Emergent fractional quantum Hall effect at even denominator = 3/2 in a triple quantum well in tilted magnetic fields

2011 J. Phys.: Conf. Ser. 334 012026

(http://iopscience.iop.org/1742-6596/334/1/012026)

Emergent fractional quantum Hall effect at even denominator ν=3/2 in a triple quantum well in tilted magnetic fields

S. Wiedmann[1,2,3*], G. M. Gusev[4], A. K. Bakarov[5], and J. C. Portal[2,3]
[1]Radboud University Nijmegen, Institute for Molecules and Materials and High Field Magnet Laboratory, Toernooiveld 7, 6525 ED Nijmegen, The Netherlands
[2]LNCMI, UPR 3228, CNRS-INSA-UJF-UPS, BP 166, 38042 Grenoble Cedex 9, France
[3]INSA Toulouse, 31077 Toulouse Cedex 4, France
[4]Instituto de Física da Universidade de São Paulo, CP 66318 CEP 05315-970, São Paulo, SP, Brazil
[5]Institute of Semiconductor Physics, Novosibirsk 630090, Russia
E-mail: *s.wiedmann@science.ru.nl

Abstract. This work reports on the experimental observation of the even-denominator state ν=3/2 in a trilayer electron system in tilted magnetic fields. The ν=3/2 state demonstrates a strong minimum in longitudinal resistance and is accompanied by a plateau in Hall resistance in a narrow range of tilt angles.

1. Introduction

The observation of fractional quantum Hall (FQH) states at even denominators, in particular at filling factor ν=5/2, has attracted much attention, motivated by implications of fault-tolerant quantum computation [1]. After its discovery [2], many theoretical works indicate that the 5/2 FQH state, observed in a single quantum well, is an exotic non Abelian Pfaffian state. This state is a subject of ongoing discussions and recent experimental studies indicate implications for the Pfaffian State and can be of importance in clarifying Pfaffian versus anti-Pfaffian as the relevant ground state [3].
On the other hand, an even-denominator FQH state has been found in high mobility bilayer systems in the lowest Landau level (LL) at filling factor ν= 1/2 which has no counterpart in a single-layer 2D system [4, 5]. So far, it is assumed that the observed ν=1/2 state in bilayer systems is most likely described by the Abelian so-called Halperin {331} state. A recent theoretical study on the ν=1/2 FQH state as function of tunneling strength and layer separation discusses whether bilayers support both an Abelian Halperin {331} and a non-Abelian Pfaffian state [6]. This work also discusses if the transition between these two states might be observed experimentally in standard transport measurements of the FQH-effect [6].

A further advance in physics of FQH states with even denominators depends on experimental search for non-Abelian states, especially in systems which are distinct from bilayers. Multi-component quantum Hall (QH) systems, which consist of multiple quantum wells separated by thin barriers, exhibit new interesting FQH states due to many-body phenomena and might contribute to the understanding of FQH states [5]. In the present work we have carried

Journal of Physics: Conference Series **334** (2011) 012026 doi:10.1088/1742-6596/334/1/012026

out magnetotransport measurements in a coupled trilayer electron system, formed by a triple quantum well (TQW) in magnetic fields up to B=34 T and at a temperature of T=100 mK. If we apply a parallel component of the magnetic field, we observe an even-denominator state at total filling factor ν=3/2, which is to the best of our knowledge, the first experimental observation of an even-denominator state in a trilayer electron system. Note that the observed ν=3/2 FQH state is a hole conjugate of the ν=1/2 FQH state (ν=3/2=2-1/2).

2. Trilayer electron system

Our samples are symmetrically doped GaAs TQWs, separated by $Al_xGa_{1-x}As$ barriers, with a high total electron sheet density of $n_s = 6.9 \times 10^{11}$ cm^{-2} and a mobility of 8×10^5 cm^2/V s. The central well width is about 220 Å and both side wells have equal widths of 100 Å. The barrier thickness is d_b=20 Å. In order to populate the central, we increased its width. Corresponding energy gaps $\Delta_{jj'}$ between populated subbands are Δ_{12}=1.34 meV, Δ_{13}=3.65 meV, Δ_{23}=2.31 meV, extracted from a self-consistent Hartree-Fock calculation, and are in agreement with the periodicity of magneto-intersubband oscillations [7, 8]. The trilayer system with corresponding parameters is sketched in the inset of Figure 1. The energies in TQWs are described by the expression $\hbar\omega_c(N + 1/2) \pm \Delta_Z/2 + E_j$, where $\hbar\omega_c$ is the cyclotron energy, Δ_Z the Zeeman energy, and E_j ($j = 1, 2, 3$) the energies of quantization in the TQW potential.

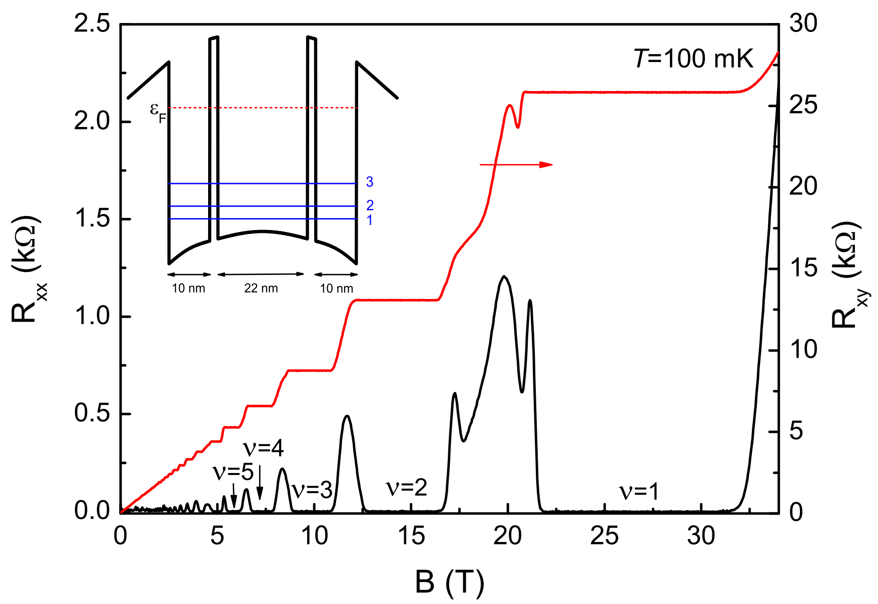

Figure 1. (Color online) Longitudinal resistance and quantum Hall effect in the trilayer electron system subjected to a perpendicular magnetic field at a temperature of 100 mK. Inset: Sketch of a TQW with corresponding subbands.

In contrast to previous studies in trilayer systems [9], the Landau fan diagram of this particular trilayer system investigated here deviates from the standard sequence of spin-split LLs separated by the subband gaps. Whereas in Ref. [9], we found FQH effect for the highest subband of each Landau level (FQH effect between, e.g. filling factors ν=2 and ν=3), we observe now FQH effect between integer filling factors ν=1 and ν=2, see Figure 1. The variation of energy gaps $\Delta_{jj'}$ with the magnetic field might be ascribed to charge transfer from the central well to the lateral wells.

3. Observation of the even-denominator state ν=3/2

Tilting the magnetic field leads to the observation of numerous minima in R_{xx} accompanied by plateaus in the Hall resistance R_{xy} at integer and fractional filling factors ν >3. For $\Theta > 37°$, integer filling factor ν=2 starts to collapse and a new FQH states are developed for ν <2. With increasing tilt angle, a new deep and broad minimum in R_{xx} appears at fractional filling factor ν= 3/2, see Figure 2(a). This minimum persists up to an angle of Θ=43.2° and then collapses. In Hall resistance, we observe a plateau quantized at $R_{xy} = 2h/3e^2$, which is shown in Figure 2(c). The even-denominator state is very sensitive to the component of the parallel magnetic field which is pointed out in Hall resistance in Figures 2(b) and (d).
A further increase of the tilt angle leads to a symmetric order in FQH states around even-denominator state ν=3/2 with denominators 5, 7, 9 etc. The best pronounced state is ν=7/3 which occurs at $B_\perp \simeq$14 T.

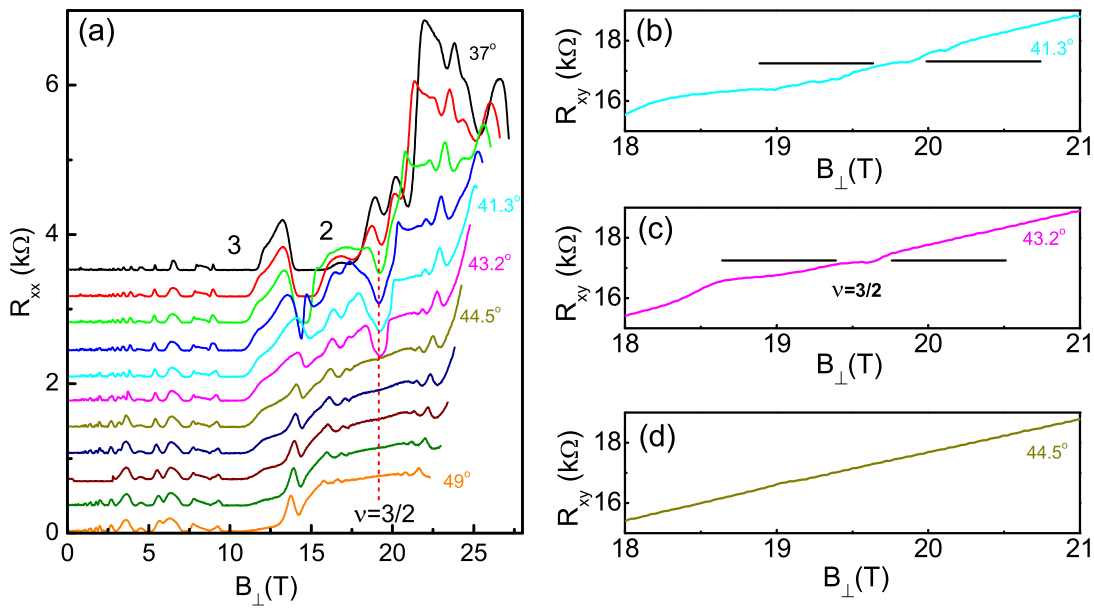

Figure 2. (Color online) (a) Longitudinal resistance R_{xx} as a function of the perpendicular component of the magnetic field for several chosen tilt angles from Θ=37° to Θ=49°. For $\Theta > 37°$ a minimum at even-denominator ν=3/2 is developed which persists until Θ=43.2°. (b)-(d) Corresponding Hall resistance exhibits a well developed plateau at ν=3/2 for Θ=43.2°.

Using the derivative of R_{xy}, we demonstrate in Figure 3(a)-(c) the evolution of magnetoresistance with increasing tilt angle for Θ=41.3°, Θ=43.2° and Θ=44.5°. Starting from the integer filling factor ν=3, we observe for Θ=41.3° a profound minima which first narrows for Θ=43.2° and is almost vanished for Θ=44.5°.

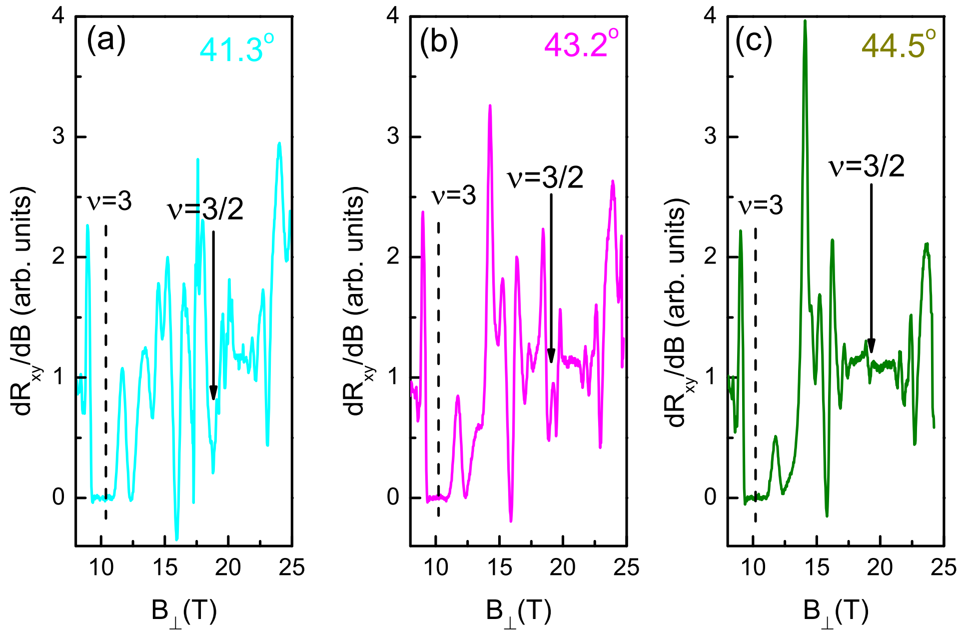

Figure 3. (Color online) (a)-(c) Evolution of magnetoresistance with increasing tilt angle. Derivative dR_{xy}/dB demonstrates a clear minimum for Θ=41.3° and Θ=43.2°. For Θ=44.5°, the even- denominator state at ν=3/2 disappears and we find several developed minima on the low- and high-field side with respect to ν=3/2.

4. Discussion

Multicomponent FQH states can be obtained by a generalization of the Laughlin state. Such incompressible states have been predicted for trilayer systems in Ref. [10]. The state at total filling factor ν=5/7 which is among the strongest states in a trilayer system, is a combination of filling factors 2/7 in the side layers and 1/7 in the central layer. This state has been found experimentally [11]. Recently, FQH states at even-denominator filling factors ν=1/2 and ν=1/4 in electron systems confined to a wide GaAs quantum well have been found with a significantly asymmetric charge distribution [12]. Those states disappear when the charge distribution is made symmetric and the subband splitting is lowered.

However, first we point out that the observation of the even-denominator state ν=3/2 in our trilayer electron system cannot be ascribed to a generalization of the Laughlin state. Second, we observe ν=3/2 in the presence of both perpendicular and parallel magnetic field and in a very narrow range $\Delta\Theta$. In general, the presence of an in-plane magnetic field adds an Aharonov-Bohm phase to the tunneling amplitude, which consequently leads to oscillations of the tunnel coupling between electronic states in the layers [13] and to a suppression of this coupling for low Landau levels. Oscillations in the tunnel coupling affect fractional quantized Hall phenomena in highly tilted samples as it has been demonstrated in Ref. [9].

Having a closer look to the sequence of fractional states around ν=3/2, one might suggest that this state in our trilayer electron system is an analog of the two-component ν=1/2 state in a wide quantum well [12]. We can further assume that the electron density is 1/3 of the total density which implies that our ν=3/2 is a ν=1/2+1 state, i.e., a ν=1/2 state with an inert background of a fully occupied LL. However, comparing our results to Ref. [12], we notice that the induced asymmetry by gating the wide quantum well gives rise to the appearance of a deep minimum in resistivity. In our TQW, we might have the situation of a slight asymmetry at high magnetic fields as well under certain conditions (tilt angles) but it could also be likely that oscillations of the tunneling gap create a favourite condition (charge distribution) for the observation of the even-denominator state ν=3/2.

5. Conclusion

In the present work we have found first experimental evidence of an even-denominator state at total fractional filling factor ν=3/2. This state is sensitive with respect to the component of the parallel magnetic field and is developed around $\Theta \simeq 42°$. We assume that our experimental finding challenges theory in order to understand the origin of this emergent ν=3/2 FQH state in a trilayer electron system in a tilted magnetic field.

Authors acknowledge financial support from CNPq and FAPESP (Brazilian agencies). Part of this work has been supported by EuroMagNET II under the EU contract number 228043.

References

[1] C. Nayak, S. H. Simon, A. Stern, M. Freedman, and S. Das Sarma, *Rev. Mod. Phys.* **80**, 1083 (2008).
[2] R. L. Willet, J. P. Eisenstein, H. L. Störmer, D. C. Tsui, A. C. Gossard, and J. H. English, *Phys. Rev. Lett.* **59**, 1776 (1987).
[3] Chi Zhang, T. Knuuttila, Yanhua Dai, R. R. Du, L. N. Pfeiffer, and K. W. West, *Phys. Rev. Lett.* **104**, 166801 (2010).
[4] J. P. Eisenstein, G. S. Boebinger, L. N. Pfeiffer, K. W. West, and Song He, Phys. Rev. Lett. 68, 1383 (1992).
[5] *Perspective in Quantum Hall Effects: Novel Quantum Liquids in Low-Dimensional Semiconductor Structures*, edited by S. Das Sarma and A. Pinczuk (Wiley and Sons, New York, 1998).
[6] Michael R. Peterson and S. Das Sarma, *Phys. Rev.* B **81**, 165304 (2010).
[7] S. Wiedmann, N. C. Mamani, G. M. Gusev, O. E. Raichev, A. K. Bakarov, and J. C. Portal, *Phys. Rev. B* **80**, 245306 (2009).
[8] S. Wiedmann, N. C. Mamani, G. M. Gusev, O. E. Raichev, A. K. Bakarov, and J. C. Portal, *Physica E* **42**, 1088 (2010).
[9] G. M. Gusev, S. Wiedmann, O. E. Raichev, A. K. Bakarov, and J. C. Portal, *Phys. Rev. B* **80**, 161302(R) (2009).
[10] A. H. MacDonald, *Surf. Sci.* **229**, 1 (1990).
[11] J. Jo, Y. W. Suen, L. W. Engel, M. B. Santos, M. Shayegan, *Phys.Rev. B* **46**, 9776 (1992).
[12] J. Shabani, T. Gokmen and M. Shayegan, *Phys. Rev. Lett.* **103**, 046805 (2009).
[13] J. Hu and A. H. MacDonald, *Phys. Rev. B* **46**, 12554 (1992).