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Electrical modulation of Curie temperature of (Ga,Mn)As channel in field-effect transistors: Mn composition dependence

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1. Introduction

The Curie temperature T_C of hole-induced ferromagnetic semiconductor (Ga,Mn)As can be controlled electrically, where its hole concentration, p, is varied in field-effect transistor structures (FETs) by applying external electric field E [1]. Here, we show x dependence of T_C, ΔT_C, and p of (Ga,Mn)As layers with various x (= 0.027-0.200), where ΔT_C is the maximum change of T_C by the application of E.

2. Experiment

The (Ga,Mn)As channel layers with thickness t were grown by using low temperature molecular beam epitaxy following the growth of 30 nm GaAs/420 nm $In_{0.15}Ga_{0.85}As$/30 nm $Al_{0.75}Ga_{0.25}As$/4 nm GaAs buffer layers on semi-insulating GaAs (001) substrate. We prepared two sets of samples; set 1 with t = 4.5 nm and x = 0.027, 0.038, 0.052, 0.072, and 0.089, and the set 2 with t = 4.0 nm and x = 0.075, 0.100, 0.125, 0.175, and 0.200. It was shown that (Ga,Mn)As with high x up to 0.200 shows an intrinsic ferromagnetism with a single magnetic phase [2]. All the samples were first processed into Hall bar geometry, and then 40-nm thick gate-insulator was deposited, which was Al_2O_3 (dielectric constant κ= 7.47) for set 1 and HfO_2 (κ= 20.17) for set 2, respectively. κ was determined by separate measurements using 100 nm Au/40 nm insulator/100 nm Au capacitors. Finally, Cr/Au gate electrode was defined on the insulator by lift-off process.

We measured the temperature dependence of sheet and Hall resistance (R_{sheet} and R_{Hall}) using a constant DC current of 1 μA under E. Applied E range for set 1 and set 2 is ±5 and ±4 MV/cm, respectively. Δp, the maximum modulation of p by E, was determined to be ~0.85×10^{20}cm^{-3} for set 1 and ~1.5×10^{20}cm^{-3} for set 2, and they are almost independent of x and show good agreement with the ideal values expected from the capacitance as $\Delta p_{cal} = 2\kappa\varepsilon_0 E/(et)$. p increases in proportion to x, where p was determined from the E dependence of R_{sheet}.

T_C was determined from the Arrott plots assuming that R_{Hall} is proportional to magnetization. Figure 1 shows x dependence of (a) T_C and (b) ΔT_C for all the samples (closed symbols for set 1 and open symbols for set 2). For both sets, T_C almost increases in proportional to x, whereas ΔT_C tends to decrease as x increases. The smaller ΔT_C for higher x is not expected from the conventional p-d Zener model for three-dimensional ferromagnetic semiconductors [3].

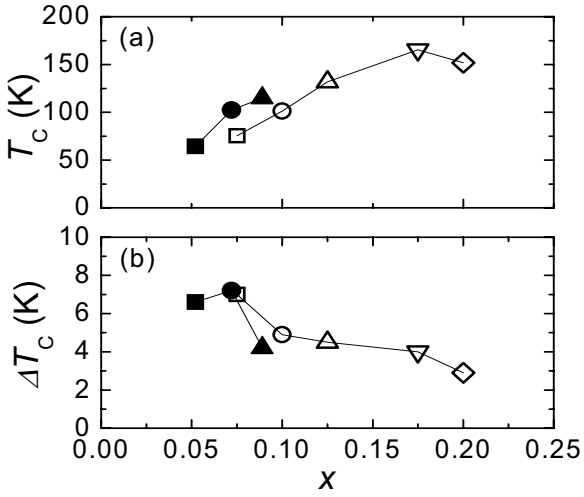

Figure : x dependence of (a) T_C and (b) ΔT_C.

3. Summary

We have investigated the x dependence of the Curie temperature T_C and its modulation ΔT_C by electric fields for $Ga_{1-x}Mn_xAs$-FETs with various Mn composition (x = 0.027–0.200). The magetotransport measurements revealed that the samples with higher x have higher T_C and larger hole concentration, whereas ΔT_C has a tendency to decrease as x increases.

Reference

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