Magnetic Imaging Techniques

Laura Heyderman
Mesoscopic Systems
ETH Zurich - Paul Scherrer Institute
5232 Villigen PSI, Switzerland
http://www.psi.ch/lmn/magnetic-nanostructures

In order to fully understand the behaviour of magnetic materials, it is very important to know how the magnetic configurations look at the microscopic scale. There are several microscope techniques that have been developed to observe magnetic domains, which have evolved hand-in-hand with techniques developed to, for example, measure material microstructure or determine surface properties. These techniques can be based in the laboratory or at large scale facilities. Laboratory based techniques include magnetic force microscopy, Kerr microscopy and transmission electron microscopy. At synchrotron x-ray facilities, photoemission electron microscopy and transmission x-ray microscopy are available.

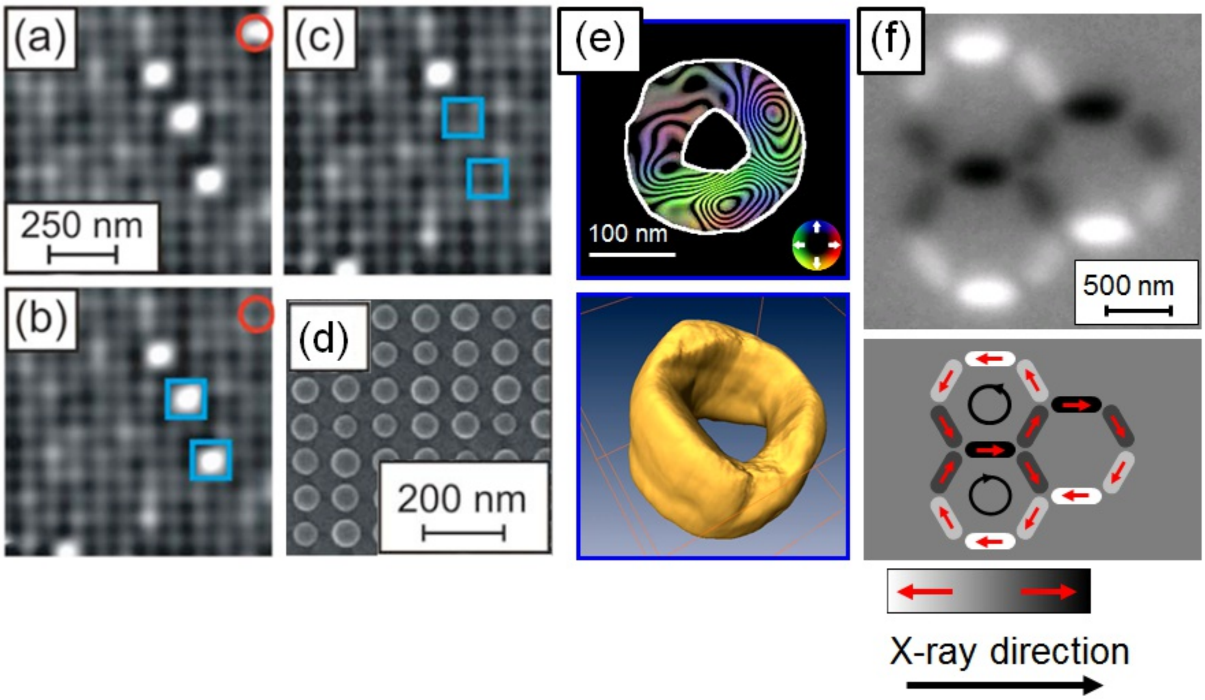

Figure 1: Images demonstrating the usefulness of using different imaging techniques for the understanding of microscopic magnetic phenomena (a-c) MFM images of switching events in Co/Pt multilayer caps [1] coated on polystyrene nanospheres (d). (e) Electron holography image of the magnetic flux lines in a nanoscale magnetite ring depicted together with an electron tomography image of the same ring [2]. (f) Synchrotron x-ray photoemission electron microscopy image of the magnetic configuration in a so-called 'artificial spin ice' made up of interacting single domain nanomagnets [3].

Magnetic imaging techniques come with their own advantages and disadvantages, and are often complementary. Depending on the scientific or technological question that needs to be answered, there are several factors that should be taken into account in order to decide which technique to use. For example, some magnetic imaging techniques give a measure of the magnetization (Fig. 1f), while others record the magnetic induction (Fig. 1e) or are sensitive to magnetic stray fields (Fig. 1a-c). Certain techniques are more suitable for measuring the magnetic configurations in materials with in-plane magnetic anisotropy, while others are better for the measurement of materials with strong out-of-plane magnetic components. Some techniques are more quantitative than others and some provide very high spatial resolution of a few nm's, which is particularly interesting when probing magnetism in systems confined to the nanoscale. One should also consider the depth sensitivity since some imaging techniques provide information from the full thickness of the film, whereas others are only sensitive to the surface.

In terms of the sample environment, certain imaging methods require ultrahigh vacuum or other special requirements for the samples in terms of sample thickness, surface roughness, surface cleanliness, and material conductivity. For in-situ experiments, it is useful to know the maximum possible applied magnetic field or current, and whether the setup allows, for example, heating/cooling or application of strain to the samples. More advanced techniques provide not only magnetic information but also information about the crystallography, topography, chemical species, and/or electronic properties in parallel. Finally it is important to consider whether one would like to perform static or dynamic measurements and, if dynamic, what temporal resolution is required to capture the details of the evolving magnetic process.

References for Images

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Some Useful Books

Magnetic Domains: The Analysis of Magnetic Microstructures
A. Hubert and R. Schäfer

Magnetic Microscopy of Nanostructures
H. Hopster and H. P. Oepen

Magnetism: From Fundamentals to Nanoscale Dynamics
J. Stöhr and H. C. Siegmann

Magnetic Nanostructures: Spin Dynamics and Spin Transport
Springer Tracts in Modern Physics 246 (2012), Editor(s): H. Zabel and M. Farle
http://link.springer.com/book/10.1007/978-3-642-32042-2/page/1

Magnetism and Synchrotron Radiation, Springer Proceedings in Physics, Vol. 133
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