SIMULTANEOUS OBSERVATION OF ELECTRON AND HOLE CYCLOTRON RESONANCE IN GRAPHENE IN THE MAGNETIC QUANTUM LIMIT

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The unusual band structure of graphene, with unique linear dispersions, has led to the discoveries of a variety of surprising phenomena, primarily in DC transport, in the last several years. Here we report that graphene's AC or infrared properties are also highly unusual. Specifically, we have observed *electron* cyclotron resonance in *p*-type graphene – a non-intuitive phenomenon that is possible only via graphene's unique Landau-level structure. Using ultrahigh magnetic fields up to 170 T, we performed cyclotron resonance (CR) measurements in large-area graphene grown via chemical vapor deposition (CVD) at room temperature. Polarization and wavelength dependence using a tunable CO_2 laser determined the carrier type of doping and the value of the Fermi energy. Polarization-dependent magneto-transmission measurements through the use of circularly-polarized light revealed a strong unintentional *p*-type doping of CVD graphene with a small CR feature at 10 T and a larger CR feature at 65 T that corresponds to the $n = 0$ to $n = -1$ and $n = -1$ to $n = -2$ Landau level (LL) transitions, respectively. Furthermore, wavelength-dependent measurements determined the Fermi energy to be -250 meV. After annealing the graphene samples in vacuum to remove physisorbed molecules, we demonstrate that the Fermi energy can be shifted closer to the Dirac point (-34 meV), resulting in the simultaneous appearance of electron and hole CR in the magnetic quantum limit, i.e., the $n = 0$ to ± 1 transitions, with similar intensities.