Photoconductivity under the conditions of the quantum Hall effect

Yu. B. Vasil'ev, S. D. Suchalkin, Yu. L. Ivanov, S. V. Ivanov,
P. S. Kop'ev, and I. G. Savel'ev
A. F. Ioffe Physicotechnical Institute, Russian Academy of Sciences,
194021, St. Petersburg, Russia

(Submitted 15 September 1992)
Pis'ma Zh. Eksp. Teor. Fiz. **56** No. 8, 391–394 (25 October 1992)

The submillimeter-range photoconductivity of a single heterostructure has been studied under the conditions of the integer quantum Hall effect. The photoconductivity spectrum of the 2D electron gas was found for various magnetic field strengths. A sharp increase in the signal, is observed at a current ~ 300 μA, is attributed to a photoinduced disruption of the quantum Hall effect.

Although the submillimeter-range photoconductivity of a 2D electron gas in a high magnetic field has been the subject of a fair number of studies,[1-6] there is little in the way of experimental data on the photoconductivity under the conditions of the integer quantum Hall effect. In this letter we are reporting a first study of the photoconductivity of a 2D electron gas under the conditions of the quantum Hall effect, for various fixed values of the magnetic field applied to the sample. The source of electromagnetic radiation was a tunable cyclotron Ge laser, which was first used to study 2D structures in Ref. 7. The laser pulse had a length of 0.2 μs and rise and decay times no greater than 50 ns. The measurements were carried out on an AlGaAs/GaAs structure grown by molecular-beam epitaxy, with a carrier density $n = 2.6 \times 10^{11}$ cm^{-1} and a mobility $\mu = 82\,000$ cm^2/(V·s) at $T = 77$ K. The parameters of the structure were selected in such a way that in magnetic fields corresponding to a minimum in the Shubnikov–de Haas oscillations the cyclotron resonance frequencies of the electrons in the heterojunction would be in the frequency interval over which the laser could be tuned. The samples were Hall bridges 2.5 mm long and 0.3 mm wide; the distance between the potential contacts was 0.55 mm. The structure was connected in the circuit shown in the inset in Fig. 1. The dc voltage drop which appeared across the potential contacts upon the application of the radiation was measured. The radiation was directed along the normal to the surface of the structure. All the measurements were carried out at $T = 4.2$ K.

The plot of the photoresponse $\Delta\rho_{xx}$ versus the magnetic field (Fig. 1) has a cyclotron-resonance peak corresponding to an effective mass $m = 0.067 m_0$. The half-width of this peak, ~ 0.6 T, agrees approximately with the results found in Ref. 4, but the mobility of the structures used in Ref. 4 is an order of magnitude higher. This behavior of the cyclotron resonance in the photoconductivity is radically different from that of the cyclotron resonance in the absorption. In this case the half-widths for samples with the same mobility ratio differ by a factor of several units.

Figure 2 shows photoconductivity spectra recorded at various strengths of the

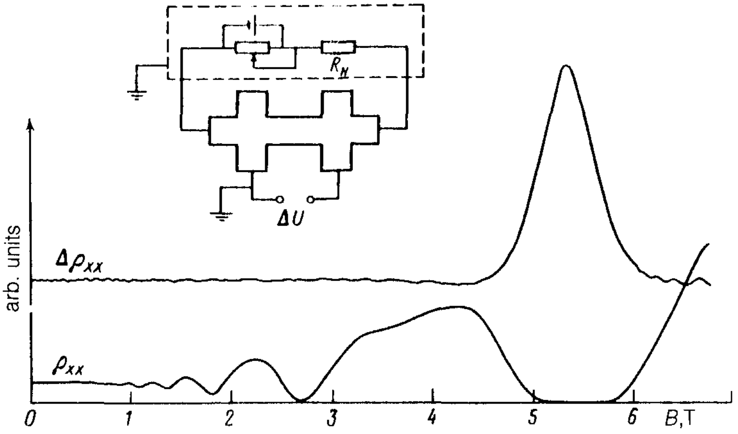

FIG. 1. The resistivity ρ_{xx} and the photoresponse $\Delta\rho_{xx}$ versus the magnetic field. The current through the structure is $I=2\ \mu$A, and the laser frequency is $\nu=72.4\ \text{cm}^{-1}$. The inset shows the circuit diagram of the structure.

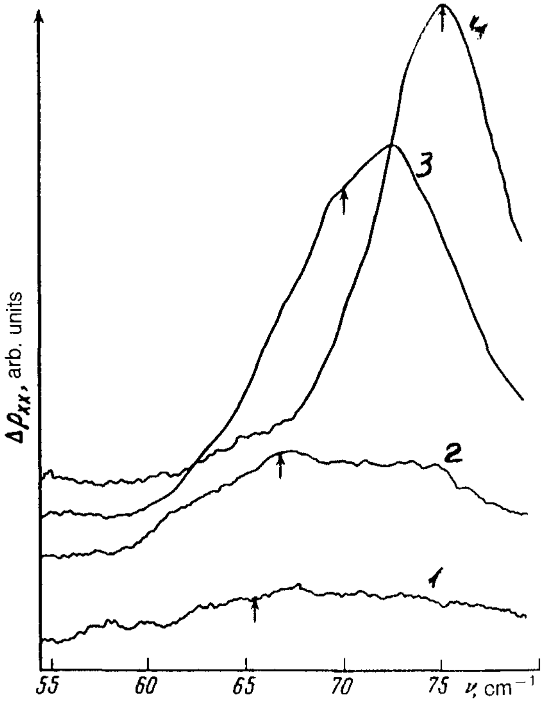

FIG. 2. Spectra of the photoresponse ($I=2\ \mu$A). *1*—Magnetic field $B=4.7$ T; *2*—4.8; *3*—5.1; *4*—5.45 T. The arrows mark the cyclotron frequencies ($m=0.067m_0$) corresponding to the given magnetic fields.

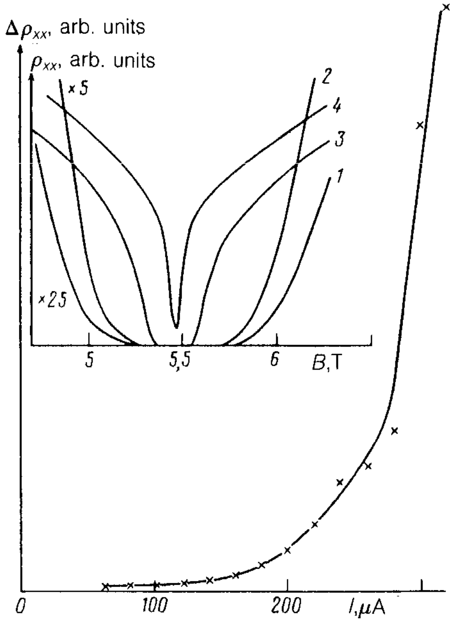

FIG. 3. The photoresponse $\Delta\rho_{xx}$ versus the current through the structure, $I(B=5.45$ T, $\nu=75.4$ cm^{-1}). The inset shows the "dissipationless" region of the Shubnikov–de Haas effect for various values of I: *1*—5 μA; *2*—90; *3*—280; *4*—350 μA.

magnetic field for a current $I=2.0$ μA through the structure. The shape of the spectral line is very sensitive to the magnetic field strength: In fields corresponding to $\rho_{xx}=0$ (the midpoint of the Hall shelf) the photoresponse spectrum is a peak with a half-width ~1 meV. Toward the edge of the shelf (as the magnetic field is reduced), this peak shrinks and its half-width broadens. Some new, poorly resolved structure also appears in the spectrum; the origin of this other structure is not yet clear.

Figure 3 shows the signal strength versus I in a magnetic field corresponding to the midpoint of the Hall shelf. At currents $I\sim 300$ μA the signal increases sharply (by ~2 order of magnitude). This region precedes the current ($I=350$ μA) at which the Hall shelf "collapses," i.e., at which the disruption of the quantum Hall effect begins (see the inset in Fig. 3). As I approaches 350 μA, the signal becomes unstable and disappears.

Two mechanisms contributing to the photoconductivity were discussed in Ref. 1: a heating of the sample and a redistribution of electrons among Landau levels, which results in a change in ρ_{xx}. Measurements of the kinetics of the photoresponse[2] do indeed reveal two times scales: a "fast" one $\tau\leqslant 0.1$ μs, corresponding to a relaxation of the photoexcited electrons, and a "slow" one $\tau\geqslant 1$ ms, corresponding to the relaxation of the lattice temperature. The current dependence $\Delta\rho_{xx}(I)$ was measured in Refs. 1 and 4; a monotonically increasing signal was found in Ref. 1 as I was raised from 0 to 40 μA, while the curve found in Ref. 4 has a peak near 20 μA. The behavior of $\rho_{xx}(B)$ as the current was varied over this range was not investigated in those studies, however.

The results obtained in the present study lead to the conclusion that in these experiments the photoconductivity is caused by a faster redistribution of electrons among Landau levels induced by resonant radiation. Our experimental estimates of the photoresponse time yield $\tau \leqslant 0.2\ \mu s$. The use of a pulsed laser with a pulse considerably shorter than in the preceding studies has made it possible to avoid the component of the photoresponse due to the heating of the sample. The energy redistribution of electrons is seen most clearly in magnetic fields corresponding to the Hall shelf, at which the Fermi level lies between Landau levels. In this case the application of the resonant radiation causes a qualitative change in the populations of the Landau levels, emptying positions in the filled upper level and putting electrons in the empty Landau level. These changes in turn give rise to a dissipation and to a nonzero ρ_{xx}. The sharp increase in the signal near $I = 300\ \mu A$ apparently occurs because the radiation stimulates a breakdown of the quantum Hall effect in this case, so ρ_{xx} increases catastrophically. With a further increase in the current, the disruption occurs independently, and the radiation does not cause any substantial changes in ρ_{xx}. This situation explains the disappearance of the signal at $I \sim 350\ \mu A$. As can be seen from the inset in Fig. 3, the dissipationless region of the Shubnikov–de Haas effect disappears at this current ($\rho_{xx} = 0$).

Questions concerning the magnitude and behavior of the half-width of the cyclotron resonance in the photoconductivity as a function of the mobility and the magnetic field lie outside the scope of this paper. The same is true of questions concerning the nature of the nonresonant structure seen in the spectra at certain values of the magnetic field. A clarification of those questions will require further experiments; we intend to carry out such experiments in the near future.

[1] J. C. Maan, Th. Englert, D. C. Tsui, and A. C. Gossard, Appl. Phys. Lett. **40**, 609 (1982).
[2] D. Stein, G. Ebert, K. von Klitzing, and G. Weimann, Surf. Sci. **142**, 146 (1984).
[3] R. E. Horstman, E. J. v. d. Broek, J. Volter *et al.*, Solid State Commun. **50**, 753 (1984).
[4] M. J. Chou, D. C. Tsui, and A. Y. Cho, *Proceedings of the Eighteenth International Conference on the Physics of Semiconductors* (ed. O. Engstrom), World Scientific, Singapore, 1986, p. 437.
[5] E. Diessel, G. Müller, D. Weiss *et al.*, Appl. Phys. Lett. **58**, 2231 (1991).
[6] E. Diessel, G. Müller, D. Weiss *et al.*, Surf. Sci. **263**, 280 (1992).
[7] K. Unterrainer, C. Kremser, E. Gornik, and Yu. L. Ivanov, Solid-State Electron. **32**, 1527 (1989).

Translated by D. Parsons