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Crystal orientation dependence of the spin current transmission in single crystalline NiO thin films

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Abstract

We investigate the spin current transmission in single crystal NiO by measuring the effective damping constant in NiO/FeNi bilayers. It is found that the spin current propagation length significantly differs depending on the crystal orientation of NiO.

1. Introduction

Antiferromagnetic spintronics [1, 2] yields several interesting advantages over conventional ferromagnetic spintronics such as zero fringing field, ultrafast dynamics, and robustness to external magnetic field. Among those promising antiferromagnetic properties, spin current transmission in antiferromagnetic materials is one of the intriguing problem in the emerging antiferromagnetic spintronics. We previously investigated the spin current transmission in a polycrystalline NiO by means of the spin pumping effect and estimated the spin transmission length through NiO to be 22±3 nm [3]. In this work, we prepared single crystalline NiO thin films with various crystal orientations and investigated the crystal orientation dependence of the spin current transmission.

2. Experimental results

The NiO (t_{NiO})/$Fe_{20}Ni_{80}$ (5)/SiO_2 (5) (unit: nm) multilayers were deposited on an Al_2O_3 (0001) and MgO (001) substrate by magnetron sputtering. By using X-ray diffraction, we confirmed that the NiO film on Al_2O_3 (0001) grows epitaxially with (111) orientation and that on MgO (001) grows with (001) orientation (Fig. 1). For the ferromagnetic resonance (FMR) measurements, these films were photolithographically patterned into a 10-µm-wide and 30-µm-long strip attached to a coplanar waveguide made of a Ti/Au layer. The active area under test is 10× 10 µm^2.

We employed FMR measurements based on the homodyne detection technique. The measurements were conducted by injecting the nonuniform RF current. This technique has already been demonstrated to enable the sensitive detection of Kittel's mode dynamics of a single ferromagnetic layer [4]. FMR spectra were taken at room temperature by sweeping an external field with a fixed frequency f. The spectrum is well fitted by the combination of symmetric and antisymmetric Lorentzians from which we are able to estimate the spectrum linewidth ΔH. The damping constant α is determined from ΔH and f using the following equation.

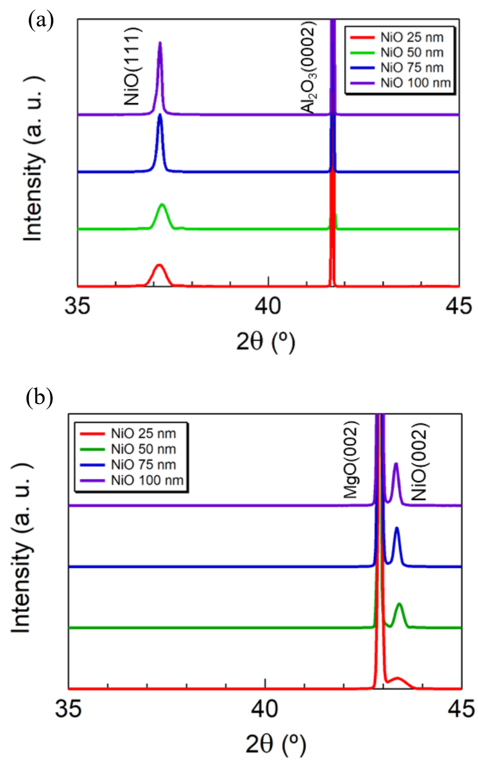

Fig. 1 X-ray diffraction of NiO/FeNi multilayers on (a) Al_2O_3 (0001) and (b) MgO (001) substrate.

$$\Delta H = \Delta H_0 + \frac{2\pi\alpha f}{\gamma}. \quad (1)$$

where ΔH_0 is the so-called inhomogeneous broadening originating from the magnetic nonuniformity.

α is plotted as a function of NiO thickness for (111) and (001) epitaxially grown NiO films (Fig. 2). The result is that α in NiO (111) shows a saturation behavior with increasing

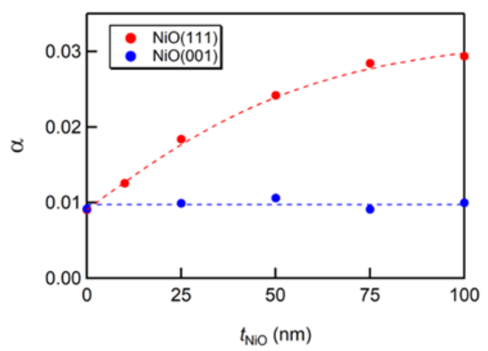

Fig. 2 t_{NiO} dependence of Gilbert damping constant (α) in single crystalline NiO.

the NiO thickness and that in NiO (001) shows the independence to increasing t_{NiO}. According to the spin pumping theory [5], the spin current generated by the precessing FeNi magnetization is dissipated by the NiO layer, and the enhancement of α is proportional to the amount of spin current dissipation. The enhancement of α by the spin pumping effect is written as

$$\alpha(t_{\mathrm{NiO}}) - \alpha(t_{\mathrm{NiO}} = 0) = \left(1 + \frac{5\sqrt{3}}{\tanh \frac{t_{\mathrm{NiO}}}{\lambda_{\mathrm{NiO}}}}\right)^{-1} \frac{g\mu_B \tilde{g}_r^{\uparrow\downarrow}}{(4\pi)^2 M_s t_{FeNi}}. \quad (2)$$

where λ_{NiO} is the spin propagation length through NiO and $\tilde{g}_r^{\uparrow\downarrow}$ is the mixing conductance related to the details of the spin transmission at the NiO/FeNi interface. The resulting λ_{NiO} in NiO (111) is 68±10 nm. The obtained λ_{NiO} is three times longer than that of the polycrystalline NiO [3]. On the other hand, there are two interpretations of the result in NiO (001) : $\tilde{g}_r^{\uparrow\downarrow} = 0$ or $\lambda_{\mathrm{NiO}}(001) \gg \lambda_{\mathrm{NiO}}(111)$. However, our previous work on the Pt/NiO (001)/Py multilayers revealed that spin current arising from Pt layer passes through NiO (001) layer and is detected in Py layer [6]. Therefore, we suggest $\lambda_{\mathrm{NiO}}(001)$ could be gigantic.

3. Conclusions

We investigated the spin propagation length λ_{NiO} in single crystalline NiO (111) and NiO(001) by referring to the effective damping constant. The resulting λ_{NiO} in NiO (111) is 68±10 nm and that in NiO (001) could be gigantic.

Acknowledgements

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