Quantitative electron diffraction and electron holography of magnetite at low temperature

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The Verwey transition in magnetite is associated with an order-of-magnitude increase in magnetocrystalline anisotropy and a change in magnetic easy axis from cubic <111> to monoclinic [001] below ~120 K. Although numerous studies have suggested that magnetic domain walls in magnetite can interact with the ferroelastic twin walls that form at low temperature, no direct evidence for such interactions has been available. Here, we use transmission electron microscopy (TEM) to image both crystallographic features and magnetic microstructure simultaneously at the nanometer scale in synthetic multi-domain magnetite, which was prepared for TEM using conventional Ar ion milling.

We use selected-area electron diffraction and convergent-beam electron diffraction (CBED) to determine crystal symmetry and to identify crystallographic orientations. Energy filtering is used to improve contrast and visibility in CBED disks. The diffraction patterns show that the low-temperature phase has a monoclinic *C*-centered lattice with the *c*-glide plane perpendicular to the *b*-axis and is likely to belong to point group *m*, suggesting that the space group is *Cc*.

We use off-axis electron holography and Lorentz TEM to study the relationships between magnetic domain walls and ferroelastic twin walls in magnetite below the Verwey transition. One of the most striking features is the formation of magnetic domains that are related to "strain-contrast-free" twins. The magnetization direction orients along the monoclinic *c*-axis of each twin domain and changes by close to 90 at each twin boundary. Simulations of the recorded electron holographic phase images [1] are used to interpret the observed magnetic structures quantitatively. The ferroelastic twin walls are observed to resist even the application of a large field of 2T and the magnetic structures at remanence can then be restored. Therefore the twins may have a strong influence on the low temperature magnetic properties of magnetite. Our analysis takes into account the effect of mean inner potential contributions to the phase shift on magnetic induction maps in wedge-shaped TEM specimens.

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[1] Beleggia, M. & Zhu, Y. (2003) *Philos. Mag.*, **83**, 1045-1055.