SOLID-STATE SENSOR CHARACTERISATION USING TWO-PHOTON ABSORPTION (TPA) TECHNIQUE

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The University of Manchester, UK

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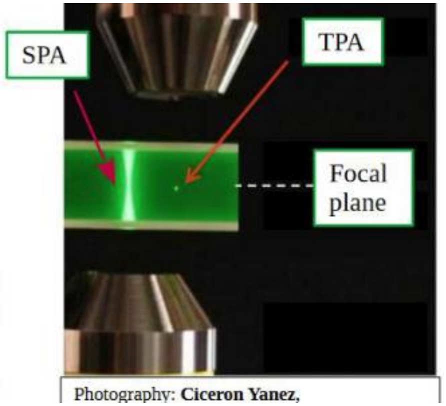
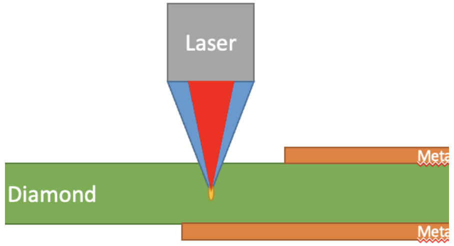
Outline

- **Introduction**
- **Set-up**
- **Measurements**
- **Summary**
- **Future**

Introduction

- TPA involves simultaneous absorption of two photons.
- Also called Two-photon excitation or Non-linear absorption.
- Unlike SPA where a single photon is absorbed.
- In TPA, a “point-like” laser probe called “voxel” is used to characterize a device.
- No photons are absorbed out of the focus.





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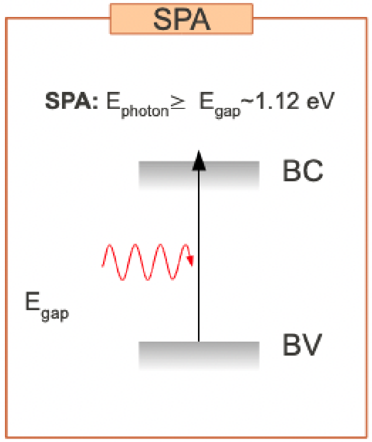
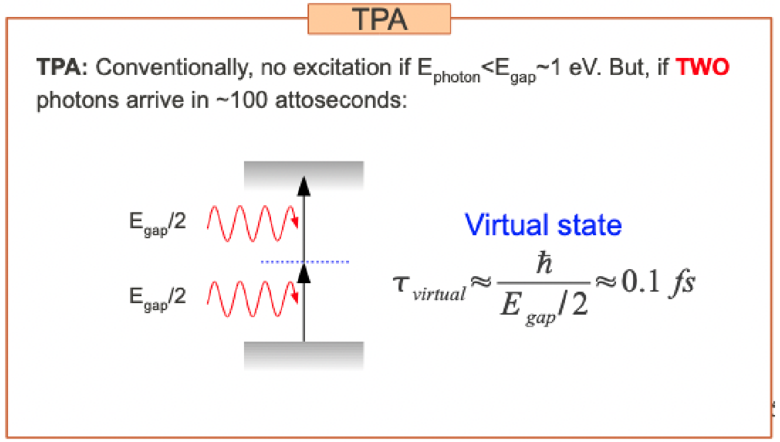
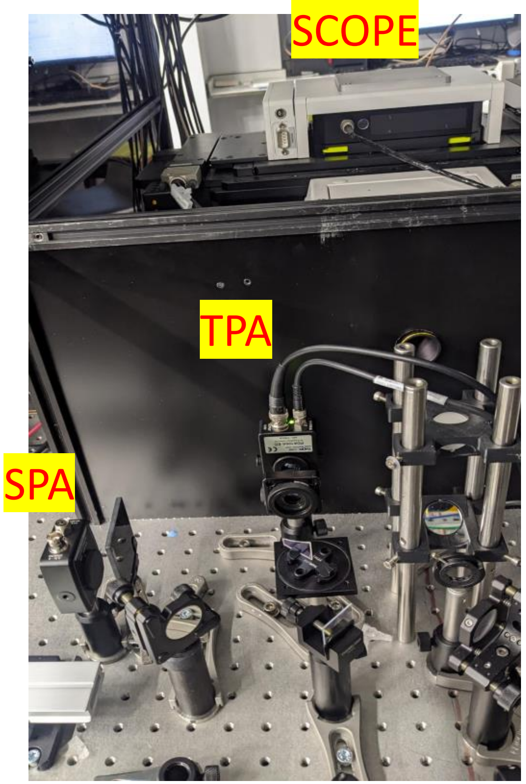
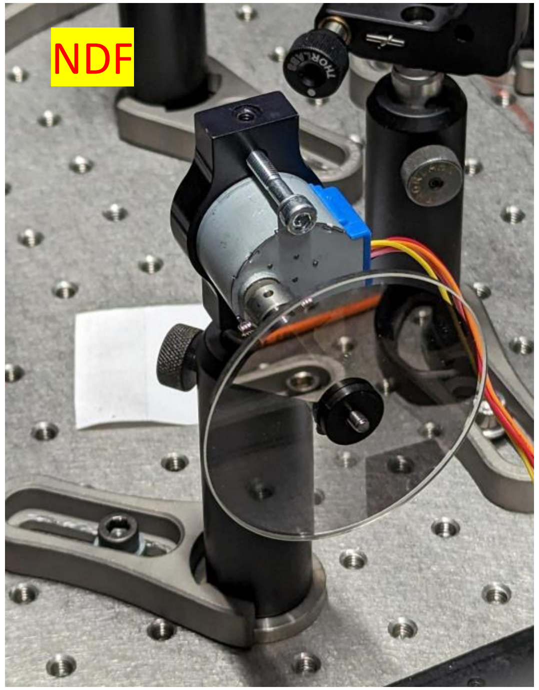
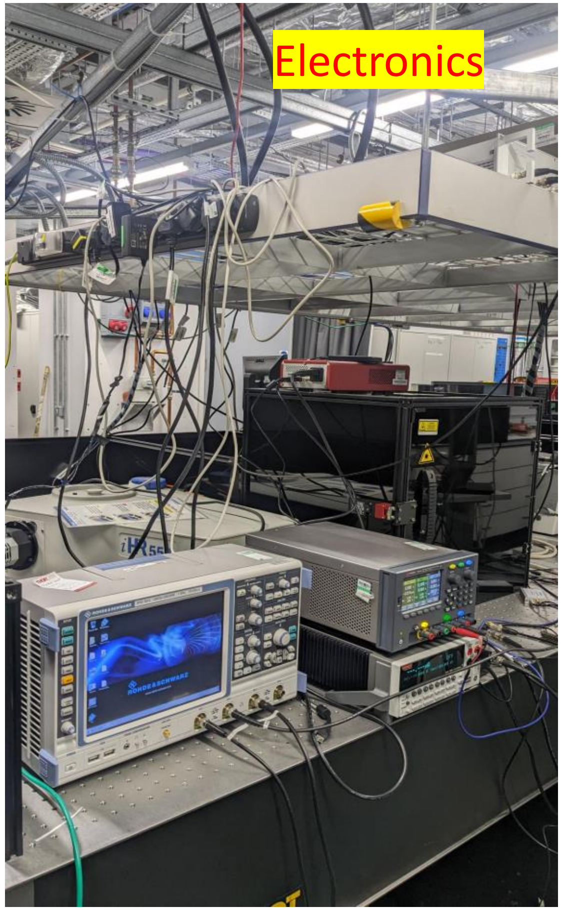
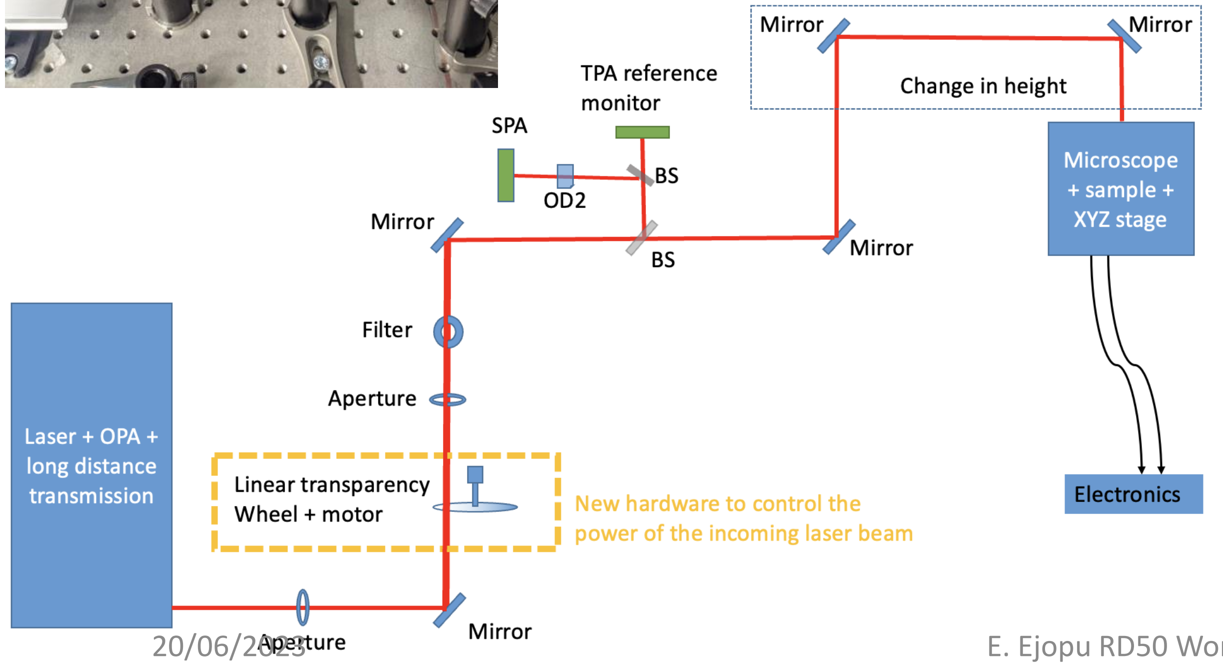












- PHAROS Femtosecond laser:
- Laser system: PHAROS Yb:Yag laser.
- Pulse duration (160 fs).
- Wavelength range from 330 nm to 16000 nm (3.757 eV to 0.077 eV).
- For Si as the DUT;
  - **Silicon sensor as reference monitor for TPA.**
  - **And Ge sensor –SPA**.
- Using an CIVIDEC C2 amplifier of 2 GHz.

Set-up Ability

- Pharos wavelength range is from 330 nm to 16000 nm.
- Tuned by the Optical Linear Parametric Amplifier (OPA).

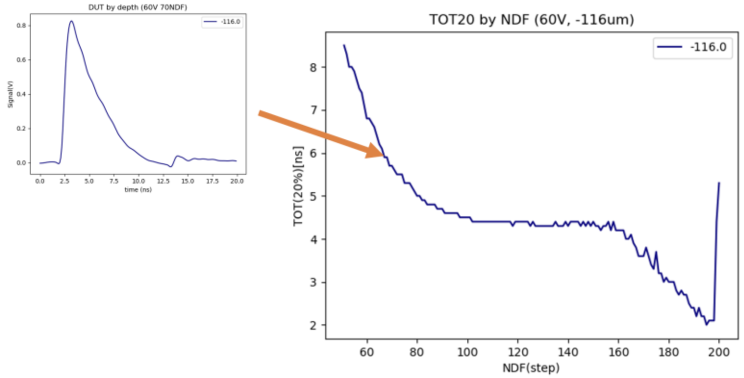
Pharos (nm)	<1000	<2500	3000 ......//........ 16,000
Silicon	<1107	<2214	
Diamond	<226 330 - 453		
Germanium	<1771.2		<3542
Silicon Carbide	<380.3 <760		
Gallium Indium	<1653	<3306	
Gallium Arsenide	<873.1 <1746		

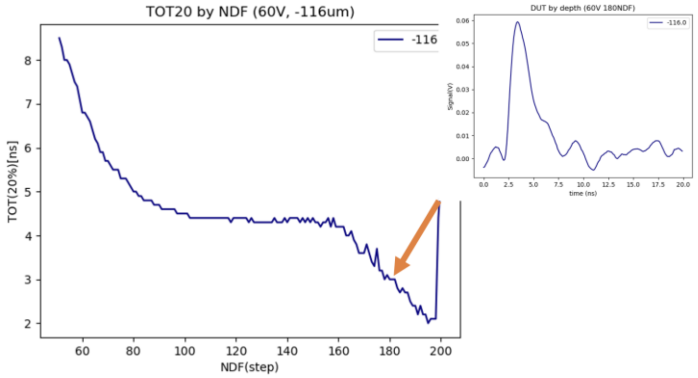
SPA TPA

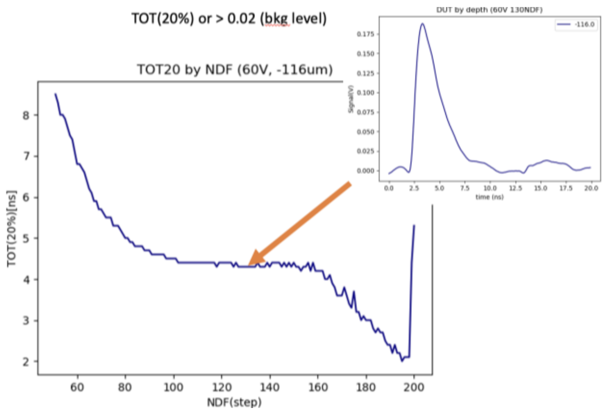
Silicon Diode Measurements

- CIS Diode.
- ToT (width at constant fraction of 20%) by NDF (approx. intensity).
- High photon intensity leads to plasma which affects the collection time.
- Low photon intensity leads to larger noise, which starts to get comparable with the signal.
- Performed in a non-plasma region.

Palomo 2019

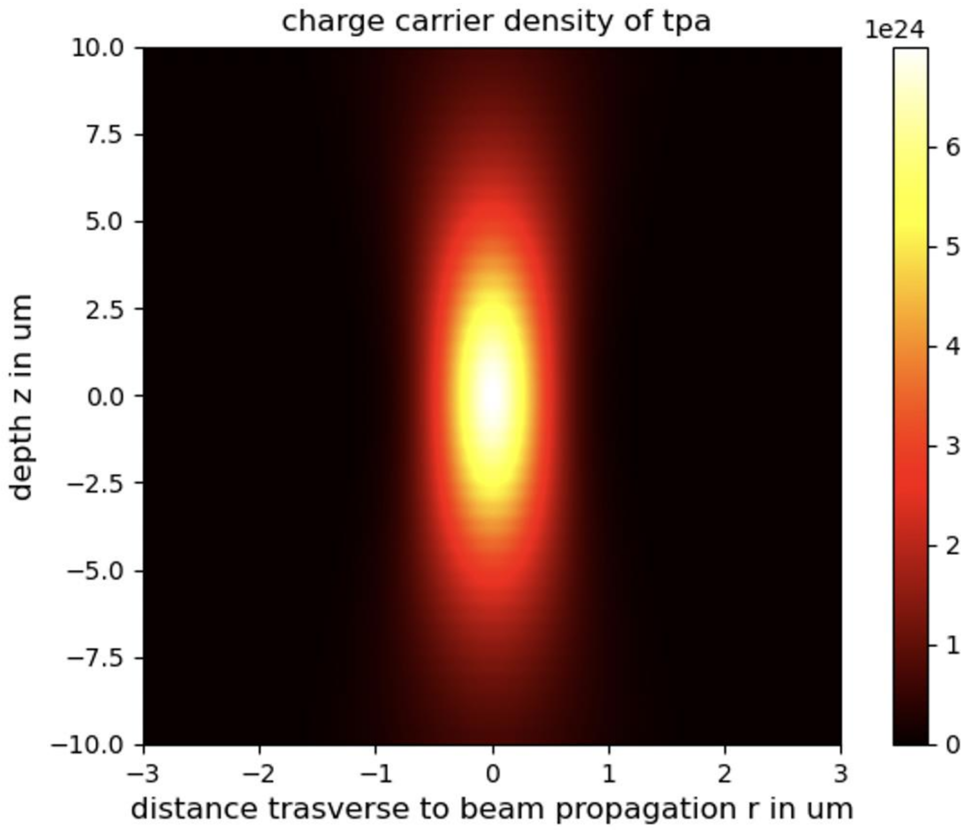






Silicon Diode Measurements

- Based on the properties of the lens (NA 0.5, 20X) we expect the following voxel shape.



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Silicon Diode Measurements

- Determination of expected amount of charge with respect to signal.
- Signal shape throughout the device depth.
- Charge distribution vs Depth well described by model.
- Spatial resolution defined by the voxel.
- Voxel was found to be 8.58 um by 1.52 um.

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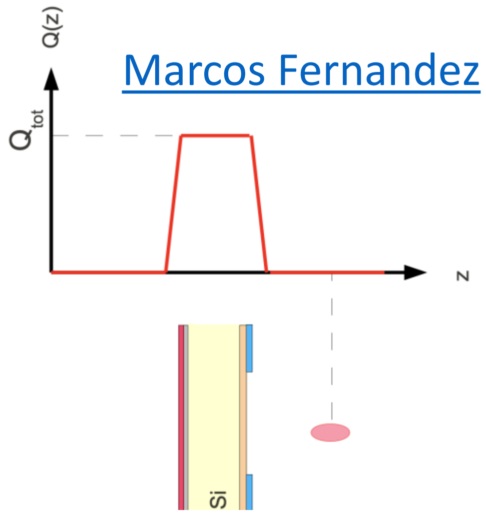
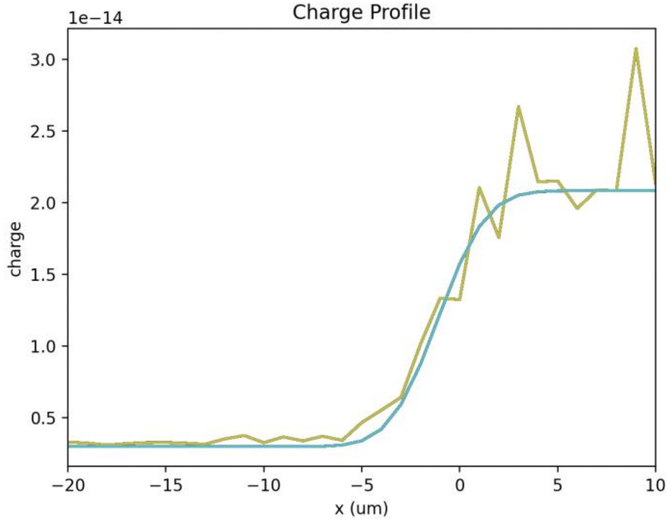
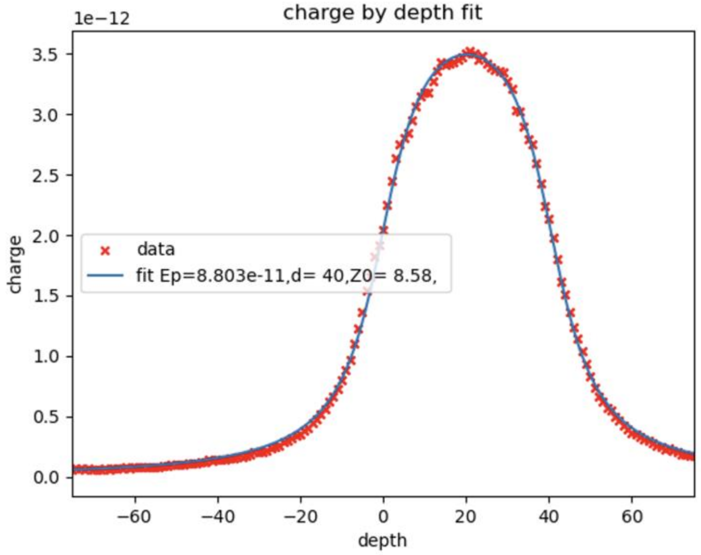
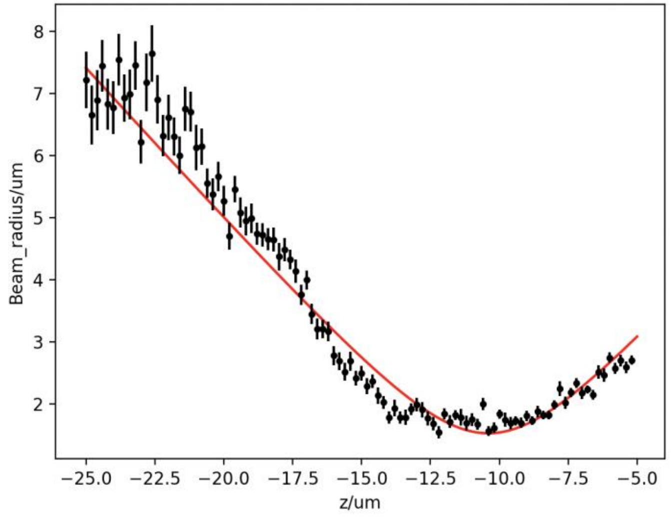




$$n_{tpa}(r,z) = \frac{E_p^2\,\beta_2\,4\ln 2}{\tau\,\hbar\omega\,\pi^{\frac{5}{2}}\,w^4(z)\,\sqrt{\ln 4}}\exp\left[-\frac{4r^2}{w^2(z)}\right].$$





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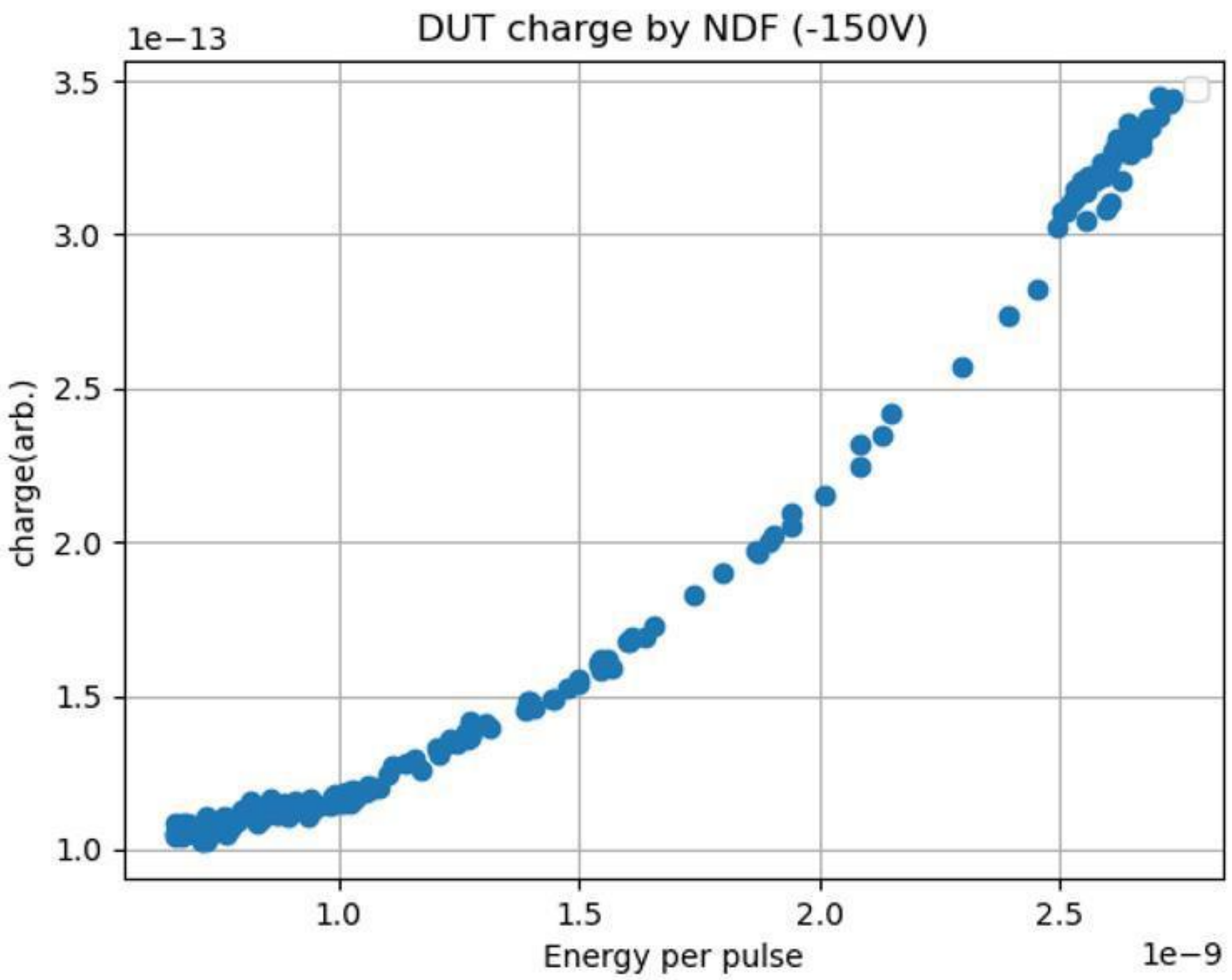
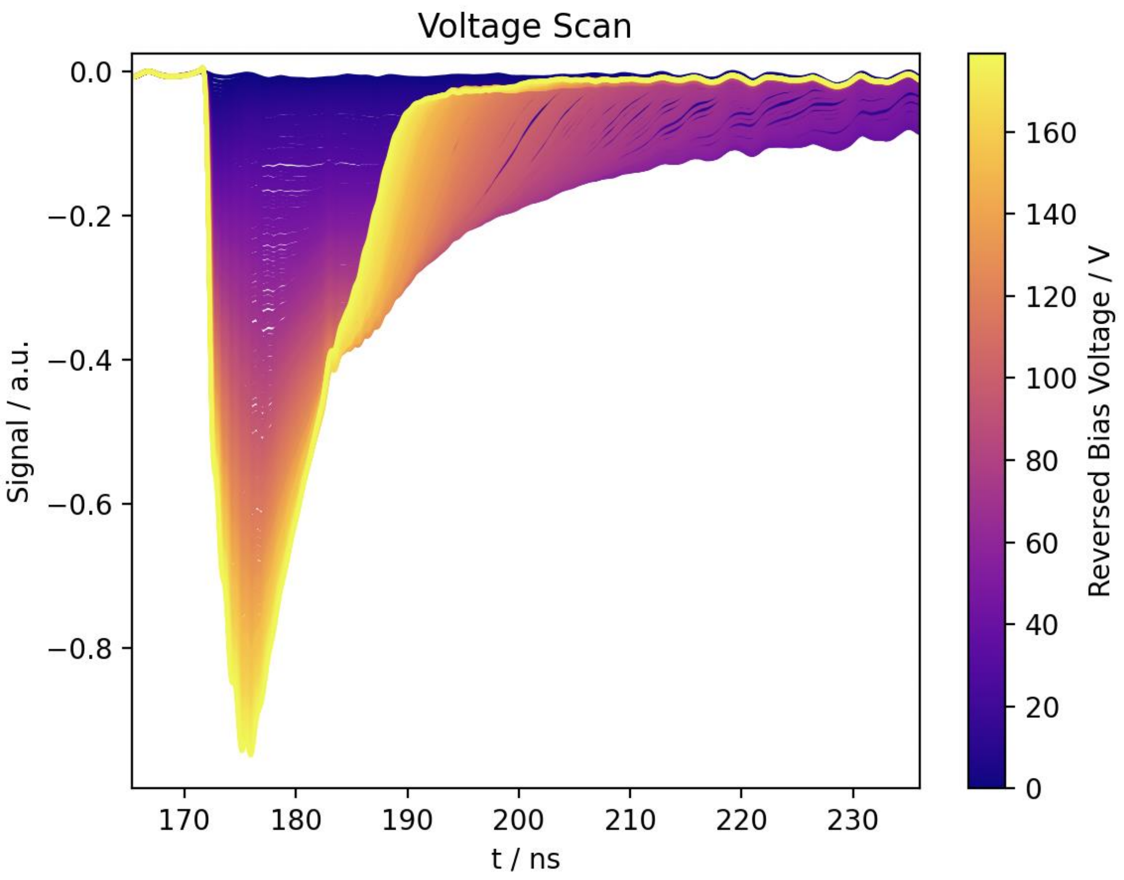
Measurements

- TPA confirmed as seen from the quadratic dependence and depth scan.
- Probability of e-h generation is proportional to intensity squared.



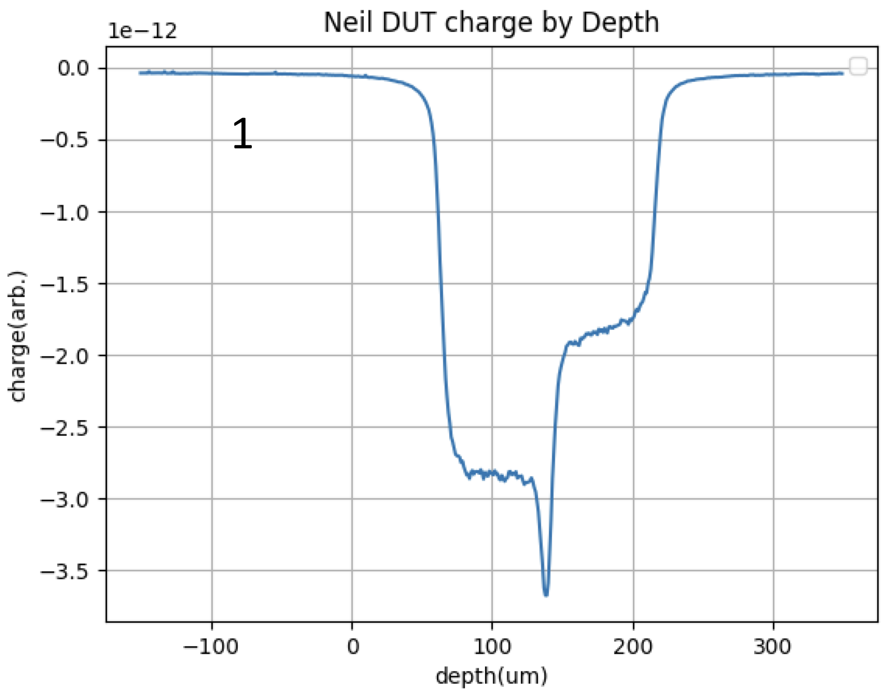
Measurements

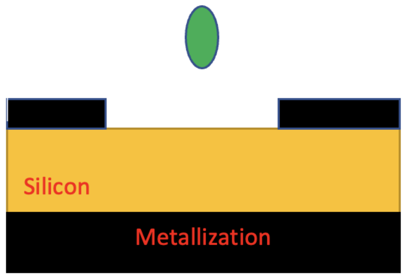
- Voltage scan involves varying voltage while depth & NDF are constant.
- Signal gets faster with increase in voltage.



Depth Scan

- PIN Diode (NLGAD run, CNM), 5.3 x 5.3 mm^2 x 275 um active volume, N-type gain layer, metallization at the back.
- Depth is varied at a constant voltage & NDF.
- Laser focused 150 μm above the sample and scan done all the way through the sample in increments of 1 μm.
- Plot of charge vs depth.





1

Depth Scan

- PIN Diode (NLGAD run, CNM), 5.3 x 5.3 mm^2 x 275 um active volume, N-type gain layer, metallization at the back.
- Depth is varied at a constant voltage & NDF.
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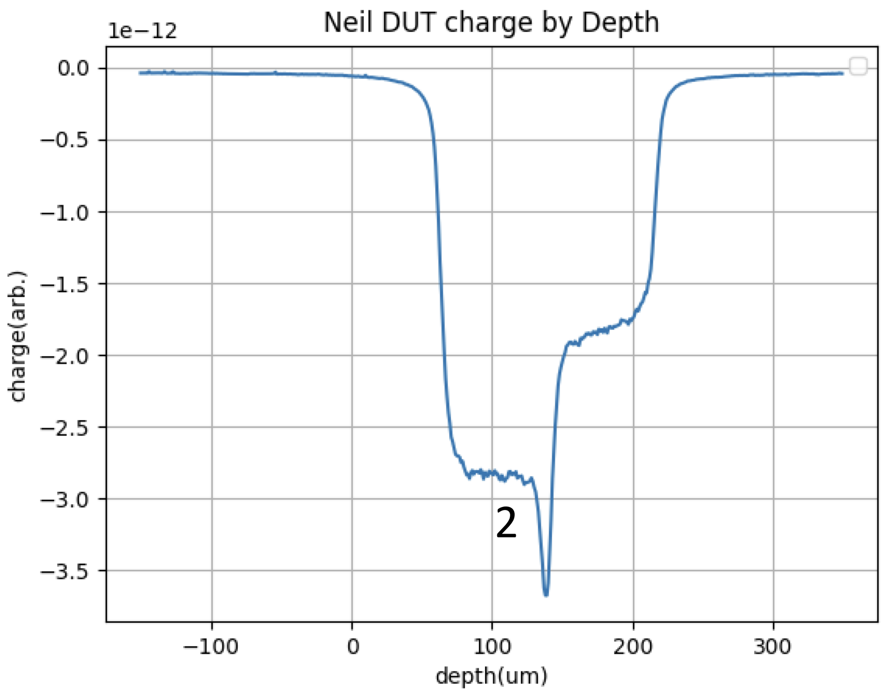
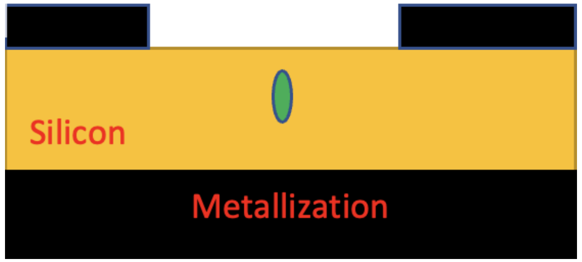
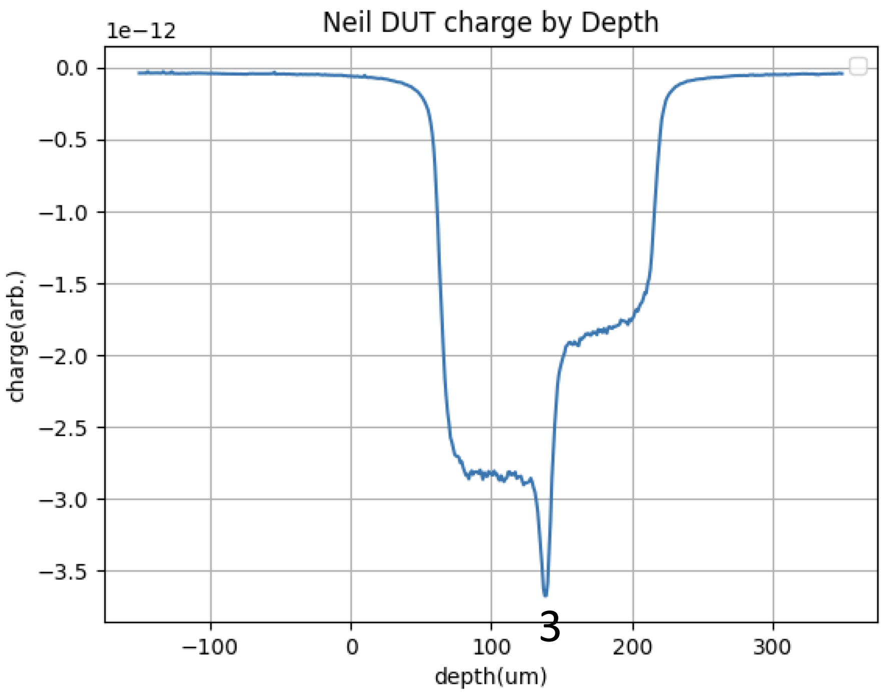


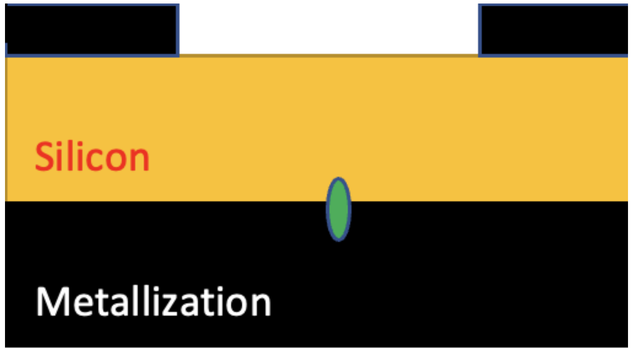


2

Depth Scan

- PIN Diode (NLGAD run, CNM), 5.3 x 5.3 mm^2 x 275 um active volume, N-type gain layer, metallization at the back.
- Depth is varied at a constant voltage & NDF.
- Laser focused 150 μm above the sample and scan done all the way through the sample in increments of 1 μm.
- Plot of charge vs depth.

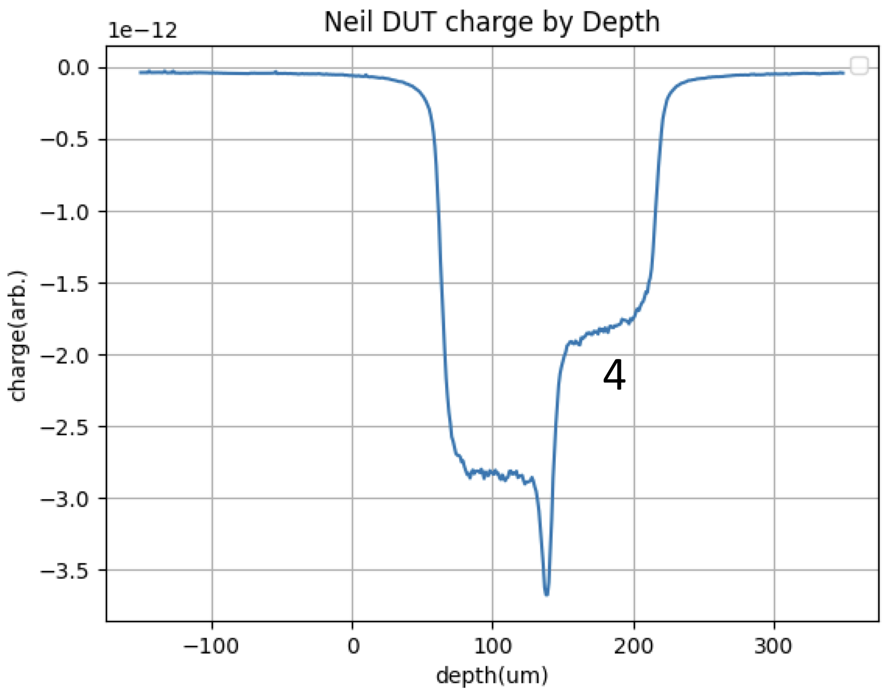


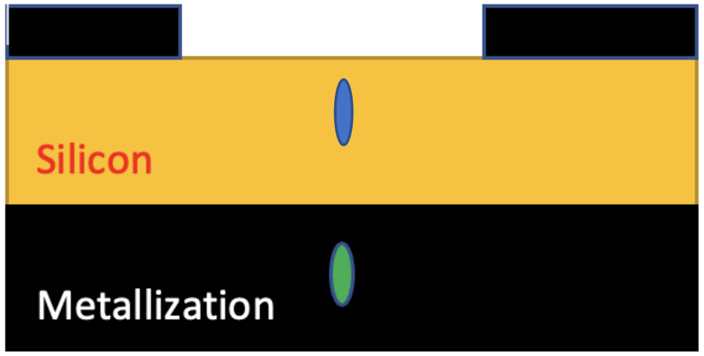


3

Depth Scan

- PIN Diode (NLGAD run, CNM), 5.3 x 5.3 mm^2 x 275 um active volume, N-type gain layer, metallization at the back.
- Depth is varied at a constant voltage & NDF.
- Laser focused 150 μm above the sample and scan done all the way through the sample in increments of 1 μm.
- Plot of charge vs depth.

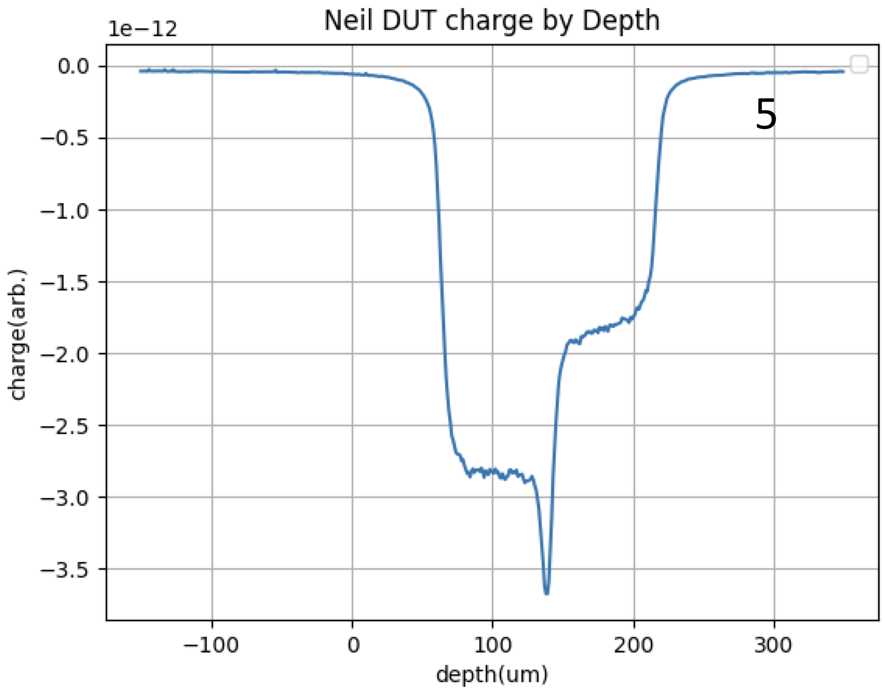


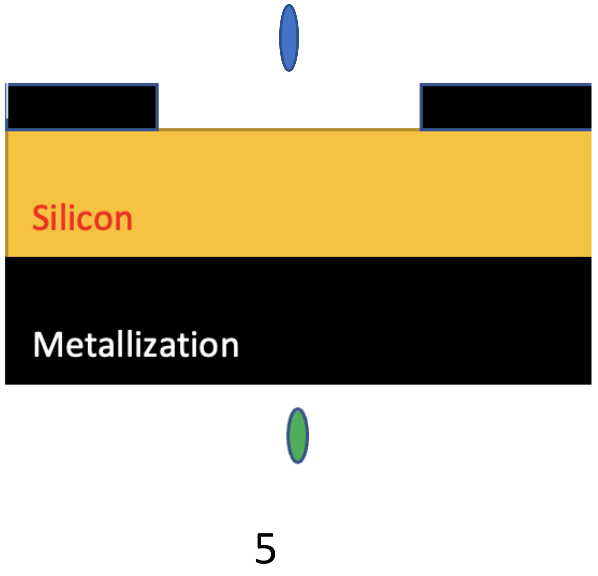


4

Depth Scan

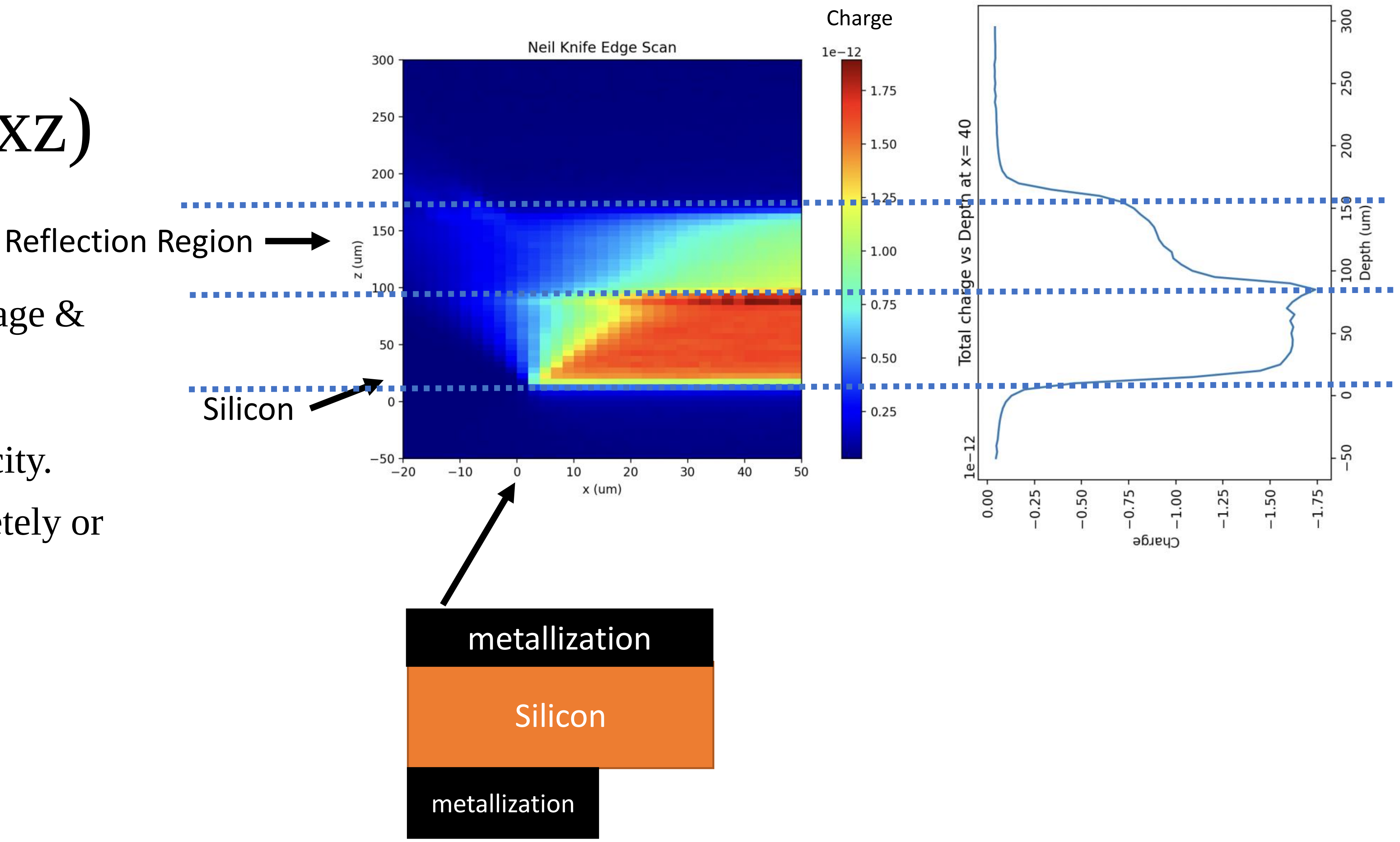
- PIN Diode (NLGAD run, CNM), 5.3 x 5.3 mm^2 x 275 um active volume, N-type gain layer, metallization at the back.
- Depth is varied at a constant voltage & NDF.
- Laser focused 150 μm above the sample and scan done all the way through the sample in increments of 1 μm.
- Plot of charge vs depth.





2D Scan (xz)

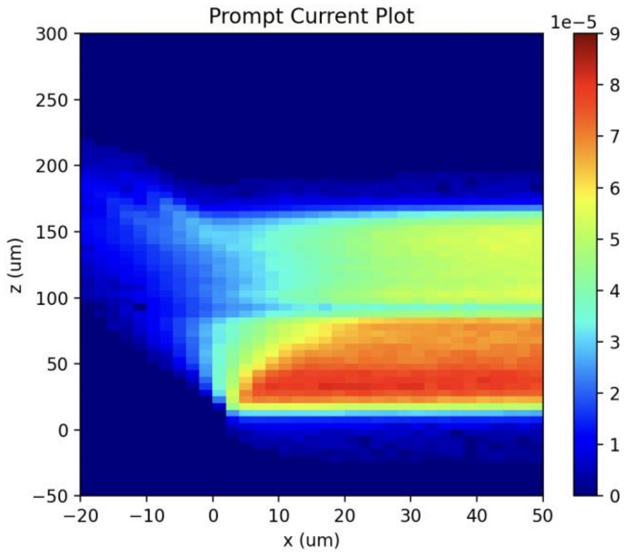
- xz scan at constant voltage & NDF.
- Allow to investigate the electric field/ drift velocity.
- Metal can block completely or partially the laser.
- Reflection at the back.

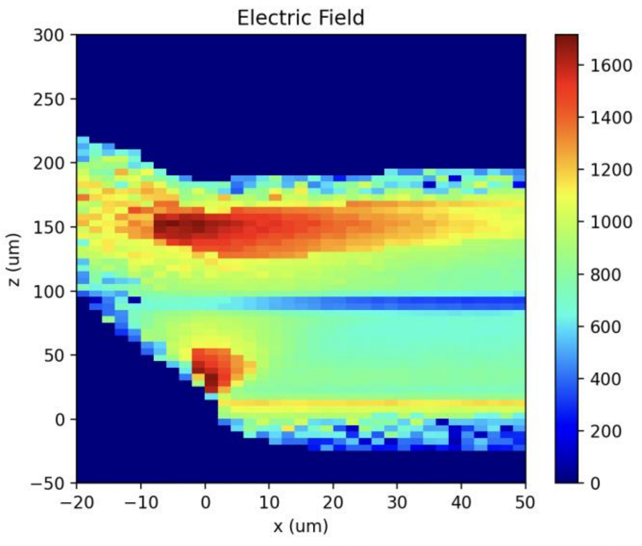


2D Scan

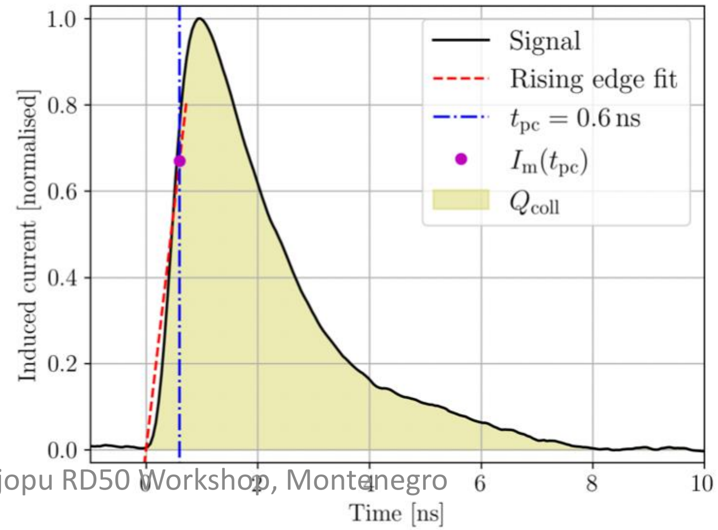
- Allow to investigate the electric field/ drift velocity.
- Current induced by drifting charge carriers on the collecting electrode is described using the Shockley-Ramo theorem; $I_m = QE_w(\mu_e + \mu_h)E$.
- Weighted prompt current $I_m/Q_{coll} = E_w(\mu_e + \mu_h)E$.

- Weighted prompt current is used to overcome the excess charge carrier distribution variation due to laser beam clipping and light reflection at metallisation or fluctuations of the laser source.



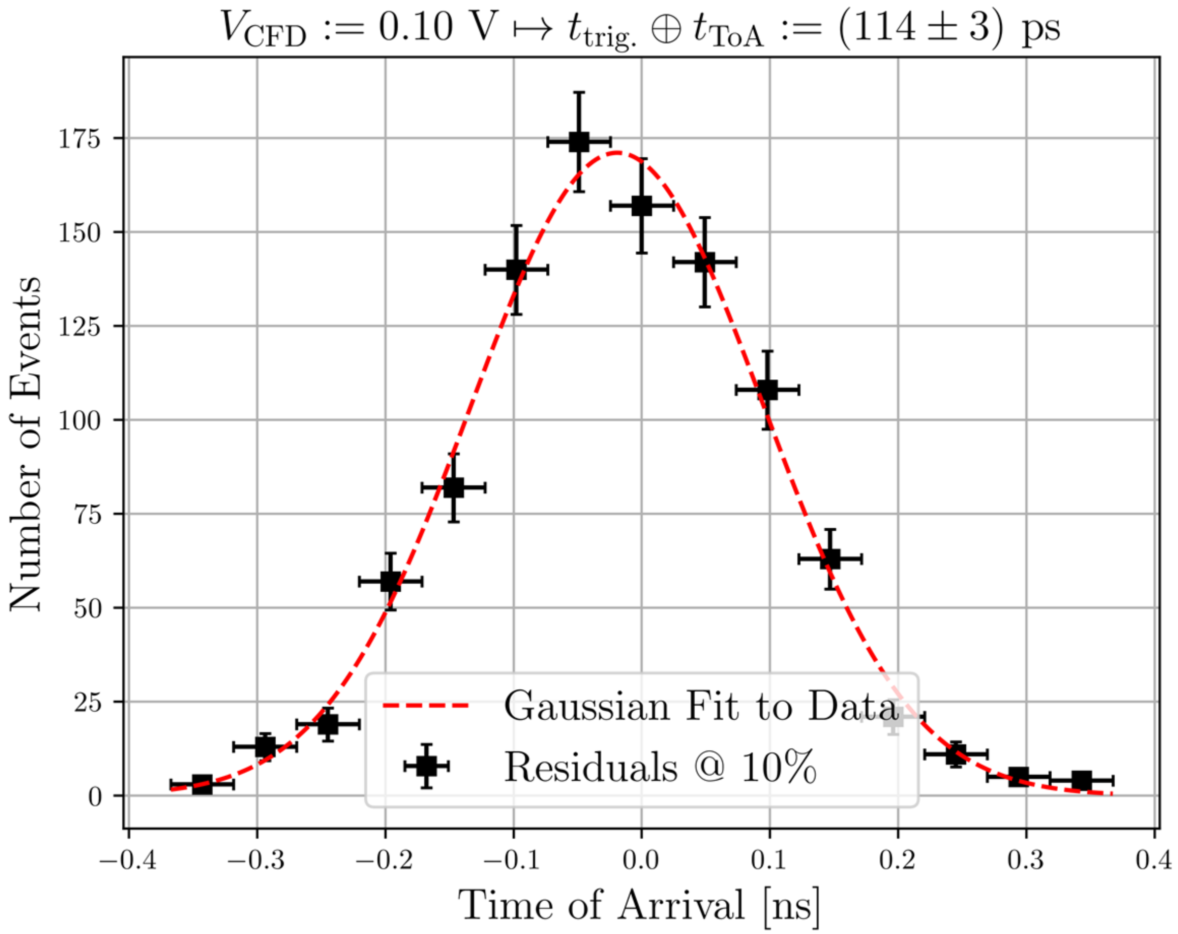


arXiv:2211.10339v1



Time Resolution Measurements

- Done for diodes, LGADs etc at a CFD of 50%.
- Multiple waveforms (1000) at same depth, voltage & energy.
- The difference between the pharos trigger arrival time, t_0 and the Signal arrival time, t_1 at a fixed fraction (50%) of the amplitude for the multiple waveforms.
- The standard deviation of the difference gives the time resolution.



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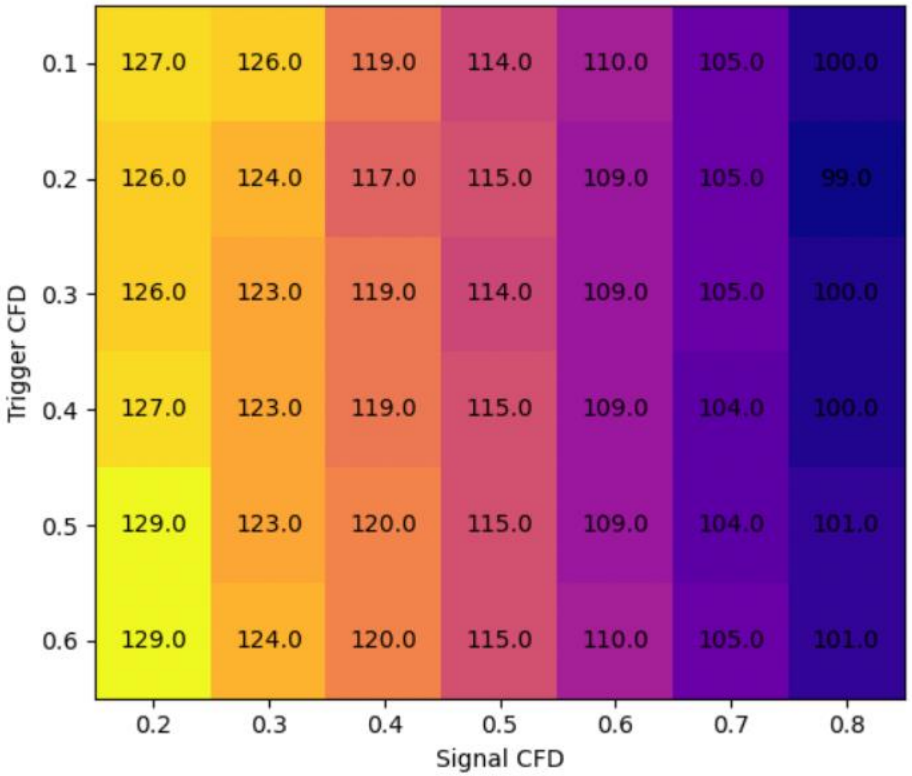
Time Resolution Measurements

- Time resolution for each combination of the trigger and signal thresholds were calculated.
- For diode, constant fraction discriminator + linear interpolation algorithm: 114 ps.
- LGADs: 52.8 ps
- Pharos trigger time resolution is 20 ps with room for improvement.



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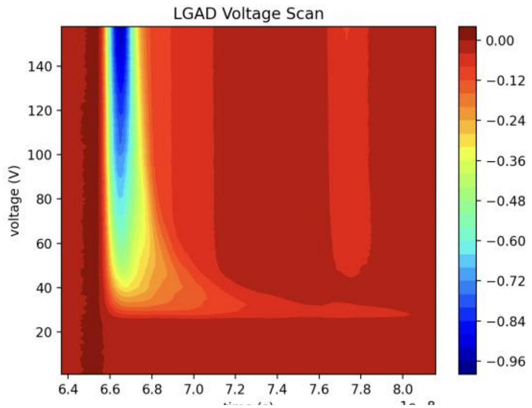
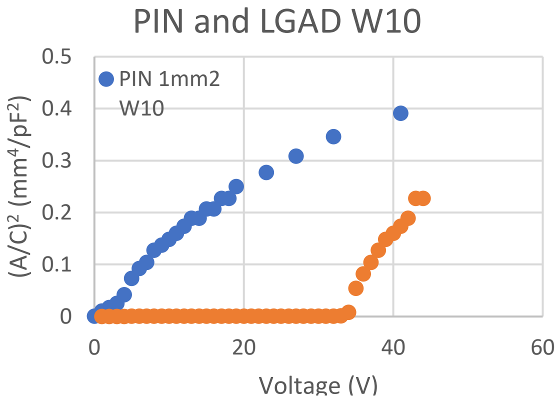
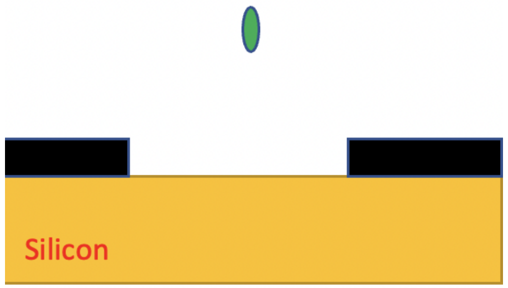
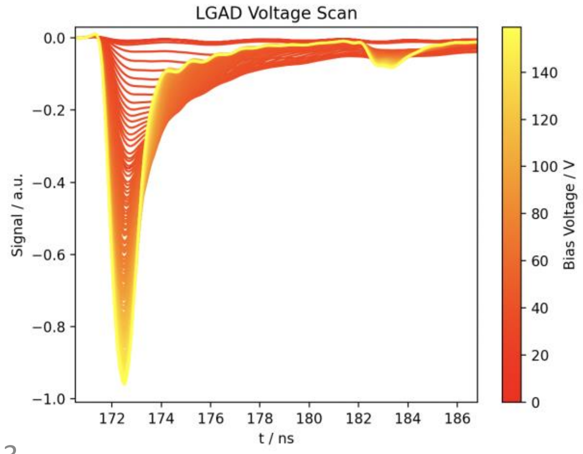
Low Gain Avalanche Detector (LGAD)

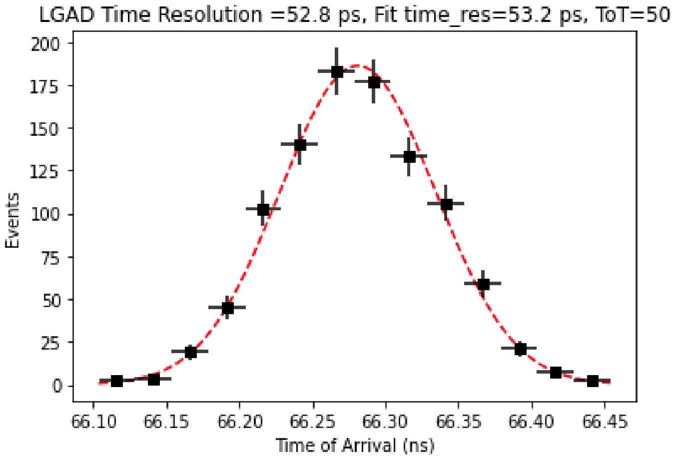
- Used 100 um thick LGAD without metallization on the back.

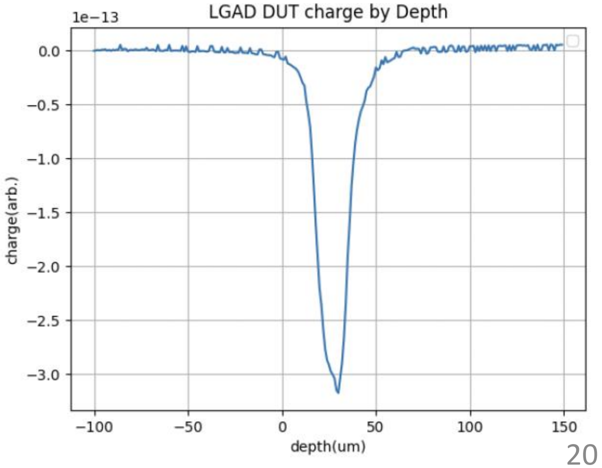


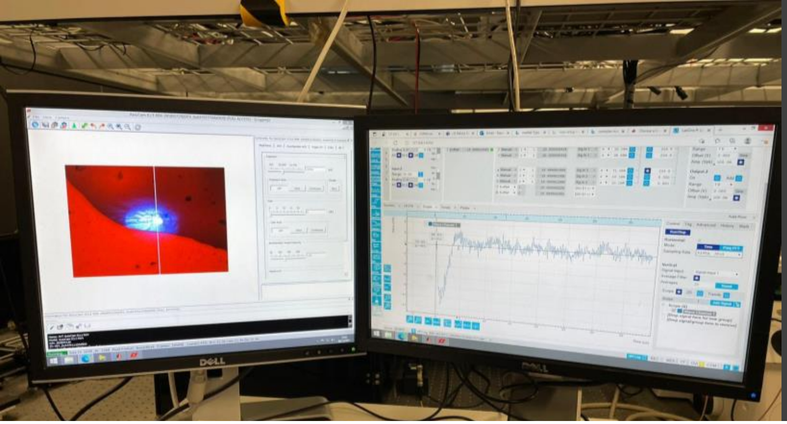


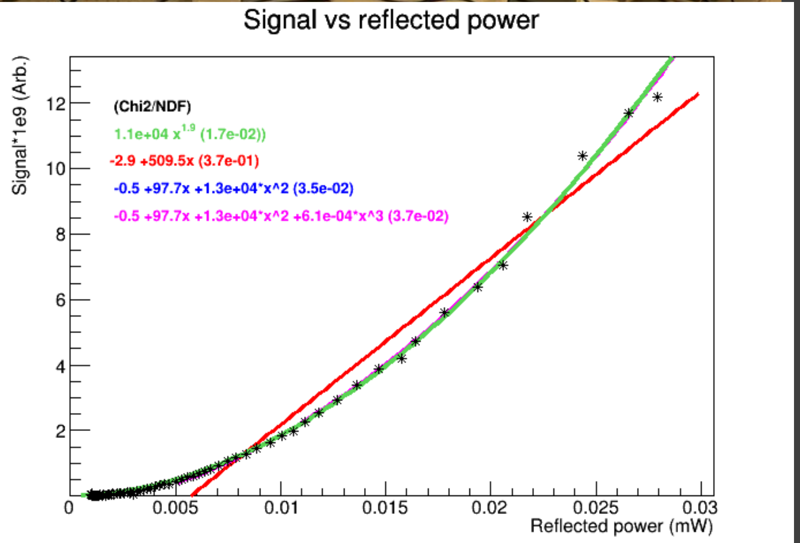


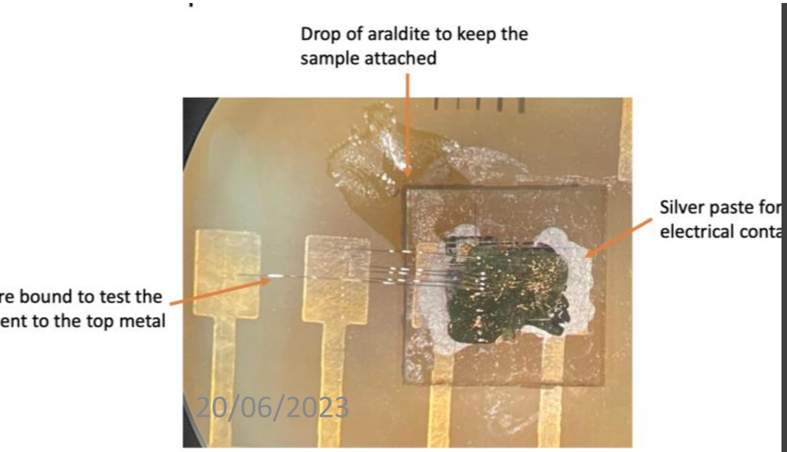


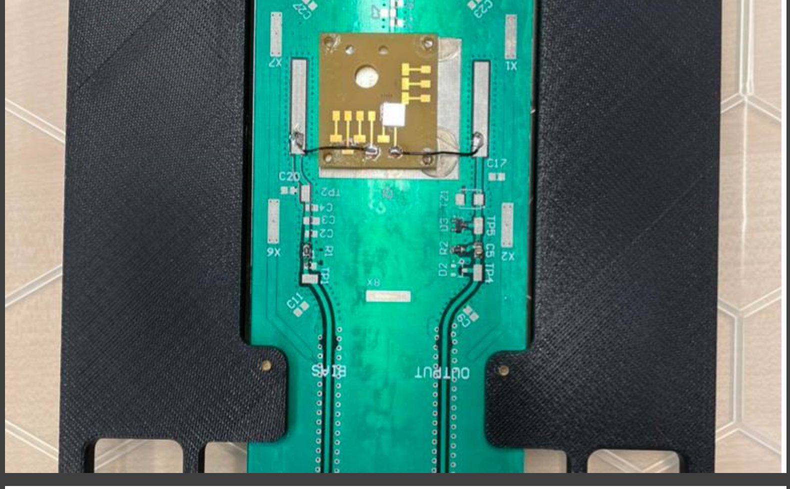


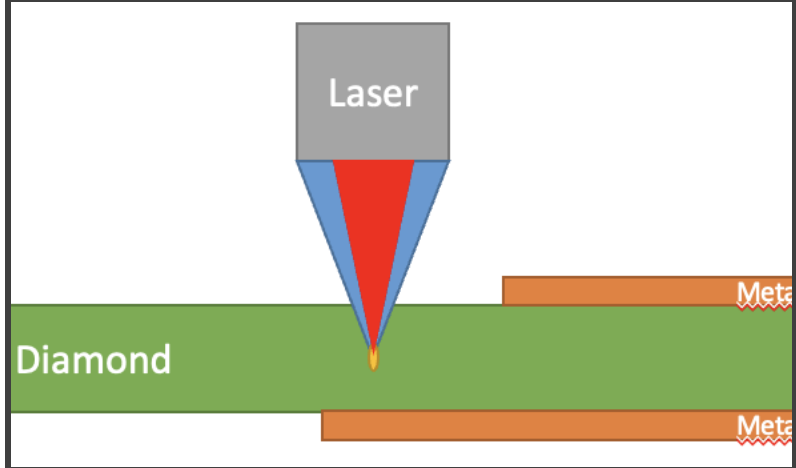


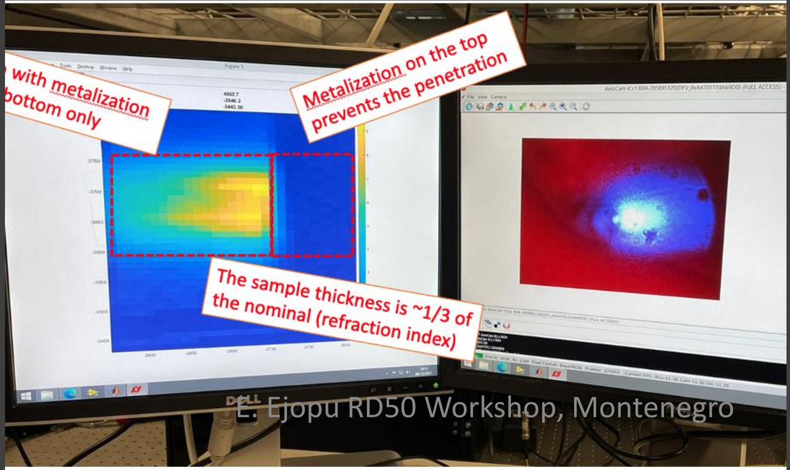






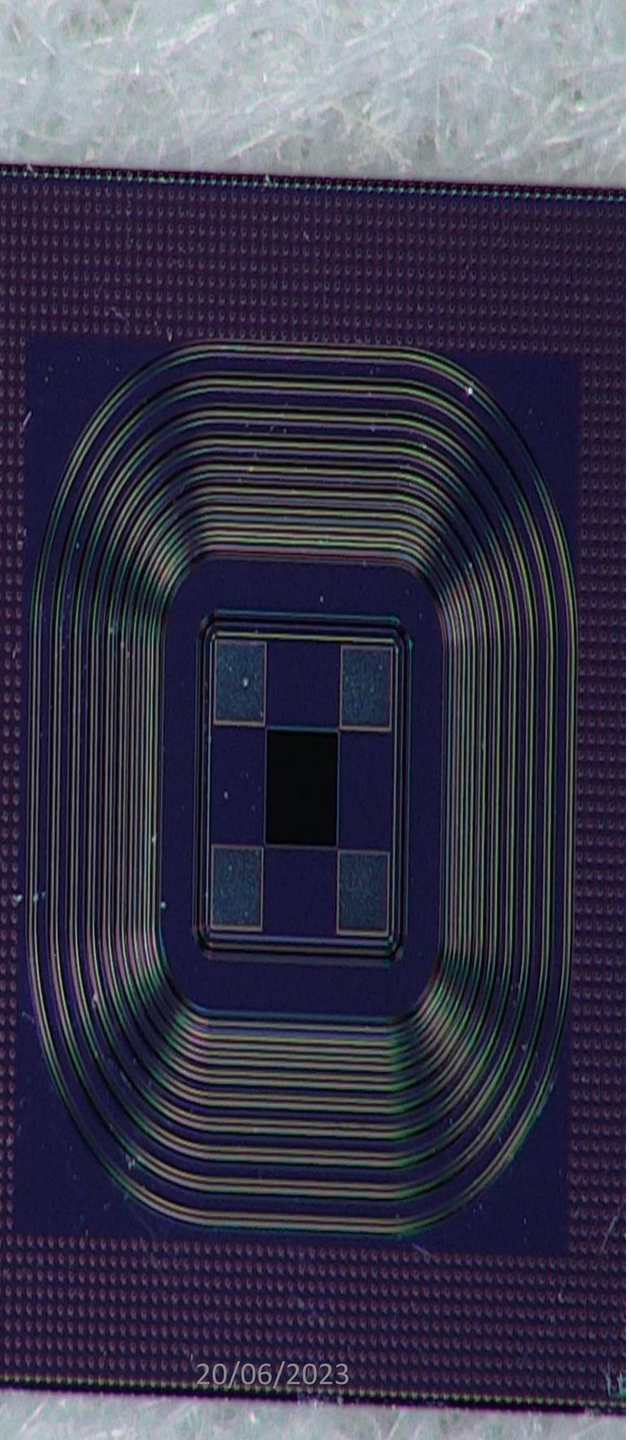






TPA using Diamond Sample

- Confirmation of TPA.
- Using a laser wavelength of 400 nm (~3.1 eV).
- E_{gap} of Diamond is 5.47 eV
- Strong indication of TPA from quadratic nature of curve.
- No signal with voxel out of the sample.



Summary

- **Performed TPA characterisation for Silicon diodes, LGADs and Diamond.**
- **Fast way to characterise devices.**
- **The set-up has a flexible range for device characterisation.**
- **Voltage, depth and edge scan and time resolution measurements.**
- **NEXT:**

➢ **Optimising trigger to get better time resolution (below 30 ps).**

➢ **Improve amplifier to 12 GHz.**

➢ **3D diamond characterisation.**

➢ **Work with irradiated devices.**

➢ **iLAGDs, Trench LGADs, Deep Junction LGADs.**

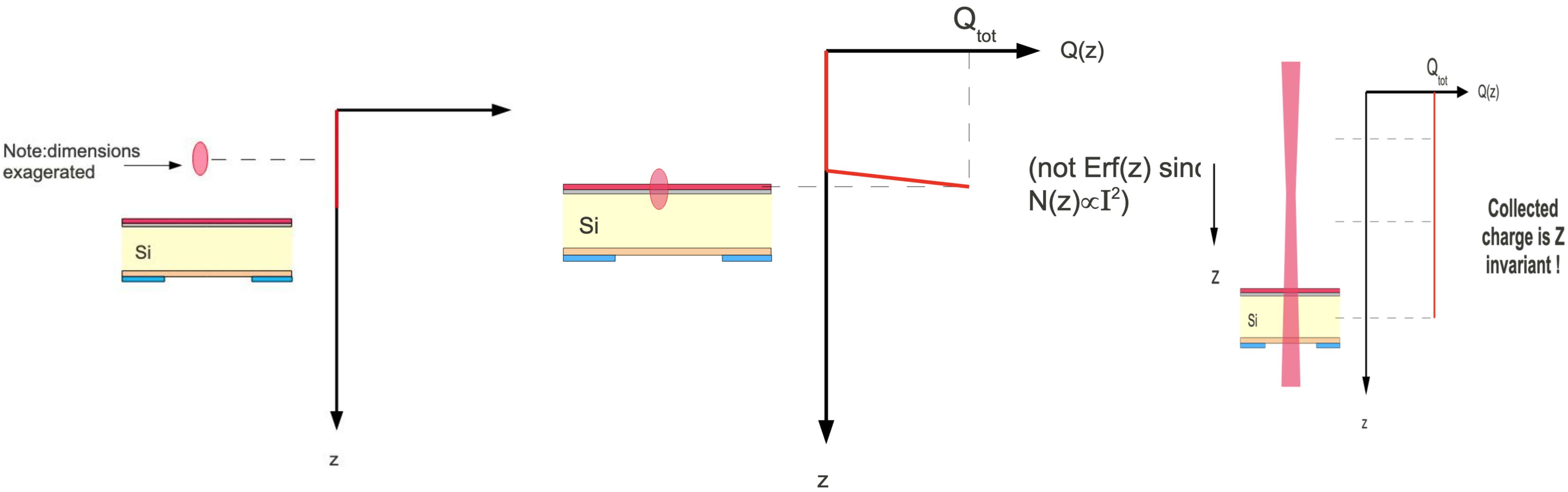
➢ **Welcome potential collaborations for more samples.**

- **Far Future; Performing temperature controlled TPA.**

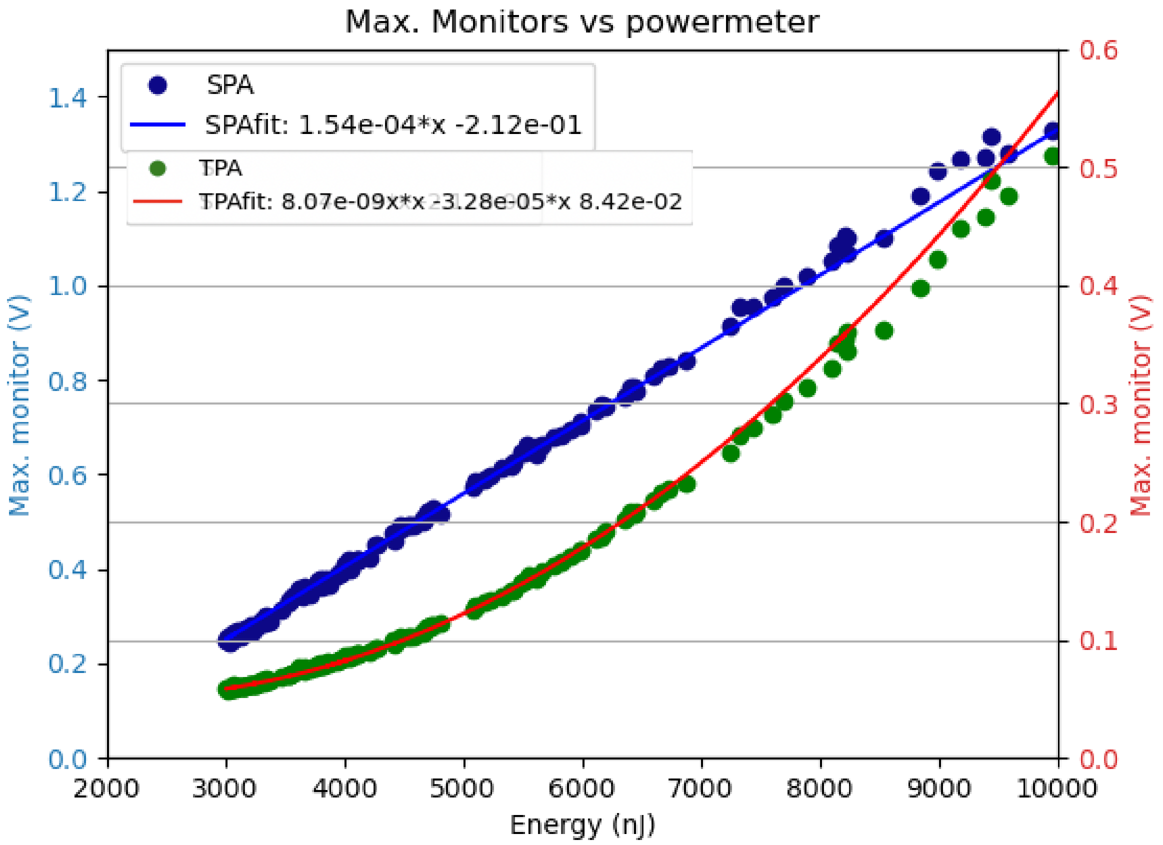
Acknowledgements

- RD50.
- Centro Nacional de Microelectronica (cnm).

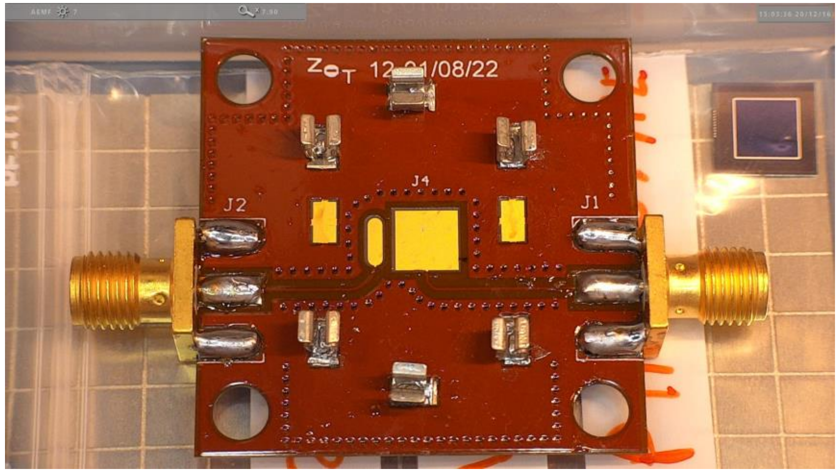
Back Up


Note:dimensions exagerated
Si
z
Si
Q_{tot}
Q(z)
z
(not Erf(z) sinc
$N(z) \propto I^2$)
z
Q_{tot}
Q(z)
Si
z
Collected charge is Z invariant !

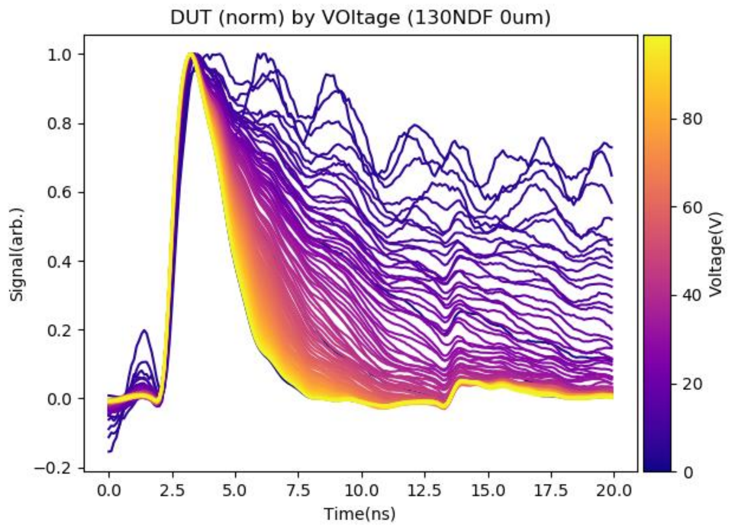
Photon Intensity Calibration (Upgraded)

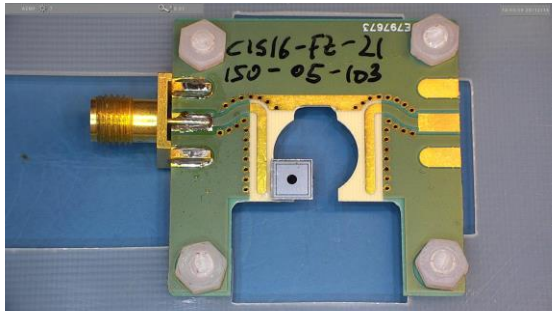


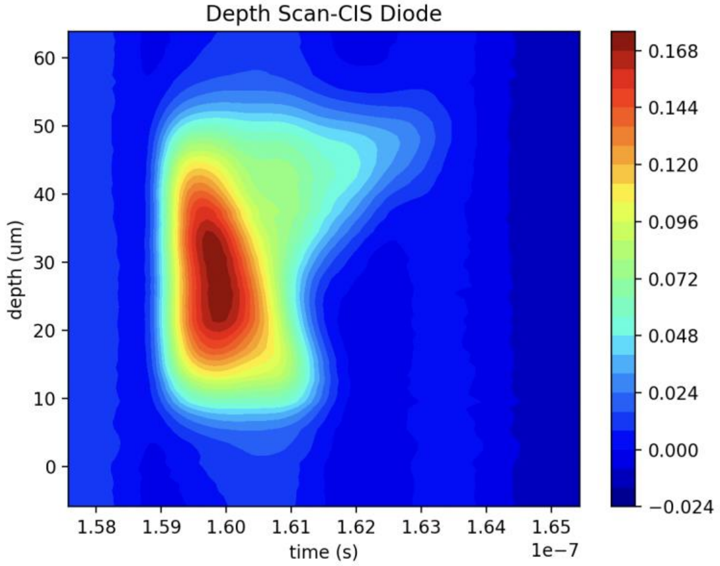
- TPA is very sensitive to energy.
- Thus, the need for SPA and TPA reference monitors.
- Energy fluctuates with time.
- Correlated the power meter and the signal in SPA & TPA.
- Energy per pulse for two different runs can be compared.

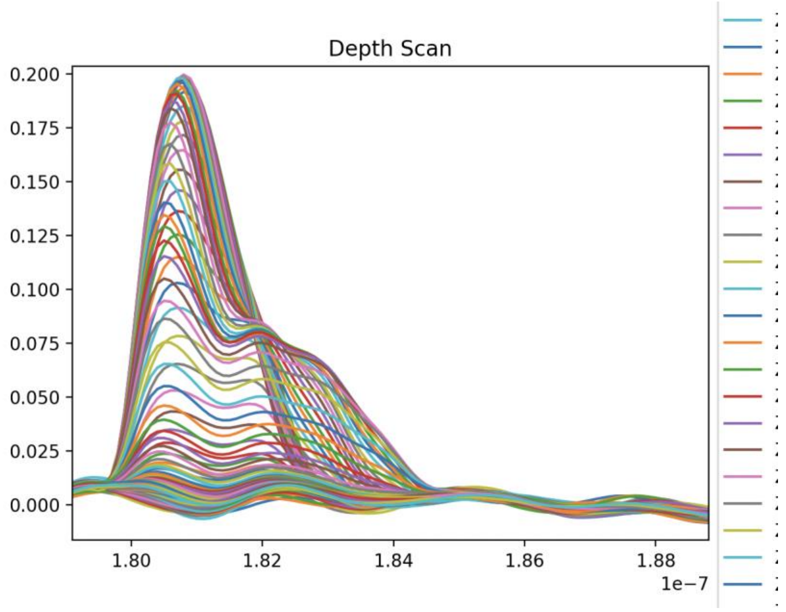


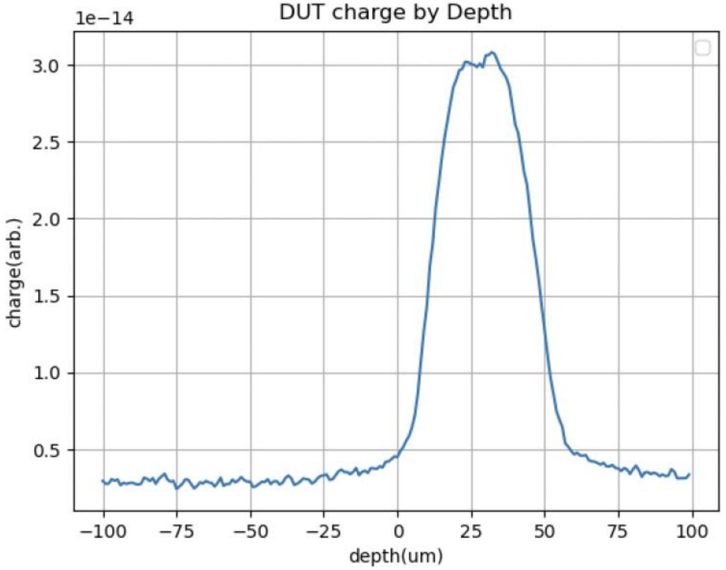
CIS Diode


DUT (norm) by VOltage (130NDF 0um)
Signal(arb.)
Time(ns)
Voltage(V)

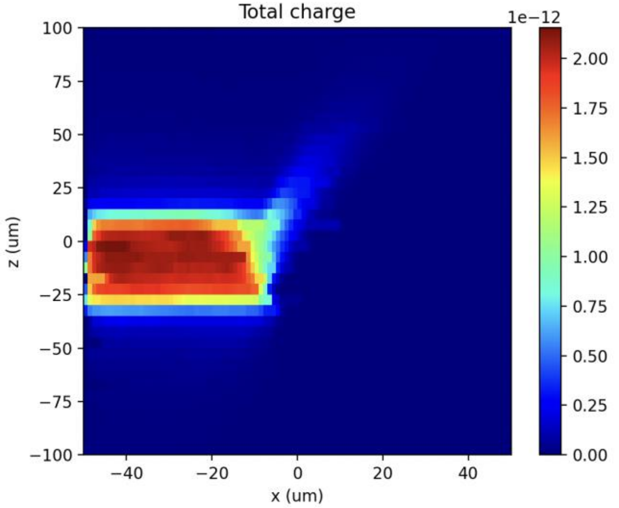

CIS16-FZ-21
150-05-103

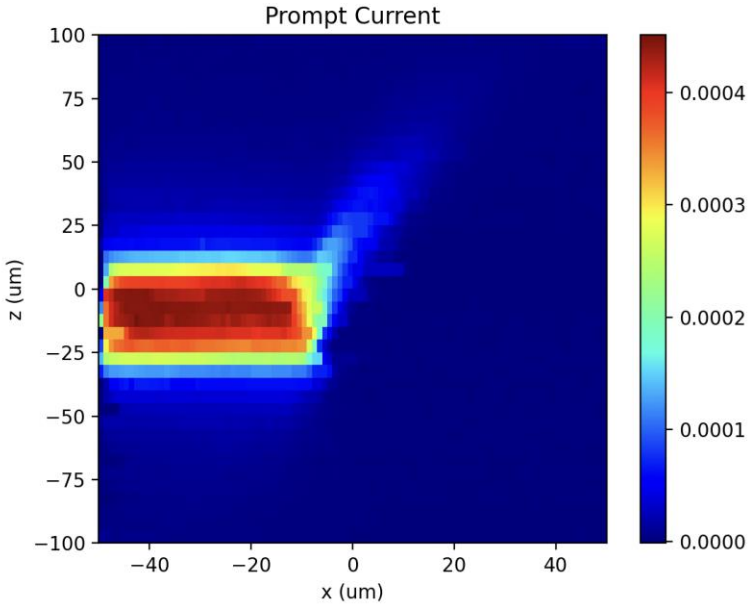

Depth Scan-CIS Diode
depth (um)
time (s)
1e−7

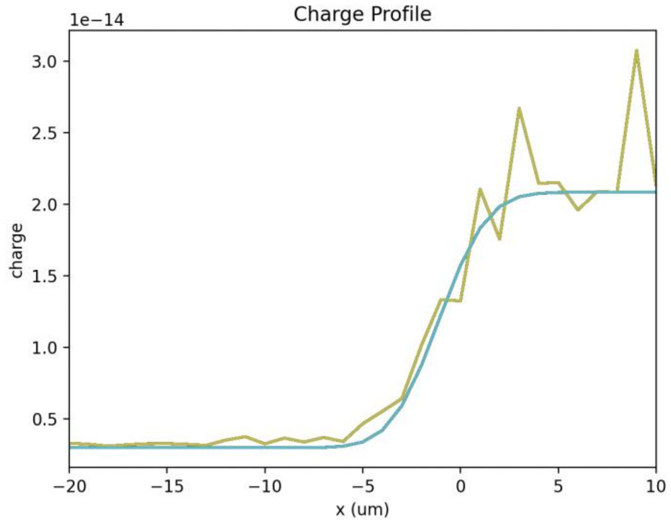

Depth Scan
1e−7

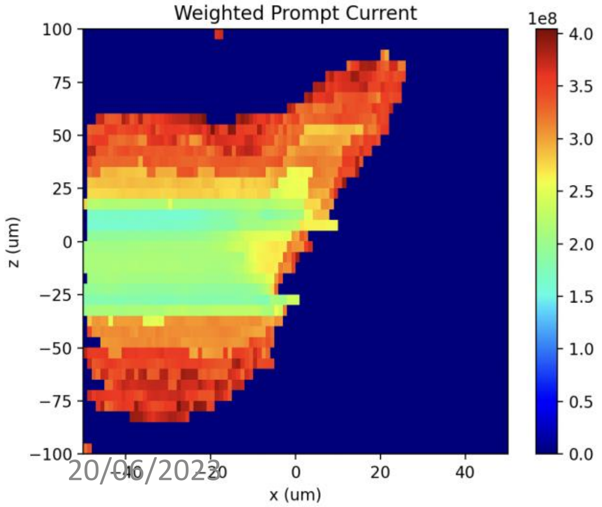

DUT charge by Depth
1e−14
charge(arb.)
depth(um)

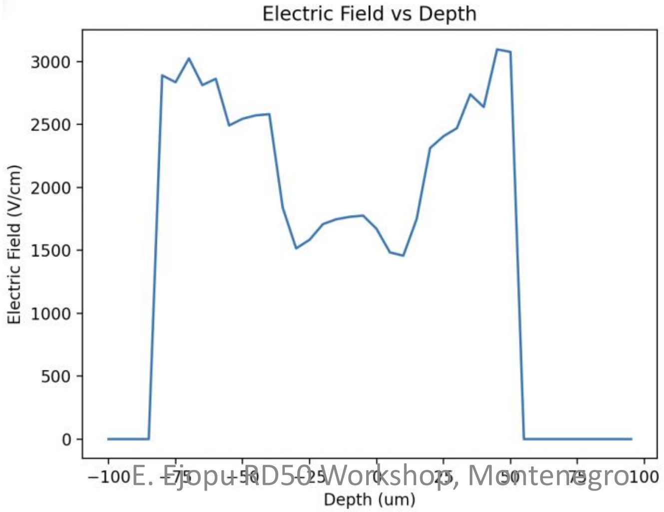
CIS Diode…

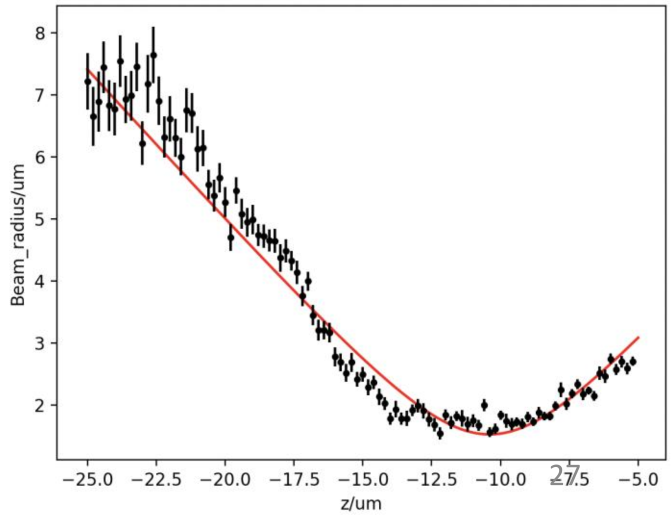

Total charge
1e−12
z (um)
x (um)


Prompt Current
z (um)
x (um)


Charge Profile
1e−14
charge
x (um)


Weighted Prompt Current
1e8
z (um)
x (um)


Electric Field vs Depth
Electric Field (V/cm)
Depth (um)


Beam_radius/um
z/um

xy scan

- Investigation of segmented devices.
- Determination of device uniformity.
- At the top, bottom and inside the device.