学位論文の要約

題目　Spin wave propagation in ferromagnetic nano-structures

（強磁性ナノ構造体中のスピン波輸送の研究）

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序論

In ferromagnet, spin disturbances can propagate as a wave, which is called a spin wave. Spin waves are firstly predicted by F. Bloch in 1929 and attract great interest in a new field called magnonics recently. Spin waves are expected to provide a new method of data transition, due to their nano-size wavelengths, and frequency of up to THz. Furthermore, Long distance (over 0.1 mm) propagation of SWs in insulators are reported, which make SWs able to transfer information over macroscopic distances.

In this thesis, two main topics on spin wave propagation in nano-structures are introduced. Experimental measurements as well as simulations are employed to study spin waves with various frequencies (GHz to THz range), various materials (ferromagnet and ferrimagnet) with different conductivity (metal and insulators), and different origins (exchange interaction and dipole-dipole interaction).

I. Superior spin pumping effect via high energy magnon propagation

The system of ferromagnet/heavy metal bilayers is actively studied in the field of spintronics as a system in which various physical phenomena exist. Recently, a new unidirectional magnetoresistance was observed and indicated to be originate from high energy magnon generation.

Considering the propagation property of spin waves, in this study we performed non-local harmonic measurements in Py(permalloy)/Pt bilayers to investigate the transportation of unidirectional MR originated from spin wave generation. In the experiment, we attached several electrodes perpendicular to the Py/Pt bilayer wire, two of which work as local electrodes and others work as non-local electrode. Both wires and electrodes are patterned into narrow wires with several 100 nm width. Non-local harmonic measurements are performed by measuring 1st

and 2nd harmonic voltage of the non-local electrodes, while applying ac current between the local electrodes. Furthermore, to better understand the propagation properties of magnon generations, non-local electrodes with different distances to the local electrodes enable a distance dependence measurement of the unidirectional magnetoresistance.

The experiment concept can be explained as follows: When a charge current flows into one part of Py/Pt bilayer, which we call local part, spin polarized current enters Py from Pt layer due to spin Hall effect. In the case that the injected spin and the local magnetic moments of Py are in the opposite directions, both the injected spin and the local spin are flipped by each other. During this process magnons are generated, which are suggested to have a frequency in the THz regime. Additionally, a GHz magnetization oscillation is reported to be induced by spin transfer torque over a threshold current. Both THz and GHz magnons transfer along the wire and reach the non-local part, which results in change of non-local voltage by the following 3 scenarios; Magnons at the non-local part pump spin current into Pt layer, which are later converted into charge current by ISHE of Pt. Meanwhile, because of the existence of magnon, resistance of non-local part of wire increases due to electron-magnon scattering. Furthermore, over a threshold current, AMR and SMR observed in the wire is rapidly reduced by GHz oscillation, for the reason that the y component of magnetic moments decreases.

From the experimental results, we observed both non-local 1st harmonic and 2nd harmonic signals. Current density dependence of non-local 2nd harmonic voltage, which originate from electron-magnon scattering, shows threshold behavior, which implying two types of magnons with different energy scales, i.e. GHz magnons and THz magnons, are involved in this process. Meanwhile, the current density dependence of 1st harmonic voltage, dominated by spin pumping, does not show clear threshold behavior, implying that although both the high energy and low energy magnons propagate to the non-local region, the high energy magnons are much more efficient for spin pumping and spin current generation.

II. Snell's law for isotropically propagating spin wave

In this study, we performed the micromagnetic simulations to investigate the refraction properties of isotropically propagating spin waves by utilizing a thickness step.

Two types of isotropic spin waves are studied in this topic: spin waves originate from exchange interaction and dipole-dipole interaction (DEFVWs), and spin waves dominated only by dipole-dipole interaction (MSFVWs). As a result, it was confirmed that both types of spin waves propagate isotropically and the Snell's law in optics can be applied in the present system, leading to the simple design of magnonic devices.

Moreover, we found that Snell's law for these two types of isotropic spin waves have different behaviors: while the refraction angle is independent of the resonant frequency in MSFVW it depends on the resonant frequency in the case of DEFVW, suggesting that the chromatic aberration effect should be taken into account in designing magnonic devices using spin waves with high wavenumbers.

We also demonstrated a new type of isotropic magnon lens. Unlike other magnetostatic spin waves that have anisotropic propagation aspects, Snell's law for isotropically propagating SWs are more simple and easy to design. Although we did not succeed in making a lens with high accuracy, we have provided a new possibility of application of optical instruments on spin waves.

III. Summary

Spin waves have attracted magnificent interest as a novel technology that have huge potential to be applicated as data transport medias, logic devices, etc. The performance of the devices based on data transport mostly relies on the conversion efficiency between propagating magnons and spin current, while the designable propagation properties are crucial for logical devices.

Researches introduced in this thesis aimed to, and eventually played the role of unveiling spin wave propagation phenomena, as well as discovering new possibilities of spin wave devices.