Measurement of the acceptor removal rate in silicon pad diodes

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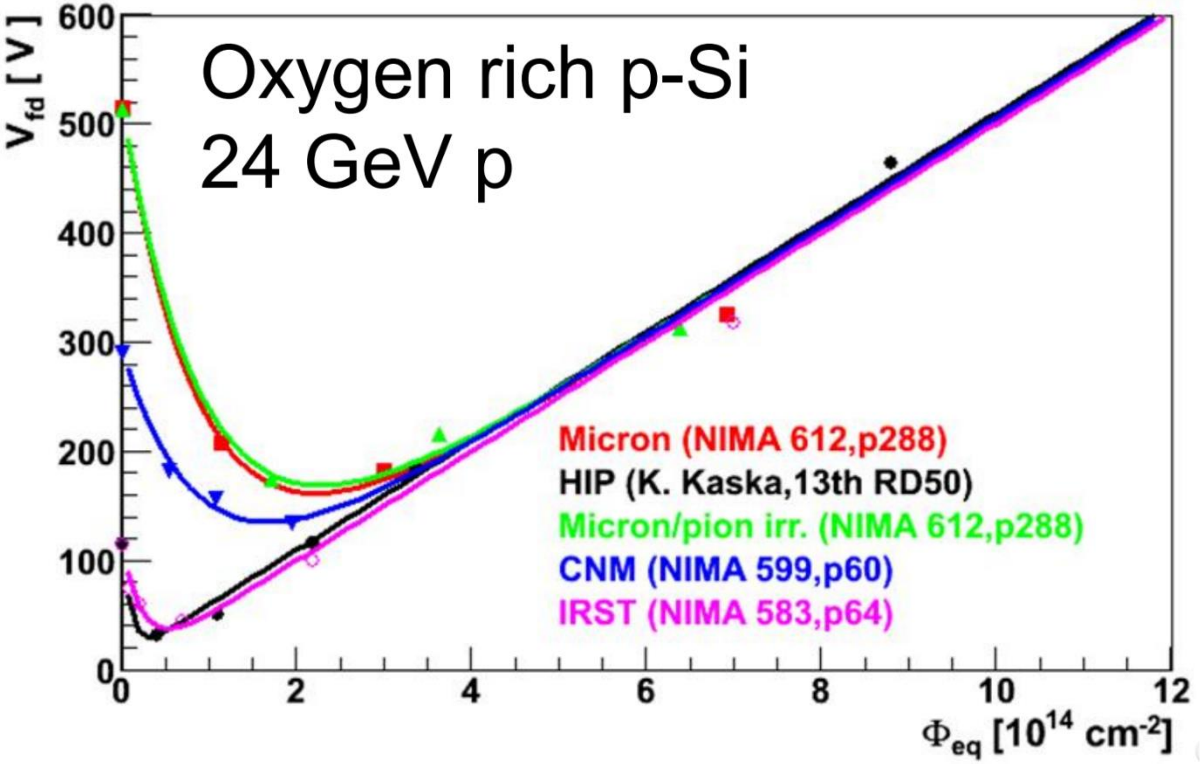
Acceptor removal

- Apparent 'acceptor removal' in high resistivity silicon detectors

- Usually described as an exponential decay of the Neff over fluence followed by a linear increase

$$N_{eff}(\Phi) = N_{eff0} \cdot e^{-c \cdot \Phi} + g_c \Phi$$

- The acceptor removal coefficient (c) is poorly studied, i.e. only few results as function of acceptor concentration exist

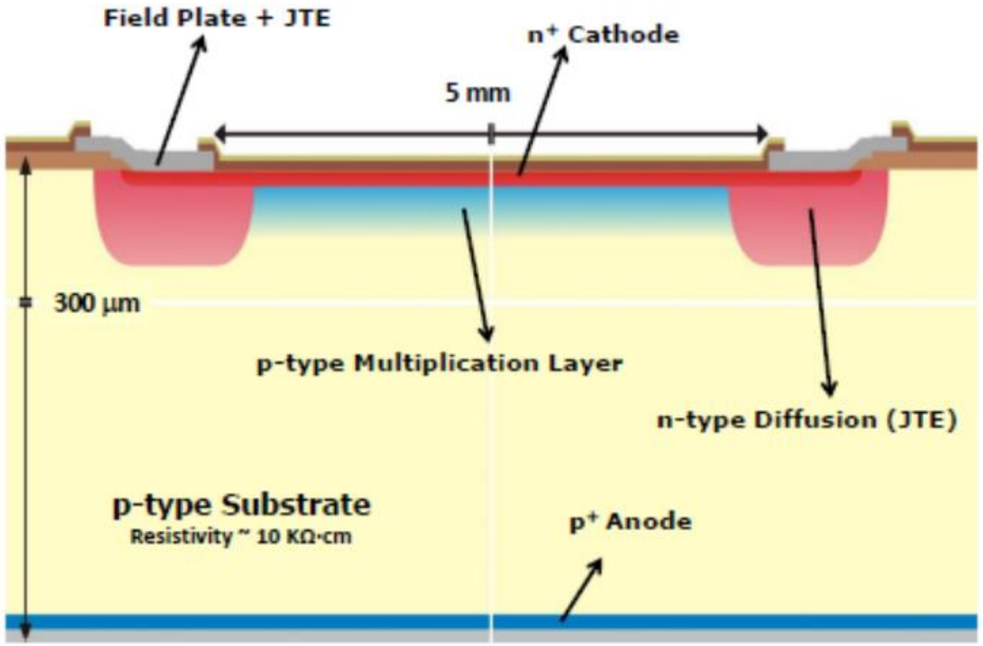


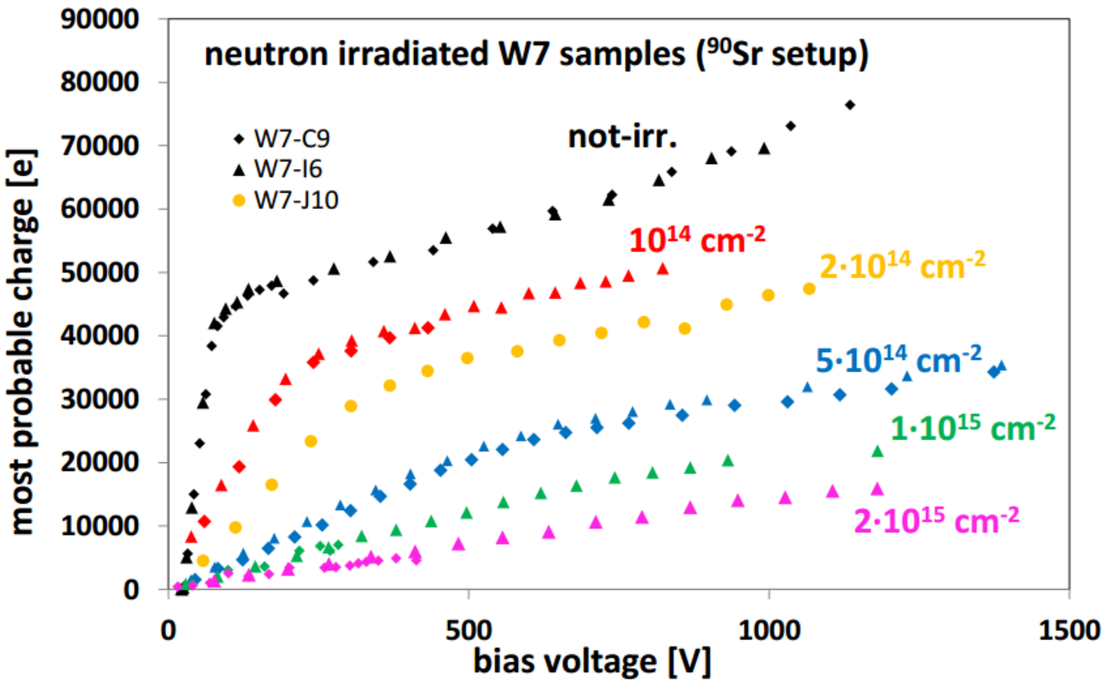
G. Kramberger, VERTEX (2016)

Motivation

Example #1: LGADs

- LGADs are sensors with gain - interesting for their timing capabilities (see yesterday's talks)
- However, the gain of these sensors decreases when exposed to radiation due to 'acceptor removal'



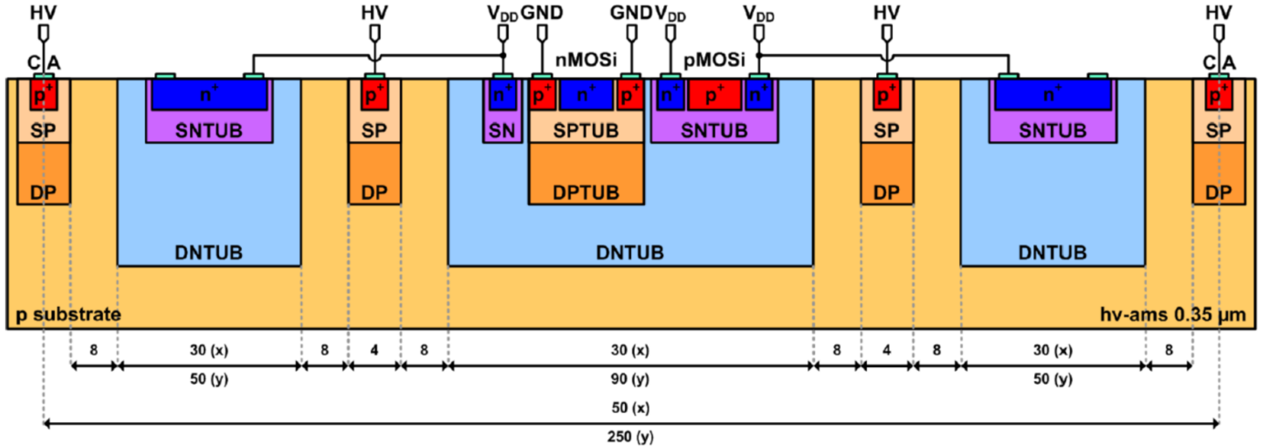


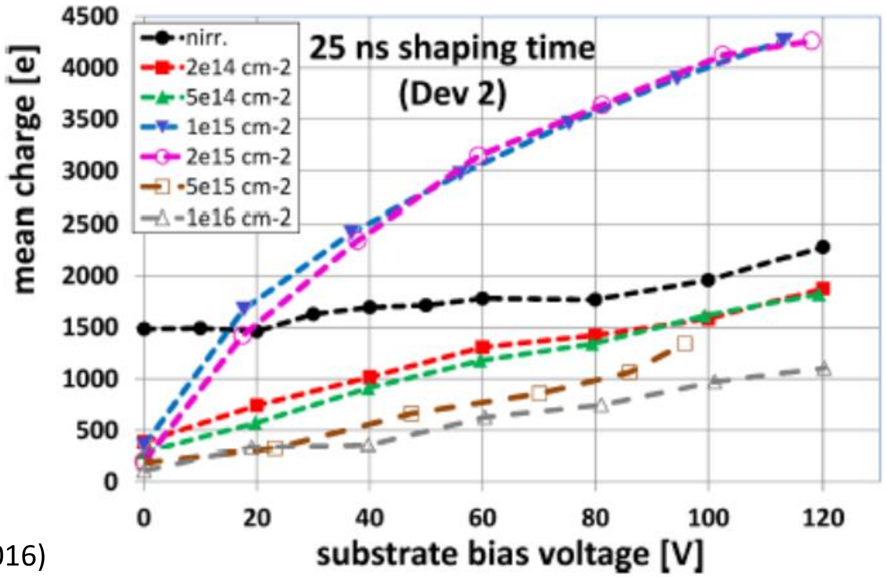
G. Kramberger et al, JINST (2015)

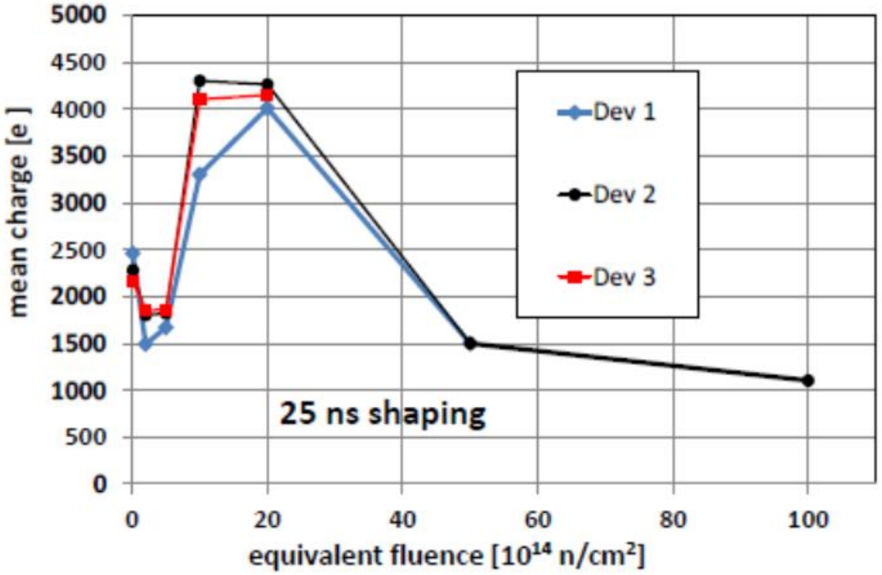
Motivation

Example #2: HVCMOS

- HVCMOS is an interesting technology for monolithic pixel sensors
- However, its charge collection varies with fluence
- Increase of CCE with fluence due to 'acceptor removal' observed

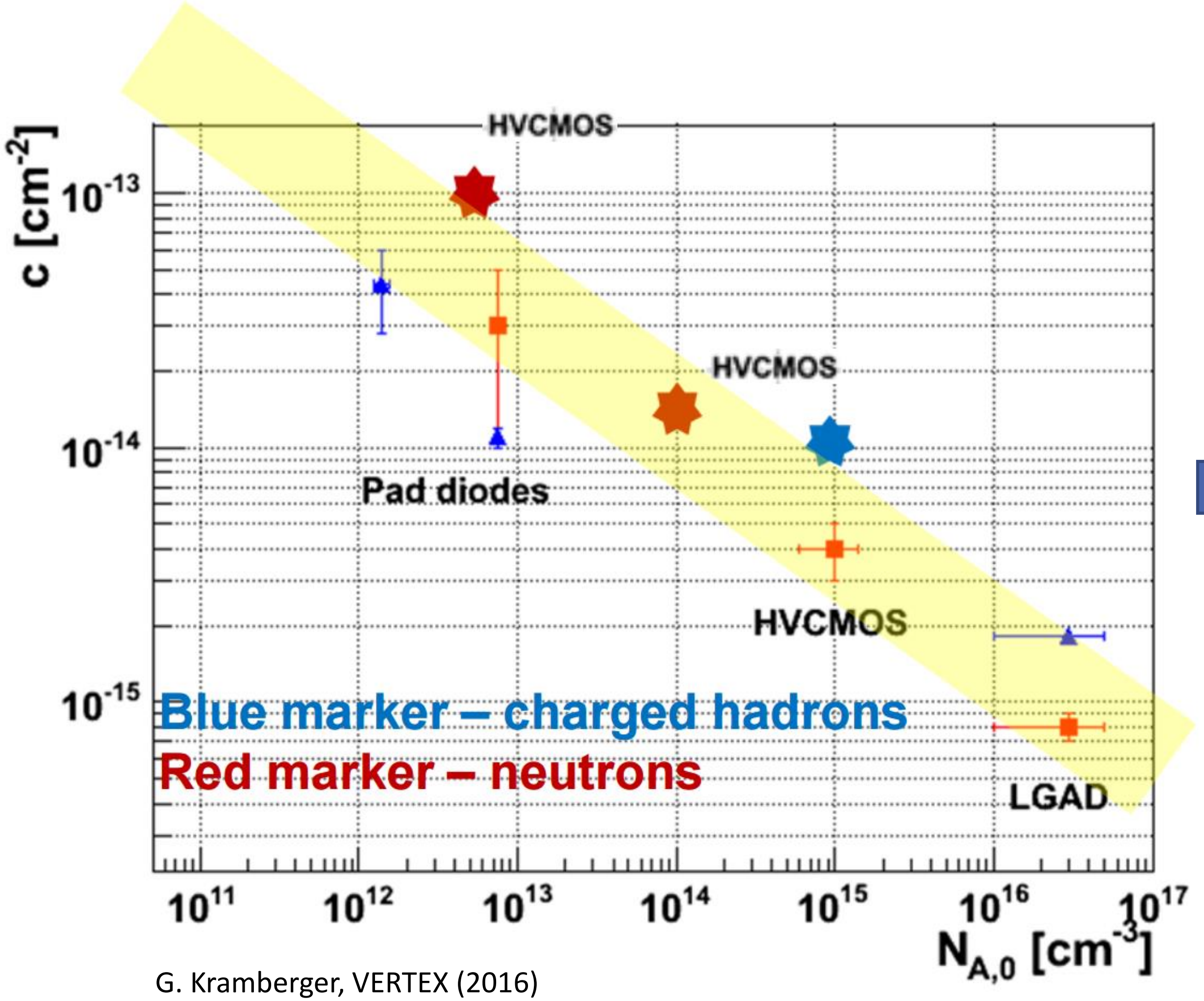






A. Affolder et al, J. Instrumentation (2016)

Acceptor removal



G. Kramberger, VERTEX (2016)

$$N_{eff}(\Phi) = N_{eff0} \cdot e^{-c \cdot \Phi} + g_c \Phi$$

The data available concerns different devices, oxygen content, material type and different measurement techniques

CiS Thin Sensors

Solution: ***dedicated characterization experiment***

A large number of sensors with the same structure with varying thicknesses, resistivities and material types

Material	Resistivity [Ω cm]	Thickness [μm]
Cz	10	50 – 150
MCz	>2000	50 – 200
FZ	>10000	100 – 285
EPI	10 – 1000	50 – 100

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EPI	10 – 1000	50 – 100

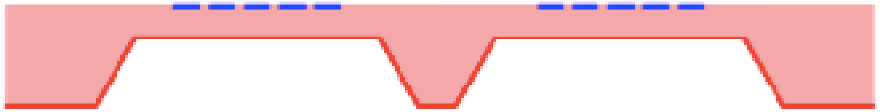
Starting Point

Float Zone (>10k Ωcm)
- 100 µm
- 150 µm
- 200 µm
- 285 µm

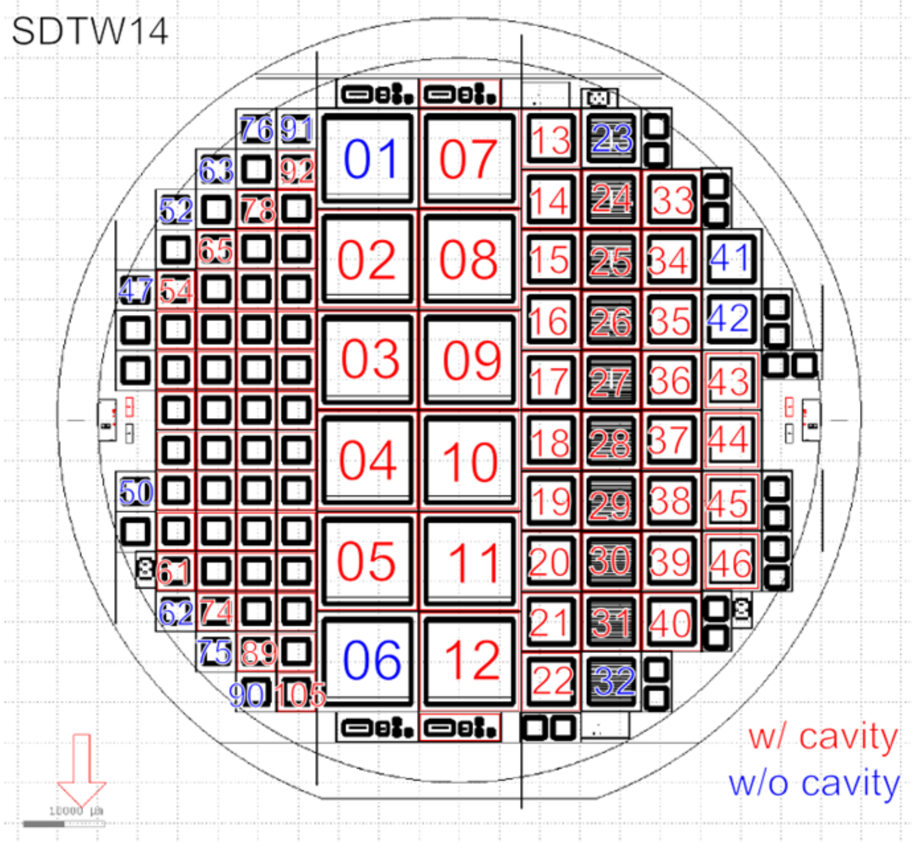
Epitaxial (50 µm)
- 10 Ωcm
- 50 Ωcm
- 250 Ωcm
- 1000 Ωcm

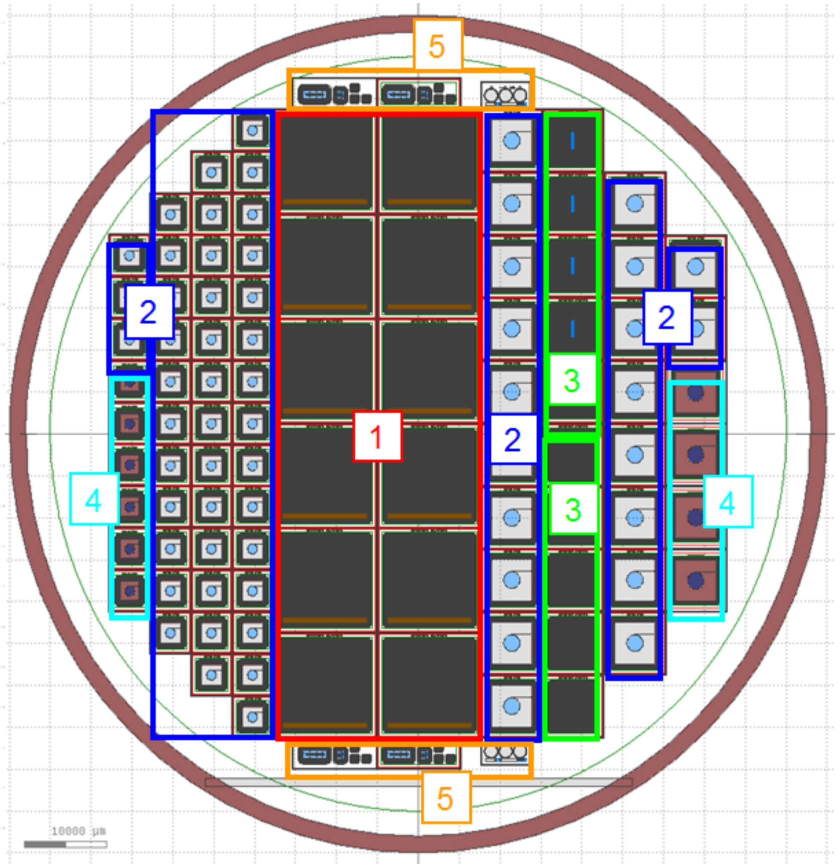
Forschungsinstitut für Mikrosensorik GmbH

CiS Thin Sensors



Thinned by cavity etching





Legend:

1. Micro Strip Sensors (80µm pitch)
2. Diodes: 5x5mm 2.5x2.5mm
3. Spaghetti Diodes: V1 (standard) V2 (special)
4. Diodes (From MPI-M) 5x5µm 2.5x2.5mm
5. Further Test Structures (From MPI-M)

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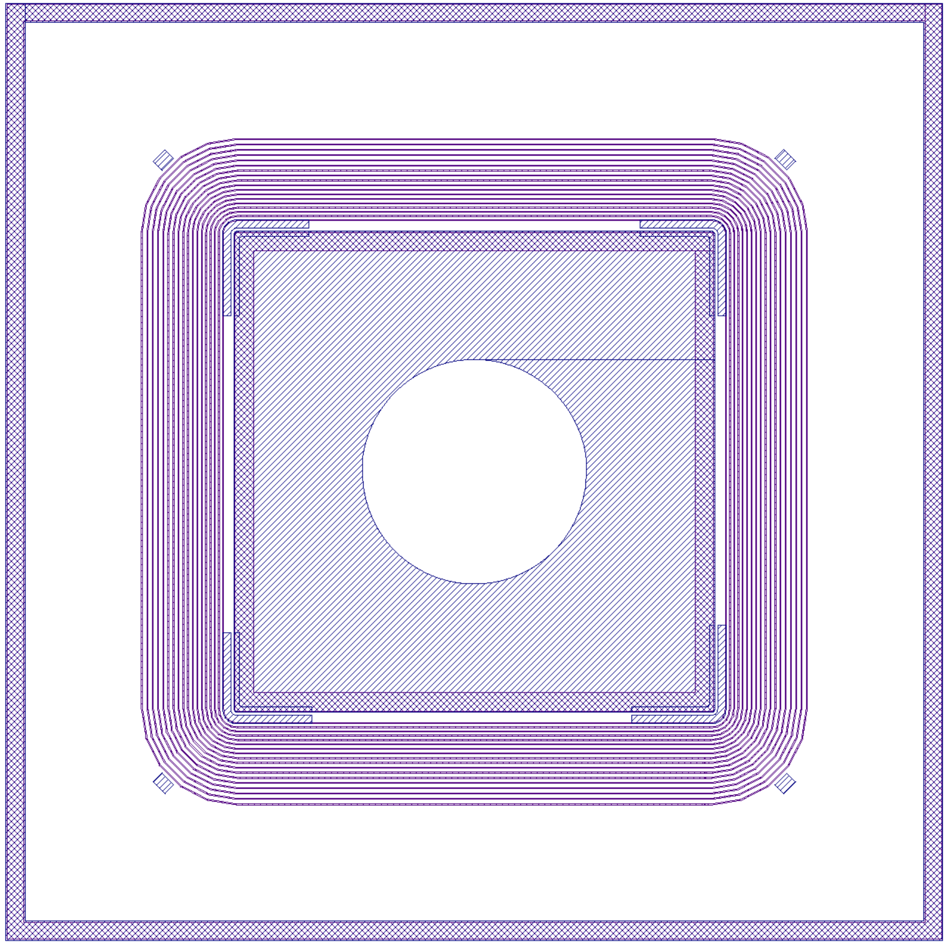
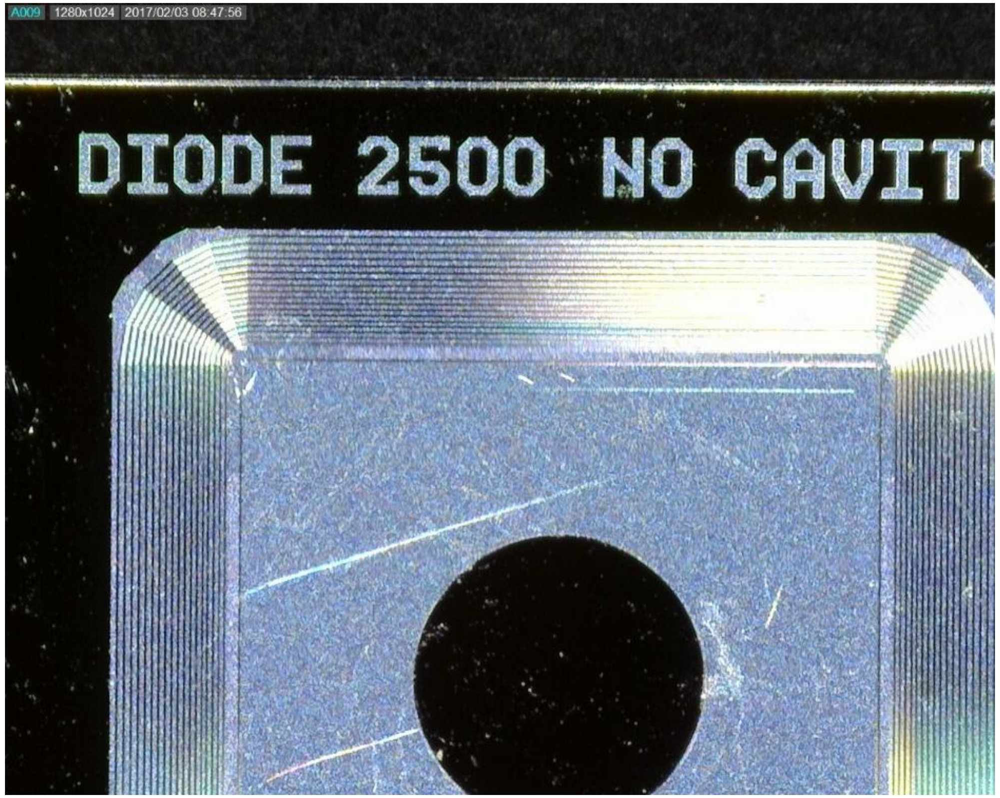
CiS Thin Sensors – Pad Diodes (2.5x2.5 mm)





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Irradiation

PROTON IRRADIATION CAMPAIGN

IRRAD facility at CERN

# Sensors	Fluence [p/cm^2]
8	1.30e13
12	6.44e13
8	1.30e14
8	5.54e14
8	1.22e15
8	1.17e16

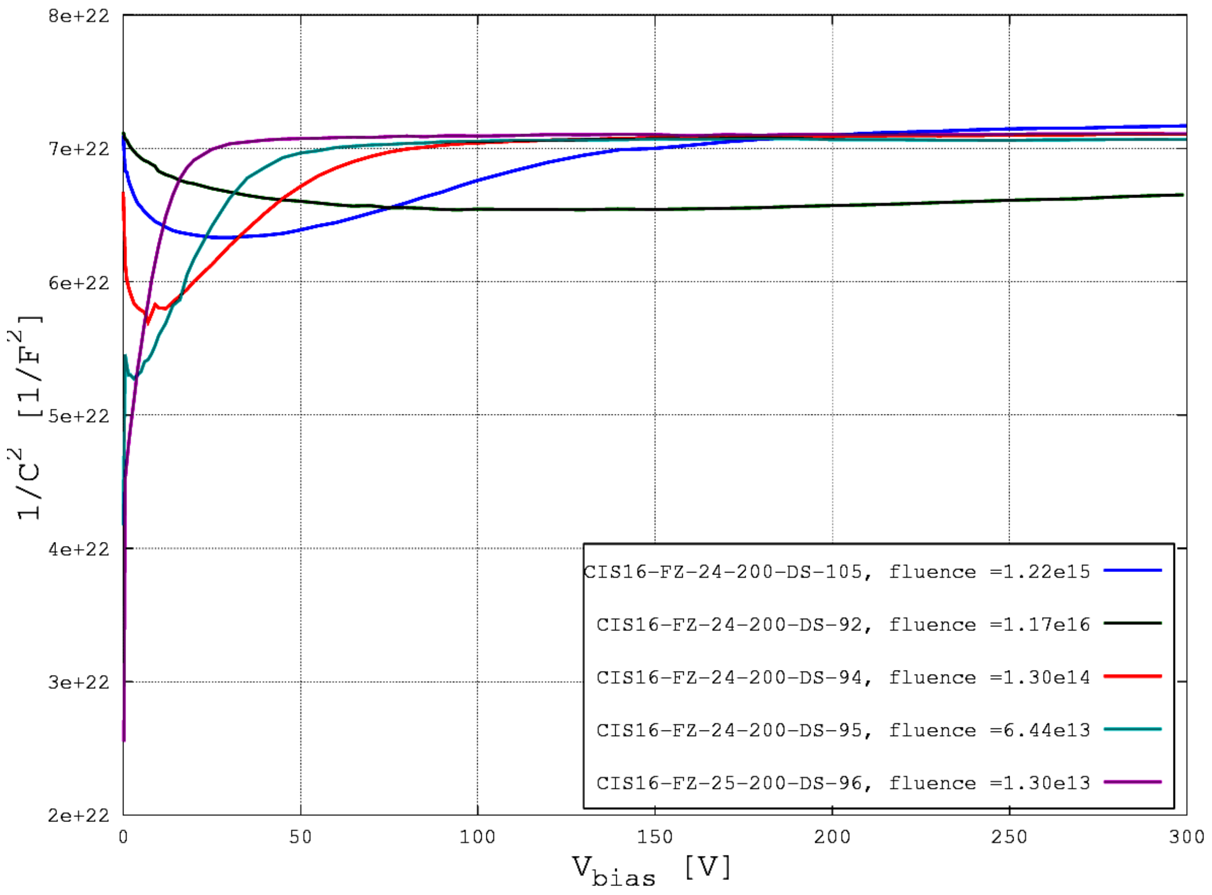
NEUTRON IRRADIATION CAMPAIGN

Reactor Centre of the Jozef Stefan Institute in Ljubljana

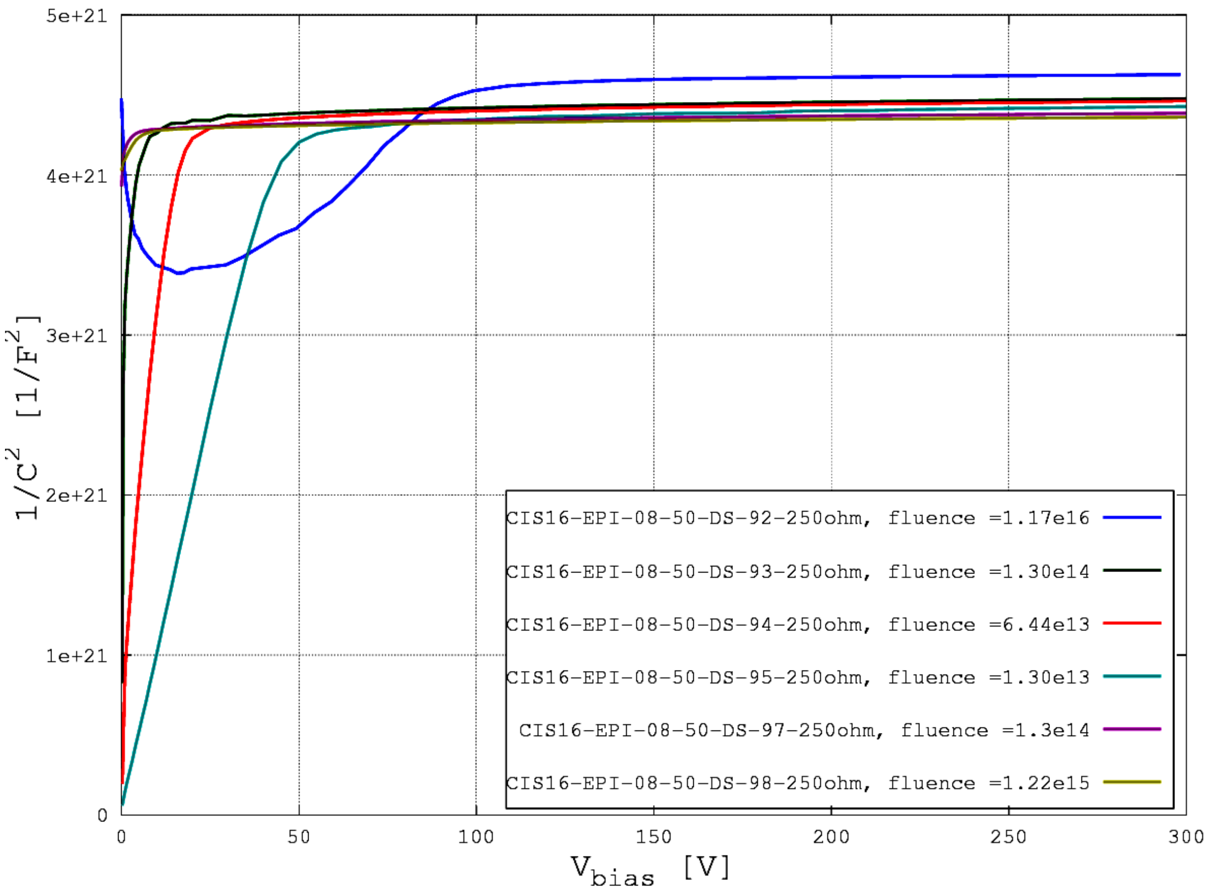
# Sensors	Fluence [n/cm^2]	# Sensors	Fluence [n/cm^2]
4	1.00e11	20	3.86e13
2	5.00e11	10	7.80e13
3	2.00e12	10	3.32e14
2	4.00e12	10	5.00e15
10	7.80e12	10	7.02e15
2	2.00e13		

Proton Irradiation Campaign

Float Zone (200 µm; @-20°C; no annealing)



Epitaxial (250 Ωcm; @-20°C; no annealing)



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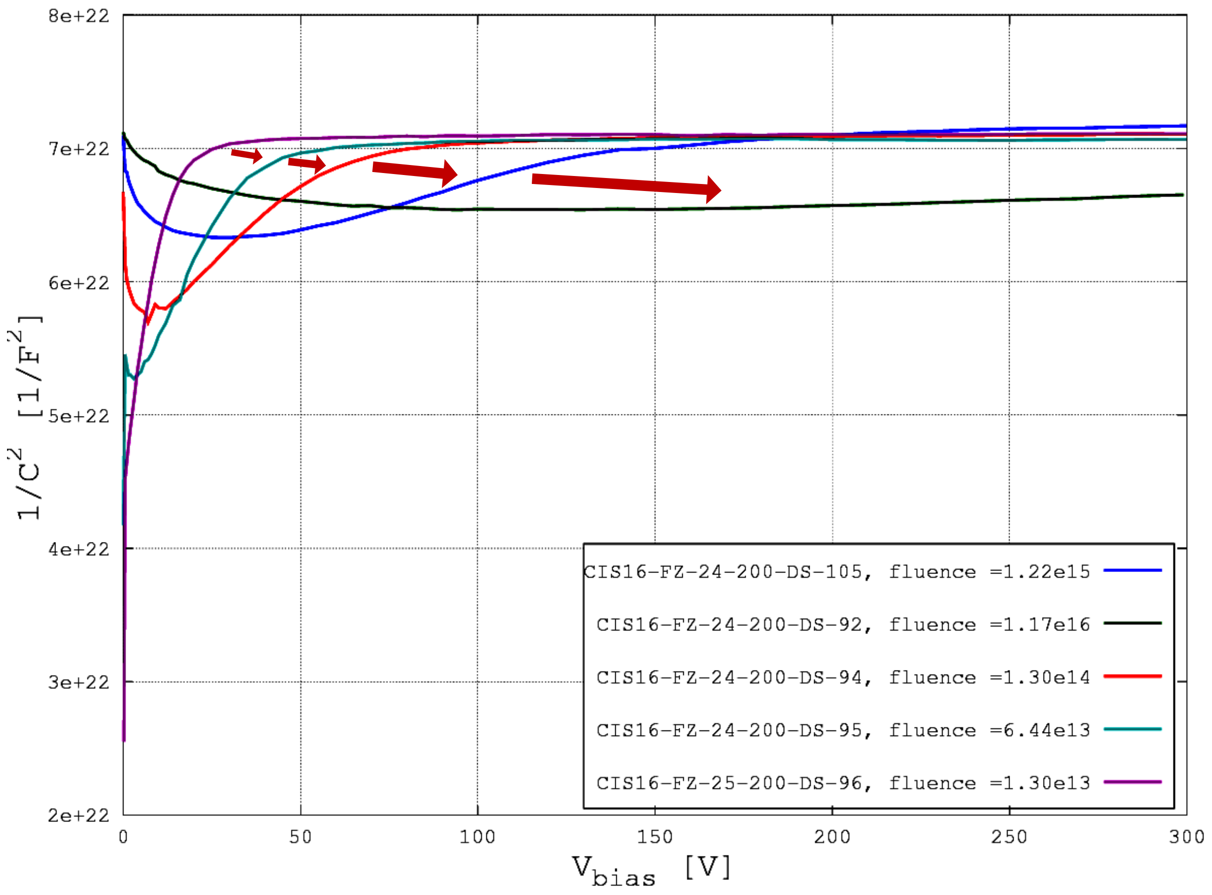

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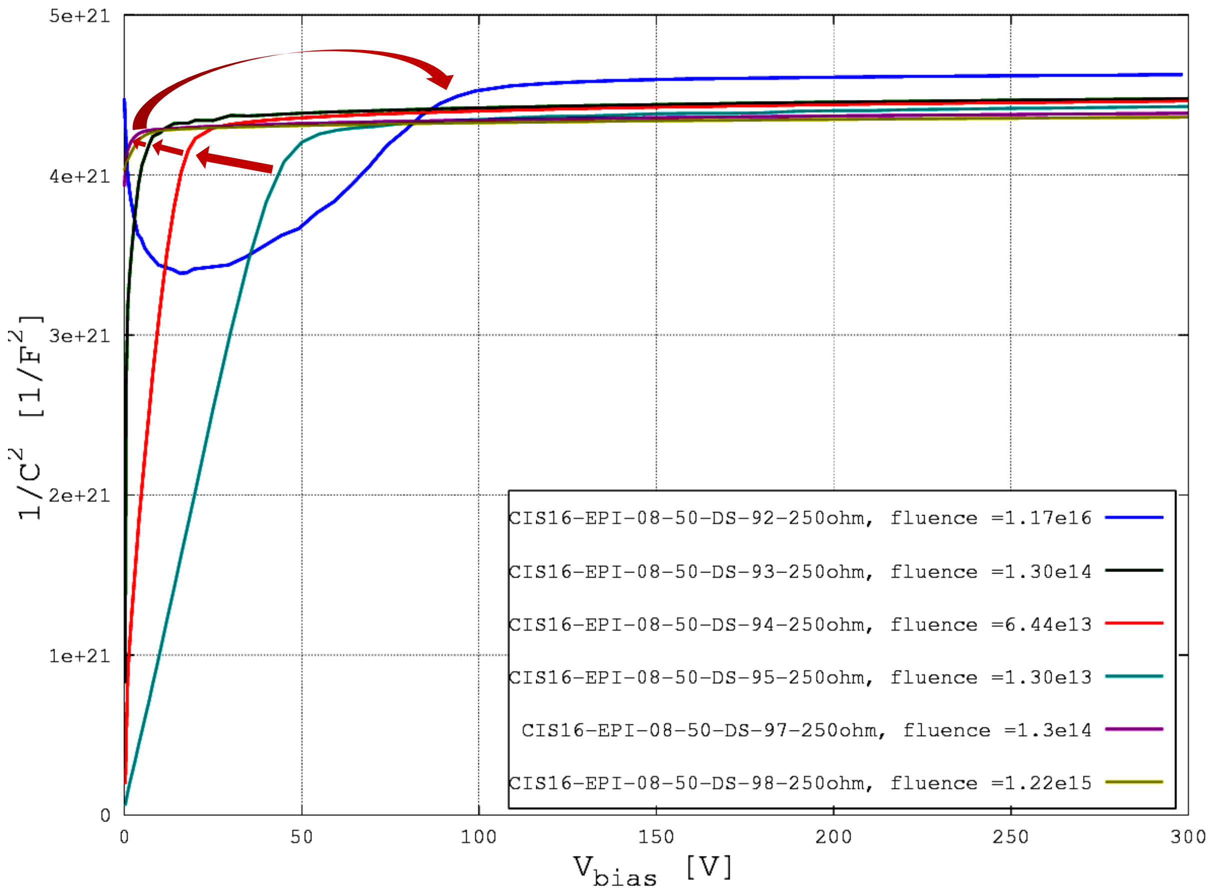


Proton Irradiation Campaign

Two methods were used to measure Neff:

- Depletion Voltage:

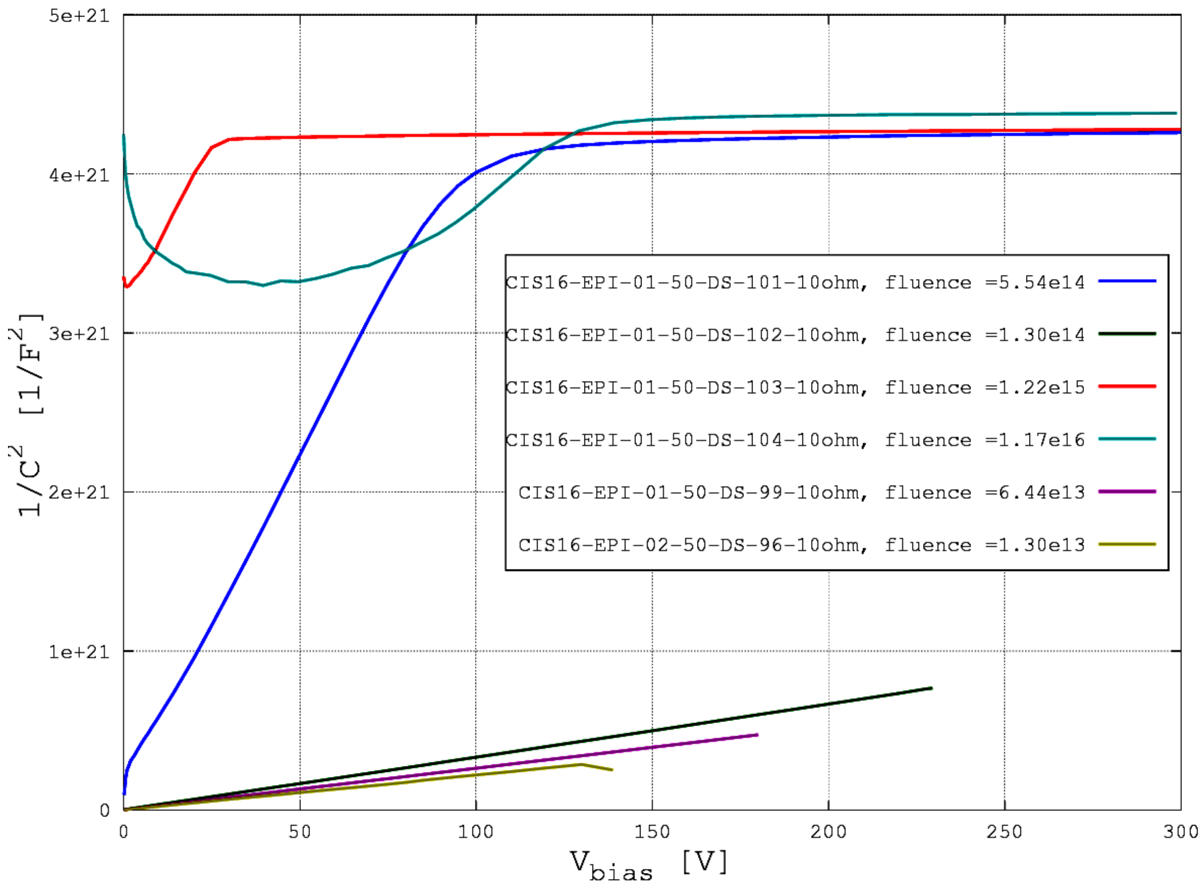
$$N_{eff} = \left(\frac{C}{A}\right)^2 \frac{2V_{dep}}{\varepsilon\varepsilon_0 q_0}$$

- $1/C^2$ Slope:

$$N_{eff} = \frac{2}{A^2\varepsilon\varepsilon_0 q_0}\frac{1}{d\left(1/C^2\right)/dV}$$

Note: at higher fluences the mode chosen for the CV measurement has an impact in the shape of the CV curve, but doesn't affect the depletion voltage measurement

Epitaxial (10 Ωcm; @-20°C; annealing: 10min 60°C)



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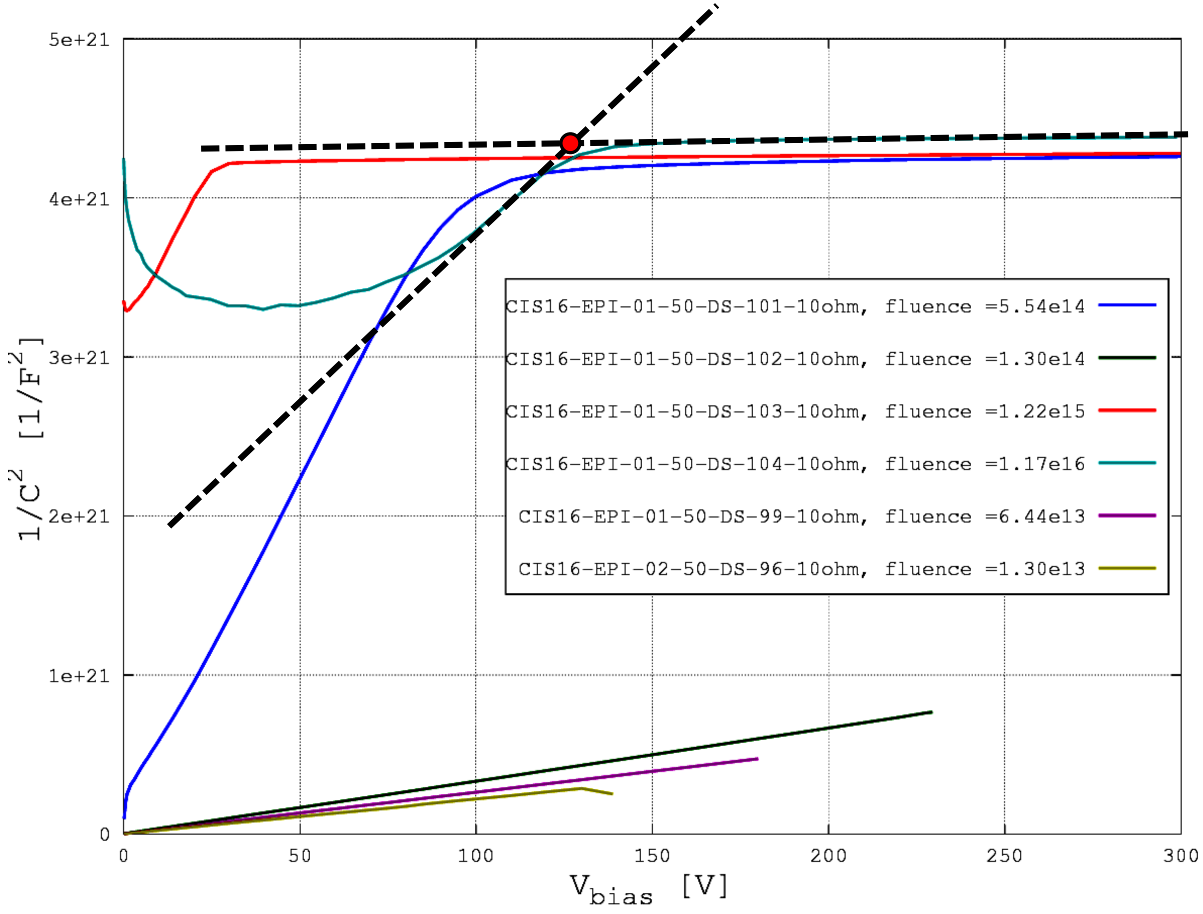

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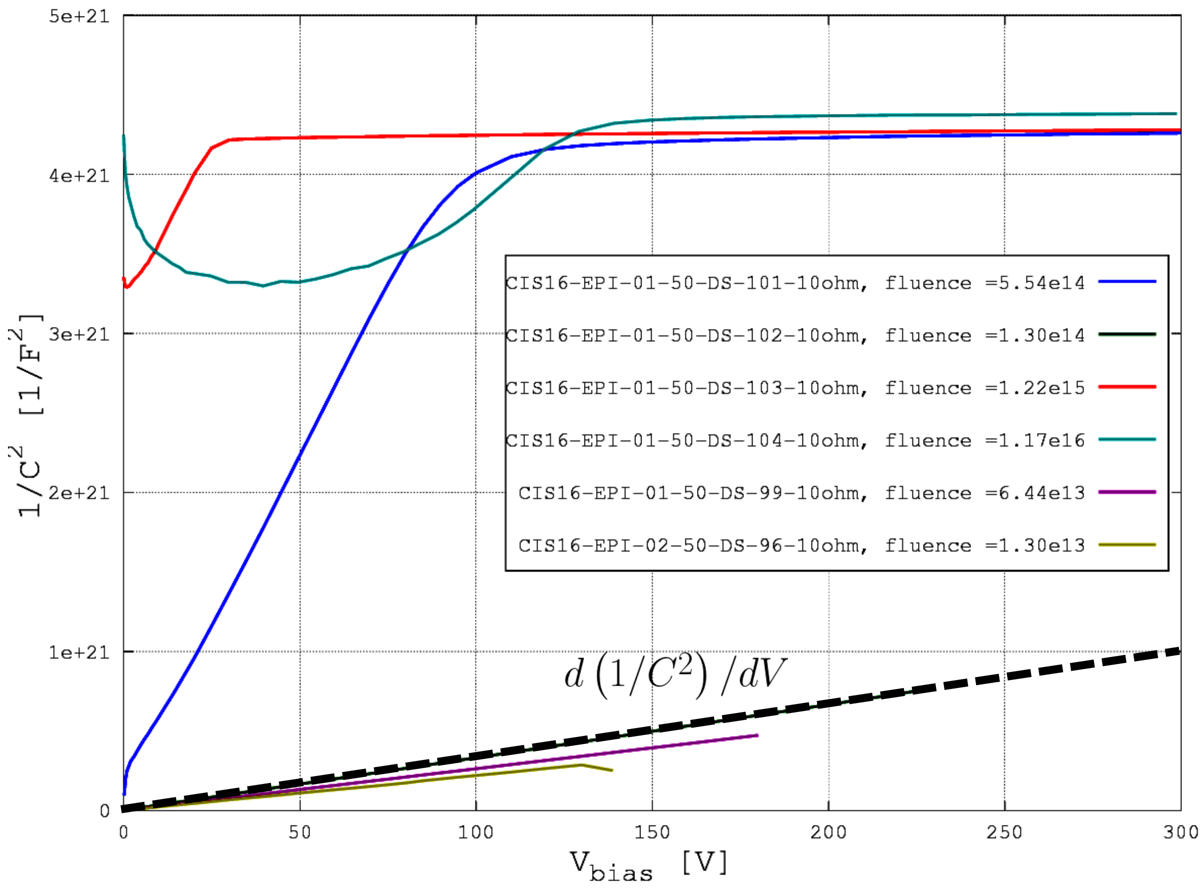
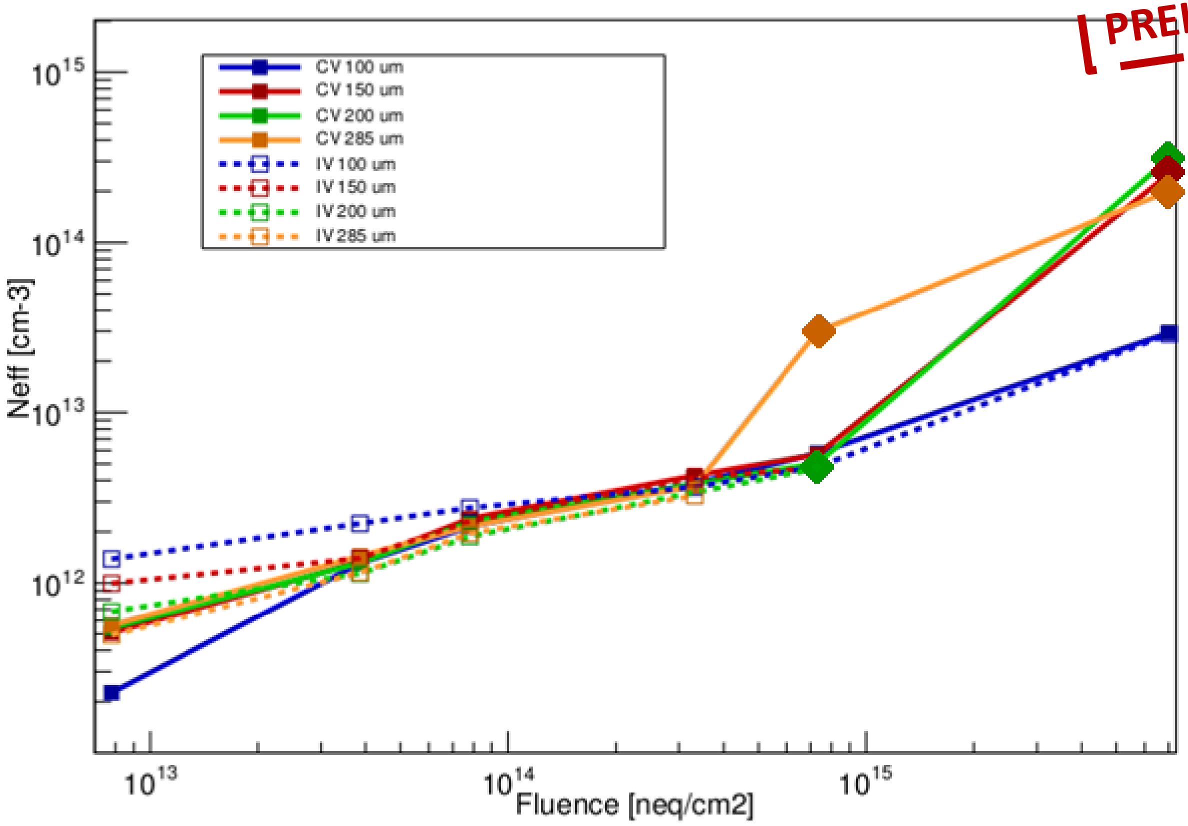
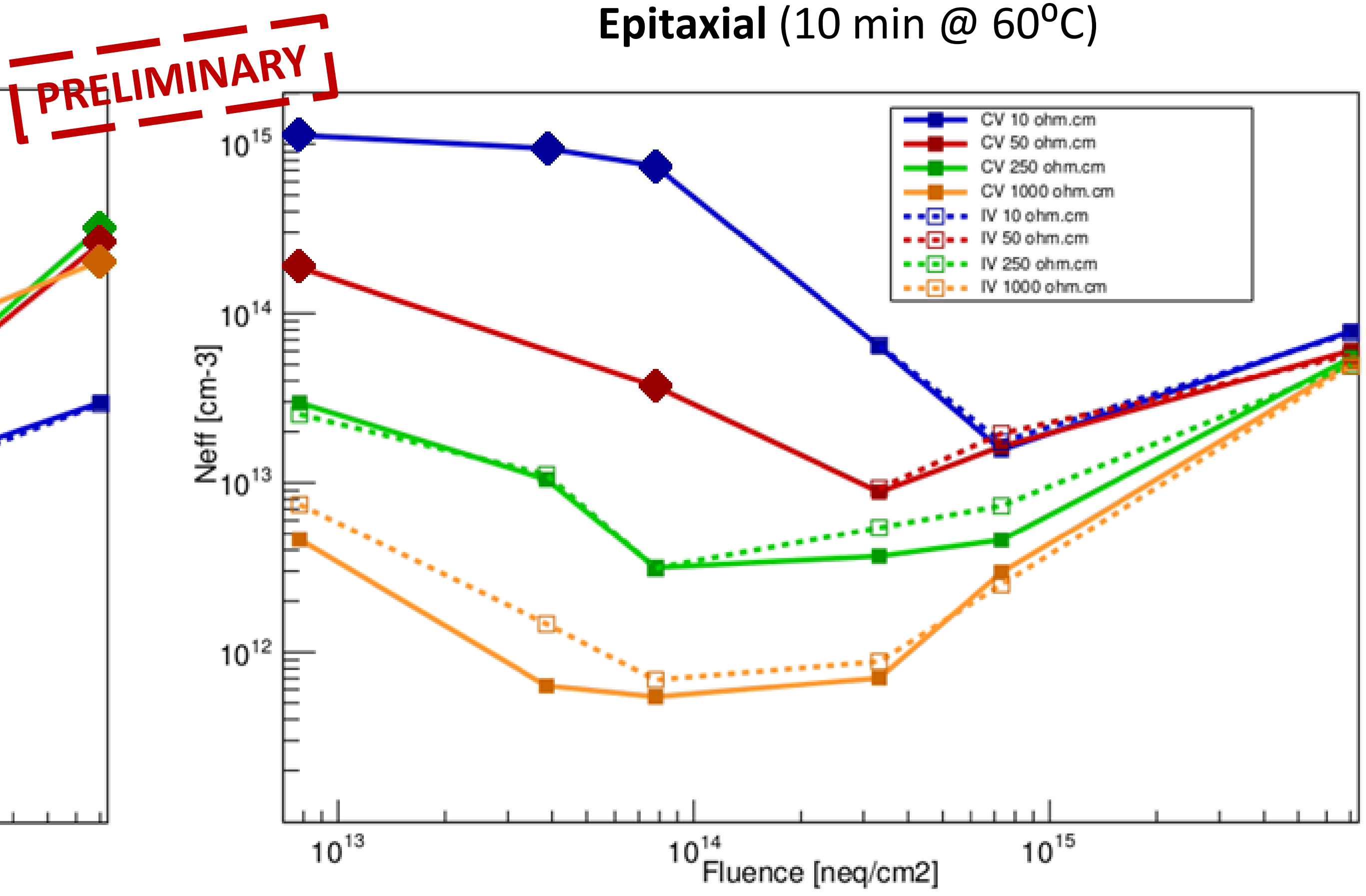


Proton Irradiation Campaign

Floatzone (No annealing)



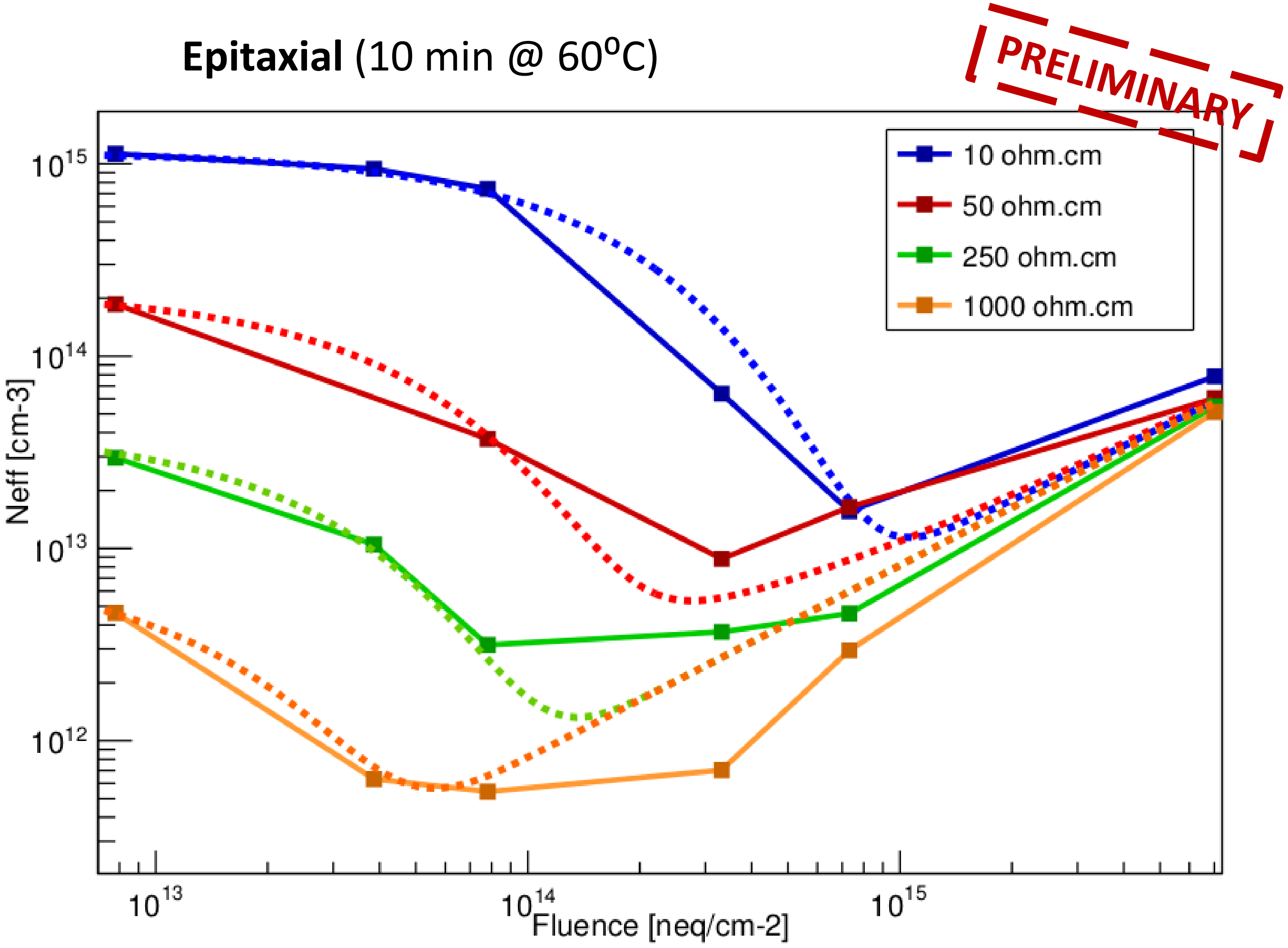
Epitaxial (10 min @ 60⁰C)



◆ Datapoints from slope ■ Datapoints from kink

Proton Irradiation Campaign

Epitaxial (10 min @ 60°C)



- Fitted function:

$$N_{eff}(\Phi) = N_{eff0} . e^{-c \cdot \Phi} + g_c \Phi$$

- The linear slope gc was constrained to be the same across the different resistivities

	measured	fitted	
ρ [Ω cm]	**$N_A(0)$**	**C [cm²]**	**g_c [cm⁻¹]**
10	1.16e15	6.5e-15	
50	2.20e14	2.3e-14	8.2e-3
250	4.21e13	3.9e-14	
1000	8.25e12	7.7e-14	

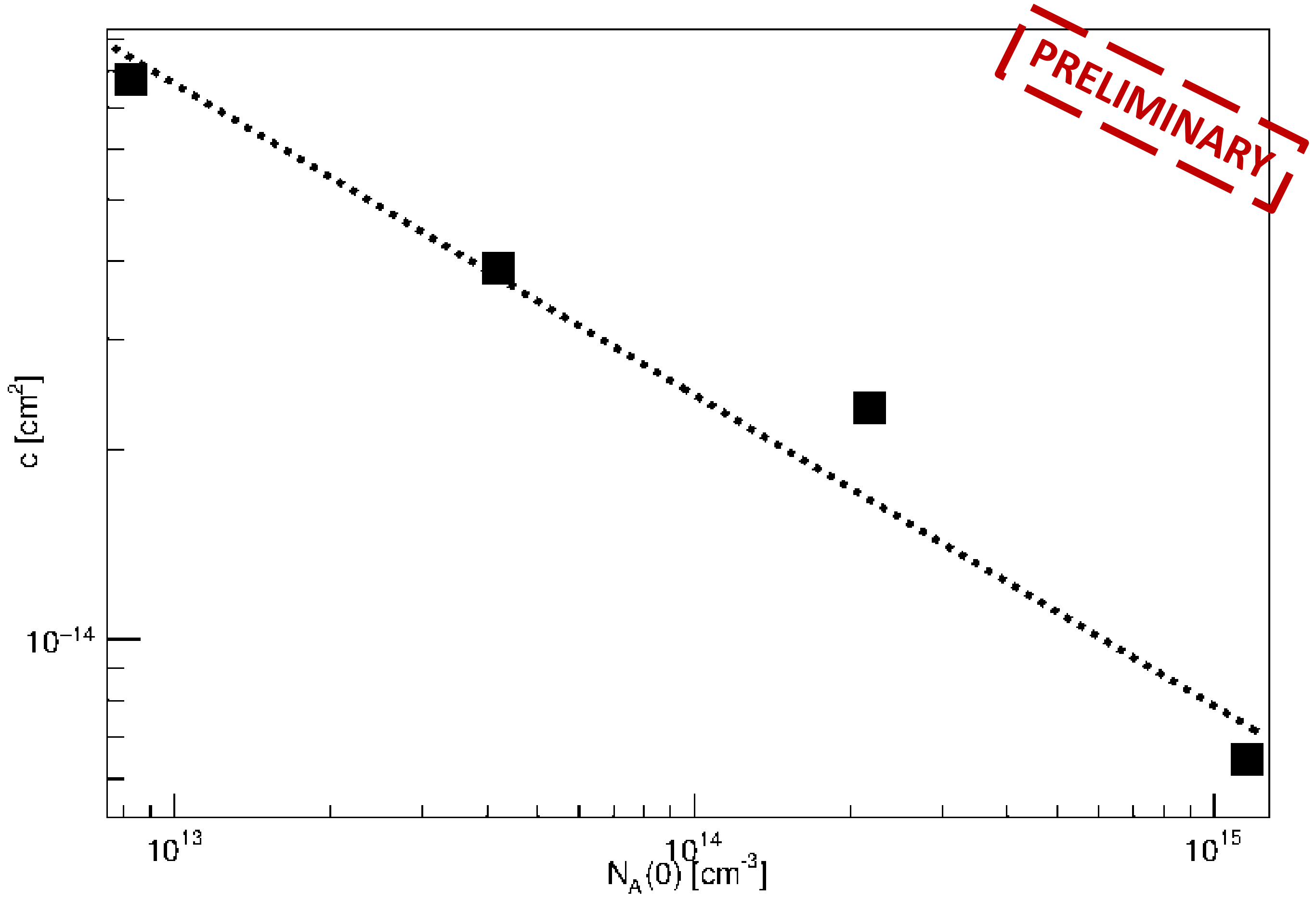
Proton Irradiation Campaign

The acceptor removal rate plotted against the initial acceptor concentration follows

$$c = a \cdot N_A(0)^{-b}$$

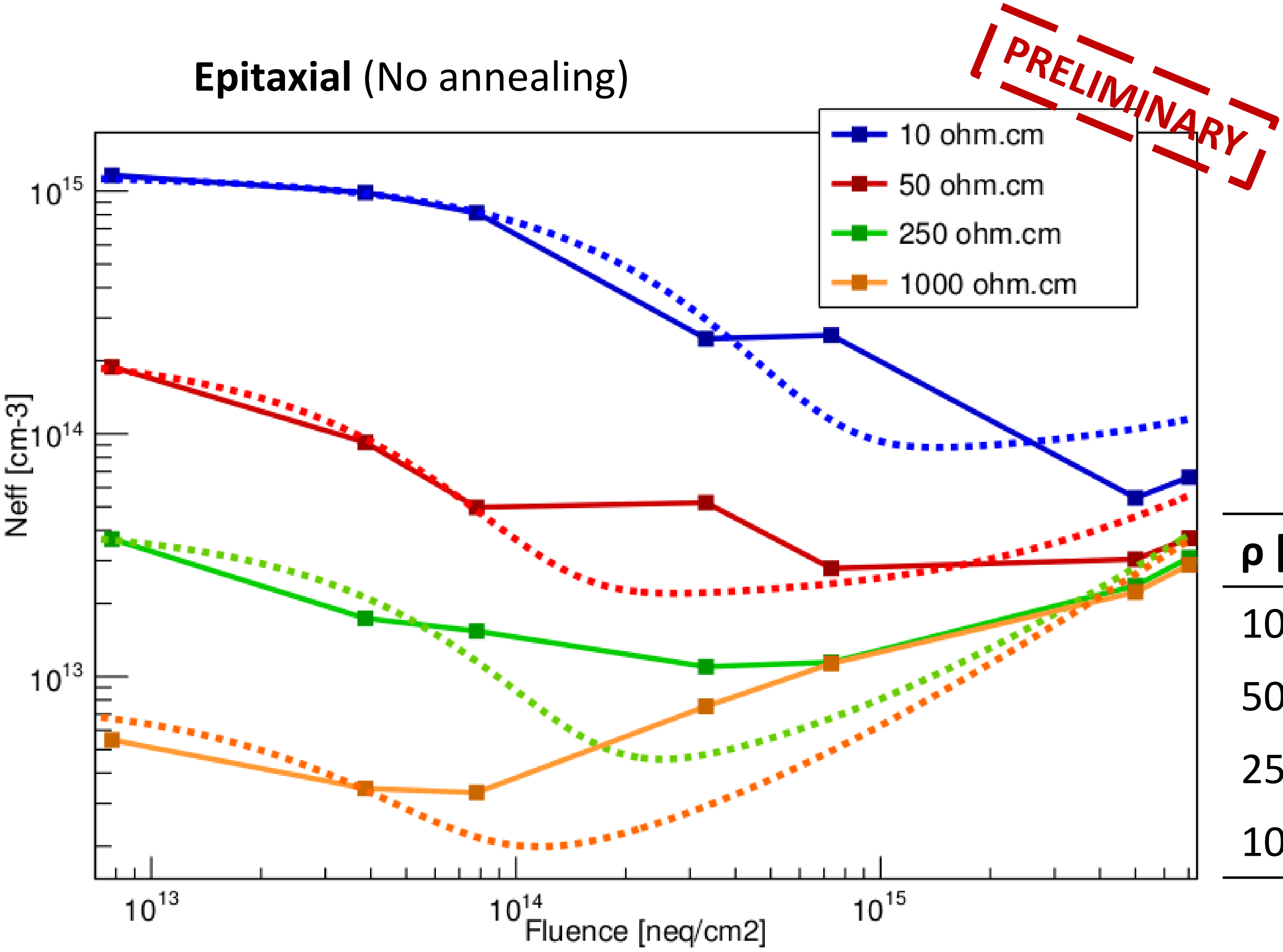
By fitting it to the data results:

a = 2.04e-7
b = 4.94e-1



Neutron Irradiation Campaign

Epitaxial (No annealing)



- Fitted function:

$$N_{eff}(\Phi) = N_{eff0} - N_c\left(1 - e^{-c\Phi}\right) + g_c\Phi$$

- The linear slope gc was constrained to be the same across the different resistivities

	measured	fitted		
ρ [Ω cm]	$N_A(0)$ [cm^{-3}]	N_c [cm^{-3}]	C [cm^2]	g_c [cm^{-1}]
10	1.16e15	1.08e15	4.88e-15	5.02e-3
50	2.20e14	1.99e14	2.54e-14	
250	4.21e13	3.90e13	2.02e-14	
1000	8.25e12	6.99e12	3.30e-14	

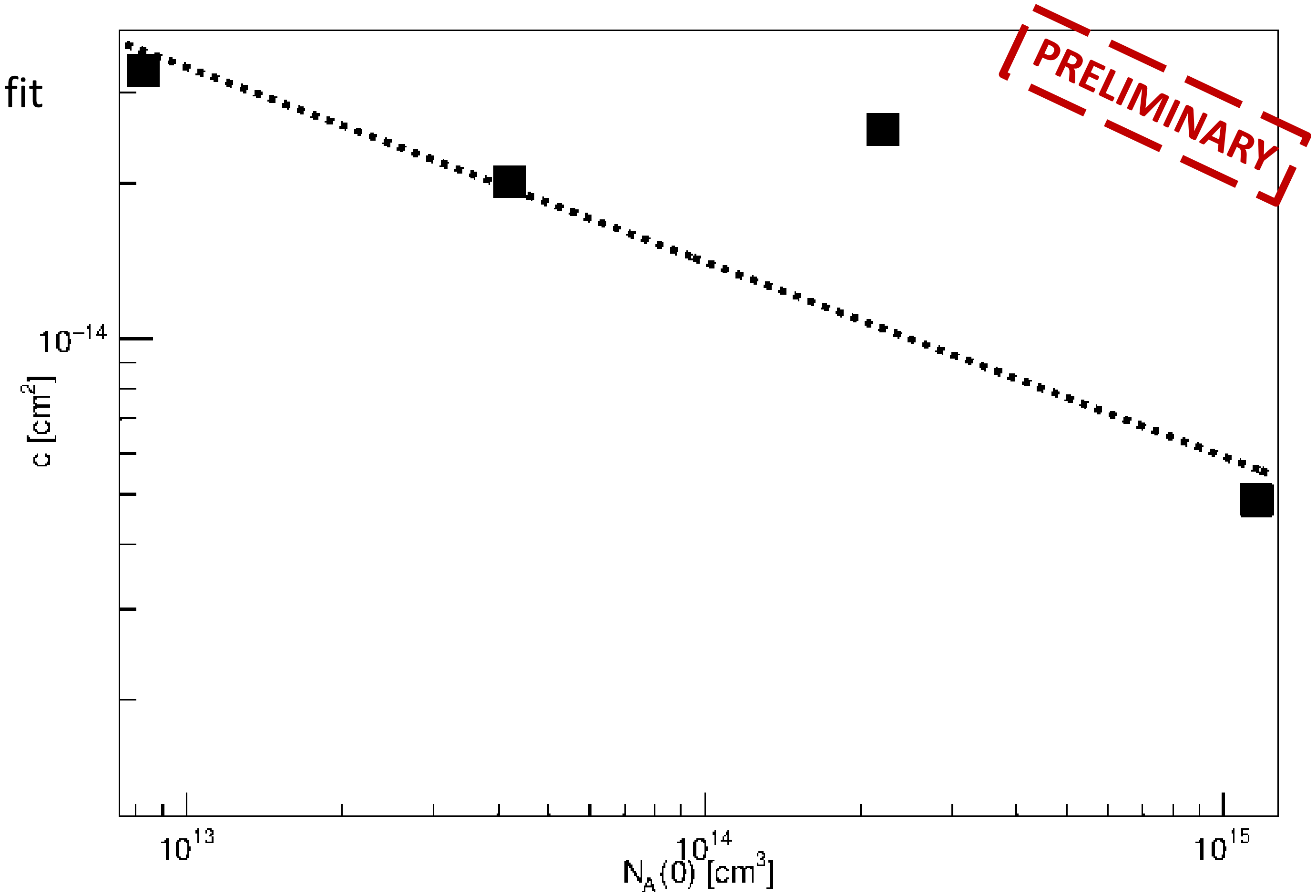
Neutron Irradiation Campaign

Again, the following equation was used to fit the data

$$c = a \cdot N_A(0)^{-b}$$

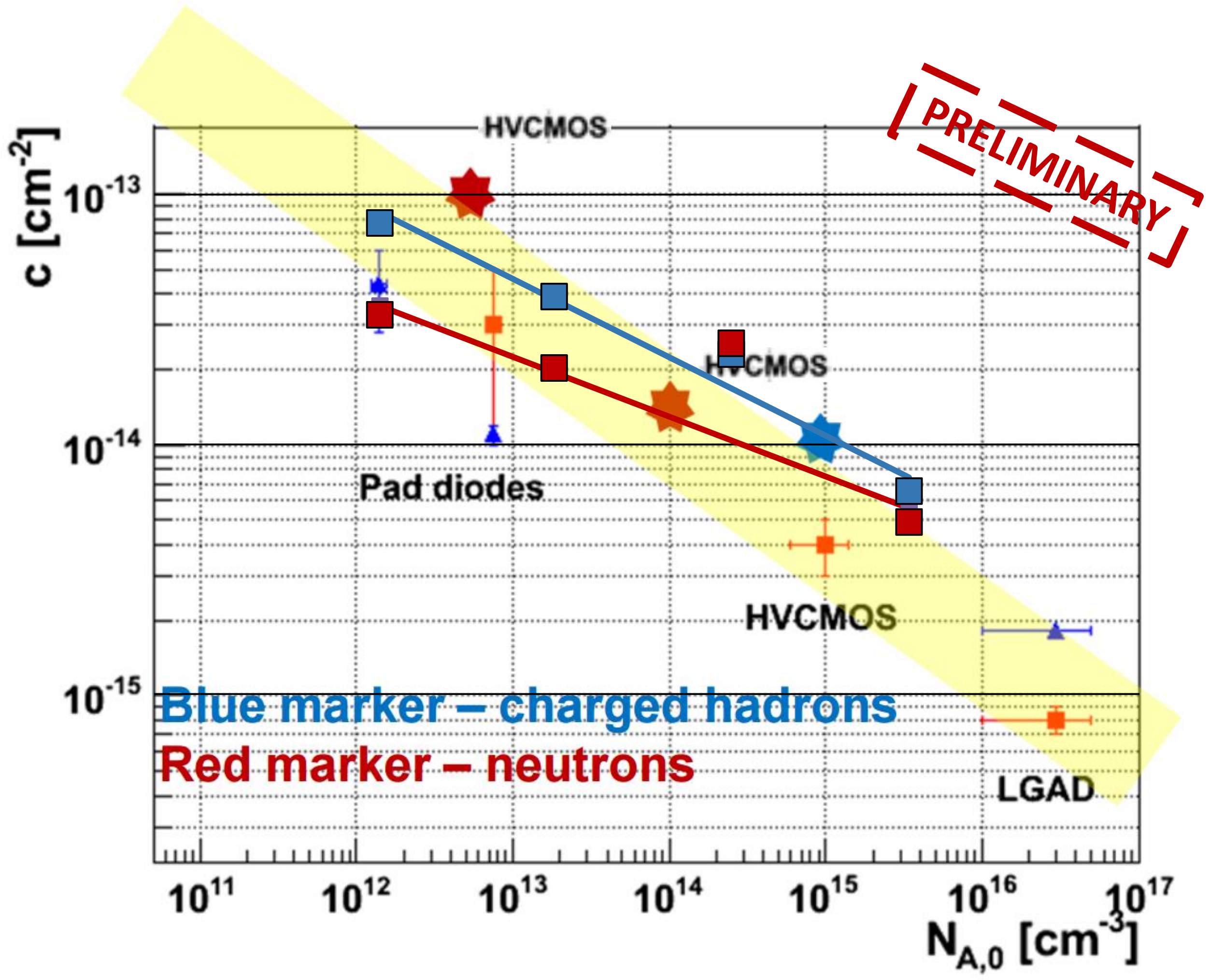
Resulting in:

a = 2.65e-9
b = 3.77e-1



Conclusion

- We verified the existence of acceptor removal in our epitaxial sensors.
- The rate at which the boron is removed is in line with the literature.
- These results are very significant as they are obtained on a material differing only in Boron content (same growth method, same Oxygen content)



Summary

- New detector technologies are under study to cope with high radiation environment and new requirements.
- Acceptor removal is very relevant for these new technologies.
- A large number of sensors was sourced with varying material types, thicknesses and resistivities.
- After irradiation, acceptor removal was observed on epitaxial sensors with varying resistivities.
- The acceptor removal rate was measured and found to roughly match the available literature values.

Future work

- These results will soon be complemented by TCT (Transient Current Technique)
- TSC (Thermally Simulated Current) measurements will allow the characterization of the defects.
- Simulation is another approach being considered.
    - Main question: Can the observed acceptor removal be matched to the generation of Boron related defects.