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反平行結合した GdFeCo 二層膜の磁化ダイナミクス計測

Measurement of Magnetization Dynamics of Anti-parallelly Coupled GdFeCo Double Layer Films

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Abstract: In recent years, the importance of understanding dynamic properties of magnetic materials is increasing. Clarifying the dynamics of magnetization in multilayered magnetic film is important issue for ultrafast optical control application to spintronic devices, not only storage media. In this study, we investigated precessional motion in multilayered structures such as exchange coupled and decoupled GdFeCo double layer films by all-optical pump-probe method. As a result, precession of each magnetic layer in decoupled film show independent magnetic properties each other. By contrast, the magnetization in tightly exchange coupled film shows a single mode precessional motion. Moreover, we found a unique non-sensitivity on applied magnetic field in precession frequency. This is caused by different temperature dependency on dynamic property of magnetization in each layer.

1. Introduction

The speed limits for magnetization reversal are great interest. We reported the dynamic behavior of ferrimagnetic GdFeCo alloy film in vicinity of the angular momentum compensation, where the dynamics of the system is highly accelerated owing to the divergence of effective Gilbert damping factor α_{eff} and precession frequency f [1]. Moreover we demonstrated ultrafast precessional switching can be triggered with femtosecond pulsed laser irradiation [2]. So, ultrafast laser heating is a efficient way to accelerate recording speed for heat assisted magnetic recording. Clarifying magnetization dynamics in multilayered film is important issue for ultrafast optical control application to spintronic devices, not only storage media. In this study, we investigate ultrafast dynamic behavior of magnetization in exchange coupled / decoupled magnetic double layer films.

2. Film Structure Design and Experimental Set-up

We designed multilayered structure of GdFeCo double layer films with / without SiN interlayer. The film structures are SiN (60 nm) / Layer A: $Gd_{27}Fe_{63.9}Co_{9.1}$ (10 nm) / SiN (x nm) / Layer B: $Gd_{22}Fe_{68.2}Co_{9.8}$ (10 nm) / SiN (5 nm) / AlTi (10 nm) / glass sub. (Sample I: x = 5, Sample II: x = 0). All the films are prepared by magnetron sputtering. Inserted SiN layer between Layer A and B in Sample I decouple exchange and electrical conduction between two magnetic layers. Heavy rare earth (RE) Gd and transition metal (TM) FeCo sublattice magnetization in each magnetic layer are anti-parallelly coupled each other in perpendicularly magnetized GdFeCo alloy. Net magnetization (M_{net}) of Layer A is same direction of RE magnetization (M_{RE}). M_{net} of Layer B is same directions of TM magnetization (M_{TM}).

The ultrafast magnetic responses of the GdFeCo double layer samples are measured by all-optical pump-probe method excited by high-intense 400 nm wavelength light and probed by low-intense 800 nm wavelength light. Pulse width of laser light is 90 fs (FWHM), and applied angle θ_H of external DC magnetic field H_{ext} is 65° from vertical axis of the film surface. Magneto-optical effect probed by 800 nm (~1.55eV) wavelength light in amorphous Gd-TM alloy is contributed by mainly M_{TM} sublattice.

Figure 1 shows the magneto-optical Faraday hysteresis loops of (a) Sample I and (b) Sample II that is measured by time-resolved measurement set-up without pump light irradiation. The hysteresis loop composed of Layer A (outer) and B (inner) is clearly confirmed in Sample I. Faraday rotation $\Delta\theta_F$ of each layer are almost same. We define

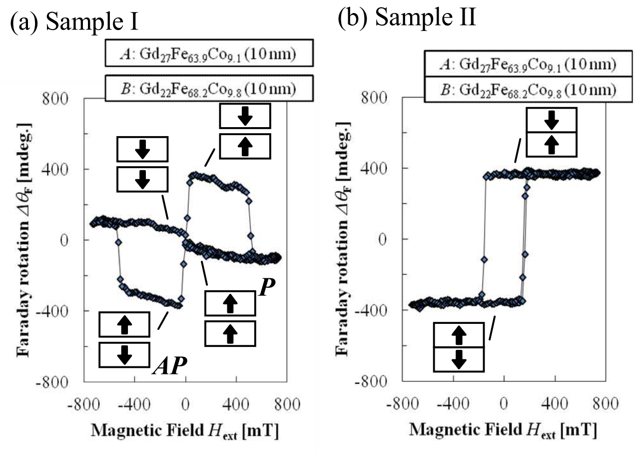

Figure 1. Faraday hysteresis loops of (a) decoupled and (b) exchange coupled GdFeCo double layer films measured by time-resolved observation set-up without pump laser irradiation. Inset figures show the directions of M_{net} in each magnetic layer.

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parallel (P-) and anti-parallel (AP-) state of double layer by direction of M_{net} in each layer. By contrast, in Sample II, exchange coupled double layer show single-phase hysteresis loop as shown in Figure 1(b). The direction of M_{TM} in Layer A and B is parallel in applied field range.

3. Results and Discussion

Figure 2 shows the precessional motion of Sample I in P- and AP-state excited by 0.2 mJ/cm^2 pump light with H_{ext} = 320 mT. The difference of $\Delta\theta_F$ is caused by M_{TM} of Layer B is opposite direction in each state. The sum and difference of the experimental $\Delta\theta_F$ resulting from P- and AP-state, representing $\Delta\theta_F$ of Layer A and B, respectively such as shown in Figure 3. The demagnetization of Layer A is about 5 times as large as Layer B within ~ps range. This is caused by the difference of absorbed optical energy in each magnetic layer and suppressing inter-layer electron thermal diffusion with non-conductive intermediate layer [3]. The damped oscillation of Layer A and B are clearly observed and the frequency are about 30 and 12 GHz, respectively. Thus precession of each magnetic layer in decoupled film show independent magnetic properties each other.

Meanwhile, damped oscillation without beat is clearly observed in Sample II; therefore the magnetization of each layer are coupled tightly even in precession. Figure 4 shows the pump energy F_p and H_{ext} dependency of α_{eff} and f in Sample II derived from experimental results. Especially, non-sensitivity on H_{ext} in f (f = 22~24 GHz) in F_p = 0.2 mJ/cm^2 case. Note that f is proportional to the product of effective gyromagnetic ratio γ_{eff} and effective magnetic field H_{eff} in LLG formalism. By contrast, H_{ext} dependency of f is clearly observed in F_p = 0.8 mJ/cm^2 case (f = 9~30 GHz) as usual tendency of precession. This F_p dependency is caused by anti-parallelly coupled Layer A and B have different temperature dependency of magnetization. M_{net} in each layer decrease total magnetization of film M_{total} and demagnetized field H_d which affects to decrease anisotropy field H_a. Thus precession of exchange coupled GdFeCo double layer depend on magnetization of each layer.

4. Acknowledgements

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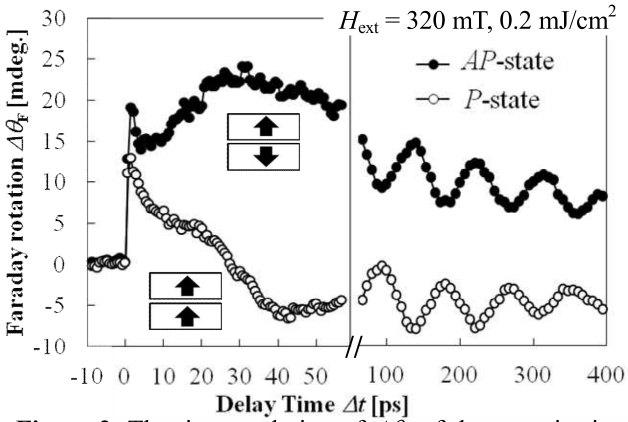

Figure 2. The time evolution of $\Delta\theta_F$ of demagnetization and recovering process with precession in parallel (P-) and anti-parallel (AP-) state of Sample I.

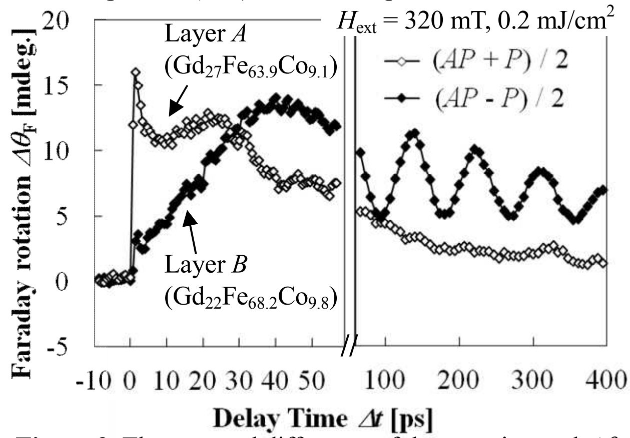

Figure 3. The sum and difference of the experimental $\Delta\theta_F$ data resulting from parallel (P-) and anti-parallel (AP-) state of Sample I, representing $\Delta\theta_F$ of each layer.

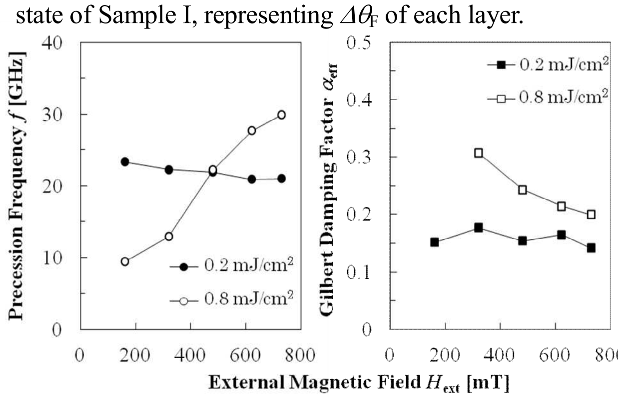

Figure 4. Pump energy and applied external magnetic field dependency of precession frequency f and effective damping factor α_{eff} of Sample II.