Terahertz Radiation Induced Edge Currents in Graphene

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Abstract—We report on the observation of edge photocurrents in graphene layers excited by polarized terahertz (THz) radiation. We demonstrate that shining laser radiation on the boundary of unbiased monolayer graphene at room temperature results in a direct electric current along the sample edge. The current contains a substantial contribution which is solely driven by the light's helicity and reverses its direction upon switching the helicity sign.

Of the many studies of graphene, a substantial portion is devoted to the physics of graphene edges. In transport experiments edge effects are usually masked by bulk properties, nonetheless the graphene edges are expected to play a crucial role in the electronic properties of graphene-based nanoscale devices. Here, we present an opto-electronic method to uniquely distinguish edge from bulk scattering by exploring edge photocurrents in graphene samples illuminated by terahertz (THz) radiation. For circularly polarized light the edge current is observed to form a vortex winding around the edges of the square-shaped samples. Its direction reverses upon switching the radiation helicity from left- to right-handed. Evidently, the photocurrent is caused by the local symmetry breaking at the sample edges resulting in an asymmetric scattering of carriers driven by the radiation electric field. It gives rise to a directed electric current along the sample boundary in a narrow stripe of width comparable to the mean free path. We show that the photocurrent measurements provide direct access to electron transport at the graphene edges and allow mapping the variation of scattering times along the edges.

The currents are generated employing THz circularly polarized radiation of a *cw* methanol laser operating at a wavelength of 118 µm as well as a pulsed ammonium high power laser delivering the wavelengths 90, 148 and 280 µm. Two types of samples were studied: small-area graphene flakes with typical sizes of 10 to 30 µm, prepared by mechanical exfoliation technique, and large-area graphene epitaxially grown on a 4H-SiC(0001) substrate with a size of 3x3 and 5x5 mm^2.

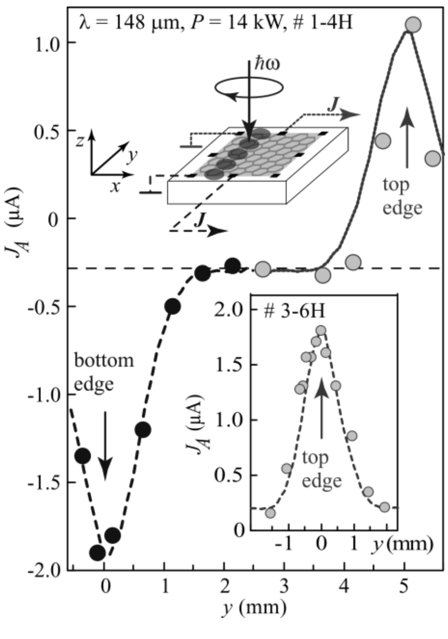

Figure: Spatial distribution of the circular photocurrent. The current reverses it's sign for two parallel edges and vanishes in between. Inset: Experimental geometry of the setup and detailed spatial resolution of the peak, respectively.

Normal incident illumination of the edge of unbiased large-area samples between any pair of contacts results in a photocurrent. By contrast, if the laser spot is moved toward the center the signal vanishes. The detected signal depends strongly on the radiation polarization. In particular, the photocurrent has opposite direction for right- and left-handed circularly polarized radiation. To prove that the photocurrent is caused by illuminating the graphene edges, we scanned the laser spot across the sample along the y-axis. The signal was picked up from a pair of contacts at the sample top and bottom edges aligned along the *x*-axis. The experimental geometry and the photocurrent versus the spot position are shown in Fig. 1. The current reaches its maximum for the laser spot centered at the edge and rapidly decays with the spot moving. A comparison of $J_A(y)$ with the independently recorded laser profile (lines) shows that the signal just follows the Gaussian intensity profile. Investigating the current excited by circularly polarized radiation for different pairs of contacts we observed that it forms a vortex around the sample edge. We note, that at oblique incidence of radiation, the edge current is superimposed with the interior circular ac Hall effect [2].

Microscopically the photocurrent is caused by the local symmetry breaking at the sample edges resulting in an asymmetric scattering of carriers driven by the radiation electric field. It gives rise to a *dc* electric current along the sample boundary in a narrow stripe of the width comparable with the mean free path. The experimental observations are well described by the microscopic theory of edge currents developed in the framework of the Boltzmann kinetic equation. By expanding the electron distribution function up to second order in the *ac* electric field of THz radiation we derive the analytical equation for the total electric current resulting from the action of the electric field accompanied by diffusive electron scattering at the sample edges. Only carriers within the distance of the mean free path to the edge contribute to the current, limiting the considerations to one dimension. Comparison of the experimental observations with theory reveals that the edges of *n*-type graphene layers exhibit *p*-type conductivity. This result is in agreement with results from scanning photocurrent microscopy [3] and spatially resolved Raman measurements [4].

Our observations clearly demonstrate that illuminating monolayer graphene edges with polarized terahertz radiation at normal incidence results in a *dc* edge current. The effect is directly coupled to electron scattering at the graphene edges and vanishes in bulk graphene. While the circular edge photocurrents should exist in any two-dimensional charge carrier system the specific properties of graphene, i.e., the high velocity of massless Dirac fermions, facilitate the experimental observation. Our results suggest that the circular photocurrents can be effectively used to study edge transport in graphene even at room temperature.

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