Short decay times of the THz photoresponse in quantum Hall Corbino detectors with spectral tunability

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Abstract. The THz photoconductivity of quantum Hall systems (QHS) around filling factor ν=2 has been investigated. As radiation source a pulsed p-Ge Laser tunable in the frequency range form 1.7 THz to 2.5 THz is used. Via variation of the magnetic field, the carrier concentration (tuned by a gate) and the source drain voltage the spectral resolution of QHS as THz detector is determined. The spectral resolution is found best at voltages close to the breakdown value. In addition we report time resolved measurements with relaxations times from 20 ns to 150 ns.

INTRODUCTION

Far infrared (FIR) photoconductivity in quantum-Hall-(QH)-systems [1] is interesting both with respect to the applications for FIR detection and also with respect to the basic understanding of the conductivity mechanisms. QHS are promising for high sensitive and spectral tunable FIR detectors [2]. In these systems the transition from the QH in the dissipative state is used. Even so QH-detectors have been under research for over 20 years there are still open questions about the fundamental photoconductivity mechanisms.

In this work we present spectrally and time resolved photoresponse (PR) measurements of QH-systems in Corbino geometry. The FIR-source is a pulsed light-hole p-Ge Laser [3], which can be tuned in the frequency range from 1.7 THz to 2.5 THz (180μm to 120μm). The monochromatic radiation and the short switching times allow spectral and time resolved measurements.

EXPERIMENTAL SETUP

The Laser system (FIR source) and the QH-sample (FIR detector) are mounted in a He bath cryostat ($T \approx 4$K). The magnetic fields (≤ 4T for the Laser, ≤ 10T for the detector) are generated by superconducting coils.

MBE grown GaAs/AlGaAs heterojunctions are used to realize a two dimensional electron system (2DES). Mobility and carrier concentration are $n_s = 2.1 \cdot 10^{15}\,\mathrm{m}^{-2}$ and $\mu = 50\,\mathrm{m}^2/(\mathrm{Vs})$. By photolithography the sample is structured in circular Corbino geometry (inner / outer radius: 500 μm / 1500 μm).

In the time resolved measurements an impedance matched detector circuit is used (time constant approx. 6 ns; see Figure 2A) and the Laser is driven by a special FET-based high power pulse generator, which provides very fast switching times (approx. 20 ns).

SPECTRAL RESOLUTION

The response of QH-samples to FIR radiation is due to two mechanisms: The bolometer effect, which is pinned at the QH minimum and cyclotron-resonance (CR), appearing at $E_{\mathrm{Laser}} = \hbar\omega_c = \hbar eB/m^*$ (with the GaAs-effective mass $m^* = 0.067 m_e$) [4]. Variation of the magnetic field B enables spectral tunability.

The following method is used to qualify the spectral resolution: The Laser is adjusted at a certain wavelength. The PR is measured versus B around the filling factor ν=2. This is done for different carrier concentrations, tuned by a gate voltage. At the maximum of the PR the relative position of the Fermi energy in the density of states of the 2DES is constant and the wavelength dependent effect on the spectral resolution is avoided.

Via variation of both the magnetic field and the carrier concentration a determination of the spectral resolution is possible. This is done for different source-drain voltages V_{SD}, as seen in Figure 1.

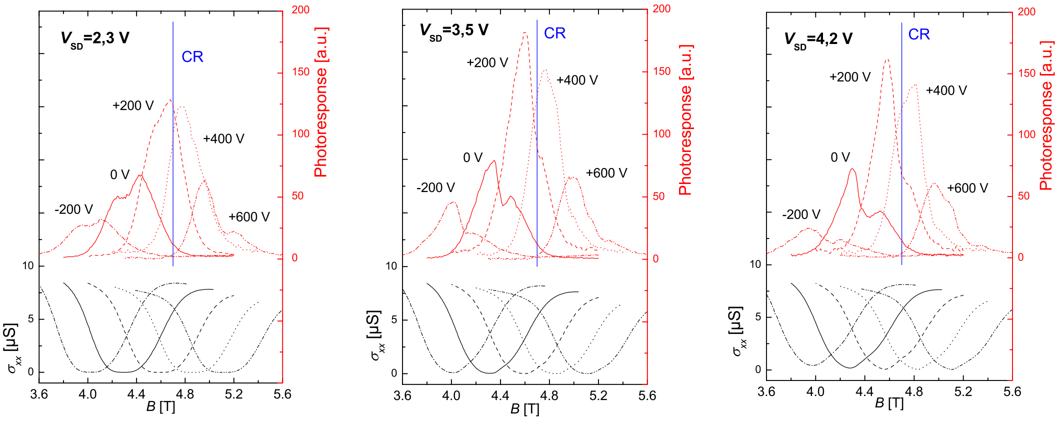

FIGURE 1. In the lower part transport curves around ν=2 are shown. The upper part shows PR versus B for different gate voltages (marked at the curves). It is displayed for three different V_{SD}. The CR position corresponds to $E_{Laser} = 8.13$ meV.

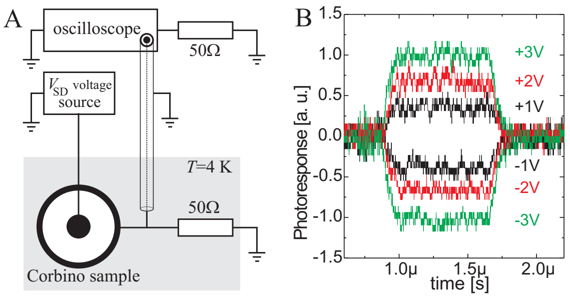

FIGURE 2. Time resolved PR measurements: A: Circuit with impedance matched signal line. B: PR versus time at filling factor $\nu = 2$, the photonenergy is E_{Laser}=8.28 meV, V_{SD} is marked at the curves.

TIME RESOLVED PHOTORESPONSE

With the pulsed Laser radiation time resolved PR is measured. Figure 2B shows the PR over the time for different V_{SD}. The start of the radiation causes a fast increase of the PR signal. During the illumination the PR stays constant. Finally the stop of the radiation causes fast relaxation of the PR. The magnitude of the PR depends on V_{SD}, as expected.

RESULTS AND DISCUSSION

Our investigations show, that the spectral resolution of the Corbino shaped FIR detectors is a function of the source-drain voltage V_{SD}. At low V_{SD} voltages the spectral resolution is relatively low. It reaches the maximum around the QH breakdown voltage V_c=3.5V. Further increasing of V_{SD} beyond the breakdown voltage causes a decreasing of the spectral resolution after all. Our data show the highest spectral resolution of $\Delta E/E \approx 0{,}07$ at a $V_{SD} = 3.5$ V. An earlier investigated sample (meander shaped) shows less spectral resolution, which is reached at currents above the breakdown value [5, 6].

In the time resolved measurements we see fast relaxation times from 20 ns to 150 ns. These time scales are comparable to those reported in [7] (estimated by an indirect method), but several orders of magnitude shorter in comparison to data published at meander type detectors [2, 4]. We find the relaxation time changing with variation of V_{SD}.

In conclusion, our Corbino devices are suitable for spectrally tunable FIR detectors with short response times.

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REFERENCES

1. K. von Klitzing *et al.*, Phys. Rev. Lett. **45**, 494 (1980)
2. Y. Kawano *et al.*, J. Appl. Phys. **89**, 4037 (2001)
3. E. Gornik, A. A. Andronov (Ed.), Opt. Quantum Electron., **23** Special Issue, 111 (1991)
4. N. G. Kalugin *et al.*, Phys. Rev. B **66**, 085308 (2002)
5. A. Hirsch, Diploma thesis, TU-Braunschweig (2003)
6. C. Stellmach *et al.*, Semicond. Sci. Technol. **19**, 454 (2004).
7. K. V. Smirnov *et al.*, JETP Letters **71**, 31 (2000)