Direct Observation of Stochastic Behavior in Nanoscale Magnetism

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The degree of stochasticity of local domain nucleation process and magnetic domain-wall motion along magnetic nanowires is a key issue in current technological developments of novel classes of logic and storage devices [1,2]. Furthermore the understanding of the non-deterministic domain nucleation and domain wall motion is a scientific challenge to be overcome for application.

A statistical analysis of high-resolution magnetic soft X-ray microscopy images recorded at BL 6.1.2 revealed the stochastic behavior of domain nucleation process in CoCrPt alloy film [3] and the domain-wall depinning field in notch-patterned $Ni_{80}Fe_{20}$ (permalloy) nanowires [4]. In Fig. 1, their statistical nature in repeated experiments are clearly visible. Figure 1(a) shows domain configurations taken under an applied magnetic field of +400 Oe in two repeated cycles, together with the overlapped image, where red and green spots represent the first and second measurements, respectively, and the black spots indicate the coincident nucleation sites between the two measurements. The domain nucleation process of CoCrPt alloy film is not deterministic, but stochastic for repeated hysteretic cycles. Three representative domain wall evolution image sequences for wires of w = 150, 250, and 450 nm are shown in Fig. 1(b). Here, the colors from red to blue indicate the domain-wall pinning and depinning-field strenghts. Within repeated experiments carried out at the same wire under identical measurement conditions the domain-wall depinning field also shows random behavior, as visualized by various colors. While thermal effects can be accounted for to explain the stochastic character in the nucleation process, the non-deterministic character in domain-wall depinning at a notch can be explained by the multiplicity of domain wall types generated in the vicinity of a notch.

Based on the experimental observation, we provide the possibility that the domain nucleation process and domain-wall motion can be controllable by appropriate designing of magnetic thin film and nanowire, which is valuable insight into magnetic process in general, it opens the path to further technological developments in spintronics applications.

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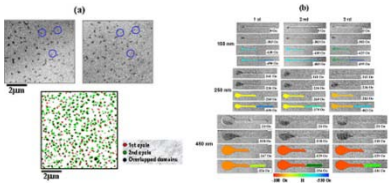

Fig. 1. (a) Magnetic domain configurations taken in the repeated measurements, together with the overlapped domain configuration. (b) Domain wall evolution patterns taken from three consecutive experiments under identical measurement conditions for wires of width w = 150, 250, and 450 nm. The color scale represents the field when a domain wall is pinned and depinned at a notch.