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High-frequency susceptibility of soft ferromagnetic nanodots

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Abstract

The dynamic susceptibility spectra of a soft ferromagnetic nanodot supporting a vortex-type magnetic configuration is studied in the frequency range 0.1–20 GHz by means of dynamic micromagnetic simulations. The frequency evolution of the detected magnetic excitations as a function of both dot radius ($40 \leqslant R \leqslant 160$ nm) and dot thickness ($5 \leqslant L_z \leqslant 80$ nm) is reported.

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Keywords: Micromagnetism; Dynamic susceptibility; Magnetic nanodot; Magnetic vortex

The magnetic properties of nano-scale objects such as cylindrical platelets, denoted hereafter circular nanodots, are today under great consideration mainly due to their potential applications in high-density magnetic storage and spin electronic devices [1]. It was shown [2] that for a circular nanodot possessing an appropriate aspect ratio (ratio of the dot thickness L_z to the dot radius R) the equilibrium magnetic configuration corresponds to a vortex-like structure.

The purpose of this paper is to investigate the high-frequency linear magnetic excitations existing in such a magnetic configuration. The dynamic susceptibility spectra were determined using two three-dimensional (3D) codes we had developed [3,4]. The first one calculates a stable configuration of the magnetization vector by solving the Landau–Lifshitz equation in the time domain. The second one computes the full dynamic susceptibility tensor from the linearization of the Landau–Lifshitz equation around the equilibrium configuration. The material parameters used in the calculations are typical for isotropic Permalloy, namely, the saturation magnetization $M_S = 8 \times 10^5$ A/m, the exchange constant $A = 1.3 \times 10^{-11}$ J/m, the gyromagnetic ratio $\gamma = 1.76 \times 10^{11}$ s^{-1} T^{-1}. The damping parameter corresponds to $\alpha = 0.05$. The used mesh sizes are $\Delta_x = \Delta_y = \Delta_z = 2.5$ nm. Within the range of dot sizes, $40 \leqslant R \leqslant 160$ nm and $5 \leqslant L_Z \leqslant 80$ nm, a stable vortex-type configuration exists even if that does not coincide with the ground state for low values of L_z and R [5]. As an illustration, the computed equilibrium magnetic configuration for a nanodot with $L_z = 20$ nm and $R = 80$ nm is depicted in Fig. 1. A detailed analysis points out that the vortex core radius depends on the coordinate along the dot thickness (z-axis) and its mean value exceeds that predicted by theoretical models [2].

For the same nanodot, the top part in Fig. 2 shows the imaginary part of two terms of the dynamic susceptibility tensor, in-plane element χ''_{xx} and perpendicular element χ''_{zz}. These spectra exhibit two main magnetic excitations for χ''_{xx}, noted (1) and (2), and one excitation, noted (3), for χ''_{zz}. The spatial distribution of the corresponding susceptibility tensor elements at each resonance frequency is reported in the bottom part in Fig. 2. For χ''_{xx} the low-frequency resonance at 0.94 GHz arises from the spins located within the vortex core whereas the high-frequency resonance at 10 GHz of weaker intensity corresponds to the excitation of spin regions with high values of M_y or M_z. For χ''_{zz}, the

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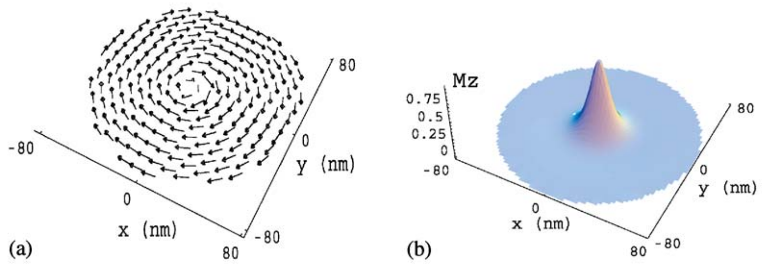

Fig. 1. Vortex magnetic structure in a circular nanodot with $L_z = 20$ nm and $R = 80$ nm: (a) in-plane magnetization components, (b) perpendicular magnetization component.

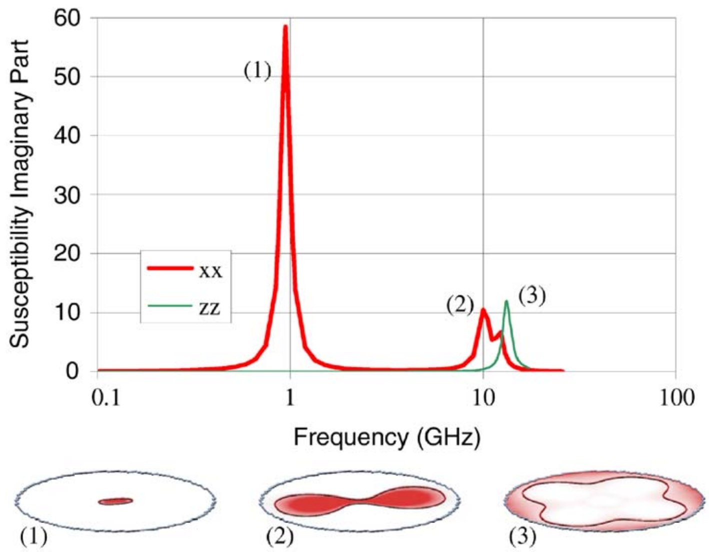

Fig. 2. Top: χ''_{xx} and χ''_{zz} as a function of frequency. Bottom: spatial distribution of χ''_{xx} or χ''_{zz} at each resonance frequency in the mid-plane $z = 0$. High susceptibility values in grey.

magnetic resonance appearing at 14.65 GHz results from the response to the peripheral zone of the nanodot. In contrast to modes (1) and (2), mode (3) strongly depends on the coordinate along the z-axis.

The frequency evolution of these modes was investigated as a function of both dot radius and dot thickness. Fig. 3 shows that the resonance frequency of the vortex mode is an increasing function of L_z and a decreasing one of R. This behaviour is in agreement with theoretical models recently proposed [6,7]. However, these theoretical resonance frequencies appear noticeably lower than the numerical ones. The assumption of a dot magnetization distribution independent of the z-coordinate used in these models seems to be too restricted.

For $L_z > 40$ nm, a second vortex mode appears at a higher frequency and the structure of the two vortex modes becomes strongly inhomogeneous along the dot thickness. Within this range of dot sizes, the resonance frequencies of modes (2) and (3) are slightly modified.

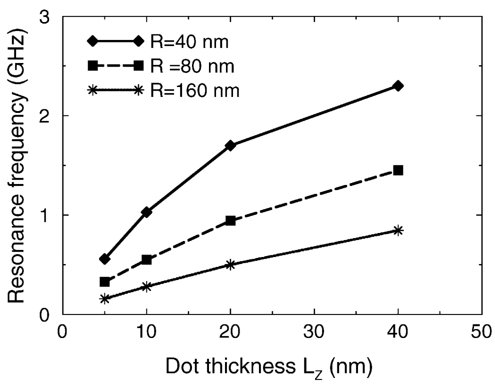

Fig. 3. Vortex mode frequency as a function of the dot thickness L_z and dot radius R.

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