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Snell's Law for Magnetostatic Forward Volume Wave

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Abstract

As Snell's law was proved valid for spin wave, manipulation of spin waves can be considered in analogy with optics. However, the reported Snell's law is only for magnetostatic surface wave, which has anisotropic dispersion relation. In this study, we perform a micromagnetic simulation to investigate the Snell's law for isotropic spin wave, magnetostatic forward volume wave.

1. Introduction

Control of spin wave (SW) propagation is one of crucial tasks in magnonics [1]. As one of the important properties of the propagation, refraction of magnetostatic surface spin wave (MSSW) has been investigated [2-5]. However, MSSW has anisotropic dispersion relation and it should be taken into count the angle dependent wave vector of SW. Although an analogy between SW and light is expected, such anisotropic SW requires complex calculation and it is not easy to apply techniques grown in optics.

In contrast, magnetostastic forward volumes wave (MSFVW) [6] can be an ideal option. MSFVW is a mode of magnetostatic SWs which has an isotropic dispersion relation. However, the refraction property of MSFVW has not been reported yet. In this study, we perform a micromagnetic simulation to discuss on the Snell's law for MSFVW.

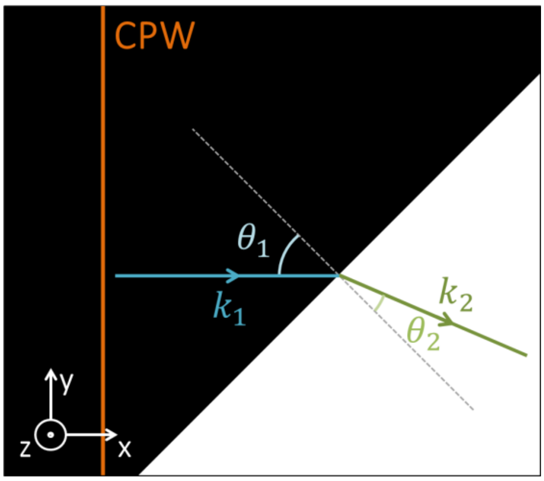

Figure 1 Refraction of SW in between two areas of different thickness (Black area represents area of 100 nm while white area represents area of 50 nm). SW is excited at the CPW area by radio frequency (RF) magnetic field in x direction, with a frequency of 0.9 GHz and amplitude of 1 mT. k_1 and k_2 are the wave vectors before and after refraction, respectively. θ_1 and θ_2 correspond to the angle of incident and refraction, respectively.

2. Results and Discussions

In this study, micromagnetic simulation is performed by Mumax3 [7]. Cell size of $50 \times 50 \times 50$ nm is used for calculation which is much smaller than the wavelength of excited magenetostatic SW. To absorb the SW reflections at the right edge of calculation area, damping constant at the last 6 μm is set to increase gradually to 1. A refraction of SW at the boudary of two magnetic media is calculated using a material parameter of Yttrium iron garnet (YIG) with the following parameters: saturation magnetization $M_s = 139$ kA/m, exchange constant $A_{ex} = 4.15$ pJ/m, Gilbert damping constant $\alpha = 1 \times 10^{-4}$. Here, two media consists of different thickness (50 and 100 nm). Since a wavevector of magnetostatic SW depends on a thickness of magnetic film, two regions behave as different media and a thickness step works as the boundary. A magnetic field (200 mT), is applied to +z direction and MSFVW is excited by a coplanar waveguide (CPW) in the thicker area. The excited SW propagates through the step with an incident angle (θ_1). Due to the thickness step, the origin wave vector k_1 changes into k_2, and the SW in thinner region propagate with an angle θ_2 to the normal (Fig.1). The relationship between the angles of incident and refraction is described by Snell's law (Eq.(1)).

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{k_2}{k_1} \qquad (1)$$

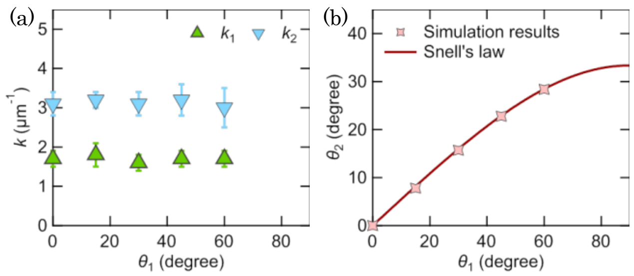

Figure 2 (a)Wave vector k_1 and k_2 versus θ_1. (b)The angle of refraction θ_2 versus the angle of incident θ_1. Pink data points are the simulation results. The red solid line is a calculated result based on Snell's law (Eq. (1)). Here, for the calculation, we used k_1 and k_2 which are showed in Fig.2(a).

In the case of MSFVW, due to the isotropic dispersion property, the wave vectors depend only on the medium, but not on the direction of propagation. Thus, the ratio k_2/k_1 is expected to be constant for any θ_1. From the simulation, k_1, k_2 and θ_2 with various θ_1 are obtained. As illustrated in Fig.2 (a), both k_1 and k_2 do not depend on θ_1. The expected relationship between θ_1 and θ_2 is furtherly calculated using obtained k_1 and k_2. It is clarified that the result of simulation shows well agreement with Snell's law (Fig.2 (b)). Detailed analysis will be discussed in the presentation.

3. Conclusions

We performed a simulation of refraction of MSFVW using the thickness step. As a result, the refraction property of MSFVW has been proved to follow the same Snell's law, as light in isotropic media. Our results widen the possibility of application of optical instruments on SW devices, i.e. lens and spectroscopes.

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