Weak Formulations for Calculating Spin Wave Dispersion Relation in Magnonic Crystals

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Abstract

A spin wave (SW) is a physical phenomena that represents a propagating precessions of magnetic moments. Periodically arranged magnetic slabs, i.e., one-dimensional magnonic crystal (MC) with the finite thickness are subject of our study. An alternating external magnetic field that induce precession of magnetic moments in the subjected area can serve as a source of spin wave excitation. The neighboring magnetic moments will not remain fixed, but also start to precess, due to long range dipole and short range exchange interactions between magnetic moments, the spin wave start to propagate. The strengths of dipole or exchange interactions are dependent on the structural parameters of structure, i.e., thickness (d) and lattice constant (a) of the MC, see Fig. 1 and they will have impact on the dispersion of SW.

Here we use the and the PDE mode for modeling equation written in the weak form. The eigenvalue and the eigenfrequency solvers are used to solve eigenvalue problems. The unit cell of periodic structure is defined in 2D geometry with Dirichlet boundary conditions on the edges parallel to the surface of MC and with PBC on the edges perpendicular. The fields are assumed to be in the form of Bloch wave with in-plane and perpendicular to external field wave-vector component. Two principaly different approaches can be used in order to define the set of governing equations based on:

1. Maxwell equations (curl H=0, div B=0) together with linearized Landau-Lifthsitz equation, where exchange interaction is taken into account as effective magnetic field.

2. Wave equation, where frequency dependent permeability tensor is defined from linearized Landau-Liftshitz equation in exchange free limit.

Which way of calculating energy of the SWs is more advantageous is mainly determined by the structural parameters of the structure. On the Fig. 2 we present the comparison of magnonic band gaps for structure with parameters described in the caption. It is an example of dispersion relation of structure, where both dipole and exchange interactions play an important role. A shift of the magnonic band structure due to the exchange interaction can be taken into account only using the 1st approach. On the other hand, the 2nd approach might be crucial to investigate the structures with large values of thickness and lattice constant, since the exchange interactions give origin to quantized waves across the thickness (difficult to observe in the experiments). Increasing the thickness lower the energy of these solutions and cause the dispersion of experimentally

observed modes not visible in dense spectrum.

We have implemented a FEM with the use of COMSOL Multiphysics® to define the properties of spin wave excitations in MC. It is important to investigate spin wave properties in various structures, due to they potential application, i.g., in storage or processing of information devices. The FEM gives advantages over other methods, i.g., including the finite conductivity, flexibility in defining the geometry, time of computation. We analyze and compared two approaches in details and define the limits of structural parameters values to which they should be apply to.

Reference

11/12 reviewed by Laura

Figures used in the abstract

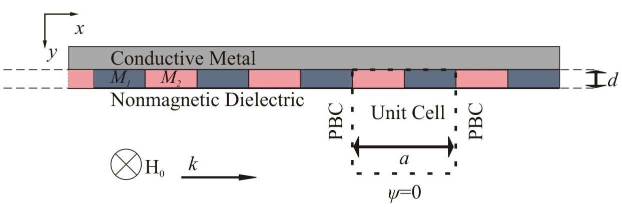

Figure 1: The structure of 1D MC with a layer of a conductive metal on the top surface at y = 0. The MC is composed of alternating, infinitely long ferromagnetic stripes that have different saturation magnetization. The bias field directed along the stripes axis (the z axis). The SW propagate along the x axis. The rectangular unit cell used in calculations is marked by dashed line. The PBC are used along the x-axis.

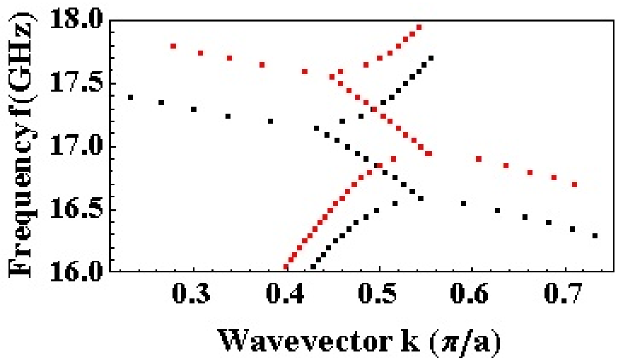

Figure 2: The comparison of the magnonic band gaps of the structure presented on the Fig1, with the following parameters: M1=0.95*10e6 A/m, M2=1.05*10e6 A/m, a=500 nm, d= 30 nm, H=0.1 T, sigma=10e15 S/m. The red points present gap calculated using the 1st approach, while the black dots using the 2nd approach.