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Enhancement of ferromagnetism by manipulating the wavefunctions in n-type ferromagnetic semiconductor (In,Fe)As quantum wells

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In quantum wells (QWs) containing a n-type ferromagnetic semiconductor (FMS) (In,Fe)As thin layer, the quantum size effect (QSE) gives a unique opportunity to tune the ferromagnetism by manipulating the two dimensional wavefunctions using a gate voltage V_G. This method has enabled us to effectively decrease the Curie temperature (T_C) of a (In,Fe)As thin film ($\Delta T_C/T_C$ = -42%) with almost no change in carrier density[1]. Here we show that by designing an appropriate QW structure, T_C of the (In,Fe)As thin film can also be enhanced with the same method.

We used a trilayer QW consisting of InAs (2 nm)/ $(In_{0.94},Fe_{0.06})As$ (5 nm)/ InAs (3 nm)/ Si-doped InAs (5 nm) on AlSb (300 nm), grown on a semi-insulating GaAs (001) substrate by molecular beam epitaxy. The sample was patterned into a 50×200 μm^2 Hall bar; a Au/Cr side-gate electrode was deposited; then the channel was covered with an electrolyte to form the FET structure. The transport and magnetic properties of the trilayer QW were characterized mainly by Hall measurements. The Si donors in the bottom 5 nm InAs layer supply electrons into the QW, as well as attract the electron wavefunctions towards the AlSb barrier side (see the left inset of Fig. 1). Thus, the electron carriers and the Fe magnetic moments in the QW are initially separated when the gate voltage V_G is 0. When applying positive V_G, the two dimensional wavefunctions are moved towards the (In,Fe)As layer, thus the overlap of the wavefunctions and the local Fe magnetic moments is increased. As a result, T_C is enhanced and reaches a maximum when the overlap is largest at V_G = 2 V (middle inset of Fig.1). Further increase in V_G to 3 - 4 V leads to a decrease in T_C because the overlap is decreased (right inset of Fig.1). As shown in Fig. 1, while the electron sheet density (n_{sheet}) of the QW is nearly unchanged (largest Δn_{sheet}= 1.3×10^{12} cm^{-2}), T_C of the (In,Fe)As layer was increased from the initial value of 27 K (V_G = 0 V) to 35 K (V_G = 2 V) and then decreased to 30 K (V_G = 4 V). This result indicates that one can freely control the T_C-V_G relationship by designing the magnetic QW structure. The present electrical control of ferromagnetism by wavefunction manipulation in n-type FMS QW demonstrated in this study is attractive for novel device applications.

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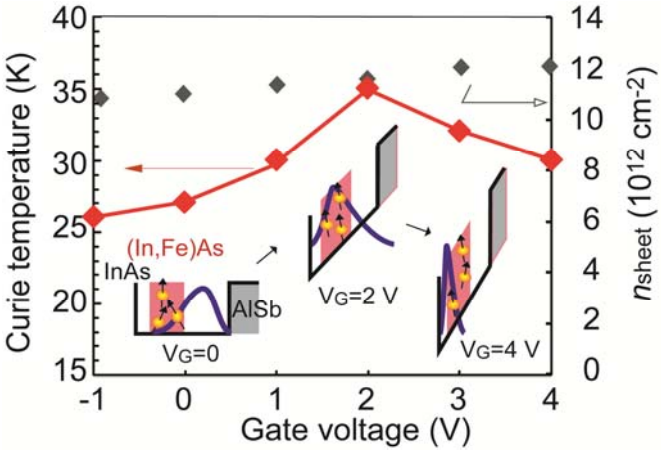

Fig. 1 Change of T_C (red diamonds) and n_{sheet} (grey diamonds) of the (In,Fe)As FET structure with different gate voltage V_G. The change of T_C is caused by the movement of the electron wavefunction inside the trilayer InAs/(In,Fe)As/InAs QW (illustrated in the insets).

References: [1] L. D. Anh et al.,61st JSAP Spring Meeting, 19p-E7-14, Aoyama Gakuin University, March 17-20, 2014.