Graphene based heterostructure ballistic rectifier THz frequency detection for quantum applications

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Abstract: We demonstrate a single layer graphene heterostructure based ballistic rectifier detectors with high sensitivity at 3 terahertz (THz) frequency showing carrier rectification effect and sensitive light detection

Graphene shows remarkable performances in the far-infrared, with extremely high mobility (300.000 cm^2V/s), ultrafast (ps) relaxation times, broadband absorption and a tuneable by gating energy gap, hence representing a very promising material platform for ultra-sensitive THz detectors[1-2]. State-of-the-art nanofabrication technologies enabled in the last decades the development of structures smaller than the carrier mean free path (λ) of single layer graphene (SLG), promising to active in graphene, ballistic rectification effects.

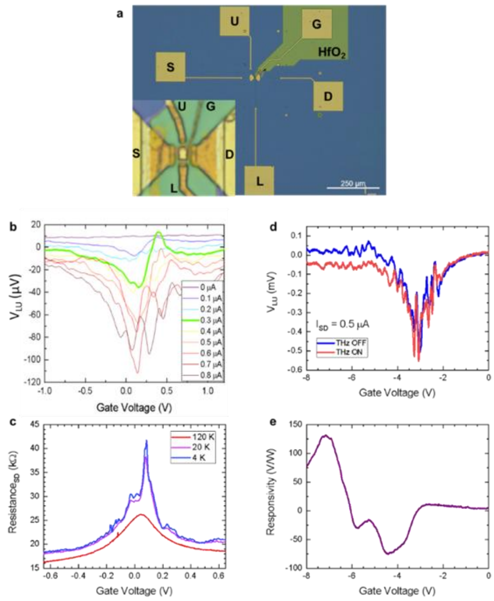

Fig. 1 (a) Optical image of one of the fabricated antenna-coupled BRs. (b) Four-terminals electrical characterization: V_{LU} *vs.* V_G measured at different forcing I_{SD} currents, measured at RT. The green curve shows the effect of geometrical rectification when ballistic transport is activated. (c) Two-terminals source-drain resistance as a function of gate voltage for one of the devised architectures, measured at different heat-sink temperatures, ranging from 4 K to 120 K. (d) Four-terminals measurement of transverse voltage, under different illumination states. The difference between *on* (red curve) and *off* (blue curve) states correspond to the ballistically rectified THz signal. (e) Voltage responsivity measured as a function of V_G in a standard two-terminals configuration, using a lock-in technique

Here we report on the development of low-temperature high-speed graphene-based nano-rectifiers, also known as ballistic rectifiers (BRs). The devices core structure comprises a hexagonal boron nitride (hBN)-single layer graphene (SLG)-hBN stack, embedded in an asymmetric four-terminal cross-junction. All the flakes are stacked with dry transferring technologies. The device channel has been set to 100nm, smaller than λ (~1 µm).The optical images of one prototypical device are shown in Figure 3a. To demonstrate the key rectification process of the structure, electrical transport measurements are applied to the device mounted in a cryostat cooled down at 4.3 K. Two-probes characterization showed electron mobility $\mu > 10^4$ $cm^2V^{-1}s^{-1}$ at room temperature (RT) and increasing up to 10^5 $cm^2V^{-1}s^{-1}$ at 4 K (Figure 3c). Four-probes (4W) characterization was used to demonstrate ballistic rectification: we measured the voltage difference arising between the U and L contacts (V_{LU}) when of small (< 1µA) dc source-drain current is forced (Figure 3b). We then characterized the optical response of the BR by illuminating it with a 2.8 THz quantum cascade laser (QCL) with up to ~1 mW average output power. We measured the characteristics of the BR as a function of gate voltage under different conditions of illumination. Figure 3d shows the measured transverse voltage (V_{LU}) when the BR is in the dark and when it is illuminated with an optical power of 0.5 mW. The difference between the two curves indicates THzinduced photovoltage, underpinned by ballistic rectification. In order to further characterize the photo response, we measured the detector voltage responsivity (R_v). To this end, a lock-in detection technique was employed to improve the single-to-noise ratio (SNR). Figure 3e shows R_v as a function of VG. A maximum R_v ~100 V/W, corresponding to a Johnson-noise-limited noise equivalent power (NEP) of 17 pWHz$^{-1/2}$.

In conclusion, we demonstrate a hBN-SLG-hBN heterostructure based ballistic rectifier THz detectors. It shows high sensitivity at ~3THz using QCL as THz source. By varying V_g, we unveil the carrier rectification between upper and lower contact.

References

[1] I. Gayduchenko, S. G. Xu, G. Alymov, M. Moskotin, I. Tretyakov, T. Taniguchi, K. Watanabe, G. Goltsman, A. K. Geim, G. Fedorov, D. Svintsov and D. A. Bandurin, " Tunnel field-effect transistors for sensitive terahertz detection," Nature communications, 12(1): 543(2021).
[2] Gregory Auton, Dmytro B. But, Jiawei Zhang, Ernie Hill, Dominique Coquillat, Christophe Consejo, Philippe Nouvel, Wojciech Knap, Luca Varani, Frederic Teppe, Jeremie Torres, and Aimin Song, " Terahertz detection and imaging using graphene ballistic rectifiers," Nano letters, 17(11), 7015-7020 (2017).