Radiation-induced coherent quantum phenomena in the transport of graphene based *n-p* and *n-p-n* junctions.

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We report a theoretical study of radiation-induced quantum interference effects in low-dimensional graphene based *n-p* and *n-p-n* junctions. It has been shown that the resonant interaction of propagating electrons with an electromagnetic field (EF) can lead to the appearance of the dynamic gap in the quasi-particle spectrum [1-2]. Such a gap bears a remarkable resemblance to the Rabi frequency. The presence of the gap leads to a suppression [1] or enhancement [2] (*ballistic photocurrent*) of the electron transport in graphene based nanostructures.

In the presence of an externally applied radiation the ballistic transport of electrons in *n-p* junctions is determined by two processes, namely, by the resonant absorption of photons near the "resonant points" and by the strong reflection from the junction interface, occurring at the "reflection points". There are two paths corresponding to the propagations of electrons through the junction (see Fig. 1), and the interference between these two paths manifests itself by large oscillations of the ballistic photocurrent I_{ph} as a function of the gate voltage V_G or the frequency ω of the radiation. This coherent quantum phenomenon resembles Ramsey quantum beating and Stueckelberg oscillations well-known in atomic physics [3].

In the ballistic transport of irradiated graphene based *n-p-n* junctions (see Fig. 2a) we studied the quantum resonances. By making use of the Floquet analysis and the quasi-classical approach we analyze the dynamics of electrons in the presence of time and coordinate dependent potential *U(z,t)* (Fig. 2b). In the absence of EF the resonant tunneling results in a set of sharp resonances in the dependence of dc conductance σ on the gate voltage V_G [4]. In irradiated *n-p-n* junctions we obtain the Fano-type resonances (Fig. 3) that is due to the interplay of two effects: the resonant tunneling through quasi-bound states [4] and the quantum-interference effect in the region between the resonant points, where the resonant absorption (emission) of photons occurs, and junction interfaces.

A suitable radiation frequency may be in the THz or in the infrared optical region. The effects can be observed in one- and two-dimensional *n-p* and *n-p-n* junctions based on carbon nanotubes, monolayer or bilayer graphene nanoribbons.

References

[1] M. V. Fistul and K. B. Efetov, Phys. Rev. Lett., 98 (2007) 256803.
[2] S. V. Syzranov, M. V. Fistul, and K. B. Efetov, Phys. Rev. B, 78 (2008) 045407.
[3] M. V. Fistul, S. V. Syzranov, A. M. Kadigrobov, and K. B. Efetov, Phys. Rev. B, 82 (2010) 121409(R).
[4] P. G. Silvestrov and K. B. Efetov, Phys. Rev. Lett., 98 (2007) 016802.

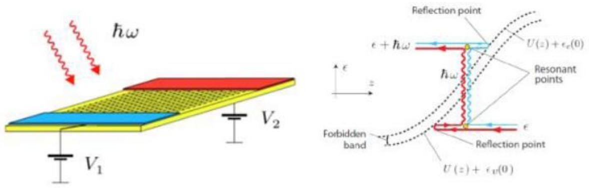

Figure 1 Schematic of irradiated graphene based *n-p* junction and typical electron trajectories.

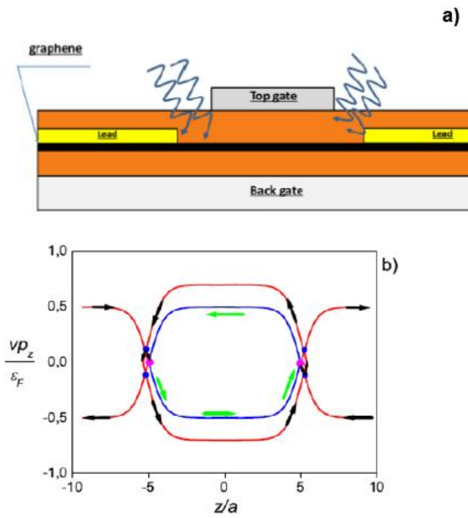

Figure 2 a) Schematic of irradiated graphene based *n-p-n* junction; b) The quasi-classical phase trajectories of electrons in irradiated *n-p-n* junctions.

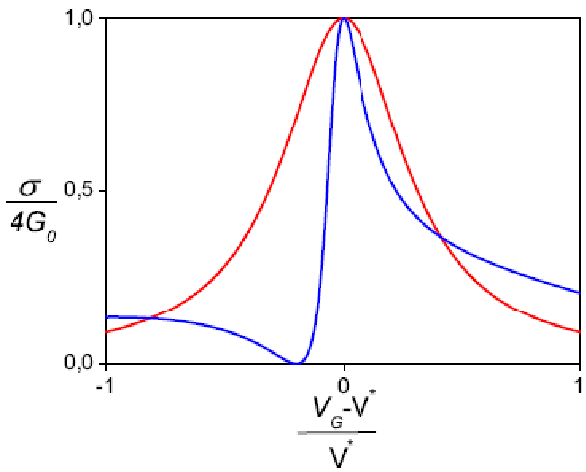

Figure 3 The typical resonant peaks in the dependence of dc conductance on the gate voltage, σ(VG). The peaks shape changes from a symmetric one in the absence of EF (red curve) up to asymmetric one, i.e. the Fano type, as the EF is applied [blue curve].