THz detection with epitaxial graphene field effect transistors on silicon carbide

F. Bianco[1*], D. Perenzoni[2], D. Convertino[3], S. L. De Bonis[1], D. Spirito[1], M. S. Vitiello[1], C. Coletti[3], M. Perenzoni[2], and A. Tredicucci[4]

[1*] NEST, Istituto Nanoscienze-CNR and Scuola Normale Superiore, P.za S. Silvestro 12, 56127 Pisa (Italy)
[2] Fondazione Bruno Kessler (FBK), via Sommarive 18, 38123, Povo, Italy
[3] CNI@NEST, Istituto Italiano di Tecnologia, P.za S. Silvestro 12, 56127 Pisa (Italy)
[4] NEST, Istituto Nanoscienze-CNR and Dipartimento di Fisica "E. Fermi", Università di Pisa, L.go Pontecorvo

The great interest in fast room-temperature detectors for the far infrared (or terahertz THz) part of the electromagnetic spectrum is strongly encouraged by the large variety of THz applications in biomedical and security imaging. In particular, many efforts are currently dedicated to develop compact, portable, sensitive, very fast imagers. Recently, a novel type of fast devices employing graphene sheets have been reported to efficiently detect THz light at room temperature thanks to a plasma-wave-assisted mechanism [1-3]. These detectors consist of field effect transistors whose channel is composed by graphene (GFET). Thanks to GFETs high quality electronics properties, graphene-based THz detectors are highly promising for fabricating focal plane sensing devices with high responsivity and ultrafast response time. In order to fabricate an array of GFET-detectors, large area graphene is strictly needed. For this reason, epitaxial graphene (EG) is an interesting solution, as high quality graphene sheets can be directly grown on insulating substrate, like silicon carbide, in wafer-scale dimensions without the requirement of high-fidelity transfer processes to preserve the graphene sheet quality.

In this work, we show the experimental results on the THz detection by means of antenna-coupled EGFETs on silicon carbide.

The detector consisted of a log-periodic circular-toothed antenna, whose lobes represented the source and top-gate of the EGFET, while the drain was a metal line (Fig. 1.a). The FET channel graphene was a bilayer graphene sheet, with residual trilayer inclusions, grown on semi-insulating nominally on-axis-oriented 4H-SiC(0001) substrate.

The detection properties were characterized by focalizing onto the detector active region the radiation emitted by a broadband THz source in spectral range from 230 to 375 GHz. The photovoltage was then measured by means of a lock-in amplifier while varying the applied gate voltage and keeping source/drain voltage equal to 0 mV.

The photoresponsivity was estimated in ~0.25 V/W and noise-equivalent-power ~ 80 $\mathrm{nW}/\sqrt{\mathrm{Hz}}$.

From the analysis of the experimental photovoltage measured as a function of the applied gate bias (magenta curve in Fig. 1.b), two independent detection mechanisms were identified (as schematically represented in Fig. 1.c). The first one is the plasma-wave assisted-detection. According to the plasmonic mechanism, a GFET illuminated by THz radiation responds with a finite dc signal proportional to the incident power [4]. This is the result of the simultaneous modulation of the carrier density and drift velocity and the consequent excitation of plasma wave in the FET channel (Fig. 1.c). The second mechanism is the thermoelectric effect. This was induced by the presence of carrier density junctions created at the interface of p-ungated and p/n-gated regions across our FET channel [5-7]. As a result, a local heating is induced at the junction edge on the source side (Fig. 1.c), owing to the asymmetric funneling of the THz radiation onto the FET channel caused by the antenna operation.

Assuming the hydrodynamic transport model for the plasmonic regime and the Mott formulation for the thermoelectric effect, we calculated the functional dependence of both the plasmonic and thermoelectric photovoltages on the gate bias (black and grey curves in Fig. 1.b, respectively). The superposition of these photovoltages reproduced qualitatively well the measured photovoltages. Moreover, analyzing more in details the behavior of measured photovoltage with regard to the competition of the two mechanisms (in fact, they exhibited the similar functional dependences on the gate voltage but with opposite sign), the change of the sign of the measured photovoltage demonstrated the stronger contribution of the plasmonic detection compared to the thermoelectric mechanism.

Although responsivity improvement is necessary due to detrimental competition of the two detection mechanisms, these results demonstrate that plasmonic detectors fabricated by epitaxial graphene on silicon carbide are potential candidates for fast large area imaging of macroscopic samples.

References

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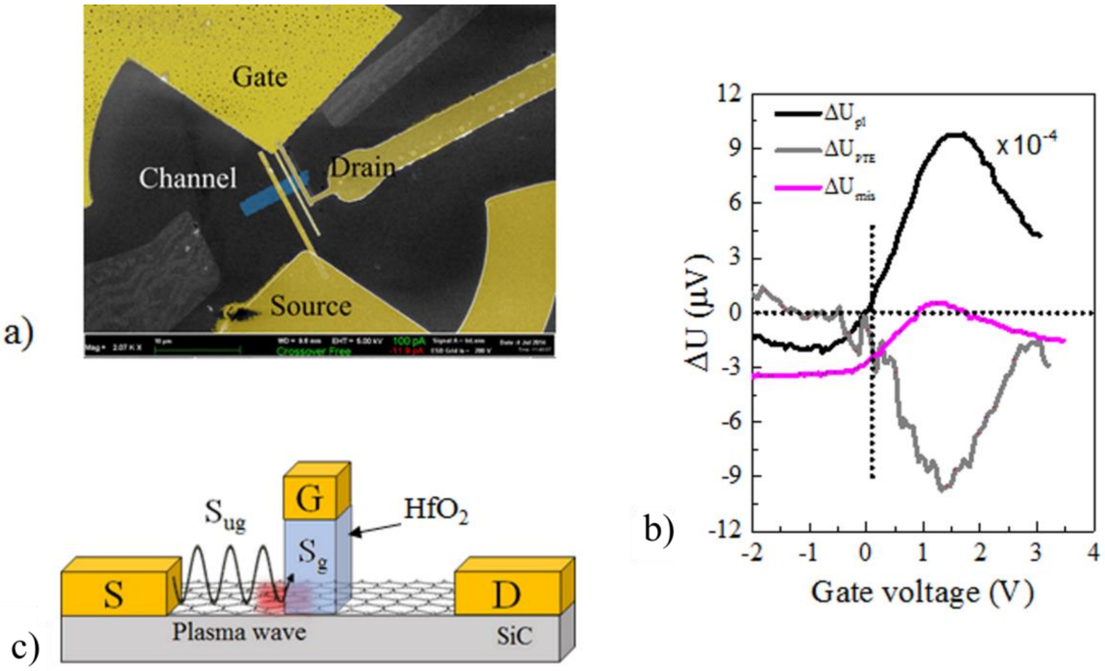

Figure 1: a) False-color SEM image of the device; b) Calculated plasmonic (black line), thermoelectric (grey line) and measured (magenta line) photo-induced voltage ΔU as a function of the gate voltage at 263 GHz. The dashed vertical and horizontal lines indicate the charge neutrality point and ΔU = 0 V, respectively; c) Schematic representation of the detection mechanism. Red shaped area indicates the locally heated area due to the carrier density junction at the interface of ungated and gated regions with thermopower S_{ug} and S_g, respectively. Plasma waves are excited along the channel by the THz-induced gate and source/drain potentials modulation.