Quantitative Vectorial Magnetometry of Antiferromagnetic Domain Structures Using XPEEM

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Magnetic imaging of a ferromagnet is a common experimental approach to understand the physics of these systems. The shape of the domain pattern, the size of the domains or the domain walls inhibit important information on the magnetic energies contributing to the system. Studying of the evolution of the pattern under stress, external fields or changing temperature reveals furthermore information of the dynamic properties of the magnetism. In case of a ferromagnet, which exhibits a net magnetization, optical techniques that employ the fact that the optical properties of a material depend linear on the orientation between light polarization and magnetization vector are used. This can be done for example either in the visible region with Kerr microscopy, or using x-ray magnetic circular dichroism in a photoemission electron microscope.

Imaging of an antiferromagnetic structure is much more challenging, because the antiferromagnetic domains are magnetically compensated and exhibit no net magnetic moment. However, the symmetry breaking caused by the presence of a magnetically preferred axis gives rise to another class of polarization dependent optical properties. These effects are usually of second order that means quadratic in the magnetization and therefore smaller. Initial approaches to image the antiferromagnetic structure of NiO single crystals were already made in the late 1950's for example by Roth et al. [3] where the theoretically expected bulk domain structure was found.

Today the determination of the antiferromagnetic structure at the surface only by separating it from the underlying bulk signal is crucial in understanding magnetic coupling phenomena in ferromagnet-antiferromagnet layered structures as these attract great interest in new magnetic storage media. As the coupling takes place across the interface of these systems, the bulk structure of the antiferromagnet is of minor interest. Therefore new techniques had to be developed. X-ray magnetic linear dichroism the analogon to x-ray magnetic circular dichroism was shown to obtain exactly this information [1,2]. Its polarization dependence allows furthermore the exact determination of the antiferromagnetic axes in each domain with respect to the crystal axes.

The antiferromagnetic domain structure of an ex-situ cleaved NiO(001) crystal was imaged using photoemission electron microscopy (PEEM). Therefore X-Ray Magnetic Linear Dichroism (XMLD) was used as a contrast mechanism to distinguish between different antiferromagnetic axes. By changing the polarization of the incoming synchrotron radiation, produced by a bending magnet at the Advanced Light Source, and rotation of the sample we are able to determine the directions of the antiferromagnetic axes with respect to the crystal axes. It is found that the antiferromagnetic axes at the surface of the cleaved crystal are exactly the same as in bulk NiO.

We therefore took a series of images with different polarization in different geometries. The polarization was changed from pure horizontal to a mixed horizontal/vertical state. The sample was rotated so that the angle between horizontal polarization component and in plane [100] axes was changed from –30 to 0 to 45 deg. Figure 1 shows the results we obtained for linear and plane polarization at 45 deg. With linear polarization a striped domain pattern is visible. The antiferromagnetic domains are separated by walls parallel to in plane [100] directions. The width of the domains, typically observed, lies between 1 and 20 micrometer and the can extend over 100s of microns. Because the polarization vector lies completely in the sample surface when linear polarization is used, only information on the in plane distribution of the antiferromagnetic axes can be obtained. Now we acquired additional images using circular polarization. Circular polarization can be represented as a linear combination of horizontal and vertical light polarization with a certain phase shift. As the phase shift does not play a role in a linear dichroism experiment, the effective polarization is still linear but now rotated away from the horizontal towards the vertical direction. This means that the resulting polarization now has a component that points out of the surface plane. Consequently we are now able to distinguish between the out of plane components of different domains as it is shown on the right side of figure 1. Each in plane domain splits up into two different domains with different out of plane components that are now separated by [110] walls. The ensemble forms a zig-zag like fourwall pattern that minimizes the magnetic energy of the structure. Again the detailed analysis of the evolution of the contrast upon rotating the sample around its surface normal the exact direction of the antiferromagnetic axes can be determined. We found that the easy axes of this domain pattern are the four different <121> crystal axes. That means that the antiferromagnetic axes always incline an angle of roughly 35 deg with the surface and about 30 deg with the [001] domain walls. The typical error for these values is +/-5 deg.

This is the first experiment in which the domain structure at the surface of an antiferromagnet could be determined with reasonable high precision. This allows us to study reorientation and coupling process in antiferromagnet-ferromagnet layered structure in great detail. Especially the interaction between the surface antiferromagnetic domains and a ferromagnetic layer on top is currently under investigation.

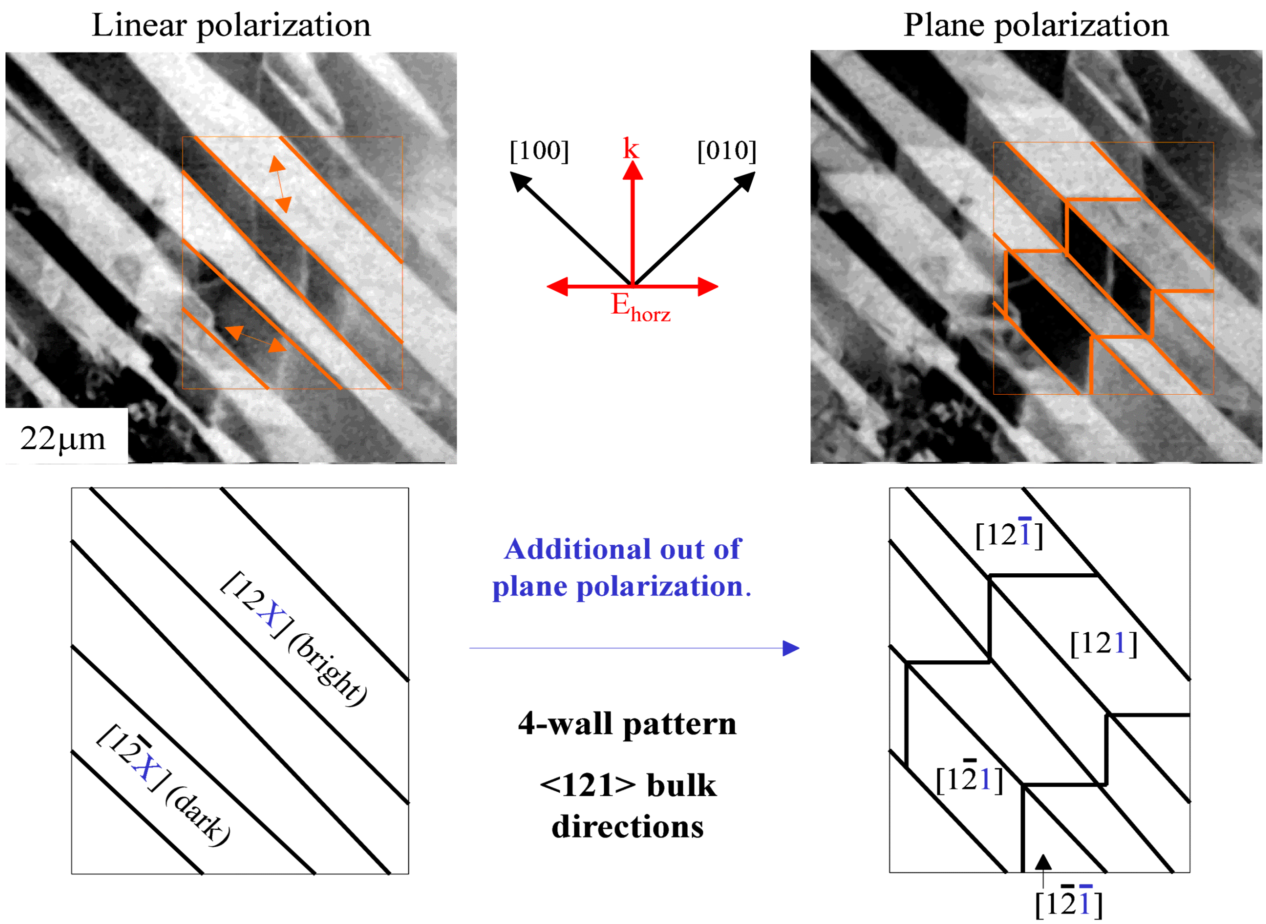

Figure 1. XMLD Images of a NiO(001) surface taken with linear (left) and plane polarization (right). The field of view is 22 micrometer. The in plane crystal axes and the relative alignment of the horizontal polarization component are shown by the legend between the images. Changing from linear to plane polarization each in plane antiferromagnetic domain split up into two sub domains with different out of plane component. A detailed analysis of the angle dependence of the contrast leads to the direction of the antiferromagnetic axes as they are mentioned in the sketch on the bottom.

REFERENCES

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