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CoFeB Inserted Perpendicular Magnetic Tunnel Junctions with CoFe/Pd Multilayers for High Tunnel Magnetoresistance Ratio

K. Mizunuma[1], J. H. Park[1], S. Ikeda[1], H. Yamamoto[2,1], K. Miura[2,1], H. Gan[1], H. Hasegawa[1], J. Hayakawa[2], K. Ito[2], F. Matsukura[1], and H. Ohno[1]

[1] Laboratory for Nanoelectronics and Spintronics, RIEC, Tohoku Univ.,
2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan
Phone: +81-22-217-5555 E-mail: cota1215@riec.tohoku.ac.jp
[2]Advanced Research Laboratory, Hitachi, Ltd.,
1-280 Higashi-koigakubo, Kokubunji-shi, Tokyo 185-8601, Japan

1. Introduction

Spin transfer torque magnetic tunnel junctions (MTJs) with perpendicular magnetic anisotropy electrodes attract much interest from the possibility of nonvolatile spin devices compatible with the latest technology node (< 45 nm) in DRAMs having reduced critical switching current (I_{c0}) as well as high thermal stability (E/k_BT) [1]-[4]. Currently, perpendicular MTJs with ferromagnetic electrodes such as rare-earth based amorphous alloys, multilayers and ordered alloys are actively being studied and demonstrated by a number of groups [4]-[10]. For perpendicular MTJs, I_{c0} and E/k_BT are in a trade-off relation [1]. In order to reduce I_{c0}, it is necessary to moderately reduce E/k_BT. From this view point, multilayer electrodes have advantages; multilayer is relatively easy to control M_s and H_k by changing the number of the layer stack and the thicknesses. In addition, multilayer films are comparatively easy to realize perpendicular magnetic anisotropy, yet show high magnetic thermal stability. However, it is not clear how one can achieve high tunnel magnetoresistance (TMR) in MTJs based on multilayers. In this study, we employed CoFe/Pd multilayer as perpendicular anisotropy electrodes. The magnetic and TMR properties of MTJs with $Co_{90}Fe_{10}$/Pd multilayer based electrodes and an MgO barrier with CoFeB are investigated in order to establish the technology for high TMR ratio. The $Co_{90}Fe_{10}$ used here is known as zero-magnetostriction composition.

2. Experimental procedure

The rf-sputtered MTJ films studied here have a pseudo-spin-valve (PSV) structure; from the substrate side, buffer-layer/Pd(1.2)/[$Co_{90}Fe_{10}$(0.2)/Pd(1.2)]$_3$/ $Co_{20}Fe_{60}B_{20}$ (1.8)/ MgO(2)/$Co_{20}Fe_{60}B_{20}$(1.8)/ [Pd(1.2)/$Co_{90}Fe_{10}$(0.2)]$_{10}$/ Pd(1.2)/cap-layer (in nm). For comparison, we fabricated MTJs consisting of buffer-layer/[Pd(1.2)/$Co_{90}Fe_{10}$(0.2)]$_3$/ MgO(2)/ [$Co_{90}Fe_{10}$(0.2)/Pd(1.2)]$_{10}$/ cap-layer and buffer-layer/ Pd(3.6)/ $Co_{20}Fe_{60}B_{20}$(1.8)/MgO(2)/ $Co_{20}Fe_{60}B_{20}$ (1.8) / Pd(12)/ cap-layer. All junctions were fabricated using a conventional photolithography process. The completed MTJs were annealed at 200 ~ 300^{o}C under an applied magnetic field of 4 kOe. The TMR ratio was measured at room temperature (RT) using a dc four probe method with out-of-plane magnetic field of up to 5 kOe. The film structures were investigated by high resolution transmission electron microscopy (HRTEM) and by fast Fourier transform (FFT) of the digitized HRTEM image. The compositions were analyzed by secondary ion mass spectrometer (SIMS).

3. Results and discussion

Fig.1 shows the annealing temperature (T_a) dependence of the TMR ratio for the MTJs with Pd(1.2)/[$Co_{90}Fe_{10}$(0.2)/Pd(1.2)]$_3$/ $Co_{20}Fe_{60}B_{20}$ (1.8)/ MgO(2)/$Co_{20}Fe_{60}B_{20}$(1.8)/ [Pd(1.2)/$Co_{90}Fe_{10}$(0.2)]$_{10}$/ Pd(1.2) multilayer stack structure. The TMR ratio at RT increased up to 43% after annealing at 200^{o}C and then rapidly decreased at T_a over 250^{o}C. By inserting the CoFeB layers between CoFe/Pd multilayers and MgO barrier, the TMR ratio increased from 1.5% to 43%. However, in this MTJ system, high TMR ratios of several hundred % as shown in the previous reports of CoFeB/MgO/CoFeB MTJs with in-plane magnetic anisotropy [11],[12] were not obtained after annealing at T_a over 250^{o}C.

To understand the reasons for the low TMR ratio in the MTJs with the CoFeB insertion layers, high-resolution transmission electron microscopy (HRTEM) was employed for structural characterization. Fig.2 shows cross-sectional HRTEM image for the MTJ with $Co_{20}Fe_{60}B_{20}$ insertion annealed at 300^{o}C which showed low

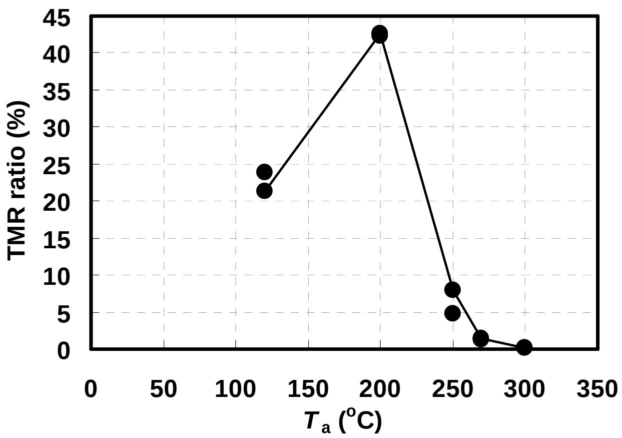

Fig.1 TMR ratio as a function of annealing temperature (Ta) for the MTJs with buffer-layer/ Pd(1.2)/[$Co_{90}Fe_{10}$(0.2)/Pd(1.2)]$_3$/ $Co_{20}Fe_{60}B_{20}$ (1.8)/ MgO(2)/$Co_{20}Fe_{60}B_{20}$(1.8)/ [Pd(1.2)/ $Co_{90}Fe_{10}$(0.2)]$_{10}$/ Pd(1.2)/ cap-layer stack.

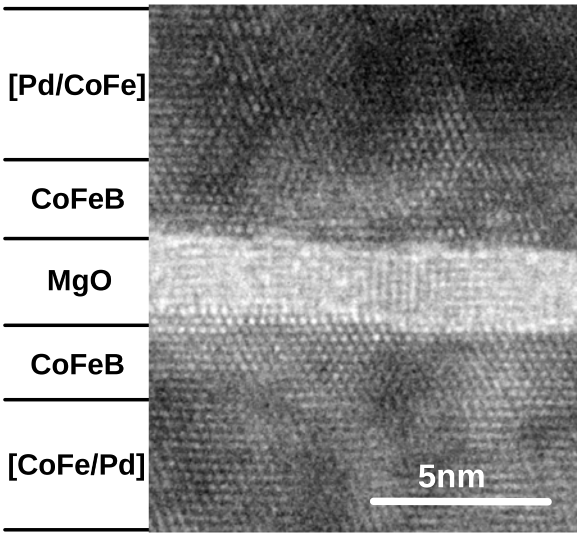

Fig.2 Cross-sectional HRTEM images for a Pd(1.2)/[$Co_{90}Fe_{10}$(0.2)/Pd(1.2)]$_3$/ $Co_{20}Fe_{60}B_{20}$ (1.8)/ MgO(2)/$Co_{20}Fe_{60}B_{20}$(1.8)/ [Pd(1.2)/$Co_{90}Fe_{10}$(0.2)]$_{10}$/ Pd(1.2) stack after annealing at 300^{o}C.

TMR ratio of less than 1%. The MgO barrier have (001) oriented texture, whereas the top and bottom CoFeB electrodes consist of fcc (111) or bcc (011) oriented texture according to the FFT images (not shown). The fcc (111) or bcc (011) oriented crystallization of the inserted, initially amorphous, CoFeB layers is likely to be one of the reasons for the low TMR ratios, because high TMR ratios require bcc (001) oriented ferromagnetic electrodes and MgO (001) barrier. It is known that NiFe [13], [14] or CoFe [15], [16] adjacent to CoFeB acts as a template for crystallization of initially amorphous CoFeB into fcc(111) or bcc(011) oriented texture through annealing over crystallization temperatures which strongly depend on the thermal diffusion of B into the adjacent layers. We investigated the B diffusion by SIMS analysis. A simple structure of Pd(3.6)/$Co_{20}Fe_{60}B_{20}$(1.8)/MgO(2)/$Co_{20}Fe_{60}B_{20}$(1.8)/Pd(12) was used only for this analysis. Fig. 3(a) and 3(b) show the composition depth profiles of B, Pd and Co in the samples before and after annealing at T_a = 300^{o}C, respectively. In as-deposited state of Fig. 3(a), B is located in CoFe, whereas after annealing B diffuses into Pd. These observations suggest that the diffusion of B into Pd layers reduces the crystallization temperature of CoFeB at the CoFeB/Pd interfaces, and crystallization of CoFe(B) into fcc(111) or bcc(011) oriented texture starts from the fcc (111) Pd seed layers.

4. Conclusions

The insertion of CoFeB layers between CoFe/Pd multilayers and MgO barrier caused an increase of TMR ratio up to 43%. However, the TMR ratio rapidly decreased at T_a over 250^{o}C. The degradation of the TMR ratio for the MTJs annealed at high T_a may be related to the crystallization of CoFe(B) into fcc(111) or bcc(011) texture resulting from the diffusion of B into Pd layers. Even higher TMR ratio can be expected in MTJs with perpendicular magnetic CoFe/Pd multilayer electrodes, which realize bcc (001) orientation of CoFeB by suppression of B diffusion between the CoFe/Pd multilayer and the CoFeB layer.

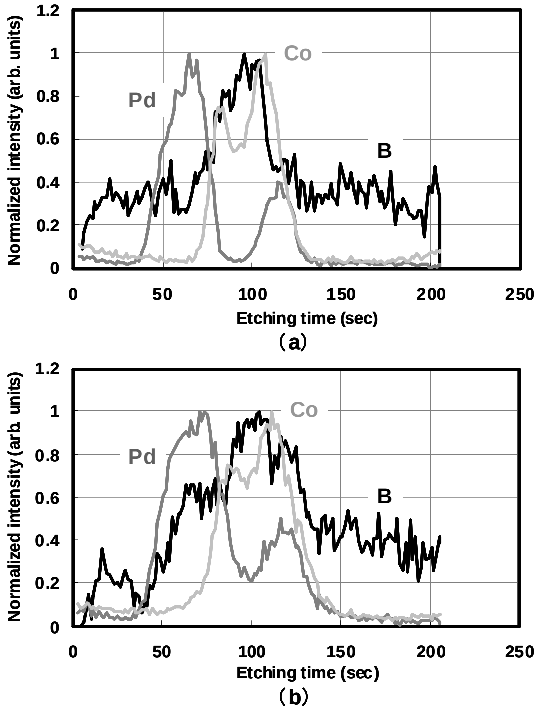

Fig.3 Composition depth profiles of B, Pd, and Co in the samples with buffer-layer/Pd(3.6) / $Co_{20}Fe_{60}B_{20}$(1.8) / MgO(2) / $Co_{20}Fe_{60}B_{20}$ (1.8) / Pd(12) / cap-layer stack (a) before and (b) after annealing at 300^{o}C analyzed by SIMS.

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