

Thermal donor generation in Czochralski silicon particle detectors

M. Bruzzi¹⁾, J. Härkönen²⁾, Z. Li³⁾, P. Luukka²⁾, D. Menichelli¹⁾, E. Tuovinen¹⁾

¹⁾ University of Florence

²⁾ Helsinki Institute of Physics, CERN/PH, Switzerland

³⁾ Brookhaven National Laboratory, Upton, NY11973-5000, USA

In Framework of CERN RD50 Collaboration

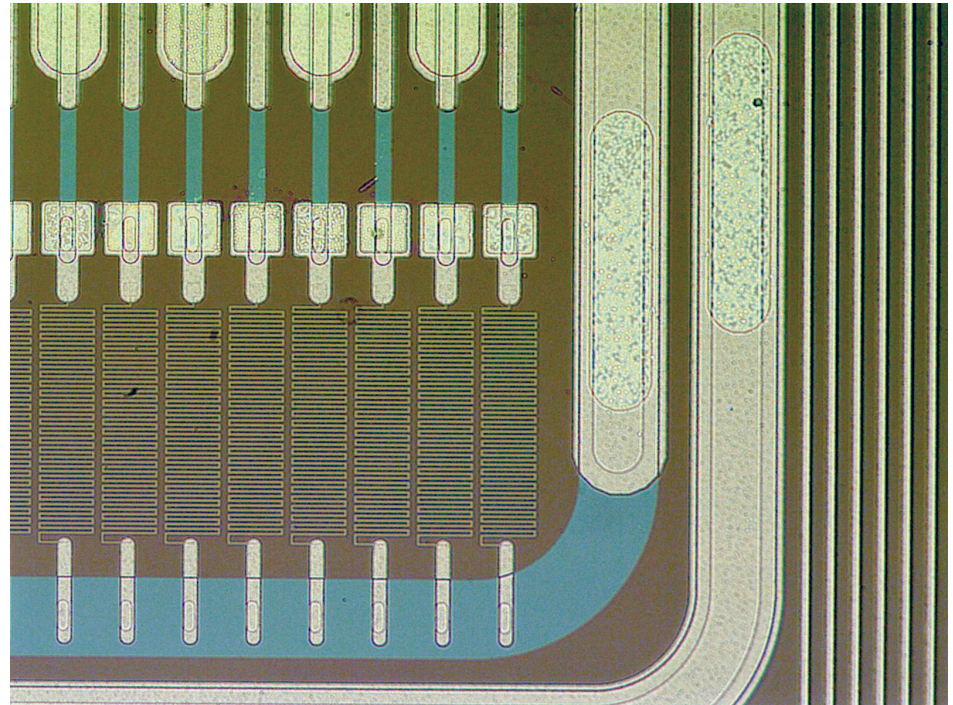
OUTLINE

- Motivation
- Thermal Donors (TD) in oxygen rich silicon
- Processing of MCz-Si detectors with TDs
 - Introduction of TDs
 - DLTS spectra
 - Annealing of p-type MCz-Si with TDs
 - Conclusions



Motivation

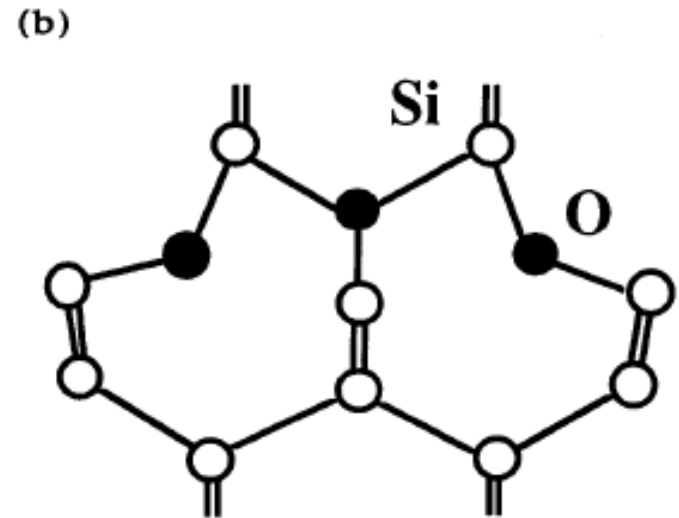
- n+/p-/p+ detector signal comes from electrons having three times higher mobility than the holes
- The detectors used in particle tracking systems must be fully depleted at reasonably low operating voltage
- By introduction of TDs, the V_{fd} of detectors can be adjusted in wide range



Thermal Donors in Cz-Si

- TDs are oxygen complexes that form shallow states in Si band gap below the conduction band.
- High O content leads to Thermal Donor (TD) formation at temperatures 400°C - 600°C.
- TD formation can be enhanced if H is present.

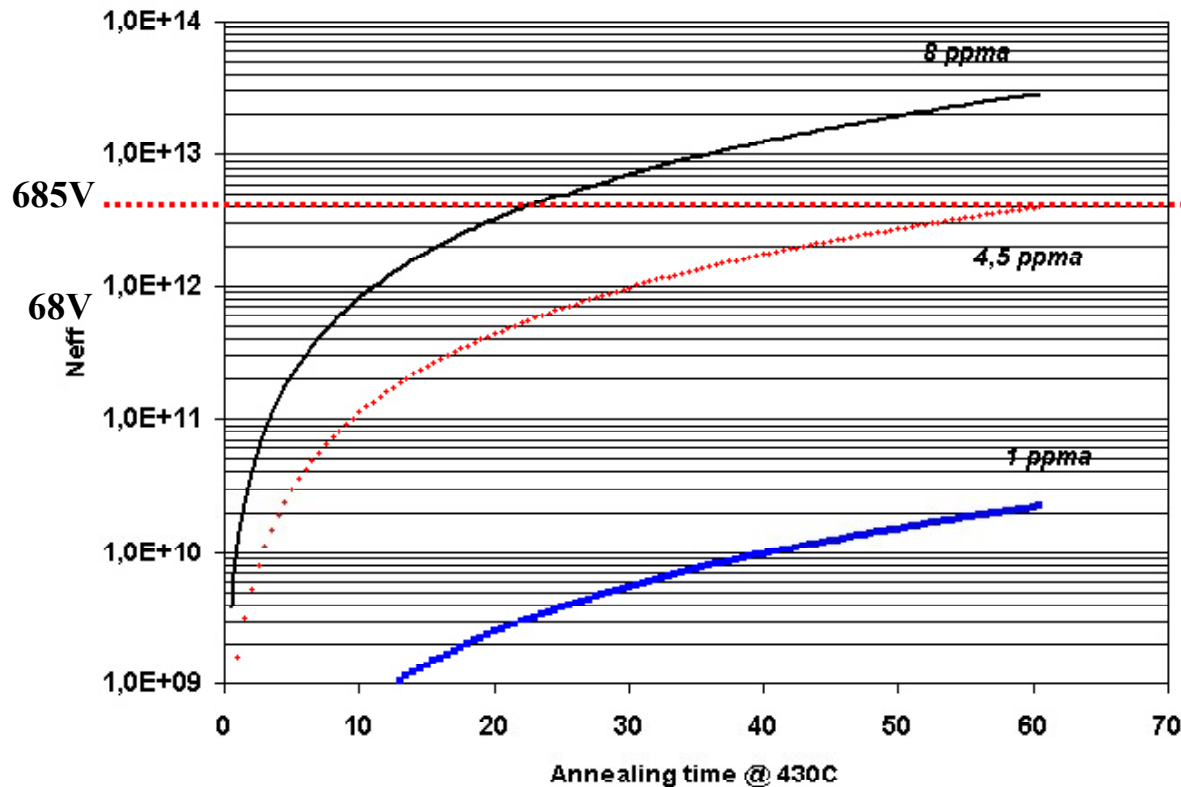
- Typical process steps at 400°C - 600°C
 - Aluminum sintering (e.g. 30min @ 450°C)
 - Passivation insulators over metals (LTO, TEOS etc ~600°C + H₂ from Si₃H₄ process gas)



D.J. Chadi, Phys. Rev. Lett. 77, 861-864 (1996)

Thermal Donor generation

- TD formation depends on
 - O concentration in silicon
 - Temperature
 - Amount of H in detector processing

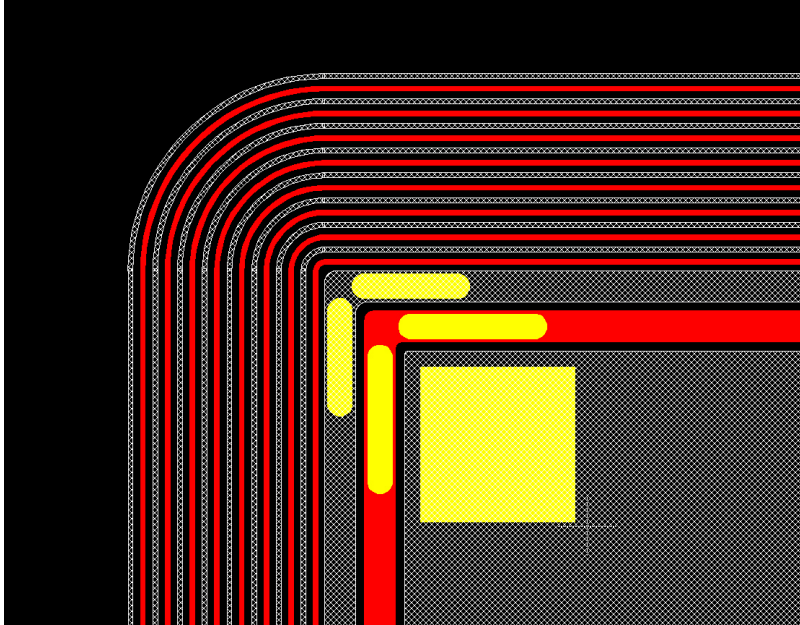


Cz-Si,
 $O_i \approx 8 \cdot 10^{17} \text{ cm}^{-3}$

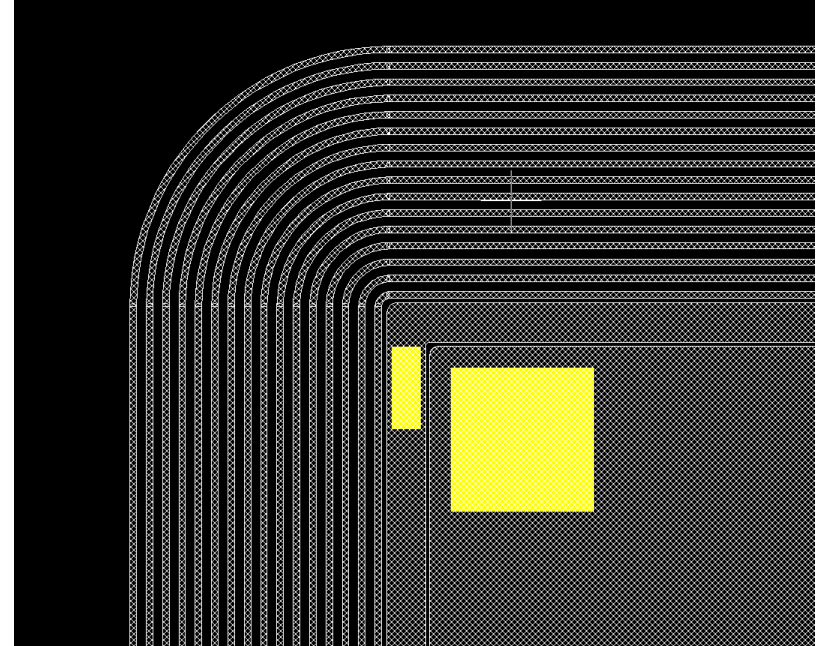
MCz-Si,
 $O_i \approx 4,9 \cdot 10^{17} \text{ cm}^{-3}$

Oxygenated Fz-Si,
 $O_i \approx 1 \cdot 10^{17} \text{ cm}^{-3}$

Sample processing

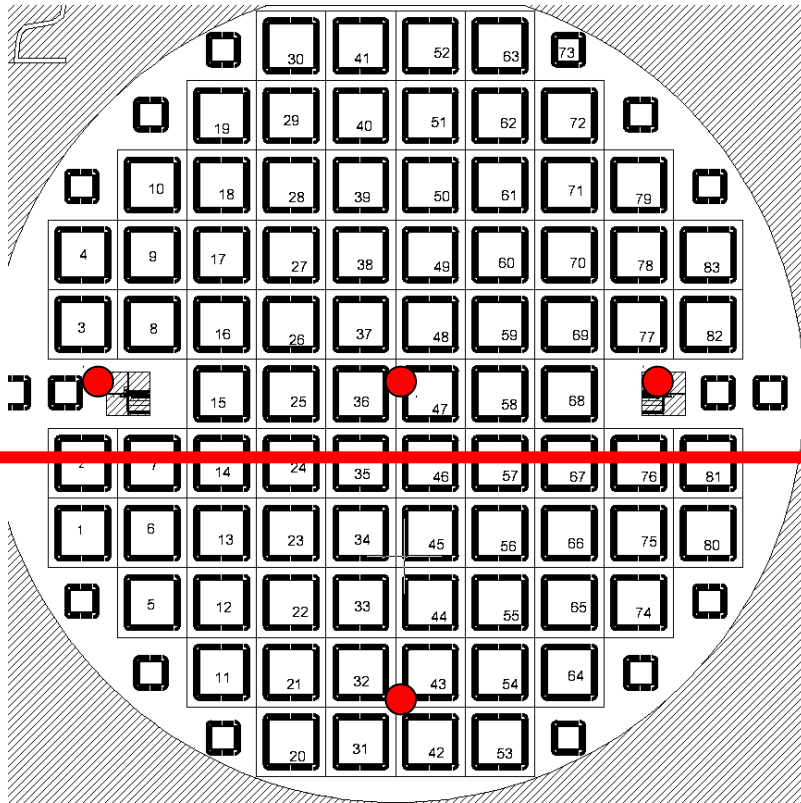


- $n^+/p^-/p^+$ diodes with p-stops
- TD generation 35 and 45 minutes
- 5 mask levels



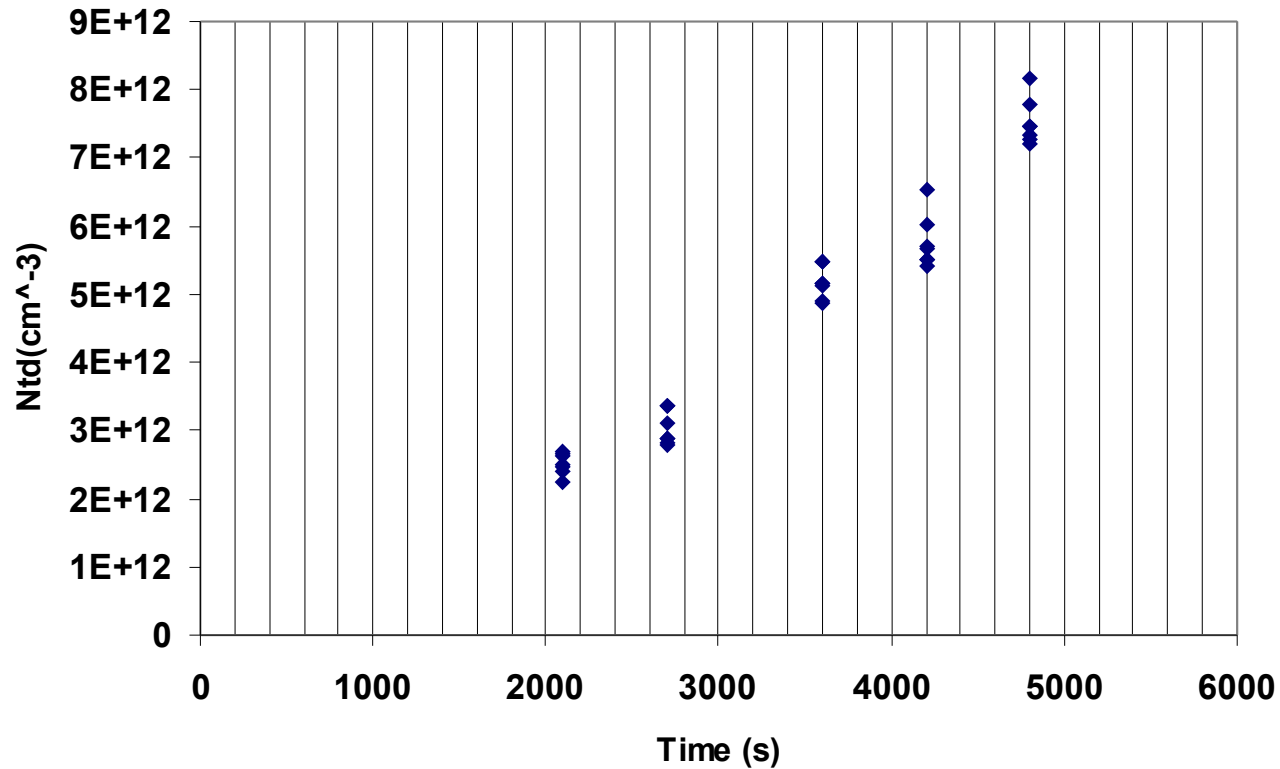
- $p^+/p^-/p^+$ diodes
- TD generation 60, 70 and 80 minutes
- 4 mask levels
- TD induced type-inversion

Thermal Donor generation (experimental results)

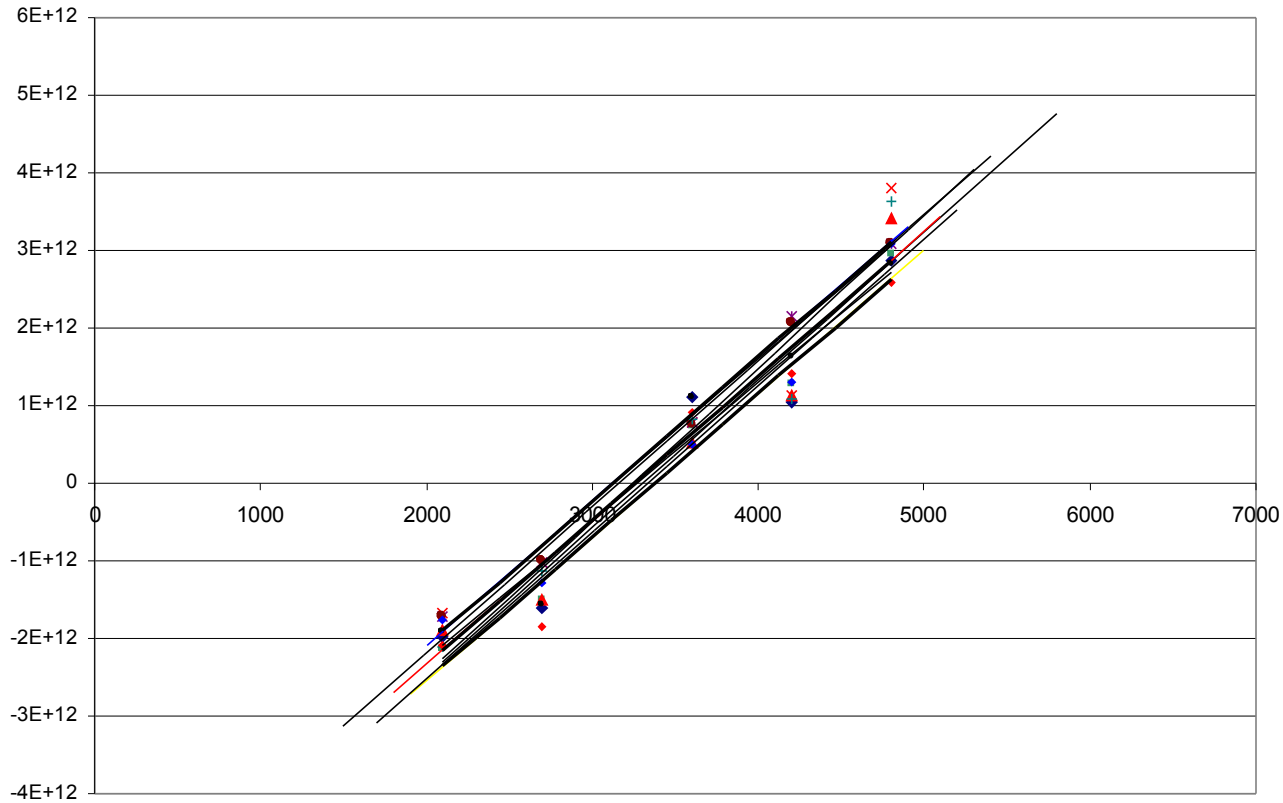


- O concentration from FTIR measurements
- Thick reference wafer
- Center $4,95 \cdot 10^{17} \text{ cm}^{-3}$
- Right $4,89 \cdot 10^{17} \text{ cm}^{-3}$
- Left $4,93 \cdot 10^{17} \text{ cm}^{-3}$
- Right $4,93 \cdot 10^{17} \text{ cm}^{-3}$

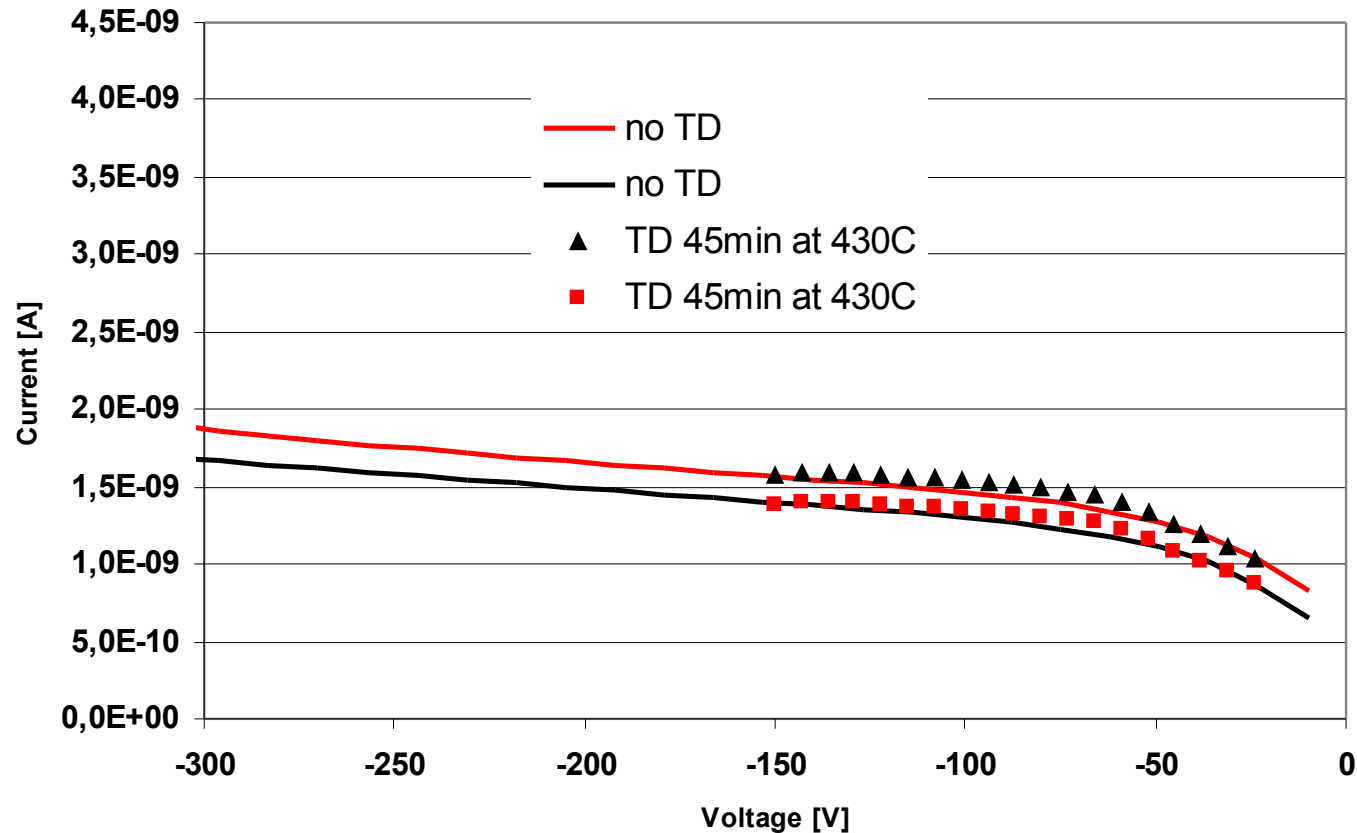
Thermal Donor generation (experimental results)



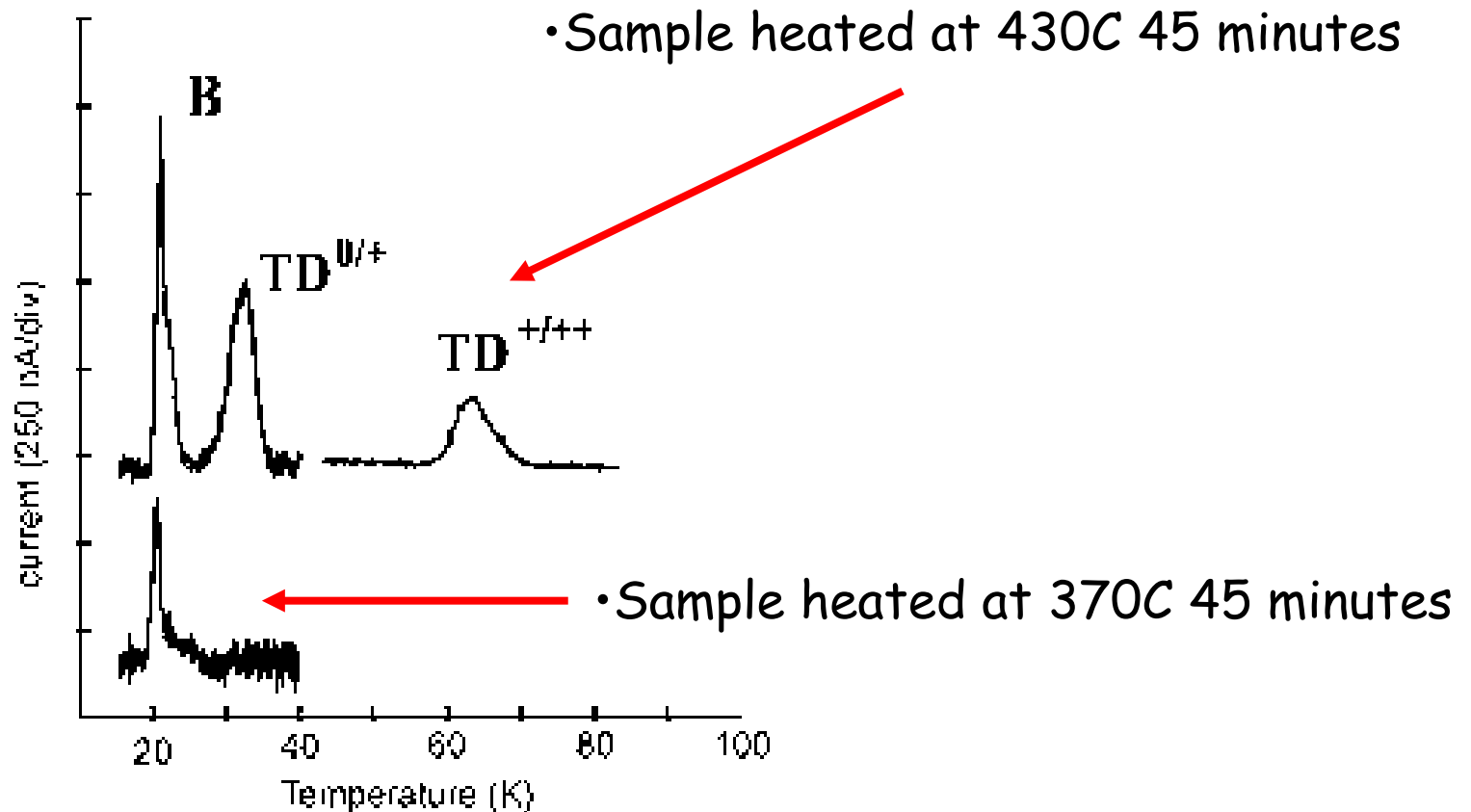
Thermal Donor generation (experimental results)



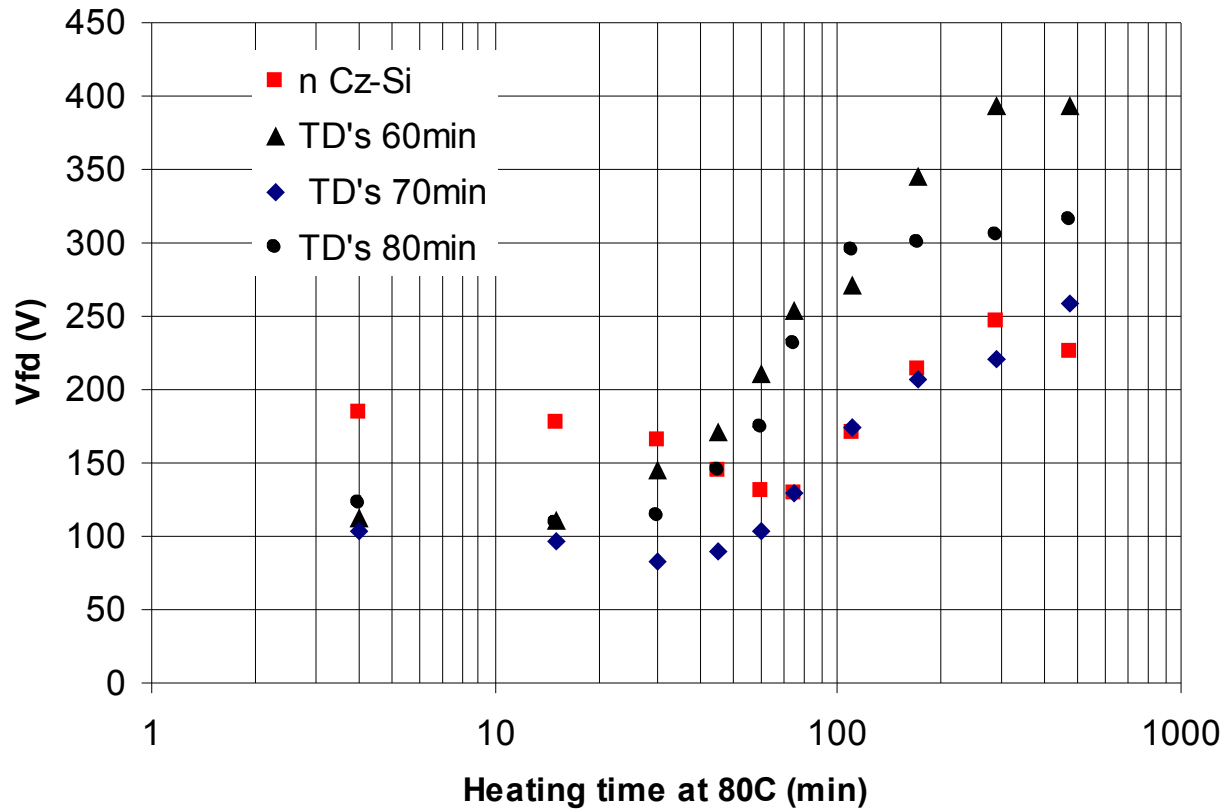
Leakage current



Deep Level Transient Spectroscopy



Annealing of proton irradiated detectors



$\cdot 1,5 \cdot 10^{14} \text{ cm}^{-2}$ 1MeV
neutron equivalent.

Conclusions

- Thermal Donors can be introduced into MCz-Si detectors at 430°C during the aluminum sintering.
- It is low temperature, low cost process, no additional process complexity >> feasible solution for large scale experiments ?
- Effective resistivity range is very wide in TD-process $500\Omega\text{cm} < \sigma < \sim 10\text{ k}\Omega\text{cm}$
- No increase of leakage current
- With this method it is possible to adjust the V_{fd} of p-type MCz-Si n+/p-/p+ detectors

