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# Micromagnetic structures in square magnetic nanodots

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## Abstract

The structure of magnetization in magnetic square dots is studied in the range of tens of nanometer by means of micromagnetic simulations. Two magnetic configurations are found, *diagonal* and *vortex* structures for thin films, *flower* and *vortex* for magnetic nanocubes and a hybrid *flower* in bulk and *vortex* near the surfaces for dots with thicknesses larger than dot edge length. © 2002 Published by Elsevier Science B.V.

*Keywords:* Micromagnetism; Nanodot; Magnetostatic; Simulation

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The rapidly decreasing size of magnetic devices has increased the interest in magnetic structures for particles at nanoscale dimensions. Nanoimprint lithography can result in magnetic nanostructures which seem applicable for ultrahigh recording media [1]. For such high densities perpendicular recording seems to be appropriate [2]. Magnetic dots with a thickness higher than dot base dimensions exhibit perpendicular magnetic orientation. This makes an interesting review of the magnetic layer thickness influence on magnetic structures for magnetic dots.

Micromagnetic simulations prove to be specially appropriate for nanoparticles. Calculations with cell dimensions over the *exchange length* may result in computational errors due to an undervaluated exchange energy. On the other hand, magnetostatic energy evaluation becomes very time consuming for grids with a large number of cells. At nanoscale dimensions we can work with grids with not a large number of cells, keeping cell dimensions below the *exchange length*. Calculations have been performed following a Labonte scheme [3] minimizing exchange, anisotropy and magnetostatic energies. The evaluation of magnetostatic energy is accelerated by means of the fast Fourier transform technique [4]. Parameters used in the calculations are typical for permalloy $M_s = 800\,\mathrm{emu/cm^3}$, $A_{ex} = 1.3 \times 10^{-6}\,\mathrm{erg/cm}$ and an uniaxial anisotropy of $K = 100\,\mathrm{erg/cm^3}$ parallel to the $x$-axis has also been considered. The criterion for convergence used was a maximum variation in magnetization director cosines smaller than $2 \times 10^{-4}$ and the grid cells used were cubes of 3.125 nm edge length. These latter parameters were used in all calculations in order to keep the same error when making comparisons.

While anisotropy can play an important role in magnetic distribution in dots with dimensions in the range of hundreds of nanometers [5] at the scale of tens of nanometers, magnetization distribution appears mainly dependent on exchange and magnetostatic interactions. From the exchange point of view, magnetization tries to get nearly parallel in order to reduce the exchange contribution. From the magnetostatic point of view, magnetization tries to avoid surface poles. The smaller the sample is, the more important the exchange becomes and so dots of few tens of nanometers exhibit nearly parallel magnetic configurations. For bigger dots magnetization tries to avoid surface poles and dots exhibit circular rotating magnetization configurations. Certain transition dimensions appear for which these two different structures have nearly the same energy.

For thin film magnetic dots calculations lead to two different configurations as shown in Fig. 1 [6,7], one with magnetization parallel to the square diagonal, *diagonal*, and another with rotating magnetization, *vortex*. A third structure can be reached with magnetization parallel to dot edge although with higher energy than that with magnetization parallel to the dot

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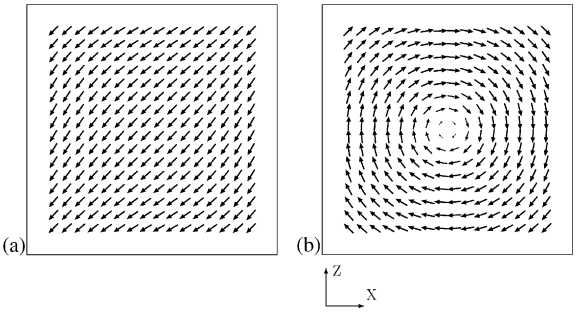

Fig. 1. (a) diagonal and (b) vortex magnetization configurations in a 50 × 50 nm base, 12.5 nm height magnetic dot.

Table 1
Magnetic energy in a 10 nm thick dot for different dot dimensions

| Dot edge (nm) | Diagonal (erg) | Vortex (erg) |
|---|---|---|
| 25 | $5.6 \times 10^{-12}$ | No convergence |
| 50 | $1.4 \times 10^{-11}$ | $2.1 \times 10^{-11}$ |
| 100 | $3.3 \times 10^{-11}$ | $3.0 \times 10^{-11}$ |
| 200 | $6.9 \times 10^{-11}$ | $4.3 \times 10^{-11}$ |

diagonal. Table 1 shows the magnetic energy for different dot dimensions. The smaller the dot, the more stable is the *diagonal* state, while the bigger the sample the more stable is the *vortex* state.

The effect of the thickness on the magnetic energy figures can be seen in Table 2. The *diagonal* state becomes more stable for thinner sample. No convergence is even reached for the *vortex* state for very small thicknesses. For the cube, the *diagonal* state dissapears in favor of the *flower* state [8]. It can be seen that the energy of the *flower* and *vortex* states are very similar for a nanocube of 50 nm edge length. For a thicker sample a new magnetic distribution appears as a mix of the *flower* and *vortex* structures. Fig. 2 shows the magnetic layout in the lower, middle and upper layers in a $50 \times 50\,\mathrm{nm}^2$ base, 100 nm height magnetic dot. In this case the magnetization in the center is parallel to the large axis while upper and lower layers exhibit a *vortex*-like structure with the same distribution but opposite directions.

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Table 2
Magnetic energy in 50 × 50 nm dots for different thicknesses

| Thickness (nm) | Diagonal (erg) | Vortex (erg) |
|---|---|---|
| 6 | $6.6 \times 10^{-12}$ | No convergence |
| 12 | $2.0 \times 10^{-11}$ | $2.7 \times 10^{-11}$ |
| 25 | $5.8 \times 10^{-11}$ | $5.2 \times 10^{-11}$ |
| 50 | $9.9 \times 10^{-11}$ | $9.9 \times 10^{-11}$ |
| 100 | No convergence | $1.7 \times 10^{-10}$ |

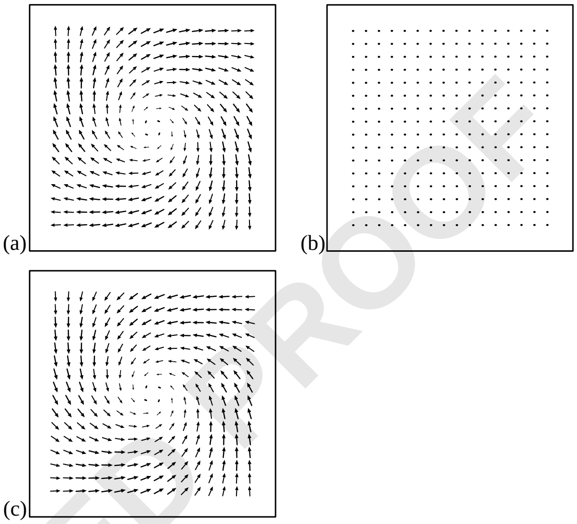

Fig. 2. Magnetization in (a) bottom, (b) middle and (c) top layers in a 50 × 50 nm base, 100 nm height magnetic dot.

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