

## Theoretical Study of Single and Bilayer Graphene Nanoribbons Photodetectors

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Graphite-related materials such as graphene have been extensively studied in recent years due to their exceptional electronics, optoelectronics, and mechanical properties. Graphene holds great promise for novel photonics devices [1]. Recently, Bilayer Graphene Nanoribbons (BLGNRs) have attracted considerable attention both in experimental and theoretical works [2]. BLGNRs have a direct and relatively narrow band gap, which can be tuned by applying an electrical field perpendicular to the graphene sheet [3]. So, a widely field-tunable band gap in bilayer graphene with infrared (IR) absorption spectroscopy is achievable [4]. These factors render graphene as suitable candidates for future optoelectronics, especially for IR applications.

In this paper we have performed a comprehensive study of GNRs and BLGNRs based IR photodetectors.

An atomistic real space tight-binding approach for the description of the electronic band structure is employed [5]. To explore the physics of such devices quantum mechanical simulations have been performed, employing the Non-Equilibrium Green's Function formalism (NEGF). The NEGF formalism allows studying the time evolution of a many-particle quantum system. Knowing the single-particle Green's functions of a given system, one may evaluate single-particle quantities such as carrier concentration and current density. The many-particle information about the system is cast into self-energies which are part of the equations of motion for the Green's functions. Green's functions enable a powerful technique to evaluate the properties of a many-body system both in thermodynamic equilibrium and non-equilibrium situations. We employed the NEGF method along with a tight-binding model to study quantum transport in IR photodetectors based on GNRs and BLGNRs. Electron-photon interactions have been modeled by adding an appropriate self-energy to the kinetic equations [6,7].

The devices response is studied for a wide range of photon energies. The energy conversion efficiency as a function of the incident photon energy, ribbon's width, and orientation is evaluated. As a quantitative measure we investigated the quantum efficiency of these photodetectors. This quantity is defined as  $\alpha = (I_{ph}/q)/(P_{op}/\hbar\omega)$ , where  $I_{ph}$  is the photocurrent and  $P_{op}$  is the incident optical power. This quantity corresponds in fact to the energy conversion efficiency of a photodetector. The quantum efficiency of GNR and BLGNR devices as a function of the incident photon energy has been compared for different structures with armchair and zigzag edges. Also, the optical properties of chiral graphene have been investigated in this paper for the first time. Our results indicate that the efficiency is maximized, when the photon energy matches the band gap. The maximum quantum efficiency ranges from 9% to 11% for GNRs and it is fairly independent of the band gap.

Another figure of merit of interest for photodetectors is the photo-responsivity defined as  $I_{ph}/P_{op}$ . Our calculations give the upper limit for graphene based photodetectors.

In summary, we present a study of GNR and BLGNR based photodetectors employing the NEGF method. The results show excellent properties such as very fast photoresponse to high frequencies and good quantum efficiency, demonstrating that graphene based photodetectors are promising candidate for future optoelectronic applications.

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