Exchange coupling, antiphase boundaries, and the origin of self-reversed thermoremanent magnetization

Richard J. Harrison1, Takeshi Kasama2,3, Thomas A. White3, Edward T. Simpson3 and Rafal E. Dunin-Borkowski3

1. Department of Earth Sciences, University of Cambridge, U.K.
2. Frontier Research System, Institute of Physical and Chemical Research, Hatoyama, Saitama, Japan
3. Department of Materials Science and Metallurgy, University of Cambridge, U.K.

Part I: Electron Holography

Self-reversed thermoremanent magnetization (SR-TRM) in the ilmenite-hematite system is thought to result from negative exchange coupling between antiphase domains (APBs) and antiphase domain boundaries (APBs), which form after rapid cooling through an Fe-Ti ordering transition. Here we present a study of exchange coupling at APBs using a combination of off-axis electron holography and Monte Carlo simulations.

Fig. 2. Nord and Lawson (1992) and Hoffman (1993) proposed that APBs in ilmenite-hematite act as the x-phase. The model requires that the APBs are Fe-enriched relative to the APDs. The nature of the magnetic exchange coupling at APBs, and how it leads to self reversal, is still debated.

Fig. 3. A simple model of two APDs separated by an APB shows that the switch round of Fe-rich and Ti-rich layers at an APB should lead to a 180° reversal of the net ferrimagnetic moment.

Fig. 4. Normally when a TEM image is recorded, we see the spatial distribution of intensity, all information about the phase of the electrons is lost. Electron holography is an interference technique that allows the phase information to be recovered.

Fig. 5. When electrons pass through a magnetic sample, they undergo a phase shift determined by the in-plane component of magnetic induction.

Fig. 6. The direction and magnitude of the in-plane component of magnetic induction can be calculated from the gradient of the holographic phase shift. This is then represented by the hue and intensity of a colour: Blue-purple and yellow-green colours correspond to magnetoisation in opposite directions, as shown by the double arrow. Black corresponds to zero in-plane component of magnetoisation.

Fig. 7. The sample edge is indicated by the grey line. Prior to each measurement, the sample was exposed to a saturating field with an in-plane component of +1000 mT, followed by a smaller field with an in-plane component of (a) -1.9 mT, (b) -10.6 mT, (c) -12.8 mT. The dark bands indicate regions with weak in-plane magnetisation magnetic domain walls. Dark bands that separate regions of blue and green colour correspond to 180° magnetic and chemical walls (e.g., at regions labelled ‘1’ and ‘2’, respectively). Dark bands that are surrounded by regions of the same colour correspond to 0° magnetic walls (e.g., at regions labelled ‘3’).

Wall profiles determined by holography

Fig. 9. Line profiles taken across the three different domain walls types allow the magnetisation profile across the wall to be determined quantitatively. Free standing 180° walls are well described by classical equation for a Bloch wall with width 19 nm. Chemical walls show a more complex profile with a sharper reversal of magnetisation (upper limit of 7 nm). 0° walls are well described by a tanh profile, and are significantly wider than free-standing walls (average of 50 nm).