Pergamon

Solid State Communications, Vol. 97, No. 2, pp. 83–87, 1996

0038-1098/96 $9.50+.00

0038-1098(95)00660-5

UNIVERSAL CONDUCTANCE FLUCTUATIONS IN A TWO-DIMENSIONAL ELECTRON GAS NEAR FILLING FACTOR ν=1/2.

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(*Received* 1 *August* 1995; *accepted* 21 *September* 1995 *by P. Burlet*)

We report magnetoresistance measurements on a two-dimensional electron gas at low magnetic field and near Landau filling factor ν=1/2 in mesoscopic samples. Aperiodic reproducible resistance fluctuations have been found in both cases. In order to show that the fluctuations in a strong field are due to the quantum interference of the composite Fermions, we have compared coherence properties for the electrons and composite particles.

Keywords: A. nanostructures; D. fractional quantum Hall effect.

Universal conductance fluctuations (UCF) due to quantum interference of the electron waves under specific configuration of the random potential have been a subject of much experimental and theoretical work [for review, see 1]. Recently it has been suggested, that a system of electrons at half-filled Landau levels can be transformed to the Fermi gas of quasi particles (composite Fermions) at zero effective magnetic field. Away from the filling factor ν=1/2, quasi particles experience an effective magnetic field $B_{eff}=B-B_{1/2}$, as has been proved by the observation of geometrical resonance's of composite Fermions in an antidot lattice [2], and magnetic focusing experiments [3]. One can assume, that in addition to semi-classical behaviour, composite Fermions (CF) exhibit quantum interference, and, as a result- it should be possible to observe universal conductance fluctuations. However, a smooth random electrostatic potential experienced by electrons at zero field is transformed (because of local density fluctuations) to a non uniform or even random magnetic field for composite Fermions. Conductance fluctuations in a system with random magnetic scattering have already been calculated [4]. The average amplitude for the conductance fluctuations are calculated to be close to a universal value of $1/\sqrt{7}\, e^2/h$. Experimentally aperiodic variations in the conductance in the fractional quantum Hall effect regime have been studied in mesoscopic samples near ν=1/3, when diagonal resistance ρ_{xx} was close to zero [5]. However, conductance fluctuations around filling factor of a half remains to be investigated.

In this paper, we have measured the magnetoresistance of a mesoscopic bridge lithographically defined in a high mobility two dimensional electron gas (2-DEG) near zero magnetic field and close to filling factor 1/2. We observe UCF of electrons close to zero magnetic field and of CF close to ν=1/2. The amplitude of the UCF for the quasi particles is an order of magnitude smaller than the amplitude of the UCF for the electrons and the correlation magnetic field is an order of magnitude larger for the CF's. This is consistent with a phase coherence length for the CF's which is smaller than the phase coherence length for electrons. The UCF for electrons is found to be symmetric about B=0 in contrast to the UCF for the quasi particles which are not symmetric around $B_{1/2}$ because of the inhomogenous random character of the effective magnetic field experienced by the CF's.

For the investigation a conventional

(AlGa)As/GaAs modulation doped heterostructure with a two dimensional electron gas with an electron density of (1.7 - 2.0) x 10^{11} cm^{-2} and mobility of (40-60) $m^2V^{-1}s^{-1}$ was used. Macroscopic samples were fabricated using photolithography to define a Hall bar geometry. In addition mesoscopic samples were produced using electron beam lithography to define a bridge (constriction) in the centre current carrying arm of a classical Hall bar. A number of mesoscopic samples were studied with bridge lengths between 2-5 μm and a physical width of around 1 μm. Due to depletion effects the electrical width varies with illumination at low temperatures but is typically between 0.1 and 0.3 μm. For the measurements the sample was mounted directly in the mixing chamber of a top loading dilution refrigerator. The sample could be illuminated in situ by means of a GaAs light emitting diode. Magnetic fields up to 15T were applied perpendicular to the 2-DEG and the resistance measured using conventional phase sensitive detection with an a.c current of less than 10nA at 6.7 Hz.

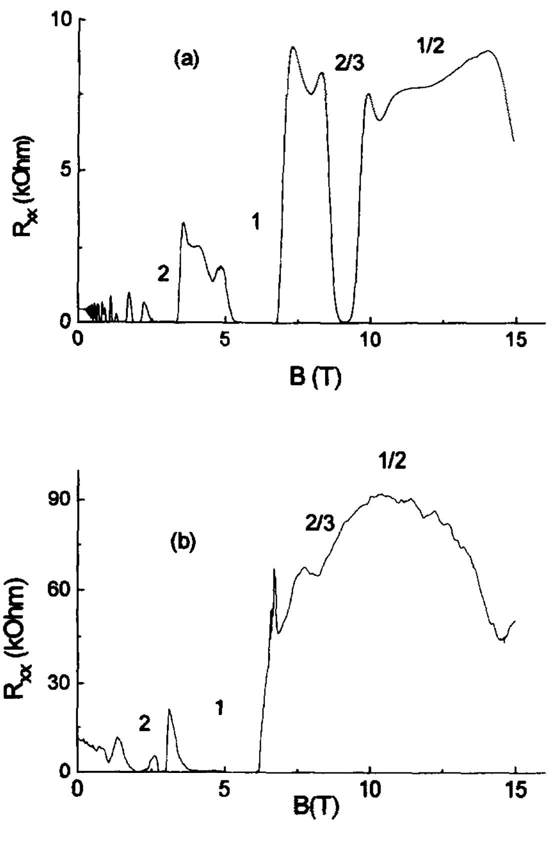

Figure 1.
Typical magnetoresistance of macroscopic (a) and mesoscopic (b) samples measured at 50mK with the magnetic field applied perpendicular to the layers. The Landau level filling factors are indicated for reference.

Figure 1. shows typical magnetoresistance curves for both macroscopic and mesoscopic samples measured at 50 mK. In the macroscopic sample the expected minimum in resistance is observed around ν=1/2 corresponding to the metallic CF state. In contrast for the mesoscopic sample there is a maximum in resistance is observed which decreases parabolically around ν=1/2. In addition, the fractional minima, clearly apparent in the macroscopic sample are strongly suppressed and reproducible resistance fluctuations are observed. A similar behaviour is found for electrons around B=0, the Shubnikov de Haas oscillations are suppressed and conductance fluctuations appear.

This behaviour can be seen in more detail in figure 2 which shows the magneto resistance around B=0 and $B=B_{1/2}$. Comparing figures 2a and 2b we see that the typical frequency of the aperiodic fluctuations is larger for the electrons than for the quasi particles. The UCF for the electrons are symmetric around B=0 in contrast to the CF's. This can be seen more clearly in fig 2c in which the background magnetoresistance has been removed. The temperature dependence of the conductance fluctuations for the quasi particles is shown in figure 3. The amplitude decreases with increasing temperature due to the decrease in the phase coherence length as expected for UCF's. In order to perform a quantitative analysis we have calculated the root mean square (rms) amplitude of the resistance fluctuations and correlation magnetic field both for electrons around B=0 and for the quasi particles around B = $B_{1/2}$. The results of this analysis is shown in Figure 4. Increasing temperature destroys the phase coherence leading to an increase in the correlation magnetic field and a decrease in the amplitude of the fluctuations for both the electrons and the CF's. Theory predicts the following expression for the correlation magnetic filed in the one dimensional case

$$B_c = \Phi_0 / L_\varphi W \qquad (1)$$

where Φ_0 is the quantum flux, L_φ is the coherence length and W is the width of the sample. The rms amplitude for the one dimensional case is given by [6]:

$$\Delta\sigma = 0.7\frac{e^2}{h}\left(\frac{L_\varphi}{L}\right)^{\frac{3}{2}} \qquad (2)$$

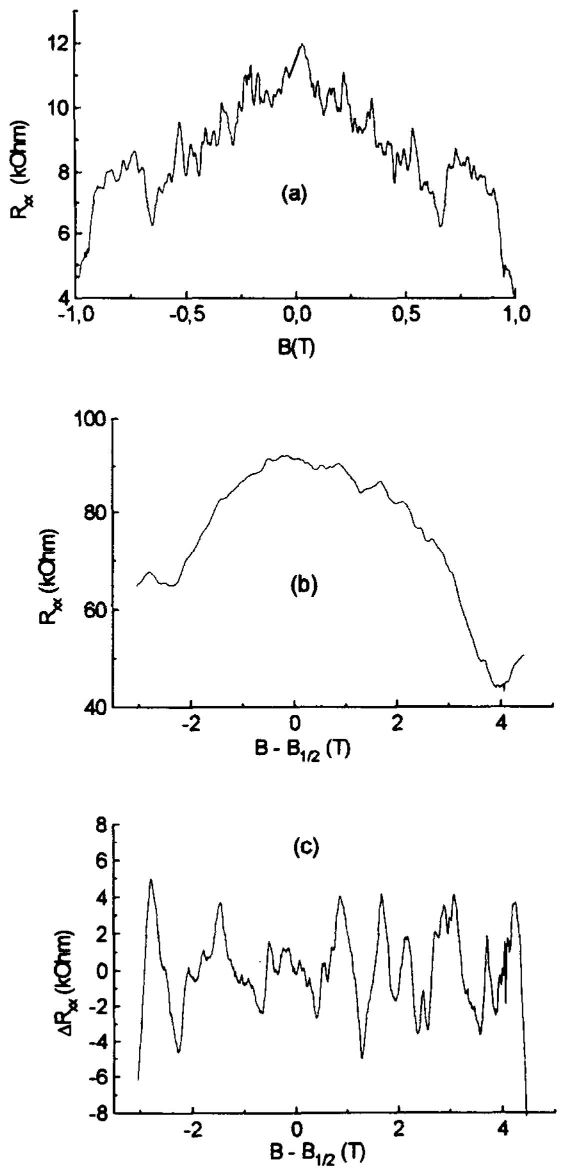

Figure 2.
Aperiodic resistance fluctuations for a mesoscopic sample (L=5μm) measured around B=0 (a) and $B=B_{1/2}$ (b). In (c) the parabolic background has been subtracted. All measurements were performed at 50mk.

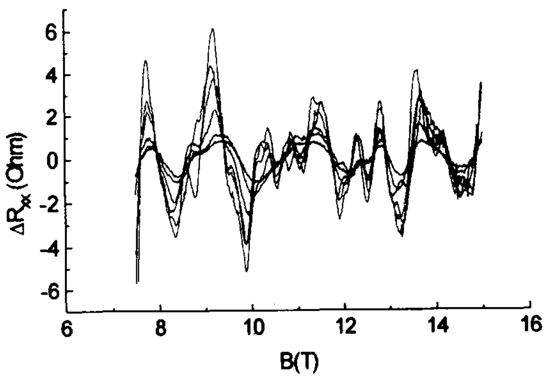

Figure 3.
Typical magnetoresistance curves at temperatures between 0.1 and 1K measured around ν=1/2. The amplitude of the fluctuations decreases with increasing temperature.

where L is the length of the constriction, if $L_\varphi < L$. We assume that for electrons we have a quasi ballistic case and therefore we expect a mean free path of approximately 1-2 μm. In this case we can also assume that the coherence length L_φ = 1-1.5 μm as has been shown from measurements of Aharonov Bohm effect in quasi ballistic rings [7]. Using L_φ=1.5μm and from the correlation magnetic field of 0.008T we obtain a sample width W=0.17 μm for electrons. Using the correlation magnetic field of 0.1 T for CF's we obtain an L_φ of 0.125 μm. However, substituting this value of L_φ in Equation 2 we obtain a ratio of the rms amplitude for electrons and CF's of 40 compared to the experimentally observed factor of 10.

There are two possible explanations for this discrepancy. Firstly, it is possible that the measured correlation magnetic field for electrons underestimates L_φ due to flux cancellation effects for ballistic trajectories scattered by sample boundaries [8]. Secondly, for the CF's the correlation magnetic field can be overestimated because of flux cancellation due to the alternating sign of the effective magnetic field due to spatial variation of the 2-D electron density. We are unable to distinguish between the two mechanisms but nevertheless we can estimate that the phase coherence length L_φ = 0.125-0.25 μm for the CF's. This value is realistic when we consider the smaller mean free path for CF's when compared to electrons.

The phase coherence length L_φ is expected to vary as $T^{-1/3}$ for the one dimensional case [9]. The mechanism which is responsible for the loss of phase memory is electron-electron scattering in the presence of impurities. Equation 1 then predicts that B_c varies as $T^{1/3}$ as observed experimentally in Figure 4a. Similarly the rms amplitude of the conductance fluctuations is expected to vary as $(L_\varphi)^{3/2} \sim T^{-1/2}$ as observed in Figure 4b.

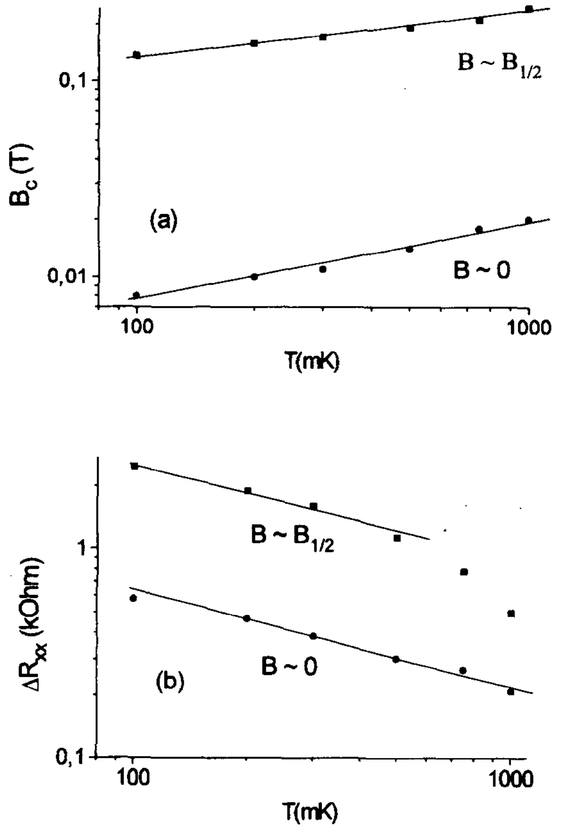

Figure 4.
Magnetic correlation field (a) and rms amplitude (b) of the fluctuations for electrons (B~0) and composite Fermions ($B \sim B_{1/2}$) as a function of temperature. The solid lines are fits to the experimental data, $B_c(CF) \sim T^{0.33}$, $B_c(\text{electrons}) \sim T^{0.37}$, $\Delta R_{xx}(\text{CF and electrons}) \sim T^{-0.45}$.

However, at above 400mk, the rms amplitude of the fluctuations decreases more quickly for the CF's, which is related probably to the destruction of the Chern Simmons term. A similar effect has previously been observed in geometrical resonance experiments when the mean free path of CF's starts to be dramatically reduced with increasing temperature [10].

Finally it is interesting to compare the estimated rms amplitudes with experimentally determined values. Unfortunately in order to deduce the conductance's it is necessary to use the tensor relation between the measured resistance and the conductance. For CF's Hall resistance ρ_{xy} does not play the same role as for electrons and therefore we do not include this term in our analysis [4]. Under these assumptions we estimate that rms ($\Delta\sigma$) for electrons is 0.34 x 10^{-5} Ohm^{-1} and 0.26 x 10^{-6} Ohm^{-1} for CF's. Assuming L_φ=1.5 μm we calculate rms ($\Delta\sigma$) = 0.6 x 10^{-5} Ohm^{-1} for electrons approximately a factor of two smaller. Using L_φ = 0.25 μm for CF's we calculate a value of 0.6 x 10^{-6} Ohm^{-1} assuming that the CF's move in a homogeneous magnetic field. Under the more realistic assumption of a non homogeneous magnetic field we calculate 0.2 x 10^{-6} Ohm^{-1} [4].

In conclusion, we have observed universal conductance fluctuations of electrons around B=0 and of composite Fermions around a filling factor ν=1/2. The temperature dependence of the rms amplitude and the correlation magnetic field are very similar for electrons and for composite Fermions giving evidence that similar phase relaxation mechanisms at the Fermi surface are at work for electrons and for CF's. This lends further support to the model in which CF's are considered as particles with a well defined Fermi surface. However, because of the heavy mass CF's have a smaller phase coherence length and consequently larger magnetic correlation field and smaller rms amplitude of the fluctuations. As the UCF's are very sensitive to the specific disorder potential, it possible to use this technique to probe the non homogeneous and random effective magnetic field close to ν=1/2.

Acknowledgments

This work is supported by the European INTAS program (grant 94 668). We thank V.Fal'ko for discussions.

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