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Acoustic properties of metal/antiferromagnet epitaxial multilayers

金属/反強磁性エピタキシャル多層膜の音響特性

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1. Introduction

Spintronics is the field of science that utilizes not only charge of electrons but also properties of spins. It has been widely studied and applied to information storage devices. So far, spintronics has focused mainly on ferromagnets, but in recent years antiferromagnets have been getting attention[1)]. One reason is that physical phenomena in ferromagnets have also been observed in antiferromagnets such as the spin transfer torque[2)]. Another reason is that antiferromagnets have the potential to improve information storage devices[1)]. Antiferromagnets are internally magnetic, but magnetic spins orient in opposite directions, and consequently, do not generate the magnetic moment macroscopically. Antiferromagnets show magnetic resonance frequencies in a THz band, which are about 100 times larger than those of ferromagnets. These properties lead to a higher density of magnetic elements, higher stability of magnetic information against external magnetic fields, and higher speed of information writing in information storage devices.

Although antiferromagnetic resonance is a fundamental physical phenomenon, no report appears for antiferromagnetic nano-thin films, because of small volumes, where interactions between antiferromagnet and external fields are too weak to be detected with existing methods. Therefore, we have focused on phonon-spin interactions to excite antiferromagnetic resonance in nano-thin films. Excitation of ferromagnetic resonance by phonons has been reported in thin films[3)], and the phonon-spin interaction has also been theoretically shown in antiferromagnets[4)].

In this study, we make NiO/Pt multilayers and excite sub-THz phonons. NiO is a representative antiferromagnet, and it shows a high Néel temperature of 523 K and a high antiferromagnetic resonance frequency of ~1 THz[5)]. To excite THz phonons in the antiferromagnet/metal multilayer, we make phononic crystals to localize the THz band coherent acoustic phonons in thin films using the acoustic Bragg effect[6)].

2. Experiment

NiO and Pt monolayers and multilayers were epitaxially grown on Al_2O_3 (0001) substrate by the RF magnetron sputtering method. At first, we clean the substrate three times by alternative frequency mode ultrasonic irradiation (33 and 40 kHz) in NMP (N-Methyl-e-pyrrolidone), IPA (Isopropyl alcohol), and ultrapure water. The solution temperature is 60 °C and the irradiation time is 10 min. Then, we further remove contamination by ambient-gas plasma cleaning for 10 min. The base pressure, Ar pressure, and sputtering power were 1×10^{-5} Pa, 0.8 Pa, and 50 W, respectively. We keep the specimen temperature at 433 °C during the deposition to epitaxially grow the films. The multilayer specimen consists of seven periods of NiO (12.1 nm) and Pt (7.6 nm), which are the quarter wavelength of 140-GHz longitudinal phonons.

To study the acoustic properties of the films, we use picosecond ultrasound spectroscopy[7,8)], which uses ultrafast laser pulses as a pump and probe light to excite and detect high-frequency coherent phonons in a sample. **Figure 1** is a schematic of the optical system.

We use a Ti-sapphire pulse laser whose wavelength is 800 nm and divide the pulse light into the pump and the probe light by a polarization beam splitter (PBS). The corner reflector changes the arrival time of the pump light to the sample. The

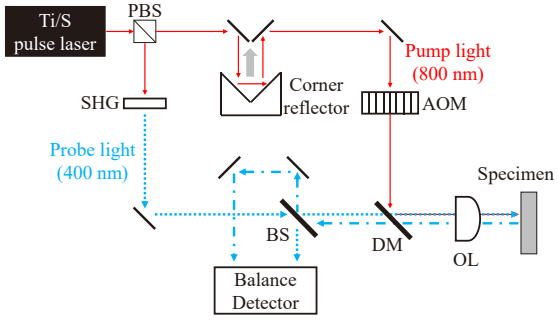

Fig. 1 Schematic of optical. Solid and dashed lines denote pump and probe light, respectively.

pump light is modulated at 100 kHz by an acousto-optical crystal modulator (AOM). The probe light wavelength is converted into 400 nm by a second harmonic generator (SHG). Both lights incident perpendicularly on the sample through an objective lens, and the reflected lights are distinguished by a dichroic mirror (DM), which reflects the 800-nm pump light and transmits the 400-nm probe light. The beam splitter (BS) separates the probe light before incidents on the sample, and a balance detector (BD) collects these two lights. By inputting the intensity difference into a lock-in amplifier, we detect the probe light's reflectivity changes due to the acoustic perturbations.

3. Results and discussions

Figure 2 (a) shows X-ray diffraction (XRD) spectra of the single and multilayer films. We find that NiO and Pt single layers epitaxially grew in <111> orientation, and multilayer also grew in the same orientation. **Figure 2 (b)** shows the X-ray reflectivity (XRR) measurement results. In monolayer films, the calculated reflectivity agrees well with the measured reflectivity. While in the multilayer film, we could not observe small periodic reflectivity changes due to large roughness. Therefore, it is difficult to determine the thickness of NiO and Pt layer independently. However, the total thickness of the NiO and Pt layers can be determined from the large-amplitude and long-period reflectivity changes. The obtained thicknesses of NiO and Pt layers are 10.92 nm and 7.60 nm, respectively.

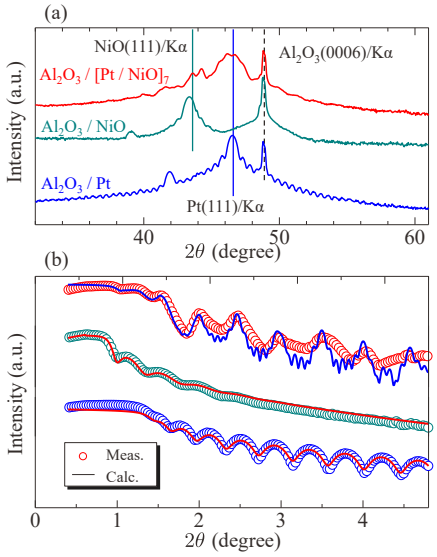

Fig. 2 (a) and (b) are XRD and XRR spectra of [Pt (7.6nm) / NiO (12.1nm)]$_7$, NiO (20nm) and Pt (20nm) on Al_2O_3 substrate, respectively.

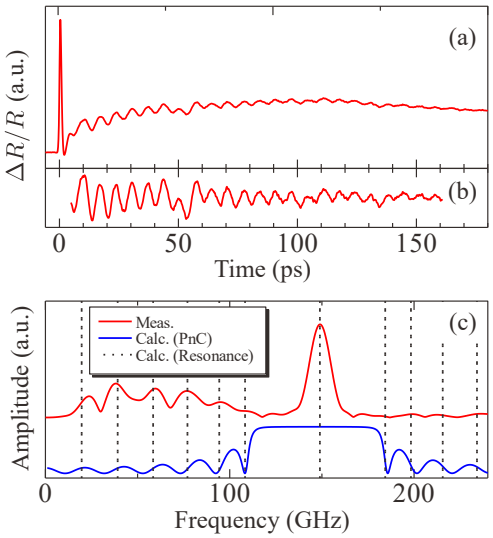

Fig. 3 (a) Time-resolved reflectivity change. (b) Background subtracted data. (c) FFT spectra.

We excited a single resonance mode of 149 GHz, as shown in **Figure 3 (a)** and **(b)** by picosecond ultrasonics. **Figure 3 (c)** shows the corresponding fast-Fourier transform spectrum with calculated resonance frequencies. The measured and calculated frequencies agree well with each other, insisting that we succeeded in making phononic crystals of antiferromagnet/metal multilayers. We aim to raise the frequency to a THz band to excite the antiferromagnetic resonance in the future.

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