Current-perpendicular-to-plane giant magnetoresistance in ferromagnetic semiconductor (Ga,Fe)Sb heterostructures with high Curie temperature

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Ferromagnetic semiconductors (FMSs), which show both the properties of ferromagnets and semiconductors, are needed for future low-power spintronics devices. To realize practical spin devices, both p-type and n-type FMSs which have high Curie temperature (T_C) are required, but prototypical Mn-doped FMSs (In,Mn)As or (Ga,Mn)As show only p-type with $T_C \leq$ 200 K [1]. On the other hand, we have successfully grown Fe-doped FMSs; p-type (Ga,Fe)Sb with $T_C \simeq$ 340 K [2] and n-type (In,Fe)Sb with $T_C \simeq$ 335 K [3], which are promising for devices operating at room temperature. To realize practical spintronics devices, the spin-valve effect is one of the basic and necessary characteristics. We have recently demonstrated current-in-plane giant magnetoresistance (CIP-GMR) effects in (Ga,Fe)Sb heterostructures [4], but the MR ratio was less than 2%, which is very small. Further improvement of the MR, by optimizing the geometry and structure, is necessary.

In this work, we demonstrate the CPP-GMR effect in a spin-valve structure using high-T_C (Ga,Fe)Sb. Generally, the magnetoresistance (MR) ratio of CPP-GMR is larger than that of CIP-GMR, because the MR is not only caused by the spin-dependent scattering at the ferromagnetic/nonmagnetic interfaces but also by the spin-dependent density of states of the ferromagnetic layers. As shown in Fig. 1(a), the samples examined here consist of ($Ga_{0.8}$,$Fe_{0.2}$)Sb (50 nm, $T_C >$ 320 K)/ InAs (5 nm)/ ($Ga_{0.8}$,$Fe_{0.2}$)Sb (40 nm, $T_C >$ 320 K) grown on an n-type Si-doped InAs buffer (200 nm) and an n+InAs substrate by low temperature molecular beam epitaxy (LT-MBE). Figure 1(b) shows the MR measured at 3.5 K with a magnetic field ***H*** applied perpendicular to the film plane. Clear GMR of ~ 3.5% is observed, whose peaks (≃ ±250 G) agree with the coercive forces of the magnetizations of the (Ga,Fe)Sb layers observed by magnetic circular dichroism (MCD) magnetometry. Although the observed MR of 3.5 % is not high enough for practical devices, this result of the spin-valve (GMR) effect in Fe-doped FMS heterostructures is an important step for device applications of high-T_C FMSs and heterostructures.

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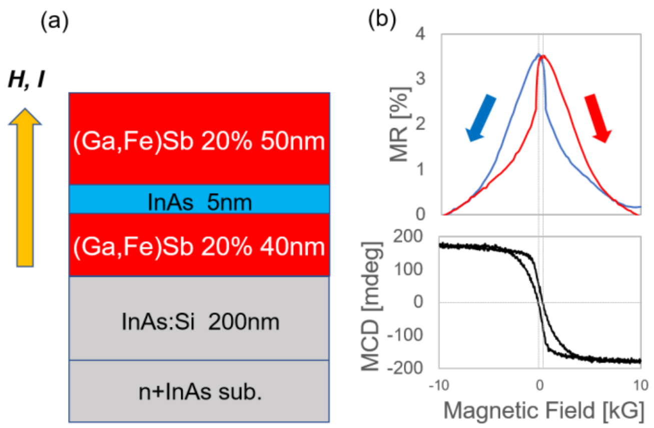

Fig. 1. (a) Schematic sample structure and measurement geometry. (b) Magnetoresistance of a ($Ga_{0.8}$,$Fe_{0.2}$)Sb (50 nm)/ InAs (5 nm)/ ($Ga_{0.8}$,$Fe_{0.2}$)Sb (40 nm) structure measured at 3.5 K (upper panel) and the normalized hysteresis measured by MCD in the same sample (lower panel). The magnetic field ***H*** and current ***I*** are applied perpendicular to the film plane. In (b), the red and blue curves are magnetic-field-sweep directions of – to + and + to –, respectively.

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