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Time constant of far IR response of quantum Hall device

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Abstract. The characteristic time of far IR response of quantum Hall effect detector in GaA/AlGaAs has been investigated versus the magnetic field. The response time is shown to increase dramatically with the field due to the spatial separation of photoexcited electrons and holes captured by localized states formed by the disordered potential.

Introduction

Quantum Hall effect (QHE) device is known to be a sensitive detector of far infrared (FIR) radiation [1–5]. At QHE the Hall resistance is quantized and the longitudinal resistance R_{xx} vanishes. The finite R_{xx} emerges when electrons and holes are excited by FIR radiation at cyclotron resonance (CR) in the delocalized (extended) states near the Landau level centers above and below the Fermi level E_F . A thorough investigation of the photoresponse has been undertaken recently [5]. The results obtained revealed the key role of the random potential in the mechanism of FIR-photoresponse. The present paper deals with the magnetic field dependence of the response time that has been shown to be consistent with the response mechanism proposed in [5].

1. Experimental

Samples under study were Hall bars fabricated on selectively doped heterostructure GaAs/Al_{0.3}Ga_{0.7}As with two-dimensional electron gas (2DEG) ($\mu_{4.2K} = 8 \times 10^5 \text{ cm}^2 \cdot \text{s}$, $n_s = 2.8 \times 10^{11} \text{ cm}^{-2}$). They have a long 2DEG channel $50 \mu\text{m} \times 170 \text{ mm}$ in size patterned in a zigzag shape and fitted into an area of $4 \times 4 \text{ mm}^2$ [1, 5]. The sample placed in the liquid helium in the center of a superconducting solenoid was biased by a d.c. current of $3 \mu\text{A}$. As a broad band FIR emitter we used bulk p-Ge crystal ($N_A - N_D = 2 \times 10^{13} \text{ cm}^{-3}$) of $8 \times 4 \times 0.5 \text{ mm}^3$ in size, ohmic contacts being deposited onto $8 \times 0.5 \text{ mm}^2$ opposite faces. The emitter was excited with a voltage pulses of 16 V and 200 μs in duration with a repetition rate 8 Hz. The emitter was placed in the same cryostat, the emitter radiation being guided to the sample through a metallic light pipe of 7 mm in diameter and 30 cm long. The pulsed response from the detector was analyzed using either digital oscilloscope or boxcar integrator. To provide a possibility of the detector tuning the 2DEG concentration was successively increased by the detector band-gap illumination using a GaAs light emitting diode. The increased 2DEG concentration persisted up to the heat recycling of the sample.

2. Results and discussion

Typical magnetic field dependences of R_{xx} and photoresponse are shown in Figures 1(a-c) for three different values of 2DEG concentration. It is clearly seen that the response

occurs near the $R_{xx}(H)$ minima at the even values of the filling factor $\nu = 4$ and $\nu = 2$. In Figure 1(a) the photoresponse at both the $\nu = 4$ and $\nu = 2$ consists of two prominent peaks that is a general trend observed if QHE plateaus are well developed [5]. It is clearly seen in Figures 1(b-c) that after a band-gap-illumination the depths of R_{xx} minima decrease (probably due to nonuniform increase of 2DEG concentration) thus resulting in a single peak structure of the response. Figures 1(d-f) give examples of the response oscillograms recorded either in the 'right' peak maxima (Fig. 1(d)) or in maxima of single peak structures Figures 1(e,f). Some data on $\tau(H)$ dependence are summarized in Fig. 2. It is clearly seen that within a single series of measurements the response time exponentially increases with the magnetic field that is consistent with the mechanism of FIR-response of QHE device proposed in [5]. It is known that there is a

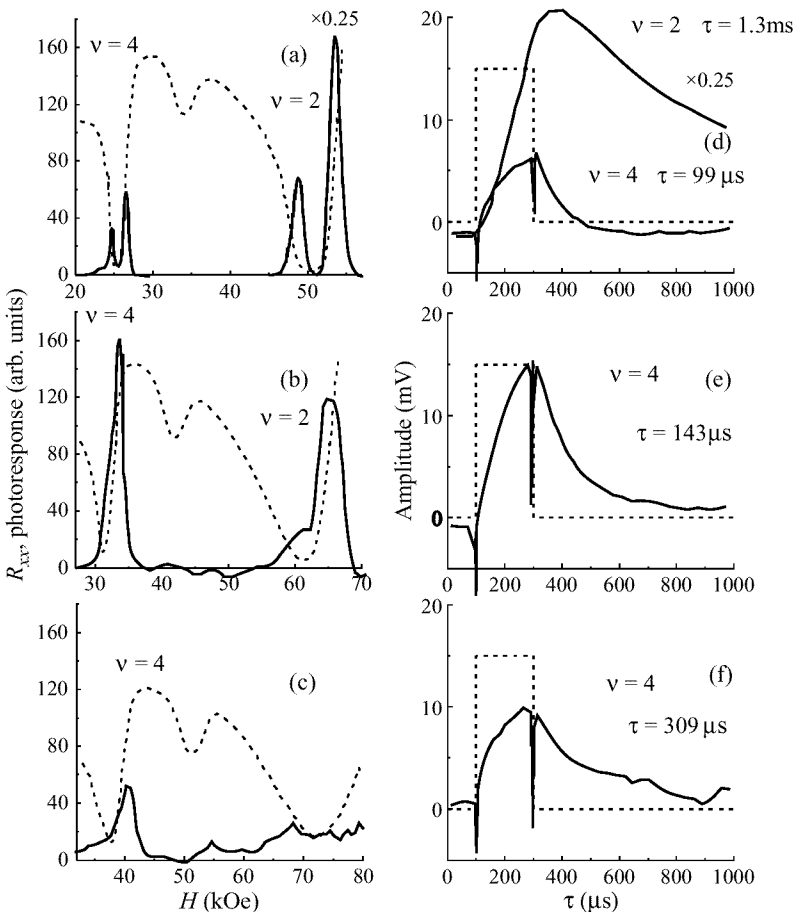


Fig. 1. Longitudinal resistance R_{xx} (brouken curves) and photoresponse of QHE detector (solid curves) versus the magnetic field before (a) and after (b),(c) band-gap illumination, $T = 2.2$ K. Solidcurves in plots (d)-(f): examples of the response oscillograms measured at $\nu = 4$, $H = 25.9$ kOe and $\nu = 2$, $H = 52.9$ kOe (d), $\nu = 4$, $H = 31.7$ kOe (e) and $\nu = 4$, $H = 39.4$ kOe (f), brouken curves: oscillograms of the voltage pulses applied to the emitter.

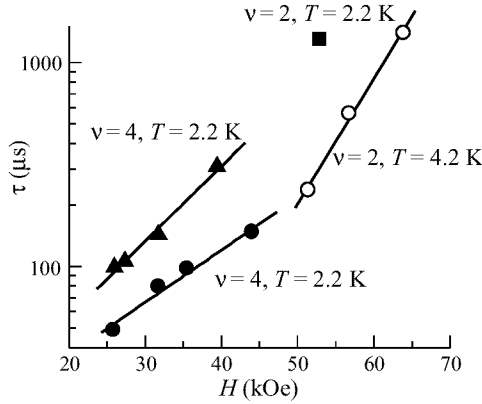


Fig. 2. Time constant of QHE detector photoresponse versus the magnetic field measured at the successive increase of 2DEG concentration produced by band-gap illumination of the sample. Two different series of $\tau(H)$ data at $\nu = 4$, $T = 2.2$ K were obtained one after another after heating the sample up to the room temperature and subsequent cooling down. To the author's opinion this testify a nonreproducibility of 2DEG in one in the same GaAs/AlGaAs sample (from one cooling to another one).

long-range random potential in 2DEG systems at high magnetic field, the amplitude of the fluctuation potential reaching the order of $\hbar\omega_c$ in the close vicinity of QHE state [6]. When an electron and a hole are photoexcited at CR in Landau levels above and below E_F , respectively, the excited electron (hole) will rapidly (within 10 ns) fall into a local minimum (maximum) energy (i.e. into a localized state). This spatial separation prevents the excited carriers from quickly recombining. The localized electron (hole) can be excited occasionally to a delocalized state formed around the Landau level center. Once delocalized, the nonequilibrium electron (hole) participates in the longitudinal conductivity thus giving rise to the photoresponse, recaptured by localized states etc. At low enough both the lattice temperature and the excitation level the time constant of FIR response is closely related to the recombination lifetime of localized carriers separated by the characteristic distance ΔY . In strong magnetic fields in high mobility samples ΔY could exceed significantly the magnetic length $l_B = (\hbar c/eH)^{1/2}$ that is the extension of a carrier wavefunction. Thus the recombination may be strongly suppressed due to the small overlapping between the electron and hole wavefunctions [5]:

$$\tau = A \exp[(\Delta Y/l_B)^2] = A \exp[(\Delta Y)^2 eH/\hbar c] = A \exp(H/H^*). \quad (1)$$

From the slope of $\lg \tau(H)$ dependences (Fig. 2) one can determine the characteristic magnetic fields H^* and obtain the following data for $\Delta Y = (\hbar c/eH^*)^{1/2}$:

- $\nu = 4$, $T = 2.2$ K (closed circles): $H^* = 17.0$ kOe, $\Delta Y = 200$ Å;
- $\nu = 4$, $T = 2.2$ K (triangles): $H^* = 11.8$ kOe, $\Delta Y = 235$ Å;
- $\nu = 2$, $T = 4.2$ K (open circles): $H^* = 7.1$ kOe, $\Delta Y = 300$ Å.

The figures obtained are noticeably less than those obtained recently in a similar 2DEG system using a scanning probe technique with a spatial resolution of 900 Å: ($\Delta Y = 900 - 2000$ Å) [7]. However it should be noted that in the present work we have determined the

smallest characteristic length of the disordered potential which is responsible for the shortest lifetime of the photoexcited carriers. In general, if measured with sufficient accuracy, there is long-lived components in the response decay [5] that is a signature of relaxation kinetics in disordered systems.

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