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(Ga,Fe)Sb: a new p-type ferromagnetic semiconductor

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Ferromagnetic semiconductors (FMSs) have attracted much attention since they exhibit both semiconducting and magnetic properties, which may be useful for non-volatile and low-power-consumption electronic devices. Although Mn-based III-V FMSs, such as (In,Mn)As and (Ga,Mn)As, have been intensively studied, 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.[1,2] Furthermore, the origin of ferromagnetism of Mn-based FMSs is under debate. Recently, a new Fe-based n-type III-V FMS (In,Fe)As was successfully grown and exhibited surprisingly large *s-d* exchange interaction[3], which is promising for high-temperature ferromagnetism. In this work, a new Fe-based p-type FMS, $(Ga_{1-x},Fe_x)Sb$ (x = 3.9 – 13.7%), has been successfully grown by low-temperature molecular beam epitaxy. Figure 1(a) shows the magnetic circular dichroism (MCD) spectra of a 100 nm-thick (Ga,Fe)Sb sample (x = 3.9%) at various temperatures. The MCD spectra indicate that (Ga,Fe)Sb has the zinc-blende band structure with spin-splitting induced by *s,p-d* exchange interactions. The inset in Fig. 1(a) shows T_C plotted as a function of $xp^{1/3}$, where p is the hole concentration at room temperature. We see that T_C is proportional to $xp^{1/3}$, suggesting that ferromagnetism of (Ga,Fe)Sb is hole-induced. The highest T_C is 140 K for the sample with x = 13.7%. As shown in Figs. 1(b) and (c), the MCD-H characteristic and anomalous Hall effect of this sample exhibit the same clear hysteresis, demonstrating the presence of ferromagnetic order. The hysteresis becomes linear at 300 K, indicating that the sample does not contain superparamagnetic Fe nanoclusters. Note that the obtained highest T_C (140 K) is much higher than that of other Mn-doped narrow-gap FMSs; (Ga,Mn)Sb (T_C = 25 K) [4] and (In,Mn)As (T_C = 90 K).[2] Our results indicate that Fe-based FMSs are promising for semiconductor spintronic devices.

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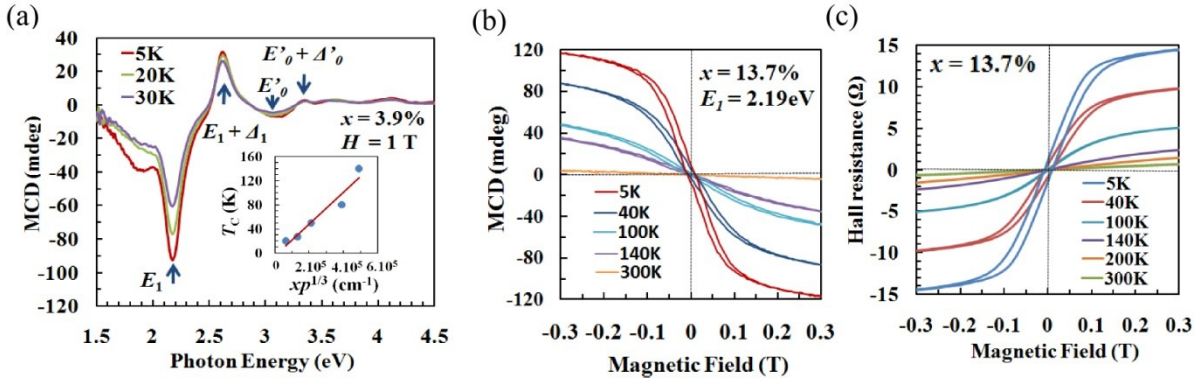

Fig. 1(a) MCD spectra measured at various temperatures of a 100 nm-thick (Ga,Fe)Sb (x = 3.9%) sample. Inset shows $xp^{1/3}$-dependence of T_C. (b) MCD-H characteristic measured at a photon energy of 2.19 eV of a 100 nm-thick (Ga,Fe)Sb (x = 13.7%) sample. (c) Temperature dependence of the Hall resistance for the same sample in (b).

1. L. Chen *et al.*, Nano Lett. **11**, 2584 (2011).
2. T. Schallenberg and H. Munekata, Appl. Phys. Lett. **89**, 04250713 (2006).
3. P. N. Hai *et al.*, Appl. Phys. Lett. **101**, 182403 (2012); Appl. Phys. Lett. **101**, 252410 (2012)**;** Appl. Phys. Lett. **100,** 262409 (2012); L. D. Anh *et al.*, Appl. Phys. Lett. **104**, 042404 (2014).
4**.** E. Abe *et al.*, Physica E **7,** 981 (2000).