Degradation of High Resistivity Float Zone and Magnetic Czochralski N-type Silicon Detectors subjected to 2-MeV Electron Irradiation

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Introduction & Abstract

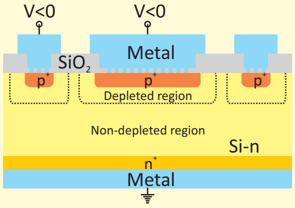
Particle tracking detectors made on **high resistivity (HR) float zone (FZ) silicon** are widely used in **high energy physics experiments**. Results from CERN RD48 & RD50 collaborations have shown that **diffusion oxygenated FZ (DOFZ) Si can better withstand the high hadron fluences** expected for 10 years operation of the **Large Hadron Collider at CERN** [1]. Now, semiconductor industry interests and developments have enabled the production of **magnetic Czochralski (MCZ) Si** wafers **with sufficiently HR and** with a **well-controlled high concentration of interstitial oxygen.** In order to shed some further light on the **behavior of the HR MCZ n-type material under electron irradiation** [2,3], we investigate here the **effects of 2 MeV e- irradiation,** up to a fluence of $5\cdot10^{16}$ e/cm^2, on the **electrical and carrier lifetime properties** of **p-on-n silicon diodes fabricated on different substrate materials**, including **HR standard** & **oxygenated FZ**, as well as **HR MCZ Si.**

Devices & Experimental

- **Main specifications of the 3 HR Si substrates studied**

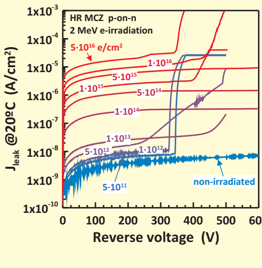
Substrate	HR MCZ Si	HR FZ Si	HR FZ Si Diffusion Oxygenated
Wafers supplier	Okmetic	Topsil	Topsil
Type	n	n	n
Crystal orientation	<100>	<100>	<100>
Wafer thickness (d)	300 ± 10 µm	280 ± 15 µm	280 ± 15 µm
Resistivity	1.05 ± 0.09 k± ·cm	4.5 ± 0.6 k± ·cm	2.5 ± 0.1 k± ·cm
Dop. concentration	$3.9 \pm 0.4 \pm 10^{12}$ cm^{-3}	$9 \pm 1 \pm 10^{11}$ cm^{-3}	$1.64 \pm 0.07 \pm 10^{12}$ cm^{-3}
Average [O$_i$]	$4.6 \pm 0.2 \pm 10^{17}$ cm^{-3}	$< 9 \pm 10^{15}$ cm^{-3}	$1.7 \pm 0.4 \pm 10^{17}$ cm^{-3}
Average [C]	$9 \pm 1 \pm 10^{15}$ cm^{-3}	$5.4 \pm 0.4 \pm 10^{15}$ cm^{-3}	$5.7 \pm 0.3 \pm 10^{15}$ cm^{-3}

- **Fabricated p-on-n diodes**



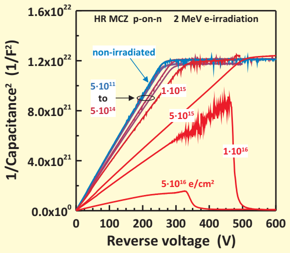
- **2 MeV e-irradiation @ Room T** (Dynamitron, Takasaki-JAERI, Japan)
  Fluences (ϕ) from $5\cdot10^{11}$ to $5\cdot10^{16}$ e/cm^2
- **I-V & C-V characterization**
  2 Keithley 2410 SourceMeters + Agilent 4284 Precision LCR meter
- **Minority carrier recombination lifetime (τ_r) measurements**
  Semilab WT-1000 microwave photoconductance decay (µW-PCD)

I-V & C-V degradation



Typical degradation I-V
HR MCZ, HR FZ, HR DOFZ

Generation-recombination centers
(bulk damage)

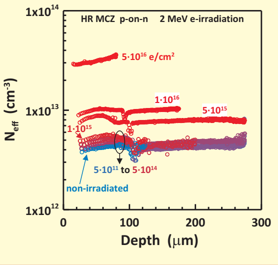


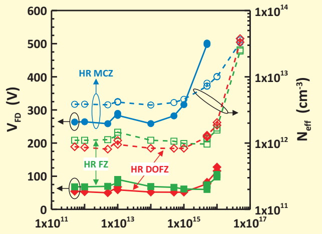
Degradation of C-V curves
after the highest e- fluences

Full wafer thickness
depletion voltage (V_{FD})

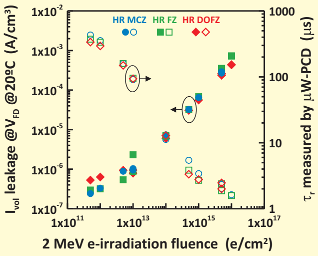
Effective free carrier conc. (N_{eff})

$$N_{eff} = \frac{2\varepsilon_0\varepsilon_{Si}}{q\cdot d^2}\cdot V_{FD}$$





I-V, generation & recombination lifetimes



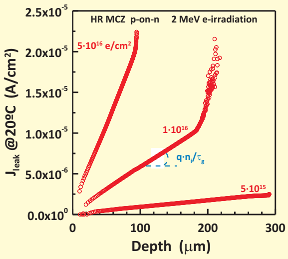
Siimilar trend for leakage current increase for all 3 HR Si substrates

$I_{vol} = \alpha\cdot\phi$ $I_{vol} = \dfrac{J_{leak}}{depth}$

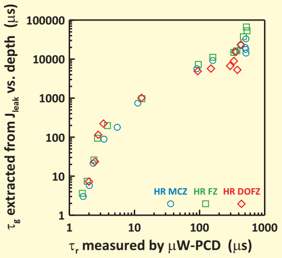
$\alpha \sim 5.5\cdot10^{-20}$ A/cm

Good agreement with literature for standard resistivity Si [4]

µW-PCD τ_r **values monotonously decreasing** with **e-irradiation fluence**



Generation lifetime τ_g extracted from J_{leak} vs. depletion depth

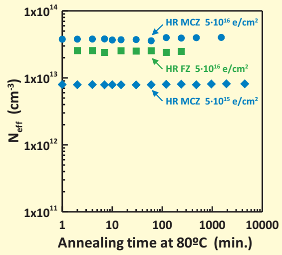


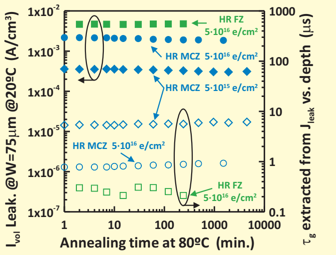
Certain **correlation** between **degradation** of τ_g and **µW-PCD** τ_r

Assuming intermediate ϕ region with $\tau_g/\tau_r \approx$ **40-50** $\dfrac{\tau_g}{2\cdot\tau_r} = \cosh\dfrac{E_T - E_i}{kT}$

Dominant effective trap level estimated at **~ 100 mV from midgap**

Thermal annealing effects





Under the limited experimental conditions studied, **no significant changes are observed for diode characteristics after 80ºC thermal annealing**

Conclusions

A **progressive degradation** is observed for all devices, pointing to a **generation of bulk damage.** Interestingly, **a significant increase of the effective donor concentration** is observed after the **highest fluences** for **all materials. This degradation in the electrical properties should be taken into account** for applications **under high energy e- environments.**

References

[1] G. Lindström, et al., Nucl. Instr. & Meth. A 466 (2001), 308.
[2] B. Dezillie, et al., IEEE Trans. Nucl. Sci. 47 (2000), 1892.
[3] S. Dittongo, et al., Nucl. Instr. & Meth. A 546 (2005), 300.
[4] A. Vasilescu, et al., http://sesam.desy.de/members/gunnar/Si-dfuncs.html

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