Magnetotransport in a (100)Si/ Sige/Ge -Based Heterostructures with 2DHG of Ultra High Mobility in 100% Pure Ge Quantum Wells in High Magnetic Fields B>16T and T<350 mK

Mironov, O.A., Leadley, D.R. (University of Warwick,Physics, UK); Suslov, A.V. (NHMFL)

Introduction

The extremely high 2DHG mobility of over 1.3×10^6 cm^2/Vs ($P_s=2.9\times10^{11}$ cm^{-2} at T<10K) [1-4] and low hole effective mass (0.063 ± 0.001)m_o determined from Shubnikov-de Haas oscillations (SdHO) has enabled the fractional quantum Hall effect (FQHE) to be observed for the first time in a compressively strained (0.65%) sGe-QW (20 nm) selectively doped by boron [5]. The sGe-SiGe/(001)Si-based heterostructures grown by the RP-CVD method (ASM, Epsilon 2000) [1-2]. The 2DHG mobility in our system is more than ten times higher than previously reported for similar SiGe-based heterostructures grown by use of LEPE-CVD [6] and MBE [7] and very comparable to the latest results published for 2DEG in undoped gated stretched sSi-QWs on SiGe-buffer [8].

Experimental

Magneto-transport measurements were performed using a standard AC lock-in (NHMFL Cell 8: at 25mK-900 mK/ 35T and SCM-2 facility: 350 mK/18T in January 2014) and DC delta-mode techniques (SCM-1: 19 mK-900 mK/ 18T in July 2014). The longitudinal magnetoresistance $R_{xx}(B)$ of 3 square-shaped samples of 4mm×4 mm sizes [9] was measured (at SCM2 -one sample, and at SCM1- two more samples from the same wafer 11-289AD) at various tilt angles in magnetic fields up to 18 T.

Results and Discussion

Measured angle dependence study revealed that the SdHO are only controlled by perpendicular magnetic field at Θ=0°, rather than the total field B (with no obvious SdHO at Θ =90°), indicating a 2DHG transport behavior. The fast Fourier transform (FFT) spectrum of $\Delta R_{xx}(1/B)$ at Θ =0° (B was perpendicular to the sample plane) shows one frequency peak (B_{FFT} = 5.8T, Ps=2.8×10^{11} cm^{-2}), which are clearly indicating the one sub-band occupation for heavy hole Ge-valence band, and which is splitted from light-hole band for ~ 70 meV due to 0.65% compressive strain of Ge-QW. The SdHO 2DHG sheet density are in good agreement with Hall effect data results (±3%).*Firstly*, our NHMFL results confirm that the FQHE is a truly universal and material independent phenomenon while *secondly*, should allows us further study the energy gap between the states of Composite Fermions (CF) in a sGe 2D holes. The FQHE features observed at 26 mK and around one half filling factor (at B~23T) include five CF Landau levels (LLs) ranging from v=1/3 to v=5/11, while more states are observed in higher LLs around v=3/2 (at B~ 8T) and 5/2 (at B ~ 4.8T).

Additionally to our recent discovery of resistance anisotropy at B=0 in [110]-directions of (001)Si substrate plane for a 2DHG in sGe-QWs [3], during NHMFL-experiments, we observed much stronger anisotropy effect under presence an in-plane magnetic field B|| [10]. When an in-plane field is applied along x direction, the Rxx maxima grow, while the Ryy maxima decrease. At T = 350 mK, the ratio Rxx/Ryy reached 3×10^4, corresponding to the ratio in resistivity ρxx/ρyy ~35 [10]. The anisotropy persists to filling factors as high as ~ 40 and roughly coincides with the collapse of spin-splitting. Our results are different from similar anisotropy observations in unstrained GaAs-QWs and sSi-QW/SiGe[11] due to the absence of minima at half-filling in the easy transport direction, and persistence to much higher temperatures and filling factors. During experiments in July 2014 at NHMFL (SCM-1,19 mK-900 mK) we completed detailed investigations of angle and temperature dependencies in more wider ranges, as to first preliminary results in January 2014 at only 350 mK and Θ = 0º , 53º , and 56º [10].

Conclusions

Further FQHE and CF analysis and strongly anisotropic magneto-transport at high filling factors could lead to the first CF- mass and spin splitting evaluations for 2D holes in compressively strained sGe-QWs by means of an angle dependent experiments in the extended temperature and B>35T ranges.

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