Homogeneity and thermal donors in p-type MCz-Si detector materials

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Outline

- Processing issues.
- Thermal Donors (TD) in Cz-Si
- Homogeneity of samples
- Conclusions

Samples

- Samples were processed on p-type MCz-Si wafers.

- The starting material was 4″ diameter double-side-polished 300$\pm$2 μm thick <100> Cz-Si wafers.

- The nominal resistivity, measured by the four point probe method, of the boron-doped wafers was 1800 Ωcm.

- Two types of pad detectors were processed at the Microelectronics Center of Helsinki University of Technology: $p^+/p^-/n^+$ -diode structures and $n^+/p^-/p^+$ structures processed with a different mask set.
    - The active pad implanted area was 5 $\times$ 5 mm^2. It was surrounded by one wide (100 μm) and 16 (16 μm wide) small guard-rings .
    - The distance between the active area implant and the first guard ring was 10 μm.
    - A 1 mm diameter round opening in the front metallization was left for TCT measurements

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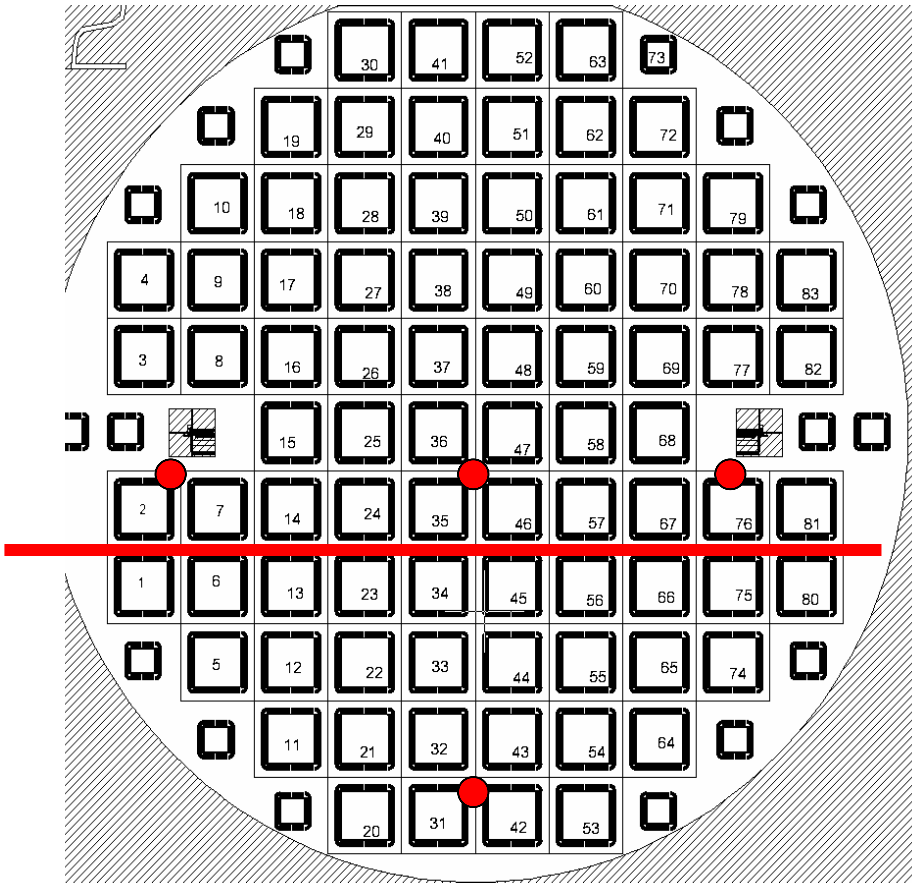
Interstitial oxygen concentration in MCz-Si material



- Oxygen concentration was measured by the Fourier Transformation Infrared (FTIR) spectroscopy at the Institute of Electronic Materials Technology (ITME), Warszawa, Poland from a 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}

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°C – 600°C.

•TD formation can be enhanced if H is present.

•Typical process steps at 400°C – 600°C
- Aluminum sintering (e.g. 30 min @ 450°C)
- Passivation insulators over metals (LTO,TEOS etc ~600°C + 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 within 0.01 eV-0.2 eV energy range below the conduction band.

•High O content leads to Thermal Donor (TD) formation at temperatures 400°C – 600°C, which can yield to a TD concentration comparable with the initial doping concentration in the high resistivity silicon.

•TD formation can be enhanced if H is present.

•Effective resistivity can be adjusted in p-type MCz-Si 500 Ωcm $< \sigma < \sim$10 kΩcm

•With this method it is possible to engineer the V_{fd} of p-type MCz-Si $n^+/p^-/p^+$ detectors

Thermal donor formation

- Formation of TDs has often been explained to be due to so-called anomalously fast diffusing species (FDS).

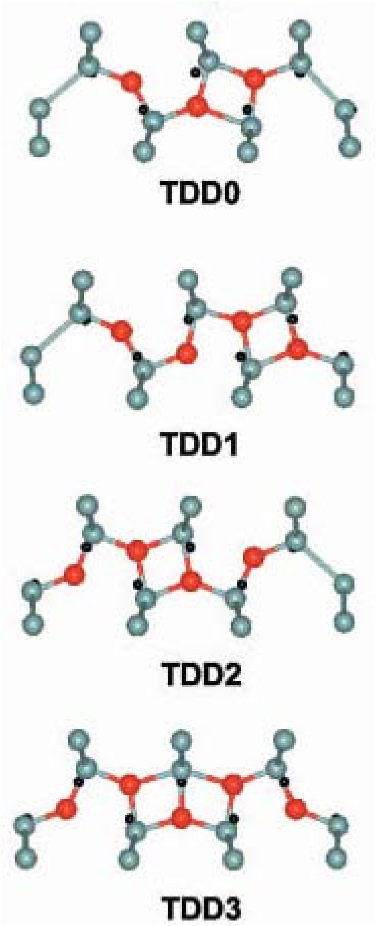
- Oxygen dimers (O_2) and trimers (O_3) among other oxygen complexes have been proposed to be such FDS's.

- Additionally, a fourth-power dependence of thermal donor generation rate on the oxygen concentration has widely been quoted.

- The fourth-power reaction order assumption for the generation rate has generally been accepted to be evidence that the core of the TD defect consist of four oxygen atoms.

Thermal donor formation

- There are, however, experimental observations based on the infrared absorption method that claim strong deviations from the fourth-power dependence, which originally was established to be TD generation at 450°C.
- With lower temperatures, at e.g. 430°C, the exponential dependence in the formation has been reported to be close to 1.83.
- Additionally, Y. J. Lee et al have shown by total energy calculations that the TD formation is not due to the FDS's but oxygen chains that move and capture relatively unmoving oxygen atoms. They report a reaction order close to 2.



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

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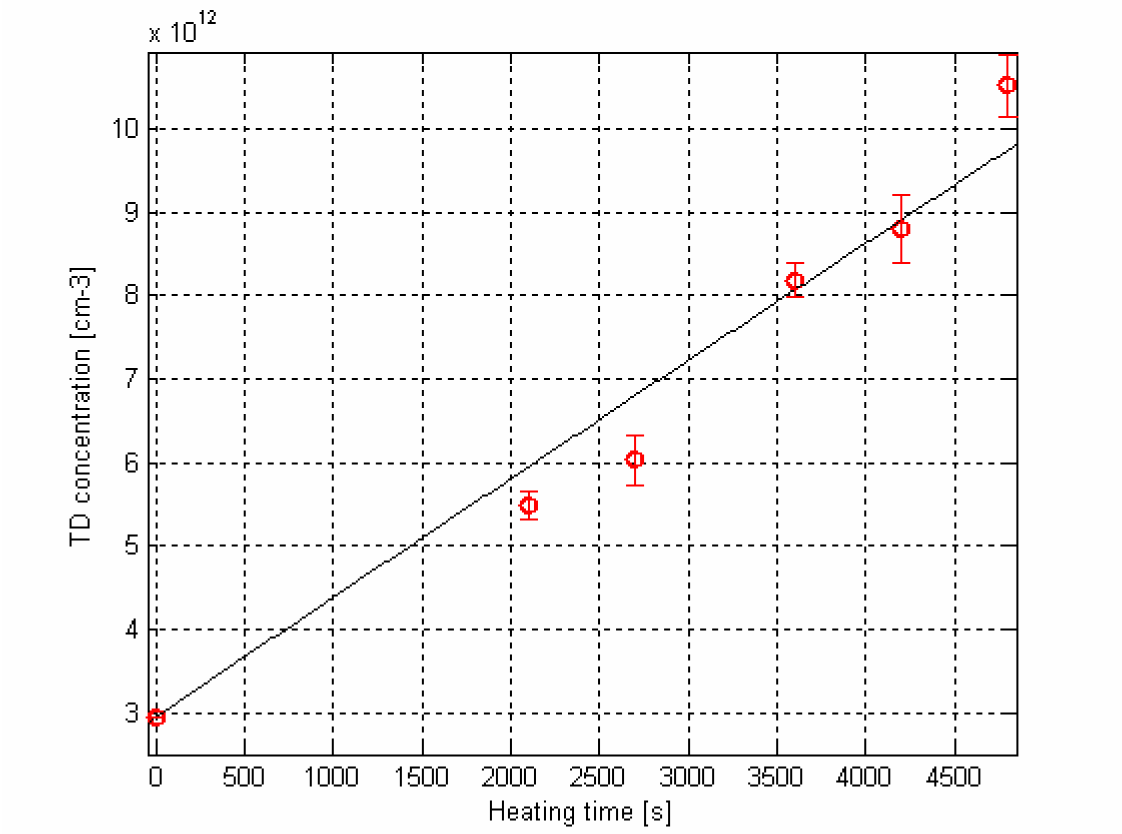
Thermal donor generation (experimental results)



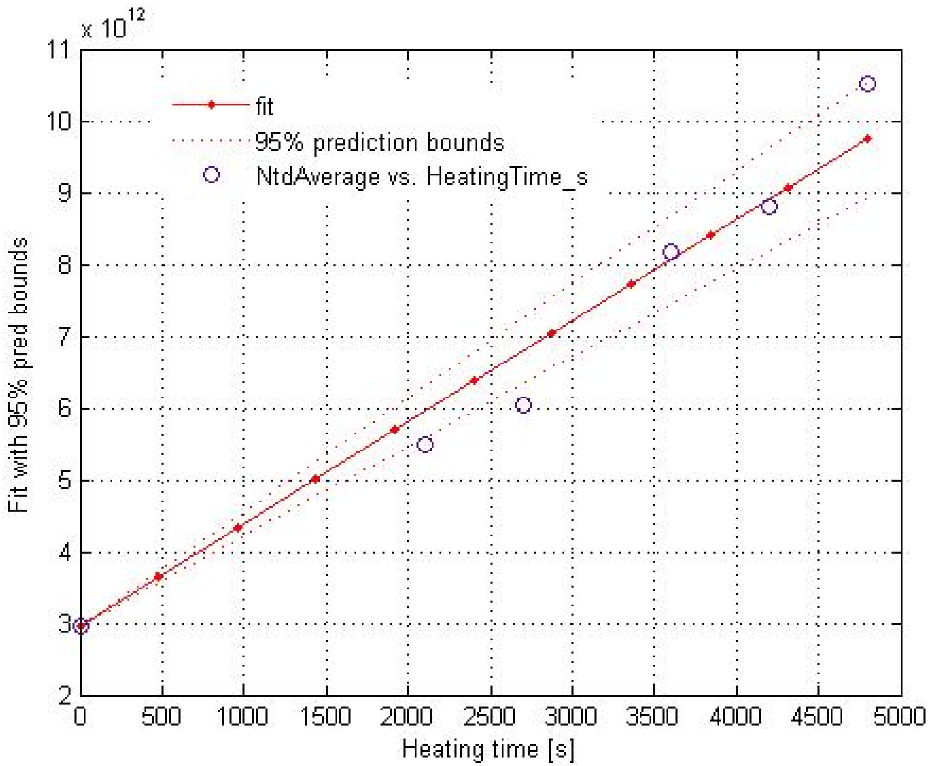
The TD formation is almost linear

It is therefore obvious that the empirical models claiming fourth power dependence on the oxygen concentration, cannot explain our experimental results.

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

Fitting of the model

Exponential fit of the proposed model to the experimental data. The data points correspond to the average of the measurements of N_{eff}.



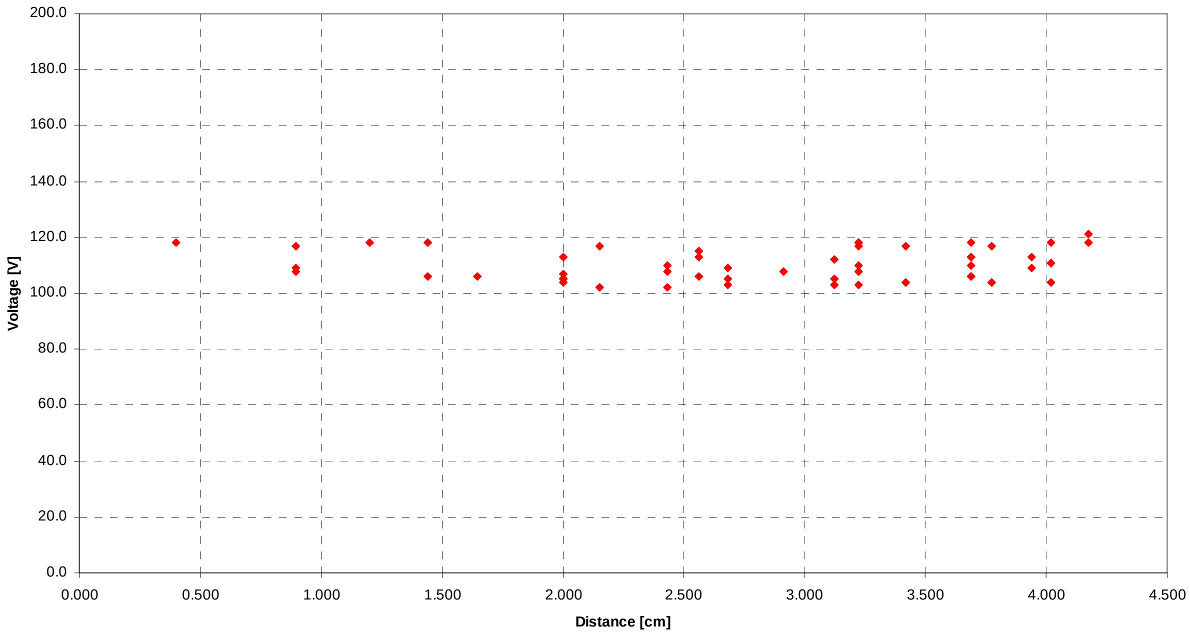
We have made an effort to improve the existing models by following the time and temperature depended equation with two fitting parameters.

Fitting gives following result:

exponent to which the oxygen concentration is raised

$$N_{TD}(t,T) = 6.824\times 10^{-20} O_i^{1.893}\left(1 - e^{-6.60789\times 10^{-6} D_i O_i t}\right) + N_{TD}(0)$$

Homogeneity



	P-stop 1×10^{15} cm^{-2}	P-spray	V_{fd}[V]	I_{leak}[nA]	Yield [%]
P042	X	-	110±5.5	3.2±2.1	93
P068	X	1×10^{12} cm^{-2}	115±5.7	2.6±2.0	91
P069	X	3×10^{12} cm^{-2}	115±4.4	2.2±1.8	84
P082	X	5×10^{12} cm^{-2}	112±4.6	3.3±2.4	86
P083	-	3×10^{12} cm^{-2}	106±4.4	2.6±2.4	58

- The values of V_{fd} and I_{leak} are expressed as average±standard deviation.

The yield percentage refers to the number of bad samples out of 57 excluded from data.

- Each wafer consisted of 80 diodes from which 57 were measured.
- The sample was considered to be bad if breakdown occured before the full depletion.

Conclusions

- There is a good agreement between the calculations and the experimental data, based on measurement of V_{fd}, if the TD generation is assumed to obey $N_{TD} \propto O_i^{1.89}$ dependence on the oxygen concentration.

- There is technological importance in TD's. The shallow donors have twofold influence on the macroscopic properties of the detectors:

  - First, shallow oxygen thermal donors can be utilized during the fabrication process in order to manipulate the effective doping concentration (N_{eff}) of the silicon bulk.

  - Second, the shallow donors interact with the radiation defects and influence the radiation hardness of the detectors.

- With TD generation method it is possible, with low cost and with a process of low thermal budget, to fabricate detectors with high oxygen concentration that can be depleted at voltages less than 100 V.