to be clarified.

A full determination of strains inside each domain needs to reproduce similar curves at least around two other nodes in the mean reciprocal lattice. This operation has to be repeated for other samples with various thickness. It is a time expensive operation and it was not possible to make use of this method during the time evolved to the HE-1515 experiment alone.

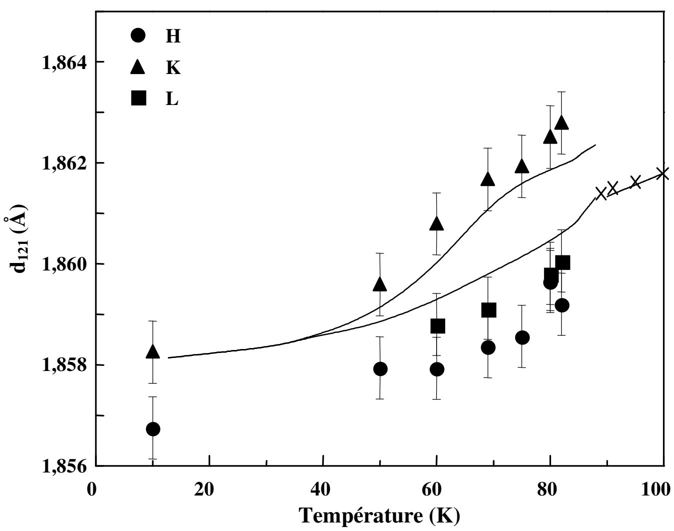

Figure 3: Thermal variation of intereticular distances d(121) for each cristallo-magnetic domain in a 75 nm (110)Eu sample.

Nevertheless, the HE-1515 experiments have been completed by SQUID and neutron diffraction measurements in order to test the influence of a magnetic field, so that all these results allowed us to develop a magneto-elastic model including exchange, elastic and magneto-elastic energy terms able to explain part of our observations. In particular, the tilt angle seems to come from the competition between exchange energy and magneto-elastic energy terms originating from shear strains (which are not present in bulk Eu).

These 3 years studies are consigned in the Stéphane Soriano's thesis (Nancy, December 2003). They already gave rise to posters communications (Dourdan 2001, Grenoble 2001, Marseille 2002, Rome 2003) and to a first contribution accepted for publication in IEEE Transaction on Magnetism (2003). More detailed and concise articles are now in progress.