Development of Graphene-Based Ionizing Radiation Sensors

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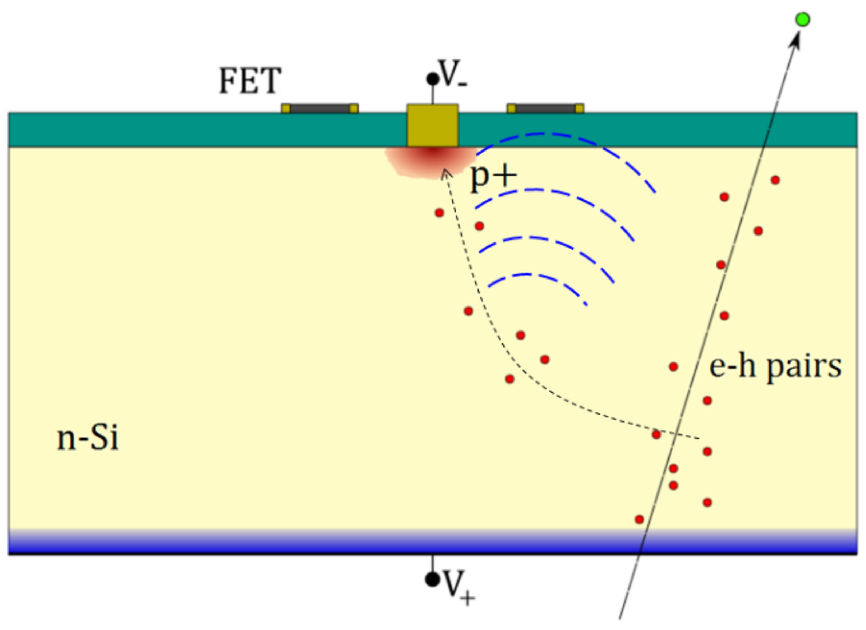
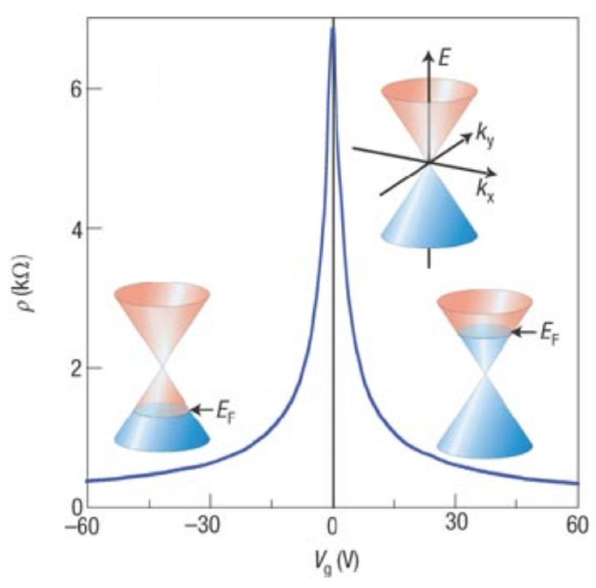
Summary

We present the first steps to develop radiation sensors based on the graphene field effect transistor technology. The layout of the sensors was designed with the help of Sentaurs TCAD [1]. We simulated static operations and the dynamic response to radiation with Sentaurus and calculated the source-drain current through the graphene layer with an analytical model [2, 3]. The transistors were produced at NEST by depositing high quality, single-layer, polycrystalline graphene on silicon chips manufactured by FBK. To overcome the high contact resistance between graphene and aluminum contacts, the oxide layer on the aluminum had to be broken by applying a high source-drain voltage. To protect open channels from closing again, we added Cr/Au overlays on top of the graphene and the Al contacts. Finally, we investigated the prototypes by performing sweep measurements of the topgate voltage and the backgate voltage. Here, we observed modulation of the source-drain current and observed the crossing of the Dirac point.

Introduction

The proposed sensor exploits the ambipolar behavior and the sharp variation of the conduction of graphene near its charge neutrality point (Dirac point) using the semiconductor substrate to absorb radiation. When ionizing radiation hits the silicon substrate, electron-hole pairs are produced. Holes drift to the top-contact varying the field below the graphene layer next to the contact. This field change shifts the Fermi energy in the 2D graphene layer and the conductivity of the graphene is modulated.





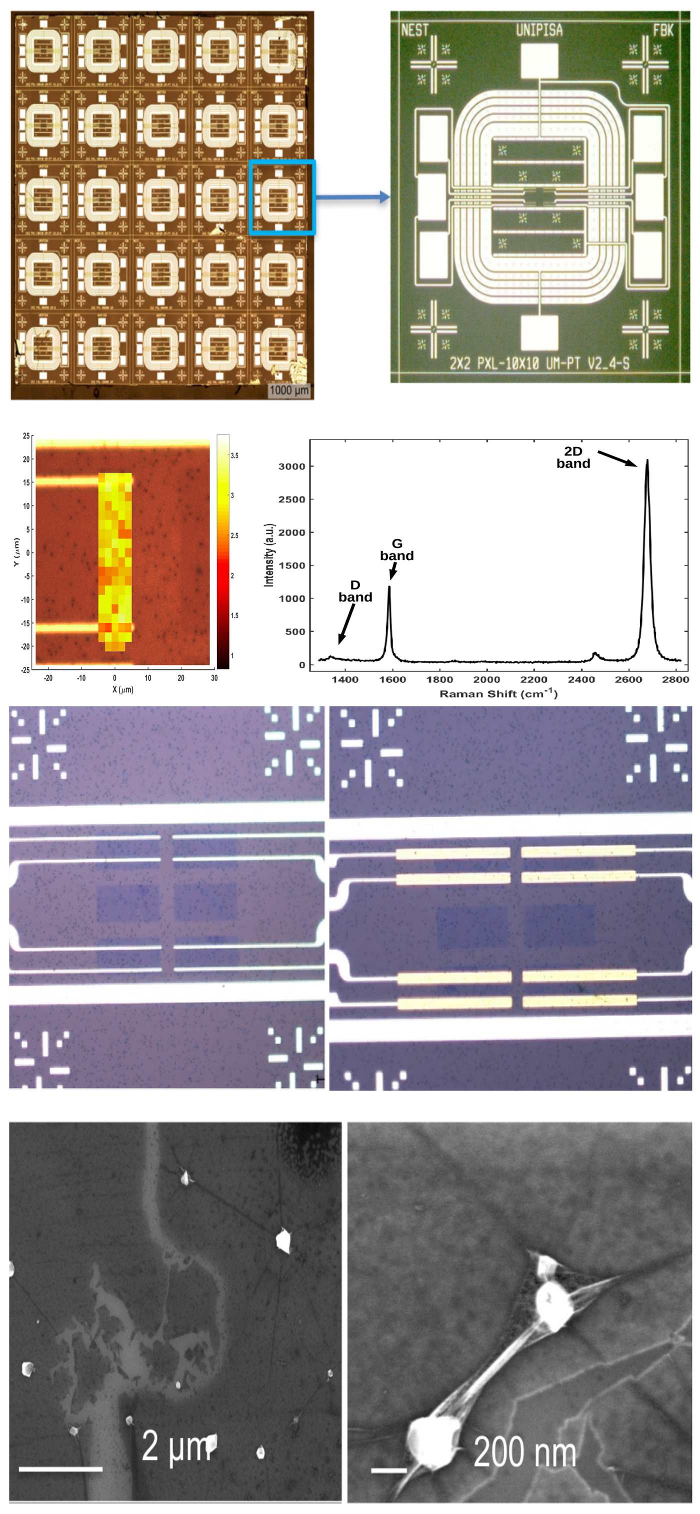
GFET Production

- Silicon structures were designed and produced according to the well-defined design rules of Si detector technology.
- Polycrystalline graphene was grown via chemical vapor deposition on Cu substrate and transferred on Si absorber by PMMA assisted transfer.

  → MicroRaman spectroscopy (weak D-peak and 2D/G > 3) clearly indicates that high quality, single-layer graphene was synthesized.
- Oxidation of aluminum contacts:

  → Need to break the oxide layer.

  → Cr/Au overlays deposited to avoid re-oxidation.
- Silicon residue from the removal of the Al from the SiO_2 leads to cracks in the graphene layers.



Simulation

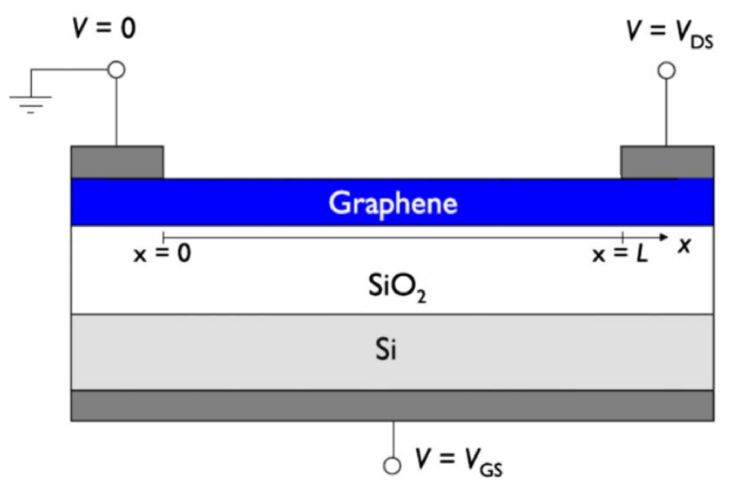
- Simulation of GFETs with Sentaurus TCAD [1].
- No 2D materials in Sentaurus!

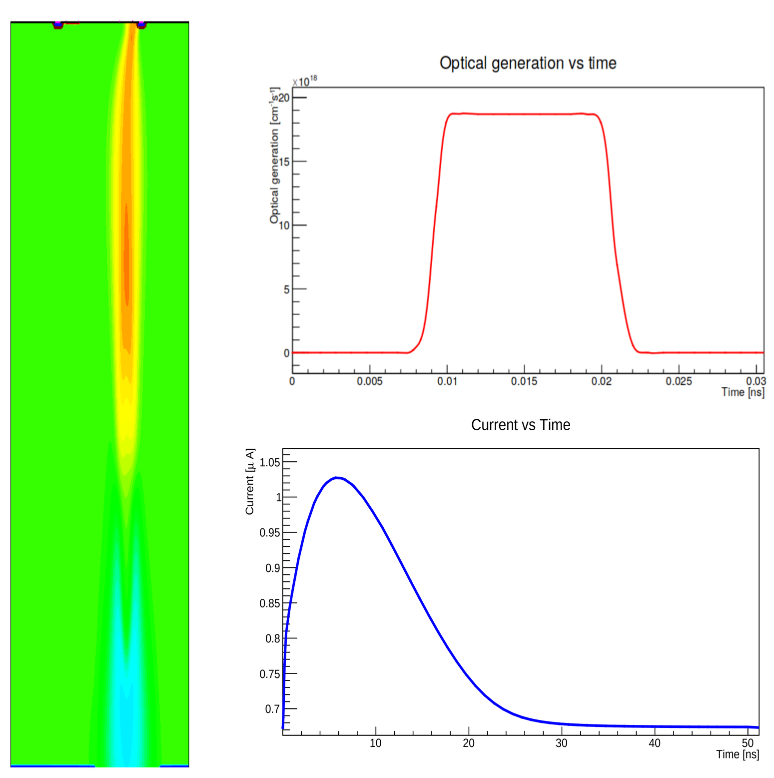
  → Graphene needs to be added to the material list [2].

  → Use of analytical model in the graphene layer [3]: $I_{DS} = \frac{\int_0^{V_{DS}} \rho_{sh}(V)dV}{L - \mu \int_0^{V_{DS}} \nu_{sat}^{-1} dV}$.
- We simulated the time dependent source-drain modulation of the sensor.

  → Simulating the interaction of a highly penetrating IR-laser (1060 nm).

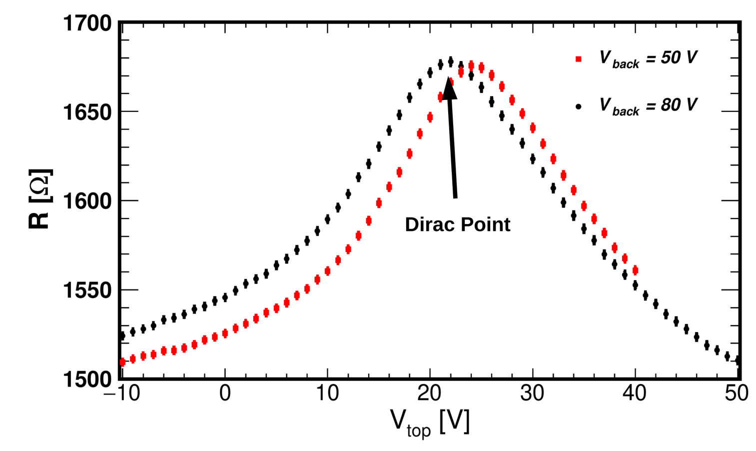
  → Creating 23000 e-h pairs in the substrate. The same number of e-h pairs that a MIP produces in 300 μm Si.

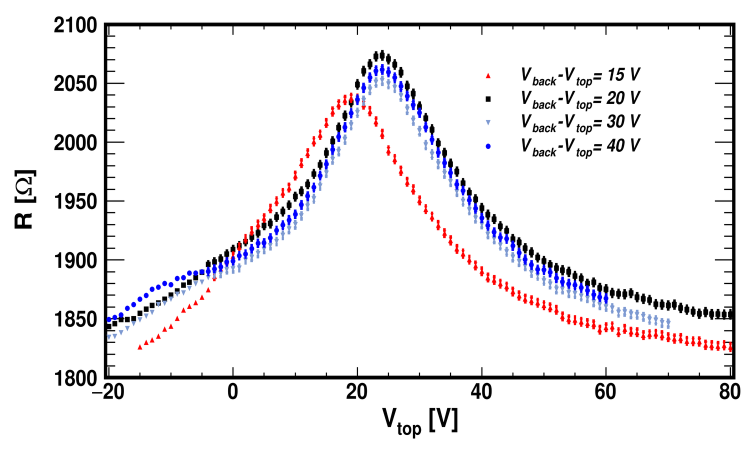


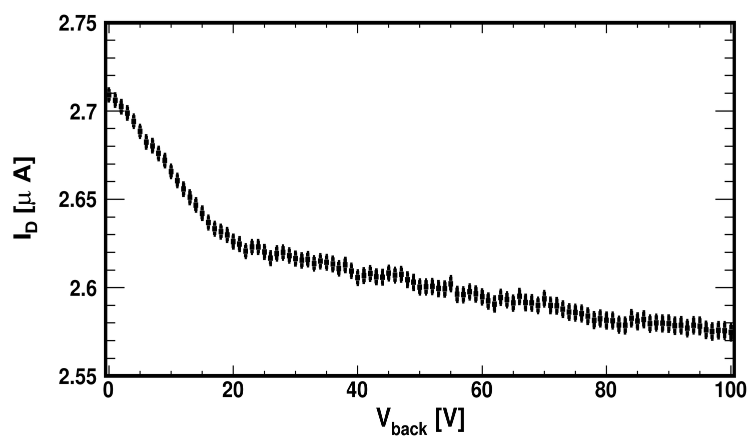


Measurements

- The crossing of the Dirac point was observed by over-depleting the sensor with high constant backgate voltage and sweeping the topgate voltage.
- Dirac voltage is stable for a fully depleted sensor (depletion voltage ∼20 V), when topgate voltage and backgate voltage are swept simultaneously.
- Modulation in the source-drain current at fixed topgate bias as a function of the backgate voltage. No ambipolar behavior was observed.

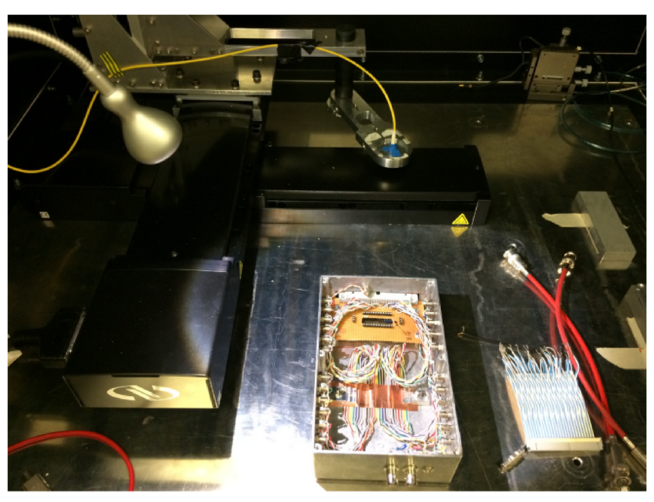






Current Activities

- Production of new silicon substrates with gold contacts at FBK.
- Irradiation test with IR laser and a β-source.
- Determination of sensitivity to Minimum Ionizing Particles.
- Optimization of sensor design.



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