

Photocurrent in graphene n-n' junctions

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The carbon atoms in graphene are arranged in a honeycomb lattice, and due to its two interpenetrating Bravais sublattices the charge carriers acquire an additional degree of freedom known as pseudospin. The pseudospin orientation turns out to be coupled with the direction of particle motion in a way similar to the spin-orbit coupling in semiconductors, see Fig. 1. The pseudospin-dependent selection rule constrains the possible optical transitions between the valence and conduction bands in the presence of the linearly polarized light, see Fig. 1. The pseudospin selection rule in optical excitations can be understood from the effective interaction Hamiltonian which contains a coupling term between the pseudospin operators (Pauli matrices) and the vector potential characterizing a linearly polarized electromagnetic wave. The carriers have opposite pseudospin orientations in the valence and conduction bands. The pseudospin flip is necessary to excite any valence electron to the conduction band as long as momentum transfer is negligible.

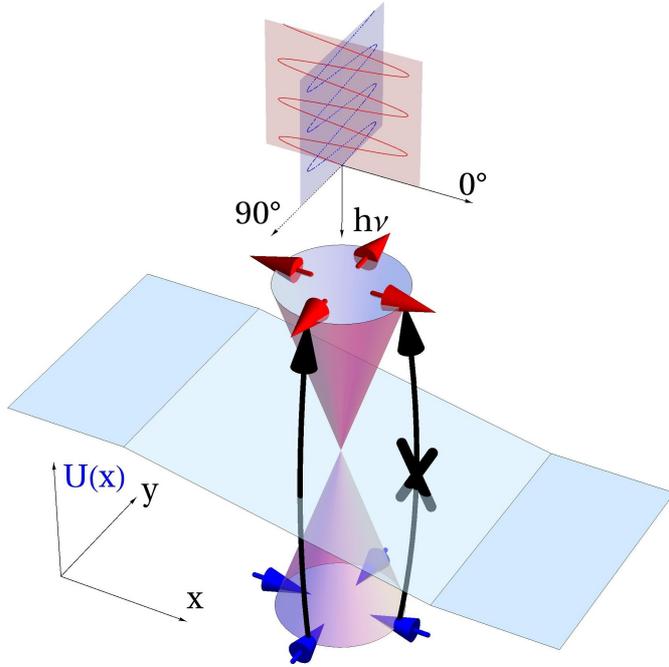


Fig. 1. The pseudospin-dependent selection rule for interband optical excitations in the presence of the electromagnetic radiation polarized along x-axis (zero polarization angle). The potential profile $U(x)$ forming the junction is also shown.

To be specific we set linear polarization along x-axis, i. e. the polarization angle is zero, as shown in Fig. 1. The interaction Hamiltonian is trying to rotate the pseudospin about the polarization direction. If the pseudospin and polarization direction are parallel with each other then the pseudospin orientation obviously does not change and the interband transition does not occur. In the opposite case, when the polarization is normal to the pseudospin orientation, the pseudospin can flip easily and the interband transition probability is maximal. As consequence the photovoltage measured on the irradiated n-n' junction depends strongly on the angle between the top contact long edge and light polarization plane.

In contrast to the previous work [1] we employ the Boltzmann equation [2] which includes a built-in potential $U(x)$ characterizing graphene n-n' junction as well as the photocarriers' generation rate due to the linearly polarized radiation of power W . The resulting photovoltage contains polarization angle dependent contribution V_{osc} which reads

$$-eV_{osc} = 0.023 W \frac{\tau \lambda^2 v_F^2}{4\pi c^2} \ln(1 + \Delta U / \mu) \cos(2\theta).$$

Here, the factor 0.023 is the single layer absorption, $\tau = 10^{-12} s$ is the photocarriers' life-time [3], λ is the radiation wavelength, v_F is the Fermi velocity, ΔU is the built-in potential step, μ is the chemical potential at zero $U(x)$, and θ is the polarization angle. Note, that there is also a term which is independent of θ .

Moreover, an irradiated sample experiences heating and, therefore, the electrons are subject to the temperature gradient there. The temperature gradient gives rise to the thermoelectric current flow which

is complementary to the photoelectric term. Most important is that the thermoelectric response depends mostly on the radiation power converted to heating and is not sensitive to any particular light polarization. In contrast, the photoelectric response *does* depend on the polarization angle that makes it possible to separate these two effects in the total response measured. This is schematically shown in Fig. 2.

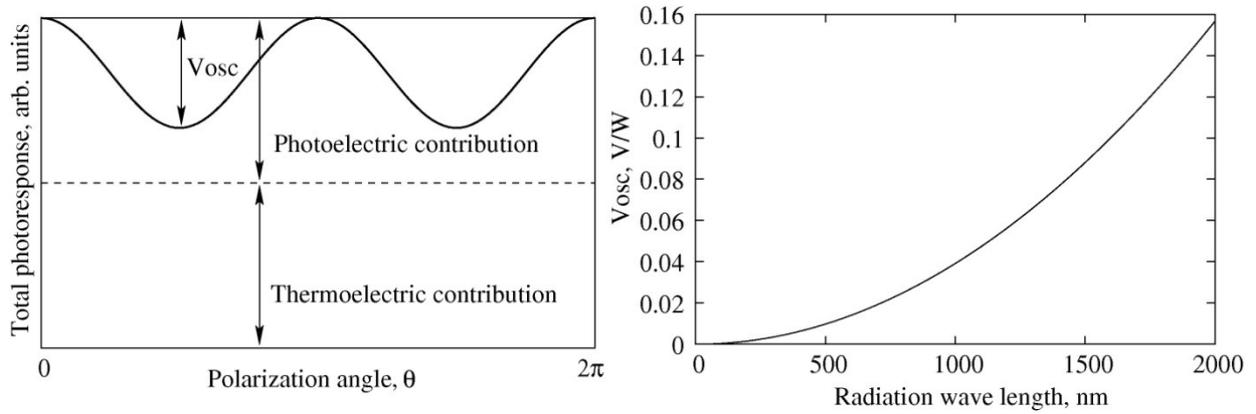


Fig. 2. Left panel: Relative contributions to the total photoresponse shown schematically. Right panel: The oscillating contribution V_{osc} given in Volts per Watt as a function of λ computed from the formula given in the main text. The potential step is taken to be equal to the chemical potential.

The model considered above allows making the following predictions: (i) The photoelectric contribution in the photoresponse oscillates with the polarization angle θ whereas the thermoelectric one is not sensitive to θ at all. (ii) The amplitude of V_{osc} increases with the radiation wavelength as λ^2 . Thus, the photoelectricity may play a major role in the total photoresponse at larger wavelengths. (iii) The amplitude logarithmically depends on the potential step ΔU and increases slowly with ΔU as soon as the latter becomes comparable with the initial chemical potential. At the incident radiation power of the order of $100 \mu W$ and $\lambda \sim 1000 nm$ the photovoltage amplitude can be as high as $10 \mu V$.

The model can be generalized for graphene p-n junctions. The photovoltage behavior is qualitatively similar to the one considered above as long as the potential step ΔU is higher than the temperature.

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References

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