Calculations of the FMR Spectrum in 1D Magnonic Crystals

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Abstract

A ferromagnetic resonance (FMR) in a bulk ferromagnetic material is associated with absorption of electromagnetic wave by uniformly processing magnetic moments. However, in structures with confined geometries, also the non-uniform processions is formed, so called spin waves, and they can have significant contribution to the FMR signal. FMR spectra of the periodic microstructures (one-dimensional magnonic crystals or 1D MCs) were obtained using COMSOL and results of these calculations were successfully compared with an experimental data. The structure composed of alternating stripes of Co and permalloy (Py) with 6.6 and 3.4 micrometers width, respectively and 50 nm thickness was fabricated (Figure 1). Experiments were performed using conventional FMR technique at constant frequency 9.85 GHz. In order to calculate the FMR spectrum of MCs, we are obliged to find the possible formation of the dynamical magnetization components as standing waves. The Landau-Lifshitz (LL) equation simultaneously with the equation for magnetostatic potential has been implemented in the frequency domain for monochromatic spin waves. By assuming the solutions in the form of a Bloch waves we were able to define a system of equations that governs the magnetic potential and dynamic parts of magnetization components in MC. The obtained eigenvalue problem have been implemented and solved in the partial differential equation (PDE) module for a 2D geometry. As a result we have obtained the set of eigenvalues (resonance fields) at defined frequencies. For each eigenvalue we found corresponding spatial dependence of the dynamic magnetization. The overlapping integral of the uniform external electromagnetic field and the spin wave amplitude was calculated in order to obtain the relative intensity of electromagnetic wave absorption, thus reproducing the FMR spectrum. We have found good agreement between numerical calculations and FMR experimental data when the external bias magnetic field was applied in plane of the MCs film, along the stripes (Figure 2). The parameters values have been chosen as these measured for the investigated sample. Implementation of the LL equation in the PDE Interface allows us also to calculate the dispersion relation of the spin waves,

i.e., frequency as a function of the wave-vector, in MCs. We have developed the method of calculation the FMR spectra in MCs with the use of PDE Interface. It has been applied to reproduce the measurement results in 1D MC composed of Co and Py stripes. The presented tool allows to analyze periodic structures with various geometries and material parameter compositions, being at the same time a tool that can serve for optimization and tuning the absorption of electromagnetic waves in ferromagnetic materials. MCs as investigated in this study have been considered in recent years also as candidates for electromagnetic metamaterials possessing negative refractive index or zero refractive index materials. Our tool can be a competitive in the spin waves calculations in MCs to time consuming micromagnetic simulations.

Figures used in the abstract

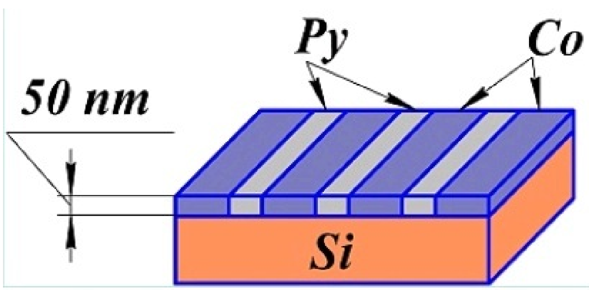

Figure 1: The one-dimensional magnonic crystal composed of alternating stripes of Co and permalloy (Py) on Si substrate.

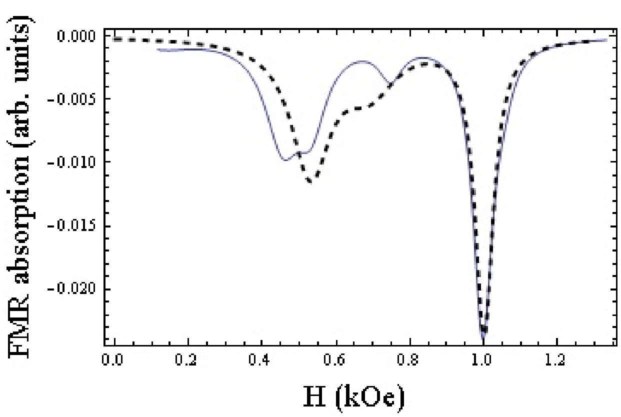

Figure 2: The measured FMR spectrum (continuous line) and the calculated FMR spectrum (dashed line), normalized to the most intensive FMR signal for 1D MCs.