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Angular Dependence of Exchange Stiffness Constant of NiFe Thin Film

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The exchange stiffness constant A_{ex} was linearly propositional to the difference of spin waveresonance field H_{SWR} and ferromagnetic resonance field H_{FMR}. In this work, we measured theH_{SWR} and H_{FMR} with in-plane angles in order to analyze the angular dependence of A_{ex} in NiFethin film with thickness of 100 nm. The A_{ex} of NiFe thin film was shown isotropic behavior notdepending on the in-plane angles. The measured value of A_{ex} was 10.9×10^{-7}erg/cm and its valueshould be applied to the spin wave devices.

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I. Introduction

Spins in atoms that make up magnetic materials areall aligned in one direction by ferromagnetic couplingbetween spin-spin coefficient. When a magnetic field isapplied to the ferromagnetic material, each of the spinsprecesses around the direction of the magnetic field. Thewave produced by the precessing spins is called as a spinwave. The propagation characteristics of the spin wavetraveling through the ferromagnetic depend on the exchange stiffness constant (A_{ex}) which mediates the vibration of the spins. This exchange stiffness constant A_{ex} isused for spin device studies using spin waves as well asgeneration or destruction of magnetic domains and sizeanalysis of magnetic domains[1–3]. In addition, the exchange stiffness constant A_{ex} is used to analyze the magnetic properties of the exchange spring structure combined with soft magnetic magnetism, which is emergingas a media material of next generation magnetic memory.

However, the exchange stiffness constant A_{ex} has a characteristic that varies depending on the composition of themagnetic material and the fabrication conditions[4].

All magnetic spins are precessed equally in the magnetic thin film[5, 6]. Ferromagnetic resonanceis calledwhen coherent preccession and resonance conditions aresatisfied. On the other hand, when the spin wave produced by the precessing magnetic spins proceeds in thethickness direction of the thin film material and meets thestanding wave conditions, we define it as spin wave resonance occurs. Ferromagnetic resonance (FMR) and ferromagnetic and spin resonances measured using the device are analyzed using Landau-Lifshitzt-Gilbert (LLG)equations of motion. When a ferromagnetic resonancesignal and a spin plate resonance signal are simultaneously measured using an FMR device using a specificfrequency, there is a characteristic that is linearly proportional to the difference between the spin wave resonancemagnetic fields. The method of obtaining the exchangestiffness constant Aex of ferromagnetic materials is used.Therefore, in this study, we measured the ferromagneticand spin wave resonance signals in the horizontal plane of 100 mm thick NiFe material according to magnetic fieldangle.

II. Method

NiFe thin film, a ferromagnetic material, was heattreated for 3 minutes at a temperature of 250 ˚C. Using a $Ni_{80}Fe_{20}$ target on a Si substrate with a thermaloxide film in a high vacuum DC magnetron stutteringmethod. In order to improve the crystallinity of NiFefoil, Ta(5nm)/Cu(5 nm) was deposited as a lower layer, and Ta(5 nm) was deposited on top of NiFe to preventsurface oxidation of the NiFe barrier thin film. The laminated structure of the fabricated NiFe thin film was

$Si/SiO_2/Ta/Cu/NiFe(100\ mm)/Ta$, and the magneticfield resonance and spin wave resonance signals according to the magnetic field strength of the deposited NiFethin film were Bruker, an FNR measuring device. XeprCo., Ltd. was used and measured at a fixed frequency of9.89 GHz (X-band). Exchange Stiffness Constant A_{ex} ofNiFe thin film is analyzed using the angle dependence offerromagnetic and spin wave resonance signals accordingto the long angle ΦH.By measuring the ferromagneticresonance, spinwave resonance Derived. Also to measure the saturation magnetization of NiFe, ferromagneticresonance with magnetic field angle ΘH at out-of-plane signal was measured.

III. Result And Discussion

Ferromagnetic resonance signals are characterized bycrystal anisotropy, induced anisotropy, anisotropic characteristics such as interlayer bonding force and exchangebias of multilayer thin films. Meanwhile, spin wave resonance signal is used to analyze the exchange stiffness constant and the thickness dependent spin wave resonance.

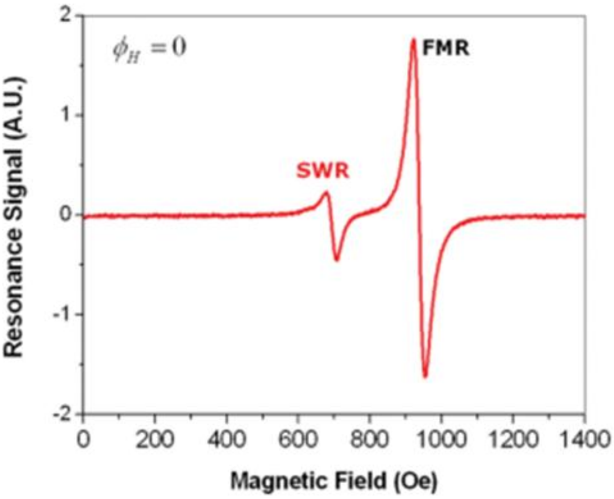

FIG. 1. Measured resonance signals with magnetic field ateasy axis (ΦH = 0°) in NiFe thin films with thickness of 100nm.

Magnetic field H_{SWR} is expressed as follows.

$H_{SWR} = H_{FMR} - \frac{2Aex}{Ms}(\frac{n\pi}{t})^2$(1)

where H_{FMR} is the ferromagnetic resonance magneticfield, and t and M_s are the thickness and saturation magnetization of the thin film. The exchange stiffness constant A_{ex} of the magnetic material is a physical propertyof the magnetic material indicating the elastic characteristics of the spin waves.n is an integer indicating thestanding wave mode of the spin wave (n = 1,2,3,4, ...).

The difference between the magnets is inversely proportional to the square of the thickness of the thin film and isproportional to the exchange stiffness constant A_{ex} andthe saturation magnetization M_s of the magnetic material. From equation (1), the exchange stiffness constant
A_{ex} is expressed as follows.

$A_{ex} = (H_{FMR} - H_{SWR})\frac{M_s t^2}{2\pi^2 n^2}$(2)

In this study, the resonance signals were measured according to the magnetic field strength to analyze the exchange stiffness constant A_{ex} of NiFe thin films with athickness of 100 nm.

Fig. 1 shows the resonance signal characteristics measured according to the magnetic field strength in the direction of easy magnetization of NiFe material with athickness of 100 nm. Two resonance signals were measured for NiFe material having a thickness of 100 mm.
The resonance field shown at 932 Oe of magnetic field corresponds to the ferromagnetic resonance magnetic fieldH_{FMR}, and the resonance field at 685 Oe, which is lower than the ferromagnetic resonance magnetic field, is thespan wave resonance magnetic field H_{SWR} due to thestanding wave resonance of the spin wave traveling in thethickness direction. Only standing wave modes where n=1 were measured. Therefore, in this study, the exchange stiffness constant A_{ex} in the standing wave modecorresponding to n = 1 was obtained by substituting Eq.(2). In order to analyze the angular dependence of theexchange stiffness constant A_{ex} of NiFe thin film, theferromagnetic and spin wave resonances according to themagnetic field angle ΦH in the in-plane are used in thefollowing equation (4). Magnetic fields were measuredrespectively. Fig. 2 (a) and (b) are the ferromagnetic resonance magnetic fields measured in the horizontal plane.

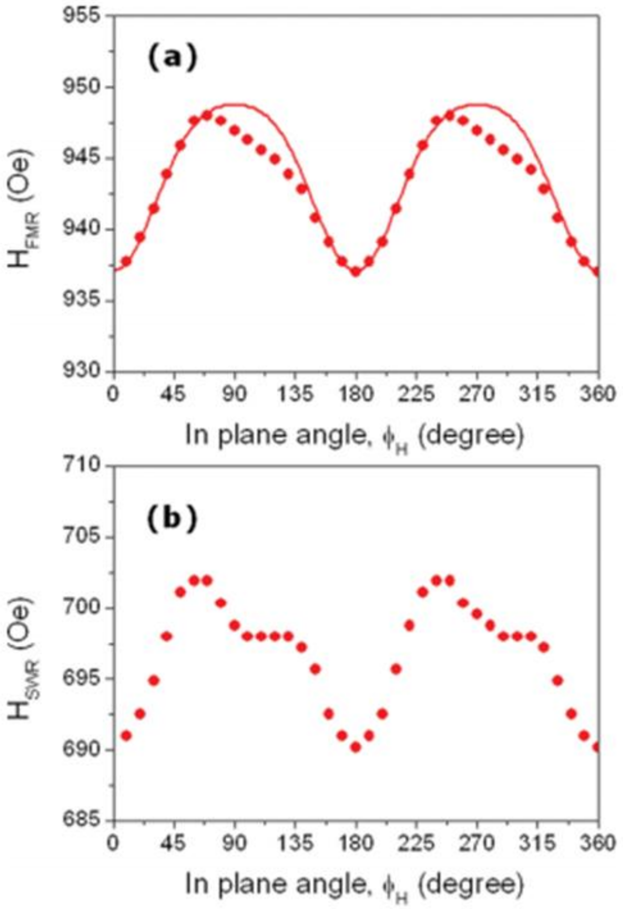

FIG. 2 (a) Ferromagnetic resonance field HFMR and (b) spin wave resonance field HSW R with in plane magnetic field angle ΦH measured in NiFe thin film with thickness of 100 nm. The solid lines are fitted by Eq. (3).

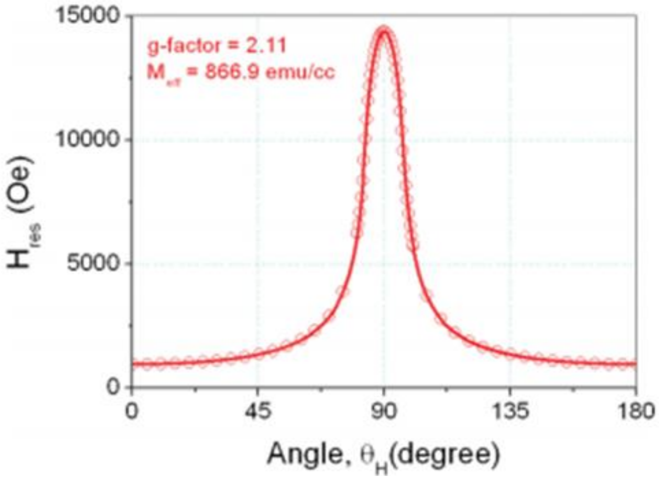

FIG. 3 Ferromagnetic resonance field HFMR with out-of plane magnetic field angle θH measured in NiFe thin films with thickness of 100 nm. The solid lines are fitted by Eq. (4).

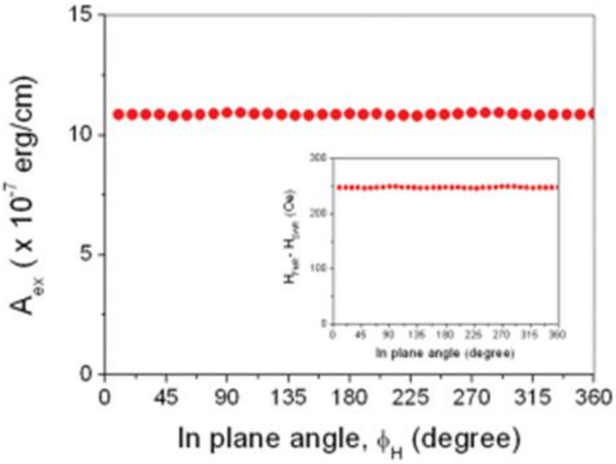

FIG. 4 (a) Angular dependence of exchange stiffness constantA_{ex} measured in NiFe thin films with thickness of 100 nm.

Horizontal angle dependence of HFMR and spin wave resonance magnetic field HSW R. It is seen. NiFe shows thatthe anisotropic magnetic field HK is less than the saturation Very small $4piM_s >> H_{res} >> H_K$ The resonancemagnetic field H FMR is simply expressed as follows.

$H_{FMR} = \omega\gamma$

2 1

$4\pi Ms$

$-$ HKcos2φH $-$ HC cos4ΦH (3)

Where γ = gμB is the gyromagnetic of the magnetic spin and g, μB, and are the g-factor, the Boa magnetone constant, and the Planck constant, respectively. **Ω** is the microwave $\omega = 2\pi f$), and ΦH represents the angle of the magnetic field measured from the axis of easy magnetization in the horizontal plane of the thin film material.

The solid line in 2(a) is the result of calculating the ferromagnetic resonance magnetic field according to the angle using equation (3). The magnetic field was HK = 6.0 Oe and the biaxial anisotropy constant HC = 1.1Oe.

On the other hand, according to the angle shown in 2 (b), the spin wave resonance magnetic field was shifted toward the lower magnetic field than the ferromagnetic resonance magnetic field, and the same anisotropy characteristic as the ferromagnetic resonance magnetic field was observed. In equation (2), Aex has a property proportional to the saturation magnetization of the magnetic material. Therefore, in this study, the ferromagnetic resonance magnetic field which is different from the magnetic field angle in the vertical plane was measured to

deriveMs of NiFe thin film.

Fig. 3 shows the ferromagnetic resonance magnetic field with respect to the vertical magnetic field angle in the NiFe thin film. The solid line at 3 calculates the HFMR for the perpendicular magnetic field direction

(θH). The following equation (4) was used.

ω

γ

= (Hrescos(θH−θM) − 4πMef f cos2

θM×

∩(Hrescos(θH−θM) − 4πMef f cos2θM

(4)

Where Mef f is the effective saturation magnetization andθM is the magnetic domain in the vertical plane.

From the calculation result of Formula (4), the value of g = 2.11 and Mef f = 866.9 emu/cm2 of NiFemateri

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FIG. 2. (a) Ferromagnetic resonance field HFMR and (b) spin wave resonance field HSW R with in plane magnetic field angle ΦH measured in NiFe thin film with thickness of 100 nm. The solid lines are fitted by Eq. (3). FIG. 3. Ferromagnetic resonance field HFMR with out-of plane magnetic field angle θH measured in NiFe thin films with thickness of 100 nm. The solid lines are fitted by Eq.

(4). FIG. 4. (a) Angular dependence of exchange stiffness constant Aex measured in NiFe thin films with thickness of 100 nm.

whose thickness is 100 nm was obtained. Mef f is expressed as follows
Mef f = MS +
Ks
2πMst
+
Ku
2πMs
(5)
HKu = 2Ku/Ms of NiFe thin film is about 5.7 Oe. It is very small and 2Ks/ tMs due to the surface anisotropy constant is very small when the thickness is 100 nm. Thus, ignoring the second and third terms on the right side of Eq. (5) makes it possible to approximate Mef f as Ms. Therefore, in this study, the saturation magnetization Ms = 866.9 emu/cm2 of NiFe thin film Was obtained. Fig. 4 shows the dependence of the horizontal plane angle of Ex on the NiFe thin film. Aex has a constant valueAex = 10.9 × 107
erg/cm according to the magnetic field angle in the horizontal plane, and it can be seen that it has isotropic properties in the horizontal plane. This isotropic characteristic is shown in Fig. 4. It can be seen
that it reflects the isotropic properties of (HFMR–HSW R) according to the horizontal angle. In order to analyze the validity of NiFe obtained in this study, the results of comparing the calculations and measurements presented in other papers are shown in Fig. 5.
As shown in Fig. 5, the calculated Aex of Ni, Fe, Co, andNiFe were 9.7, 20.1, 30.0, and 13.0 × 107
erg/cm, respectively. The Aex of NiFe thin films heat-treated at temperature showed values of 7.2, 10.7 and 12.9 10 7 erg / cm, respectively [5]. The exchange stiffness constant Aex thus varies depending on the structure, composition and fabrication conditions of the material. Exchange stiffness constants for NiFe Materials with 100nm thickness is heat treated at 250 ◦C. The value of Aex = 10.9 × 107
erg/cm is determined by Wei et al. [5] at
300 ◦C. It was similar to the value of Aex = 10.7 × 107
erg/cm measured on the treated NiFe material. Therefore, the Aex of the NiFe thin film obtained in this study
is a valid value, and this value can be used for spin wave
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FIG. 5. (a) Composition dependence of exchange stiffness constantAex. The red star symbol shows present work. The black diamond symbols are measured values at different temperature [5] and blue circle symbols are calculated values [17]
device research using spin waves, generation/destruction of magnetic domains and size analysis of magnetic walls.
The Aex for the Ni, Fe and Co thin films shown in Fig. 5 will be compared with the calculated values through later measurements.

IV. Conclusion

To analyze the angle dependence of Aex linearly proportional to the difference between HSW R and HFMR and inversely proportional to saturation magnetization. In the horizontal plane of NiFe thin film having a thickness of 100 nm, HSW R and HFMR were measured according to the magnetic field angle. In order to measure the saturation magnetization of the NiFe thin film, the ferromagnetic resonance magnetic field was measured in the out-of-plane according to the magnetic field angle. Using (HSW R - HFMR) and Msvalues measured on a 100 nm thick NiFe thin film material heat-treated at 250◦C, Aex of the NiFe thin film was obtained. Aex of the material is independent of the magnetic field angle of the horizontal plane and Aex = 10.9 × 107 erg/cm was obtained. The value of the constant Aex is determined by Wei et al. It is similar to the value of Aex = 10.7 × 107 erg/cm measured in the data. Therefore, we use spin wave in this study.
This value can be used to study spin wave devices using spin waves, to generate / disappear magnetic domains, and to analyze the size of magnetic walls.

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