A New Approach in Si Detector Radiation Hardness/Tolerance Improvement

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Introduction

- For SLHC, with 10^{35} luminosity, total radiation fluence can be as high as 10^{16} n_{eq}/cm^2

- At this highest fluence, detector degrades in many ways:
  - High leakage current (I_L): $4x10^{-1}$ A/cm^3 at RT!
  - High full depletion bias (V_{fd}): 6400 V for 200 μm thick STD FZ detector!
  - Low charge collection distance (CCE): 10 to 20 μm regardless of detector detector thickness and depletion depth!

- Radiation hard/tolerant Si detectors have to improve with regard to all three problems listed above
- Most conventional approaches may solve only one to two problems
- Need a new, simple/easy approach

Current/Conventional Approaches

- **Defect/Impurity/material Engineering (DIME)**

Approach	Good for	Technology
Oxygenation/MCZ (RD50)	V_{fd}	Easy
Diamond/SiC/Ga/N, etc. (RD42, 50)	V_{fd}	Easy

- **Device Structure Engineering (DSE)**

3d (RD50)	CCE (τ_{tr}), V_{fd}	V. Difficult
Semi-3d (RD50)	V_{fd}	Easy
Thin detector (RD50)	V_{fd}	Difficult

- **Device Operational Mode Engineering (DOME)**

Cryogenic detector (RD39)	I_L, V_{fd}	V.Difficult
	CCE (τ_{tr})?	Very low T

New Approaches

Device Recovery/Improvement Via Elevated temperature annealing (DRIVE)

- Back in May, 2004, during the CERN RD39 and RD50 collaboration meeting period, Z. Li and J. Harkonen discussed the possibility of elevated temperature annealing of radiation damaged n and p-type MCZ Si detectors based on the TD generation in these materials/detectors
- Thermal annealing of radiation damage has been a conventional way for material/device recovery
- It has not been used so far in HE physics detector field for STD FZ and oxygenated FZ detectors because :
  - If the annealing temperature is too high (>450 °C), it will destroy the detector and/or electronics
  - If the annealing temperature is too low (< 450 °C), the reverse annealing (generation of more negative space charges) will make the detector worse

New Approaches

Device Recovery/Improvement Via Elevated temperature annealing (DRIVE) (continues)

- However, for MCZ Si material/detectors, thermal annealing in the temperature range from 200 °C to 450 °C will generate TD (positive space charge)
- By playing the annealing T and time, [O] (n-type or p-type MCZ Si), one may adjust the TD creation rate in such a way to cancel the reverse annealing effect, and even better, to compensate the original (as-irradiated) negative space charges, which may bring the full depletion voltage down to a manageable range
- ETA will also anneal out/down the detector leakage current, and improve detector CCE by annealing out trapping centers
- The **DRIVE** approach may therefore offer a technology to improve all three areas:
  - I_L, V_{fd}, CCE (τ_{tr})
- The degree of difficulty may vary depending on the annealing techniques

New Approaches

Device Recovery/Improvement Via Elevated temperature annealing (DRIVE) (continues)

The degree of difficulty may vary depending on the annealing techniques

Technique	Degree of difficulty	Other components affected
o Oven annealing	low	yes
o Rapid Thermal Process (RTP)	high	less
o Light (lamp) annealing	medium	little

The lamp annealing may be done locally, and within the detector system (no disassemble necessary)

Comparison and summary of radiation induced detects

introduction rate of stable defects

$N_{eff} = \beta_{\gamma,n,\mathrm{n_{eq}}} \cdot \Phi_{\gamma,n,or\,\mathrm{n_{eq}}}$, ($\Phi_\gamma$ in Mrad, Φ_n and $\Phi_{\mathrm{n_{eq}}}$ in $\mathrm{n_{eq}/cm^2}$)

Detector Type	Gamma β_γ (1/Mrad-cm^3)	n (1 MeV) β_n (1/n_{eq}-cm)	Proton $\beta_{n_{eq}}$ (1/ n_{eq}-cm)	Normalized Rad-hard factor
CFZ	-1.82x10^9	-0.022	-----	1
MCZ	**2.92x10^9**	-0.017	**-0.0045**	5
(old) FZ	-8.0x10^9	-0.023	-0.022	1
HTLT oxygenated	**4.1x10^8**	-0.023	**-0.0094**	2.4

Introduction rate of reverse anneal generated defects

$N_{eff}^{rev} = \beta_{rev,n\,or\,\mathrm{n_{eq}}} \cdot \Phi_{n\,or\,\mathrm{n_{eq}}}$, ($\Phi_n$ and $\Phi_{\mathrm{n_{eq}}}$ in $\mathrm{n_{eq}/cm^2}$)

Detector Type	n (1 MeV) β_n^{rev} (1/n_{eq}-cm)	Proton $\beta_{n_{eq}}^{rev}$ (1/ n_{eq} -cm)	Normalized Rad-hard factor
CFZ	-0.062		1
MCZ	-0.050	**-0.0096**	5-7
(old) FZ	-0.073		1

0.014 total

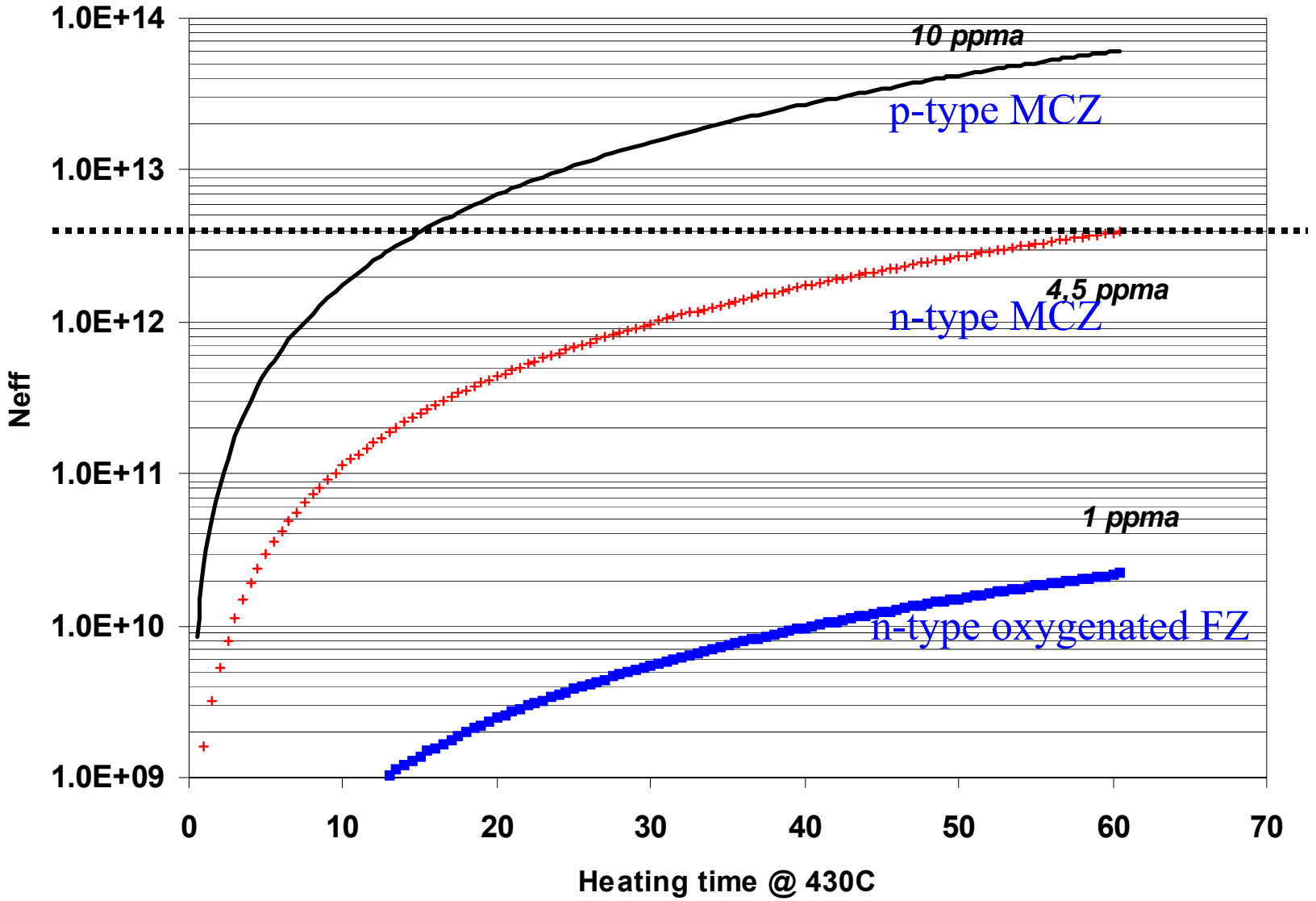
Very low already for n-type MCZ Si detectors May be even lower for p-type MCZ detectors

Table 2 Gamma irradiation induced changes in as-processed p-type MCZ Si detectors

Detector #	Initial N_{eff} (Resistivity)	Change in N_{eff} (ΔN_{eff})	+SC build-up rate
P351-A	-1.326×10^{12} cm^{-3} (10.5 kΩ-cm)	3.32×10^{12} cm^{-3}	8.25×10^{9} cm^{-3}/Mrad
P330-A	-4.38×10^{12} cm^{-3} (3.2 kΩ-cm)	3.25×10^{12} cm^{-3}	8.08×10^{9} cm^{-3}/Mrad

The rate of positive SC build-up in p-type MCZ Si is much higher than those observed before for pre-irradiated and as-processed n-type MCZ Si detectors (2.8×10^{9}) --- may be due to higher [O] in p-type MCZ Si

TD generation in different Si with different [O]

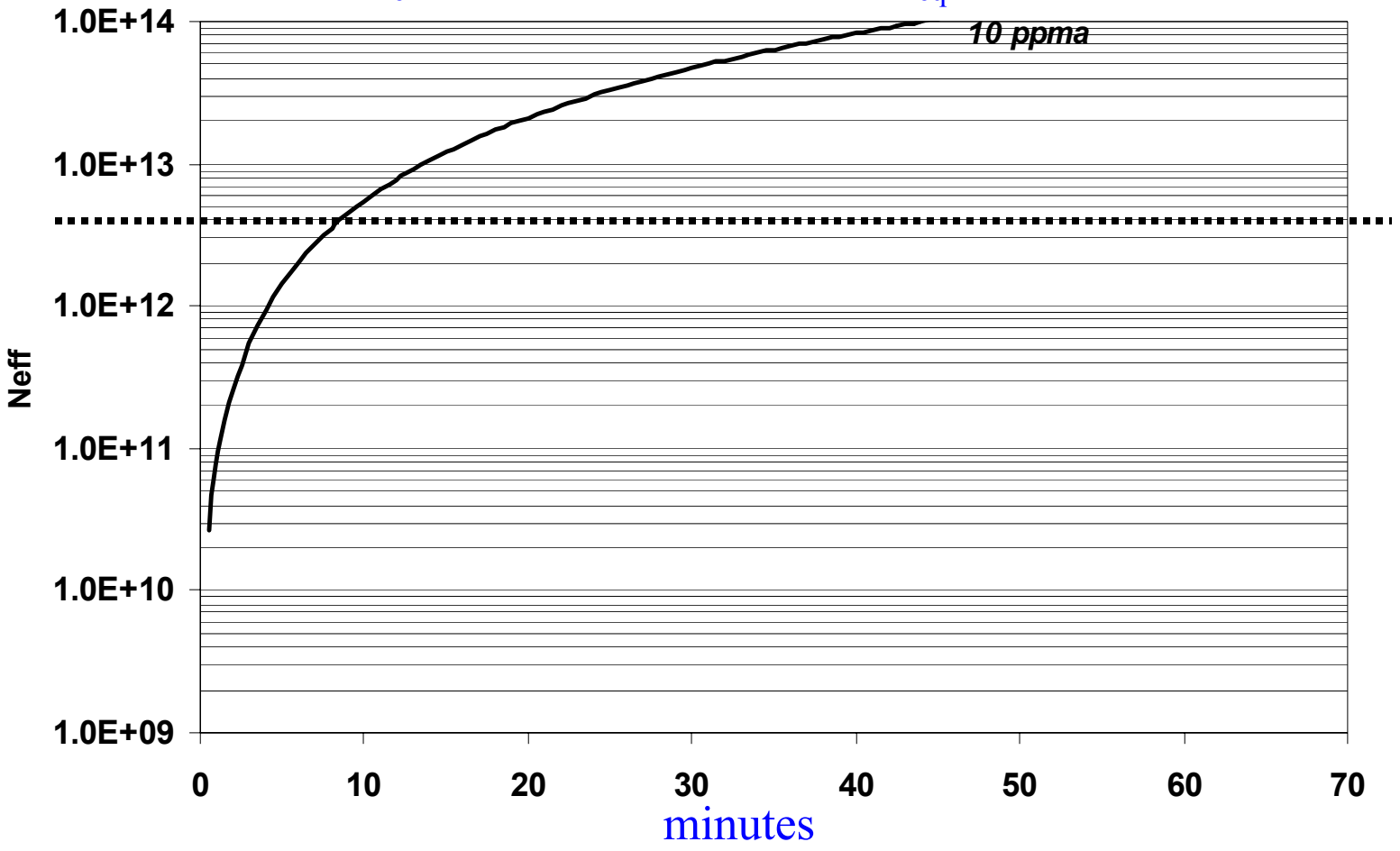


TD generation at 450 °C in p-type MCZ

One can reach >10^{14} /cm^3 in TD concentration in one hour!

Might be enough to cancel – SC generated in irradiation and during reverse anneal

N_{eff} in the 10^{14}/cm^3 for 10^{16} n_{eq}/cm^2



Summary

- The conventional approaches may not solved all the radiation induced problems

- The new approach, DRIVE, could offer a perfect solution to radiation induced problems, especially at high fluences for SLHC

- By changing annealing temp, time, one may get a perfect receipt for different fluences

- P-type MCZ Si may be the best material due to its higher [O] than that of n-type MCZ

- Different annealing techniques may be used for DRIVE depending on the experiment conditions