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Capacitance Measurements and Depletion Voltage for Annealed Fz and MCz Diodes

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Outline

- Motivation
- Experiment Set up
- V_{fd} Extraction
- V_{fd} dependence on annealing and fluence
- Comparison of devices at 80 minutes anneal time

Motivation

ATLAS Upgrade will reach fluences of $7x10^{14}$ n_{eq}/cm^2 for the short Si strip detectors. The work presented here is part of a larger effort to fully characterize different types of Si sensors intended for this fluence region.

Electrical Properties:

- Type Inversion (N_{eff})
- Depletion Voltage (V_{fd})
- Efficiency Voltage (from CCE)

Dependence on:

- p,n,π^+ Irradiation
- Annealing

This Talk: a detailed study on V_{fd} behavior after proton irradiation and annealing.

Devices

Si Diodes:

	n-on-p Fz	**p-on-n Fz**	**n-on-p MCz**	**p-on-n MCz**
Manufacturer	HPK	Micron	Micron	Micron
Resistivity	13 kΩ-cm	3.3 kΩ-cm	1.9 kΩ-cm	1.4 kΩ-cm
Active Area	3mmx3mm	3mmx3mm	3mmx3mm	3mmx3mm
Thickness	300 μm	300 μm	300 μm	300 μm
Initial V_{fd} [V]	75	95	520	220

Irradiations/Annealing

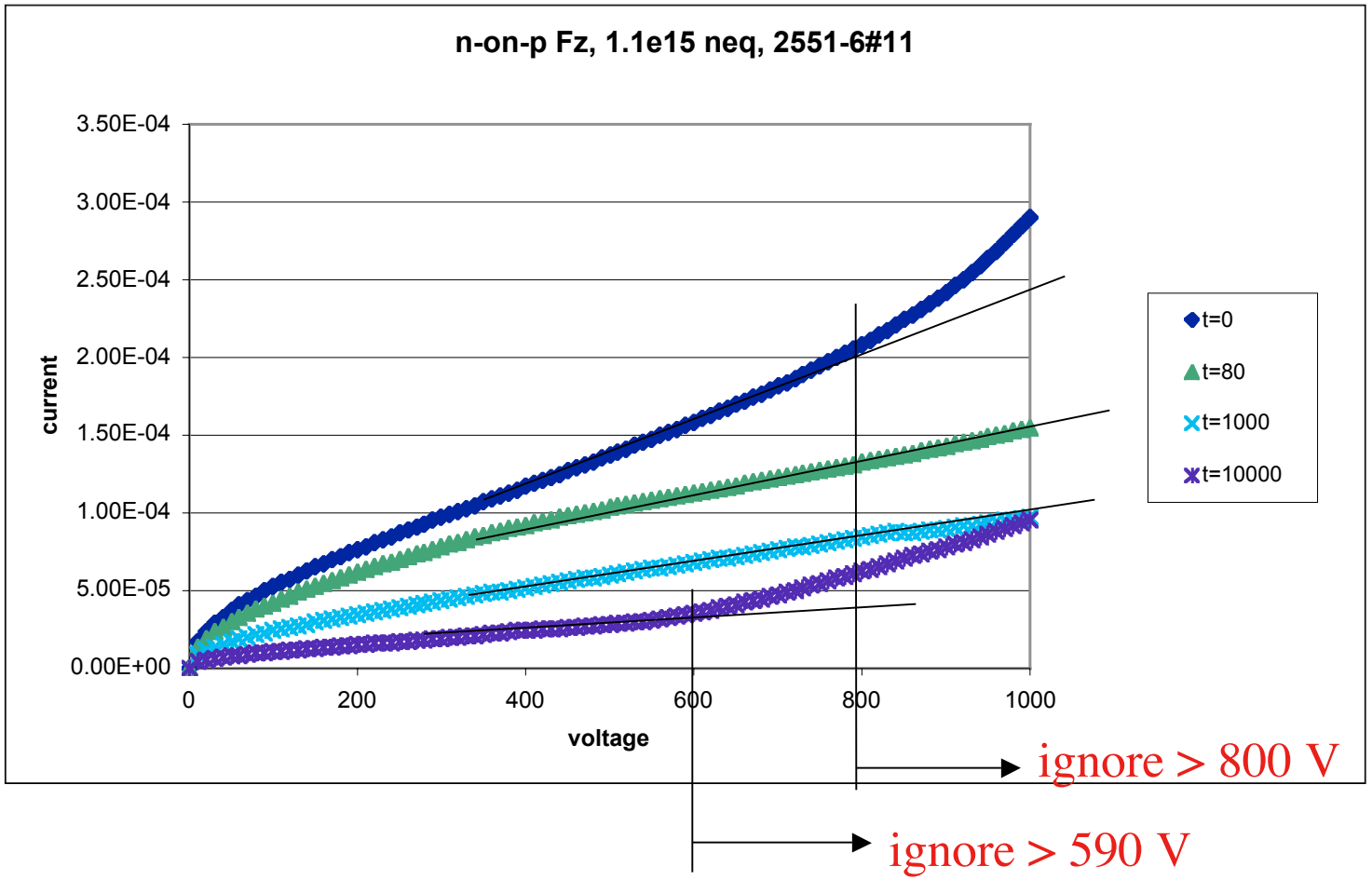
Irradiations:

- 800 MeV protons at Los Alamos
- Hardness Factor: 0.71
- 5e11 protons per pulse at 1 Hz
- 2 cm diameter beam spot
- fluences reached in < 24 hours
- stored in freezer immediately after
- Fluences:
  - 1.1×10^{14} p/cm^2 = 7.8×10^{13} n_{eq}/cm^2
  - 2.2×10^{14} p/cm^2 = 1.5×10^{14} n_{eq}/cm^2
  - 1.5×10^{15} p/cm^2 = 1.1×10^{15} n_{eq}/cm^2

Annealing:

- 60 ºC
- Steps: 10, 80, 1,000 and 10,000 minutes

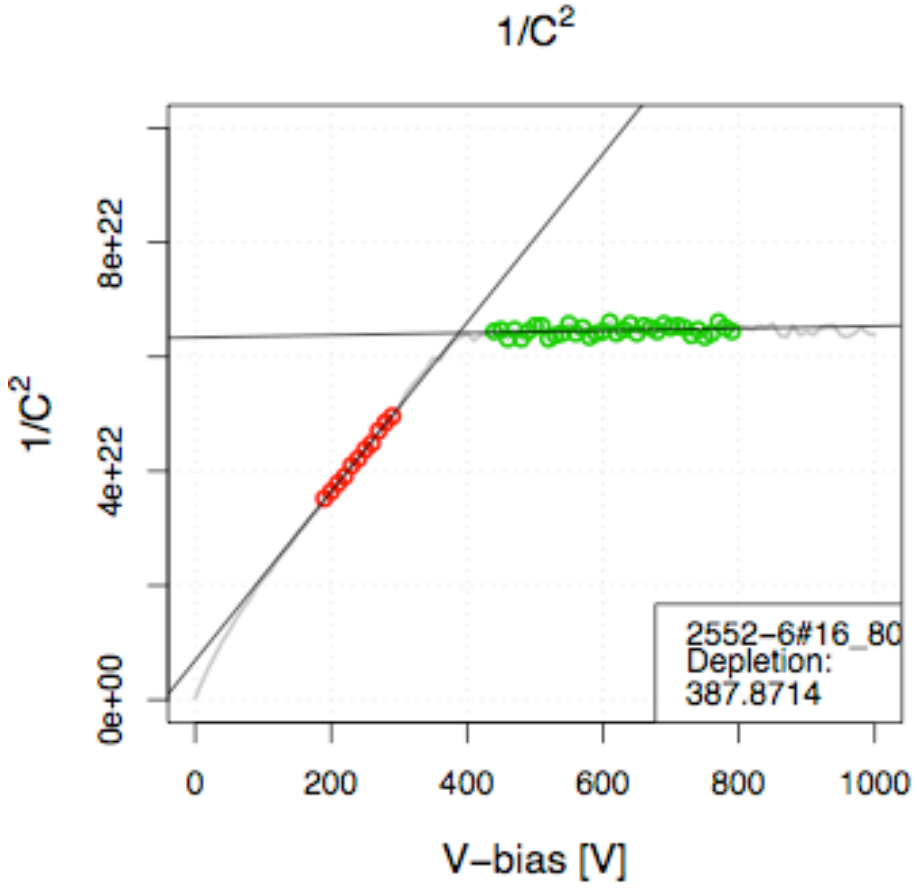
IV Measurements



IV Measurements:

- All measurements at 20 ºC
- Identify "superlinear" behavior for each IV curve--possible indication of thermal runaway
- Ignore data on CV curves above superlinear threshold

Full Depletion Voltage

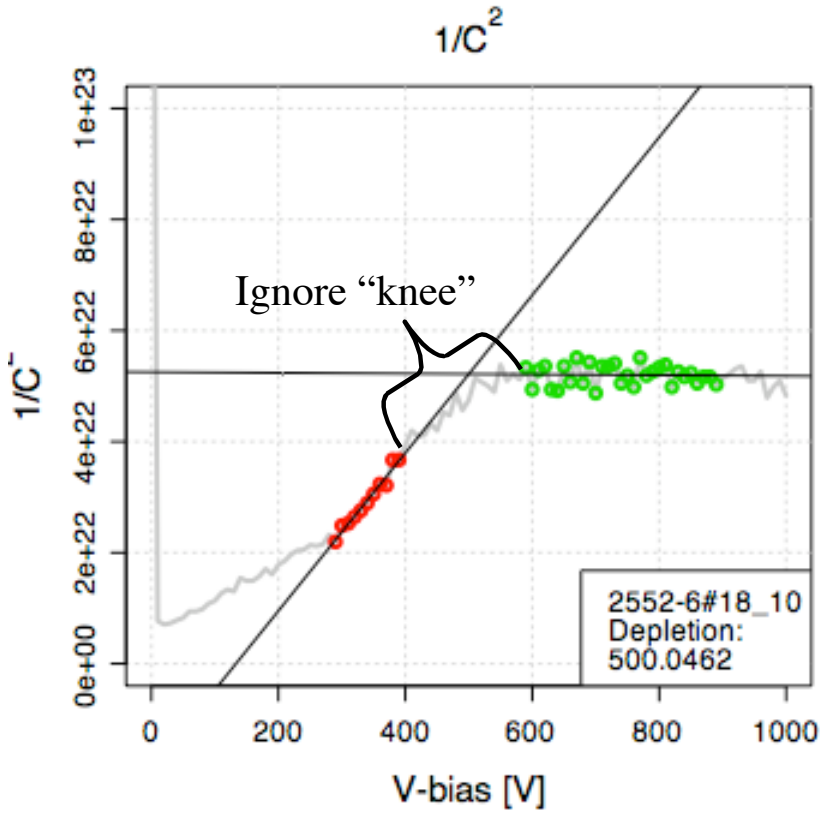


n-on-p MCz irradiated to 7.8×10^{13} n_{eq}/cm^2 after 80 minutes anneal time.

Measurements:

- CV curves measured at 10 kHz.
- V_{fd} was determined by fitting two straight lines to the ascending part and the plateau part of the curve and taking the intersection of the lines.

Full Depletion Voltage



n-on-p MCz irradiated to 1.1×10^{15} n_{eq}/cm^2 after 10 minutes anneal time. $V_{fd} = 500 \pm 10$ V.

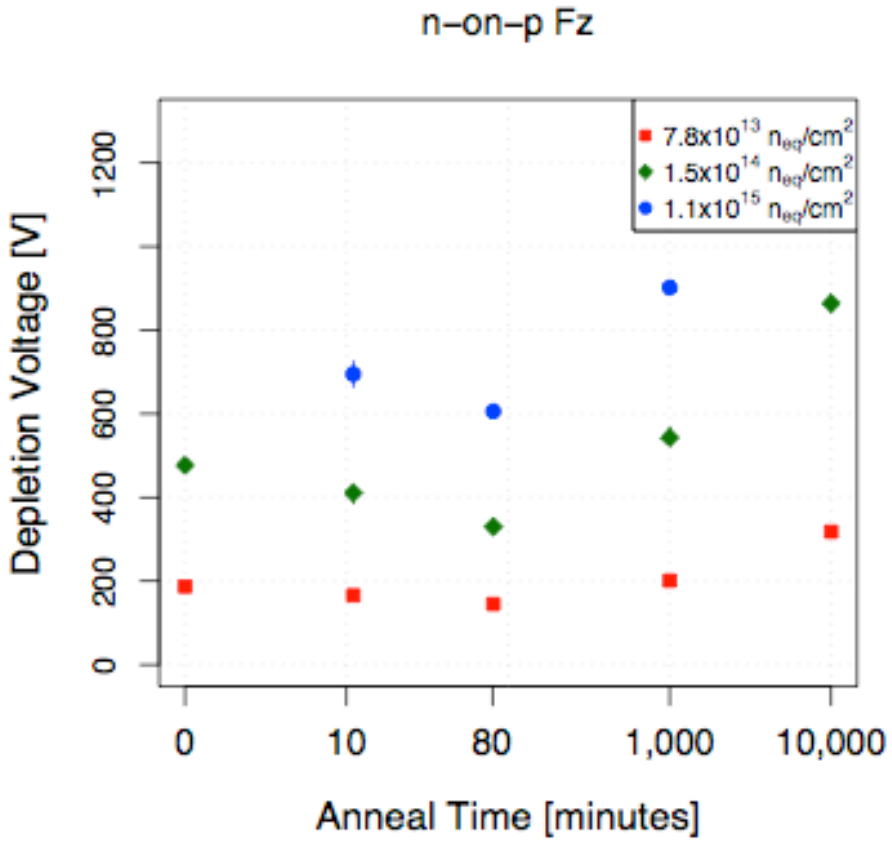
Fit Method:

In some samples the $1/C^2$ curve has more structure. In these cases V_{fd} was found fitting the last steeply ascending part of the curve (not the "knee") and the final plateau section.

Error on the fit was estimated in each case for the prescribed fit method and represented in the plots of V_{fd}.

n-on-p Fz

800 MeV protons

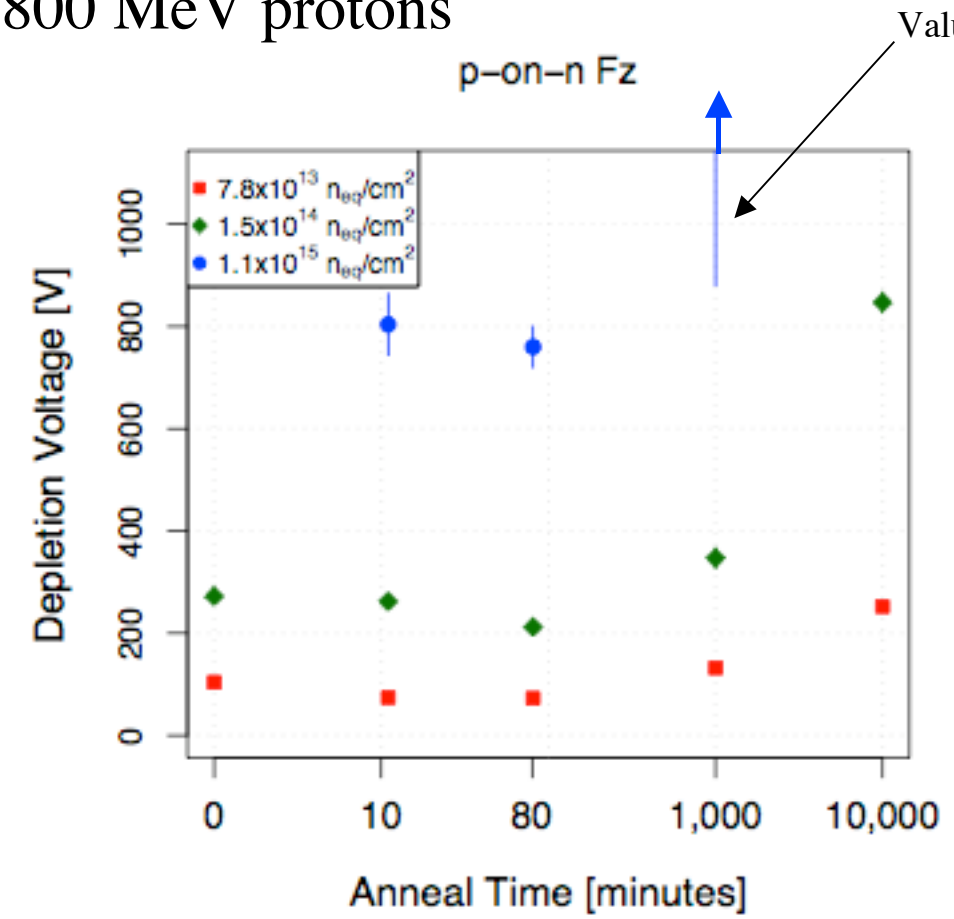


Observations:

- some beneficial annealing before 80 minutes
- more pronounced for higher fluences
- this is consistent with the theory n-on-p Fz starts with -sc before irradiation, stays -sc after 800 MeV proton irradiation, then while positive space charge is introduced in the first part of annealing we observe beneficial annealing, and in the later part of annealing -sc is introduced and we see reverse annealing.

p-on-n Fz

800 MeV protons

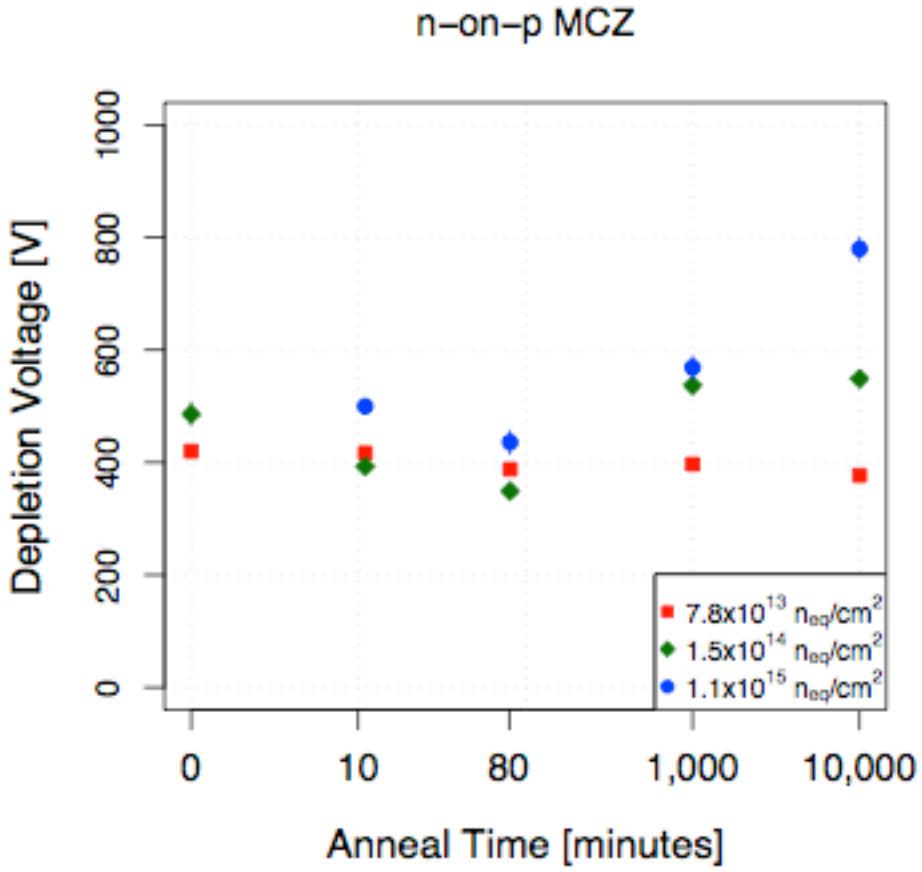


Observations:

- The p-on-n Fz shows the largest dependence of V_{fd} on annealing.
- The line with the arrow indicates that V_{fd} could not be determined, but was greater than some value.
- consistent annealing behavior of +sc before proton irradiation and -sc after proton irradiation--period of beneficial then reverse annealing

n-on-p MCz

800 MeV protons

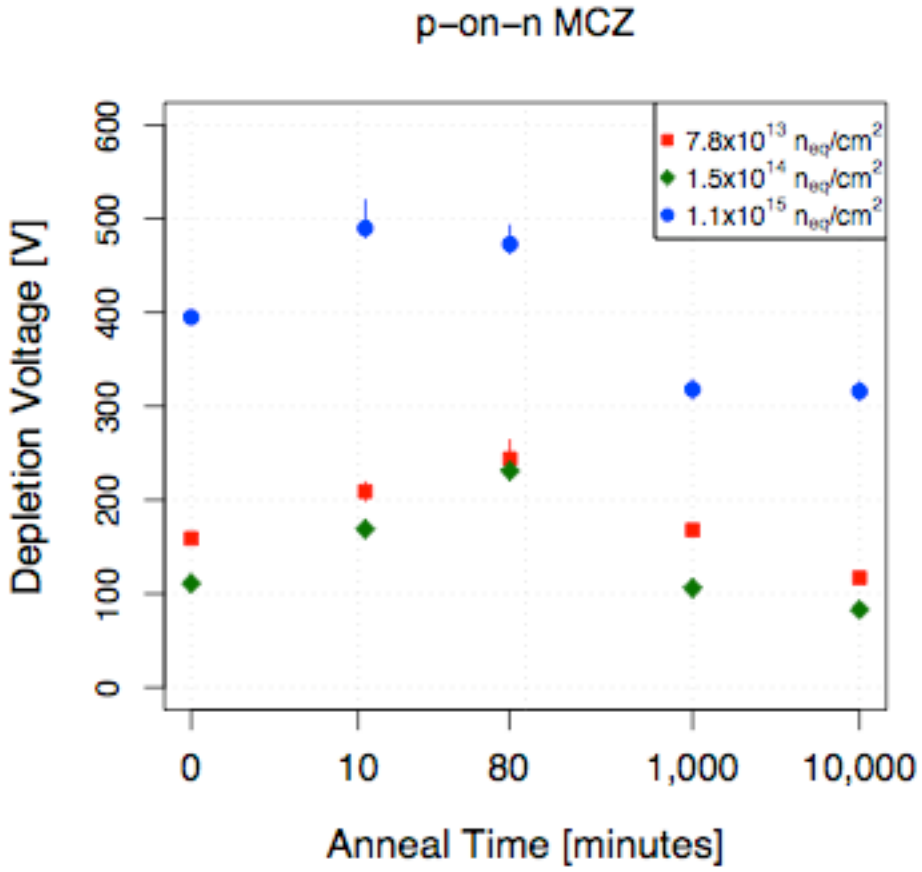


Observations:

- limited beneficial annealing before 80 minutes
- least dependence on fluence for V_{fd}
- lowest fluence shows almost no change
- consistent annealing behavior of -sc after proton irradiation--period of beneficial then reverse annealing

p-on-n MCz

800 MeV protons



Observations:

• shows n-type like annealing behavior--it starts with +sc before irradiation, stays positive after 800 MeV *proton* irradiation

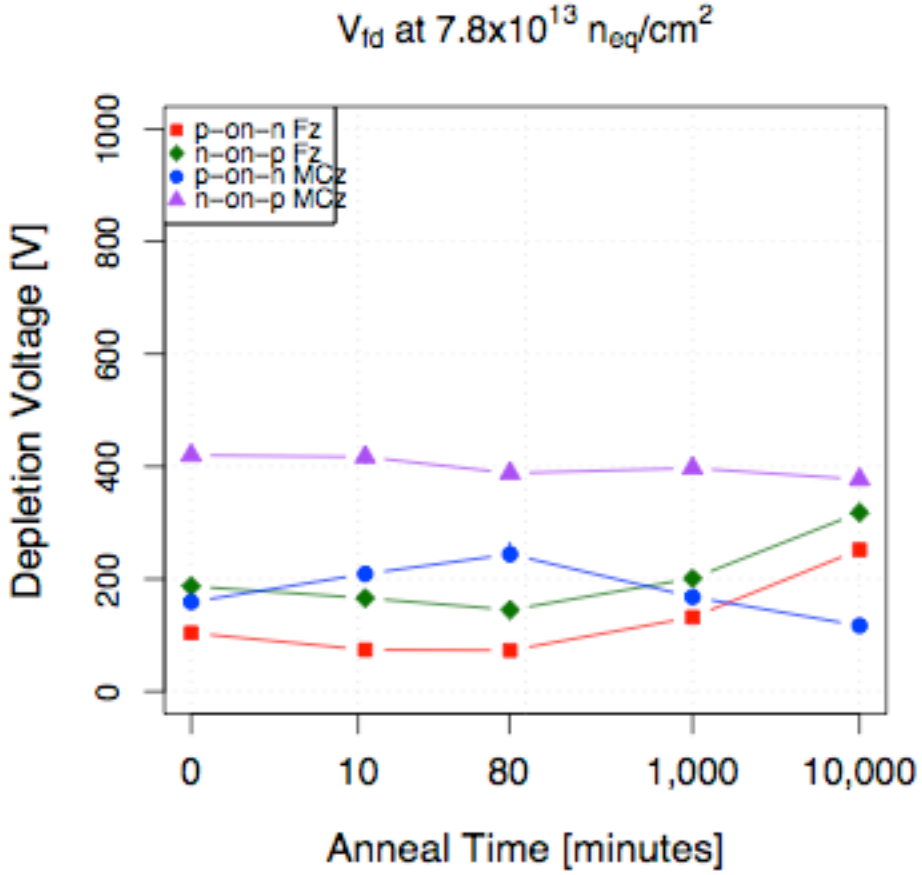
• initial introduction of more +sc causes non-beneficial annealing in first annealing steps and then beneficial annealing when -sc is added

=> no type inversion after proton irradiation!!

• consistent with previous observations in talk by Gregor Kramberger for the 12th RD50 Workshop

V_{fd} at $7.8x10^{13}$ n_{eq}/cm^2

800 MeV protons

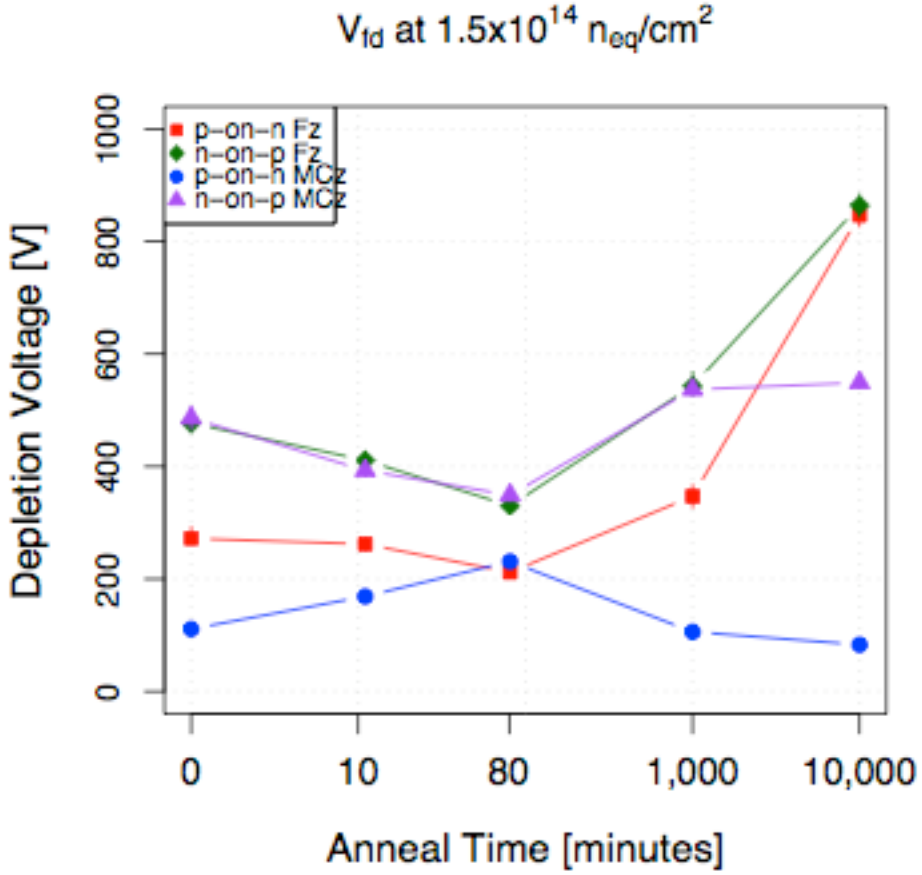


Observations:

- subdued annealing behavior at low fluence
- n-on-p MCz shows almost no change
- n-type annealing still present in p-on-n MCz

V_{fd} at $1.5x10^{14}$ n_{eq}/cm^2

800 MeV protons

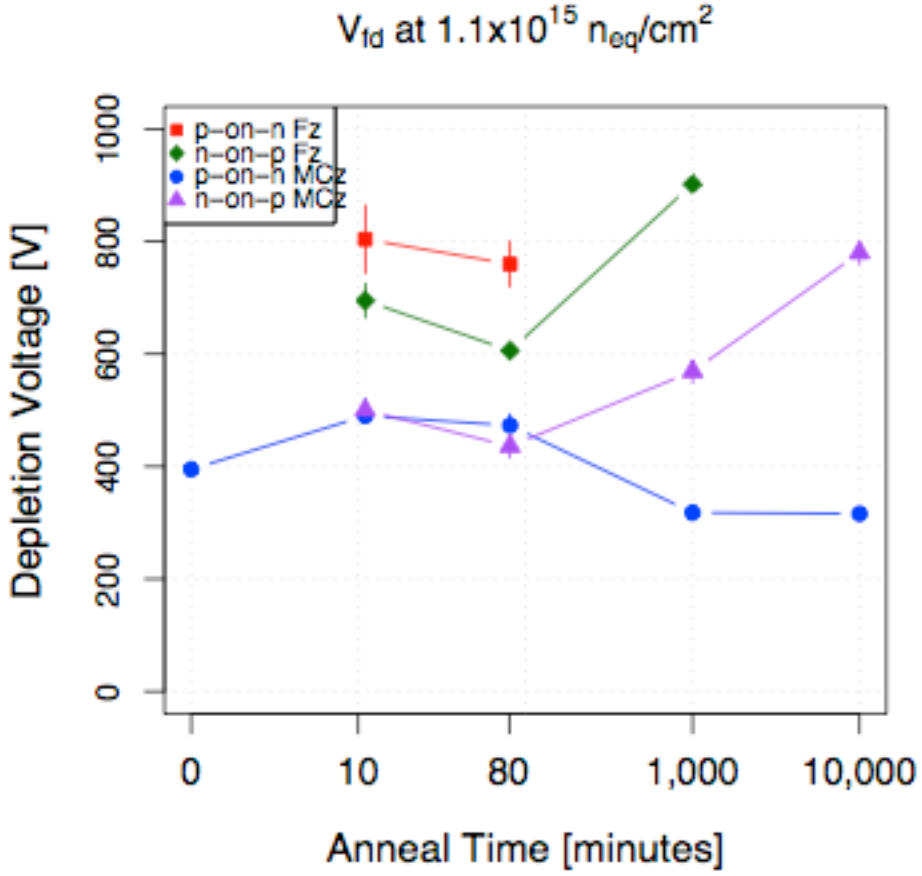


Observations:

- both Fz devices have strong reverse annealing at 10,000 minutes
- n-on-p MCz appears to have saturated

V_{fd} at $1.1x10^{15}$ n_{eq}/cm^2

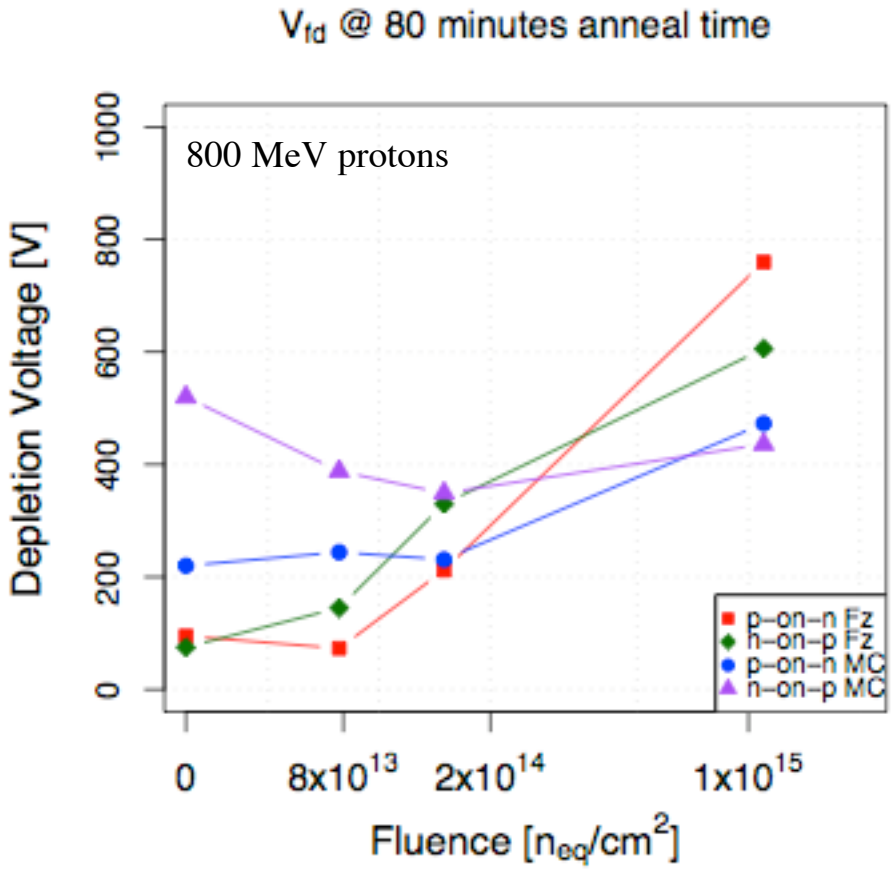
800 MeV protons



Observations:

- did not reach saturation for n-on-p for this highest fluence
- p-on-n MCz may have reached beneficial annealing limit (about to type invert?)

Comparison @80 minutes



Observations:

- Note: 80 minutes was where the minimum value of V_{fd} was reached--shows the most beneficial annealing for "p-type" samples (all but p-on-n MCz)
- Fz show greatest increase of V_{fd} with increasing fluence
- n-on-p MCz shows little change

Summary

- Beneficial annealing is observed for the first 80 minutes (slightly sooner for samples irradiated to 1.1×10^{15} n_{eq}/cm^2) anneal time and then V_{fd} begins to increase for samples shown to have -sc after proton irradiation:
  - n-on-p Fz
  - p-on-n Fz
  - n-on-p MCz
- p-on-n MCz shows annealing behavior typical of n-type devices that have +sc after proton irradiation.

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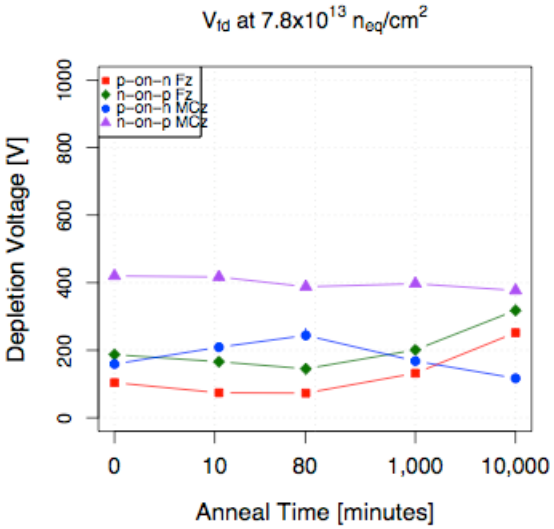
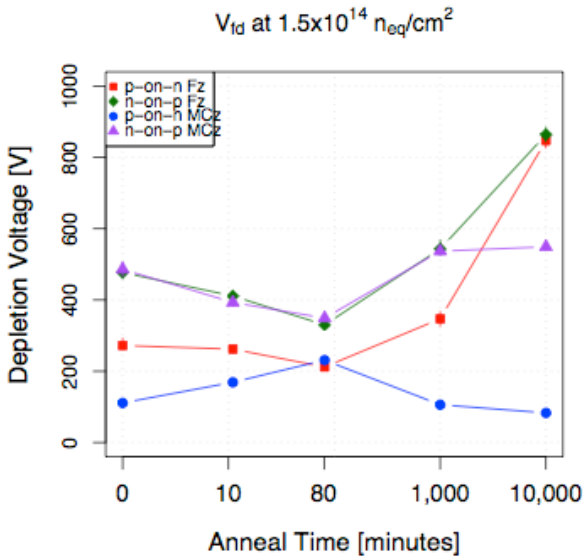
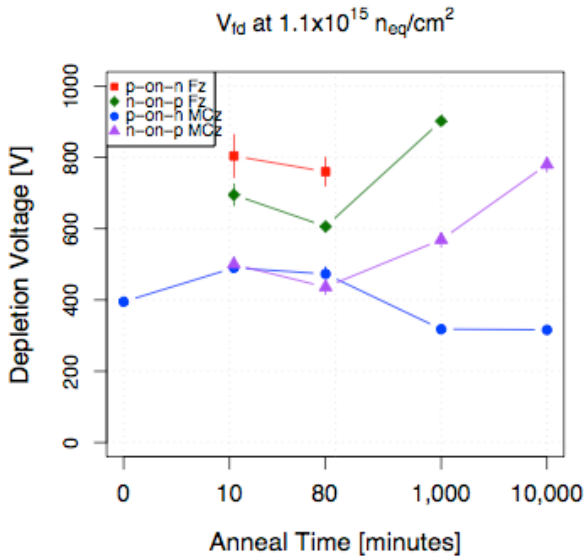
Extra Slides

V_{fd} Evolution







Future Work

- Compare V_{fd} from CV curves to measurements from other groups.
- Compare depletion voltages of CV and CCE measurements.

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In the first part of the the annealing curve you introduce positive space charge, then it switches to negative.

Fz n-type, p-on-n Before: + After: - (after proton irradiation)

Fz p-type, n-on-p Before: - After: -

MCz n-type, p-on-n Before: + After: +

MCz p-type, n-on-p Before: - After: -