APPLICATION NOTE

DPC STEM Imaging of Magnetic Structure in a Hexaferrite

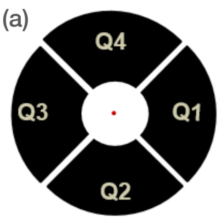
Differential Phase Contrast STEM (DPC-STEM), available on Thermo Scientific™ Talos™ and Themis™ TEMs, is used to image the strength and distribution of magnetic fields in and around a sample, thus directly displaying the magnetic domain structure. DPC STEM uses the four segments of the Dark field detector. The signals are simultaneously acquired to measure shifts of the diffraction pattern. The Velox software on Thermo Scientific TEM instruments has an option for live DPC acquisition fully integrated in the user interface.

What makes this technique so valuable is its ability to directly image complex materials used in data storage and electronic devices. Here, we look at domain structure and domain walls (Bloch walls) in an M-type barium hexaferrite, which is a hard magnetic material showing promise for use in magnetic data storage devices currently being developed.

The structure of the DPC STEM detector used is shown in Fig. 1 (a) together with the images taken on each quadrant of the detector from the hexaferrite in (b).

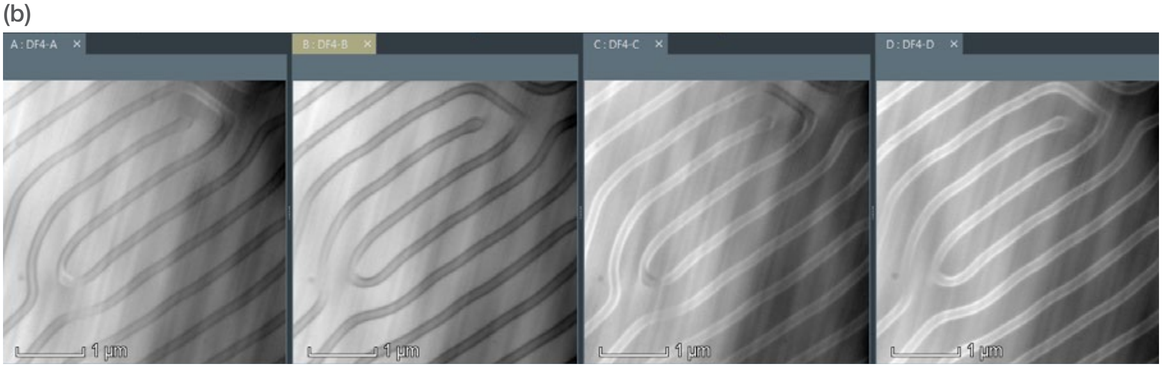
The STEM disk position moves away from the center of the detector due to the influence of magnetic fields in the sample, and the distance and direction of this shift is measured from the change in signal hitting the four detectors, which is easily turned into 2D maps of the vertical and horizontal magnetic fields (Fig 1c).

(a)



4 Segment DF4 Detector

(b)



(c)

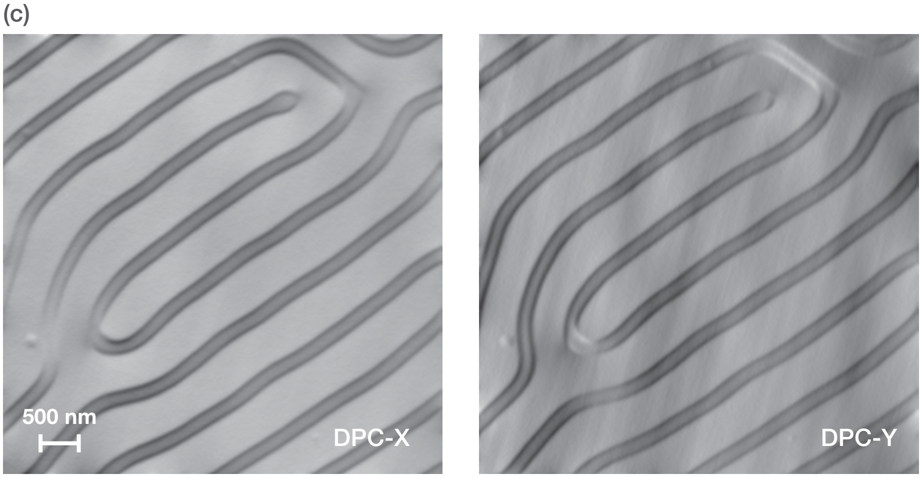


Figure 1. DPC STEM in Velox. Sample courtesy H. Nakajima and S. Mori, Osaka Prefecture University

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The relative strength and orientation of the magnetic field in each domain is visible in the map. The variation in magnetic field across the domain wall indicates what type of wall is present and the wall thickness. Observation of defects and variations in the wall structure helps understand how these would affect the overall performance of the material. Because the technique works with in-focus STEM images and provides quantitative information about the field strength as well as the field orientation, it is a powerful technique for visualizing magnetic structure.

Various other visualizations are also possible to highlight different aspects of the magnetic structure. For example, Fig 2 (a) shows the magnitude of the magnetic field at each point, and (b) shows the field orientation, in a colourwheel representation.

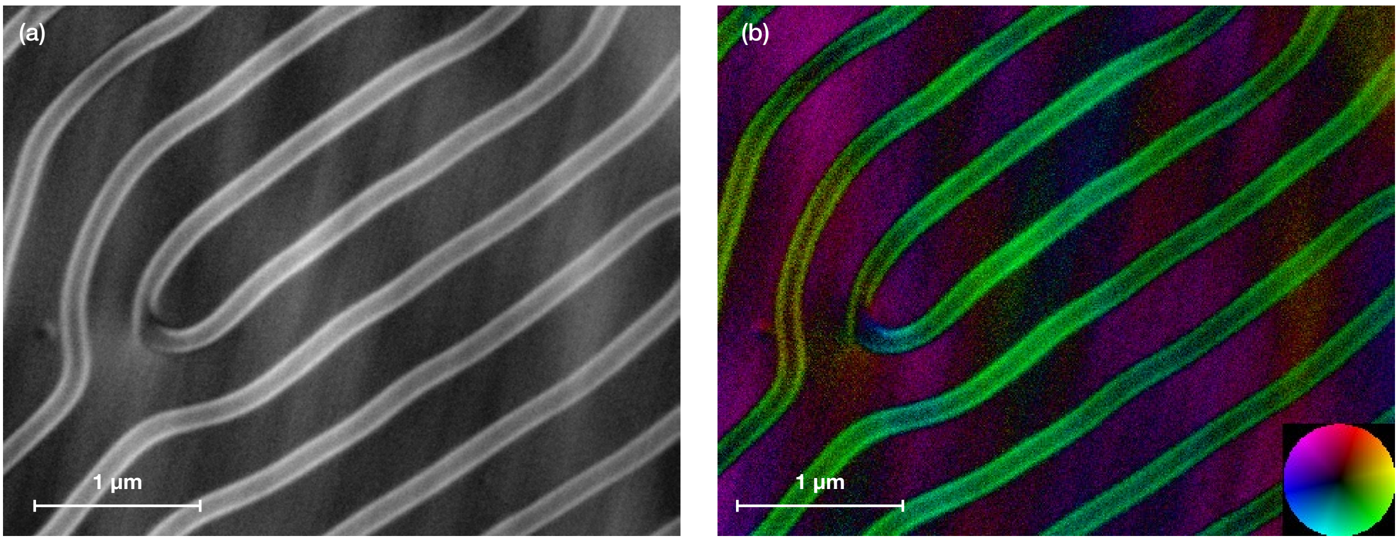

Figure 2. Representations of magnitude and orientation of magnetic field.

An arrow-map representation such as Fig. 3 is also valuable, containing information about both the magnetic field strength and orientation in a single plot.

In addition to the examples provided in this application note, DPC-STEM has shown exciting promise in a number of emerging fields. One such field is spintronics, where it is important to determine the micromagnetic state of sub-µm patterned magnetic materials. Another emerging field is optoelectronics, where quantum wells in non-centrosymmetric materials cause strong piezoelectric fields that modify the band structure of these devices. Where successful research relies upon nanometer-scale characterization of electric and magnetic properties, DPC-STEM offers advantages beyond today's commonly used techniques.

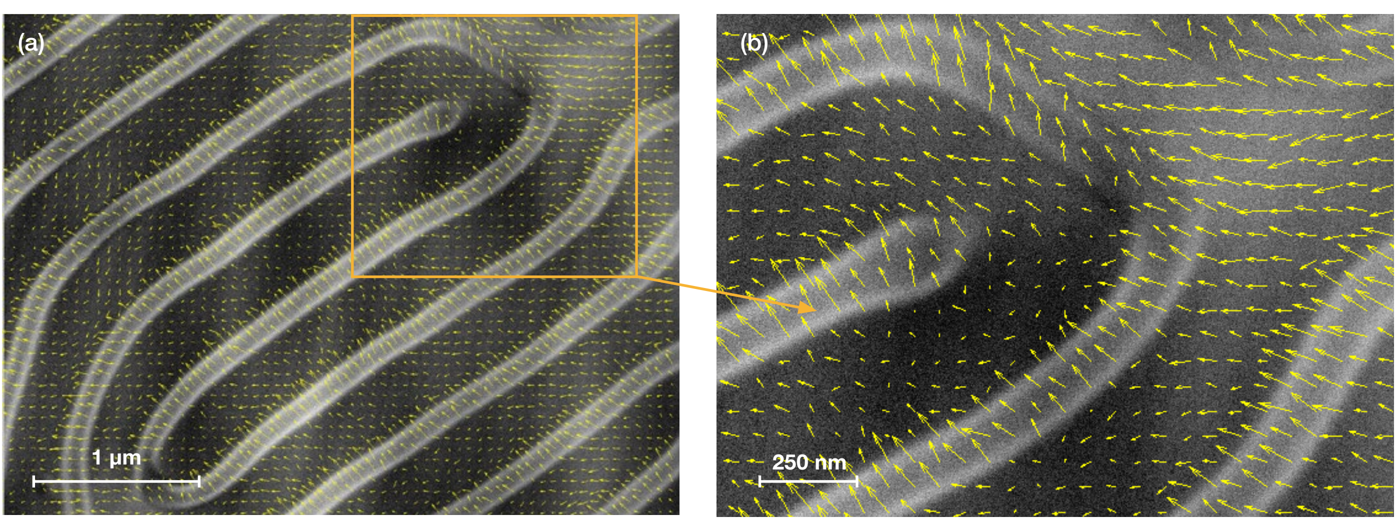

Figure 3. Arrow-map representations of strength and orientation of magnetic field.

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