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Detection of heating effect due to magneto-static surface spin wave in CoFeB film

Kazuto Yamanoi[1], and Takashi Kimura[1, 2]
[1] Department of Physics, Kyushu University
744 Motooka, Fukuoka 819-0395, Japan
[2] Research Center for Quantum Nano-Spin Sciences, Kyushu University
744 Motooka, Fukuoka 819-0395, Japan
Phone: +81-92-802-4083 E-mail: yamanoi@phys.kyushu-u.ac.jp

Abstract

The heating effect due to the magneto-static surface spin wave generated in a ferromagnetic CoFeB film has been investigated experimentally. The spin wave is found to increase the temperature of the Cu wave guide in contact with the CoFeB. The magnitude of the temperature change decreases with increasing the propagating distance from the antenna and is approximately 1 K after 7-μm propagation from the antenna. The present method can be extended to the detection of other-type spin waves and is useful for developing the dynamical spin-caloritronics.

1. Introduction

The dynamical motion of the magnetization in the ferromagnetic metal under the micro-wave irradiation such as the ferromagnetic resonance (FMR) and spin wave (SW) excitation is unique and attractive properties for next-generation telecommunication devices because of its high frequency range. Moreover, the spin-wave spin current propagating in a ferromagnetic metal have great potential for the robust carrier in novel spintronic devices such as logic circuit and signal processing device with the high speed and low power operation. So far, the propagating properties of the spin waves in the various systems have been investigated intensively.

Recently, the dynamical motion of the magnetization in the ferromagnetic metal is found to produce the heat dissipation, resulting in the temperature increase of the ferromagnetic metal[1]. We demonstrated that the temperature increase due to the FMR of the CoFe-based alloy is as high as 10 K under the micro-wave irradiation[2]. We also demonstrated that this temperature increase can be the driving force of the thermal spin injection[3]. Thus, the heating effect due to the magnetization dynamics is important for the manipulation of the dynamical motion of the magnetization as well as for proper understanding the spin-current-induced phenomena. From this view point, we expect that a similar heating effect occurs by the generation of the spin wave. In this paper, we investigate the heating effect due to the generation of the magneto-static surface spin wave.

2. Experimental procedure

The device used for the present study consists of a ferromagnetic CoFeB film and a pair of Cu coplanar wave-guides (CPW) for excitation and detection antenna of the standing magneto-static surface spin wave (MSSW), as shown in Fig. 1. The thickness for CoFeB and Cu are 30 nm and 100 nm, respectively. The length L between two antenna is defined as Fig. 1, was varied from 10 μm to 50 μm. The in-plane external magnetic field is applied along the Cu wire direction in order to fix the precession axis of the magnetization. The MSSW was generated by flowing a high-frequency ac current in the one CPW and was detected by the another antenna. The measurement was performed at room temperature.

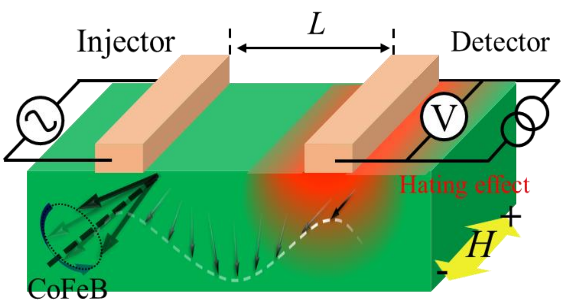

Fig. 1 Schematic illustration of the fabricated device consisting of a CoFeB film and coplanar wave-guides.

3. Experimental results and discussion

First, we characterize the propagating property of the MSSW in the present sample. We clearly confirmed the spin-wave propagation. The attenuation length can be estimated to be 15 μm, which is a typical value in the amorphous ferromagnetic metal.

We then study the heating effect due to the spin wave generation. Here, the dc electrical resistance of the detecting CPW is detected for the evaluation of the temperature. Figure 2 shows the field dependence of the resistance for the detecting CPW under the micro-wave irradiation on the CPW injector. Here, the input micro-wave power is 10 mW and the micro-wave frequency was changed from 5 GHz to 11 GHz. The field dependence of the resistance clearly exhibits the signature of the heating effect due to the magnetization dynamics for all the frequencies. Here, we define the magnetic field H_{res} where the resistance takes a maximum value.

The relationship between H_{res} and microwave frequency is consistent with the Kittel's equation for the MSSW with the saturation magnetization of 1.7 T. Thus, we conclude that the detected resistance increase is caused by the heating effect of the propagation of the MSSW.

We then estimate the temperature increase due to the spin wave and the attenuation length for the spin wave by preparing the similar devices with the different interval L between the injector and detetor. The temperature change is estimated by comparing the temperature dependence of the CPW. From the analysis of the resistance spectra with the temperature dependence of the Cu resistance, we were quantitatively able to estimate the temperature change due to the standing MSSW. Here, we defined the maximum value of the temperature change due to the standing MSSWs as ΔT. Figure 3 shows the temperature ΔT as a function of L under the 11-GHz micro-wave irradiation with the input power of 10 mW. We find that ΔT decreases exponentially with increasing the distance L. From the fitting, the attenuation length of the MSSW was estimated to be about 15 μm, which is consistent with the result by using the vector network analyzer.

We also observed the non-reciprocal relationship by changing the propagating direction of the spin wave as shown in Fig. 4. This result also supports that the observed resistance change is surely caused by the heating effect due to the spin wave generation and propagation.

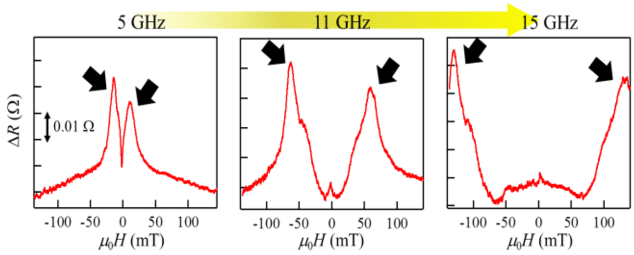

Fig. 2 Field dependence of the resistance for the Cu coplanar waveguide under the micro-wave irradiated of various frequencies with the 10 mW.

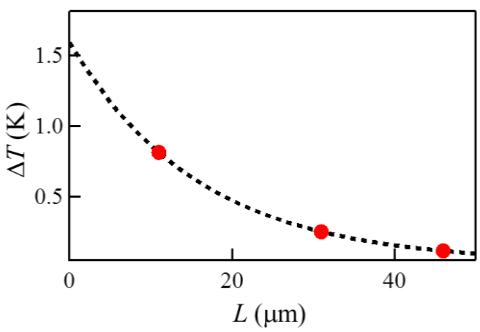

Fig. 3 Temperature increase as a function of L at 10 mW. The attenuation length estimated to be about 15 μm.

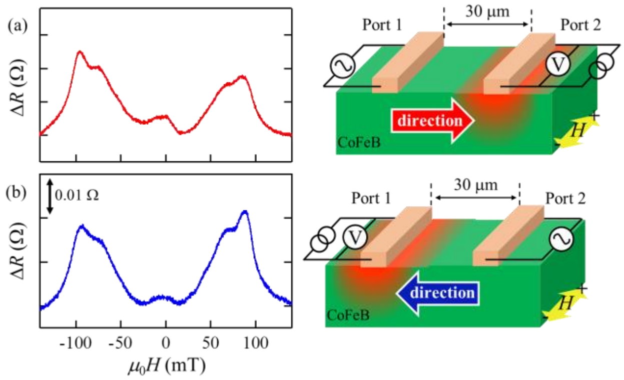

Fig. 4 Non-reciprocal relationship of electrical resistance for the Cu coplanar wave-guide under the configurations: (a) transmission direction is from port 1 to port 2 with micro-wave irradiation of 13 GHz with the 10 mW. (b) transmission direction is from port 2 to port 1 with micro-wave irradiation with 13 GHz.

3. Conclusion

We demonstrated that the MSSW produces the heating effect of the ferromagnetic CoFeB film. The temperature increase due to the spin wave monotonically decreases with increasing the propagating distance. The results based on the present experiment provide quantitative information about the temperature increase and the attenuation length for the spin wave. Since the present method consists of a simple electrical resistance measurement, this technique can be extended to the detection of other-mode spin waves such as magneto-static backward volume spin wave (MSBVW) and magneto-static forward volume spin wave (MSFVW).

References

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