ESRF	**Experiment title:** Identifying spin-spirals in 2D using X-ray linear dichroism (XLD)	**Experiment number**: HE 3406 **Ref. No 24759**
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Abstract :

The experiment HE3406 aimed to demonstrate potentials and limits of x-ray liear dichroism (XLD) as a complementary, quantitative technique to local spin-sensitive microscopy techniques in the field of surface nanomagnetism. As a model system the cycloidal antiferromagnetic spin spiral ground state of the Mn monolayer on W(110) was used (see Fig. 1 of the proposal for HE3406), which has been observed recently in SP-STM measurements. The system allows for a systematic and quantitative comparison between experiment and theoretical predictions on a complex non-collinear magnetic system. One focus is the fundamental question if the x-ray magnetic linear dichroism (XMLD) and the so-called natural linear dichroism (XNLD) contributions to XLD can be disentangled in the submonolayer coverage regime.
The results of the 9-shift experiment HE3406 were successful since: (i) we were able to prepare high-quality Mn/W(110) samples, where in STM a clean step-flow growth of Mn is visible upon deposition at ~500K, (ii) we have clearly observed temperature dependent features in the XLD in polar incidence which seem to be distinguishable from XNLD effects as we will explain furthermore below.

Experiment and Results :

SP-STM only provides qualitative information on relative orientations of neighboring magnetic moments. In contrast, the X-ray based technique like XMCD and XMLD contain both quantitative magnetic and electronic information, both of which are highly susceptible to the symmetry and quality of the local chemical bonding configuration [2]. While for antiferromagnetic systems XMCD signals vanish since they reflect $\langle m \rangle$, XMLD reflects the average square of the moments $\langle m^2 \rangle$ and can be used to detect antiferromagnetic or complex non-collinear magnetic phases. HE3406 aimed to discover potentials and limits of XMLD techiques in the field of surface nanomagnetim.
During HE3406 samples of approximately 70% of a Mn monolayer on W(110) were prepared *in situ* and were characterized by STM. The growth procedure is described in HE3406. A typical STM image proves single layer step-flow growth of Mn and a high quality of the samples. It should be mentioned at this point that the UHV preparation of this system is challenging and it has required a large input of work from the ID08 beamline technicians and scientists: the results of the sample preparation part is of general interest for future projects.

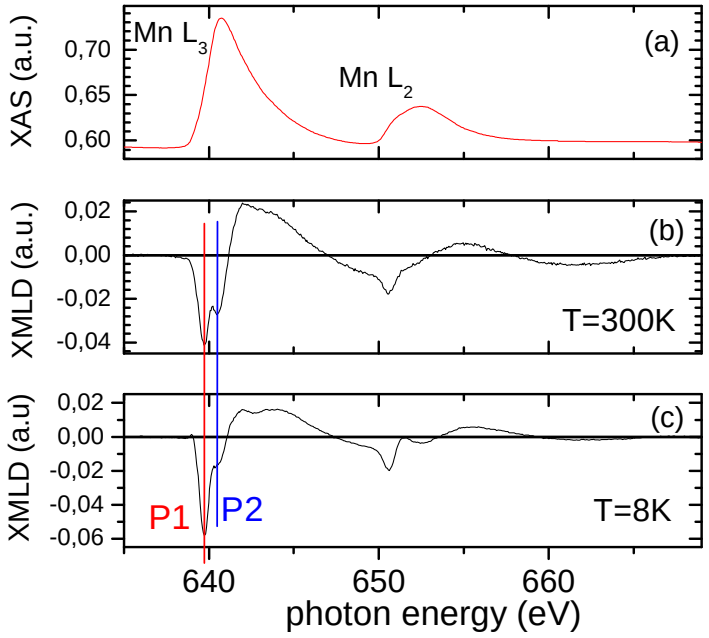

Fig.1: Mn $L_{3,2}$ XAS showing a metallic spectral shape. (a)-(c) XMLD taken in polar incidence with linear polarization along the [1-10] and [001] directions ($\hat{\varepsilon}_{II}$ and $\hat{\varepsilon}_{\perp}$, respectively) for T=300K and T=8K. See figure 2 for details on the measuring geometry.

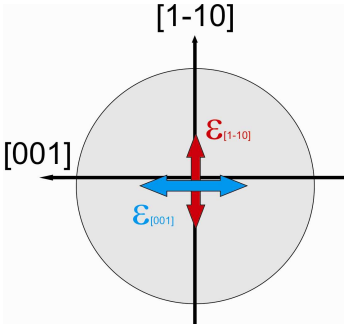

Fig.2: Sketch for details on the measuring geometry

The results of HE3406 included temperature dependent XLD measurements at the Mn $L_{3,2}$ edge in polar geometry for two different crystal orientations (i) W[1-10] parallel to the horizontal polarizaton mode ($\hat{\varepsilon}_{II}$) of the Apple II undulator and (ii) W[1-10] about 55° rotated from $\hat{\varepsilon}_{II}$ (Comment: since the polarization could not be set in arbitrary directions by the Apple II undulator we had to rotate the W(110) crystal *ex situ* by 55°). XMCD data were taken in polar and grazing incidence and the negligible signal proved the expected antiferromagnetic nature of the spin spiral ground state of the Mn monolayer. The essential results are summarized in Fig. 1 and Fig. 3): (a) Mn $L_{3,2}$ XAS and XLD spectra for (b) room temperature and (c) T=8K. These measurements were taken W[1-10] parallel to the horizontal polarizaton mode ($\hat{\varepsilon}_{II}$) of the Apple II undulator according to geometry a) in Fig. 2 of the proposal for HE3406 where the maximum magnetic effect is expected. The XLD spectra in Fig. 1 are normalized to the XAS intensity. Comparing the normalized XLD at 300K and 8K some features in the spectra have clearly temperature dependent intensities (see Fig.3) while other parts of the spectra remain rather constant. XNLD contributions due to switching $\hat{\varepsilon}$ from parallel to perpendicular with respect to [1-10] are indeed expected to be temperature independent. On the other hand plotting the intensities of the temperature dependent features P1 and P2 in Fig. 3, a clear trend is observed: increasing the temperature from 8K to 300K the XLD changes monotonically until T=180K for both P1 and P2. Beyond this temperature P1 shows a distinct minimum at around 230K and raises again afterwards, while P2 stays rather constant and has a final increase at T=300K. This non-monotonic behaviour could be reproduced for several samples, however, the absolute temperature value of the minimum of the P1 signal was sample dependent.

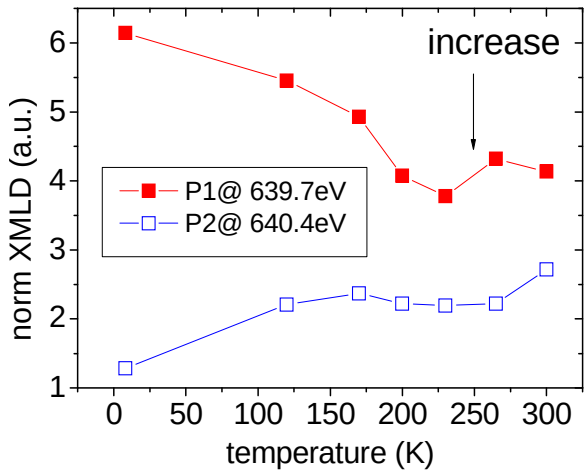

Fig. 3: Temperature dependece of P1 and P2.

If the temperature dependences of the intensities P1 and P2 in Fig. 3 can be attributed to changes in the cycloidal antiferromagnetic spin spiral state then the initial decrease e.g. of the intensity of P1 at lowest temperatures are according to the findings in Bode et al. [1] up to 230K. Beyond this temperature the systems

properties are unknown, and an increase e.g. in the signal of P1 could reflect a phase transition where the spin spiral state changes its configuration. From our xmcd data which show vanishing signals we know that the nearest neighbor magnetic coupling between adjacent Mn-atoms remains antiferromagnetic also above temperatures of T=230K. However, the phase transition could be such, that the spin-spiral structure is destroyed and the system flips into a perfect antiferromagnetic state with the spins in the plane and along [1-10], which enhances the XMLD in geometry a) in Fig. 2 of the proposal for HE3406.

References

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[2] G. van der Laan, E. Arenholz, R. V. Chopdekar, and Y. Suzuki, Phys. Rev. B 77, 064407 (2008)