Investigation of Switching Fields of Magnetic Nanoparticles With Magnetic Force Microscopy

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Magnetic quantum cellular automata (MQCA) has been proposed as an alternate paradigm for computing. This architecture takes advantage of the fact that if magnetic particles are sufficiently small, in the submicron regime, they adopt single domain configurations. In doing so, each particle becomes binary, adopting either a purely "up" configuration or a purely "down" configuration. Thus, an inherent requirement for an MQCA system is to know the conditions under which elements switch between these states, and to control this reproducibly. Both experimental [1] and theoretical [2] investigations into MQCA systems rely on particle shape anisotropies as an intrinsic part of their architectures for input or control structures, while requiring other elements to be strictly uniform so that their switching behavior is consistent.

Recent work [3] has investigated more precisely the effect of shape anisotropy on the magnetic state of a particle. Further investigation is needed to accurately identify what effect slight-to-moderate anisotropies have on the switching fields of magnetic nanoparticles. Magnetic particles were designed and patterned (Fig. 1) with and without flaws along their edges via electron beam lithography with standard liftoff processes. Particles were patterned in small arrays with fiducial marks so that individual particles could be reproducibly identified. Unlike the recent work, our particles were based on the more common ellipse-shaped particles.

Using publicly available code [4] simulations were carried out to predict whether the virgin state of the particles would be a single domain or some other multi-domain configuration. Simulations also yielded predictions of the magnetic coercivity of these particles. Thus, a theoretical magnetic switching phase diagram was constructed.

Magnetic force microscopy (MFM) (Fig. 2) with an *in-situ* magnetic field allows for the investigation of the domain structure of magnetic nanoparticles. An ensemble hysteresis loop was measured by imaging while applying external magnetic fields of varying strength. The ensemble switching distribution was observed. Particles in the ensemble with switching fields much higher or lower than the mean ensemble switching field were identified. Using a scanning electron microscope (SEM), these particles were then examined for defects or characteristic edge roughness which could explain their atypical switching behavior.

References:

[1] R. P. Cowburn, M. E. Welland, Science **287**, 1466 (2000)
[2] G. Csaba, W. Porod, A. I. Csurgay, Int. J. Circ. Theor. Appl. **31**, 67 (2003)
[3] D. K. Koltsov, M. E. Welland, J. Appl. Phys. **94**, 3457 (2003)
[4] http://math.nist.gov/oommf

Figures:

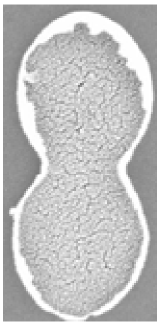

Fig. 1: SEM image of typical patterned particle, approximately 730 nm long with largest and smallest widths 320 nm and 200 nm, respectively.

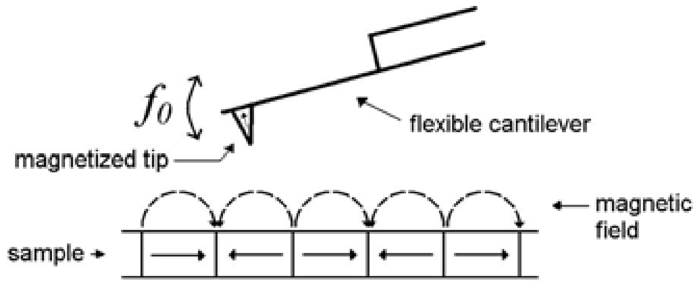

Fig. 2: Principle of MFM, a scanning probe technique