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Observation of Magnetic Domain Dynamics by Higher and Wider Ranges of Applied Magnetic Fields using Lorentz Microscopy

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Lorentz microscopy [1], which has several different modes [2], is widely used to observe magnetic domain and domain wall structures in magnetic materials, because it allows us to observe dynamics of domain structures at high resolutions. When we observe dynamical interactions of structures under external magnetic fields, the objective lens is usually used to apply magnetic fields to specimens [3]. However, at high applied magnetic fields, the following effects on the optical system, magnification changes, defocusing drifts, and image distortions, become very large, making it difficult to observe dynamics of magnetic structure changes caused by applied magnetic fields.

In this study, to overcome these difficulties we combined the first intermediate lens and the objective lens into a pair lens system, and observed dynamic behavior of the domain structures while magnetic fields were varied.

Figure 1 shows a schematic diagram of the optical system. The objective lens works as the magnetic field generator for the specimen materials. The first intermediate lens compensates the distortions due to the objective lens and focus specimen images just on the object plane of the second intermediate lens, which controls imaging conditions, such as defocus distance (Δf) in the Fresnel mode. We constructed this optical system on a 300-kV transmission electron microscope (TEM, HF-3300S) and observed Fresnel images continuously from 0 to ±500 mT.

Figure 2 shows Fresnel images with increasing the magnetic field around 150 mT. The specimen material was Sc-substituted *M*-type hexaferrite ($BaFe_{12-x-\delta}Sc_xMg_\delta O_{19}$) [4, 5] and single crystalline thin film specimens were prepared using a focused ion beam instrument (NB-5000). Figure 2(a) shows five magnetic bubbles and five line-shaped domains having Bloch lines at the edge of the Bloch domain walls. By increasing magnetic fields, the line-shaped domains were shrunk and became type-I or type-II magnetic bubbles. Dynamical observations allowed us to easily find out how the line-shaped domains turn to the bubbles.

Our TEM, HF-3300S, has five lenses under the objective lens, i.e., one additional lens is installed compared with conventional TEMs, making it possible to construct more flexible optical system. We have also confirmed that this system is applicable to electron holography observations [6].

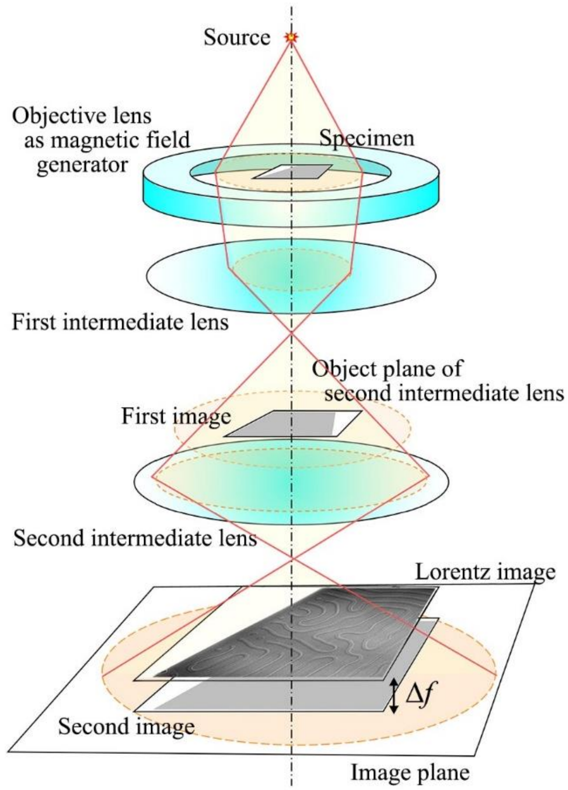

Figure 1. Schematic diagram of the optical system for the Lorentz microscopy. The pair lens system composed of the objective and first intermediate lenses makes images on the object plane of the second intermediate lens.

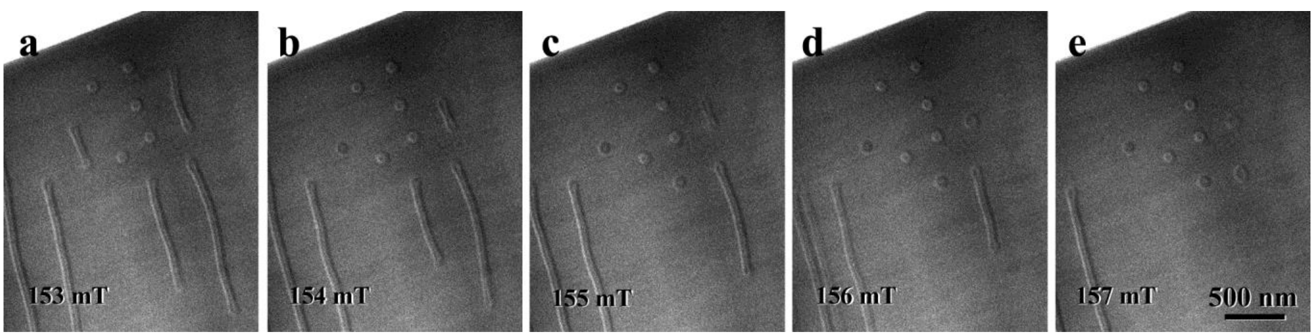

Figure 2. Fresnel images with increasing applied magnetic fields.
Exposure time of each image was 1 sec. Line-shaped domains were shrunk and turn to bubbles with the increase in external magnetic fields.

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