The relationship between magnetic microstructure and anti-phase domain size in epitaxial magnetite thin films

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Thin films of magnetite (Fe_3O_4) that have been grown epitaxially on MgO exhibit unusual magnetic and electrical properties that are thought to result from the presence of anti-phase boundaries (APBs) across which magnetic spins couple antiferromagnetically [1]. Lorentz microscopy studies have suggested that 50-nm-thick magnetite films contain distinct magnetic regions that are 2-4 times the anti-phase domain (APD) size [2]. These results are apparently inconsistent with magnetic force microscopy measurements, which suggest the presence of magnetic regions that are 10 times the APD size in 9.5- and 75-nm-thick films [3]. In order to resolve this conflict and to address the relationship between the local magnetic induction and the positions of the APBs, we have examined a 25-nm-thick magnetite film using off-axis electron holography. Preliminary results from this study are presented here.

Figure 1 shows a low-magnification Lorentz image of a free-standing 25-nm-thick single crystalline magnetite film, which has been removed from its MgO substrate for examination in plan-view geometry in the transmission electron microscope (TEM) [1]. At higher magnification, this image shows both magnetization ripple and domain walls in zero-field conditions. Dark-field images of the film, which were recorded at 300 kV using a Philips CM30 TEM equipped with a LaB_6 filament, revealed the presence of APDs that are irregular in shape and have an average size of 25 nm (Figure 2). Off-axis electron holograms of the same region of the film were recorded at 300 kV using a Philips CM300 field emission gun TEM equipped with an electron biprism and a Lorentz minilens. Each hologram was recorded in zero-field conditions after applying a known in-plane magnetic field to the specimen using the conventional microscope objective lens. The holograms were used to measure a value for the coercive field of the film of ~200 Oe, in agreement with earlier bulk measurements [4]. Figure 3 shows two representative remanent magnetic states, recorded after applying in-plane magnetic fields of 1048 Oe to the specimen in the directions indicated in the figure. The magnetic induction is highly complicated. In addition to magnetic domains that are several hundreds of nm in size (similar to the dimensions observed using MFM [3]), fine magnetic features are evident on a scale of 10-40 nm (similar to the dimensions observed using Lorentz microscopy [2]). These features, which appear to be associated with the magnetization locally going out of the plane of the film, are presently being correlated with the APB positions [5].

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Figure 1. Low-magnification Lorentz image of a 25-nm-thick magnetite film, acquired in field-free conditions. The arrow indicates the area observed using dark-field imaging and holography.

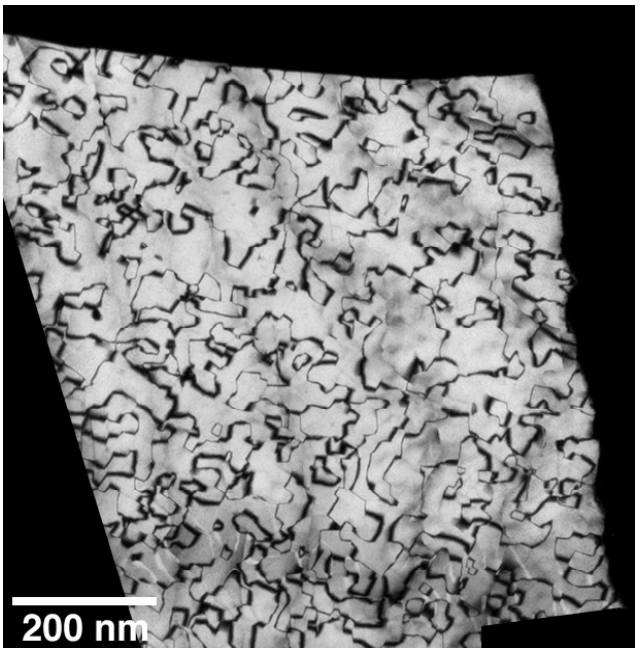

Figure 2. Dark-field image of the area indicated by an arrow in Figure 1, acquired using a 220 reflection close to the [-11-3] zone axis. The dark contrast corresponds to the positions of some of the APBs in the film.

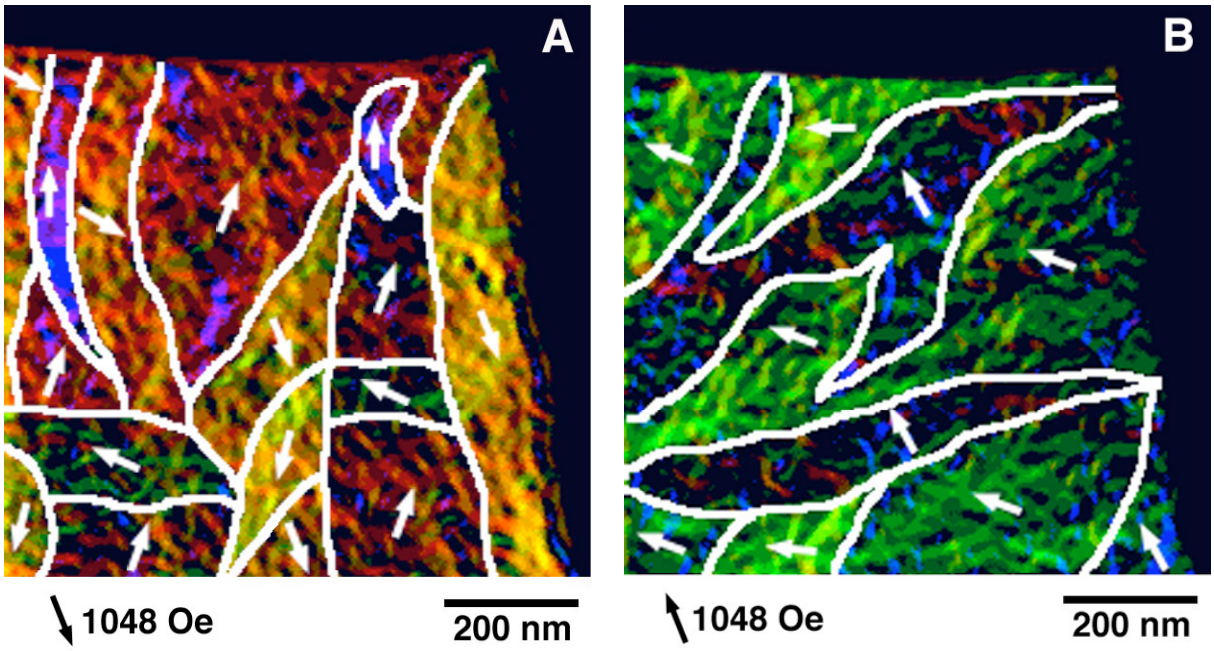

Figure 3. Magnetic induction maps of the region of the magnetite film shown in Figure 2, recorded using off-axis electron holography after applying in-plane fields of 1048 Oe to the specimen in the directions indicated. Areas with similar magnetization directions are outlined in white, with the approximate magnetization directions within them marked using arrows.