Graphene-Enabled Silicon-Integrated Radiation Detector for Low Penetrating Particles

Radiation Detectors Group

Centro Nacional de Microelectrónica IMB

CSIC Consejo Superior de Investigaciones Científicas

23rd iWoRiD

28th June 2022

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Introduction

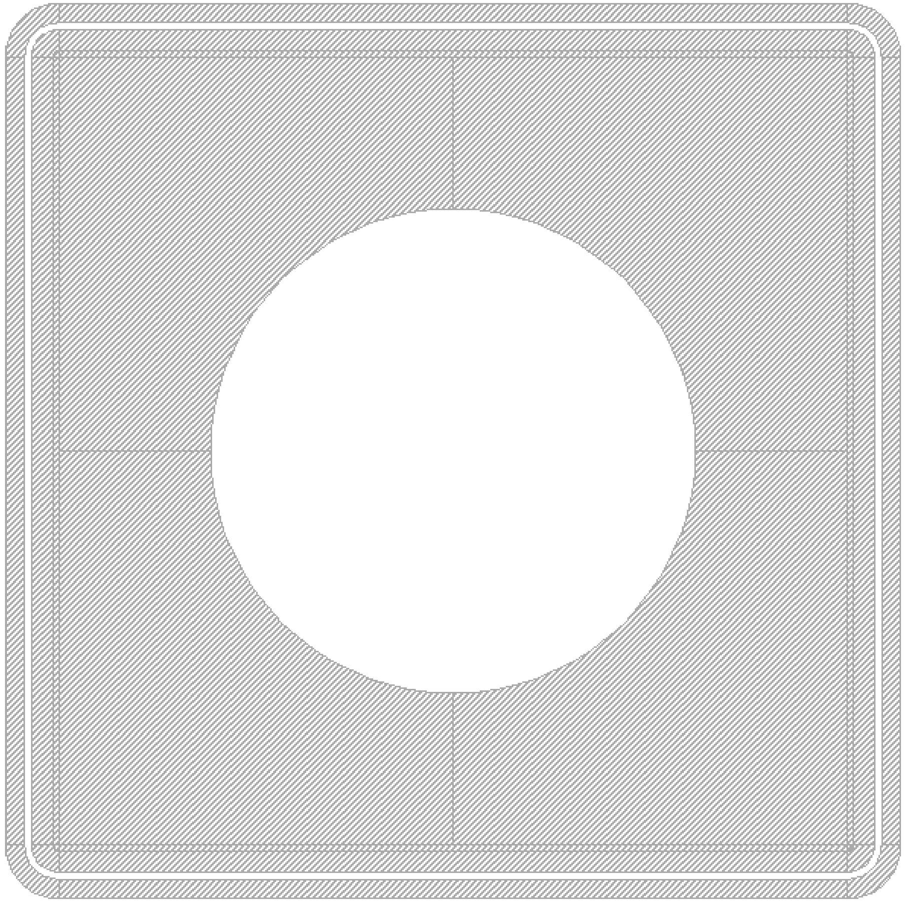
- Motivation
- Detector Concept
- Simulation
- Measurements
- Prospects

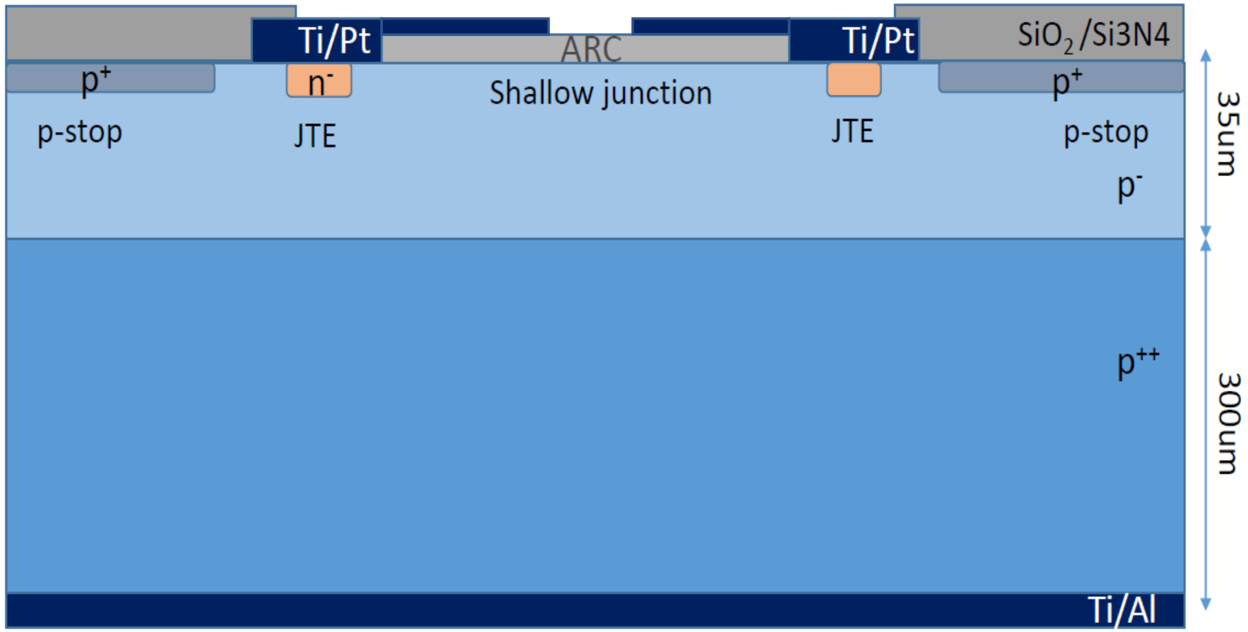
Motivation

- We wanted to create a "junction" with a minimum dead layer.
- We are interested in detecting low-penetrating particles such as ions, electrons, protons and "Soft X-rays"
- "Soft X-rays" can be used to study biological samples.
- Specfcially we want to build a detector capable of studying X-rays with an energy in the so-called "water window", between the Carbon and Oxygen edges (282 eV to 533 eV – Carbon and Oxygen being present in all biological samples).

Detector Concept – How we got here

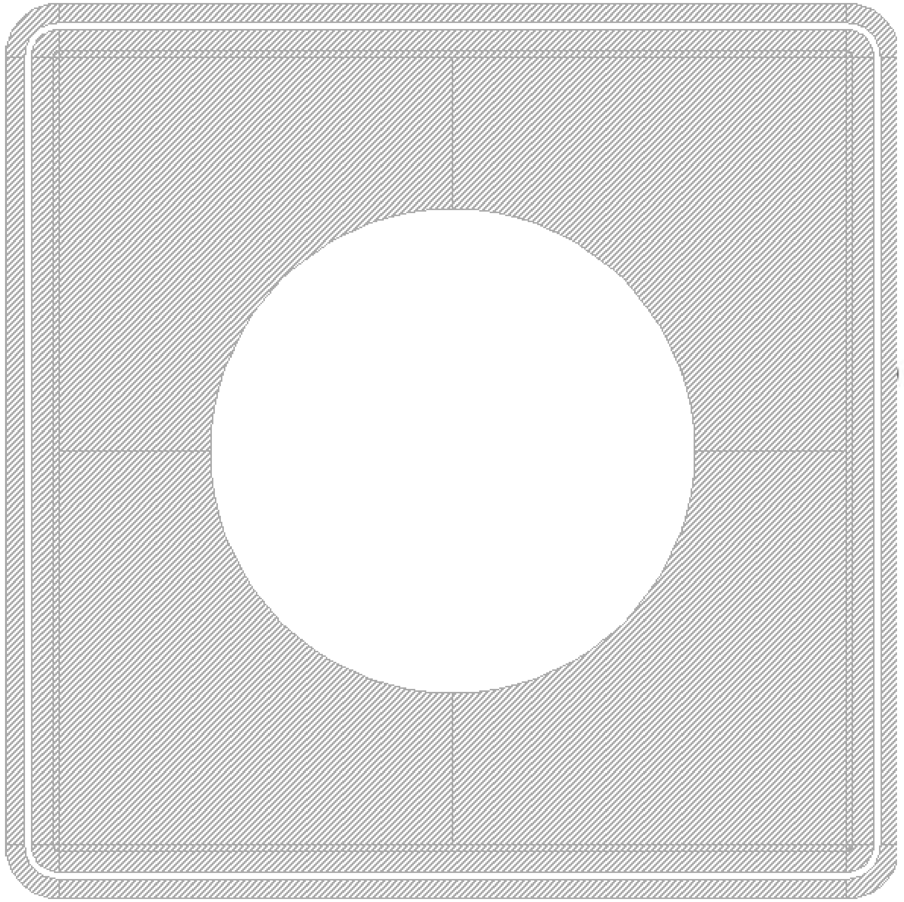
Metal Opening

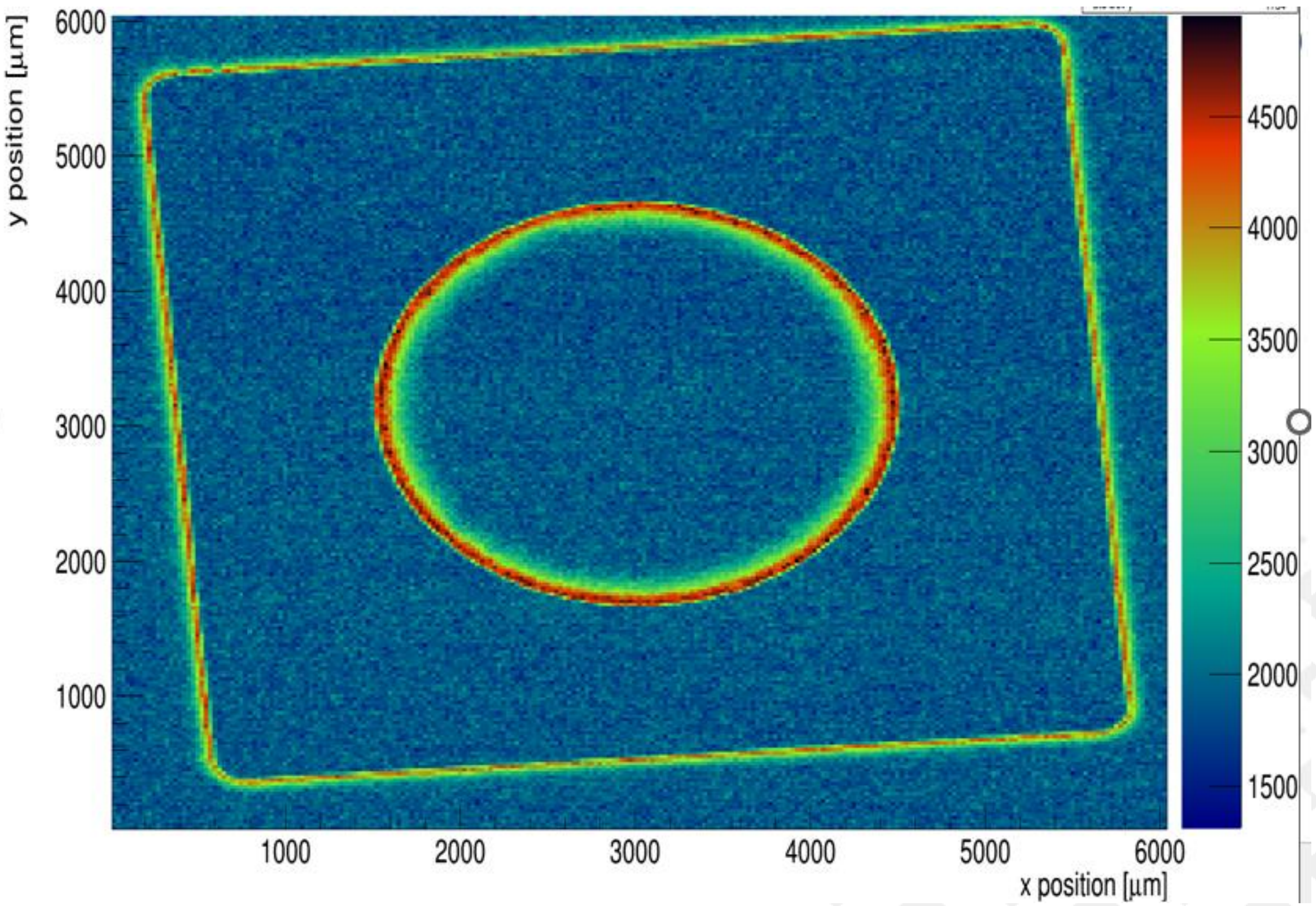




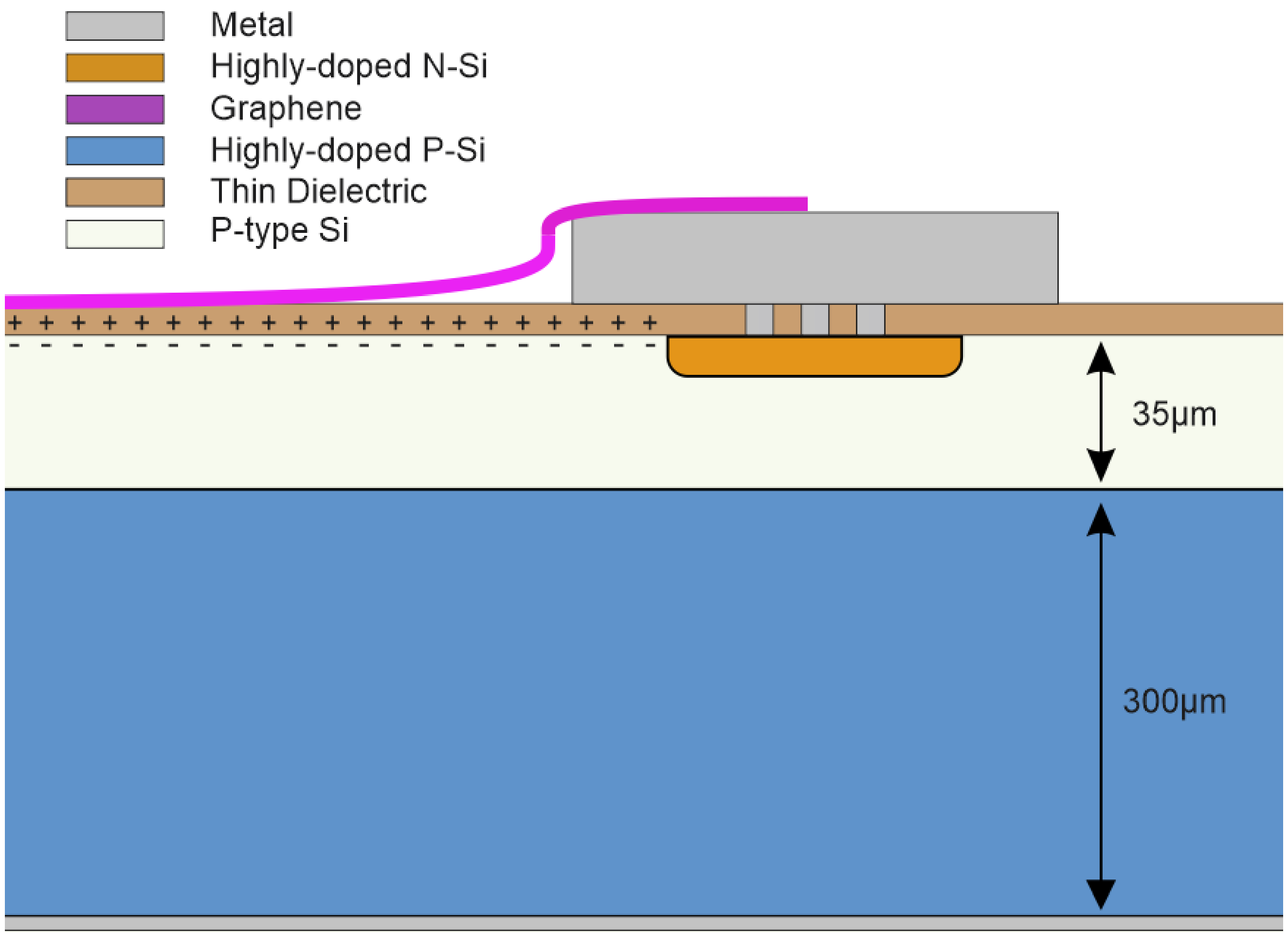
Detector Concept – How we got here

Metal Opening



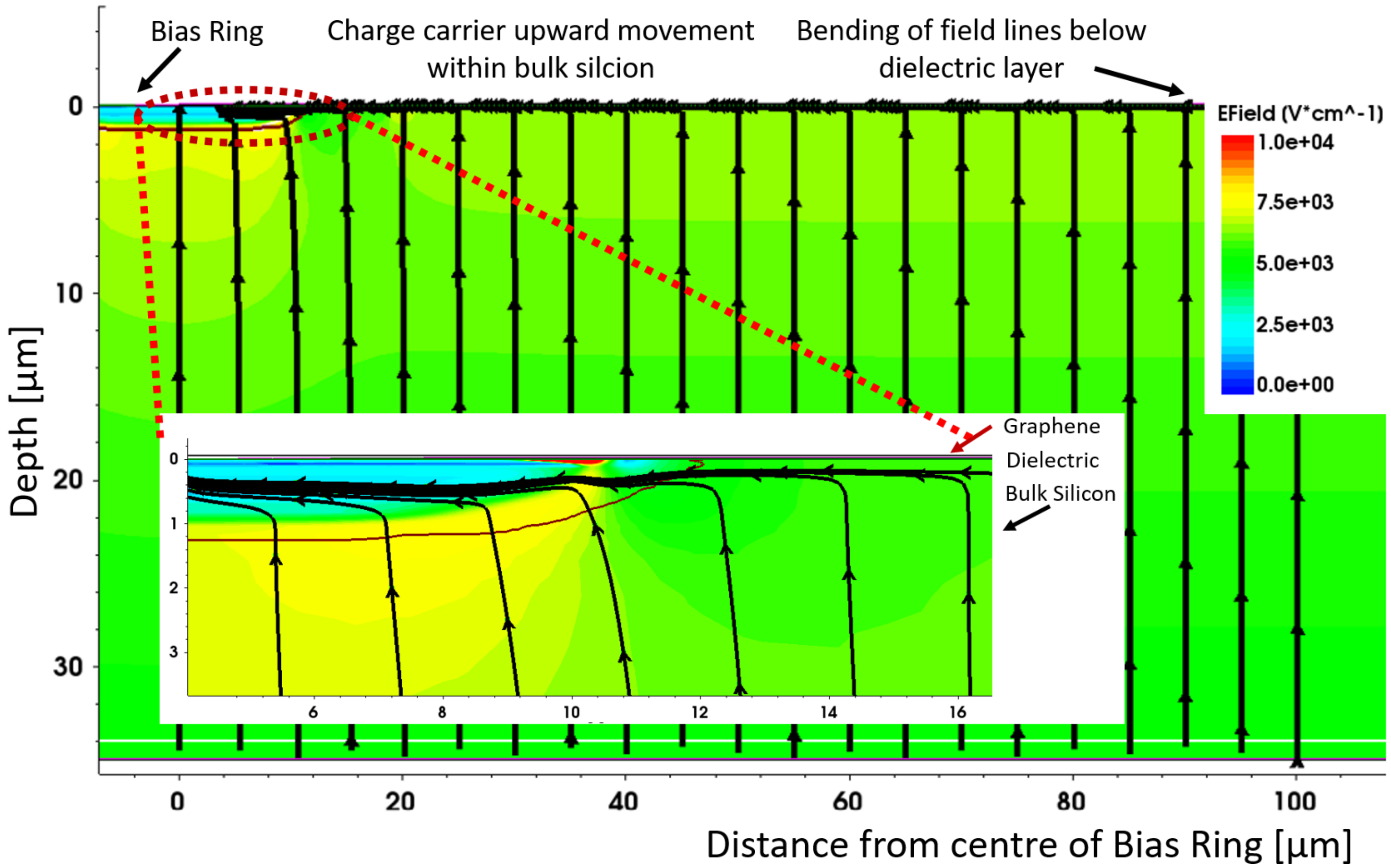


Detector Concept – Graphene-on-Insulator-on-Silicon (GIS)



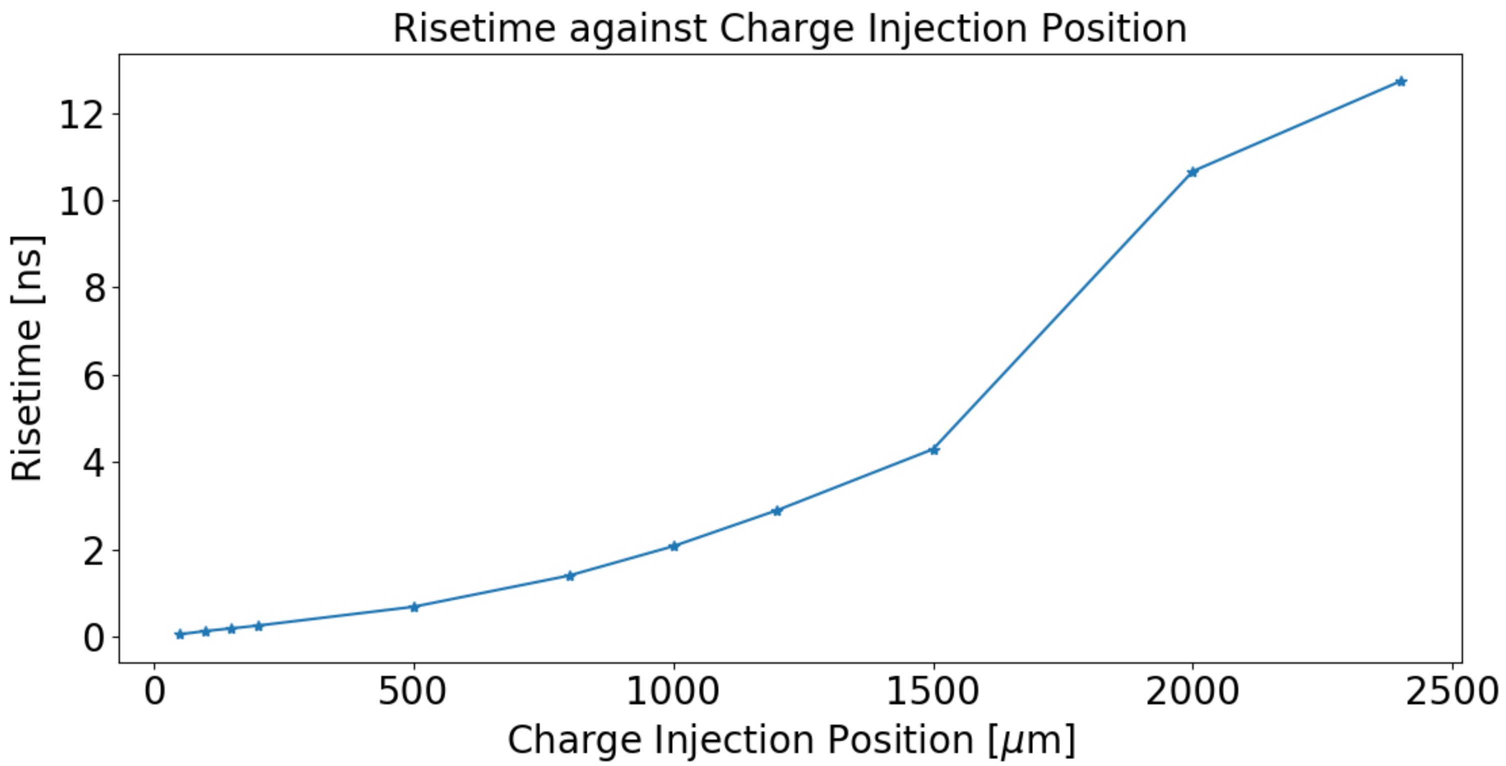
- Absorption layer (the 35um Si) and bulk Si (the 300um Si)
- **Graphene placed on top of thin dielectric (3nm) in electrical contact with metal.**
- Reverse bias applied to metal with ohmic contact to the highly-doped N región.
- Detector depletes under the N-electrode and under all regions of the detector with Graphene on top.
- An inversión layer is present at the interface of Oxide/Silicon
- **Dead región is defined by the thickness of the oxide. -> 3nm**

TCAD Simulation



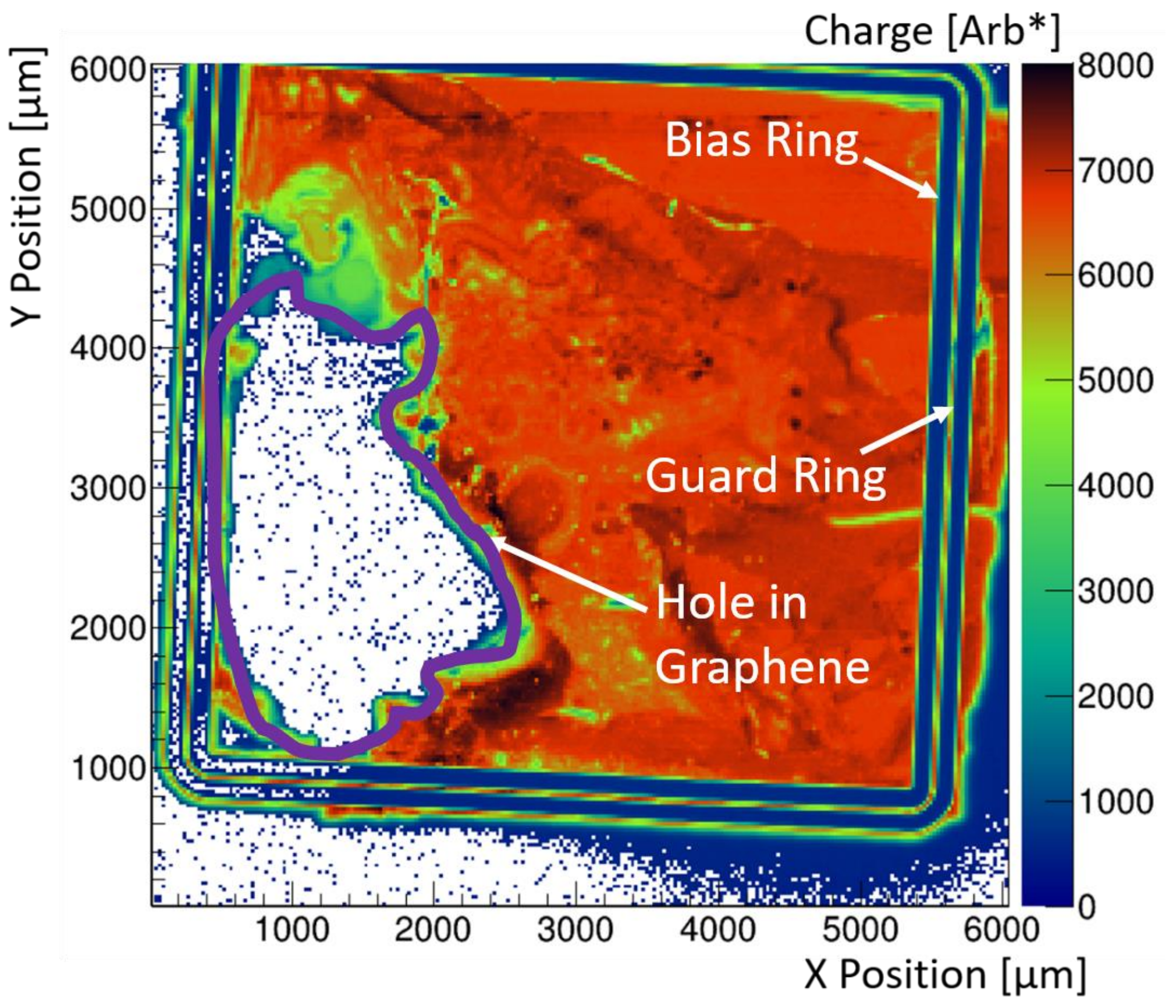
- TCAD model developed using Sentaurus TCAD.
- Graphene model doesn´t exist, instead a modified model of polysilicon used.
- Image shows Electric field lines.
- Charge carrier shows upward movement within the bulk silicon.
- **Bending of the lines at the Surface , below the dielectric layer towards the bias ring(Highly doped N region).**

Simulation

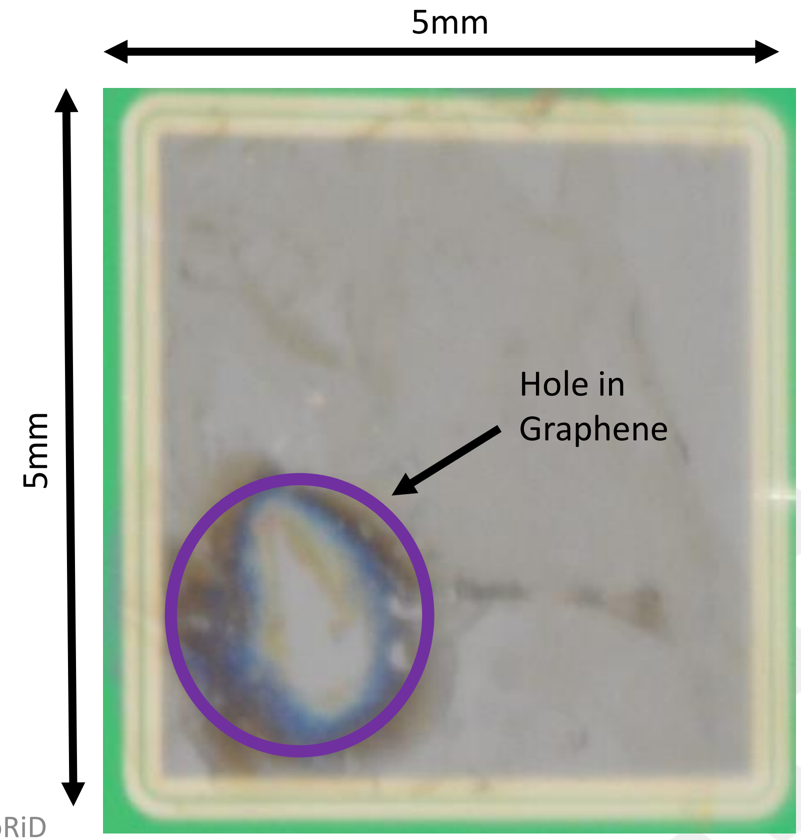


- **Simulation** shows that the risetime of the signal is dependant on the inital charge injection position.
- This is due to the difference in time required for the charge to travel along the surface of the detector.
- The **risetime** is proportional to both the distance to the collection electrode and the resistance of the device below the surface.

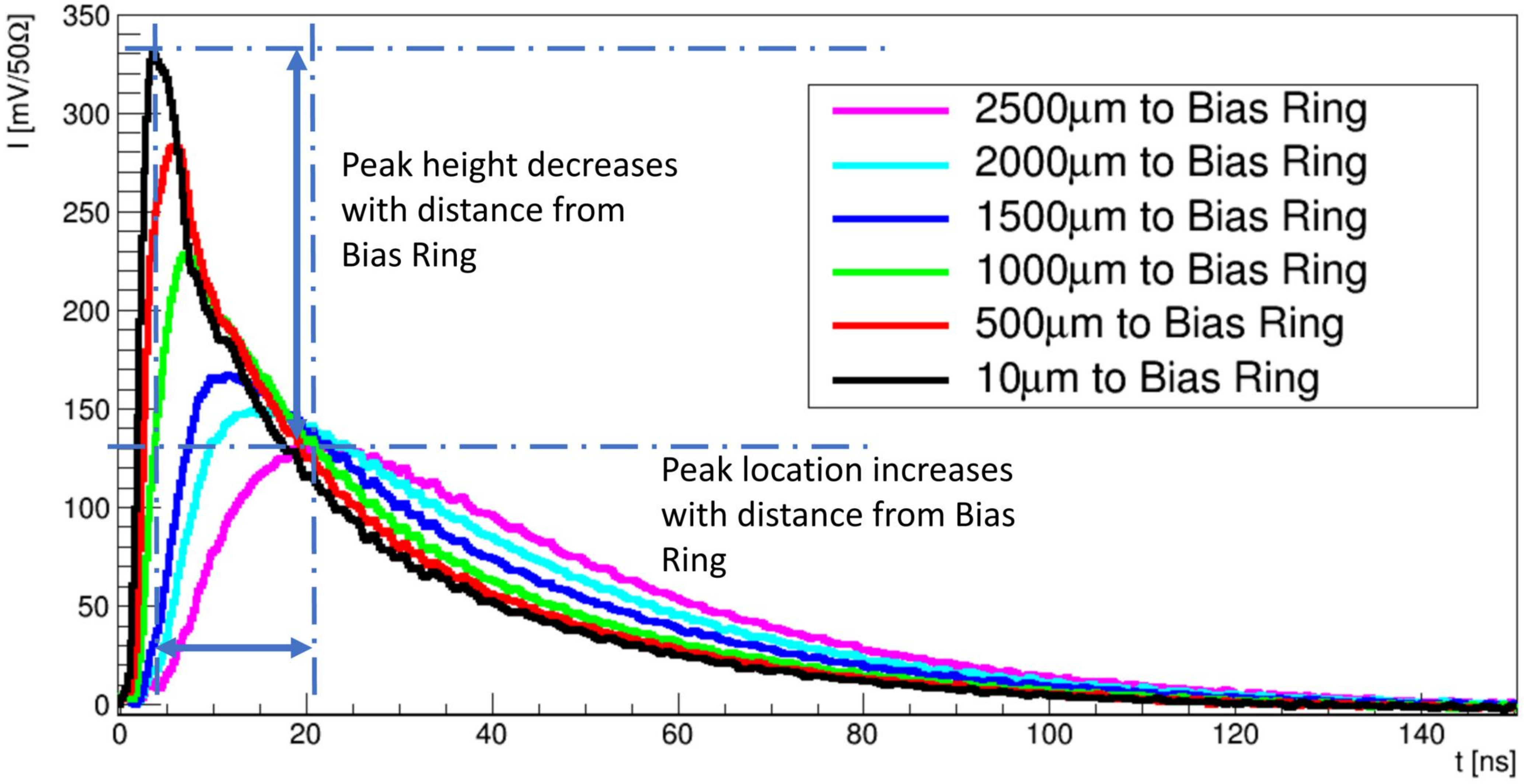
TCT



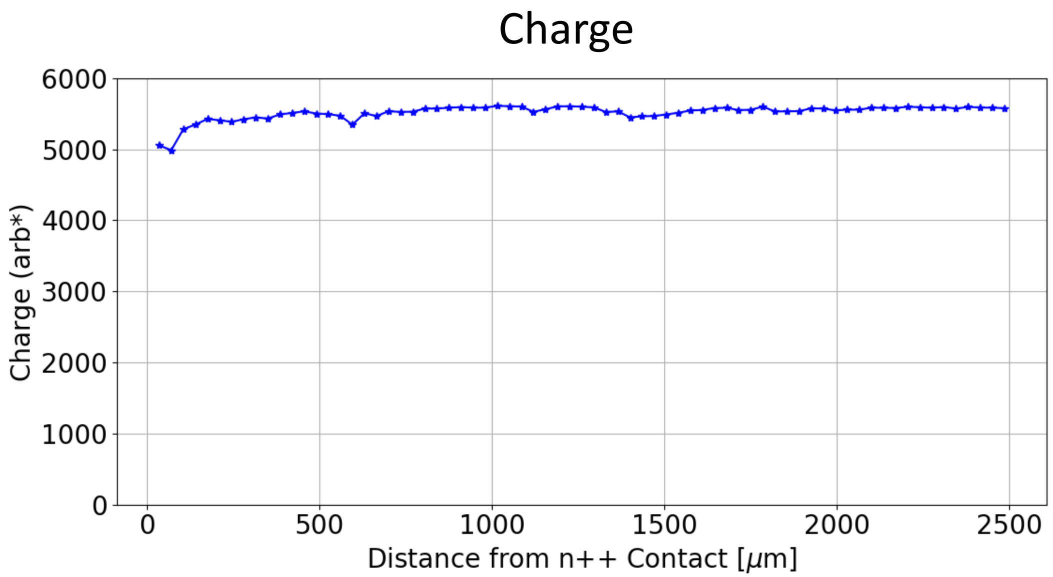
- 2D TCT scan of entire detector area using a Blue laser (**405nm**).
- Charge collected over entire area is **uniform**.
- The region where there is a hole in the graphene shows zero charge collected.



TCT

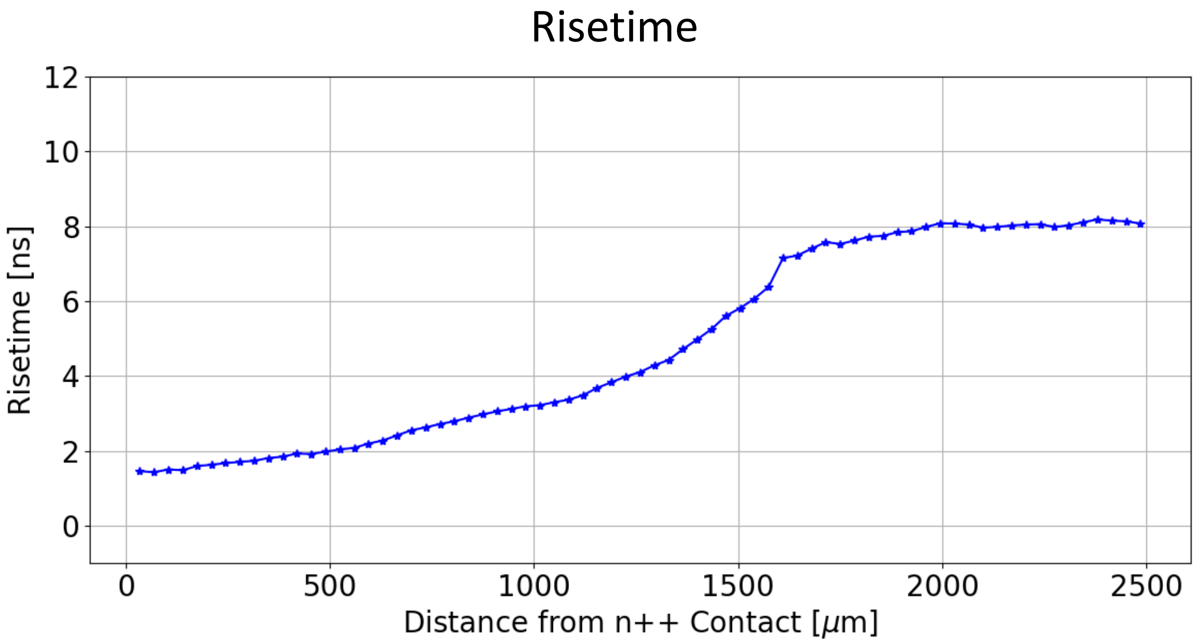

I [mV/50Ω]
t [ns]
2500µm to Bias Ring
2000µm to Bias Ring
1500µm to Bias Ring
1000µm to Bias Ring
500µm to Bias Ring
10µm to Bias Ring
Peak height decreases with distance from Bias Ring
Peak location increases with distance from Bias Ring

TCT

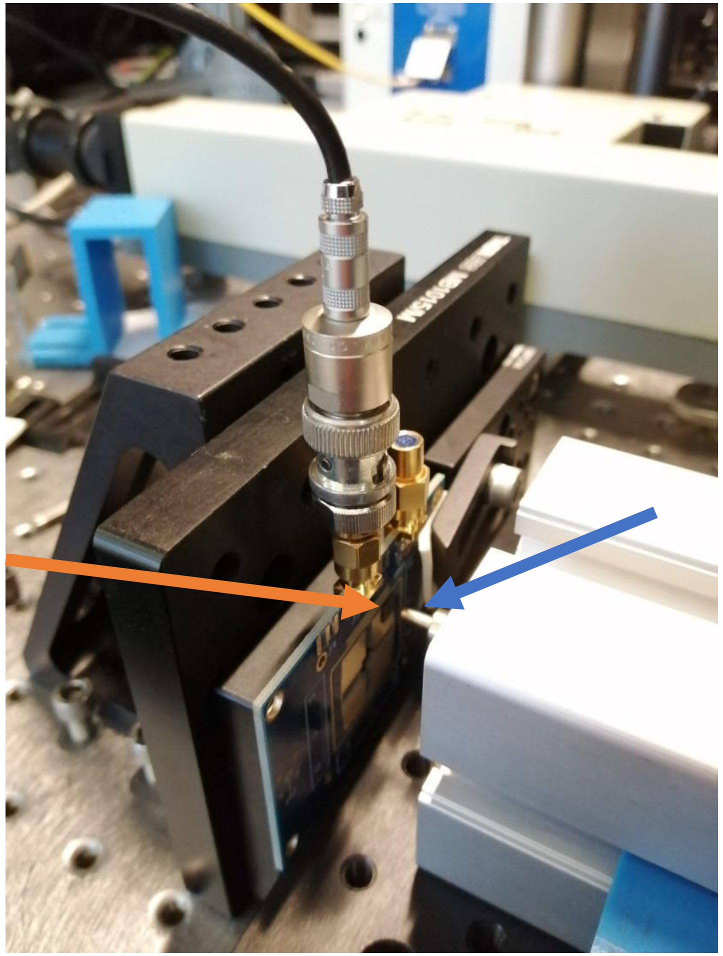


- **Charge** as function of injection position is uniform.
- Collection time and risetime can be different but all charge is collected.

- Measurements show that the **risetime** of the signal is dependant on the inital charge injection position.
- As expected from the simulation



Photoresponsivity Setup

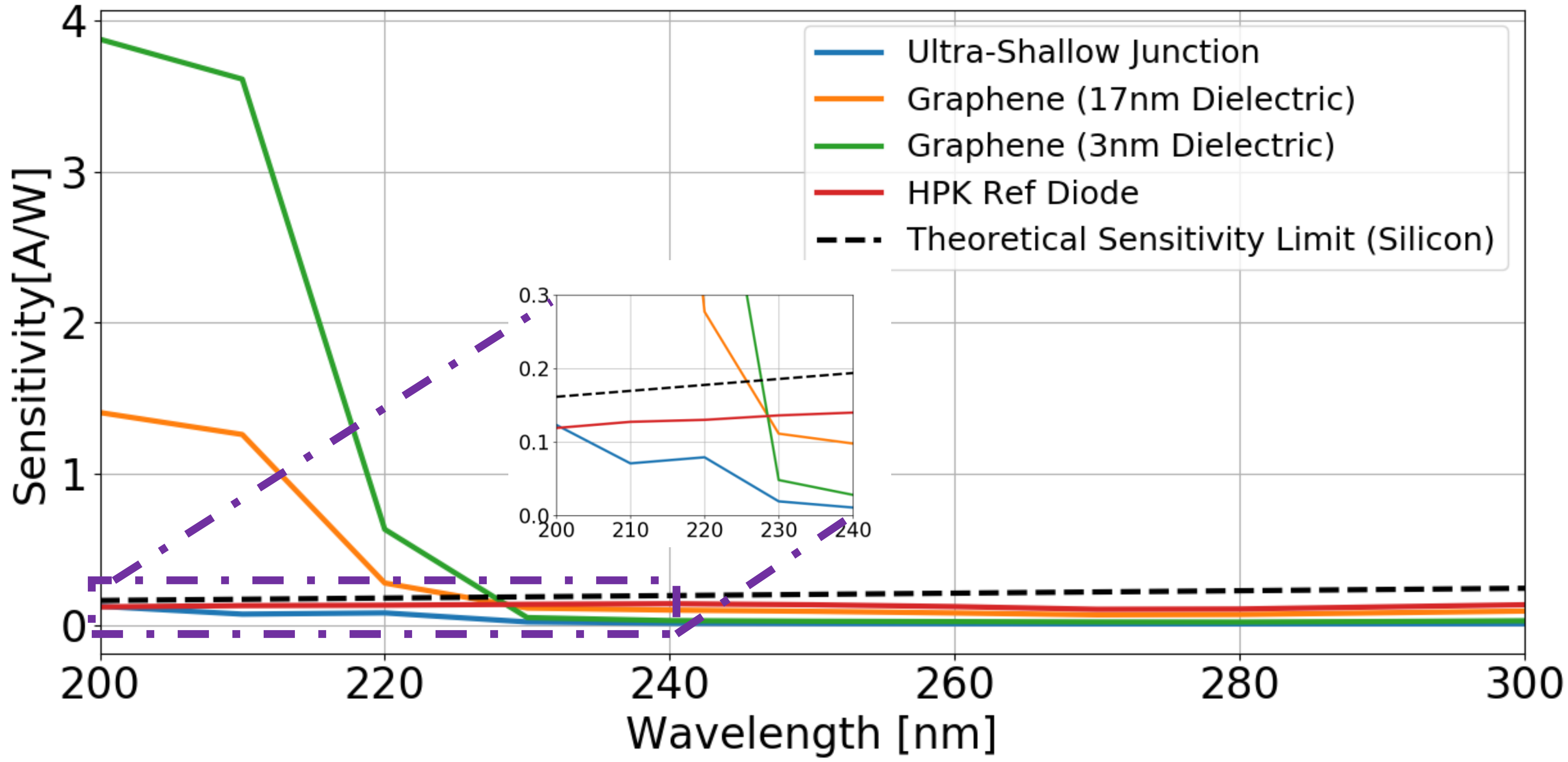


Detector

Output from Monochromator

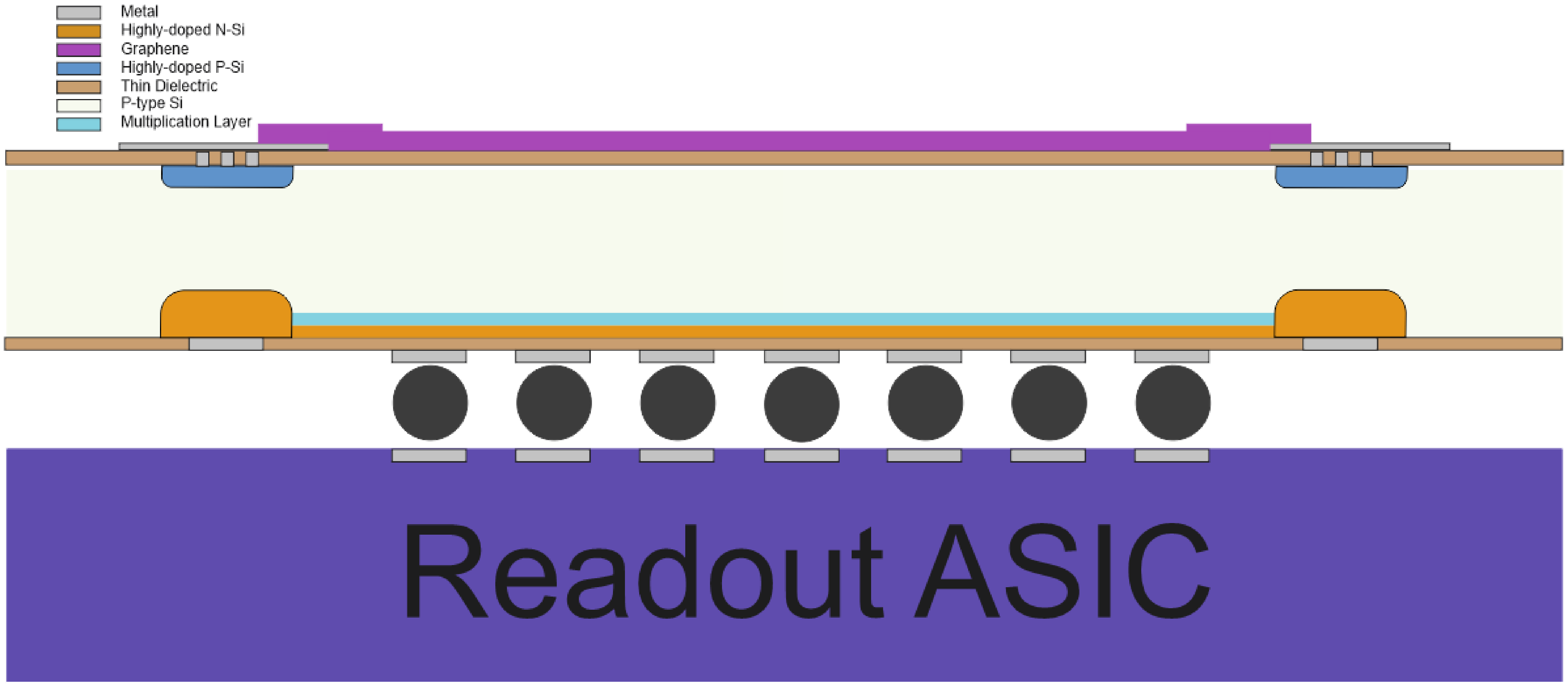
- **Monochromator** system used to modify the wavelength of light (200-800nm).
- The detector was biased to a **fixed voltage** and a sweep of wavelength performed.
- The **photocurrent was measured as a function of wavelength**.
- The responsivity was then calculated based on measurements of a **calibrated** HPK diode.
- All measurements performed in the Detector Development Lab at the **University of Glasgow** with the help of Dr Dima Maneuski. (Dima.Maneuski@glasgow.ac.uk)

Photoresponsivity



- Photo response of fabricated detectors show a variety of responses.
  To note the **max responsivity** of a silicon detector at 200nm is 0.17A/W
  The HPK reference diode shows good sensitivity at the full wavelength range.
  The devices with graphene show a superior response at wavelengths below 230nm.
  It is thought that the graphene must undergo gating (which is voltage dependant) in order to collect light at these wavelengths.
  https://www.sciencedirect.com/science/article/abs/pii/S1748013210001623?via%3Dihub
- Main feature is that the devices are active at the full wavelength range.
- **Penetration depth of light of 200nm is approx 4nm**.

Prospects – AC-LGAD coupled with GIS



Conclusions

- **A device with a minimum dead area has been presented, which has been made utilizing the, almost, transparent nature of graphene.**
- **The device has a uniform charge collection across the entire area but the shape of the signal varies depending on the point of charge interaction.**
- **An LGAD device with this window could be produced for imaging of soft X-rays and DUV light.**
- **Next stage is in production. The first LGAD device with this transparent window will be produced at CNM this year using the AC-LGAD technology.**

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Acknowledgements

This work has been financed by the Spanish Ministry of Science and Innovation (MCIN/AEI/10.13039/501100011033/)

Project references: SPID202000X118404SV1

Thanks for your attention!

Backup

Simulation Model

TABLE I. Material parameters of Graphene used for model[16].

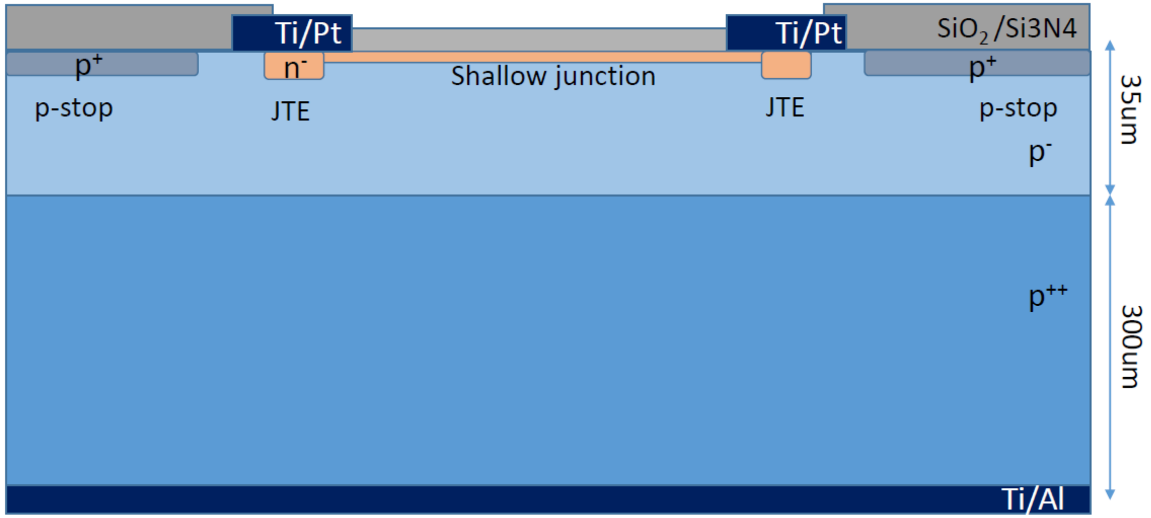
Parameters	Description	Value
E_G(eV)	Bandgap	0
χ	Permittivity	25
$\mu_n(cm^2/Vs)$	Electron mobility	10,000
$\mu_p(cm^2/Vs)$	Hole mobility	10,000
X(kg/mole)	Affinity	4.248
v_{sat}	Electron saturation velocity	$4x10^7$

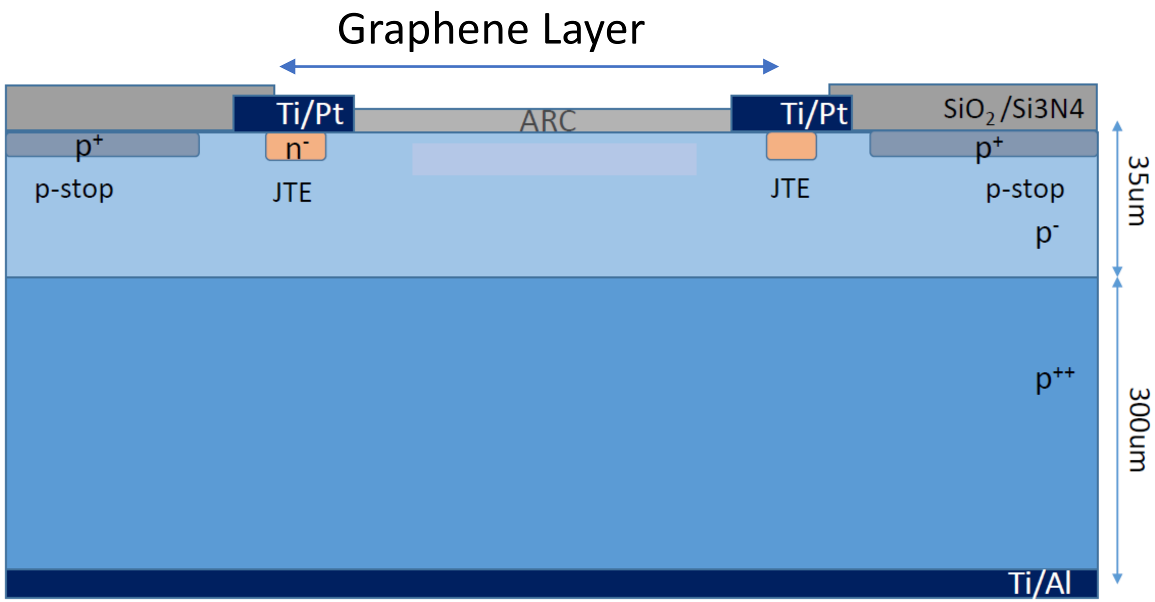
16 K. J. Singh, T. Thingujam, and M. Kumar, "Tcad based modeling and simulation of graphene nanostructured fet (gfet) for high frequency performance," ADBU Journal of Engineering Technology (AJET) 6, 49 (2017).

Si Detectors

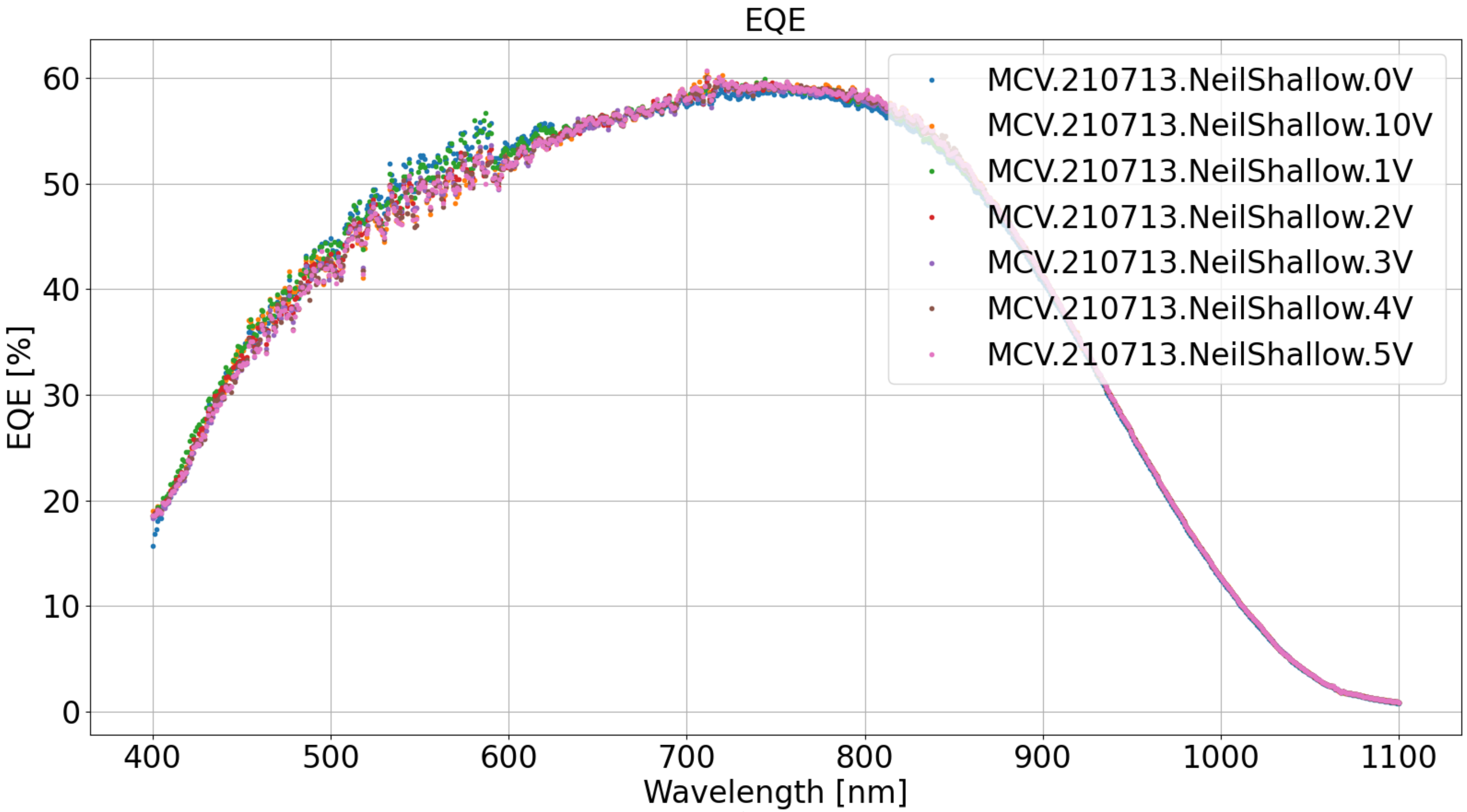
W2
Active bulk 35 µm
JTE
P shallow junction
S1 and S3 with metal on the Surface
S2 and S4 without metal

W3
Active bulk 35 µm
JTE
NO P shallow junction – Graphene Deposited
S1 and S3 with metal on the Surface
S2 and S4 without metal

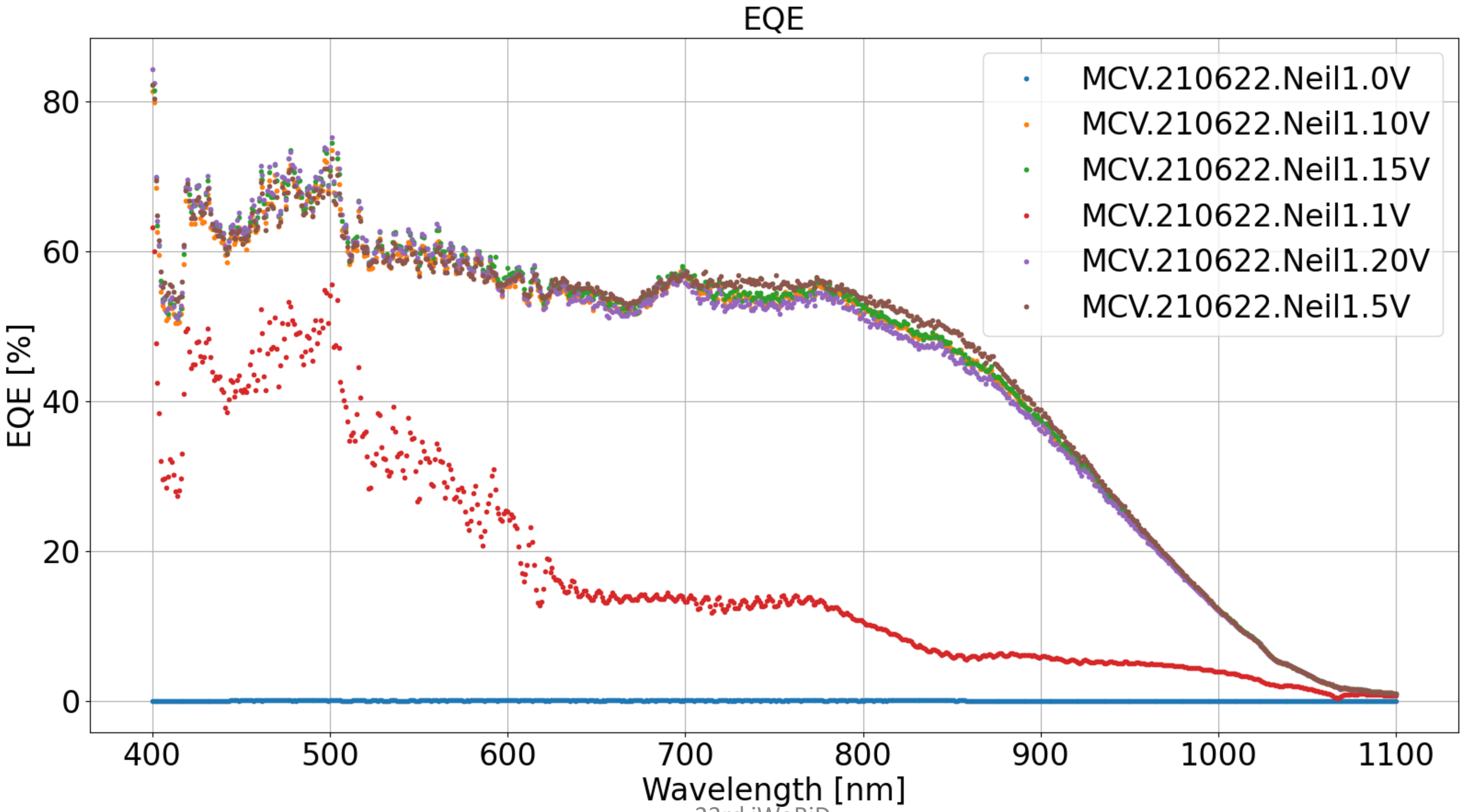




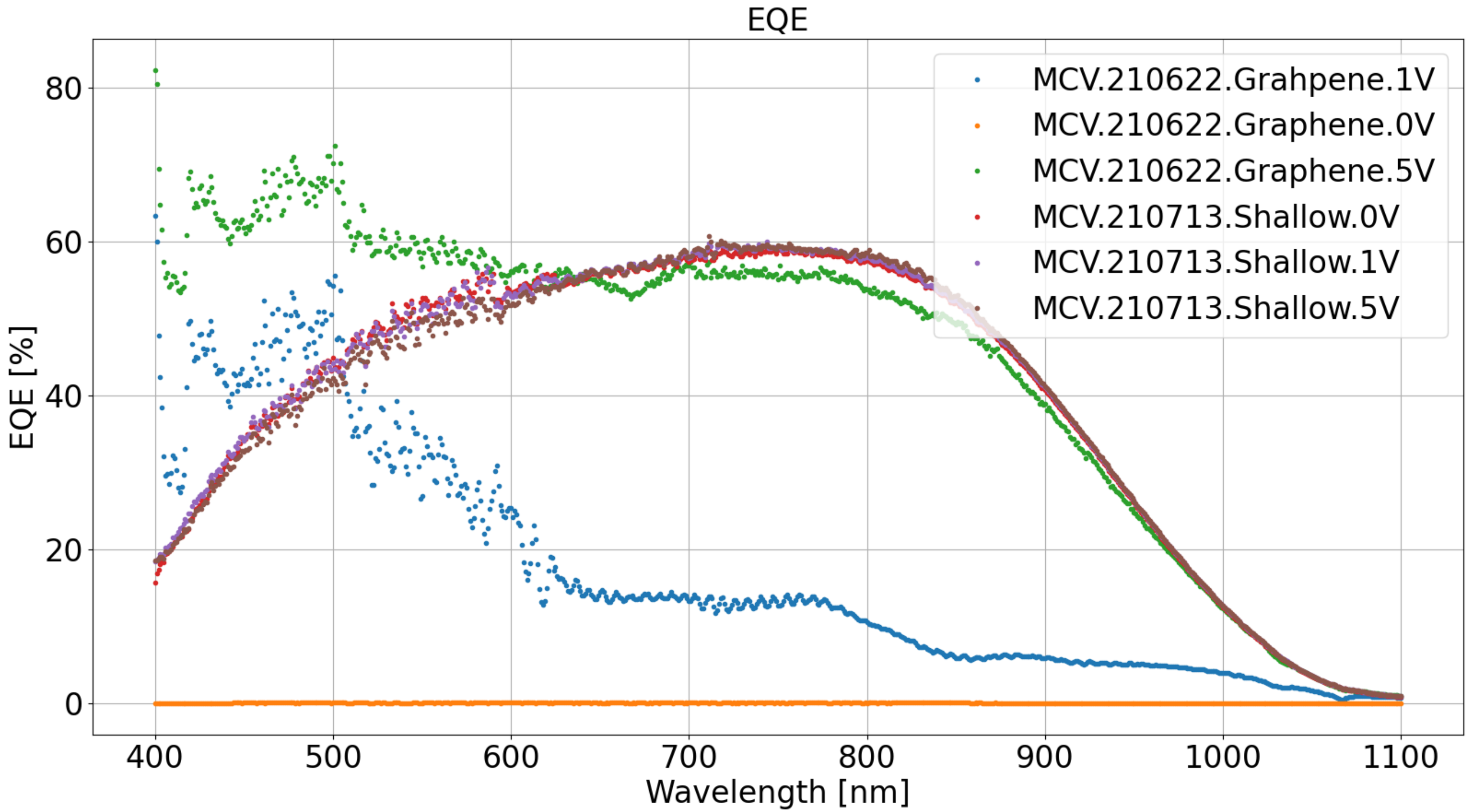
Measurements of EQE- ShallowImplant



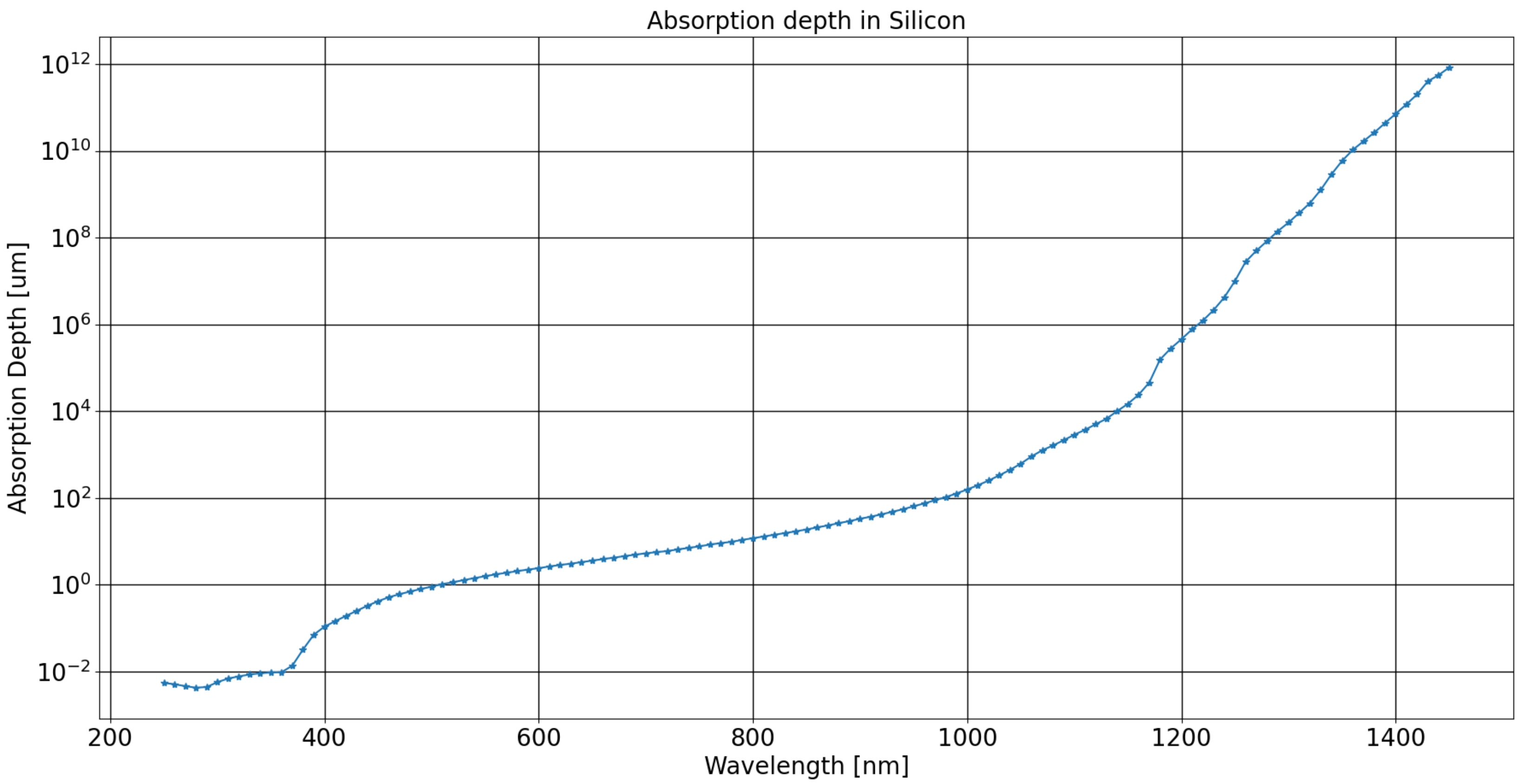
Measurements of EQE– NoImplant with Graphene



Measurements of EQE– Comparison



Absorption Depth in Silicon



Absorption depth in silicon