Magnetotransport Measurements on Ferromagnetic (In,Mn)Sb Thin Films

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Introduction

Semiconductor spintronics offer many unique capabilities that can potentially revolutionize electronics and computing. One of the requirements for realizing these capabilities is that the Curie temperature for ferromagnetism should be higher than room temperature. Our group has previously synthesized ferromagnetic InMnAs by metal-organic vapor phase epitaxy (MOVPE) with a $T_C$ of 330 K and attributed it to the presence of nanoscale clusters of magnetic ions. We predicted that a related semiconductor material InMnSb would have a high Curie temperature. Our group has successfully grown epitaxial thin films of this material. SQUID magnetometry measurements show that the material is ferromagnetic at room temperature. Structural characterization indicates that the films are single phase and secondary magnetic phases like MnSb are absent. The electronic transport properties of these alloys is not well understood. Presumably the valence band is spin split due to the presence of Mn in the material. Prior work on MBE grown films indicate the presence of an anomalous Hall effect (AHE) at low temperature, which is a signature of a carrier mediated mechanism. We measured electrical transport in the (In,Mn)Sb thin films as a function of temperature and field to observe the AHE.

Experimental

The magnetoresistance of several InMnSb films were measured. The films were grown on semi-insulating GaAs (100) substrates. Films with Mn concentration of <1% to 5% were used in this experiment. InMnSb films were patterned into Hall bars for the simultaneous measurement of Hall Effect and magnetoresistance. Constant current of 5mA was sourced and the potential difference created due to the Hall effect and resistance of the material were measured. The magnetic field was perpendicular to the flow of current and was swept between -18 to 18 T. The measurement was carried out at temperatures ranging from 1.4K to 298K.

Results and Discussion

Hall effect was measured up to 18 T. The sign of the Hall voltage indicated that the films are p-type. A hole concentration of $10^{19}$ cm$^{-3}$ and mobility of $10^{2}$ cm$^2$/Vs was calculated from the Hall data. A clear hysteresis was observed in the Hall voltage indicating that the films are ferromagnetic over the temperature range studied. The Hall resistivity is described by the equation $\rho_{xy} = R_0 B + R_A M$ where $R_0$ and $R_A$ are the normal and anomalous Hall coefficients, $B$ is the applied magnetic field and $M$ is the magnetization. The films exhibited an anomalous Hall Effect over entire temperature range. It was observed that $R_A$ is proportional to the longitudinal resistivity ($\rho_{xx}$) leading to a magnetoresistance dependant Hall voltage. A negative magnetoresistance was observed at temperatures below 15K. As the temperature is increased, the magnetoresistance changed sign and positive magnetoresistance was observed until 298K; a magnetoresistance as high as 6% was observed at this temperature. The magnetoresistance can be described using the Khosla-Fisher model. The scattering of carriers by fluctuations in the Mn ion concentration may be the cause for the positive magnetoresistance at higher temperatures.

Conclusions

The observation of an AHE effect in InMnSb supports the ferromagnetic nature of this material at room temperature. Furthermore, the presence of AHE points to the carrier mediated ferromagnetism in this material. The origin of the positive magnetoresistance at high temperature is presently being analyzed.

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