SAND2015-0380R

# Competing Quantum Hall Phases in the Second Landau Level in Low Density Limit

W. Pan (Sandia National Labs); A. Serafin, J.S. Xia, Y. Liang, N.S. Sullivan (University of Florida and NHMFL); K.W. Baldwin, K.W. West, L.N. Pfeiffer, and D.C. Tsui (Princeton University)

## Introduction

Up to date, studies of the fractional quantum Hall effect (FQHE) states in the second Landau level have mainly been carried out in the high electron density regime, where the electron mobility is the highest. Only recently, with the advance of high quality low density MBE growth, experiments have been pushed to the low density regime [1], where the electron-electron interactions are strong and the Landau level mixing parameter, defined by $\kappa = e^2/\varepsilon l_B/\hbar\omega_c$, is large. Here, $l_B = (\hbar e/B)^{1/2}$ is the magnetic length and $\omega_c$ = eB/m the cyclotron frequency. All other parameters have their normal meanings. It has been shown that a large Landau level mixing effect strongly affects the electron physics in the second Landau level [2].

## Experimental

We carried out ultra-low temperature transport studies in very low density and high quality two-dimensional electron system at the high B/T facilities in Gainesville. Sample A has a low temperature electron density and mobility of $n=5\times10^{10}$ cm$^{-2}$ and $\mu= 10\times10^6$ cm$^2$/Vs, respectively. The quantum well width is 60nm. In sample B, $n=4.1\times10^{10}$ cm$^{-2}$ and $\mu = 9\times10^6$ cm$^2$/Vs. Low frequency (~ 7Hz) lock-in technique was utilized to measure the magnetoresistance $R_{xx}$ and $R_{yy}$.

## Results and Discussion

Figure 1 shows $R_{xx}$ and $R_{yy}$ at three temperatures of T ~ 16, 18, and 24mK in sample A. Noticeably anisotropic transport is clearly seen at n=7/2 at T ~ 16mK. This anisotropy disappears at T ~ 24 mK. Figure 2 shows the 5/2 energy gap as a function of density. Data from other work Ref. [1,3] are also included. The inset highlights the data points in the low density regime. The 5/2 energy gap first decreases with increasing density, reaches a minimal value at n ~ $5.0\times10^{10}$ cm$^{-2}$, and then increases with increasing density. This density dependence is consistent with a spin transition in the fractional quantum Hall effect.

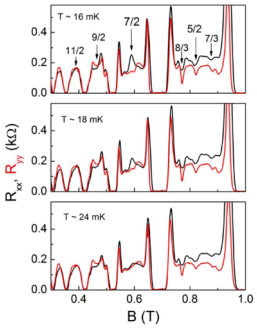


Figure 1

## Conclusions

Our result shows that the 7/2 state, a FQHE state in high density samples, becomes anisotropic in a sample of density $n = 5.0\times10^{10}$ cm$^{-2}$. In another sample with a lower electron density of $4.1\times10^{10}$ cm$^{-2}$, strong 8/3, 5/2 and 7/3 FQHE states were observed. Comparison with previous data suggests that the 5/2 state may be spin-unpolarized in this sample. Our results demonstrate that in the low density regime the strong electron-electron interactions and large Landau level mixing effect play an important role in competing ground states in the second Landau level.

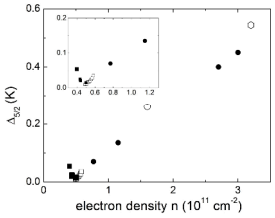


Figure 2

## Acknowledgements

The work was supported by the DOE Office of Basic Energy Science. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. The work at Princeton was funded by the Gordon and Betty Moore Foundation and Keck Foundation. A portion of this work was performed at the National High Magnetic Field Laboratory, which is supported by National Science Foundation Cooperative Agreement No. DMR-1157490, the State of Florida, and the U.S. Department of Energy.

## References

[1] Pan, W., et al, RRL **108**, 216804 (2012); Liu, G., et al, PRL **108**, 196805 (2012); Samkharadze, N., et al, arXiv: 1302.1444;
[2] Chesi S. and D. Loss, PRL. **101**, 146803 (2008); A. Wójs, C. Tőke, and J.K. Jain, PRL. **105**, 096802 (2010); E.H. Rezayi and S.H. Simon, PRL. **106**, 116801 (2011); I. Sodemann and A.H. MacDonald, arXiv: 1302.3896.
[3] H.C. Choi, H.C., et al, PRB, **77**, 081301 (2008); C. R. Dean, C.R., et al, PRL **100**, 146803 (2008).