Landau level crossing and anti-crossing of bilayer two-dimensional hole gas in Ge/SiGe quantum well

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Recent development of crystal growth technology enable us to fabricate high mobility two-dimentional hole gas (2DHG). Particularly, the 2DHG in strained Ge is remarkable since it reveals large hole mobility and small effective mass almost comparable to that of electron. However, there have been only few studies on the quantum Hall effect (QHE) and its angular dependence of 2DHG in strained Ge/SiGe quantum well (QW). Since heavy hole of Ge does not couple with in-plane magnetic field, it was not possible to observe Landau level (LL) crossing of this material with a tilted magnetic field. Here we show, by using bilayer 2DHG in Ge/SiGe QW, clear LL level crossing and anti-crossing can be observed.

A QW consist of 20 nm $Si_{0.35}Ge_{0.65}$/20 nm Ge/20 nm $Si_{0.35}Ge_{0.65}$ is grown on $Si_{0.35}Ge_{0.65}$/Si(001) virtual substrate by using gas-source MBE. By introducing *p*-type doping on the top and bottom side of QW, bilayer 2DHG is created in the well. A sheet hole density of the bilayer 2DHG is 6.0×10^{11} and 7.3×10^{11} cm^{-2}, respectively, and average mobility is 35,000 cm^2/Vs. A Hall resistance R_{xy} and longitudinal R_{xx} is measured at 50 mK under the magnetic field $B_\perp$ perpendicular to the sample as shown in Fig. 1. Resistance minima appeared at the filling factor ν=(2N+2), because of the bilayer QHE. We measured magnetic field angle θ dependence of R_{xx} and plotted versus $1/\cos\theta$ as shown in Fig. 2. R_{xx} periodically changes with respect to $1/\cos\theta$, indicating this is due to the crossing of the LLs. Up to three-times of the crossing was observed within our measurement range. This is very distinct from single layer 2DHG sample where LL crossing was not observed within the same field range.

We also observed anti-crossing of the LLs (not shown). Furthermore, a weak anti-localization was observed in the low-field data of R_{xx}. Thus we think anti-crossing is due to the large spin orbit interaction of the 2DHG in Ge/SiGe QW. This system enables us to study various LL physics in high mobility 2DHG.

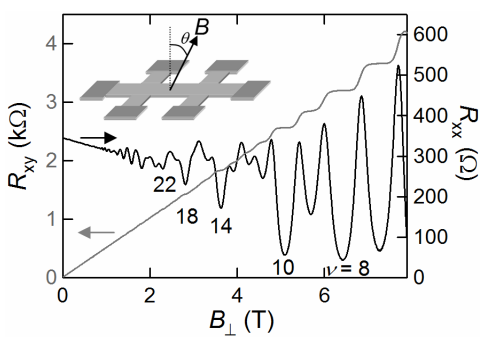

Fig. 1: Perpendicular magnetic field ($\theta = 0$) dependence of R_{xy} and R_{xx}.

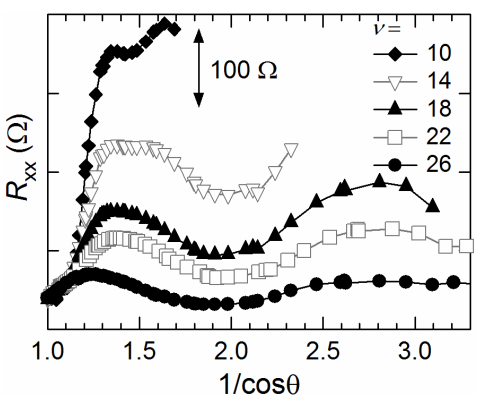

Fig. 2: R_{xx} vs. $1/\cos\theta$ at various ν.