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FE 박막에서의 자기폭풍 : 완전한 자기벡터 표현

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MAGNETIC VORTICES IN A SINGLE Fe THIN FILM: A COMPLETE MAGNETIZATION VECTOR REPRESENTATION

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I. Introduction

Spins around magnetic domain walls and at magnetic nanostructures such as interfaces interact in a complicated network and the spin configurations change their local properties. Experimentally, it is difficult to determine local spin directions around domain walls with conventional microscopes including magnetic force microscope (MFM), and scanning electron microscope with polarization analysis (SEMPA). Theoretical approach is, however, more straightforward, but not simple in 2- and 3-dimensional walls. Theoretical work has predicted a variety of spin configurations such as magnetic vortices where spins are in a state of spiral like storm. Clear magnetic vortices and complicated spin configurations have never observed in experiments as far as a complete vectorial magnetization (vector representation) is concerned. In this work, imaging of direct magnetic contrast was recently obtained with a strong absorption contrast through magnetic circular dichroism at large resonant absorption edges using scanning transmission x-ray microscope (STXM). By analyzing the images taken with three different propagation vectors of elliptically polarized soft x-rays, we obtained a clear image of 3-dimensional spin vectors with a spatial resolution of about 200 nm. The complete vector representation of spins has never made with conventional microscopes such as SEMPA and MFM.

2. Experimental method

A photon-based STXM was used to image magnetic domain structures of a single Fe film 30 nm thick. One of most advantages of the photon-based microscopes is element specificity because of a spectroscopic characteristic of magnetic circular dichroism (MCD) contrast, $\Delta\mu$, which refers to the difference in absorption between the left and right circularly polarized x-rays[1]. At a specific threshold energy depending on element, MCD contrast is remarkably enhanced by dipole transitions of core-level electrons to 3d valence level, which add element specificity to photon based microscopes. In addition, $\Delta\mu$ is proportional to $\mathbf{k}\cdot\mathbf{M}$ where $\mathbf{k}$ is the propagation vector of circularly polarized beam and **M** is the magnetization vector. To determine spin directions, **k**-dependent imaging via measuring transmitted intensities through samples is necessary with a titiling capability of STXM. Figure 1 shows the images taken with three **k**-incidences of soft x-rays

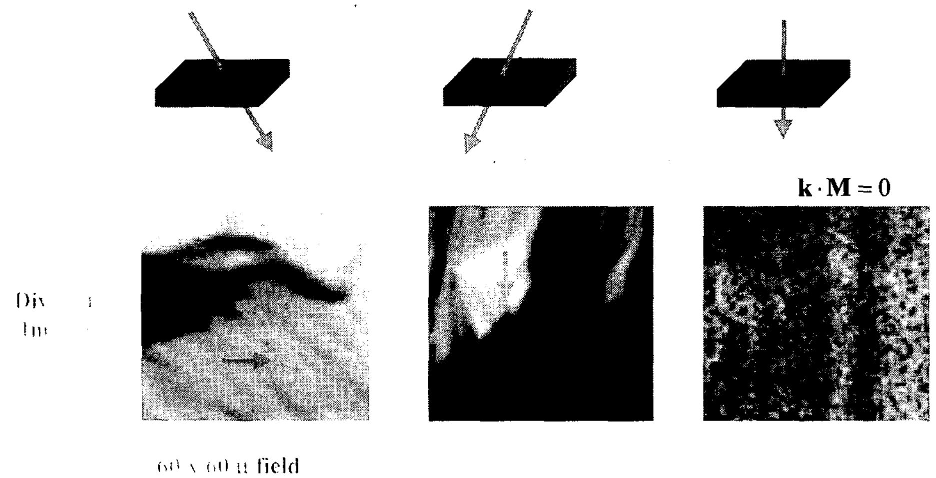

Fig. 1. Images taken with 3 different **k**-incidences to the film surface. Divided images represent approximately MCD contrast, $\Delta\mu$.

3. Results and Discussion

Using a simple analysis of the images shown in Fig. 1, based on $\Delta\mu \sim \mathbf{k}\cdot\mathbf{M}$, a clear image of the directions of local spins is obtained in a single thin Fe film demagnetized. Around the walls between 180° magnetic domains, left- and right-handed vortices are formed to lower the magnetostatic energy of spins. As the film thickness decreases magnetostatic energy becomes dominant to govern spin configuration. The perpendicular component of **M** is evidently ignored except for at the cores of the vortices, thus the spin spirals are in-plane. Detailed analysis and results will be presented.

4. Conclusion

Typical domain walls are mostly predicted by calculations based on models available but remain unclear in experiments. For the first time, we demonstrated how to obtain a full magnetization vector image and found clear vortices along domain walls. This work opens the door toward an experimental breakthrough to observe a full magnetization vector, especially, in a complicated network of spins such as domain walls.

5. References

[1] J. Stohr et al, Science **259**, 658 (1993).