Irradiation studies of p-Si using Schottky diode and PN junction

Rodney Aiton[1]; Yebo Chen[2]; Christoph Thomas Klein[1]; Matt Kurth[2];
Thomas Koffas[1]; Adnan Malik[3]; Angela Mccormick[1]; Garry Tarr[1];
E. Giulio Villani[3]; Robert Vandusen[1]; Dengfeng Zhang[4]; Hongbo Zhu[5]

1. Carleton University; 2. IHEP, CAS; 3. STFC-RAL; 4. University of Sheffield;
5. Zhejiang University

Nov. 29, 2022

The 41st RD50 Workshop@Sevilla, Spain

Introduction

- p-type silicon is and going to be used on hybrid and MAPS silicon detectors, ATLAS, CMS, ALICE, etc,

- Understanding of radiation damage is crucial for proper operation and evaluation of detectors in harsh radiation environment,

- Schottky diodes and PN junctions have been designed and fabricated on p-type epitaxial silicon wafers,

- Aim to gain reliable TCAD models for the radiation damage of p-type silicon,

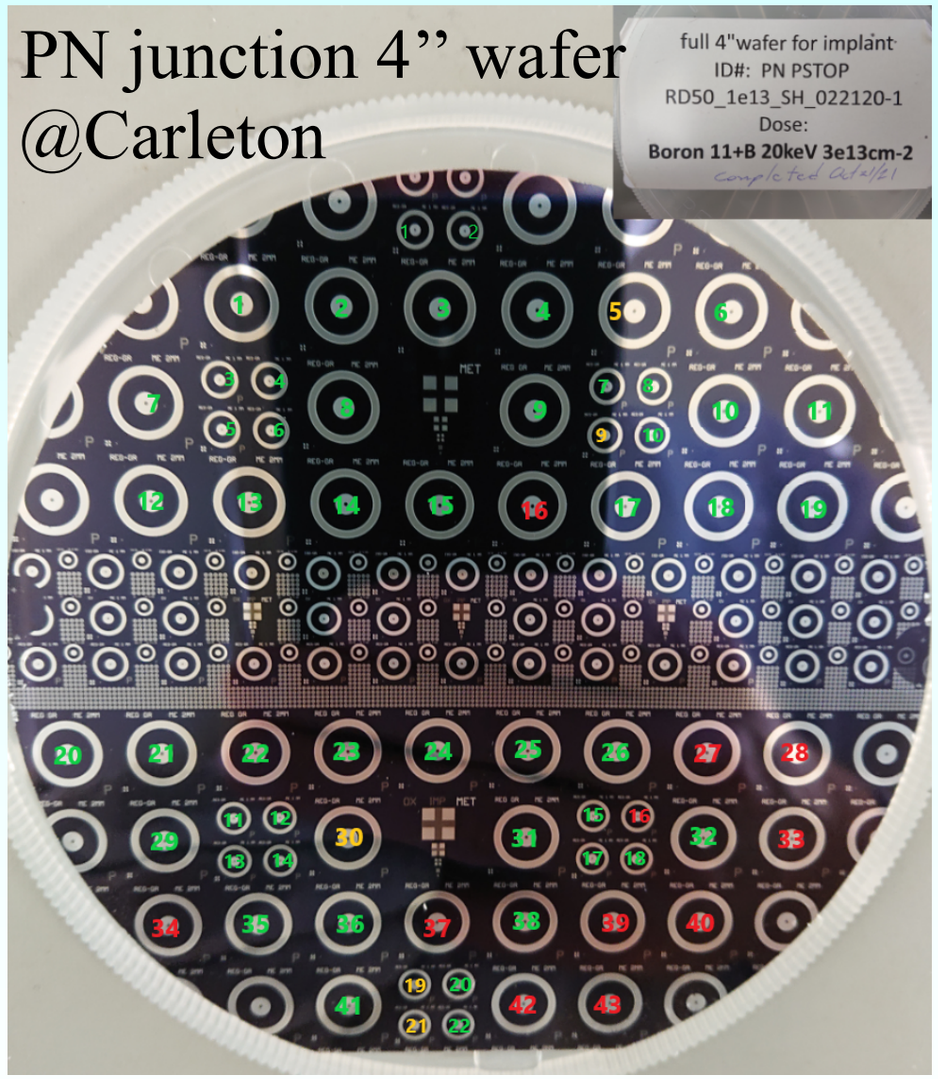
- Updates on Charge Collection Efficiency(CCE) and Defect characteristics will be presented.

Wafer and device layout

- Schottky diodes fabricated on 6-inch wafer, PN junctions on 4-inch wafer,
- 4 layouts for both Schottky diodes and PN junctions,
- More details in Giulio's report at 36th RD50 Workshop.

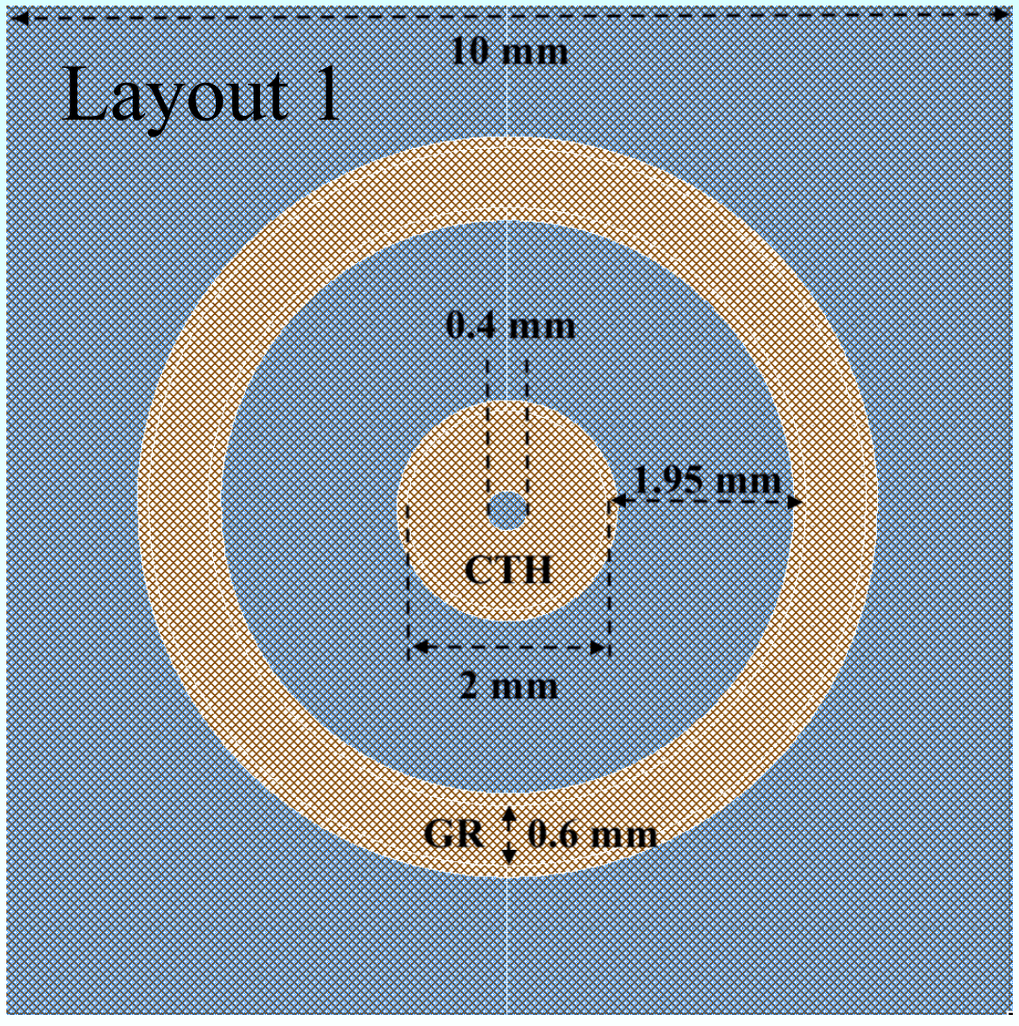
Schottky Diode 6" wafer @RAL

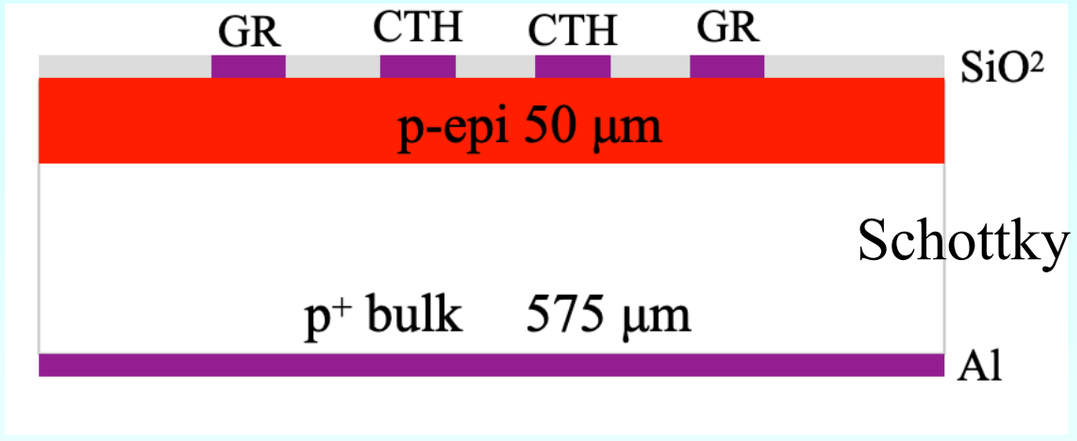
PN junction 4" wafer @Carleton



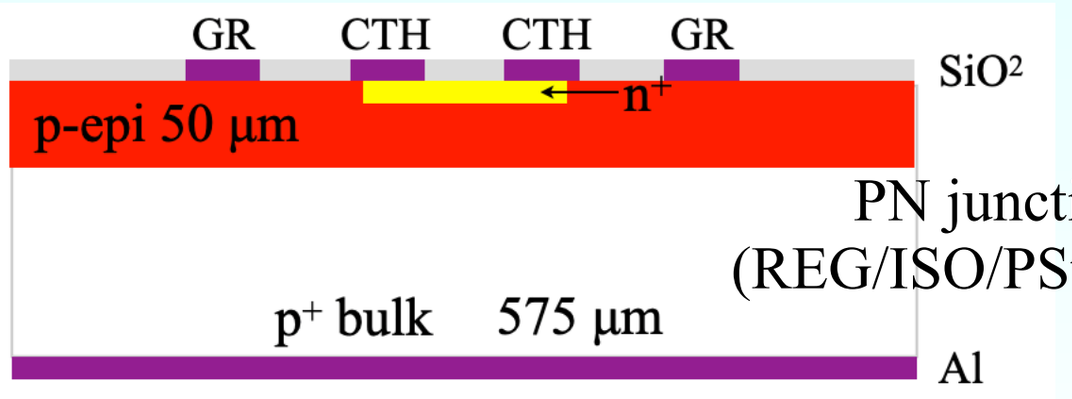
Wafer and device layout

	Layout 1	Layout 2	Layout 3	Layout 4
Cathode Ø [mm]	2	1	0.5	0.1
Guard Ring width [mm]	0.6	0.30	0.15	0.03
Central hole Ø [mm]	0.4	0.2	N.A.	N.A.



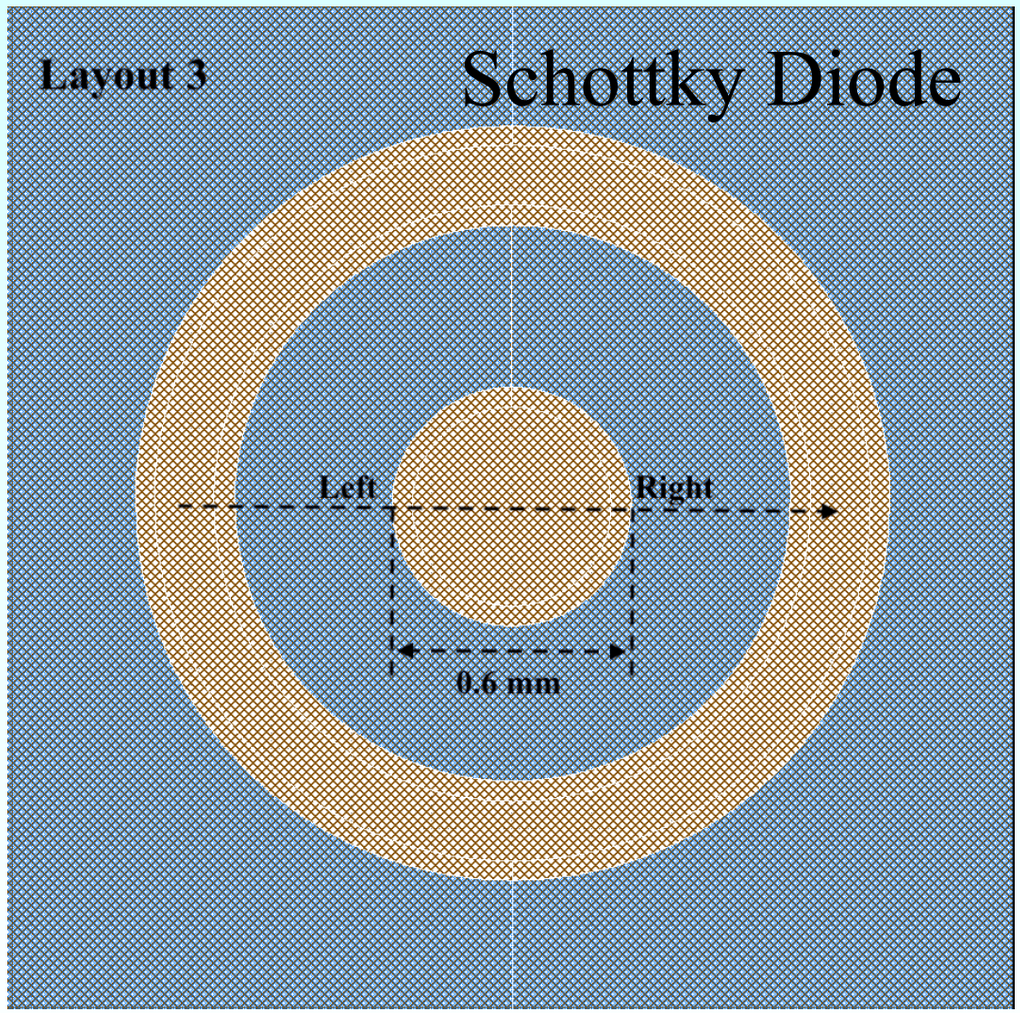


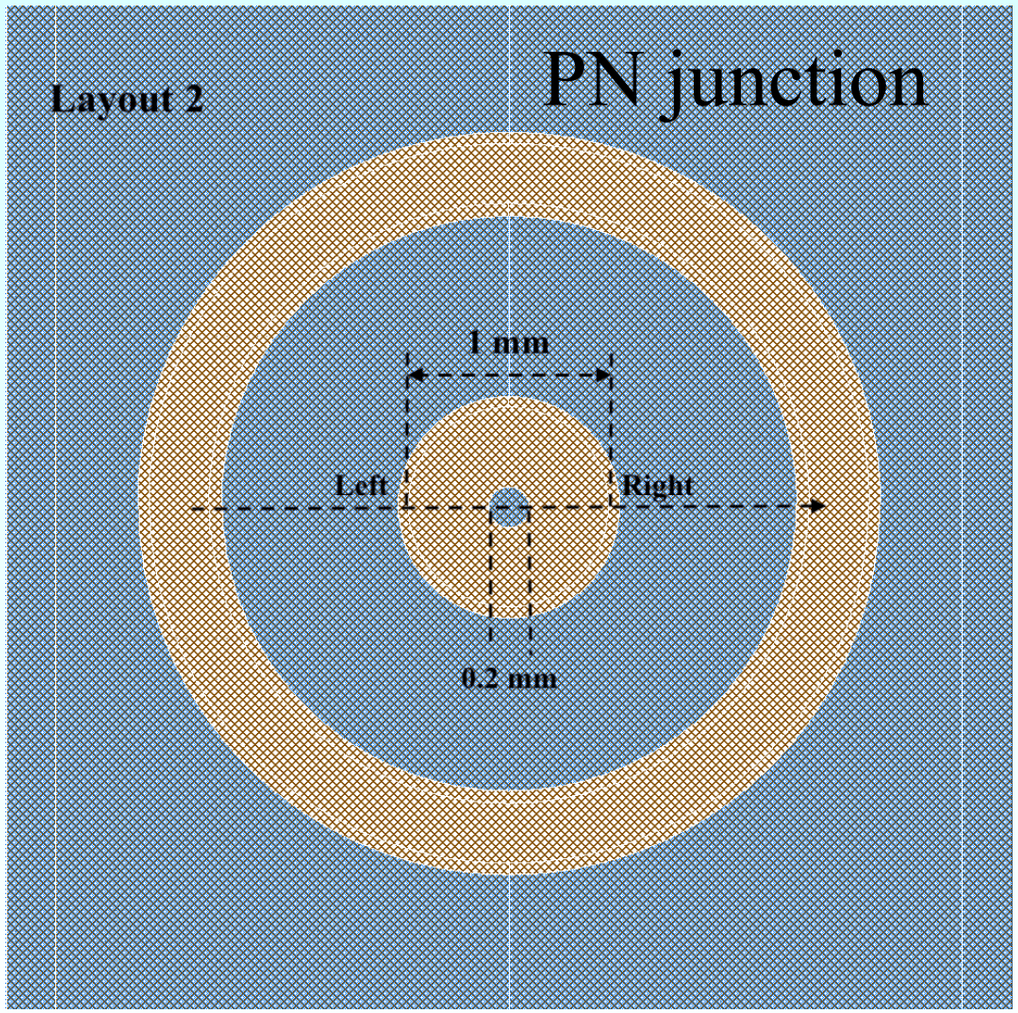
Schottky Diode



PN junction
(REG/ISO/PStop GR)

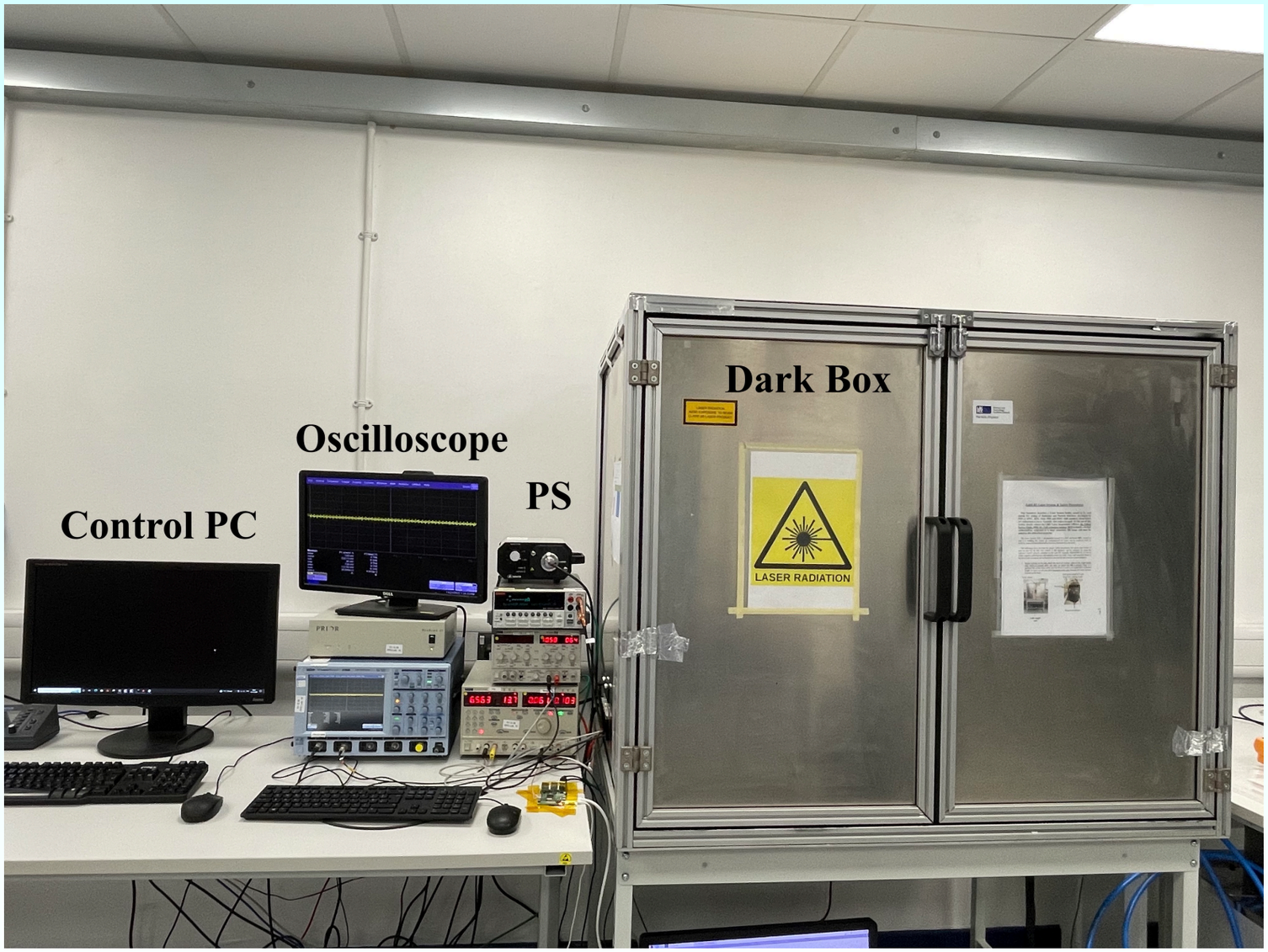
Charge Collection Efficiency

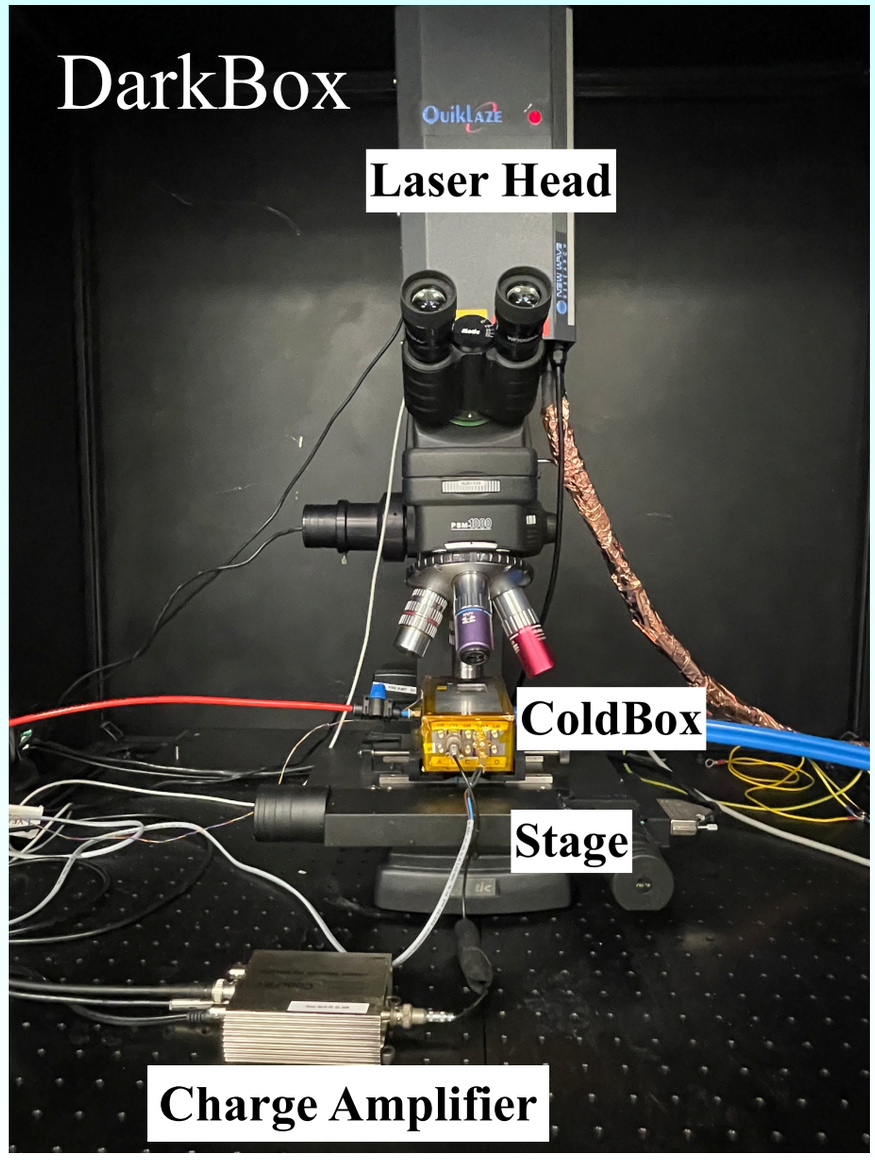




Setup for Charge Collection Efficiency

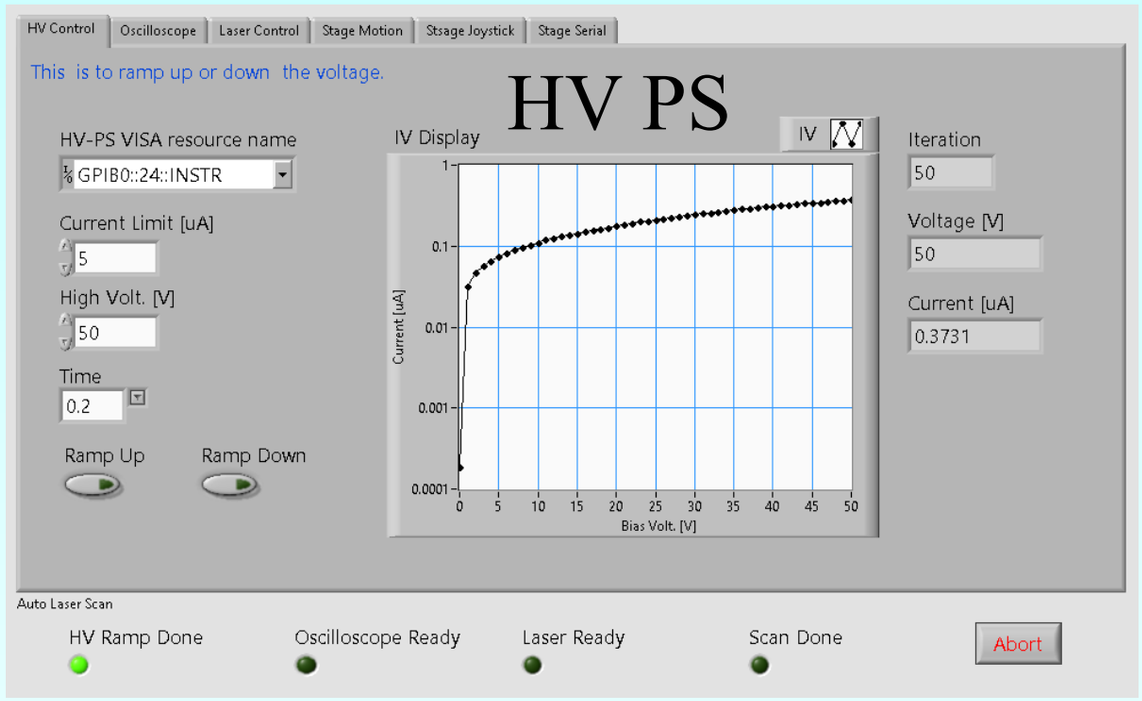
- Laser: IR(1064 nm), 5 μm×50 μm, 23.44 ± 0.2 pJ
- Stage: move step of 5 μm
- Temperature: 20 - -20 °C
- More details in Matt's report at 40th RD50 Workshop.

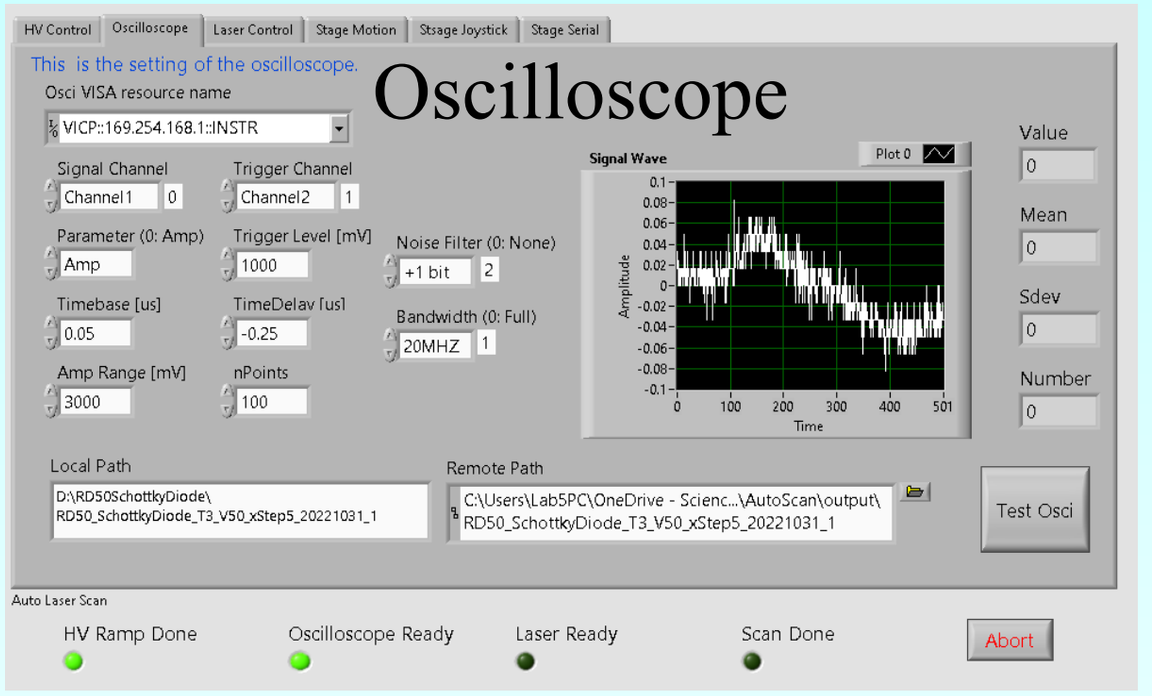


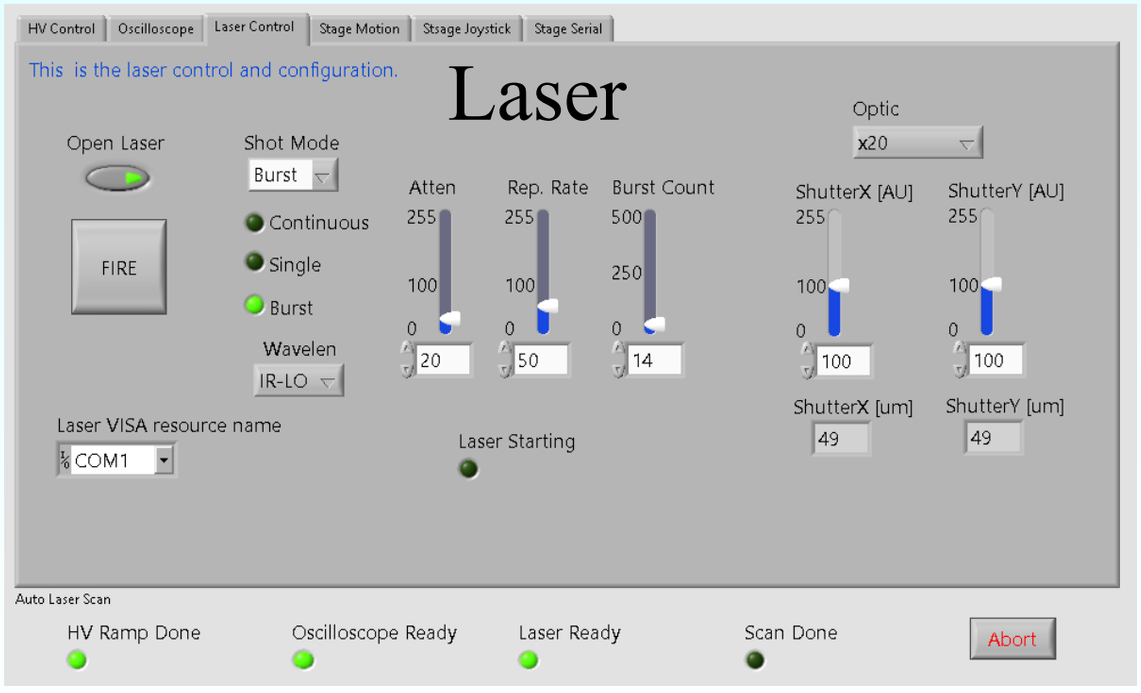


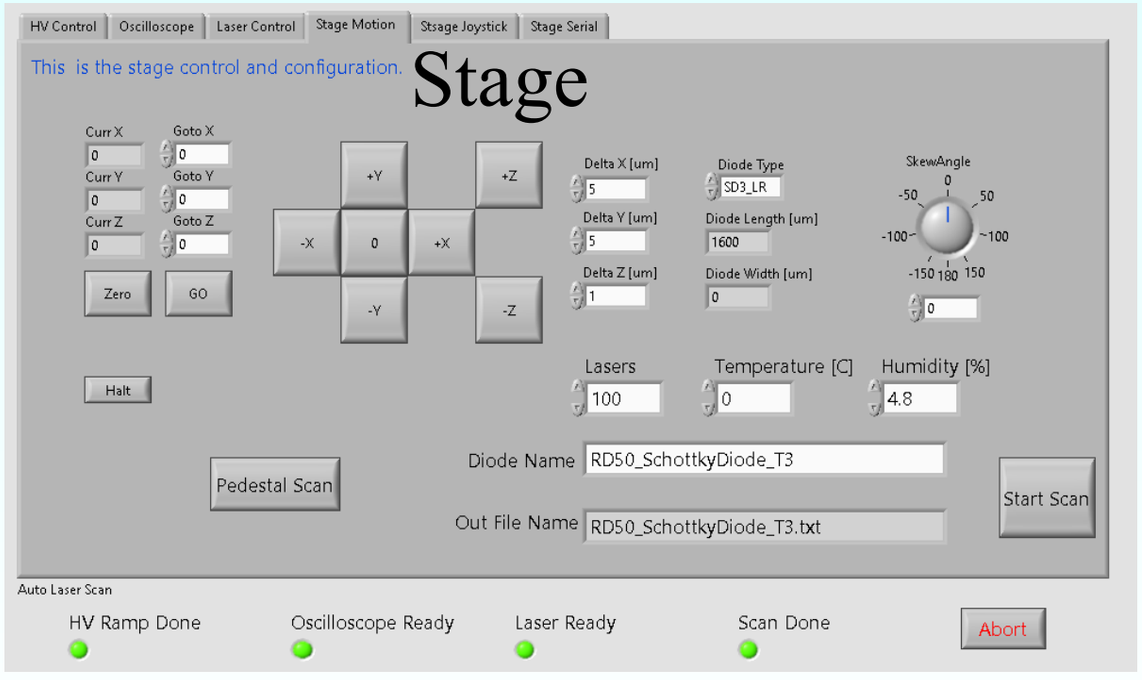
Setup for Charge collection efficiency

- Automatic scanning program developed in LabVIEW.



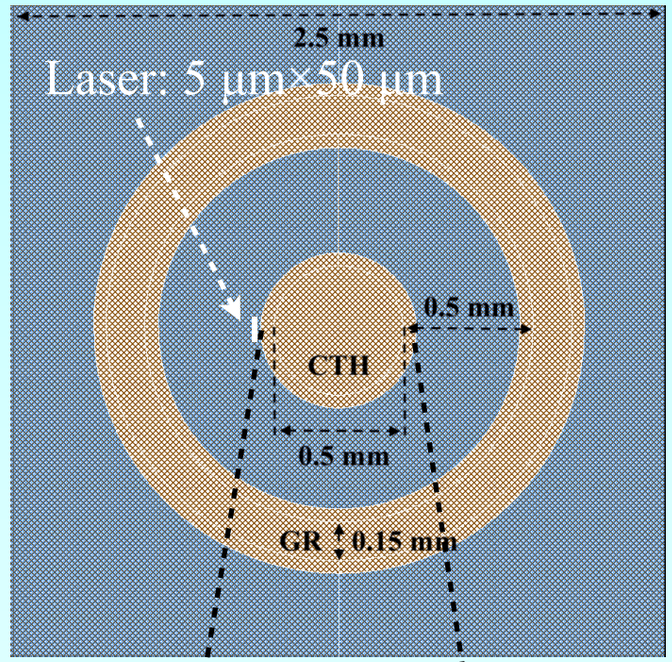


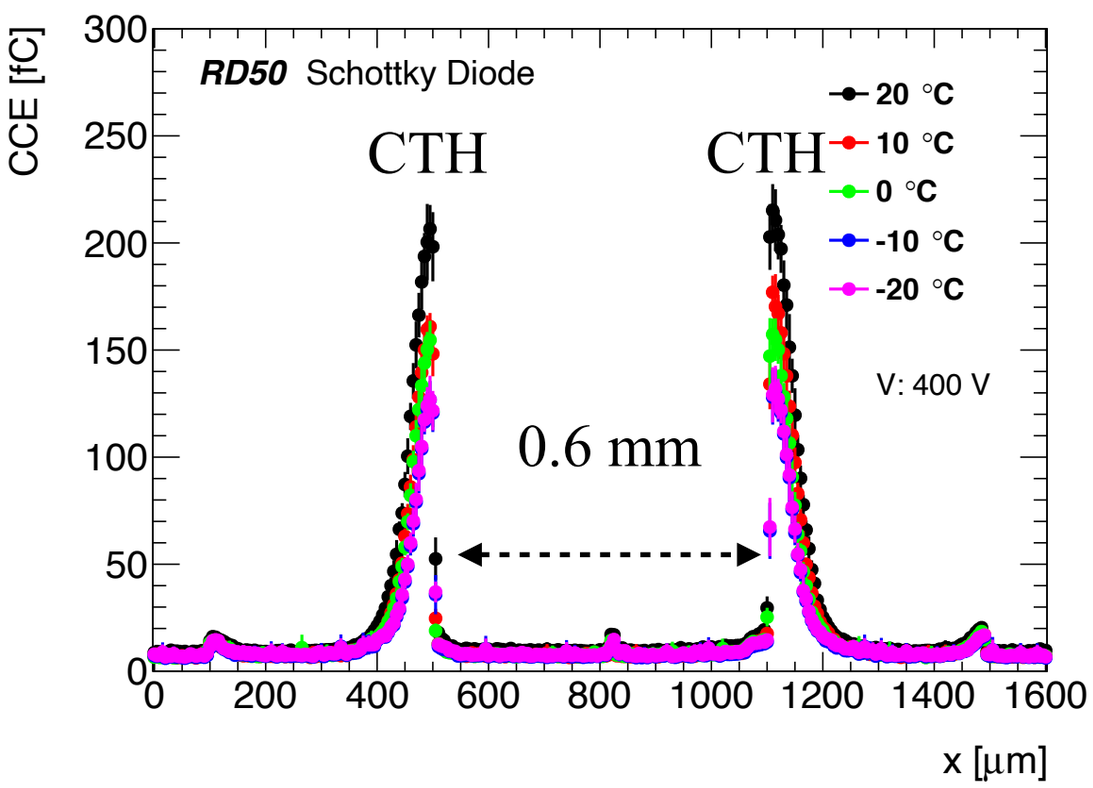


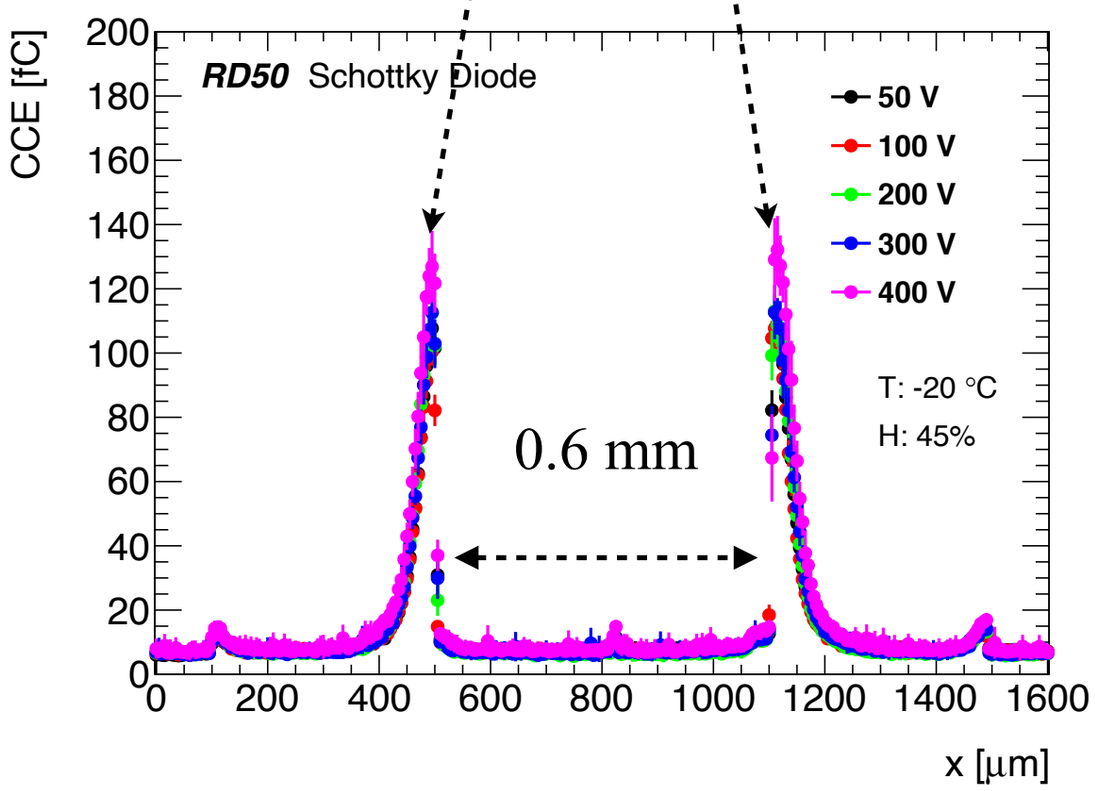


CCE of un-irradiated Schottky diode

- T3 Schottky diode with no central laser hole
- Bias Voltages: 50, 100, 200, 300, 400 V
- Temperatures: 20, 10, 0, -10, -20 °C

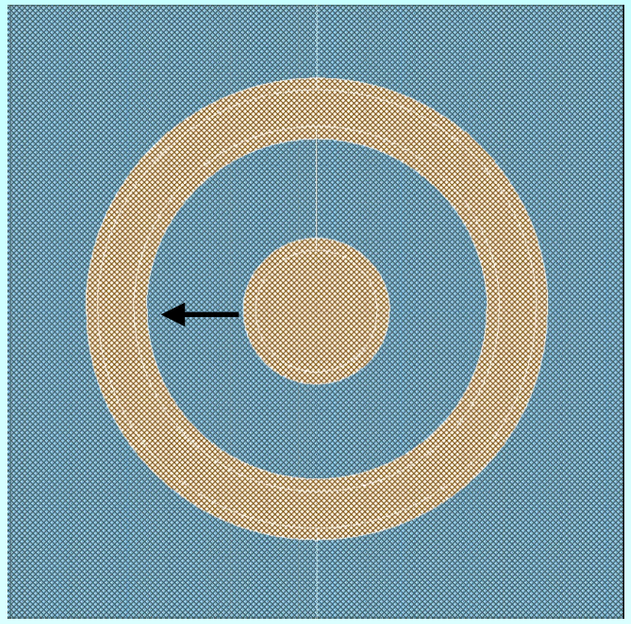


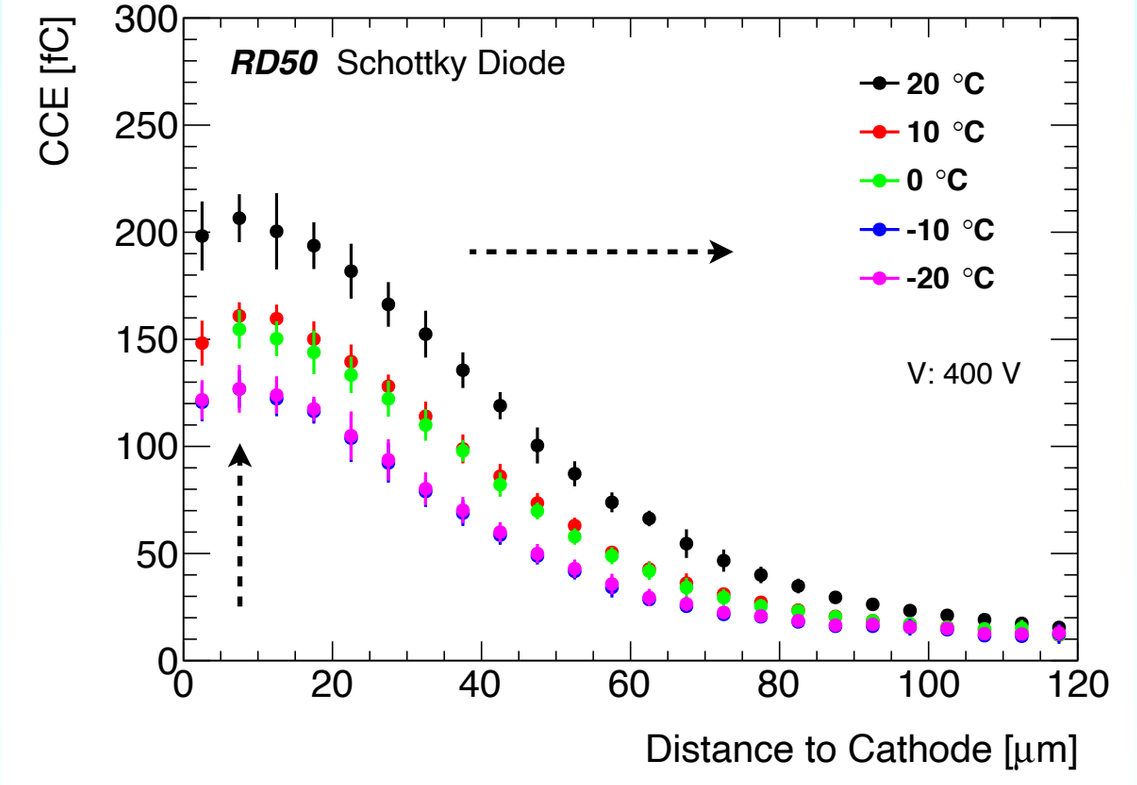


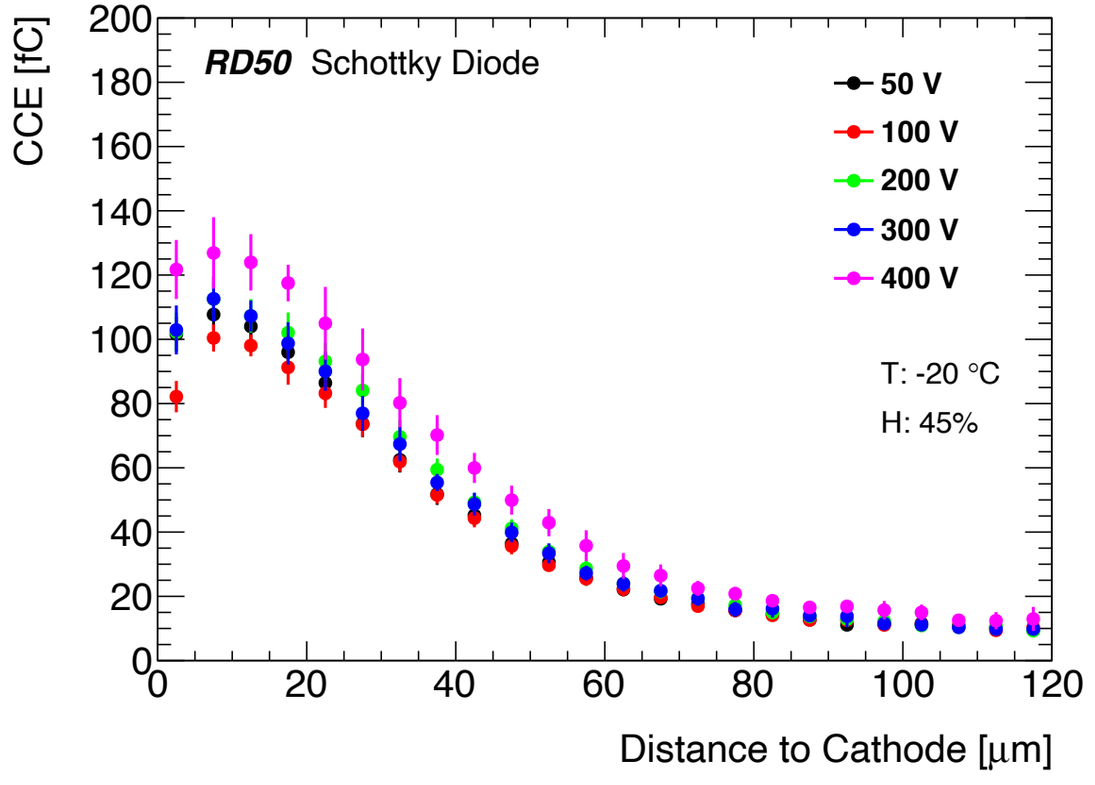


CCE of un-irradiated Schottky diode

- Depleted thickness decreases with increased distance from the cathode edge,
- At fixed bias voltage, the higher the temperature, the larger the CCE, still under investigation,
- At low temperature, not significant improvement on CCE for various bias voltages.

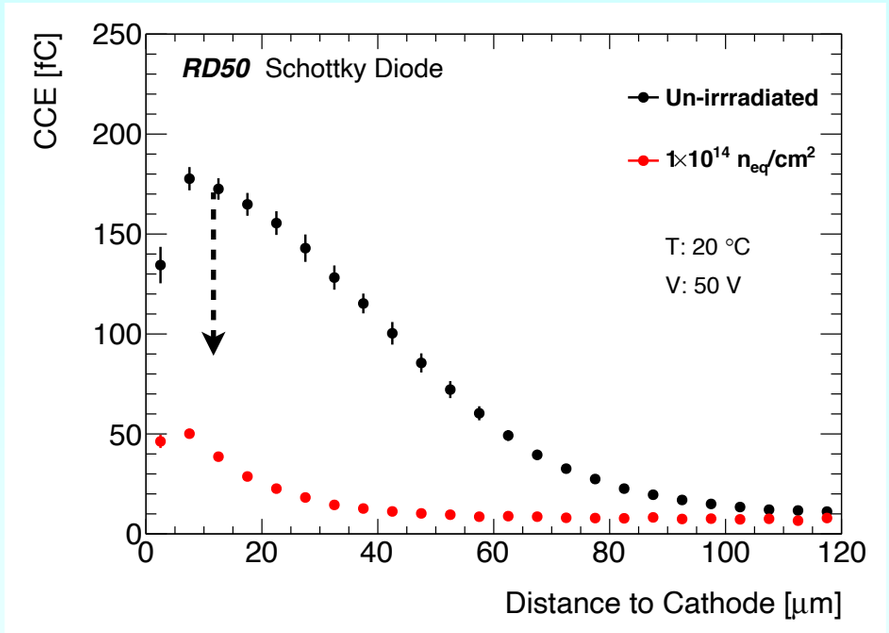


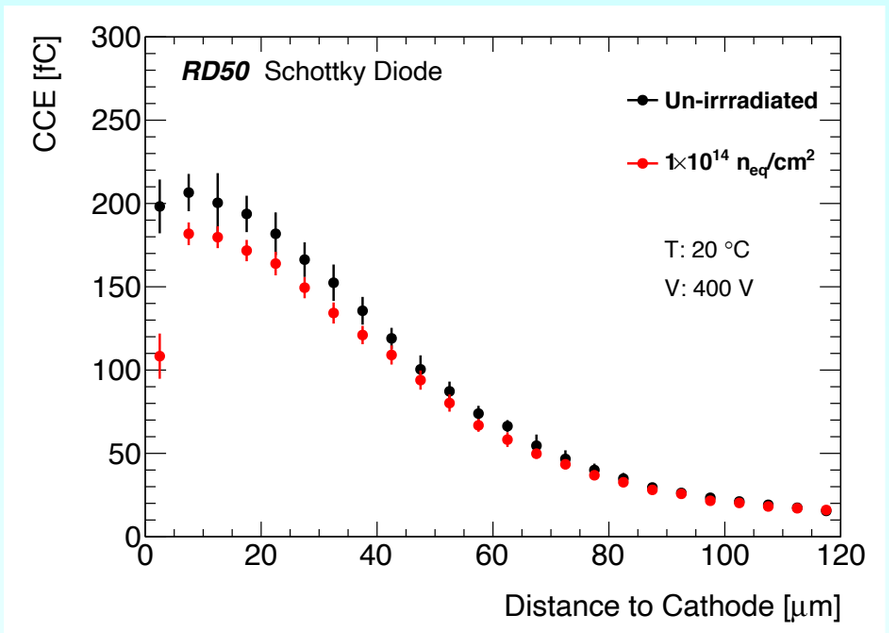


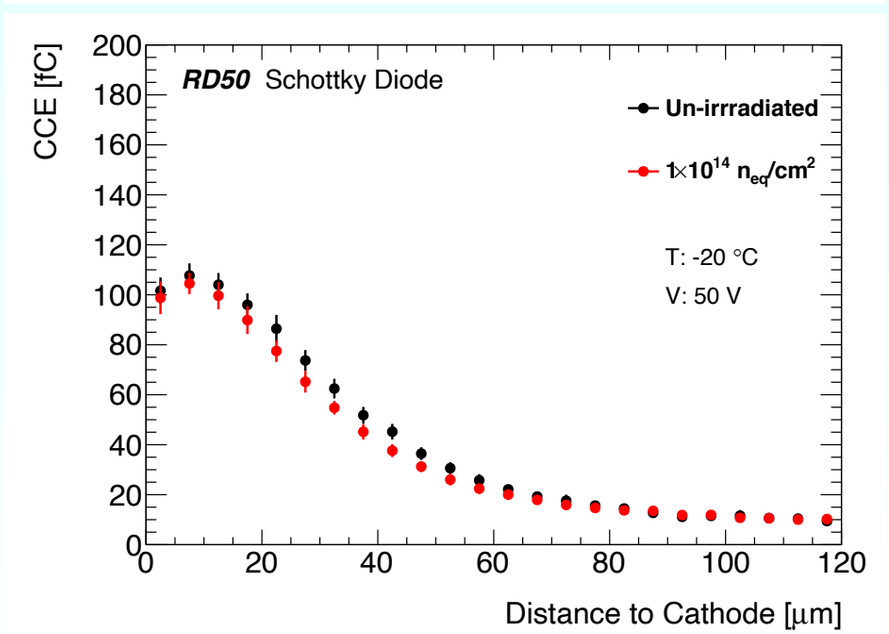


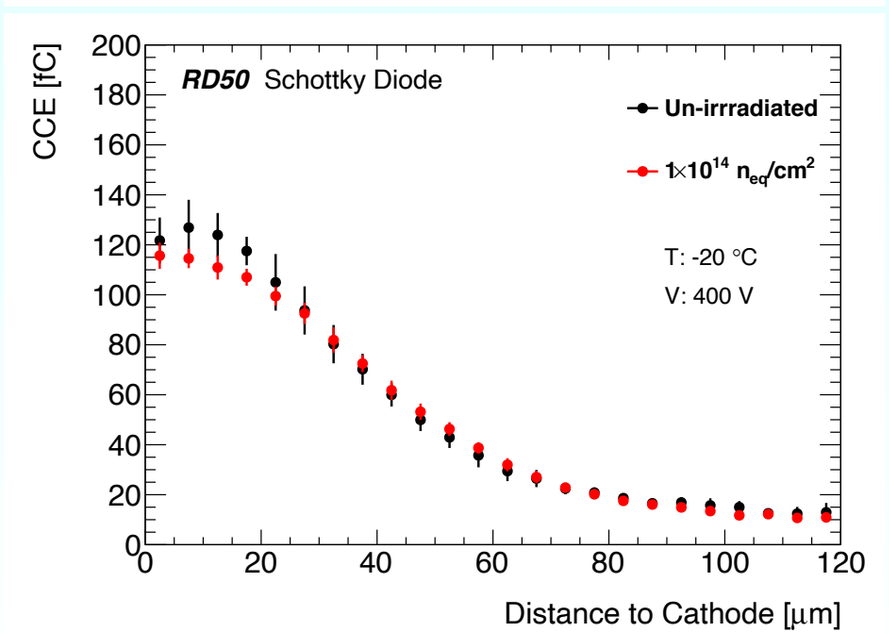
CCE of Schottky diode

- CCEs of un-irradiated and irradiated($1 \times 10^{14}\ n_{eq}/cm^2$) Schottky diodes(T3),
- Low temperature or hight voltage mitigated the charge trapping.



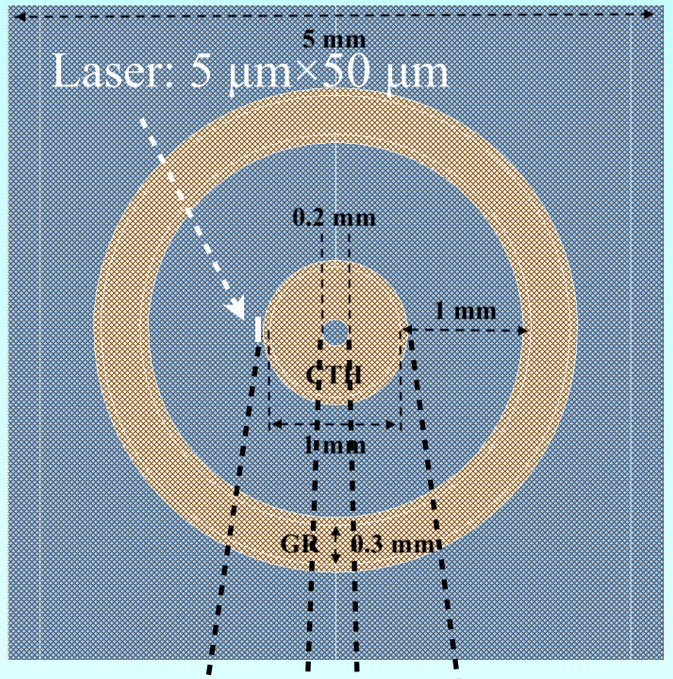


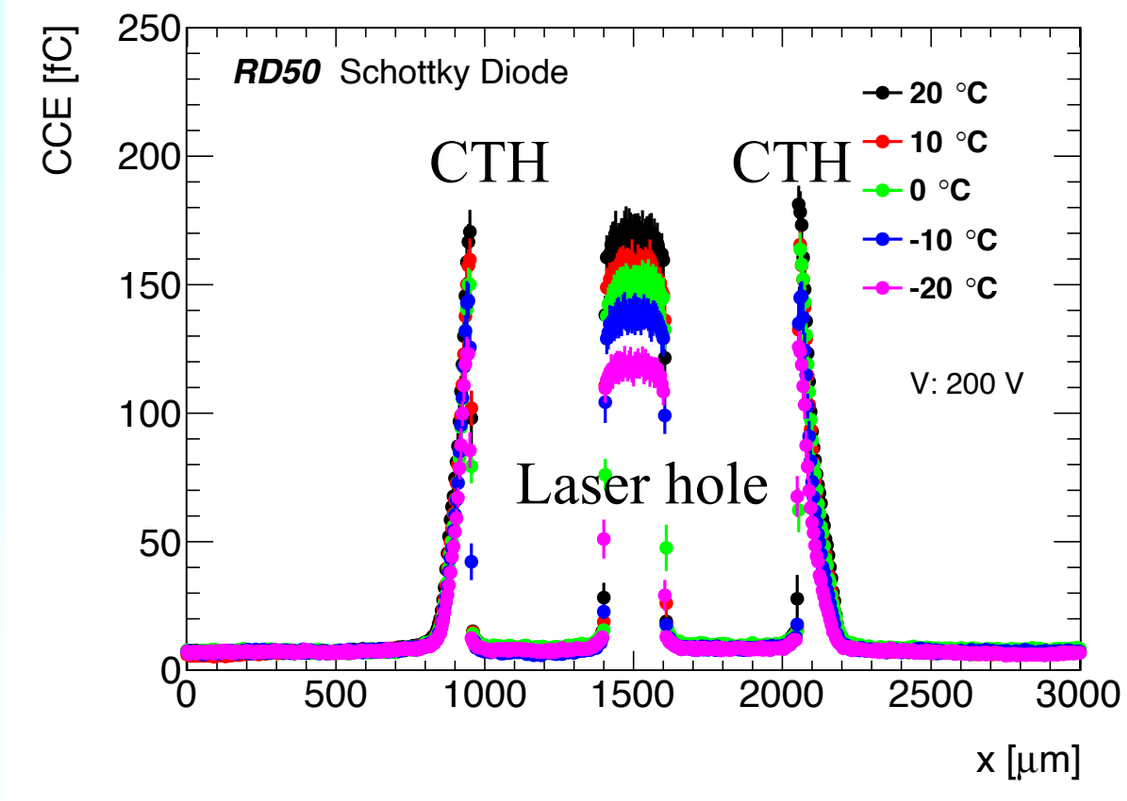


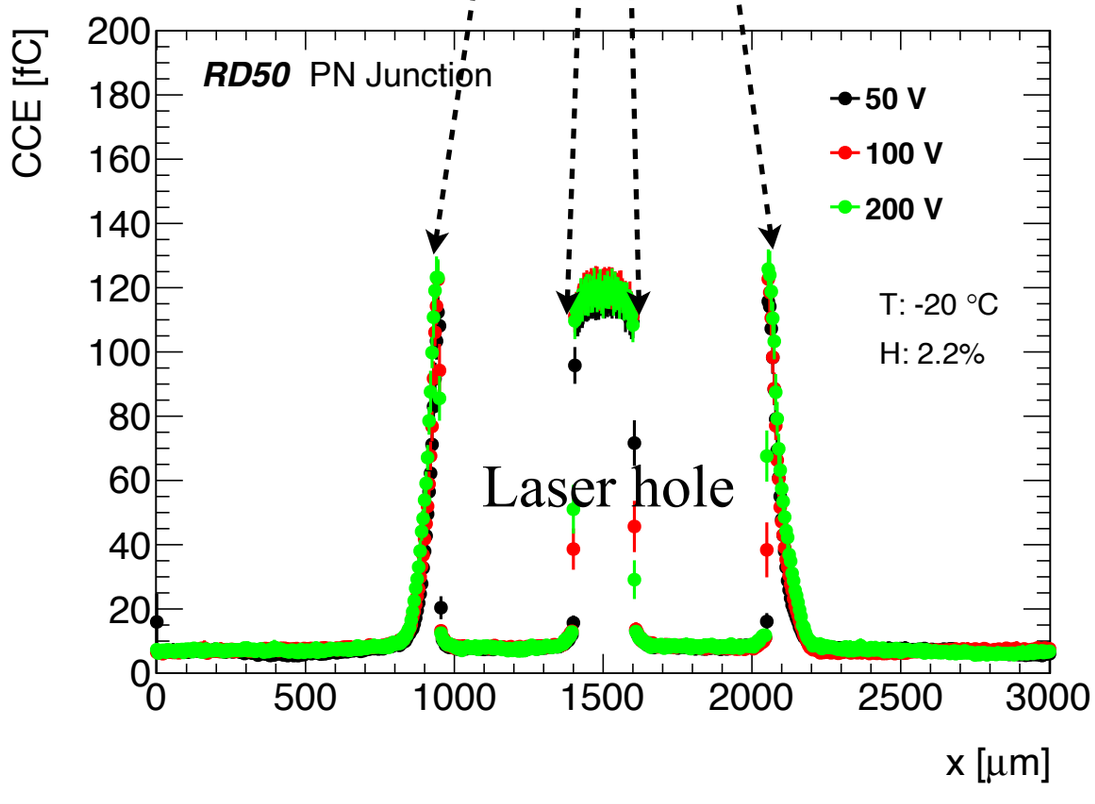


CCE of un-irradiated PN junction

- T2 PN junction with 0.2 mm central hole,
- Bias Voltages: 50, 100, 200 V
- Temperatures: 20, 10, 0, -10, -20 °C

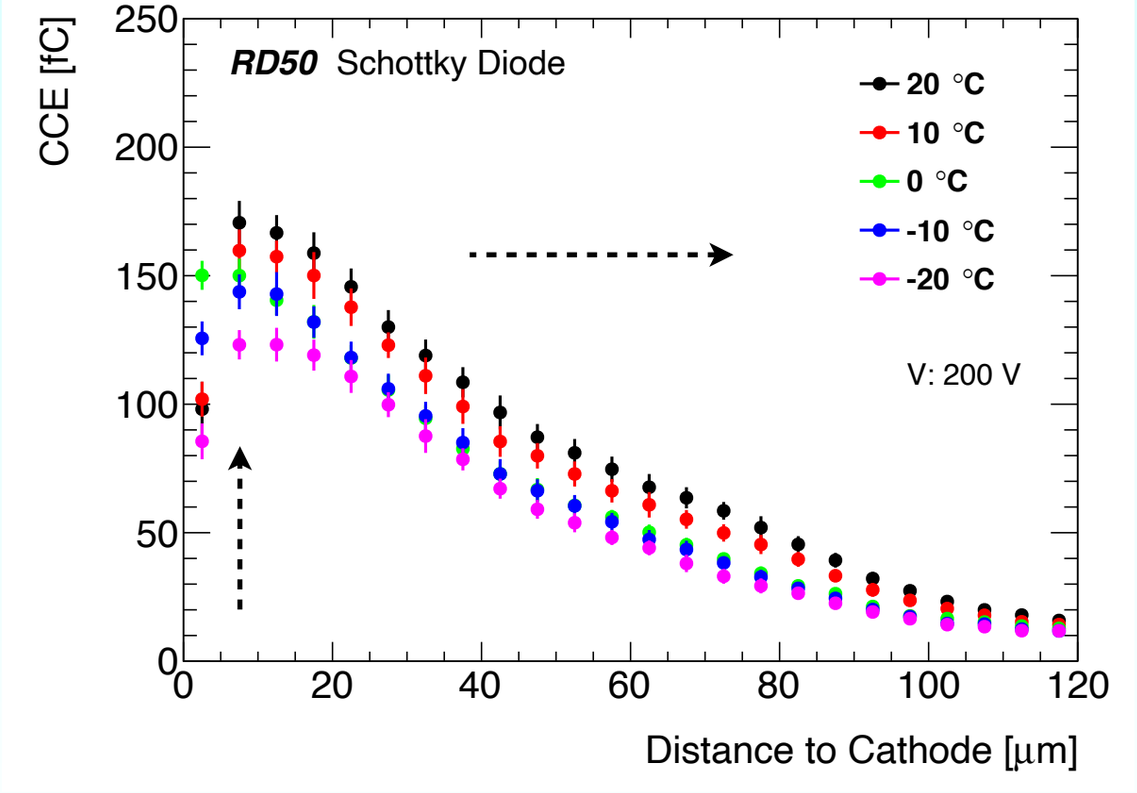


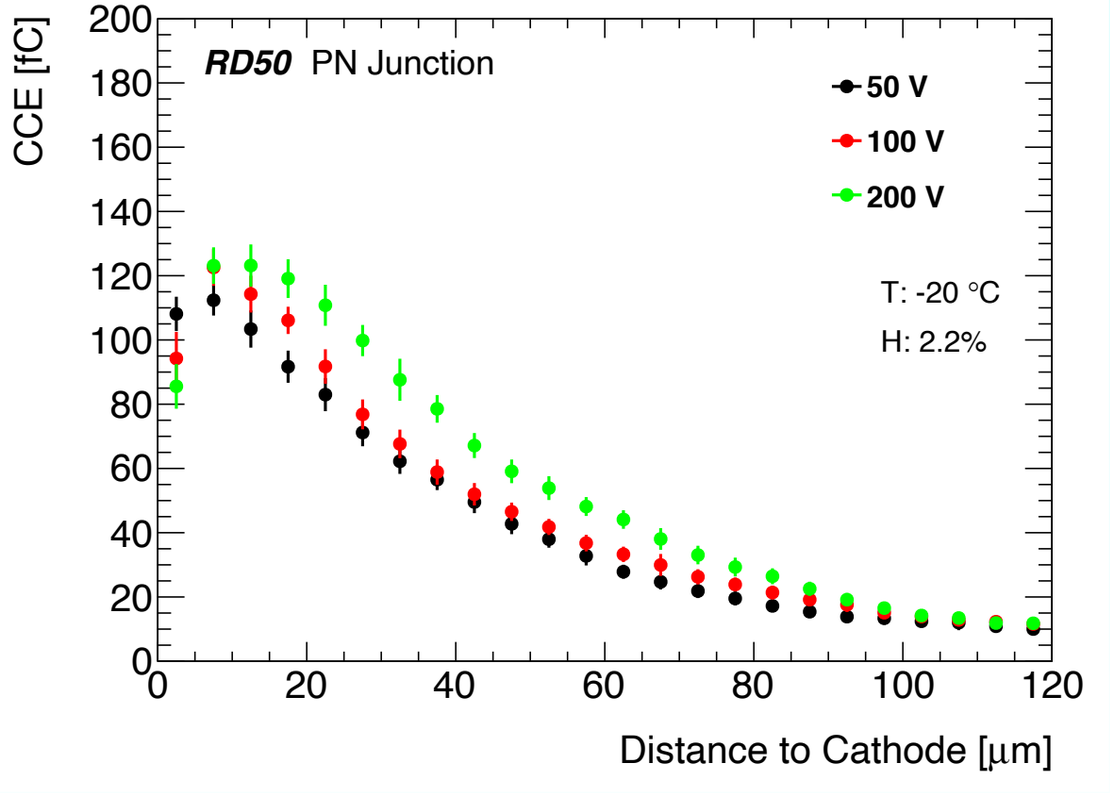




CCE of un-irradiated PN junction

- Depleted thickness decreases with increased distance from the cathode edge,
- At fixed bias voltage, the higher the temperature, the larger the CCE, still under investigation,
- At low temperature, not fully depleted up to 100 V.

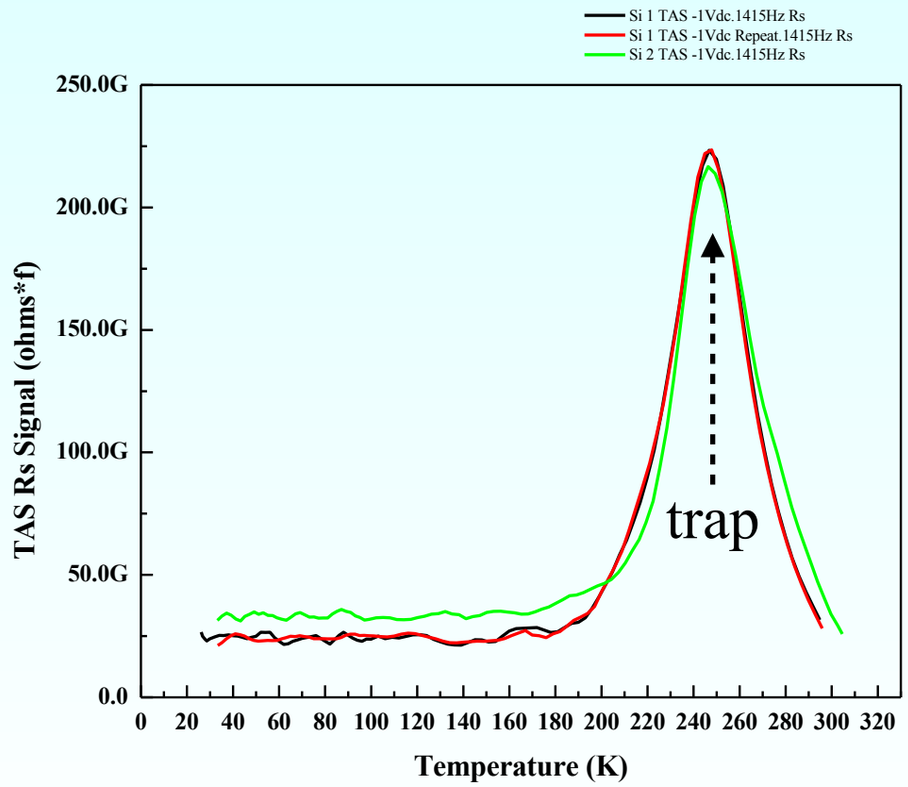


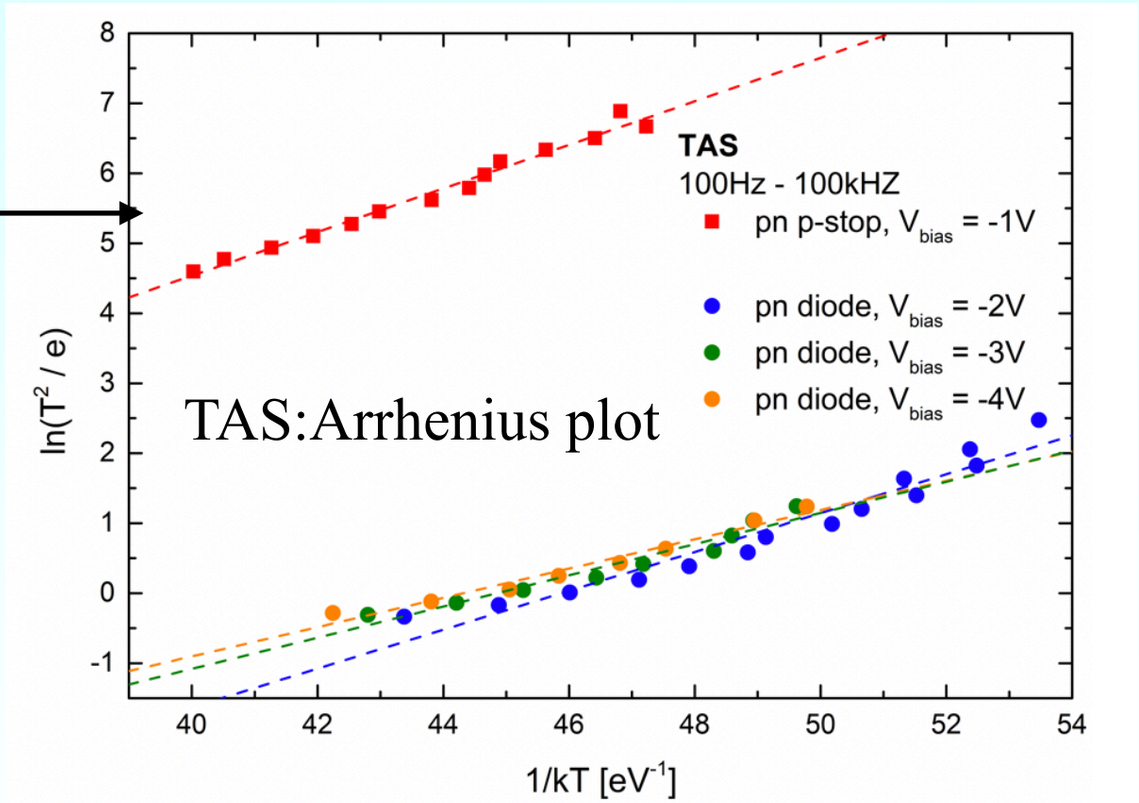


Defect characteristics in TAS and DLTS

Thermal Admittance Spectroscopy(TAS)

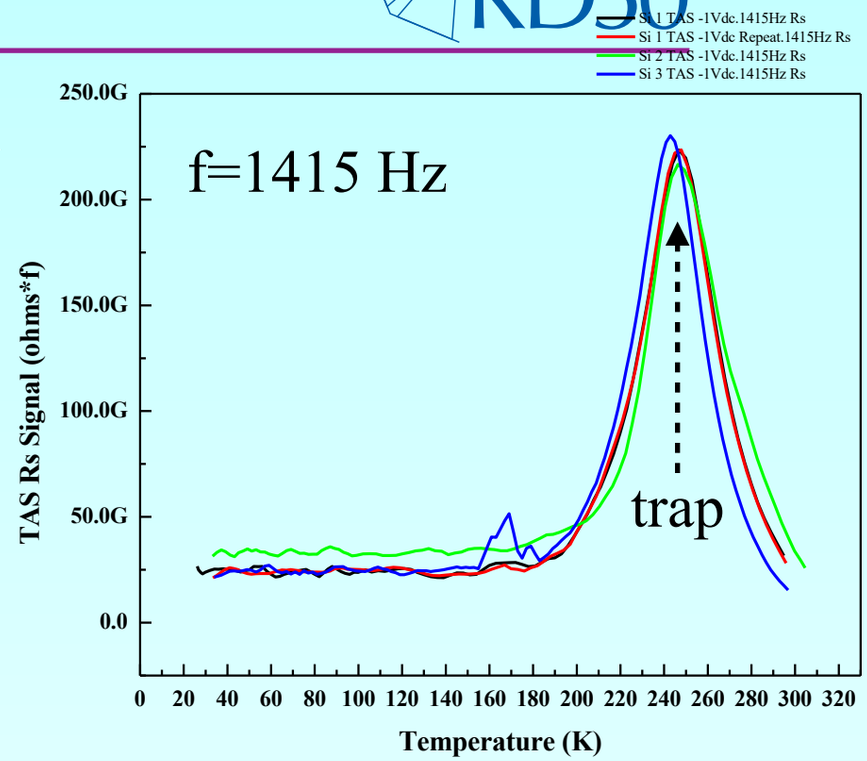
- TAS is steady-state measurement method to detect traps in the semiconductor:
  - Measure capacitance-C and conductance-G as function of frequency and temperature,
  - Defect contribution to C/G depending on test signal frequency and temperature,
  - Steps in C or peak in G temperature dependence indicate thresholds for new traps contributing.





Defect characteristics of Schottky diode in TAS

- Un-irradiated Schottky diode has been shown in Christoph's report at 40th RD50 Workshop,
- 3 Irradiated(1×10^{15} n_{eq}/cm^2) T3 Schottky diodes:
  - Frequency: 20 Hz -100 kHz,
  - 100 mV test signal amplitude, -1 V DC voltage applied on back.



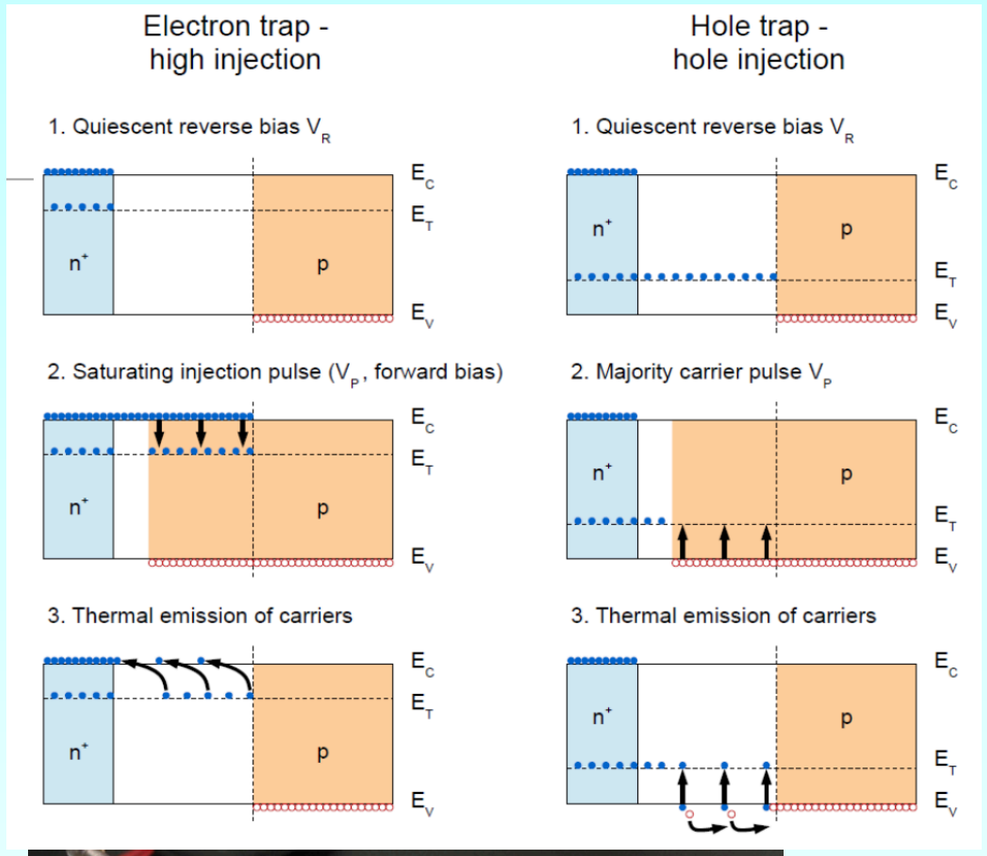
Arrhenius Summary

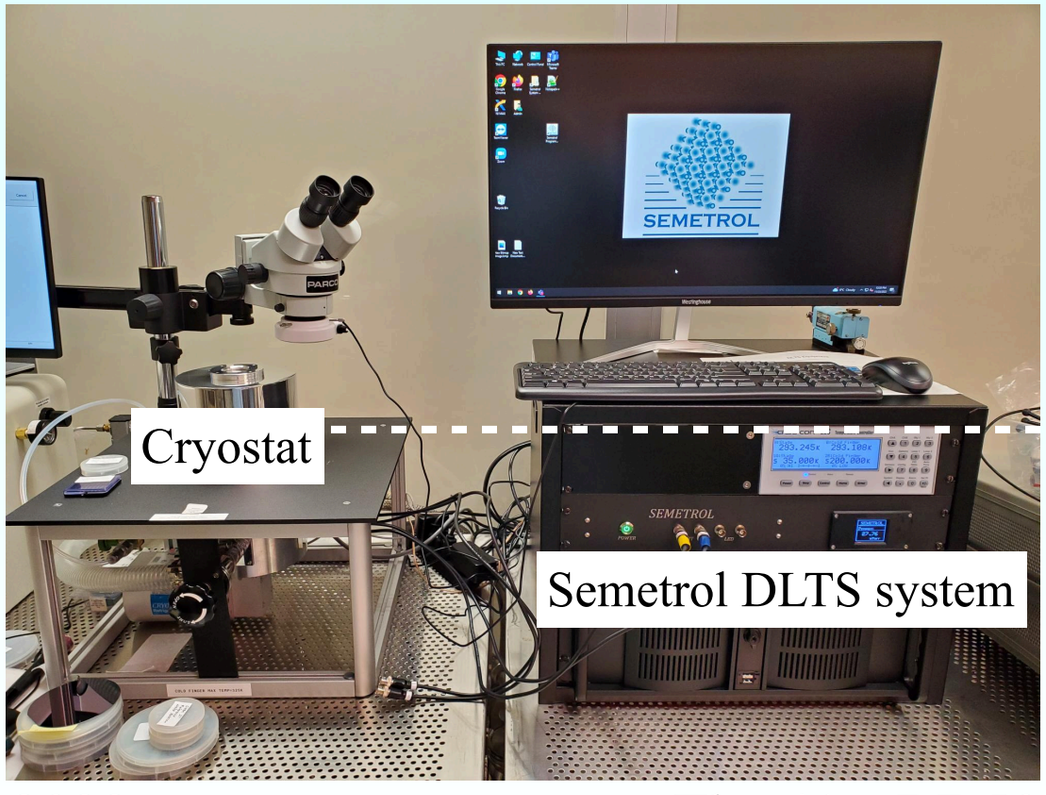
File Name:	Midpoint Temperature (K)	Et (eV)	Delta Et (eV)	Capture Cross Section (cm^2)	Delta Sigma Mult.-Div. Factor
Si 1 TAS -1Vdc.Rs Arr	243.7	0.433	0.006	3.6E-14	1.3E+0
Si 1 TAS -1Vdc Repeat.Rs Arr	236.8	0.422	0.008	2.2E-14	1.5E+0
Si 1 TAS -5Vdc.Rs ARR	243.0	0.409	0.010	7.5E-15	1.7E+0
Si 2 TAS -1Vdc.Rs Arr	242.2	0.486	0.008	4.0E-13	1.5E+0
Si 3 TAS -1Vdc.Rs ARR	239.3	0.445	0.009	9.3E-14	1.5E+0

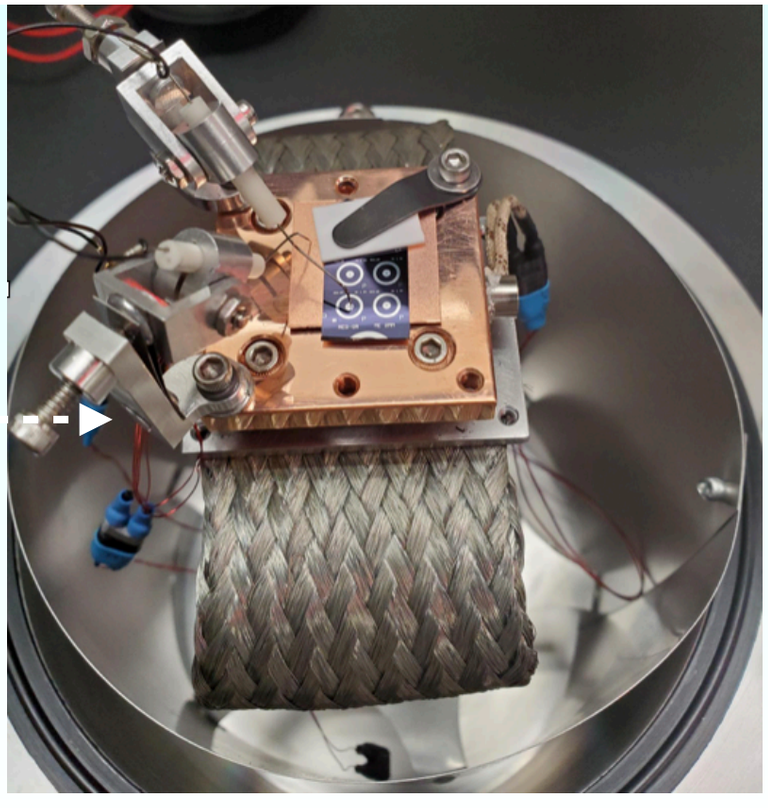
- Trap energy is 0.4-0.5 eV above the valence band with the scattering of ~ 60 meV,
- Error bar on each individual measurement is < 10 meV.

Current Deep Level Transient Spectroscopy(I-DLTS)

- Detects and amplifies current transients:
  - DUT is under constant reverse bias,
  - Fill pulse with specific voltage and duration,
  - Similar to DLTS, but no AC test signal, measures current transients.
- Useful for characterizing samples with small variations in capacitance, complement with TAS for each other.
- More details in Christoph's report at 40th RD50 Workshop.

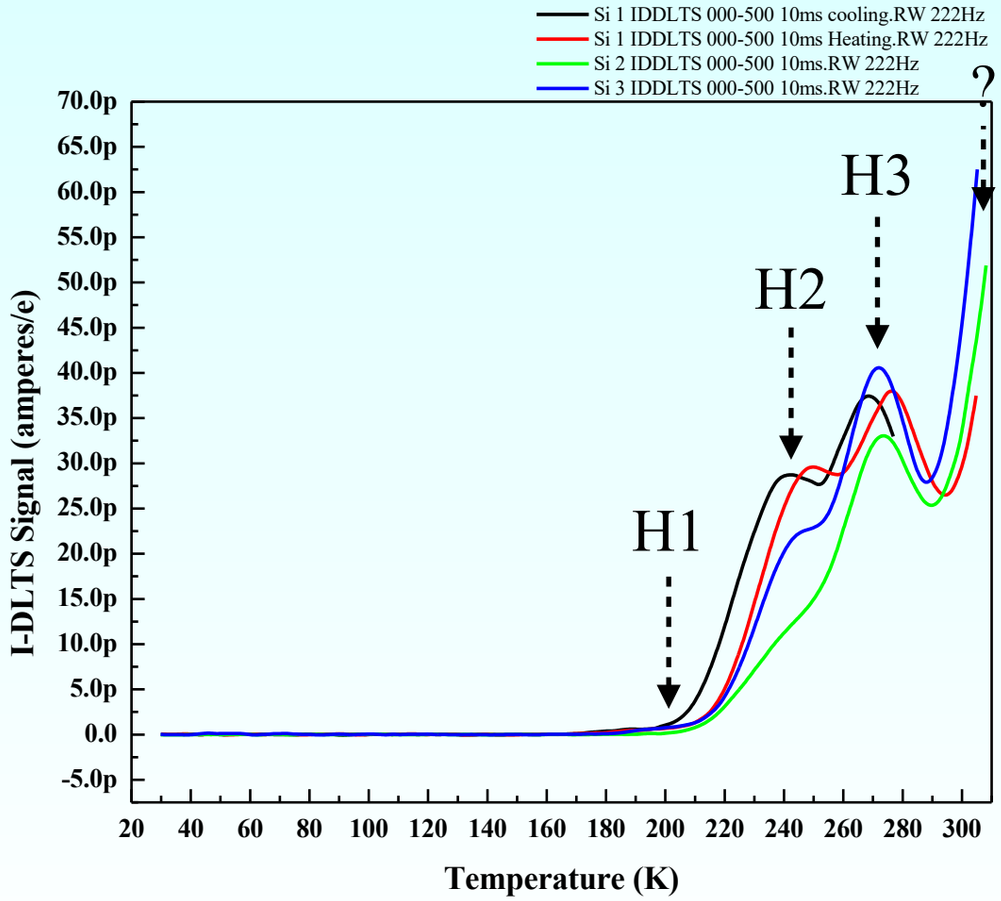






Defect characteristics of Schottky diode in I-DLTS

- 3 Irradiated(1×10^{15} n_{eq}/cm^2) T3 Schottky diode,
- Filling pulse 0 V in 10 ms, then measure at -5 V(back),
- Trap signals at 200, 240, 270 K, possible trap at >300 K,
- Arrhenius plots to extract trap energy and cross-section.



Trap Concentration

Nt ($1/cm^3$)	Si-1	Si-2	Si-3
H1	3.3E+08	1.0E+08	4.3E+08
H2	7.3E+09	4.3E+09	1.0E+10
H3	1.9E+10	1.8E+10	2.4E+10

Trap Energy

	Midpoint T (K)	E_t (eV)	ΔE_t (eV)	$\sigma(cm^2)$	$\Delta\sigma$
H1	200				
H2	250	0.46	0.009	2.4E-15	1.5
H3	275	0.58	0.014	4.5E-14	1.8

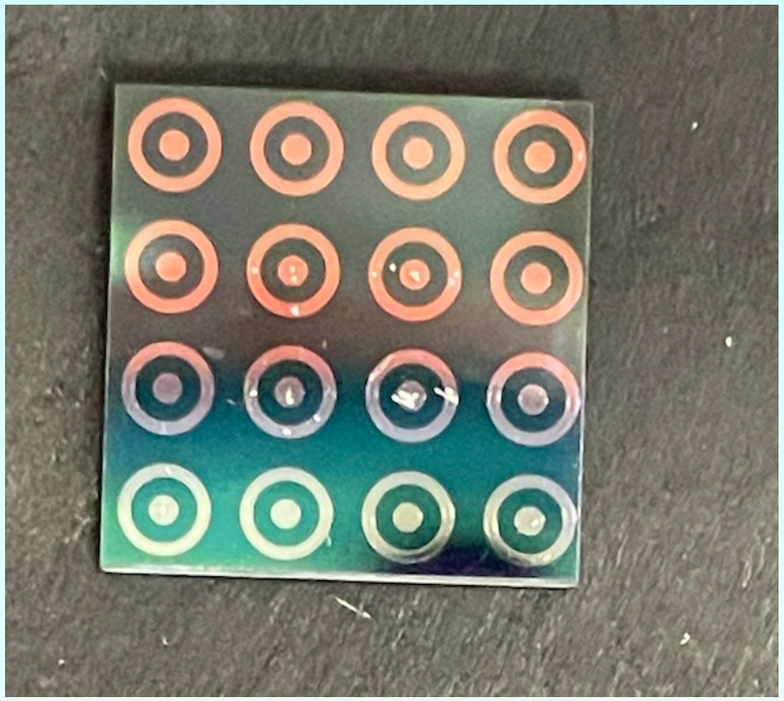
Summary and Outlook

- Several types of Schottky diode and PN junction were fabricated at RAL and Carleton,
- CCEs were measured on un-irradiated Schottky diode and PN junctions,
- Defect characteristics of irradiated Schottky diode were measured in TAS and I-DLTS,
- Need further understanding of the current measurement results, and compare with simulation,
- Irradiated PN junctions will come soon for CCE and defect measurement,
- Import the detected defects into TCAD for simulation.

Thanks

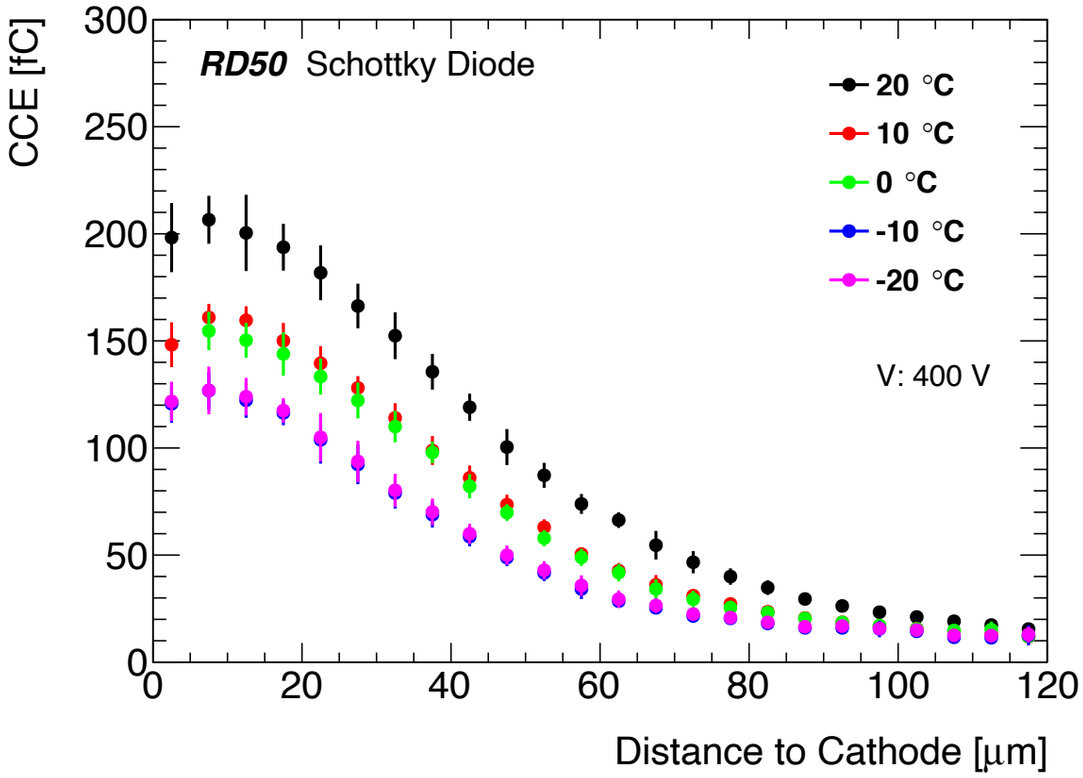
Backup

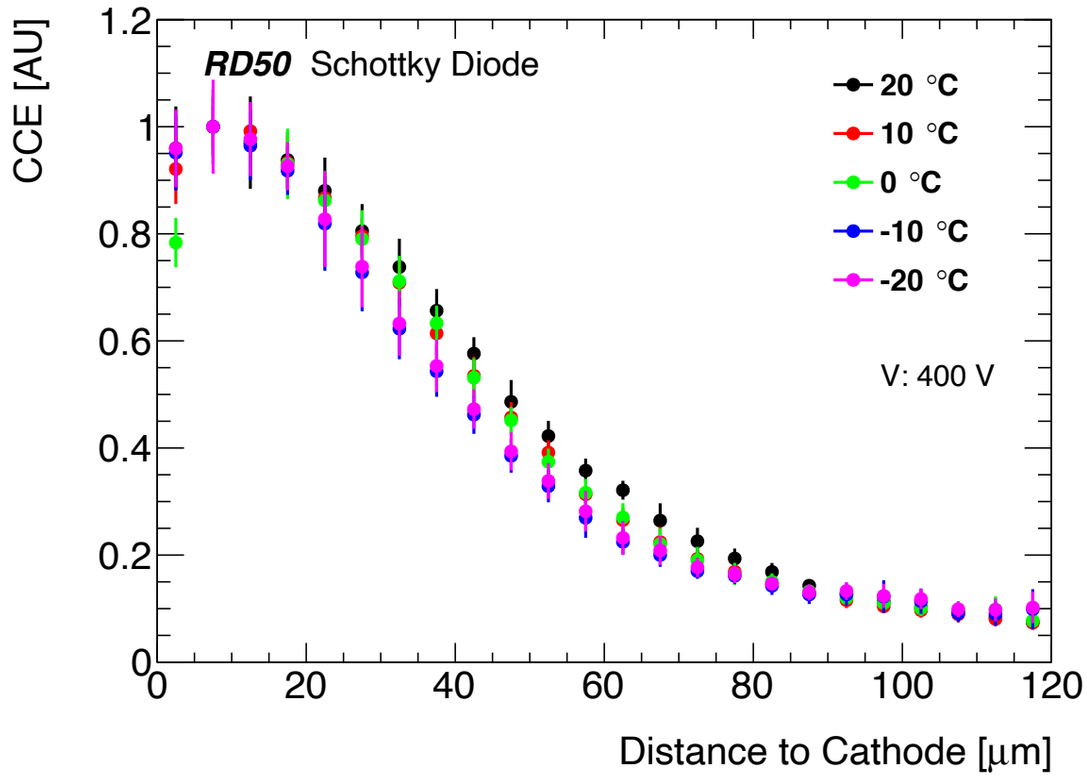
Diced Die

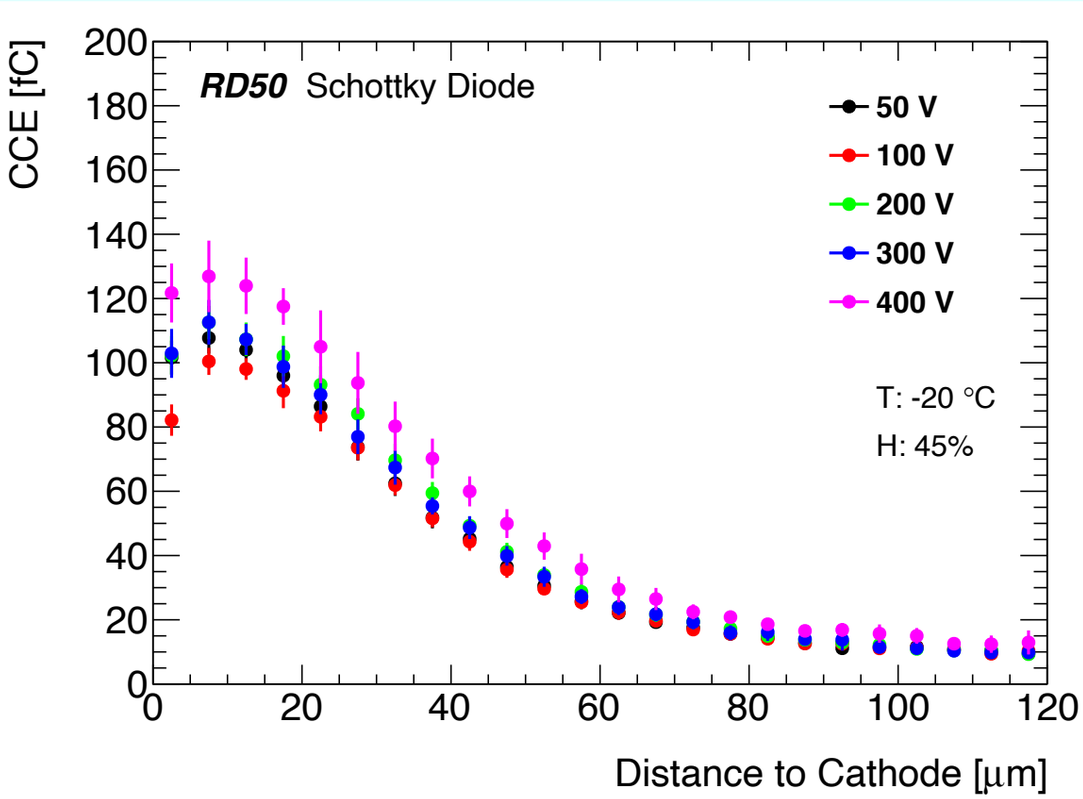


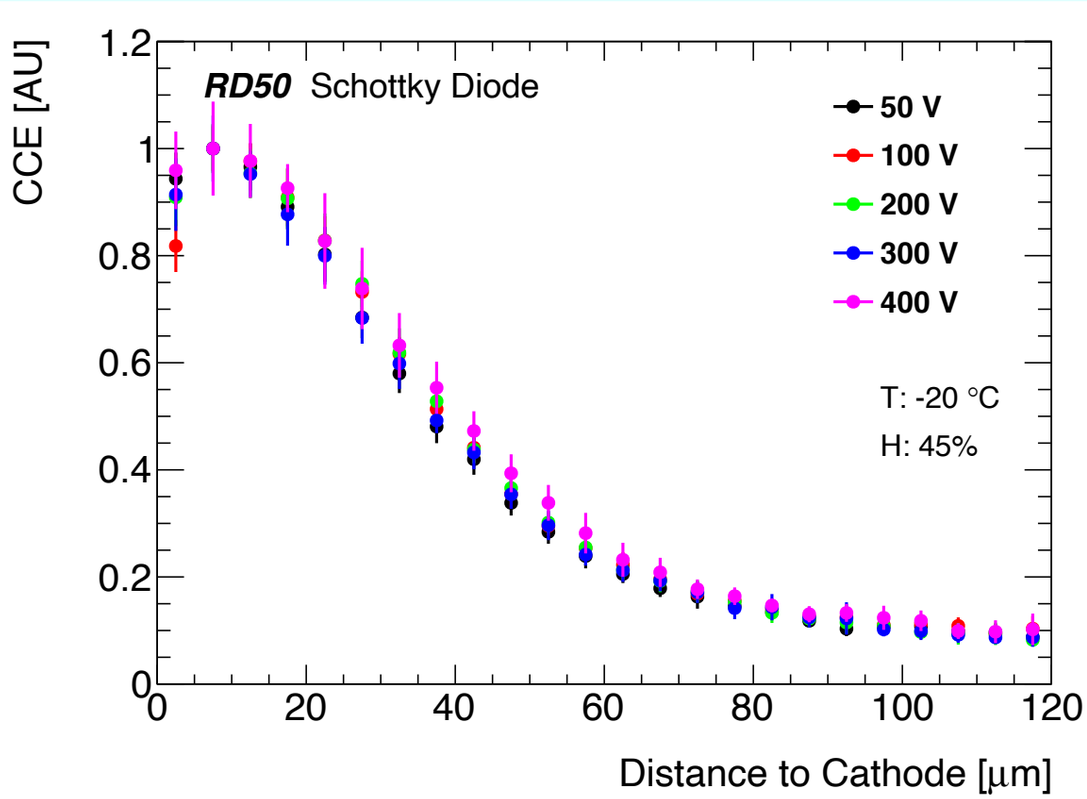

REG-GR
ME 1 MM
REG-GR
ME 1 MM
REG-GR
ME 1 MM
REG-GR
ME 1 MM
REG-GR
ME 2MM

CCE of un-irradiated Schottky diode

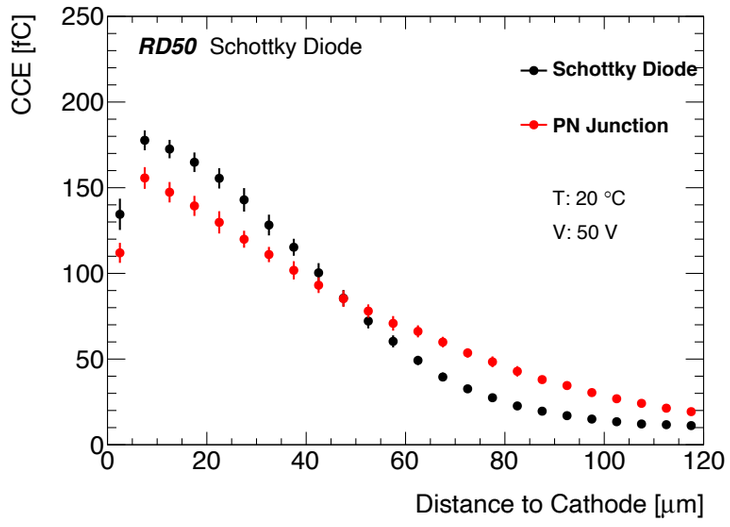


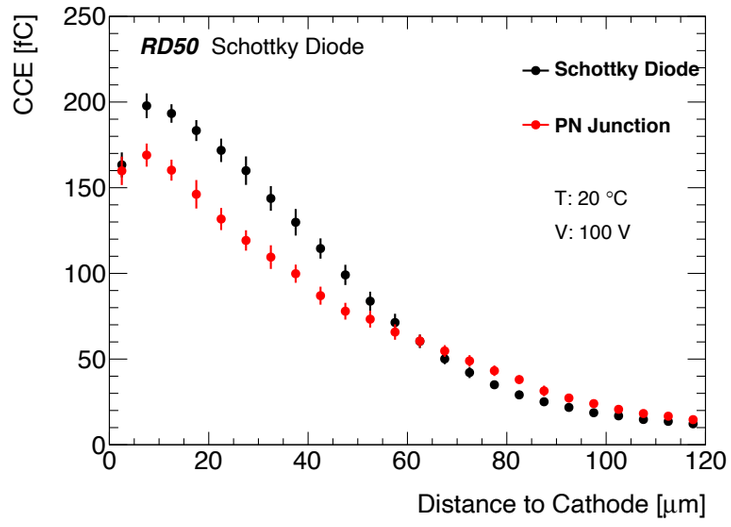


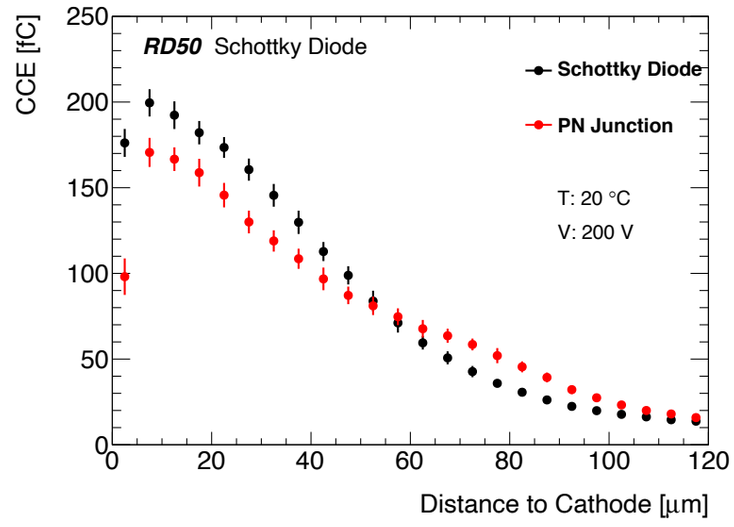


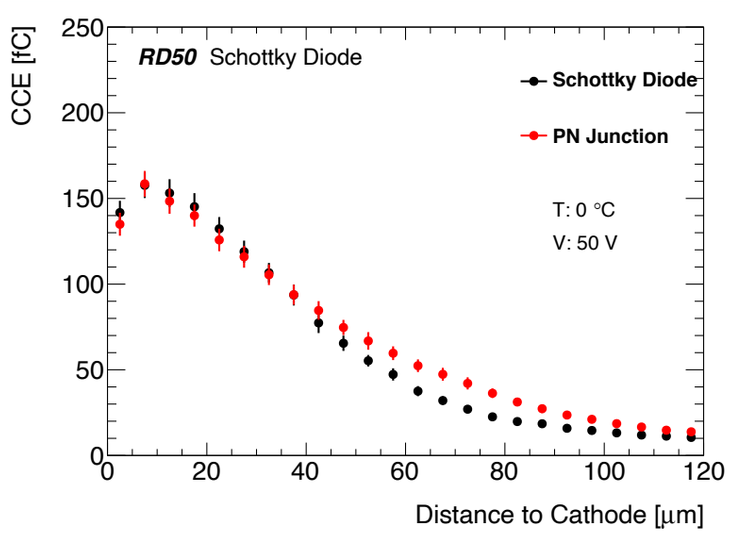


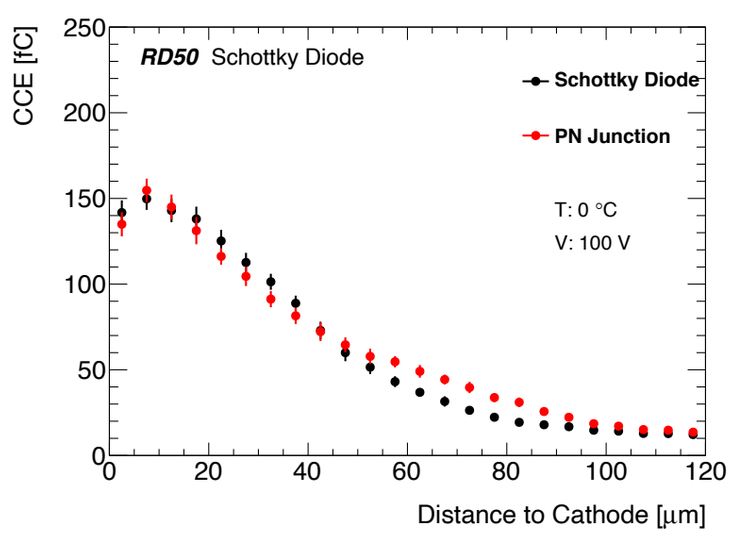
CCE of un-irradiated Schottky diode and PN junction

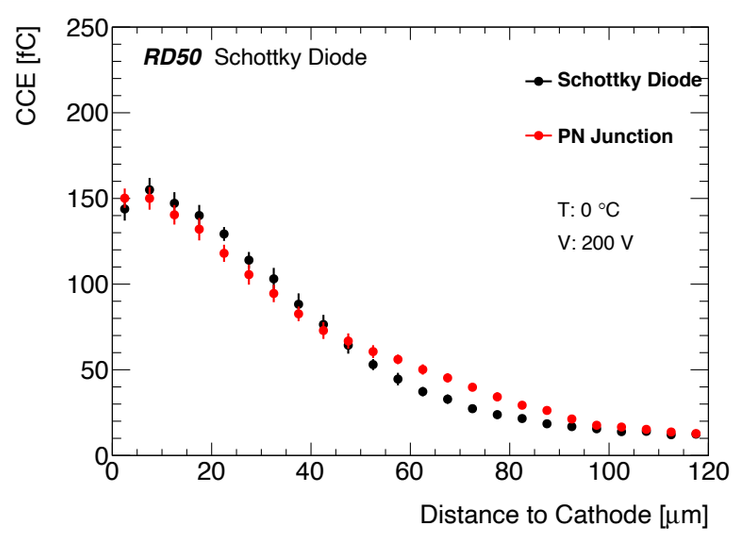


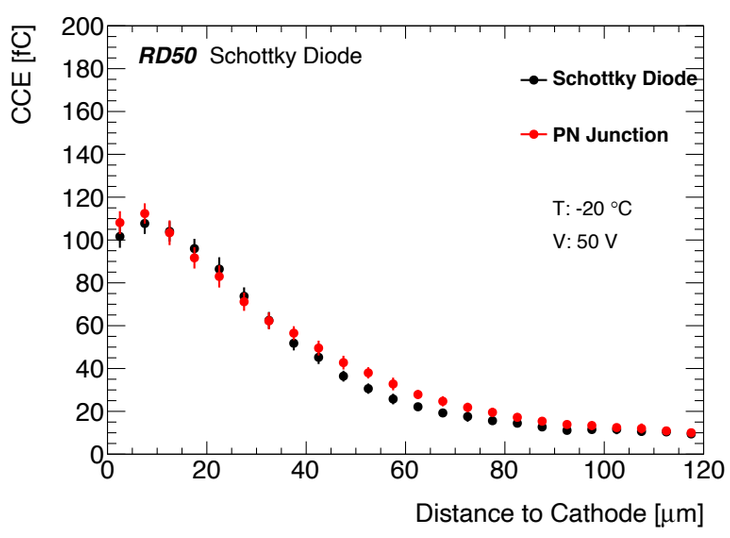


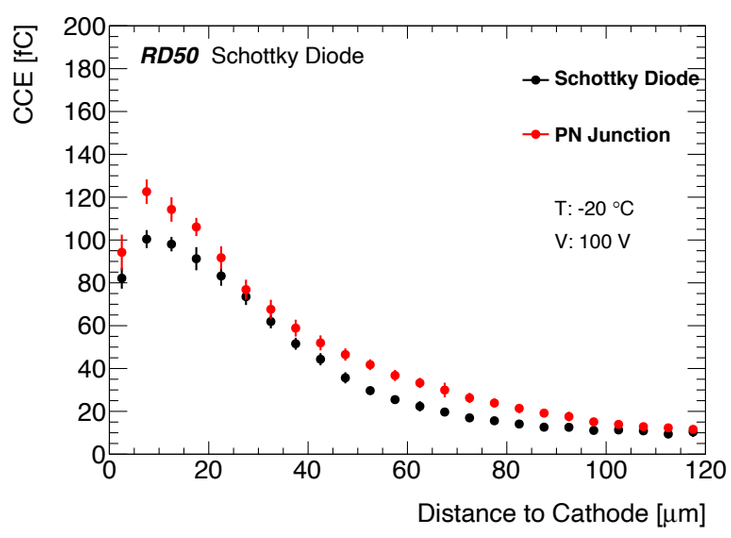


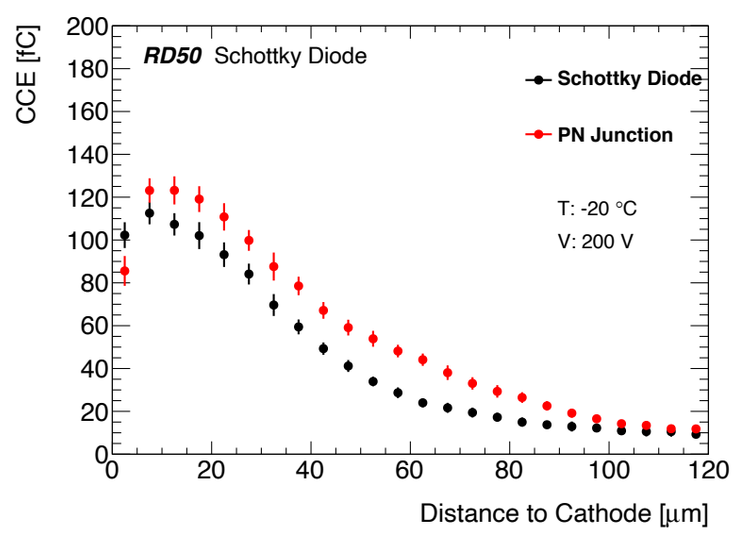






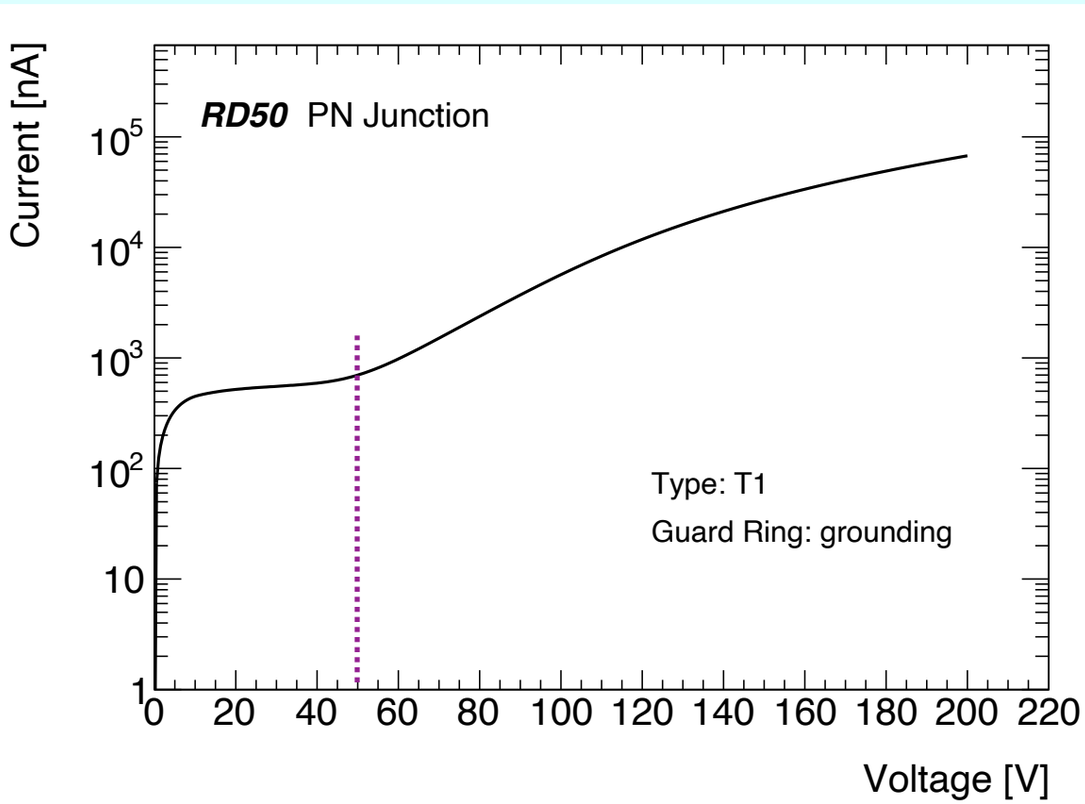


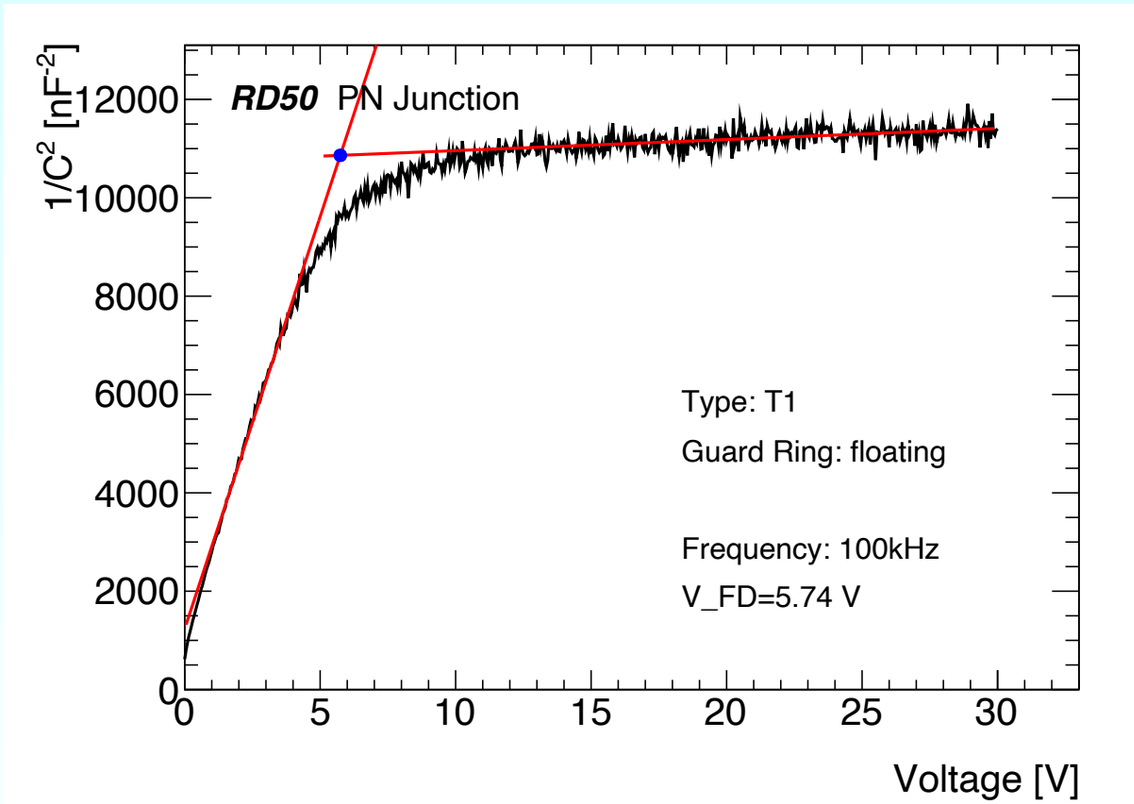




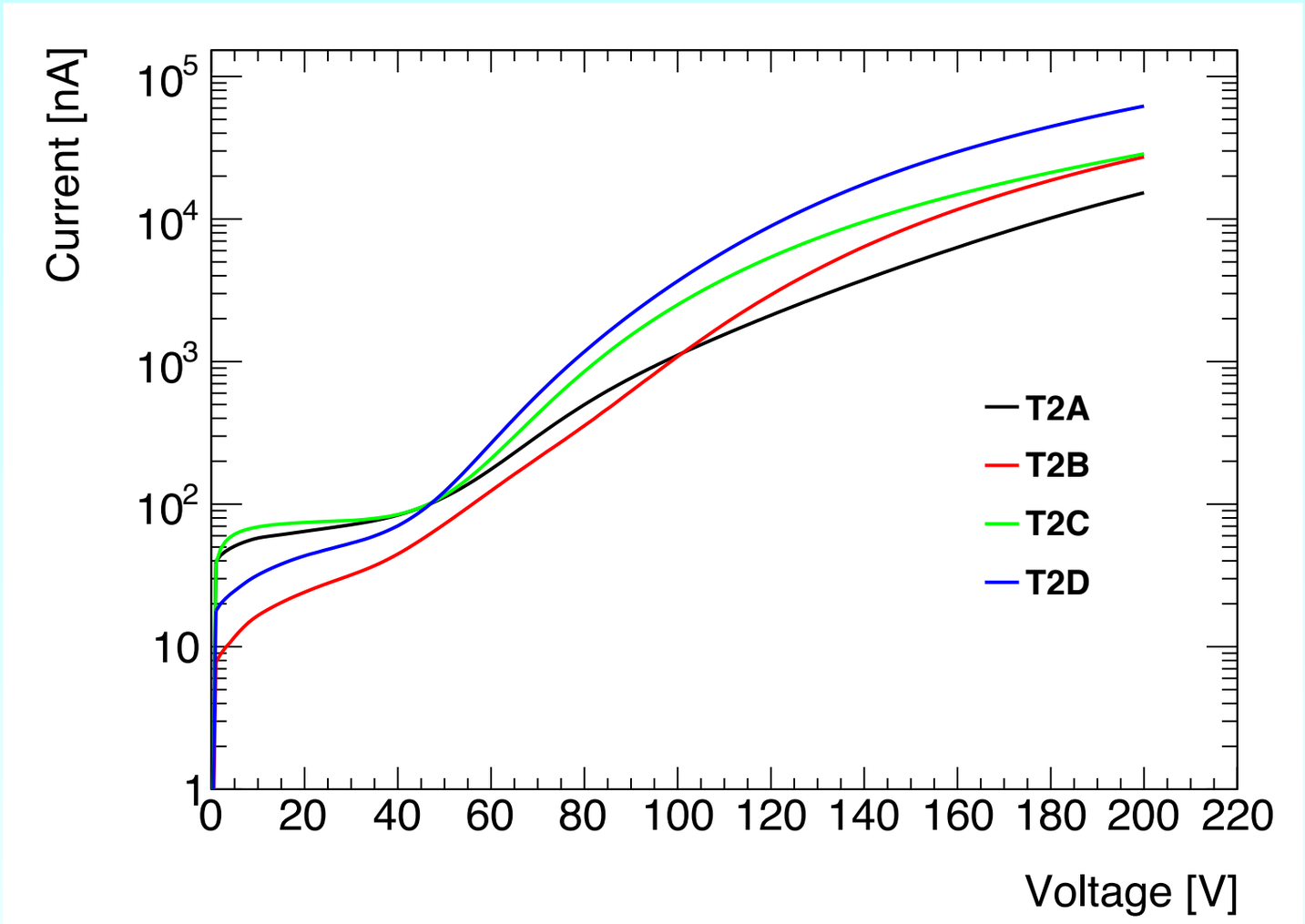
IV/CV of un-irradiated PN junction

- Some leakage current for voltage above 50 V, but no breakdown up to 200 V
- Fully depleted voltage is ~5.74 V





CV of un-irradiated PN junction



IV/CV of un-irradiated PN junction

- Fully depleted voltage is ~6 V