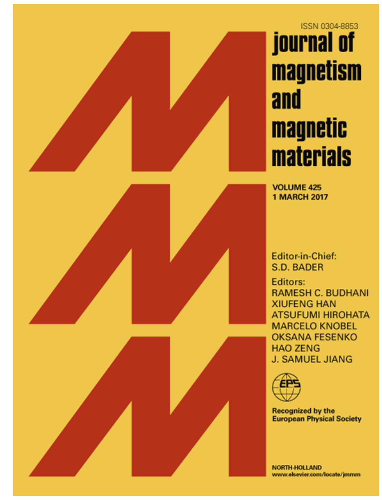

Absorbing boundary layers for spin wave micromagnetics

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Absorbing boundary layers for spin wave micromagnetics

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Abstract

Micromagnetic simulations are used to investigate the effects of different absorbing boundary layers (ABLs) on spin waves (SWs) reflected from the edges of a magnetic nano-structure. We define the conditions that a suitable ABL must fulfill and compare the performance of abrupt, linear, polynomial and tan hyperbolic damping profiles in the ABL. We first consider normal incidence in a permalloy stripe and propose a transmission line model to quantify reflections and calculate the loss introduced into the stripe due to the ABL. We find that a parabolic damping profile absorbs the SW energy efficiently and has a low reflection coefficient, thus performing much better than the commonly used abrupt damping profile. We then investigated SWs that are obliquely incident at 26.6°, 45° and 63.4° on the edge of a yttrium-iron-garnet film. The parabolic damping profile again performs efficiently by showing a high SW energy transfer to the ABL and a low reflected SW amplitude.

Keywords: Magnetization dynamics, micromagnetic simulations, magnonics, spin waves

1. Introduction

Easier access to computational resources over the last decade has led to the development of many micromagnetic packages that solve the Landau-Lifshitz (LL) equation for magnetic nano-structures. These packages are being used to study spin wave mode profiles and spectra in a quest to build devices with novel functionalities [1–3]. One approach to these studies is to perturb the ground state with a broadband excitation, and then extract the spin wave (SW) dispersion characteristics [4–7]. However, simulation boundaries are known to affect the dissipative dynamics of the magnonic spectra in such studies [8, 9], and we artificially increase the damping α at the boundaries, to absorb the SW reflections. The increase in α can be smooth, e.g. using a hyperbolic tangent function [10], or abrupt [11]. The latter approach was used to attenuate SW reflections, and to calculate the dispersion and scattering parameters in magnonic devices [12, 13]. More recently, an exponential increase in damping was used to curb reflections in the study of skyrmions and the Dzyaloshinskii-Moriya interaction in magnetic nanostripes [14, 15].

In this article, we define the return loss using transmission line models, to study the impact of using artificial regions of high α, or absorbing boundary layers (ABLs), at the edges of the device. We propose a parabolic increase in α and show that it causes less spurious SW reflections than an abrupt increase in α. We compare the parabolic profile against the abrupt, linear and the tan hyperbolic profile, for different angles of incidence. The parabolic profile also aligns the micromagnetic community more closely with the accepted polynomial form of perfectly matched layers (PMLs) in finite difference time domain (FDTD) simulations of Maxwell's equations [16].

To our knowledge, this is the first exhaustive study of ABLs using the graphics processing unit (GPU) accelerated finite difference (FD) micromagnetic package MuMax3 [17]. We also provide the codes for post processing the simulation data and raw data for the figures in a code repository for easy reproduction [18].

2. Normal incidence of spin waves

The time evolution of the magnetization is described by the LL equation [19, 20]

$$\frac{\partial \mathbf{m}}{\partial t} = \gamma' \left[(\mathbf{m} \times \mathbf{H}) + \alpha \left(\mathbf{m} \times (\mathbf{m} \times \mathbf{H}) \right) \right], \tag{1}$$

where $\mathbf{m} = \mathbf{M}/M_S$ is the normalized magnetization, and $\mathbf{M}$ and $\mathbf{H}$ are the total magnetization and effective field at time t, respectively. $\gamma' = \gamma\mu_0/(1+\alpha^2)$, with $\gamma < 0$ being the electron gyromagnetic ratio, α the phenomenological damping coefficient and μ_0 the permeability of free space. We consider a stripe of permalloy ($Ni_{80}Fe_{20}$) having dimensions $4000 \times 1000 \times 5\,\mathrm{nm}^3$, as shown in Figure 1 (a). The structure was proposed as a micromagnetic sample problem for studying SW dynamics and dispersion [7]. We choose a simple geometry with known solutions for the mode profiles.

The material parameters used for permalloy were the saturation magnetization $M_s = 800\,\mathrm{kA/m}$ and exchange constant

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ABL - Absorbing Boundary Layer; SW - Spin Wave; LL - Landau-Lifshitz; PML - Perfectly Matched Layer; FDTD - Finite Difference Time Domain; GPU - Graphics Processing Unit; FD - Finite Difference; YIG - Yttrium Iron Garnet; Transmission line - Tx line