Spin-polarized currents of Dirac fermions at cyclotron resonance

C. Zoth[1], P. Olbrich[1], P. Vierling[1], K. M. Dantscher[1], G. V. Budkin[2], S. A. Tarasenko[2], V. V. Bel'kov[2], D. A. Kozlov[3], Z. D. Kvon[3], N. N. Mikhailov[3], S. A. Dvoretsky[3], and S. D. Ganichev[1]

[1] *Terahertz Center, University of Regensburg, Regensburg, Germany*
[2] *A.F. Ioffe Physical-Technical Institute, St. Petersburg, Russia*
[3] *Institute of Semiconductor Physics, Novosibirsk, Russia*

We report on the observation of giant spin-polarized photocurrents in HgTe-based quantum well (QW) samples of width close to the critical thickness, at which a gapless state and the Dirac spectrum emerge [1]. The study of the photocurrent, accompanied by the measurements of radiation transmission as well as Shubnikov-de Haas and quantum Hall effects, reveals that the current enhancement is caused by cyclotron resonance (CR) in a Dirac fermion system. We develop a microscopic theory of the effect and show that the current originates from spin-dependent scattering of carriers heated by radiation.

The excitation of a MBE-grown (013) oriented HgTe/$Hg_{0.3}Cd_{0.7}Te$ QW sample with low power terahertz (THz) radiation of *cw* CH_3OH THz laser operating at a frequency of 2.54 THz results in a *dc* electric current caused by the photogalvanic effect. Applying a magnetic field perpendicular to the QW plane and studying the field dependence of the photocurrent, we observe that the current exhibits a resonance with a magnitude exceeding the photocurrent at zero magnetic fields by several orders of magnitude [2]. We observed that the magnetic field B_c at which the resonant photocurrent emerges can be tuned from negative to positive values by changing the type of carriers in the same sample applying optical doping [3]. Moreover the value of B_c depends on free carrier concentration and increases with rising Fermi energy. For our QW samples with the carrier density $(1 - 10)\cdot 10^{10}$ cm^{-2} and THz radiation with the photon energy $\hbar\omega$ = 10.35 meV, the resonant photocurrent appears at correspondingly low magnetic fields B_c = 0.42 – 1.2 T. The photocurrent data, accompanied by measurements of radiation transmission as well as Shubnikov-de Haas and quantum Hall effects, give evidence that the enhancement of the photocurrent is caused by cyclotron resonance in a Dirac fermion system. From the resonance positions measured for several electron densities we find that the electron Fermi velocity is almost constant, being about $7\cdot 10^5$ m/s. The value is in a good agreement with the electron velocity for 2D Dirac fermions in HgTe/HgCdTe QWs of critical thickness, $v = 6.3\cdot 10^5$ m/s, obtained from the energy dispersion calculated in [1]. The strong dependence of the CR position on the carrier density indicates the Dirac character of the energy spectrum in the QWs with an energy-independent electron velocity. The resonant photocurrent is also detected in HgTe-based QW samples with the width L_w = 20 nm, which are characterized by a quadratic dispersion. Here CR, proved by the same experimental methods, is observed at a substantially larger magnetic field $B_c \sim 3$ T, with its position barely dependent on the carrier density.

The microscopic origin of the current is discussed in terms of the cyclotron motion, spin-dependent scattering and Zeeman splitting. We show that the current is spin-polarized and its enhancement comes from three constructively contributing factors: strong spin-orbit coupling, large *g*-factor in HgTe/HgCdTe QWs, and efficient radiation absorption at CR.

[1] B. Büttner *et al*., Nature Phys. **7**, 418 (2011).
[2] P. Olbrich *et al.*, preprint http://arxiv.org/abs/1301.4572.
[3] Z.D. Kvon *et al.*, JETP Lett. **94**, 816 (2011).