CPP-GMR devices using $C1_b$-type half Heusler alloys

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Current-perpendicular-to-plane giant magnetoresistance (CPP-GMR) devices are promising as read heads for hard disk drives (HDDs) for achieving ultrahigh density magnetic recording of more than 5 Tbit/inch^2. Half-metallic Heusler alloys have shown great potential for enhancing CPP-GMR effect due to their high spin polarization. Half-metallic Heusler alloys are classified into full- and half-Heusler compounds with the chemical formula of X_2YZ in the $L2_1$ structure and XYZ in the $C1_b$ structure (X and Y: transition metals; Z: non-magnetic element). For half-Heusler alloys, the bandgap of minority spin originates from d-band hybridization of elements X and Y, which can form a larger bandgap compared to that in full-Heusler alloys. From the origin of the bandgap, half-Heusler alloys are beneficial for the development of high-performance CPP-GMR devices owing to the suppression of thermal activations on the bandgap. In this work, we fabricated half-Heusler alloy films (NiMnSb,[1,2]) PtMnSb, and NiMnSb with doping Ti) and investigated the CPP-GMR effect in the nanojunctions using the half-Heusler alloys.

Half-Heusler NiMnSb and PtMnSb alloy films were optimized with varying deposition temperatures on Cr/Ag-buffered MgO(001) substrates by investigating structural and magnetic properties. Fully (001)-oriented NiMnSb epitaxial films with flat surface and high magnetization were achieved at the substrate temperature of 300 °C. In the case of PtMnSb films, epitaxial growth was achieved at 200 °C while high magnetization was observed at 500 °C. Further, anisotropic magnetoresistance (AMR) effect was measured in the half-Heusler alloy films since negative AMR effect was reported to be a fingerprint for half-metallic band structure.[3)] A modest AMR value with negative sign was found in the NiMnSb films while a remarkably negative AMR effect was observed in the PtMnSb films. Epitaxial CPP-GMR devices using both the NiMnSb and the PtMnSb films were fabricated, and room-temperature (RT) CPP-GMR ratios for the half-Heusler alloys were determined for the first time. A CPP-GMR ratio of 8% (21%) at RT (4.2 K) was observed in the fully epitaxial NiMnSb/Ag/NiMnSb structures and a very low CPP-GMR ratio of 0.7% was shown in PtMnSb/Ag/PtMnSb nanojunctions at RT. In addition, TEM observation was carried out in order to examine the degree of $C1_b$ order in the NiMnSb film. It is found that $L2_1$ like structure is dominant in the NiMnSb alloy film while $C1_b$ order is rarely observed. This indicates a poor half metallicity for the NiMnSb film, which is consistent with the results of AMR and CPP-GMR. Nevertheless, the inconsistency between CPP-GMR and AMR effects was found in the PtMnSb material system, which could be due to high spin-orbit interaction in the PtMnSb films owing to Pt. Furthermore, in order to improve the $C1_b$ order in half-Heusler alloys, the element of Ti was doped into NiMnSb films. The epitaxial structure of the NiMn(Ti)Sb films was achieved at a post annealing temperature of 500 °C on Cr/Ag-buffered MgO(001) substrates. However, the NiMn(Ti)Sb based multilayers showed much weaker AMR effect and reduced CPP-GMR ratios compared to pure NiMnSb based samples. The result reveals the ordering structure was degraded by doping Ti at the current deposition condition. Table 1 summarizes the values of both AMR and CPP-GMR in half-Heusler based multilayers with NiMnSb, PtMnSb, and NiMn(Ti)Sb at RT. Reference data[4)] for $Co_2(Mn_{0.6}Fe_{0.4})Si$ were also shown. This study indicates that it is still challenging to improve the $C1_b$ ordering structure in half Heusler alloys for CPP-GMR applications at the current stage.

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Table 1, AMR and CPP-GMR in half-Heusler based multilayers with NiMnSb, PtMnSb, and NiMn(Ti)Sb at RT.

	NiMnSb	PtMnSb	NiMn(Ti)Sb	Ref.[4)]: $Co_2(Mn_{0.6}Fe_{0.4})Si$
AMR	−0.1%	−0.17%	−0.07%	−0.2%
CPP-GMR	8%	0.7%	1.5%	55%