Thermal donors in MCz-Si n- and p-type Detectors at different process temperature, irradiation and thermal treatments

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Magnetic Czochralski Si diodes

Producer	Manufacturer	wafer	name	diode	maxT	min @ 430C	process	fluence
Okmetic	IRST	91		p+/n/n+	380	0	0	0
Okmetic	IRST	160		p+/n/n+	380	0	TD killing	0
Okmetic	IRST	164		p+/n/n+	380	0	0	4,00E+14
Okmetic	IRST	364		p+/n/n+	430	?	0	0
Okmetic	IRST	66		n+/p/p+	380	?	low p-spray	0
Okmetic	IRST	182		n+/p/p+	380	?	?	4,00E+14
Okmetic	Helsinki	?	p6	n+/p/p+	380	0		0
Okmetic	Helsinki	p330	p7	p+/p/n+	430	120		0
Okmetic	Helsinki	p330	p57	p+/p/n+	430	120		0
Okmetic	Helsinki	p330	p…	p+/p/n+	430	10		0

(yellow)	studied up to now at Florence
(white)	to be measured

1. TD activation by Thermal Treatment

Thermal treatment after process

- MCz-Si few kΩcm (Okmetic)
- 430°C up to 120min
- $p^+/p/n^+$ diodes Helsinki University
- in collaboration with J. Harkonen and Z. Li.

J. Harkonen et al. 4th RD50 Workshop, May, CERN;
M. Bruzzi et al. 5th RD50 Workshop, October, Florence .

2. TD activation during detector process

Contact sintering temperatures 380°C and no LTO

Standard (420°C and LTO)

MCz-Si few kΩcm (Okmetic)

$p^+/n/n^+$ diodes Helsinki University

SMART project (INFN italian network).

3. TD activation by irradiation ?

- MCz-Si few kΩcm (Okmetic)
- 380°C and no LTO
- p-on-n and n-on-p diodes IRST
- Irradiation at CERN 24GeV/c up to $4\text{x}10^{14}$ cm^{-2}
- SMART project INFN

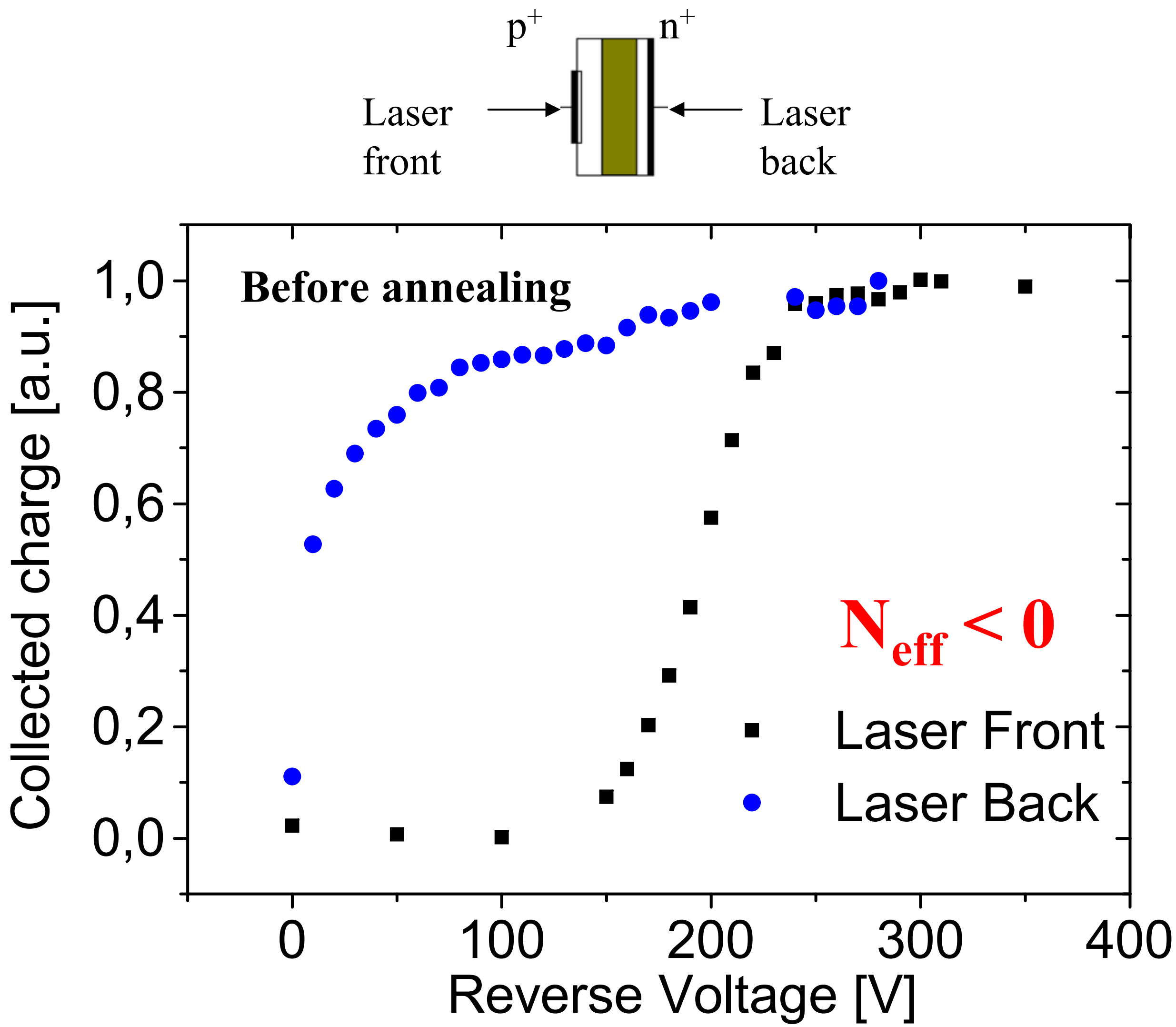
1. TD by Thermal treatment – Helsinki diodes

- Six $p^+/p/n^+$ diodes (active area 0.25cm^2, thickness 300µm) manufactured on p-type Cz Si Okmetic wafers (nominal resistivity 5kΩcm) at the Helsinki University of Technology, Finland .

- Devices studied at BNL by Transient Current Technique using a pulsed infrared laser (660nm) beam placed close either front or back electrodes. Collected charge measured in the range 0-400V, to determine full depletion voltage and sign of the effective space charge concentration N_{eff}.

- An isothermal annealing cycle has been performed at 430°C with different time interval from 45min to 120min. TCT has been measured before and after each annealing step.

Signal integrated in time, plotted against Vrev to determine the N_{eff} sign



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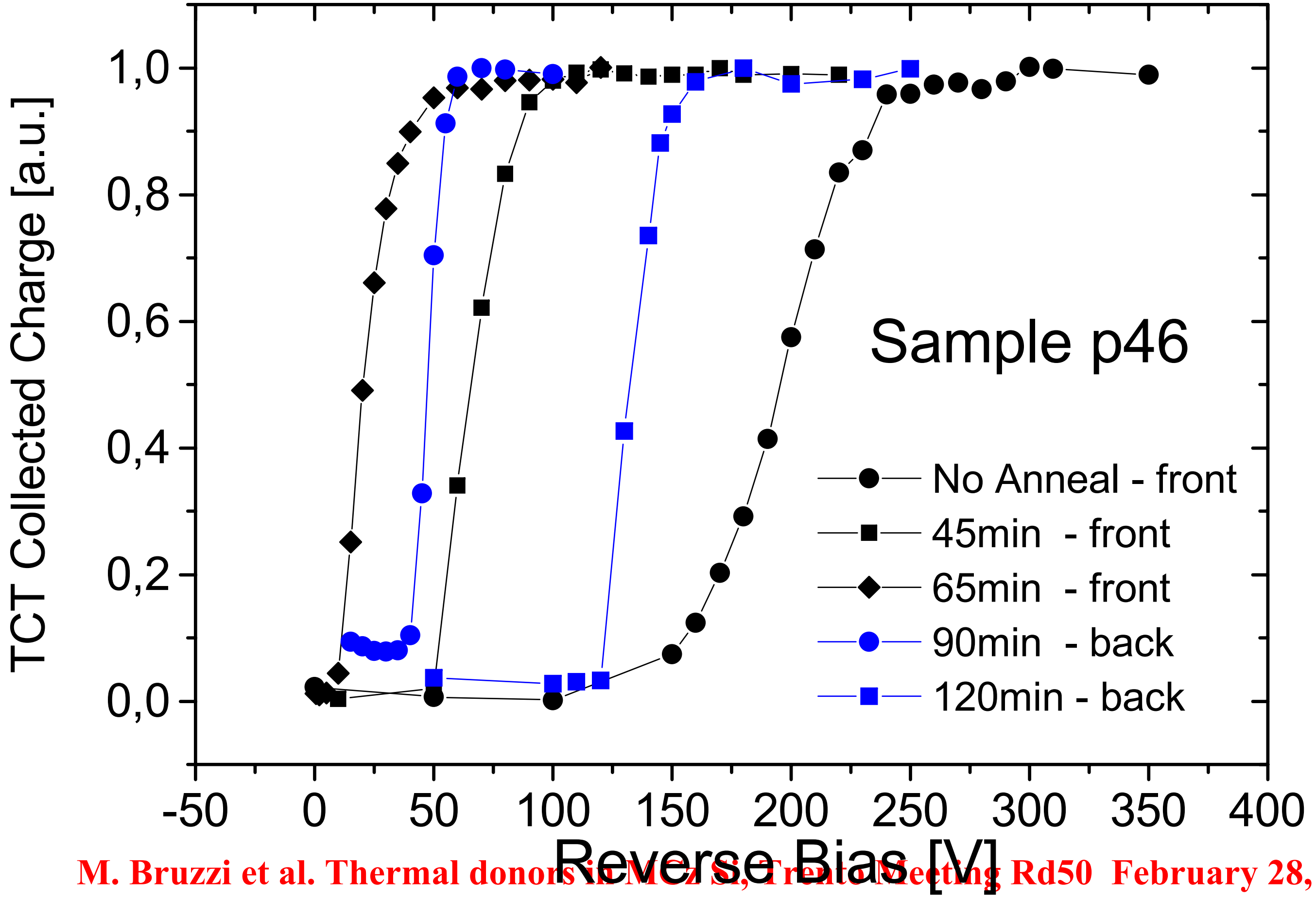
The TCT measurements are repeated for each diode after 5 different annealing steps (0-45-65-90-120min) at 430°C. Samples invert from p to n-type in between the two last annealing steps.

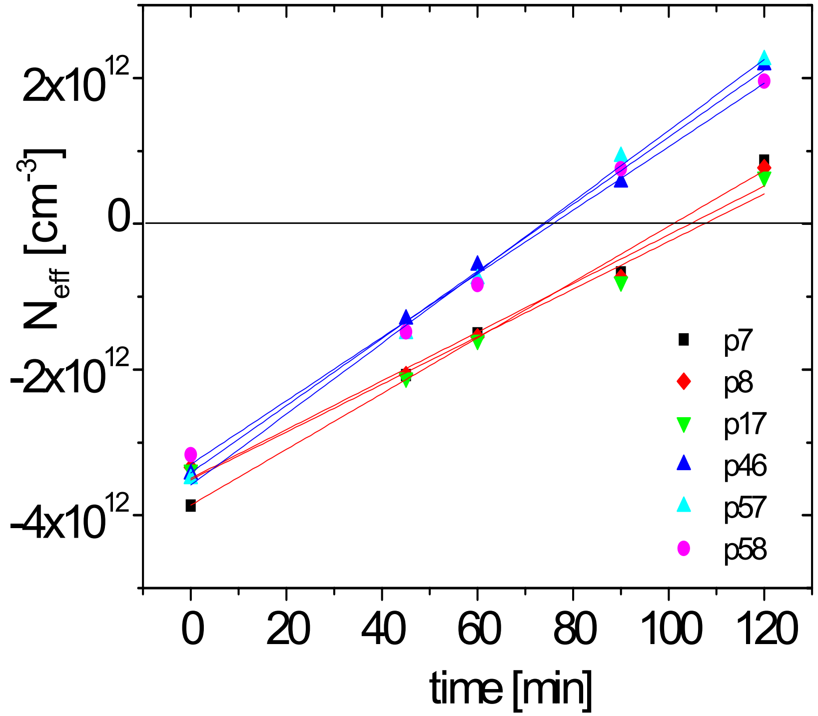


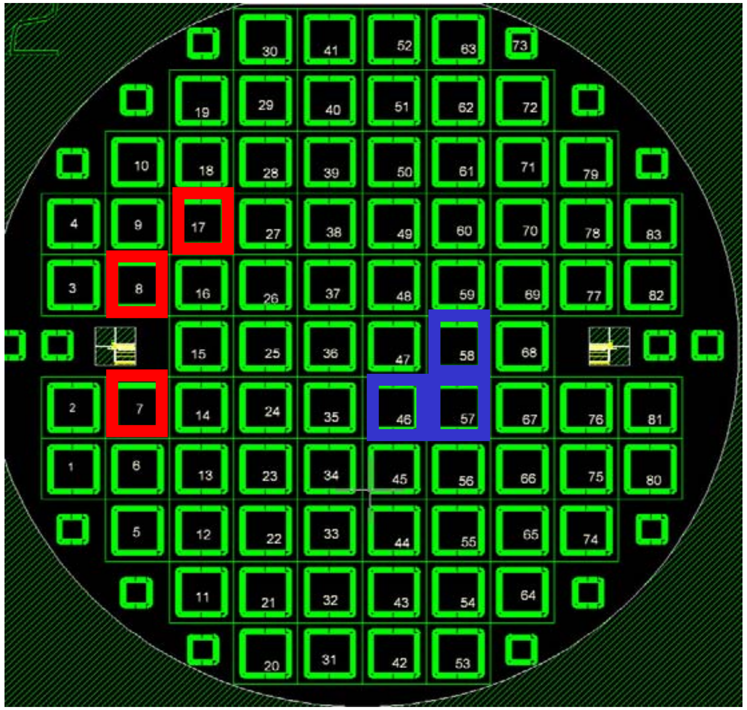
BULK:

P-type

N-type

The generation rate for N_{eff} is not correlated to the initial N_{eff} value, but depend on the position of the diode inside the wafer → O_i concentration or other impurity involved





Initial N_{eff} (red)/N_{eff} (blue) = 1.05

Final N_{eff} (red)/N_{eff} (blue) = 2.8

In the simple hypothesis:

$$N_{eff} = N_{eff}(0) + b(T) * t$$

b = (3.48 ± 0.30) x 10^{10} cm^{-3}/min

b = (4.61± 0.25) x 10^{10} cm^{-3}/min

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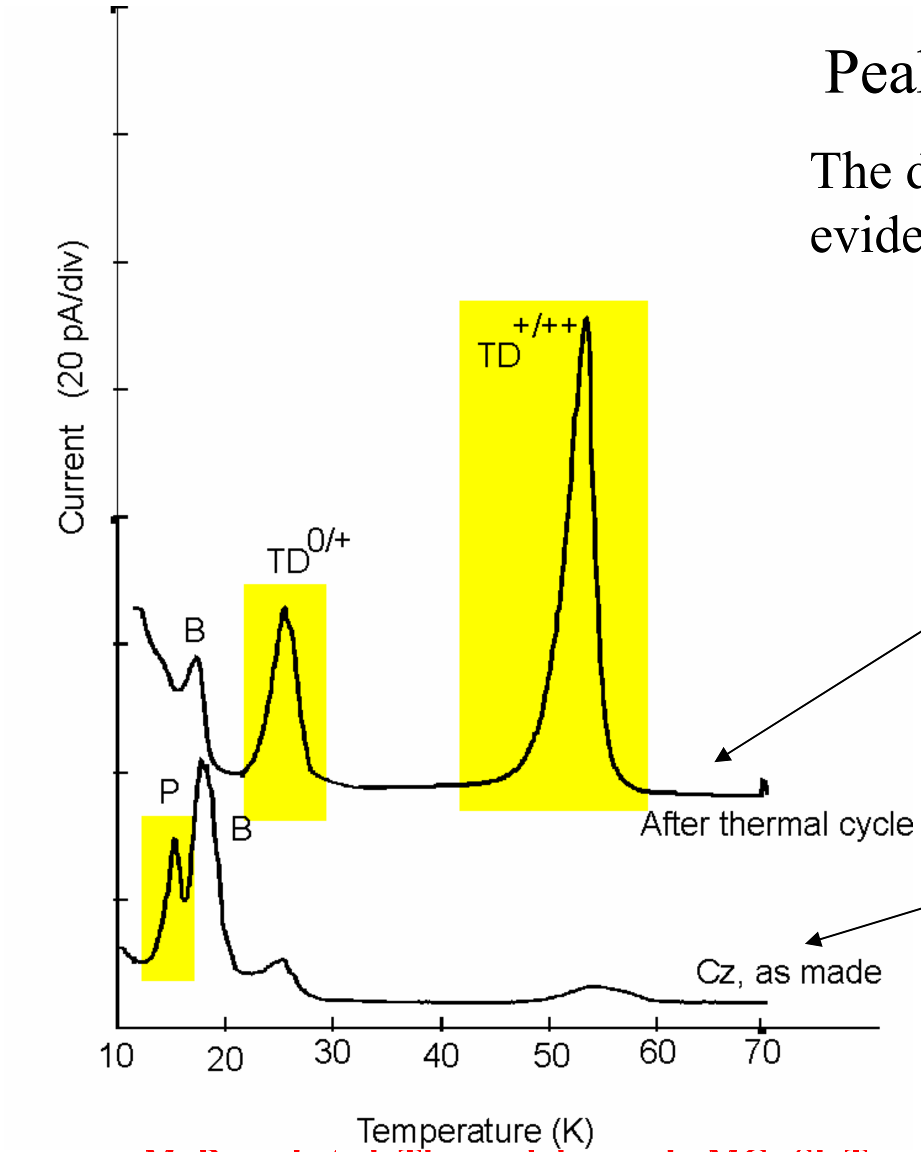
Comparison of TSC spectra before and after thermal treatment at 430°C



Peaks in yellow are donors

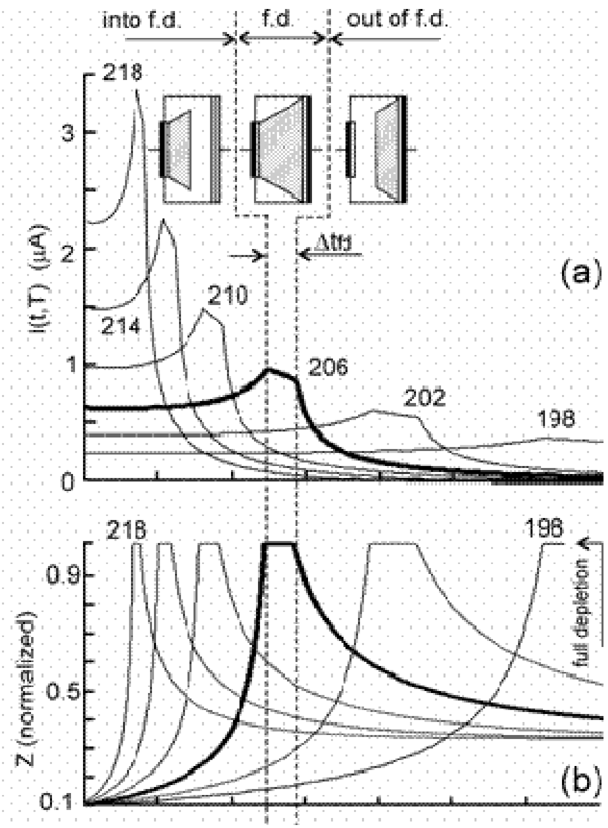
The donor-like behaviour was proved by evidence of Poole-Frenkel effect

Helsinki diodes $p^+/p/n^+$ after thermal treatment

before

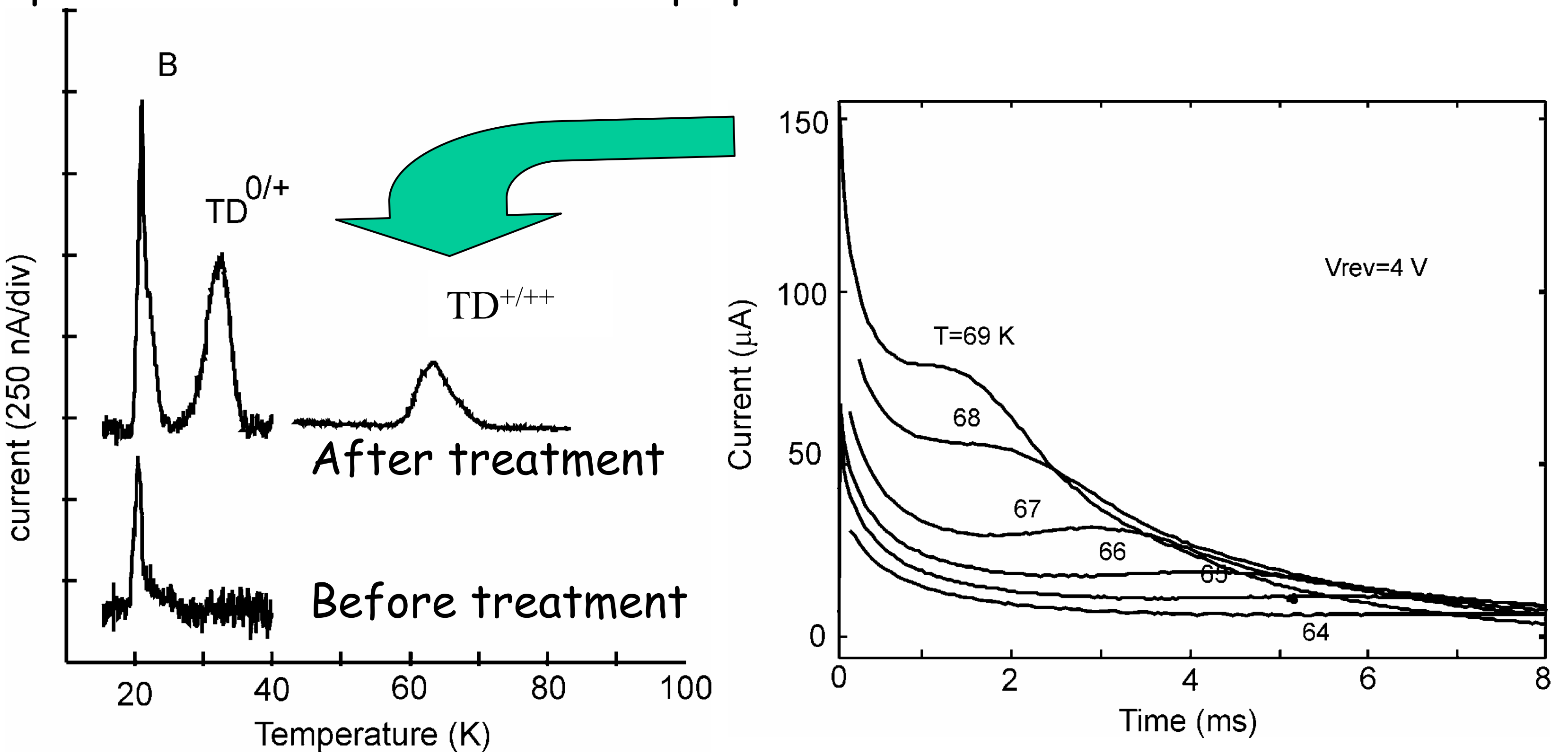
Evidence of type inversion by I-DLTS

Non monotonic transient of current in I-DLTS are due to changes of N_{eff} and type inversion of the space charge. The emission of carriers from a trap can produce the type inversion of the space charge. When this occurs, if $V_{rev} < V_{fd}$, during the thermal scan the active volume increases, reach the total volume and then decreases, causing a non-monotonic current transient. By measuring the temperature at which the current maximum is observed it is possible to reveal which energy level is responsible of type inversion.



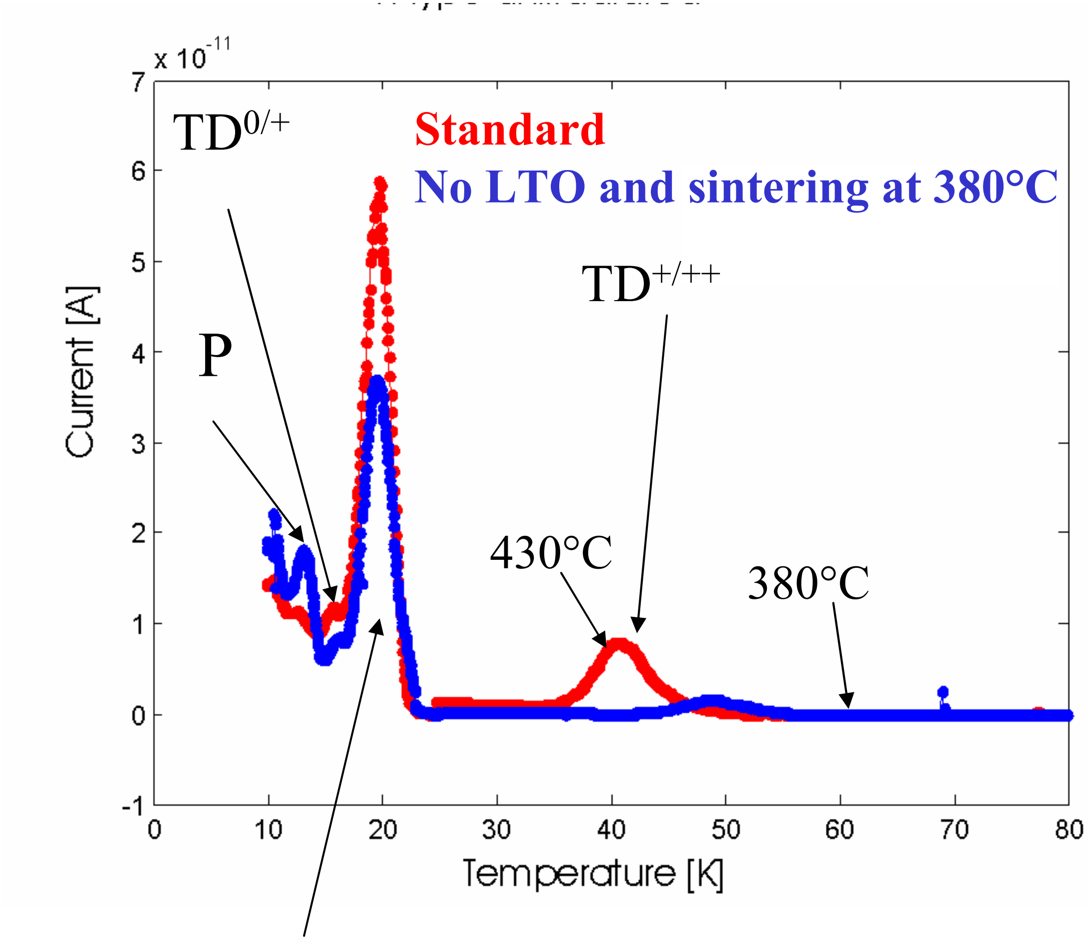
D. Menichelli et al. Phys. Rev. B (2004)

Experimental results – iDLTS on p+ p n+ Helsinki diode after 120min at 430°C



Before thermal treatment, current transients are monotonic. This means that the space charge, wich is settled by Boron, is not changing type. After 120min at 430C, the current transient presents a peak at T = 60K, in proximity of the emission of the $TD^{+/++}$. So it is demonstrated that $TD^{+/++}$ is responsible of the change of type of the space charge at this annealing stage.

2. TD by process treatment – IRST p-on-n diodes



Unknown level, no donor like behaviour

In standard process the TDs are activated, if T < 380°C the TDs are almost absent.
An unknown energy level at 20K is present, <u>which is not a donor</u>.

3. TD activation by irradiation

p-on-n IRST
no LTO and sintering at 380°C
24GeV/c p up to 4x10^{14}p/cm^2
annealing of 1260min at 60°C
Full depletion voltage 93V.

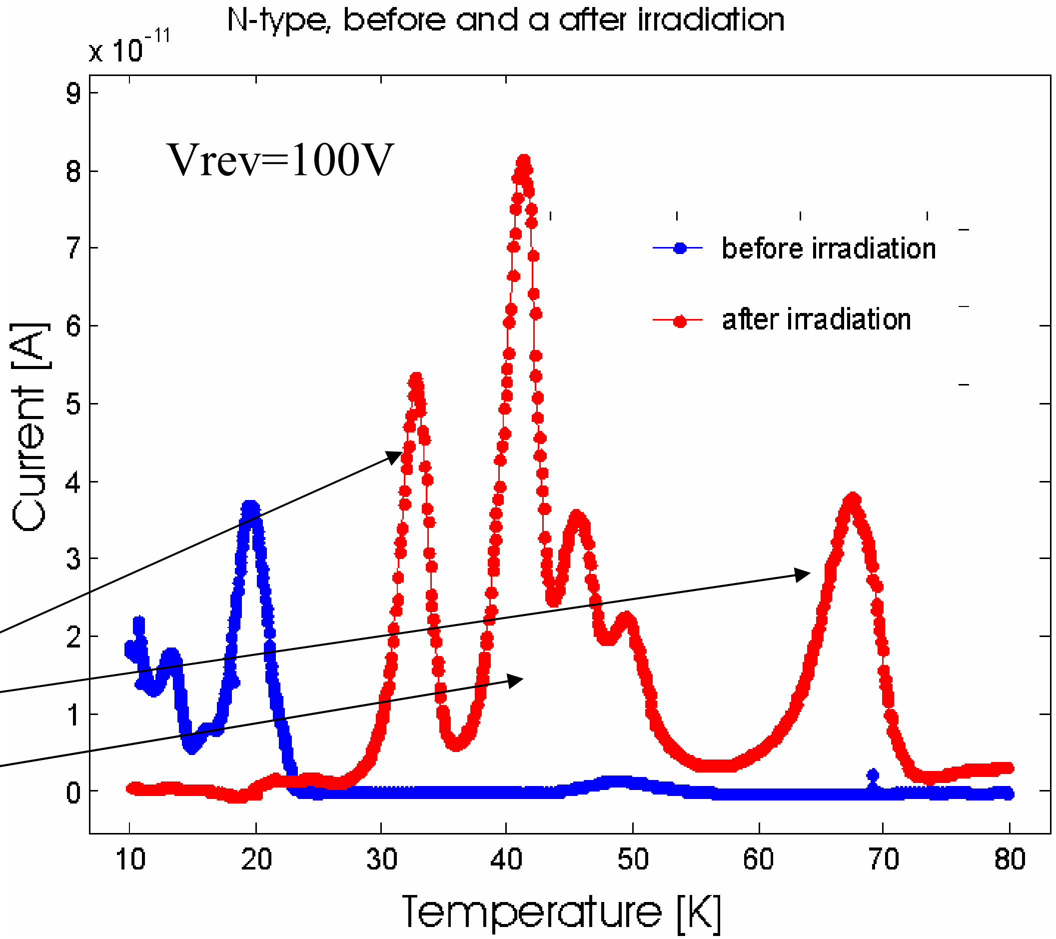
Main results

Removed : P and peak at 20K

Formed: peak at 30K – donor

CiCs – VO

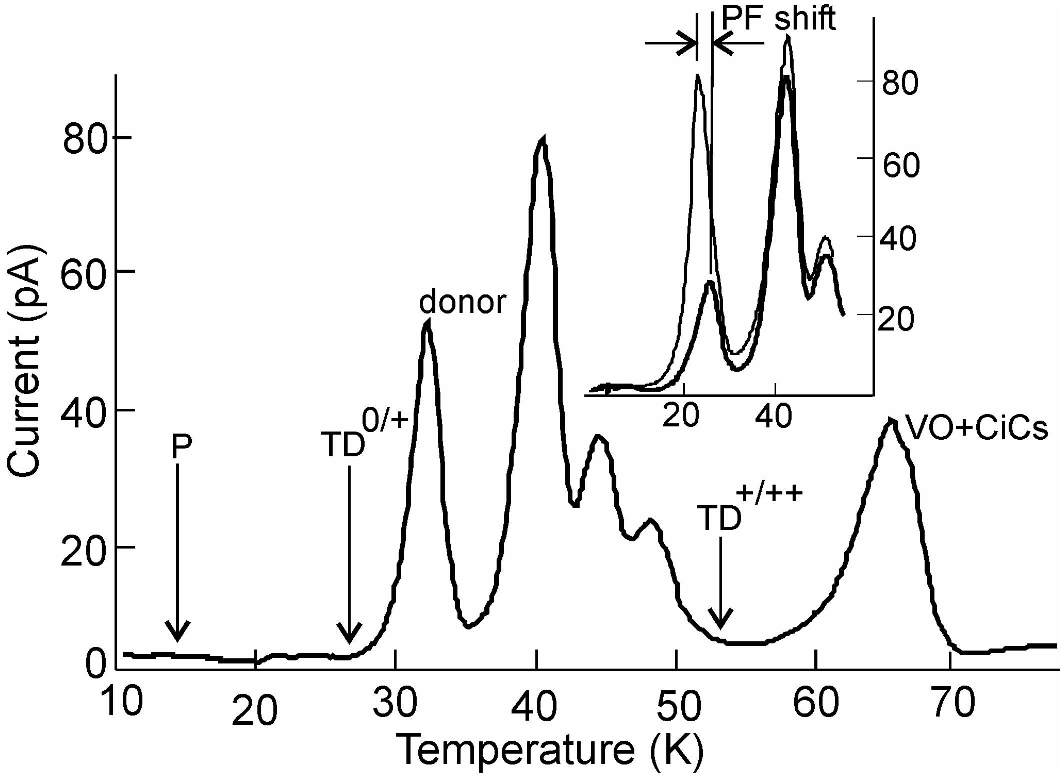
group at 40-50K



No evidence of TD activation after irradiation

The radiation-induced peak at 30K is a donor (not a TD)

Shallow TSC peaks observed in a MCZ Si diode after irradiation with a 24GeV proton irradiation up to $4x10^{14}$ cm^{-2}. In the inset, the Pool-Frenkel shift observed on peak at 30K when the applied voltage is 100V (black line) and 200V (light line) is shown. This effect evidences the donor-like nature of the related energy level.



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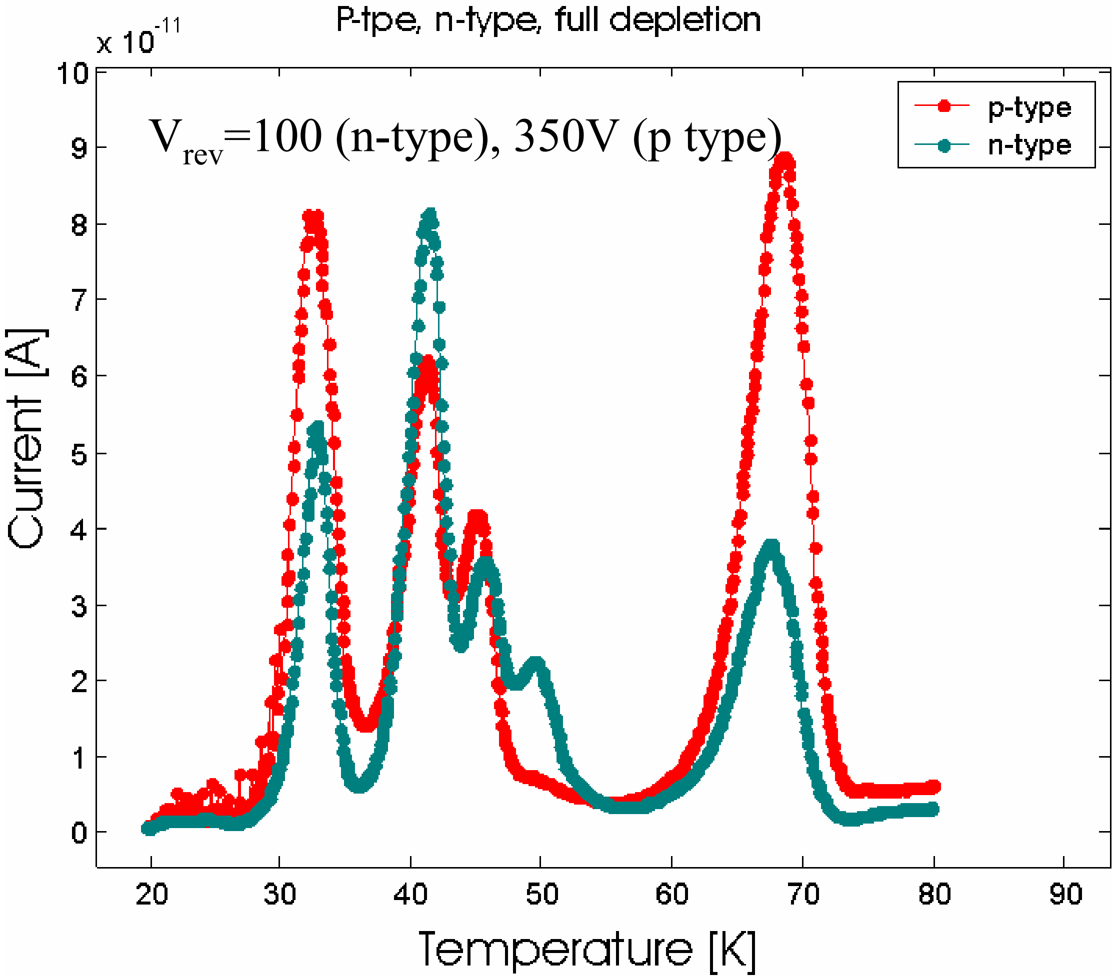
Comparison p- and n-type MCZ after irradiation

n-on-p IRST
p-spray dose of $5x10^{12}cm^{-2}$
24GeV/c p up to $4x10^{14}p/cm^2$
annealing of 180min at 80°C
Full depletion voltage 337V.

Main results:

Same peaks formed
Lower 50K peak IO_2?



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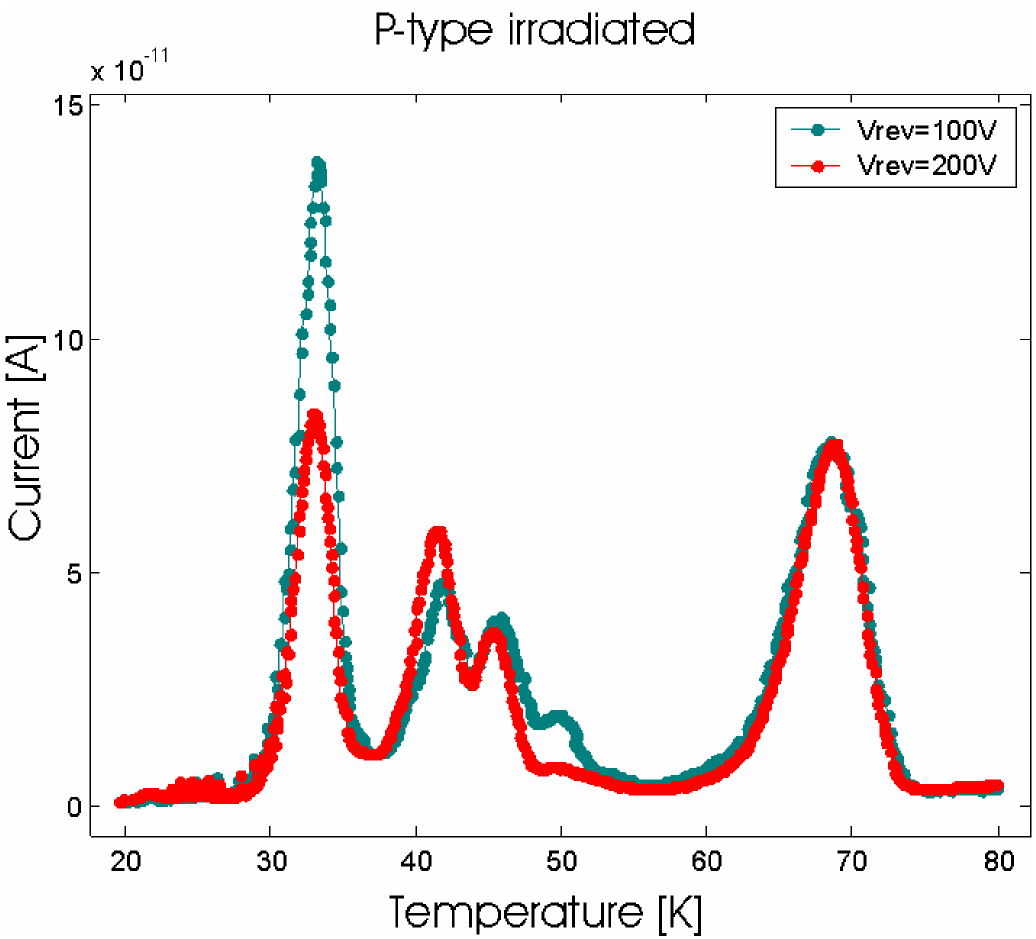
In the low T range peak heights change if $V_{rev} < V_{fd}$: non uniformity?
50K peak IO_2 more visible at low voltage



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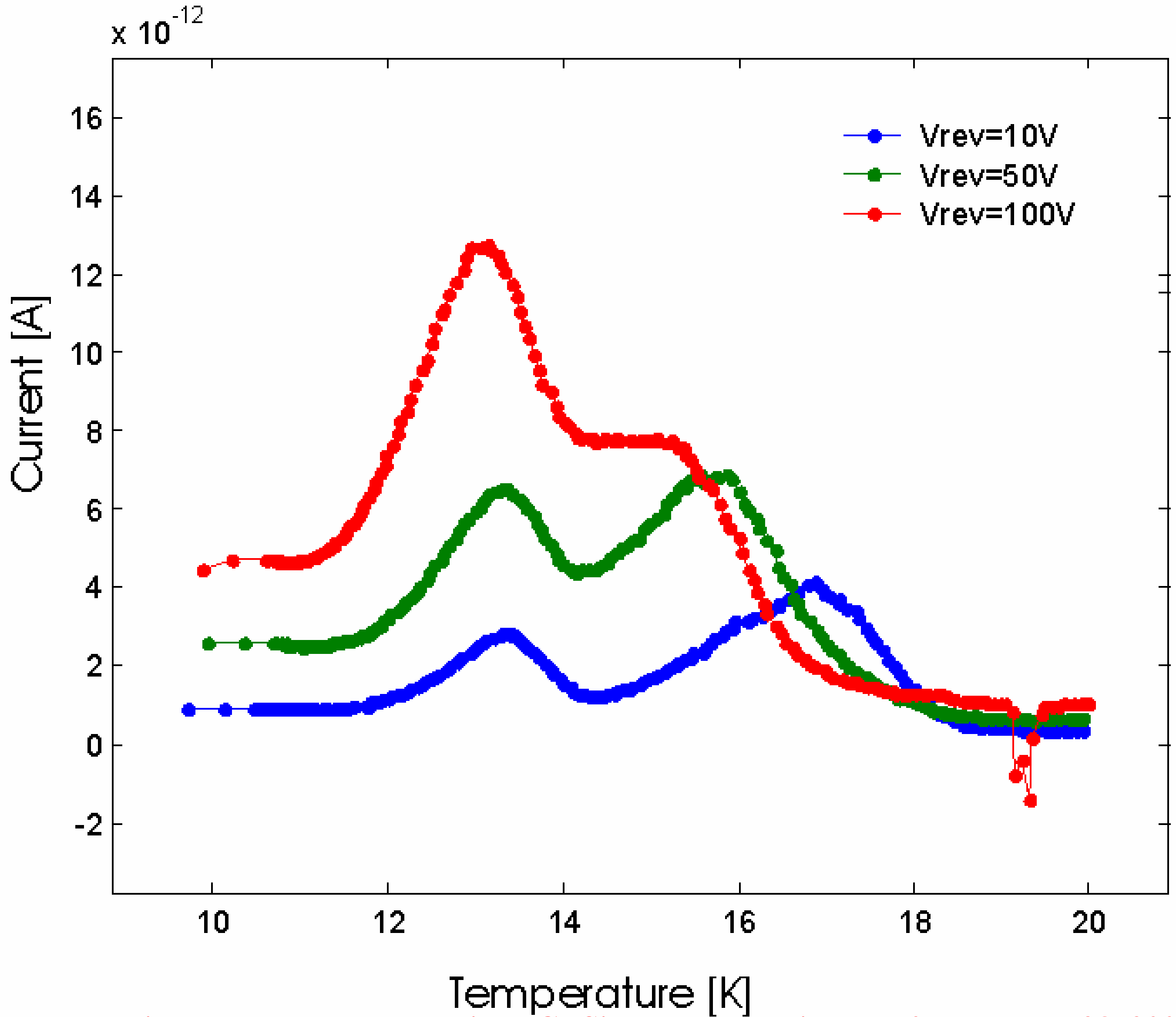
p-type: B dopant still present after irradiation



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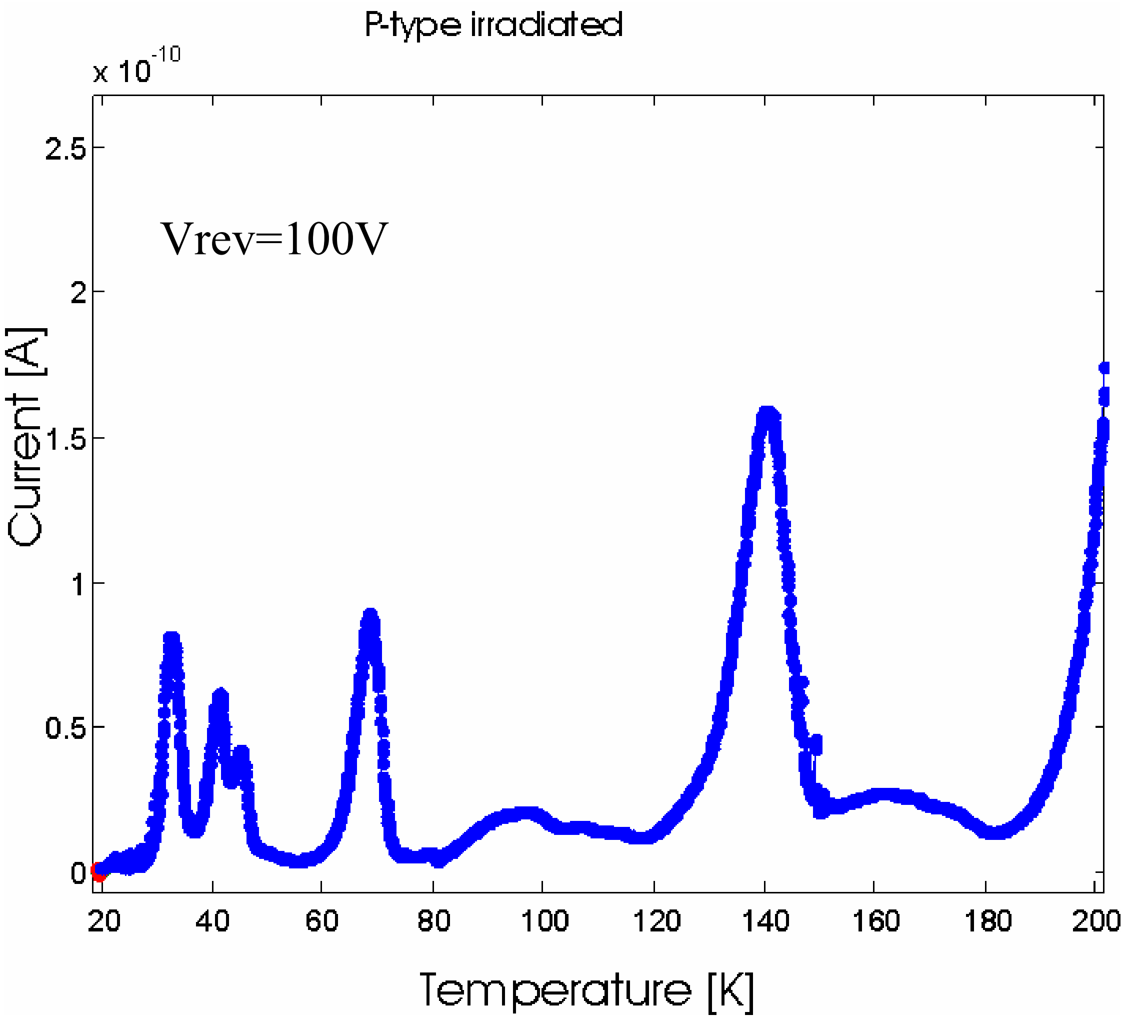
In the high T range , TSC peaks similar to n-type



Conclusions

- Thermal Donors can be activated by thermal treatment at 430°C, they compensate B dopant in p-type MCz Si and provoke type inversion.

- A process at 380°C and no LTO is sufficient to keep TDs within negligible amounts

- Irradiation does not activate thermal donors. A shallow donor level at 30K is produced by irradiation both in p-type and n-type MCz Si.

- while in n-type Si P is removed, B is not removed in p-type !

- Other defects as C_iC_s, VO, V_2 C_iO_i are produced in p- and n-type MCz Si by irradiation.

- Evidence of type inversion in irradiated MCz Si can be obtained by I-DLTS in the whole T range. Measurements are under way.