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Magnetic domain wall energies in Fe/Cu(100) measured from direct observations of thermal fluctuations using SPLEEM

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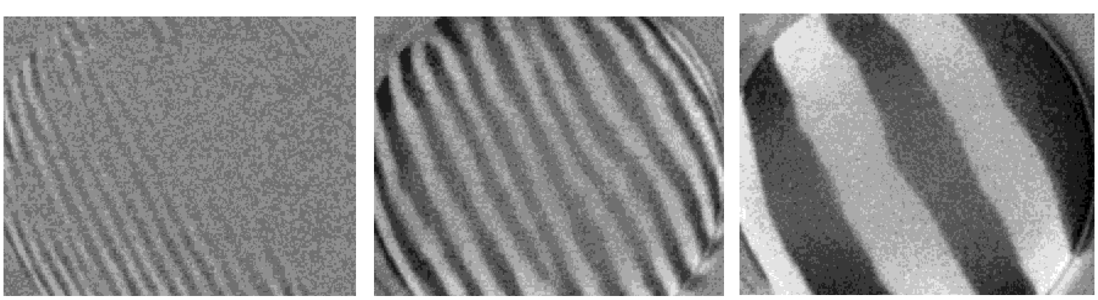
The dynamic properties of magnetic domain walls are one of the most important factors governing the magnetic properties of materials. For example, the fact that read/write data rates in magnetic storage devices are currently limited to the nanosecond range is a direct consequence of the limited speed at which magnetic domain walls can move in small magnetic structures.

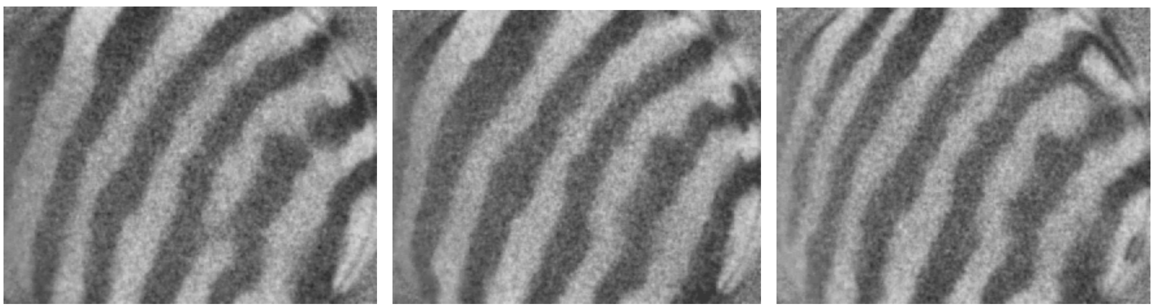
From a fundamental viewpoint, it is essential to understand how much free energy is associated with magnetic domain walls. The objective of our work is an experimental determination of domain wall free energy in a thin film system. The measurement is based on using spin polarized low energy electron microscopy (SPLEEM) to observe thermally activated fluctuations in equilibrium domain configurations.

Epitaxial films of Fe on Cu(100) surfaces with thickness in the range of two to four atomic layers are a convenient system for this measurement. The films belong to a class of quasi-two-dimensional magnets where the magnetic anisotropy favors magnetization in the direction perpendicular to the film plane. One aspect of this class of magnetic systems is the appearance of magnetic stripe domain phases: Under equilibrium conditions and in the absence of applied fields, the micro-magnetic structure of many perpendicular systems is a regular pattern of stripe-domains with alternating out-of-plane magnetization. The stability of these patterns is commonly attributed to the competition between the short-ranged exchange-coupling (favoring parallel spin alignment) and the long-range dipolar interaction (favoring anti-parallel spin alignment.) A number of different theoretical discussions cited in the recent review [1] all predict the existence of striped phases for systems of this type, qualitatively consistent with previous experimental observations [2,3].



A series of SPLEEM micrographs (field of view 7 micrometer) is shown here to illustrate the appearance and thickness dependent periodicity of the magnetic stripe-domain phase during the growth of a Fe/Cu(100) film in the thickness range from 2.0 to 2.1 monolayer. Contrast in SPLEEM images depends on the orientation of the local magnetization vector, in data shown here bright and dark regions are magnetized up and down, respectively. When Fe deposition is terminated, the stripe-phase periodicity of a given film remains stable.

Remarkably, real-time sequences of SPLEEM images of the domain structures in such films, acquired at a rate of several frames per second, show that the positions and shapes of individual domain walls constantly fluctuate about their equilibrium positions. We have tracked these domain wall fluctuations on the 10nm-10micrometer length-scale. It is difficult to convey the liveliness of this motion in a sequence of still frames, but the changes of the wave-like shapes of the domain wall structures can be seen in three images, taken several seconds apart, which are shown below.



We analysed these domain wall fluctuations by adapting the capillary wave formalism that had been developed to understand fluctuations of atomic steps at surfaces [4]. From this analysis it is possible to determine quantitative estimates of the domain wall energy, or stiffness. Consistent with theoretical models, stripe width and wall stiffness both increase with film thickness: in the range of 2.0 to 2.2 monolayer film thickness we find domain wall energies in the range of about 1 to 4 kT/nm. The measurements made with this novel technique compare favourably with estimates of domain wall energies based on reasonable values of exchange- and anisotropy energies.

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