# Ferromagnetic Resonance of Localized Nonuniform States in Magnetic Nanostructures

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We report the micromagnetic modeling of ferromagnetic resonance (FMR) for localized nonuniform states in different thin film ferromagnetic nanostructures. The FMR frequency spectra and spatial distributions of the oscillation amplitude are calculated by numerical solution of Landau-Lifshitz equation using the standard Object Oriented MicroMagnetic Framework (OOMMF) code [1]. As an example here we present the results for localized FMR modes associated with domain wall in permalloy nanowire and for skyrmion state in thin film multilayer structure Co/Pt spatially modified by ion beam.

The spectrum of the magnetization oscillations in the nanowire with transverse domain wall is shown in Fig. 1(a). The intense peaks 1 and 2 correspond to the oscillations localized in the domain wall area. Appropriate distributions of the FMR amplitude are shown in Fig. 1(c,d)

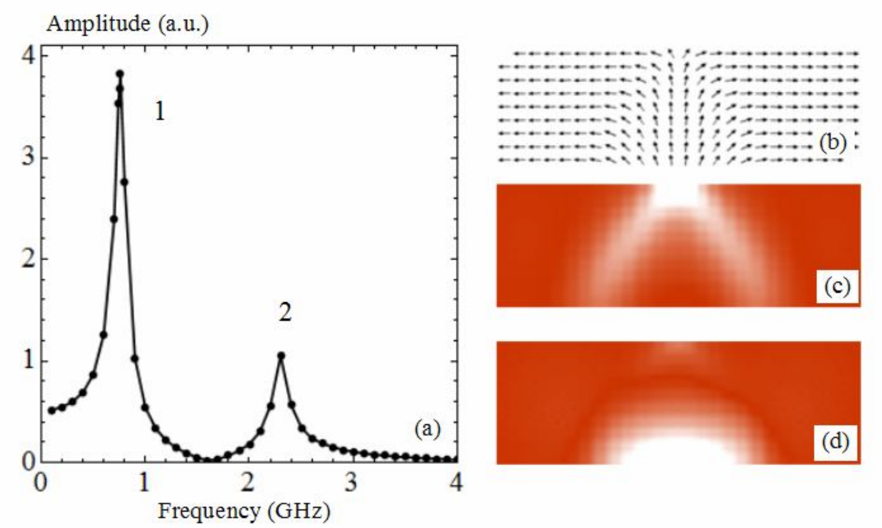


**Fig. 1.** (a) is the spectrum of magnetization oscillations in the nanowire with transverse domain wall. (b) is the magnetization distribution in the domain wall. (c) and (d) are the FMR amplitude distributions associated with the peak 1 and 2 respectively.

Another perspective objects are skyrmions states in CoPt multilayer films with perpendicular anisotropy, locally irradiated with He focused ion beam [2], that The irradiation leads to lokal decrease of the anisotropy. Fig. 2 shows the spectrum of the magnetization oscillations in such structure. The peaks 1 and 2 are associated with the localized oscillations within the irradiated areas (the diameter is 100 nm) (see Fig. 2 b,c). The peak 3 is connected with the resonance of the film as a whole (see Fig. 2d).

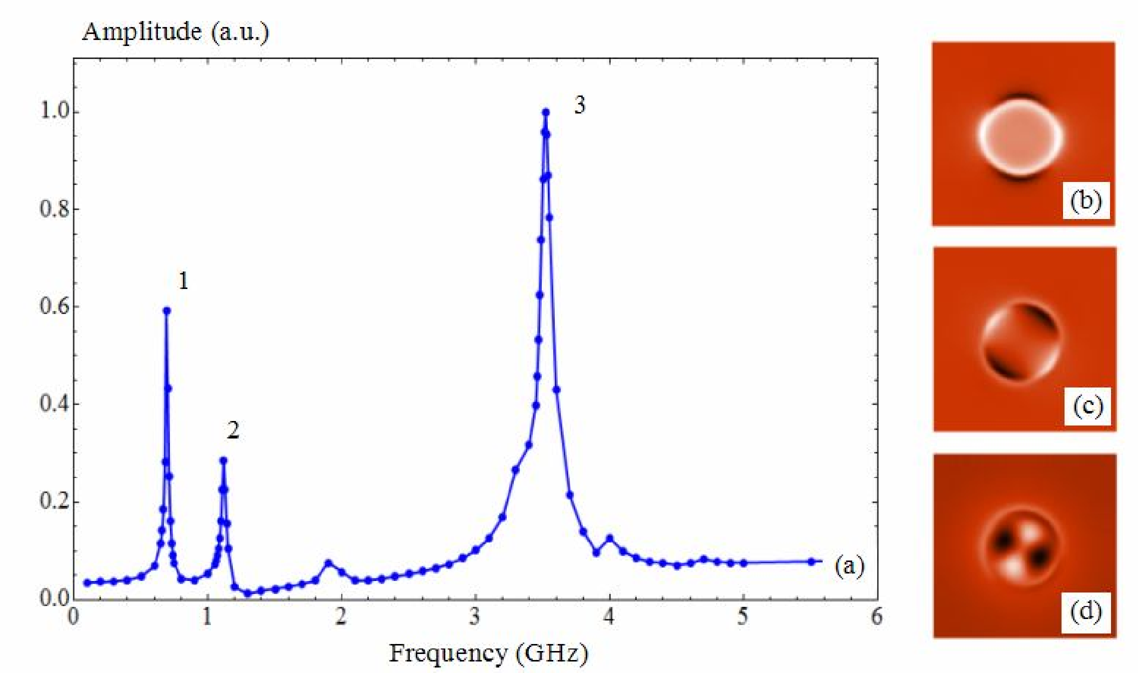


**Fig. 2.** (a) is the spectrum of the magnetization oscillations for the skyrmion states in the CoPt with circular areas of modified anisotropy. (b), (c) and (d) are the distribution of the FMR amplitude associated with the peak 1, 2 and 3 respectively.

Evidently the controlled rearrangement of nonhomogeneous states in ferromagnetic nanostructures can be exploited to create tunable magnetic components of the microwave electronics.

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[1] M.J. Donahue and D.G. Porter, “OOMMF User's Guide”, Interagency Report NISTIR 6376, NIST, Gaithersburg, http://math.nist.gov/oommf

[2] M. V. Sapozhnikov, S. N. Vdovichev, O. L. Ermolaeva, N. S. Gusev, A. A. Fraerman, S. A. Gusev, and Yu. V.Petrov, Appl. Phys. Lett., **109**, 042406 (2016).