ROOM TEMPERATURE SPIN FLOPPING IN Gd/Fe MULTILAYERS PREPARED WITH OBLIQUE INCIDENCE OF Gd AND Fe ATOMS

H. KIRIAKE, M. NAWATE, K. DOI, S. HONDA and T. KUSUDA

Dept. of Physical Electronics, Faculty of Engng., Hiroshima Univ., 1-4-1 Kagamiyama, Higashi-Hiroshima 724, Japan

Gd/Co and Gd/Fe multilayers composed of large bilayer thickness have exhibited spin flopping at low temperature [1,2]. GdFe/Fe multilayer and Gd/Fe double structured multilayer have also exhibited spin flopping at room temperature. [3,4].

We observed the spin flopping phenomena at room temperature in Gd/Fe multilayer prepared by electron beam evaporation with oblique incidence of Gd and Fe atoms. We report here the magnetization process and the magnetoresistance at room temperature.

Gd and Fe layers were deposited alternately at $4 \sim 8 \times 10^{-7}$ Torr on glassslide. Substrate position to the Gd and Fe crucible were chosen as Fig.1. Here, incident direction of Gd and Fe atoms to the substrate are also shown. Bilayer thickness D was varied from 4Å to 200Å, while the thickness ratio of Gd layer to Fe layer was held unity. Total thickness of the films was between 1300Å and 1600Å.

Films prepared with the oblique geometry of Fig.1(a) exhibited a uniaxial anisotropy in the film plane for D larger than 16Å. Films with D between 16Å and 22Å exhibited spin flopping at room temperature. Fig.2 shows the typical magnetization curve for Gd(9Å)/Fe(9Å) multilayer. The magnetization curve for easy direction indicates the rectangular loop at low field and the abrupt increase at around 0.5kOe and then magnetization M approaches the saturation value, $M_s = 88 \text{ emu/cm}^3$. When H become large enough to rotate spin against the anisotropy energy, a collinear alignment of Gd and Fe spins abruptly changes into a twisted alignment, spin flopping occurs. On the other hand, the magnetization curve for the hard direction, M increases gradually and approaches the saturation value of 88 emu/cm^3 . Fe and Gd spin, antiparallel with each other at 0 kOe, rotates gradually to H direction from normal direction.

Films prepared with another oblique geometry of Fig.1(b) exhibited neither uniaxial anisotropy nor spin flopping. Films prepared with perpendicular incidence of atoms to the substrate as shown Fig.1(c) did not exhibit spin flopping, either.

Fig.3 shows the H dependence of the resistance and corresponding M - H curve at room temperature for a Gd(9Å)/Fe(9Å) multilayer prepared by the geometry of Fig.1(a). In the case of the resistance for current J parallel to the easy axis (a), longitudinal resistance $\rho_{||}$ increases with H at first. The resistance $\rho_{||}$ begins to decrease at the spin flopping field H_{sf} , and then slightly increases. On the other hand, the transverse resistance $\rho_{\perp}$ decreases monotonically with H . When J is normal to the easy axis (b), the resistance $\rho_{\perp}$ and $\rho_{||}$ behave just the opposite to $\rho_{||}$ and $\rho_{\perp}$. Resistance is larger when J and Fe spin are parallel to each other than they are perpendicular [2]. So, changes of in $\rho_{||}$ and $\rho_{\perp}$ at H_{sf} implies that Fe spin inclines against H direction at H_{sf} .

In conclusion, for Gd/Fe multilayers, a uniaxial anisotropy is found to be important for occurrence of the spin flopping at room temperature. In particular, in this study, it is noted that the spin flopping occurs in the films with thin Gd and Fe layers such as 3~4 monolayers.

- [1] S.Tunashima, T.Ichikawa, M.Nawate and S.Uchiyama, J. de Phys.C8,(Suppl), 1803 (1988).
- [2] Y.Kamiguchi, Y.Hayakawa and H.Fujimori, Appl. Phys. Lett.,55,1918(1989).
- [3] H.Dohnomae and T.Shinjo, J. Mag. Soc. Jpn.,14,331(1990)
- [4] Y.Kamiguchi, H.Fujimori, Y.Hayakawa and K.Takanashi,J.Mag.Soc.Jpn., 355(1990)

Fig.1.Substrate position to the Gd and Fe crucible and incident direction of Gd and Fe atoms to the substrate.

Fig.2.M-H curve at room temperature for a Gd(9 Å)/Fe(9 Å) multilayer. H is applied in the plane of the sample.

(a) Resistance for J parallel to easy axis.

(b) Resistance for J normal to easy axis.

Fig.3.Magnetoresistance and Magnetization M at room temperature, for a Gd(9 Å)/Fe(9 Å) multilayer.