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Electrical control of ferromagnetism in n-type ferromagnetic semiconductor (In,Fe)As quantum wells

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(In,Fe)As is a n-type ferromagnetic semiconductor (FMS) whose intrinsic electron-induced ferromagnetism has been confirmed by various experiments[1,2,3]. Electron carriers in (In,Fe)As reside in the conduction band, thus having small effective mass (0.03~0.17 m_0)[2], relatively high mobility (~500 cm^2/Vs), and long coherence length (>40nm)[4]. These give rise to novel effects such as the quantum size effect (QSE) which makes this FMS promising for applications utilizing magnetic quantum heterostructures. Recently, ferromagnetism of a trilayer InAs/(In,Fe)As/InAs QW grown on GaAs has been changed by manipulating the carrier wavefunctions using surface wet etching[4].

In this work, we demonstrate the electrical control of ferromagnetism in such a trilayer QW using field-effect transistor (FET) structure with an electrolyte gate. The trilayer QW consists of InAs (2nm)/ ($In_{0.94}$,$Fe_{0.06}$)As (8nm)/ InAs (5nm) on AlSb (50nm), grown on a semi-insulating GaAs (001) substrate by molecular beam epitaxy. The sample was etched 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. When applying the gate voltage V_G from 0 to –3 and 6 V, the sheet electron density (n_{sheet}) in the trilayer QW was changed from 6×10^{12} to 5.5×10^{12} and 8×10^{12} cm^{-2}, respectively. Although the change in n_{sheet} is small, the Curie temperature (T_C) of the (In,Fe)As layer was decreased from the initial value of 24 K (V_G = 0 V) to 17 K (V_G = 6 V) and 14 K (V_G = –3 V) (see Fig.1). This is caused by the movement of the wavefunction of electron carriers towards the ends of the trilayer QW, thus decreasing the overlap of the wavefunction and the local Fe magnetic moments. We demonstrate reversible control of the ferromagnetism of n-type FMS (In,Fe)As by a gate voltage, proving its intrinsic electron-induced ferromagnetism, as well as opening up new possibilities of device applications. This work is supported by Grant-in-Aids for Scientific Research including the Specially Promoted Research, the Project for Developing Innovation Systems of MEXT. L.D.A acknowledges the Research Fellowship of JSPS.

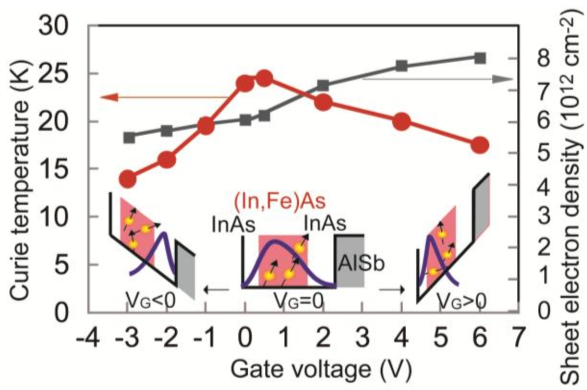

Fig. 1 Change of T_C (red circles) and n_{sheet} (grey squares) of the (In,Fe)As FET structure with different gate voltage V_G. The change of T_C is caused by the movement of the electron wavefunction inside the trilayer InAs/(In,Fe)As/InAs QW (illustrated in the insets).

References: [1] P. N. Hai et al. , Appl. Phys. Lett **101,** 182403 (2012). [2] P. N. Hai et al., Appl. Phys. Lett, **101,** 252410 (2012). [3] P. N. Hai et al., Appl. Phys. Lett. **100,** 262409 (2012). [4] L. D. Anh *et al.* , arXiv:1309.5283 [cond-mat.mtrl-sci].