Growth and characterization of insulating ferromagnetic semiconductor (Al,Fe)Sb

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To inject a highly-spin-polarized current into semiconductors is essential to realize spin-based electronic devices. One promising way is to use a ferromagnetic insulator as a tunneling barrier to filter out one type of spin, due to the different barrier heights for up-spin and down-spin carriers (the "spin-filtering effect"). So far, however, most of the potential spin-filter materials like Europium chalcogenides or complex oxides are not compatible with mainstream semiconductors, making it difficult to use these materials as spin-filters in semiconductor devices. Thus, an insulating ferromagnetic material that is compatible with zinc-blende type semiconductors is highly desired.

Recently, we have successfully grown Fe-based FMSs[1]. With Fe as magnetic impurities one can fabricate n-type FMS (In,Fe)As[1] and p-type FMS (Ga,Fe)Sb[2], and both materials show unexpectedly strong ferromagnetism. Here, we investigate the structural and magnetic properties of Fe-doped AlSb, which has a wider bandgap (~1.6 eV at 300 K). Realization of ferromagnetism in (Al,Fe)Sb would provide a good spin-filter, that can be combined with (In,Fe)As and (Ga,Fe)Sb to create a variety of III-V semiconductor spin devices.

The $(Al_{1-x},Fe_x)Sb$ thin films were grown on GaAs (001) substrates by low temperature molecular beam epitaxy, with various growth temperatures T_S (236 – 280℃) and Fe concentrations x (0 - 14%). The crystal structure of these samples was carefully studied by X-ray diffraction and high-resolution scanning transmission electron microscopy (scanning TEM). Transport properties were characterized by Hall effect measurements, while magnetic properties were characterized by magnetic circular dichroism (MCD) and superconducting quantum interference device (SQUID) magnetometry. At room temperature, all the samples show p-type conduction with hole concentrations around 10^{17} cm^{-3}, which are not correlated with the Fe concentrations. The resistivity increased with decreasing temperature,that is insulating behavior at low temperture. (Al,Fe)Sb samples with $x \leq 10\%$ maintain good zinc-blende crystal structure. The sample with 10% Fe shows ferromagnetism with a Curie temperature (T_C) of 40 K. Intrinsic ferromagnetism was confirmed for (Al,Fe)Sb with $x \leq 10\%$ by MCD analyses. In the sample with 14% Fe, a sudden drop of the mobility and T_C to 10 K was observed, which may be due to a microscopic phase separation in the crystal. We will discuss on the possible mechanism of the observed ferromagnetism.

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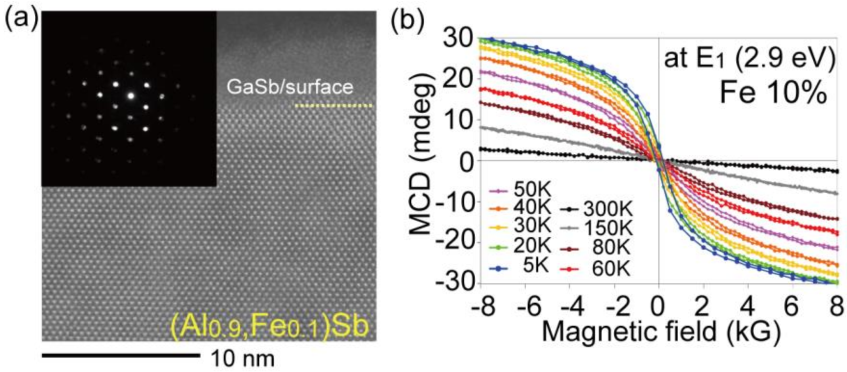

Fig. 1. (a) Scanning TEM image of a (Al,Fe)Sb layer with 10% Fe. The inset is the transmission electron diffraction pattern that indicates the zinc-blende crystal structure. (b) Magnetic field dependence of the MCD intensity at E1 measured at various temperatures for the same (Al,Fe)Sb sample with 10% Fe. From the Arrott plot of these data, the Curie temperature was estimated to be 40 K.

References

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