Epitaxial growth and characterizations of quaternary alloy ferromagnetic semiconductor (In,Ga,Fe)Sb

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Ferromagnetic semiconductors (FMSs) are promising materials for spintronics applications because of their high compatibility with the semiconductor technology. To realize practical devices operating at room temperature, both p-type and n-type FMSs with high Curie temperature (T_C > 300 K) are required. Thus far, although the prototypical FMS (Ga,Mn)As has been intensively studied, it shows only p-type conduction with low T_C ($\leq$ 200 K) [1]. Recently, we have successfully grown Fe-doped III-V FMSs with high T_C; both p-type (Ga,Fe)Sb with T_C = 400 K [2] and n-type (In,Fe)Sb with T_C = 385 K [3]. For device applications of these new Fe-doped FMSs, we have to control their fundamental material properties, including the lattice constant, band structure, carrier type, T_C and magnetic anisotropy.

In this work, we have created a new type of Fe-doped quaternary alloy FMS, $(In_{1-x-y},Ga_x,Fe_y)Sb$, with room-temperature ferromagnetism. We grew heterostructures consisting of (from top to bottom) InSb (2 nm) / $(In_{0.74},Ga_{0.1},Fe_{0.16})Sb$ (15 nm) / AlSb (100 nm) / AlAs (6 nm) / GaAs (100 nm) on a semi-insulating GaAs(001) substrate by low-temperature molecular-beam epitaxy (LT-MBE). Figure 1(a) shows an X-ray diffraction (XRD) spectrum of our sample and the lattice constant of $(In_{0.74},Ga_{0.1},Fe_{0.16})Sb$. The XRD spectrum suggests that the $(In_{0.74},Ga_{0.1},Fe_{0.16})Sb$ layer grown by LT-MBE maintains the zinc-blende crystal structure without any other second phases. The lattice constant of $(In_{0.74},Ga_{0.1},Fe_{0.16})Sb$ follows the Vegard's law, suggesting that In and Ga atoms reside in the group-III sites. Figure 1(b) shows normalized magnetic circular dichroism (MCD) spectra measured at 5 K with a magnetic field of 1 T, 0.5 T and 0.2 T applied perpendicularly to the film plane. These spectra overlap on a single spectrum in the whole photon-energy range from 1.5 eV to 4.5 eV, indicating intrinsic and homogeneous ferromagnetism in the $(In_{0.74},Ga_{0.1},Fe_{0.16})Sb$ film. From the Arrott plot of the MCD intensity *vs*. magnetic field (MCD - *H*) curves, we estimate the T_C of the $(In_{0.74},Ga_{0.1},Fe_{0.16})Sb$ film to be 320 K. This high T_C and good crystal quality are promising for realizing more materials functionalities and device applications.

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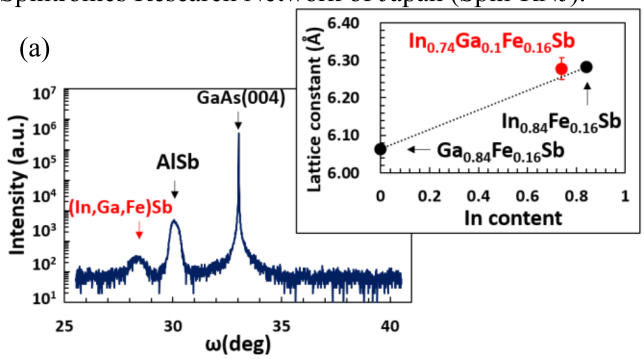

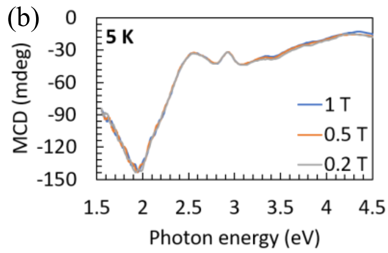

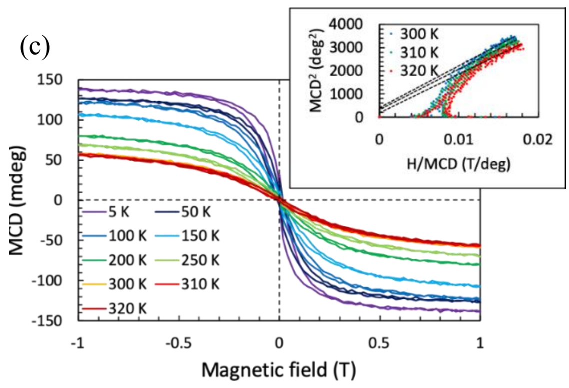

Figure 1(a) XRD spectrum of our sample and the lattice constant of $(In_{0.74},Ga_{0.1},Fe_{0.16})Sb$. (b) Normalized MCD spectrum measured at 5 K with a magnetic field of 1 T, 0.5 T and 0.2 T applied perpendicularly to the film plane. (c) MCD - *H* curve of $(In_{0.74},Ga_{0.1},Fe_{0.16})Sb$ measured at a photon energy of 1.94 eV and the Arrott plot.

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