Quantum Hall Resistance Anomalies Observed at $\nu = 1/3$ and $1 < \nu < 2$ in Two-Dimensional Hole System

Katsuyoshi Kodera, Yoshiaki Hashimoto, Akira Endo, Shingo Katsumoto and Yasuhiro Iye

Institute for Solid State Physics, University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8581, Japan

Abstract. Magnetotransport measurements on two-dimensional hole gas samples revealed anomalous behavior at low temperatures in two specific regions of Landau level filling ν. Although the fractional quantum Hall (FQH) states develop normally as temperature is lowered down to $\sim$ 100 mK, the zero resistance state around $\nu \sim 1/3$ becomes unstable as temperature is further lowered and aperiodic fluctuations develop. By contrast, the $\nu = 2/3$ and other FQH states seem to be intact down to the lowest temperature (20 mK). Another anomalous behavior is observed in the range $1 < \nu < 2$, where resistance fluctuations develop below $\sim$ 400 mK, which overwhelm the FQH features at ν = 5/3 or 4/3. The physical origin of these anomalies is yet to be identified.

Keywords: GaAs/AlGaAs, 2D hole gas, fractional quantum Hall effect
PACS: 73.43.-f; 73.40.-c; 73.63.Hs;

Two-dimensional electron system (2DES) subjected to high magnetic field and low temperature has proved to be an inexhaustible spring of fascinating physics. They exhibit a variety of many body states including a series of fractional quantum Hall (FQH) states, Wigner solid, stripe and bubble phases, and composite fermion liquid[1]. Two-dimensional hole system (2DHS) constitutes another system of great interest which is so far less explored. Although much of physics of the quantum Hall systems is thought to be independent of the sign of carriers, there are a few characteristics such as large effective mass and strong spin-orbit coupling that highlights the uniqueness of 2DHS. With steady improvement in the quality of 2DHS, phenomena unique to 2DHS have been uncovered.

In this work, we report on anomalous behavior of 2DHS at the filling factor $\nu \sim 1/3$ and $1 < \nu < 2$.

There are two categories of 2DHS samples. One is those grown on the (100) surface with Be as acceptor[2]. The other is those grown on the (311)A surface of GaAs where Si acts as acceptor[3]. Majority of the high mobility 2DHS studied in recent years belong to the latter category[4][5][6][7]. As for the (100) substrate, Manfra *et al.* have recently succeeded in making very high mobility 2DHS with carbon acceptor[8]. The 2DHS samples used in the present work are fabricated on the (100) substrate with Be dopant.

The growth sequence of our sample was as follows: A 600nm thick GaAs buffer layer was initially grown on a GaAs (100) substrate, followed by 50 repeats of a 2.5-nm GaAs/ 2.5-nm $Al_{0.3}Ga_{0.7}As$ superlattice. A 1 μm thick GaAs layer was then grown followed by a 100nm thick undoped spacer layer of $Al_{0.3}Ga_{0.7}As$ and a 100nm thick $Al_{0.5}Ga_{0.5}As$ doped with Be with density 7.5×10^{17} cm^{-3}. The structure was completed with a 15nm thick $Al_{0.5}Ga_{0.5}As$, followed by a 25nm thick GaAs capping layer. The entire structure was grown at 600 °C. This structure resulted in a relatively low 2DHS density $p = 1.1 \times 10^{11}$ cm^{-2} and decent Hall mobility $\mu = 3 \times 10^5$ cm^{2}V^{-1}s^{-1}. (Analysis of low field magnetotransport data revealed the carrier density of the two bands to be 3.2×10^{10} and 7.9×10^{10}cm^{-2}, respectively.) From the analysis of the Shubnikov-de Haas oscillations, the effective mass and quantum mobility were estimated to be $M^* \sim 0.5 m_0$ and $\mu_q \sim 1 \times 10^5$ cm^{2}V^{-1}s^{-1}. The parameter characterizing the ratio of Coulomb interaction and Fermi energy is estimated as $r_s = m^* e^2/(4\pi\varepsilon\hbar^2\sqrt{\pi p}) \approx 12$, where p is the 2DHS density and other parameters have their usual meanings. The sample was shaped in a standard Hall bar with AuZn ohmic contacts.

Figure 1 shows magnetoresistance traces at representative temperatures measured with probe current of 1 nA at frequency 13 Hz. The trace at higher temperature looks normal with a series of FQH states with well-developed Hall plateaus and zero diagonal resistance. However, anomalous behavior was observed at two specific filling ranges when the system is further cooled.

Around filling $\nu = 1/3$, the zero resistance state became unstable at $T < 100$ mK. The magnetoresistance showed aperiodic fluctuations, whose amplitude was sensitive to the probe current and increased with decreasing temperature. The fluctuation in ρ_{xy} was less conspicuous. The fluctuation pattern was reproducible and independent of the sweep rate of the magnetic field. Given the surprising observation, we duly checked for any problems with the electrical contacts, but found none. The

CP850, *Low Temperature Physics: 24th International Conference on Low Temperature Physics;*
edited by Y. Takano, S. P. Hershfield, S. O. Hill, P. J. Hirschfeld, and A. M. Goldman

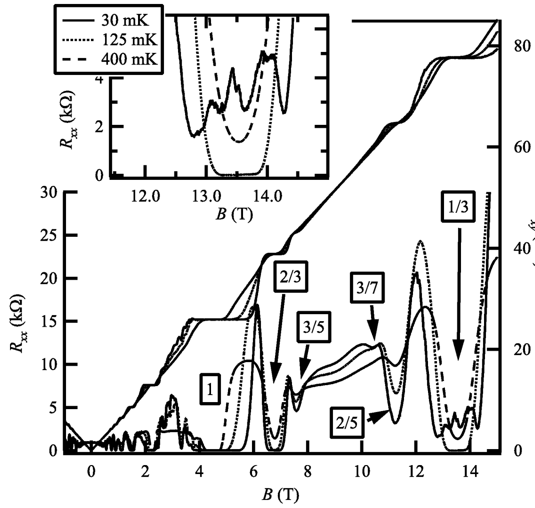

FIGURE 1. Magneto- and Hall resistance traces at temperatures $T = 30, 135, 400$ mK. The inset shows the part in the vicinity of $\nu = 1/3$ in an expanded scale.

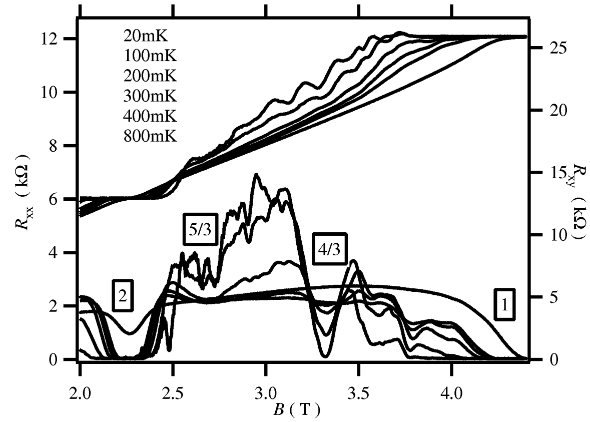

FIGURE 2. Magneto- and Hall resistance traces in the range of $1 < \nu < 2$ at different temperatures.

anomalous behavior around $\nu = 1/3$ is in marked contrast with the normal behavior around $\nu = 2/3$ down to the lowest temperature (20 mK). Thus it is unlikely to be spurious phenomenon caused by the measurement system. The anomalous behavior around $\nu = 1/3$ disappears either by slightly raising the temperature ($T > 100$ mK) or by passing a modest probe current ($I > 10$ nA). The fluctuation is aperiodic, but fluctuation period typically falls in the range of 0.03-0.1 T.

It is interesting to compare the present result with those reported for 2DHS by other groups. Manoharan *et al.*[4] observed insulating phases adjacent to the $\nu = 2/5, 1/3$ and 2/7 FQH liquid phases, and argued that the insulating phases are Wigner solid. Csathy *et al.*[7] reported anomalous magnetoresistance oscillation in the vicinity of $\nu = 1/3$, which occurred at $B \approx 1.2$ T for their very low density 2DHS. They speculate that the phenomenon is a sign of phase coexistence of the $\nu = 1/3$ FQH liquid and a Wigner solid.

Next, we turn to the filling range $1 < \nu < 2$, shown in Fig. 2. Here, aperiodic fluctuation was observed both in ρ_{xx} and ρ_{xy} at $T < 400$ mK, which seemed to overwhelm the FQH features at $\nu = 5/3$ and 4/3. Again the anomalous behavior disappeared at higher temperatures or under larger probe current, but it seemed somewhat more robust than that around $\nu \sim 1/3$. A similar phenomenon was observed in another sample taken from the same wafer, albeit with smaller amplitude and different fluctuation pattern. This sample was equipped with a front gate. The gate turned out to be not very effective in changing the hole density, so that the overall shape of the magnetoresistance trace was essentially unchanged. However, the fluctuation pattern in the range $1 < \nu < 2$ showed systematic evolution with the gate voltage.

It is interesting to see if the difference in the crystal orientation or the substrate, (100) and (311), has anything to do with the observed phenomena.

ACKNOWLEDGEMENTS

The work is supported in part by Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sport, Science and Technology (MEXT), Japan. One of the authors (K.K.) acknowledges the support provided by the Japan Society for the Promotion of Science (JSPS) fellowship.

REFERENCES

1. *Perspectives in Quantum Hall Effects : Novel Quantum Liquids in Low-dimensional Semiconductor Structures*, edited by S. D. Sarma and A. Pinczuk, New York: John Wiley and Sons Ltd., 1995.
2. H. L. Stormer, and W. T. Tsang, *Appl. Phys. Lett.* **36**, 685–687 (1980).
3. W. I. Wang, E. E. Mendez, T. S. Kuan, and L. Esaki, *Appl. Phys. Lett.* **47**, 826–828 (1985).
4. H. C. Monoharan, and M. Shayegen, *Phys. Rev. B* **50**, 17662–17665 (1994).
5. M. Y.Simmons, A. R. Hamilton, S. J. Stevens, D. A. Ritchie, M. Pepper, and A. Kurobe, *Appl. Phys. Lett.*, **70** 2750–2752 (1997).
6. S. J.Papadakis, E. P. De Poortere, M. Shayegan, and R. Winkler, *Phys. Rev. Lett.* **84**, 5592–5595 (2000).
7. G. A.Csathy, D. C.Tsui, L. N.Pfeiffer, and K. W.West, *Phys. Rev. Lett.* **92**, 256804 (2004).
8. M. J.Manfra, L. N.Pfeiffer, K. W.West, R. de Picciotto, and K. W.Baldwin, *Appl. Phys. Lett.* **86**, 162106 (2005).