Spin-polarized currents of Dirac fermions at cyclotron resonance

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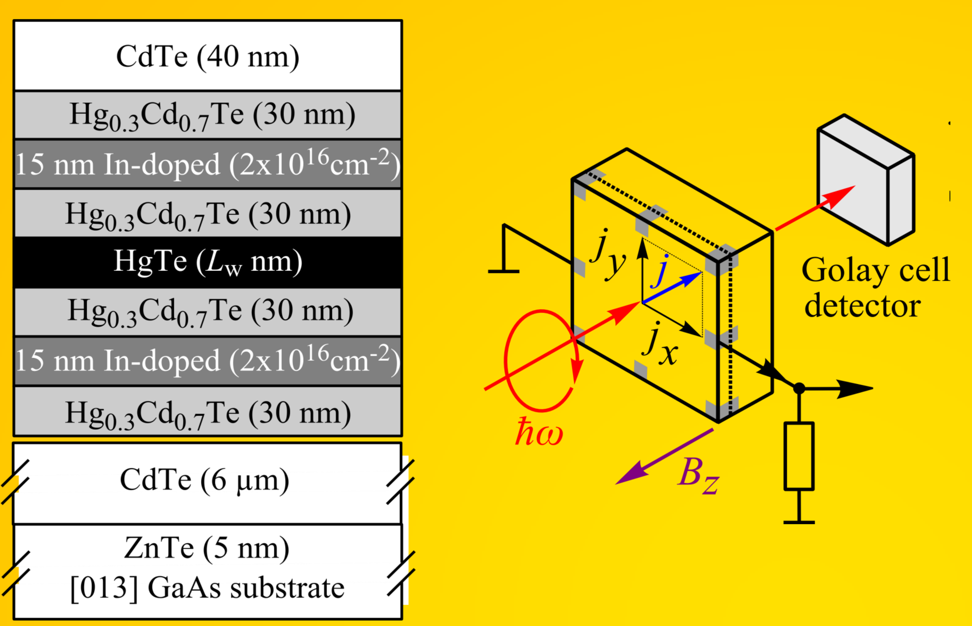
Abstract

We report on the observation of a giant photocurrent in HgTe/HgCdTe quantum wells (QW) of critical thickness, at which a Dirac spectrum emerges [1]. Exciting QWs of 6.6 nm width by terahertz (THz) radiation and sweeping an external magnetic field, we detect a resonant photocurrent. Remarkably, the position of the resonance can be tuned by means of optical doping. The photocurrent data, accompanied by measurements of radiation transmission prove that the photocurrent is caused by cyclotron resonance (CR) in a Dirac fermion system [2], which allows us to obtain the effective electron velocity $v = 7.2\times10^5$ m/s, which is in accordance with [3]. We develop a microscopic theory of the effect and show that the inherent spin-dependent asymmetry of light-matter coupling in the systems of Dirac fermions causes the current to flow.

Samples and Setup

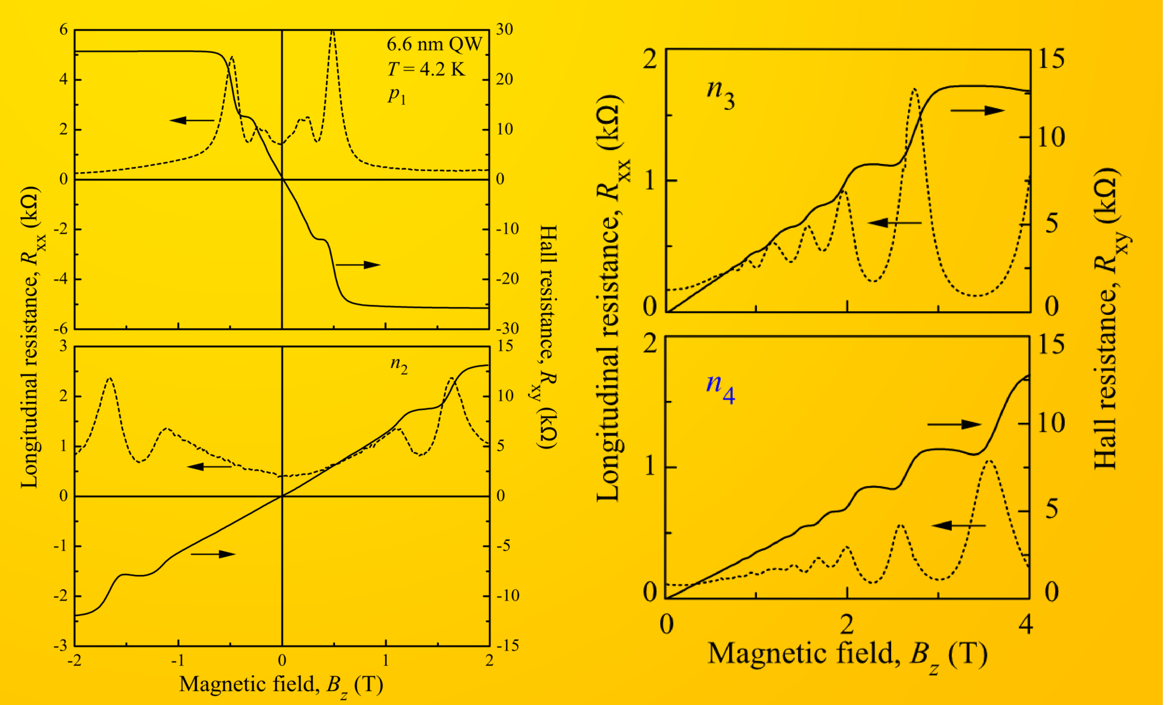


- CH_3OH cw laser:
  → f = 2.54 THz
  → $\hbar\omega$ = 10.35 meV
- normal incidence of radiation
- no external bias
- Lock-in technique

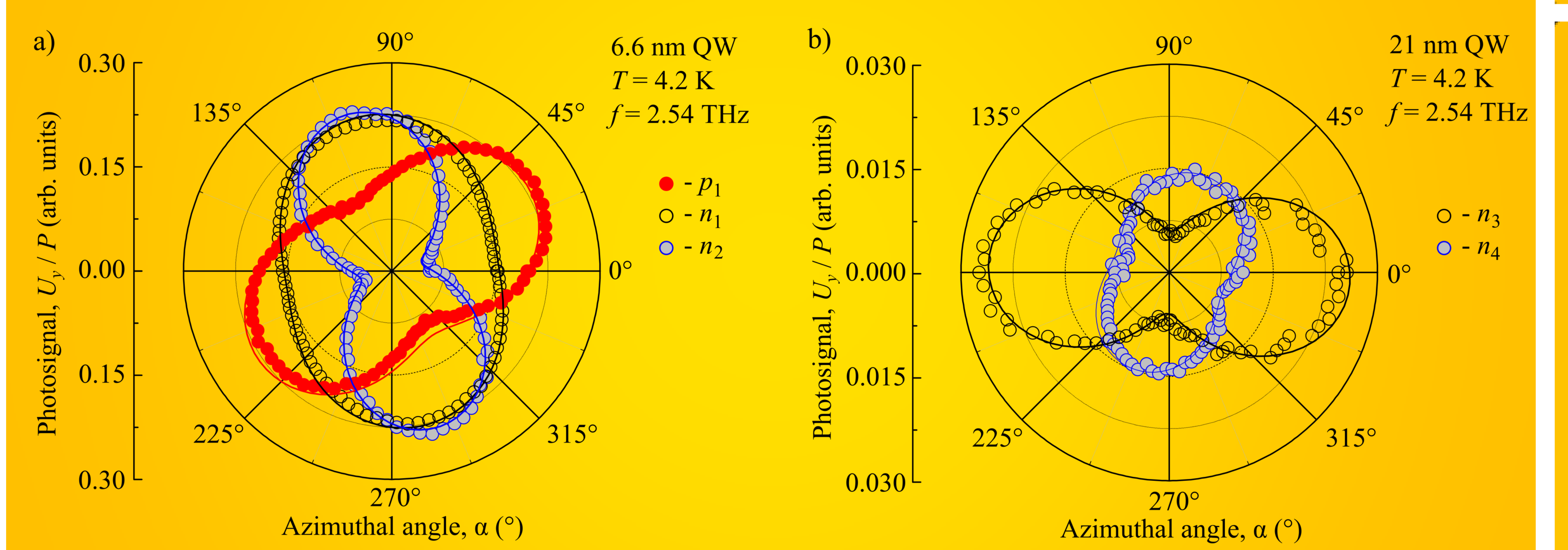
carrier density variable by optical doping:

L_W = 6.6 nm:
p_1 = 1.5 10^{10} cm^{-2}
n_1 = 3.4 10^{10} cm^{-2}
n_2 = 11.0 10^{10} cm^{-2}

L_W = 21 nm:
n_3 = 18.0 10^{10} cm^{-2}
n_4 = 24.0 10^{10} cm^{-2}



Photocurrent at Zero Magnetic Field



Polarization dependence of the photovoltage normalized by radiation power. Fits after: $U_y(\alpha)/P = A + B\sin(2\alpha) + C\cos(2\alpha)$.

Conclusion

6.6 nm HgTe sample:

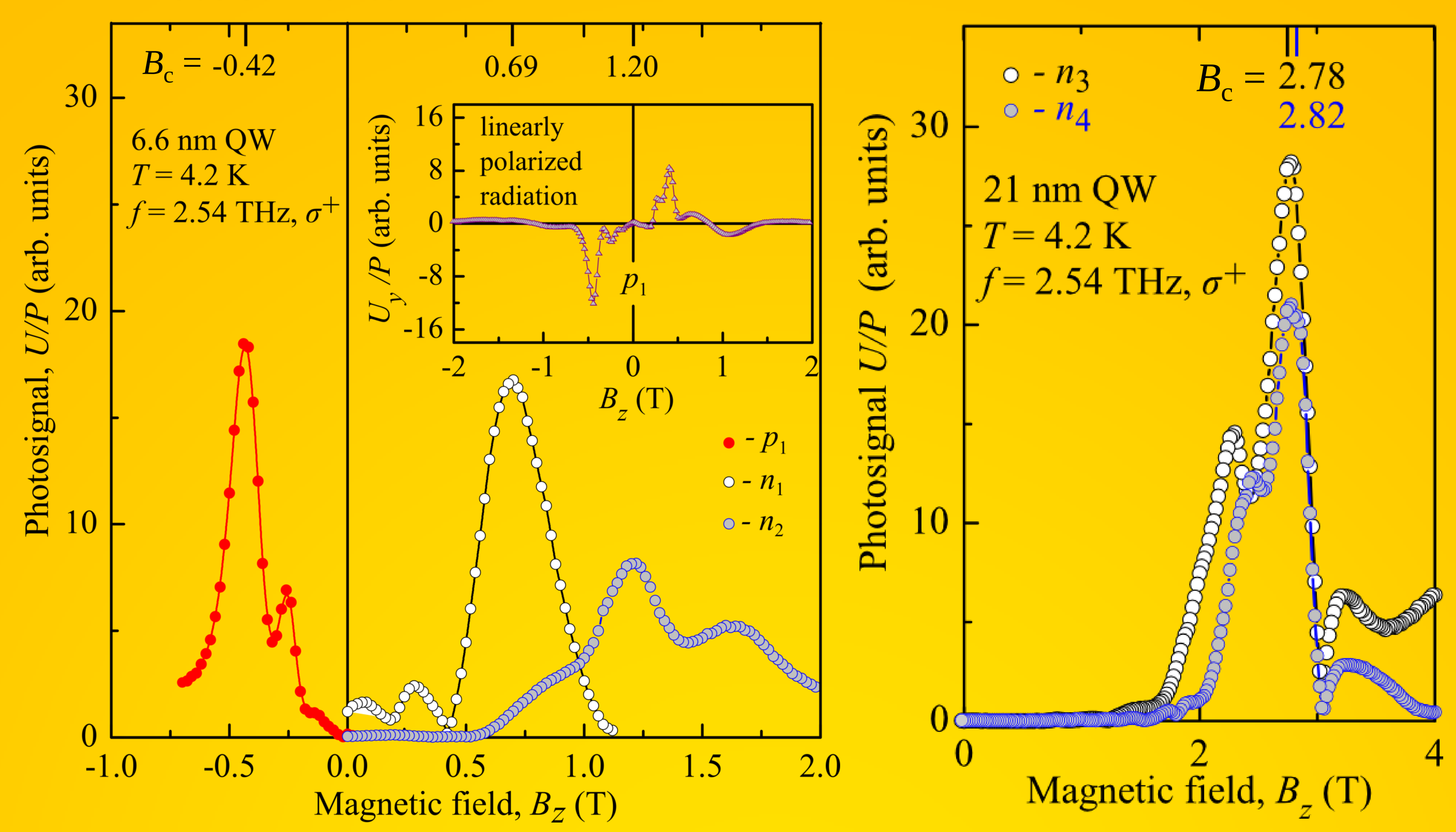
- resonant current is caused by CR
- peak shift of photosignal and radiation absorption by optical doping
  → characteristic for linear energy dispersion
- due to linear dispersion CR position is given by $|B_c| = \sqrt{2\pi n}(c\hbar\omega)/|ev|$
- experimental determination of the Fermi velocity ~ 7.2 10^5 m/s
- spin-polarized current is not simply enhanced by absorption at CR ~$(\omega_c\tau_p)^2$
- novel mechanism of current formation is developed

References

[1] P. Olbrich *et al.*, PRB, in progress, (2013).
[2] Z.D. Kvon *et al.*, JETP Lett. **94**, 816 (2011).
[3] B. Büttner *et al.*, Nature Phys. **7**, 418 (2011).

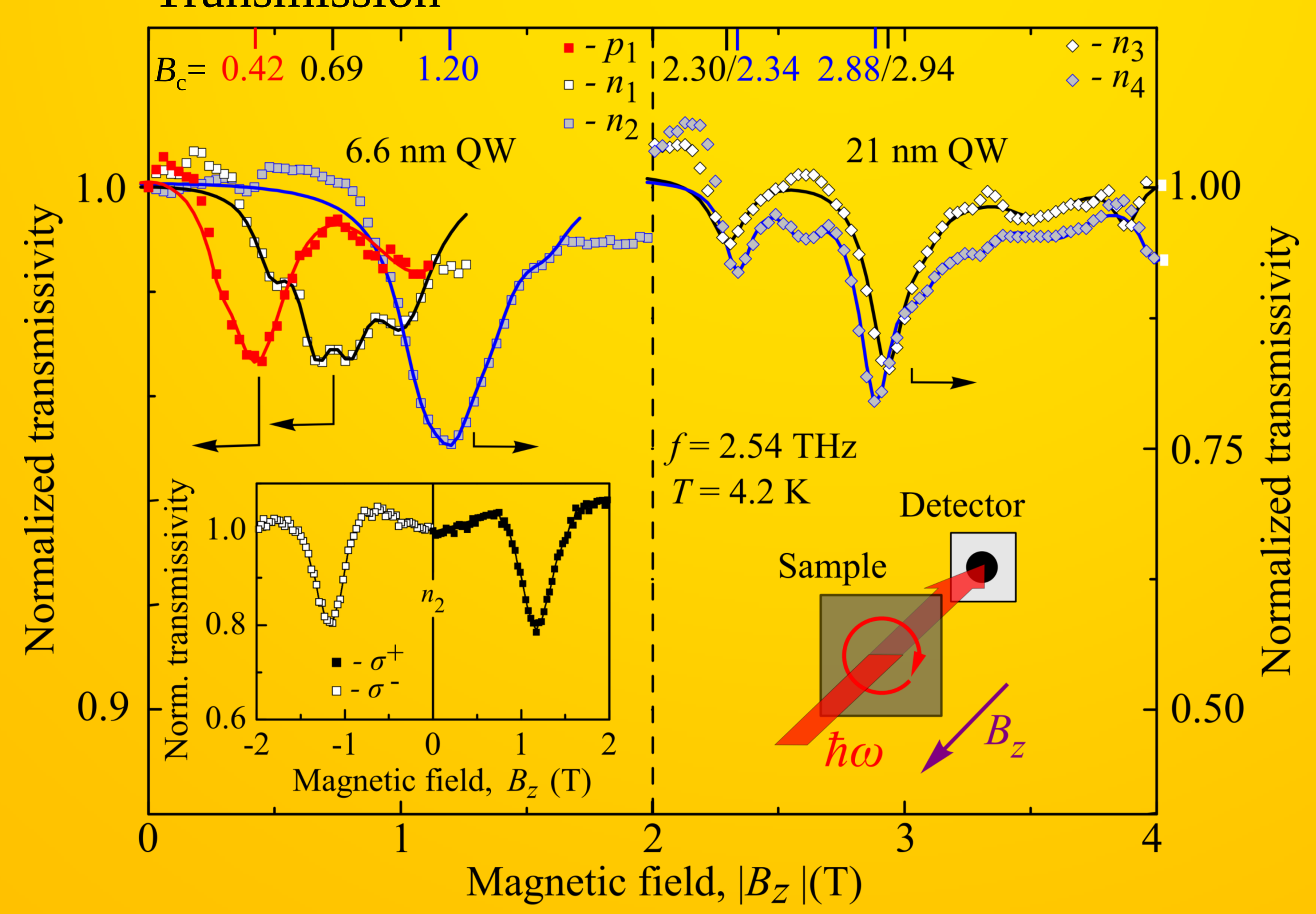
Results

Photocurrents



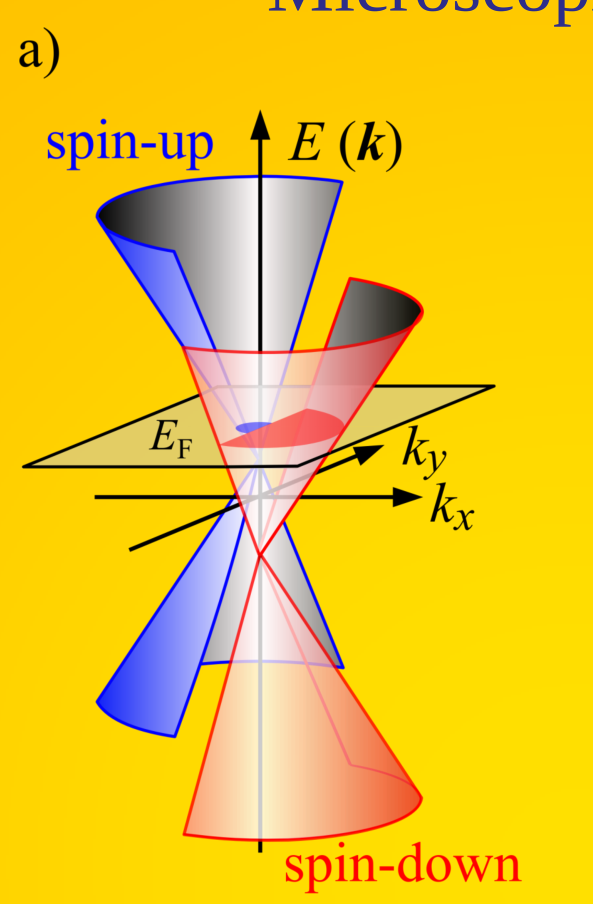
Photosignal as a function of B_z for right-handed circular polarized radiation and linear polarization (inset) for different carrier densities. Resonance position depends on carrier density/type in 6.6 nm sample and is independent for 21 nm sample.

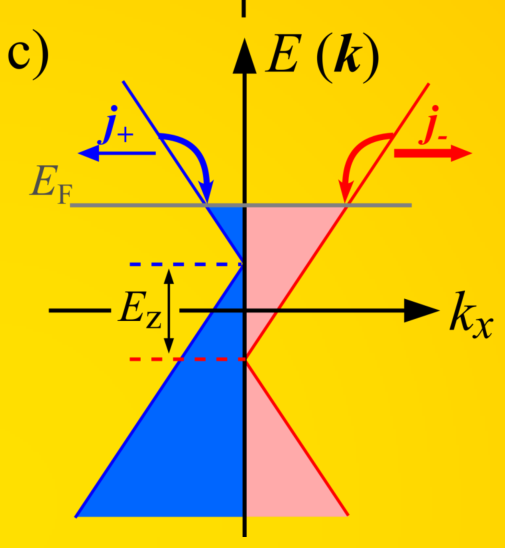
Transmission



Magnetic field dependence of radiation absorption for different carrier densities. The inset shows radiation absorption for right- and left-handed circular polarized radiation for 6.6 nm sample and carrier density n_2.

Microscopic Theory





spin and k-dependent energy relaxation of a heated electron gas

$$V_{kk'} = V_0 + V_{\alpha\beta}\sigma_\alpha\left(k_\beta + k'_\beta\right)$$

electron – phonon – interaction

a)-c) Zeeman effect results in imbalance in k-space, yielding a photocurrent:

$$|j| = \left|\frac{ev\sin(2\theta)}{2\sqrt{2}E_F\omega_c}\frac{g\mu_0 B}{E_F}\xi I\eta\right| \qquad U = \left|j\frac{\omega_c\tau_p a}{\sigma}\right|$$

estimated current for low temperatures and applied magnetic field

$$\eta = \frac{2e^2E_F}{c\hbar^2 n_\omega}\frac{\tau_p}{1+(\omega-\omega_c)^2\tau_p^2}$$

absorbance in vicinity of CR

$$\sigma = e^2E_F\tau_p/2\pi\hbar^2$$

conductivity at zero field

current j ~ radiation absorption (η)
SOI strength (ξ)
Zeeman splitting ($g\mu_0 B$)