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THz-Photoconductivity of Quantum Hall Systems in Quasi-Corbino-Geometry

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Abstract The THz-photoresponse (PR) between two separately contacted edge-channels of a two-dimensional electron gas in the quantum Hall regime is investigated. We use a not-simply-connected sample geometry, which is topologically equivalent to a ring shape (Corbino-geometry). At filling factors $\nu < 2$, spectrally resolved PR-measurements show a Lorentzian resonance, centered at the cyclotron-frequency, whereas above the integer filling factor, an asymmetric broadening is observed. Two independent contributions to the PR-signal can be resolved. One contribution clearly results from bolometric heating inside the bulk and the other one is caused by a non-bolometric mechanism.

Keywords 2DEG · QHE · THz detection · RHMF09

First experimental studies of THz photoresponse in quantum Hall systems started in the early 1980s (see e.g. [1–3]). There was a long history of discussion about the mechanism of the THz photoresponse in integer quantum Hall (IQHE) devices. Two contributions to the PR were observed, a non-resonant signal as well as a cyclotron resonant (CR) component. Today it is well established that the non-resonant part is caused by a lattice heating of the whole sample, whereas the CR signal arises

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form electron gas heating (see e.g. [4, 5]). It has been found, that the filling factor dependence of the CR signal is similar to that of the temperature derivative of the longitudinal resistance R_{xx} (see e.g. [4–6]). This signal is therefore commonly called "bolometric". Recently, experiments have shown a deviation of the PR from the bolometric model at filling factors $\nu > 2$ and low bias currents [5]. They suggest that the deviation from the bolometric model arises from the non-equilibrium edge channel transport, which affects the PR. However, the effect of edge channel transport on the PR is not yet fully understood.

In this work we study the PR signal using a sample structure which is topological equivalent to a Corbino-geometry, however, the circumference is greatly enlarged by a meander-like patterning (see [7]). The sample is fabricated from a MBE grown GaAs/AlGaAs heterostructure containing a two-dimensional electron gas (2DEG) 110 nm below the surface. The carrier concentration and the mobility are about $n = 2.62 \times 10^{11}$ cm^{-2} and $\mu = 288100$ cm^2/V s, respectively. Applying a constant current I_{SD}, we measure the non-local voltage U_{rr} and its change ΔU resulting from THz illumination [7]. The THz-induced change in conductivity ΔS leads to

$$\Delta U = \left(\frac{1}{S_0} - \frac{1}{S_0 + \Delta S}\right) I_{SD} \approx \frac{\Delta S}{S_0^2} I_{SD}, \tag{1}$$

with the conductance $S_0 = I_{SD}/U_{rr}$.

Figure 1 shows the temperature derivative of the conductance $\partial S/\partial T$ (open triangles) compared to the photoconductance ΔS calculated according to (1) at a temperature of $T = 300$ mK, a bias of $I_{SD} = 2$ nA (open blue circles) and $I_{SD} = 4$ nA (filled blue circles). The line shape of the photoconductivity is similar to $\partial S/\partial T$ below and slightly above the integer filling factor. Furthermore, the photoconductance ΔS is independent of the bias current at filling factors $\nu < 2$. Spectrally resolved PR measurements at $T = 300$ mK show a perfect Lorentzian resonance with a center frequency slightly below the cyclotron-resonance obtained by transmission measurements at $T = 4.2$ K (Fig. 2). This suggests that the photoconductance in a

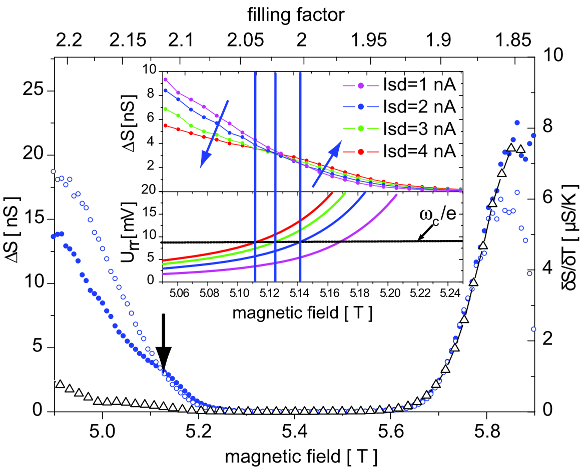

Fig. 1 (Color online) Photoconductance ΔS calculated according to (1) at 300 mK, a bias of $I_{SD} = 2$ nA (*open blue circles*) and $I_{SD} = 4$ nA (*filled blue circles*) compared to the temperature derivative of the conductance $\partial S/\partial T$ (*open triangles*). *Inset*: Photoconductance ΔS at a bias ranging from $I_{SD} = 1$ nA to 4 nA compared to the dc voltage U_{rr} without illumination. *The vertical lines* indicates the B-field, where the voltage U_{rr} reaches a value given by the Landau-level separation $\hbar\omega_c/e$

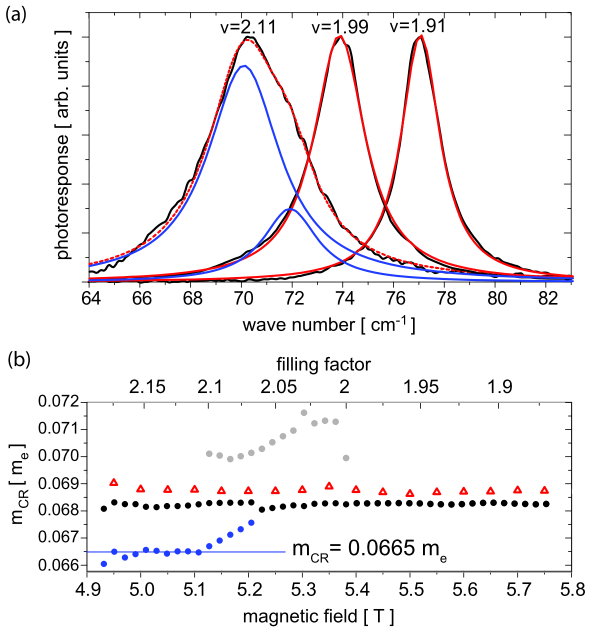

Fig. 2 (Color online) (**a**) Spectrally resolved PR at $T = 300$ mK, $I_{SD} = 4$ nA and different filling factors (*solid black lines*). *The solid red lines* shows single Lorentzian fits to the resonances and *the dashed red line* represents the sum of two Lorentzian fits (*blue lines*) to the resonance at $\nu = 2.11$. (**b**) Effective mass determined from the resonance position (*dots*) compared to the effective mass from transmission measurements at $T = 4.2$ K (*open triangles*). *The gray dots* represent a third Lorentzian profile, which is needed to fit the PR spectra in the range of $\nu = 2.10$ to $\nu = 2$

quasi-Corbino-geometry can be described by the bolometric electron heating model at filling factors $\nu < 2$ in agreement with results obtained on a Hall-bar sample [4].

The situation changes at filling factors $\nu > 2$. Here we observe a strong deviation between the photoconductance ΔS and $\partial S/\partial T$, which is unexpected in the bolometric model. Furthermore, we observe a decreasing photoconductance ΔS with increasing bias down to a filling factor of $\nu = 2.12 - 2.11$ whereas ΔS increases at lower filling factors (arrow in Fig. 1). This can be seen in more detail in the inset, where the photoconductance ΔS (upper part) and the dc voltage U_{rr} (lower part) at different bias currents ranging from $I_{SD} = 1$ nA to 4 nA is shown. As indicated by the vertical lines (inset of Fig. 1), the bias dependence of the photoconductance can be related to a voltage drop across the sample of the order of the cyclotron energy gap $\hbar\omega_c/e$. Further measurements at $T = 4.2$ K (not shown) confirm this correlation. In addition, spectrally resolved measurements at a temperature of 300 mK reveal two contribution to the PR at filling factors $\nu > 2$, as shown for $\nu = 2.11$ in Fig. 2(a). Below the integer filling factor only one contribution is observed. Figure 2(b) shows the corresponding effective mass, as determined from fitting the resonance by a Lorentz curve (circles). For comparison the effective cyclotron mass, determined by transmission measurements using a FT-spectrometer with a broadband detector at a temperature of $T = 4.2$ K is also shown in Fig. 2(b) (open triangles). The grey dots represent a third Lorentzian profile, which is needed to fit the PR spectra in the range of $\nu = 2.10$ to $\nu = 2$. The interpretation of this third Lorentzian curve is not entirely clear and it may actually be an artifact from the fitting procedure. Comparing the PR measurements with the transmission measurements, allows us to identify the lower energy resonance (filled circles) to be a bolometric resonance due to the cyclotron absorption. This bolometric resonance is observed over the whole investigated B-field range and yields an effective mass of $m_{CR} = (0.0682 \pm 10^{-4})m_e$, which is in good agreement with the literature [8, 9]. The position of the second resonance, which is only observed above the integer filling factor, yields a significantly reduced effective mass of $m_{CR} = (0.0665 \pm 2 \times 10^{-4})m_e$ down to a filling factor of $\nu = 2.1$. Although an entirely different geometry used in this work a comparable deviation form the bolometric model is observed on samples with Hall-bar-geometry by Hirakawa et al. [5]. They attribute the shift in resonance frequency as well as the deviation of the PR amplitude from $\partial R_{xx}/\partial T$ observed at filling factors $\nu > 2$ to the occurrence of dissipationless edge states and their influence on the transport mechanism at quantum Hall condition. The involvement of edge states would also explain the different effective mass, since the edge potential has a strong influence on the Landau-level transition energies [10, 11].

Using a sample structure which is described in [11], allows the investigation of the PR across two adjacent edge states on the same sample boundary without any bulk effects. It can be shown, that the PR of such a sample arises from a photo induced current generated inside the edge states [12]. Therefore we presume that the origin of the non-bolometric resonance observed in the present work is also related to a photo current, generated inside the edge states along the two sample boundaries.

In conclusion we have studied the THz-photoresponse of a meander-like patterned quasi-Corbino-sample at quantum Hall conditions. Two contribution to the PR are observed, which can be attributed to the edge and bulk transport. The contribution originating from the bulk is observed independent of the filling factor and can be identified as a bolometric response, due to the cyclotron absorption inside the bulk. The contribution from the edge is clearly non-bolometric and arises only at filling factors $\nu > 2$. We conclude that the non-bolometric contribution originates from a photocurrent generated inside the edge states along the sample boundary.

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