C−9

Thickness dependency of effective magnetization in GdFeCo ferrimagnetic thin films

*Ryohei Ueda[1], Hiroki Yoshikawa[1] and Arata Tsukamoto[2]

The anti-parallel coupled two sub-lattice magnetization system such as GdFeCo Rere Earth (RE) and Transition Metal (TM) thin films has compensation phenomena. It allows us large compositional and temperature dependency of magnetic properties like net magnetization or net angular momentum[1) 2)], then it may have large film thickness dependency of magnetic properties. In this study, we measured the thickness dependence of static and dynamic magnetic properties in ferrimagnetic GdFeCo thin films and we find that this films have large thickness dependency of effective magnetization

1. Introduction

In the magnetic thin film below the several tens nm thick, because of the magnetic contribution from interfacial region may become larger as the thickness becomes thinner, magnetic properties are assumed to change by the film thickness. Especially in anti-parallel coupled sub-lattice system such as GdFeCo can have large compositional and temperature dependency of net magnetization and net angular momentum[1) 2)] because of the magnetization and angular momentum compensation phenomena. Then it may have large film thickness dependency of magnetic properties. In this study, we measured and discussed the thickness dependency of effective magnetization in GdFeCo ferrimagnetic thin film by static and dynamic magnetic properties.

2. Thickness dependency of the magnetic static properties

In this research, we prepared the films SiN (60 nm) / $Gd_{22}Fe_{68.2}Co_{9.8}$ (t nm) / SiN (5 nm) / glass. (t = 10, 15, 20, 25) that has different GdFeCo layer thickness by magnetron sputtering method. These samples are ferrimagnetic which have heavy rare earth Gd moment (M_{RE}) and transition metal FeCo moment (M_{TM}) sublattice magnetization anti-parallelly coupled each other. First, the static magnetic properties measured by Superconducting Quantum Interference Device - Vibrating Sample Magnetometer (SQUID-VSM). Second, we used Magneto-optical Kerr effect (MOKE) probed by 600 nm wavelength light in amorphous Gd-TM alloy is contributed by mainly M_{TM} sublattice.Therefore we can find that which moment is same direction of net magnetization(M_{net}), M_{TM} or M_{RE}. Figure 1 shows the thickness dependency of saturation magnetization M_s and uniaxial magnetic anisotropy energy K_u in GdFeCo thin films with 10 to 25 nm-thick. K_u was almost independent with thickness, however M_s had large thickness dependency. And we found that direction of M_{TM} is same as the direction of M_{net} measured by MOKE. These results seem that Gd composition effectively decreased as thickness thinning. Then we supposed the model in which the magnetic layer consist from interfacial part and internal part. And we determined the interfacial magnetization M_{sf} emu/cm^2, magnetic anisotropy energy K_{sf} erg/cm^2, internal magnetization M_v emu/cc and magnetic anisotropy energy K_v erg/cc (Figure 2). Then M_st and K_ut are shown in the following expressions.

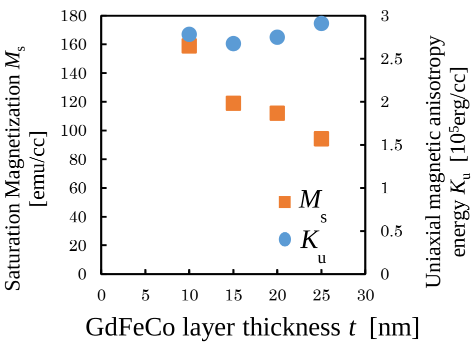

Figure 1 Thickness dependency of M_s and K_u in GdFeCo thin films.

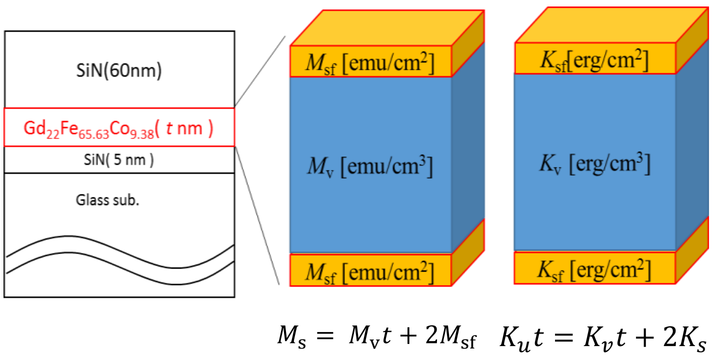

Figure 2 The model which has the interfacial magnetic layer parts and the internal magnetic layer parts.

$$M_st = M_vt + 2M_{sf} \quad (1)$$
$$K_ut = K_vt + 2K_{sf} \quad (2)$$

1:Graduate course of Electronic Enginieering CST, Nihon-Univ. 2: Depertment of Electronic Engineering, CST, Nihon-Univ.

These show that M_v = 54.85 emu/cc, $2M_{sf}$ = 1.0×10^{-4} emu/cm^2 and K_v=3.0×10^5 erg/cm^3 , $2K_s$=0.035 erg/cc. When t = 10nm , M_v・t = 5.5×10^{-5} emu/cm^2 is smaller than $2M_{sf}$ =1.0×10^{-4} and K_v・t = 3.0×10^{-1} erg/cm^2 is larger than $2K_{sf}$ = 3.4×10^{-2} . It means that contribution from the interfacial region to M_s is large, however K_u is small in this thick range. And these results suggest that this film effectively have high conposition ratio of the trantsition metal in the interfacial region.

3. Thickness dependency of the magnetic dynamic properties

The ultrafast magnetic response of these sample was measured by all-optical pump-probe method excited by high-intense 800 nm wavelength light and probed by low-intense 400 nm wavelength light. Pulse width of laser light is about 90 fs (FWHM), and external DC magnetic field H_{ext} = 178 mT was applied from θ_H = 72° of vertical axis of the film surface. From this measuring of the transient response of precession motion, we estimated the precession frequency f and gilbert damping factor α. Figure 3 and Figure 4 show the thickness dependency of f and α in GdFeCo thin films with 10 to 25 nm-thick. In dynamic properties, Gilbert damping factor α and precession frequency f decreased as the thickness become thinner. f is proportional to effective magnetic field H_{eff} that is the vector sum of anisotoropic magnetic field and demagnetization field and applying magnetic field. When thinning thickness, M_s increased and H_{eff} decreased, as a result, f will be decreasing. About α, the relationship between the magnetic static properties and α has not yet been understood, it shows that α have large thickness dependence in GdFeCo thin films.

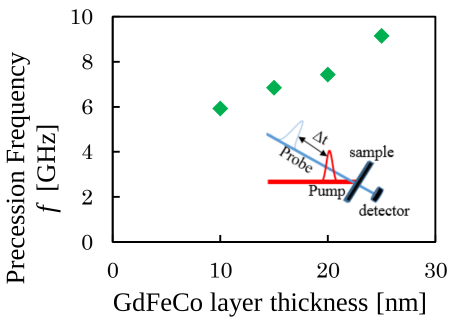

Figure 3 Thickness dependency of precesion frequency f in GdFeCo thin films.

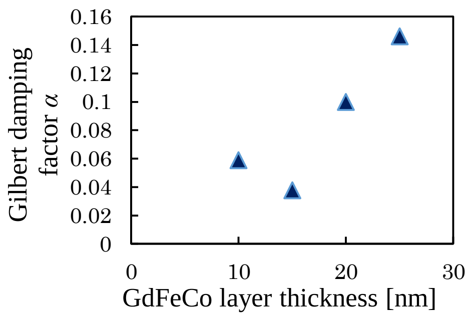

Figure 4 Thickness dependency of Gilbert damping factor α in GdFeCo thin films.

3. Summary

In this study, we measured the thickness dependency of static and dynamic magnetic properties in ferrimagnetic GdFeCo thin films. In the magnetic static properties, M_s have large thickness dependency in GdFeCo thin films. However, K_u was almost independent with thickness. It means that contribution from the interfacial region to M_s may be large, however K_u may be small in this thick range. In the magnetic dynamic properties, f decreased from 9 GHz to 6 GHz and α also decreased from 0.14 to 0.06 as the thickness becomes thinner . About α, the relationship between the magnetic static properties and α has not yet been understood, however it shows that α have large thickness dependency in GdFeCo thin films and it also suggest that this film effectively have high conposition ratio of the trantsition metal in the interfacial region.

Acknowledgements

This work is partially supported by a Grant of MEXT- Supported Program for the Strategic Research Foundation at Private Universtities 2013-2017 and MEXT-supported Grant-in-Aid for Scientific Research on Innovative Areas "Nano-Spin Convesion Science" 2014-2018.

References

[1] A. Tsukamoto, T. Sato, S. Toriumi, and A. Itoh "Precessional switching by ultrashort pulse laser : Beyond room temperature ferromagnetic resonance limit", *Journal of Applied Physics*, vol. 109, 07D302 (2011).

[2] C. D. Stanciu, A. V. Kimel, F. Hansteen, A. Tsukamoto, A. Itoh, A. Kirilyuk, and Th. Rasing : *Phys. Rev. B* **73**, 220402(R) (2006).