Site-specific chirality in magnetic transitions

S Löffler¹, I Ennen¹², C Kübel³, A Auge², A Hütten² and P Schattschneider¹⁴

¹. Institute of Solid State Physics, Vienna University of Technology, Vienna, Austria.
². Thin films and Physics of Nanostructures, Bielefeld University, Bielefeld, Germany.
³. Institute for Nanotechnology, Karlsruhe Nano Micro Facility, Eggenstein-Leopoldshafen, Germany.
⁴. University Service Center for Transmission Electron Microscopy, Vienna University of Technology, Vienna, Austria.

stefan.loeffler@tuwien.ac.at

Keywords: EMCD, Heusler, channeling

In recent years, investigating magnetism on the nanometer scale has become increasingly important. Be it for the development of new data storage devices, for new, emerging technologies such as spintronics, for material science, or for fundamental physics, measuring and understanding the magnetic structure is indispensable.

The established X-ray magnetic circular dichroism (XMCD) technique serves well for analysing magnetism, but has several shortcomings – most notably, it requires synchrotron radiation. Hence, it is extremely difficult to use it to study magnetism on a sub-micrometer scale. The emerging energy-loss magnetic chiral dichroism (EMCD) technique [1], on the other hand, can be applied in transmission electron microscopes (TEM) and thus is inherently capable of high spatial resolution [2].

In this work, we investigate the site-specificity of the EMCD signal. Even with (near-)parallel illumination, the strong elastic scattering of electrons in crystals severely influences the EMCD signal [3]. In a crystal with basis and, say, two different atomic species, the two strongly excited plane waves have different relative phase shifts at non-equivalent crystallographic sites. Under not very stringent conditions, assuming two sites A and B, one can see a phase shift close to π/2 at site A and the opposite phase shift at site B. If these sites are occupied by different elements with ferromagnetic coupling, an EMCD experiment will result in magnetic signals with opposite sign for the two elements, in complete contrast to XMCD. By exploiting site-specificity, one can thus obtain magnetic information with sub-unitcell precision [4].

Here, we used the technologically interesting Ni₂MnSn Heusler alloy for demonstration purposes. The approximately 25 nm thick sample was first tilted into a systematic row condition including the (200) diffraction spot. For these conditions, the simulated EMCD signal strength is shown in fig. 1. From that, it is clear that the Mn atoms are located in areas which – due to channelling effects – have mainly negative contributions to the EMCD signal. On the other hand, the Ni atoms are located in areas that have primarily positive contributions to the EMCD signal. Thus, one would expect opposite signs in the total, collected EMCD signals of the two atom species.

Fig. 2 shows the experimental setup and data. The measurements were performed on an FEI Titan 80-300 TEM at room temperature. To avoid inconsistencies due to, e.g., sample drift, both EMCD positions were recorded at the same time. To accomplish this, the diffraction pattern was aligned in such a way that the energy-dispersive axis of the spectrometer was perpendicular to the systematic row. In the subsequently recorded spectra, the vertical axis thus corresponds to the momentum transfer q parallel to the systematic row. Therefore, it is possible to extract data for both EMCD positions and both elements from one measurement. The EMCD signal obtained after conventional power-law background subtraction is also given in fig. 2. The change of sign between Mn and Ni is clearly obvious and is in perfect agreement with theoretical predictions. Also the values of about 16 % EMCD signal at the Ni L₃ edge and 9 % at the Mn L₃ edge are in reasonable quantitative agreement with simulations.

This shows that using site-specific EMCD, it is indeed possible to obtain sub-unitcell information of crystalline samples in a conventional TEM, even without the need for last-generation aberration correctors.

References
[5] The authors gratefully acknowledge funding from the Austrian Science Fund (FWF) under grant number I543-N20.

Figure 1. x-z map of the EMCD contributions of different regions of the sample (left) and variation of the total signal strength for Ni and Mn with thickness (right).

Figure 2. (a) Schematic drawing of the measurement setup. (b) Sketch of the position of the spectrometer entrance aperture (SEA) relative to the diffraction pattern. (c) recorded spectrum; the rectangles show the regions of data extraction, the curly brackets show the position of the Mn and Ni edges, respectively. (d) Spectra after extraction and background subtraction, together with the EMCD difference signal.