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In Situ Observation of Magnetic Domain Structure by Electron Holography and Lorentz Microscopy with a Magnetizing Stage

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A specially designed magnetizing stage has been developed in order to apply the magnetic field in the specimen plane in a TEM. Fig. 1 shows a schematic drawing of the tip of the magnetizing stage. In this stage, the magnetic field produced by a coil can be conducted to a specimen through yokes, and the field can be increased up to tens of thousands A/m. This stage enables us to observe dynamical changes of magnetic domain structure of soft magnetic materials by in-situ Lorentz microscopy and electron holography.

Using the magnetizing stage, we studied domain structures of the two types of electrical steel sheets, i.e. doubly oriented electrical steel sheets and non-oriented electrical steel sheets. In the specimen of the doubly oriented electrical steel sheet, the typical 90^o and 180^o magnetic domain walls and their movement caused by external magnetic fields were observed in in-situ experiment. In the latter non-oriented electrical steel sheet, it was observed that the distribution of domain walls were more complicated and the small precipitates were presented. We observed some domain walls pinned by such precipitates.

In this study, we used a JEM-3000F electron microscope which is equipped with a field emission gun, a biprism and a magnetically shielded objective lens [1] in order to take Lorentz micrographs and electron holograms. We used an additional deflection coil in TEM column to take back the beam deflected by the electromagnet specimen holder.

Fig. 2 shows Lorentz micrographs taken form the doubly oriented silicon iron sheet. In the figures, black and white lines correspond to the magnetic domain walls. It is noted that magnetic domain walls are parallel to the [100] and [010] directions. With the increase of the external magnetic field in the film plane, some of the magnetic domain walls being parallel to the horizontal line disappear, and it is seen that the magnetic domain structure is more sensitive to the applied magnetic field than that of the non-oriented silicon iron sheet. These features are well corresponding to their magnetic properties.

Fig. 3 shows phase images reconstructed from electron holograms of a non-oriented electrical steel sheet. In Fig. 3a, no external magnetic field was applied. In Fig.3b, 2.2 kA/m of external magnetic field was applied, and the domain structure was changed. In the figures, black lines (or white lines) correspond to the lines of magnetic flux. The direction of lines of magnetic flux is indicated by the arrows. The regions where the orientation of lines of magnetic flux changes sharply correspond to the magnetic domain walls.

References

[1] D.Shindo, et al, *Script Mater*. **48**, (2003) 851-856

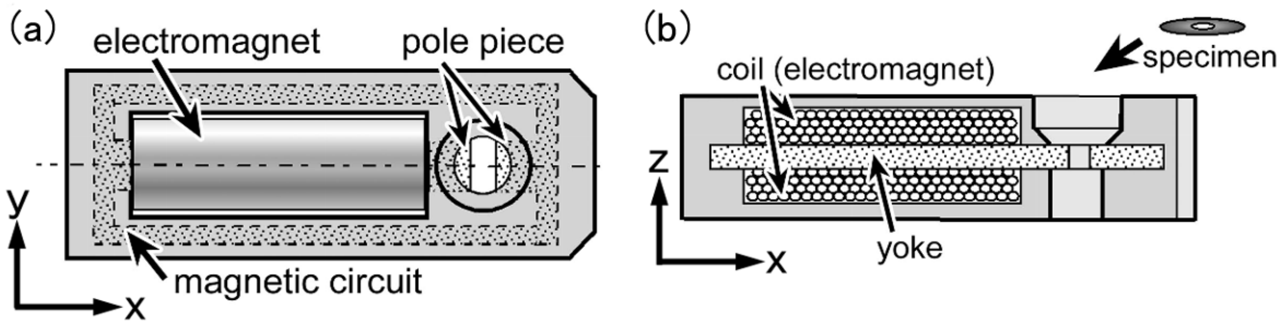

FIG. 1. Schematic drawings of the tip of the magnetizing stage. A TEM specimen is mounted on the pole piece. (a) A top view. (b) Cross section including the dotted line in (a).

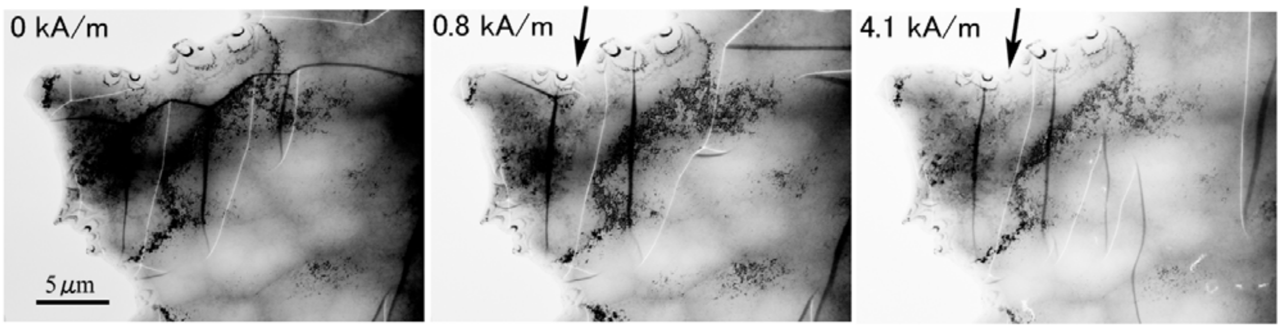

FIG. 2. In situ Lorentz-microscopic observation of migration of the domain walls in a doubly oriented silicon iron sheet with the application of the external magnetic field into the film plane. The large arrow indicates the direction of applied magnetic field.

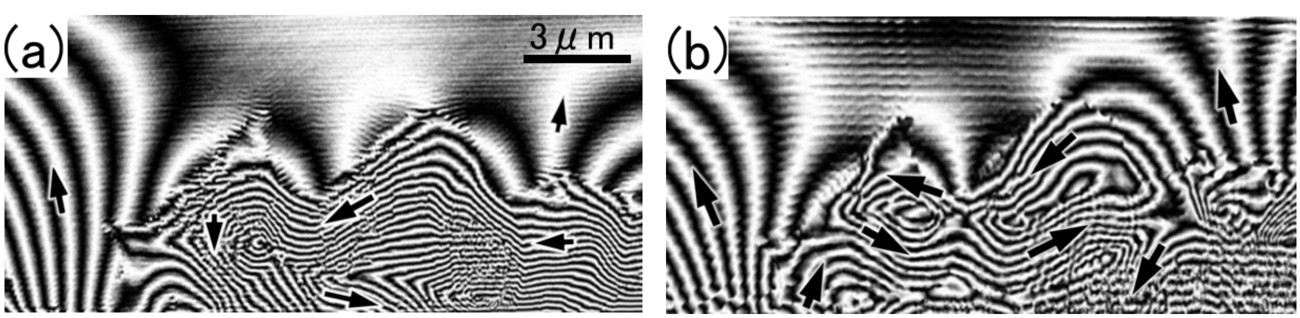

FIG. 3. Phase reconstructed images taken from a non-oriented electrical steel sheet. The external magnetic fields were (a) 0 A/m and (b) 2.2 kA/m.

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