THz detectors with HgTe and InSb quantum wells

F. Gouider[1], Yu. B. Vasilyev[2], J. Könemann[3], C. Brüne[4], H. Buhmann[4], P.D.Buckle[5] and G. Nachtwei[1]
[1]Institut für Angewandte Physik, Technische Universität Braunschweig, D-38106 Germany
[2]A. F. Ioffe Physical Technical Institute, RU-194021 St. Petersburg, Russia
[3]Physikalisch-Technische Bundesanstalt, D-38116 Braunschweig, Germany
[4]Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany
[5]QinetiQ Ltd, Malvern WR14 3PS, United Kingdom

Abstract—**Terahertz-frequencies in semiconductor quantum wells are of interest due to the opportunity for making devices that operate at THz frequencies. In this study we present magnetotransport and magnetooptical data obtained in the magnetic field range 0 < *B* < 7T at QH detectors patterned as Corbino rings on AlInSb/InSb/AlInSb and HgCdTe/HgTe/HgCdTe quantum well wafers.**

I. Introduction

We investigate the fast THz-photoresponse (PR) of devices with HgTe QWs embedded in CdHgTe barriers and InSb QWs embedded in AlInSb barriers which are aimed at obtaining photosignals at smaller magnetic fields. The THz radiation is provided by a *p*-Ge laser which operates with a magnetic field and high voltage for the electrical pumping. The stimulated emission is caused by transistions between Landau levels of light holes [1]. The laser is tunable in the range between 1.7 to 2.5 THz (corresponding to wavelengths between 120 and 180 µm or energies from 7 to 12 meV) [2]. The laser is pulsed with a pulse rate of 1 Hz and pulse lengths of about 1 µs with steep switching flanks.

The measurement of the THz photoconductivity (Corbino discs) or of the photoresistivity (Hall bars), called photoresponse (PR) for both cases, requires a low-noise circuit. For the Corbino-shaped samples (inner and outer radii of the 2DEG are r_1=500µm and r_2=1500 µm) the photoresponse (PR) is measured via a resistor of R_V = 1 kΩ. The signal passes a coaxial cable and finally reaches a digital oscilloscope. For time resolved measurements the coaxial cable is terminated with a resistor of 50 Ω at the input of the digital oscilloscope to achieve a low time constant for the detector circuit (better than 10 ns).

The experiments were performed in a cryostat system with a superconducting coil (B_{max} = 10 T at T = 4.2 K) and a variable temperature insert (VTI) [3].

II. Results

We have investigated the Shubnikov-de Haas (SdH) effect and the current-voltage (I_{SD}-V_{SD}) to characterize the samples. The longitudinal conductivity σ_{xx} of a Corbino sample is proportional to the source-drain current I_{SD} at a source-drain voltage V_{SD}. For homogeneous systems, it is

$$\sigma_{xx} = \frac{I_{SD}}{V_{SD}} \frac{\ln(\frac{r_2}{r_1})}{2\pi}.$$

The corresponding results are presented in Fig.1 for InSb QWs and in Fig.3 for HgTe QWs. From this is the carrier densities of n_s= 2.8 10^{15} m^{-2} and n_s= 2.5 10^{15} m^{-2} and the electron mobilities of $\mu_{e=}$ 4.2 m^2/Vs and $\mu_{e=}$ 19 m^2/Vs are determined. From the nonlinearities in the *I*-*V*-curves, the operational conditions of the samples working as THz detectors can be determined [4].

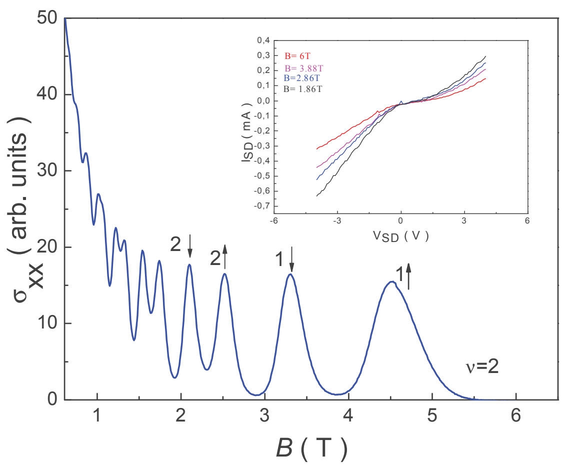

Figure1: Conductivity σ_{xx} of a Corbino device patterned on a wafer with a InSb quantum well (QW) with a thickness of d_{QW} = 30nm as a function of the magnetic field B (Shubnikov-de Haas (SdH-) effect). Insets the current-voltage (I_{SD}-V_{SD}) curve.

We performed transmission measurements to observe the cyclotron resonance (CR) . The results are shown in Fig.2 the cyclotron mass is approximately m_c= (0.0218 ± 0.0003)m_0 for InSb QWs and m_c= (0.019 ± 0.0003)m_0 for HgTe QWs.

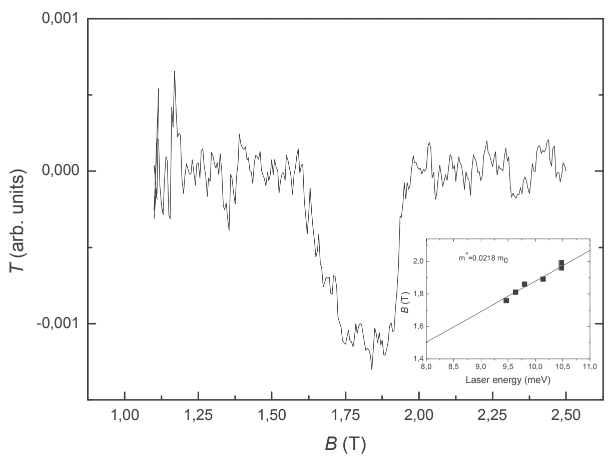

Figure2: This figure shows the transmission signal measured at a 4x4mm^2 square of the wafer of an InSb sample at B = 1.85T (ν = 6) at a photon energy of E_{ph}= 9.68meV of the *p*-Ge laser. The inset shows the magnetic field position of the resonance minimum as a function of the laser energy in the range of 9.46meV $\leq E_{ph} \leq$ 10.48meV. This dependence is linear yielding a cyclotron mass of m_c= (0.0218 ± 0.0003)m_0. The magnetic field B is applied perpendicular to the wafer (corresponding to the Faraday configuration).

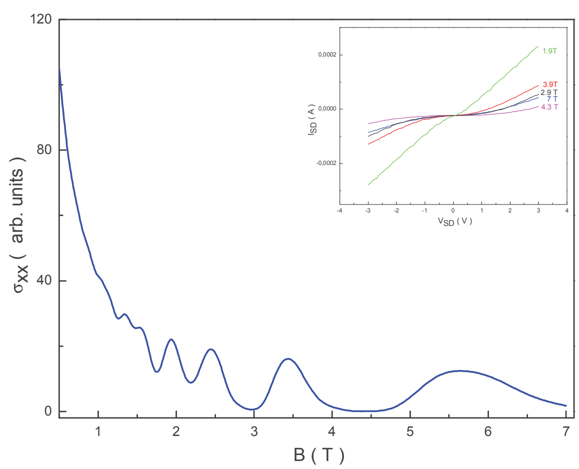

Figure3: Conductivity σ_{xx} and the current-voltage (I_{SD}-V_{SD})of a Corbino device patterned on a wafer with a HgTe quantum well (QW) with a thickness of d_{QW} = 8nm as a function of the magnetic field B (Shubnikov-de Haas (SdH-) effect).

After this characterization the THz photoconductivity of various devices patterned on HgCdTe/HgTe/HgCdTe and AlInSb/InSb/AlInSb quantum well wafers were measured. The PC signal is measured during the laser pulse, when the optically excited system is in a stationary equilibrium (the PC is not influenced by the switching processes of the laser). In Fig.4 we show the PC of the sample with HgTe QWs as a function of the magnetic field and the laser energy in a coloured plot, the black squares, measured by the transmission of THz waves through the samples in the energy range 7 $\leq E_{laser} \leq$10.2 meV. The white line shows the position of the CR in the magnetic field as a function of the radiation energy E_{laser} for m_c =0.022m_0.

Photoconductivity signals are observable for even and for odd filling factors. These results are interesting for understanding the basic physics of the interaction of a 2DES and THz radiation and for the application of HgTe as well as InSb-based devices as THz detectors. From the photoresponse (PR) signals it is difficult to distinguish between a bolometric and a cyclotron resonance (CR) contribution to the signal. The transmission as function of B as shown in the inset of Fig.2 and by the black square in Fig.4 are due to the CR. However for the PC as shown in the colour plot of Fig.4 the behavior is more complex. Whereas the PC shown in Fig.4 is dominated by the bolometric (BO) contribution, the CR influences strongly the PC signal for HgTe sample with d_{QW} =12 nm and d_{QW} =21 nm.

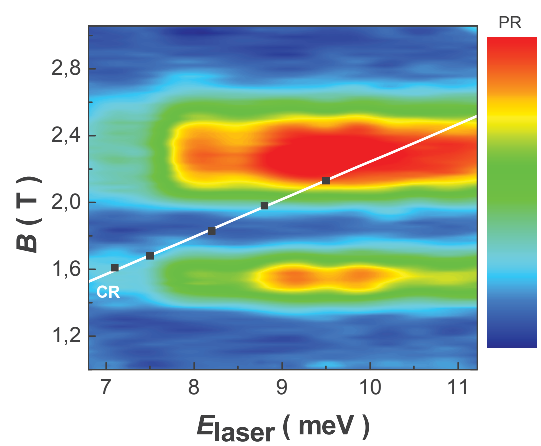

Figure4: Photoresponse as a function of the magnetic field and the laser energy for a HgTe sample with d_{QW} =8 nm .

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