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

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In collaboration with

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# Samples

## Mainly 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 |

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

…plus a p+nn+ STFZ diode manifactured by IRST, Irradiated up to $3x10^{14}$ p/cm$^2$.

**The following investigations have been carried out**

**1. TD activation by Thermal Treatment**

Thermal treatment after processing in $p^+/p/n^+$ diodes

- MCz-Si few kWcm (Okmetic)
- 430°C up to 120min

See also: 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 at 380°C without LTO vs. standard 420°C with LTO
MCz-Si few kWcm (Okmetic) p+/n/n+ diodes

**3. TD activation by irradiation**

STFZ and MCz-Si few kWcm (380°C without LTO)
Irradiation at CERN 24GeV/c up to $4x10^{14}$ $cm^{-2}$

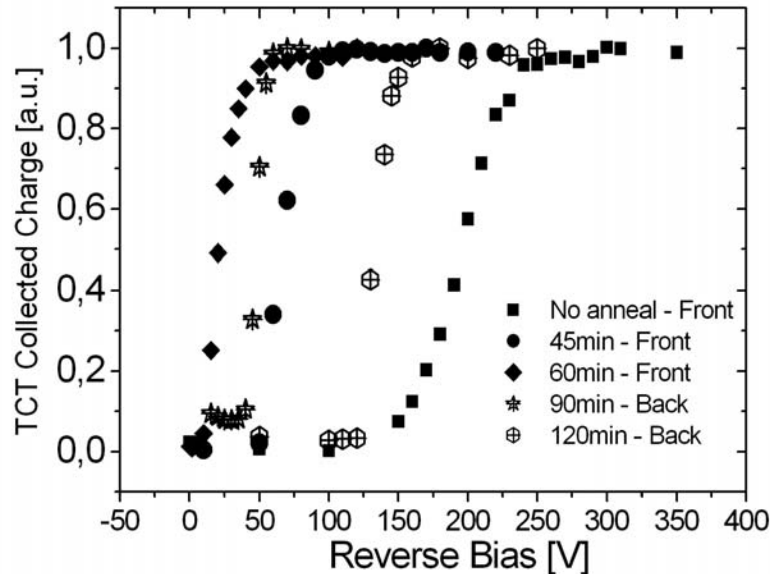
# 1. TD by Thermal treatment – Helsinki diodes

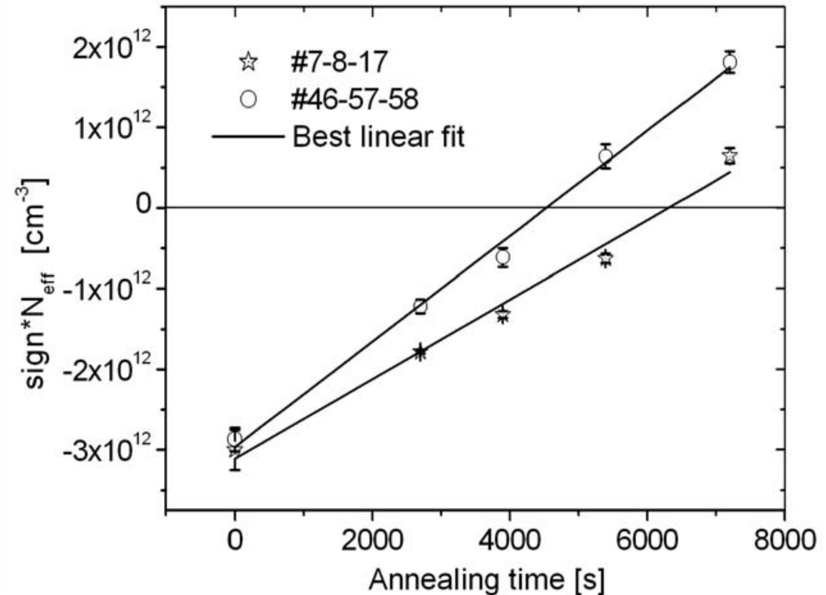
- Six $p^+/p/n^+$ diodes (0.25cm$^2$, 300mm) manufactured on p-type Cz Si Okmetic wafers at the Helsinki University of Technology, Finland.

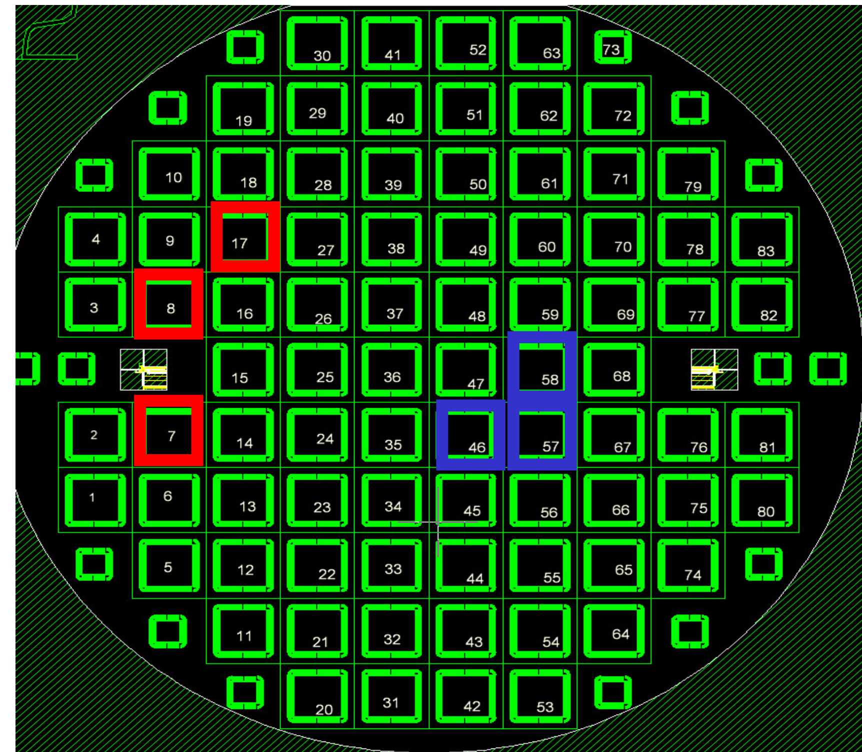
- Devices studied at BNL by TCT using a pulsed infrared laser (660nm). Collected charge measured in the range 0-400V, to determine full depletion voltage and sign of $N_{eff}$.

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

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.





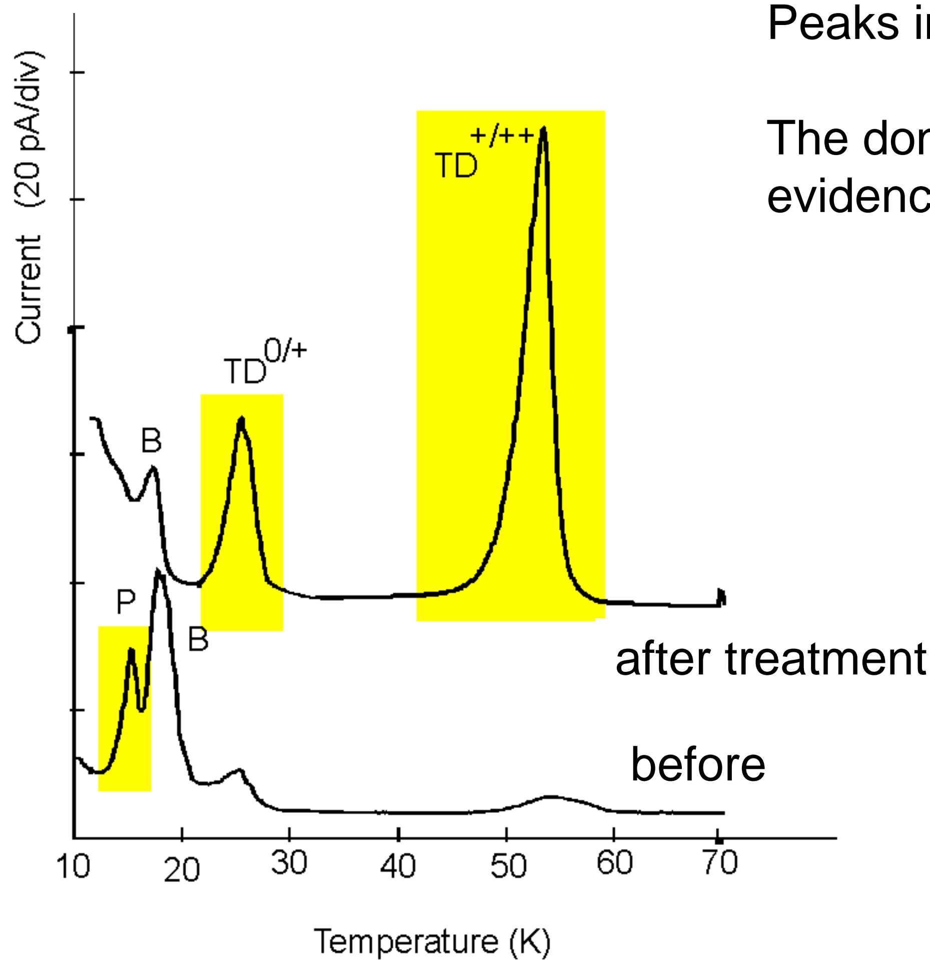

The generation rate for $N_{eff}$ is not correlated to the initial $N_{eff}$ value, but depend on the position of the diode inside the wafer → $O_i$ concentration or other impurity involved. In the simple hypothesis:

$$Neff = Neff(0) + b(T) \cdot t$$

**b = ( 3.5 ± 0.3) ·$10^{10}$ cm$^{-3}$/min**

**b = ( 4.6± 0.3) · $10^{10}$ cm$^{-3}$/min**

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




Peaks in yellow are **donors**

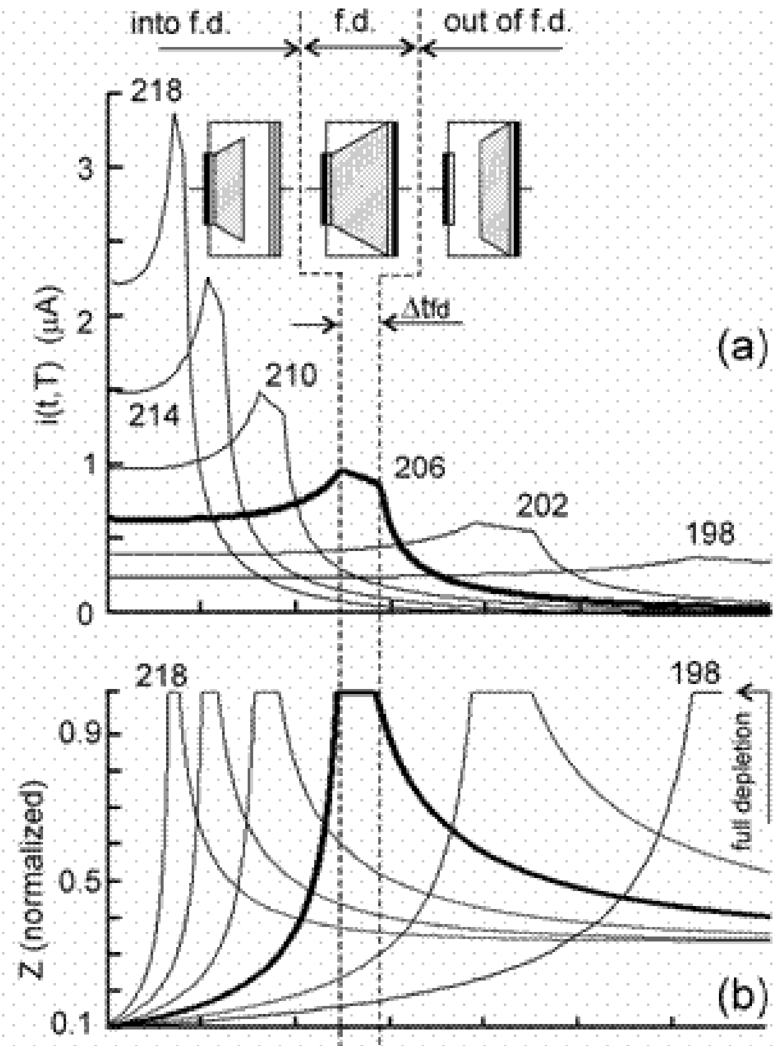
The donor-like behaviour was proved by evidence of Poole-Frenkel effect

# Evidence of type inversion by I-DLTS

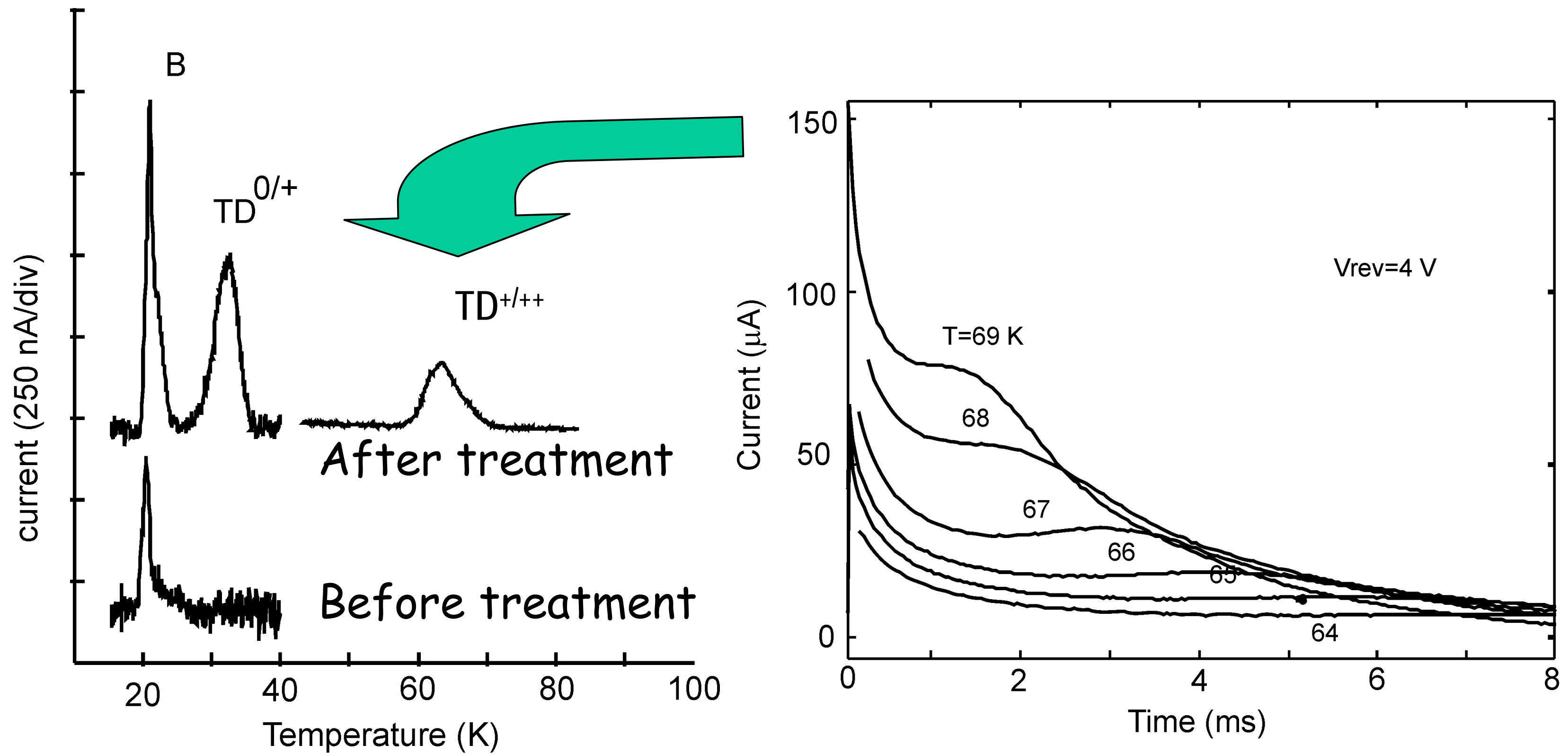
Non monotonic transient of current in I-DLTS are due to changes of $N_{eff}$ and SCSI. When SCSI occurs, if $V_{rev} < V_{fd}$ , the active volume increases, reach the total volume and then decreases, producing a non-monotonic current transient.

By measuring the temperature at which this effect is observed it is possible to reveal which energy level is responsible of SCSI.

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

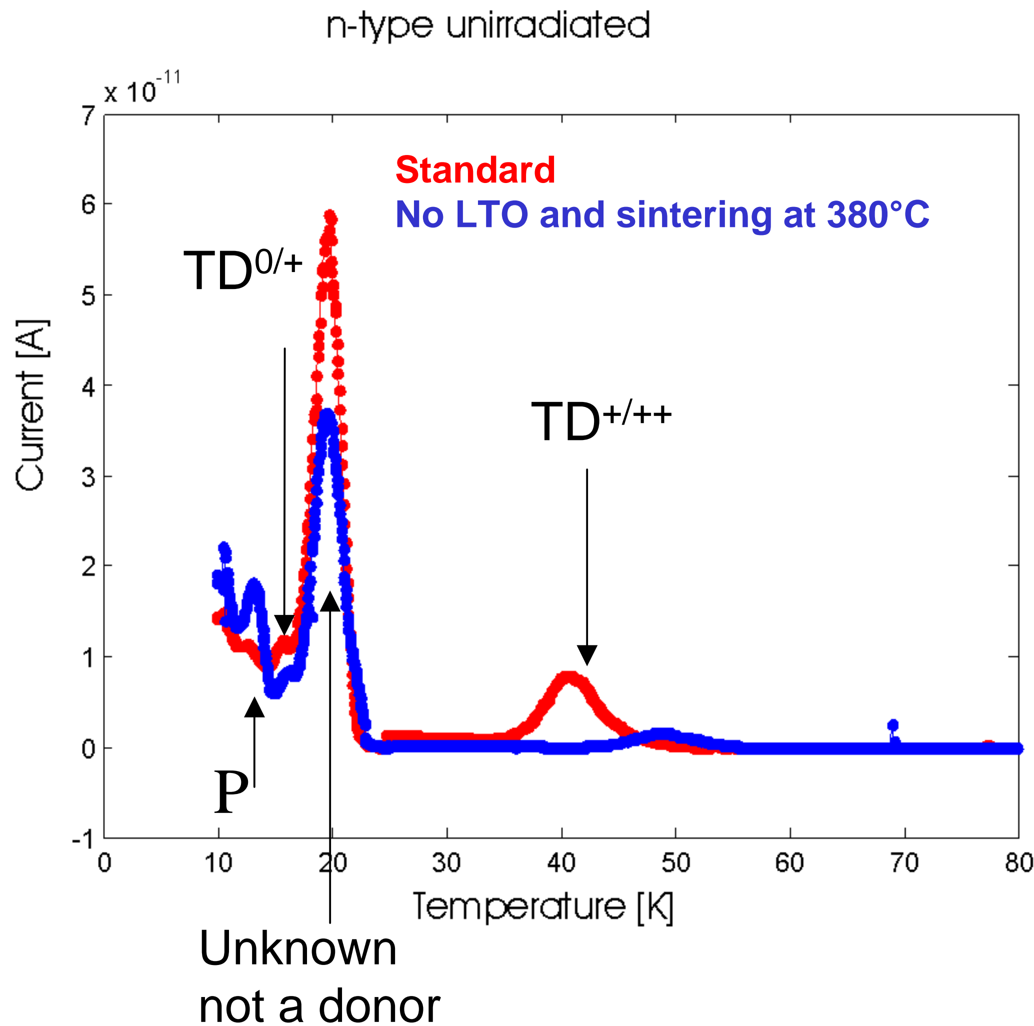


# iDLTS on p+ p n+ Helsinki diode after 120min at 430°C




Before thermal treatment, current transients at constant temperature are monotonic, i.e. the space charge sign, wich is settled by Boron, is not changing. After 120min at 430 °C, the current transient become non monotonic close to T = 60 K. It follows that $TD^{+/++}$ is responsible of the SCSI at this annealing stage.

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




In standard process the TDs are activated at 420 °C; if T < 380°C the TDs are almost absent. An unknown energy level at 20K is present, <u>which is not a donor</u>.

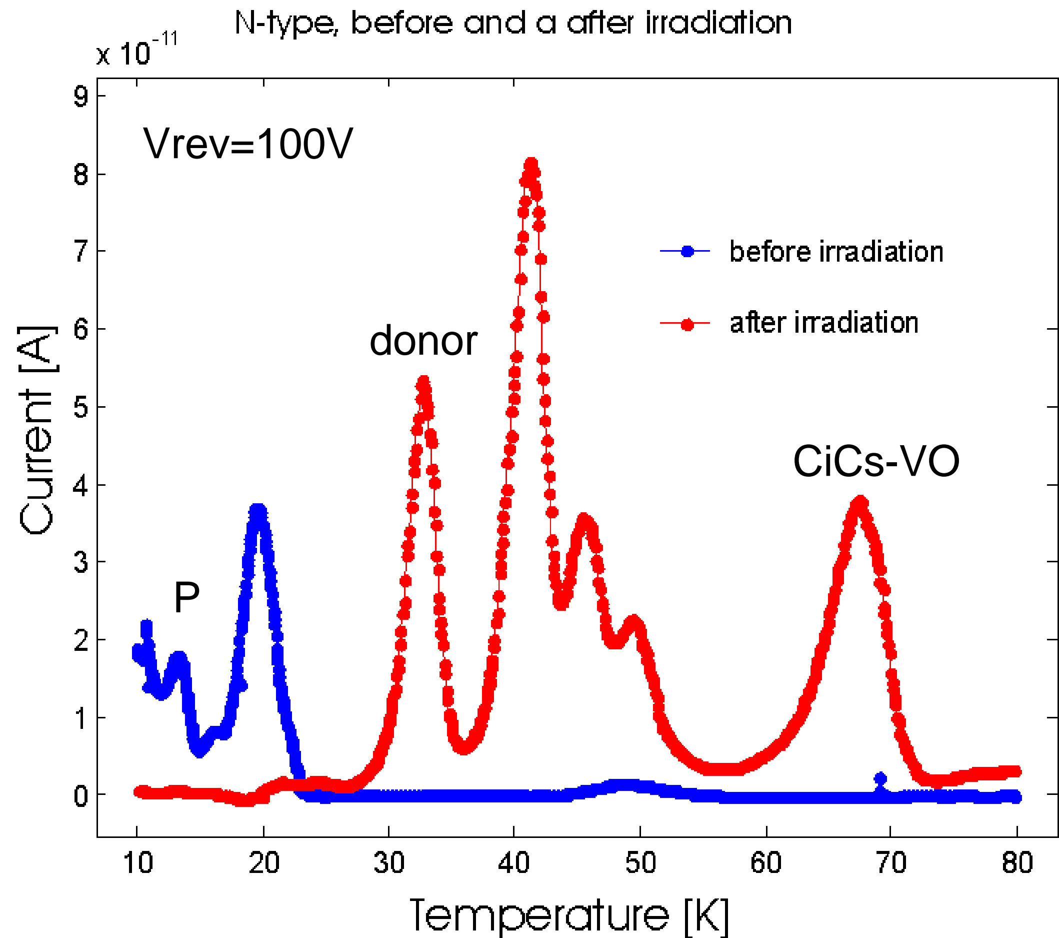
# 3. TD activation by irradiation

p-on-n IRST
**no LTO, sintering at 380°C**
24GeV/c p up to $4x10^{14}p/cm^2$
Annealing: 1260min at 60°C
Full depletion at 93 V

**Removed** : P and 20 K peak

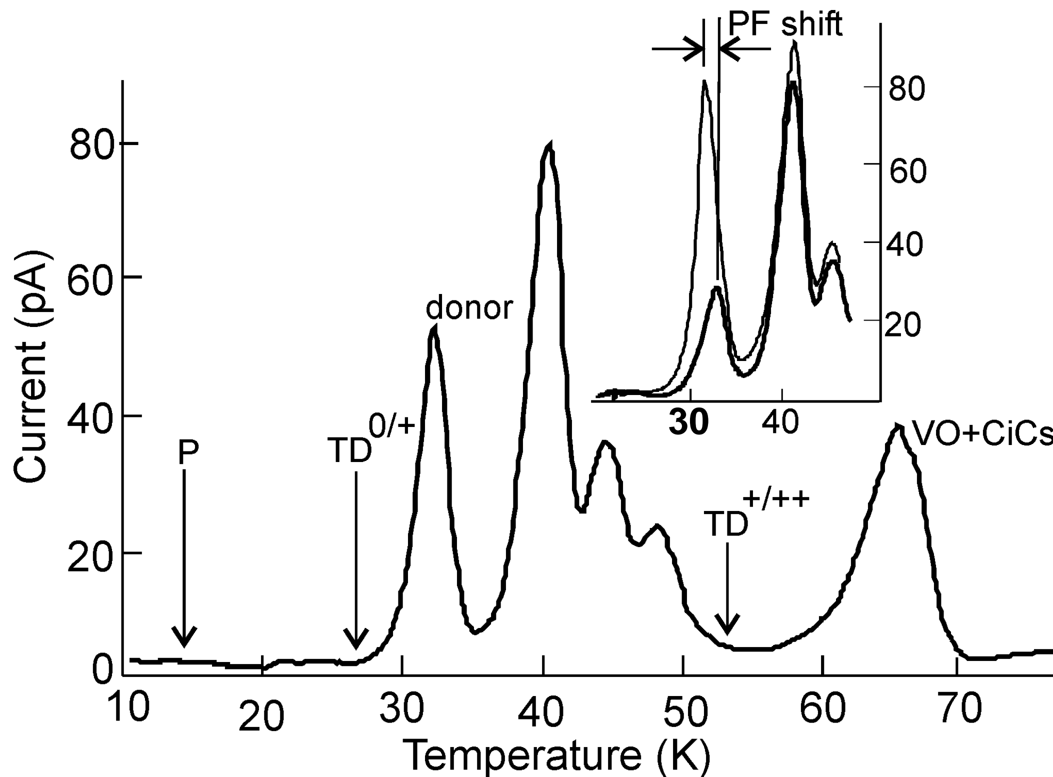
**Formed**:
30 K peak (donor)
CiCs–VO
40-50K peaks

**No evidence of TD activation after irradiation**



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

Shallow TSC peaks observed in a MCZ Si diode after irradiation with a 24 GeV proton irradiation up to $4x10^{14}$ $cm^{-2}$. In the inset, the Poole-Frenkel shift observed on peak at 30 K when the applied voltage is 100 V (thick line) and 200V ( light line) is shown.

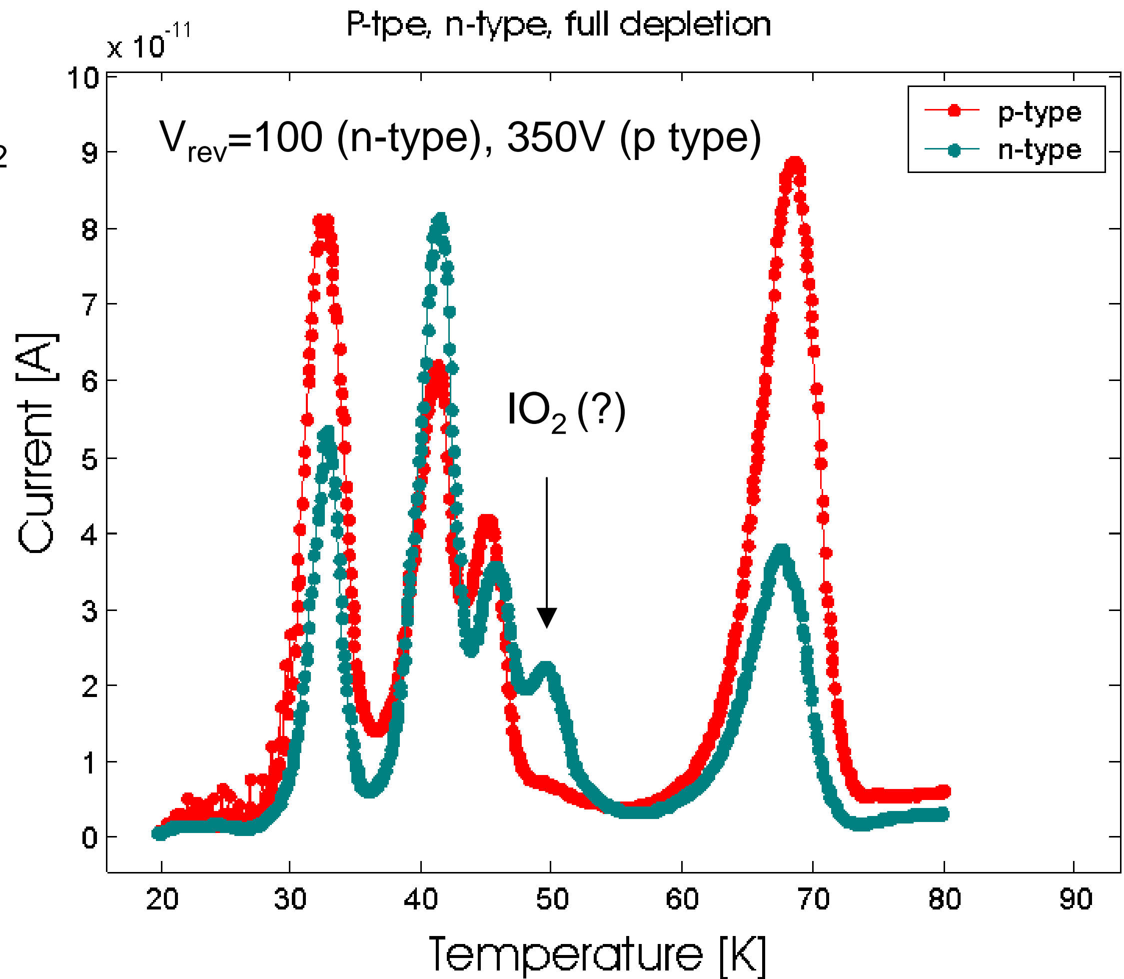



D. Menichelli,, Rd50 6th workshop, Helsinki, June 2-4 2005

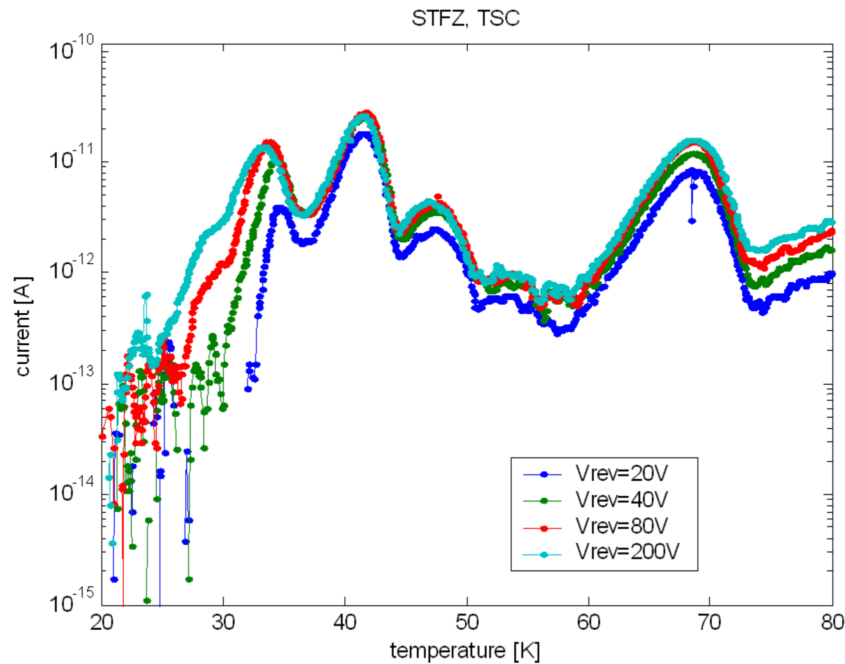
# Comparison p- and n-type MCZ after irradiation

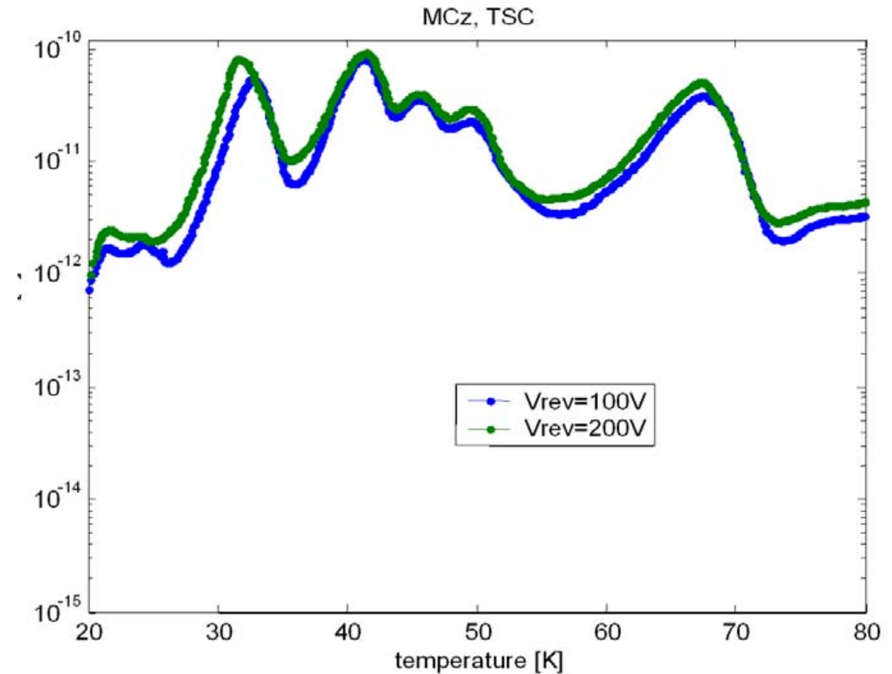
n-on-p IRST
p-spray dose of $5x10^{12}cm^{-2}$
24GeV/c p up to $4x10^{14}p/cm^2$
annealing of 180min at 80°C
Full depletion voltage 337V.

**Main results:** Same peaks are formed



# Comparison of TSC spectra for irradiated FZ and MCz Si




Proton irradiated: 24GeV p 3-4x$10^{14}$cm$^{-2}$

In FZ, donor close to 30K and VO have a concentration at least **five times** lower with respect to MCz Si.

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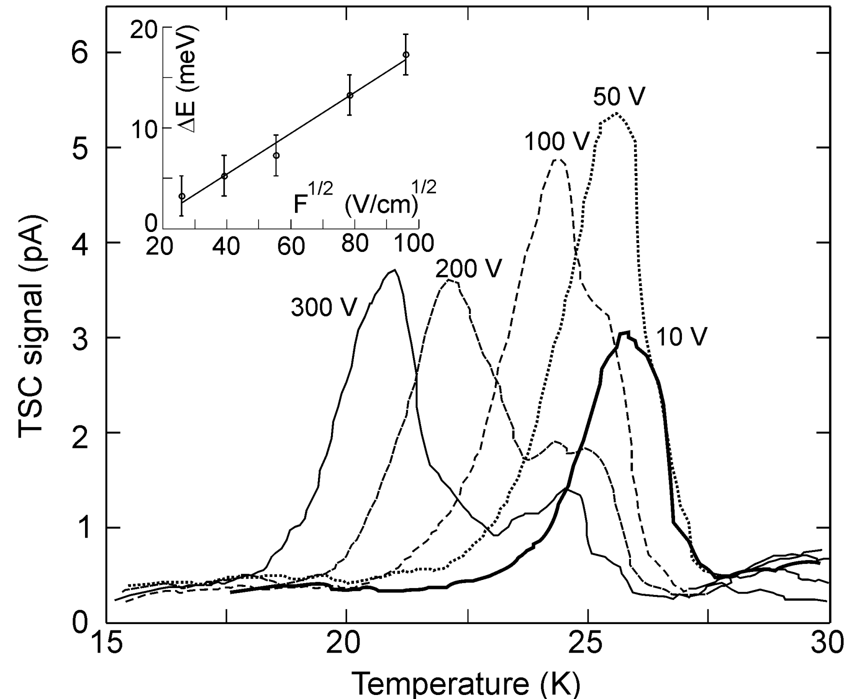
A donor has been observed also in STFZ after $\gamma$ irradiation at a slightly lower Temperature.

A hypothesis. The donor at 25 K produced by $\gamma$ and the donor at 30 K produced by protons may be due to the same defect.

The temperature shift may be due to the electric field around the defect, if it is and extended one.




TSC spectra of STFZ after 300 Mrad $\gamma$ from $^{60}$Co (sample from Hamburg).

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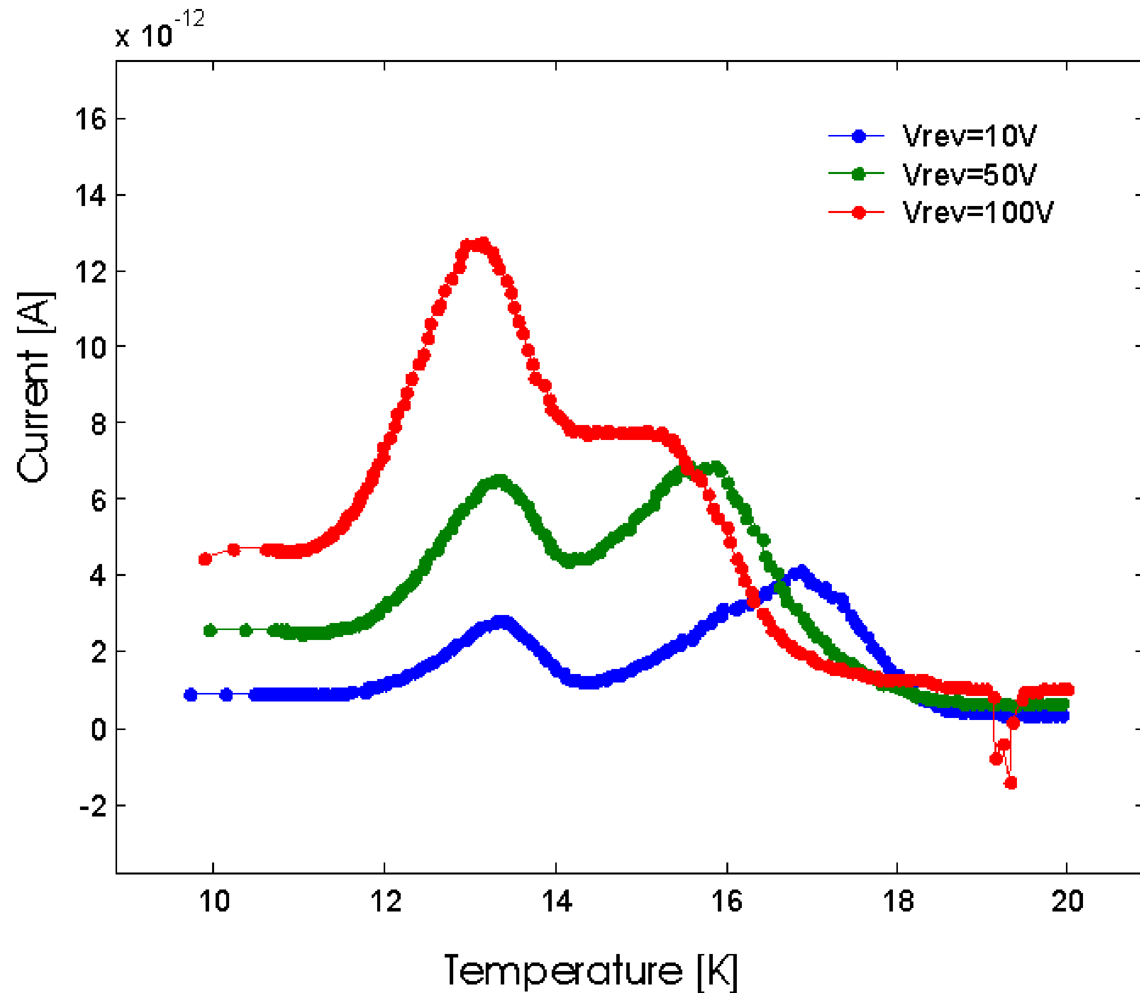
## p-type: B doping impurity is still present after irradiation

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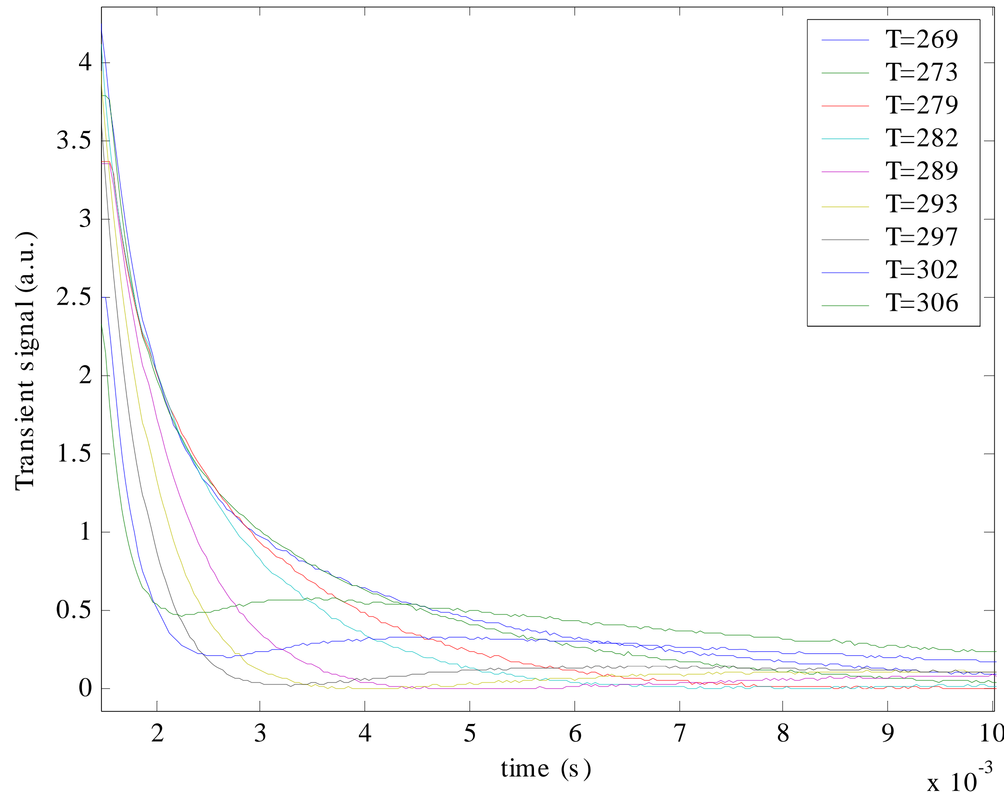
# SCSI detected by current transients measurement




In irradiated n-type STFZ, a -/+ SCSI takes place during $V_2^{-/0}$ discharge, and a new one ($I^{0/+}$) close to 300 K.

In irradiated n-type MCZ only sign inversion due to $V_2^{-/0}$ is observed.

# Conclusions

- Thermal Donors can be activated by thermal treatment at 430°C. They compensate B dopant in p-type MCz Si and provoke Space Charge Sign Inversion.

- A process at 380°C, without LTO, is sufficient to keep TDs within negligible amount.

- 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, as well as in STFZ. Comparison with gamma irradiated sample suggests that this may be an extended defect.

- After irradiation, inversion at 300 K due to $I^{0/-}$ is observed in STFZ, but not in n-type MCZ. This may be due to the different concentration in the shallow donor (30 K peak), which causes a space charge compensation.

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