

Temperature Dependent Magnetic Linear Dichroism by Momentum-Resolved EELS

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Since the advent of the spin-based electronics, tremendous efforts have been focused on fabrication and characterization of nanomagnetic structures. Since the spin transport occurs through the bulk of multi-layered nanostructures, probes directly sensitive to the magnetic anisotropy of the bulk and its interfaces are of great interest. So far, intense research activities to probe the magnetic anisotropy have been centered on polarized synchrotron X-ray spectroscopy techniques. However, the spatial resolution of these techniques is currently limited to ~50 nm. Therefore, there is an urgent need for a technique capable of probing the magnetic anisotropy on length scale less than a few nanometers.

Previously, we confirmed the possibility of detecting nanometer scale magnetic anisotropy (magnetic linear dichroism (MLD)) at room temperature [1], which Yuan and Menon proposed using STEM-based momentum-resolved EELS [2]. MLD was extracted by taking the difference of two spectra acquired from an oriented single crystal with different convergence angles (α) with the EELS collection angle (β) fixed, hence changing the ratio of parallel to perpendicular components of the scattering vector (FIG. 1). However, these experiments left a question whether the difference is originated from its structural anisotropy rather than spin or magnetic anisotropy. α -Fe₂O₃ has antiferromagnetic ground state with spins on specific neighboring planes oriented in opposite directions. It exhibits magnetic phase transition at 263K, known as Morin temperature, without structural change. At room temperature, its magnetic moments are perpendicular to the c-axis. Below the Morin temperature its magnetic moment flips 90 degree and orients along the c-axis.

Here, we present an investigation of the temperature dependent MLD in microcrystalline α -Fe₂O₃ (hematite) particles, using the momentum-resolved EELS with a nanometer-scale electron probe in a 120kV Schottky field emission TEM/STEM (Philips FEI Tecnai F20). By use of lower acceleration and extraction voltage and careful removal of instrumental and environmental instability, we achieved the energy resolution lower than 0.7 eV (FWHM of zero loss peak). Low temperature experiment was performed using a Gatan liquid nitrogen double tilt holder.

FIG. 2 shows the experimental Fe L₂₃ EEL spectra acquired above and below the Morin temperature with fixed acquisition geometry and their difference spectrum. The incident beam (convergence angle of the order of the Bragg angle) was parallel to the c-axis of the (001) oriented microcrystalline. The difference spectrum clearly shows negative peaks. This agrees with the calculated MLD spectrum based on the atomic multiplet calculation for the octahedrally coordinated Fe³⁺ ion in α -Fe₂O₃ (Fig. 3 and 4). Recently, van Aken et al. demonstrated temperature dependent MLD on a single crystal natural hematite sample by momentum-resolved EELS [3]. The present result is also consistent with the result obtained by the synchrotron X-ray MLD experiment on a single crystal α -Fe₂O₃ [4], and supports that MLD is independent of the structural anisotropy.

References

- [1] Y. Ito, M. van Veenendaal, R.E. Cook, N. Menon, B.D. Armstrong, D.J. Miller, *Microscopy and Microanalysis* 9 Suppl. 2, (2003) 314CD.
- [2] J. Yuan, N.K. Menon, *J. Appl. Phys.* 81, (1997) 5087; N.K. Menon, J. Yuan, *Ultramicroscopy* 78, (1999) 185.
- [3] P.A. van Aken, S. Lauterbach, *Phys. Chem. Minerals* 30 (2003) 469.
- [4] P. Kuiper et al., *Phys. Rev. Lett.* 70 (1993), 1549.
- [5] This work is supported by the US Department of Education, State of Illinois under HECA, NIU URA program, and work at Argonne, carried out in the Electron Microscopy Center, is supported by the U.S. Department of Energy, Basic Energy Sciences-Materials Sciences, under Contract #W-31-109-ENG-38.

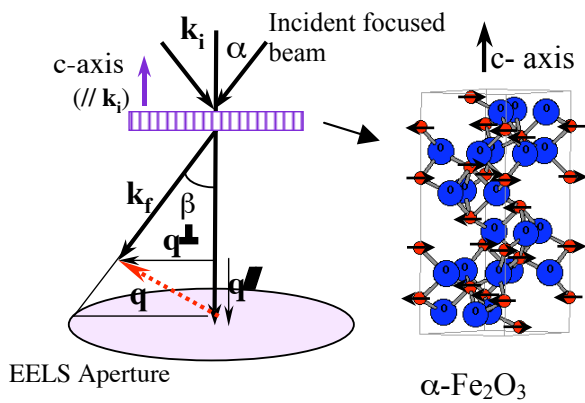


FIG. 1. Experimental geometry for MLD, and crystal and spin orientation of $\alpha\text{-Fe}_2\text{O}_3$ at room temperature.

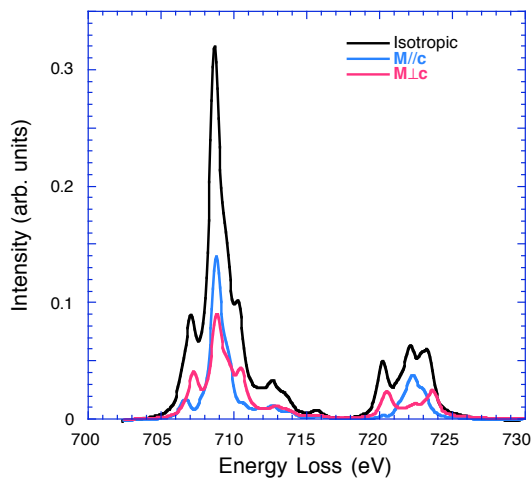


FIG. 3. Theoretical isotropic Fe^{3+} spectrum in $\alpha\text{-Fe}_2\text{O}_3$ and its components. Spin orientation is perpendicular to c-axis. Blue: $\mathbf{M} // \mathbf{c}$; Pink: $\mathbf{M} \perp \mathbf{c}$; Black: Isotropic spectrum.

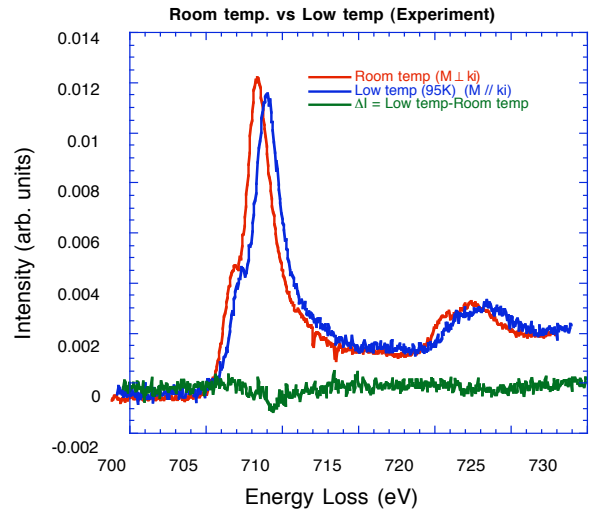


FIG. 2. Experimental Fe L_{23} and difference spectra of $\alpha\text{-Fe}_2\text{O}_3$ (001) orientation. Red: 300 K ; Blue: 95 K; Green: Difference spectrum.

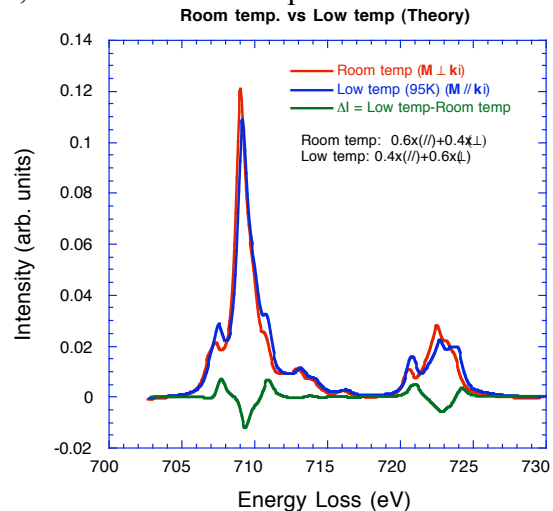


FIG. 4. Theoretical Fe L_{23} difference spectrum (MLD). The negative peaks at 709 and 722 eV of the difference spectrum indicate that the spin is flipped from perpendicular to parallel to c-axis.