Can silicon operate beyond 10^{15} n/cm^2 ?

DEFECT ENGINEERING – Oxygen Dimer Si

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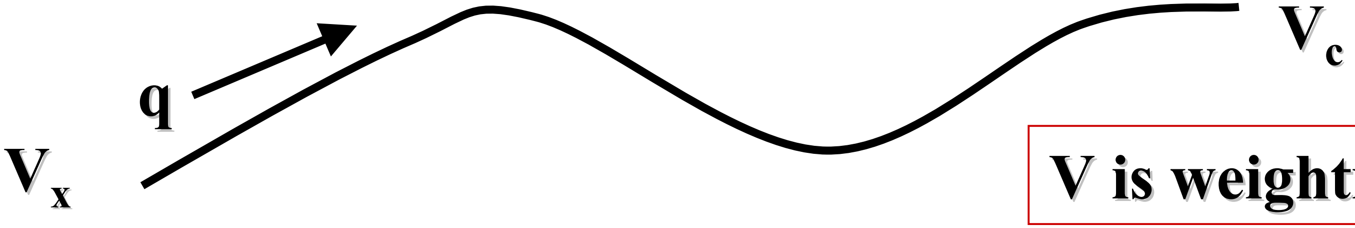
OUTLINE

1- BACKGROUND
2- KEY ISSUE – signal efficiency in irradiated detectors
3- SOLUTIONS

a OPERATING CONDITIONS (T, Forward/Reverse Bias ?)
b DEFECT ENGINEERING (Dimer oxygenated Si)
c DEVICE ENGINEERING (e.g. 3D Sherwood Parker)

4- CONCLUSIONS

RAMO's theorem + trapping



V is weighting potential

Signal = q x $P_{qc}(x)$ x CORR x $(V_c - V_x)$

$$P_{qc} \approx e^{-t_D/t_{eff}}$$

$t_{eff} = \tau_T$ Trapping Only (Forward Bias)

$1/t_{eff} \approx \frac{1}{\tau_T}\left(1 - \frac{1}{2}\, t_D/\tau_T\right)$ Trapping & Emission (Reverse Bias)

$$\frac{1}{t_{eff}} = K\phi$$

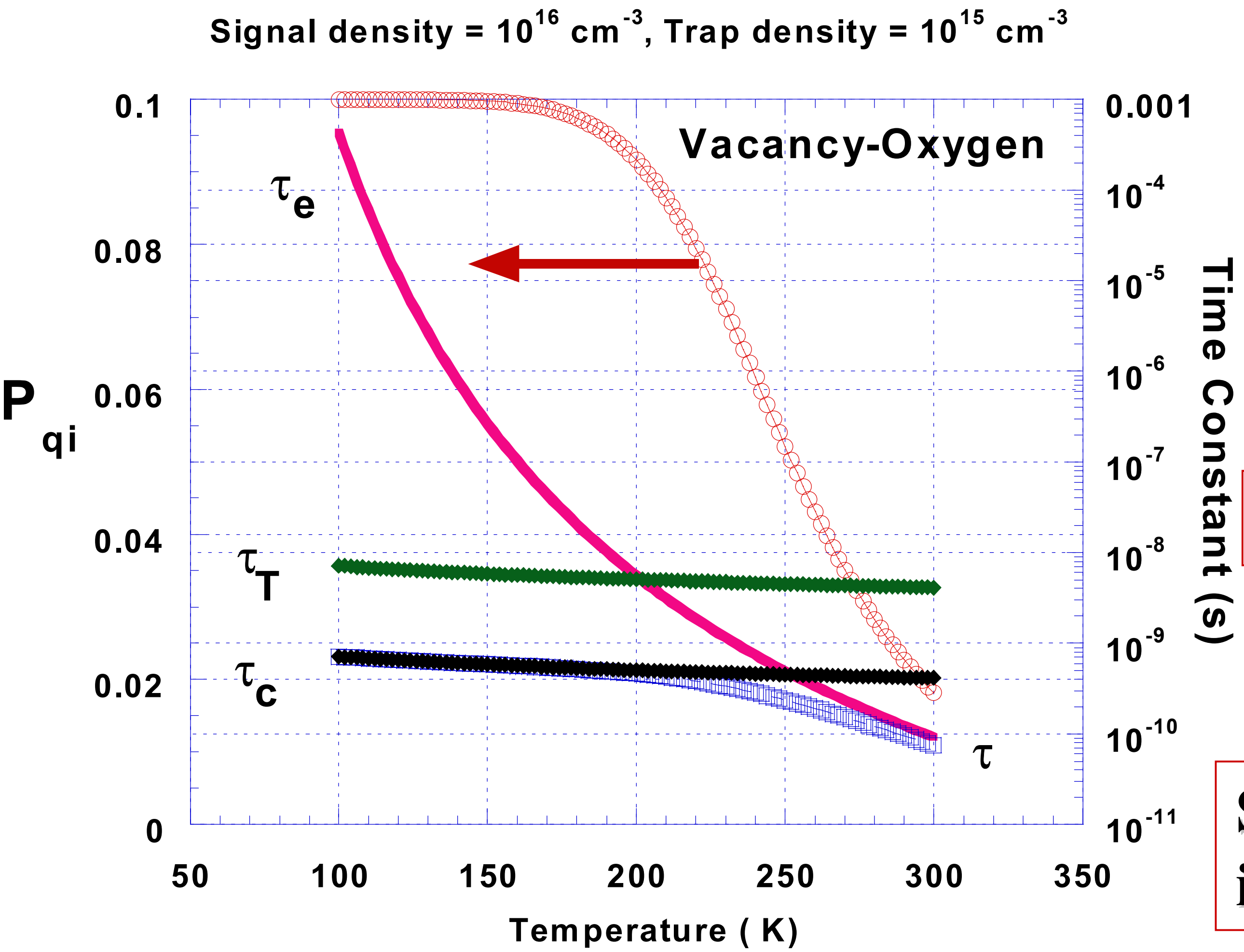
Drift Time = $d/\mu E$

$\tau_T = (N_T \sigma V_{th})^{-1}$

t_{eff} and μ vary with temperature

$P_{qi} = 1 - P_{qc}$

P_{qi} prop. $1/t_{eff}$



$\tau_c = (n_s \sigma v_{th})^{-1}$

$\tau_T = (N_T \sigma v_{th})^{-1}$

τ_e prop. $\exp(\Delta E/kT)$

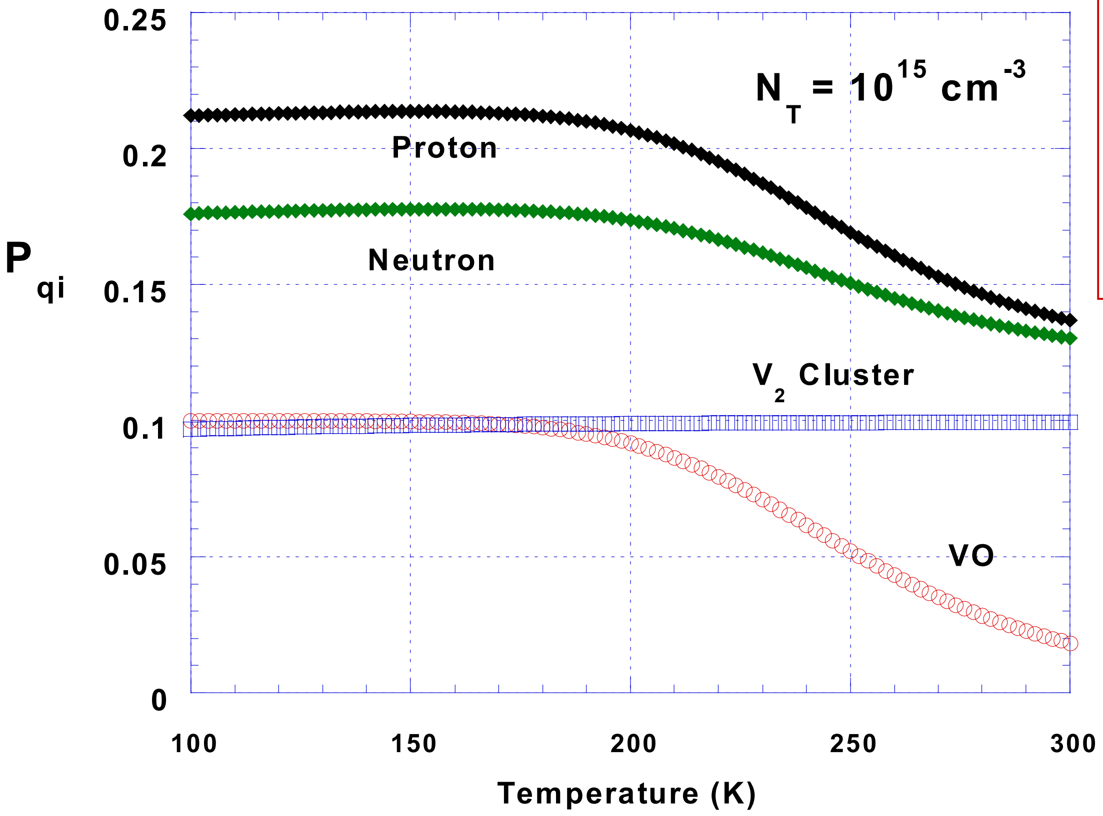
$1/\tau = 1/\tau_e + 1/\tau_c$

Same theory as used in CCD's

For depletion case (Reverse Bias)
T < 200K   Trapping Controlled
T > 200K   Emission Controlled

For Forward Bias
Always Trapping Controlled

For electron trapping – $t_D = 10$ ns



Conclusion

NIEL Violation

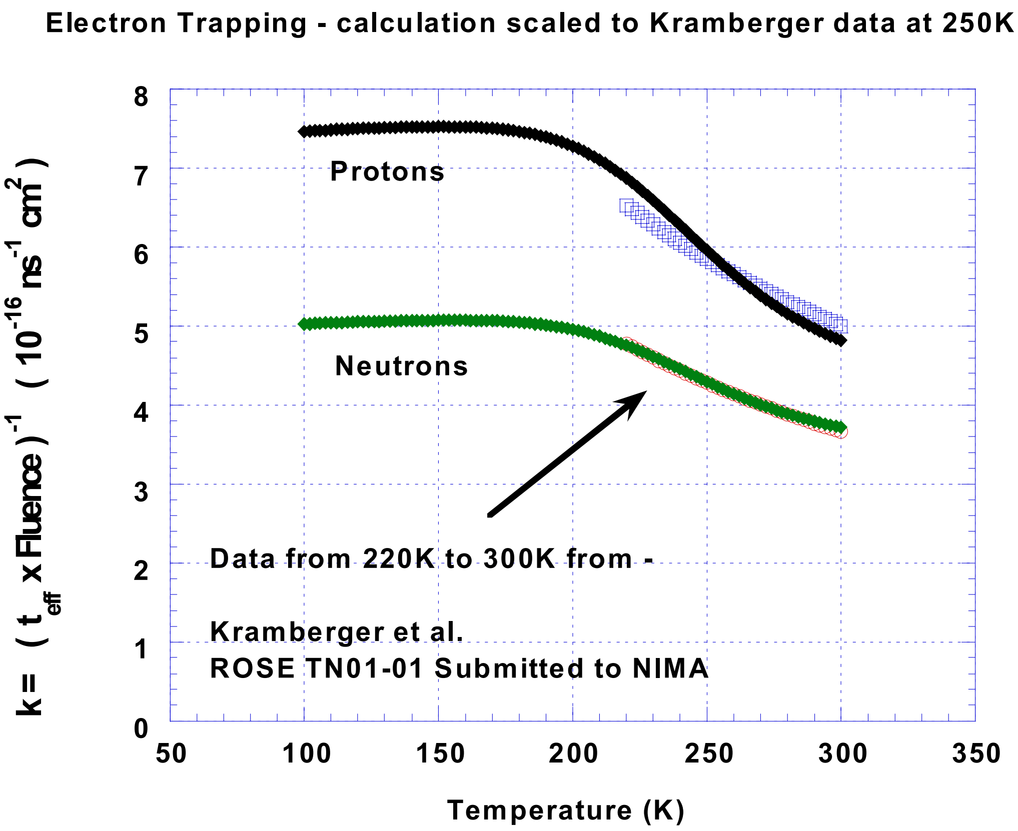
Charged hadrons worse

Aside :

$P_{qi} = (\tau/\tau_T) \times (1 - \exp(-t_D/\tau))$

Same in CCDs

Introduction rates (cm^{-1})	n	p
VO	0.6	0.96
V2 + Cluster	1.2	1.2



Note:

Kramberger et al.
See NIEL Violation
n/p trapping NOT the same for same equiv. 1 MeV n fluence.

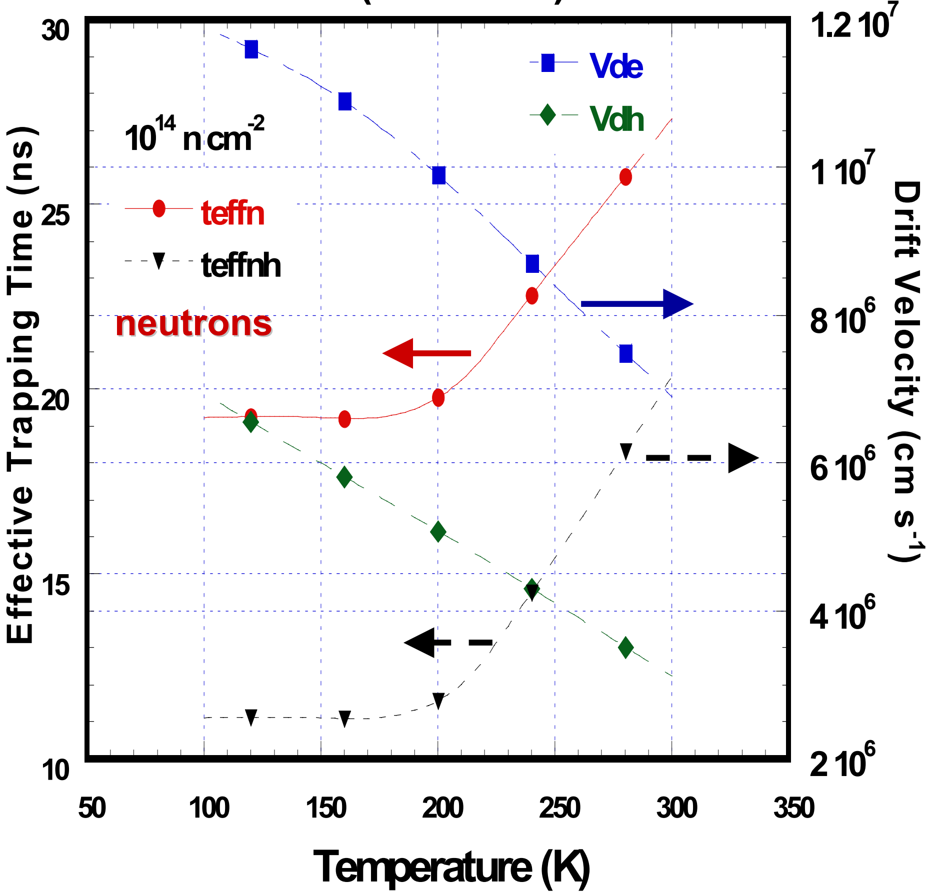
Conclusion:
VO causes this difference

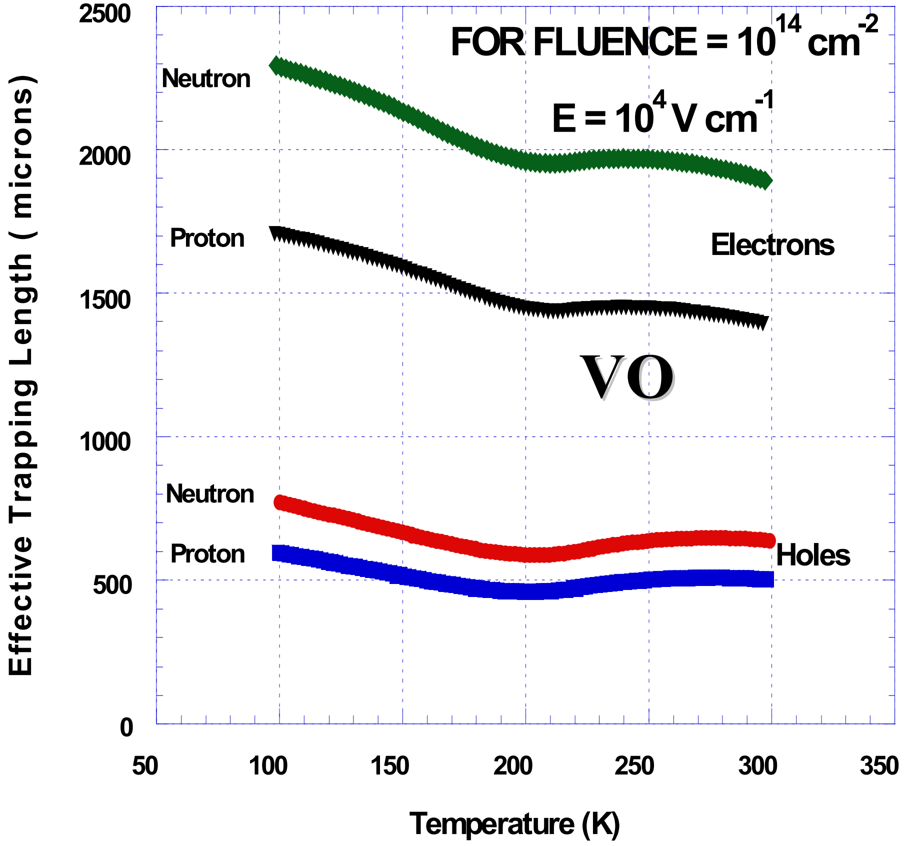
NOTE : Below 200K this parameter is the same for Forward and Reverse bias

EFFECTIVE DRIFT LENGTH

$$L_{eff} = \tau_{eff} \times V_{drift}$$

E = 10^4 V cm^{-1} (1V/micron)





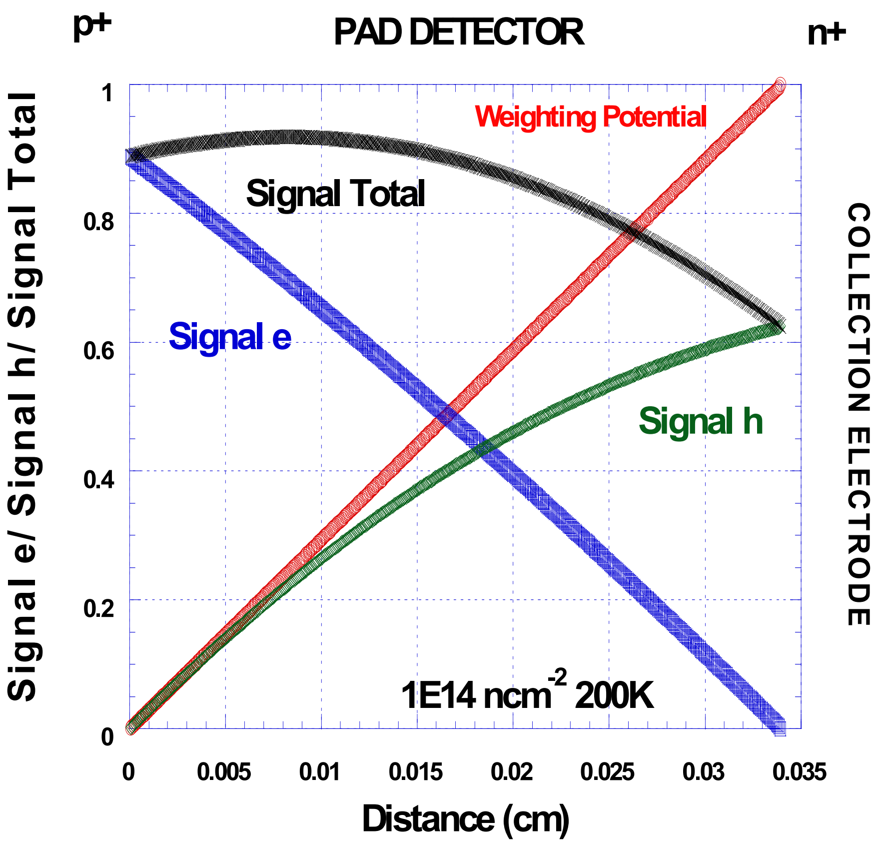
Data for neutron and protons for effective trapping time 220K-300K from Kramberger et al

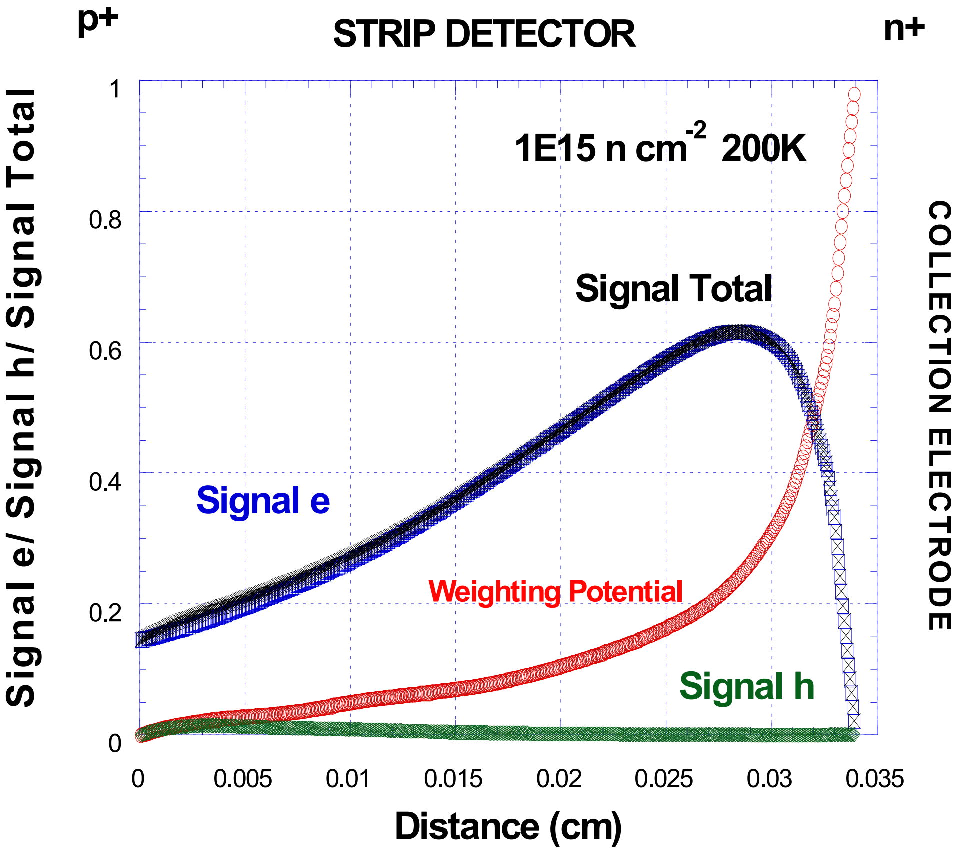
SIGNAL FORMATION - RAMO'S THEOREM

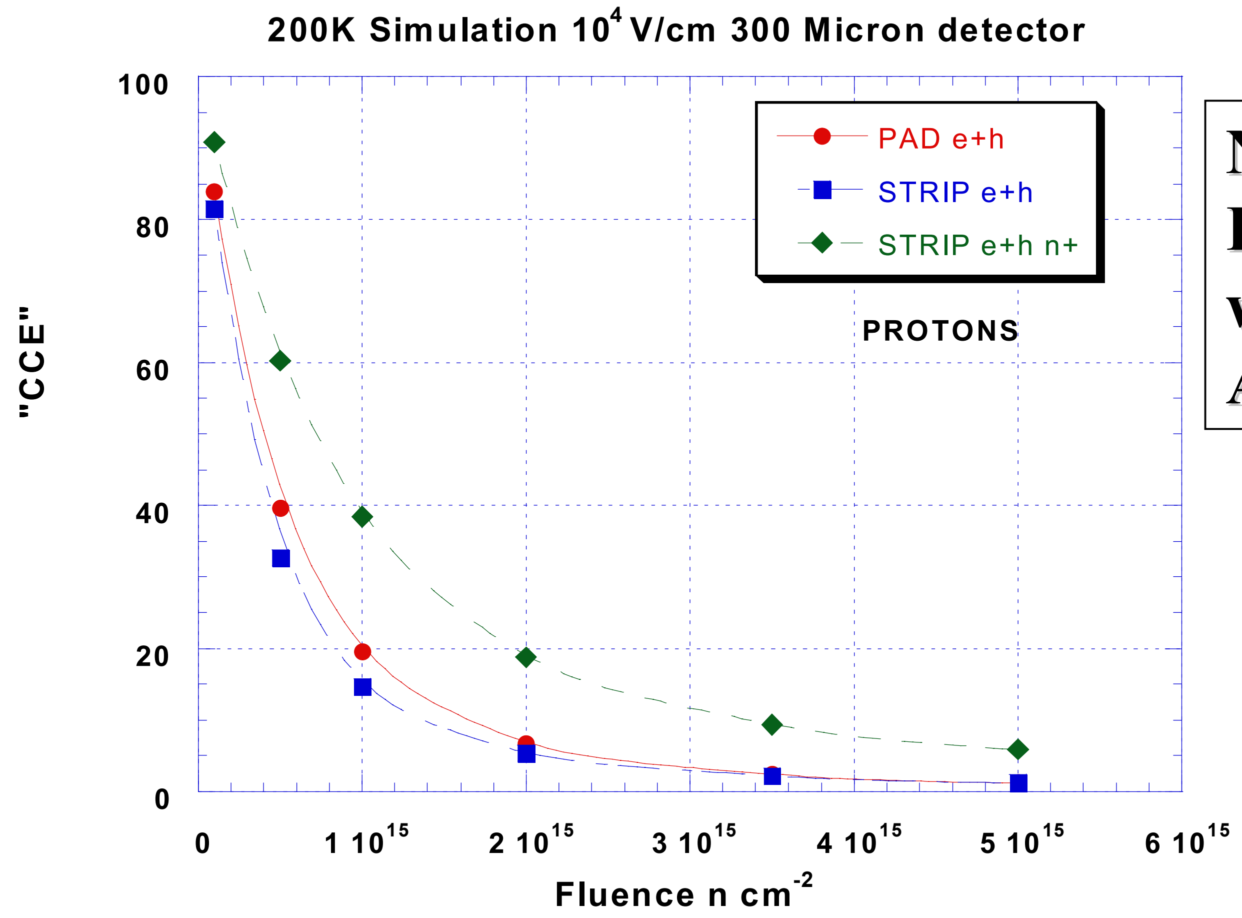
IMPORTANCE OF THE WEIGHTING POTENTIAL

PADS AND SEGMENTED DETECTORS ARE VERY DIFFERENT

← **Holes** **Electrons** →



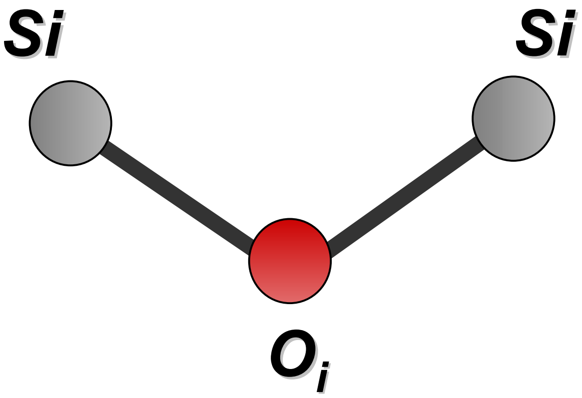




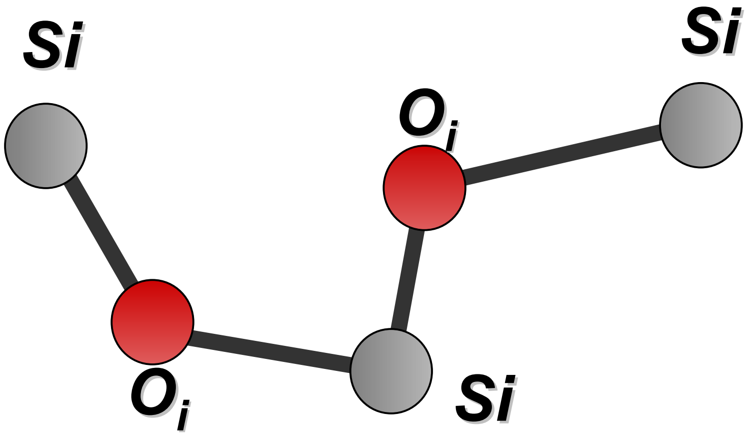
Note:
Pad results same whether you collect At n+ or p+ contact

CONCLUSION – collect electrons !!!!!
If one can remove VO then we should do better

SOLUTIONS (b) DEFECT ENGINEERING - O DIMER



OXYGEN INTERSTITIAL



OXYGEN DIMER

HIGH TEMPERATURE ^{60}Co γ IRRADIATION
AT T > 350 ^{0}C VO BECOMES MOBILE AND CAUSES OXYGEN TO CLUSTER

QUASI CHEMICAL REACTIONS:

$V+O_i \Rightarrow VO_i$

$VO_i + O_i \Rightarrow VO_{2i}$

$I + VO_{2i} \Rightarrow O_{2i}$

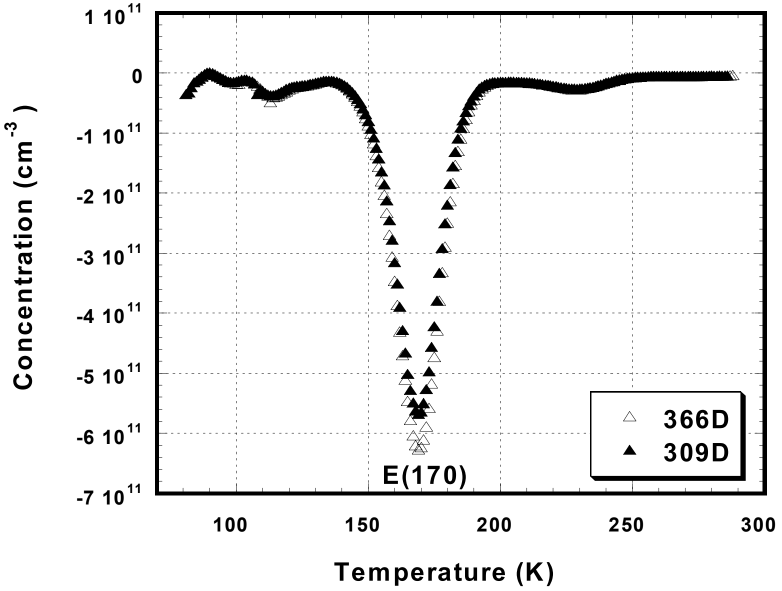
Method variation on L. Lindstroem work

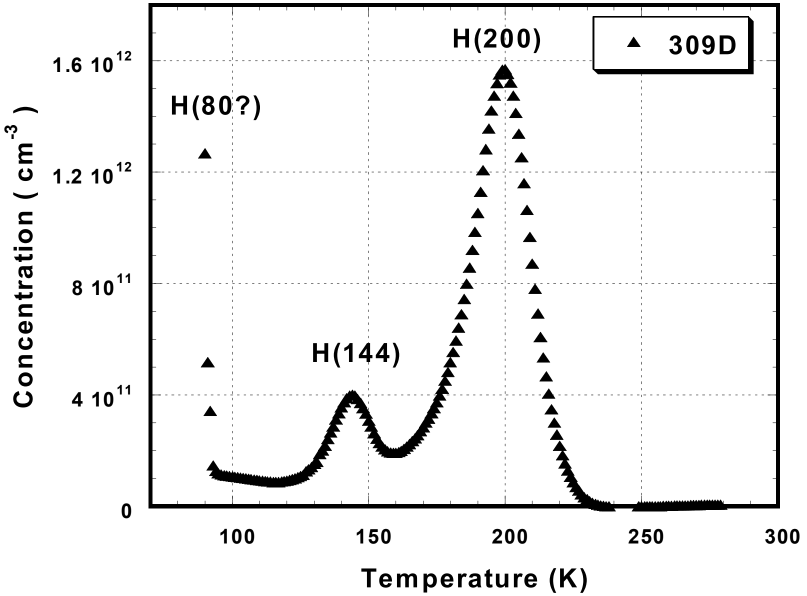
VO --------> VO_2 NEUTRAL
V_2O --------> V_2O_2 NEUTRAL

EXPECT CHANGE IN MACROSCOPIC EFFECTS
SHOULD IMPROVE CCE FOR ELECTRONS

ALSO – O_{2i} diffuses very rapidly. Possibility of low-temp diffusion For DOFZ !!!!

DEFECTS IN “DIMERED” MATERIAL



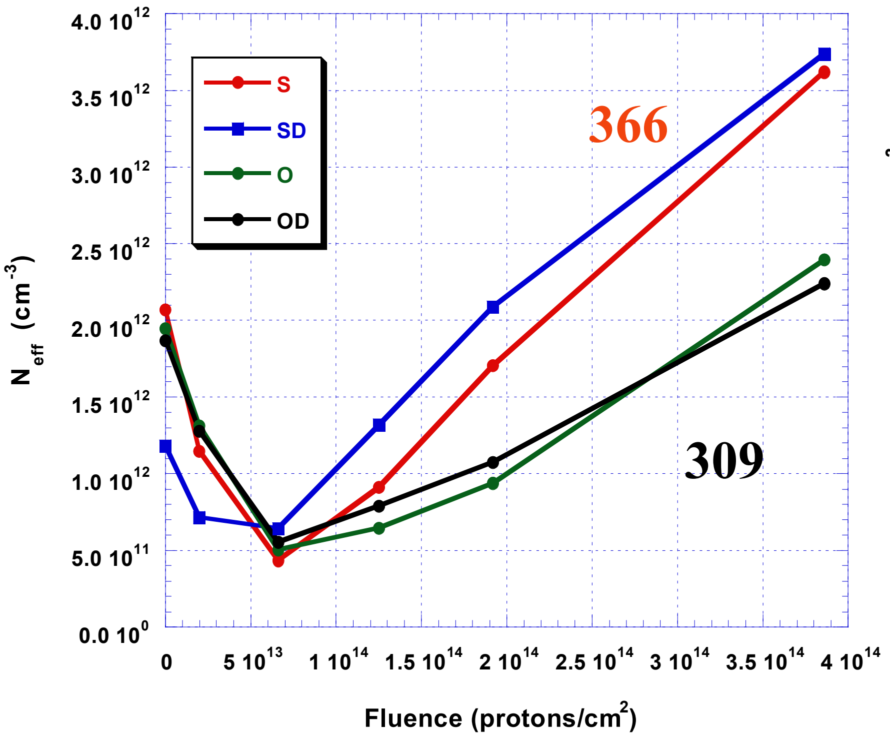


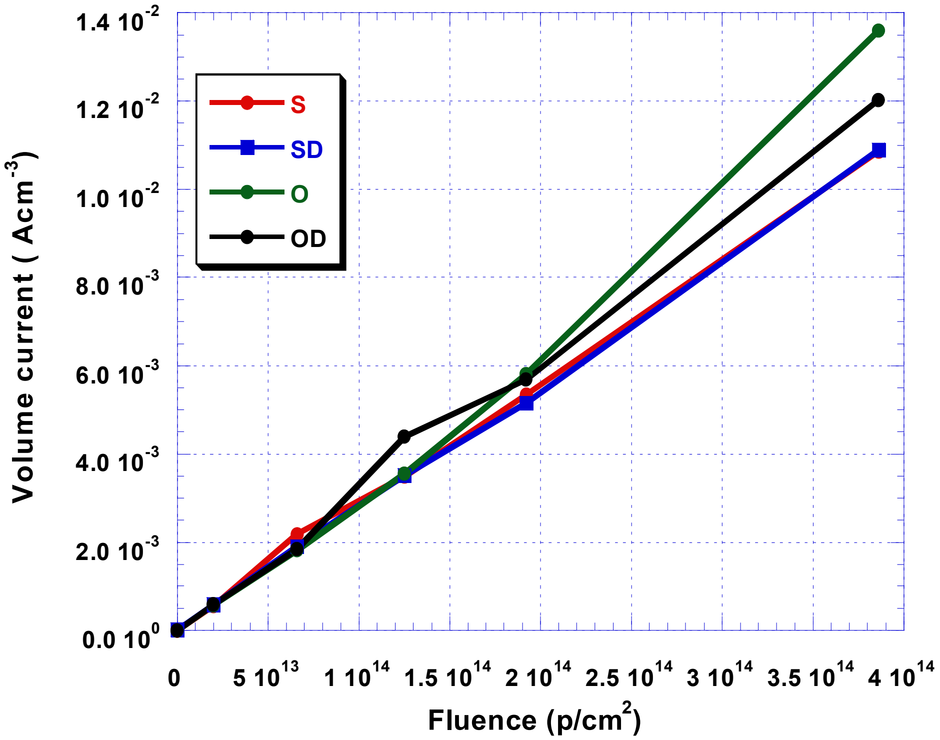
309D Oxygenated and “dimered”
366D Standard and “dimered”

Electron (E) or Hole (H) trap	**Energy Level (eV)**	**Identification**
E(170)	E_c - 0.32	Probably VOH [11]
H(200)	E_v + 0.36	C_iO_i (0/+) Charge state [1]
H(144)	E_v + 0.2	Unknown
H(80?)	Approx. E_v + 0.1	Not fully resolved. Unknown.

EXPERIMENTAL RESULTS

IV and N_{eff} AFTER 24GeV/c p–irradiation

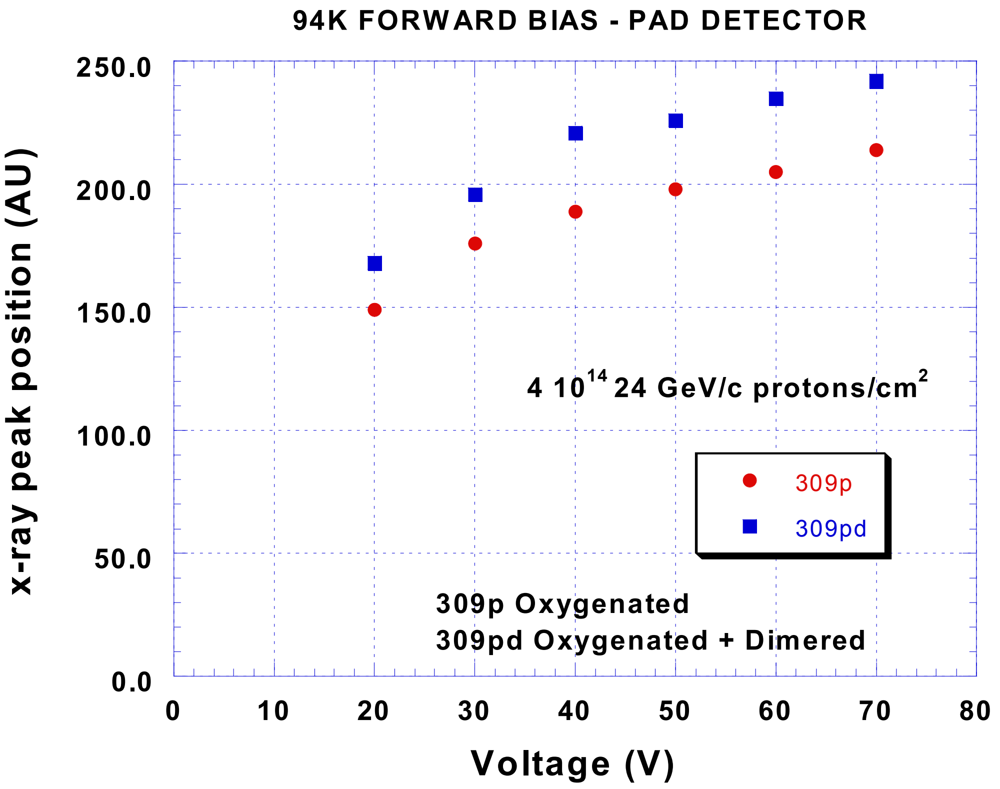




Oxygenation shows normal improvement

Leakage current looks the same in all samples.

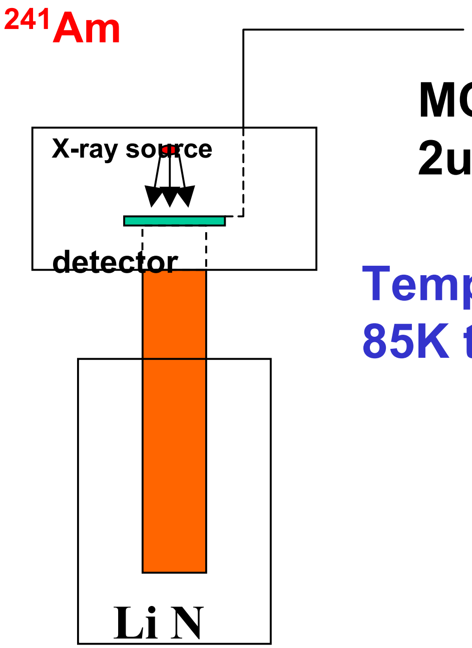
$\alpha \sim$ 3E-17 A cm^{-1}



Small improvement – do not expect anything spectacular at this fluence – also a PAD detector

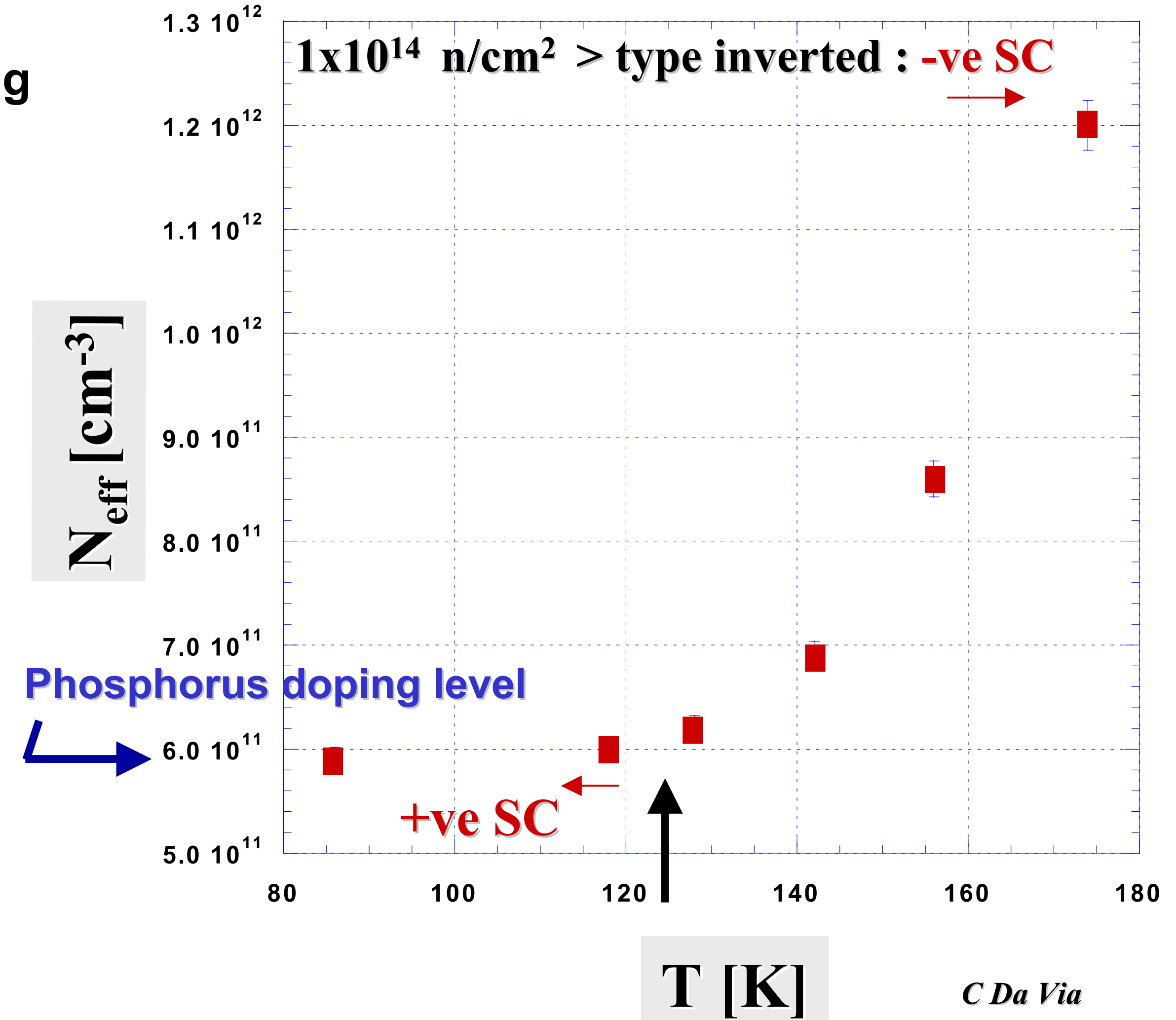
CONTROL OF THE SPACE CHARGE WITH TEMPERATURE

energy level occupancy ~ $e^{-\Delta E/kT}$

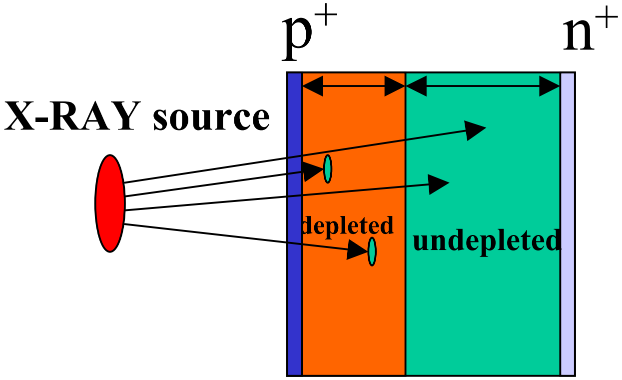


MCA
2us shaping

Temperature
85K to 300K

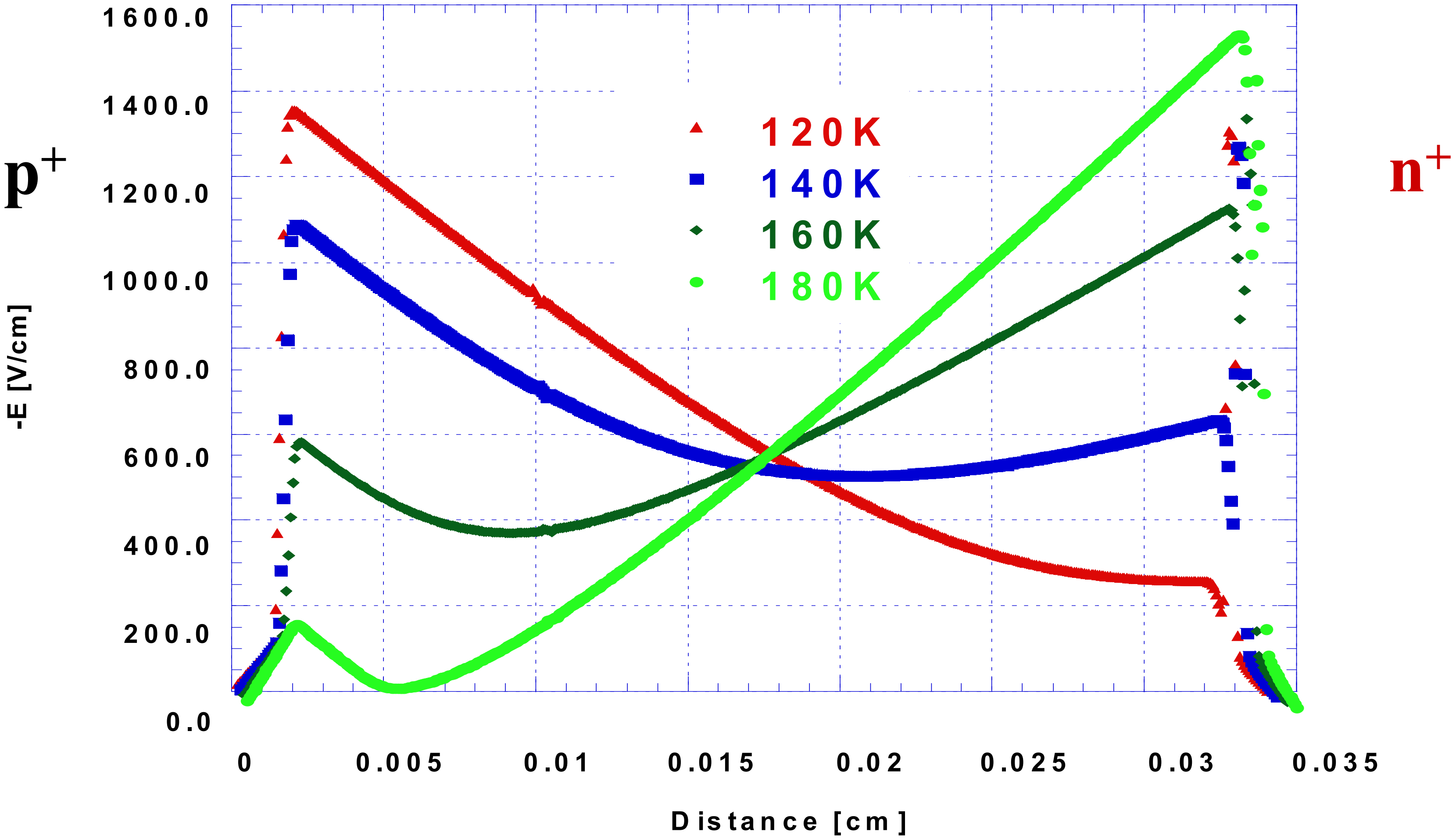


Phosphorus doping level



C Da Via
To be published

ELECTRIC FIELD DISTRIBUTION VERSUS TEMPERATURE AFTER 1E14 n/cm^2

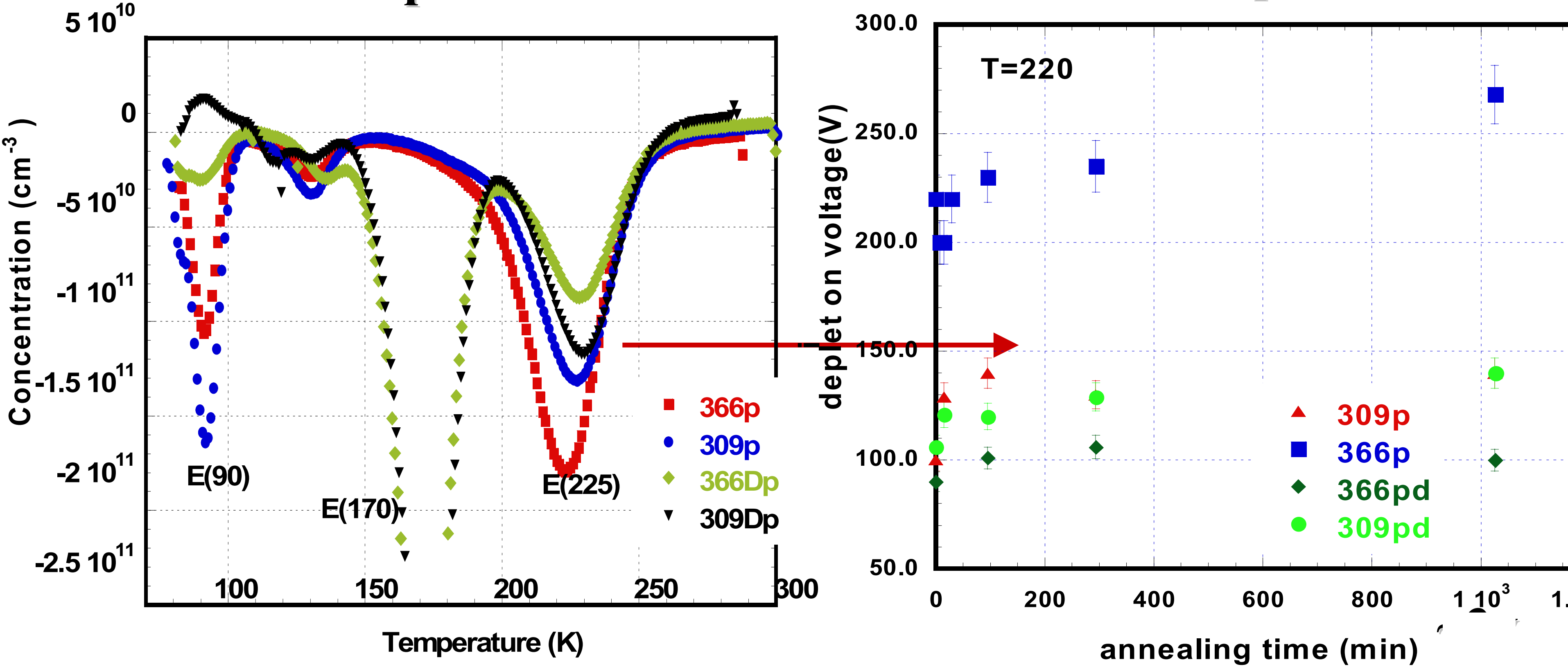


OXYGEN DIMERED SILICON AFTER 24GeV/c PROTON IRRADIATION

Anneal at 80 ^{o}C – Equiv. to about 13 yr RT

$1.1x10^{11}$ p/cm^2

$4x10^{14}$ p/cm^2



Radiation induced traps DLTS spectra

SC after reverse annealing Measurements at 220K

Depletion voltages in various samples before and after annealing

Material	V_{Dep} 300K Volts Note 1	V_{Dep} 223K Volts Note 2	ΔV RA 300K Volts Note 3	ΔV RA 223K Volts Note 4
Standard	288	200	975	65
Oxygenated	189	100	740	40
Standard Dimered	288	90	-	0 to 10
Oxygenated Dimered	180	100	-	40

Note 1: Inferred from CV measurement at room temperature
Note 2: Inferred from x-ray count-rate measurement as function of voltage at 223K.
Note 3: Calculated using Hamburg parameterisation of standard and oxygenated silicon.
Note 4: Inferred from x-ray count-rate measurement as function of voltage.

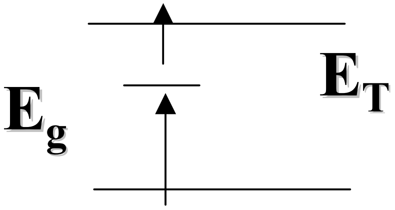
TEMPERATURE DEPENDENCE OF DEPLETION VOLTAGE

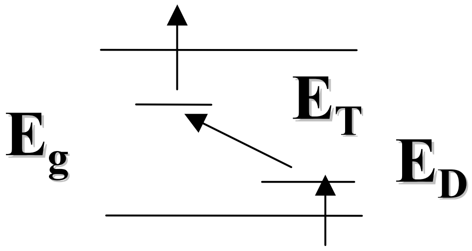
Occupancy prop. Exp($\Delta E/kT$)

SRH $\Delta E = E_g - 2E_T$

Inter-Centre Charge Transfer (ICT) $\Delta E = E_g - 2E_T + E_D$

For V_2 $\Delta E = -0.28$ eV SRH, $\Delta E = -0.08$ eV ICT





Temp. Dependence of RA part of depletion voltage = -0.2 eV

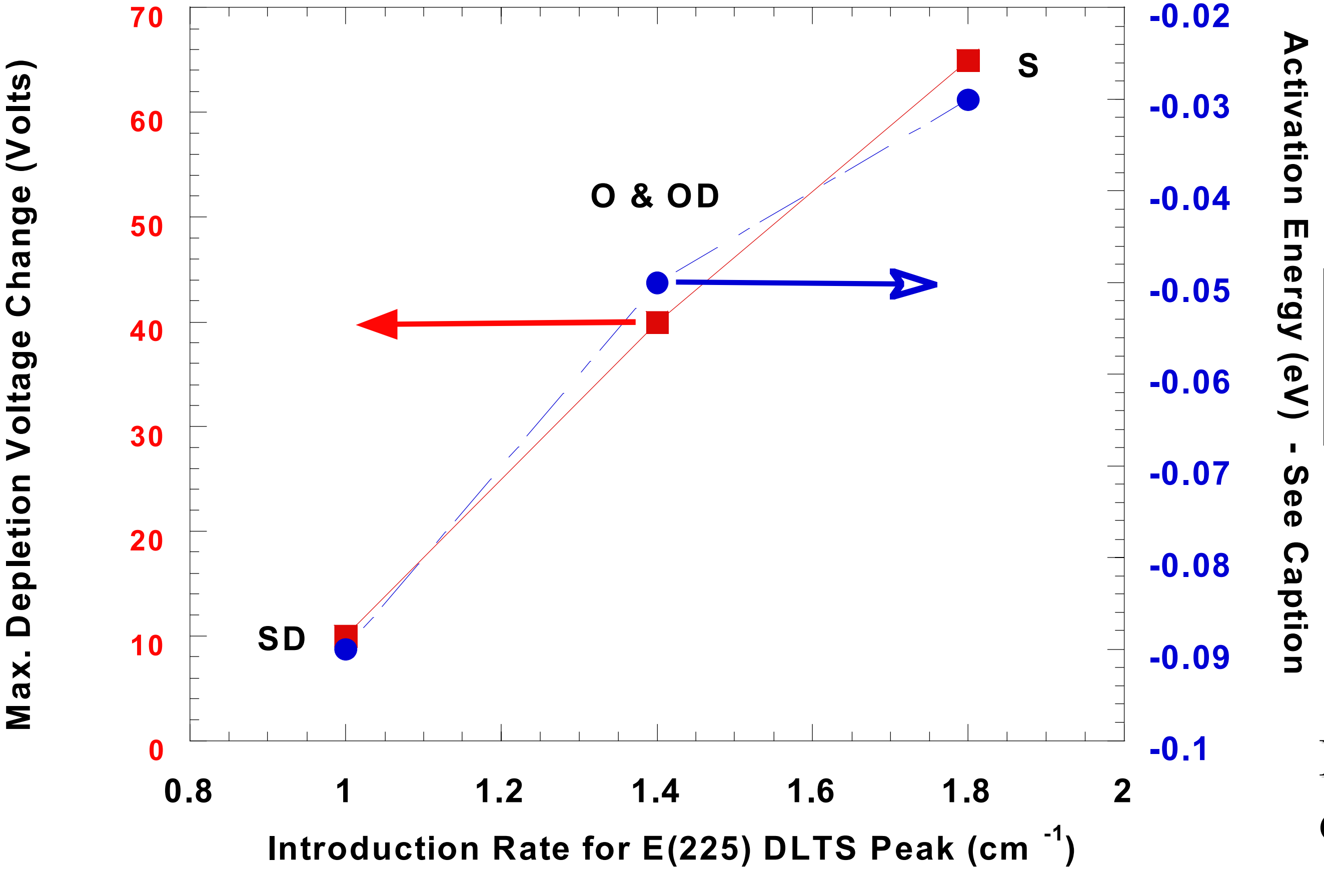
Temp. Dependence of Non -RA part of depletion voltage Approx -0.06 eV (depends on material)

CORRELATION BETWEEN RA - CLUSTER INTRO. RATE & TEMP DEPENDENCE OF DEPLETION VOLTAGE (PRIOR TO RA)

BAD

Reverse Annealing

GOOD



Slow V_{dep} change with T

Temp. Dependence of space charge

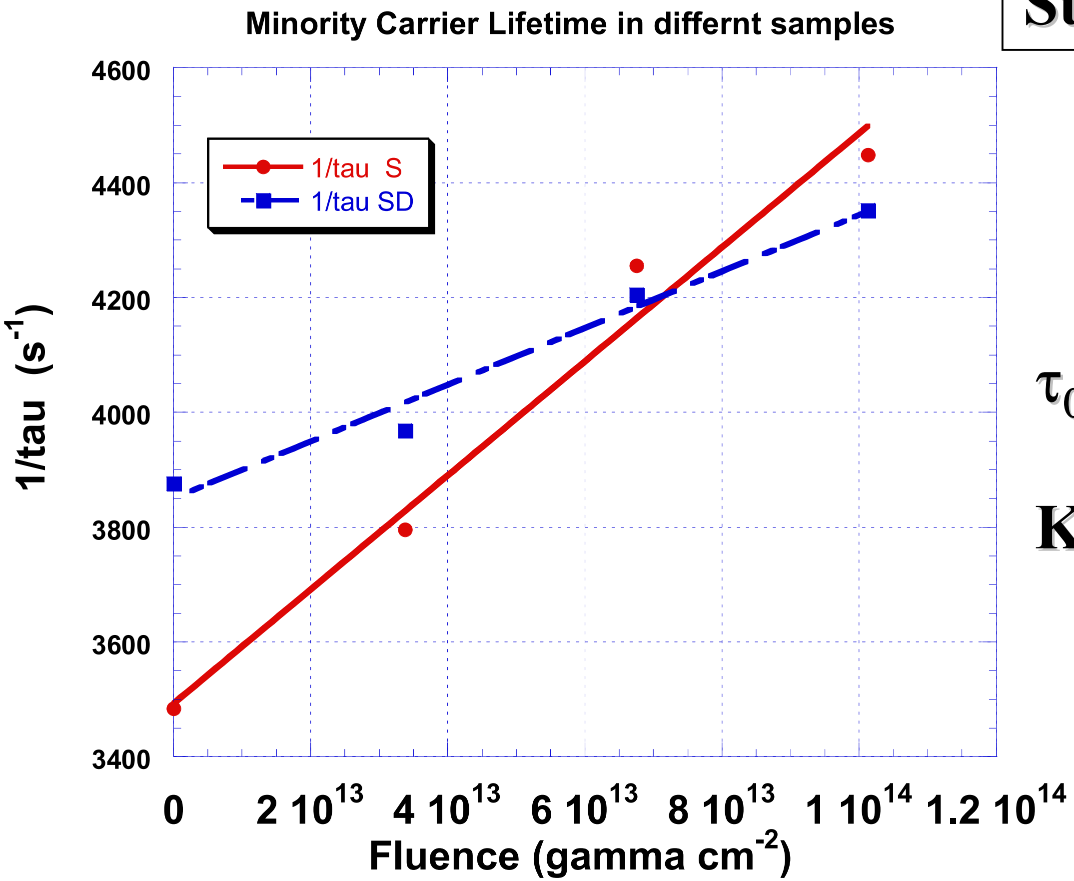
Fast V_{dep} change with T

Prior to RA

Cobalt-60 Irradiation Measure Minority Carrier Lifetime Expect VO to be important in standard Si

1Krad = 2.25E12 γcm^{-2}

Steps: 0, 15, 30, 45 Krad



$$1/\tau = 1/\tau_0 + \phi/K_\tau$$

	S	SD
τ_0	287μs	258μs
K_τ	(1.0+/-0.1) *1E11	(2.0+/-0.2) *1E11

Units $\gamma s cm^{-2}$

Factor 2 better for standard dimered silicon

VERY PRELIMINARY CONCLUSIONS FOR DIMER OXYGENATED SILICON

Evidence

- **That charge trapping has been improved**
- **That reverse annealing is suppressed in low [O] dimered Si**
- **Reverse annealing seems to be correlated with E(225) “cluster” peak**
- **That space charge temperature dependence is different in low [O] dimered Si**
- **Temperature dependence of depletion voltage BEFORE RA correlated to the size of voltage change after RA !!!**
- **Better damage parameter for minority carrier lifetime in low [O] dimered Si after gamma irradiation.**

LOT OF THINGS TO DO YET

NB: First look at how reverse annealing amplitude varies with temperature.
This may help to identify the defect causing RA
Lots of possibilities O_i to O_{2i} to O_{3i} during processing.
Low [O] and high [O] material