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ScienceDirect

Physica E 40 (2008) 1328–1331

PHYSICA E

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High sensitivity far-infrared detection by resonant inter-Landau-level scattering

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Abstract

The far-infrared (FIR) photoconductivity (PC) of a two-dimensional electron gas in the quantum Hall regime is investigated. We use a novel sample structure which is topologically equivalent to a Corbino-geometry; however, the circumference is greatly enlarged by a meander-like patterning. The geometry allows us to directly study the FIR-induced transport between edge states, which are separated by the insulating bulk region. Due to the high sensitivity of our sample structure it is possible to investigate the PC of our sample in a Fourier spectrometer using a broad band, black-body source with a very low spectral intensity compared to FIR-Lasers used in other experiments. Additionally, we present PC-measurements on a sample with gate tunable carrier density, which allows us to tune the resonance frequency.

PACS: 72.40.+w; 72.80.Ey; 73.43.–f

Keywords: EP2DS-17; 2DEG; QHE; THz detection

Far-infrared (FIR) photoconductivity (PC) in quantum Hall (QH) systems has become interesting for mainly two reasons. On the one hand, these systems are promising devices as FIR-detectors with a high sensitivity, spectral resolution and fast response [1–4,6]. On the other hand, they allow a closer understanding of the transport properties as well as the carrier dynamics in the THz-regime under QH conditions. In this work we study the PC using a novel sample structure which is topological equivalent to a Corbino-geometry. However, the circumference is greatly enlarged by a meander-like patterning (see Fig. 1). We record the photo-induced change in resistivity by applying a constant current between the inner and outer edges (contacts 1 and 2 in Fig. 1) and measuring the non-local voltage between two other well separated contacts (3 and 4), in the following denoted by U_{rr}. This setup gives us a significantly increased signal-to-noise ratio and allows us to investigate the photoresponse of our samples without the need for a FIR-Laser used in other experiments [2–4].

We use a Bruker IFS113v FTIR-spectrometer to measure the spectrally resolved photoresponse of our samples. A broad band Hg-Lamp with a black poly filter is used as the FIR light source and a Mylar 6æ(680–30 cm^{-1}) beam splitter. A system of mirrors and polished stainless steel tubes guides the FIR-radiation to the sample mounted inside a superconducting magnet. Optionally a commercial Si-bolometer can be mounted below the sample to perform transmission measurements. Sample A is fabricated from a MBE grown heterostructure containing a two-dimensional electron gas (2DEG) 110 nm below the surface. The carrier concentration and the mobility is about $n = 2.61 - 2.75 \times 10^{11}\,\text{cm}^{-2}$ and $\mu = 288\,100\,\text{cm}^2/\text{V s}$, respectively. The 2DEG in sample B is located 60 nm below the surface and has a carrier concentration and a mobility of about $n = 4.5 \times 10^{11}\,\text{cm}^{-2}$ and $\mu = 500\,000\,\text{cm}^2/\text{V s}$, respectively. This sample is furthermore equipped with a NiCr top-gate to tune the carrier density.

In this work we restrict ourselves to a filling factor $\nu = 2$ where the used beam splitter best covers the observed cyclotron frequencies. Previous work [2,5,7] has identified

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doi:10.1016/j.physe.2007.09.200

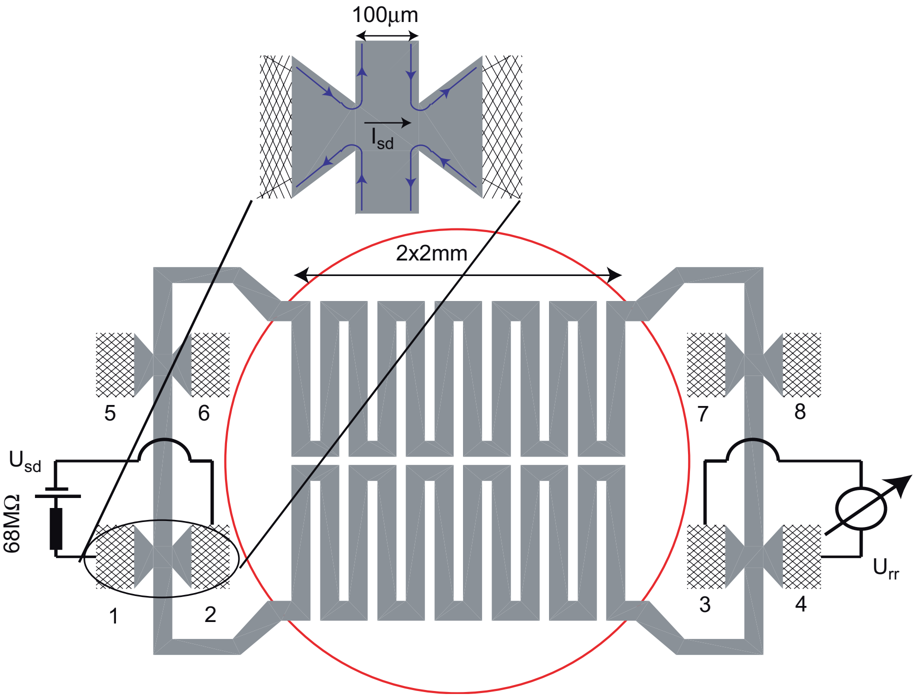

Fig. 1. Structure of samples A and B and the electrical connection.

two mechanisms for the PC-signal, a bolometric part and a contribution from resonant inter-Landau-level excitation. The bolometric response is caused by heating of the electron gas and the resulting change in conductance. It was found to have its maximum at the flanks of the Hall plateaus. Here we observe a PC-signal for a broad range of magnetic fields around integer filling factors, with a clear maximum exactly at the integer filling factor (see Fig. 2). The signal strength mainly follows the DC-voltage across the boundaries (see Fig. 2 right scale). In spectrally resolved measurements, the PC-signal exactly matches the Lorentzian shape of the cyclotron-resonance (CR) absorption, as shown in Fig. 3. From all this we can conclude that we only observe the resonant CR contribution. Fig. 3 also shows that under QH conditions the signal-to-noise ratio of our cyclotron-resonance detector is better than that of the commercial Si-bolometer. We get a full width at half maximum of about 2–3 cm^{-1} for a sample with $\mu = 2.88 \times 10^5\,\mathrm{cm}^2/\mathrm{V\,s}$ and about $1.7\,\mathrm{cm}^{-1}$ for $\mu = 1.01 \times 10^6\,\mathrm{cm}^2/\mathrm{V\,s}$.

Further measurements were performed on a sample using a geometry like the one shown in Fig. 1 but without the meander-type patterning in the center. A photo-induced change in resistance is observed, which is similar to the one of sample A, even though the length of the illuminated edge is about a factor of 12 smaller. This is a strong indication that the PC-signal is caused by an excitation of the 2DEG bulk rather than its edge. This suggests that the origin of the PC-signal is an increased conductivity between the two well separated edge-stages via photo excited bulk states. It also explains why we observe maximum PC-signal at the bulk cyclotron-frequency (see Fig. 3).

In order to investigate the possibility to realize a tunable CR-detector, sample B was provided with a semi-transparent top gate. Fig. 4(a) shows the dependence of the PC-amplitude (squares) and the DC-voltage U_{rr} (solid line) on the gate voltage. Fig. 4(b) shows the corresponding magnetic field dependence. The similarity of the traces in Fig. 4(a) and (b) suggests that the PC-amplitude is mainly given by the filling factor (see top axes in Fig. 4(a) and (b)). This opens up the opportunity to tune the sensitivity of our device independently from the magnetic field. The data in Fig. 4 differ somewhat from that in Fig. 2. The PC-amplitude and the DC-voltage no longer agree in their magnetic-field dependence and both signals become asymmetric. We attribute these observations to inhomogeneities of the carrier density, induced by the gate-electrode. Parts of the sample have an approximately 5% lower density, and give rise to the shoulder at ~7.2 T. Also, since the DC-voltage may be given by one or a few current paths, while the PC-amplitude reflects the integral response of the total illuminated area, an inhomogeneity of the carrier-density can explain the different positions of the maxima in U_{rr} and the photo-voltage. Despite the changes in the field dependence due to the topgate, the shape of the spectral resolved PC-signal remains Lorentzian.

For our best ungated samples we estimate the sensitivity to be approximately $10^7 - 10^8\,\mathrm{V/W}$ and a noise equivalent power (NEP) of $10^{-9} - 10^{-10}\,\mathrm{W}/\sqrt{\mathrm{Hz}}$. A similar sensitivity was reported in Refs. [3,4] for a hall-bar device; however, the present Corbino-geometry has the additional

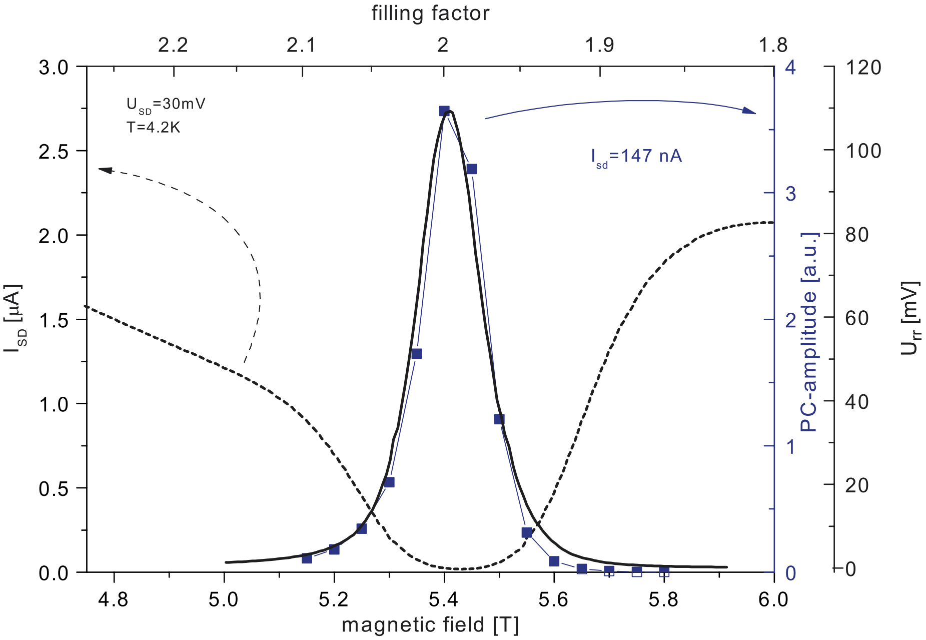

Fig. 2. The PC-amplitude (squares), the non-local voltage between contacts 3 and 4 (solid line) for a constant source–drain (SD) current and the SD current (dashed line) for a constant SD-voltage at different magnetic fields.

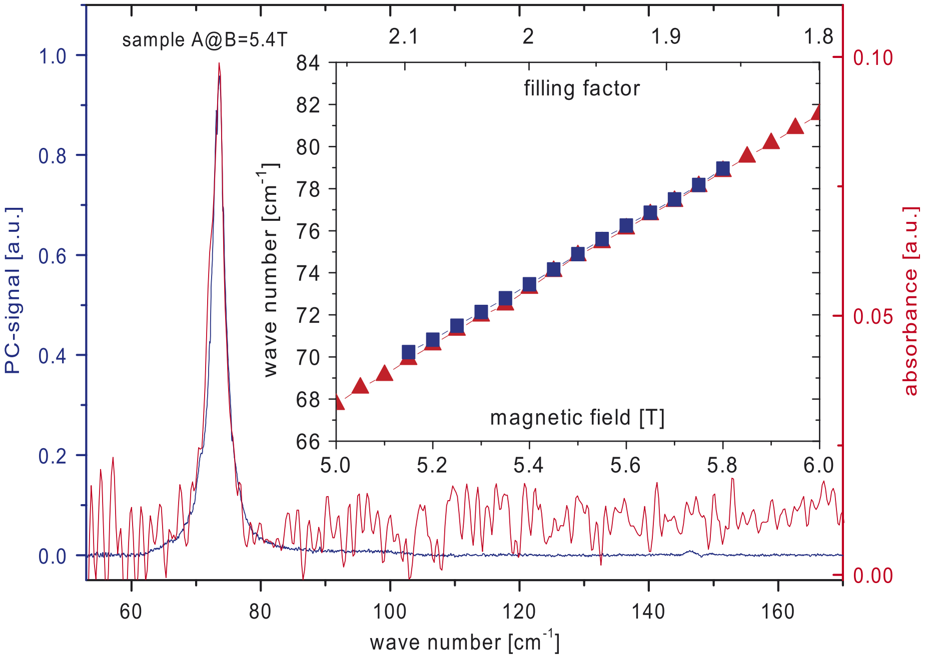

Fig. 3. The PC-signal of sample A is compared with the CR-absorption obtained by transmission measurements. The inset shows the center position of the resonance (squares PC, triangles CR) at different magnetic fields.

advantage of a very low dark current. The sensitivity of the gated sample is reduced by a factor of roughly 50–100 compared to a ungated sample, which can again be explained by an enhanced inhomogeneity. The quality of the gated samples might be increased by using a back-gate instead of a top(front)-gate.

We can conclude that the observed PC-signal is clearly a resonant photo-induced edge channel scattering through the insulating bulk of the 2DEG under QH conditions (see also Ref. [1]). Furthermore, we have shown the possibility to tune the sensitivity and the resonance frequency of the investigated structure independently by adjusting the gate voltage and the magnetic field, respectively. This demonstrates the possibility to realize a spectrally resolved, tunable, high-sensitivity detector using the novel sample geometry.

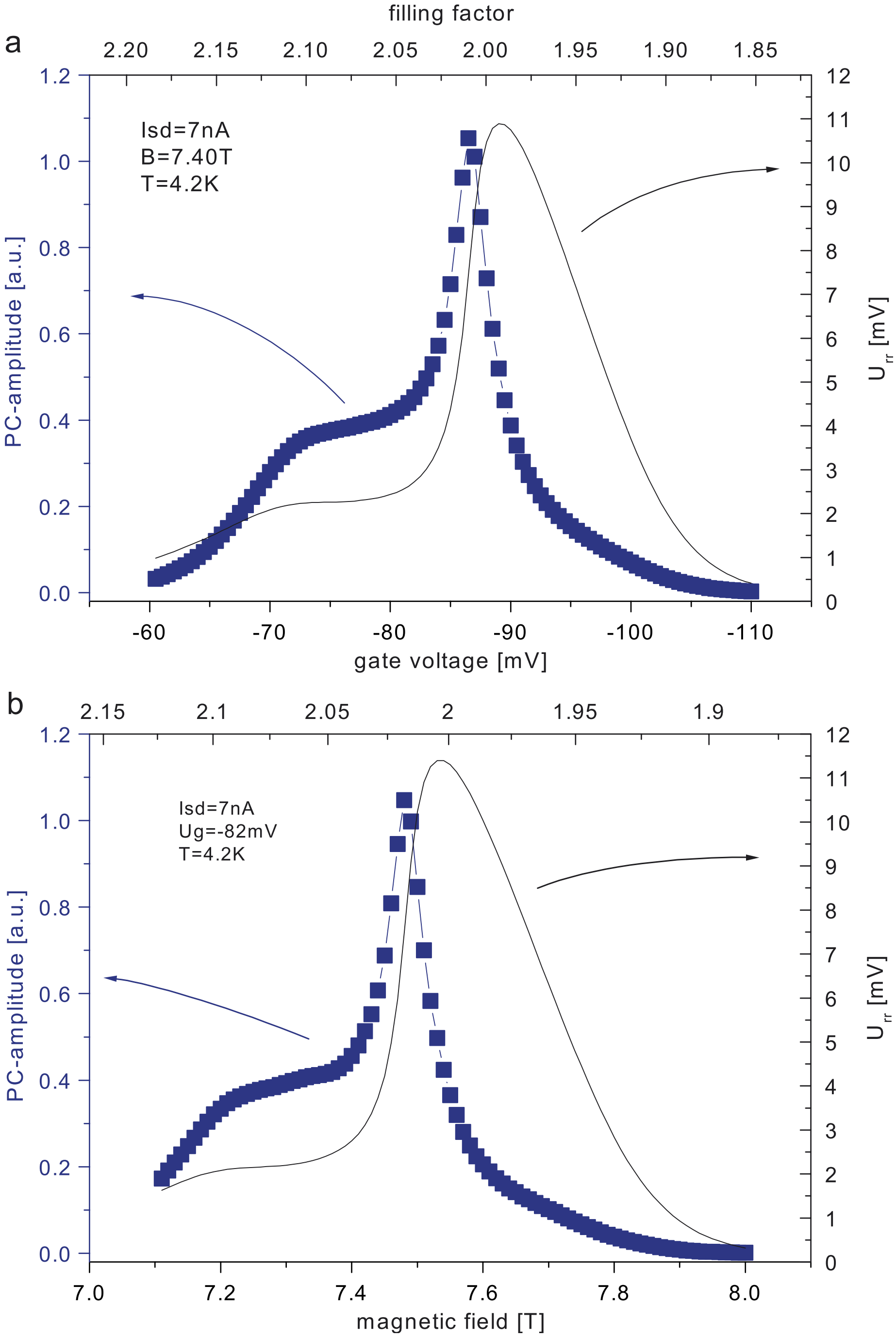

Fig. 4. (a) The PC-amplitude (square) and the non-local voltage U_{rr} (solid line) dependence on the gate voltage (carrier density) at a fixed magnetic field of $B = 7.4\,T$ is compared with (b) the corresponding magnetic field dependence at a fixed gate voltage $U_g = -82\,mV$.

This work was supported by the Deutsche Forschungsgemeinschaft (DFG, Project no. LO 705/1-3).

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