Hole Transport in Impurity Band and Valence Bands Studied in Moderately Doped GaAs:Mn Single Crystals

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GaAs very heavily doped, or alloyed, with Mn at compositions exceeding about 1 at.% is regarded as a prototype material of carrier-induced ferromagnetic semiconductors. Carrier transport in GaMnAs is correlated with magnetic properties and the discussion is continued about their mutual relations. It has been reported recently in Ref. 1 that even in samples with Mn composition of 5-7%, the Fermi level resides in the impurity band (IB) and the transport within IB may dominate over one in the valence bands. This was regarded as a reason for a very low hole mobility usually measured in GaMnAs and a high hole effective mass observed.

In this report, temperature-dependent Hall effect measurements in the temperature range 25-400 K are presented and discussed in moderately doped GaAs:Mn with Mn composition from the range about \((1-5) \times 10^{19} \text{ cm}^{-3}\). Single crystalline samples were prepared by an equilibrium growth method (Czochralski). Equilibrium growth has proven fruitful since these Mn compositions are still below the equilibrium Mn solubility limit in GaAs (undetermined precisely in the literature, but expected by present authors to exist above 0.2 at.% and below 1 at.% from the technological attempts and annealing studies). Mn compositions studied here extend to higher values than reported in early literature from 70-80-ies on Mn-doped GaAs, and falls slightly below the Mn range in recent studies related to ferromagnetism, above ~1 % Mn.

Results for moderately doped GaAs:Mn samples were interpreted within the multi-carrier transport model including light and heavy hole bands and the impurity band. We show that such model can fairly well describe both Hall concentration and mobility versus temperature. No hopping transport involving isolated Mn centers was observed at these Mn concentrations, as seen from the temperature dependence. For the highest doped sample studied (Mn~5x10^{19} \text{ cm}^{-3}) the Hall concentration is nearly constant in the range T=25-50K indicating transport within IB partially occupied (Fermi level located within IB). At higher temperatures transport in the valence bands dominates and we see that the transition temperature increases for higher Mn concentrations. In the highest doped sample (Mn~5x10^{19} \text{ cm}^{-3}) the width of IB, deduced from a reduction of Mn thermal ionization energy, is about 50 meV and IB still remains separated from the valence band. Hole mobility, in the studied range of Mn compositions, is mostly limited by ionized impurities at temperatures relevant to valence band transport. Below T~100 K the ionization of acceptors is not effective and the scattering for a fixed concentration of ionized centers (coming from a small compensation) is observed, while above about 100 K the ionization of acceptors inverts the character of mobility vs. T.

We also notice that a metallic transport within the impurity band observed shows that the Metal-Insulator transition in GaAs:Mn occurs through IB in Mn concentration range studied here.