Magneto-optical and magneto-transport characteristics of heavily Fe-doped ferromagnetic semiconductor (Ga,Fe)Sb

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For more than two decades, most of the studies on III-V based ferromagnetic semiconductors (FMSs) have been concentrated on Mn-doped FMSs, such as (In,Mn)As and (Ga,Mn)As. However, the maximum Curie temperature T_C of (Ga,Mn)As (200 K) and (In,Mn)As (90 K) are still much lower than room temperature despite their high hole densities (10^{20}-10^{21} cm^{-3}) [1,2]. Furthermore, there has been a dispute on the band structure and the origin of ferromagnetism. Recently, we have successfully grown a new p-type Fe-doped FMS $(Ga_{1-x},Fe_x)Sb$ (x = 3.9 – 13.7%) thin films by low-temperature molecular beam epitaxy (LT-MBE). $(Ga_{1-x},Fe_x)Sb$ (x = 3.9 – 13.7%) is an intrinsic FMS and has zinc-blende-type crystal structure with spin split band structure. In particular, T_C (140 K) of $(Ga_{1-x},Fe_x)Sb$ at x = 13.7% is the highest in narrow gap III-V FMSs, indicating that (Ga,Fe)Sb is promising for high-T_C FMS [3]. In this paper, we present the magneto-optical and magneto-transport properties of heavily Fe-doped $(Ga_{1-x},Fe_x)Sb$ with x = 17% and 20% grown by LT-MBE. Figure 1(a) shows the MCD spectra of our (Ga,Fe)Sb samples at 5K with a magnetic field of 1 T applied perpendicular to the film plane. For a reference, we also show the MCD spectrum of an undoped GaSb, in which the MCD intensity is very small. In contrast, the MCD spectra of (Ga,Fe)Sb show strongly enhanced peaks at E_1 (2.19 eV) and $E_1+\Delta_1$ (2.63 eV), corresponding to the optical critical point energies of the GaSb band structure [4,5]. Furthermore, we see no broad background which would be observed if metallic Fe nanoclusters existed. This result indicates that heavily Fe-doped $(Ga_{1-x},Fe_x)Sb$ (x = 17% and 20%) still maintains the zinc-blende crystal structure with large spin-split band structure due to the s,p-d exchange interaction. Figures 1(b) and 1(c) show the MCD-H characteristic and anomalous Hall effect (AHE), respectively, of the sample with x = 20% at various temperatures. Clear hysteresis was observed at low temperature, demonstrating the presence of ferromagnetic order. The hysteresis disappears at 300 K, indicating that the sample does not contain superparamagnetic Fe nanoclusters. Furthermore, the obtained T_C (230 K) of Ga,Fe)Sb (x = 20%) is the highest value reported in III-V FMSs so far. Our results open up a new possibility for room temperature FMS.

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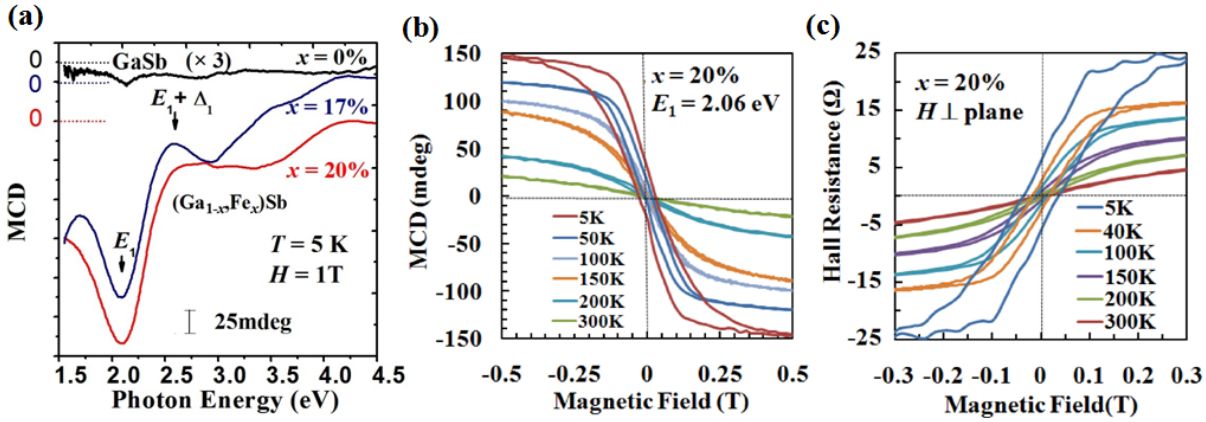

Fig. 1. (a) Reflection MCD spectra measured at 5 K under a magnetic field of 1 Tesla applied perpendicular to the film plane for samples with x = 17% and 20%. MCD spectrum of a reference undoped GaSb sample is also shown. (b) MCD-H characteristics and (c) Hall resistance of the $(Ga_{1-x},Fe_x)Sb$ sample with x = 20% at various temperatures.

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