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

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5. Zhejiang University

Nov. 29, 2022

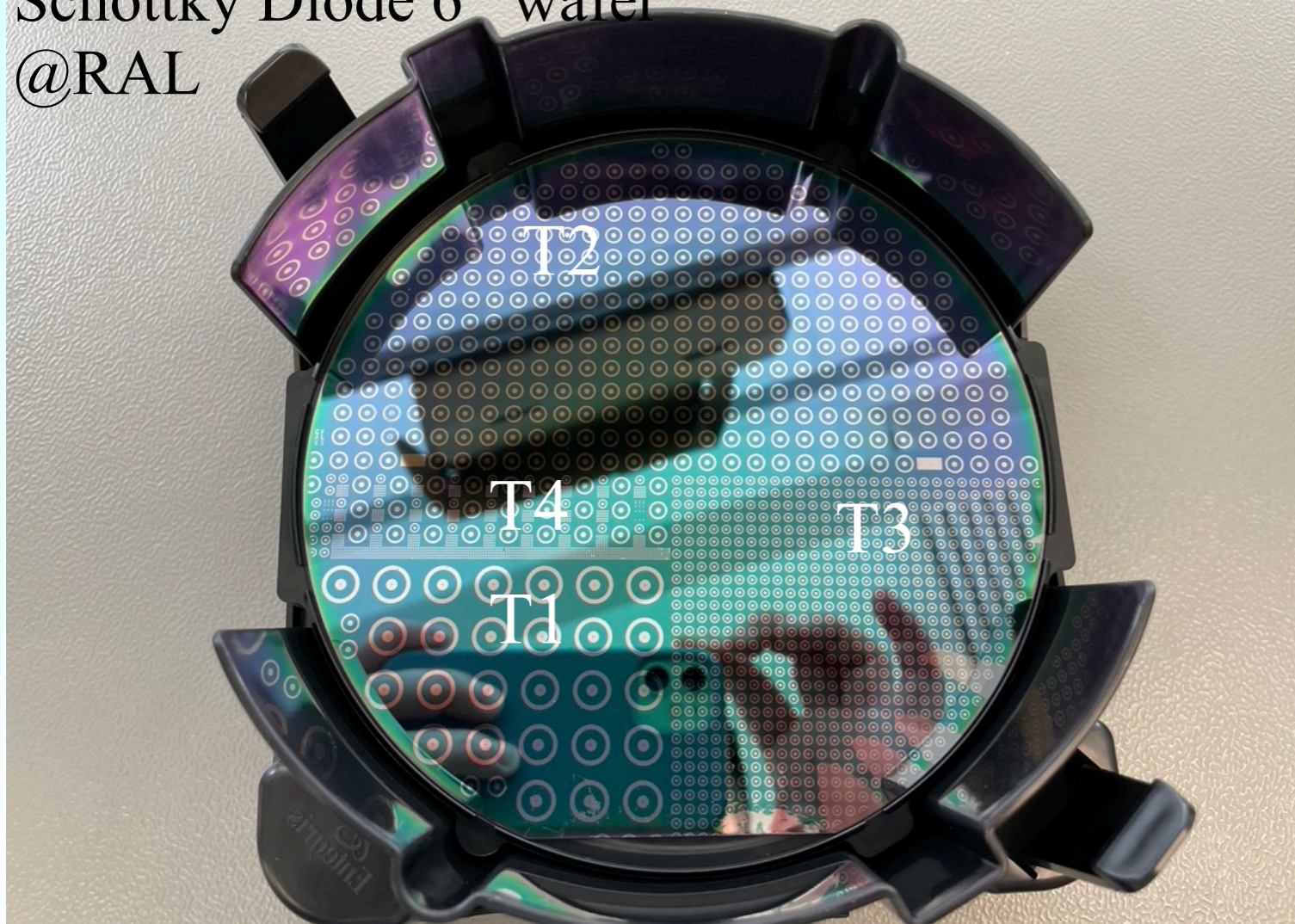
The 41st RD50 Workshop@Sevilla, Spain

- 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.

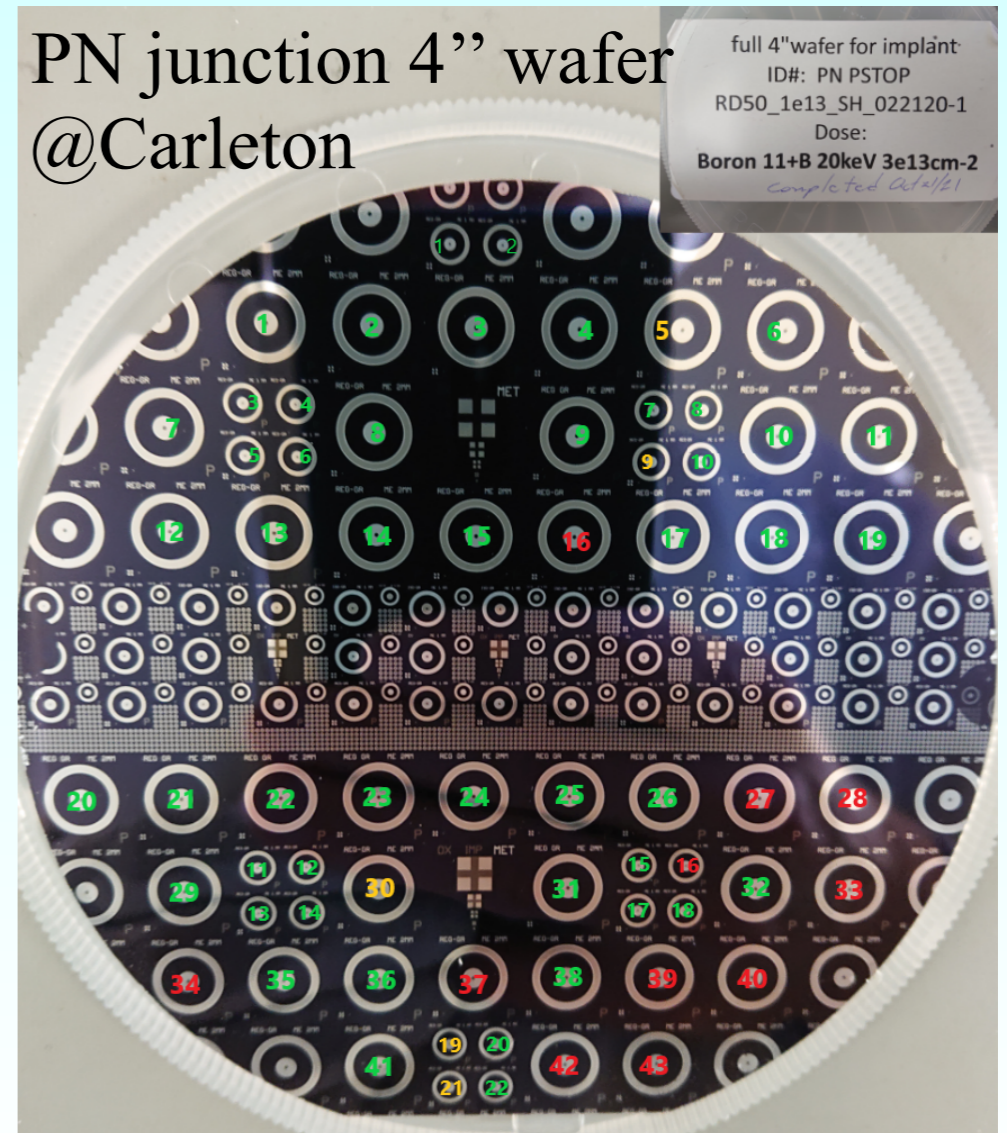
Wafer and device layout

- 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

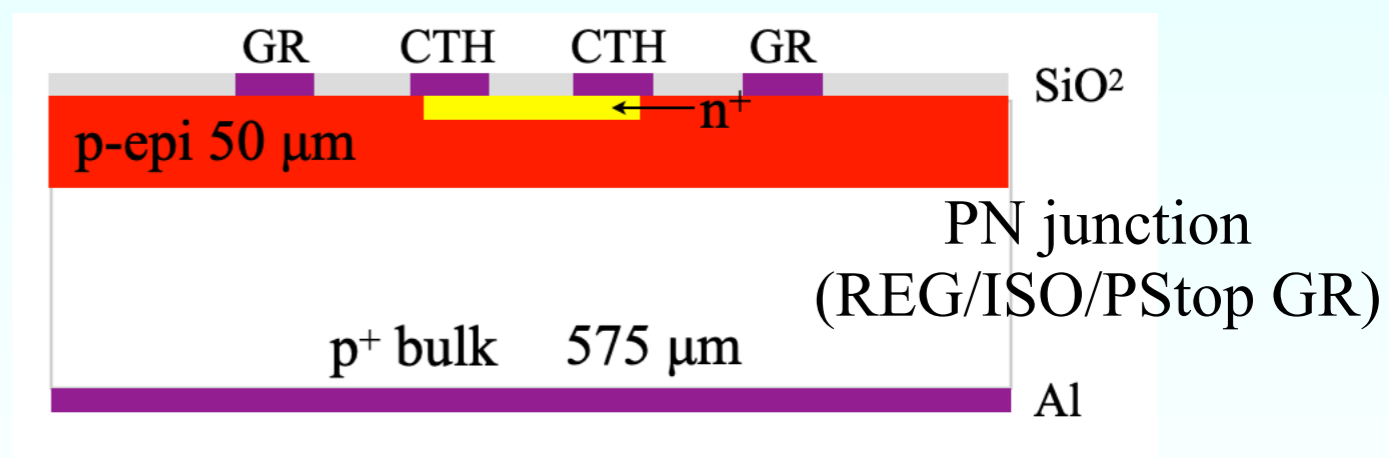
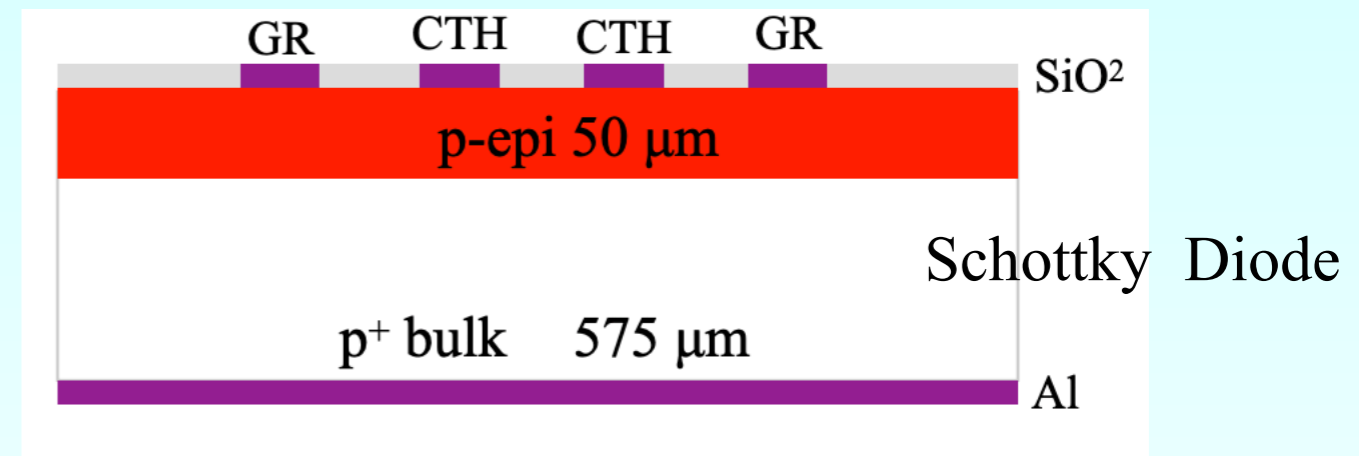
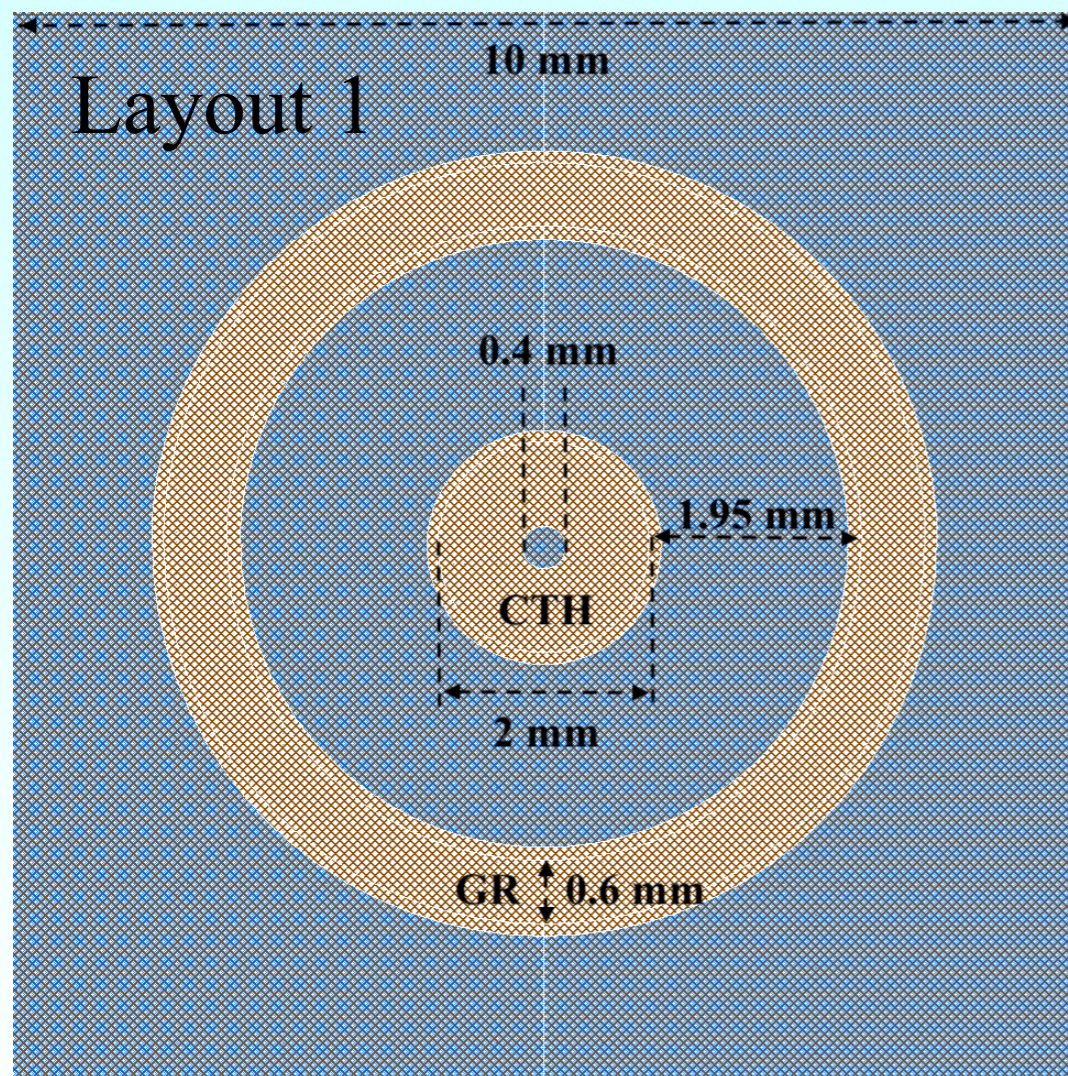


PN junction 4" wafer
@Carleton

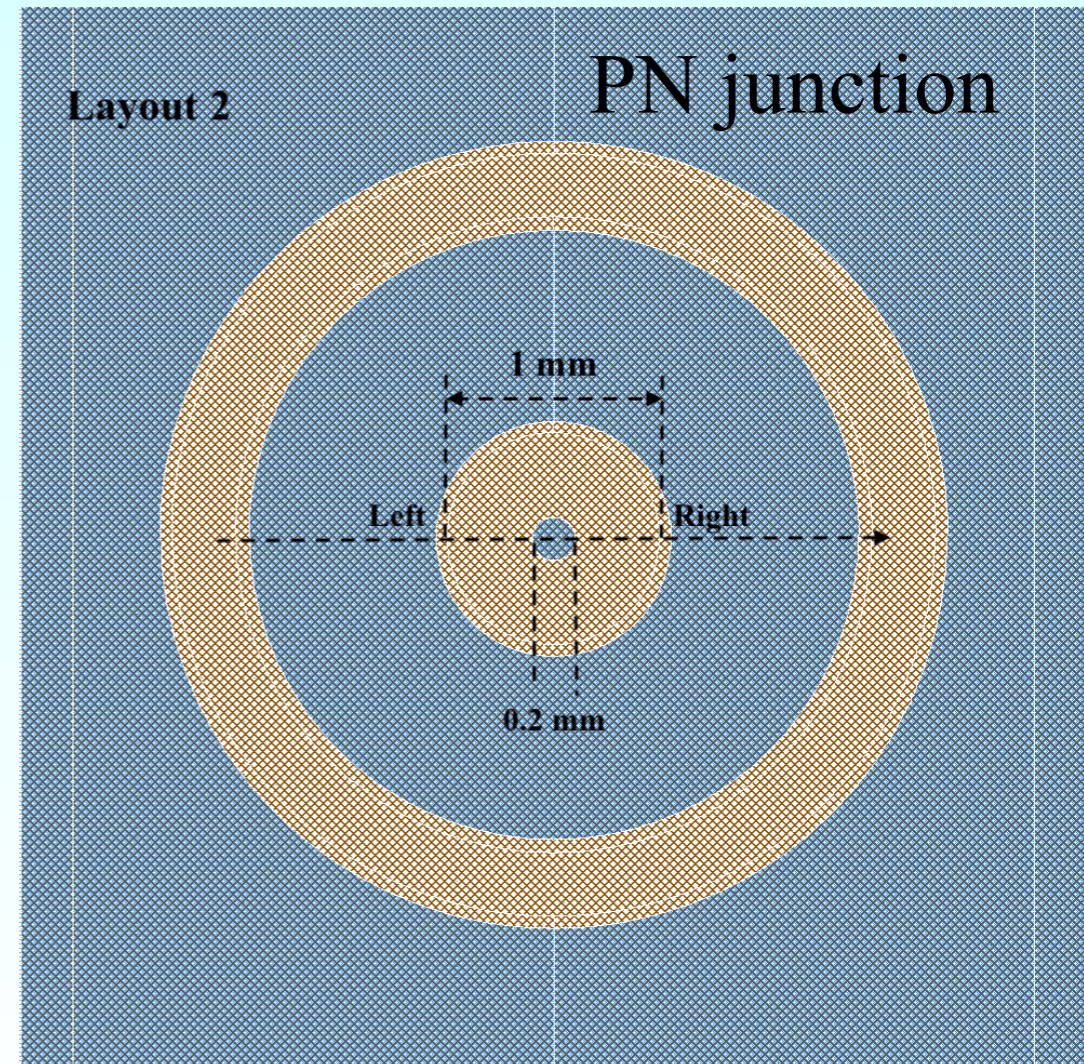
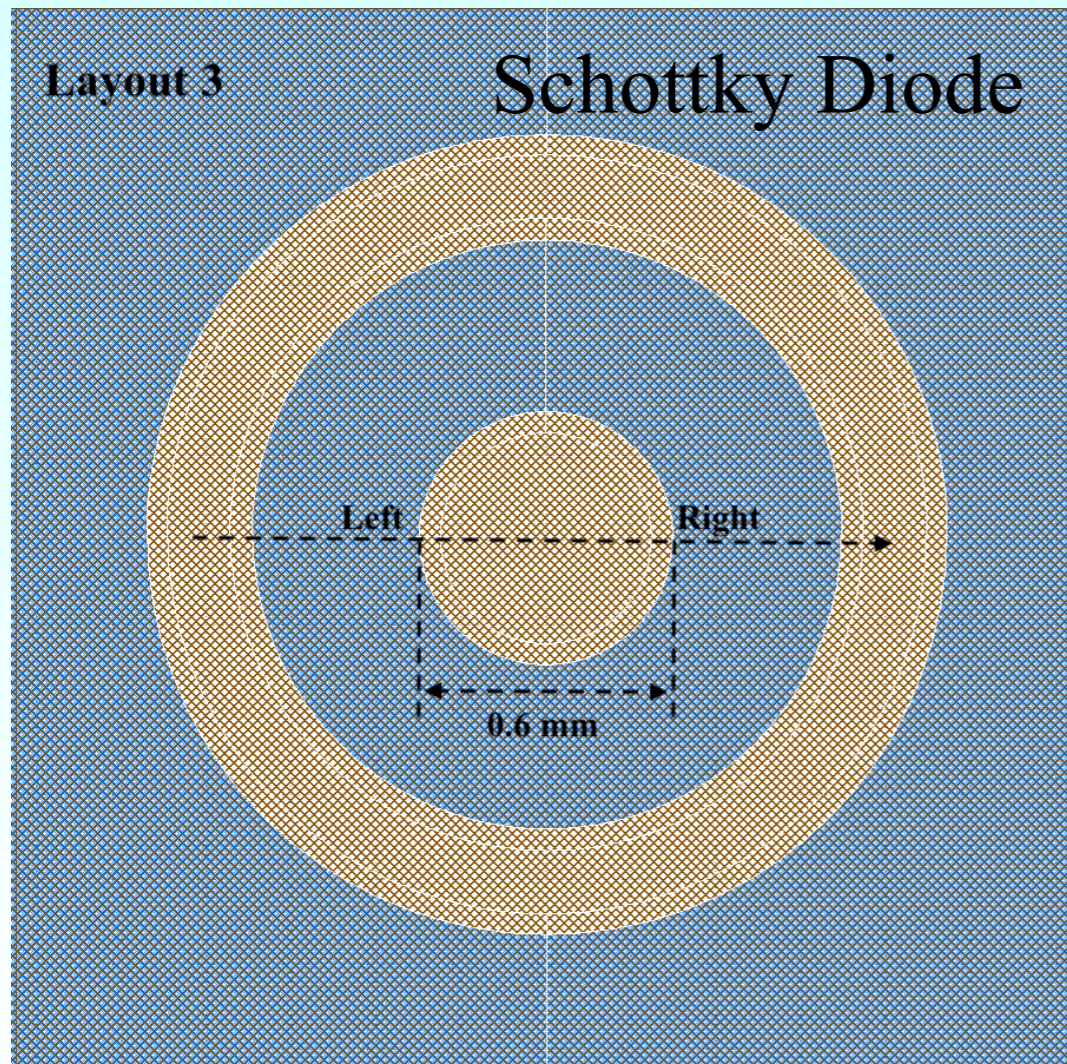


Wafer and device layout

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

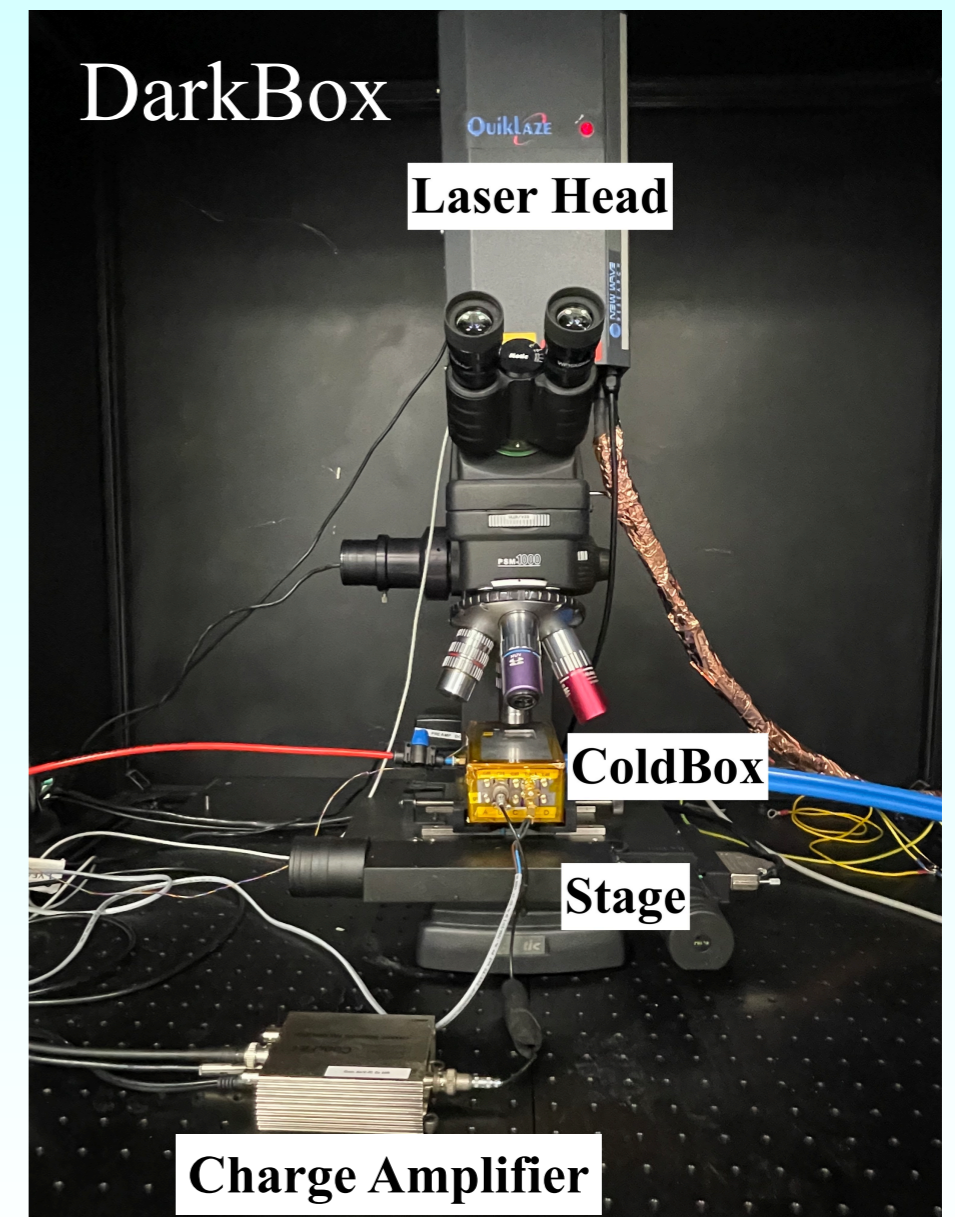
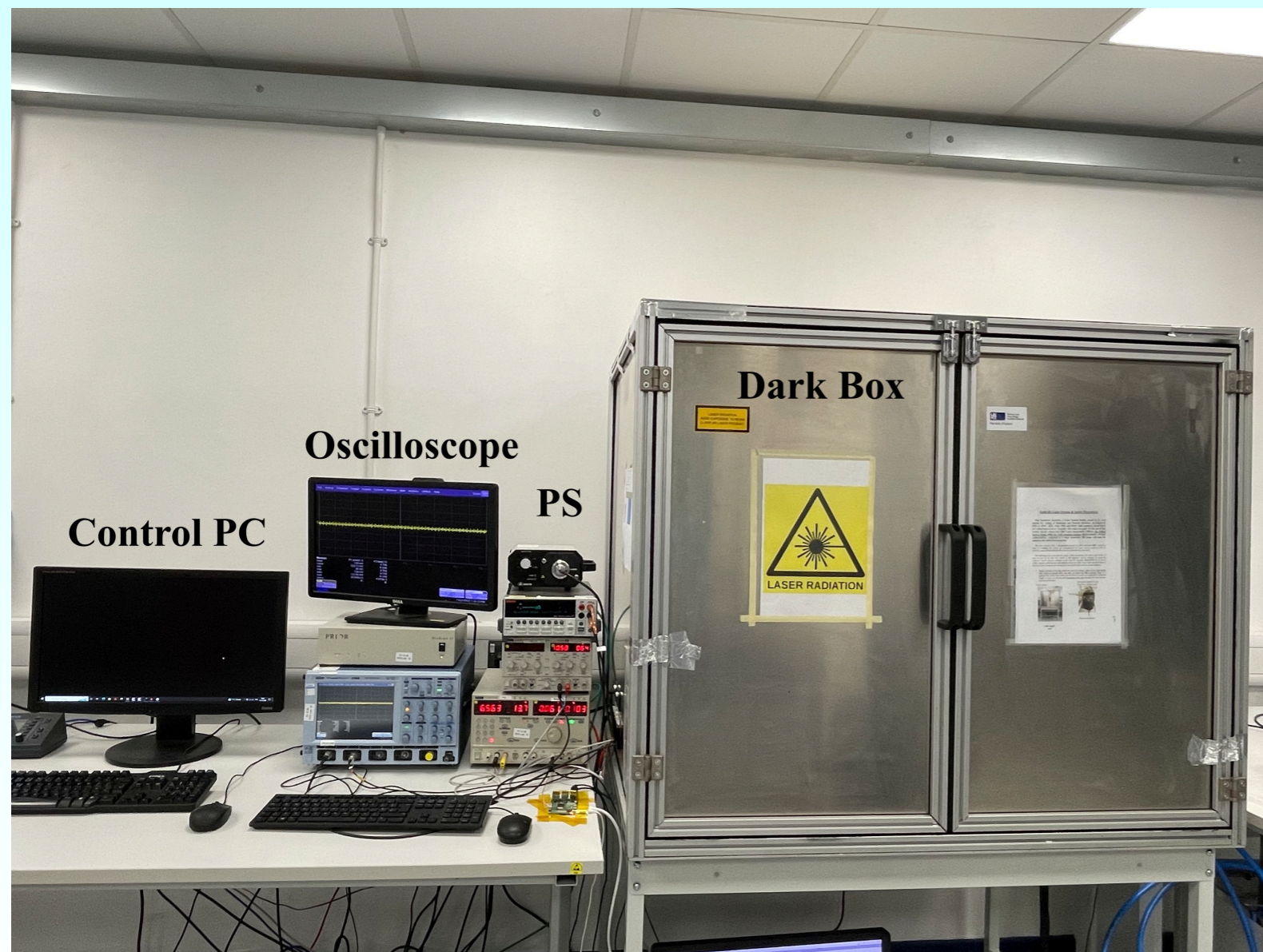


Charge Collection Efficiency



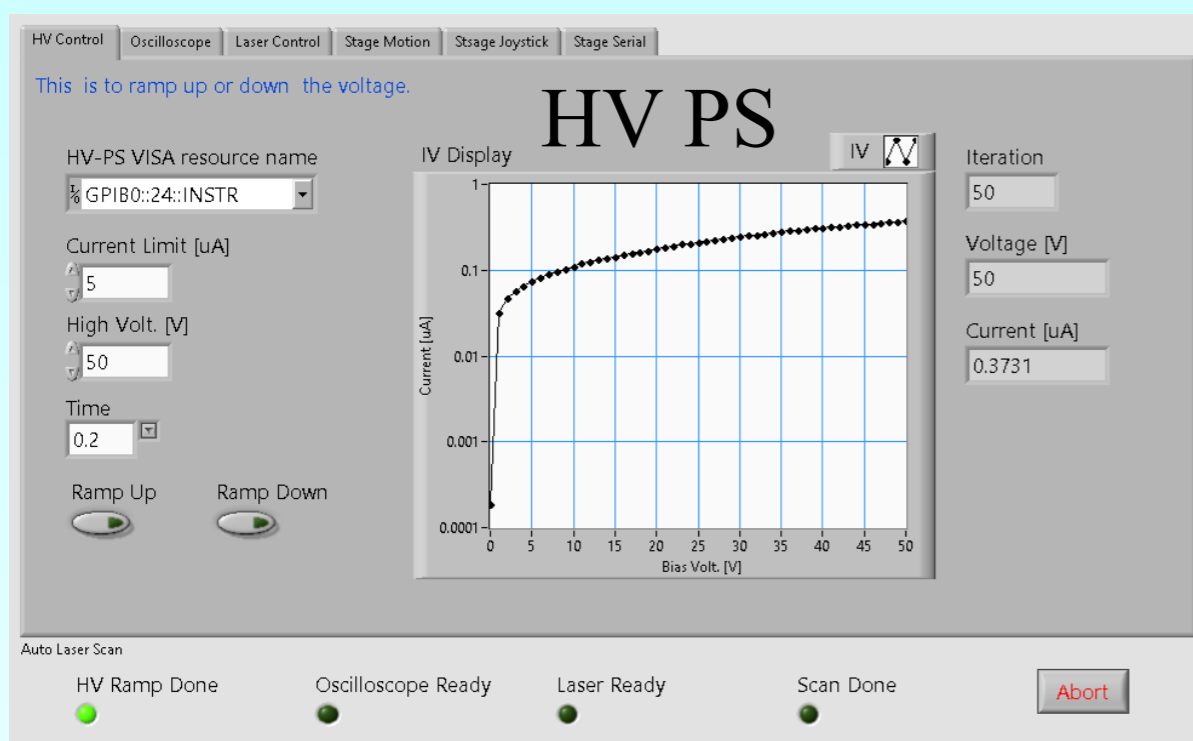
Setup for Charge Collection Efficiency

- Laser: IR(1064 nm), $5\ \mu\text{m} \times 50\ \mu\text{m}$, $23.44 \pm 0.2\ \text{pJ}$
- Stage: move step of $5\ \mu\text{m}$
- 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.



HV PS

This is to ramp up or down the voltage.

HV-PS VISA resource name: % GPIB0::24::INSTR

Current Limit [uA]: 5

High Volt. [V]: 50

Time: 0.2

Ramp Up Ramp Down

IV Display

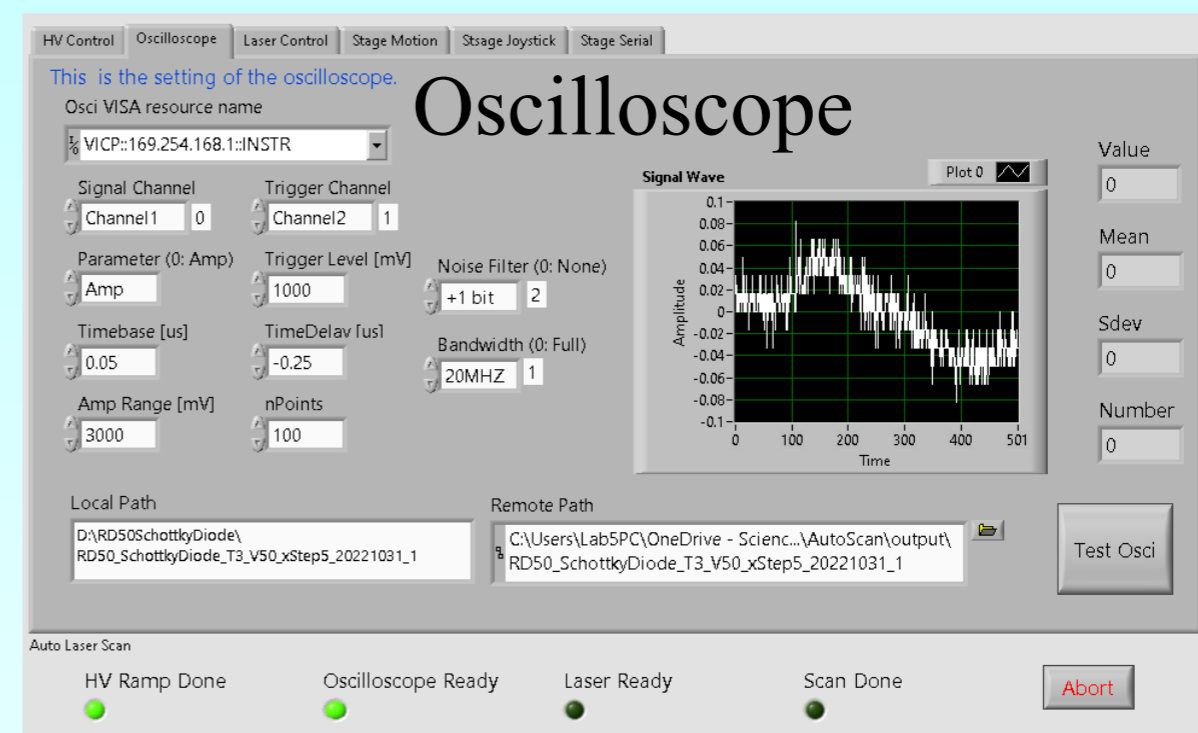
Iteration: 50

Voltage [V]: 50

Current [uA]: 0.3731

Auto Laser Scan

HV Ramp Done Oscilloscope Ready Laser Ready Scan Done Abort



Oscilloscope

This is the setting of the oscilloscope.

Osci VISA resource name: % VICP::169.254.168.1::INSTR

Signal Channel: Channel 1 0

Trigger Channel: Channel 2 1

Parameter (0: Amp): Amp

Trigger Level [mV]: 1000

Noise Filter (0: None): +1 bit 2

Timebase [us]: 0.05

TimeDelay [us]: -0.25

Bandwidth (0: Full): 20MHZ 1

Amp Range [mV]: 3000

nPoints: 100

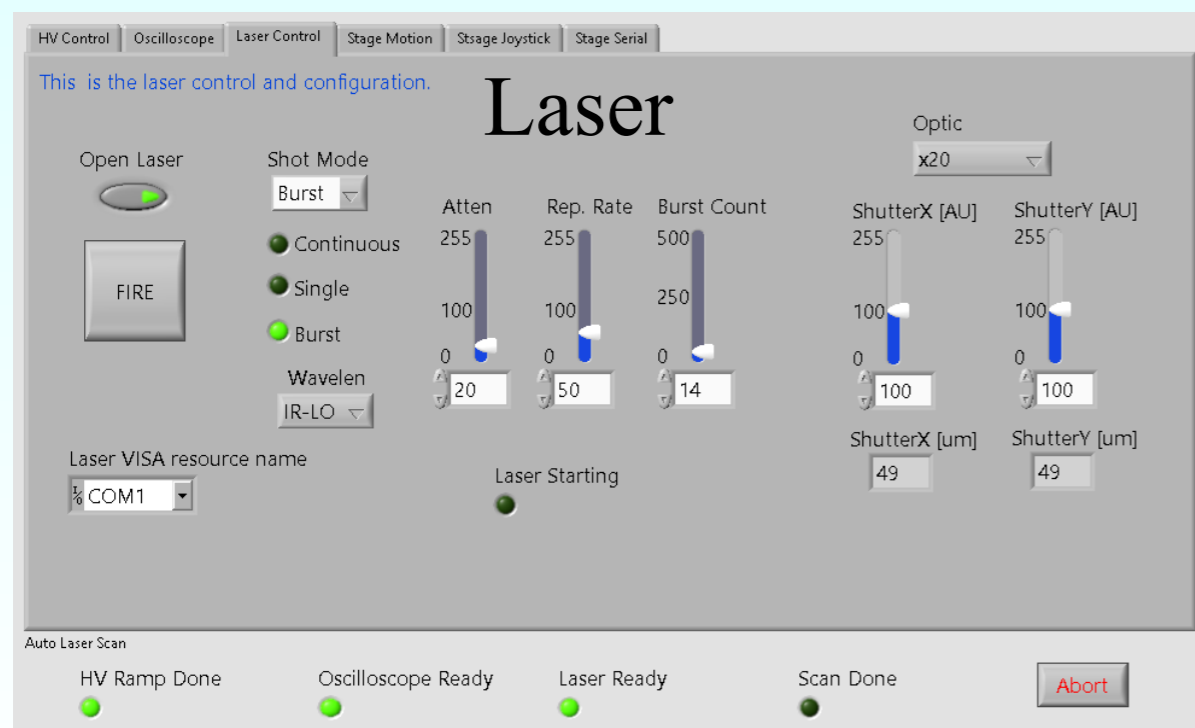
Local Path: D:\RD50SchottkyDiode\RD50_SchottkyDiode_T3_V50_xStep5_20221031_1

Remote Path: C:\Users\Lab5PC\OneDrive - Scienc...\AutoScan\output\RD50_SchottkyDiode_T3_V50_xStep5_20221031_1

Test Osci

Auto Laser Scan

HV Ramp Done Oscilloscope Ready Laser Ready Scan Done Abort



Laser

This is the laser control and configuration.

Open Laser

Shot Mode: Burst

Continuous Single Burst

Wavelen: IR-LO

Atten: 255

Rep. Rate: 255

Burst Count: 500

ShutterX [AU]: 100

ShutterY [AU]: 100

ShutterX [um]: 49

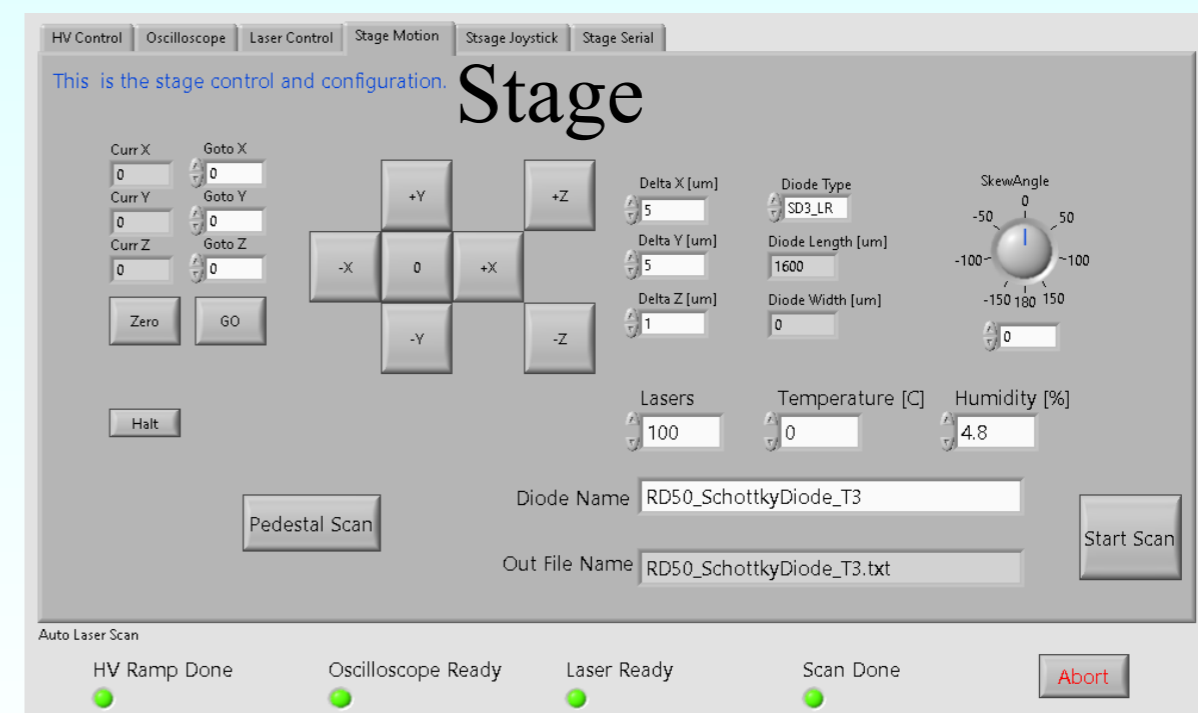
ShutterY [um]: 49

Laser VISA resource name: % COM1

Laser Starting

Auto Laser Scan

HV Ramp Done Oscilloscope Ready Laser Ready Scan Done Abort



Stage

This is the stage control and configuration.

Curr X: 0

Goto X: 0

Curr Y: 0

Goto Y: 0

Curr Z: 0

Goto Z: 0

Delta X [um]: 5

Delta Y [um]: 5

Delta Z [um]: 1

Diode Type: SD3_LR

Diode Length [um]: 1600

Diode Width [um]: 0

SkewAngle: 0

Lasers: 100

Temperature [C]: 0

Humidity [%]: 4.8

Diode Name: RD50_SchottkyDiode_T3

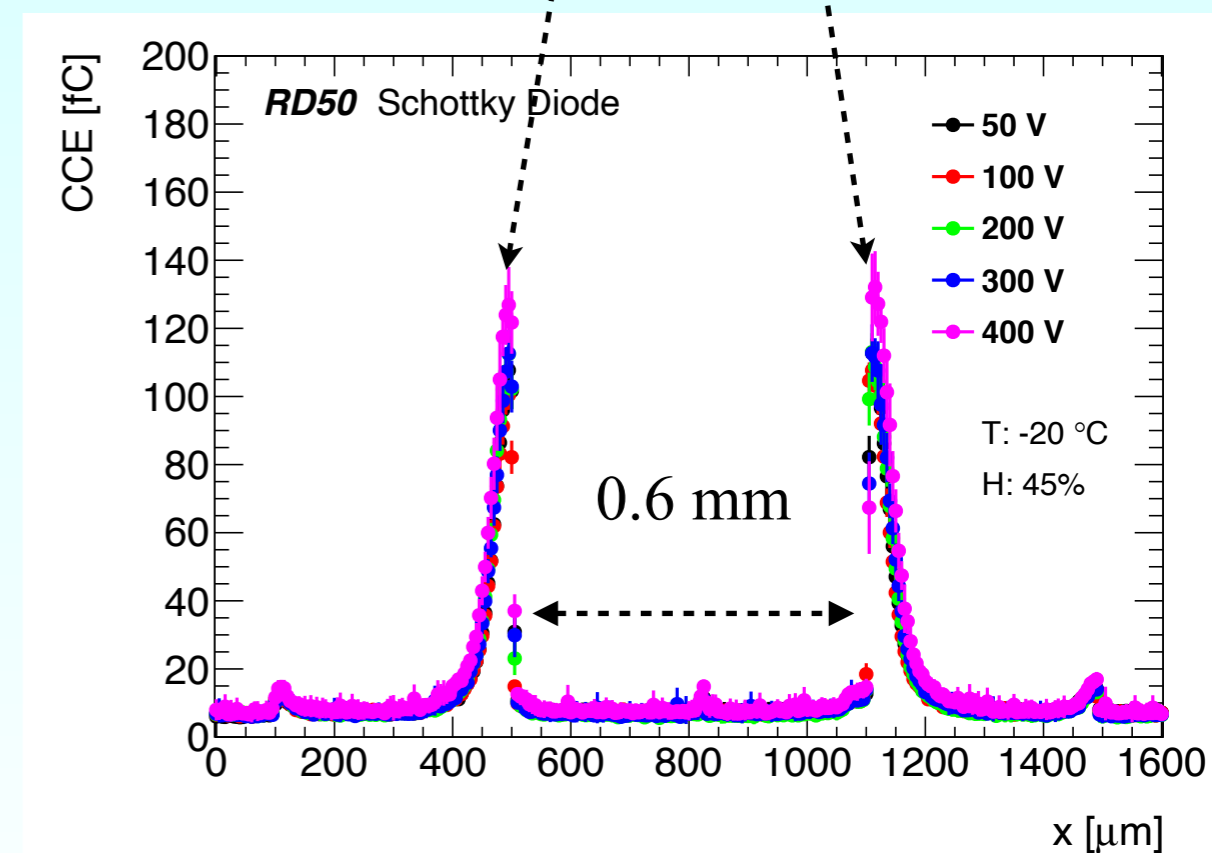
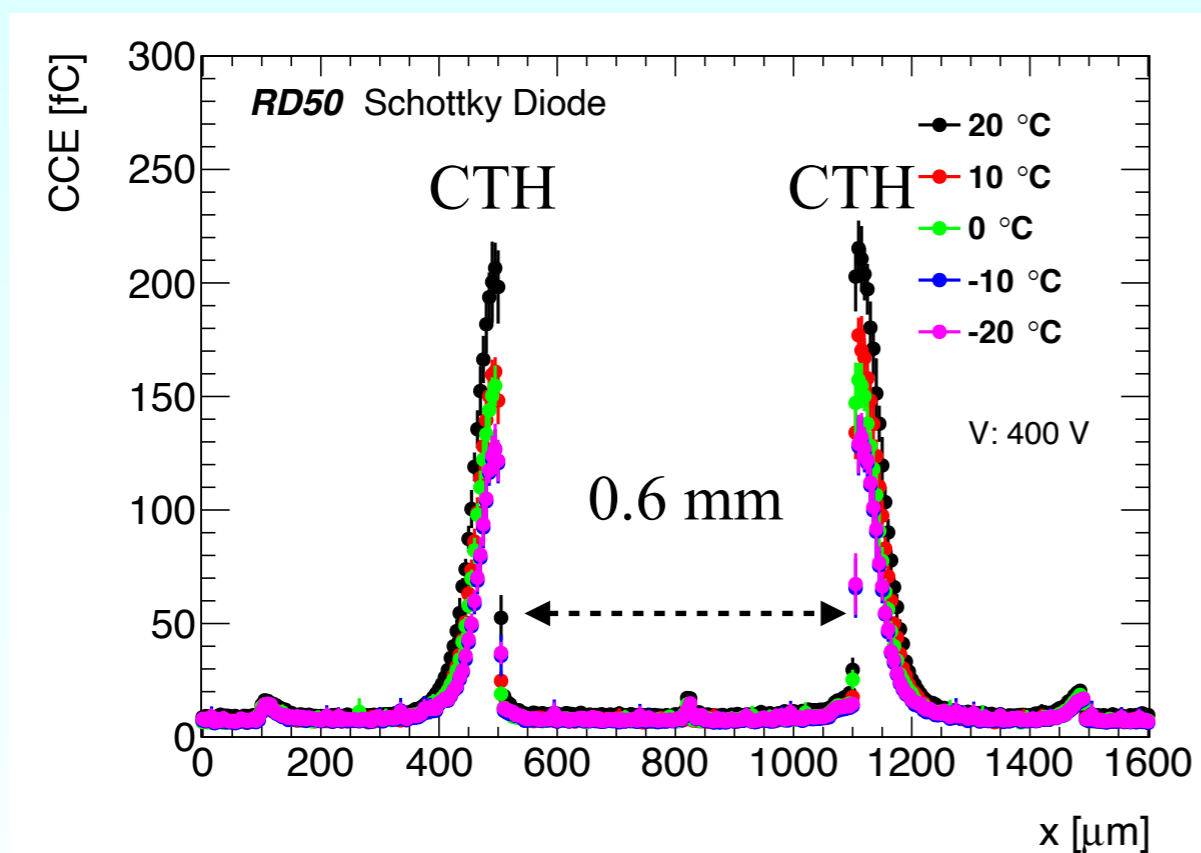
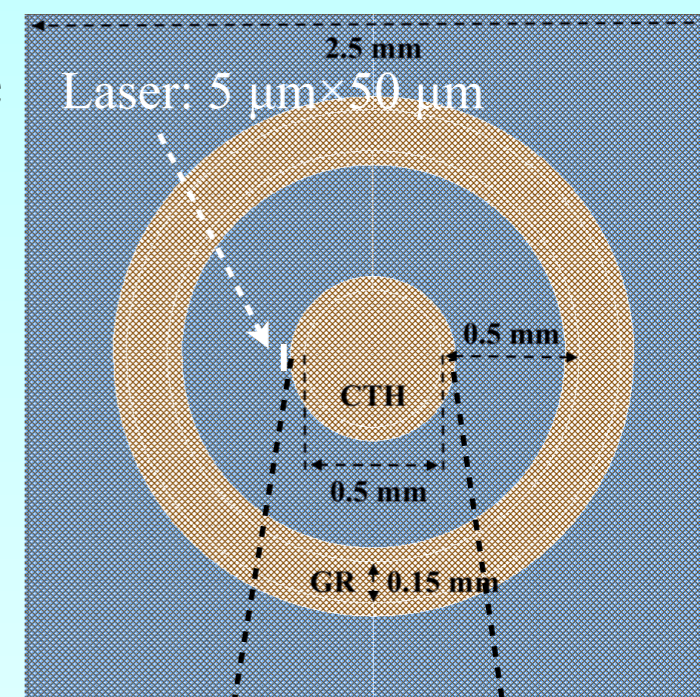
Out File Name: RD50_SchottkyDiode_T3.txt

Auto Laser Scan

HV Ramp Done Oscilloscope Ready Laser Ready Scan Done Abort

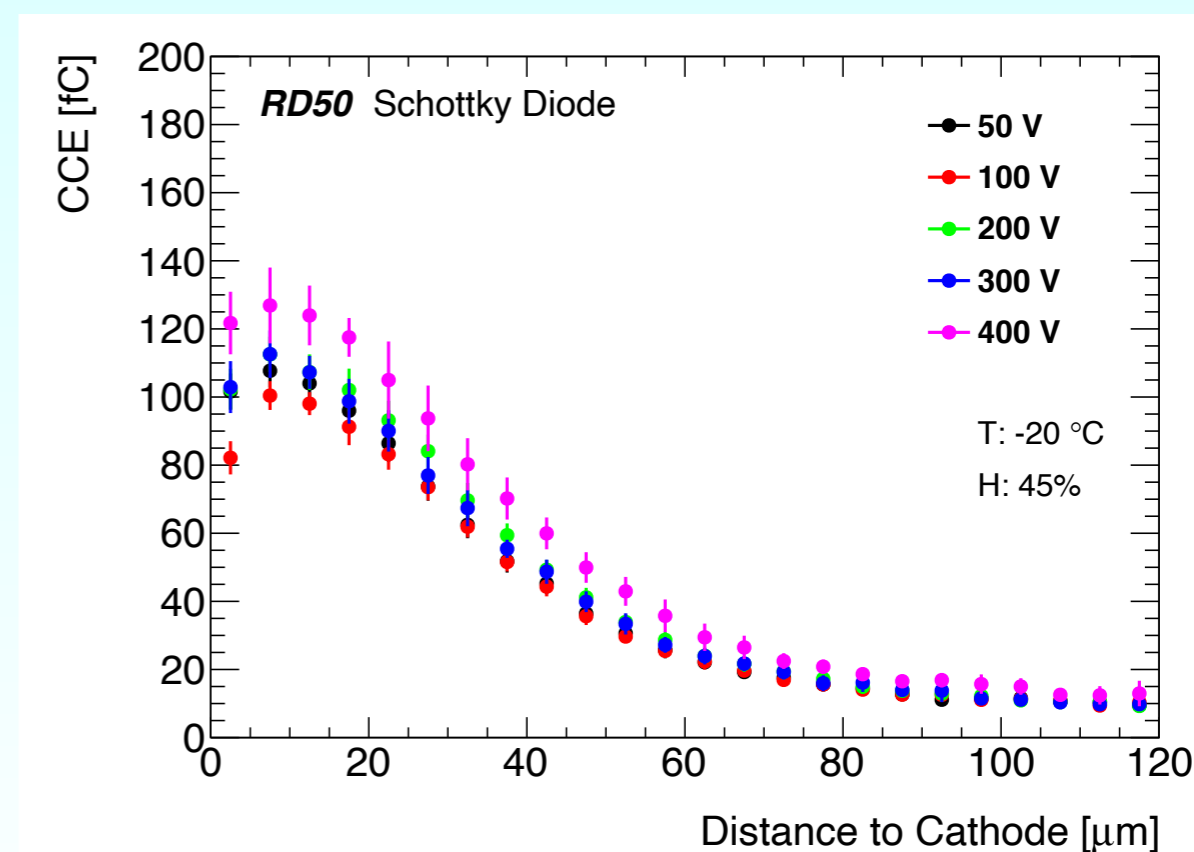
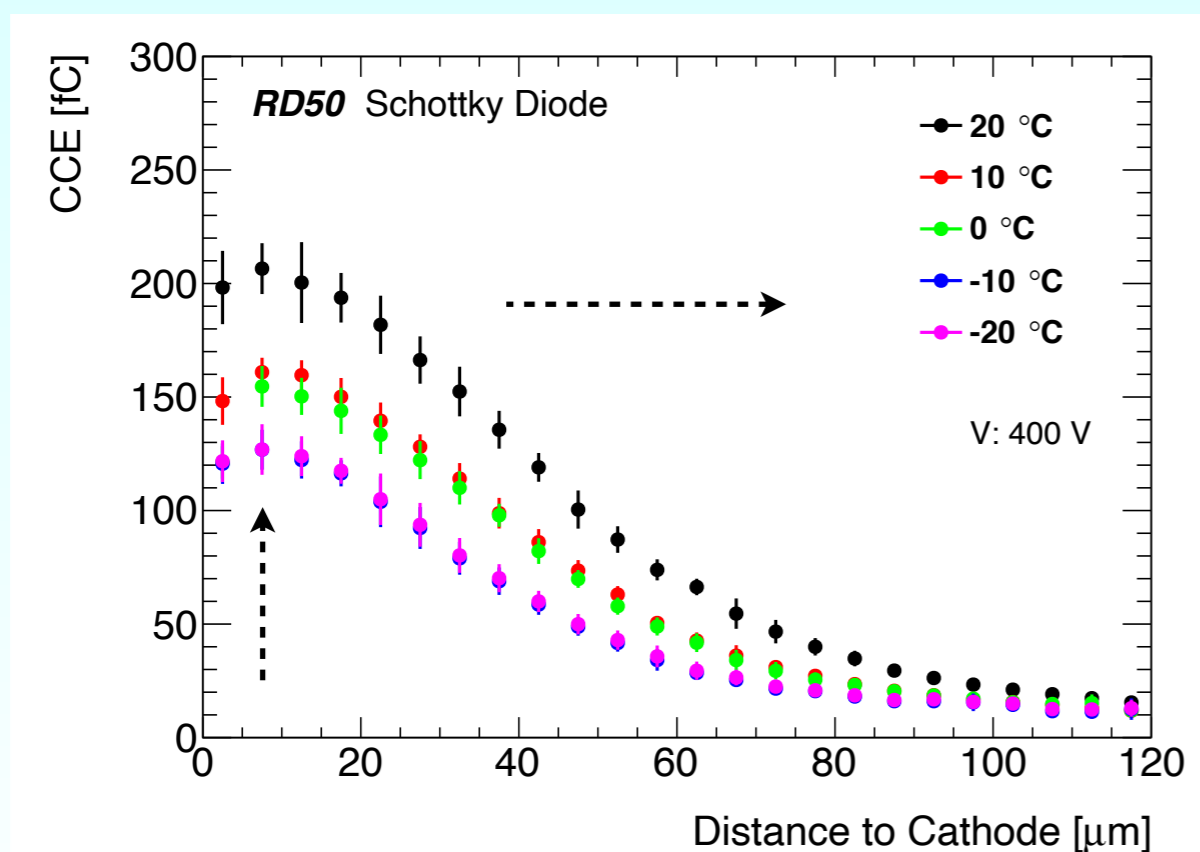
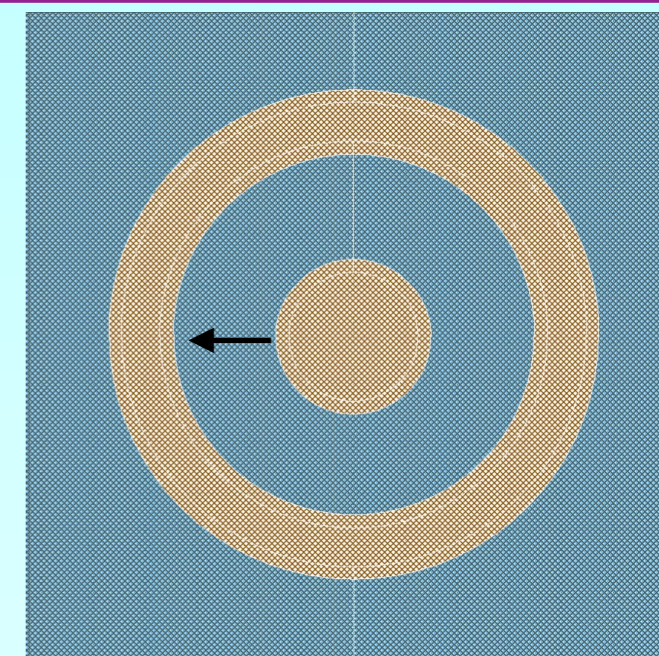
CCE of un-irradiated Schottky diode

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



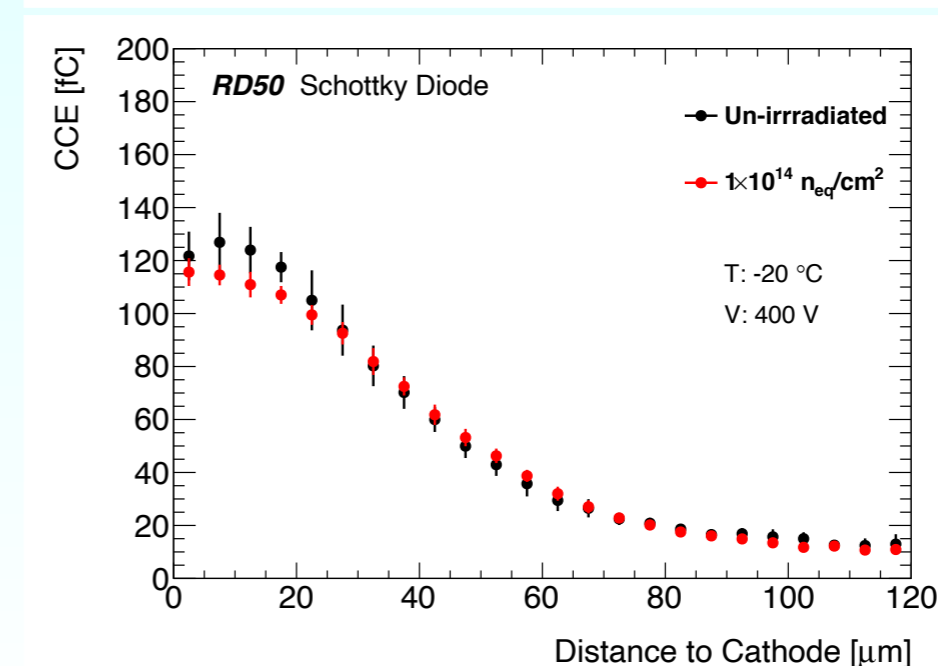
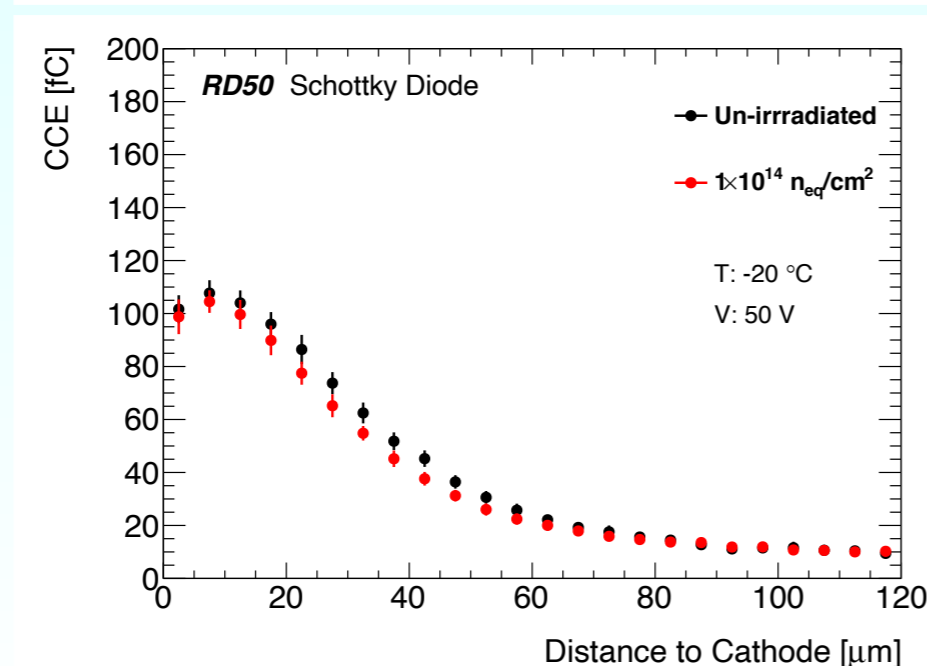
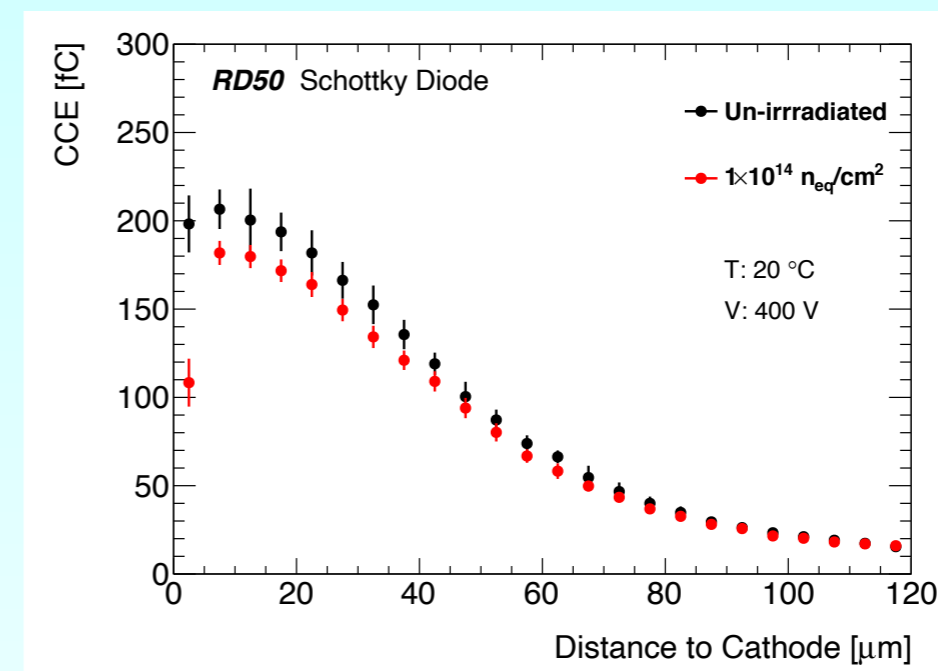
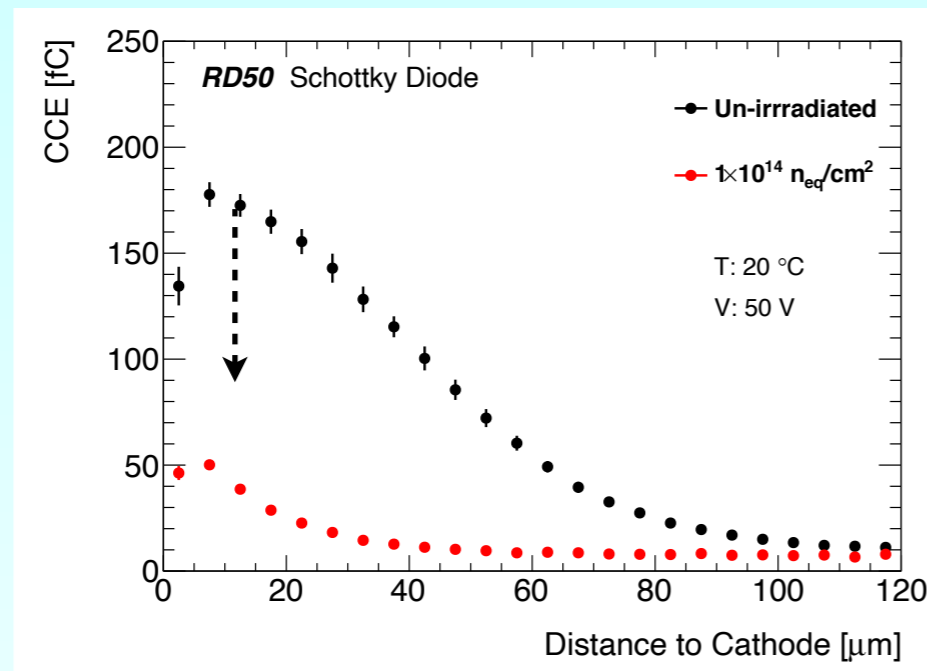
CCE of un-irradiated Schottky diode

- 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.



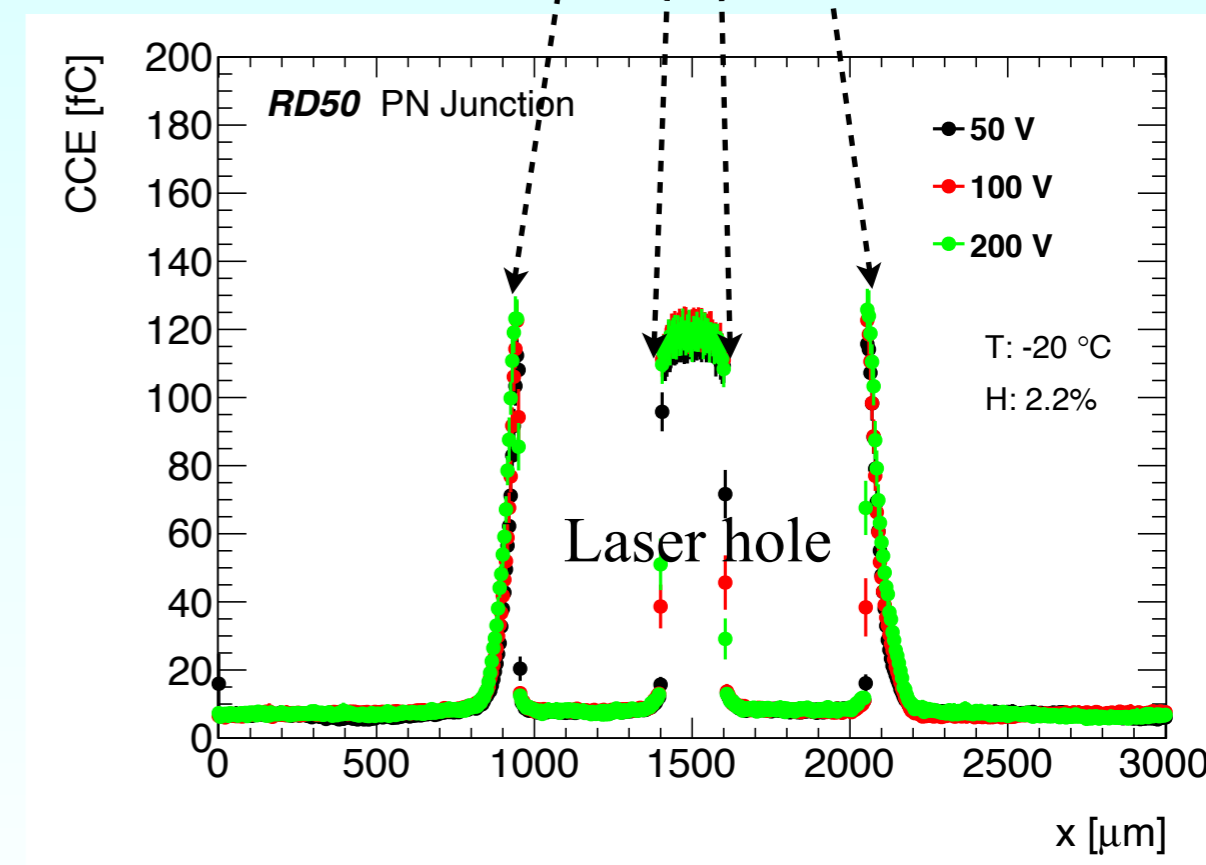
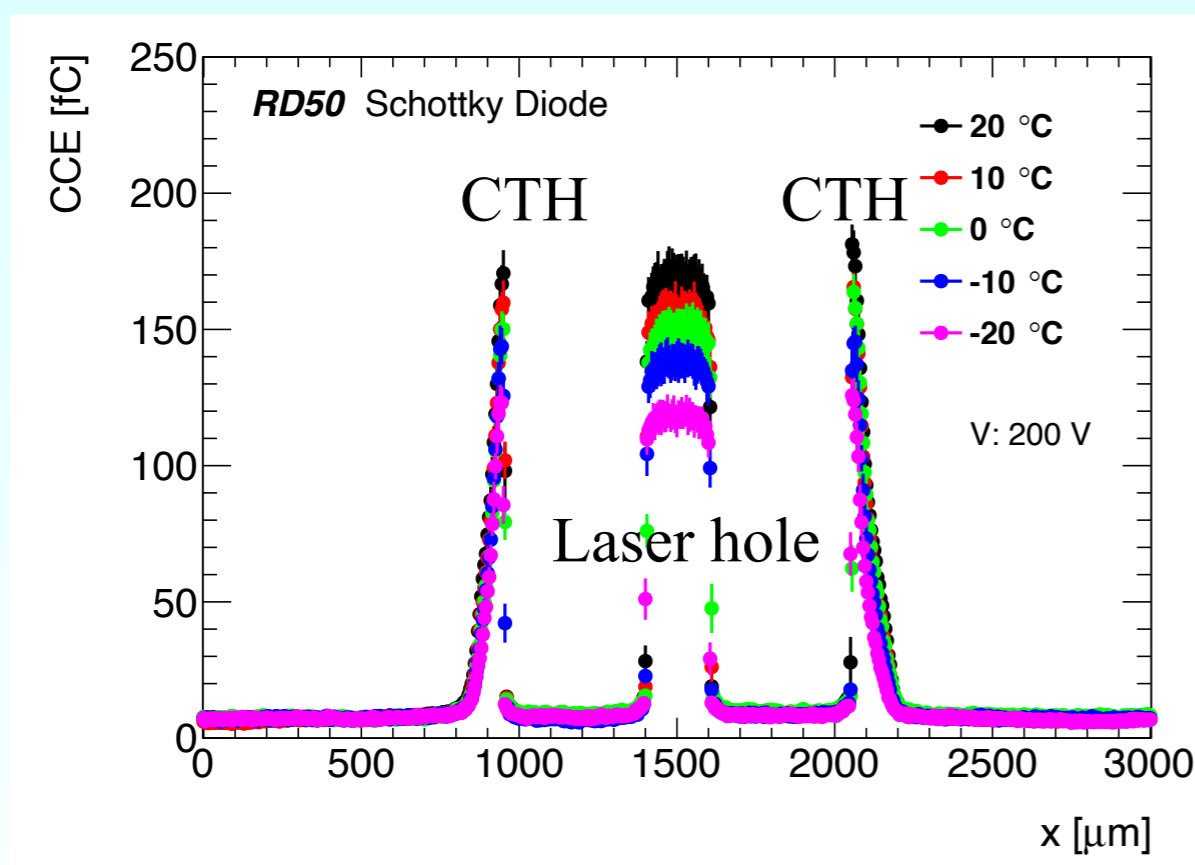
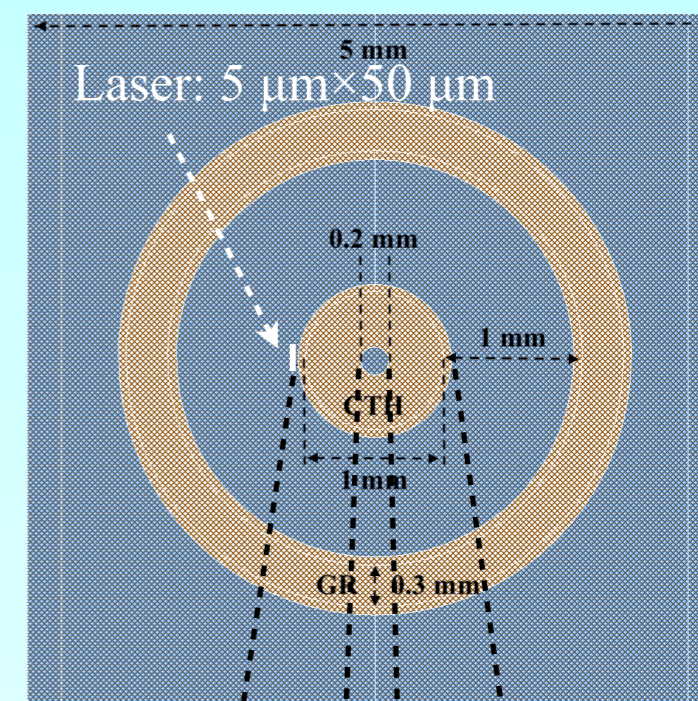
CCE of Schottky diode

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



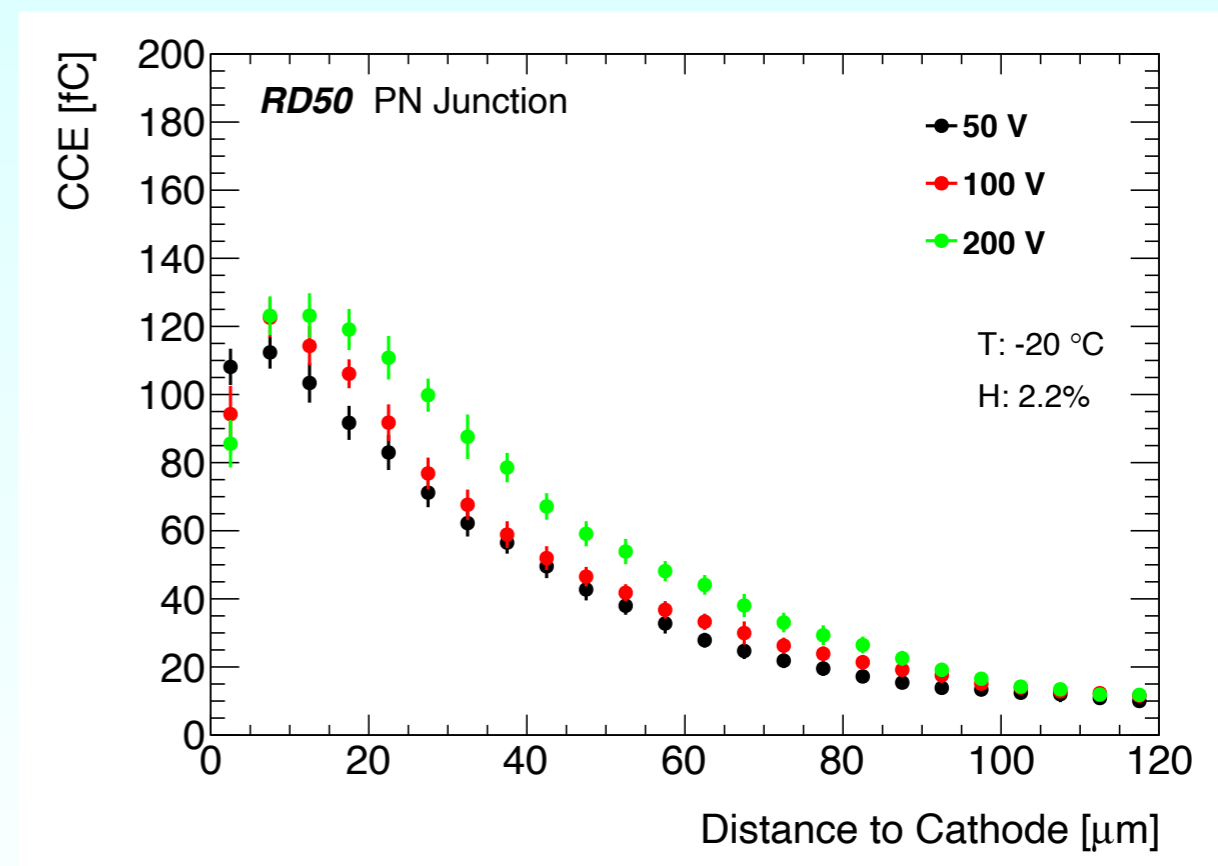
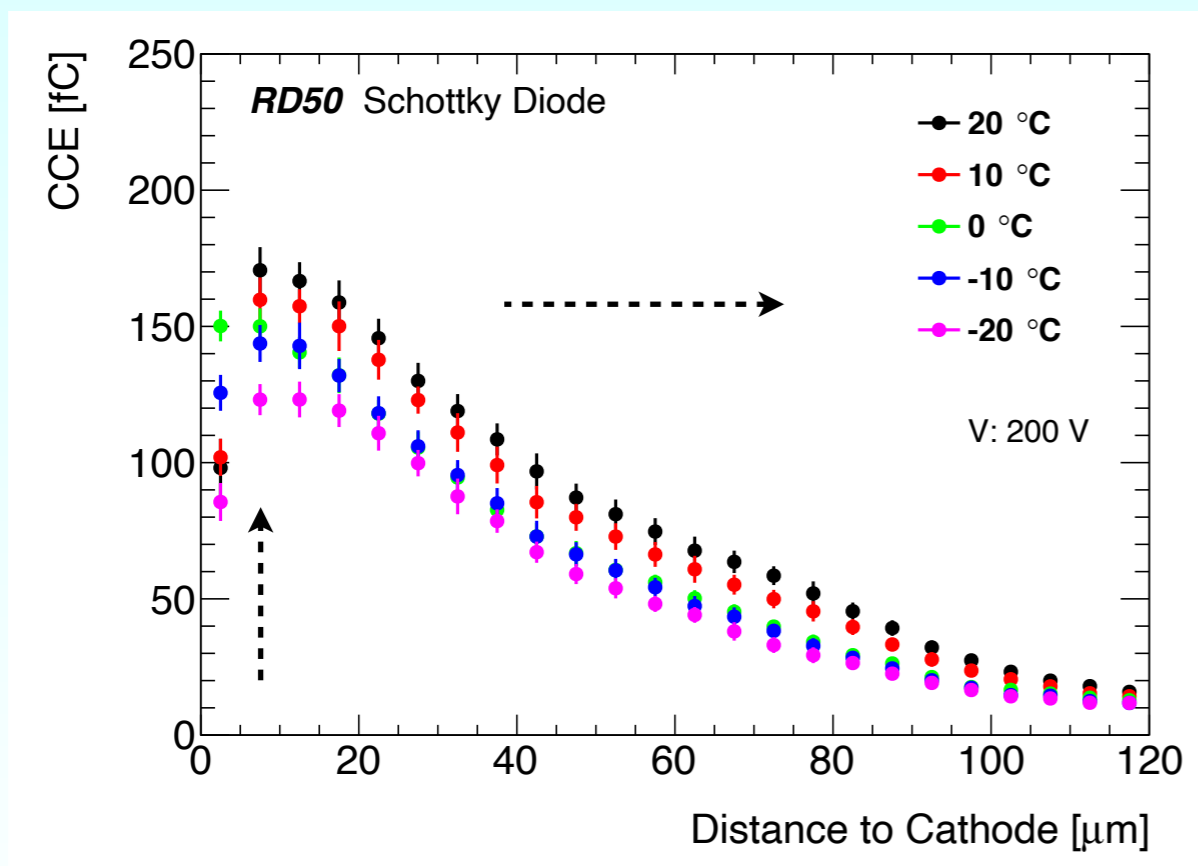
CCE of un-irradiated PN junction

- 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

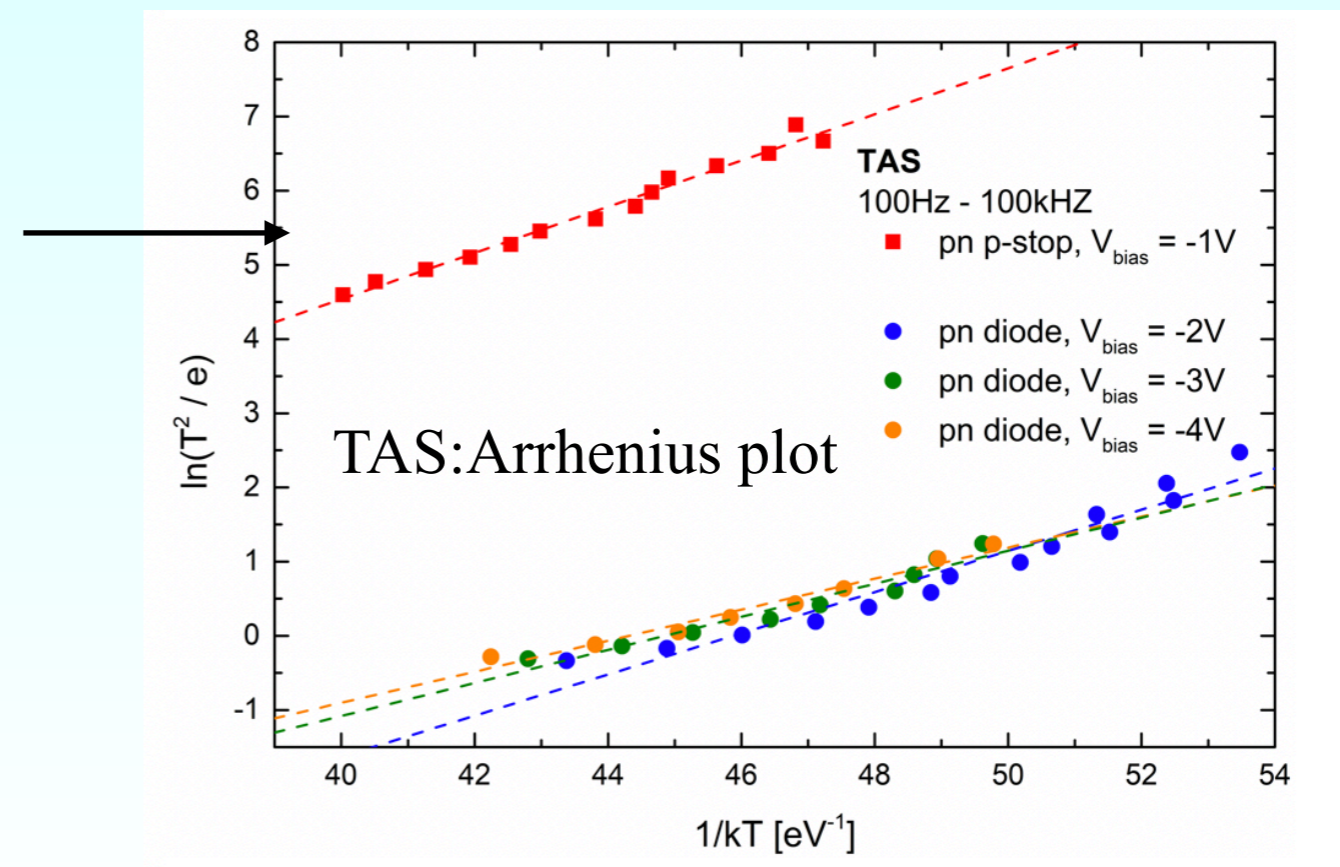
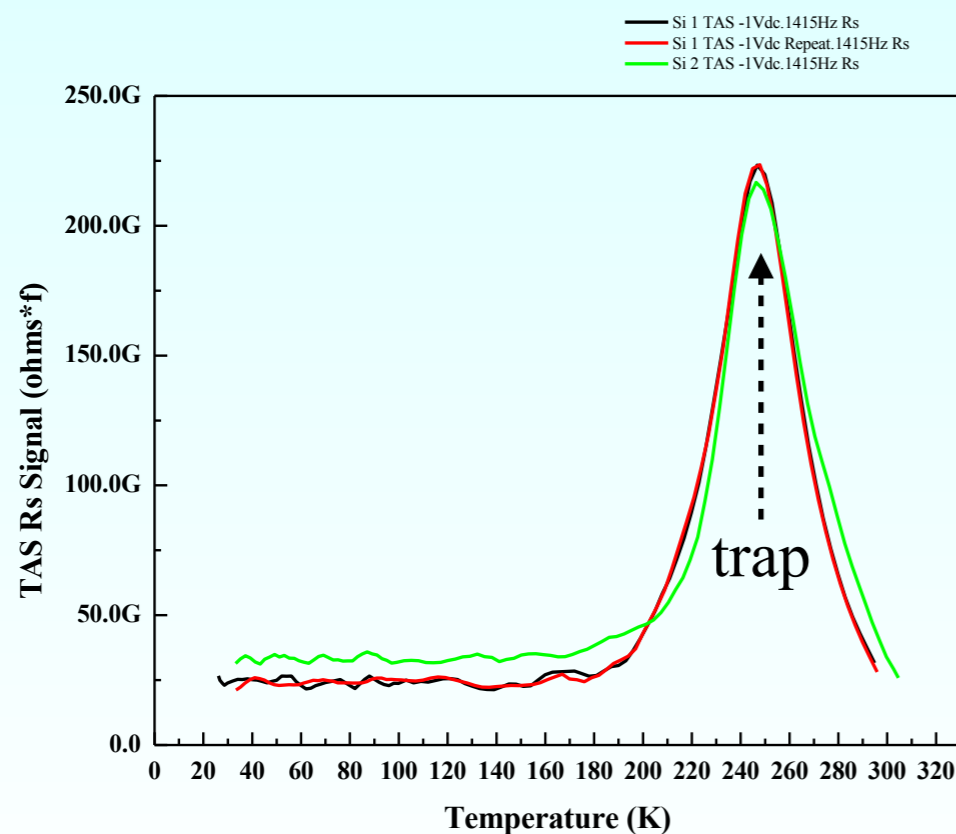
- Depleted thickness decreases with increased distance from the cathode edge,
- At fixed bias voltage, the higher the temperature, the larger the CCE, still under investigation,
- At low temperature, not fully depleted up to 100 V.



Defect characteristics in TAS and DLTS

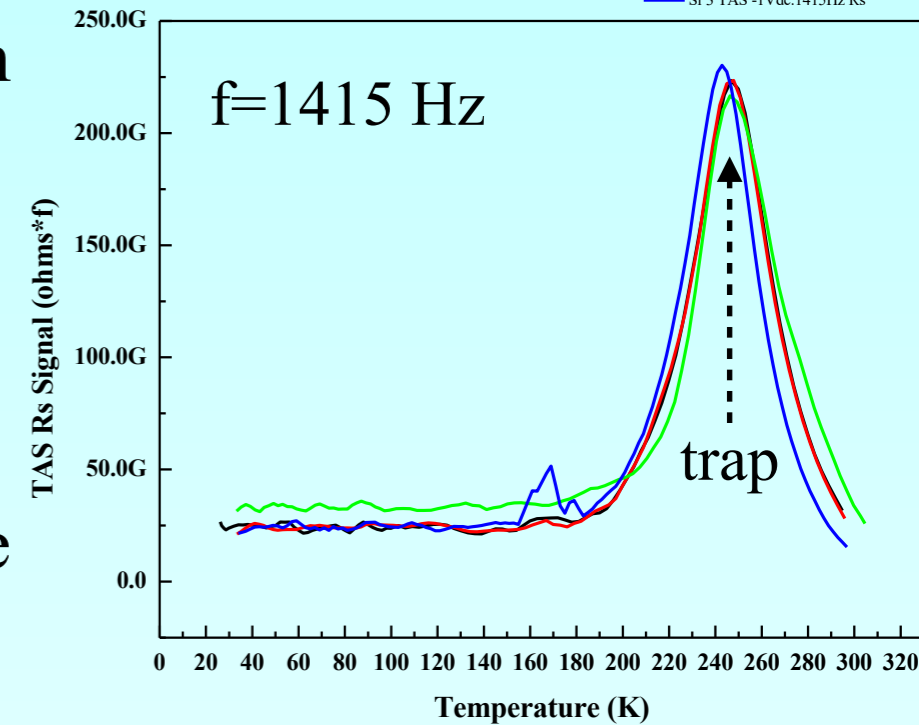
Thermal Admittance Spectroscopy(TAS)

- 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 ($1 \times 10^{15} \text{ n}_{eq}/\text{cm}^2$) T3 Schottky diodes:
 - ✦ Frequency: 20 Hz -100 kHz,
 - ✦ 100 mV test signal amplitude, -1 V DC voltage applied on back.



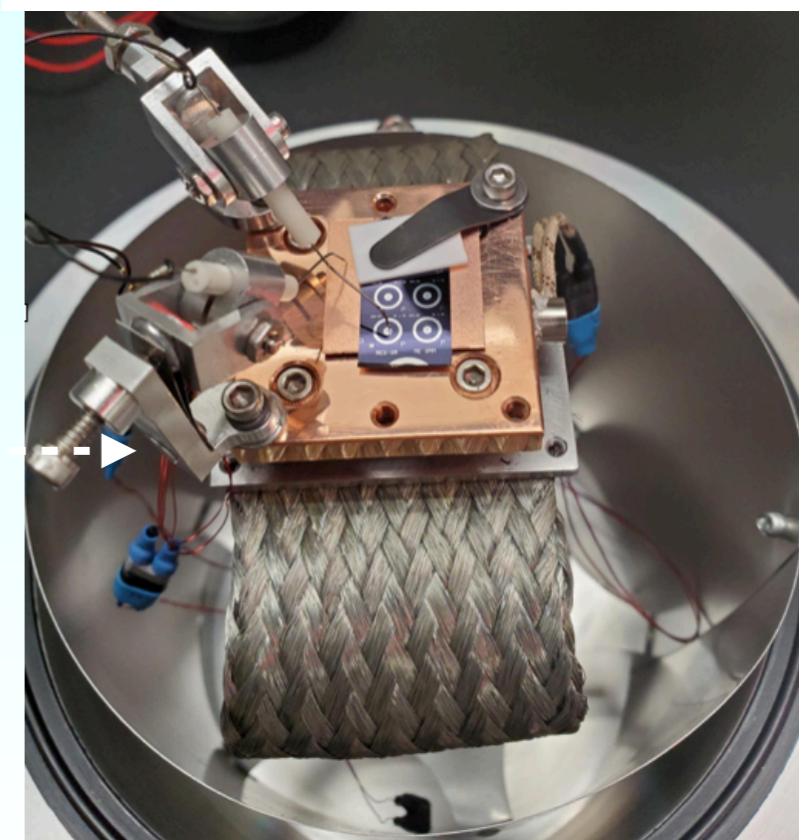
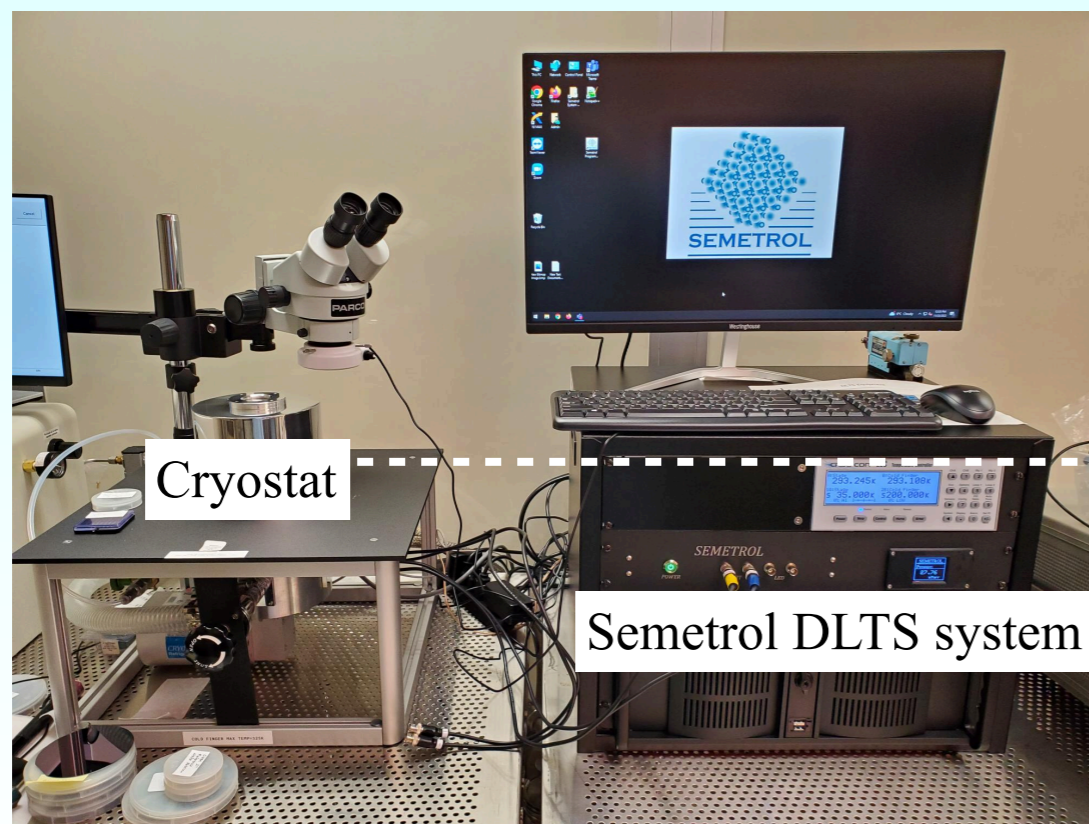
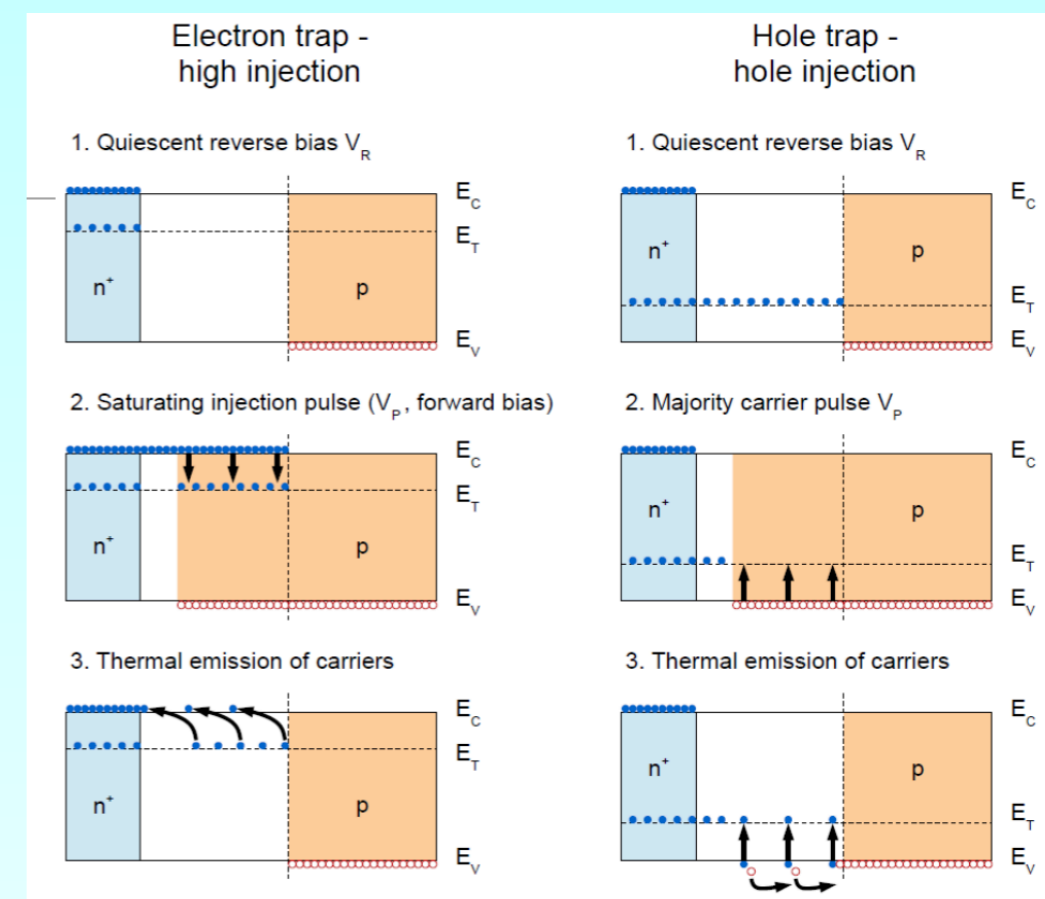
Arrhenius Summary

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 $\sim 60 \text{ meV}$,
- Error bar on each individual measurement is $< 10 \text{ meV}$.

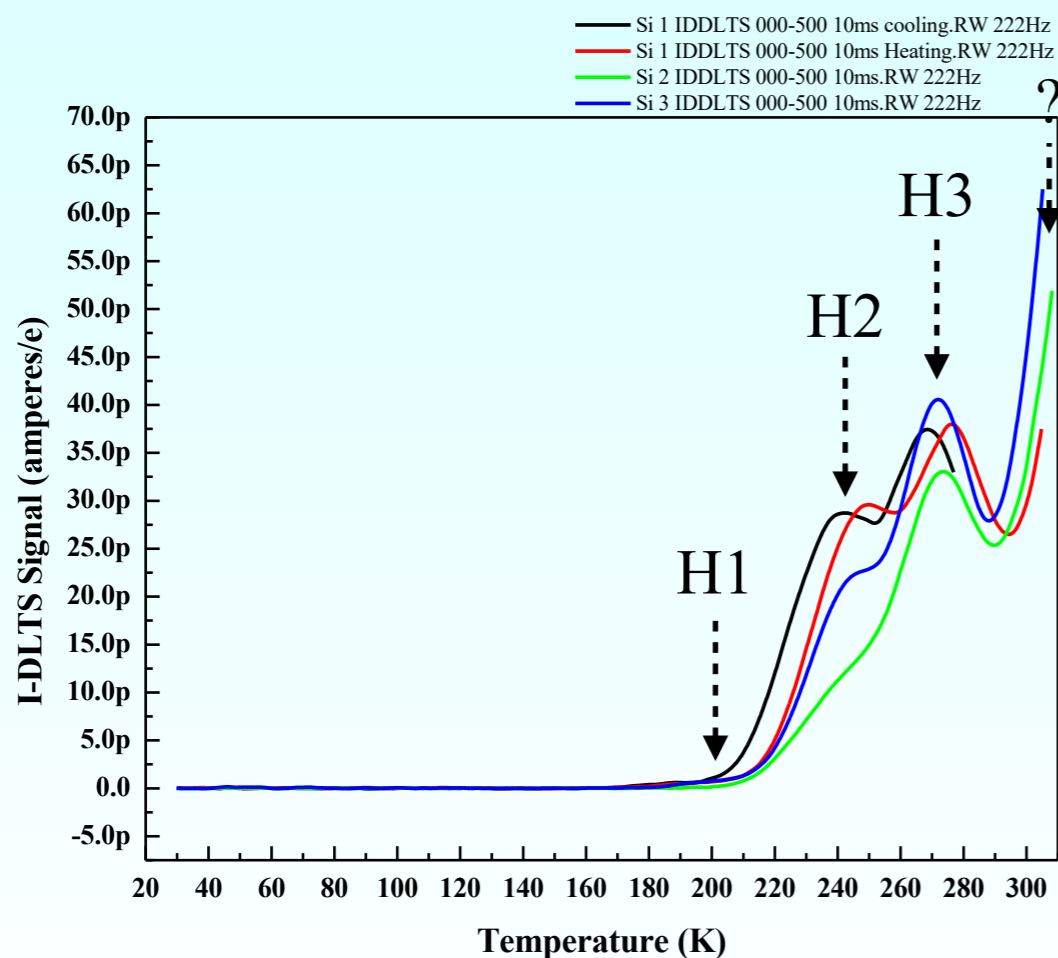
Current Deep Level Transient Spectroscopy(I-DLTS)

- 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 ($1 \times 10^{15} \text{ n}_{eq}/\text{cm}^2$) 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)	σ(cm ²)	Δσ
H1	200				
H2	250	0.46	0.009	2.4E-15	1.5
H3	275	0.58	0.014	4.5E-14	1.8

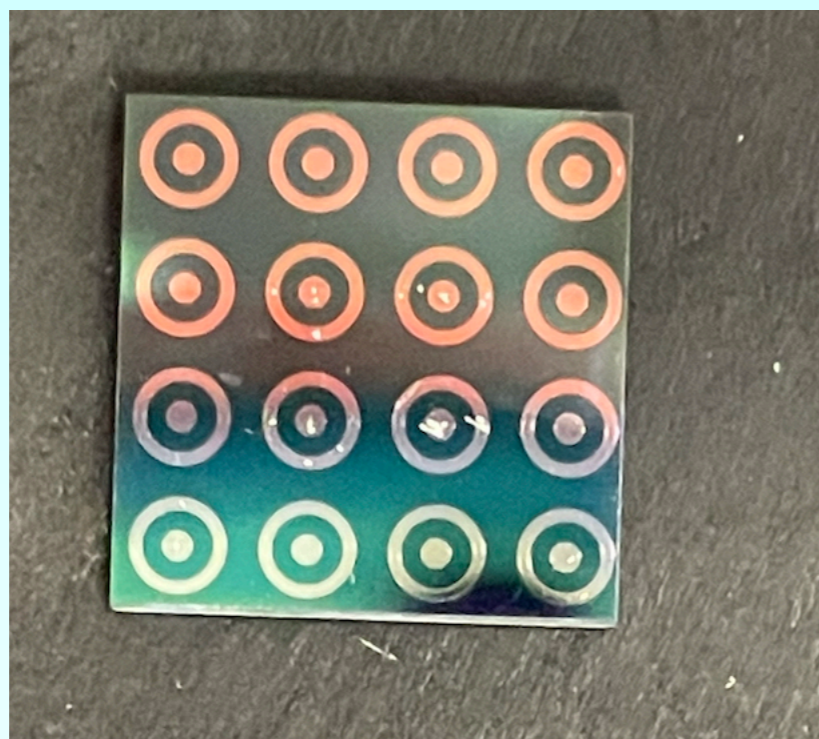
Summary and Outlook

- 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.

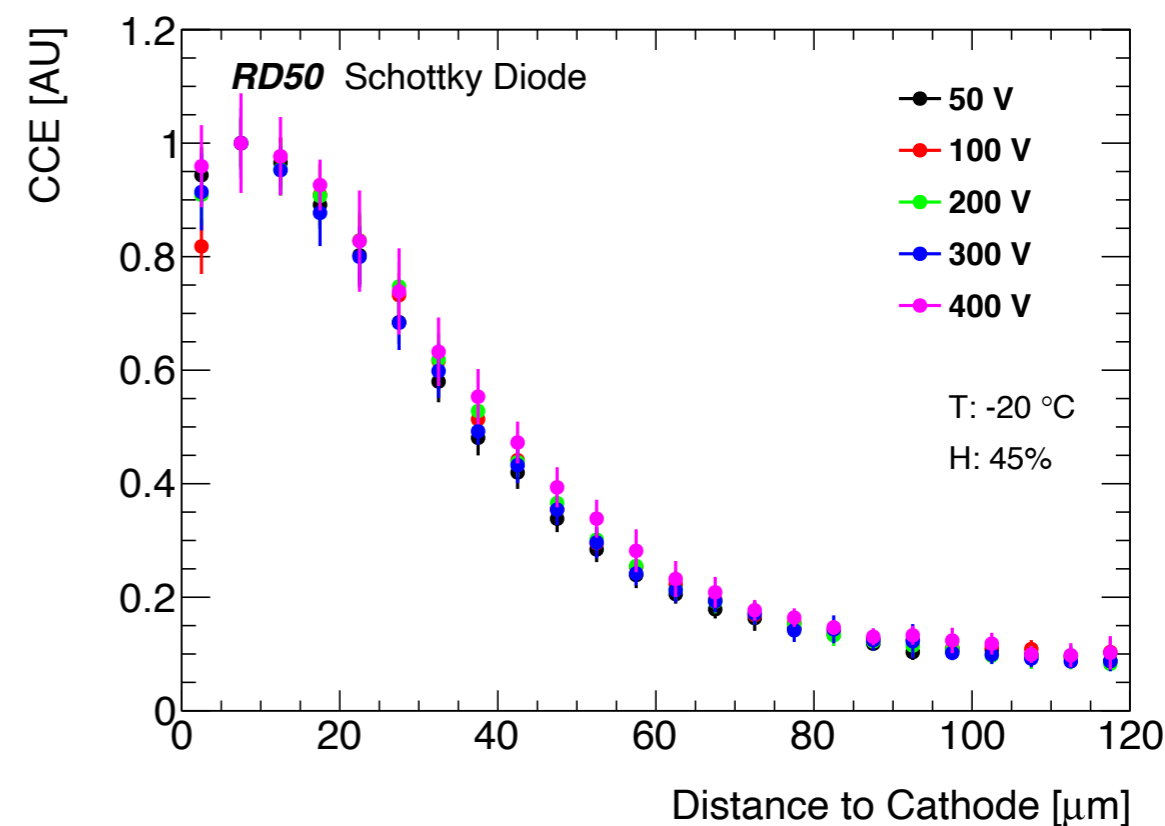
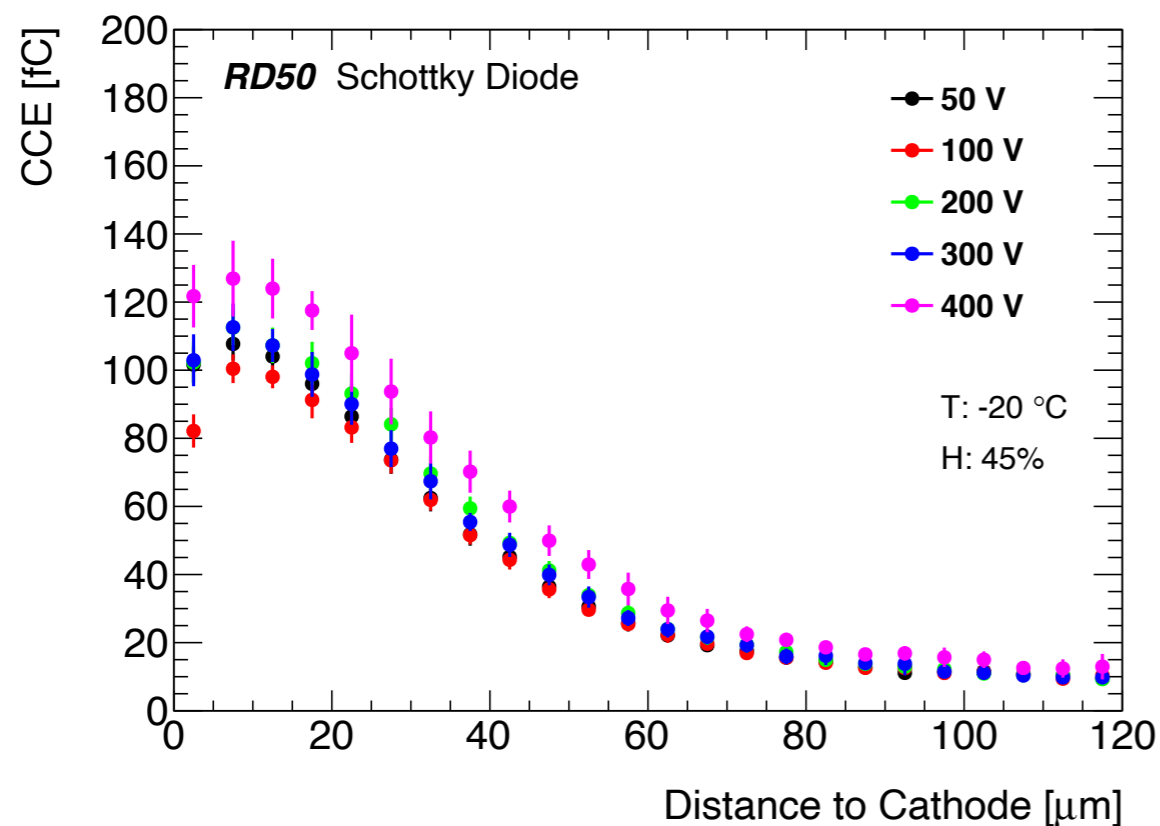
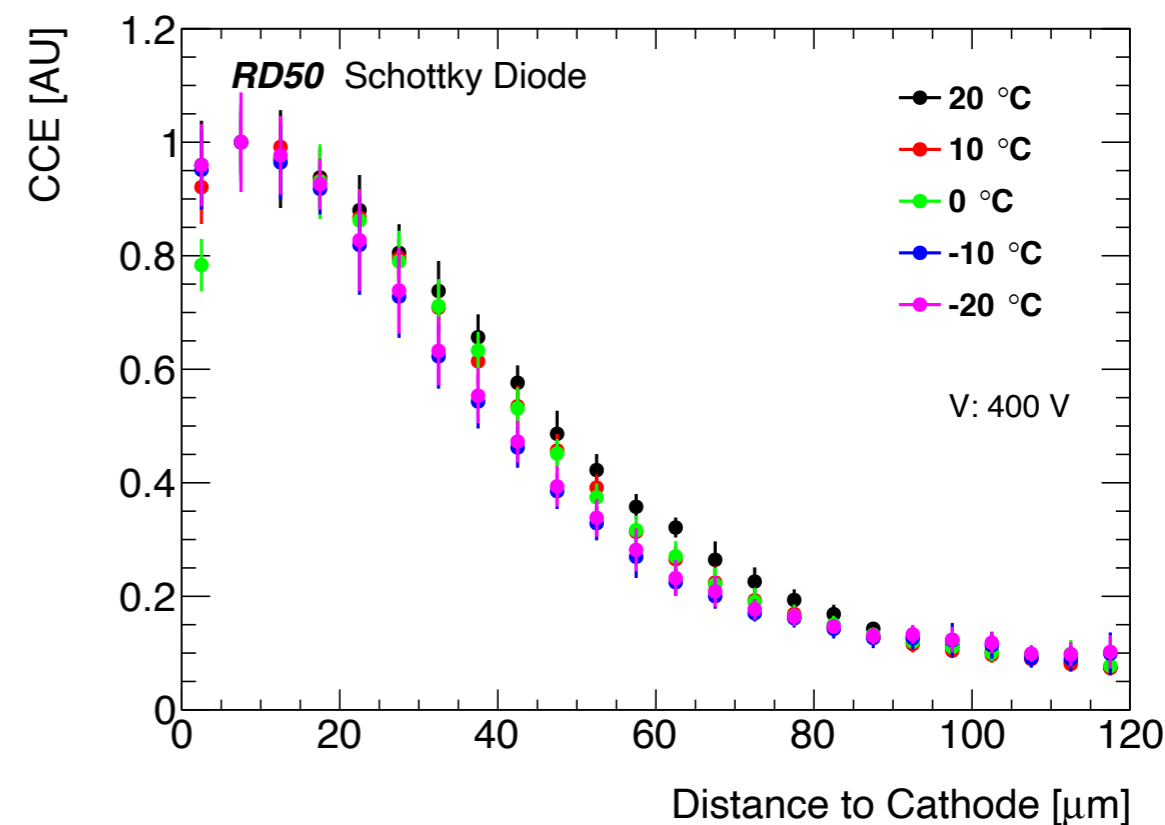
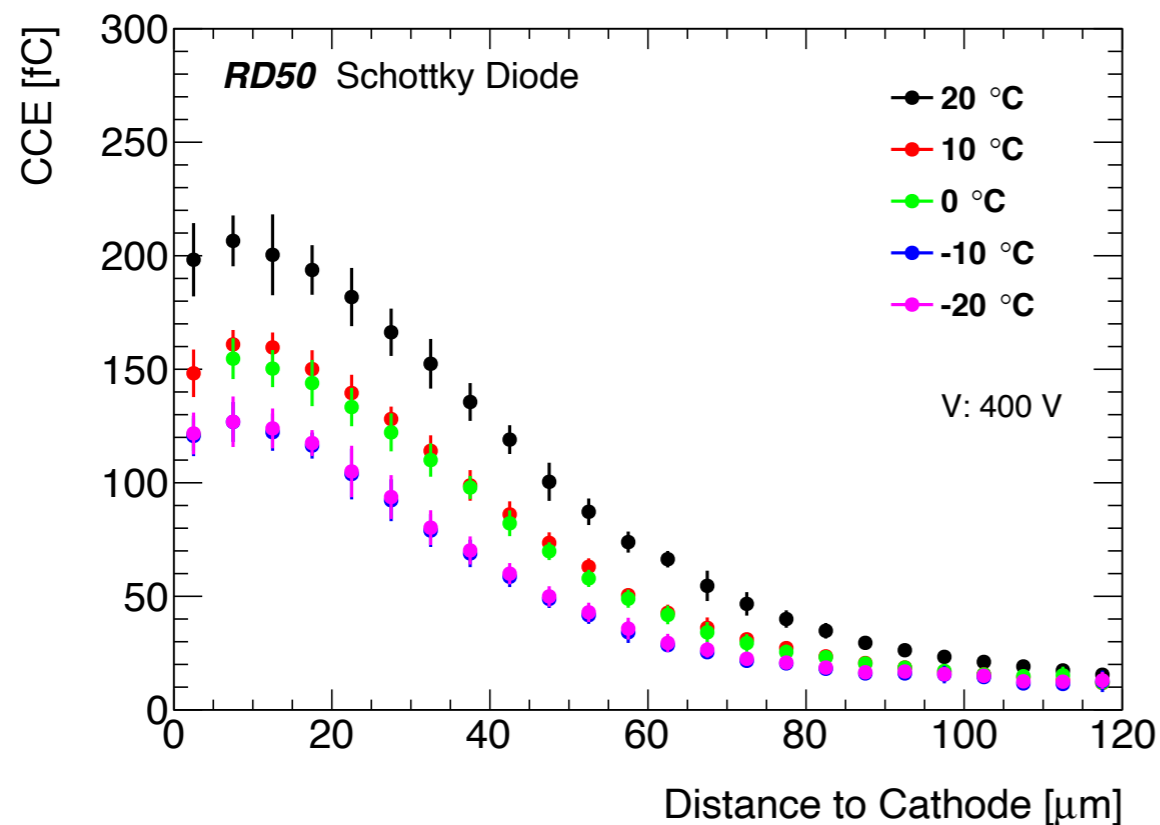
Thanks

Backup

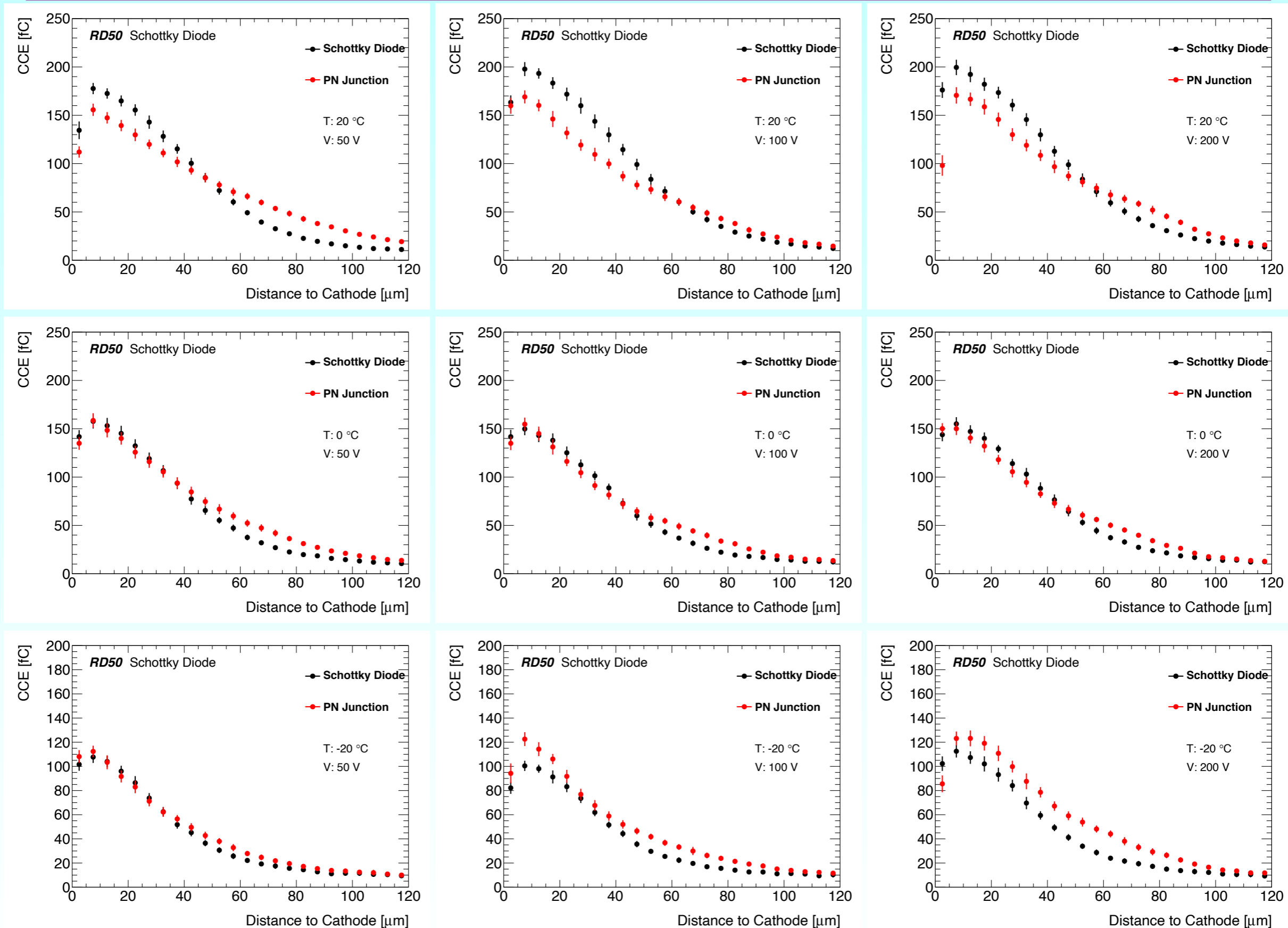
Diced Die



CCE of un-irradiated Schottky diode

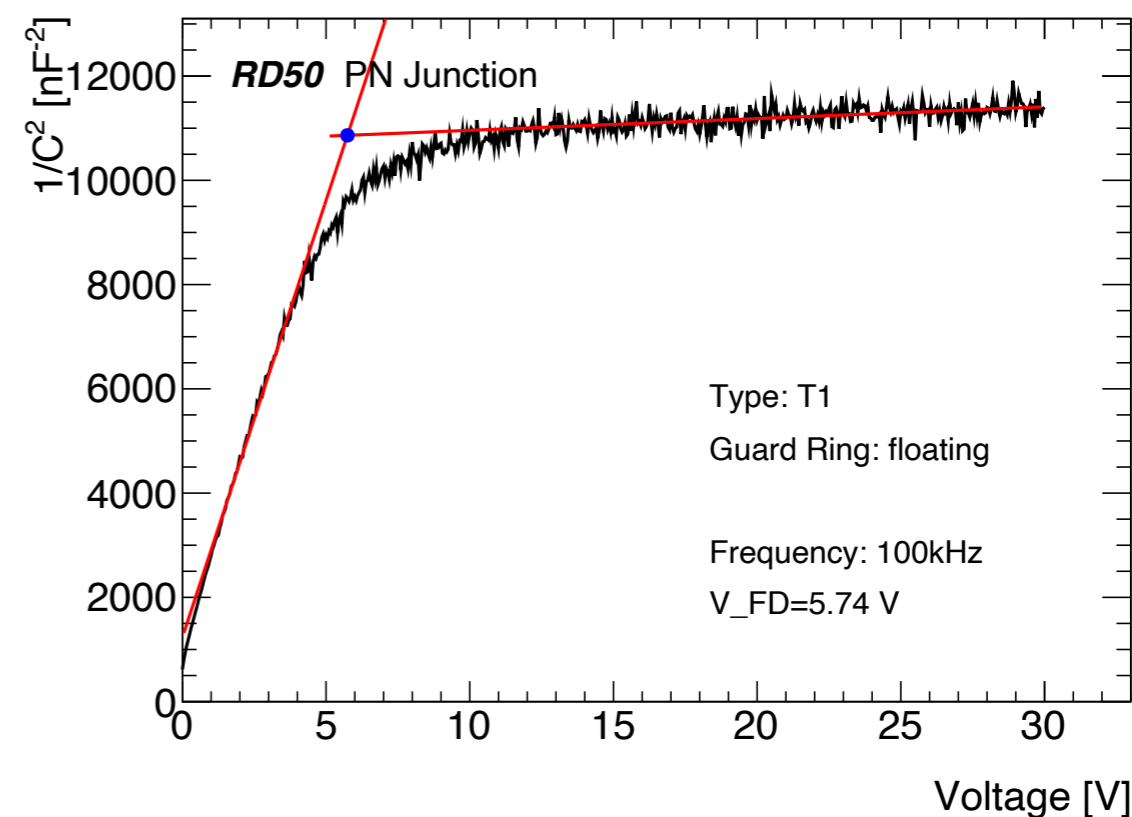
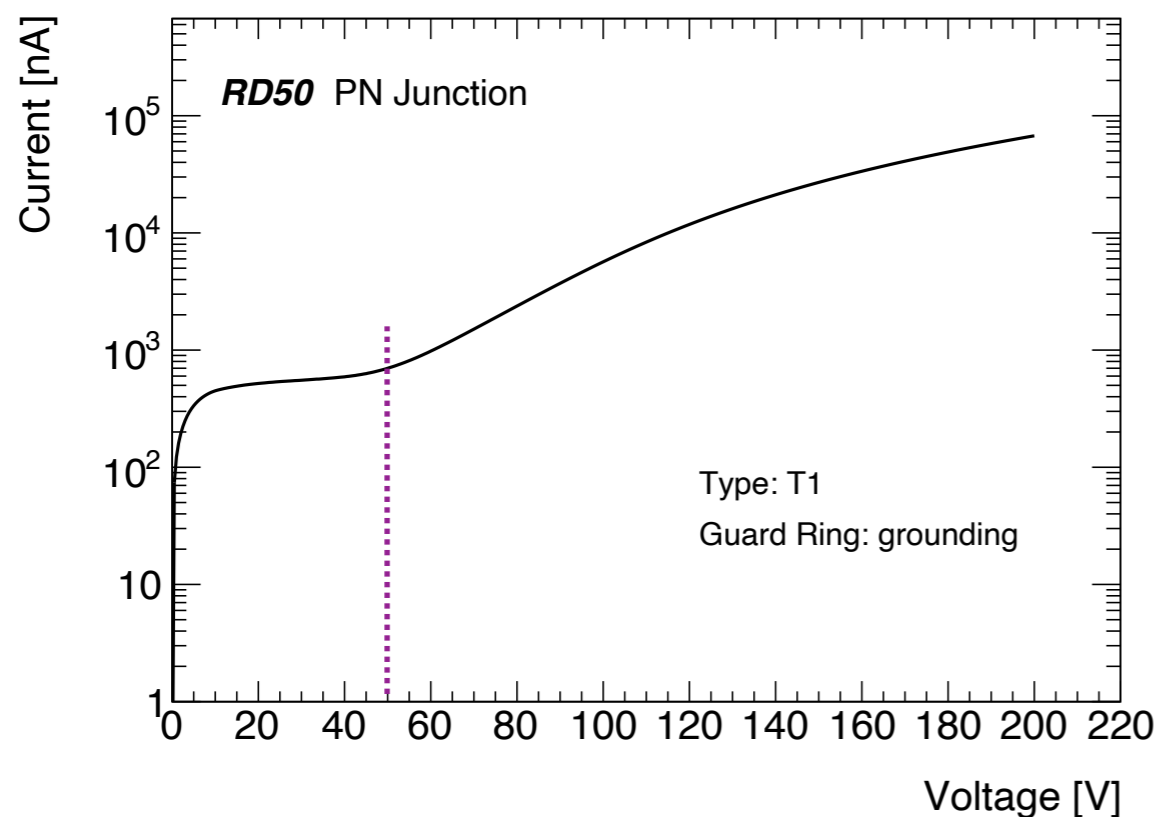


CCE of un-irradiated Schottky diode and PN junction

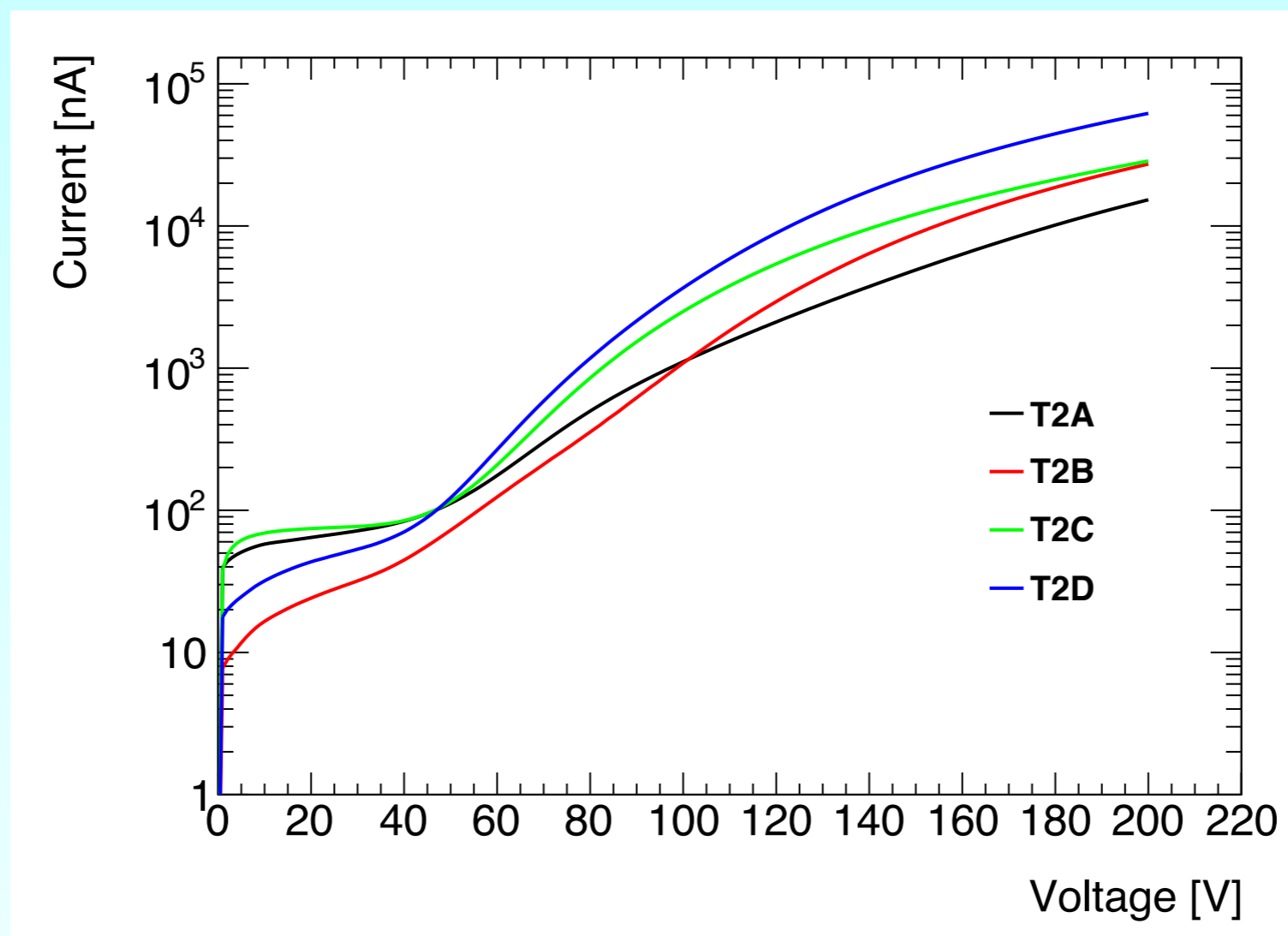


IV/CV of un-irradiated PN junction

- 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

