Irradiation effect on trapping time of silicon carbide detector

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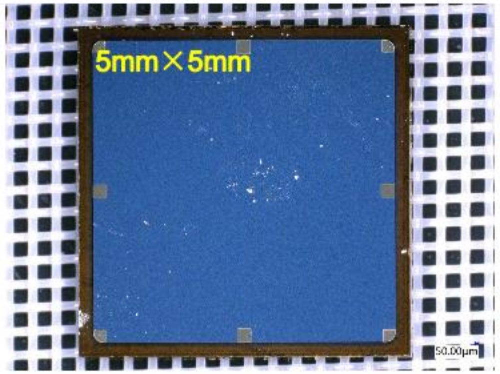
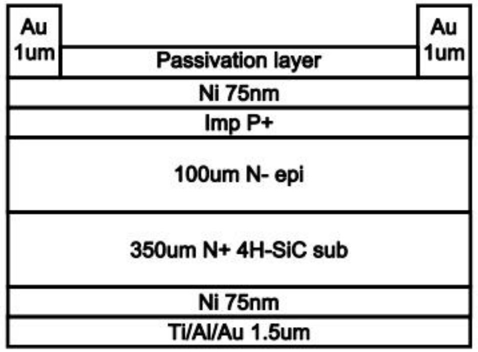
Outline

- Top-TCT on SiC PIN
- Trapping time and RASER simulation
- Irradiation effect
- Summary and Plan

SiC PIN



SiC PIN



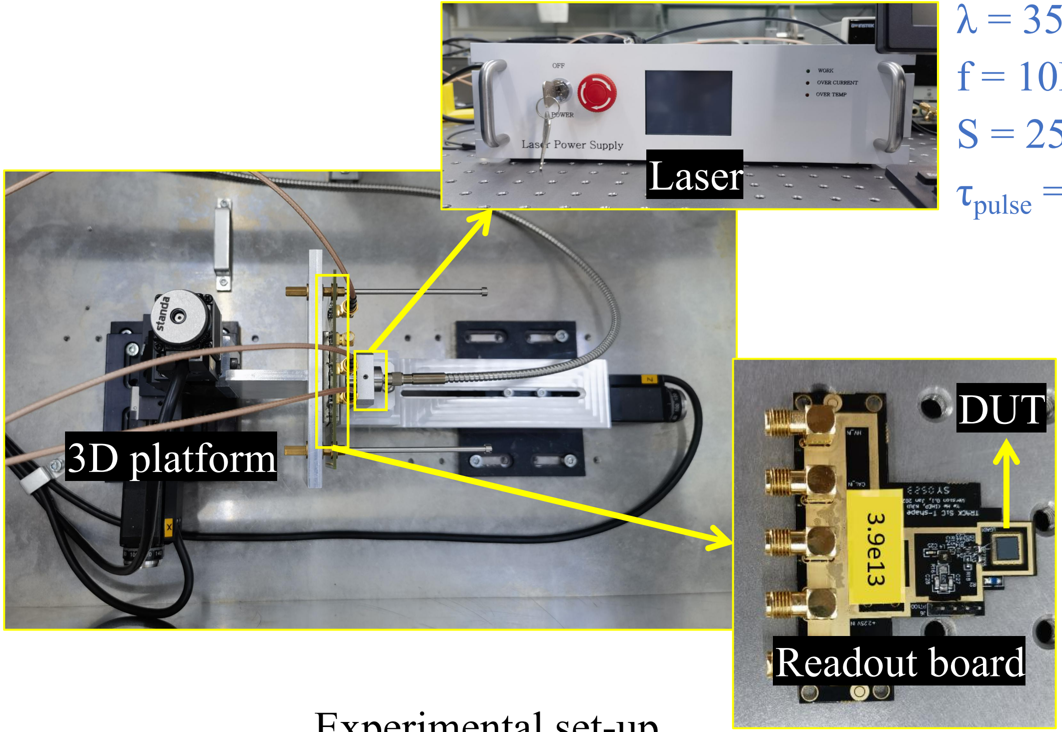
Cross section of PIN

- 5mm×5mm SiC PIN detector fabricated by Nanjing University
- 100μm high resistive active epitaxy layer and 350μm substrate
- $N_{eff} = 5.2 \times 10^{13} cm^{-3}$, $V_{dep} = 484V$

$$N_{eff} = \frac{2}{q\varepsilon A^2 d(1/C^2)/dV} \qquad V_{dep} = \frac{q|N_{eff}|d^2}{2\varepsilon}$$

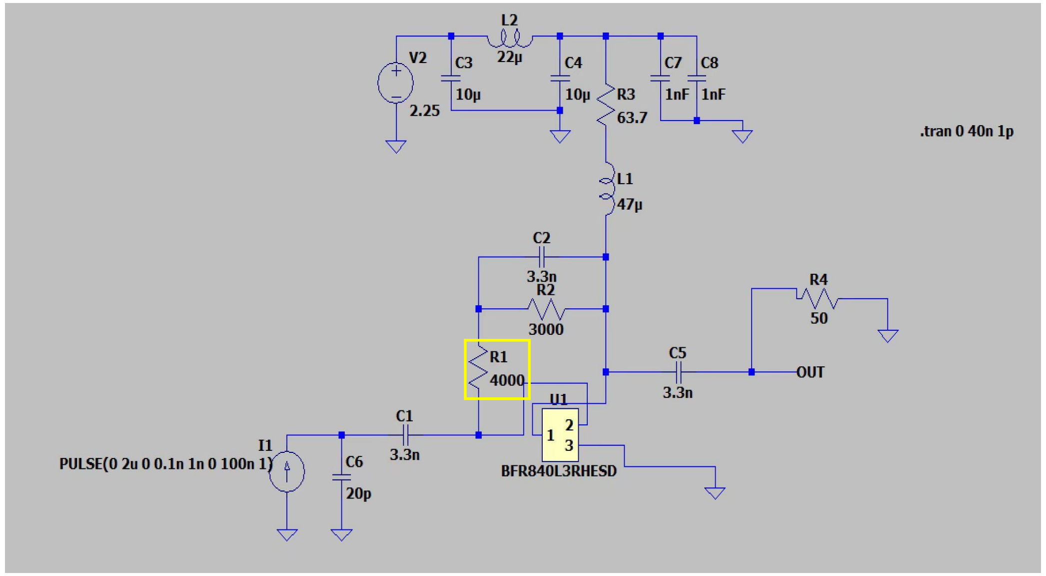
Published: Time Resolution of the 4H-SiC PIN Detector https://doi.org/10.3389/fphy.2022.718071

Experimental setup



$\lambda = 355nm$
$f = 10Hz$
$S = 25um$
$\tau_{pulse} = 8.1ns$

Experimental set-up



Circuit diagram of readout

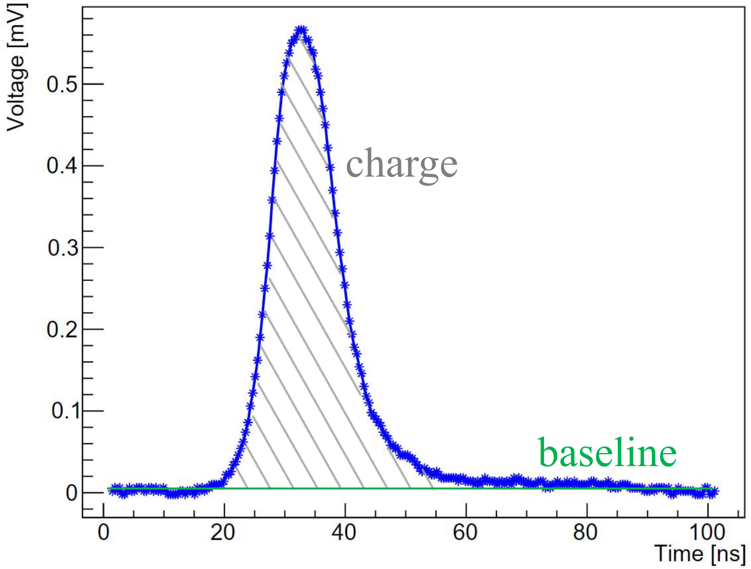
- 355nm laser is used to focus on the top surface of sic detector for top-TCT.
- Design the circuit according to UCSC board and change R1 from 475Ω to 4000Ω.

https://twiki.cern.ch/twiki/bin/view/Main/UcscSingleChannel

https://indico.cern.ch/event/1132520/contributions/5149453/attachments/2556919/4406364/SiC%20for%20beam%20monitor%20system.pdf

Charge collection and trapping time

- Collected charge: Q=I·t



Charge collection estimation

- Trapping time: $$Q = \frac{\Delta Q}{\delta x} \cdot D \cdot \frac{1}{D} \cdot v \cdot \tau = \frac{\Delta Q}{\delta x} \cdot v \cdot \tau$$

$\frac{\Delta Q}{\delta x}$: charge per unit track length

v: sum of electron and hole velocities.

RASER simulation

- RASER, fast simulation tool for time resolution of planar and 3D SiC PIN.

  Time Resolution of the 4H-SiC PIN Detector https://doi.org/10.3389/fphy.2022.718071

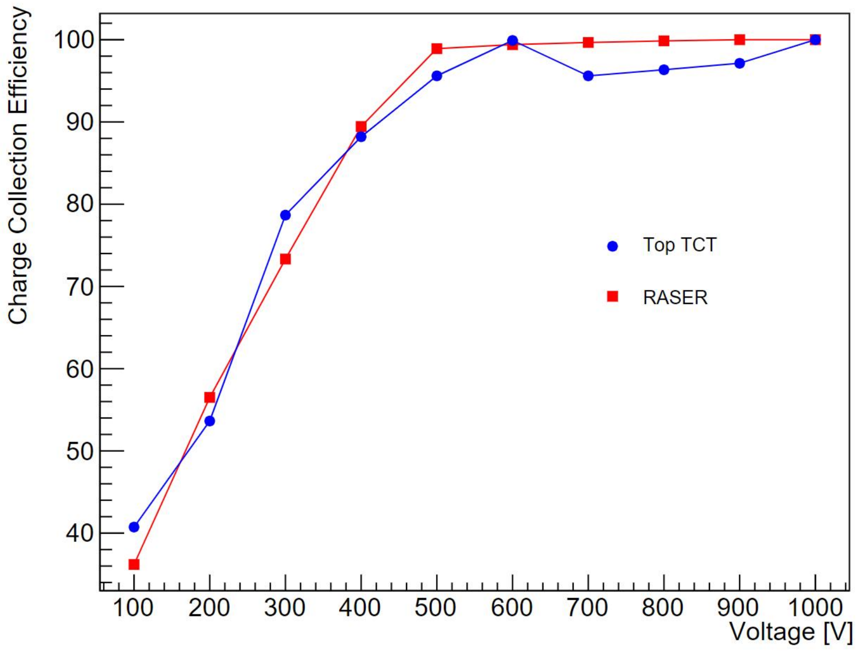
  Timing Performance Simulation for 3D 4H-SiC Detector https://www.mdpi.com/2072-666X/13/1/46

- Update:
  - DEVSIM for IV/CV and field distribution

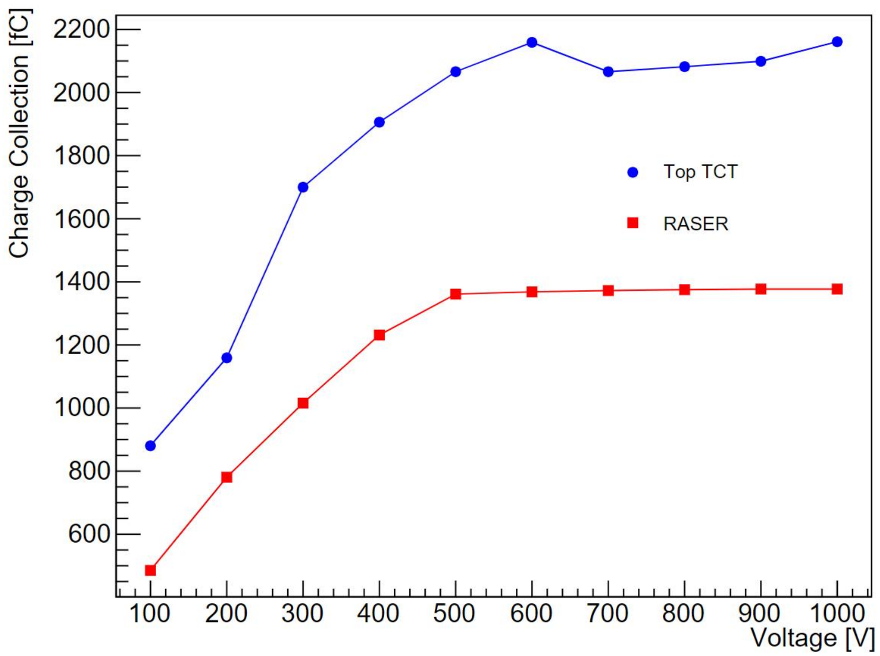
    https://indico.cern.ch/event/1132520/contributions/5149103/attachments/2556958/4406436/Xiyuan%20Zhang_41st_rd50_workshop.pdf
  - electronic circuits optimization

    NGSpice to simulate electronic circuits
    - convert the preamplifier circuits into the code as input
    - output voltage after signal simulation

Charge collection from RASER



Charge collection efficiency and RASER simulation



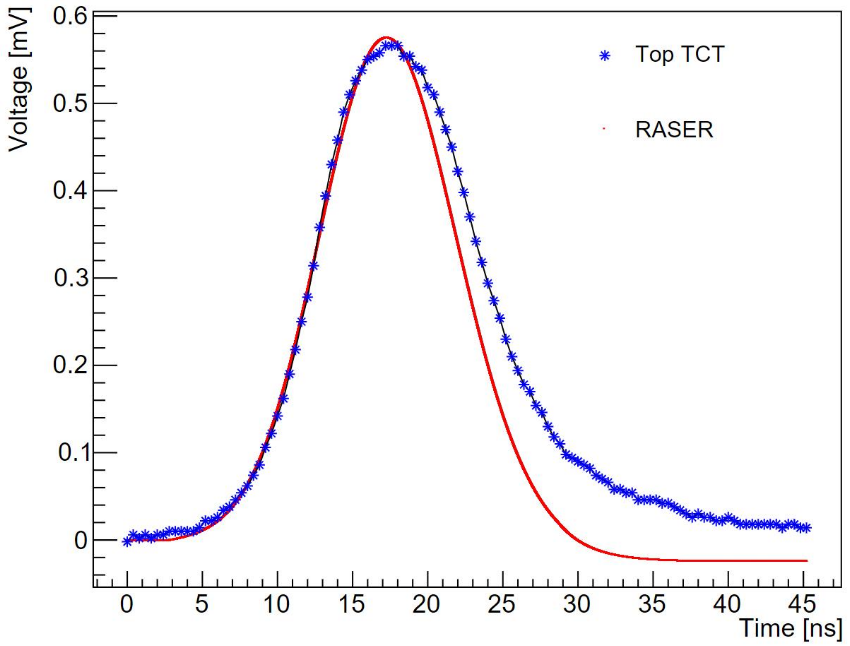
Charge collection and RASER simulation

- Simulated charge collection shows good agreement with experiment result. V_{dep} = 484V.
- Further measurement is needed for the precise laser intensity.

Waveform comparison

$$I_{e,h}(t) = Ae_0 N_{e,h} \exp\left(-\frac{t}{\tau_{\text{eff},e,h}}\right) \vec{v}_{e,h}(t) \cdot \vec{E}_w$$

contribution from trapping time

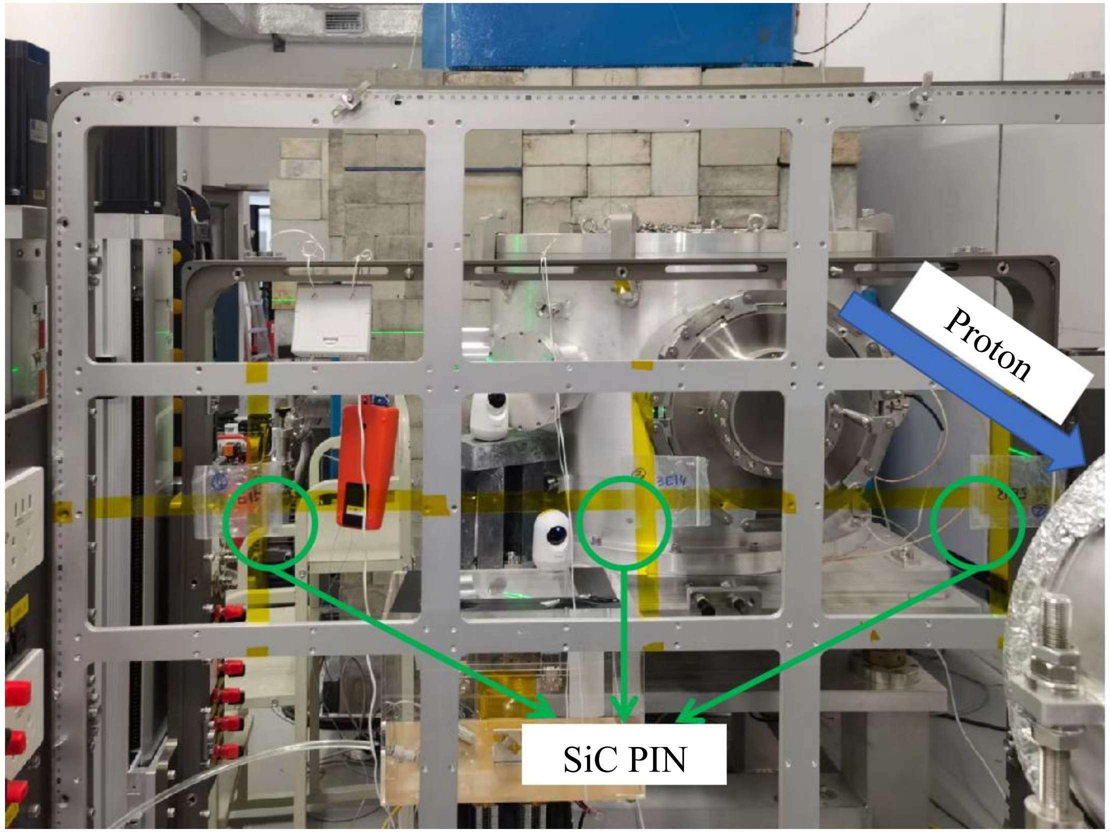


Waveform and RASER simulation

- Put trapping time in simulation, waveform shows same trend with experiment result.
- The tail of descending edge may result from the cable capacitance.

Irradiation at CSNS

- Irradiation of SiC PIN is finished at China Spallation Neutron Source(CSNS).

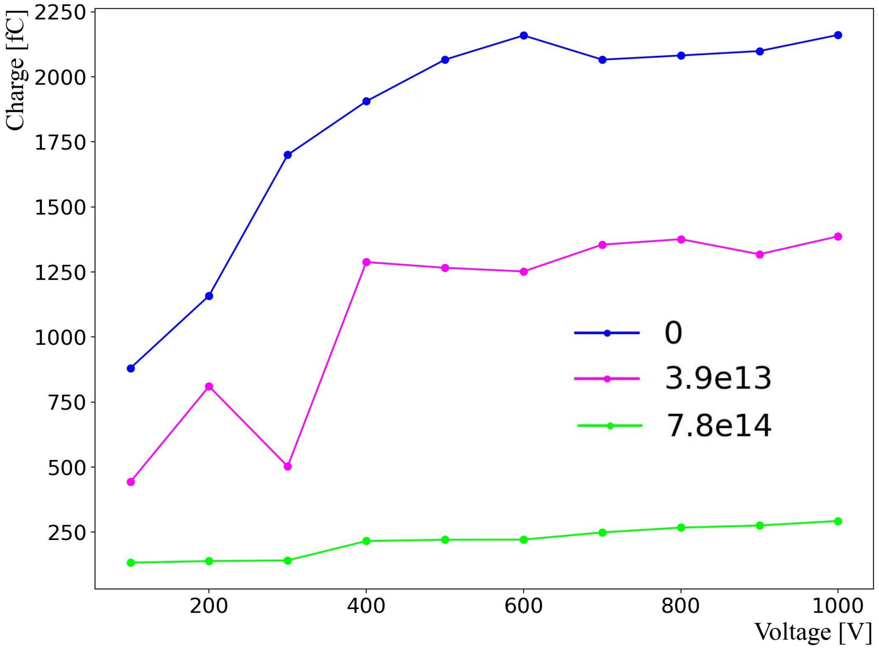


Irradiation setup

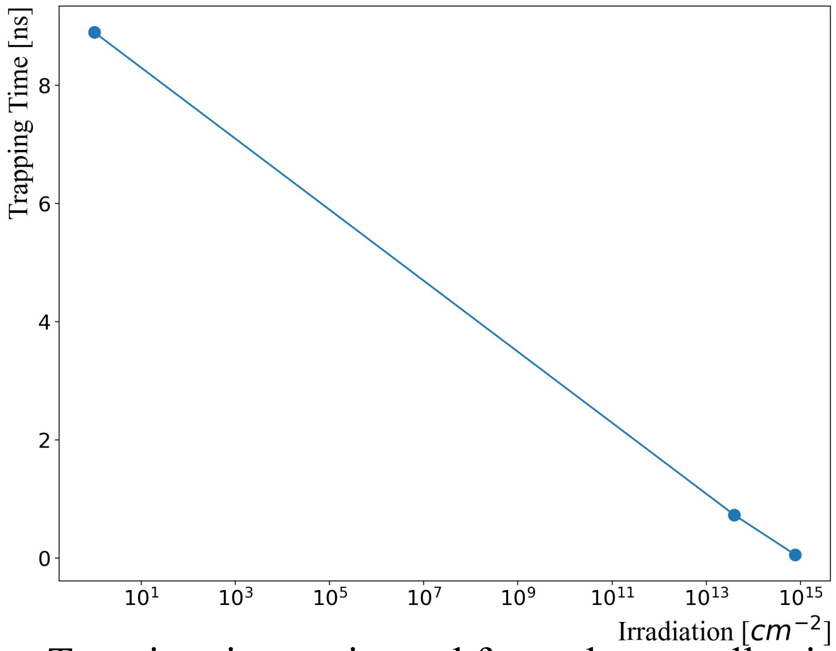
- Particle: proton
- Energy: 80MeV
- Intensity: 10mA
- Area: 20mm×20mm
- Dose: $3.9\times10^{13}n_{eq}/cm^2$, $7.8\times10^{14}n_{eq}/cm^2$
- Temperature and humidity: No control

Charge and trapping time for irradiation

- Defects caused by irradiation make charge carriers more easily captured during transport, thereby affecting the trapping time.



Charge collection after irradiation



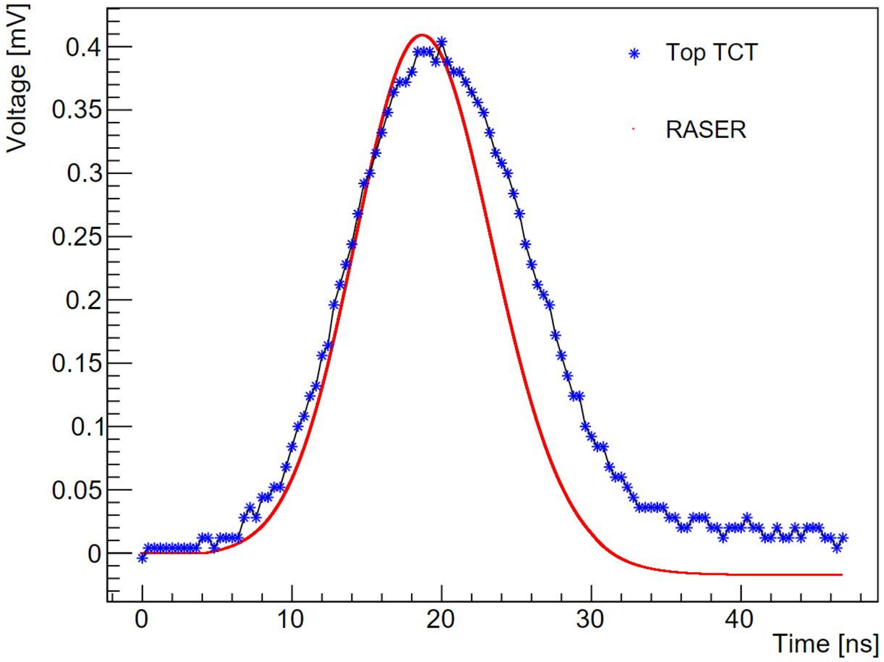
Trapping time estimated from charge collection

- Trapping time and log(irradiation dose) show good linear distribution.

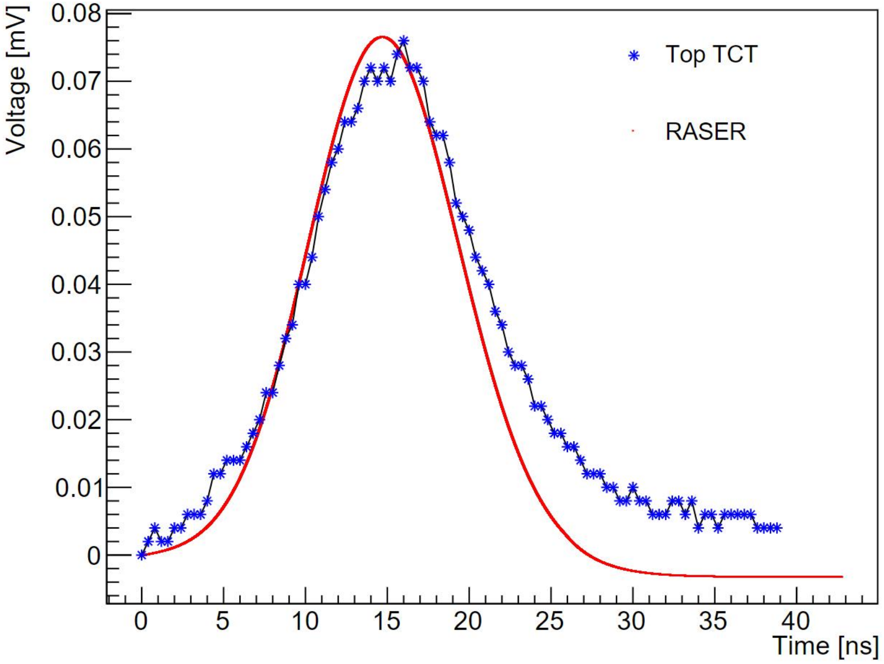
Simulation for irradiation

- Change trapping time after irradiation to research waveform

$$I_{e,h}(t) = Ae_0 N_{e,h} \exp\left(-\frac{t}{\tau_{\mathrm{eff},e,h}}\right) \vec{v}_{e,h}(t) \cdot \vec{E}_w$$



Wavefrom after 3.9e13 irradiation



Wavefrom after 7.8e14 irradiation

- RASER simulation of irradiated detectors shows good agreement with experiment.

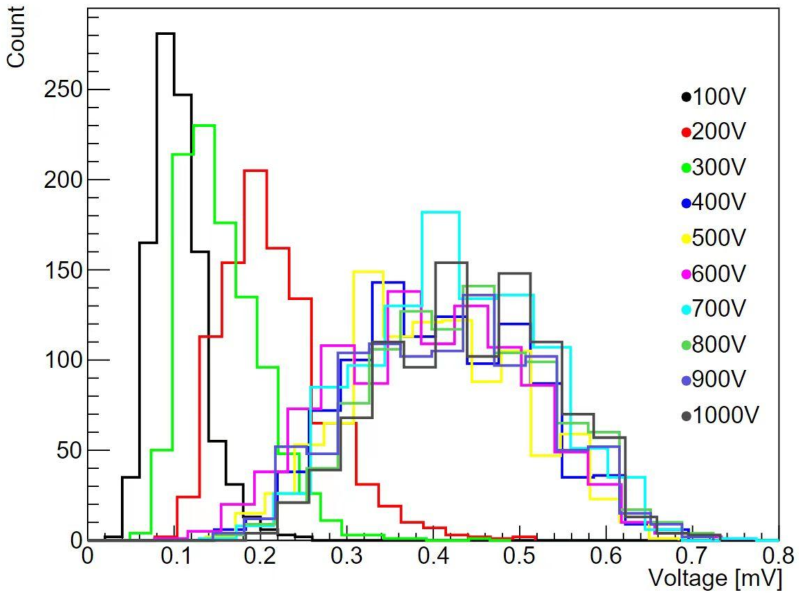
Summary and Plan

- ✓ RASER program has been updated on field calculation and readout electronics. Waveform and charge collection show good agreement.
- ✓ Trapping time works as an essential parameter for RASER simulation. Trapping time and log(irradiation dose) show good linear distribution.

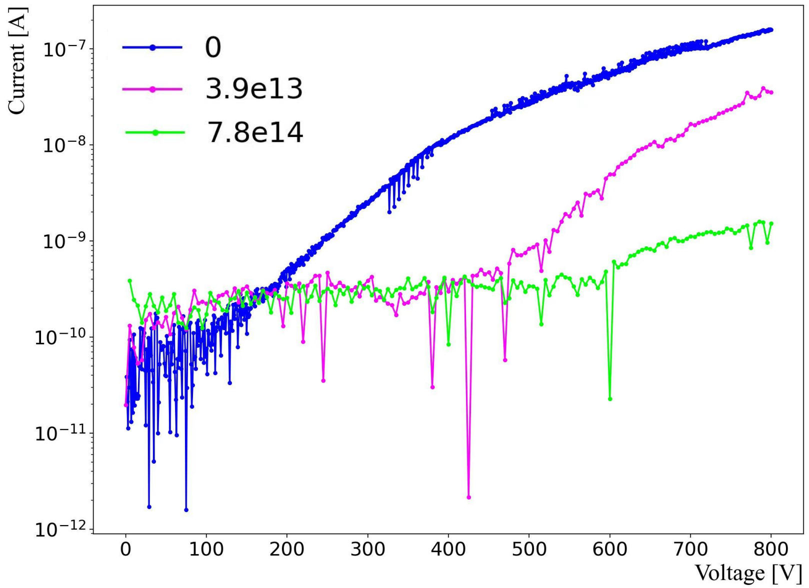
- ➢ 2 more irradiation points will be added to check the linear distribution, $1 \times 10^{11} n_{eq}/cm^2$,and $1 \times 10^{12} n_{eq}/cm^2$.
- ➢ Further study is needed for cable capacitance in electronic simulation, which causing the difference at the tail of descending edge.
- ➢ DLTS analysis will be completed for deeper understanding of defect.

Thanks for your attention.

Back-up



Amplitude vs. voltage



IV curve after irradiation