Nitrostrip

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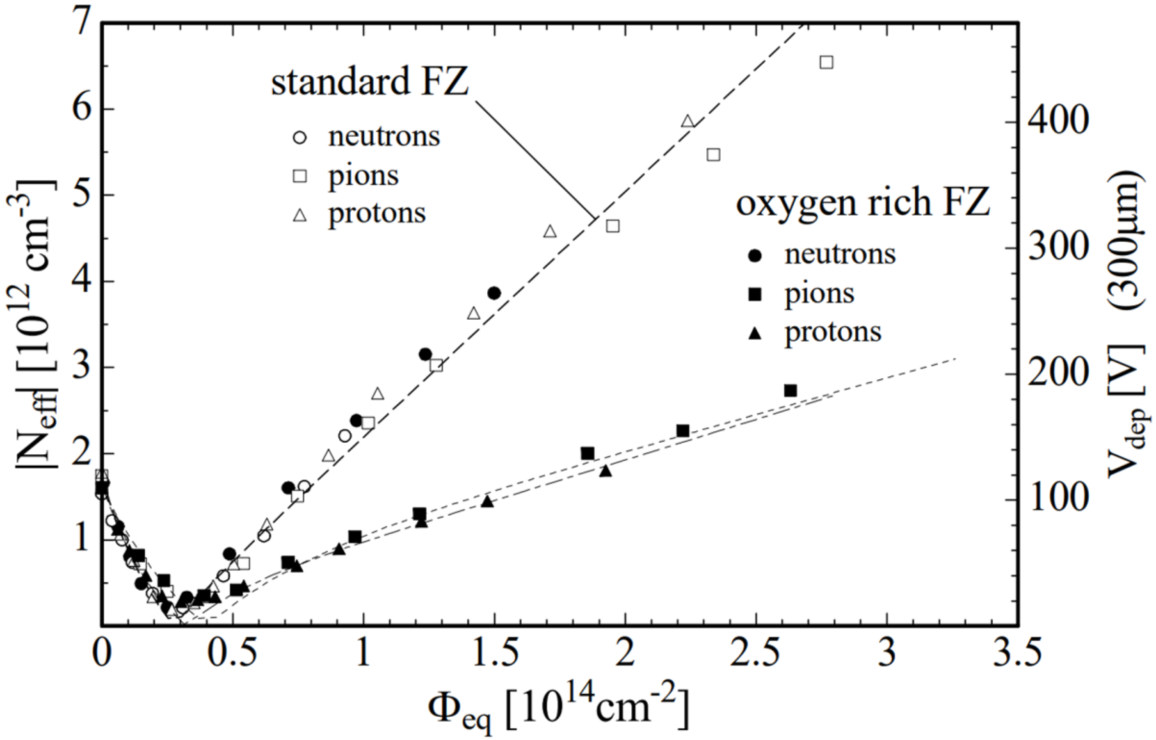
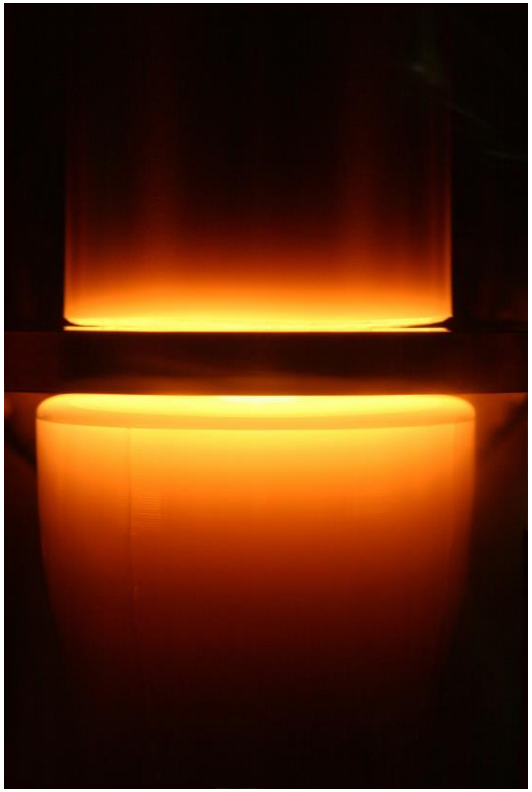
RD48 and foreign atoms

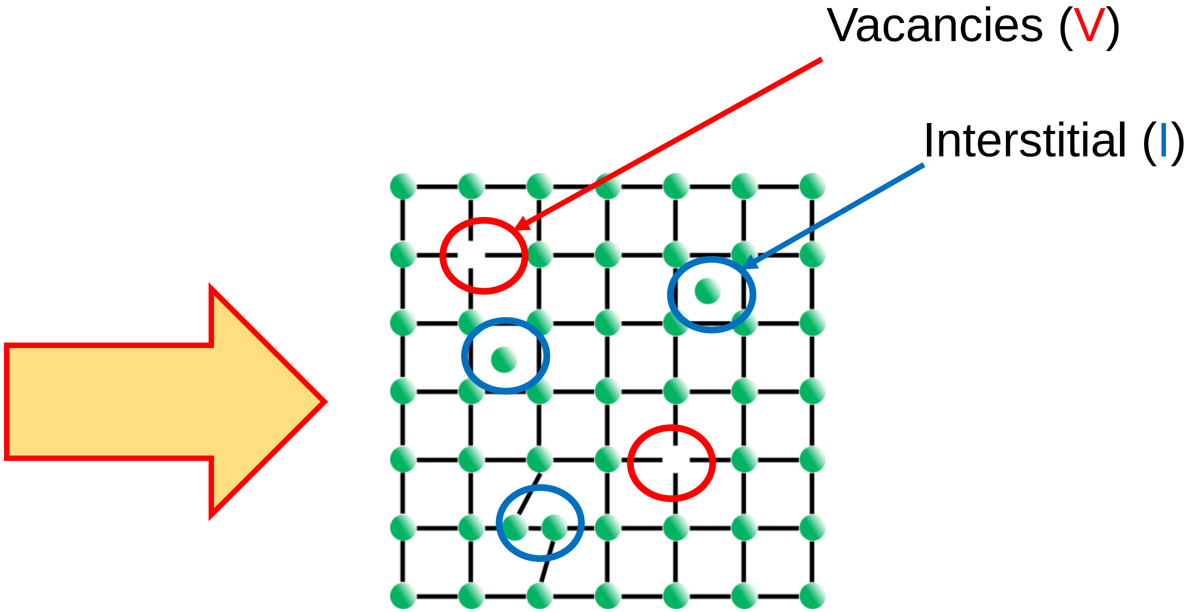


The RD48 Collaboration observed a change in the relation between fluence and effective doping concentration for oxygenated silicon.

This showed potential of enrichment with foreign atoms.

Nitrostrip - Nitrogen doped silicon





During crystal growth imperfections and defects are formed within the silicon wafer.

Nitrostrip - Nitrogen doped silicon

(1) $I + V \leftrightarrow 0$

(2) $2N_i \leftrightarrow N_2$

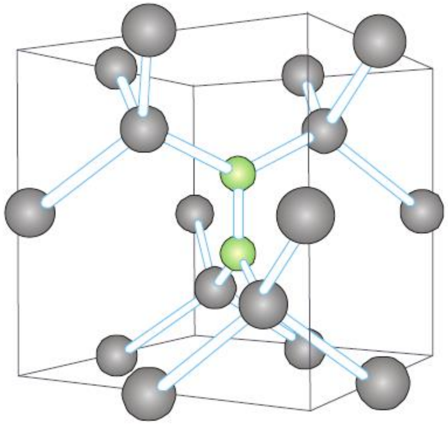
(3) $N_s + N_i \leftrightarrow N_2V$

(4) $N_2 + V \leftrightarrow N_2V$

(5) $N_2V + I \leftrightarrow N_2$

N_i=single interstitial nitrogen

N_s=substitutional nitrogen



M. Kwestarz, RD50 Workshop, November 2014

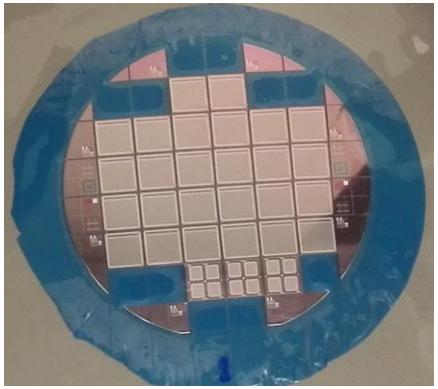
Kaminski shows:
Nitrogen enriched silicon has low density of defect centers compared to low nitrogen silicon after irradiation with neutrons.

Samples and irradiation facilities

Wafers	Label	Substrate
1-6	FZ	HR-Float Zone n-type, 2000-2400Ω cm
7-12	NIT	HR-FZ Nitrogenated n-type, 1500-1900Ω cm
13-18	DOFZ	HR-FZ Oxygenated n-type, 2000-2400Ω cm
19-24	MCz	HR-Magnetic Czochralski n-type, 800-1000Ω cm

Irradiation done in:

Ljubljana	1MeV neutrons
KIT	23MeV protons
CERN	24GeV protons



Measurement campaign

Planned measurements:

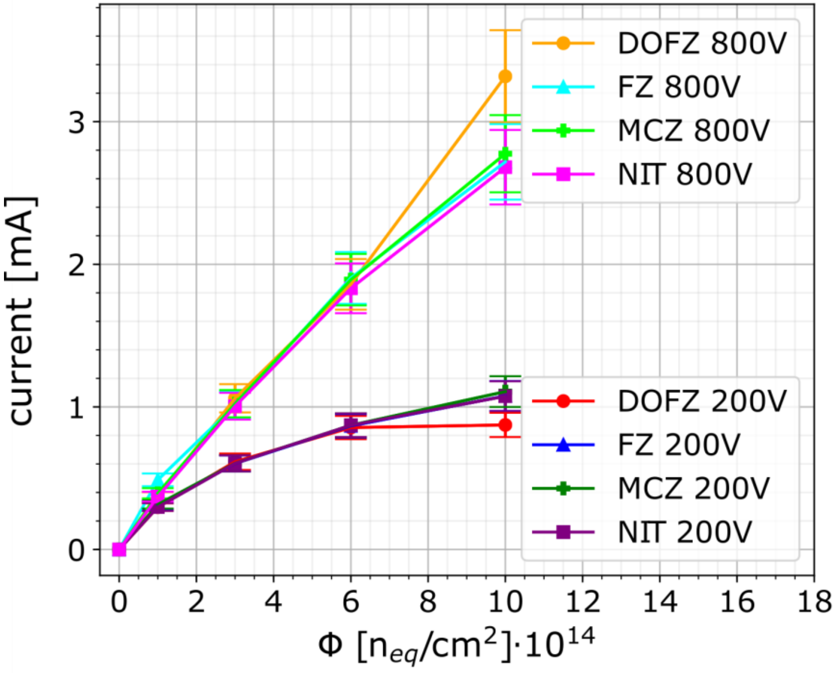
- IV curves
- Source (AliBaVa)
- Edge **T**ransient **C**urrent **T**echnique (Edge-TCT)
- **T**hermally **S**timulated **C**urrent technique (TSC)

Fluences we irradiated to range from 1e13 to 1e15 $\mathrm{n_{eq}}$/cm².

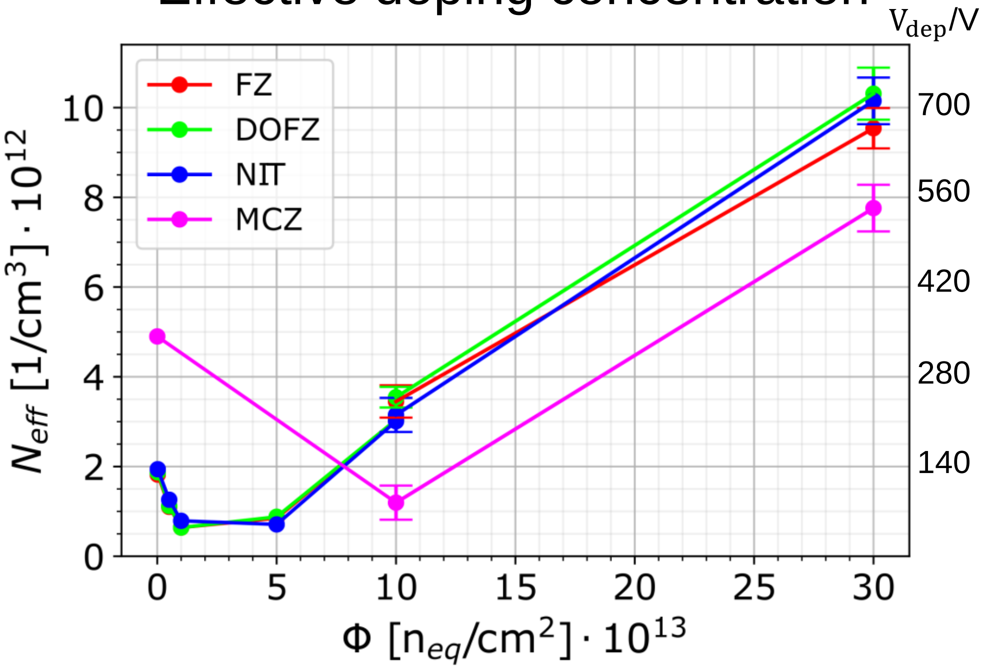
Measurements needed to be repeated for each fluence, detector type and irradiation facility!

Electrical tests – neutron irradiated

Current comparison



Effective doping concentration

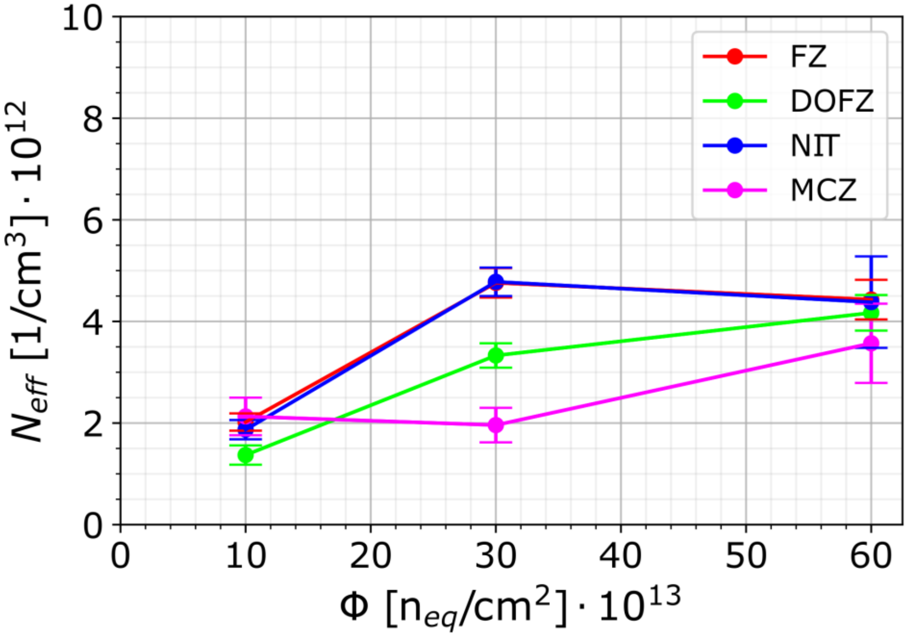


Current normalized to 20 °C.
Each fluence step corresponds to a different sensor.

No large difference in the effective doping concentration caused by different FZ processing techniques.

Electrical tests – proton irradiated

Effective doping concentration

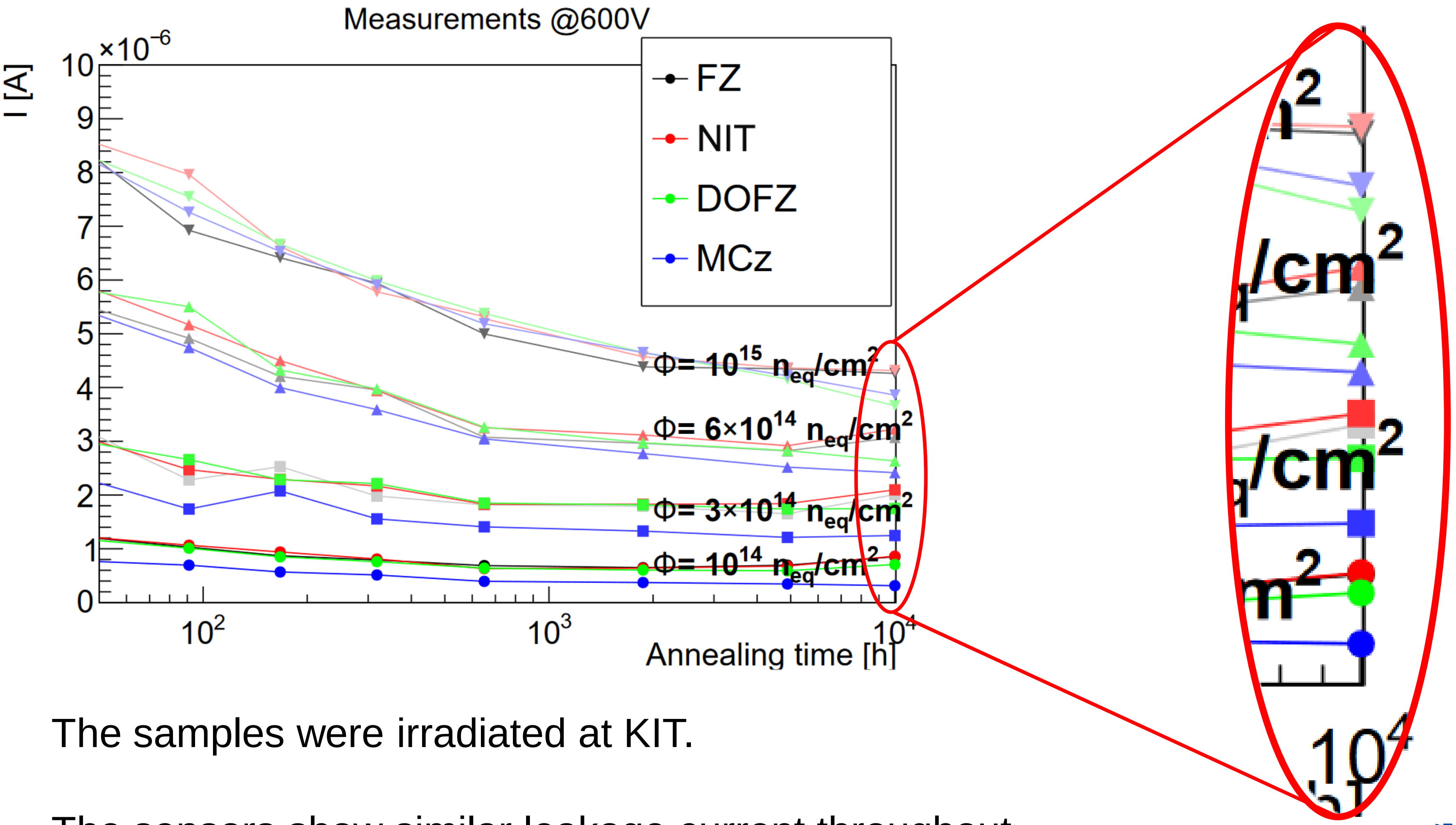


Sensor U [V]	$\Phi = 0$ [n_{eq}/cm^2]	$\Phi = 1 \cdot 10^{14}$ [n_{eq}/cm^2]	$\Phi = 3 \cdot 10^{14}$ [n_{eq}/cm^2]
DOFZ n	146 ± 3	242 ± 16	718 ± 39
DOFZ p		94 ± 13	228 ± 16
FZ n	151 ± 4	238 ± 22	660 ± 31
FZ p		138 ± 12	326 ± 20
NIT n	165 ± 5	218 ± 26	704 ± 37
NIT p		125 ± 13	327 ± 19

No large difference between FZ and NIT. DOFZ shows lower doping concentration.

Full depletion voltages of the neutron and proton irradiated samples.

IV annealing - proton irradiated



The samples were irradiated at KIT.

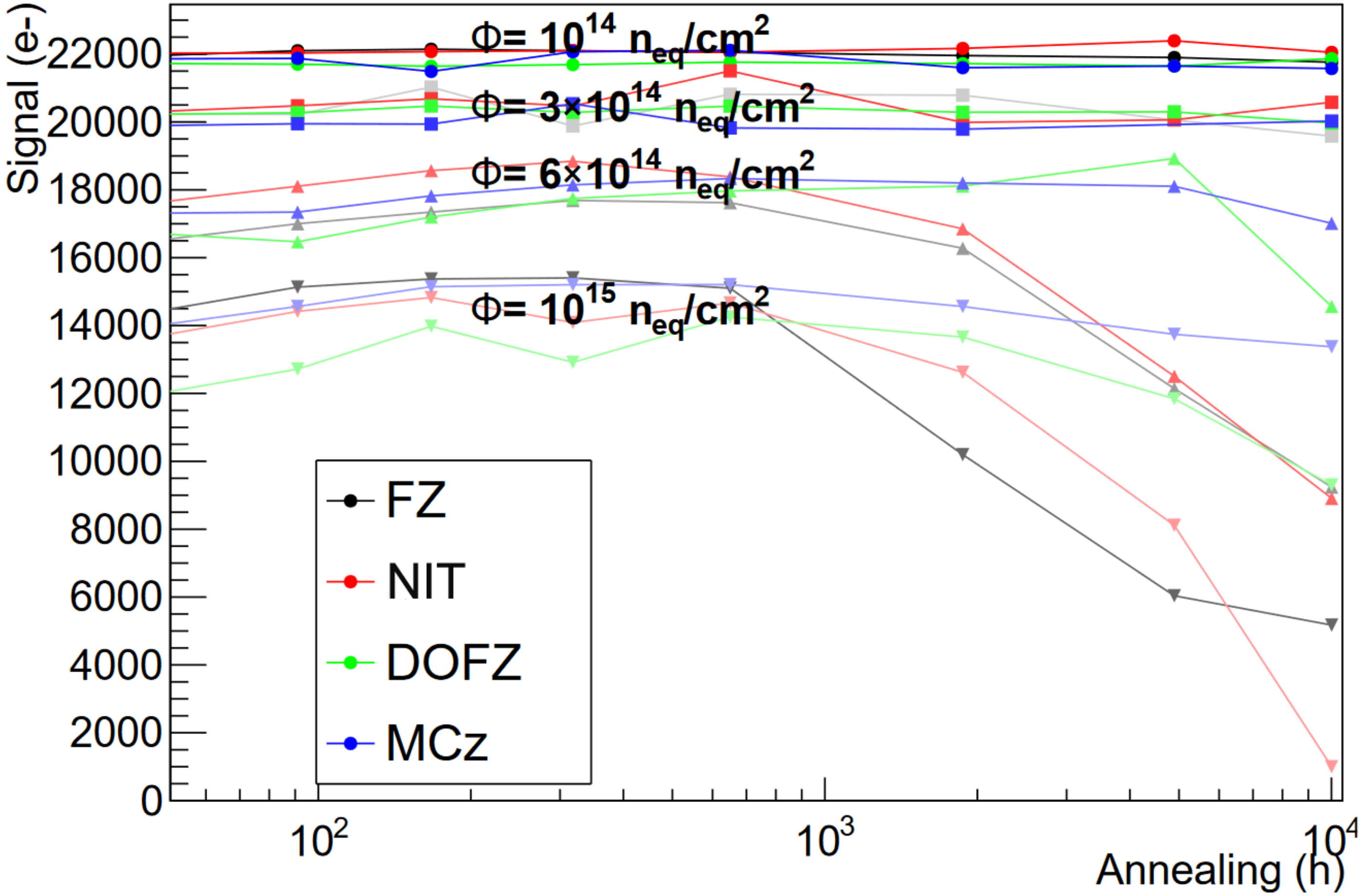
The sensors show similar leakage current throughout the annealing.


UGH

Source measurements

AliBaVa setup

Source annealing - proton irradiated



V_{dep} = 800 V

For higher radiation doses DOFZ and MCz show advantages in terms of charge collection.

Edge-TCT measurements

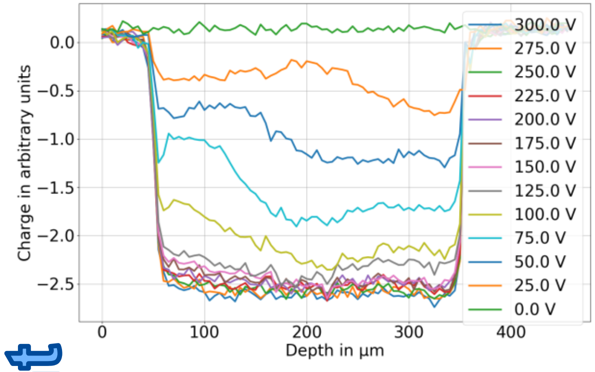
Neutron irradiated samples

Irradiation done at Jožef Stefan Institute Ljubljana.

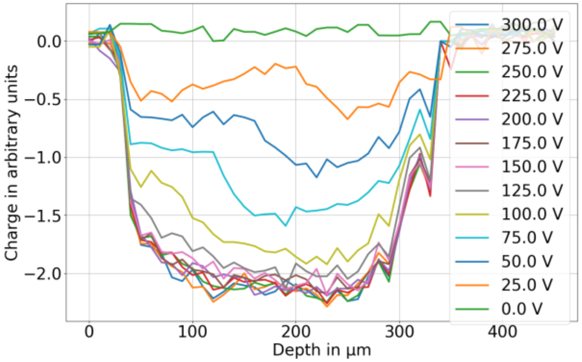
TCT-charge collection profile

Front

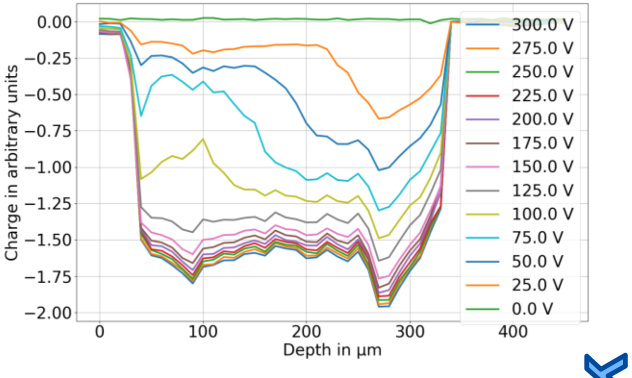
NIT 1e14 neq/cm²



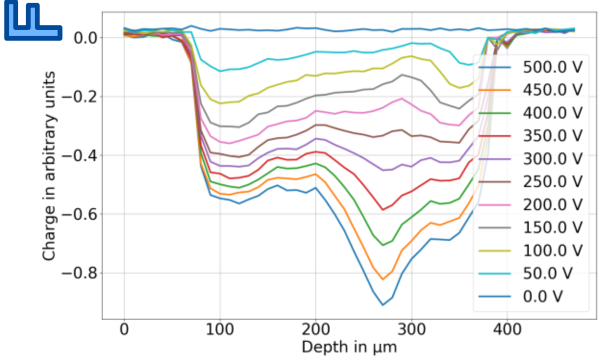
FZ 1e14



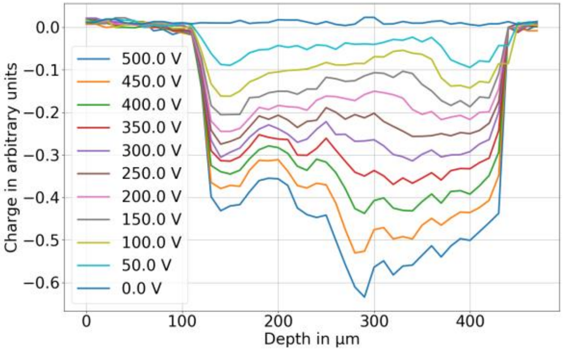
DOFZ 1e14



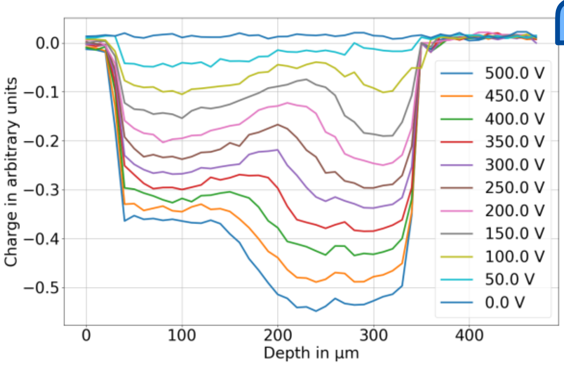
NIT 1e15



FZ 1e15



DOFZ 1e15



Back

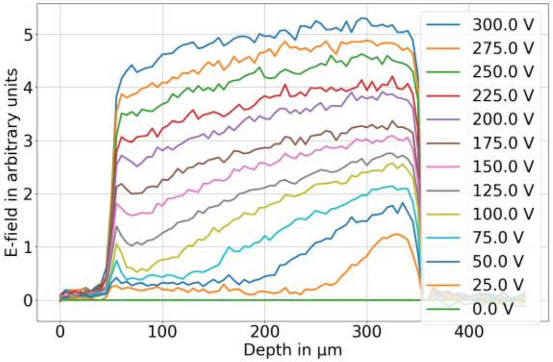
NIT 1e14 & FZ 1e14 @ ~-20 °C
Rest @ ~(-18±1) °C

Integration window: 21.5 ns

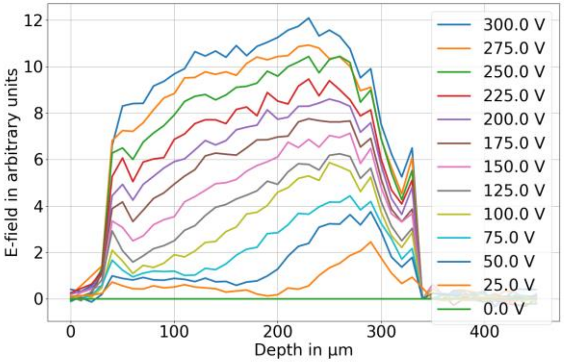
Neutron irradiated

E-Field

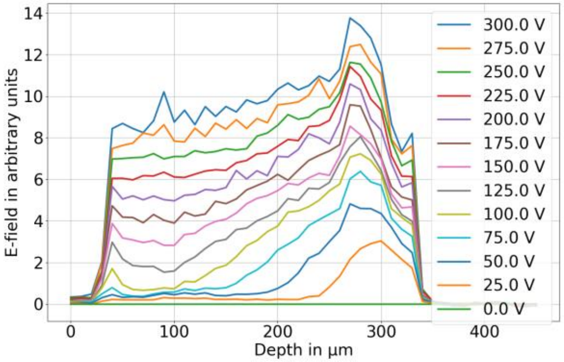
NIT 1e14 neq/cm^2



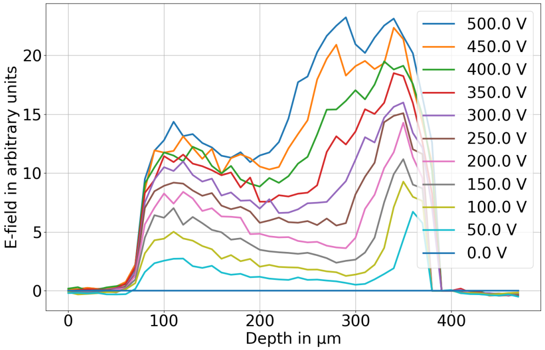
FZ 1e14



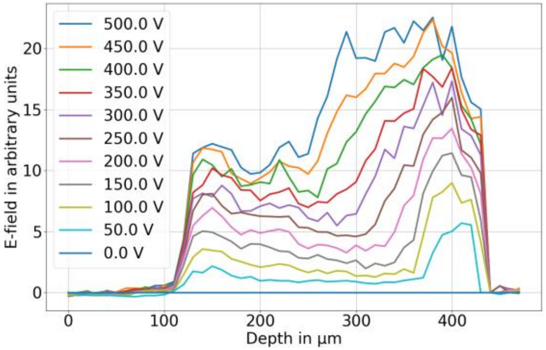
DOFZ 1e14



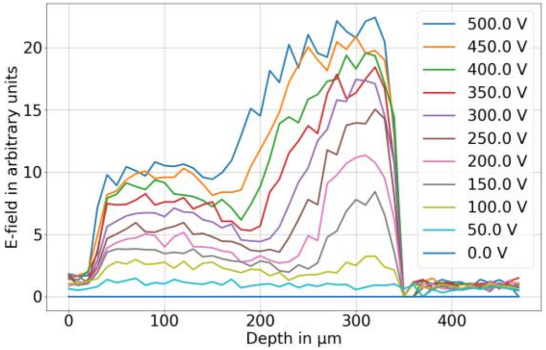
NIT 1e15



FZ 1e15



DOFZ 1e15



$$E(y) \propto \frac{I(y,t\sim 0)}{\alpha(V,I)}$$

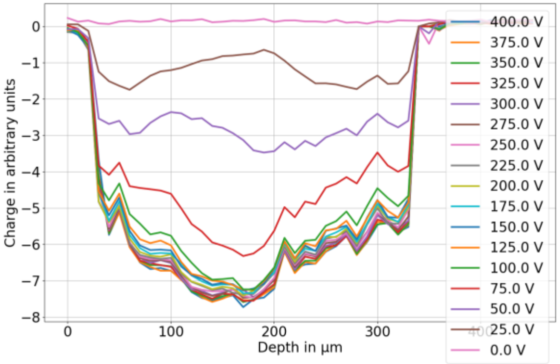
Neutron irradiated

Proton irradiated samples

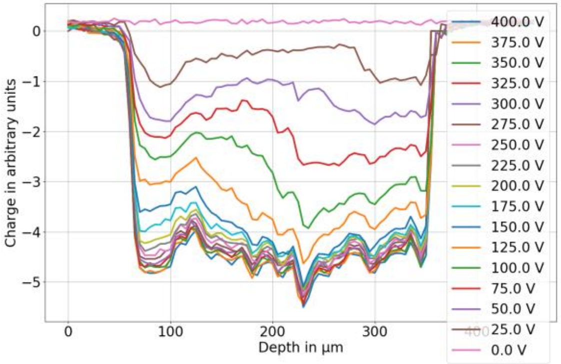
Irradiation done at SPS Cern.

TCT-charge collection profile

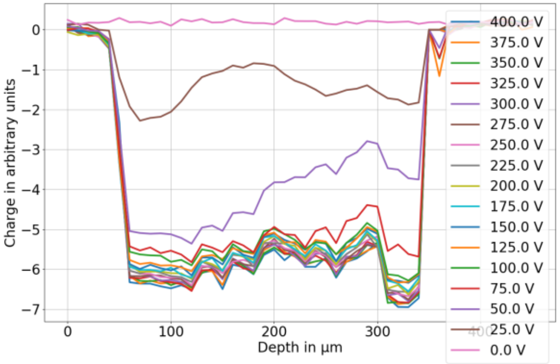
NIT 1e14 neq/cm^2



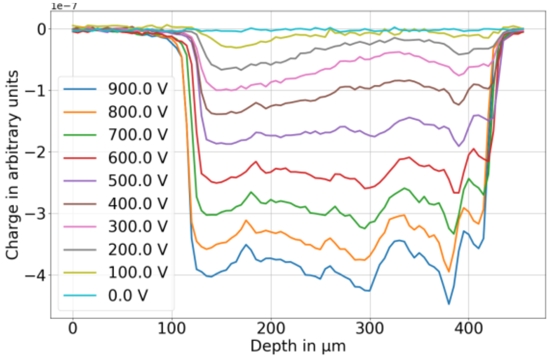
FZ 1e14



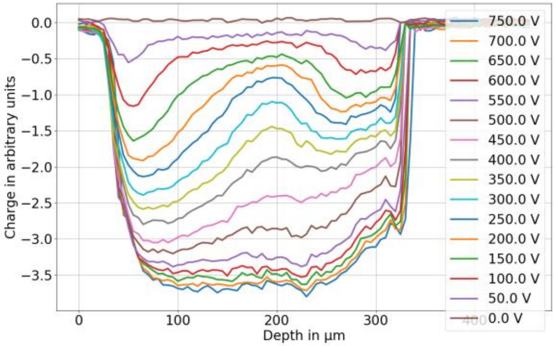
DOFZ 1e14



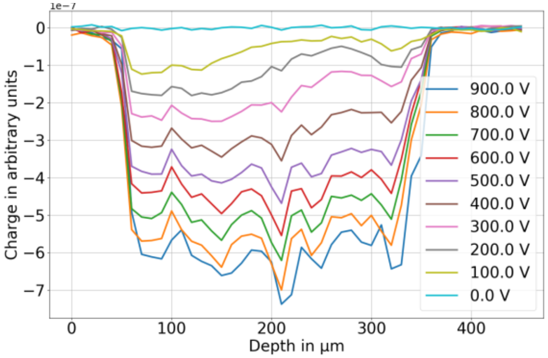
NIT 1e15



FZ 1e15



DOFZ 1e15



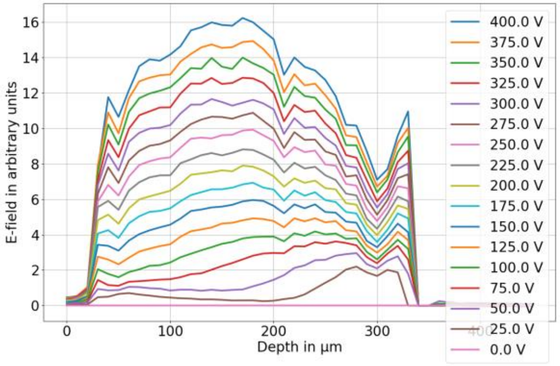
Measured @ ~(-20 ± 1) °C

Integration window: 21.5 ns

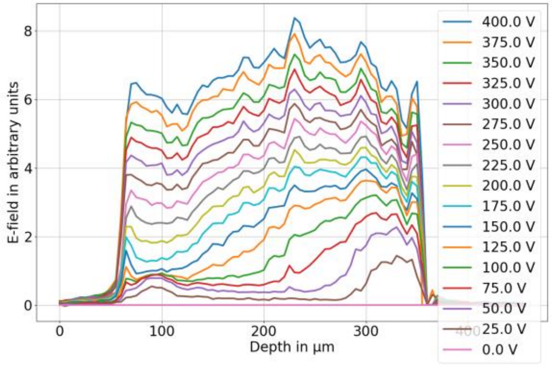
Proton irradiated

E-Field

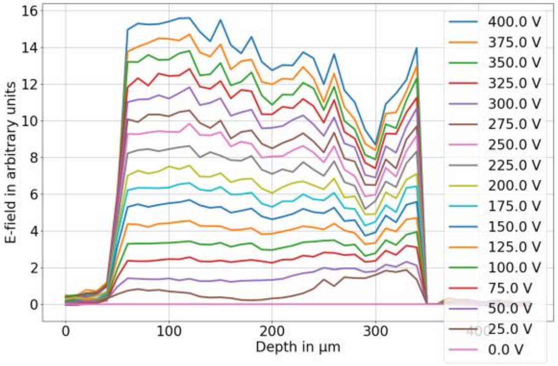
NIT 1e14 neq/cm^2



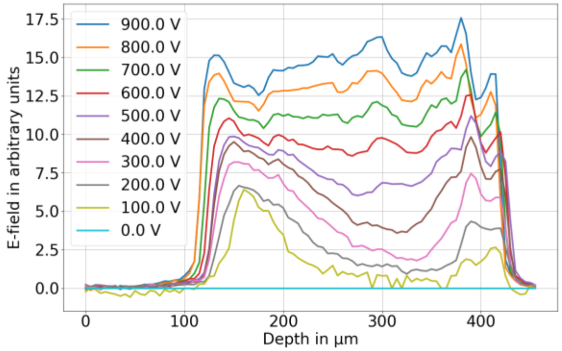
FZ 1e14



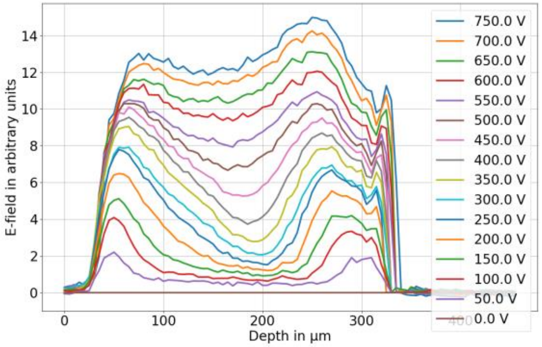
DOFZ 1e14



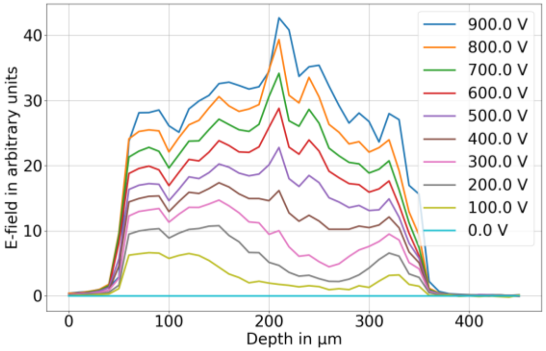
NIT 1e15



FZ 1e15



DOFZ 1e15



$$E(y) \propto \frac{I(y,t\sim0)}{\alpha(V,I)}$$

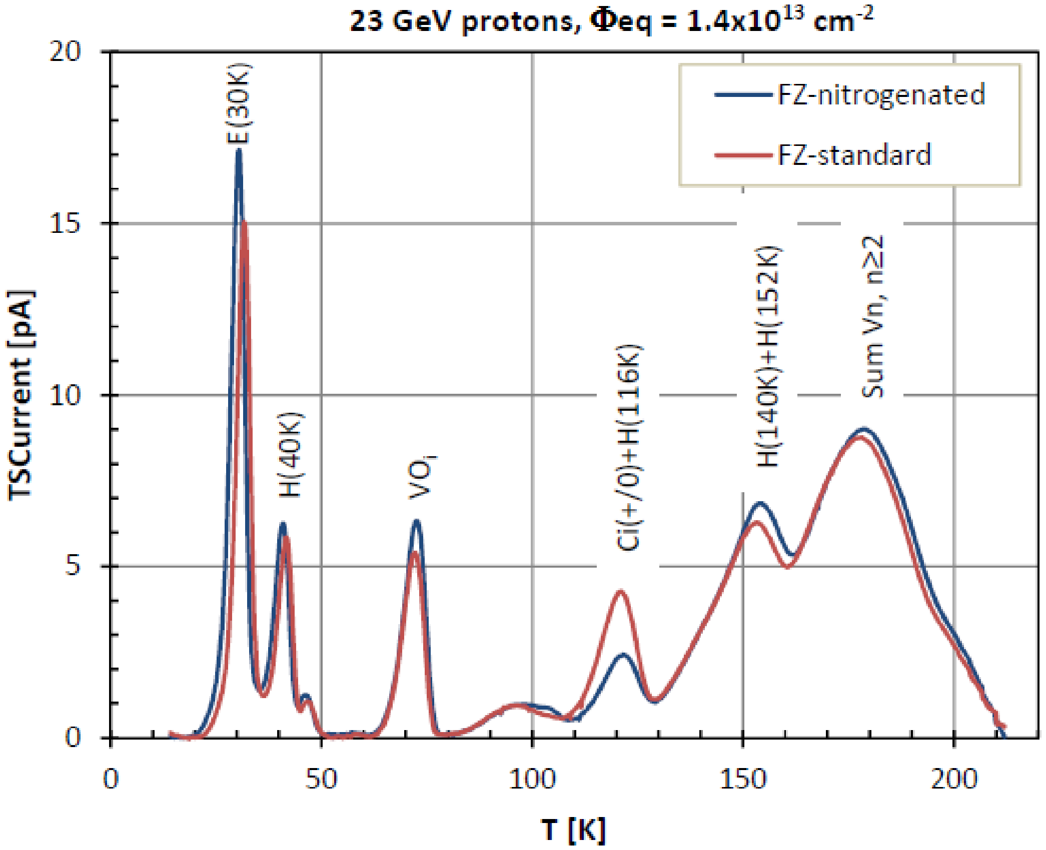
Proton irradiated


UGH

TSC measurements

Hamburg setup

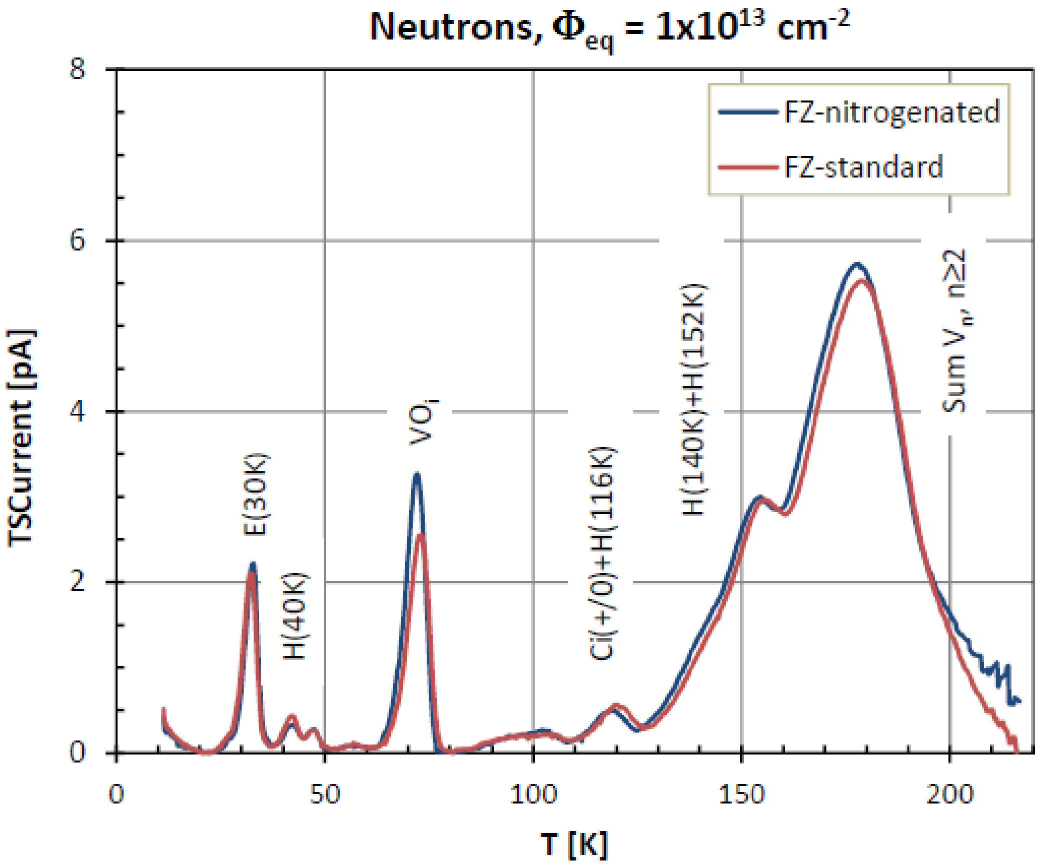
TSC –Spectra, 23 GeV protons



Defect	FZ-NIT	FZ-STD
E(30K)	$9.5x10^{11}$	$7.7x10^{11}$
H(40K)	$4.0x10^{11}$	$3.4x10^{11}$
VO	$5.2x10^{11}$	$4.2x10^{11}$
Ci+H(116K)	$3.4x10^{11}$	$5.9x10^{11}$
Sum(H)	$1.6x10^{12}$	$1.4x10^{12}$
Sum(Vn)	$3.7x10^{12}$	$3.6x10^{12}$

Vacancy defect concentration remains unchanged after enrichment with nitrogen.

TSC –Spectra, 1 MeV neutrons



Defect	FZ-NIT	FZ-STD
E(30K)	1.1x10^{11}	1.1x10^{11}
H(40K)	2.0x10^{10}	2.4x10^{10}
VO	2.5x10^{11}	2.0x10^{11}
Ci+H(116K)	6.5x10^{10}	7.3x10^{10}
Sum(H)	5.7x10^{11}	6.0x10^{11}
Sum(Vn)	2.3x10^{12}	2.2x10^{12}

The neutron irradiated sample confirms that vacancy defect concentration remains unchanged after enrichment with nitrogen.

Conclusion & outlook

- TSC measurements leave doubts, if desired nitrogen content was injected in the sensors!
- Electrical tests:
  - Under neutron irradiation FZ, NIT and DOFZ behave the same.
  - Under proton irradiation slower change of effective doping concentration observed for DOFZ.
- Source measurements:
  - Improved behavior seen in DOFZ, but NIT shows same characteristics as FZ.
- E-TCT:
  - Already low fluencies show the formation of a double junction. For higher fluencies effect becomes more pronounced.
  - Slightly improved behavior of the 1e14 neq/cm^2 proton irradiated NIT sample compared to FZ.
- Plans:
  - Investigate Nitrogen content of NIT samples.

Backup

Nitrostrip - Nitrogen doped silicon

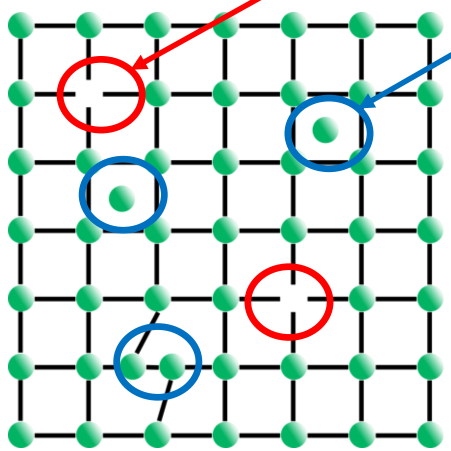
Floatzone silicon is enriched with Nitrogen atoms:

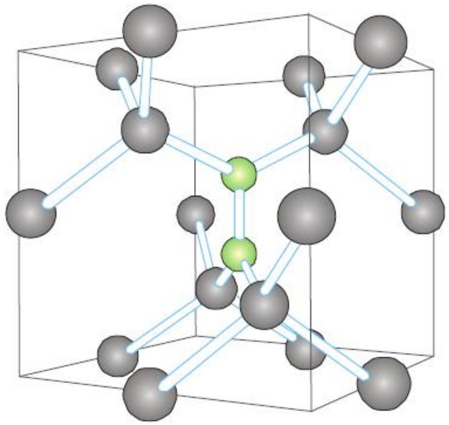
$$
\begin{aligned}
&(1) \quad I + V \leftrightarrow 0 \\
&(2) \quad 2N_i \leftrightarrow N_2 \\
&(3) \quad N_s + N_i \leftrightarrow N_2V \\
&(4) \quad N_2 + V \leftrightarrow N_2V \\
&(5) \quad N_2V + I \leftrightarrow N_2
\end{aligned}
$$

N_i=single interstitial nitrogen
N_s=substitutional nitrogen

Vacancies (V)

Interstitial (I)

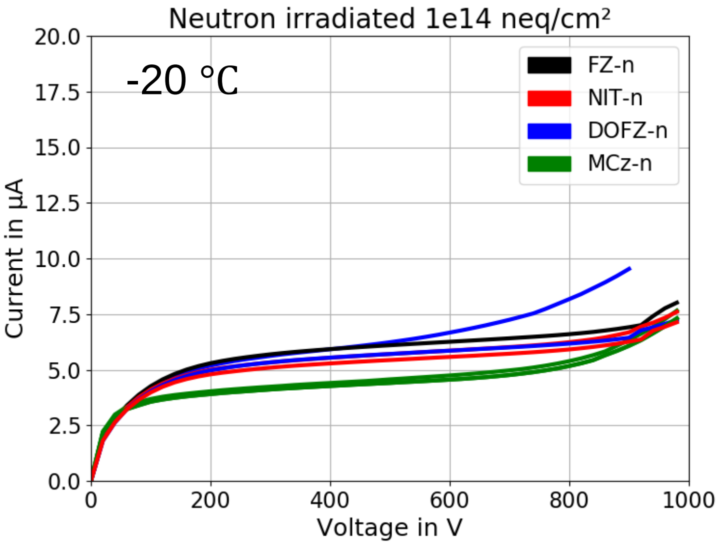


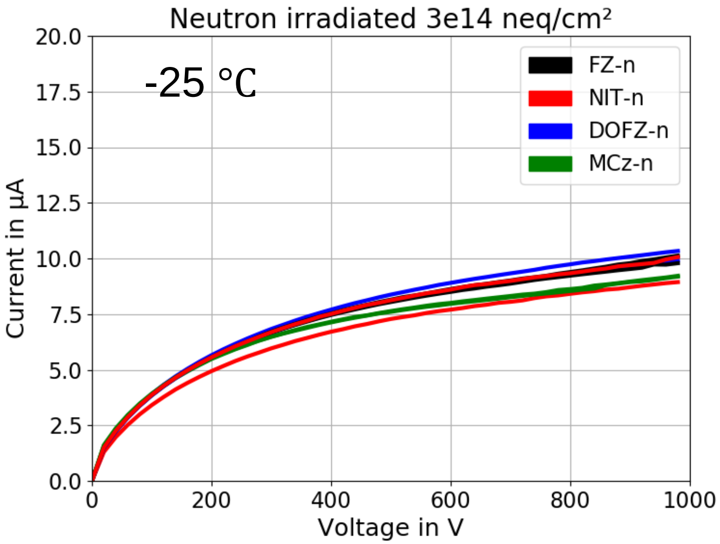


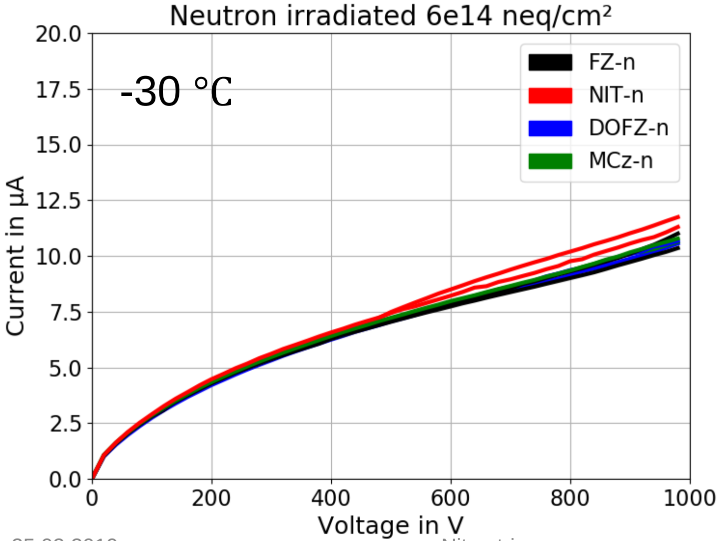
Measurements done by Kaminski show nitrogen enriched silicon has a lower density of defect centers compared to pure silicon with low nitrogen content after irradiation with neutrons.

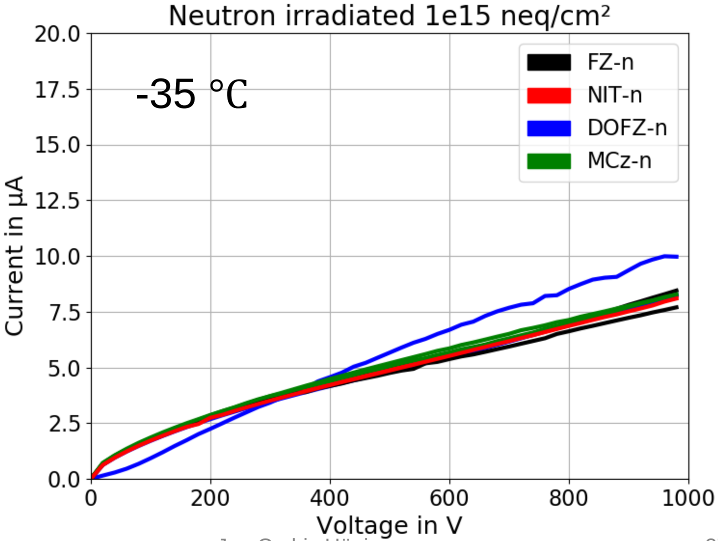
M. Kwestarz, RD50 Workshop, November 2014

Electrical tests – neutron irradiated



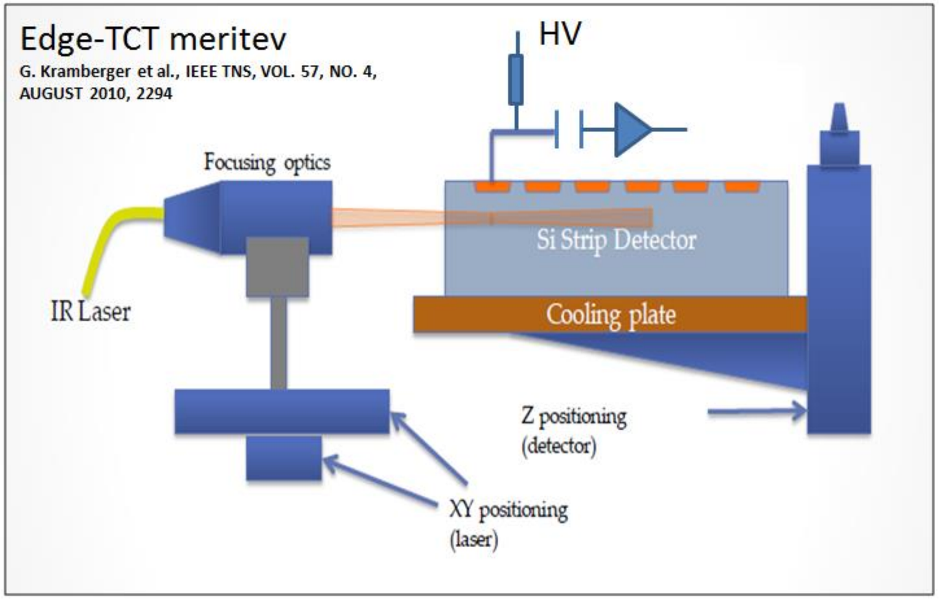


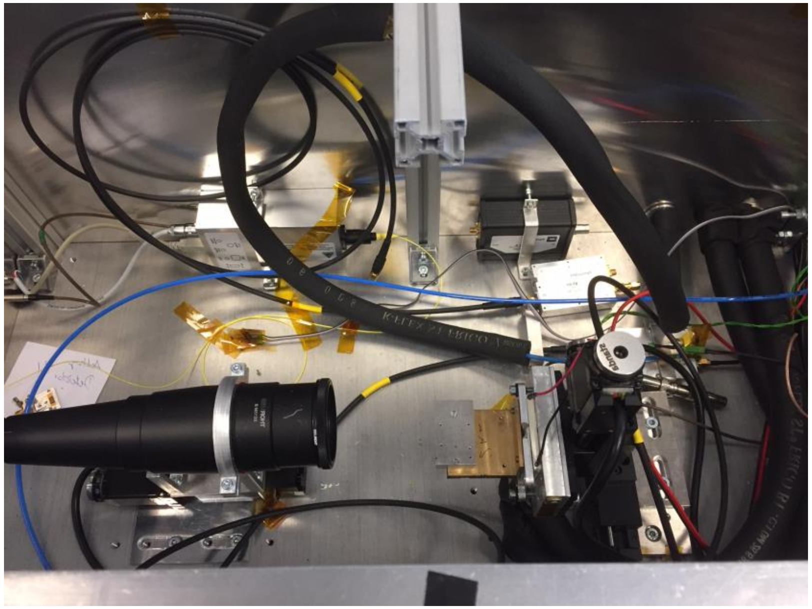




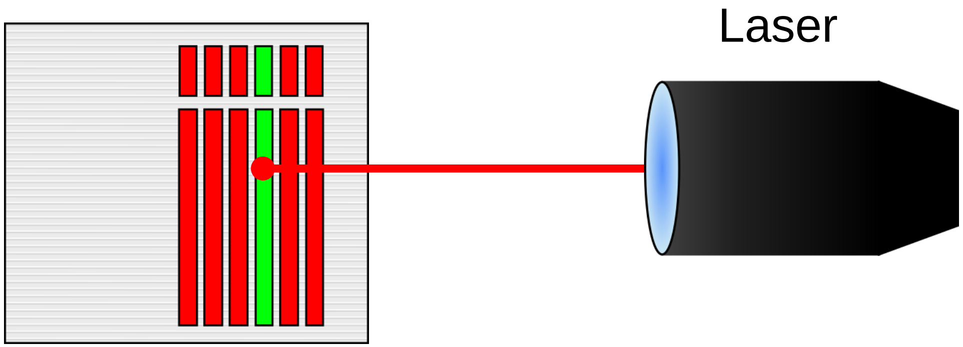
EdgeTCT – basic principle

Side view: Particulars EdgeTCT setup (similar to Freiburg setup)





Top view: Sensor

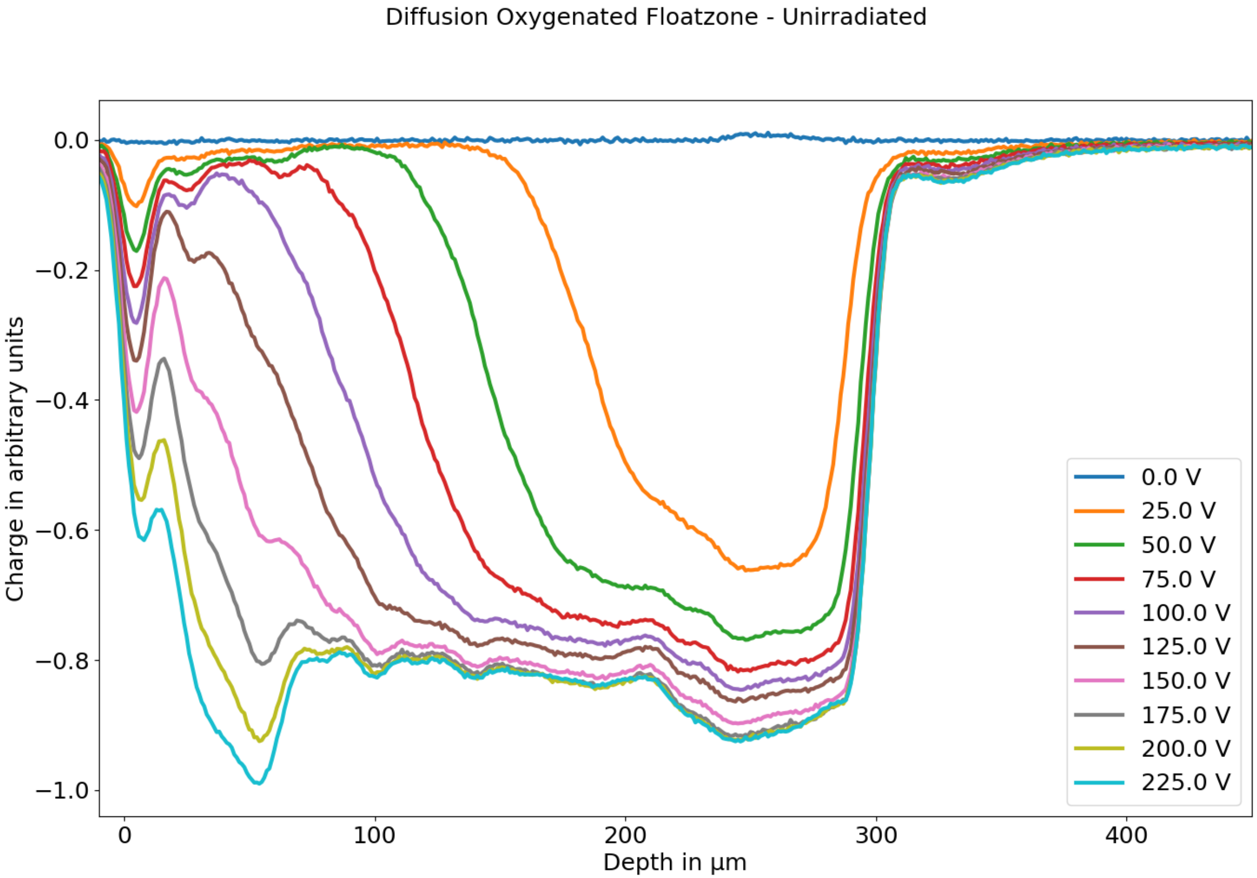


🟥 Strip - grounded

🟩 Strip - measured

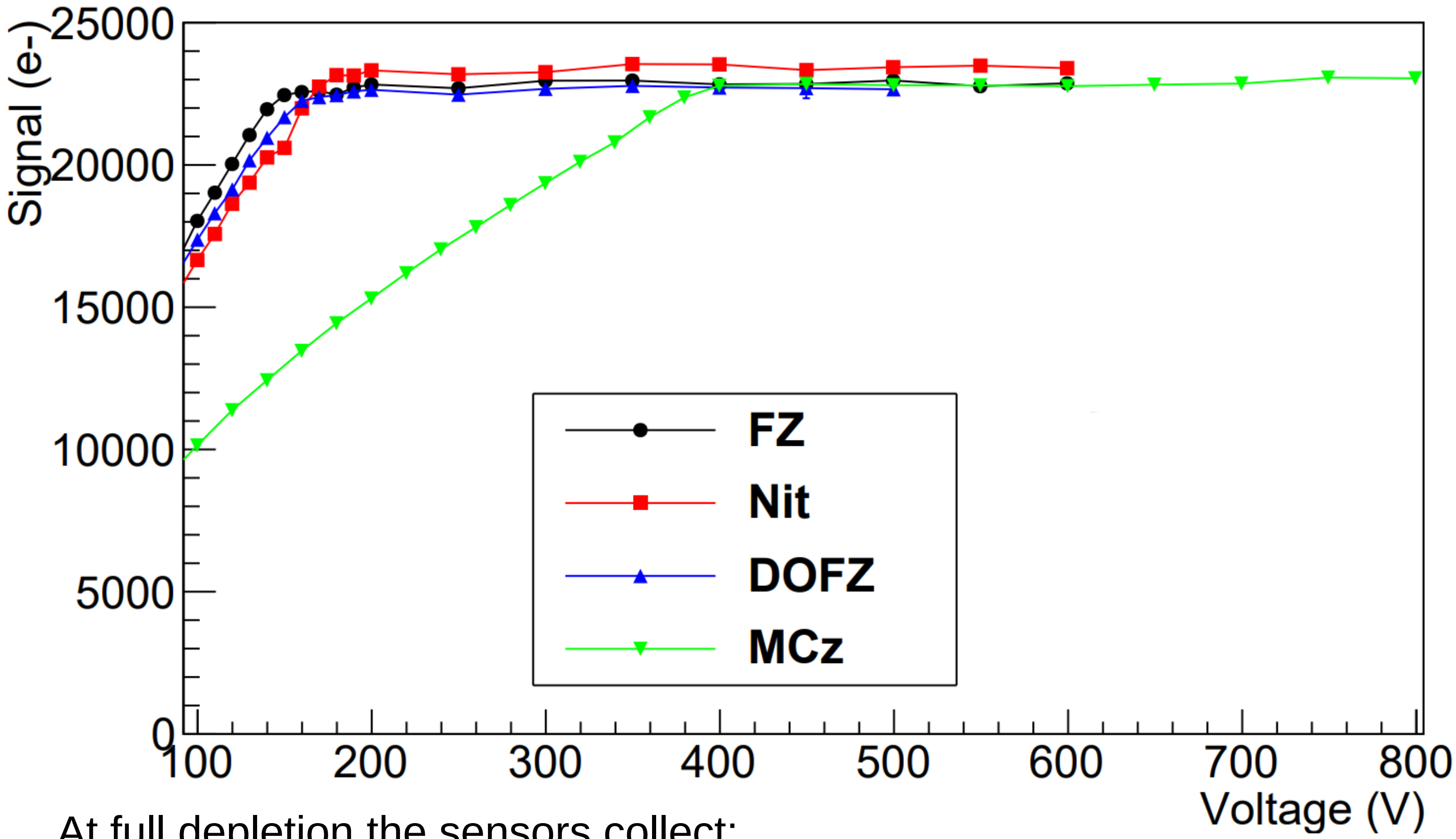
Unirradiated Sensor

Back



Front

Source measurements



At full depletion the sensors collect:

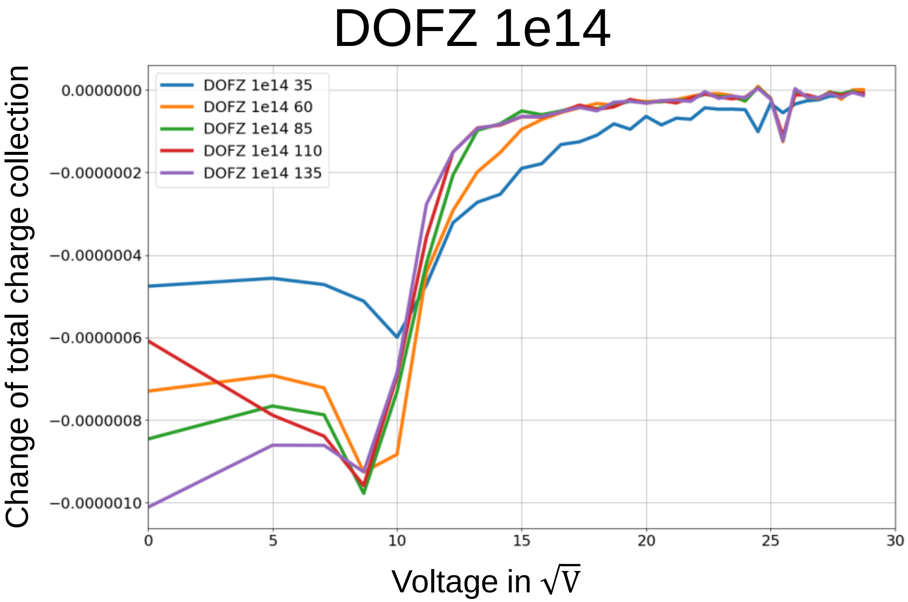
FZ ~ 23k electrons

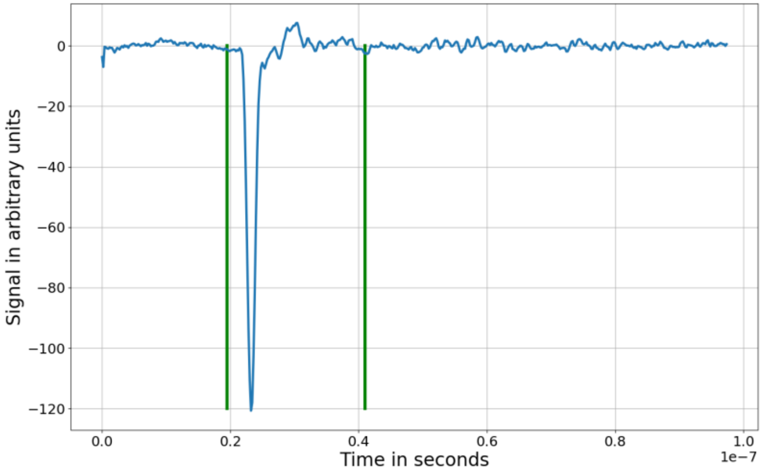
Nit ~ 23.5k electrons

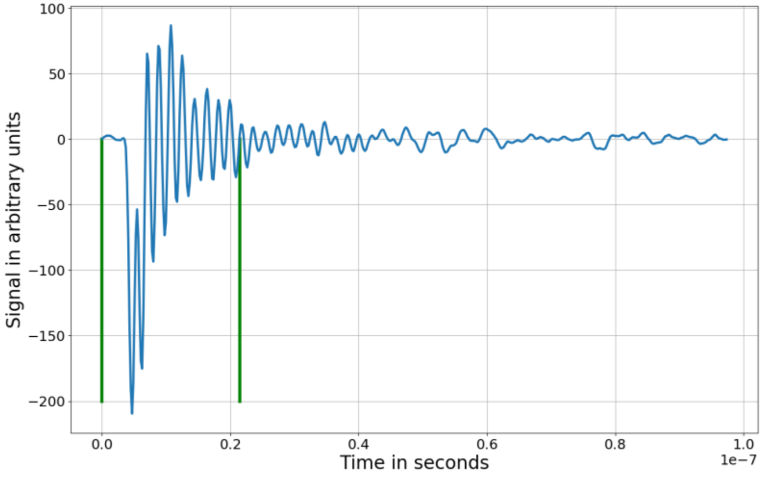
DOFZ ~ 23k electrons

MCz ~ 23k electrons

Determination of integration time

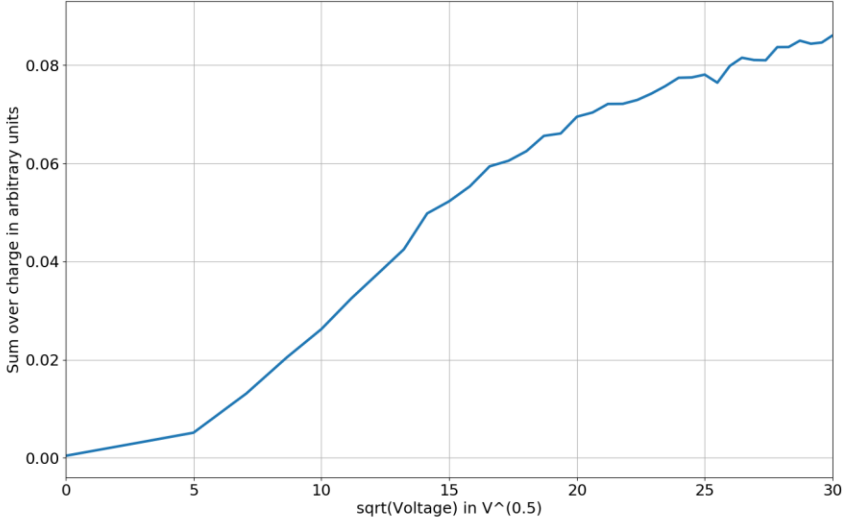


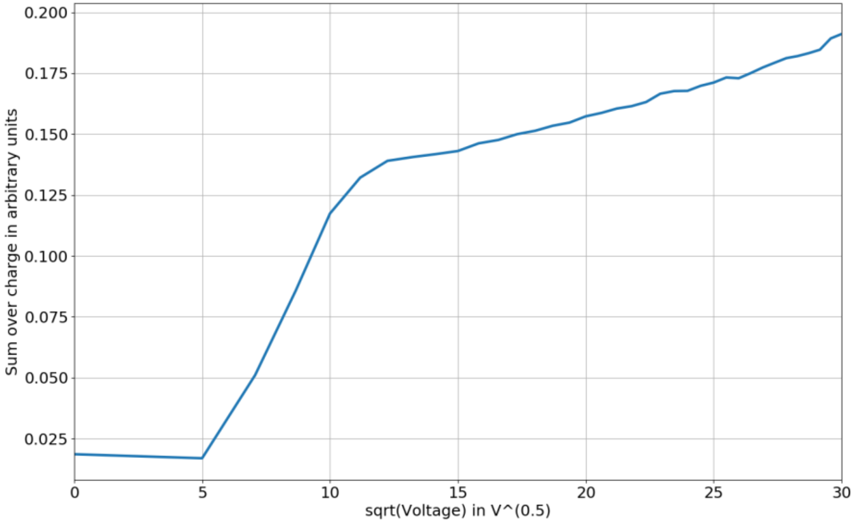




Nitrostrip depletion – neutron irradiated

Nitrostrip sensors 1e14



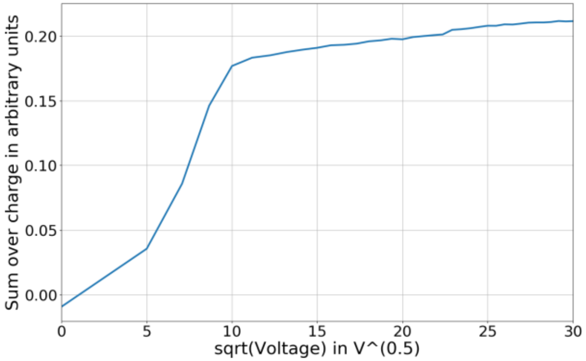


No annealing

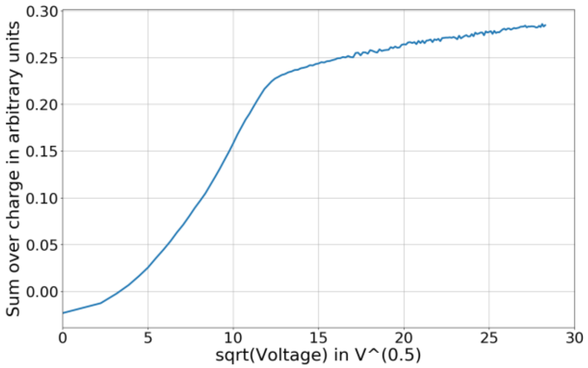
annealing ~7 days room temperature

Depletion – proton irradiated

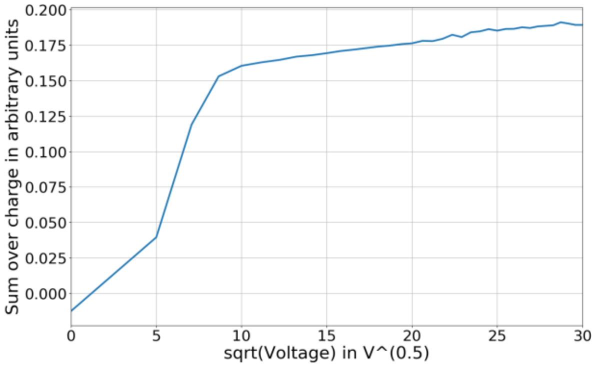
NIT 1e14 neq/cm^2



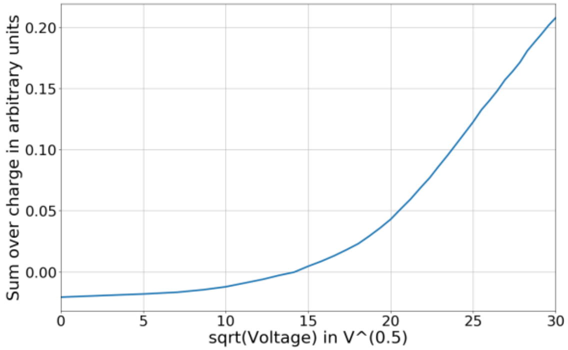
FZ 1e14



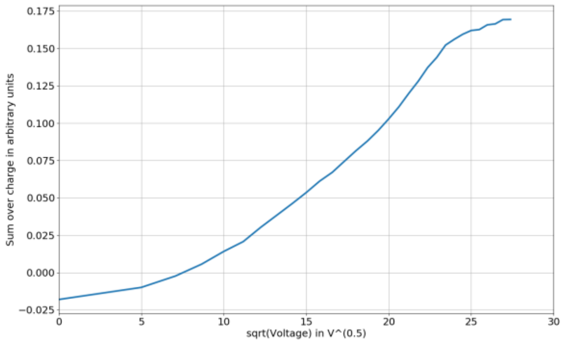
DOFZ 1e14



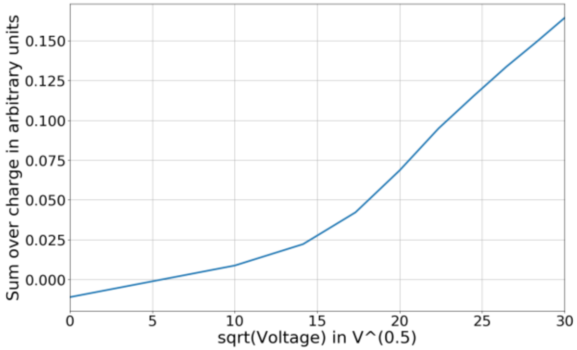
NIT 1e15



FZ 1e15



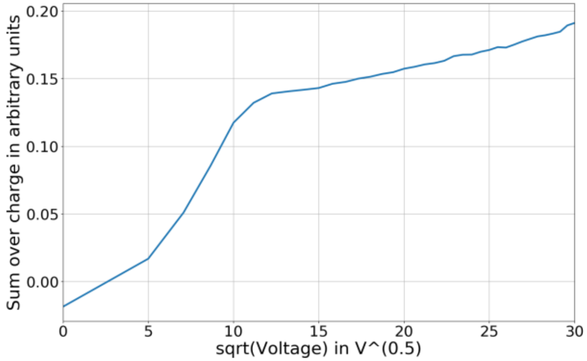
DOFZ 1e15



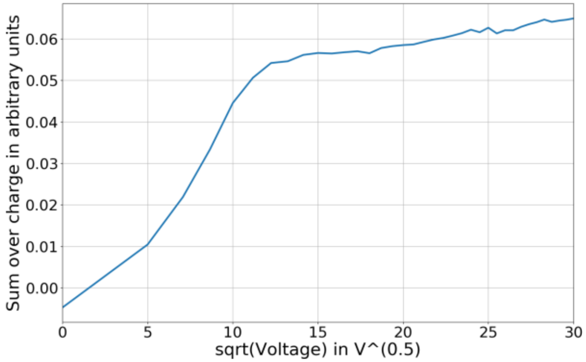
Integral over charge collection profile plotted against voltage.

Depletion characteristic

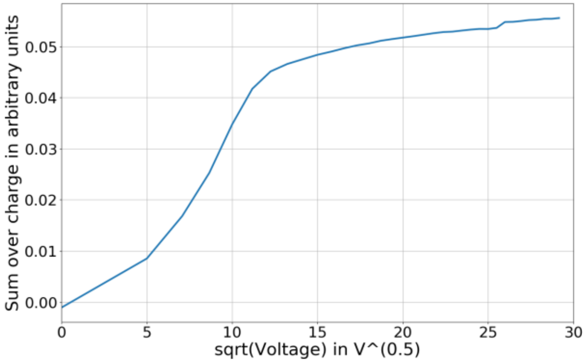
NIT 1e14 neq/cm^2



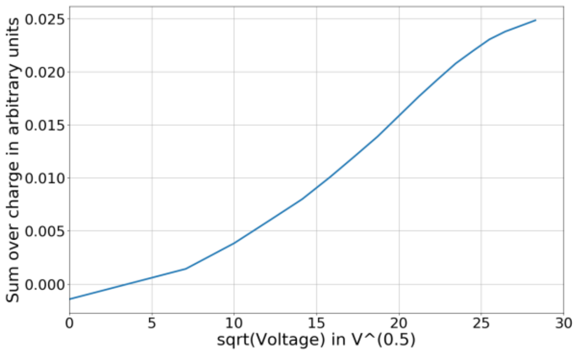
FZ 1e14



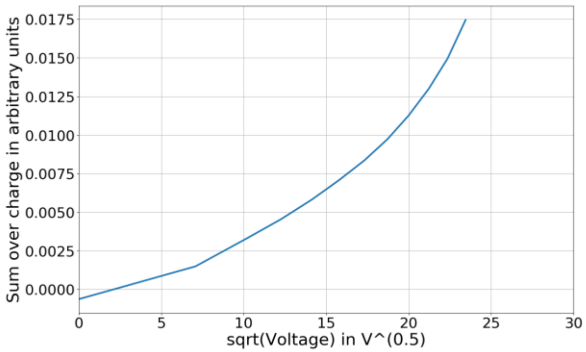
DOFZ 1e14



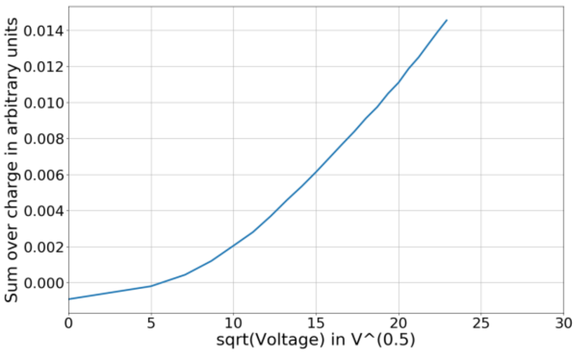
NIT 1e15



FZ 1e15



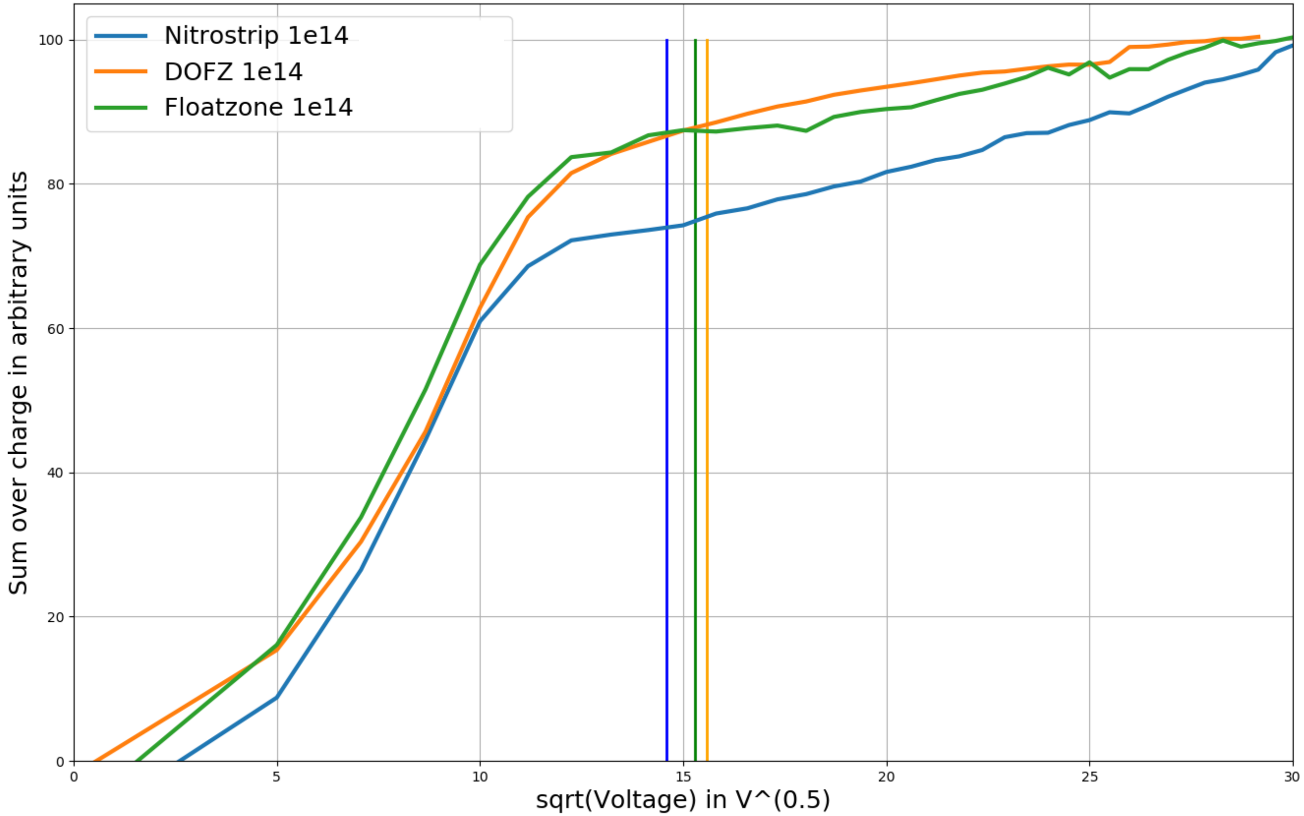
DOFZ 1e15



Integral over charge collection profile plotted against voltage.

Relative Depletion

Edge TCT results comparison 1e14



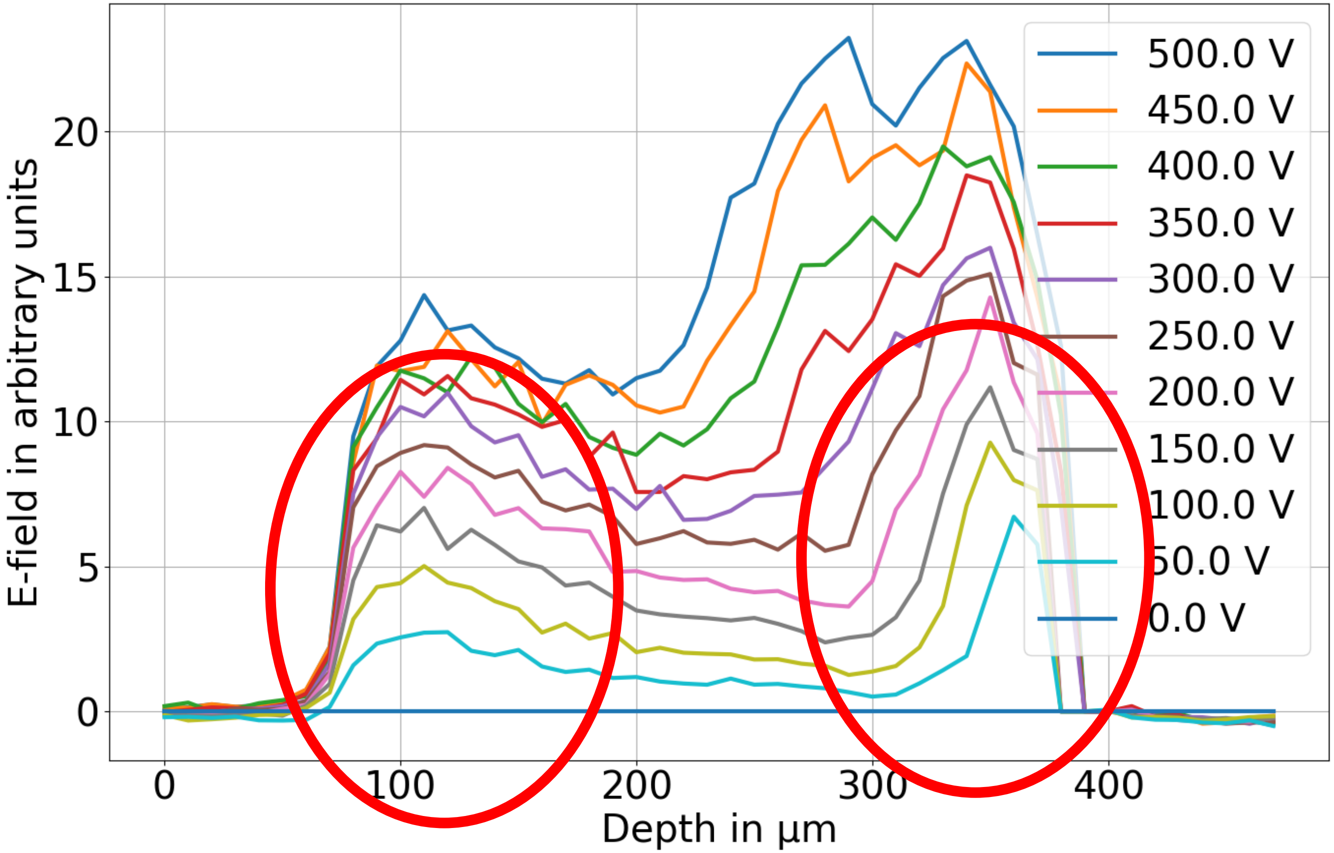
Electrical tests

Sensor	Depletion Voltage [V]
NIT	213±24
FZ	234±24
DOFZ	243±25

Electrical test results could not be confirmed here.

Double junction

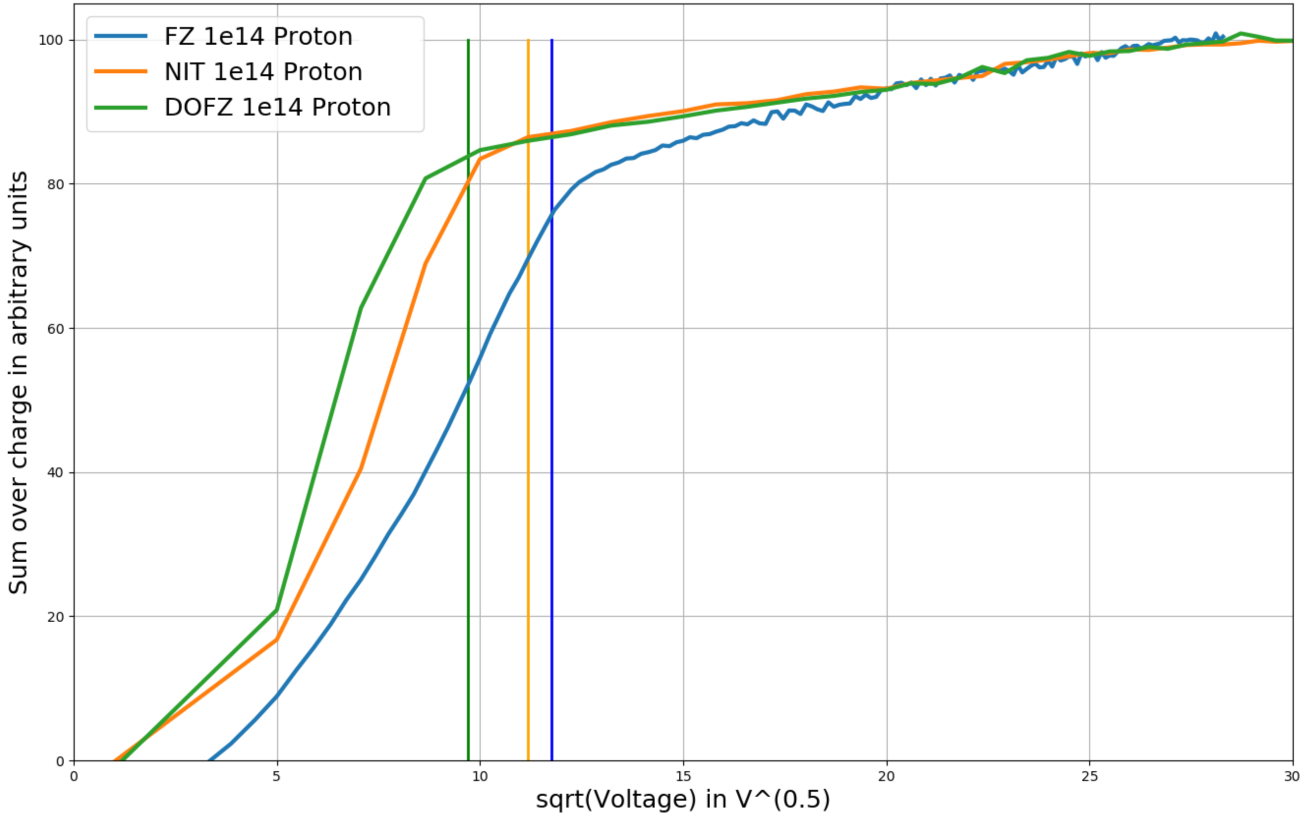
NIT 1e15



Depletion region grows from both front and back → double junction.

Relative Depletion

Edge TCT results comparison 1e14



Electrical tests

Sensor	Depletion Voltage [V]
NIT	125±13
FZ	138±12
DOFZ	94±13

Edge TCT measurement in agreement with electrical tests.

Nitrostrip - Nitrogen doped silicon

Floatzone silicon is enriched with Nitrogen atoms:

N_i=single interstitial nitrogen
N_s=substitutional nitrogen

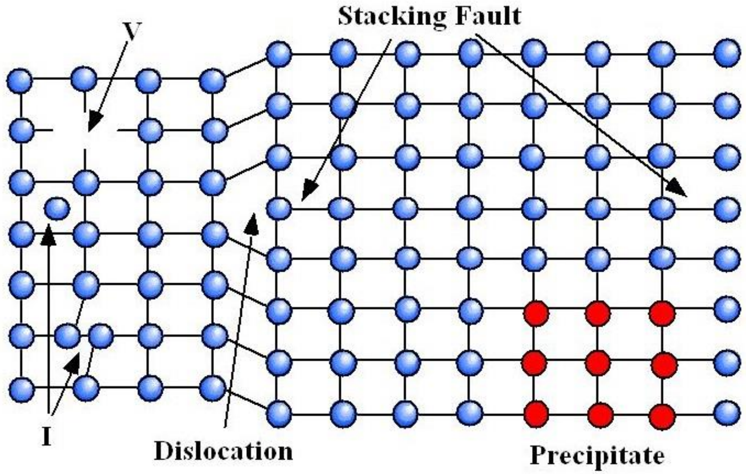
(1) $I + V \leftrightarrow 0$

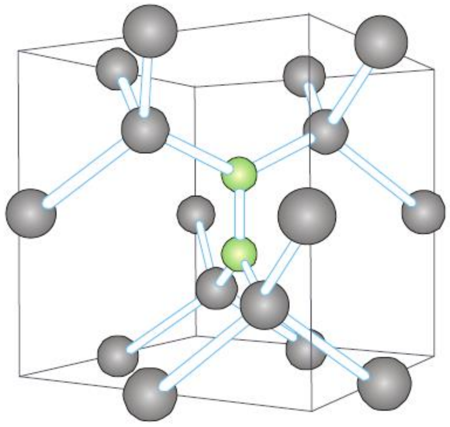
(2) $2N_i \leftrightarrow N_2$

(3) $N_s + N_i \leftrightarrow N_2V$

(4) $N_2 + V \leftrightarrow N_2V$

(5) $N_2V + I \leftrightarrow N_2$





M. Kwestarz, RD50 Workshop, November 2014

Measurements done by Kaminski show nitrogen enriched silicon has a lower density of defect centers compared to pure silicon with low nitrogen content after irradiation with neutrons.

Determination of E-field

$$I(y, t{\sim}0) \propto \frac{E(y)}{\alpha(\mu_e, \mu_h)}$$

$$N_{eff} = \frac{2\epsilon_{si}}{qw^2} V_{FD}$$

$$E(y) \propto \frac{I(y, t{\sim}0)}{\alpha(\mu_e, \mu_h)}$$

$$V_{bias} \propto \int_{y=0}^{W} E(y)\mathrm{dy}$$

$$\alpha(\mu_e, \mu_h) \propto \int_{y=0}^{W} \frac{I(y, t{\sim}0)}{V_{bias}}\mathrm{dy}$$