$p^+/n^-/n^+$ Cz-Si Detectors Processed on p-type Boron Doped Substrates with Thermal Donor Induced Space Charge Sign Inversion

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In Framework of CERN RD50 Collaboration

OUTLINE

- Cz-Si as detector material

- p-type Cz-Si detector processing issues

- Thermal Donors (TD) in oxygen rich silicon

- p-type Cz-Si detectors

- Conclusions

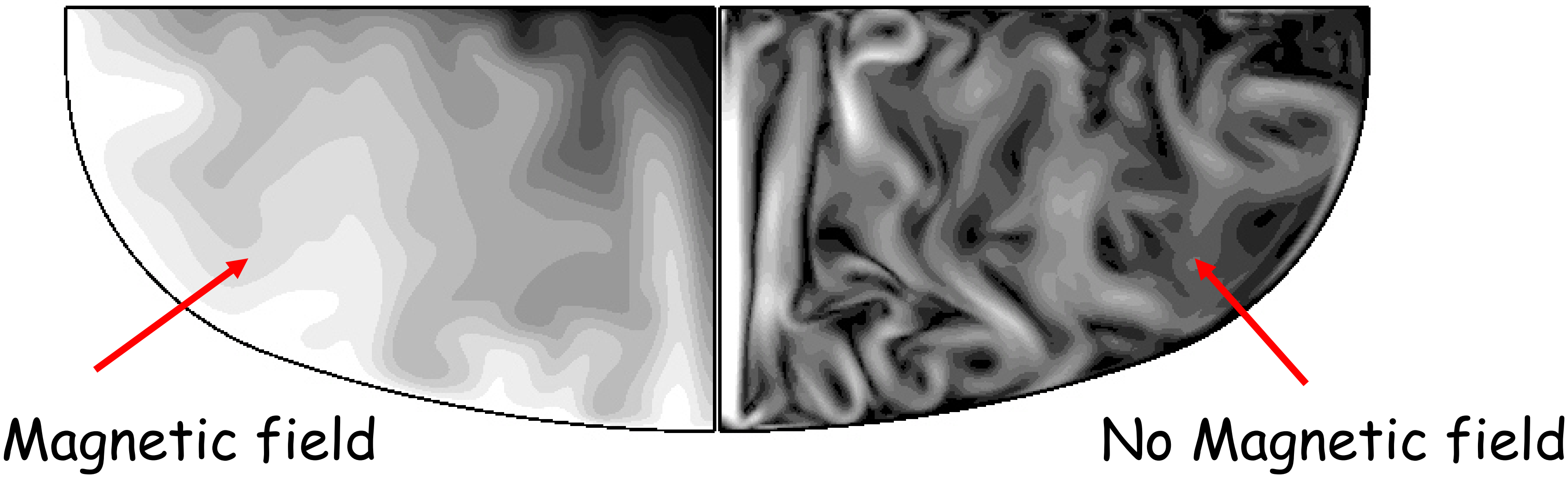
Cz-Si as Detector Material

- High resistivity Cz-Si previously not available because lack of commercial applications
- Available in large diameters (up to 300mm) and in large quantities if necessary
- Oxygen content can be adjusted by crystal pulling speed within the range from few ppma above the O solid solubility in Si
- Homogenous impurity distribution in crystal can be achieved if a magnetic field is applied during the growth
- N and P-type high resistivity Cz-Si available

Magnetic field in Cz-Si Crystal Growth

http://www.csc.fi/elmer/examples/czmhd/

- A magnetic field can be applied in the CZ system in order to damp the oscillations in the melt. The process is called magnetic Czochralski crystal growth (MCZ). The applied field creates an electric current distribution and an induced magnetic field in the electrically conducting melt. This produces a Lorentz force that influences the flow and reduces the amplitude of the melt fluctuations.



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 formationcan 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)

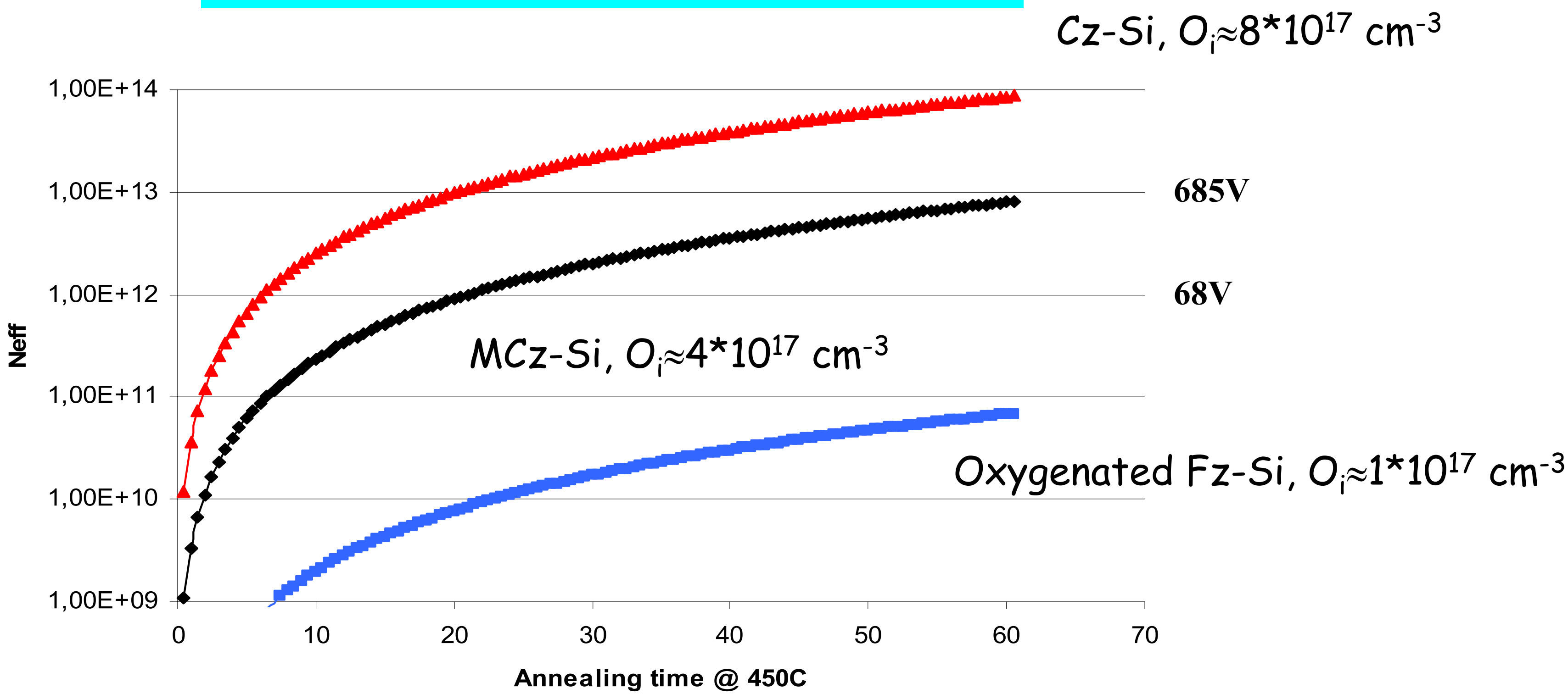
Thermal Donor generation

$$N_{TD} = \left(\frac{a}{b}\right) C_{io}^{\chi} \frac{1}{\left|N_d - N_A\right|^2} \left\{1 - e^{-bD_i C_{io} t}\right\}$$

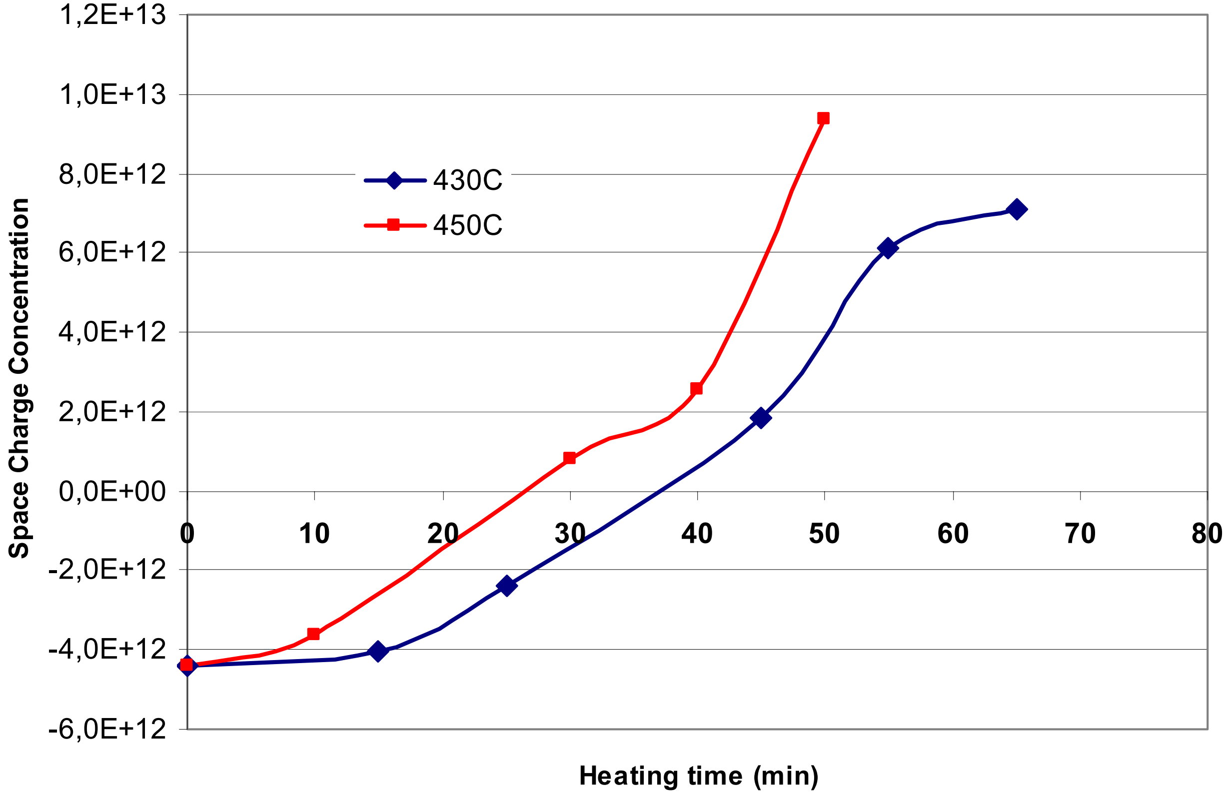
$$D_i = 0{,}13\, e^{-\frac{E_A}{kT}}$$

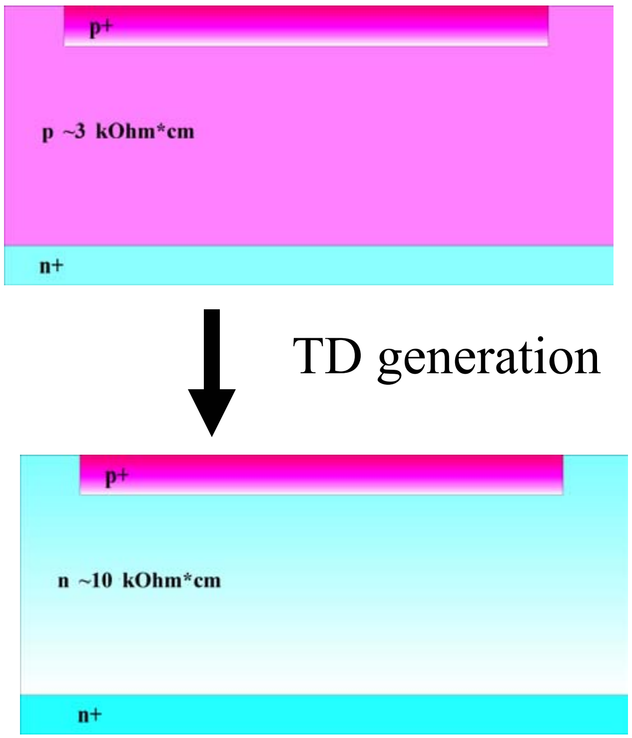
$2{,}4 \le \chi \le 2{,}6$

$E_A = 2{,}5$ eV

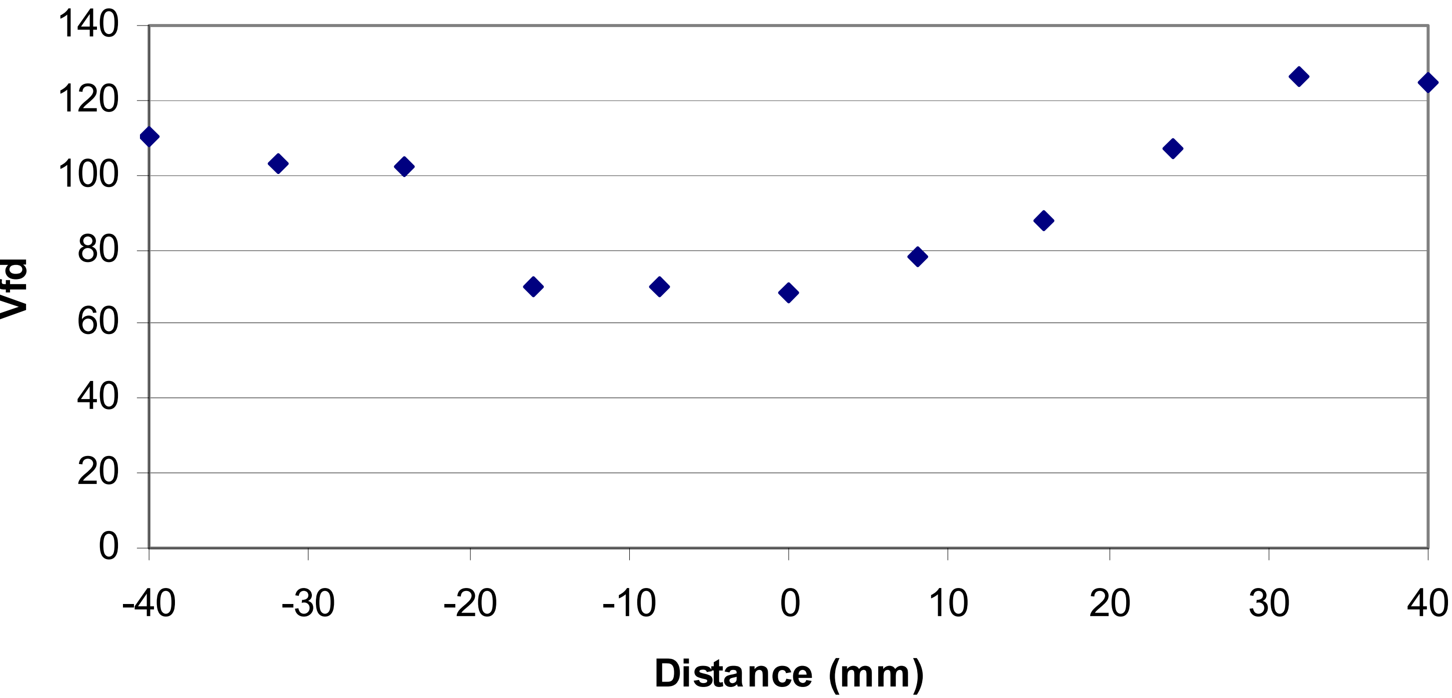


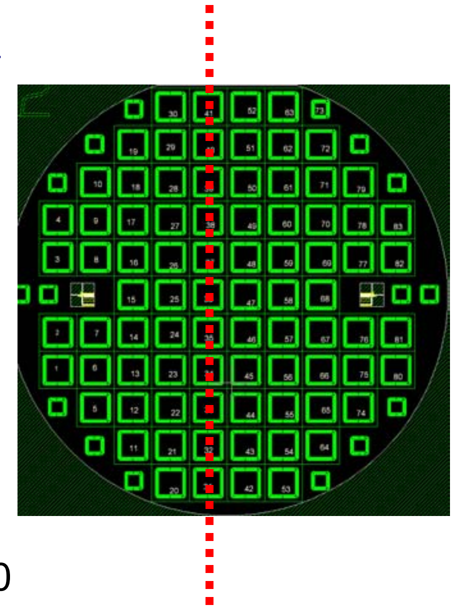
Thermal Donor generation (experimental results)





Thermal Donor generation (experimental results)



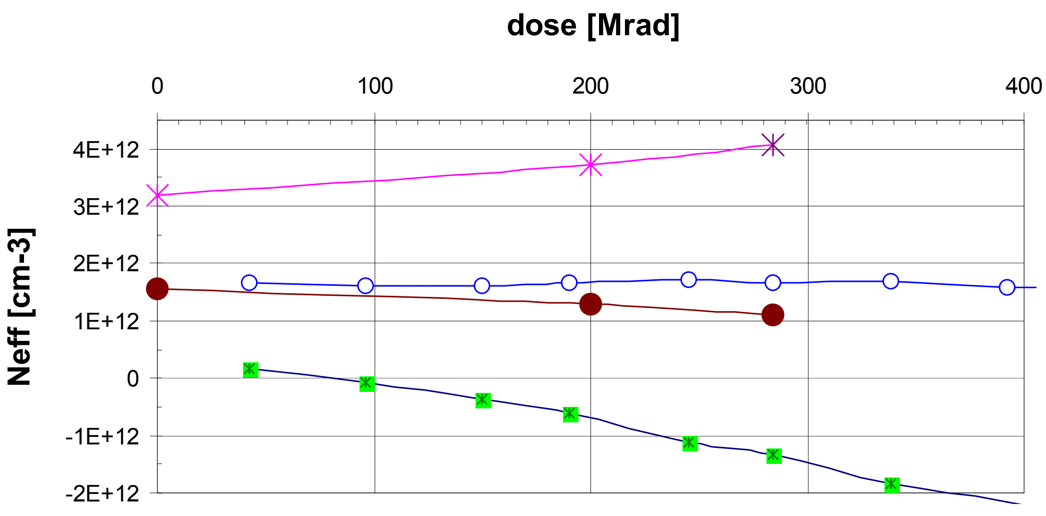


- We have not observed enhanced TD generation when the passivation was made by PECVD (Plasma Enhanced CVD) Si_3N_4 @300^{0}C, which contains H_2 10-30%.

See talk by Esa Tuovinen at 3rd RD50 Workshop
http://rd50.web.cern.ch/RD50/3rd-workshop/

P-type Cz-Si, potential for radiation hardness ?

•In gamma irradiation, positive space charge introduction as function of O concentration. Believed to be due to TD formation.



•No type inversion

•Lower β-factor 50MeV protons:
$\beta_p \approx 0{,}0054$
$\beta_n \approx 0{,}0157$

•Possibly different defect kinetics (donor removal?)

•Experimental results that p-type Oxygented detectors show higher than expected CCE after very heavy irradiation
(G.Casse at 10th Vienna Conference on Instrumentation)

Conclusions

- High O content $p^+/n^-/n^+$ detectors can be processed with p-type boron doped Cz-Si wafers by inverting p $\rightarrow$ n with TD's

- It is low temperature, low cost process >> feasible solution for large scale experiments

- Resistivity range is very wide in p $\rightarrow$ n TD-process $500\Omega cm < \sigma < \sim 10\ k\Omega cm$

- O content should be within some limits ($3ppma < O_i < 6ppma$). Magnetic field may be required in crystal growth.