

## Electrical control of magnetism in semiconductors

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### Abstract :

By utilizing the nature of carrier-induced ferromagnetism [1], the Curie temperature  $T_C$  of ferromagnetic semiconductors (In,Mn)As and (Ga,Mn)As can be modulated electrically through the change of their hole concentration ( $\Delta p$  of  $p$ ) in field effect transistor (FET) structures [2-4]. In this work, we have investigated  $T_C$  and its change of the magnitude,  $\Delta T_C$ , of (Ga,Mn)As channel as a function of its thickness  $t$  and Mn composition  $x$ .

(Ga,Mn)As layers with perpendicular magnetic easy axis were grown by molecular beam epitaxy on GaAs/AlGaAs/InGaAs/GaAs buffer layer on semi-insulating GaAs (001) substrate. We prepared (Ga,Mn)As with thickness  $t = 3.5, 4.0, 4.5,$  and  $5.0$  nm with a fixed  $x = 0.065$ , and (Ga,Mn)As with  $t = 4.0$  or  $4.5$  nm with various  $x$  from  $0.027$ - $0.200$ . The samples were processed into Hall-bar geometry with  $\text{Al}_2\text{O}_3$  or  $\text{HfO}_2$  gate insulator, and topmost Cr/Au metal gate electrode. We measured the temperature dependence of anomalous Hall resistance to determine  $T_C$  under gate electric fields  $|E|$  up to  $5$  MV/cm.

We found that  $T_C$  increases, while magnitude of  $\Delta T_C$  decreases, with increasing  $t$  as well as  $x$ , and that there exists linear relationship between  $\Delta T_C/T_C$  and  $\Delta p/p$ .

The work done with D. Chiba, Y. Nishitani, M. Endo, and H. Ohno

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[2] H. Ohno, D. Chiba, F. Matsukura, T. Omiya, E. Abe, T. Dietl, Y. Ohno, and K. Ohtani, *Nature* **408**, 944 (2000).

[3] D. Chiba, M. Yamanouchi, F. Matsukura, and H. Ohno, *Science* **301**, 943 (2003).

[4] D. Chiba, F. Matsukura, and H. Ohno, *Appl. Phys. Lett.* **89**, 162505 (2006).