# Graphene-based Field Effect Transistors for Radiation Induced Field Sensing

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Since its discovery in 2004, Graphene has emerged as platform material in a large number of applications, including microelectronic and photonic devices [1]. The rather unique electronic properties of its 2-dimensional electronic system (2DES) make graphene a promising candidate for several forefront applications in detector R&D. For example, the low heat capacitance of this material together with the weak electron-phonon interaction are the two basic properties making advantageous the use of graphene in bolometric applications [2]. Besides, the high carrier mobility and the strong collective effects dominating the electronic transport have been exploited to realize a number of novel optical devices, including photo-detectors operating in the spectral region from visible to terahertz range [3]. Here, we present the implementation of graphene-based field effect transistor (Gr-FET) as radiation sensor. The key property for the proposed application is the ambipolar transconductance, i.e. the sharp change in graphene conductivity with gate potential close to the charge neutrality point. Such behavior, while making Gr-FETs not suitable for switching applications, can be exploited to sense any change in the electric field distribution induced by a ionizing beam in the underneath absorber [4,5]. This approach could open up to the possibility of achieving high-energy resolution in radiation detection, not through direct absorption of radiation, but rather by sensing the energy absorption in an adjacent medium.

Graphene synthesis has been obtained by chemical vapor deposition (CVD) on metal substrates. The CVD process has been carried out in a controlled atmosphere of methane and hydrogen at 1040°C in a quartz-tube furnace chamber, on cm2-area copper foils with purity higher than 99.8%. The growth conditions have been initially chosen by adopting the recipe reported in [6]; then, by modifying the recipe parameters in our system, we could obtain good coverage and homogeneity of the films.

For device fabrication, the graphene must be transferred to semiconductor or insulating substrates, chosen to be suited for the target applications. To this aim, we have developed "in-house" the well-known "PMMA-method" [7], by using as carrier polymer a polyethylene-based thermal release tape (by Nitto Denko Inc.) instead of PMMA, and we have used this method to transfer single layer graphene on SiO2/Si substrates (see Fig.1). The graphene-on-SiO2/Si stack can be used as a starting structure to fabricate the first Gr-FET prototypes. Transport measurement on the Gr-FET devices is ongoing.

**References**

[1] A. K. Geim and K. S. Novoselov, "The Rise of Graphene", Nature Materials 6, 183 (2007)
[2] Xu Du et al, "Graphene based bolometers", Graphene 2D Mater. 2014; 1:1–22
[3] F. H. L. Koppens et al, Nature Nanotechnology 9, 780–793 (2014)
[4] M. Foxe et al, , IEEE Transactions on Nanotechnology II, 581 (2012).
[5] A. Patil et al, IEEE NSS-MIC Conference Record (201I)
[6] S. Bae et al, Nat. Nano 5, 574 (2010)
[7] X. Li, et al, Science 324, 1312–1314 (2009).

Besides the work on material growth and device fabrication, we have started a theoretical study on the detector architectures to be developed. With the help of T-CAD software, as a starting point we have simulated a Gr-FET realized on silicon substrate, having one micrometric strip of monolayer graphene as a gate readout electrode. The graphene gate acts as field sensing electrode, able to detect any change in the field distribution occurring in the silicon substrate upon irradiation with visible light (λ=600nm, flux=$10^{17}$ photons/s). The structure of the simulated device is reported in Fig.2(a). The evaluation of the performances and the optimization of the structure are still ongoing. The calculated transient photocurrent at the FET junctions arising from the electric field in the Si absorber is reported in Fig.2(b). We have found that the electric field produced by the e-h pairs formation upon illumination (see Fig. 2(c)) could enable the field sensing on the graphene gate by properly choosing the geometric parameters of the device (e.g. oxide thickness and substrate doping), so to produce a significant change in its conductivity.

In conclusion, we have presented our preliminary results on the development and the design of field effect transistors based on 2-dimensional layered materials usable as radiation sensors, based on graphene layers synthetized via chemical vapour deposition.
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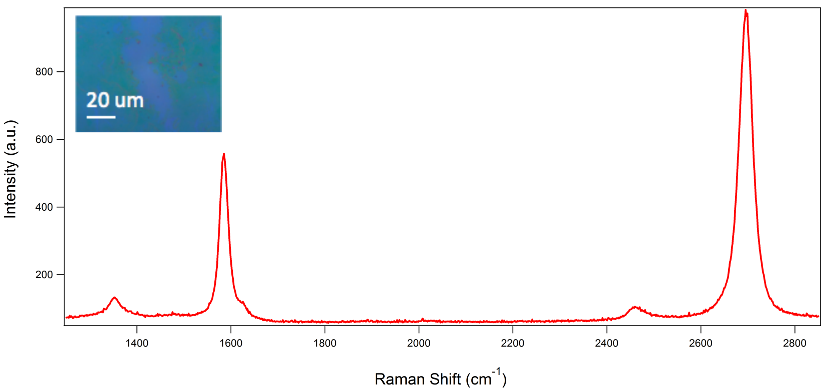


Figure 1: Raman spectra measured on graphene on SiO2/Si substrate after transfer assisted by thermal release tape on SiO2/Si substrate; *inset*: optical microscope image of the sample.

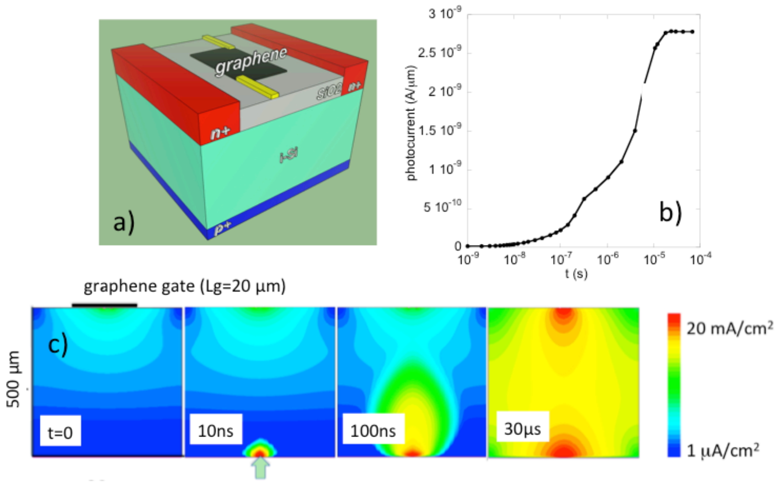


Figure 2: Simulations results; (a) structure of the Gr-FET simulated. (b) transient photocurrent measured at the FET junctions upon illumination with visible light. (c) electric field distribution calculated in the 2D section of the device arising from the e-h pairs generated.