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Cyclotron resonance quantum Hall effect detector

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Abstract. Far IR photoresponse of QHE device operating at cyclotron resonance has been inverstigated. The possibility of the detector band tuning at the simultaneous increase of the magnetic field and the 2D electron concentration (the latter due to the persistent photoconductivity after band-gap illumination) is demonstrated. Time characteristics of the response has been studied.

Introduction

Far infrared (FIR) photoresponse of high mobility two-dimensional (2D) electrons in GaAs/AlGaAs heterostructures under cyclotron resonance (CR) conditions has been the subject of several studies (see, for example [1, 2]). In high magnetic fields when the Fermi level E_F lies in localized states between two adjacent Landau levels the Hall resistance R_H is quantized to a multiple of h/e^2 and the longitudinal resistance R_{xx} vanishes. The finite R_{xx} emerges when electrons and holes are photoexcited in delocalized states near the level centers above and below E_F. Therefore quantum Hall effect (QHE) devices may serve as an excellent CR detector in FIR range. In the present work the possibility of the detector tuning as well as its time characteristics were inverstigated.

1. Experimental

The sample under study was a long Hall bar fabricated from high mobility ($\mu_{4.2\,\mathrm{K}} = 8 \times 10^5$ cm^2/Vs) with a width of 50 μm and a length of 170 mm patterned in zig-zag shape and fitted into an area 4 × 4 mm^2 [1]. All measurements were carried out at $T = 4.2$ K. The sample placed in the center of superconducting solenoid was biased by d.c. current of 3 μA. FIR radiation was guided to the sample by stainless steel light pipe. Black body source ($T = 600^\circ$C) was used to reveal the detector sensitivity bands in the whole range of the magnetic fields (up to 6 T). The spectral study was carried out using BOMEM DA3.36 FT spectrometer. The tuning was provided the simultaneous increase of the magnetic field (and correspondingly CR frequency) and the concentration of 2D electrons by band-gap illumination of the sample by near IR ($\lambda \approx 0.9$ μm) radiation of GaAs light emitting diode (LED). The increase of the concentration resulted from the illumination persists after the diode switching off up to the thermal recycling of the sample (persistent photoconductivity effect [3]). Time characteristics of the detector response were studied using broad band FIR emission of hot holes in InGaAs/GaAs multiple-quantum-well (MQW) heterostructure (see, for example [4]) excited by pulsed lateral electric field (about 10 μs in duration).

2. Results and discussion

Magnetic field dependences of longitudinal resistance R_{xx} and photoresponse on the broad band black body source radiation of QHE device (measured by two-terminal scheme) are shown in Fig. 1. 2D electron concentration obtained from the period (in 1/B scale)

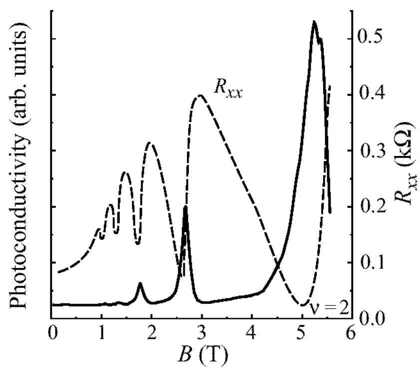

Fig. 1. Longitudinal resistance R_{xx} and photoresponse on the broad band black body source radiation of QHE device versus the magnetic field.

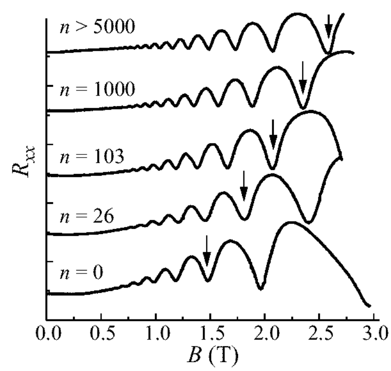

Fig. 2. Evolution of SdH oscillations under the LED radiation, n is a number of pulses. Arrows show the minimum positions corresponding to $\nu = 8$.

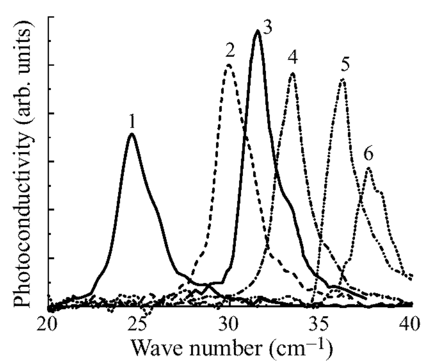

Fig. 3. Photoresponse spectra measured at magnetic fields near the R_{xx} minimum at $\nu = 6$. Spectra 1–6 correspond to increasing numbers of LED radiation pulses.

of Shubnikov–de Haas (SdH) oscillations is $n_s \approx 2.8 \times 10^{11}$ cm^{-2}. It is clearly seen that the response occurs near R_{xx} minima, i.e. at the even values of the filling factor $\nu = 2, 4, 6, 8, 10$ etc. Spectral investigation of the response shows that it consists of sharp CR line of 2 to 3 cm^{-1} in width ($m_c \approx 0.068 m_0$, cf. [5]). The response is greater for the lower values of the filling factor mainly due to the increase of the spectral density of the blackbody radiation with the frequency. The absolute measurements of the response at $\nu = 4$ and $\nu = 6$ gave the same value $S_V \approx 10^4$ V/W at NEP $\approx 10^{-11}$ W/Hz$^{1/2}$ that is comparable with the existing semiconductor photoelectric detectors.

Figure 2 illustrates the evolution of SdH oscillations with the increase of the LED radiation amount (number of pulses of 500 μs in duration). It is clearly seen that R_{xx} minimums corresponding to definite values of the filling factor shift to higher magnetic fields. This is a result of the increase of 2D electron concentration due to the persistent photoconductivity effect. The maximum shift reaches 80% in the samples under investigation that opens the possibility of continuous tuning of the detector sensitivity band. Arrows in Fig. 2 indicate the shift of the minimum corresponding to $\nu = 8$ that moves to the higher magnetic fields (and correspondingly frequencies) covering the broad range spreading over initial (before band-gap illumination) position of the minimum corresponding to $\nu = 6$. The tuning is illustrated by Fig. 3 where the photoresponse spectra measured at the magnetic fields near

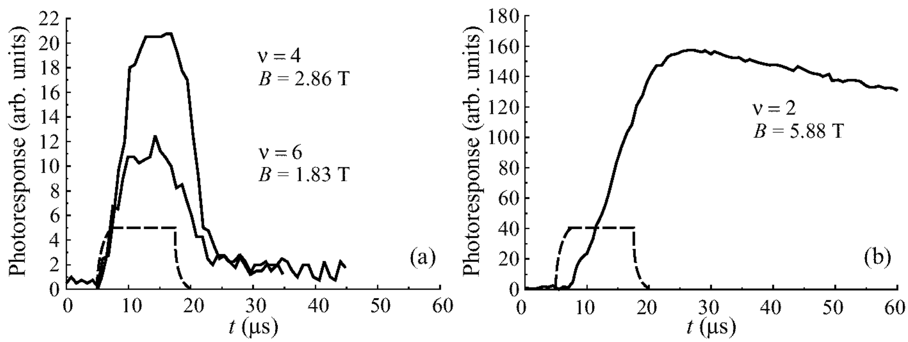

Fig. 4. Time dependences of photoresponse at $\nu = 6$ and $\nu = 4$ (a) and $\nu = 2$ (b). The dash line is the oscillogram of FIR emission puls.

R_{xx} minimum ($\nu = 6$) are presented. It is clearly seen that the photoresponse consists of the narrow CR line (FWHM about 2 to 3 cm^{-1}). By simultaneous increasing of band-gap illumination amount and the magnetic field the line is tuned to higher frequencies, its FWHM being approximately the same. Such tuning demonstrates the possibility to utilize QHE detector as spectral analyzer for the FIR range.

Another important characteristic of the detector is its response time. The results of the preliminary investigation of the detector time characteristics are shown in Fig. 4. Operating at the magnetic fields corresponding to the filling factor values $\nu = 6$ and $\nu = 4$ the detector exhibits rather fast response ($\tau \leq 5\,\mu s$) and the response oscillograms repeat that of the voltage pulse applied to the emitter. At the same time at higher magnetic fields at $\nu = 2$ the characteristic time determined from the response decay after emitter voltage switching off is much longer, about 200 μs. Moreover it is clearly seen from Fig. 4 that at $\nu = 2$ the response continues to increase after the emitter voltage switching off and reaches its maximum with some delay. Such behavior can be naturally explained by the arising in high magnetic field (at $\nu = 2$ in contrast to $\nu = 6$ and $\nu = 4$) the localized states in between the centers of Landau levels which are responsible for the quantum Hall effect. The significant part of electrons and holes generated by FIR radiation above and under the Fermi level respectively seems to be excited in long living localized states which do not participate in d.c. conductivity. The excited carriers have to relax into delocallized states thus resulting in the above delay of the photoresponse maximum.

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