Isochronal Annealing Studies of Irradiated Silicon Diodes

Beverley Craig (EP-TA1-SD)

Summer Student Project

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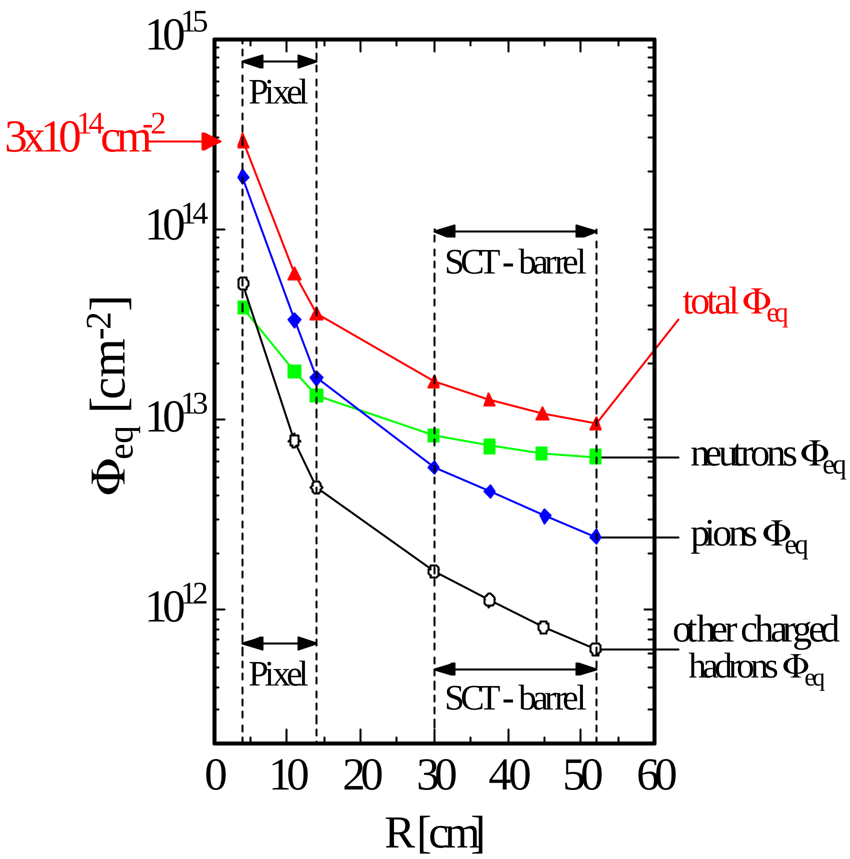
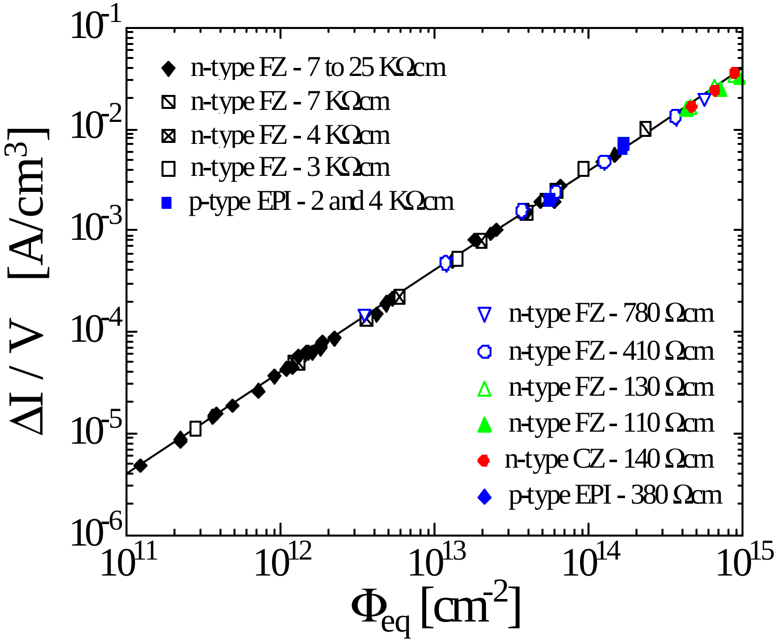
Motivation



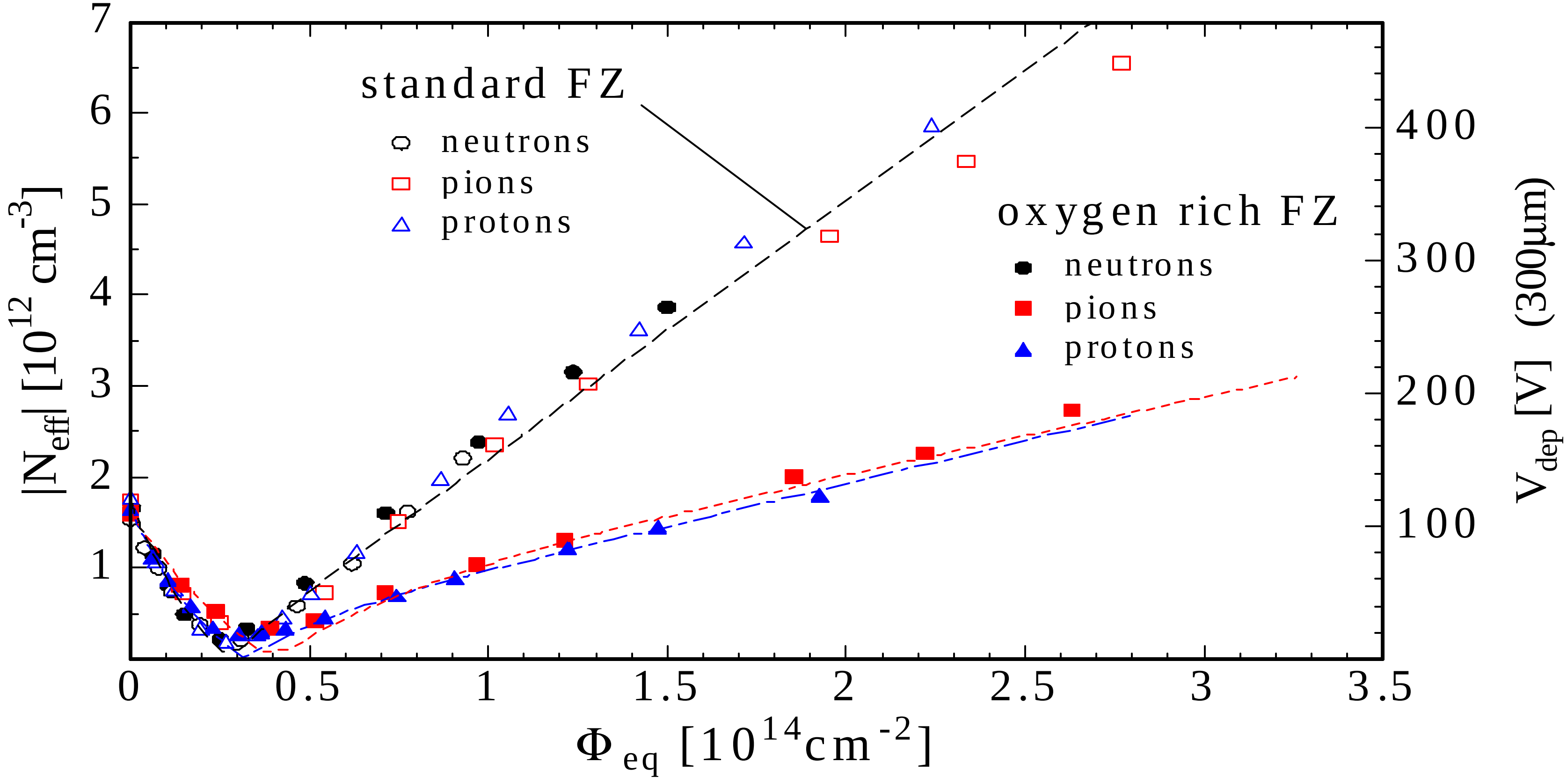
- Detectors will be harshly irradiated
- Φ_{eq} up to 3e14cm^{-2} per year
- required 10 years of useful operation

- Detector Characteristics affected by radiation:
  - -Leakage Current
  - -Depletion Voltage
  - -Charge Collection Efficiency

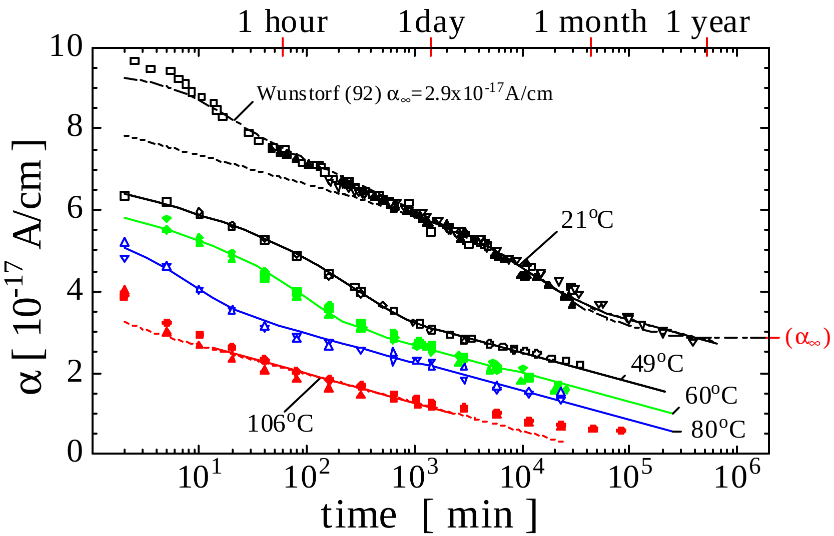
Leakage current Vs Φ_{eq}



Standard and Oxygen Enriched Silicon – particle dependence

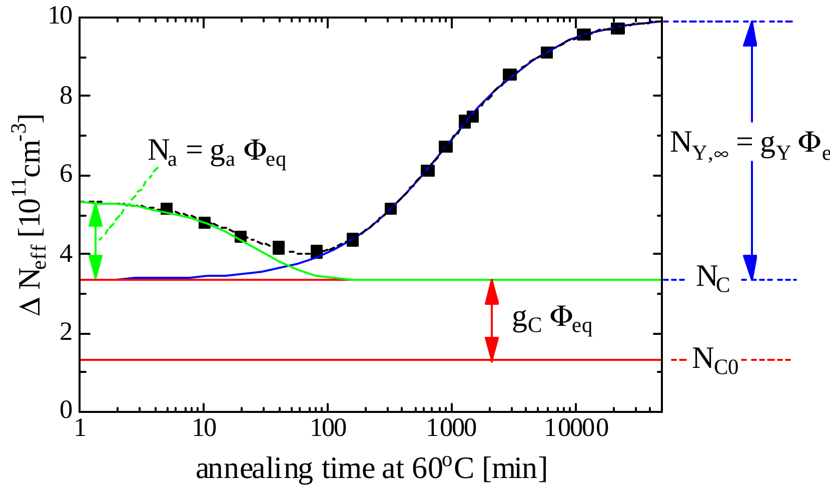


Leakage Current Annealing



I=αVΦ

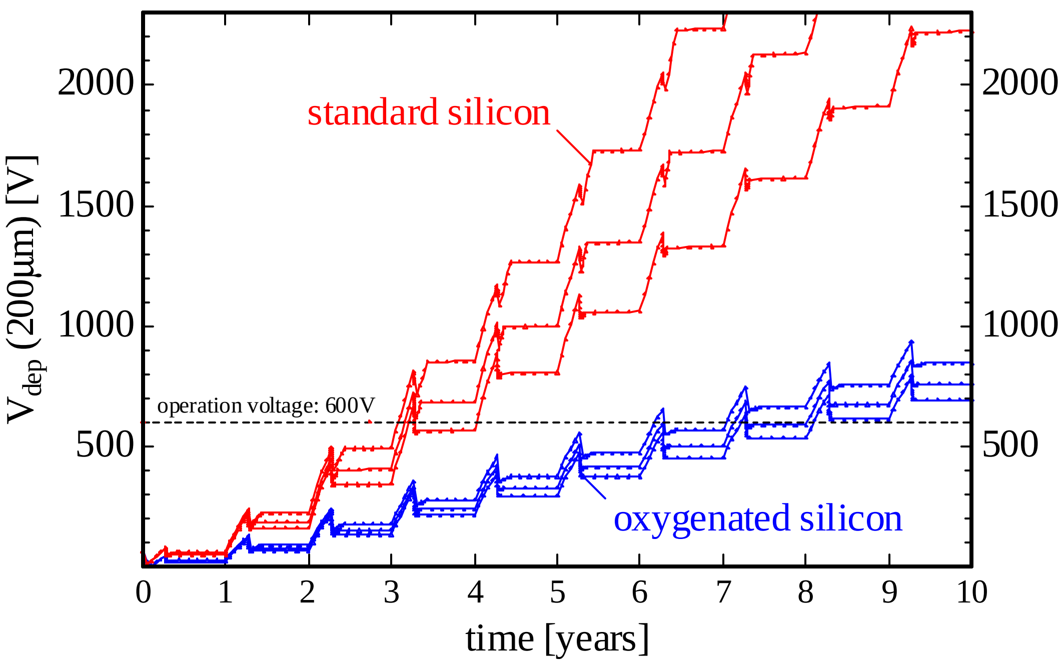
Depletion Voltage Annealing



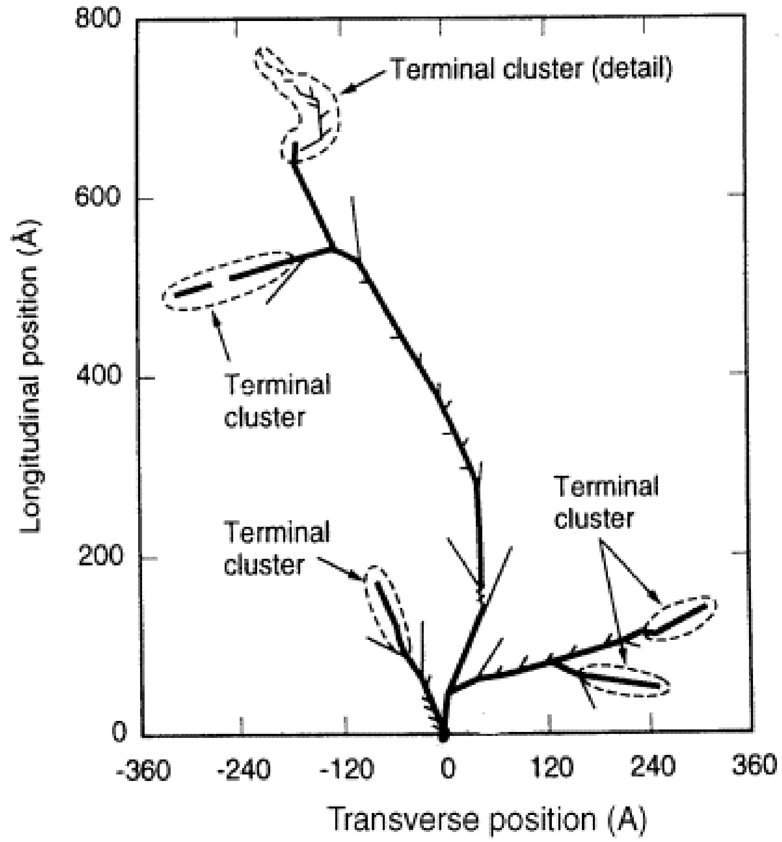
$$N_{eff} \propto \frac{V_{dep}}{d^{\wedge}2}$$

Damage Projection - ATLAS Pixel Detector - B-Layer (4cm)

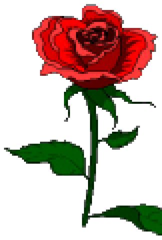
- Radiation level: ■ Φ_{eq}(year) = 3.5×10^{14} cm^{-2} **(full luminosity)**
  > 85% charged hadrons
- Three scenario: ■ 1 year = 100 days beam (-7°C)
  (1) 3 days 20°C and 14 days 17°C
  (2) 30 days 20°C
  (3) 60 days 20°C
  Rest of the year: no beam (-7°C)



Radiation Damage



- Monte carlo Simulation of 50KeV PKA, from former ROSE collaboration (RD48)
- New RD50 project
- NIEL (Non Ionizing Energy Loss)



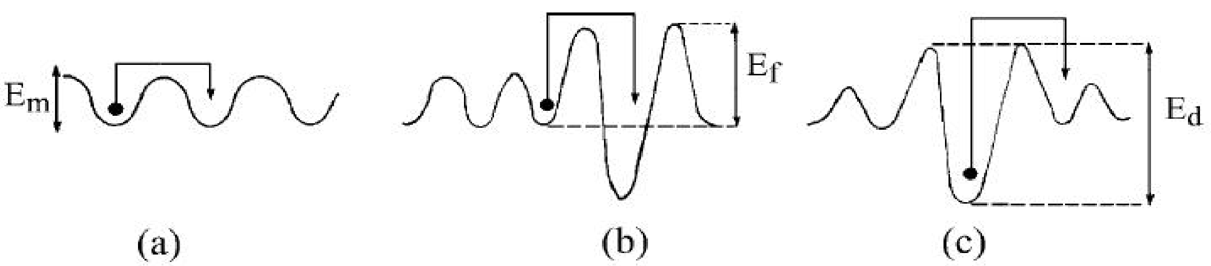
Isochronal Annealing

- 3 mechanisms

  a) migration

  b) complex formation

  c) dissociation

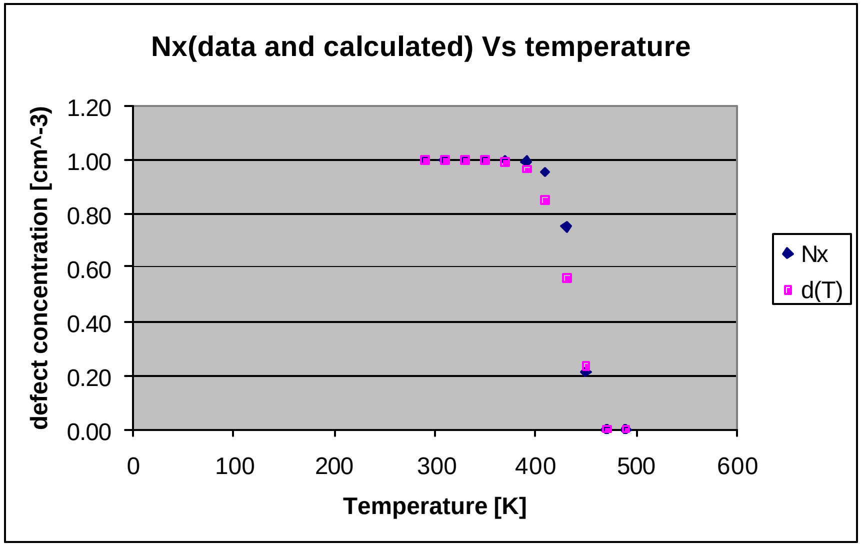


Annealing Follows exponential decay: $$N_d \propto N_{do}.\exp\left(\frac{-t}{t}\right)$$

where $$t = \frac{1}{k}\exp\left(\frac{E_A}{k_b T}\right)$$

Simulation

- Annealing Temperature :-
  defect concentration falls below 1/e-th part of the initial concentration
- Extract E_A



Experimental procedure

- Detectors provided by Hamburg group
- Irradiations at CERN PS (20GeV/c protons)and PSI (300MeV/c Π^+)
- Characteristics were taken for each detector after annealing for 15 minutes, over the range 20ºC to 280ºC in 20ºC steps.
- Plots were produced for each measurement. From these, temperature plots were constructed and comparisons made.

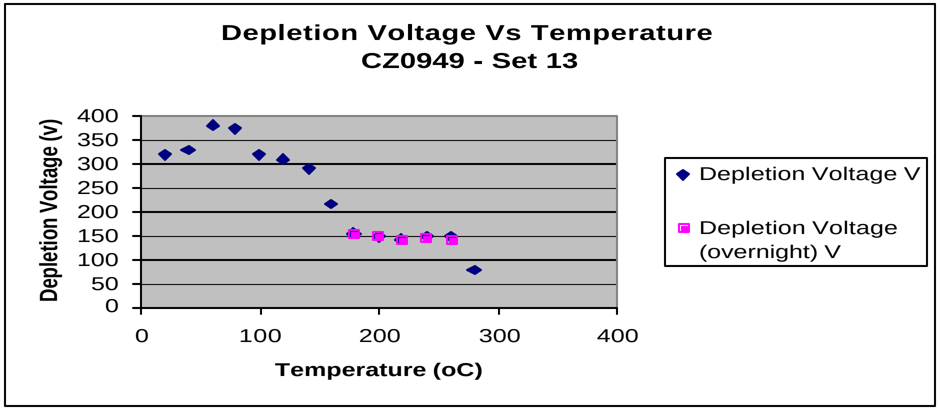
Detector Materials

Detector Name	Detector Type	Resistivity
CA09	Standard float zone silicon	4.2kΩcm
CB08	DOFZ (24hr oxygenated)	3.6kΩcm
CC11	DOFZ (48hr oxygenated)	4kΩcm
CD19	DOFZ (72hr oxygenated)	3.37kΩcm
CZ07/CZ08	Czochralski thermal donor killed	1.2kΩcm
CZ09	Czochralski thermal donor generated	1.2kΩcm

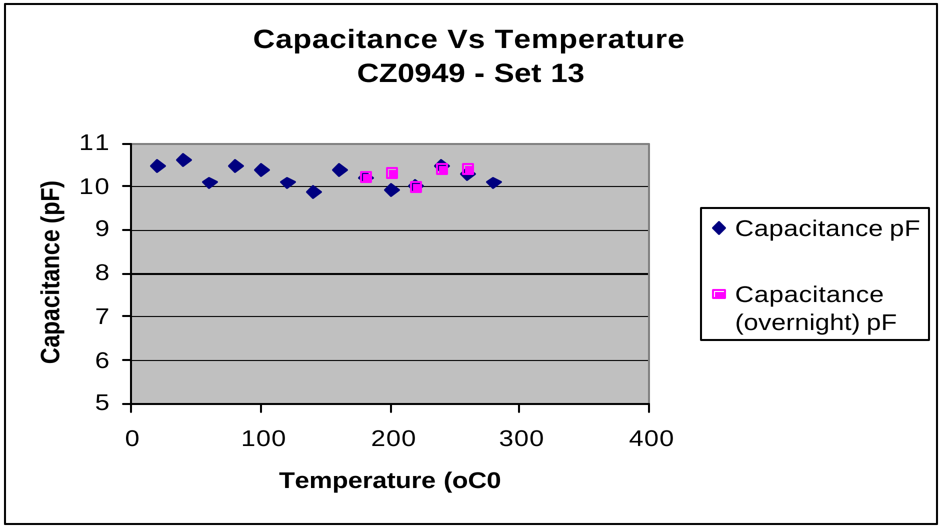
Irradiation

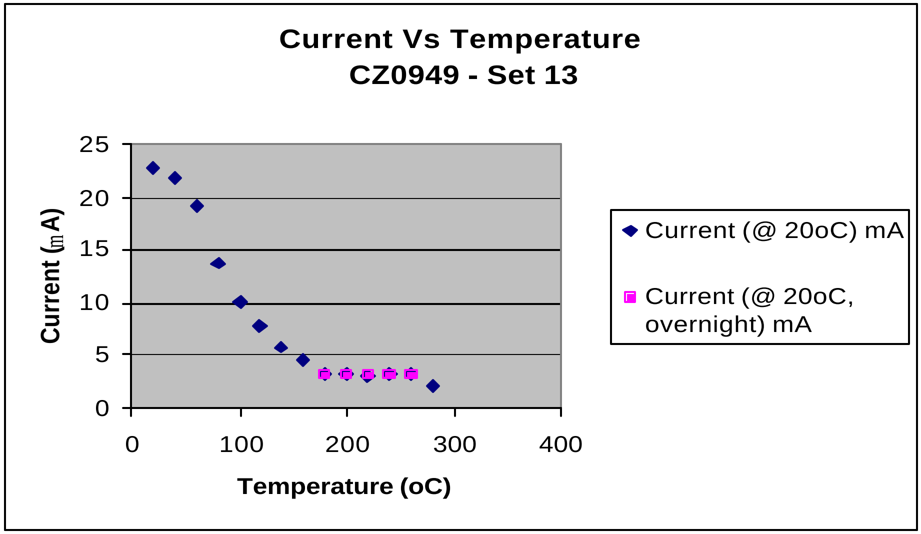
Set	Irradiating Particle	Fluence achieved [cm^{-2}]
12 [FZ, 3xDOFZ, CZ-TD, CZ-TDK]	300MeV/c pions	9.33e13
13 [FZ, 3xDOFZ, CZ-TD, CZ-TDK]	300MeV/c pions	4.18e13
190 [CZ-TD, CZ-TDK]	20 GeV/c protons	9.08e13
195 [CZ-TD, CZ-TDK]	20 GeV/c protons	3.95e13
197 [FZ, 3xDOFZ,]	20 GeV/c protons	5.23e13
198 [FZ, 3xDOFZ,]	20 GeV/c protons	9.15e13

Isochronal Annealing of Irradiated Detector (1)

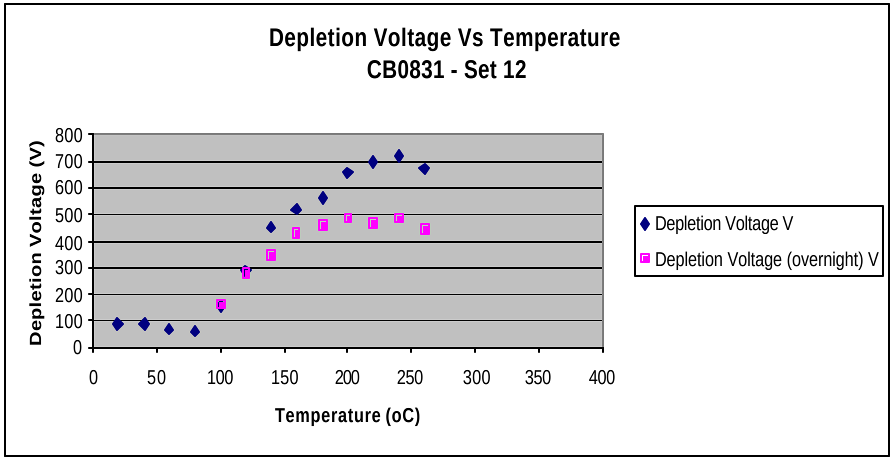


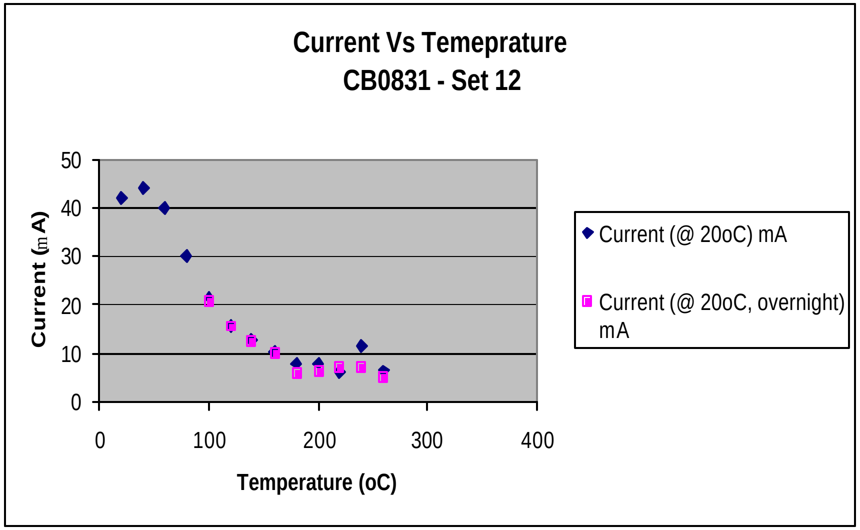
Example of a Czochralski diode





Isochronal Annealing of Irradiated Detector (1)

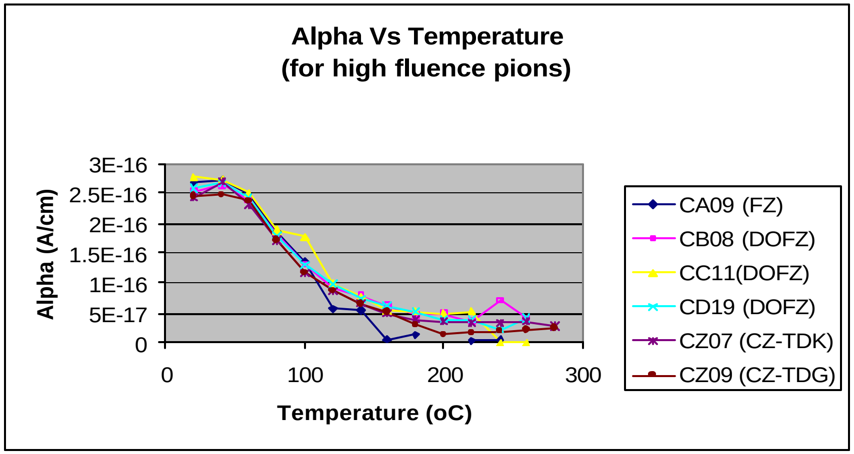


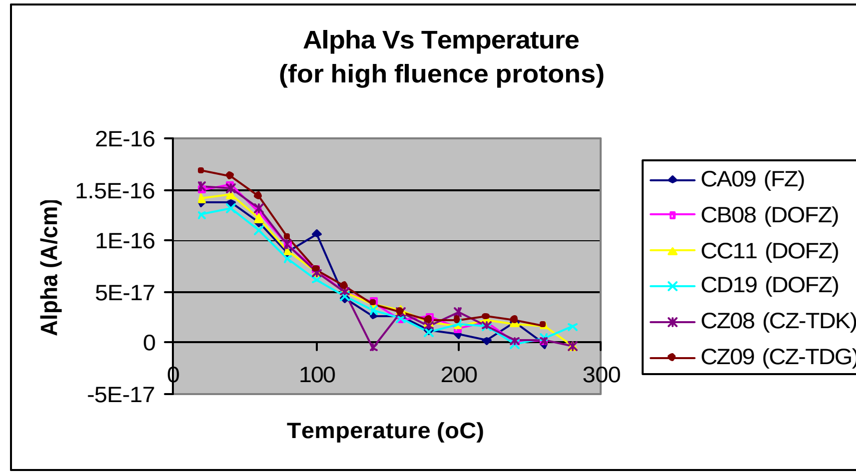


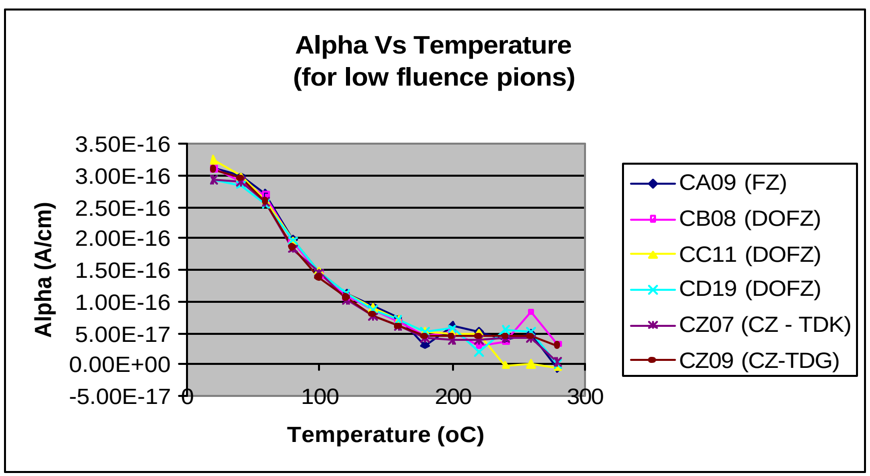
Example of a DOFZ diode

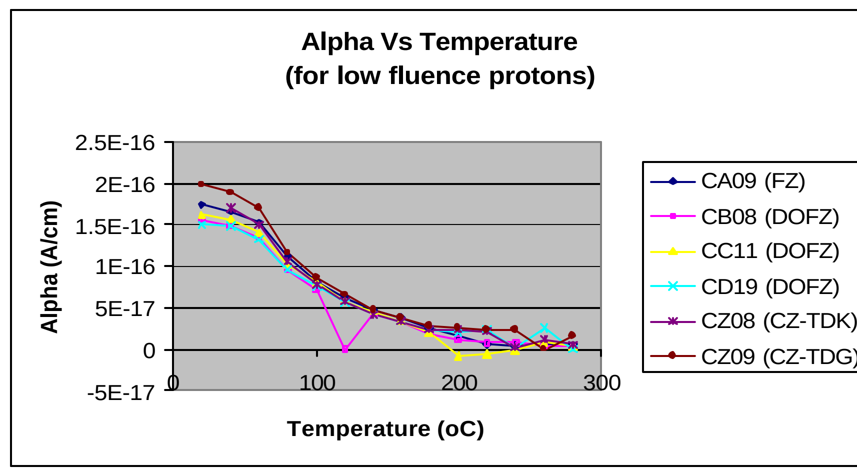
(24hr oxygenated)

a variation with temperature (I=aVF)

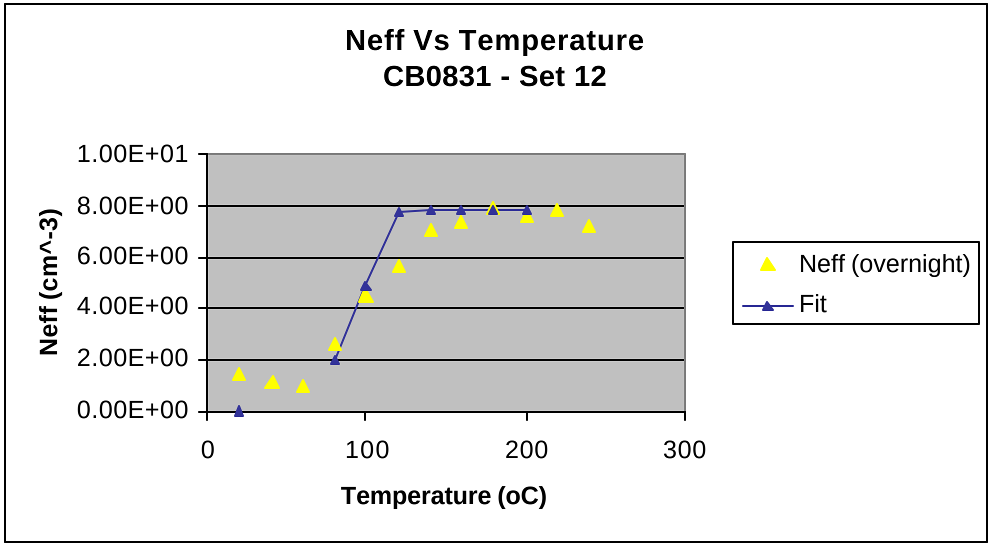


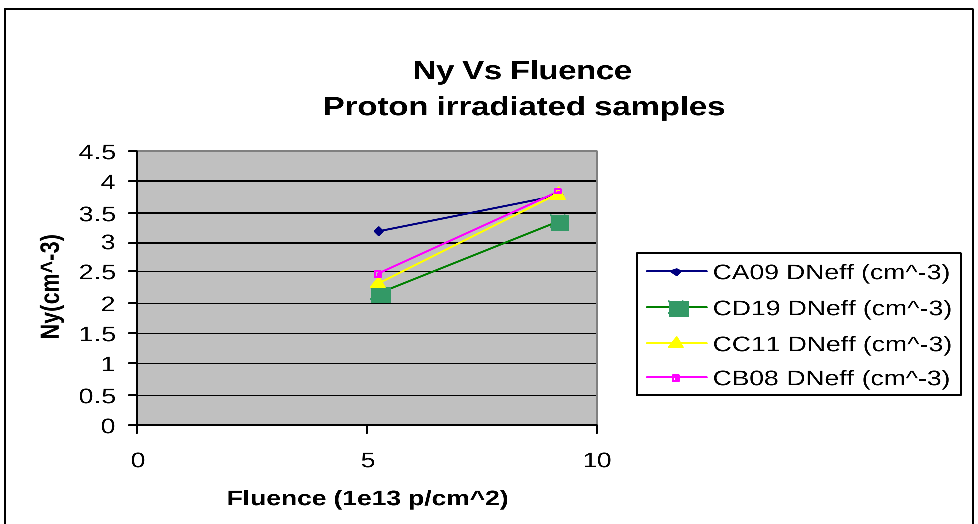






Neff Variation





	fluence (1e13/cm^2)	ΔNeff/Φ
Protons (low)		
CA09 (FZ)	5.23	0.606119
CB08 (DOFZ)	5.23	0.474187
CC11 (DOFZ)	5.23	0.449331
CD19 (DOFZ)	5.23	0.414914
CZ08 (CZ-TDK)	3.95	-0.66329
CZ09 (CZ-TDG)	3.95	-0.8481
Protons (high)		
CA09 (FZ)	9.15	0.414208
CB08 (DOFZ)	9.15	0.420765
CC11 (DOFZ)	9.15	0.417486
CD19 (DOFZ)	9.15	0.365027
CZ08 (CZ-TDK)	9.08	-0.28744
CZ09 (CZ-TDG)	9.08	-0.57819
Pions (low)		
CA09 (FZ)	4.18	1.043062
CB08 (DOFZ)	4.18	0.880383
CC11 (DOFZ)	4.18	0.901914
CD19 (DOFZ)	4.18	0.901914
CZ07 (CZ-TDK)	4.18	-0.63636
CZ09 (CZ-TDG)	4.18	-0.84928
Pions (high)	9.33	
CA09 (FZ)	9.33	0.734191
CB08 (DOFZ)	9.33	0.736334
CC11 (DOFZ)	9.33	0.708467
CD19 (DOFZ)	9.33	0.709539
CZ07 (CZ-TDK)	9.33	-0.25723
CZ09 (CZ-TDG)	9.33	-0.48124

Conclusions

- α was found to vary with fluence and temperature, but was independent of material – as expected from previous studies
- $\Delta N_{eff}/\Phi$ was lower for more oxygenated materials.
- $\Delta N_{eff}/\Phi$ is not constant -> Saturation effect.
- Depletion Voltage decreased for CZ material at higher temperatures, increased for both FZ and DOFZ. Cz is not type inverted.
- 'overnight effect' not observed for CZ N_{eff}
- 'overnight' effect not observed for α -> defect producing effect is not current producing.