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C. S. Nikhil Kumar

Magnonic Devices

Numerical Modelling and Micromagnetic Simulation Approach

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Dedicated to my parents, Naina, Supervisors Prof. Anil Prabhakar and Prof. Ashwin A. Tulapurkar

Preface

Magnonics—the study of spin waves—has seen a remarkable scope for the creation of magnetic field-controlled devices with properties tailored on the nanoscale. It aims to control and manipulate spin waves in ferromagnetic material. Spin wave can effectively carry and process information in magnetic nanostructures. The most controllability of their functioning is by an external magnetic field.

The magnonic devices which are periodically modulated in space are seen as very promising devices because of the possibility of tunning their band structure. Periodically modulated magnonic devices can also be called as "magnonic crystal" magnetic counter part of photonic crystal, with spin wave acting as information carrier. Magnonic crystals are better candidates for miniaturization, since the wavelength of spin wave is several orders of magnitude shorter than that of electromagnetic waves of the same frequency. An example of one-dimensional magnonic crystal is a multilayered magnetic structure consisting of alternated ferromagnetic layers. The basic advantage of a such device is that frequency position and width of the band gap are tunable by an applied field and through material properties. The dispersion properties can be tuned by changing the dimensions of magnonic waveguide.

Spectrum of magnonic crystal shows band gaps in which spin wave cannot propagate. Such band gaps have been experimentally studied using Brillouin light scattering spectroscopy [1, 2] and time-resolved scanning Kerr microscopy [3]. The study of magnonic crystal is first proposed in [4]. Puszkarski and Krawczyk have theoretically calculated the magnonic band structure of 2D MCs consisting of infinitely long cylindrical Fe rods periodically embedded in a yttrium iron garnet (YIG) background [5]. The materials Fe and YIG were selected for their large difference in magnetic properties, as it has been predicted that the larger the difference, the wider would be the band gap width. They investigated the position and width of band gaps in the spin wave spectrum versus period of the structure and magnetic properties.

A popular method to investigate the band structure of periodic structure is plane wave expansion method. Plane wave method has been successfully implemented in both photonic [6], phononic [7] and magnonic crystals [5, 4, 8]. We follow the main idea behind the plane wave method to investigate the band structure of periodically modulated magnonic waveguide. The equation of motion for a periodically magnetic structure is transformed into reciprocal space using Fourier transformation and Bloch's theorem. The equation of motion is then reduced to an eigenvalue problem. The numerical solutions were found out for such an eigenvalue problem by standard numerical routines. The solution yield eigenfrequencies that help to find the band structure and eigenvector yields spin wave profile inside the periodic material. One of the main objectives of this thesis is to follow the plane wave method in order to investigate the spin wave spectrum of the striped magnonic crystal in backward volume configuration. The result is published in [9]. We initially investigated the magnetostatic field inside the geometry using the idea presented in [10]. The obtained magnetostatic field is used in the governing Landau-Lifshitz equation. This helps us to reduce the equation in to an eigenvalue problem. This eigenvalue problem is solved numerically in order to investigate the spin wave spectrum. The eigenvector concept is used to investigate the spin wave profile inside the structure.

This book describes the dispersion relation of dipolar spin wave in a magnonic curved waveguide. Walker's equation in cylindrical coordinates is solved with appropriate boundary conditions. The dispersion of exchange spin waves is then calculated using perturbation theory. We validated our results by investigating the dispersion relation for a higher bending radius and compared it to that of a straight waveguide for higher bending radius. By introducing symmetry about the azimuthal direction, we also obtain analytical solutions for Walker's equation and the mode profile characteristics of dipolar spin waves in a magnonic ring. Perturbation theory is used to investigate the mode profile characteristics of magnonic ring. Finally, analytical dispersion relation of curved waveguide is compared with micromagnetic simulation. We could see a reasonable agreement of fundamental mode between simulation and analytical results and attribute the differences to the large exchange in the simulation and the weak exchange in perturbation theory.

This book also describes nanocontact-driven spin wave excitations in magnonic cavity. A spin-polarized electric current injected into Permalloy (Py) through a nanocontact exerts a torque on the magnetization, leading to spin wave (SW) excitation. We considered an array of nanocontacts on a Py film for an enhanced SW excitation. We designed an antidot magnonic crystal (MC) around the nanocontact to form a cavity. The MC was designed so that the frequency of the SW mode generated by the nanocontact lies in the band gap of the MC. The nanocontacts were placed in a line defect created in the MC by removing a row of antidots. The SW time series and power spectrum were observed at the output of the cavity. We observe that the SWs decay in the absence of the MC cavity, and when the nanocontacts are within the antidot MC cavity, the SW amplitude is amplified and stable. This is also reflected in the SW spectrum obtained at the output port. Finally, Q factor of the device is calculated using decay method and observed a high Q factor $Q = 3.8 \times 10^5$ for a current of 7.8 mA. The proposed device behaves as a SWASER (spin wave amplification by the stimulated emission of radiation).

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