Level Spectroscopy of Dirac fermions in HgTe quantum wells

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Predicted more than 60 years ago [1], the linear dispersion of low-energy charge carriers in a single layer of carbon atoms has recently been shown to exist in graphene [2]. When subjected to a magnetic field *B*, the characteristic linear dispersion of two-dimensional (2D) Dirac fermions $E = \pm c^* \hbar k$, where *c** is the electron velocity, transforms into a set of unequally spaced Landau levels (LLs) with energies $E_N = \mathrm{sgn}(N) \times c^* \sqrt{2e\hbar B|N|}$. The distinctive $\sqrt{B}$ -dependent LL energies have been probed in infrared (IR) cyclotron resonance (CR) experiments enabling direct and accurate measurements of the band velocity *c** [3-5], the only parameter defining the linear dispersion.

Very recently, it has been shown that 2D Dirac fermions can be realized in CdHgTe-based semiconductor quantum wells (QWs) with an inverted band spectrum [6,7]. Magneto-transport experiments performed with gapless HgTe QWs indicated that there is a linear spectrum of particles when the well thickness (*d*) is close to the critical value of 6.3 nm, and Hall measurements show the anomalous sequence of quantum Hall plateaus specific to Dirac systems [8]. Unlike graphene, with its two spin-degenerate massless Dirac cones at two inequivalent points in momentum space, gapless HgTe QWs are an ideal system for studying Dirac fermions because of their single spin-degenerate Dirac valley at the Brillouin zone center. However, no spectroscopic measurements of the electron velocity *c** have been reported so far.

Here we report IR magneto-spectroscopy measurements of the cyclotron resonance of Dirac fermions in HgTe QWs. We studied two HgTe / CdHgTe QW samples (d=6.5 nm, 6.6 nm) grown by molecular beam epitaxy on a (013) GaAs substrate. All measurements were performed at 4.2 K in magnetic fields up to B= 17 T using a Bruker IFS 113 FTIR spectrometer in the range of 20 to 800cm^{-1}. Cyclotron resonances are clearly resolved with energy position that scales as $\sqrt{B}$ with the slope corresponding to an electron velocity $c^* = 6.37 \times 10^5 m/s$ in both samples. In one of the samples, the CR absorption line consists of two closely spaced minima. This indicates spin degeneracy lifting caused by the spin-orbit interaction, resulting in the appearance of two identical cones for the two spin directions.

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[1] P. R. Wallace, Phys. Rev. **71**, 622-634 (1947).
[2] K. S. Novoselov et al., Science **306**, 666 (2004).
[3] M. L. Sadowski et al., Phys. Rev. Lett. **97**, 266405 (2006).
[4] Z. Jiang et al., Phys. Rev. Lett. **98**, 197403 (2007).
[5] R. Deacon et al., Phys.Phys. Rev. B **76**, 081406(R) (2007).
[6] B. A.Bernevig, T.L. Hughes, & S.C. Zhang, Science **314**, 1757 (2006).
[7] M. König et al., Science **318**, 766 (2007).
[8] B. Büttner et al., Nature Phys. **7**, 418 (2011).