TCT study of silicon epitaxial and MCZ detectors

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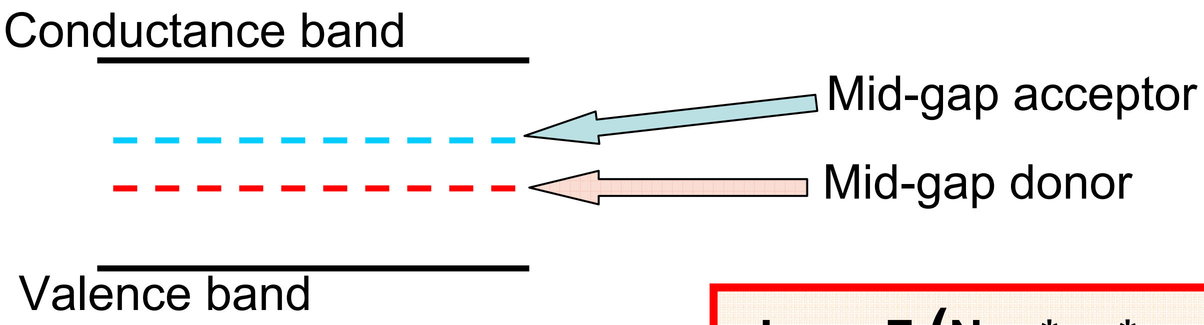
Outline

1. ***Samples and experiment***
2. ***Input data for TCT responce treatment***
3. ***TCT response in bulk and epi detectors***
4. ***Electric field reconstruction***
5. ***E(x) in cooled detectors***
6. ***Long term annealing effect***
7. ***Conclusions***

Operation effective deep levels in irradiated detectors

Mid gap levels (MGL) – Current generation, space charge introduction



Both are nearly neutral

$J_{gen} \sim \Sigma\,(N_{mgl} * \sigma * \exp(-E_{mgl}/kT)) \sim F$

$1/Tau \sim \Sigma\, N_{dl} \sim F$

$N_{eff} = \Sigma(N_{DD}^{+}) - \Sigma(N_{DA}^{-})$

Parameters of MGL

MGL1 : donor
$E_t - E_v = 0.48eV$
$\sigma = 1*10^{-15}\ cm^2$

MGL2: acceptor
$Et - Ev = 0.56eV$
$\sigma = 1*10^{-15}\ cm^2$

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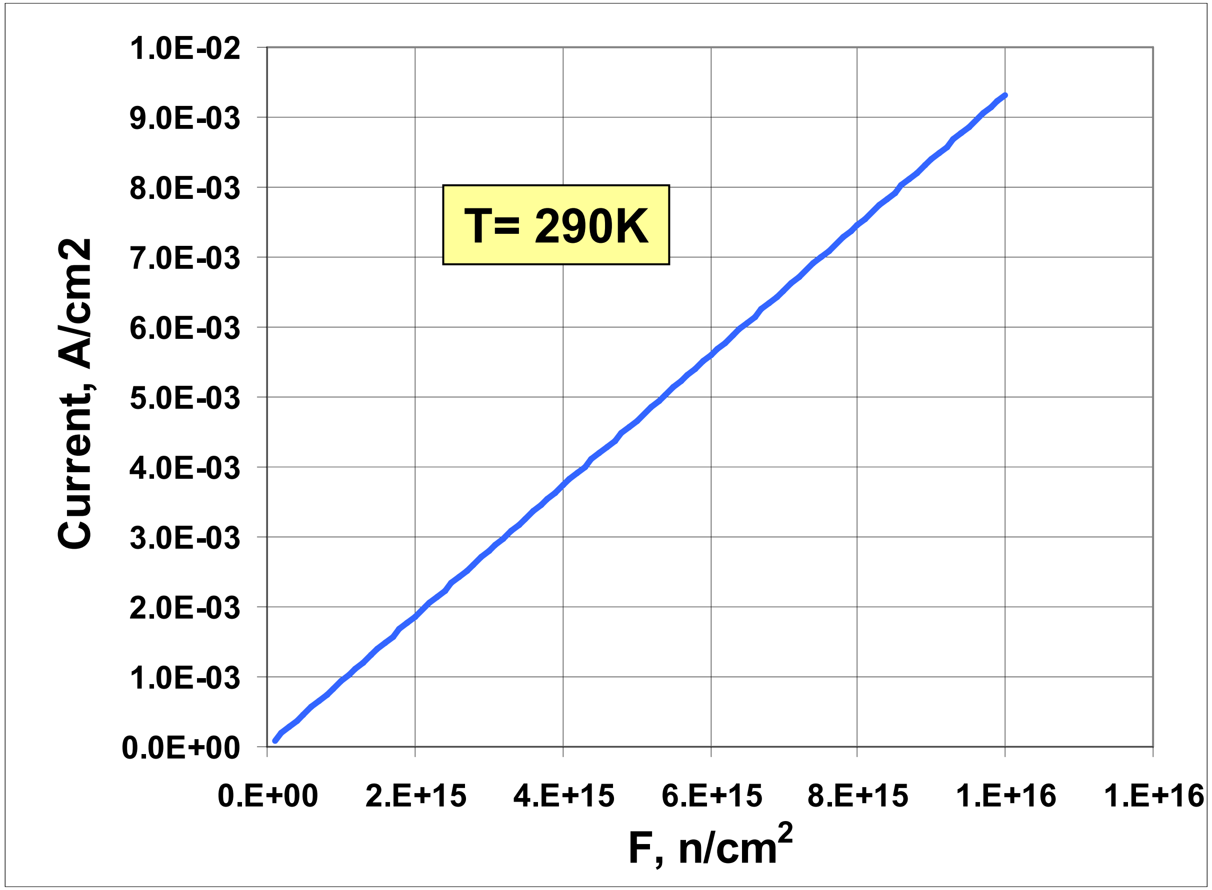
Generation current in Si PIN detectors



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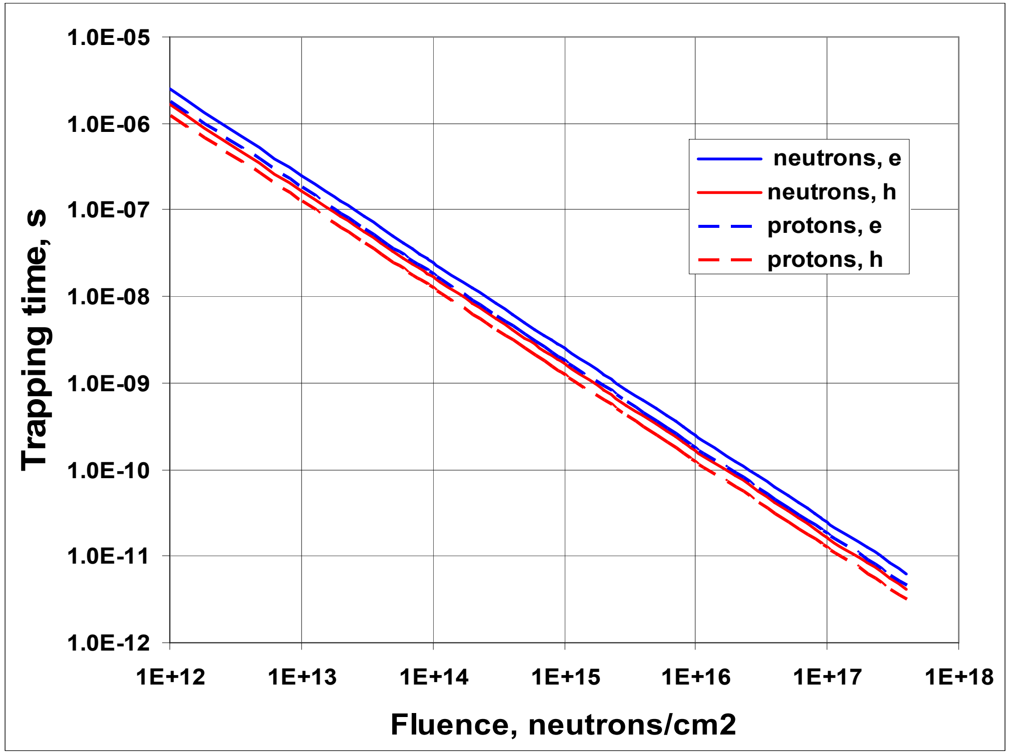
Life time degradation in Si



$$\tau(\phi) = (1/\tau_0 + \gamma\phi)^{-1}$$

Trapping probability (protons)	
$t_e 0$	1×10^3
γ_e	5.5×10^3
$t_h 0$	1×10^3
γ_h	8×10^3

Parameterization for data of G. Gramburger ….

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Samples and technique

				Annealing		Measurement
Sample #	Material	Radiation	Fluence eq.n.	T, C	Time, min	T, K
13-SMG-15	epi	neutrons	8.50E+14	no		293
12-SMG-15	epi	neutrons	8.50E+14	80	60	293
12-SMG-19	epi	neutrons	1.70E+15	80	30	293, 263
12-SMG-22	epi	protons		80	60	293, 263
187-SMG-9	MCZ	neutrons	4.20E+14	no		293, 263
187-SMG-2	MCZ	neutrons	4.20E+14	80	12	293

Technique:

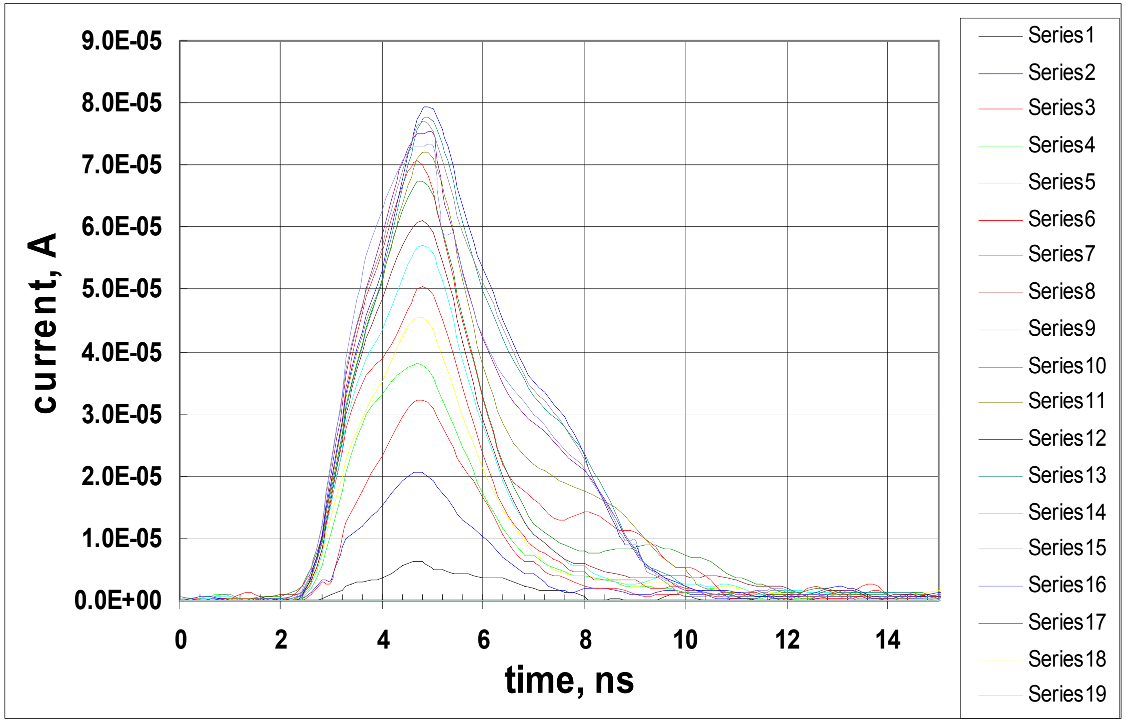
TCT setup at PTI
TCT setup response ***0.8 ns***
Temperature range ***77 – 373K***
Laser wavelength ***830um***

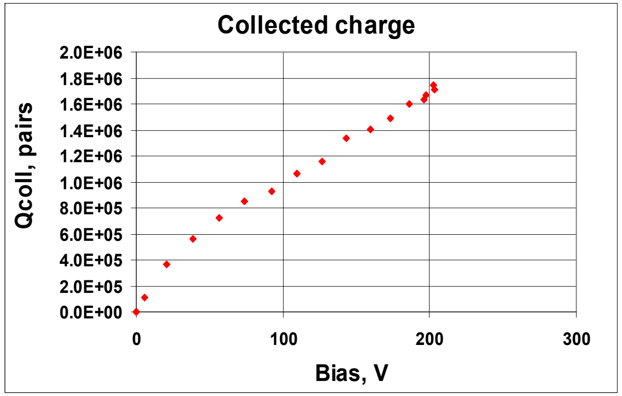
TCT data for silicon epi as irradiated detector

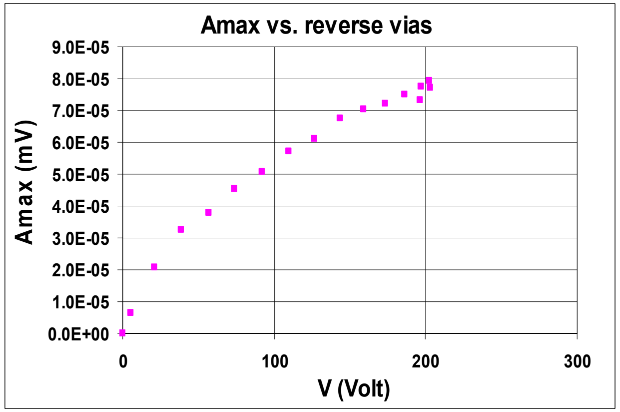
Detector W13-SMG-15
epi, 150um
Neutron irradiated: Feq = 8.5 E14 cm-2
Annealing: no

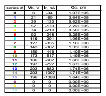
Operational parameters:
T = 293K

Extracted values
Tau tr = 3ns
Vfd = 180V









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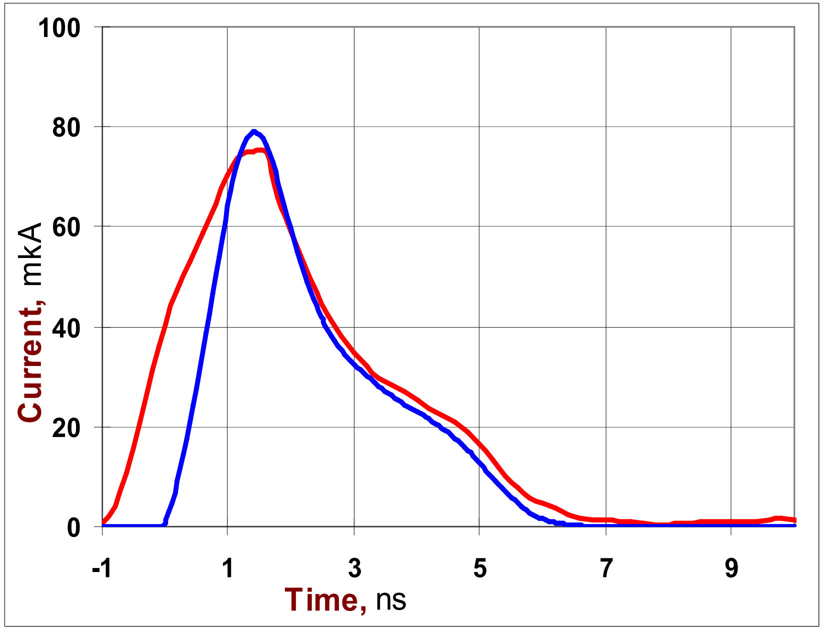
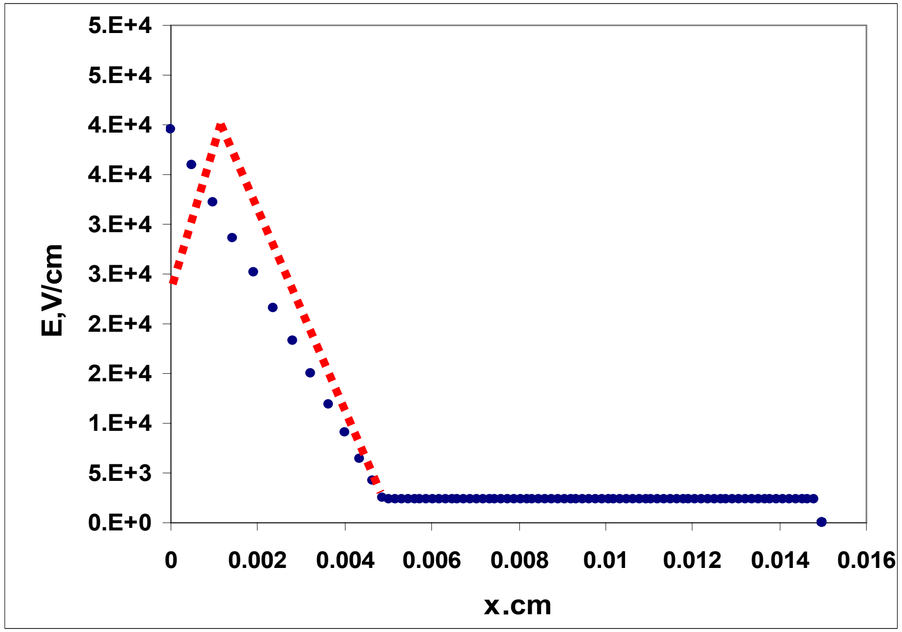
E(x) reconstruction for silicon epi as irradiated detector

Detector W13-SMG-15
epi, 150um
Neutron irradiated: Feq = 8.5 E14 cm-2
Annealing: no

Operational parameters:
V = 186V
T = 293K

Extracted values
Tau tr = 3ns
*Vfd = **180V***





Sample parameters	
d [cm]	1.50E-02
Uc[V]	0
Neff [1/cm^3	0.00E+00
tau(e), [s]	3.00E-09
tau(h), [s]	5.00E-09
TCT mode	
n[cm-1]	-3.00E+06
Ub [V]	186
a [1/cm]	5.64E+03
Temper. [K]	293
Step [ns]	0.1

Calculated values	
E1, V/cm	2600
W1, cm	0.005
Eb, V/cm	2100
Wb, cm	0.01
E2, V/cm	-1.77E+20
W2, cm	0

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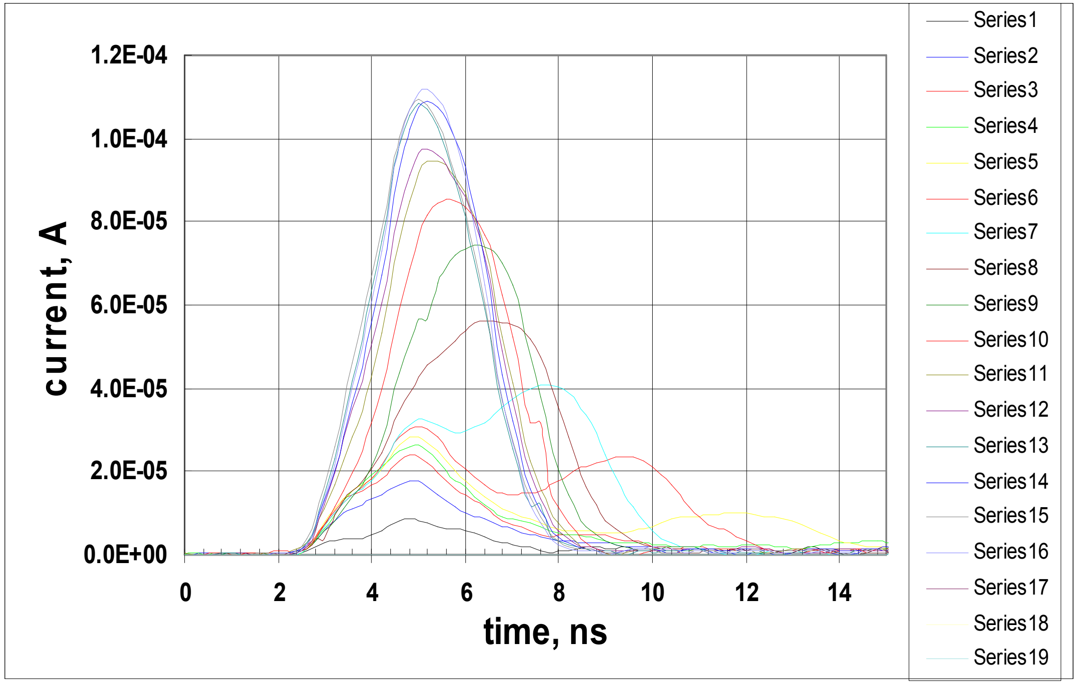
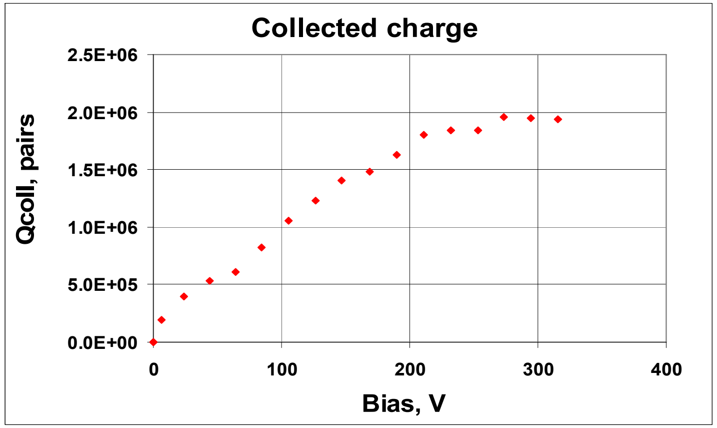
TCT data for silicon epi annealed detector

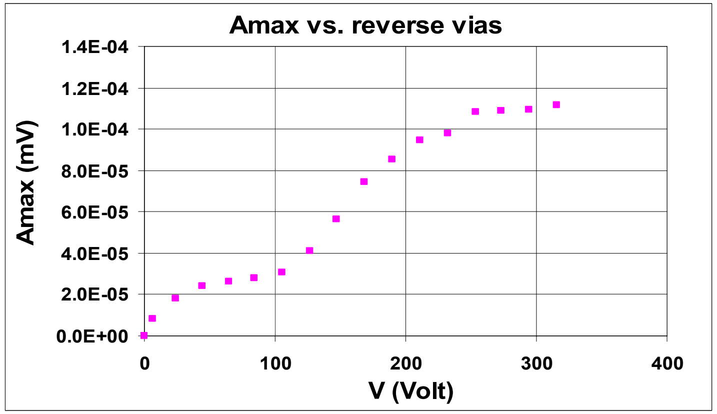
Detector W12-SMG-15
epi, 150um
Neutron irradiated: Feq = 8.5 E14 cm-2
Annealing: 80C@60min

Operational parameters:
T = 293K

Extracted values
*Vfd = **150V***







series #	Vb, V	Ir, nA	Qc, prs
0	7	-22	2.04E+05
1	24	-57	4.06E+05
2	44	-79	5.65E+05
3	65	-94	6.65E+05
4	85	-105	8.41E+05
5	106	-114	1.08E+06
6	127	-122	1.24E+06
7	147	-129	1.43E+06
8	168	-136	1.51E+06
9	190	-141	1.64E+06
10	211	-149	1.83E+06
11	232	-156	1.87E+06
12	253	-167	1.87E+06
13	274	-174	1.99E+06
14	295	-183	1.97E+06
15	316	-193	1.96E+06
0	0	0	0.00E+00
0	0	0	0.00E+00
19	0	0	0.00E+00

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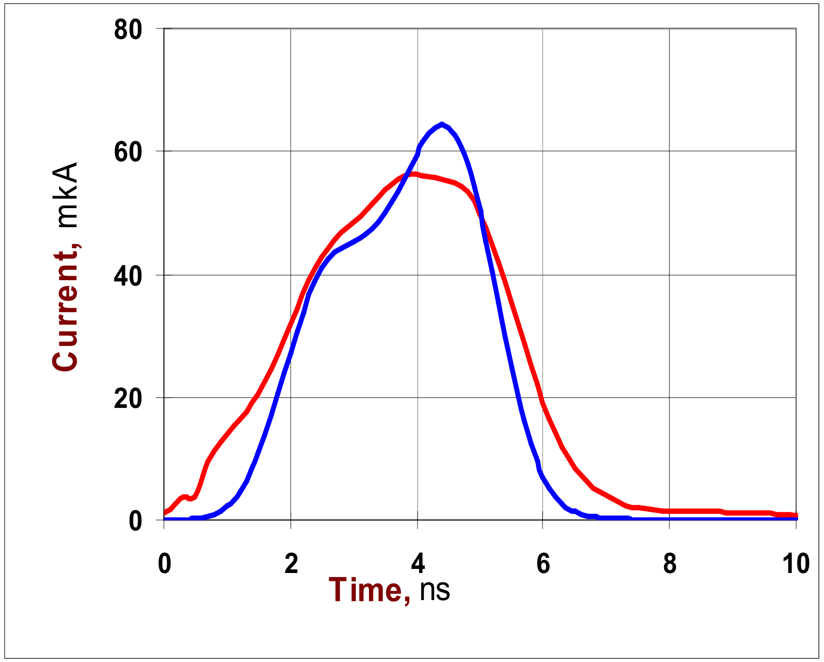
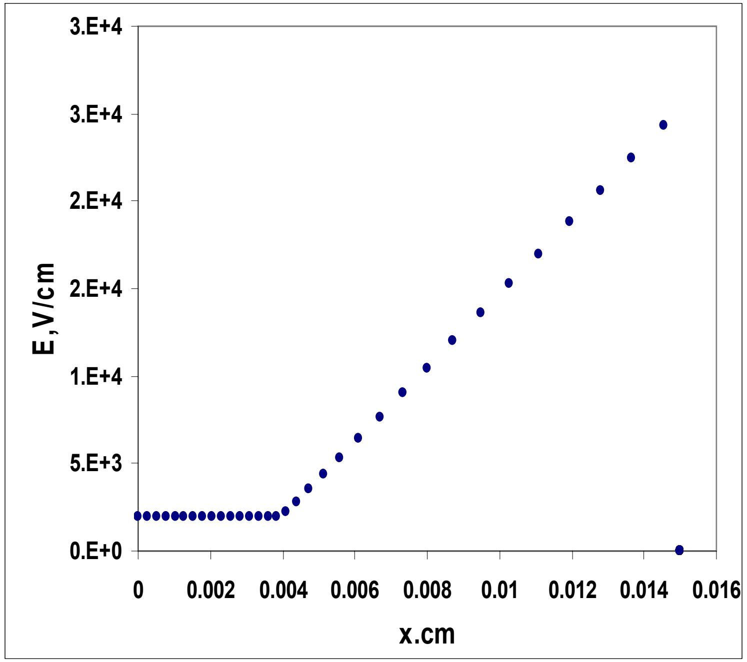
E(x) reconstruction for silicon epi annealed detector

Detector W12-SMG-15
MCZ, 150um
Neutron irradiated: Feq = 8.5 E14 cm-2
Annealing: 80C@60min

Operational parameters:
V = 147V
T = 293K

Extracted values
Tau tr = 3 ns
*Vfd = **150V***





Sample parameters	
d [cm]	1.50E-02
Uc[V]	0
Neff [1/cm^3	0.00E+00
tau(e), [s]	3.00E-09
tau(h), [s]	5.00E-09
TCT mode	
n[cm-1]	-2.20E+06
Ub [V]	147
a [1/cm]	5.64E+03
Temper. [K]	293
Step [ns]	0.1

Calculated values	
E1, V/cm	2000
W1, cm	0
Eb, V/cm	2000
Wb, cm	0.004
E2, V/cm	23272.727
W2, cm	0.011

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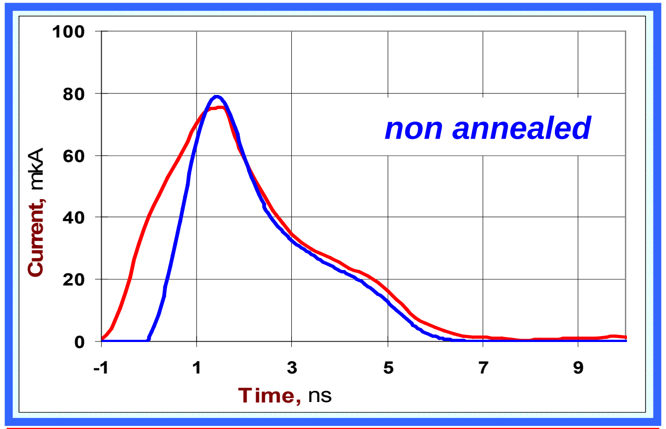
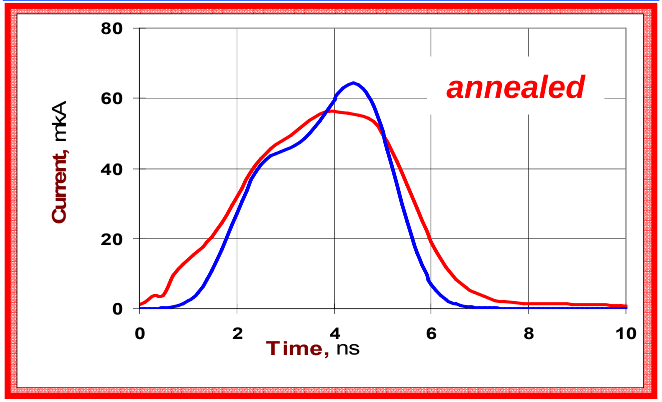
Annealing effect in silicon epi detectors

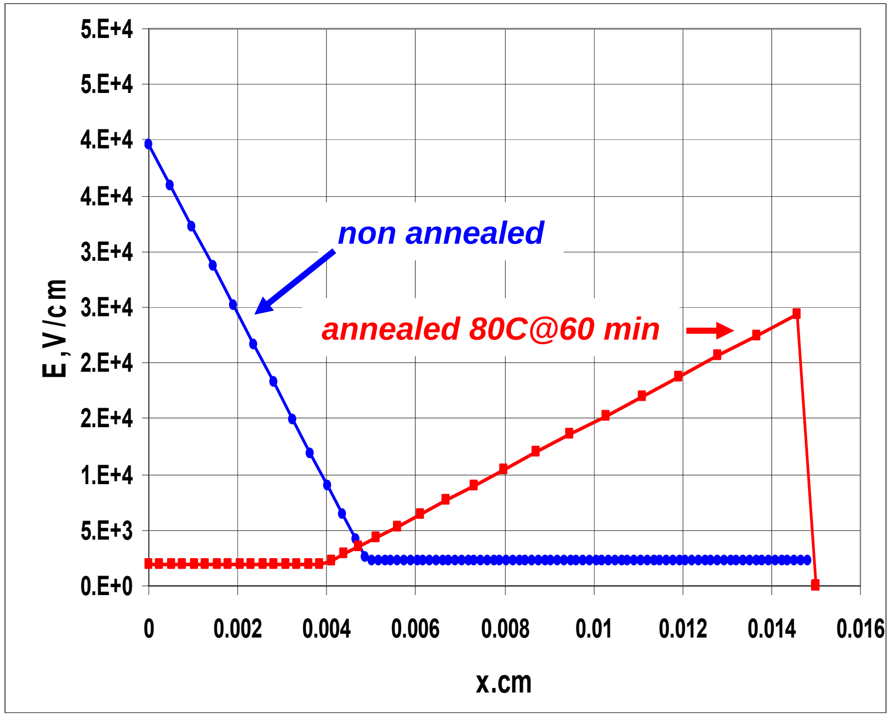
epi, 150um
Neutron irradiated: Feq = 8.5 E14 cm-2
W13-SMG-15: non annealed
W12-SMG-15: annealed 80C@60 min

Operational parameters:
T = 293K

Extracted values
Tau tr = 3 ns







Sample parameters	
d [cm]	3.00E-02
Uc[V]	0
Neff [1/cm^3	0.00E+00
tau(e), [s]	6.00E-09
tau(h), [s]	5.00E-09
TCT mode	
n[cm-1]	-2.80E+06
Ub [V]	184
a [1/cm]	5.64E+03
Temper. [K]	293
Step [ns]	0.1

Calculated values	
E1, V/cm	5200
W1, cm	0.0035
Eb, V/cm	2200
Wb, cm	0.015
E2, V/cm	21808.696
W2, cm	0.0115

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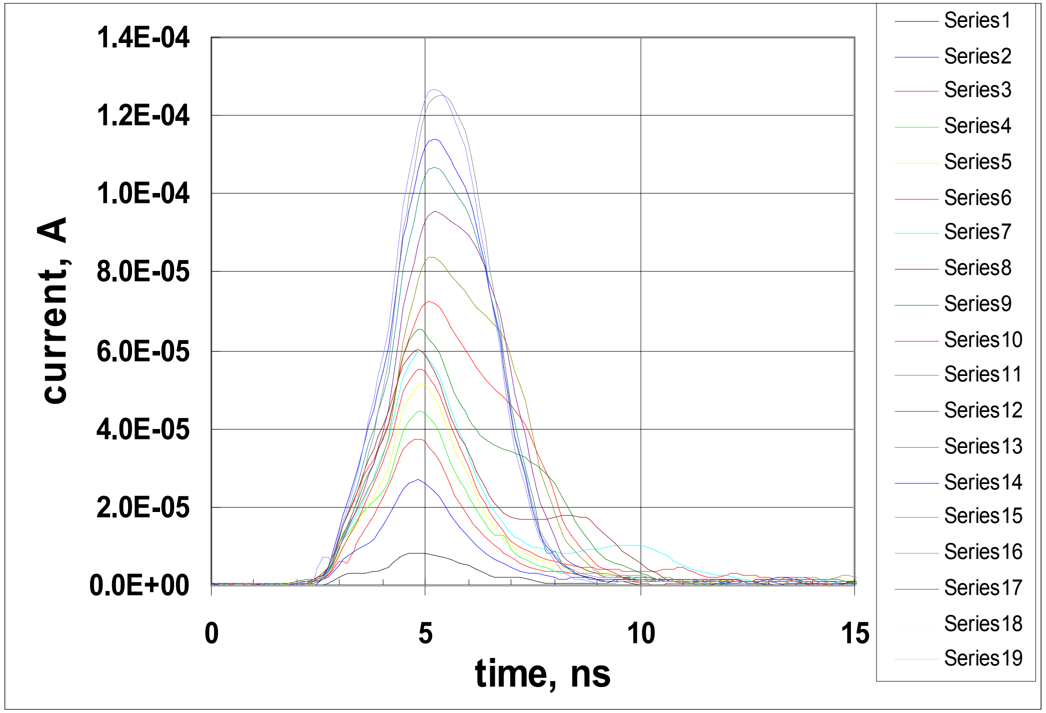
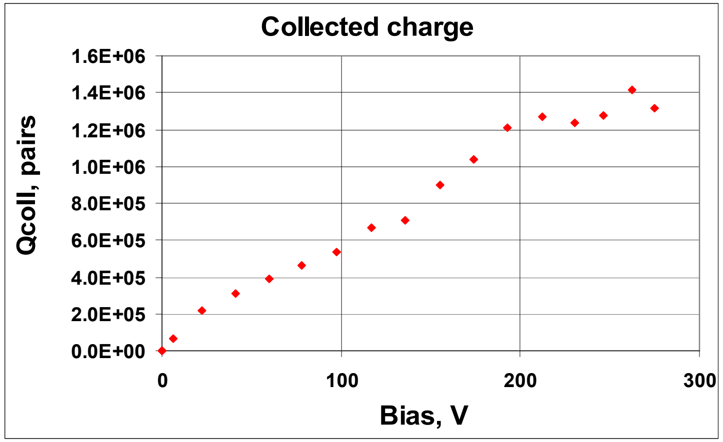
TCT data for silicon epi annealed detector

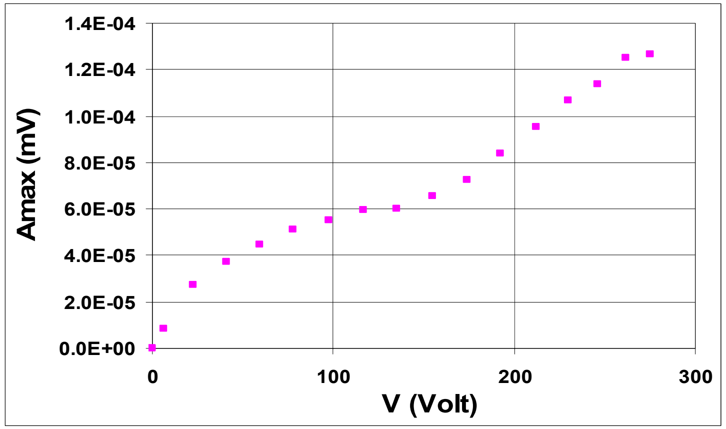
Detector W12-SMG-19
epi, 150um
Neutron irradiated: Feq = 1.7 E15 cm-2
Annealing: 80C@30min

Operational parameters:
T = 293K

Extracted values
Tau tr = 1.5 ns
*Vfd = **190V***







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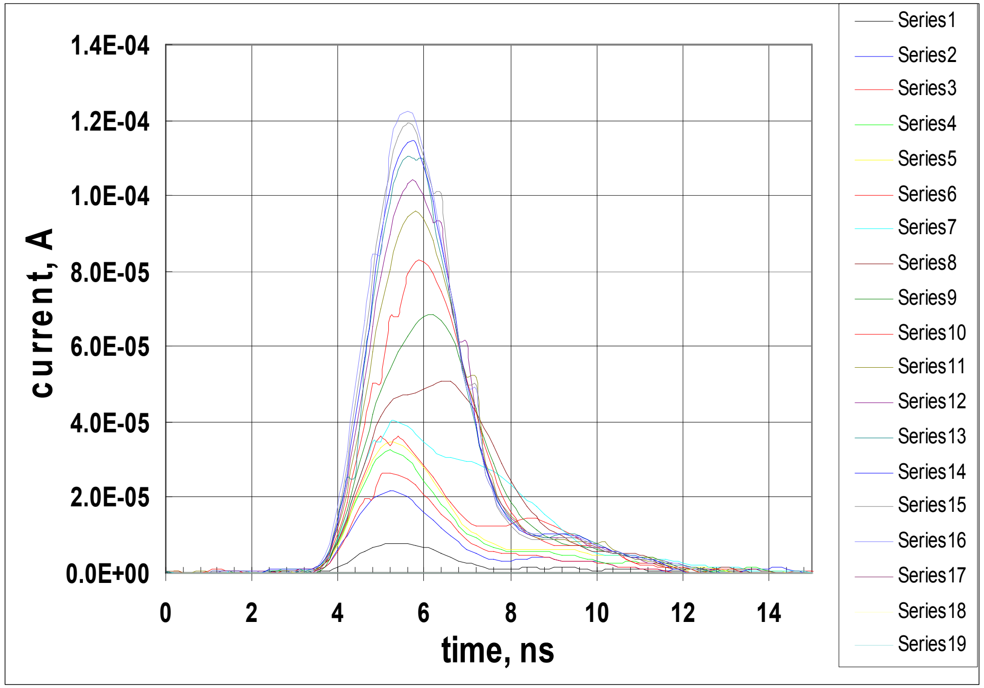
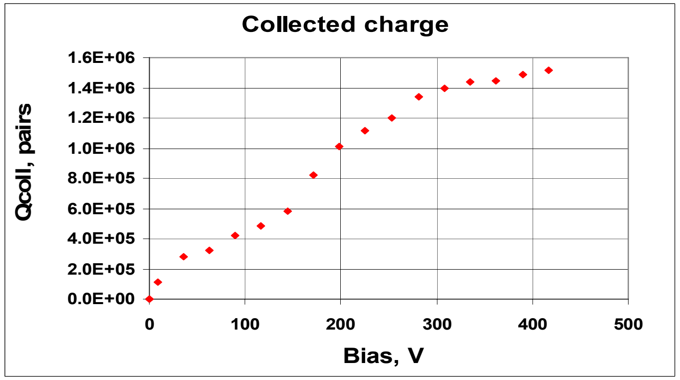
TCT data for silicon epi annealed and cooled detector

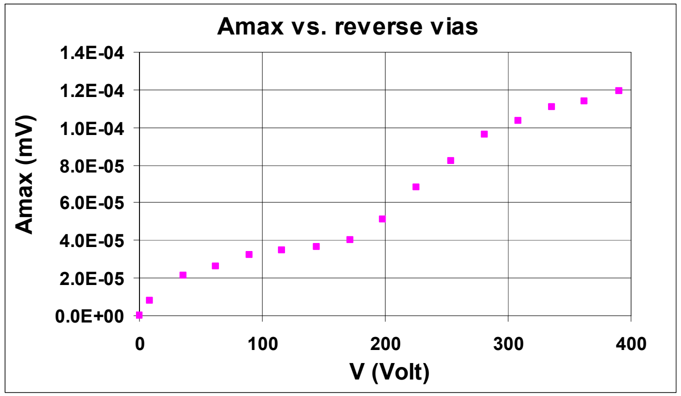
Detector W12-SMG-19-10
epi, 150um
Neutron irradiated: Feq = 1.7 E15 cm-2
Annealing: 80C@30min

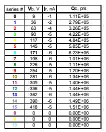
Operational parameters:
T = 263K

Extracted values
TAu tr = 1.5 ns
*Vfd = **198V***









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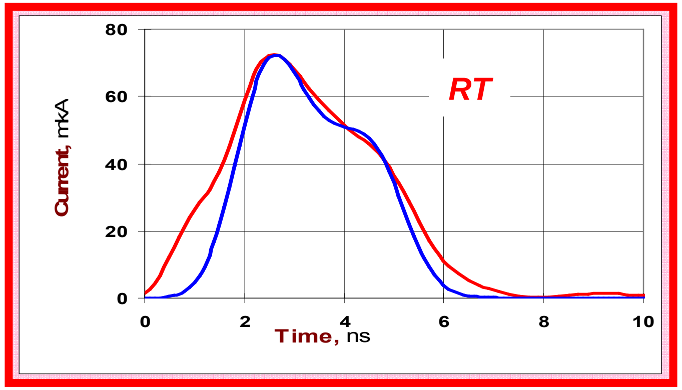
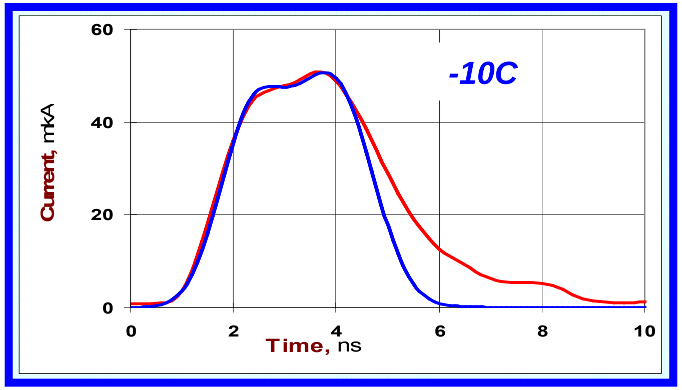
Cooling effect in silicon irradiated epi detectors

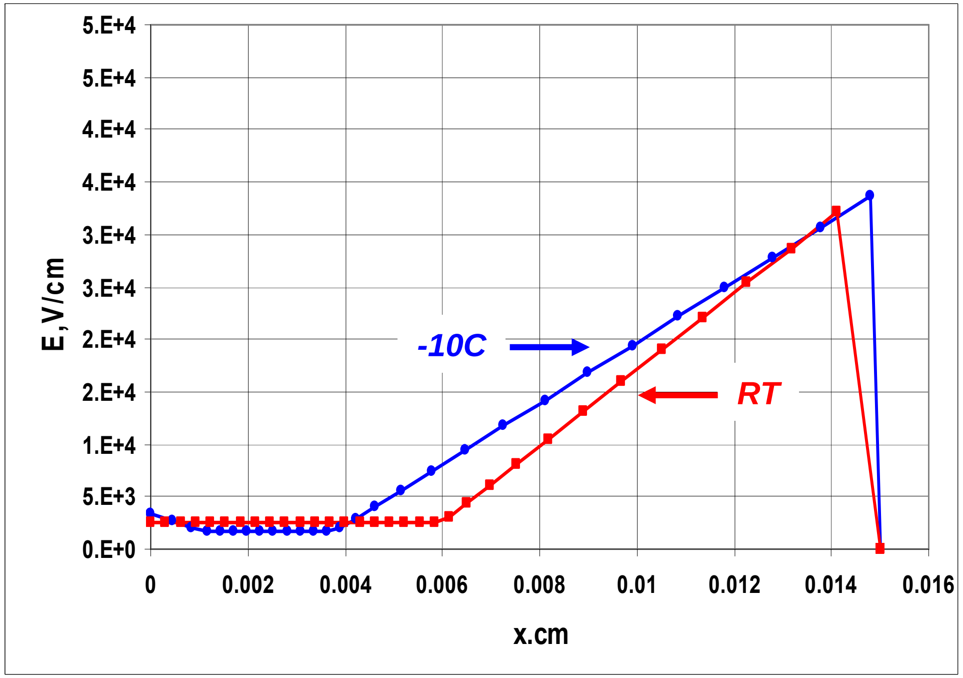
Detector W12-SMG-19
epi, 150um
Neutron irradiated: Feq = 1.7 E15 cm-2
annealed 80C@30 min
RT; -10C

Operational parameters:
V = 174V

Extracted values
Tau tr = 1.5 ns







Sample parameters	
d [cm]	3.00E-02
Uc[V]	0
Neff [1/cm^3	0.00E+00
tau(e), [s]	6.00E-09
tau(h), [s]	5.00E-09
TCT mode	
n[cm-1]	-2.80E+06
Ub [V]	184
a [1/cm]	5.64E+03
Temper. [K]	293
Step [ns]	0.1

Calculated values	
E1, V/cm	5200
W1, cm	0.0035
Eb, V/cm	2200
Wb, cm	0.015
E2, V/cm	21808.696
W2, cm	0.0115

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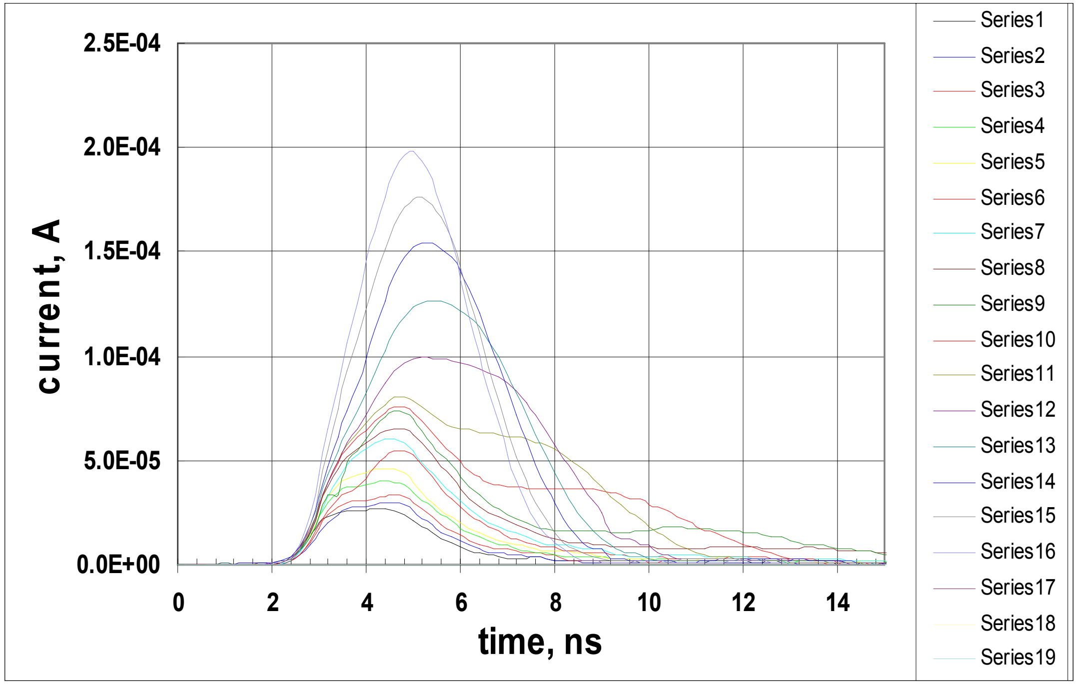
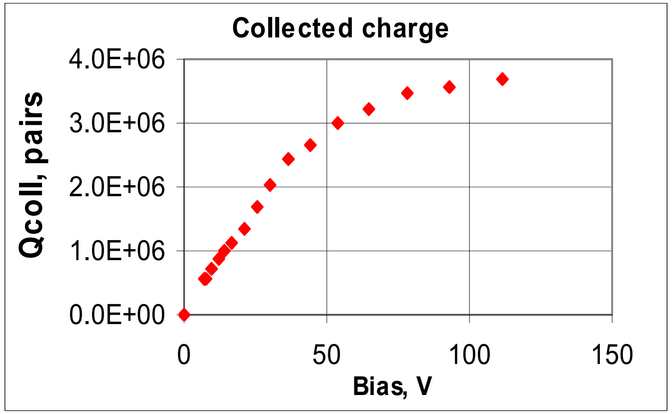
TCT data for proton irradiated silicon epi detector

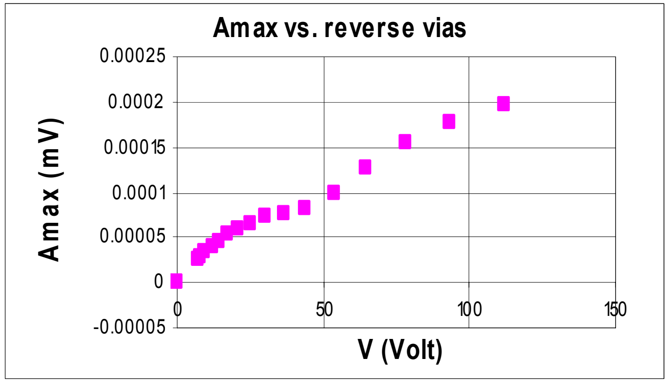
Detector W12-SMG-22
epi, 150um
Proton irradiated: Feq = 7 E14 cm-2
Annealing: 80C@60min

Operational parameters:
T = 293K

Extracted values
*Vfd = **54V***







series #	Vb, V	Ir, nA	Qc, prs
0	9	-1	1.11E+05
1	36	-2	2.79E+05
2	63	-4	3.26E+05
3	90	-5	4.22E+05
4	117	-5	4.84E+05
5	145	-5	5.85E+05
6	171	-6	8.23E+05
7	198	-6	1.01E+06
8	226	-5	1.11E+06
9	254	-5	1.20E+06
10	281	-6	1.34E+06
11	309	-5	1.40E+06
12	336	-5	1.44E+06
13	362	-6	1.44E+06
14	390	-6	1.49E+06
15	418	-5	1.51E+06
0	0	0	0.00E+00
0	0	0	0.00E+00
19	0	0	0.00E+00

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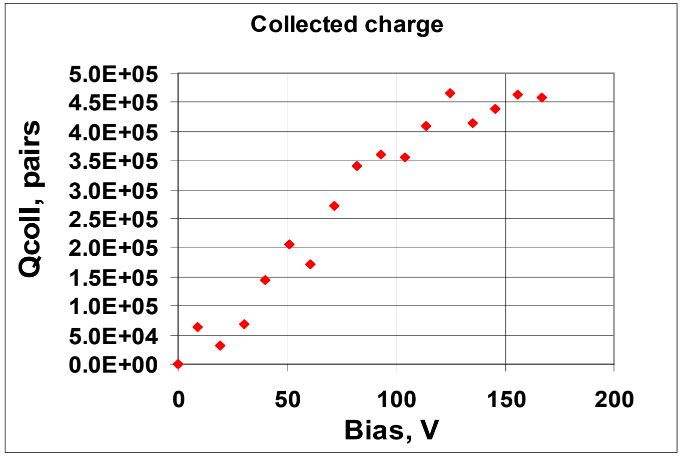
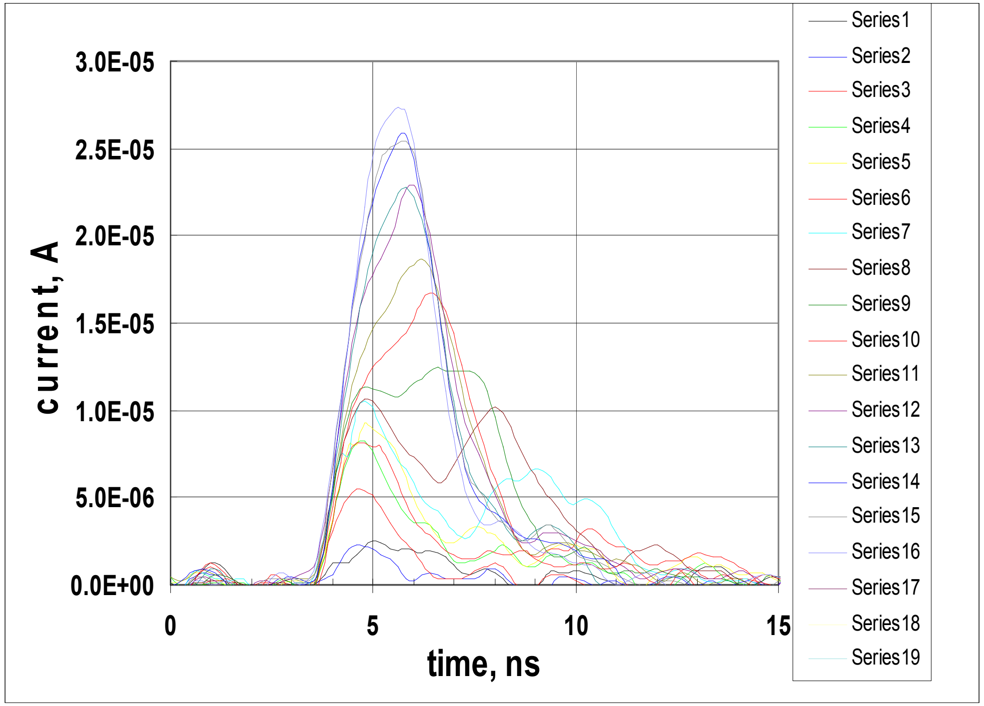
TCT data for silicon epi annealed detector

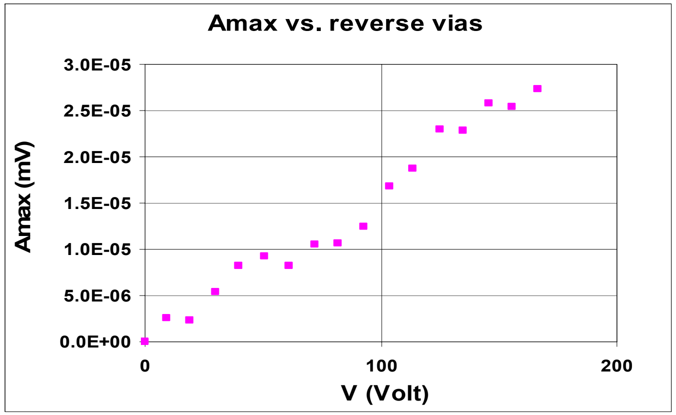
Detector W12-SMG-22-10
epi, 150um
Proton irradiated: Feq = 7 E14 cm-2
Annealing: 80C@60min

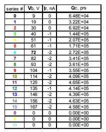
Operational parameters:
T = 263K

Extracted values
*Vfd = **92V***









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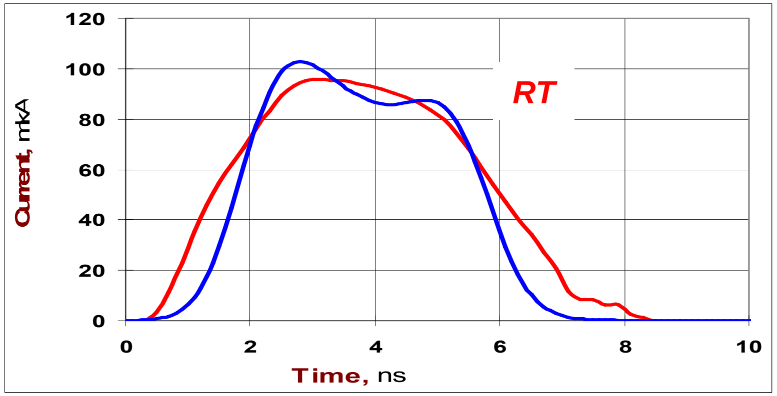
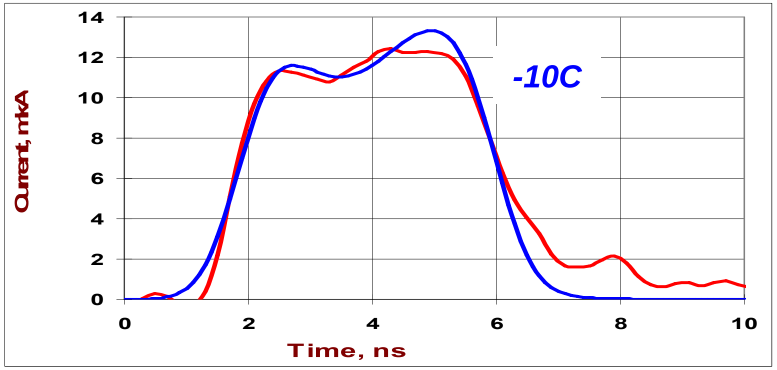
Cooling effect in proton irradiated epi silicon detectors

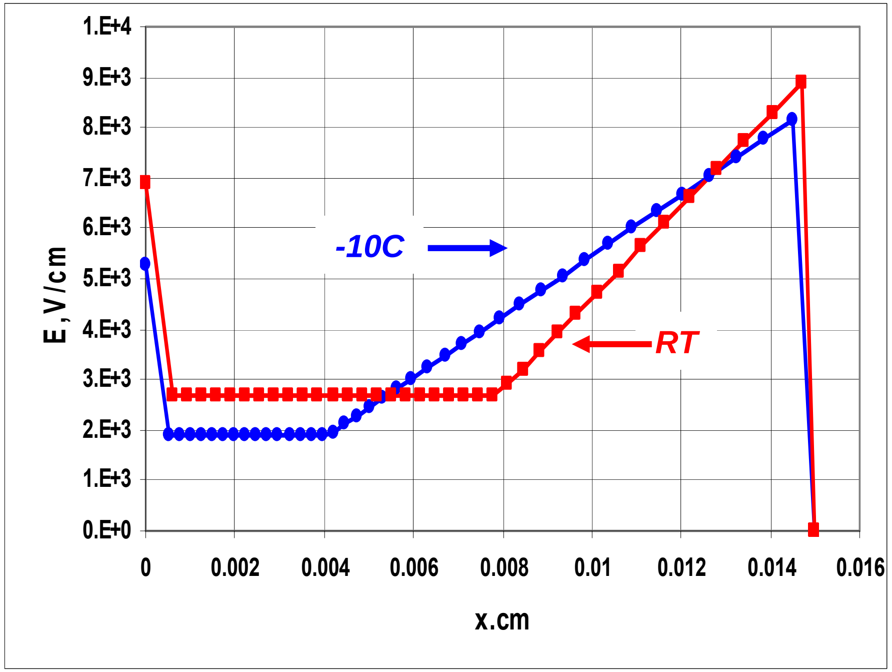
Detector W12-SMG-22
epi, 150um
Proton irradiated: Feq = 7 E14 cm-2
annealed 80C@30 min
RT; -10C

Operational parameters:
V = 92V

Extracted values
Tau tr = 4 ns







Sample parameters	
d [cm]	3.00E-02
Uc[V]	0
Neff [1/cm^3	0.00E+00
tau(e), [s]	6.00E-09
tau(h), [s]	5.00E-09
TCT mode	
n[cm-1]	-2.80E+06
Ub [V]	184
a [1/cm]	5.64E+03
Temper. [K]	293
Step [ns]	0.1

Calculated values	
E1, V/cm	5200
W1, cm	0.0035
Eb, V/cm	2200
Wb, cm	0.015
E2, V/cm	21808.696
W2, cm	0.0115

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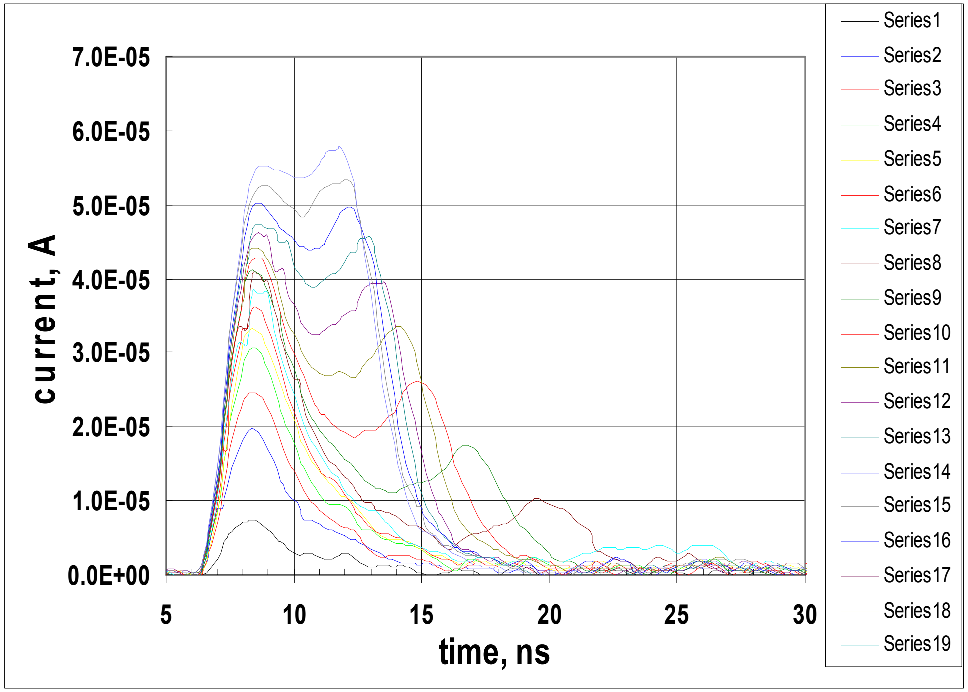
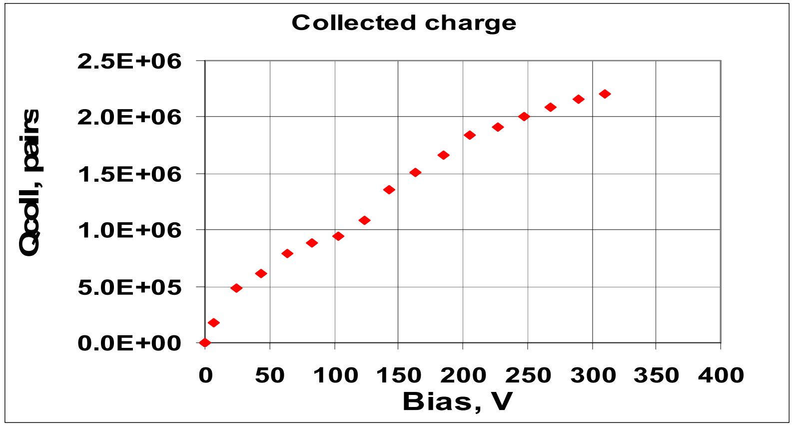
TCT data for silicon MCZ as irradiated detector

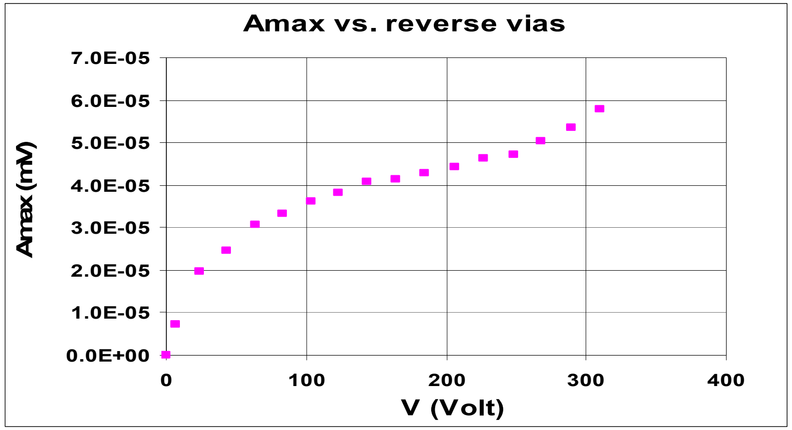
Detector W187-SMG-9
MCZ, 300um
Proton irradiated: 26 MeV, Feq = 4.2 E14 cm-2
Annealing: no

Operational parameters:
T = 293K

Extracted values
*Vfd = **206V***







series #	Vb, V	Ir, nA	Qc, prs
0	7	-20	1.80E+05
1	24	-56	4.87E+05
2	44	-83	6.13E+05
3	64	-103	7.91E+05
4	83	-122	8.89E+05
5	103	-138	9.40E+05
6	124	-155	1.09E+06
7	143	-168	1.35E+06
8	164	-181	1.51E+06
9	185	-191	1.66E+06
10	206	-200	1.84E+06
11	227	-210	1.91E+06
12	248	-220	2.00E+06
13	268	-228	2.09E+06
14	289	-236	2.15E+06
15	310	-246	2.21E+06
0	0	0	0.00E+00
0	0	0	0.00E+00
19	0	0	0.00E+00

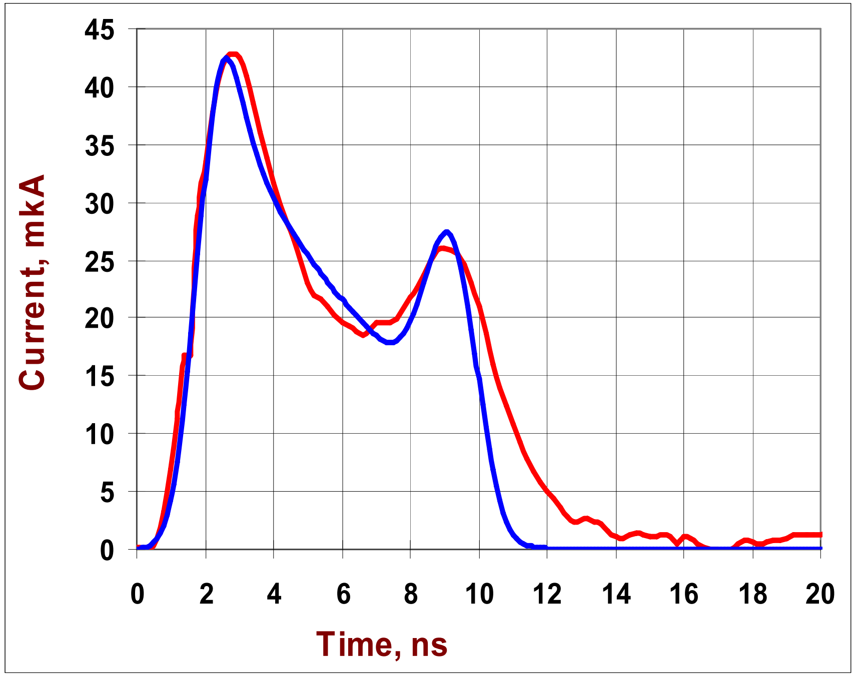
V, Eremin … , PTI, RD50, Oct. 2006

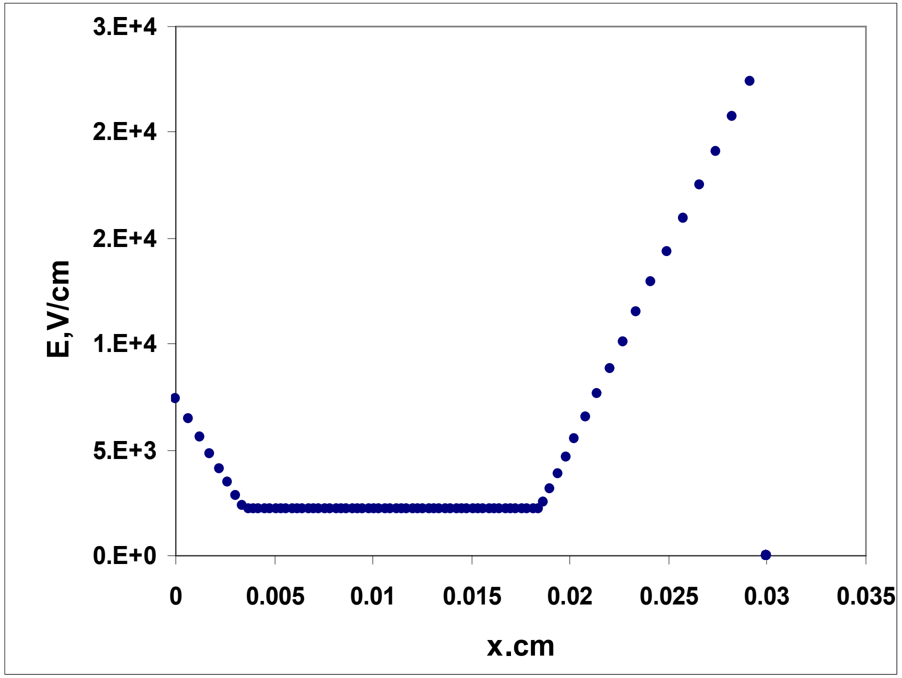
E(x) reconstruction for silicon MCZ as irradiated detector

Detector W187-SMG-9
MCZ, 300um
Proton irradiated: 26 MeV, Feq = 4.2 E14 cm-2
Annealing: no

Operational parameters:
V = 184 V
T = 293K

Extracted values
Tau tr = 6 ns
*Vfd = **180V***





Sample parameters	
d [cm]	3.00E-02
Uc[V]	0
Neff [1/cm^3	0.00E+00
tau(e), [s]	6.00E-09
tau(h), [s]	5.00E-09
TCT mode	
n[cm-1]	-2.80E+06
Ub [V]	184
a [1/cm]	5.64E+03
Temper. [K]	293
Step [ns]	0.1

Calculated values	
E1, V/cm	5200
W1, cm	0.0035
Eb, V/cm	2200
Wb, cm	0.015
E2, V/cm	21808.696
W2, cm	0.0115

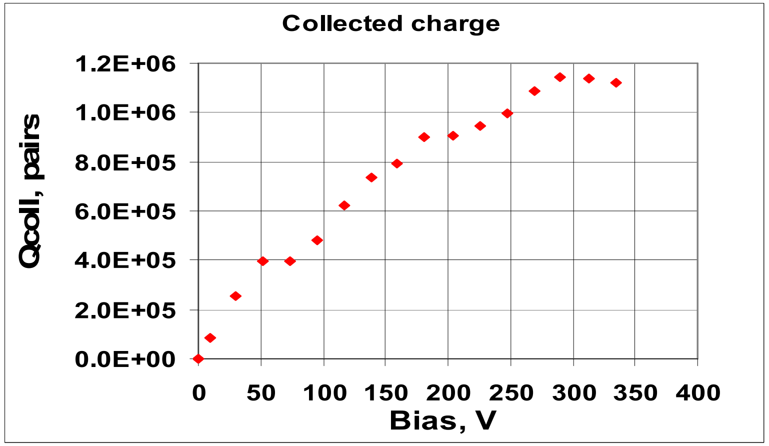
V, Eremin … , PTI, RD50, Oct. 2006

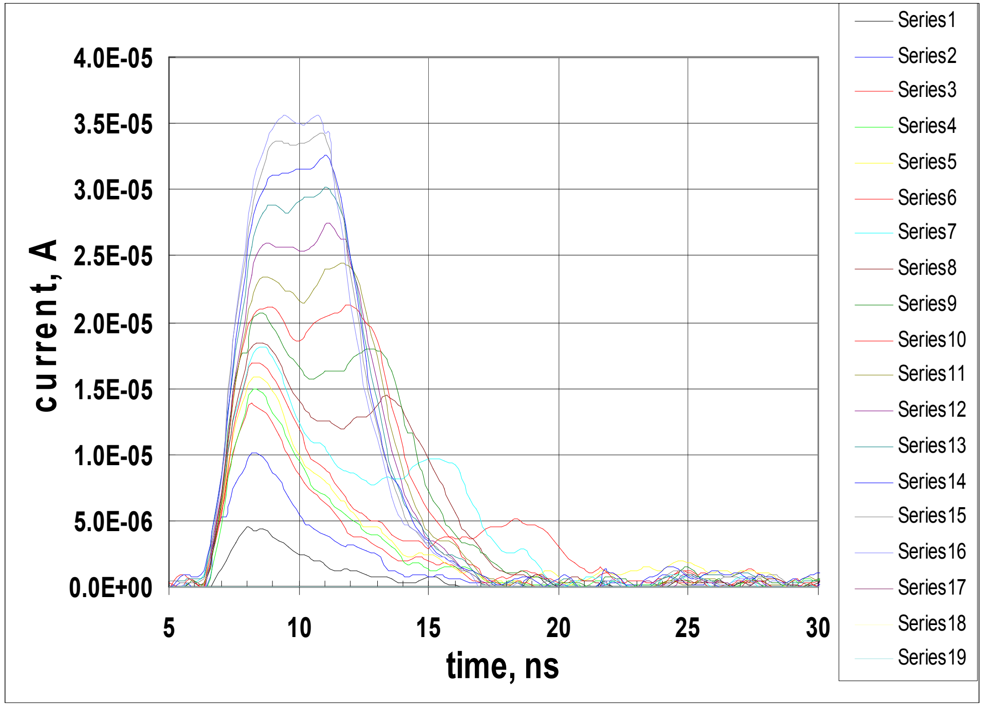
TCT data for silicon MCZ as irradiated cooled detector

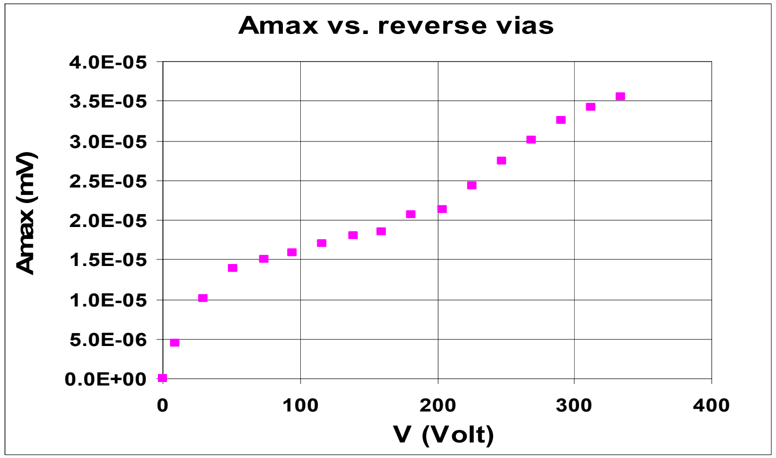
Detector W187-SMG-9
MCZ, 300um
Proton irradiated: 26 MeV, Feq = 4.2 E14 cm-2
Annealing: no

Operational parameters:
T = 263K

Extracted values
Vfd = ***180V***







series #	Vb, V	Ir, nA	Qc, prs
0	9	-1	8.42E+04
1	30	-1	2.55E+05
2	52	-3	3.94E+05
3	74	-3	3.95E+05
4	95	-3	4.83E+05
5	117	-4	6.24E+05
6	**139**	-5	7.35E+05
7	160	-5	7.91E+05
8	182	-5	8.97E+05
9	204	-4	9.05E+05
10	226	-5	9.48E+05
11	248	-5	9.97E+05
12	269	-6	1.08E+06
13	290	-6	1.14E+06
14	313	-5	1.14E+06
15	334	-6	1.12E+06
0	0	0	0.00E+00
0	0	0	0.00E+00
19	0	0	0.00E+00

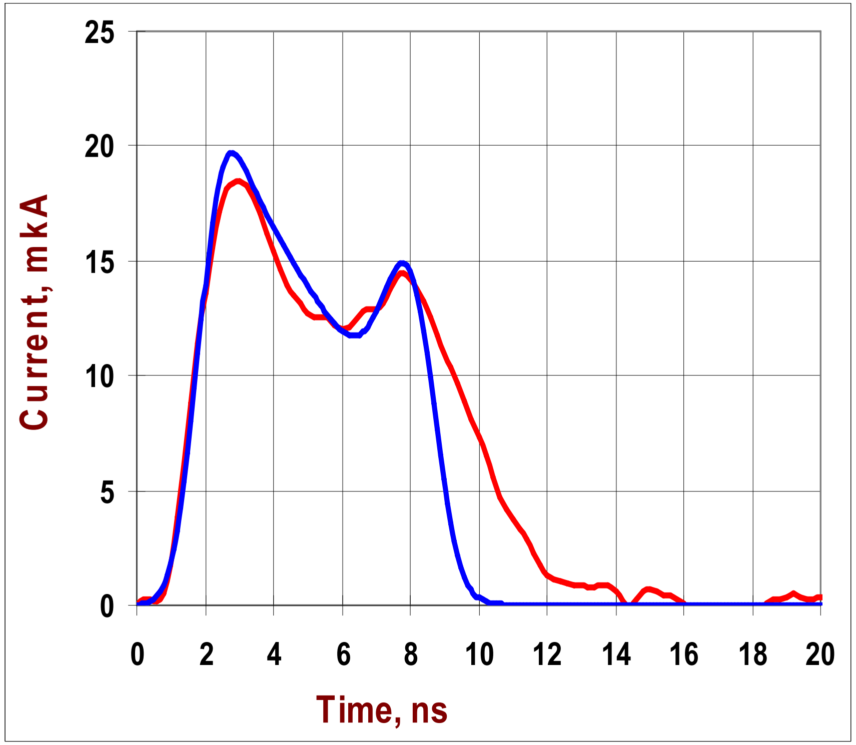
V, Eremin … , PTI, RD50, Oct. 2006

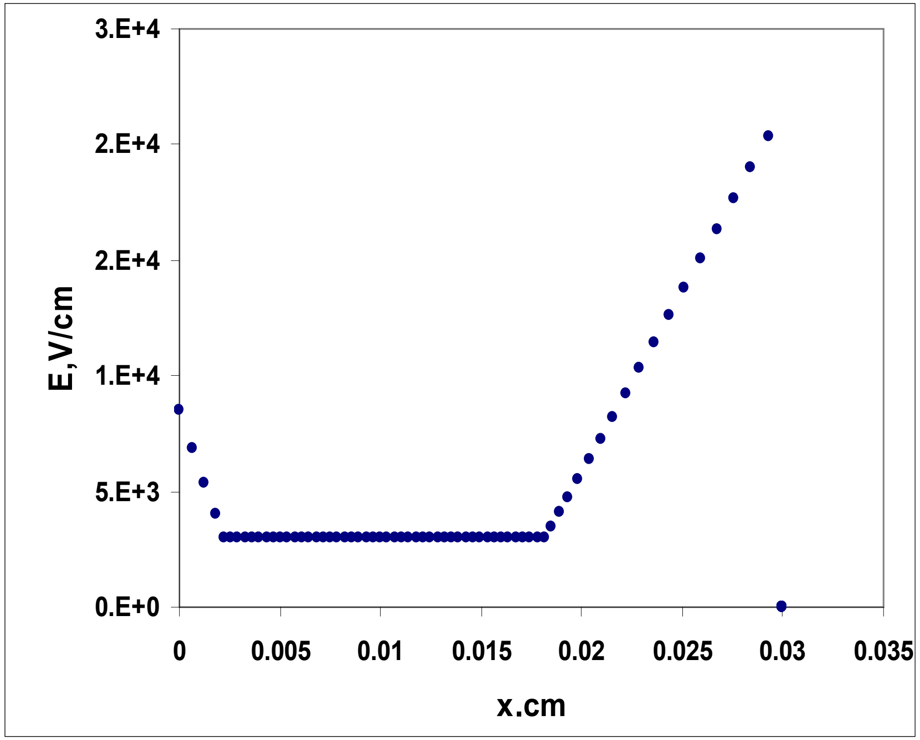
E(x) reconstruction for silicon MCZ as irradiated cooled detector

Detector W187-SMG-9
MCZ, 300um
Proton irradiated: 26 MeV, Feq = 4.2 E14 cm-2
Annealing: no

Operational parameters:
V = 184 V
T = 263K

Extracted values
Tau tr = 6 ns
*Vfd = **180V***





Sample parameters	
d [cm]	3.00E-02
Uc[V]	0
Neff [1/cm^3	0.00E+00
tau(e), [s]	6.00E-09
tau(h), [s]	5.00E-09
TCT mode	
n[cm-1]	-1.20E+06
Ub [V]	184
a [1/cm]	5.64E+03
Temper. [K]	293
Step [ns]	0.1

Calculated values	
E1, V/cm	5500
W1, cm	0.0022
Eb, V/cm	3000
Wb, cm	0.016
E2, V/cm	18466.102
W2, cm	0.0118

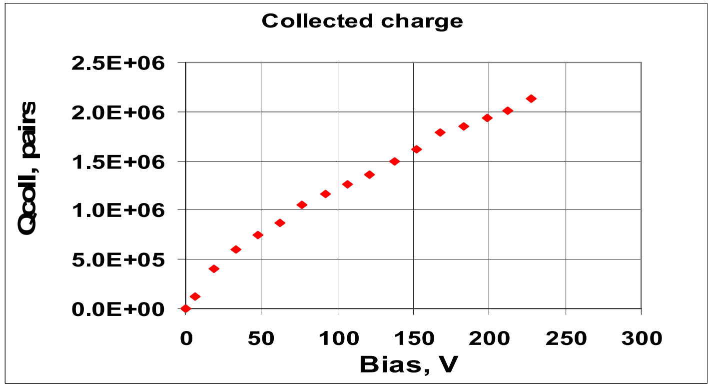
V, Eremin … , PTI, RD50, Oct. 2006

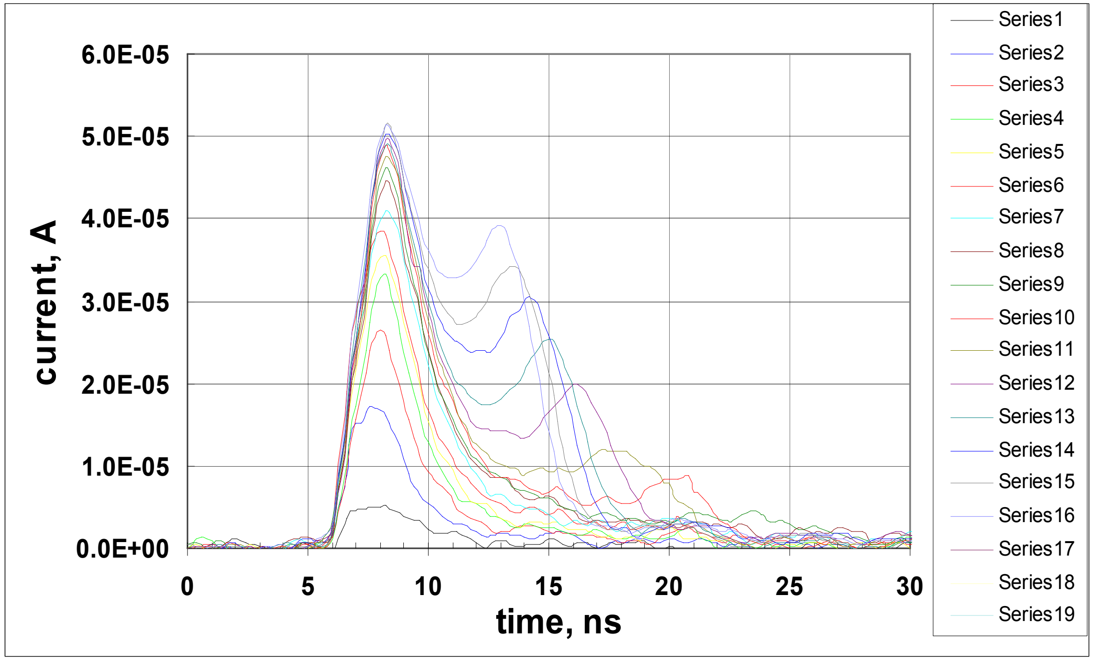
TCT data for silicon MCZ annealed detector

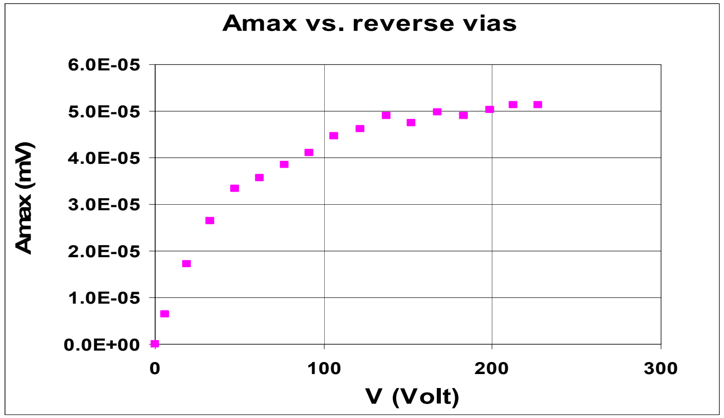
Detector W187-SMG-2
MCZ, 300um
Proton irradiated: 26 MeV, Feq = 4.2 E14 cm-2
Annealing: 80C, 12 min

Operational parameters:
T = 293K

Extracted values
*Vfd = **180V***







series #	Vb, V	Ir, nA	Qc, prs
0	6	-29	1.23E+05
1	19	-60	4.08E+05
2	33	-79	5.99E+05
3	48	-95	7.43E+05
4	62	-109	8.71E+05
5	77	-122	1.06E+06
6	92	-132	1.16E+06
7	107	-144	1.27E+06
8	122	-155	1.36E+06
9	137	-166	1.50E+06
10	152	-176	1.61E+06
11	167	-186	1.79E+06
12	184	-194	1.85E+06
13	199	-204	1.94E+06
14	212	-216	2.01E+06
15	227	-229	2.13E+06
0	0	0	0.00E+00
0	0	0	0.00E+00
19	0	0	0.00E+00

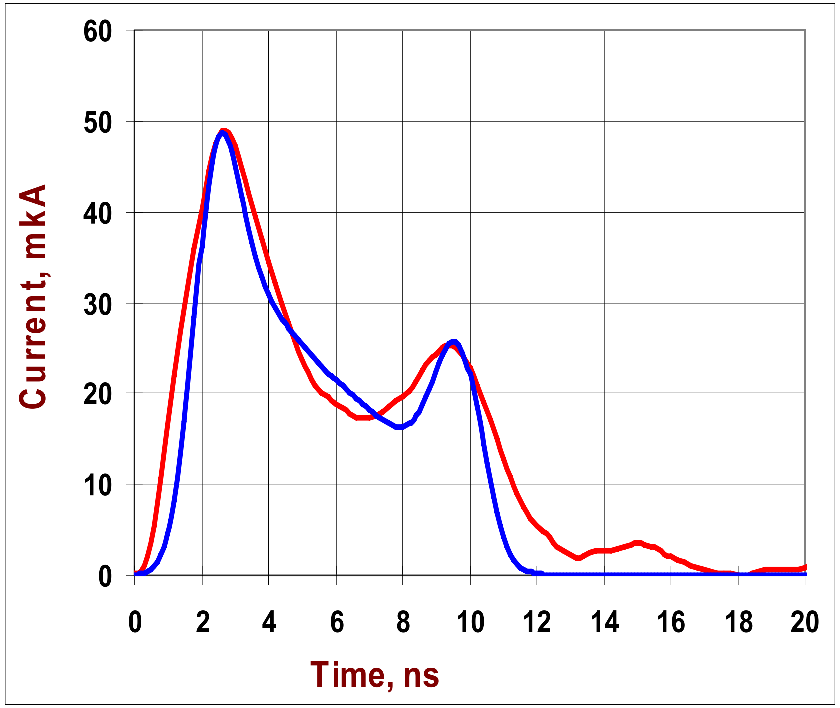
V, Eremin … , PTI, RD50, Oct. 2006

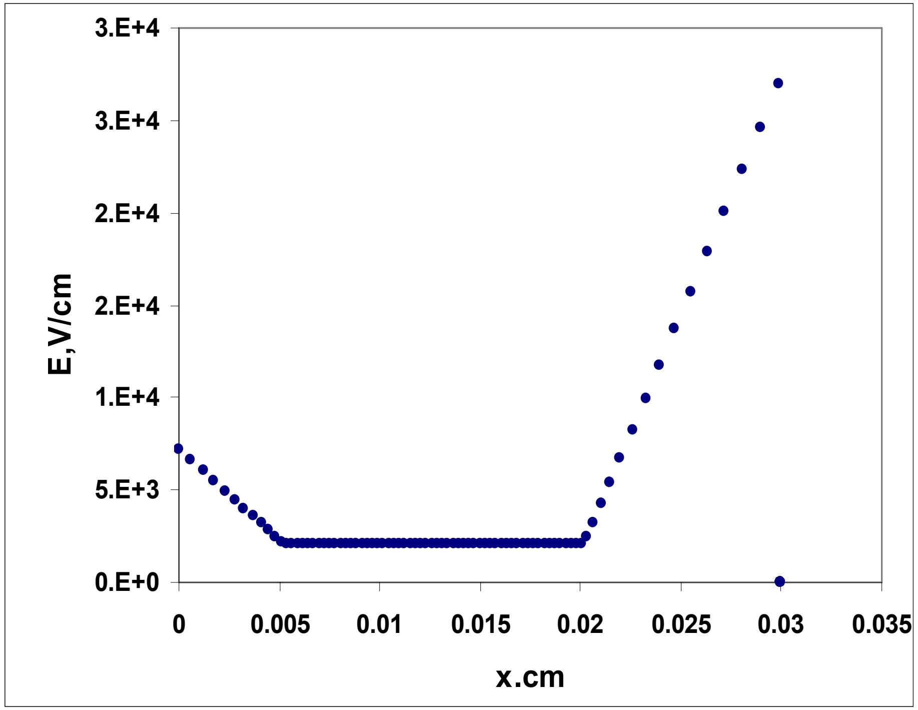
E(x) reconstruction for silicon MCZ annealed detector

Detector W187-SMG-2
MCZ, 300um
Proton irradiated: 26 MeV, Feq = 4.2 E14 cm-2
Annealing: 80C, 12 min

Operational parameters:
V = 184V
T = 293K

Extracted values
Tau tr = 6 ns





Sample parameters	
d [cm]	3.00E-02
Uc[V]	0
Neff [1/cm^3	0.00E+00
tau(e), [s]	6.00E-09
tau(h), [s]	5.00E-09
TCT mode	
n[cm-1]	-2.90E+06
Ub [V]	184
a [1/cm]	5.64E+03
Temper. [K]	293
Step [ns]	0.1

E1, V/cm	5100
W1, cm	0.0052
Eb, V/cm	2100
Wb, cm	0.015
E2, V/cm	25202.041
W2, cm	0.0098

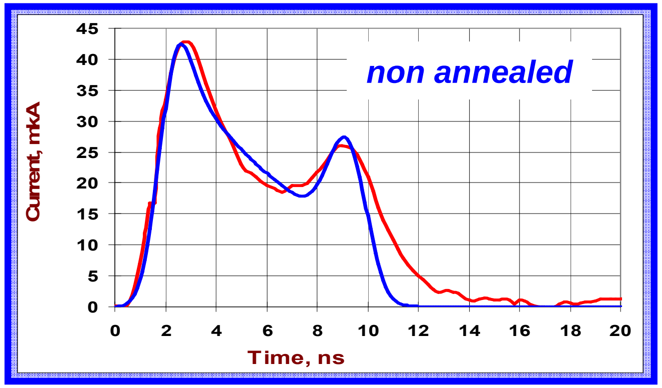
V. Eremin, RD50, October 06

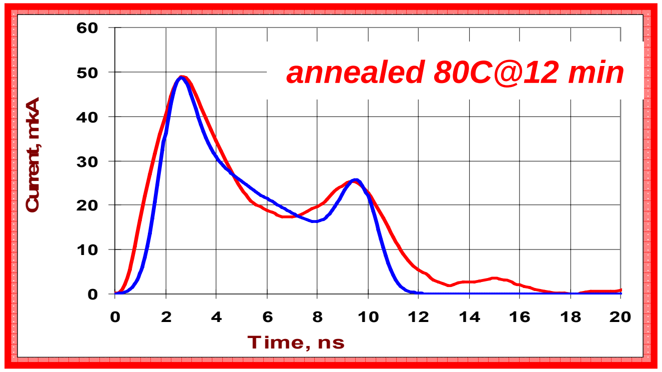
Annealing effect in silicon MCZ detectors

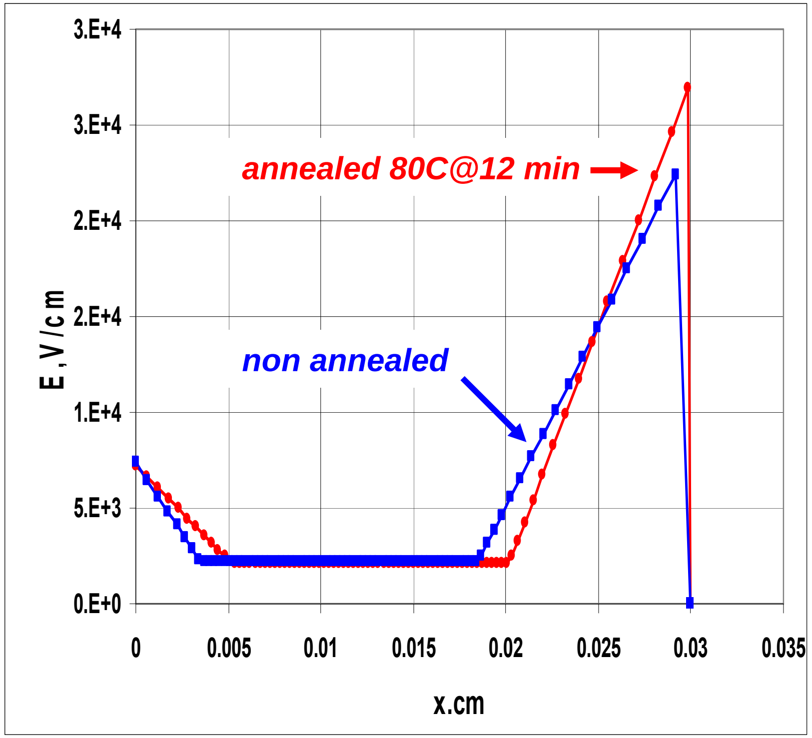
MCZ, 300um
Proton irradiated: 26 MeV, 4.2 E14 cm-2
W187-SMG-9: non annealed
W187-SMG-2: annealed 80C@12 min

Operational parameters:
V = 184 V
T = 293K

Extracted values
Tau tr = 6 ns
*Vfd = **180V***







Sample parameters	
d [cm]	3.00E-02
Uc[V]	0
Neff [1/cm^3	0.00E+00
tau(e), [s]	6.00E-09
tau(h), [s]	5.00E-09
TCT mode	
n[cm-1]	-2.80E+06
Ub [V]	184
a [1/cm]	5.64E+03
Temper. [K]	293
Step [ns]	0.1

Calculated values	
E1, V/cm	5200
W1, cm	0.0035
Eb, V/cm	2200
Wb, cm	0.015
E2, V/cm	21808.696
W2, cm	0.0115

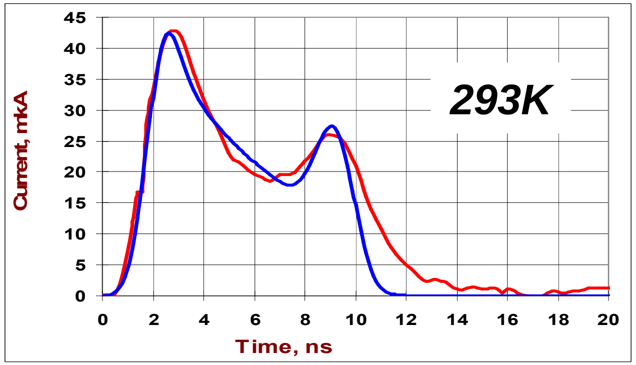
V, Eremin … , PTI, RD50, Oct. 2006

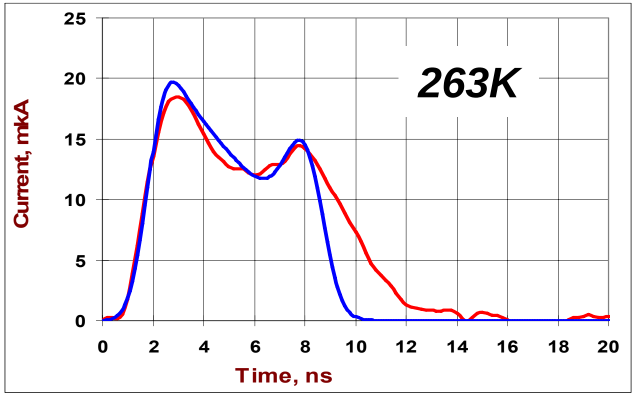
Effect of MCZ detectors cooling

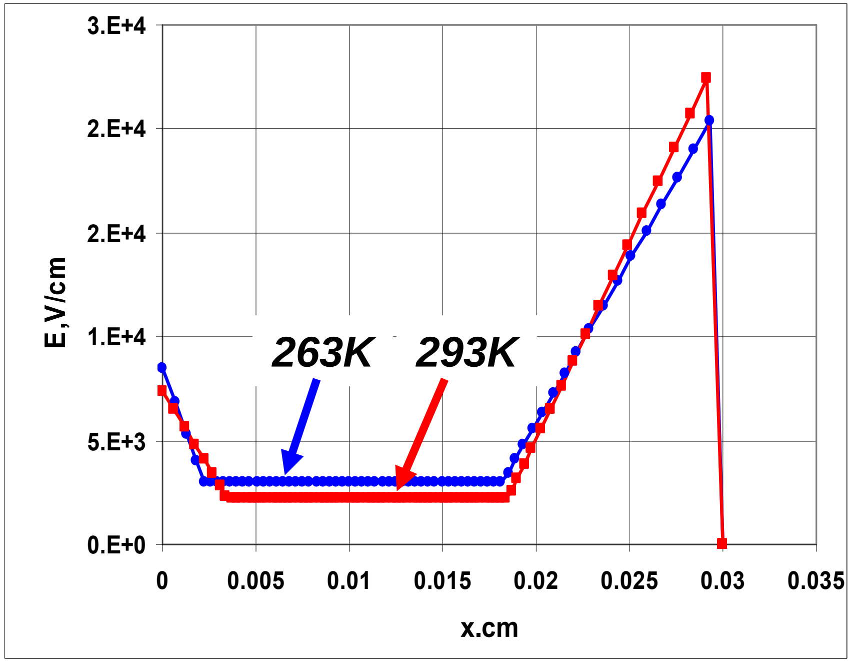
Detector W187-SMG-9
MCZ, 300um
Proton irradiated: 26 MeV, Feg = 4.2 E14 cm-2
Annealing: no

Operational parameters:
V = 184 V

Extracted values
Tau tr = 6 ns
*Vfd = **180V***







Sample parameters	
d [cm]	3.00E-02
Uc[V]	0
Neff [1/cm^3	0.00E+00
tau(e), [s]	6.00E-09
tau(h), [s]	5.00E-09
TCT mode	
n[cm-1]	-2.80E+06
Ub [V]	184
a [1/cm]	5.64E+03
Temper. [K]	293
Step [ns]	0.1

Calculated values	
E1, V/cm	5200
W1, cm	0.0035
Eb, V/cm	2200
Wb, cm	0.015
E2, V/cm	21808.696
W2, cm	0.0115

V, Eremin … , PTI, RD50, Oct. 2006

Conclusions

1. The current response of MCZ and epi- silicon based detectors is can be explained in the frame of double peak electric field distribution model with “active” electricaly neutral bias region.

2. Epi- detectors exhibit the space charge sign inversion due to high irradiation fluence or reverse annealing with high resistivity base

3. The SCSI is observed for MCZ and epi- based detectors at Feq > 4.5e14cm-3

4. The SCSI is stimulated by the long term annealing in MCZ and epi detectors

4. In MCZ based detectors the long term annealing leads to increase of the electric field at n+ contact and reduction at p+ contact.

5. The electric field in the base region is insensitive to the annealing.

3. The detector cooling redistributes the electric field with a trend of its better uniformity:

the electric field at the detector contacts reduces

the field in the thickness of neutral base slightly incre