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**Names and affiliations of applicants** (* indicates experimentalists):
*Eugen Weschke, *Christian Schüßler-Langeheine, *Alexei Yu. Grigoriev, *Holger Ott, *Denis V. Vyalikh
*Institut für Experimentalphysik, Freie Universität Berlin, Arnimallee 14, D-14195 Berlin, Germany*

Gerhard Grübel
*ESRF*


Report:
The present experiment was concerned with magnetic x-ray scattering from thin lanthanide metal films. The electronic and magnetic structure of thin films is presently intensively studied in order to determine the role of shape anisotropy and finite-size effects as well as the influence of surfaces and interfaces. In this context, lanthanides are particularly interesting because of their strong magnetic moments and significant relation between electronic, magnetic and crystal structures.
Originally, it was intended to investigate critical scattering and proximity effects in thin Ho-metal films near the Néel temperature. Due to unforeseen severe problems with the polarization analysis, however, experiments in the planned thickness range were beyond feasibility. These problems could only be solved towards the end of the beamtime, however, providing new ideas for a substantially improved polarization analysis at ID 10A. Since the initially obtained magnetic contrast was not sufficient to study very thin Ho films, an alternative experiment was carried out, which turned out to be fully in line with the original ideas and opened new perspectives for forthcoming investigations. This experiment was concerned with a first order phase transition in Dy metal, studied in films with thicknesses of $\approx 180$ monolayers.
Bulk Dy metal is helical antiferromagnetic (afm) below $T_N = 179$ K and becomes ferromagnetic (fm) below $T_C = 89$ K. This latter transition is accompanied by an uniaxial lattice distortion, which breaks the hexagonal symmetry of the helical phase. Accordingly, strain at interfaces is known to stabilize the fm and the afm phase in Dy/Y [1] and Dy/Lu [2] multilayers, respectively. We studied Dy films grown *in situ* on W(110) under UHV conditions in a small chamber directly attached to the dif-

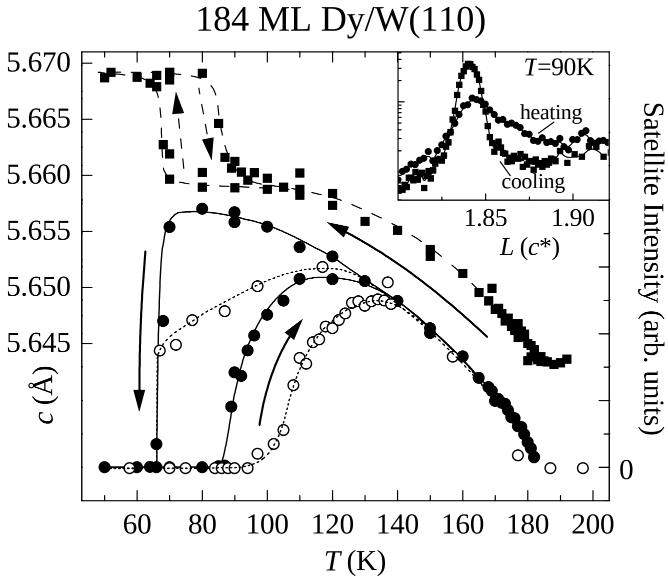


Figure 1: $c$-axis parameter (upper curve) and magnetic-satellite intensity (lower curves) as determined at the $L_3$ resonance (002-$\tau$; solid symbols) and at the $M_5$ resonance (000+$\tau$; open symbols). The inset shows longitudinal scans through the (002-$\tau$) satellite.

fractometer. With the incoming beam linearly polarized in the scattering plane ($\pi$-polarization), the magnetic-scattering signal was detected in the $\pi\sigma$ channel using a graphite (006) analyzer crystal. Typical scans across the (002-$\tau$) magnetic satellite in this geometry are shown in the inset of Fig. 1. Also, Fig. 1 displays the $c$-axis parameter as obtained from the position of the (002) Bragg peak (solid squares) and the intensity of the magnetic (002-$\tau$) satellite (solid circles) as a function of temperature. Upon cooling below 70 K, the $c$ axis undergoes an abrupt expansion, which is characteristic of the transition into the fm phase in bulk Dy. Accordingly, the magnetic-satellite intensity, which represents the order parameter of the helical phase, vanishes simultaneously. The situation is different upon heating. While the lattice distortion disappears after a hysteresis of about 20 K within a narrow temperature interval, the magnetic satellite reappears only gradually over a larger temperature range, closing the hysteresis loop not below $\approx$ 135 K. The inset shows longitudinal scans through the (002-$\tau$) satellite taken at 90 K for the cooling and heating path, respectively. The small width of the peak observed upon cooling indicates that afm order exists throughout the whole film, which is not the case upon heating, as seen in a much broader peak. Obviously, substantial parts of the films stay ferromagnetic, with magnetic and crystalline structure being decoupled. It appears plausible to explain the delayed transition of the film by the presence of the substrate, because the W(110) surface is expected to induce a rectangular distortion of the basal plane of Dy and hence a clamping of ferromagnetic domains at the interface. This is, however, not the case, as shown in a subsequent surface sensitive experiment in the soft x-ray region at BESSY II, making use of the strongly reduced penetration depth for x-rays at the $M_5$ resonance of Dy. Recorded with a probing depth of only $\approx$ 3 nm, the satellite intensity (open circles in Fig. 1) exhibits an even more delayed onset upon heating from the fm phase, showing that near the surface, the helical afm order occurs only at higher temperatures than in the remaining parts of the film: Obviously the surface stabilizes the ferromagnetic phase.

Due to the strong absorption, a chacterization of the magnetic structure across the entire film is not possible at the $M_5$ resonance, stressing the importance of complementary experiments with hard and soft x-rays.

[1] M. Hong *et al.*, J. Appl. Phys. **61**, 4052 (1987).
[2] R. S. Beach *et al.*, PRL **70**, 3502 (1993).