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High Thermal Stability of Magnetic Tunnel Junctions with Perpendicular Magnetic Anisotropy using a Co_2FeAl Full-Heusler Alloy

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In recent years, the magnetic random access memory (MRAM) with magnetic tunnel junctions (MTJs) using the half-metal (HM) is being actively researched due to high TMR ratio, superior thermal stability and low power consumption [1]. Co-based full-huesler materials have been predicted to be HMs with high curie temperature (T_C) about 1,300°C, thermal stability and low damping constant (α) of around 0.001 [2].

In this study, we focused on Co_2FeAl (CFA), one of the full-heusler HMs with T_C=980°C, and stable energy band gap on minority spin electron [3]. We fabricated multilayer-stacks on thermally oxidized SiO_2/Si amorphous substrate (001) with 12-inch wafer. And the films of multilayer were deposited on SiO_2/Si substrates by ultra-vacuum magnetron sputtering with a base pressure of around 10^{-8} torr at room temperature. The stack structures consist of, from the substrate side, MgO (7.5)/Pt (10.0)/CFA (1.4)/MgO (2.0)/Pt (7.0) and Ta (5.0)/$Co_2Fe_6B_2$(CBF) (1.05)/MgO (1.0)/Ta (5.0) were fabricated where numbers are nominal thickness in nanometres as shown in Figs. 1. In general, bottom Pt and Ta layers act as a seed for crystallization to enhance the properties of perpendicular magnetic anisotropy (PMA). Especially, Ta is the perfect assistant with CFB by absorbing the boron in CFB [4]. After sputtering fabrication, *ex-situ* annealing was progressed at a temperature ranging from 250°C to 350°C in a vacuum environment above 10^{-6} torr for two hrs with an out-of-plane magnetic field of 3 Tesla. Figure 1 shows the out-of-plane magnetization versus external magnetic field (*M-H*) curves of the multilayer-stacks annealed at T_{ex}=300°C. The curves indicate saturated magnetization (M_S) of CFA multilayer-stack is higher than that of CFB multilayer-stack. The high M_S induces the high anisotropy energy density $K_u = M_S H_k/2$. It suggests MTJ using CFA material can be endured more back-end heat budget such as metallization than CFB material. In particular, superior thermal stability of CFA material was confirmed by followed experiments.

It was obviously obtained that the PMA can be realized at an *ex-situ* annealing temperature of higher than 275°C. Surprisingly, the K_u values annealed at higher than 275°C increased with increasing *ex-situ* annealing temperature, as shown in Fig. 2. CFA multilayer-stack has larger K_u at a high temperature resulting that CFA crystallization was formed by a large thermal energy.

Figure 3(a) and (b) show that the *M-H* curves of magnetization under the sweep of out-of-plane magnetic field for CFA and CFB multilayer-stacks. It indicates that although PMA characteristics of CFB multilayer-stack are disappeared at 350°C, that of CFA multilayer-stack are still observed. We demonstrated that CFA material has a superior thermal stability to back-end heat budget of semiconductor fabrication process.

In our presentation, we present the superiority of CFA material by explaining the results of low damping constant. In addition, we will review the magnetic properties of CFA using VSM, XRD and HR-TEM, etc.

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Reference

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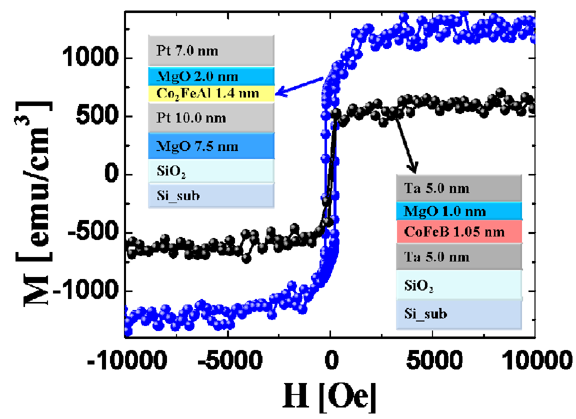

Fig. 1. *M-H* curves of out-of plane of CFB and CFA multilayer-stacks annealed at 300℃.

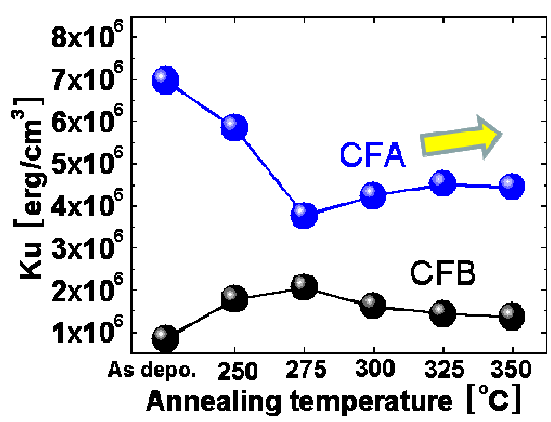

Fig. 2. K_u values with increasing *ex-situ* annealing temperature.

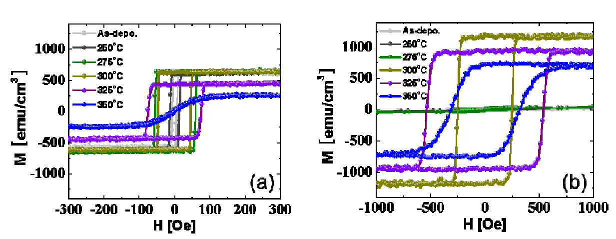

Fig. 3. *M-H* curves of out-of-plane: (a) CFB and (b) CFA multilayer-stacks (as-deposition and annealed at T_{ex} = 250, 275, 300, 325, and 350 °C).