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Magnetic Czochralski silicon as detector material

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Outline

- Motivation to use Czochralski silicon (Cz-Si).
- Why not before ?
- Crystal growth.
- Processing issues.
- Thermal Donors (TD) in Cz-Si
- P-type magnetic Cz-Si
- Radiation Hardness
- Summary

Esa Tuovinen loading MCz-Si wafers into oxidation furnace at the Microelectronics Center of Helsinki University of Technoly, Finland.

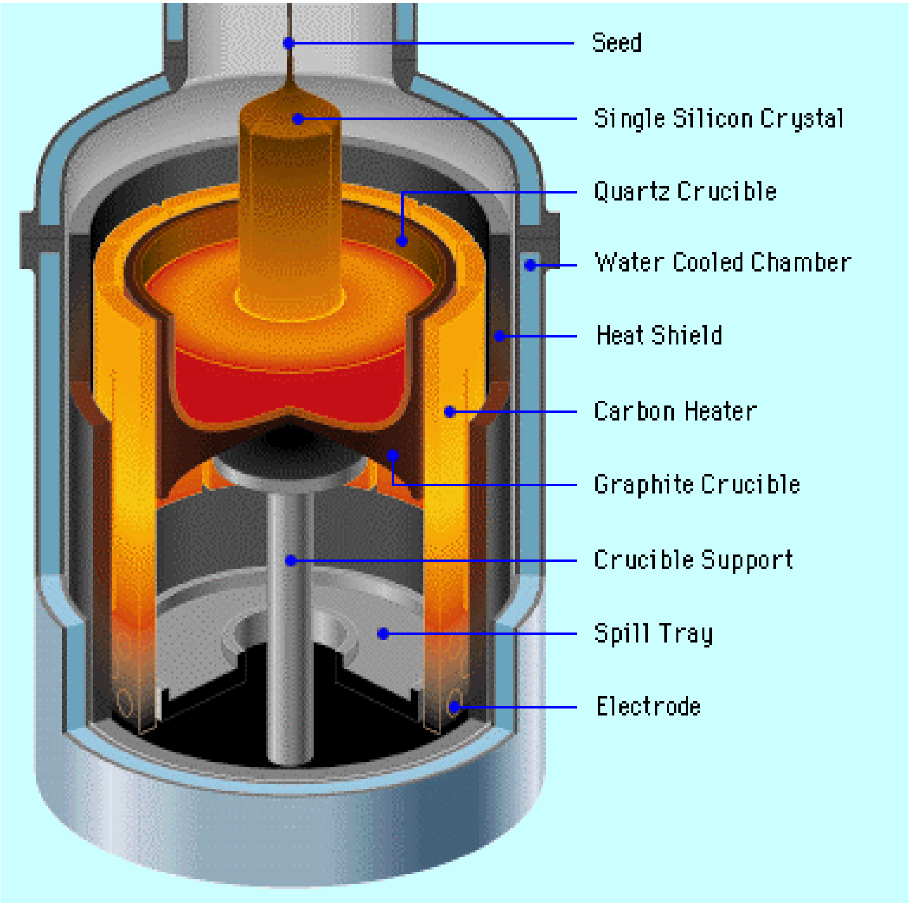
Why Cz-Si ?

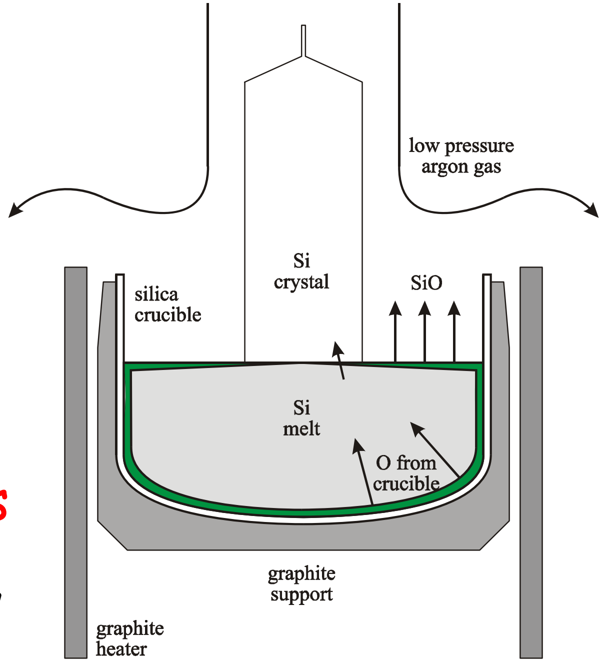
- Cz-Si available in larger diameters
- Lower wafer cost
- Better compatibility with advanced CMOS processes
- Oxygen brings significant improvement in thermal slip resistance
- Oxygen gives significant radiation hardness advantage.

Why not before ?

* No demand for high resistivity Cz-Si -> No availability
* Price for custom specified ingot 15,000 € - 20,000 €
* Now RF-IC industry shows intrest on high resistivity Cz-Si
(=lower substrate losses of RF-signal)

Crystal growth





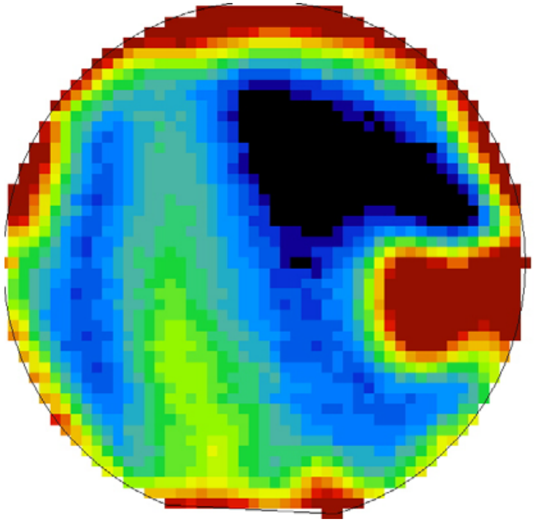
Growth parameters

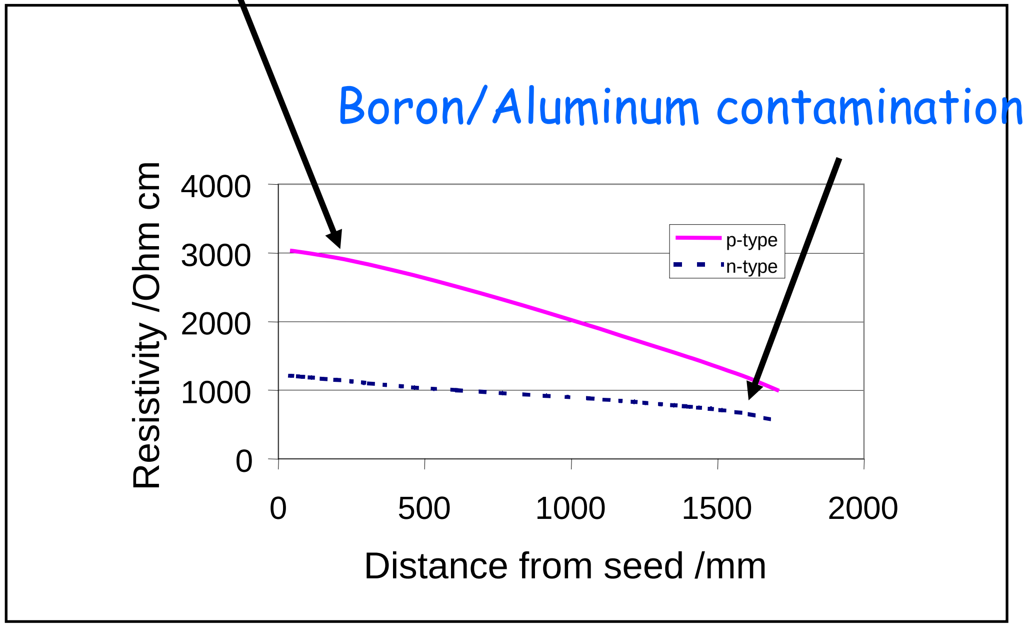
- Gas flow
- Pressure
- Purge tubes (gas flow pattern
- Crucible rotation
- Crystal rotation
- Temperature distribution
- Magnetic field

Olli Anttila, Okmetic Ltd., 6th RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders Helsinki, 2-4 June, 2005. http://rd50.web.cern.ch/rd50/6th-workshop/default.htm

Requirements for detector applications

- High resistivity
- Oxygen concentration 5-10×10^{17} cm^{-3}
- Homogeneity
- High minority carrier lifetime

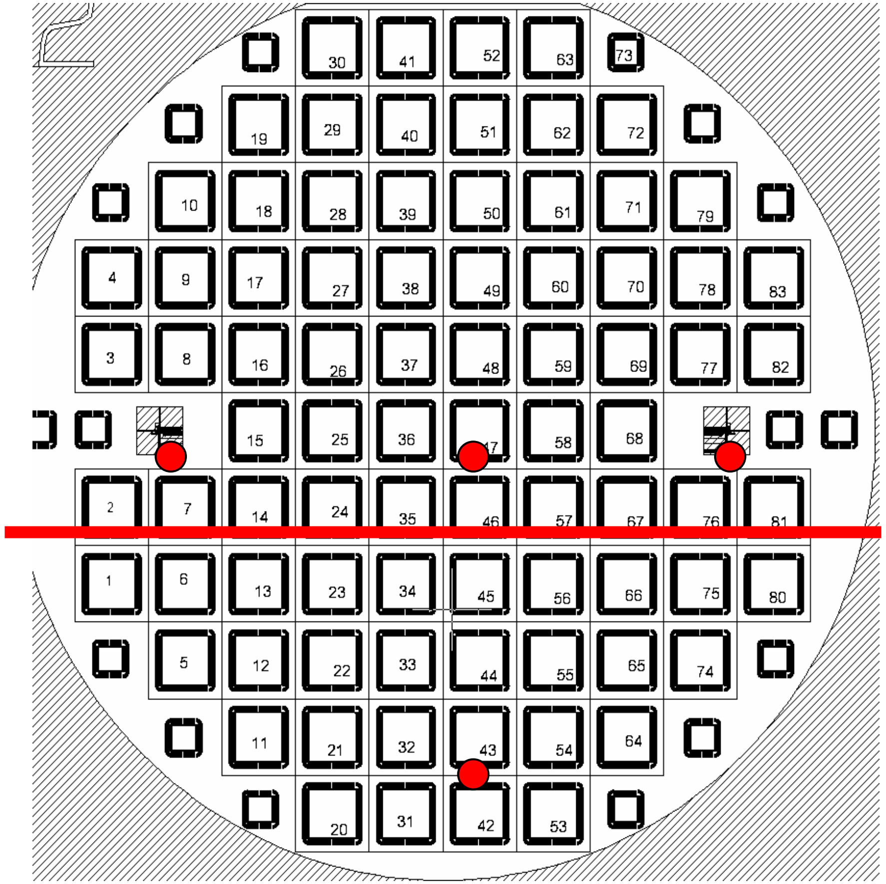




Oxygen donor compensation

Boron/Aluminum contamination

Oxygen concentration in MCz-Si



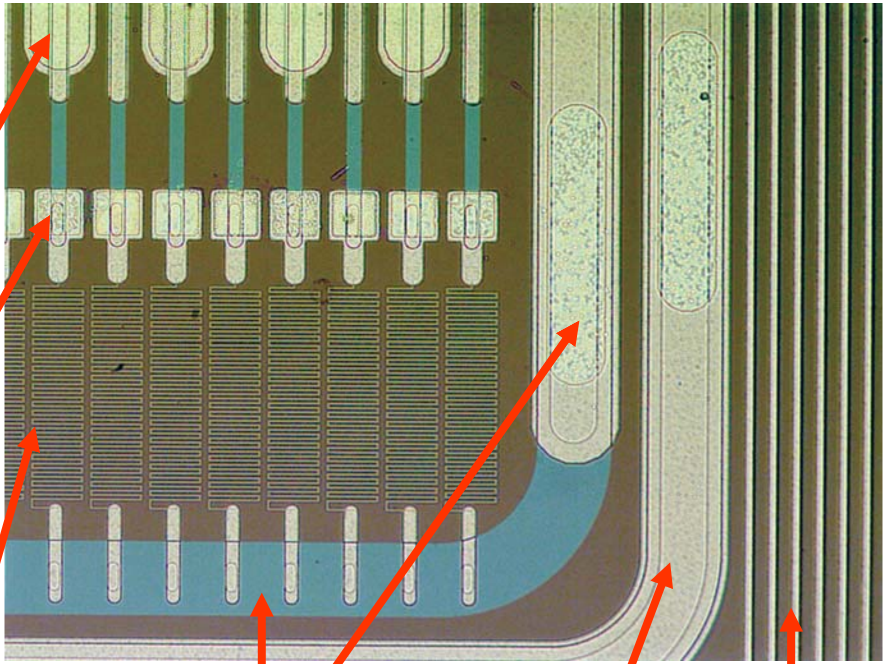
- O concentration from FTIR measurements
- Thick reference wafer

- Center 4,95*10^{17} cm^{-3}
- Right 4,89*10^{17} cm^{-3}
- Left 4,93*10^{17} cm^{-3}
- Right 4,93*10^{17} cm^{-3}

Strip detector processing

The devices were processed at Helsinki University of Technology Microelectronics Center

- with simple 5-8 level mask process:
  - 4 lithographies
  - 2-3 ion implantations
  - 2 thermal dry oxidations
  - 3 sputter metal depositions



AC-pad,bonded to read out

DC-pad,for testing

Bias resistors

Bias line

Guard Ring for isolation

multi GR

Processing of Cz-Si Detectors

- Basically no difference from standard Fz-Si detector process, except…

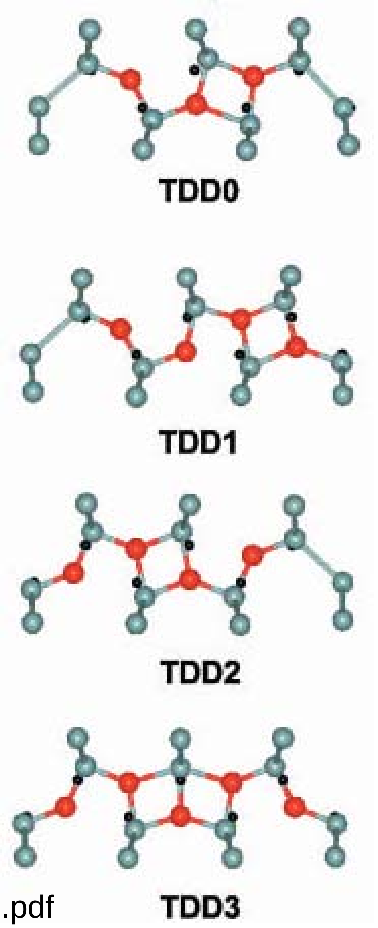
- High O content leads to Thermal Donor (TD) formation at temperatures 400^0C – 600^0C.

- TD formation can be enhanced if H is present.

- Typical process steps at 400^0C – 600^0C
  - Aluminum sintering (e.g. 30min @ 450^0C)
  - Passivation insulators over metals (LTO,TEOS etc ~600^0C + H_2 from Si_3H_4 process gas)

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 temperatures 400^{0}C – 600^{0}C.
- TD formation can be enhanced if H is present.
- Effective resistivity can be adjusted in p-type MCz-Si 500 Ωcm < σ < ~10 kΩcm
- With this method it is possible to engineer the V_{fd} of p-type MCz-Si n+/p-/p+ detectors



J. von Boehm, http://www.csc.fi/lehdet/tietoyhteys/TY3_2004.pdf

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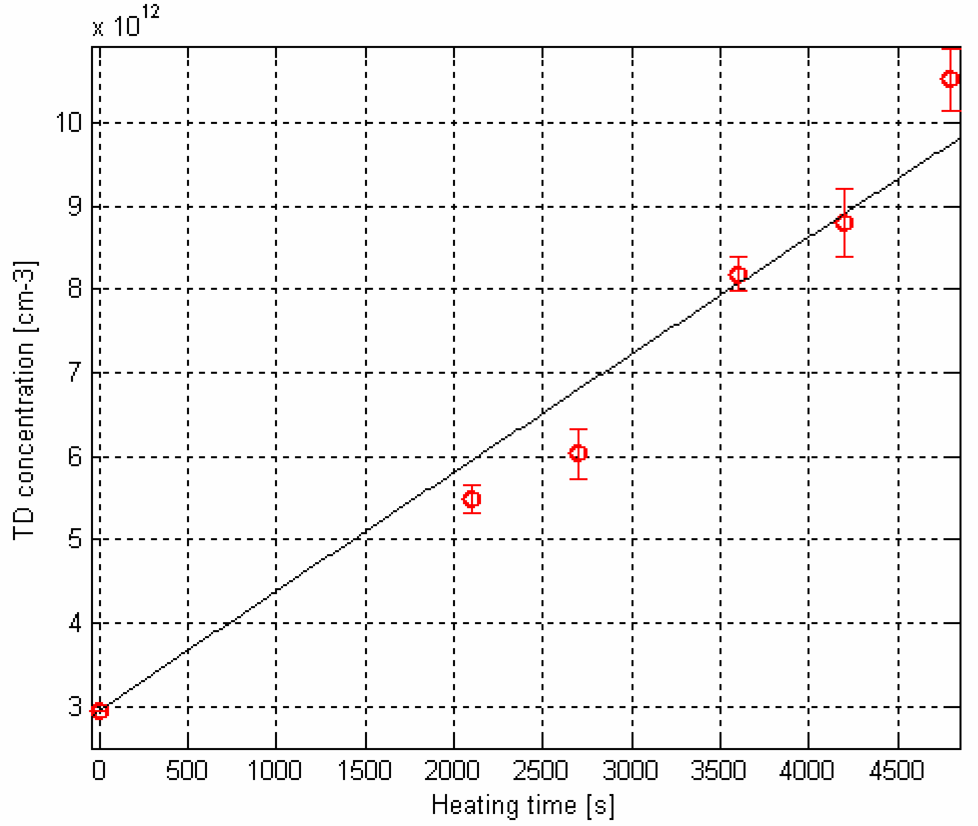
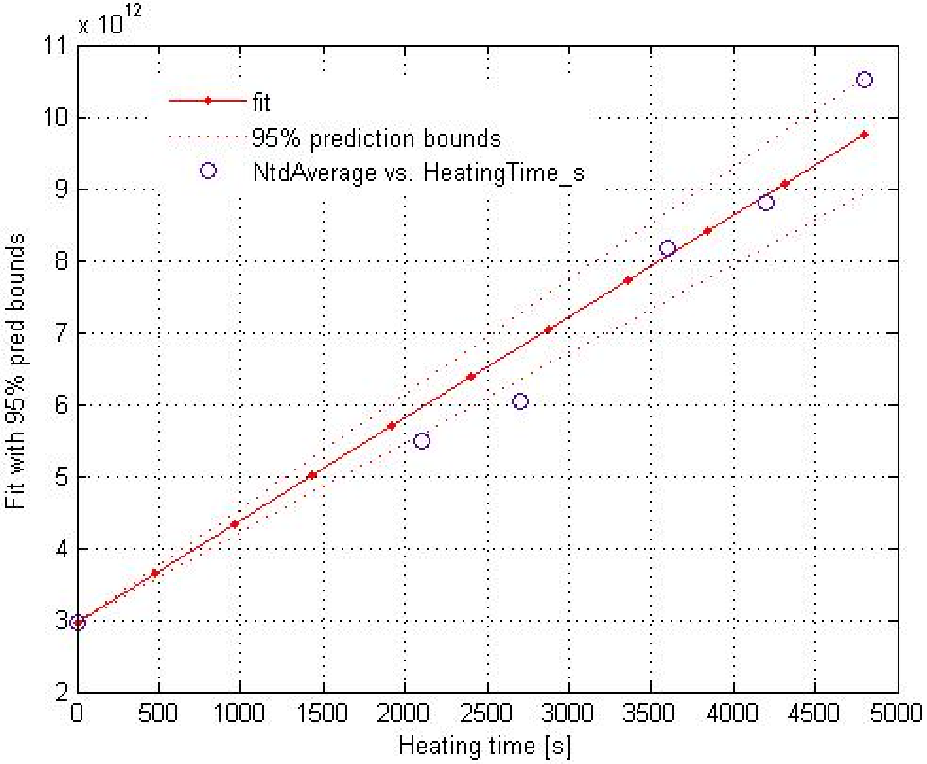
Thermal Donor generation (experimental results)



- One data point is average of 10 diodes over the wafer diameter
- Error bars represent standard deviation

Fitting of the Model II



$\chi=1.893$

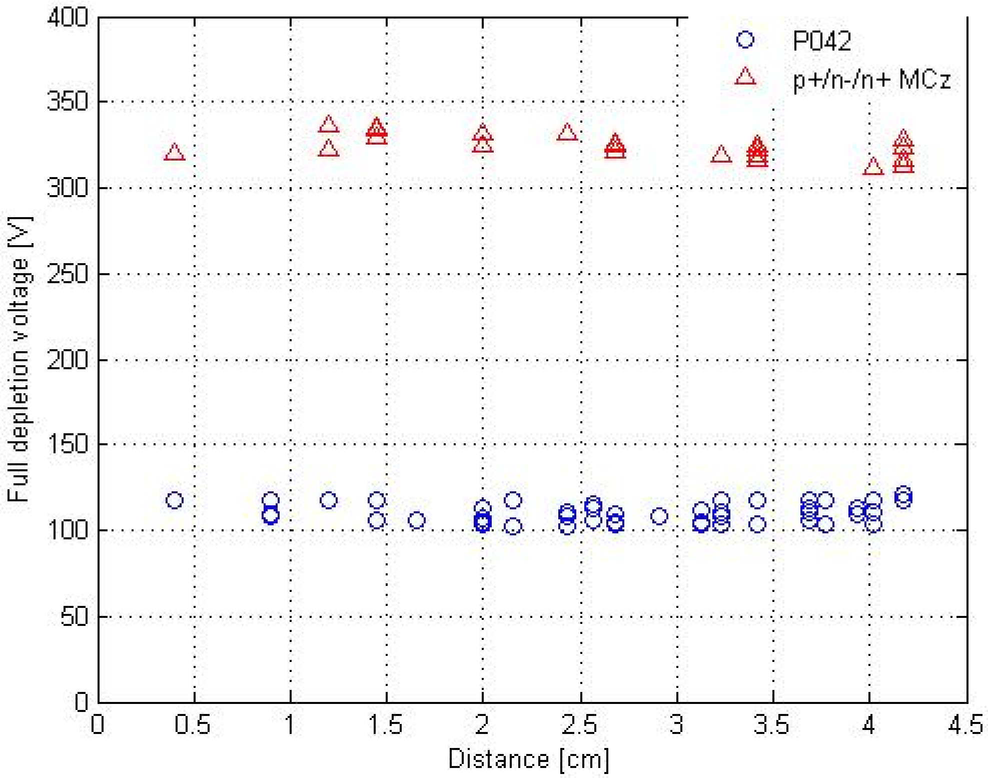
$c=6.824\times10^{-20}$

$b=6.60789\times10^{-6}$

$$N_{TD}(t,T)=a*O_i^{1.893}\left(1-e^{-bD_iO_it}\right)+N_{TD}(0)$$

Homogeneity

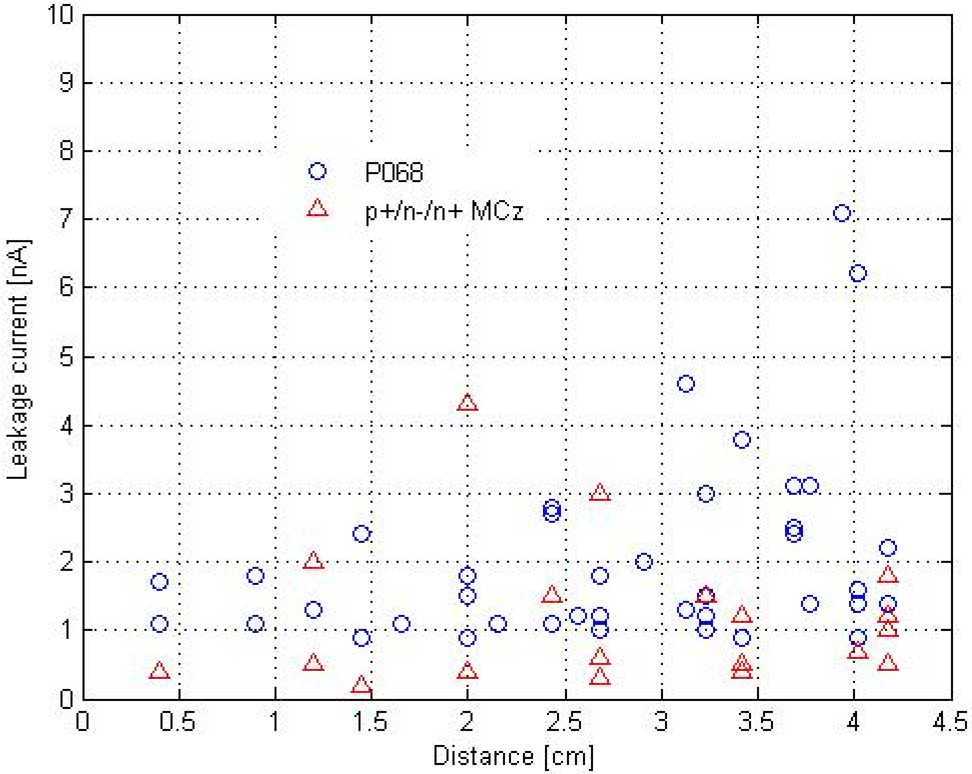
Full Depletion Voltage with respect of distance from wafer center



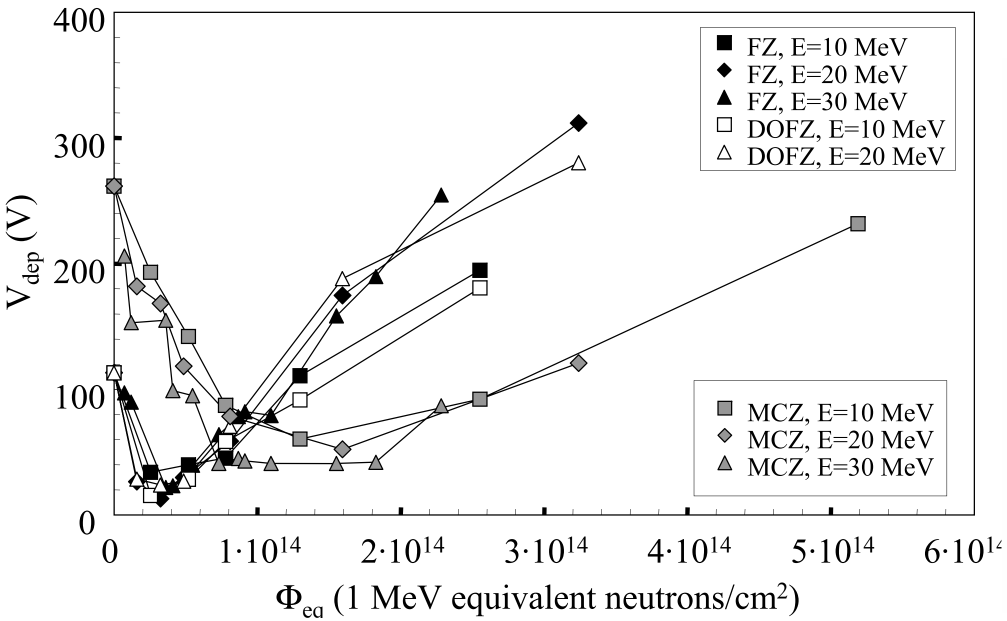
Homogeneity

Leakage current with respect of distance from wafer center

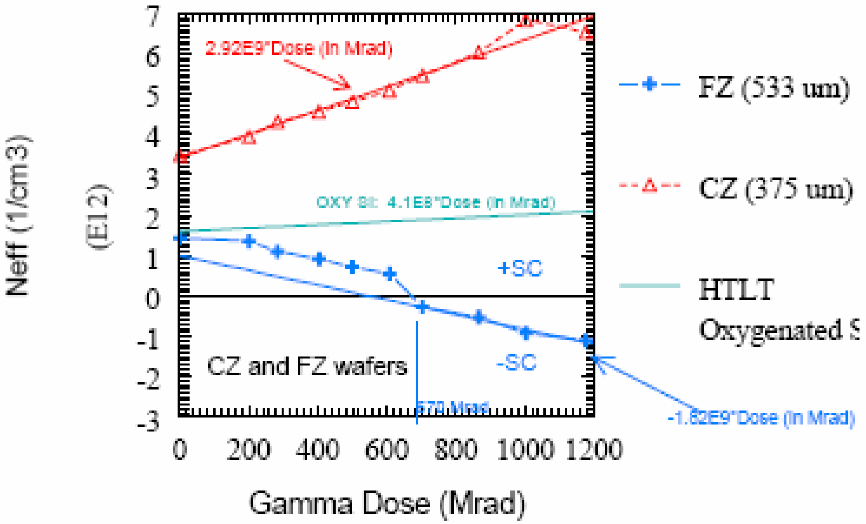
P068 is $n^+/p^-/p^+$ device with p-stop implant ($1\times10^{15}cm^{-2}$) and p-spray $1\times10^{15}cm^{-2}$



Radiation hardness of MCz-Si



Z.Li, J. Härkönen, E. Tuovinen, P. Luukka *et al.*, Radiation hardness of high resistivity Cz-Si detectors after gamma, neutron and proton radiations, IEEE Trans. Nucl. Sci., **51** (4) (2004) 1901-1908.



Proton radiation: Less prone for V_{fd} increase than std Fz-Si or Diffusion oxygenated Fz-Si
Neutron radiation: No significant difference

Gamma radiation: Increase of positive space charge.
Beneficial for Linear Collider applications ?

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Summary

- MCz-Si is commercially available in large quantities with resistivity 1000Ωcm (n-type) and 2 kΩcm (p-type).
- MCz-Si shows better radiation hardeness againsta protons than Fz-Si materials. No improvment against neutron and no difference in leakage current.
- Thermal Donors can be introduced into MCz-Si detectors at 430°C during the aluminum sintering, i.e. b low cost process, no additional process complexity.
- Leakage current and V_{fd} in p-type MCz-Si n+/p-/p+ and $p^+/n^-/n^+$ detectors is homogenous over the wafer diameter.