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Enhancement of Spin Wave Group Velocity in Ferrimagnets at Angular Momentum Compensation Temperature

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Abstract

In this study, we theoretically investigated properties of magnetostatic spin waves in rare-earth and transition-metal ferrimagnets with various angular momentum. It is known that ferrimagnets has two resonance modes, high- and low- frequency modes, depending on the precessional direction of the magnetization. We found that both resonance modes show a maximum group velocity at angular momentum compensation temperature. Furthermore, the low-frequency mode shows higher group velocity than the high-frequency mode at any temperature. Our findings are the key to advance both the physics and the technology to develop research field of magnonics based on the antiferromagnetic spin waves.

1. Introduction

Antiferromagnets are attracting material for spintronics because of their properties such as no stray field and ultrafast dynamics [1]. However, their field immunity makes it difficult to utilize antiferromagnets. Rare-earth (RE) and transition-metal (TM) ferrimagnets also possess the antiferromagnetically coupled sublattices, and their magnetization and angular momentum can be varied by changing the chemical composition or temperature in contrast to the antiferromagnets. In particular, magnetization dynamics of RE–TM ferrimagnets at the vicinity of angular momentum compensation point have intensively been investigated [2], because the antiferromagnetic spin dynamics with a finite net magnetization is achieved at this point. Even though previous researches have studied on spin waves in RE–TM ferrimagnets [3], the influence of the angular momentum on spin wave group velocity has never been investigated so far.

In this study, we discuss the properties of magnetostatic spin waves in ferrimagnets with various angular momentum.

2. Results

We consider a RE–TM ferrimagnet in which the magnetizations of two sublattices are antiferromagnetically coupled. Their angular momentums are expressed as

$$\mathbf{s}_{1,2} \equiv s_{1,2}\mathbf{n}_{1,2} \tag{1}$$

where $s_{1,2}$ are the magnitude of their angular momentums, and $\mathbf{n}_{1,2}$ are unit vectors that indicate the direction of their angular momentums. We first derive spin wave dispersion for a ferrimagnetic thin film. For the Néel vector $\mathbf{n}$ of the ferrimagnet, the expanded Landau-Lifshitz- like (LL-like) equation is

$$s_{\mathrm{net}}\dot{\mathbf{n}} + \rho\mathbf{n} \times \ddot{\mathbf{n}} = \mathbf{n} \times \mathbf{f}_{\mathbf{n}} \tag{2}$$

where s_{net} is the net angular momentum, ρ is a moment of inertia with respect to the Néel vector. $\mathbf{f}_{\mathbf{n}}$ is an effective magnetic field for driving $\mathbf{n}$ and consists of the external magnetic field, the shape magnetic anisotropy (demagnetization) field, and the dipolar field due to the presence of the spin waves. By solving Eq. 2, we obtained resonance frequency and group velocity of spin wave.

In the calculations, we use the experimental value for the temperature dependence of the magnetization $M(T)$ of $Gd_{40}Co_{60}$ obtained in our previous study [4], as shown in Fig. 1. This data can be fitted by the element-specific magnetization by a power law to estimate $M(T)$ of each element. The temperature dependence of angular momentum $s_{\mathrm{net}}(T)$ was calculated according to the relationship,

$$s_{1,2} = M_{1,2}/\gamma_{1,2} \tag{3}$$

where $\gamma_{1,2}$ are the gyromagnetic ratio of each sublattice. Solid lines in Fig. 1 show $M(T)$ and $s_{\mathrm{net}}(T)$ estimated from Eq. 3. The compensation temperature of magnetization (T_{M}) and angular momentum (T_{A}) was estimated to be 173 K and 235 K.

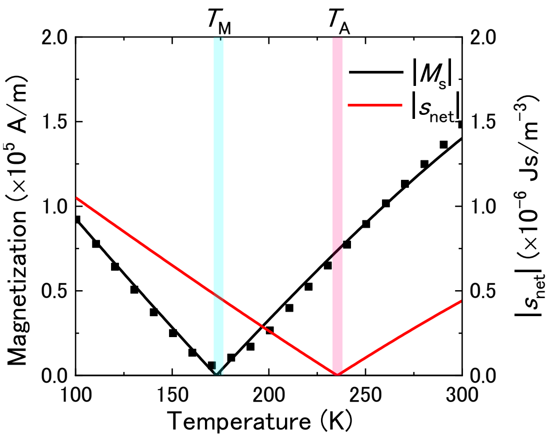

Fig.1. The temperature dependence of the magnetization $M(T)$ of $Gd_{40}Co_{60}$ obtained in our previous study [4] and the estimated value of the net angular momentum $s_{\mathrm{net}}(T)$ according to Eq. 3.

It should be noted that in the following calculations we used the value of angular momentum corresponding to each temperature.

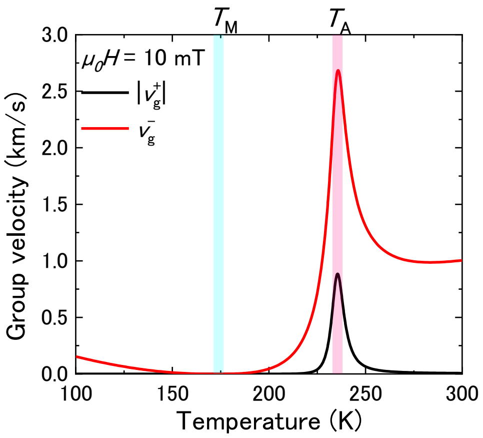

Fig. 2. The temperature dependence of group velocity of the magnetostatic surface wave (MSSW) mode under the 10 mT.

Figure 2 shows the numerically calculated group velocity as a function of temperature under the magnetic field of 10 mT in the case of spin wave propagation perpendicular to the magnetization direction, so-called magnetostatic surface wave (MSSW). At all temperature range, v_g^- (red line) is higher than v_g^+ (black line), resulting from frequency difference of two modes. Interestingly, v_g^+ and v_g^- rapidly increase at the vicinity of T_A and both v_g^+ and v_g^- reach its maximum at T_A because net angular momentum approaches to zero. Because of larger magnetization (thus larger dipolar field), v_g^- is larger at $T > T_A$ than at $T < T_A$ and this results in asymmetric temperature dependence of v_g^-.

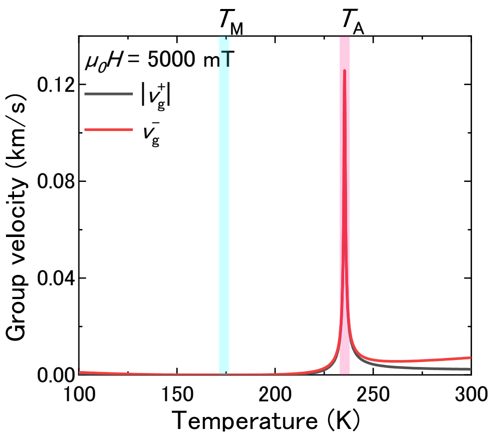

Fig. 3 The temperature dependence of group velocity of the magnetostatic spin wave (MSSW) mode under the 5000 mT.

When the high external magnetic field ($H \gg M$) of 5000 mT is applied, the group velocities of the two modes are approximately equal at T_A, as shown in Fig. 3. Nevertheless, the enhancement of spin wave group velocity at T_A is reproduced even under the high magnetic field. Therefore, the antiferromagnetic spin dynamics at the vicinity of T_A is important to understand the spin wave properties of RE-TM ferrimagnets.

3. Conclusions

We investigated the temperature dependence of magnetostatic surface spin waves in ferrimagnets with various angular momentum. The group velocity takes the maximum at T_A in both modes, and large group velocity is expected especially in the low frequency mode. Because the antiferromagnetic spin dynamics can be expected at T_A, our result will be useful to expand the research area of antiferromagnetic spin waves.

Acknowledgements

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