Magnonic band gaps of metallic one-dimensional magnonic crystals

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Magnonics is one of the most fascinating research fields in spintronics. Spin waves (SWs), also called magnons, have attracted special attention because of their potential application as information transport and processing for novel spin devices. In recent our work, some important characteristics on spin waves were reported, such as nonreciprocity [1, 2] and conductivity effect [3]. Among magnonics, magnonic crystals (MCs) are one of the most attractive topics for both fundamental physics and future applications. MCs, which are analogous to photonic crystals, are defined as artificial media with spatially periodic variation of some of their magnetic parameters. As a result, MCs show modified spectra compared with plain films. SWs with certain frequency ranges cannot be allowed to propagate in MCs and forms rejection bands, that is, band gaps. The formation of band gap can be used to not only the SW filters but also control of group velocity, for example, generation of the slow magnon. So far, research on MC using YIG have been the mainstream because of their ease of sample preparation. Recently, there were some reports about metallic MCs, but the most of the metallic MCs had structural periods ranging from 0.1 to 1 μm because metals have a shorter propagation length of SW (10 μm order) than that of YIG (mm order) and ones try to make a lot of periodic structures in a limited length. The wave numbers affected by them, however, are too high to access using antenna method. It is important to detect the influence of MCs on SWs by all electrical measurement method for development of novel spin wave devices. In this study, metallic 1D-MCs consisting of Py strips with periodic grooves were investigated. We measured the propagation properties of the magnetostatic surface wave (MSSW) in the Py MCs by an antenna method and demonstrated the electrical detection of the magnonic bandgaps.

Py strips with a width of 100 μm and a thickness d of 50 nm were prepared on high-resistivity Si/SiO_2 substrates. The periodic grooves with a depth of 25 nm were formed by Ar^+ ion milling. The grooves are aligned perpendicular to the propagation direction. The lattice constant (D) was 2.0, 3.0, and 4.0 μm, and the grooves with a width of $D/2$ were separated by $D/2$ (see Fig. 1). We also fabricated an unstructured film for comparison. A 80-nm-thick SiO_2 layer were deposited for isolation and a pair of coplanar waveguides (CPWs) of signal (S)-ground (G) type was formed for excitation and detection antennae. The widths of S, G lines, and the SG-gap were 1.0, 50, and 1.0 μm, respectively. A vector network analyzer and a microprobe station with an electromagnet was used for spin wave transmission measurement.

Micromagnetic simulation of spin-wave propagation were performed using the Object Oriented Micromagnetic Framework (OOMMF) software package based on the Landau-Lifshitz equation. The excitation field of the SG type antenna was separately calculated using MATLAB, and a Gaussian pulse excitation with a pulse width of 50 ps was applied in OOMMF using the calculated field profile. The SW spectra can be obtained by Fast Fourier Transformation (FFT).

Figure 2 (a) shows the spectra mapping as a function of distance x from an excitation antenna for the Py MC with $D = 2$ μm. The dispersion relation was also obtained by FFT along x (Fig. 2(b)). It has some pronounced dispersion branches and the clear magnonic band gaps can be observed at $k = \pi/D$ and $2\pi/D$. The spectrum at detection point (Fig. 2(c)) shows some dips at corresponding the band gap frequency. Thus, the introduction of a periodic structure yields rejection frequencies in spin wave spectrum.

Figure 3 shows the experimental (red) and calculated (blue) results of normalized spin-wave spectra for an unstructured film and MCs under $\mu_0H = 20$ mT. In the unstructured film, there is no dip in the spectra of both experimental and calculated results. The shapes of the spectra for the MCs are obviously different from that for the unstructured film and have obviously large dips (denoted as first dips) at the specified frequencies. The calculated spectra for the MCs have obvious first (large) and second (small) dips. In experimental spectra of MCs, second dips are not so clear because of the small oscillations due to interference. The oscillation around here is, however, distorted compared to the unstructured film, and the frequencies of the dips for the experimental and calculated spectra are almost equal. Additionally, they depend on D. Therefore, we judged that it is the influence of existence of 2nd dip. Thus, we succeeded in the electrical detection of magnonic band gaps for Py 1D-MCs with periodic grooves utilizing an antenna method.

Reference

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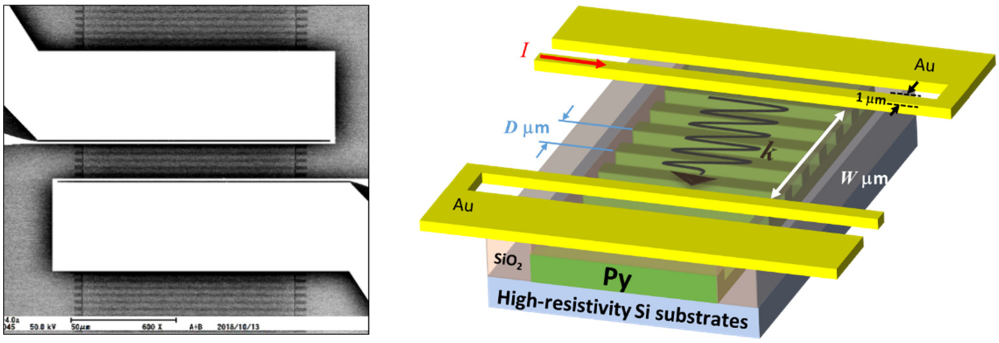

Fig. 1 SEM photograph and schematic illustration of a Py MC sample.

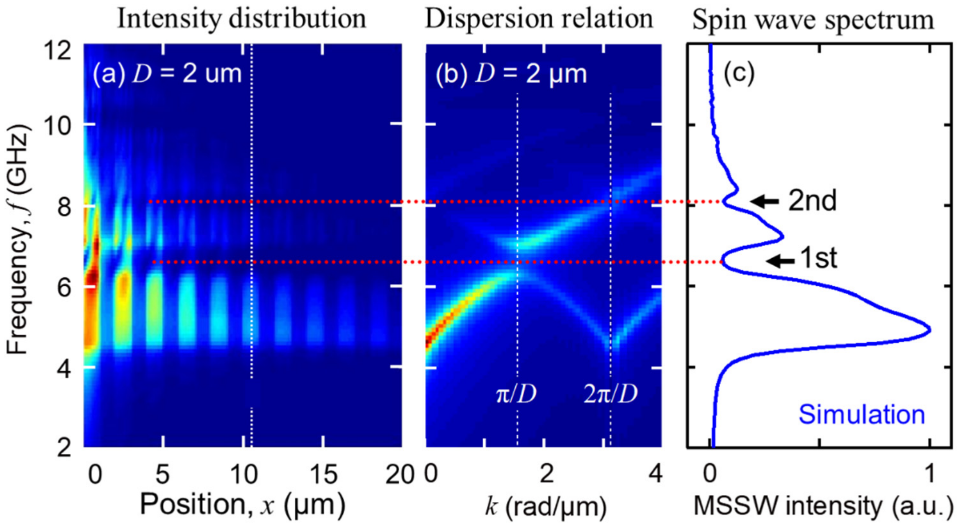

Fig. 2 Simulated intensity distribution, dispersion relation, spin wave spectrum of a Py MC with $D = 2$ μm.

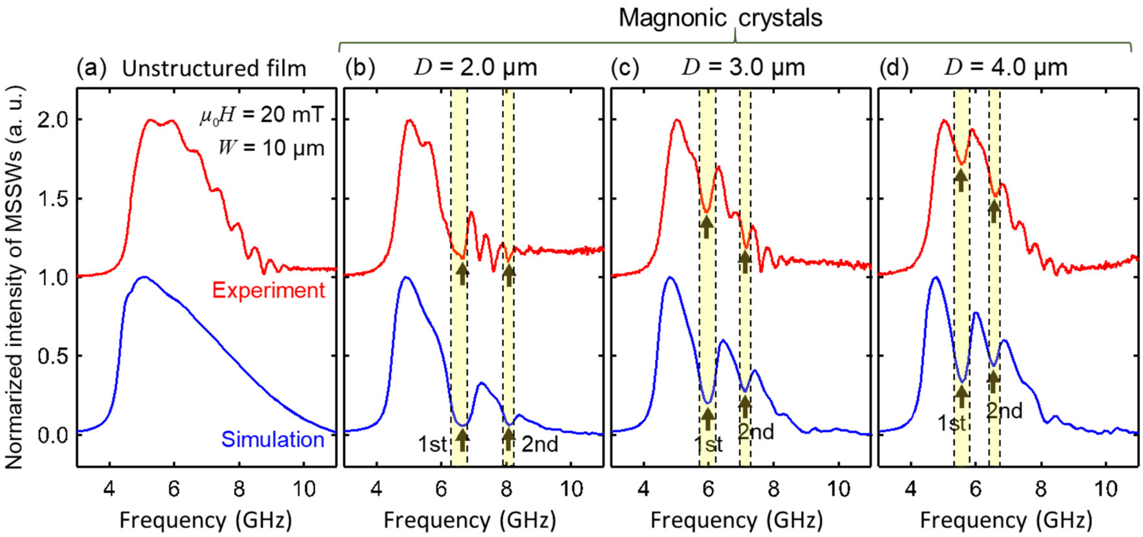

Fig. 3 Spin wave spectrum for an unstructured film and MCs of experimental and simulated results.