Compositional dependence of g-factor and damping constant of (Gd\(_{100-x}\)RE\(_x\))FeCo alloy films (RE = Yb, Tm, Er)

R Komiya\(^1\), T Kato\(^1\), N Nishizawa\(^2\), S Tsunashima\(^1\), S Iwata\(^1\)

\(^1\) Graduate School of Engineering, Nagoya University
Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
\(^2\) Division of Advance Science and Biotechnology, Osaka University,
Yamadaoka 2-1, Suita, Osaka 565-0871, Japan

E-mail: takeshik@nuee.nagoya-u.ac.jp

Abstract. Time domain magnetization dynamics of (Gd\(_{100-x}\)RE\(_x\))FeCo (RE = Yb, Tm, Er) alloy films with various compositions were measured by pump-probe method using a high energy ultra short pulse fiber laser, and their g-factors and damping constants were estimated. The g-factor of GdFeCo became large near the angular moment compensation point \(C_A\), which is qualitatively consistent with the simple mean field model. On the other hand, the damping constants took a maximum near magnetization compensation point, which is not described by the mean field model. Substitution of Tm or Er for Gd results in the significant increase of damping constant; (Gd\(_{90}\)Tm\(_{10}\))FeCo and (Gd\(_{90}\)Er\(_{10}\))FeCo exhibit roughly 3-6 times large damping constant compared to GdFeCo, while (Gd\(_{90}\)Yb\(_{10}\))FeCo has almost the same damping constant as GdFeCo. This means that the damping constant is significantly modified by the orbital moment of RE atoms.

1. Introduction

Understanding of the magnetization dynamics in magnetic thin films is one of the recent critical issues to develop ultra-high speed magnetic sensors and memories. In general, magnetic loss increases at very high frequencies because of the occurrence of a magnetic resonance, and the loss limits the maximum operating frequency of the magnetic devices. In magnetic thin films, the resonance frequency will be raised to several GHz by the increase of the magnetization i.e., the increase of the demagnetizing field. However, at present, CoFe based alloy layers with high magnetic moment have been already used in many magnetic devices, and drastic increase of the magnetization from CoFe alloys is not thought to be possible. In ferrimagnetic rare-earth (RE) transition metal (TM) alloy systems, their angular momentums are known to be compensated even at the RE-TM composition having a small saturation magnetization due to the difference in the g-factors between RE and TM sublattice magnetic moments. The compensation of the angular momentum is reported to lead to the divergence of the effective g-factor as well as the effective damping constant [1-6].

In the previous paper, we first reported the application of the ultra-short pulse fiber laser to excite the magnetization precession, and discussed the magnetization dynamics of GdFeCo with various compositions [6]. In this work, in order to study the effect of substitution the other RE for Gd on the magnetization dynamics, compositional dependence of g-factor and damping constant of (Gd\(_{100-x}\)RE\(_x\))FeCo (RE = Yb, Tm, Er) films have been investigated.
2. Experiment

SiN (140 nm) / (Gd₁₀₀−ₓ(REₓ)(Fe₉₀Co₁₀))₁₀₀−ₓ / Al₉₆Cu₃₃ (100 nm) / SiN (10 nm) / oxidized Si substrate was prepared by using an rf magnetron sputtering system. The content C of the film was controlled by varying the number of Gd and RE chips on the Fe₉₀Co₁₀ target. Hysteresis loops were measured by an alternating gradient field magnetometer (AGM), and Kerr loops were checked by a polarized angle modulation method.

Time-domain magnetization dynamics of GdREFeCo was measured by pump-probe method using high-power fiber laser with a wavelength of 1560 nm, a pulse width of 1 psec, a maximum energy of 2 μJ/pulse, and a repetition frequency of 200 kHz. The pump and probe beams were focused onto the GdREFeCo films with diameters of 60 μm and 15 μm, respectively. The probe beam was incident normal to the film surface and Kerr rotation of the reflected probe beam was analyzed to monitor the perpendicular component of the magnetization, \( M_z \), after the illumination of the pump beam. Typical fluences of the pump and probe beams are 1-4 mJ/cm² and 0.3-0.4 mJ/cm², respectively.

3. Results and Discussion

Figure 1 shows typical time domain magnetization dynamics measured for (a) Gd₂₃.₃(Fe₉₀Co₁₀)₇₆.₇ and (b) Gd₂₇.₀(Fe₉₀Co₁₀)₇₃.₀ films. The fluence of the pump beam was set to be (a) 1.8 and (b) 1.3 mJ/cm². The \( M_z \) component is excited at delay time of \( \Delta t \sim 0 \). From Fig. 1, one can see that the precessional frequency and relaxation time of GdFeCo are significantly dependent on the composition. The difference of the precessional frequency between the two samples is not described by the difference in the anisotropy field \( H_A \), since the \( H_A \) is estimated to be 1 kOe and 600 Oe for Gd₂₃.₃(Fe₉₀Co₁₀)₇₆.₇ and Gd₂₇.₀(Fe₉₀Co₁₀)₇₃.₀, respectively. The magnetization dynamics of GdFeCo is analyzed by the numerical fit with the Landau-Lifshitz-Gilbert (LLG) equation [7] based on the mean field model [1], and the effective \( g \)-factor \( g_{\text{eff}} \) and the effective damping constant \( \alpha_{\text{eff}} \) are evaluated. More detailed description is provided in the previous paper [6]. For Gd₂₃.₃(Fe₉₀Co₁₀)₇₆.₇ film, in which the net magnetization is parallel to the transition metal moment (we call this as TM-rich film), \( g_{\text{eff}} \) and \( \alpha_{\text{eff}} \) are 3.3 and 0.12, respectively. While for the Gd₂₇.₀(Fe₉₀Co₁₀)₇₃.₀ film (RE-rich film), the \( g_{\text{eff}} = 1.4 \) and \( \alpha_{\text{eff}} = 0.07 \) was obtained, which means that the \( g \)-factor can be widely tuned by varying the composition.

Figure 2 shows the dependences of effective \( g \)-factor \( g_{\text{eff}} \), and effective damping constant \( \alpha_{\text{eff}} \) of the (Gd₁₀₀−ₓ,Ybx)ₙ₉₀(Fe₉₀Co₁₀)₁₀₀−ₓ films as a function of saturation magnetization \( M_s \). The figure was taken from the samples prepared changing composition C keeping \( x \) constant. Since the magnetization compensation point \( C_{M_s} \) shifts with increasing Yb content \( x \), we plotted the data as a function of \( M_s \) to avoid the shift. Positive \( M_s \) indicates TM-rich samples, and negative \( M_s \) RE-rich samples. The closed circles, open triangles and open squares represent the data of Yb substitution of \( x = 0, 3 \) and 10, respectively. In the case of GdFeCo, the \( g_{\text{eff}} \) takes maximum value around \( M_s = 30 \) emu/cc which is

![Fig. 1 Time domain magnetization dynamics measured for the (a) Gd₂₃.₃(Fe₉₀Co₁₀)₇₆.₇ and (b) Gd₂₇.₀(Fe₉₀Co₁₀)₇₃.₀ films after the excitation of the pump beam.](image-url)
near angular momentum compensation point \( C_A \) while the damping constant \( \alpha_{\text{eff}} \) becomes large near magnetization compensation point \( C_M \). The compositional dependence of the \( g_{\text{eff}} \) is qualitatively consistent with the simple mean field model [1, 6], however this model does not describe the dependence of \( \alpha_{\text{eff}} \) shown in Fig. 2. When the Gd atoms are substituted by the Yb atoms, the \( g_{\text{eff}} \) and \( \alpha_{\text{eff}} \) have almost the same as those of GdFeCo. This means that the Yb atoms in GdYbFeCo do not contribute to its magnetization. In the Yb metal, it is known that the Yb tends to supply 2 electrons for the conduction band and have the electronic structure of \( 4f^{14} \) showing zero magnetic moment. The same situation is expected in the GdYbFeCo films, resulting in the no significant change in \( g_{\text{eff}} \) and \( \alpha_{\text{eff}} \) from those of GdFeCo.

Figure 3 shows the dependences of \( g_{\text{eff}} \), and \( \alpha_{\text{eff}} \) of the (a) \((\text{Gd}_{100-x}\text{Yb}_x)\text{C}_{(\text{Fe}_{90}\text{Co}_{10})_{100-x}}\) films as a function of saturation magnetization \( M_s \). Positive \( M_s \) indicates TM-rich samples, and negative \( M_s \) RE-rich samples.

4. Summary
Ferrimagnetic amorphous (GdRE)FeCo (RE = Yb, Tm, Er) films with various compositions were prepared and their magnetization dynamics; effective \( g \)-factor \( g_{\text{eff}} \) and effective damping constant \( \alpha_{\text{eff}} \), were investigated by all optical pump-probe measurement. In the case of the GdFeCo, the \( g \)-factor can be widely tuned by varying the composition of Gd, e.g., the maximum \( g_{\text{eff}} \) of 4.3 was observed near
angular momentum compensation point $C_A$ and the minimum $g_{eff}$ of 1.3 near magnetization compensation point $C_M$. The damping constant $\alpha_{eff}$ also significantly depends on the Gd content, and it became large near $C_M$. The substitution of Yb for Gd atoms was found to have no influence on the compositional dependence of the $g_{eff}$ and $\alpha_{eff}$, which implies that the Yb atoms do not contribute to the magnetization of GdYbFeCo. Substitution of Tm or Er for Gd results in the significant increase of damping constant; (Gd$_{100-x}$Er$_x$)$_x$(Fe$_{90}$Co$_{10}$)$_{100-x}$ and (Gd$_{100-x}$Tm$_x$)$_x$(Fe$_{90}$Co$_{10}$)$_{100-x}$, which may reflect the insufficient exchange coupling between FeCo and Er or FeCo and Tm.

Acknowledgments

The authors would like to thank Mr. M. Kumazawa and Mr. Y. Adachi of Nagoya University for assistance in the experiments and compositional analysis, respectively. The authors are grateful for the financial supports by the following grants: Grand-in-Aids for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology, SCOPE from the Ministry of Internal Affairs and Communications, and Knowledge Cluster Initiative from the Ministry of Education, Culture, Sports, Science and Technology.

References

[1] Wangsness R K 1953 Phys. Rev. 91 1085.
[2] Giles R, Mansuripur M 1991 J. Magn. Soc. Jpn. 15-S1 299
[3] Soohoo R F, Morrish A H 1979 J. Appl. Phys. 50 1639
[4] Stanciu C D, Kimel A V, Hansteen F, Tsukamoto A, Itoh A, Kirilyuk A, Rasing Th 2006 Phys. Rev. B 73 220402(R)
[5] Binder M, Weber A, Mosendz O, Woltersdorf G, Izquierdo M, Neudecker I, Dahn J R, Hatchard T D, Thiele J-U, Back C H, Scheinfein M R 2006 Phys. Rev. B 74 134404
[6] Kato T, Nakazawa K, Komiya R, Nishizawa N, Tsunashima S, Iwata S 2008 IEEE Trans. Magn. 44 3380
[7] Nakatani Y, Uesaka Y, Hayashi N 1989 Jpn. J. Appl. Phys. 28 2485