Magnetic Vortices in Sub-100 nm Magnets

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Abstract – **Presented is a quantitative study of the magnetic vortex state and the vortex core in sub-100 nm magnetic dots. Arrays of magnetic nanodots covering over 1 cm^2 are fabricated using self-assembled nanopores in anodized alumina. Transition from a vortex to a single domain state for the Fe dots is studied by magnetization measurements (SQUID, VSM, and MOKE) as a function of the dots size and magnetic field. Micromagnetic and Monte Carlo simulations confirm the experimental observations. Thermal activation and exchange bias have a large effect on the vortex nucleation field. Quantitative analysis of grazing incidence small angle neutron scattering measurements with polarization analysis, performed on 65 nm Fe dots yields the magnetization of the vortex core of 140±50 emu/cm^3 and its diameter of 19±4 nm, in agreement with the simulations results.**

1 EXTENDED ABSTRACT

Magnetism of the nanostructured magnets, which size is comparable to or smaller than ferromagnetic domain size offers a great potential for new physics. Detailed knowledge of magnetization reversal and possible magnetic configurations in magnetic nanostructures is essential for high-density magnetic memory. Many theoretical and experimental studies are focused on a magnetic vortex which in addition to a circular in-plane configuration of spins has a core, – the region with the out-of-plane magnetization. Presented is a quantitative study of the magnetic vortex state and the vortex core in sub-100 nm magnetic dots. Arrays of magnetic nanodots covering over 1 cm^2 are fabricated using self-assembled nanopores in anodized alumina, with a good control over the dot size and periodicity [1,2]. Magnetization measurements, performed using SQUID, VSM, and MOKE indicate transition from a vortex to a single domain state for the Fe dots (Figure 1) [1,3]. This transition is studied as a function of the dots size and magnetic field. Micromagnetic and Monte Carlo simulations confirm the experimental observations [4]. Thermal activation and exchange bias are found to have a large effect on the vortex nucleation field [5]. Direct imaging of magnetic moments in sub-100 nm dots is extremely difficult and has not been reported yet. Using grazing incidence small angle neutron scattering measurements with polarization analysis, dots are imaged in the reciprocal space. Quantitative analysis of such measurements performed on 65 nm Fe dots yields the magnetization of the vortex core of 140±50 emu/cm^3 and its diameter of 19±4 nm (Figure 2), in a reasonable agreement with the simulations results [1].

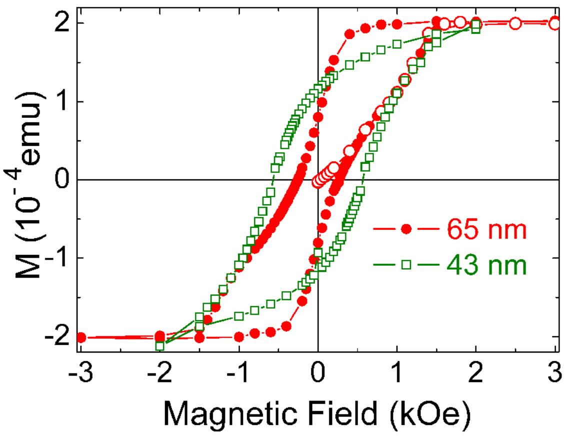

Figure 1: In-plane hysteresis loops for 20-nm-thick Fe dots that are 43 (□) and 65 (●) nm in diameter at 10 K (○- virgin curve for 65 nm dots).

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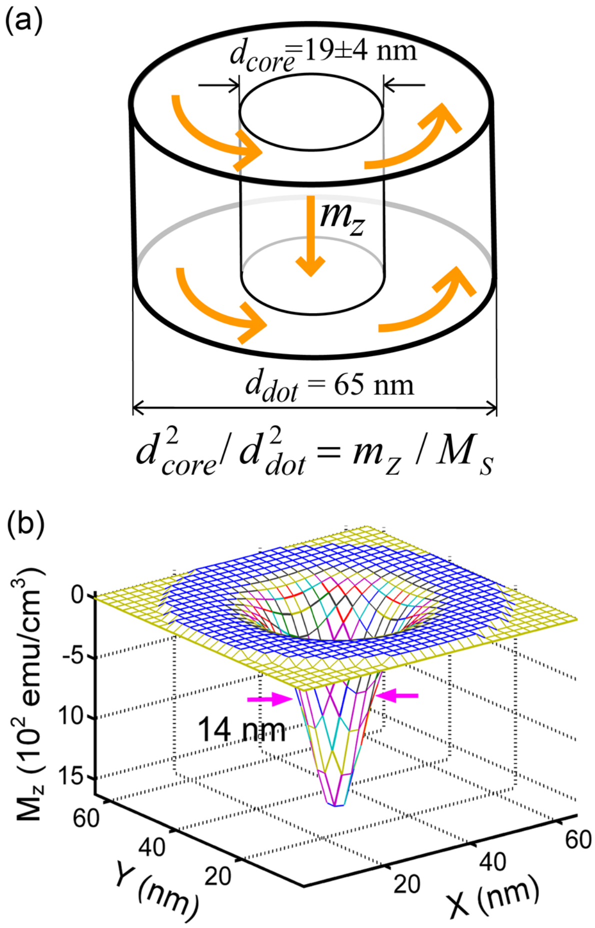

Figure 2: (a) Sketch of magnetization direction in the 20 nm-thick Fe dot with the diameter of 65 nm (per neutron measurements). (b) Out-of-plane magnetization (M_Z) profile of the vortex in the same dot, obtained using micromagnetic simulation.

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References

[1] I. V. Roshchin, C.-P. Li, H. Suhl, X. Batlle, S. Roy, S. K. Sinha, S. Park, R. Pynn, M. R. Fitzsimmons, J. Mejía-López, D. Altbir, A. H. Romero, and I. K. Schuller, “Measurement of the vortex core in sub-100 nm Fe dots using polarized neutron scattering”, EPL, in press (2009).

[2] C.-P. Li, I. V. Roshchin, X. Batlle, M. Viret, F. Ott, and I. K. Schuller, “Fabrication and structural characterization of highly ordered sub-100 nm planar magnetic nanodot arrays over 1 cm^2 coverage area.”, J. Appl. Phys., **100**, 074318 (2006).

[3] R. K Dumas, C.-P Li, I. V. Roshchin, I. K. Schuller, and K. Liu, “Magnetic fingerprints of sub-100 nm Fe dots”, Phys. Rev. B, **75**, 134405 (2007).

[4] J. Mejía-López, D. Altbir, A. H. Romero, X. Batlle, I. V. Roshchin, C.-P. Li, and I. K. Schuller, “Vortex state and effect of anisotropy in sub-100-nm magnetic nanodots”, J. Appl. Phys., **100**, 104319 (2006).

[5] R. K Dumas, C.-P Li, I. V. Roshchin, I. K. Schuller, and K. Liu, “Temperature Induced Single Domain - Vortex State Transition in sub-100nm Fe Nanodots”, Appl. Phys. Lett., **91**, 202501 (2007).