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MAGNETIZATION PROCESS OF Gd/Co MULTILAYER FILMS

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Abstract. – Gd/Co multilayer films were prepared by electron beam evaporation in a vacuum of \(10^{-7}\) Torr. The multilayer film of \((110\,\text{Å} \times 147\,\text{Å}) \times 12\) showed peculiar magnetization process around 150 K. This can be attributed to a transition of Gd spins from aligned to twisted states.

1. Introduction

In recent years, several reports have been published on rare earth-transition metal multilayer films. Most of them described the saturation magnetization \(M_s\) and the perpendicular anisotropy as functions of bilayer periods \([l, 2]\). As for \(M_s\), it was shown that the multilayer films behave like amorphous alloy films when the period is smaller than about 100 Å. However, details of magnetization process have not been reported. In this paper, we present a study on the magnetization process or magnetic phase transition of multilayer films with relatively large bilayer period (\(\sim 250\,\text{Å}\)).

2. Experimental

Gd/Co multilayer films were made by alternative deposition in vacuum of \(4-6 \times 10^{-7}\) Torr. The deposition rate was 0.7-1.0 Å/s with 10 seconds interval between the deposition of each layer. The thickness ratio \(h_{\text{Gd}}/h_{\text{Co}}\) was 3/4 and the bilayer period \(D\) in a range of 19 to 260 Å. The total thickness of layers was 1000 to 3000 Å. Immediately after the deposition, Gd/Co layers were capped by SiO layers. Auger depth profile showed considerable diffusion of Co into Gd layers.

3. Results and discussion

At room temperature, \(M_s\) averaged over bilayers is smaller than that obtained by assuming nonmagnetic Gd, and decreases with decreasing bilayer period approaching the value of amorphous alloys. At low temperatures, the magnetization of films with long bilayer period is not saturated at low in-plane fields but gradually increases with increasing field as shown in figure 1. The shape of the curve for 150 K is particularly curious.

At first we calculate the thermal average of Gd spin polarization within the framework of the molecular field theory \([3, 4]\). We assume that each Gd layer consists of \(N\) atomic layers. Then thermal average of Gd spins in layer \(i\) \((i = 1, 2, N)\) is given by,

\[
\langle S_i \rangle = S_{\text{Gd}} B_0 (g_{\text{Gd}} \mu_B S_{\text{Gd}} H_i / KT),
\]

where the molecular field for layer \(i\) is given by,

\[
H_i = \sum_{j=i-1}^{j=i+1} g_{\text{Gd}} \mu_B z_{ij} J_{ij} \langle S_j \rangle,
\]

\(B_0\) is the Brillouin function. Here \(J_{ij}\) is an exchange constant for atoms, one in layer \(i\), the other in layer \(j\), and \(z_{ij}\) is assumed to be 6 \((i = j)\) or 3 \((i = j \pm 1)\). Figure 2 shows the result of the calculation, where parameters are assumed as \(S_{\text{Gd}} = 7, g_{\text{Gd}} = 2, S_{\text{Co}} = 0.78, g_{\text{Co}} = 2.2, J_{\text{GdCo}} = -2.5 \times 10^{-16}\) (erg) \([5]\), \(J_{\text{GdGd}} = 3.2 \times 10^{-16}\) (erg), and further Co layers are assumed to be completely polarized, namely \(\langle S_0 \rangle = \langle S_N \rangle = S_{\text{Co}}\). It is seen that at 80 K or 200 K, \(\langle S_{\text{Gd}} \rangle\) is almost constant throughout the layers. At 300 K which is slightly higher than the Curie temperature of Gd metal, Gd spins are polarized only in a few atomic layers close to Co layers.

Next we calculate the magnetization curves by minimizing the magnetic free energy of the system shown...
in figure 3. The energy is the sum of exchange and Zeemann energy terms as given by,

\[ U = -\sum_{i=1}^{N} 6J_{i,i+1} \langle S_i \rangle \langle S_{i+1} \rangle \cos (\theta_i - \theta_{i+1}) + \sum_{i=1}^{N} \theta_{Gd} \mu_B \langle S_i \rangle H \cos \theta_i, \]  

where \( \theta_i \) is the angle between \( \langle S_i \rangle \) and an applied field \( H \). The equilibrium state was calculated by iteration method so that \( U \) may approach the minimum. Here \( \langle S_i \rangle \) is approximated by that obtained for \( H = 0 \). This may valid so long as \( \theta_{i+1} - \theta_i \) is small. Magnetization curves thus obtained are shown in figure 4 for Gd/Co(84 Å/110 Å) multilayer films. Abrupt increase of magnetization at about 3 kOe in curves of

\( T = 100 \) K and 200 K corresponds to the transition of Gd spins from an aligned state to twisted state as shown in figure 3. This process is quite similar to the surface spin reorientation described by Camley [4]. When the field is increased further, the magnetization becomes larger than that expected from Co moment only. This means that Gd spins become parallel to Co spins. In the experimental result shown in figure 2, the curve for \( T = 150 \) K looks quite like theoretical ones, and thus we may conclude that a transition from aligned to twisted spin structure has been observed in Gd/Co multilayer films.

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