Neutron irradiation effects in epitaxial silicon detectors

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Background:

Foreseen upgrade of LHC to Super-LHC demands development of very hard particle detectors.

Promising results were obtained with detectors based on thin epitaxial n-type layer grown on low-resistivity Czochralsky silicon substrate (G. Kramberger et al., NIMA 515 (2003) 665)

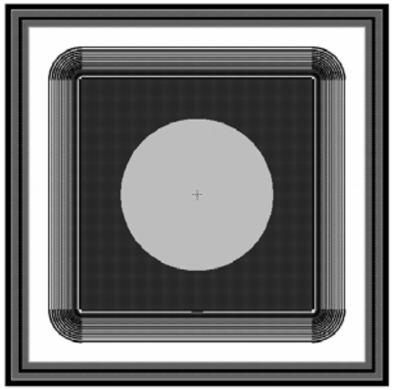
Because of donor generation during irradiation the samples do not undergo space charge sign inversion (SCSI) and their working parameters can be restored during annealing at room or above temperature.

Among other authors we also confirmed these results for the samples based on 50 um thick, 50 Ohm*cm epitaxial layer and irradiated by 24 GeV/c protons up to the fluence 10^{16} p/cm^2 (V.Khomenkov et al. NIMA 2006, in Press, available online 28 June 2006)

Scope of activity:

In present report we studied radiation hardness of epitaxial diodes irradiated by neutrons on Triga Mark II nuclear reactor (Ljubljana, Slovenia).

Pad detectors were fabricated in ITC-IRST (Trento, Italy) using SMART mask on two different types of epitaxial layer grown by ITME (Poland) on low resistivity Czochralsky substrate 300 um thick:



1) 50 um thick, 50 Ohm*cm resistivity
2) 150 um, 500 Ohm*cm

Besides, there were two different layouts:
SMG (Square) and RMG (Rounded) diodes with multiple guard-rings and working area 13.7 mm^2 and 2.3 mm^2, correspondingly

Irradiation:

1) 50 um, 50 Ohm*cm samples:

   9 SMG and 6 RMG samples were irradiated in the equivalent fluence range $(2.5\times10^{14} – 8\times10^{15})$ cm^{-2}.

2) 150 um, 500 Ohm*cm samples:

   15 SMG and 7 RMG samples were irradiated from 10^{14} up to 10^{16} cm^{-2}.

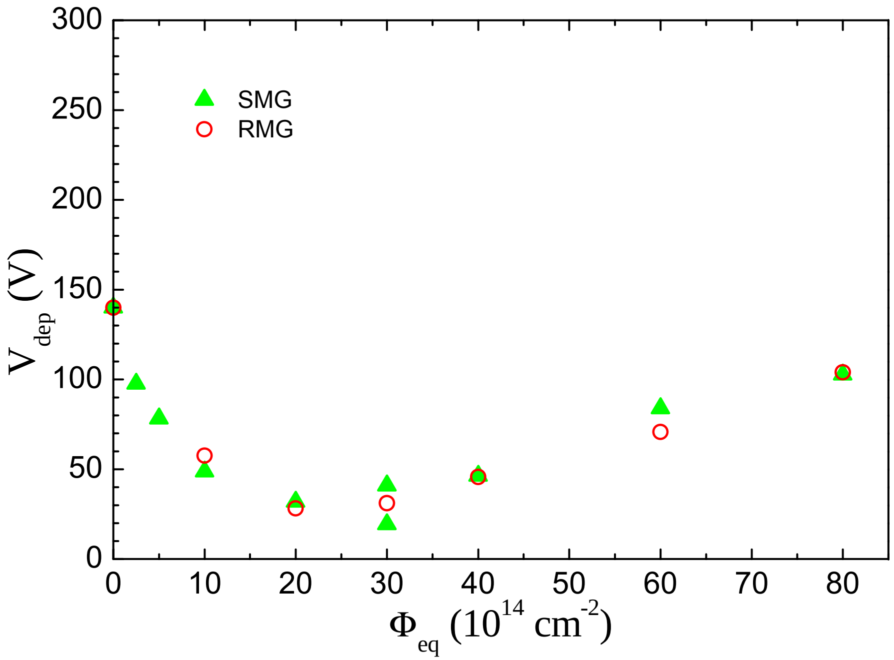
Experimental procedure:

Right after irradiation and between measurements all samples were stored at temperature $–20^{0}C$.

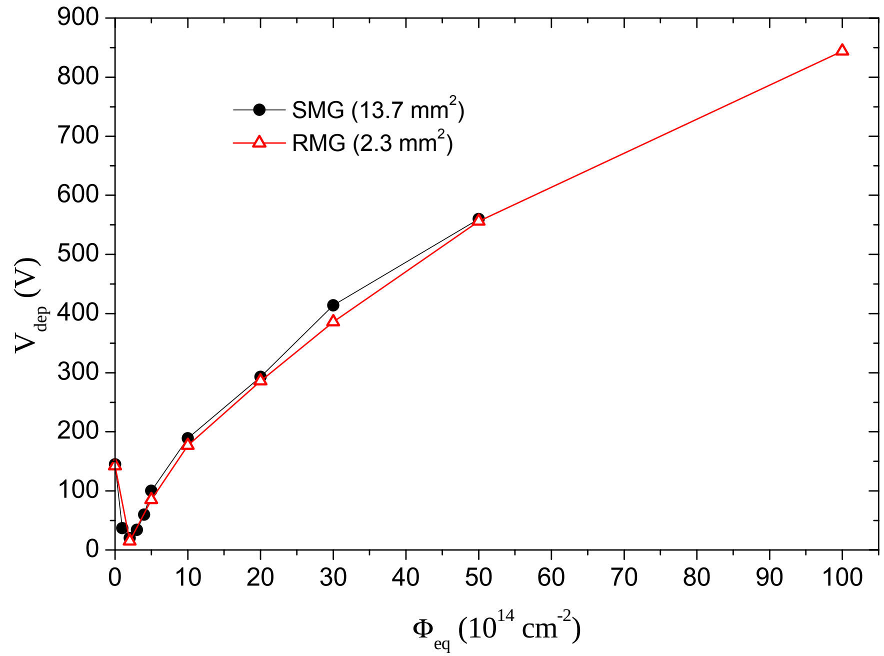
Annealing was performed at $80^{0}C$.

Before and after irradiation and after each annealing step we performed IV- and CV-measurements (10kHz, serial mode).

V_{dep} vs. Φ_{eq} after irradiation



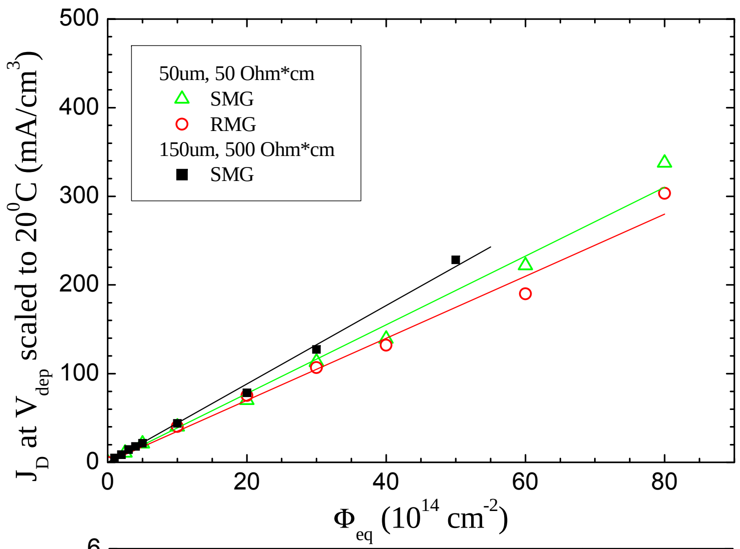
a) 50um, 50 Ohm*cm;

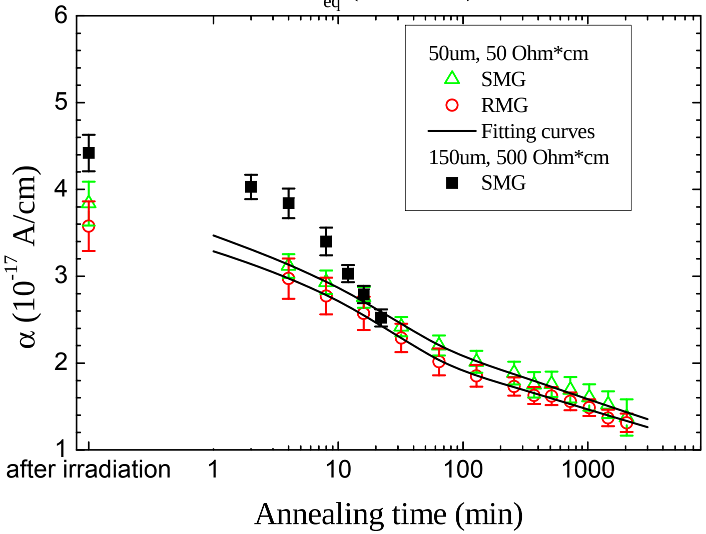


b) 150um, 500 Ohm*cm

As one can see the values for samples with diffferent layout are similar, however, the behaviour for different type epi-layers is rather different.

Annealing of reverse current J_D





As expected, the dependence $J_D(\Phi_{eq})$ is quite linear and can be described as

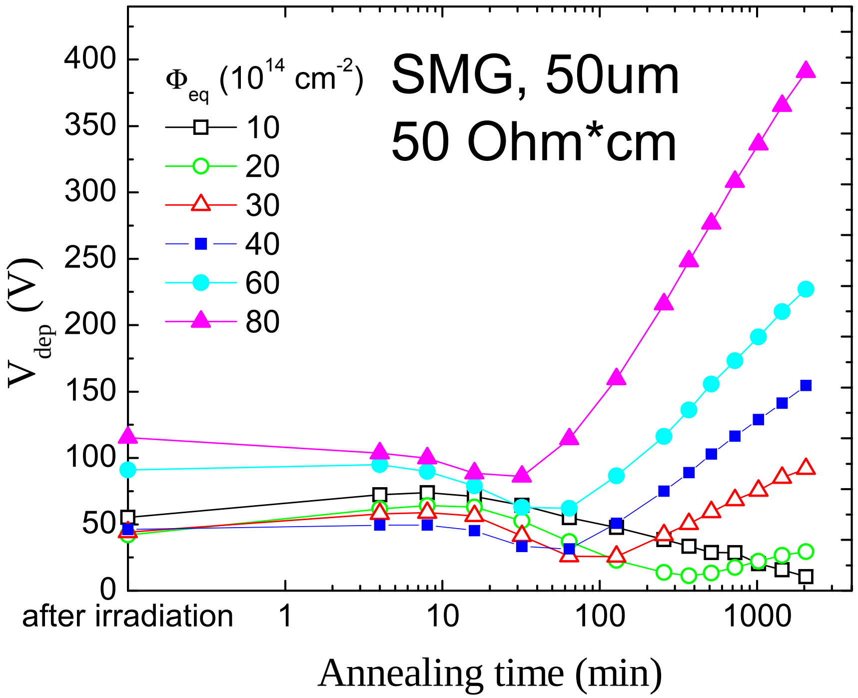
$$J_D = \alpha \times \Phi_{eq}$$

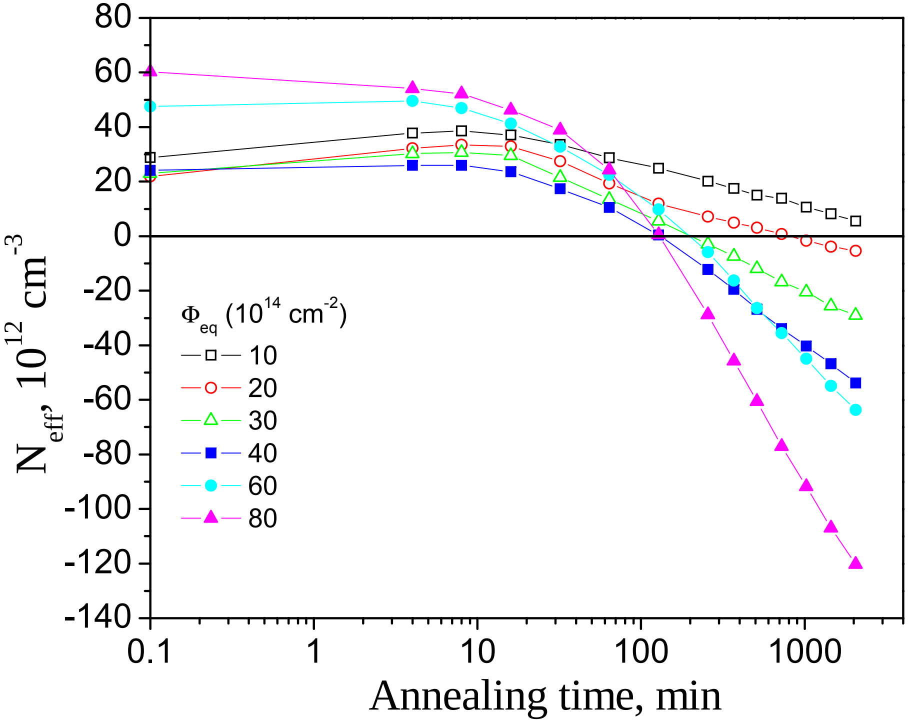
By the end of beneficial annealing (8 min at 80^0C) parameter α for 500 Ohm*cm samples is 3.84×10^{-17} A/cm.

For both SMG and RMG samples based on 50 Ohm*cm epi-layer, corresponding value is about 3×10^{-17} A/cm, which is significantly lower than expected and obtained for proton irradiated samples: $(4.1\text{-}4.9) \times 10^{-17}$ A/cm.

It should be noted, however, that low α value (3.3×10^{-17} A/cm) for neutrons was also observed on similar diodes (I.Dolenc, report on 7th RD50 Workshop, November 2005)

Annealing of V_{dep} (50 Ohm*cm)

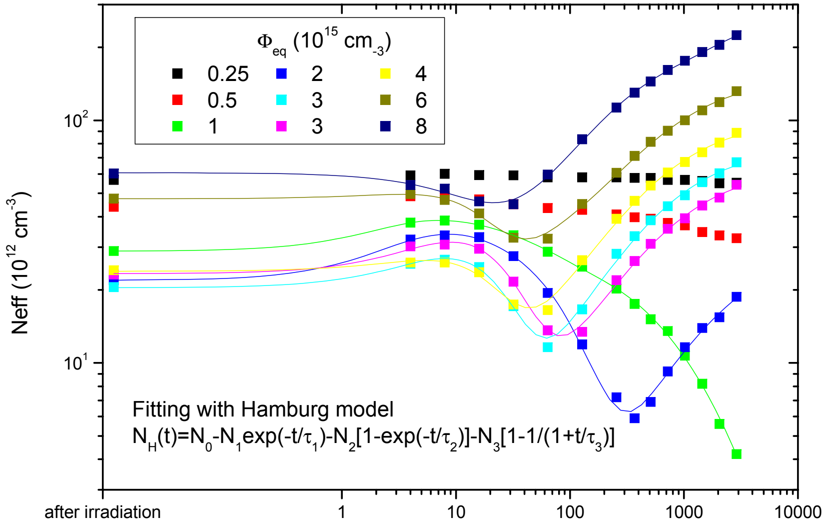


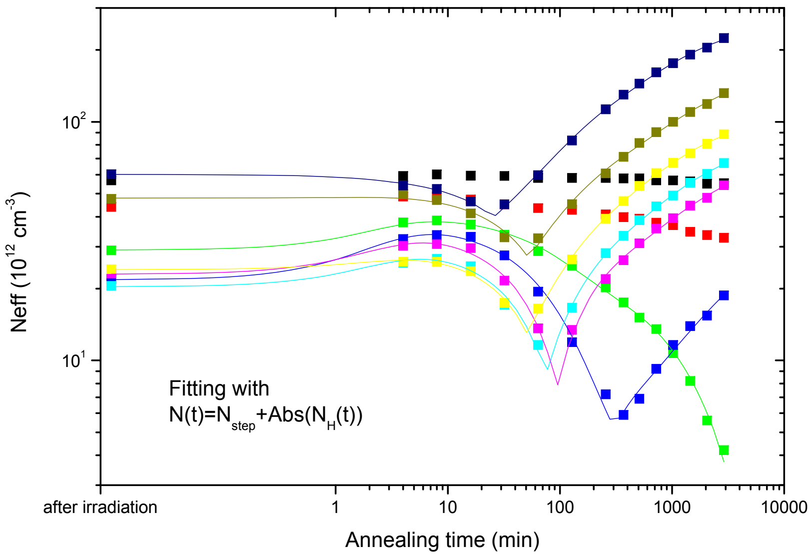


During short-term annealing V_{dep} increases, then decreases at reverse annealing stage and after SCSI increases again.

Therefore, after irradiation samples were not inverted.

Annealing of V_{dep} (50 Ohm*cm)



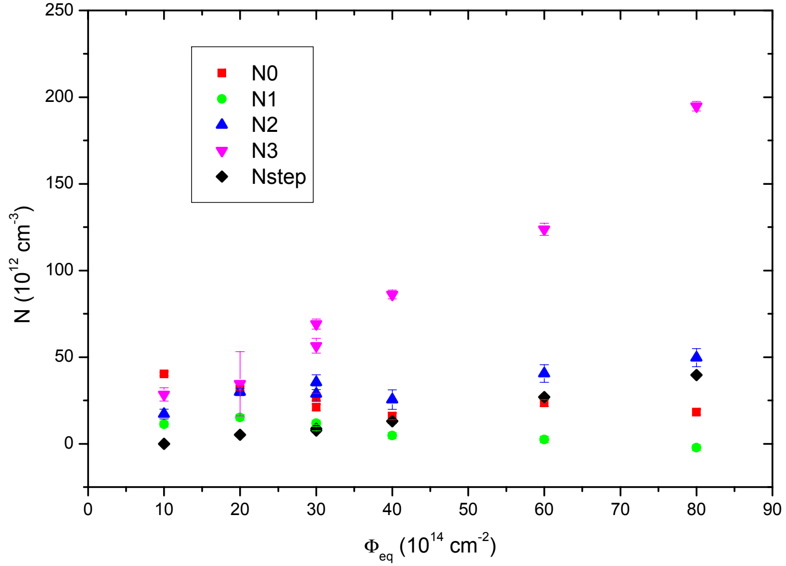


Evolution of Neff with time could not be sufficiently described with usual “Hamburg model”.

Thats why we included additional term N_{step} which does not depend on time.

Fit was successful with χ^2/DoF = 1.6.

Besides, good linear dependence of Ni parameters is observed.



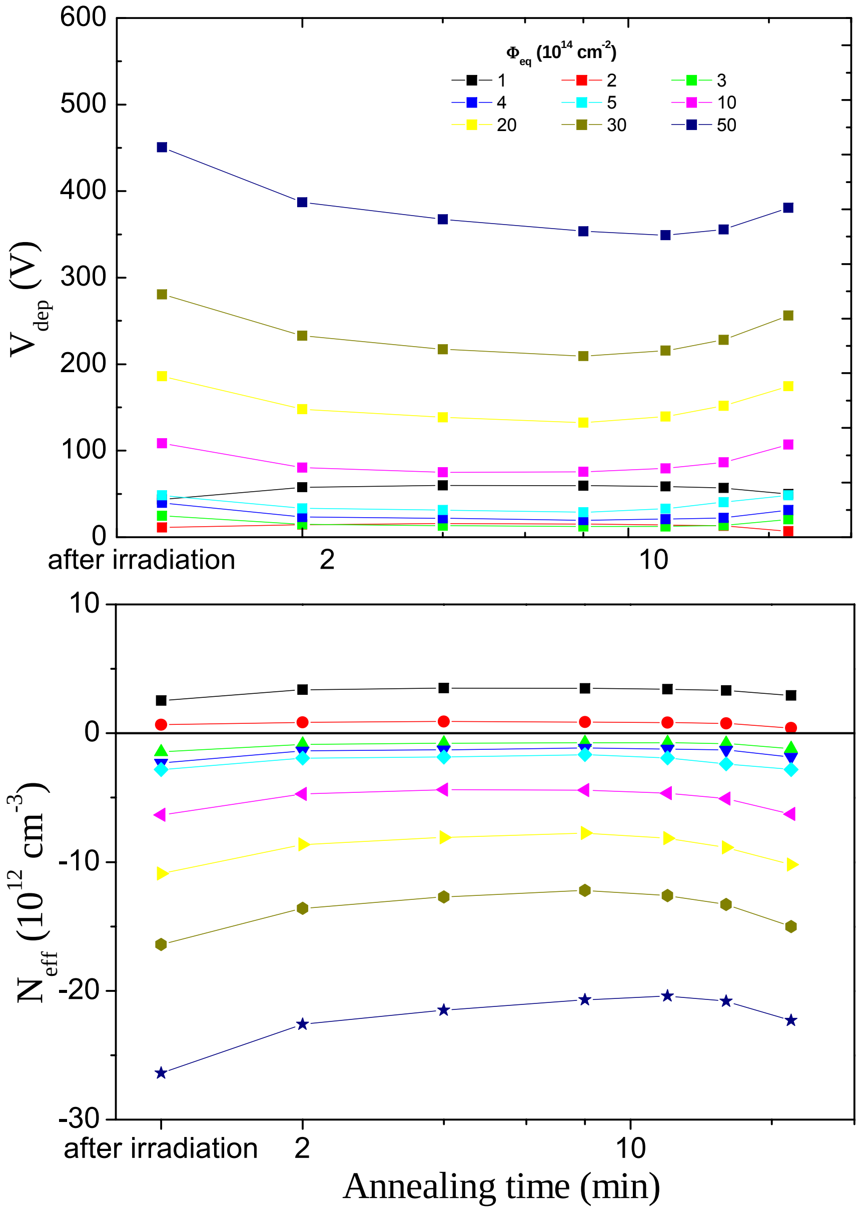
Annealing of V_{dep} (50 Ohm*cm)

Fitting with standard “Hamburg model”:

Φ_{eq} (10^{14} cm^{-2})	N (10^{12} cm^{-3})								τ (min)					
	N_0	ΔN_0	N_1	ΔN_1	N_2	ΔN_2	N_3	ΔN_3	τ_1	$\Delta\tau_1$	τ_2	$\Delta\tau_2$	τ_3	$\Delta\tau_3$
10	42	1	13	1	13	1	30	1	2.5	0.4	46	8	697	108
20	39	1	17	1	37	1	-29	3	3.3	0.5	87	7	1889	790
30	85	272	65	272	81	270	-74	2	9.4	11.0	16	16	582	89
30	63	34	40	34	59	33	-59	2	8.5	3.9	23	9	659	113
40	90	1130	66	1129	82	1128	-93	2	8.8	27.7	13	32	529	69
60	159	2998	112	2997	137	2996	-129	3	7.8	30.6	10	33	633	79
80	27	4	-34	4	-87	12	-193	15	13.9	3.0	179	34	2216	939

Fitting with standard “Hamburg model” + Nstep:

Φ_{eq} (10^{14} cm^{-2})	N (10^{12} cm^{-3})										τ (min)					
	N_{st}	ΔN_{st}	N_0	ΔN_0	N_1	ΔN_1	N_2	ΔN_2	N_3	ΔN_3	τ_1	$\Delta\tau_1$	τ_2	$\Delta\tau_2$	τ_3	$\Delta\tau_3$
10	0.0	0.0	40.3	1.0	11.3	1.7	17.1	2.8	28.4	3.8					1350	747
20	5.1	0.9	31.9	1.4	15.2	1.7	30.0	2.2	34.6	18.6					3530	4032
30	8.6	1.2	21.1	2.0	9.3	1.8	28.8	4.4	69.1	2.9					1104	249
30	7.7	1.2	27.1	2.1	11.7	1.8	35.5	4.3	56.5	4.3	2.5	0.6	86	7	1465	462
40	12.9	1.2	15.8	2.0	4.7	1.8	25.5	5.6	86.1	2.6					940	173
60	26.9	1.2	23.5	2.0	2.5	1.8	40.5	5.1	123.7	3.4					1249	182
80	39.6	1.0	18.2	1.5	-2.3	1.7	49.6	5.2	194.7	2.7					869	78



Annealing of V_{dep} (500 Ohm*cm)

Only for samples irradiated with 10^{14} and $2\text{x}10^{14}$ cm^{-2} we observe V_{dep} increase during short-term annealing.

For higher fluences, instead, it decreases reaching minimum at 8 min (beneficial annealing), and then increases.

Thus, at $\Phi_{eq} \geq 2\text{x}10^{14}$ cm^{-2} SCSI occurs for diodes made on 500 Ohm*cm epi-layer.

Conclusions

- Detectors made on high resistivity epi-layers (R=500 Ohm*cm) do not exhibit visible donor generation effect and, thus, undergo SCSI;
- Instead, detectors based on thin epi-layers with low initial resistivity are really radiationally hard;
- However, for these diodes we have yet to understand:

a) Lower, than expected, α values;

b) The behaviour of Neff with annealing time.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