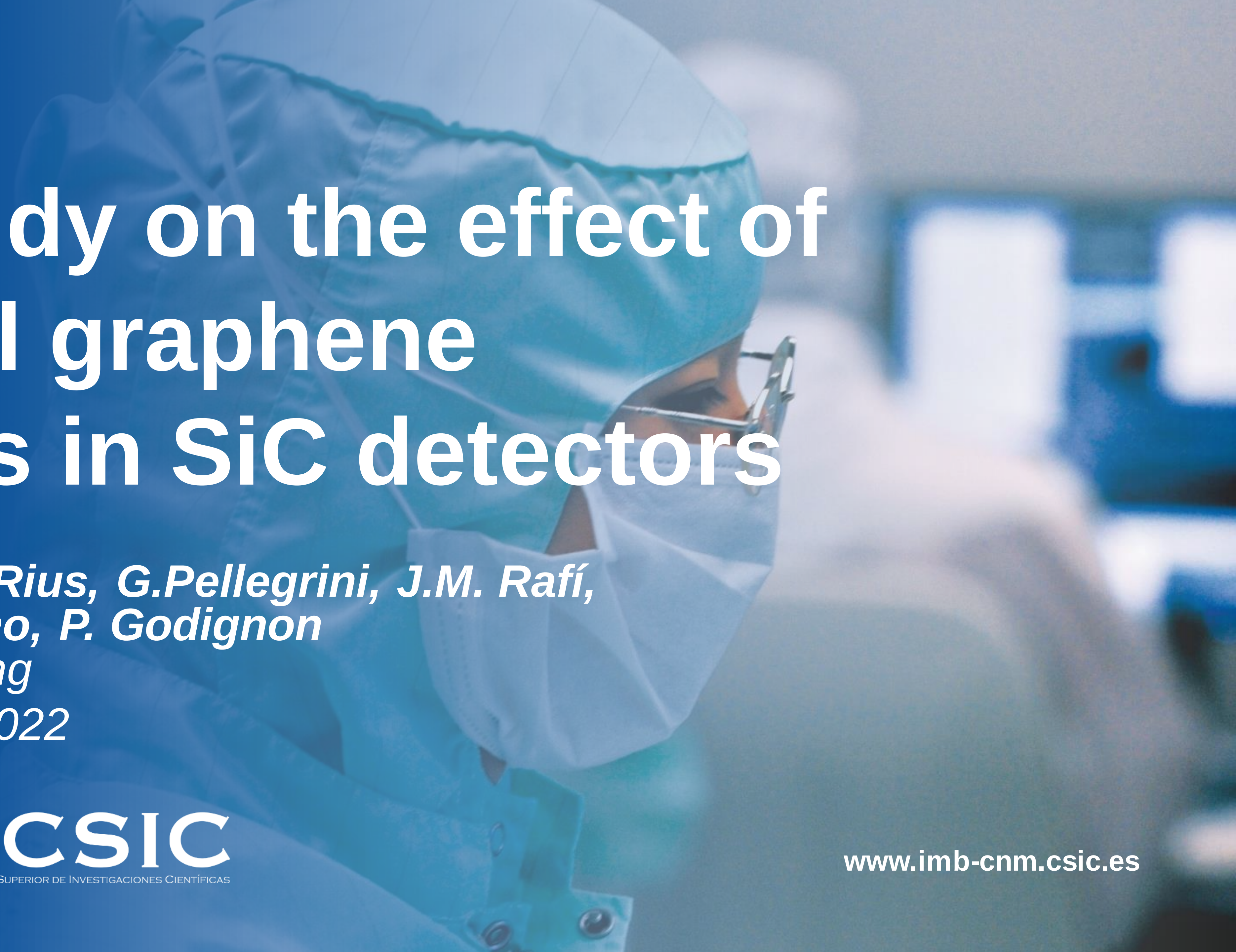

TCT Study on the effect of epitaxial graphene contacts in SiC detectors

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41st RD50 meeting

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Centro Nacional de Microelectrónica
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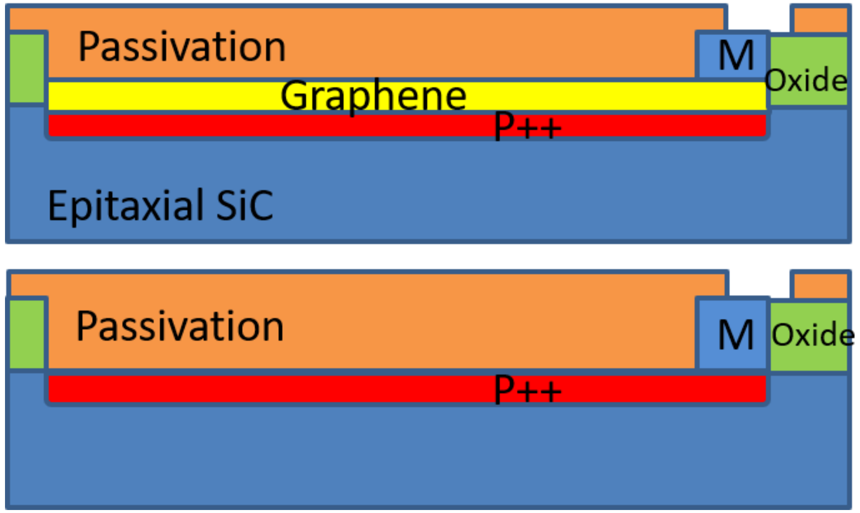
Motivation

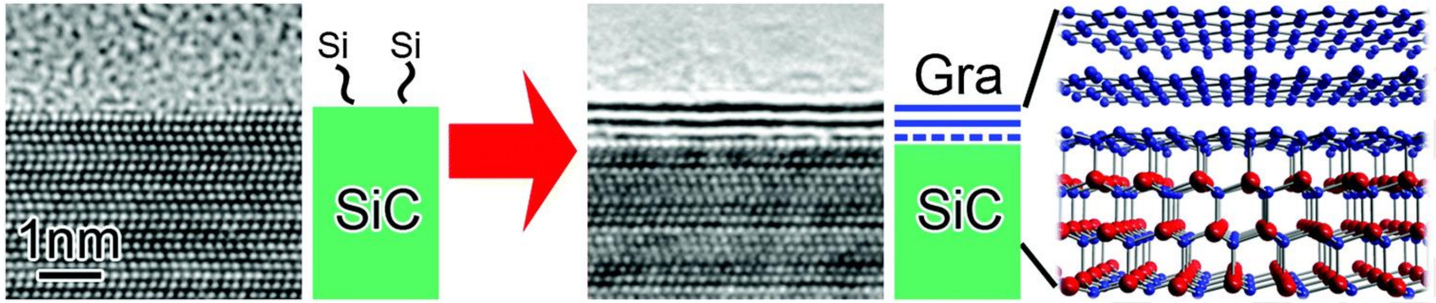
- SiC → Fast, radiation hard, good thermal conductor ⟹
- High quality 4” and 6” wafers commercially available
  - Diodes already developed
- The goal is to produce SiC devices replacing metallic contacts with graphene
  - Non-metallic active region window
  - Good for e.g. ion detection, fusion reactors, etc

	Silicon	4H-SiC	CVD Diam.
e-h pair generation energy [eV]	3.6	7.8	13
Displacement energy threshold [eV]	13-20	22-35	40-50
Thermal conductivity [W/(m K)]	148	370	1000
Electron sat. velocity (1e17 cm/s)	0.86	2	2

Epitaxially grown Graphene in Silicon Carbide (EG-SiC)

- Epitaxial growth of graphene:
  - Sublimation of Si atoms
    - High temperature process (>1500 degC)
  - Carbon arranges as graphene in surface
- Fabrication challenges
  - Metallisation: Metal lift-off failing, metal interfaced with graphene “peels off”
  - Graphene layer anisotropy





Wataru Norimatsuand Michiko Kusunoki, Phys. Chem. Chem. Phys., 2014,16, 3501-3511
G. Rius, P. Godignon, Epitaxial Graphene on Silicon Carbide: Modelling, Devices, and Applications, Pan Stanford Pte. Ltd. (2018)

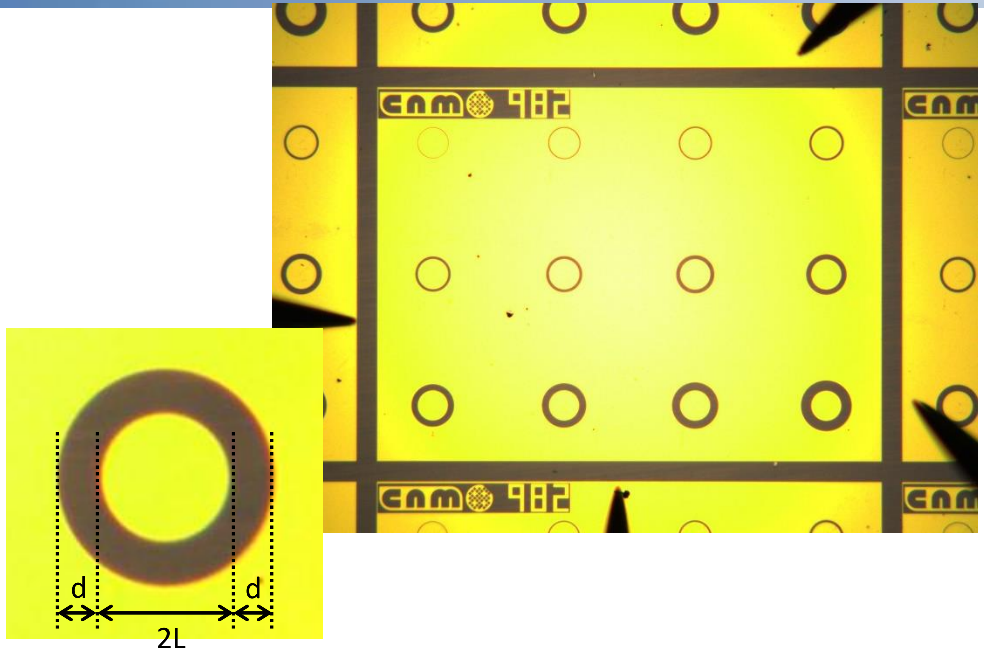
How does M-G-SiC interface behave?
What metal combination stack to chose?

Sheet resistance and contact resistivity

- Measure sheet resistance and contact resistivity via Circular Treansmition Line Method (CTLM)
  1. Measure I-V characteristics between the inner and outer metallic regions of each structure
     - Extract resistance (R_T)
  2. Resistance vs “gap” distance *d*
     - Fit linear function $R_{corr}(d) = \frac{R_T}{C} = \frac{R_{sh}}{2\pi L} d + \frac{R_{sh} L_T}{\pi L}$
  3. Extract R_{sh} and ρ_c

$$R_{sh} = 2\pi L \frac{\mathrm{d}R_{corr}}{\mathrm{d}\,d}$$

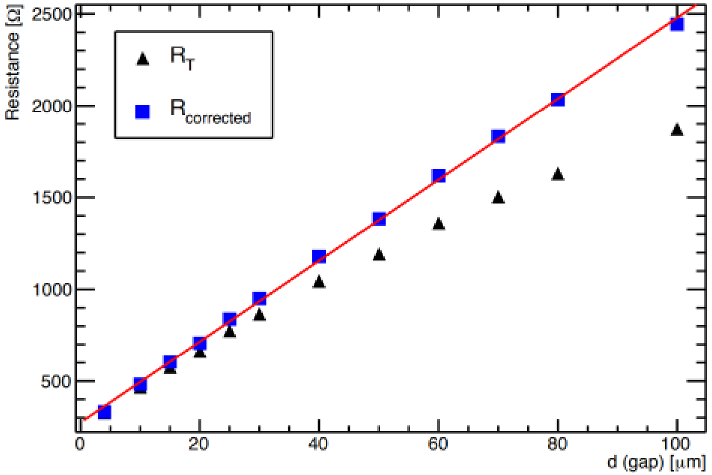
$$\rho_c = R{s_{hLT}}^2 = \frac{(\pi L R_{corr}(d=0))^2}{R_{sh}}$$

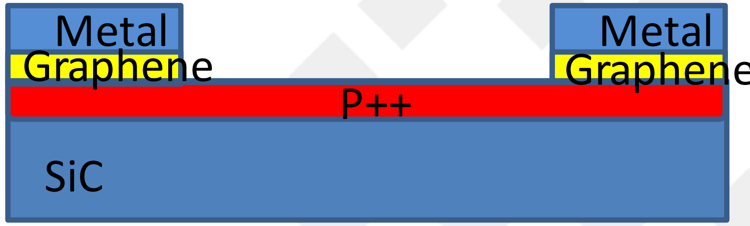


R_{sh} : related to doping concentration

ρ_c : related to metal-(graphene)-SiC contact

C: geometry correction factor $C = \frac{L}{d}\ln(1 + \frac{d}{L})$

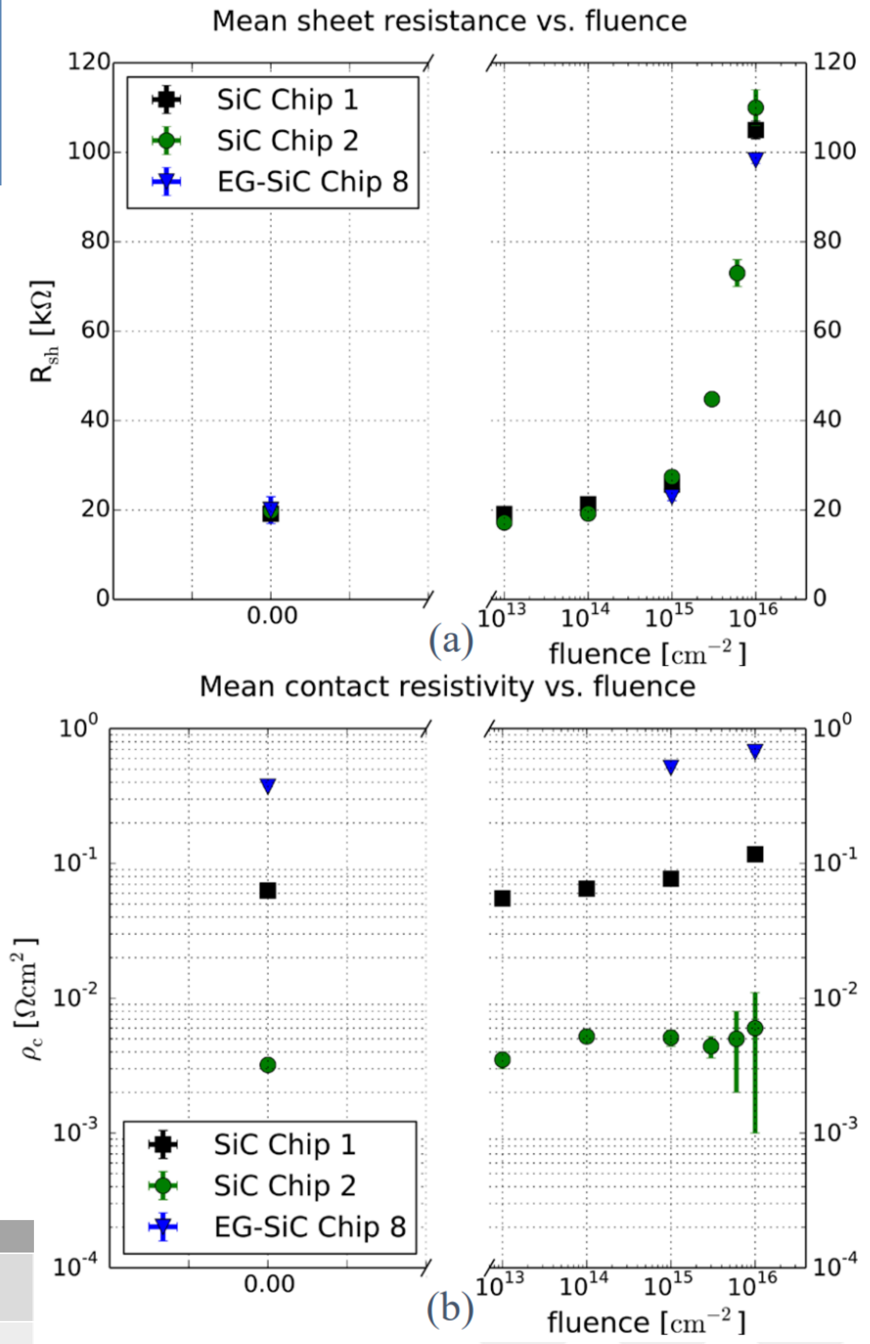




Contact resistance and contact resistivity

- Measured by CTLM in test structures
- Irradiation campaigns at the ATI Triga Mark II nuclear reactor
- R_{sh} : related to doping concentration
  - Increase as a function of fluence
    - Indication of acceptor removal
    - Consistent across EG-SiC and SiC samples
- ρ_c : related to metal-(graphene)-SiC contact
  - Increase as a function of fluence
  - EG-SiC sample much higher resistivity
    - Effect of graphene interface
  - Difference between SiC samples
    - Different metal stacks

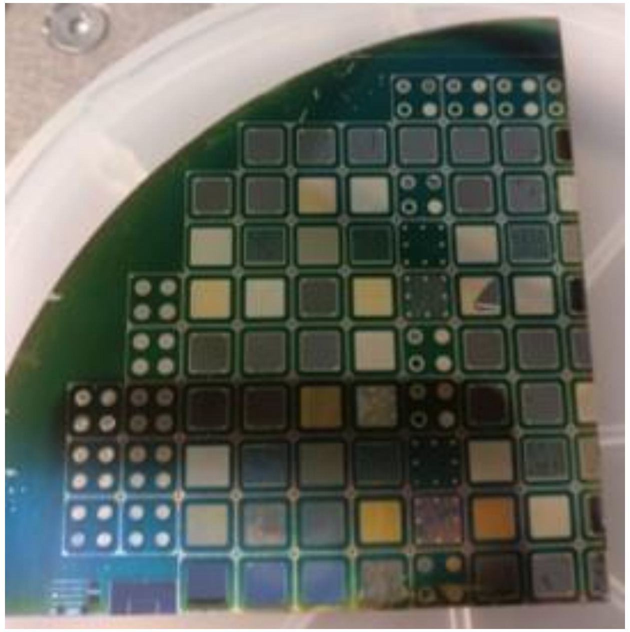
Device	Metallisation
SiC Chip1	Ti/Al/Ti/W (15/90/30/100 nm - evaporation)
SiC Chip 2	Ti/Pt/Au (20/100/100 nm - sputtering)
EG-SiC Chip8	Ti/Pt/Au (20/100/100 nm - sputtering)

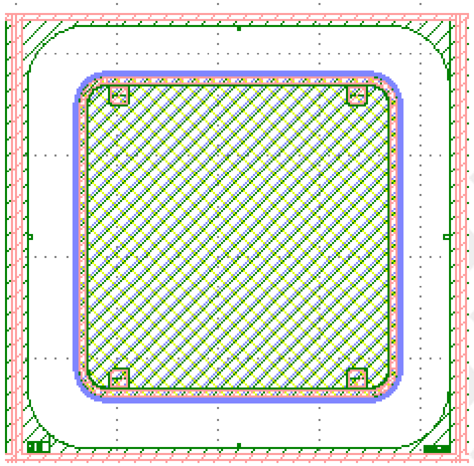


S. Otero Ugobono et al, Materials Science Forum. Trans Tech Publications, Ltd., May 31, 2022

TCT samples

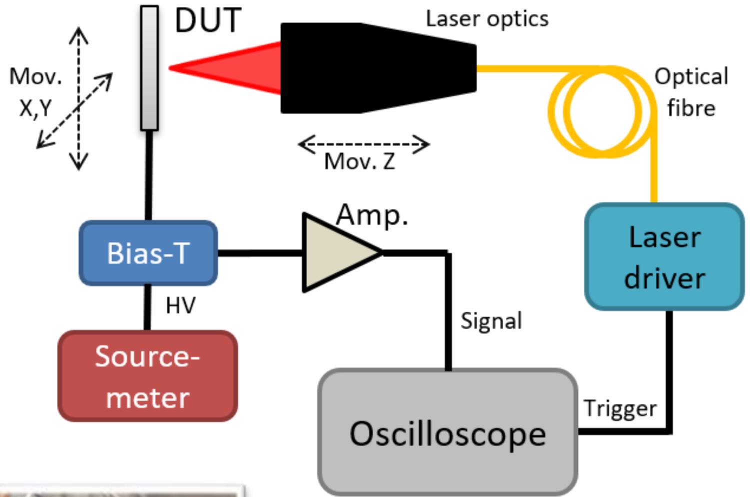
- Run 14416 with Epitaxial SiC 50 um wafer
- 3x3 mm PiN diode
- Two samples from the same fabrication run:
  - **Sample-1** collects charges through implant into a collection ring
  - **Sample-1G** EG layer between the implant and the wirebond metallic contact
- Both samples underwent the same fabrication and thermal steps
  - Able to study effect of graphene layer by comparing both samples!

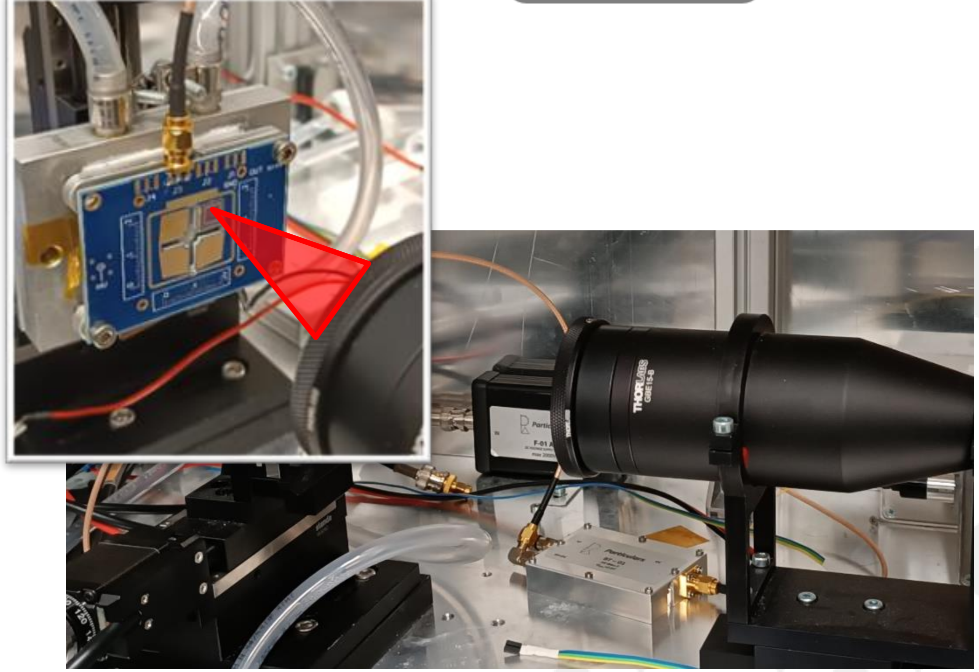


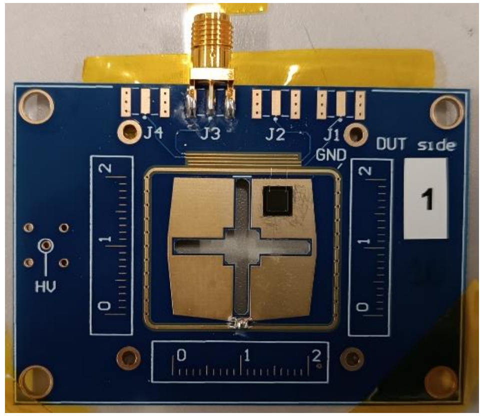


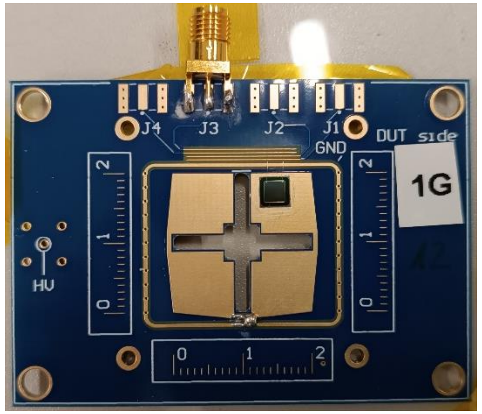
TCT setup

- Particulars Amplifier, bias-T, mechanics and optics
- Laser with λ=369 nm, 100 ps pulse width (1 kHz rep. rate)
- Agilent Infniium DSA90804A, 8GHz, 40GSa/s
  - 1000 waveform averages
- Control and data taking by custom Python code



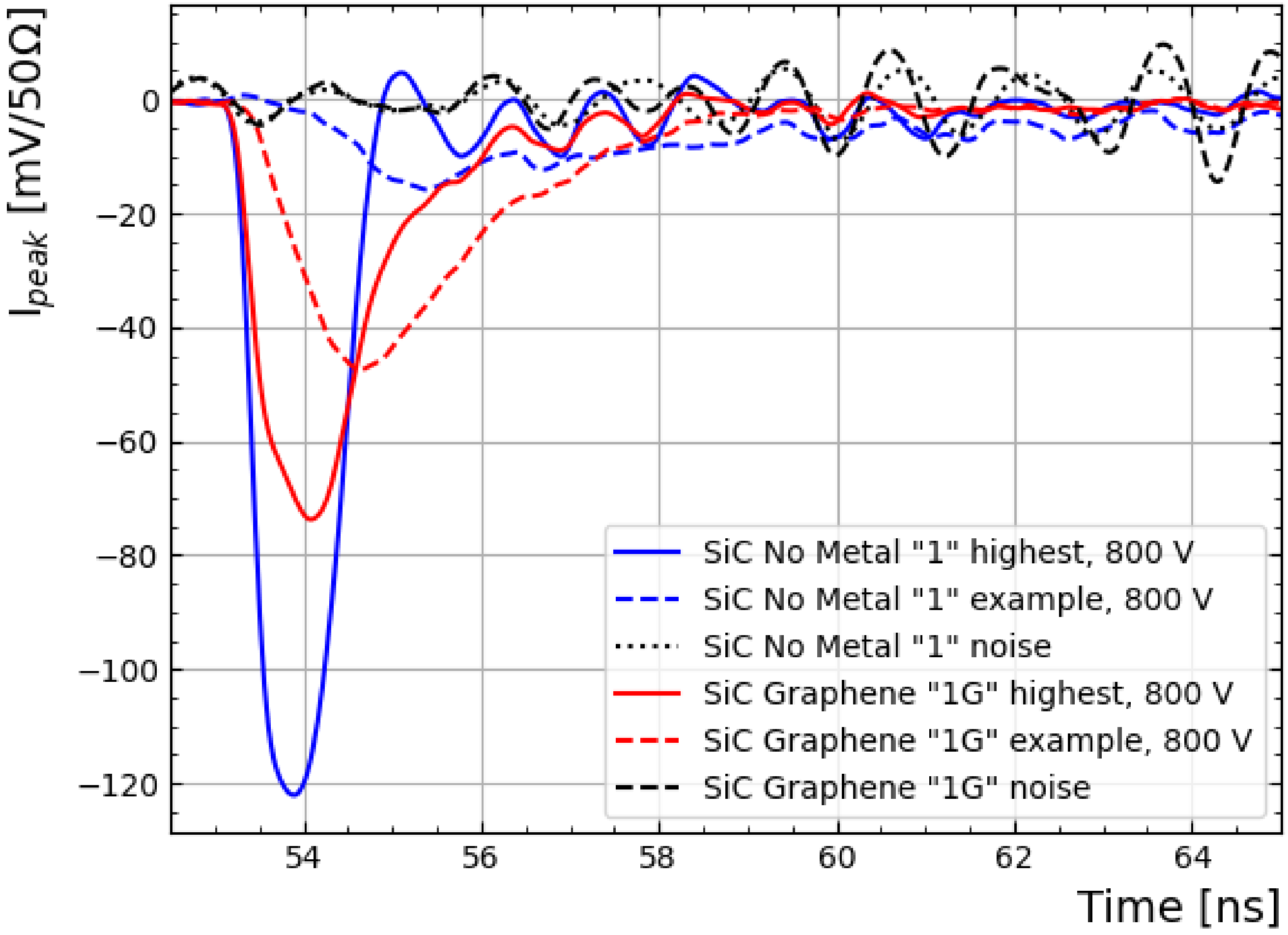






Waveforms

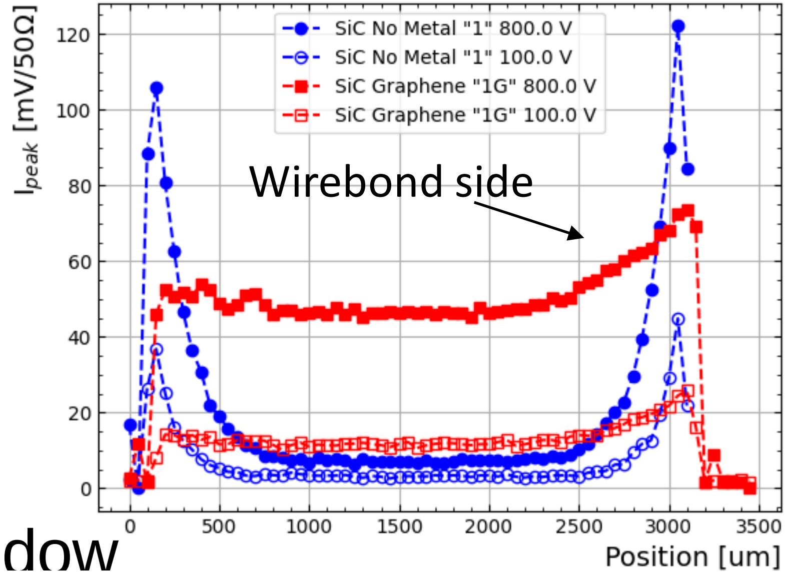
- Charge collection time varies dramatically as a function of position for Sample-1, not so much in Sample-1G
- At the edge of the collection ring (highest amplitude), both collection times are comparable

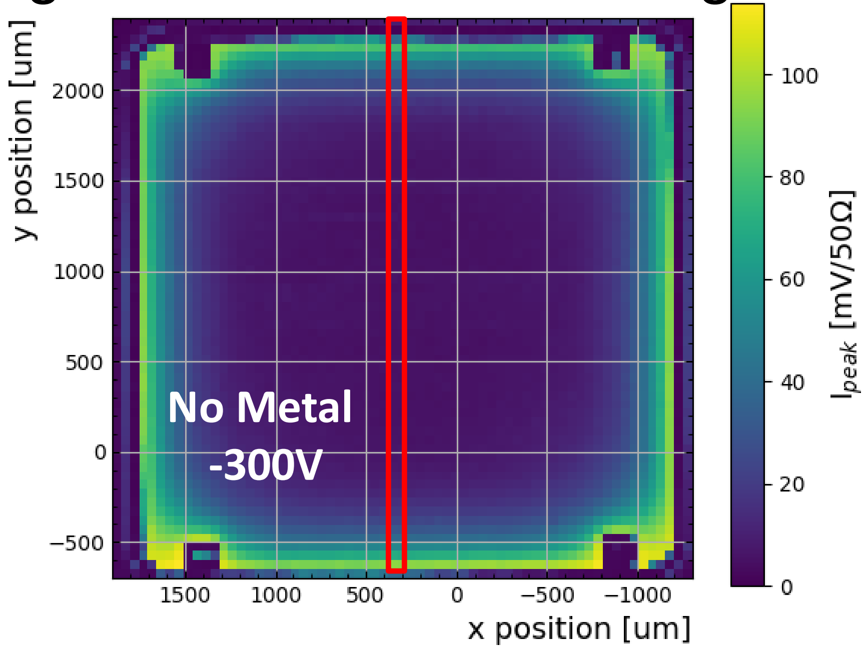


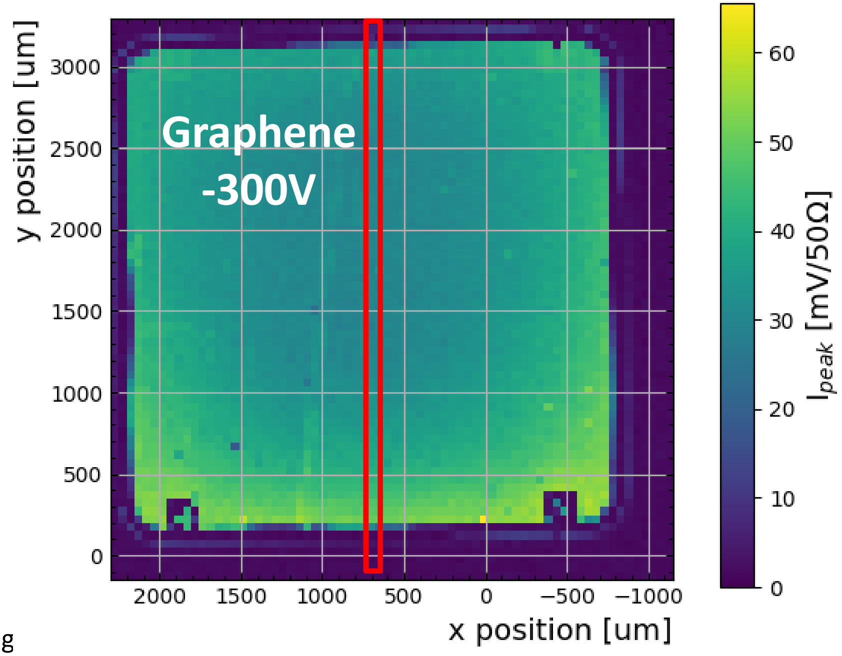
Graphene makes the diode's response more uniform across the sample by reducing the collection RC constant

Amplitudes

- Graphene diode has significantly higher amplitudes closer to the wirebond side
  - Otherwise constant at long distances (>500 um)
- Reference diode amplitude changes by one order of magnitude between the Edge and 500 um into the window

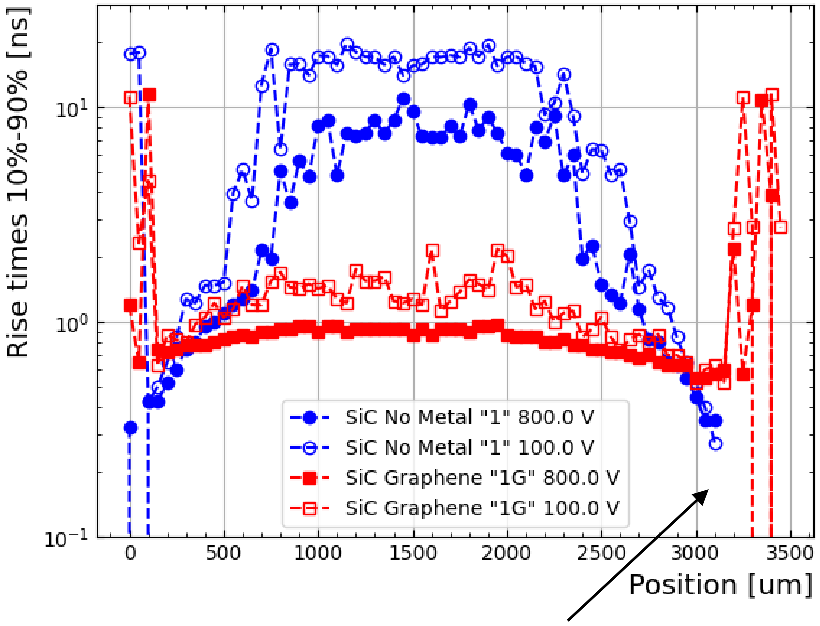




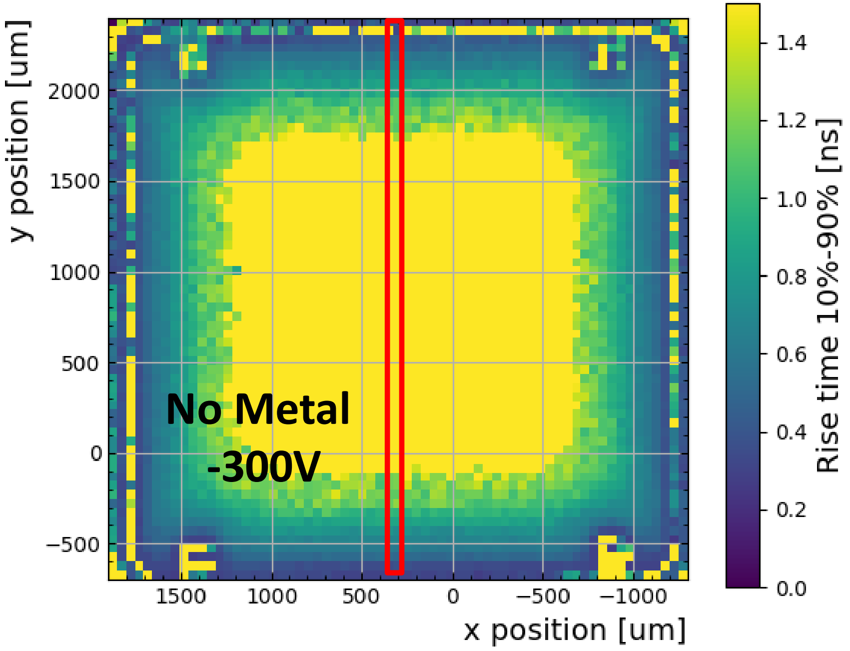


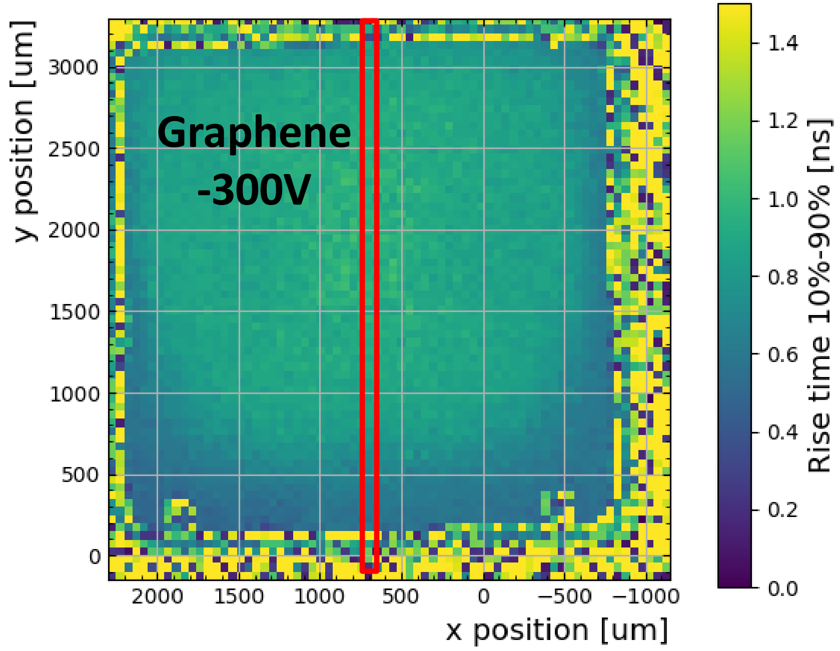
Risetimes

- Signals get significantly slower away from collection metal in Sample-1 with respect to Sample-1G



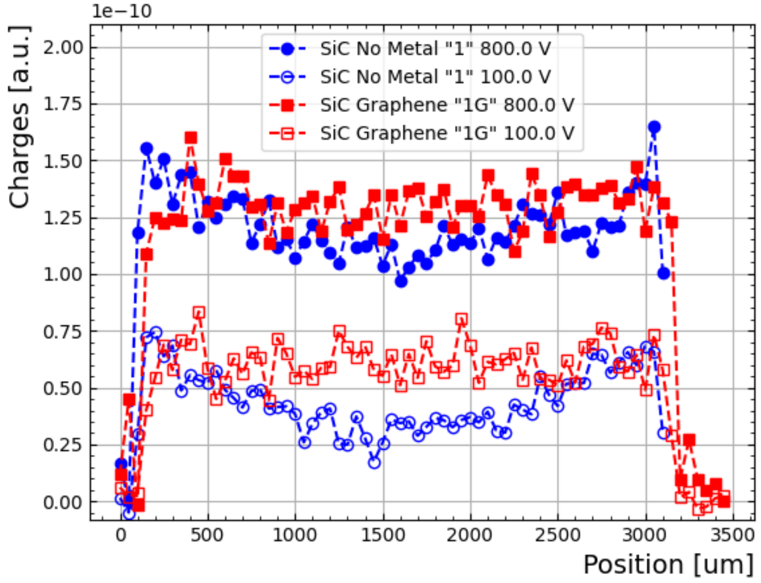
Wirebond side

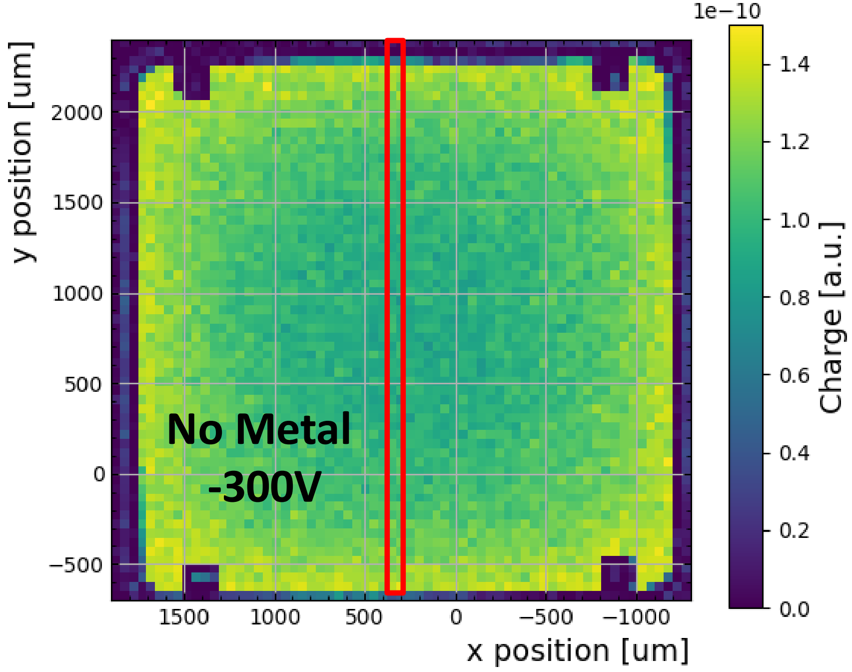


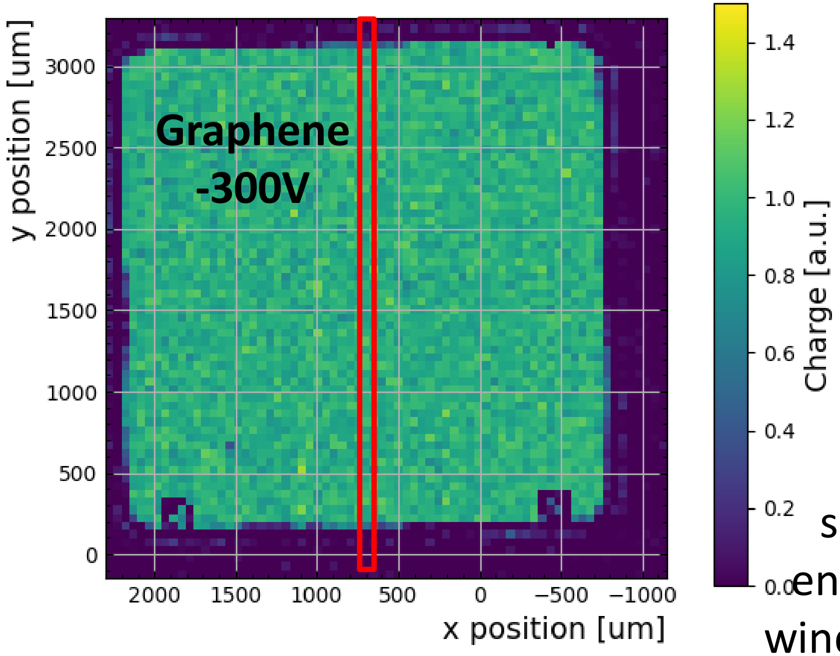


Charge collection

- Charge is very uniform as a function of position, even more in “1G” sample
  - Note that a large (40ns) integration window needs to be used for Sample-1, only 6.5 ns for Sample-1G







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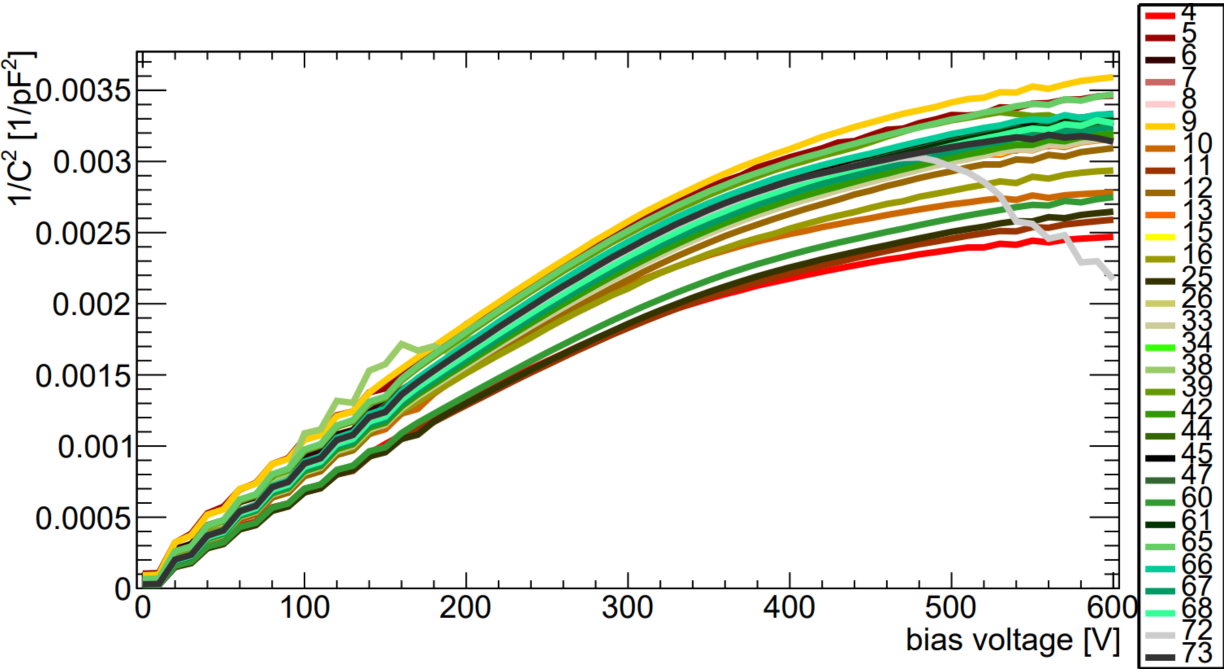
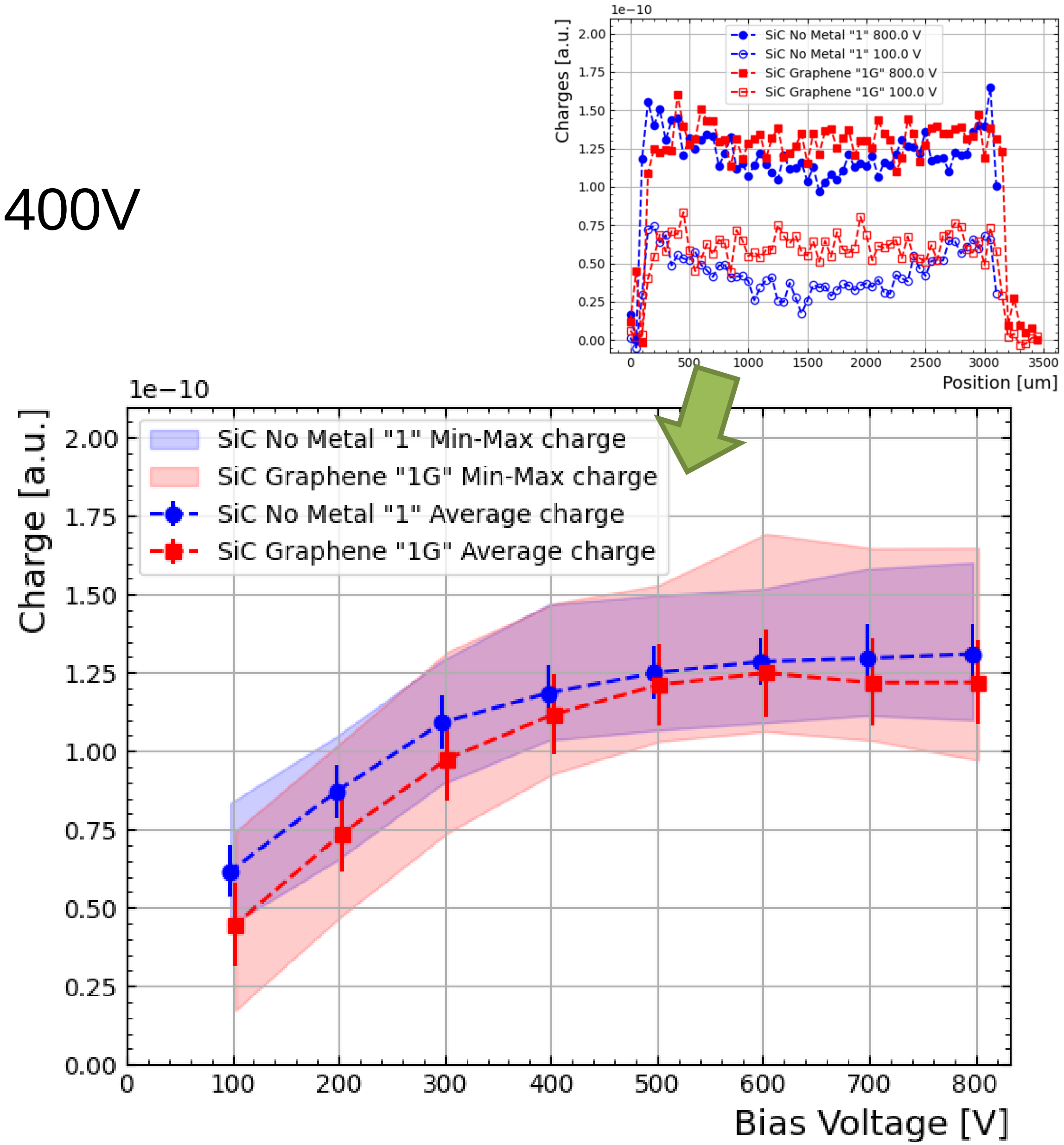
Uniform charge collection across samples (w/ large enough integration window in Sampe-1)

Charge collection vs Voltage

- Both samples seem to start to saturate at 400V
- Consistent with C-V measurements





Presence of graphene does not affect saturation voltage

Summary and Outlook

- Silicon Carbide diodes with epitaxially grown graphene contacts have been produced in IMB-CNM
- Sheet resistance increases with irradiation in either SiC and EG-SiC samples (acceptor removal)
- TCT studies where performed to study effect of graphene contacts in SiC PiN diodes
  - Uniform charge collection across the sample
  - Noticeable transient amplitude damping effect due to the RC constant, but smaller than no-metal
  - No significant effect on the saturation
- Next:
  - Irradiation campaigns of EG-SiC devices
  - Timing?