VALLEY SPLITTING OF TWO-DIMENSIONAL ELECTRONS IN SILICON IN TITLED MAGNETIC FIELDS

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Introduction

For the two-dimensional electron system (2DES) confined in a (001) Si quantum well, the in-plane tensile strain lifts the six-fold valley degeneracy in bulk Si and leaves only the two out-of-plane valleys in the bottom of the conduction band. The small energy difference between these two valley states, known as the valley splitting, has long been noticed, while its physical origin and magnetic (B) field dependence have remained as puzzling questions.

Previous experimental studies have shown that the valley splitting depends only on the perpendicular component of the B-field [1]. However, no gap measurement was reported near the coincidence point, at which interesting physics is expected due to the close proximity of Landau levels with different quantum indices at the Fermi level.

Experimental Results and Discussion

Our samples are modulation doped Si/SiGe heterostructures grown by molecular-beam epitaxy (MBE). Five samples were investigated in our study, with the 2DES densities (n) ranging from 1.4 to $3.1\times10^{11}cm^{-2}$ and mobility (μ) from 6.3 to $19m^2/Vs$. While all the samples show essentially the same behavior, here we focus on the results from the highest mobility ($\mu=19m^2/Vs$ at $n=1.4\times10^{11}cm^{-2}$) one.

The measurements at the NHMFL were carried out in the 18/20T superconducting magnet cell equipped with a top-loading dilution refrigerator with a base temperature of T=20mK. This high field and low temperature facility enabled us to access the valley split states up to very high tilt angles.

In our tilted B field experiments, a hysteretic magnetoresistance spike, normally taken as a signature of quantum Hall ferromagnetism, is observed around Landau level filling factor $\nu=3$ and close to the coincidence angle. Furthermore, we have carried out a detailed study of the energy gap at $\nu=3$, due to the valley splitting, as a function of the total field. Before the coincidence, the $\nu=3$ gap is nearly constant, ~0.4K, consistent with previous observations. However, it jumps suddenly from 0.4K to 2K at the coincidence, relaxes to 1.4K in ~ 0.5T, and eventually saturates at 1.3K. Such an asymmetric gap behavior around the coincidence was also observed for the next odd-integer quantum Hall state at $\nu=5$.

Conclusions

Our results reveal very interesting physics on the valley splitting in Si based 2DES. Out of the coincidence region, the splitting is indeed independent of the in-plane B field, though the gap differs significantly for different Landau or spin levels. The rapid rise of the inter-valley gaps towards the coincidence angles, on the other hand, can not be explained in the independent-electron model. We believe that this anomaly is related to the strong couplings of the nearly degenerate energy levels in the coincidence region.

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References

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