Relative Specific Heat at $\nu = 1/2$ Measured in a Phonon Absorption Experiment

F. Schulze-Wischeler*, F. Hohls*, U. Zeitler†*, D. Reuter**, A. D. Wieck ** and R. J. Haug*

*Institut für Festkörperphysik, Universität Hannover, Appelstraße 2, D-30167 Hannover, Germany
†High Field Magnet Laboratory, NSRIM, University of Nijmegen, Toernooiveld 7, 6525 ED Nijmegen, The Netherlands
**Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Universitätsstraße 150, 44780 Bochum, Germany

Abstract. In general it is far from being straightforward to measure the specific heat of a single two-dimensional electron system directly, since it is strongly dominated by the contribution of the substrate. Using a time-resolved phonon absorption technique, we have directly measured the specific heat C of composite fermions at half Landau level filling $\nu = 1/2$. We find a nearly linear dependence of C on temperature down to $T = 0.1$ K.

Phonon spectroscopy is an efficient tool to investigate properties of two-dimensional electron systems (2DESs) [1–4], specially thermodynamic properties. We investigate the specific heat at filling factor $\nu = 1/2$ in the fractional quantum Hall effect (FQHE) regime. The uniqueness of 1/2 is revealed in the composite fermion (CF) picture of the FQHE [5]. Here, the CF quasiparticles are constructed by attaching an even number of magnetic flux quanta ϕ_0 to every electron (two flux quanta in the $\nu = 1/2$ case). These CFs experience only an effective magnet field $B^* = B - 2\phi_0 n_e$, where n_e is the electron density and B is the magnetic field. By this the FQHE at B is mapped to integral QHE of CFs at B^*. At $\nu = 1/2$ the external field is fully canceled by the gauge field and $B^* = 0$. Here the CF model predicts the formation of a Fermi surface. The validity of this picture has been proven in many experiments [6]. In their seminal paper [7] Halperin, Lee and Read made various predictions for $\nu = 1/2$, in particular for the temperature dependence of the specific heat C: It should be nearly linear with small logarithmic corrections.

The sample used in this experiment is a typical AlGaAs/GaAs-heterostructure with a 2DES processed into a large meander with standard photo lithography and wet chemical etching, see Fig. 1. The meander has a large aspect ratio of $l/w = 10$ mm/90 μm = 111. This geometry is chosen to maximize the ρ_{xx} contribution of the two point resistances $R_{2\text{point}} \approx l/w * \rho_{xx} + \rho_{xy} + R_{\text{contacts}}$, so that also smallest changes in ρ_{xx} are measurable. A thin constantan film is evaporated on the back side and carefully adjusted to the meander. The film acts as the non-equilibrium phonon source in the experiment (called "heater").

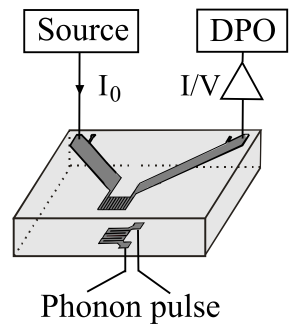

FIGURE 1. Sample and schematic setup, see text for explanation.

The resistance change due to a phonon pulse is measured In the phonon absorption experiment at filling factor $\nu = 1/2$. The phonons are created at the backside by applying 10 ns electrical pulses to the heater. They fly ballistically through the 2 mm substrate and hit the 2DES. A part of them is absorbed by the 2DES and heats the 2DES up from base temperature T_0 to a non-equilibrium temperature T_1. The 2DES is sourced with a constant current I_0 and the transient current is amplified and sampled in an ultra-fast digital phosphor oscilloscope (DPO). When the 2DES is heated up, the two-point resistance at $\nu = 1/2$ slightly drops (typically only ≈ 1 % !) which increases the measured current. Using the

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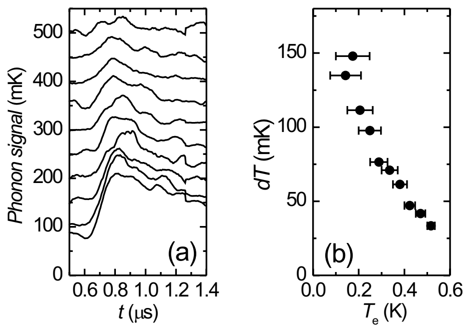

FIGURE 2. Phonon signal data at $\nu = 1/2$. (a) Phonon signal in mK versus time for *same* heater temperature ($T_H = 1.9$ K, pulse length $\tau = 10$ ns) and *different* base temperatures $T_0 =$ 75...500 mK. (b) Change in the temperature dT from T_0 to the peakvalue T_1 extracted from the left figure versus $T_e = (T_1 - T_0)/2$. The bars are the values from T_0 to T_1 and represent the worst case error.

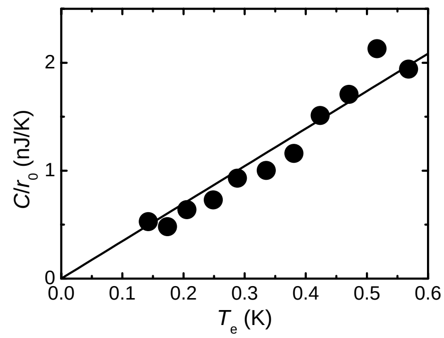

FIGURE 3. Relative specific heat C/r_0 at filling factor $\nu = 1/2$ measured in a phonon absorption experiment. The line is a fit with the theoretical excepted linear behavior through the origin [7]. Every data point is the result of 1.5 million averages. The error of the data points is given by their distribution.

measured temperature dependence equilibrium magnetotransport data as a calibration curve this current change is translated to a change of the 2DES temperature. To measure this small changes in the current, the experiment is repeated up to 1.5 million times at intervals of about 0.5 ms which allows the sample to cool after every phonon heating. For a detailed description of the phonon absorption technique see [8].

Fig. 2(a) shows the phonon signal data at $\nu = 1/2$. Here, the base temperature T_0 is varied stepwise from 75 mK to 500 mK and the 2DES temperature is measured during absorption of ballistic phonons from a standard phonon pulse with length $\tau = 10$ ns, created by applying a fixed amplitude of 0.6 V on the heater which corresponds to a heater temperature of $T_{\rm H} = 1.9$ K. The data clearly reveals that the change in temperature dT due to absorption of ballistic phonons *decreases* with *increased* base temperature T_0. This is emphasized in Fig. 2(b): The temperature change, dT, from the base temperature, T_0, to the maximum of the sample's response to the phonon absorption, T_1, extracted from the left figure versus the mean temperature, $T_{\rm e} = (T_1 - T_0)/2$, is shown. The monotonic decrease of dT is directly related to a monotonic increase of the 2DES specific heat at $\nu = 1/2$.

We can now determine the relative specific heat $C(T_e)/r_0 = (P_{\rm H}\tau)/dT$ of the 2DES at $\nu = 1/2$ from our experiment, where $0 < r_0 \leq 1$ an unknown phonon absorption coefficient and P_H is the total power of the heater. In Fig. 3 we present the relative specific heat C/r_0 measured by our phonon absorption experiment.

The prediction of Halperin, Lee and Read in Ref. 7 for the temperature dependence of the specific heat at filling factor $\nu = 1/2$ is

$$C(\nu = 1/2) = \frac{\pi}{6} m_{\rm CF} k_{\rm B}^2 T \qquad (1)$$

Our experimental data (Fig. 3) nicely confirm the predicted linear temperature dependence.

In conclusion, we have succeeded in measuring the temperature dependence of the specific heat C at $\nu = 1/2$ in a phonon absorption experiment. It shows the linear temperature dependence predicted by Halperin, Lee and Read.

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