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Large spin susceptibility of HgCdTe two dimensional electron gas in the extreme quantum limit regime

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The spin state of electrons in semiconductors has attracted much attention since Datta and Das proposed a spin FET in 1990[1]. Since the intrinsic SO coupling is strong, so is the Zeeman and Rashba effect[2] in HgCdTe. Moreover, a remarkably long spin lifetime of HgCdTe has been reported recently; 356 psec and 24 psec at 150K and 300K, respectively [3] These unique spin properties of HgCdTe can be a great advantage for spin manipulation in spintronic devices. In this study we have observed large spin susceptibility(X) of HgCdTe two dimensional electron gas(2DEG) when only one or two spin subbands are occupied. We employ two different methods to measure it. First, we used the coincidence method in tilted magnetic field introduced by Fang and Stiles in silicon MOSFET[4]. Second, we follow the parallel-field method to drive X from the full polarization condition of the 2DEG[5].

Samples of p-type $Hg_{1-x}Cd_xTe$(x=0.24) were grown by a metal-organic chemical vapor deposition method on a buffer layer of 5 μm CdTe and GaAs substrate. A HgCdTe FET with Hall bar geometry was patterned by using a photoresist and wet etched. The whole Hall-bar was encapsulated with 200nm Al_2O_3. The 1000A-thick aluminum gate was deposited on top of the insulator, and voltage probes of the Hall bar were located beneath the gate metal. All measurements were carried out at 2 K and the carrier density(n_s) and mobility are found to be $1.42\times10^{15}m^{-2}$ and 8.0 m^2/Vsec, respectively.

The spin susceptibility can be given by $X \equiv d\Delta n/dB = e/2h\, g^*m_r^*$ [5], where g* is the effective g factor, m_r^* is the effective mass divided by the free electron mass, and Δn is the difference of carrier density between up and down spin($n\uparrow - n\downarrow$). Therefore, $g^*m_r^*$ can be used for the values of X. Typical experimental plots of Shubnikov-de Haas(SdH) oscillations and the quantum Hall effect are shown in Fig.1(a). The filling factor(ν) defined by n_s divided by Landau degeneracy(eB/h) indicates that the spin splitting is resolved. When ν is lower than 1, i.e. if the field is higher than 6T, all of the electrons are fully polarized. Fig. 1(b) shows the magnetoresistance for the magnetic field($B_{||}$) applied parallel to the sample plane. With increasing $B_{||}$, the polarization, $P=(n\uparrow - n\downarrow)/n_s$ of the 2DEG increases and saturates at unity at a threshold field B_p when $g^*\mu_B B_p/2=E_F$, from which $g^*m_r^*$ is given by $2n_sh/eB_p$. From the fact that full polarization of the 2DEG can be detected at the onset of an exponential behavior in the papallel-field magnetoresistance[5], which was B_p =7.6 Tesla in our sample as indicated with the arrow in Fig. 1(b), we obtained $g^*m_r^*$ =1.6.

Fig. 2 shows the normalized Hall conductance by the fundamental conductance(e^2/h) versus the perpendicular component of magnetic field(B cos(θ)). The magnetic field was applied with tilted angle θ from the normal direction of the sample. With increasing θ, quantum Hall plateau at ν=2 and 3 disappears at θ=37° and 67°, respectively, which indicate the coincidence of spin-split Landau levels. $g^*m_r^*$ can be expressed by this coincidence angle(θ_c) : $g^*m_r^* = 2i\cos\theta_c$, where i is any positive integer. The obtained $g^*m_r^*$ from this analysis is 1.6 which is the same value from the parallel-field magnetoresistance with remarkable coherence.

This $g^*m_r^*$ is relatively large value in comparison with the other 2DEGs. For GaAs 2DEG, $g^*m_r^*$ is 0.168 which is ten times lower than our result, and $g^*m_r^* \approx 0.75$ for HgTe/HgCdTe quantum well[6]. However, the theory based on the framework of an 8x8 k•p model[7], $g^*m_r^*$ should be approximately unity. This enhanced spin susceptibility $X \sim g^*m_r^*$ in a 2DEG in HgCdTe can be related to the exchange coupling between electrons near the fully polarized regime[5] in low density 2DEG.

As a conclusion, we measured $g^*m_r^*$ of HgCdTe 2DEG system with two independent method which yield the same value, and it is remarkably large compared with any other 2DEG system. The large value of spin susceptibility as well as large g-factor is the unique properties of HgCdTe which can be utilized spintronic material.

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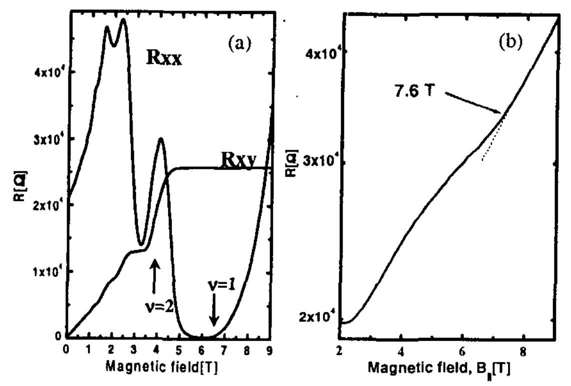

Fig. 1 (a) magnetoresistance(Rxx) and Hall resistance(Rxy) for perpendicular magnetic field. (b) magnetoresistance for parallel magnetic field. The dotted line is for eye-guide.

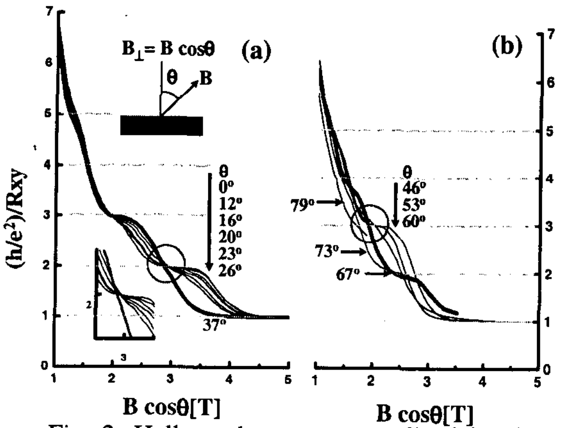

Fig. 2. Hall conductance normalized by the fundamental conductance(e^2/h) versus the perpendicular component of magnetic field for various angles(θ) between sample plane and magnenetic field.

References

[1] S. Datta and B. Das, Appl. Phys. Lett, **56**, 665 (1990)
[2] J. Hong, et. al, Journal of the Korean Physical Society, **45**, 197(2004)
[3] P. Murzyn, et al. Phys. Rev. B **67**, 235202(2003)
[4] F. F. Fang and P.J. Stiles, Phys. Rev. **174**, 823(1968)
[5] J. Zhu, et al. Phys. Rev. Lett, **90**,056805(2003) and references are therein
[6] X. C. Zhang,et al,, Phys. Rev. B. **69**, 115340(2004)
[7]M. W. Weiler, Semiconductors and Semimetals, edited by R. K. Willardson and A. C. Beer (Academic Press, New York), Vol. 16, Chap. 3 (1981)