Giant magnetoresistance in ferromagnetic semiconductor (Ga,Fe)Sb heterostructures with high Curie temperature

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Ferromagnetic semiconductors (FMSs) which show both ferromagnetic and semiconducting characteristics are promising materials for future low-power devices. To realize practical spin devices, both p-type and n-type FMSs which have high Curie temperature (T_C) are required, but (In,Mn)As or (Ga,Mn)As, which have been vigorously studied, show only p-type with $T_C \simeq 200$ 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 make practical devices, we need to realize magnetoresistance effects with these Fe-doped FMSs.

In this work, we demonstrate the giant magnetoresistance (GMR) effect in spin valve structures using high-T_C (Ga,Fe)Sb. As shown in Fig. 1(a), the samples examined here consist of ($Ga_{0.75}$,$Fe_{0.25}$)Sb (40 nm, $T_C > 320$ K)/ InAs (thickness t = 0, 3, 6, 9 nm)/ ($Ga_{0.8}$,$Fe_{0.2}$)Sb (40 nm, $T_C > 320$ K) grown by low temperature molecular beam epitaxy (LT-MBE). In these structures, current is expected to flow mainly in InAs since the (Ga,Fe)Sb layers are insulating and have much higher resistance than the n^+-type InAs layer especially at low temperature. Figure 1(b) shows the magnetoresistance of one of these spin-valve structures with t = 3 nm, measured at 3.7 K with a magnetic field **H** applied perpendicular to the film plane. Clear GMR of ~ 2% with open minor loop is observed, whose peaks (≃ ±0.1 T) are consistent with the coercive forces of the magnetizations of the (Ga,Fe)Sb layers obtained with superconducting quantum interference device (SQUID) magnetometry. We found that the GMR ratio increases (from 0.03 to 1.28%) with decreasing t (from 9 to 3 nm), which is caused by the enhancement of scattering at the InAs/(Ga,Fe)Sb interfaces. Interestingly, the MR at high magnetic field changes sign from positive to negative with increasing t, whose origin will be discussed in the meeting. This first demonstration of the spin-valve (GMR) effect in Fe-doped FMS heterostructures paves the way for device applications of these promising high-T_C FMSs.

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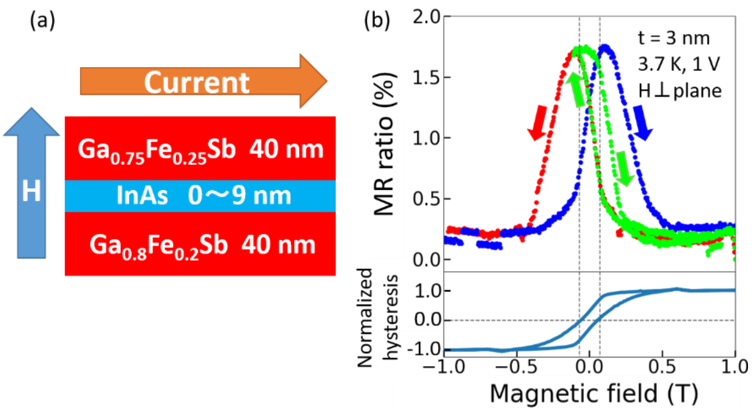

FIG. 1. (a) Sample structure. (b) Magnetoresistance of a ($Ga_{0.75}$,$Fe_{0.25}$)Sb (40 nm)/ InAs (t = 3 nm)/ ($Ga_{0.8}$,$Fe_{0.2}$)Sb (40 nm) structure measured at 3.4 K (upper panel) and the normalized hysteresis measured with SQUID in the same sample (lower panel). A magnetic field **H** is applied perpendicular to the film plane. In (b), the red and blue curves are the major loop with magnetic-field-sweep directions of + to – and – to +, respectively. The green curve is the minor loop.

References: [1] L. Chen *et al*, Nano Lett. **11**, 2584 (2011). [2] N. T. Tu *et al*, Appl. Phys. Lett. **108**, (2016). [3] N. T. Tu *et al*, Appl. Phys. Express **11**, (2018).

