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Reversal Behavior of Patterned Ferromagnetic Elements

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Understanding magnetization reversal dynamics in patterned ferromagnetic elements, or building blocks, is crucial to the development of modern magnetic storage media and spintronic devices. To achieve this goal, we fabricated patterned magnetic films in-house using a UHV film-deposition system. We acquired a state-of-the-art, field-emission TEM equipped with a custom-made objective lens (JEM2100-LM, the only one of its kind in the world) that allows superior performance (very low aberration-coefficient) for magnetic imaging and electron holography applications. We modified sample stages to accommodate a Helmholtz coil and Hall-sensor in order to apply an external in-plan magnetic field and to calibrate the field in the microscope [1]. We worked with manufacturer to build a Helmholtz holder with rotation capability to vary in-plane field direction (Figure 1). These instrumentation developments allow us to conduct quantitative magnetic structure analysis and in-situ magnetic property measurement at nanometric scale. We also developed quantitative methods to determine local magnetization using electron holography and Lorentz phase microscopy [2] to understand the magnetic properties and shape effect of individual elements, and their interaction with neighboring elements. Here, we report our study on the reversal mechanism and hysteresis behavior of micron and submicron patterned Permalloy and Co thin-film rings, squares, and ellipses with different aspect ratios.

Figure 2 shows experiment and calculation of the magnetization reversal in an elliptical element of Permalloy. The domain configuration for various stages is marked on the calculated hysteresis loop. We note that the reversal sequence begins with vortex nucleation at the edges of the element, followed by coherent rotation of the magnetization and formation of the 180° and 90° domains. Further reversal results in nucleation of vortex/anti-vortex pairs at the 180° domain walls, and the formation of cross-tie walls that act as a zipper, promoting rapid expansion of the fully reversed domains. In other experiments, studying the relaxation behavior to the remnant, or near-remnant, state for elements with different geometries, we explain how different low-energy remnant states can arise from a single parent state depending on the relaxation rate, and how the energy barrier to vortex nucleation can be measured from this rate dependence [3]. New results using a magnetic force microscope built into a TEM stage to locally induce magnetic field gradients to change the magnetic polarization of single elements, in order to study element-element interactions and magnetic reversal, will also be reported [4].

References:

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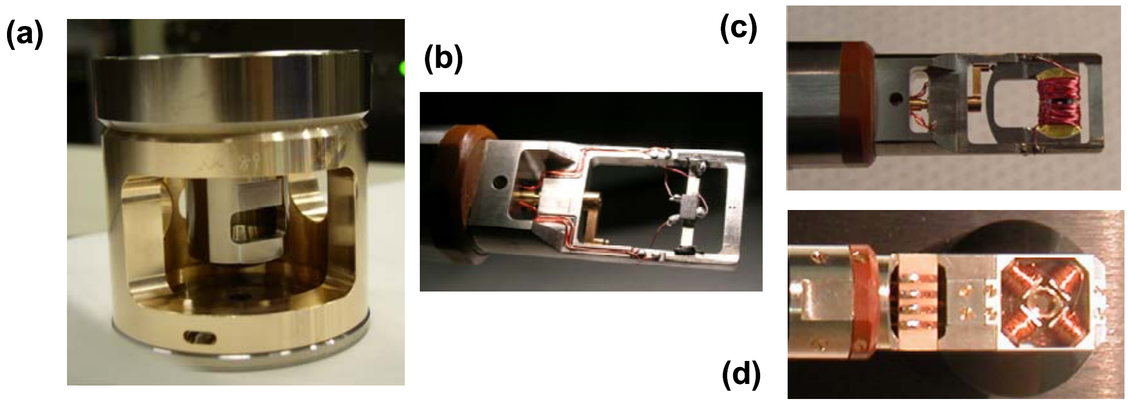

FIG. 1. (a): The field-free long-focal length (20mm) objective lens custom-designed by JEOL for the JEM2100F microscope for magnetic imaging; (b): the home-made Hall-probe holder for measuring magnetic field in the sample area inside the microscope; (c): the home-made Helmholtz coil holder for applying in-plane magnetic field; and (d): the Helmholtz holder with rotation capability custom-designed and fabricated by Gatan Inc. The instrumentation developments allow us to conduct quantitative magnetic structure analysis as well as property measurement at nanometric scale.

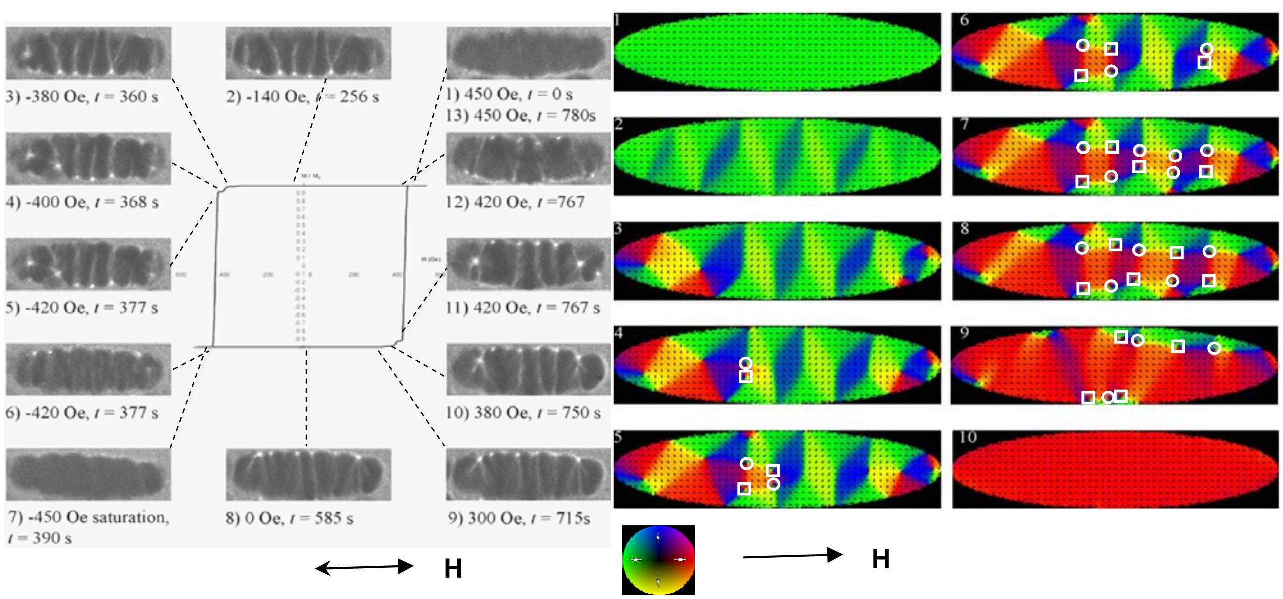

FIG. 2. (left) : Domain configurations of a Permalloy ellipse (2×8μm) extracted from a video recording showing various stages of magnetization reversal. The time and magnetic field for each image are indicated. (right) : Corresponding micromagnetics simulation. For visibility, the vector maps are encoded with a color scheme, as shown in the color legend. The white squares represent magnetic vortex structure, while white circles represent anti-vortex. The reversal mechanism involves the formation of cross-tie walls that act as a zipper, promoting rapid expansion of the fully reversed domains.