Ultra-rad-hard Sensors for Particle Physics Applications

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On behalf of CERN RD50 Collaboration

Pixel 2002, September 9-12, 2002, Carmel, CA

RD50 – 271 members

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OUTLINE

- Introduction
- Radiation induced defects levels in Si
- Radiation induced degradation of electrical properties in Si detectors
    - **Leakage current**
    - **Changes in electrical neutral bulk**
    - **Space charge transformations and CCE loss**
- RD 50's approaches to obtain ultra radiation hardness
    - **Material /impurity / defect engineering (MIDE)**
    - **Device structure engineering (DSE)**
    - **New materials**
- Future tasks to be carried out by RD 50
- Summary

Introduction

LHC L = 10^{34}cm^{-2}s^{-1} → ϕ(R=4cm) ~ $3 \cdot 10^{15}$cm^{-2} 10 years

ϕ(R=75cm) ~ $3 \cdot 10^{13}$cm^{-2}

Technology available, however serious radiation damage will result.

Possible up-grade L = 10^{35}cm^{-2}s^{-1} ϕ(R=4cm) ~ $1.6 \cdot 10^{16}$cm^{-2}

A focused and coordinated R&D effort is mandatory to develop reliable and cost-effective radiation hard HEP detector technologies for such radiation levels ---- The approval and formation of CERN RD50 Collaboration (6/02)

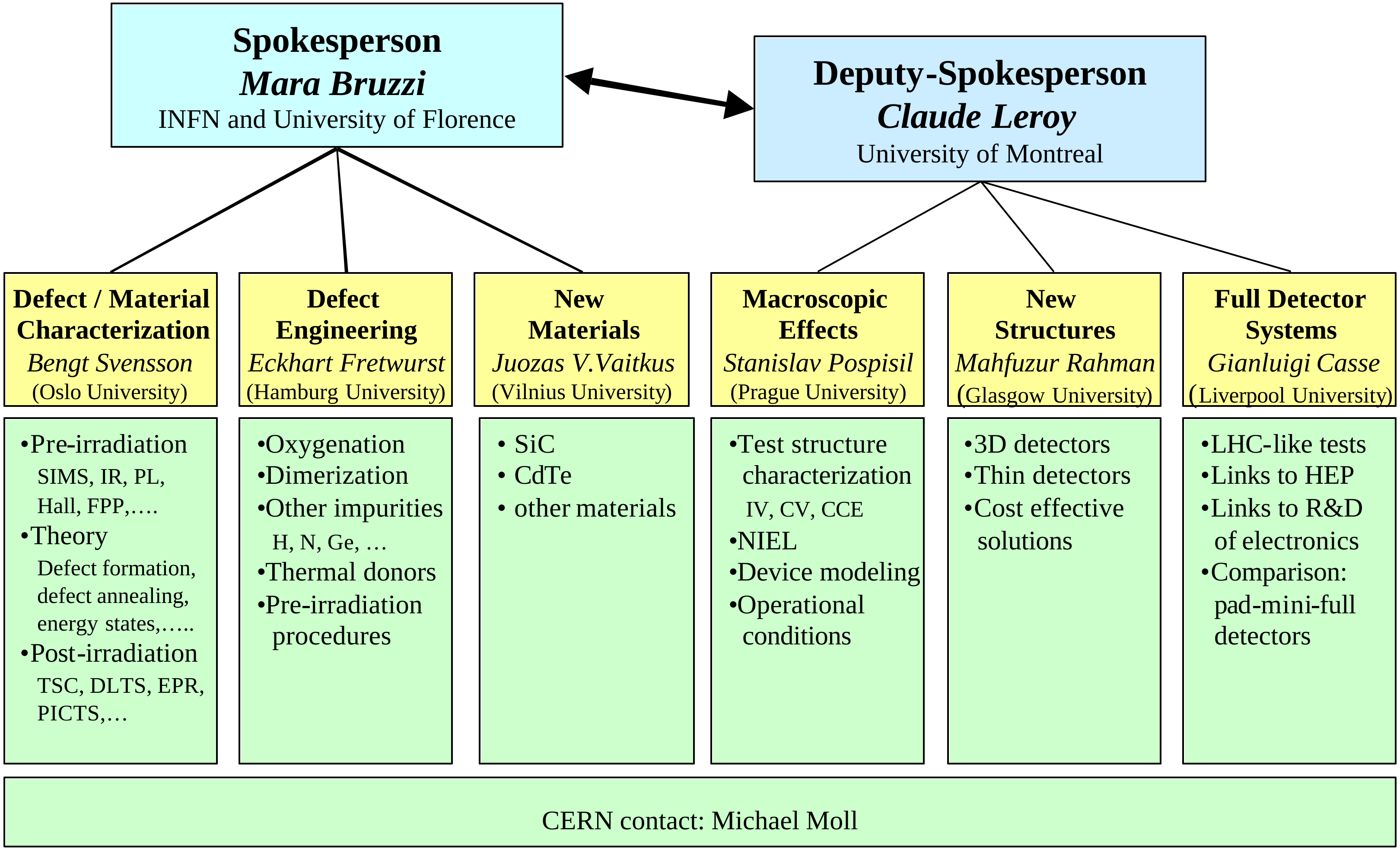
Dedicated radiation hardness studies also beneficial before a luminosity upgrade
Radiation hard technologies now adopted have not been completely characterized:

→ Oxygen-enriched Si in ATLAS pixels

A deep understanding of radiation damage will be fruitful also for the **linear collider** where high doses of e, γ will play a significant role.

CERN RD50
Development of Radiation Hard Semiconductor Devices for Very High Luminosity Colliders

Scientific Organization of RD50



Spokesperson
Mara Bruzzi
INFN and University of Florence

Deputy-Spokesperson
Claude Leroy
University of Montreal

Defect / Material Characterization
Bengt Svensson
(Oslo University)

- Pre-irradiation
  SIMS, IR, PL, Hall, FPP,….
- Theory
  Defect formation, defect annealing, energy states,…..
- Post-irradiation
  TSC, DLTS, EPR, PICTS,…

Defect Engineering
Eckhart Fretwurst
(Hamburg University)

- Oxygenation
- Dimerization
- Other impurities
  H, N, Ge, …
- Thermal donors
- Pre-irradiation procedures

New Materials
Juozas V.Vaitkus
(Vilnius University)

- SiC
- CdTe
- other materials

Macroscopic Effects
Stanislav Pospisil
(Prague University)

- Test structure characterization
  IV, CV, CCE
- NIEL
- Device modeling
- Operational conditions

New Structures
Mahfuzur Rahman
(Glasgow University)

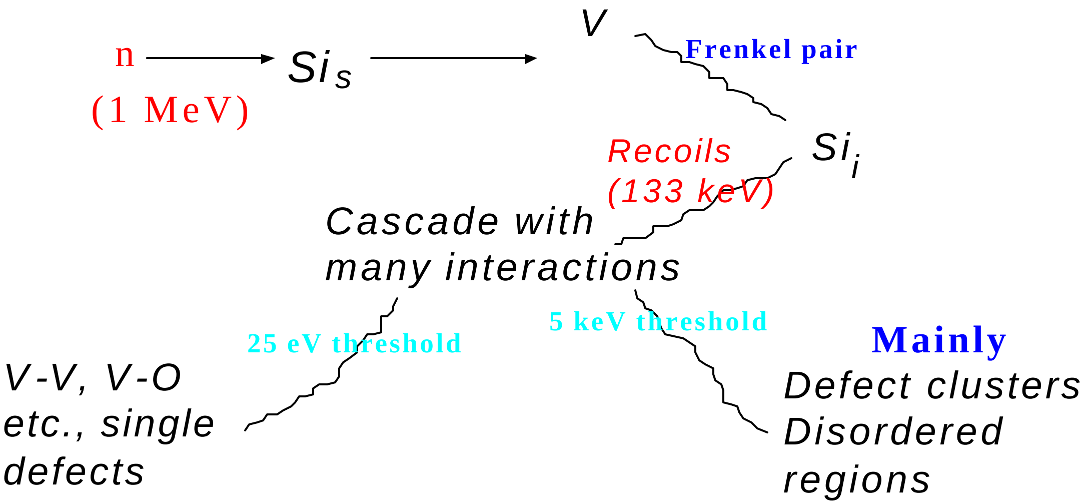
- 3D detectors
- Thin detectors
- Cost effective solutions

Full Detector Systems
Gianluigi Casse
(Liverpool University)

- LHC-like tests
- Links to HEP
- Links to R&D of electronics
- Comparison: pad-mini-full detectors

CERN contact: Michael Moll

Displacement radiation induced defects in Si -neutron



n (1 MeV) → Si_s → V

Frenkel pair

Si_i

Recoils (133 keV)

Cascade with many interactions

25 eV threshold

5 keV threshold

V-V, V-O etc., single defects

Mainly

Defect clusters

Disordered regions

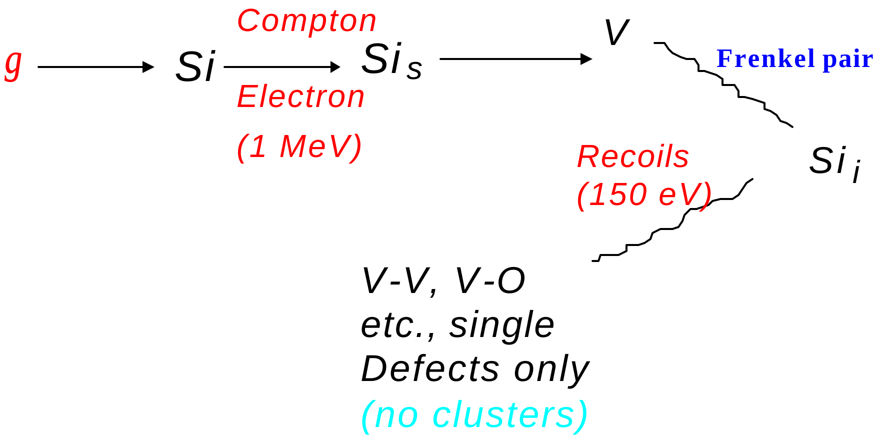
Displacement radiation induced defects in Si –charged particle (p, *p*, etc.)

It is between neutron and gamma:

Lots of single defects

plus some smaller defect clusters

Displacement radiation induced defects in Si -^{60}Co gamma ray



g → Si → Si_s → V

Compton Electron (1 MeV)

Frenkel pair

Si_i

Recoils (150 eV)

V-V, V-O etc., single Defects only (no clusters)

Comparison of defect structures

Particle type	Single defects	Defect clusters
n	x	xxxxxx
Charged particles (p, *p*, etc.)	xxxx	xx
g	xxxxxx	

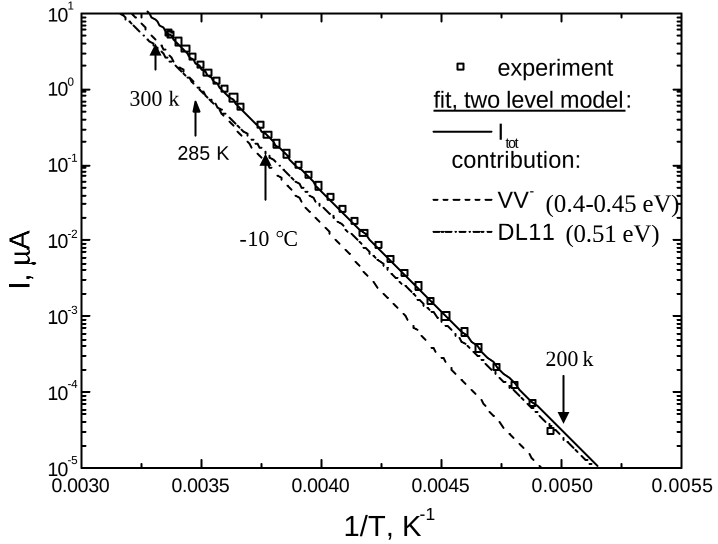
Radiation induced degradation of electrical properties in Si detectors

Leakage current temp. dependence

$$J / J_0 \; \mu \; e^{-E_a / kT}$$

E_a = 0.65 eV for 1 MeV neutron radiation

Modest cooling can help a lot!

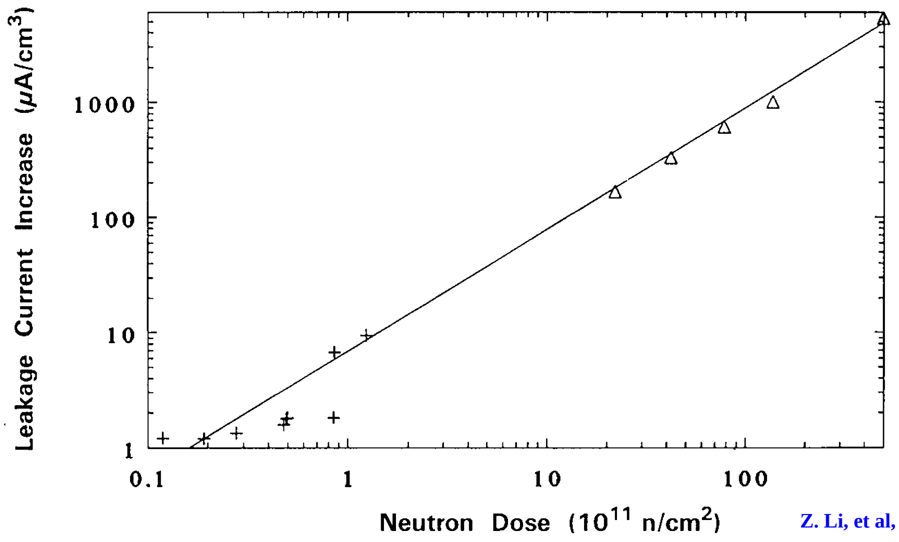


E. Verbitskaya, et al, Florence Conference, July, 2000

Increase of leakage current with fluence

$$\Delta J = a \;\; \Phi_{n,equ}$$

α: damage constant, 4-6x10^{-17} A/cm at 20 °C



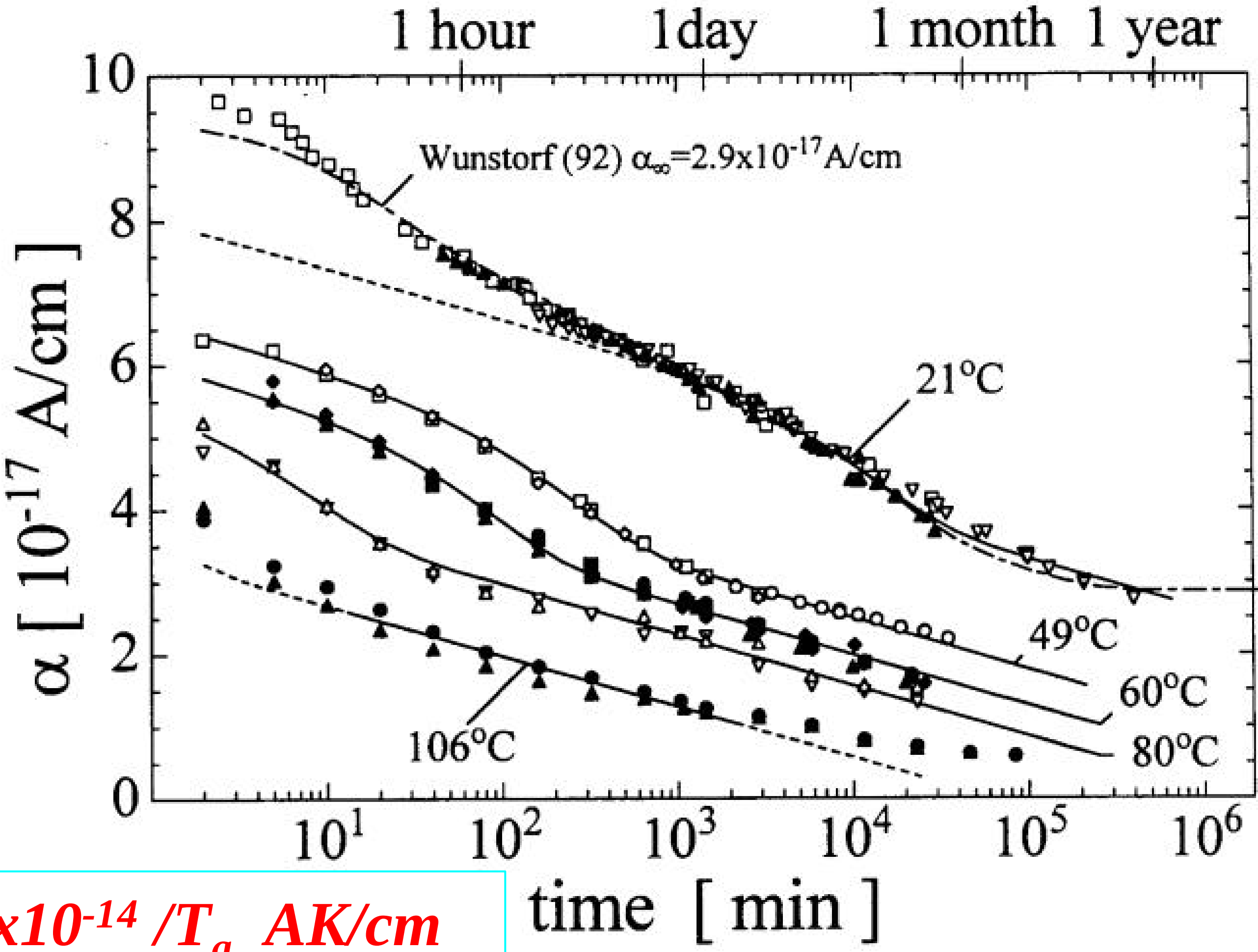
Z. Li, et al, NIM A308 (1991) 585

Parameterization of Leakage current

$J = a f_{eq}$

a: leakage current constant

Annealing behavior:



$$a(t) = a_I \cdot \exp(-t/t_I) + a_0 - b \cdot \ln(t/t_0)$$

$a_I = 1.2 \times 10^{-17}$ A/cm

$b = 3.1 \times 10^{-18}$ A/cm

$a_0 = -9 \times 10^{-17}$ A/cm$+4.6 \times 10^{-14}/T_a$ AK/cm

$t_0 = 1$ min

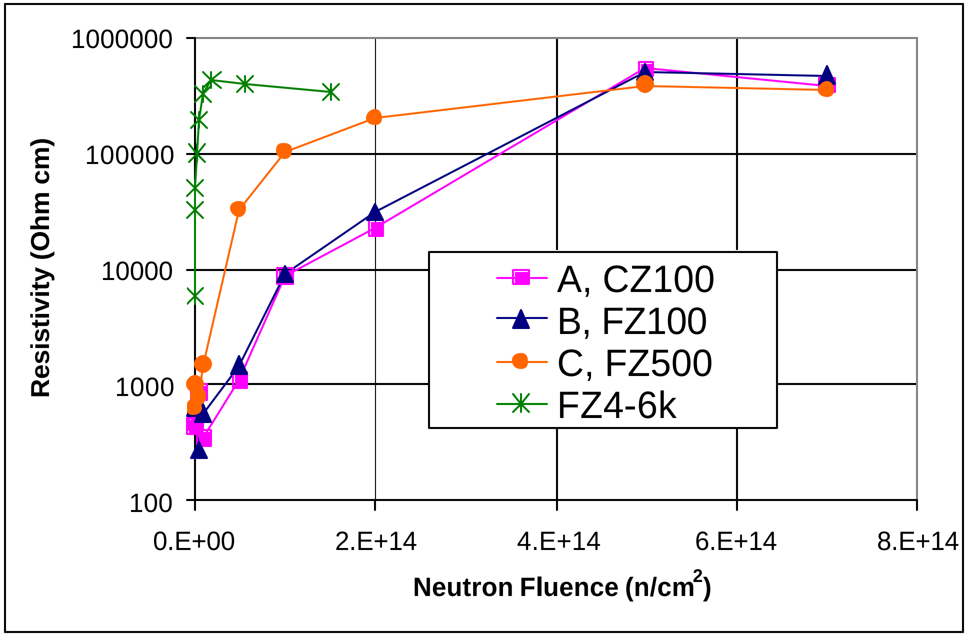
$$1/t_I = k_{0I} \exp(-E_I/k_B T_a)$$

$k_{0I} = 1.2 \times 10^{-18}$ /s, $E_I = 1.1$ eV

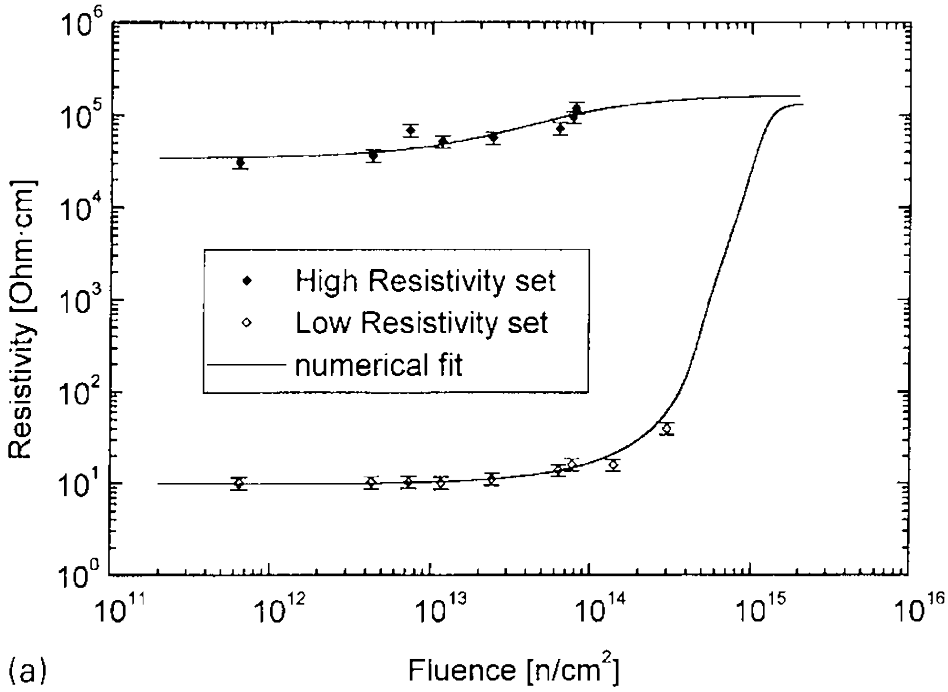
M. Moll, Ph.D. Thesis, University of Hamburg, 1999

Bulk Damage (electrical neutral bulk, ENB)

Si bulk resistivity increases with fluence and saturates near the intrinsic value of about 300 k Wcm



B. Dezillie et al., IEEE Trans. Nucl. Vol. 46, No. 3, (1999) 221



S. Pirollo et al., NIM A426 (1999) 126-130

Space charge transformations and CCE loss

Space charge transformation (SCT) takes one of the following three forms:

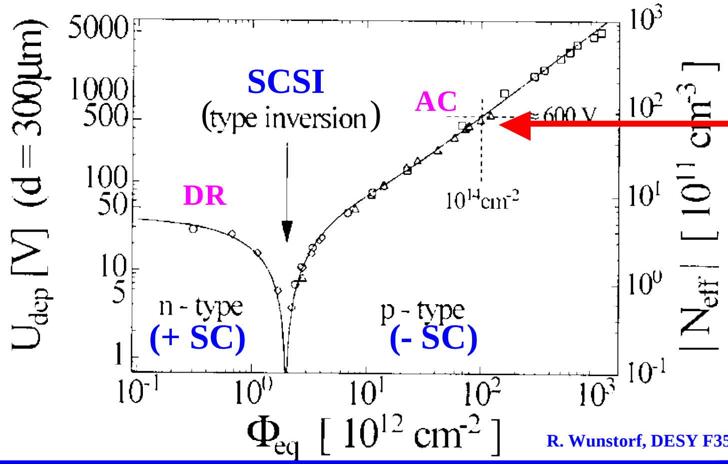
1. **Space charge becomes more negative with radiation due to the creation negative deep acceptors (As-irradiated effect)**
   - **Space charge sign inversion (SCSI) or "type inversion"**
   - **Increase in full depletion voltage (V_{fd}) due to increase of net space charge density** $V_{fd} = \dfrac{ed^2|N_{eff}|}{2\varepsilon\varepsilon_0} \rightarrow$ **CCE loss at a given bias**
2. **Increase of space charge density during annealing at RT and elevated temperatures ("Reverse annealing")**
   - **More increase of V_{fd}**
3. **Space charge modifications due to trapping by free carriers**

As-irradiated Effects

SCSI (Space charge sign inversion) --- donor removal & acceptor creation:

(DR) (AC)

$$N_{eff} = N_{d0}\, e^{-g\,\Phi_n} - b\,\Phi_n$$



R. Wunstorf, DESY F35D-97-08, 1997

Acceptor creation:

V+V ⟶ V-V

And other V-V related defects

After SCSI: $N_{eff} \approx -b\,\Phi_n$

β = 0.024 to 0.032 cm^{-1}

Donor removal:

The removal rate is not a constant

$g = \mathbf{0.1}/N_{d0}$

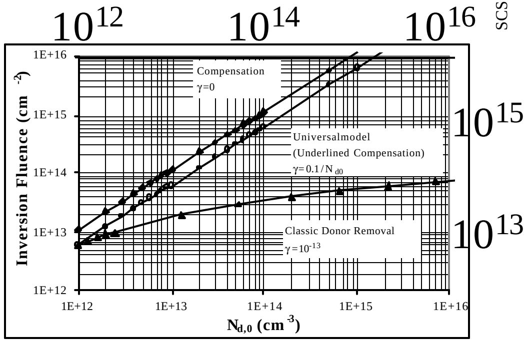
As-irradiated Effects

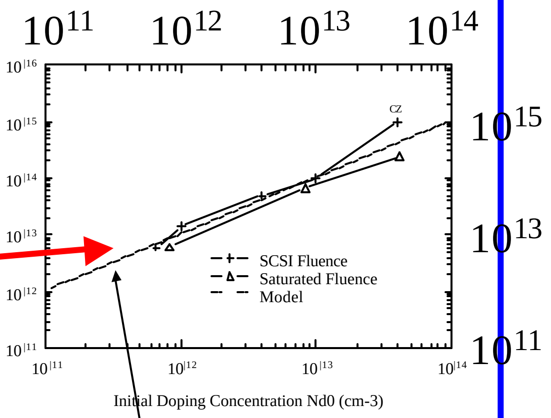
Donor removal models

V+P ⟶ P-V (E-center)

$$N_{eff} = N_{d0}\, e^{(-g\Phi_n)} - b\Phi_n \qquad (3)$$

$$\begin{cases} g = 0 & \text{Compensation } \textbf{(AC only)} \\ g = 10^{-13} & \text{Donor Removal } \textbf{(classic model)} \\ g = \dfrac{0.1}{N_{d0}} & \text{Modified model} \end{cases}$$



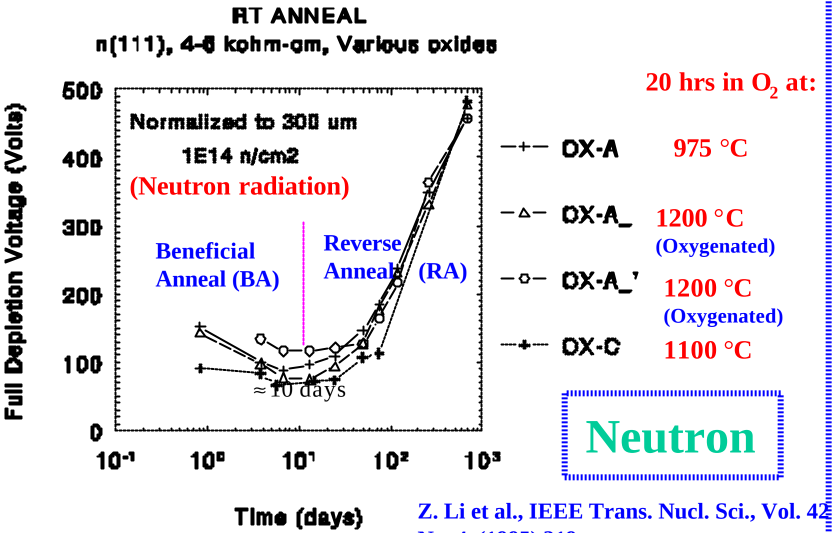


Modified model:

$g = 0.1/N_{d0}$

B. Dezillie, Z. Li, et al., IEEE Trans. Nucl. Sci., Vol. 46, No. 3, (1999) 221-227

Reverse Annealing



20 hrs in O_2 at:

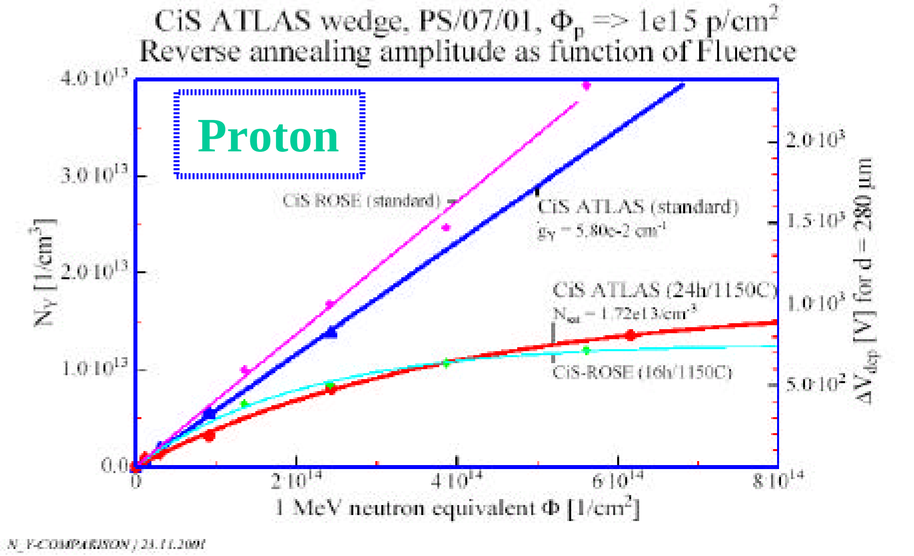
OX-A	975 °C
OX-A_	1200 °C (Oxygenated)
OX-A_'	1200 °C (Oxygenated)
OX-C	1100 °C

Neutron

Z. Li et al., IEEE Trans. Nucl. Sci., Vol. 42 No. 4, (1995) 219

V_{fd} increases with annealing time after about 10 days at RT

N_{eff} becomes even more negative



Proton

G.Lindstroem, presented on "1st Workshop on Radiation hard semiconductor devices for very high luminosity colliders", CERN 28-30 November, 2001

RT annealing

- **Possibly multiple annealing stages (two or more defects involved)**
- **First order process:**

$$N_{eff}(t) = -N_0 - N_{eff}^{r,\max}(1 - e^{-t/t})$$

- **Activated process:**

$$t_{1/2} = t \cdot \ln 2 = \frac{1}{n} e^{E_a/kT}$$

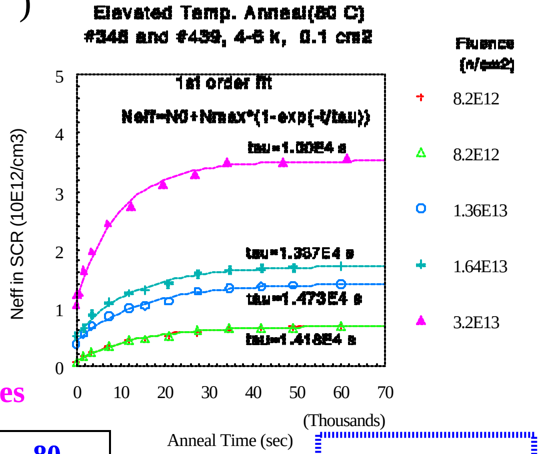
with E_a = 1.18 eV
and n = 10^{13} s

$$N_0 = 0.035 \cdot \Phi_n$$

$$N_{eff}^{\max} = 0.073 \cdot \Phi_n$$

- **It can be frozen at low temperatures**

T (°C)	-10	0	20	80
t	96.8 yr	14.6 yr	179 d	3.7 hr



Neutron

Z. Li , IEEE Trans. Nucl. Sci., Vol. 42, No. 4, (1995) 224

ET annealing

Parameterization of N_{eff} (As-irradiated and reverse annealing)

$$N_{eff} = N_{eff0} - D\, N_{eff}$$

$$D\, N_{eff} = N_A + N_C + N_Y$$

N_Y : Reverse annealing

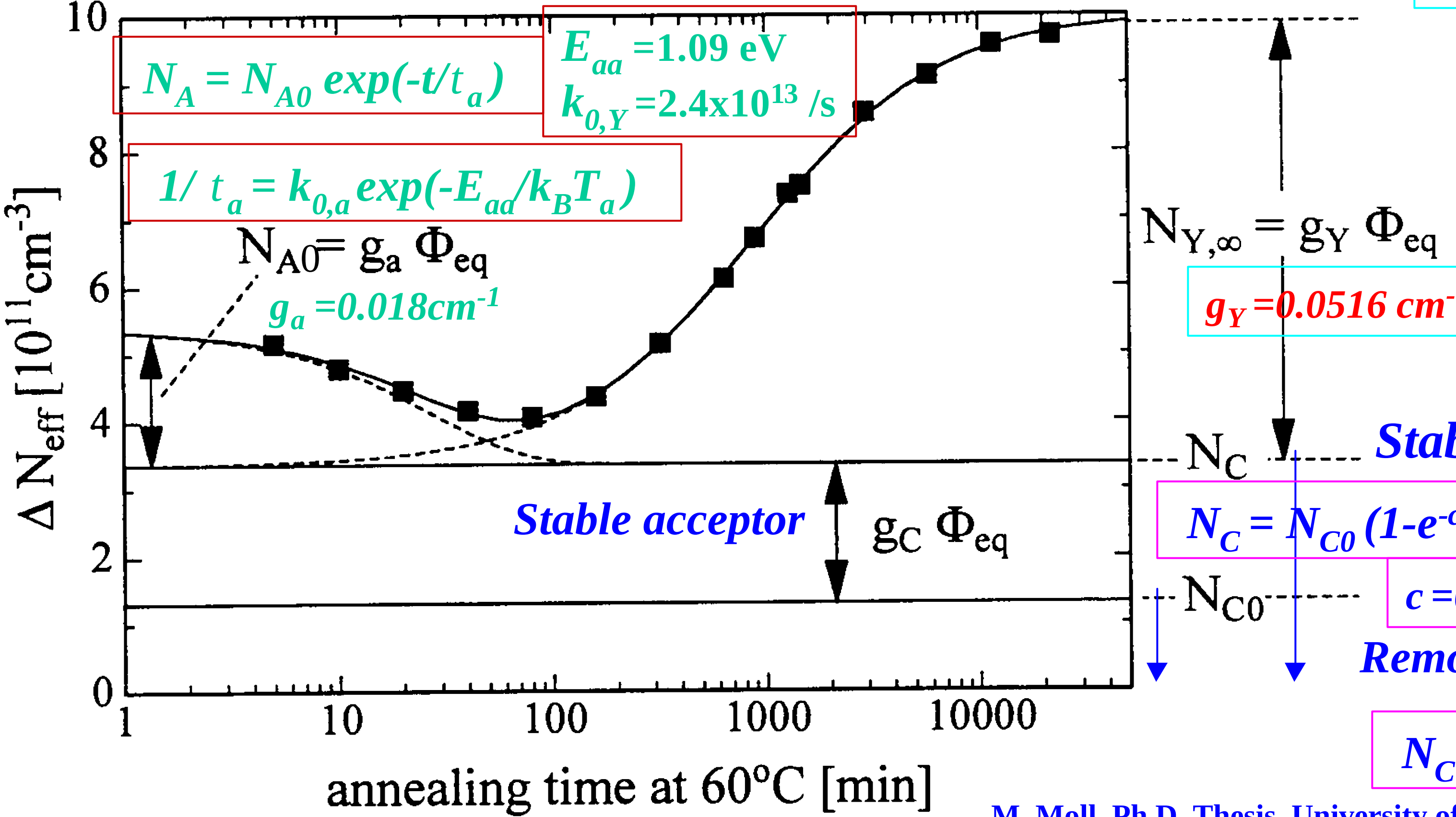
$$N_Y = N_{Y,¥}\,(1 - 1/(1+t/t_Y))$$

$$1/\,t_Y = k_{0,Y}\,exp(-E_Y/k_B T_a)$$

E_Y =1.33 eV

$k_{0,Y}$ =1.5x10^{15} /s

N_A : Beneficial annealing



$$N_A = N_{A0}\,exp(-t/t_a)$$

E_{aa} =1.09 eV

$k_{0,Y}$ =2.4x10^{13} /s

$$1/\,t_a = k_{0,a}\,exp(-E_{ad}/k_B T_a)$$

g_a =0.018cm^{-1}

g_Y =0.0516 cm^{-1}

Stable acceptor

Stable defect

$$N_C = N_{C0}\,(1-e^{-cF\, eq}) + g_C\, F_{eq}$$

c =0.1/N_{d0}

Removable donor

N_{C0} » 0.7xN_{d0}

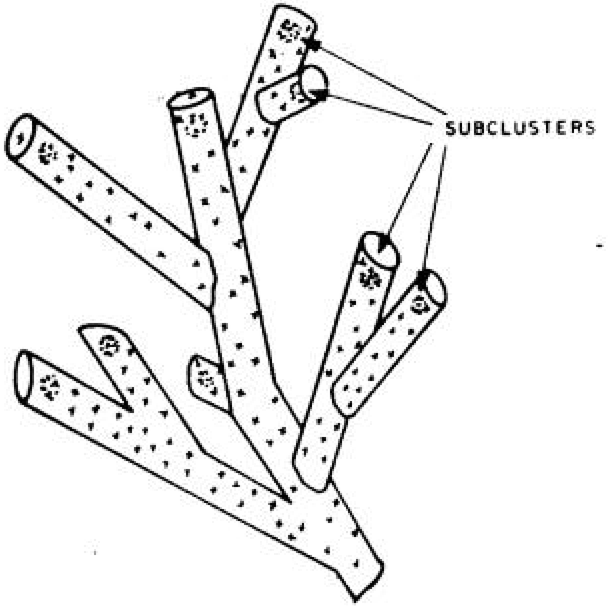
M. Moll, Ph.D. Thesis, University of Hamburg, 1999

Model for the reverse annealing

- Reverse annealing in n, p, alpha irradiated Si detectors (Clusters)

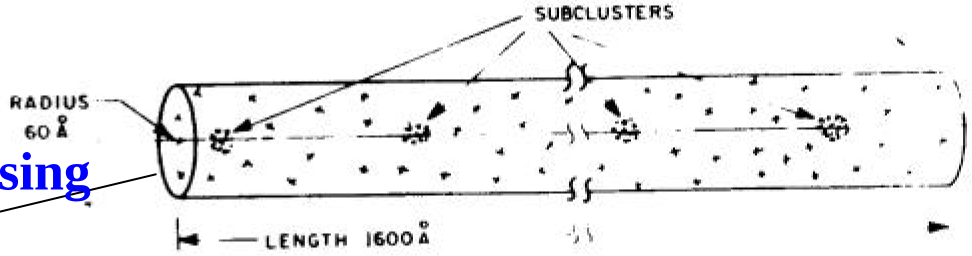
- No reverse annealing in gamma irradiated Si (Single defects only, no clusters)

- Reverse annealing may be due to the breaking off of clusters over time and temp, releasing single defects:



SUPERCLUSTER CONFIGURATION

Clusters → V-V or related defects



EQUIVALENT SUPERCLUSTER CONFIGURATION

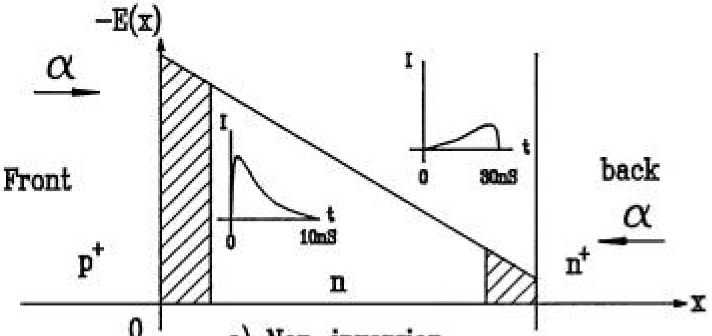
Releasing

Single defects

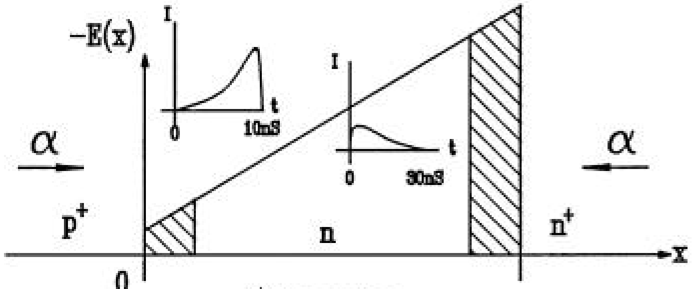
Z. Li et al., IEEE Trans. Nucl. Sci., Vol. 44, No. 3, (1997) 834

Double-Junction/Double-Peak (DJ/DP) Effect

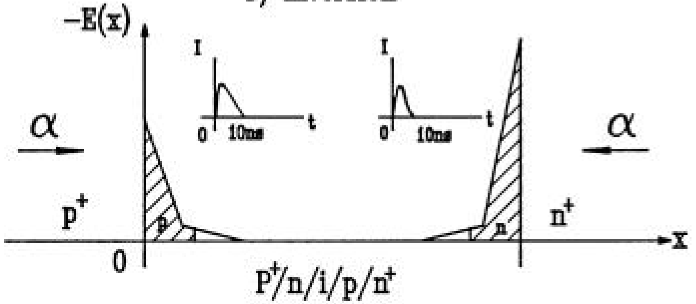
DJ/DP effect and the 2-deep level model **(Z. Li and H.W. Kraner, J. Electronic Materials, Vol. 21, No. 7, (1992) 701)**



a) Non-inversion

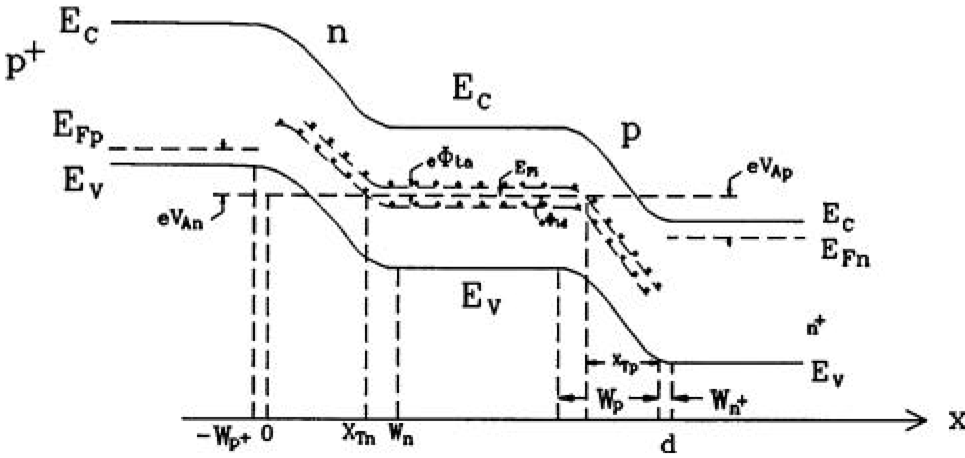


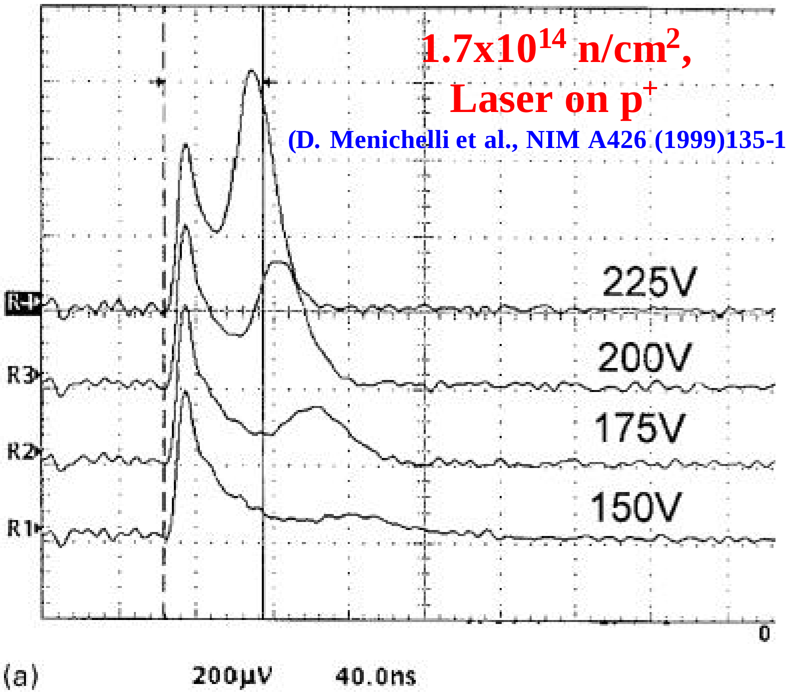
b) Inversion



P+/n/i/p/n+

c) Junction on both sides





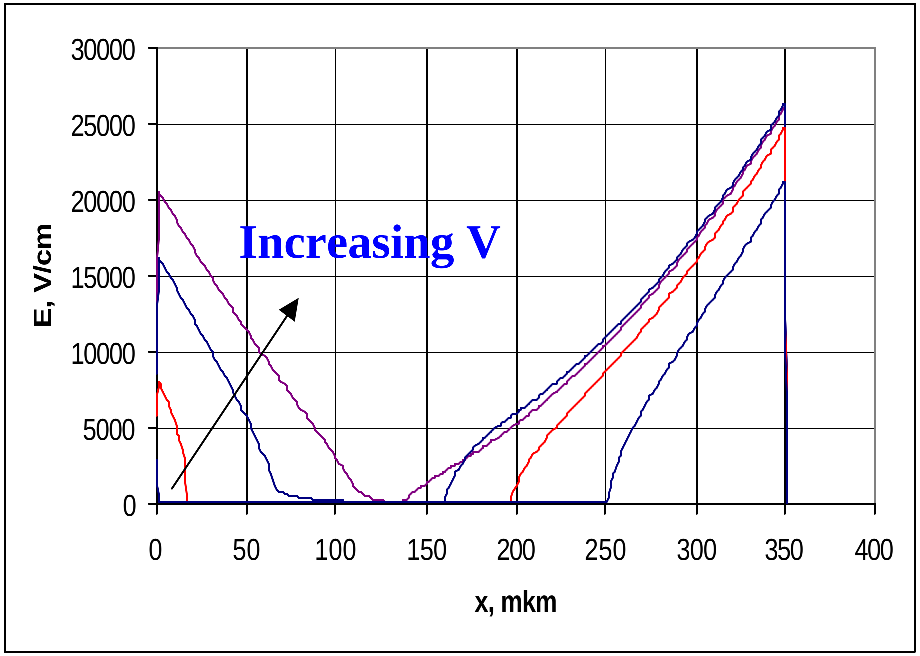
1.7×10^{14} n/cm^2, Laser on p$^+$

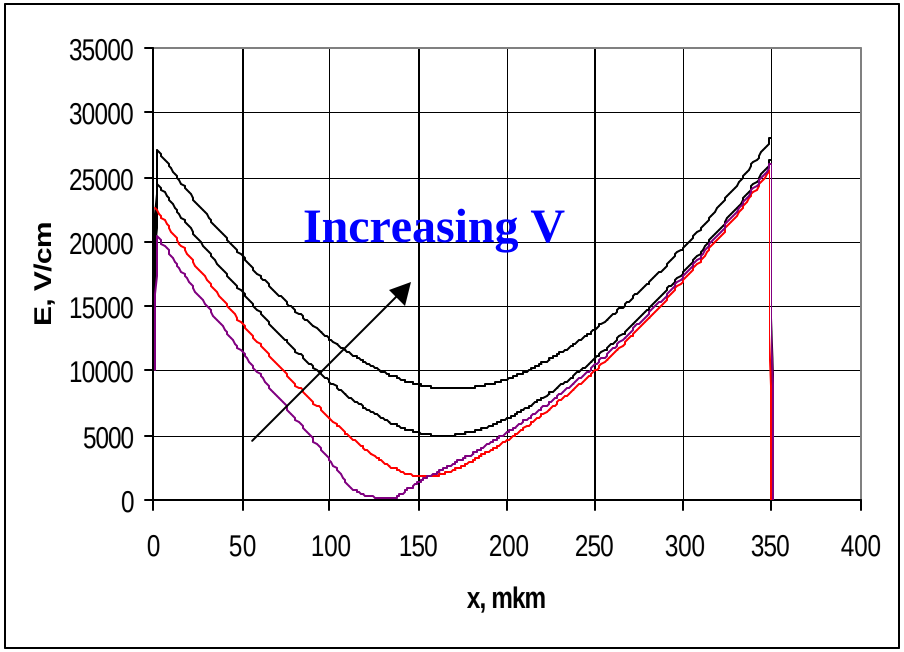
(D. Menichelli et al., NIM A426 (1999)135-139)

Detail Modeling of (DJ/DP) Effect

2-deep level model (V. Eremin et al, Nucl. Instrum. & Meth. A476 (2002) 556-564.)

DL #	Ci-Oi		Deep donor		V-V		Deep acceptor	
D/A, 0/1	0		0		1		1	
	electrons	holes	electrons	holes	electrons	holes	electrons	holes
Et=Edl-Ev	0.36	#REF!	0.52	#REF!	0.7	-0.7	0.6	-0.6
sig/e[cm2]	1.00E-15		1.00E-15		1.00E-15		1.00E-15	
sig/h[cm2]		1.00E-15		1.00E-15		1.00E-15		1.00E-15
Ndl[cm-3]	0.00E+00		4.60E+14		0.00E+00		4.00E+15	





Degradation in Charge Collection Efficiency (CCE)

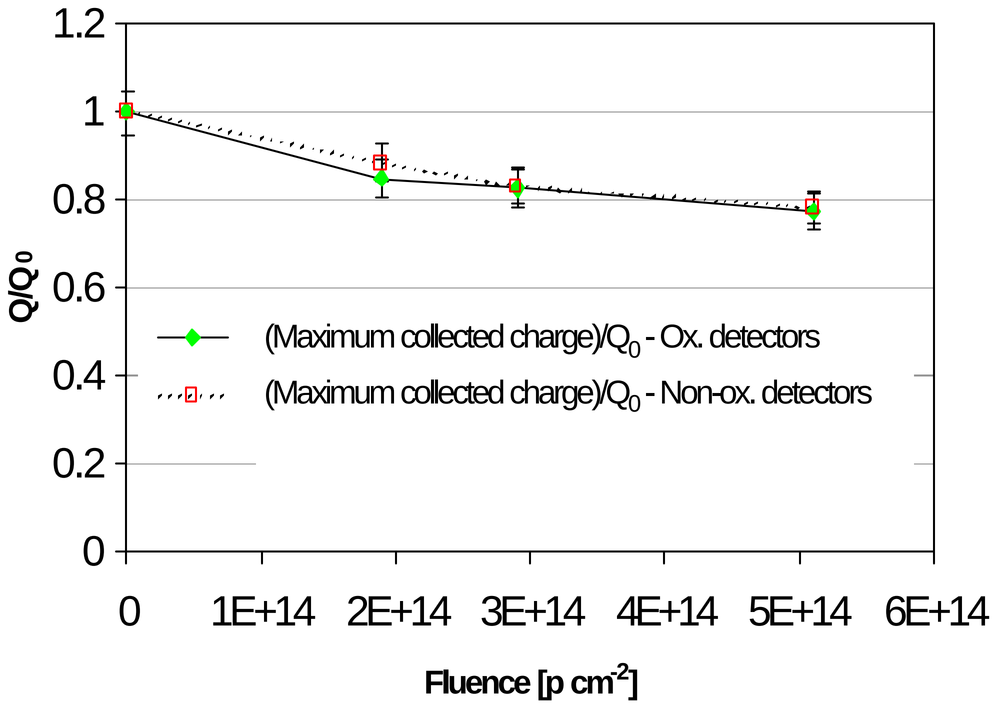
$$CCE = \frac{Q - \Delta Q}{Q_0} = \begin{cases} \frac{W}{d}\left(1 - \frac{1}{2}\frac{t_c}{t_t}\right)(a\text{, laser } (l \le 830\ nm) \\ \qquad \text{on junction side}) \qquad (10) \\ \left(\frac{W}{d}\right)^2 \left[1 - \left(\frac{1}{6}\frac{t_c^h}{t_{th}} + \frac{1}{6}\frac{t_c^e}{t_{tte}}\right)\right] \quad (MIP) \end{cases}$$

Depletion Volume term

Trapping term

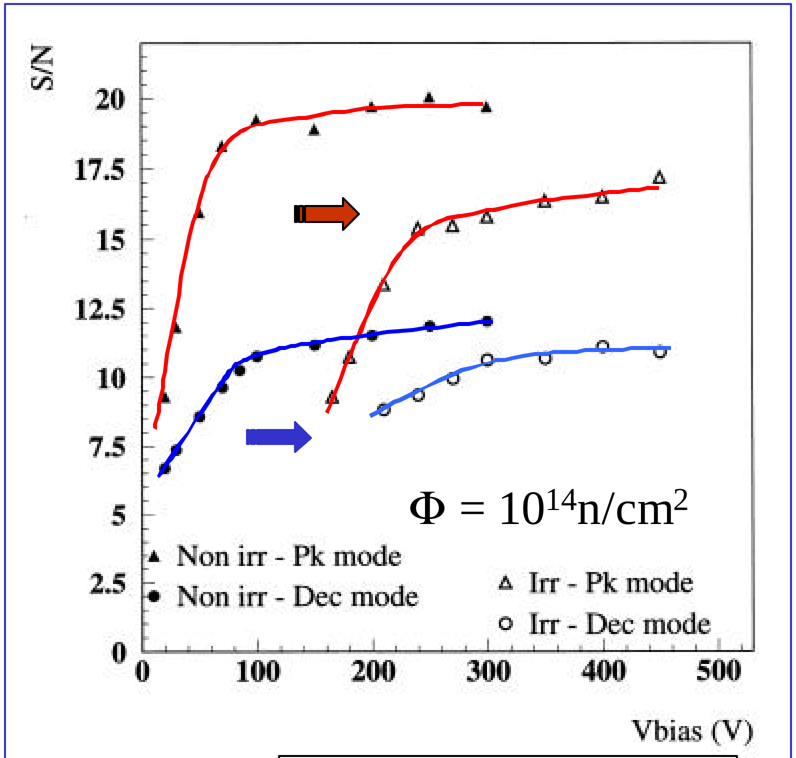
B. Dezillie et al., IEEE Trans. Nucl. Sci., Vol. 46, No. 3, (1999) 221-227

ATLAS microstrip + RO electronics



Data: Gianluigi Casse: 1st Workshop on Radiation hard semiconductor devices for high luminosity colliders; CERN; 28-30 November 2002

CMS microstrip + RO electronics



NIM A 476, (2002), 734

Radiation Hardness

Material/ impurity/defect Engineering (MIDE)

- **Impurities intentionally incorporated into Si may serve to getter radiation-induced vacancies to prevent them from forming the damaging V-V and related centers**
- **Impurities: O, Sn, N, Cl, H, etc.**

One example: oxygen O:

$$V + V \rightarrow V_2$$

$$V + O \rightarrow O - V$$

$$V + VO \rightarrow V_2O$$

Competing processes for V

If [O] >>[V] and [V-O], then the formation rates of V_2 and V_2O will be greatly suppressed:

Key: impurity concentration should be much larger than that of vacancies

Material/ impurity/defect Engineering (MIDE)

Defect kinetics model

Reactions

PKA cluster reactions

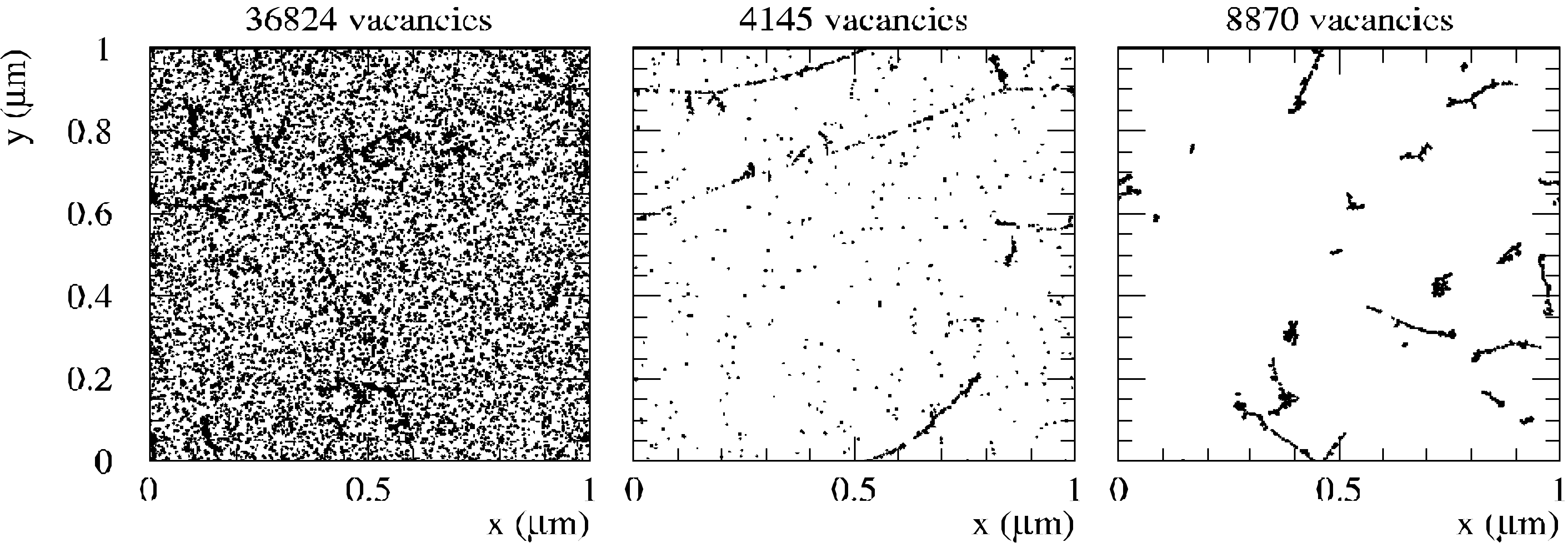
I + V ® Si **V + V ® V_2**

I reaction	V reaction	C_i reaction
I + C_s ® C_i	V + O ® VO	C_i + Cs ® CC
I + V_2 ® V	V + P ® VP	C_i + O ® CO
I + VP ® P	V + VO ® V_2O	CO + I ® COI *
I + V_3O ® V_2O	V + V_2O ® V_3O	CC + I ® CCI *

* Not thought to be electrically active

Defect structure modeling

Mika Huhtinen -
ROSE/Techn.Note/2001-02



10 MeV protons

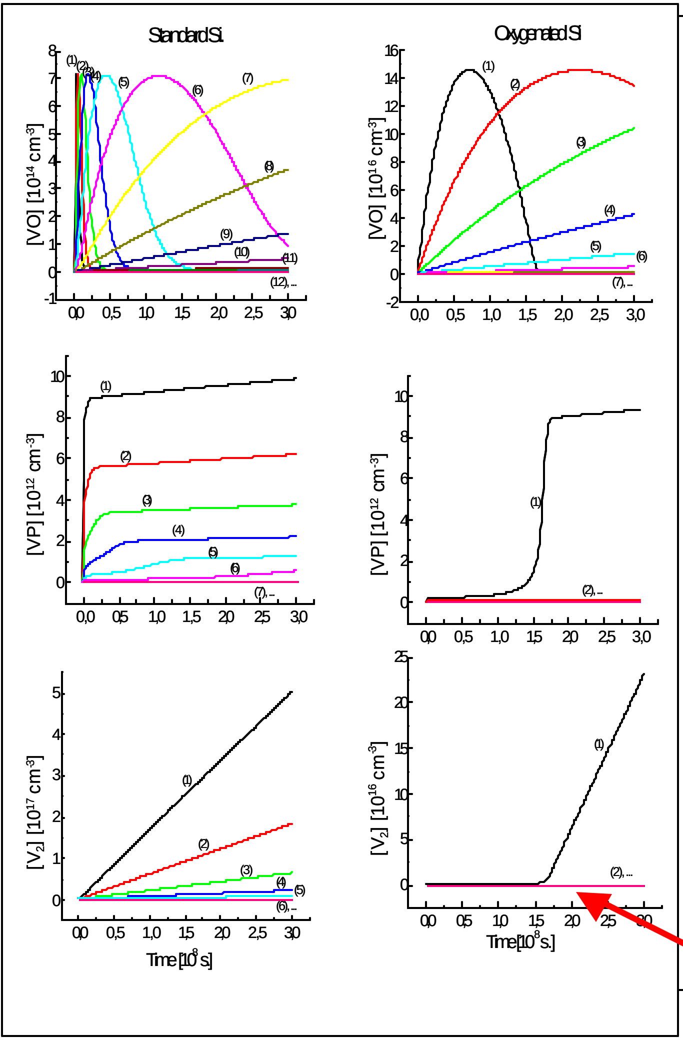
24 GeV/c protons

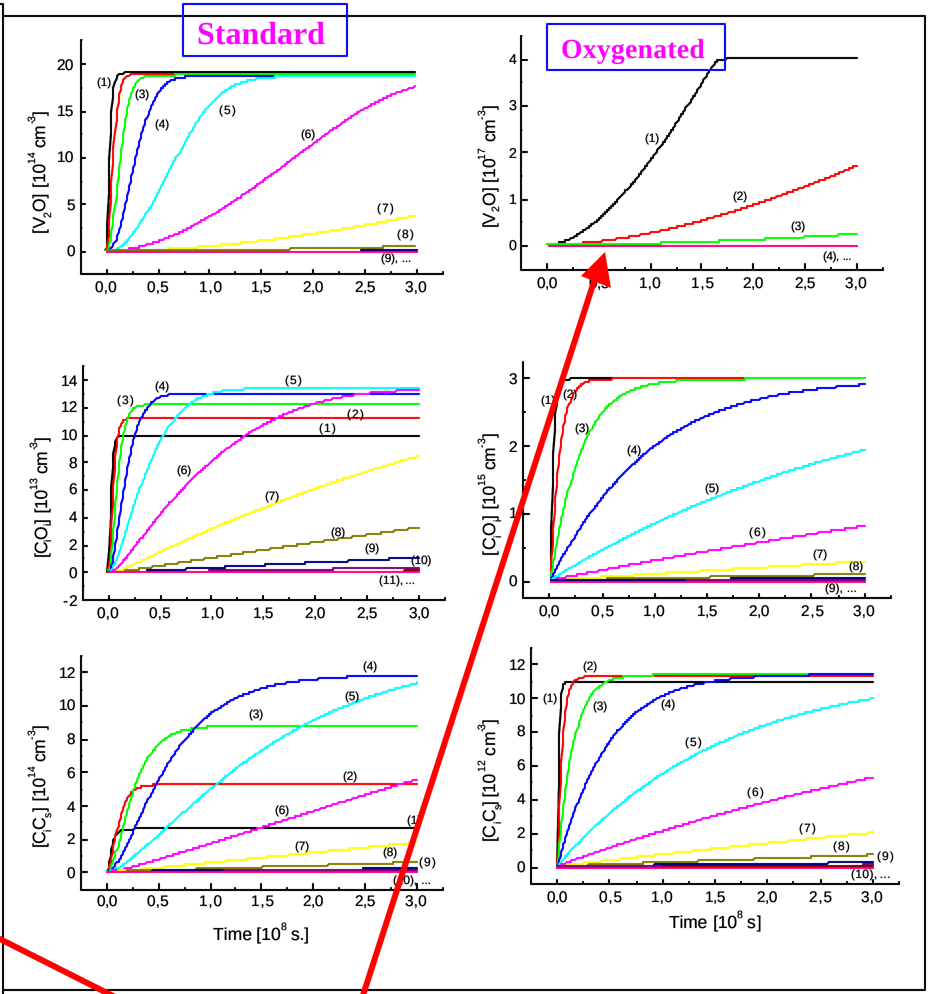
1 MeV neutrons

More clusters
for n-rad

Defect kinetics modeling

S. Lazanu et al, RESMDD02, Florence, Italy, July 10-12, 2002





"standard" Si:
10^{14} P, 2 10^{15} O, 5 10^{15} C

"oxygenated" Si:
10^{14} P, 4 10^{17} O, 5 10^{15} C

Rate dependence:
(1) G_R = 5x10^9 VI pairs/s
.
.
.
(17) G_R = 50 VI pairs/s

Both V_2 and V_2 O productions are greatly suppressed in oxygenated Si

Material/ impurity/defect Engineering (MIDE)

Review of Current Technologies

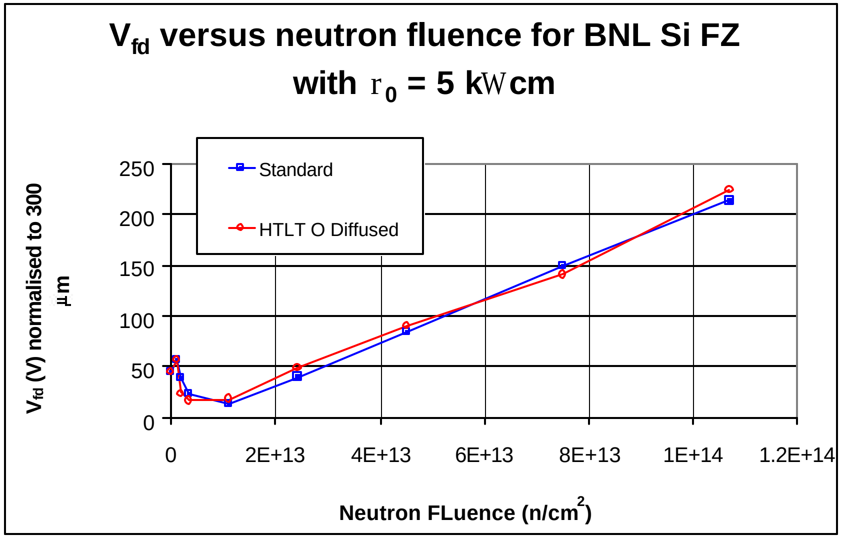
HTLT : High Temperature Long Time oxidation
Oxidation in straight O_2 at high T (up to 1200 °C) for up to 24 hrs
$[O_i]$ up to $4\cdot10^{17}cm^{-3}$, uniform up to 50 mms.
developed at BNL in 1992

DOFZ : Diffusion Oxygenated Float Zone Si
Oxidation+long time diffusion in N_2 at high T (up to 1150 °C)
$[O_i]$ up to $5\cdot10^{17}cm^{-3}$
developed in the framework of RD48 in 1998

Advanced HTLT : High Temperature Long Time oxidation
Oxidation in straight O_2 at high T (up to 1200 °C) for up to 216 hrs
$[O_i]$ up to $4\cdot10^{17}cm^{-3}$, uniform up to 400 mms.
developed at BNL in 1999

- Thermal donor (TD) suppression (no change in initial doping)
- TD introduction (initial doping dominated by TD)

o

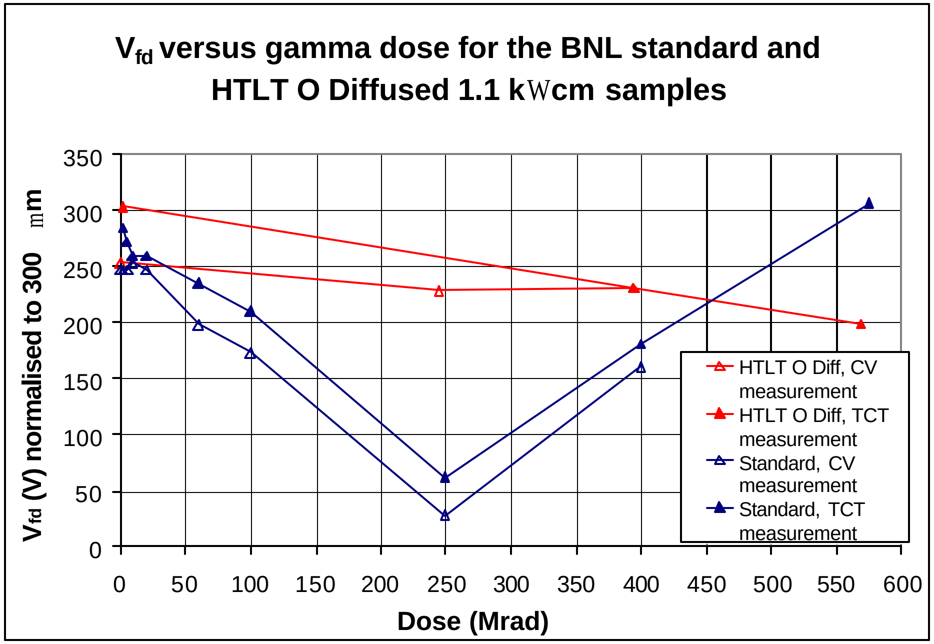


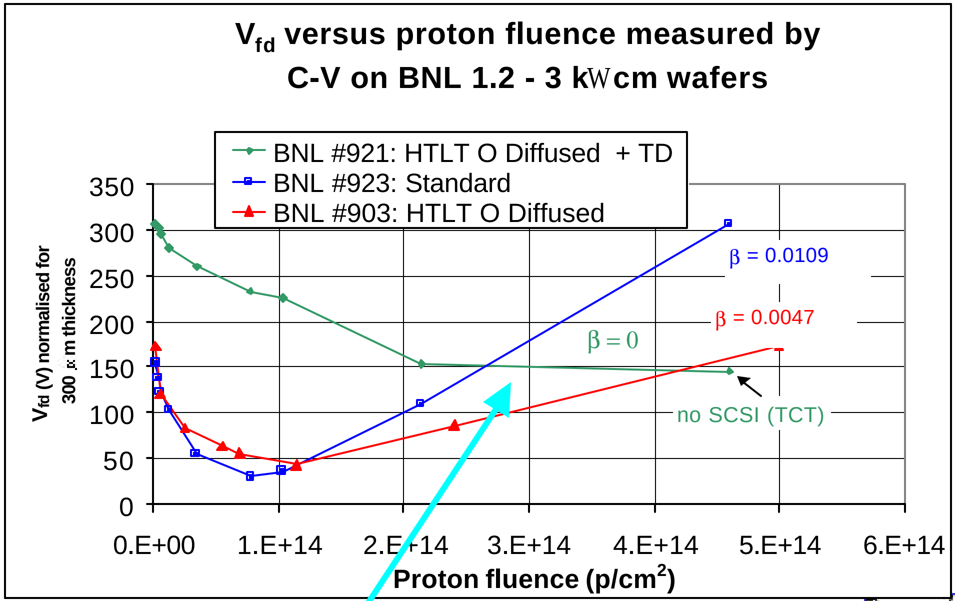
Little improvement with regard to neutron radiation by HTLT

B. Dezillie et al., IEEE Trans. Nucl. Sci., Vol. , No. , (2000) 1892-1897

HTLT technology totally improve gamma radiation hardness

Maximum improvement with regard to gamma radiation by HTLT





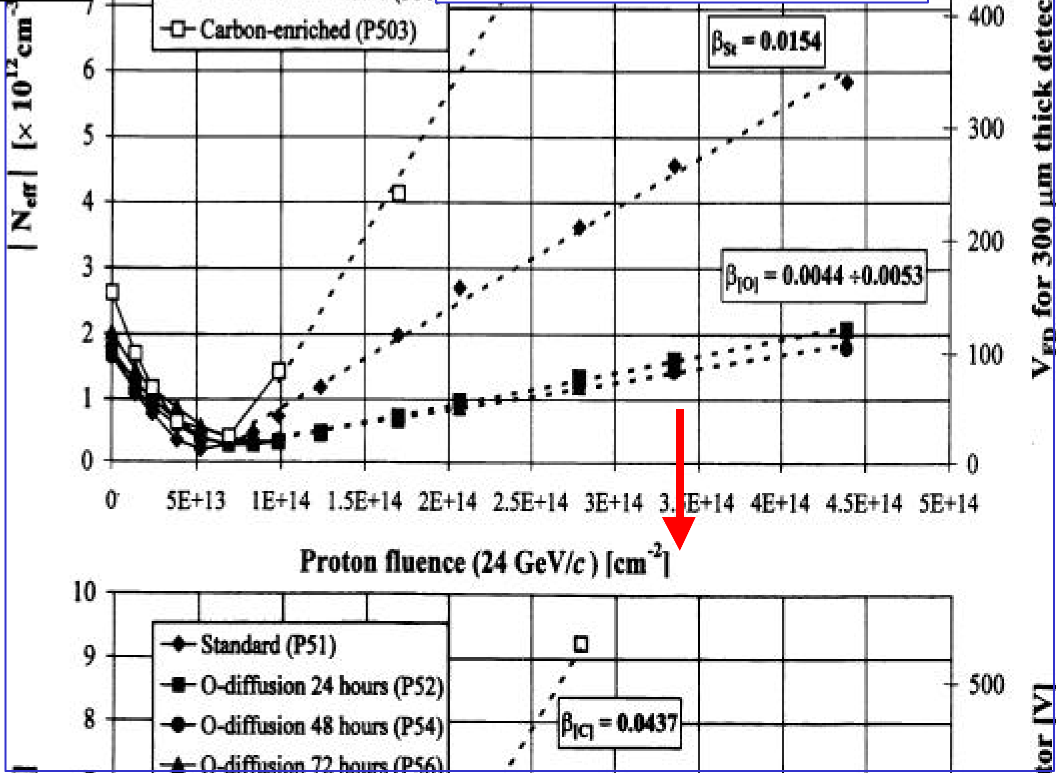
V$_{fd}$ versus proton fluence measured by C-V on BNL 1.2 - 3 kWcm wafers

B. Dezillie et al., IEEE Trans. Nucl. Sci., Vol. , No. , (2000) 1892-1897

Oxygenation **partially** **improve charged particle (p, p) radiation hardness**
By a factor of 2-3

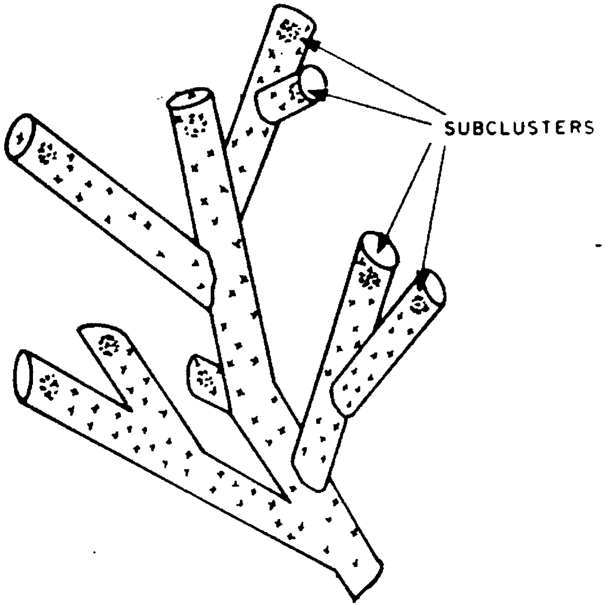
Thermal donor are not removed:
delay of SCSI

RD48, NIM A 447 (2000), 116-125

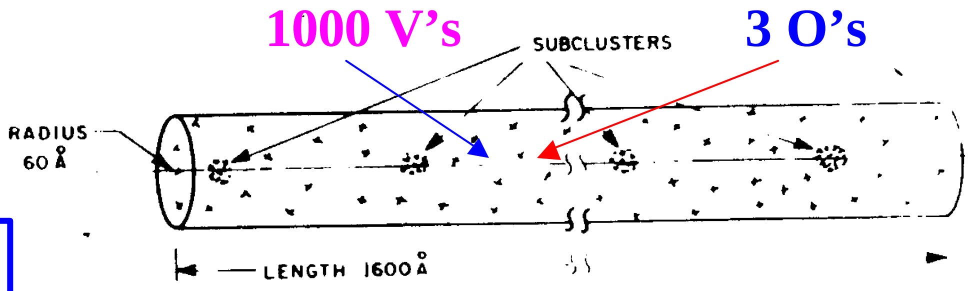


Model for the role of oxygen in rad-hardness

Particle type	Single defects	Defect clusters	Oxygen effect
n	x	xxxxxx $R_{V-V}>>1$	No
Charged particles (p, *p*, etc.)	xxxx $R_{V-V} <<1$	xx	Partial
g	xxxxxx $R_{V-V} <<1$		Yes



SUPERCLUSTER CONFIGURATION



1000 V's

3 O's

EQUIVALENT SUPERCLUSTER CONFIGURATION

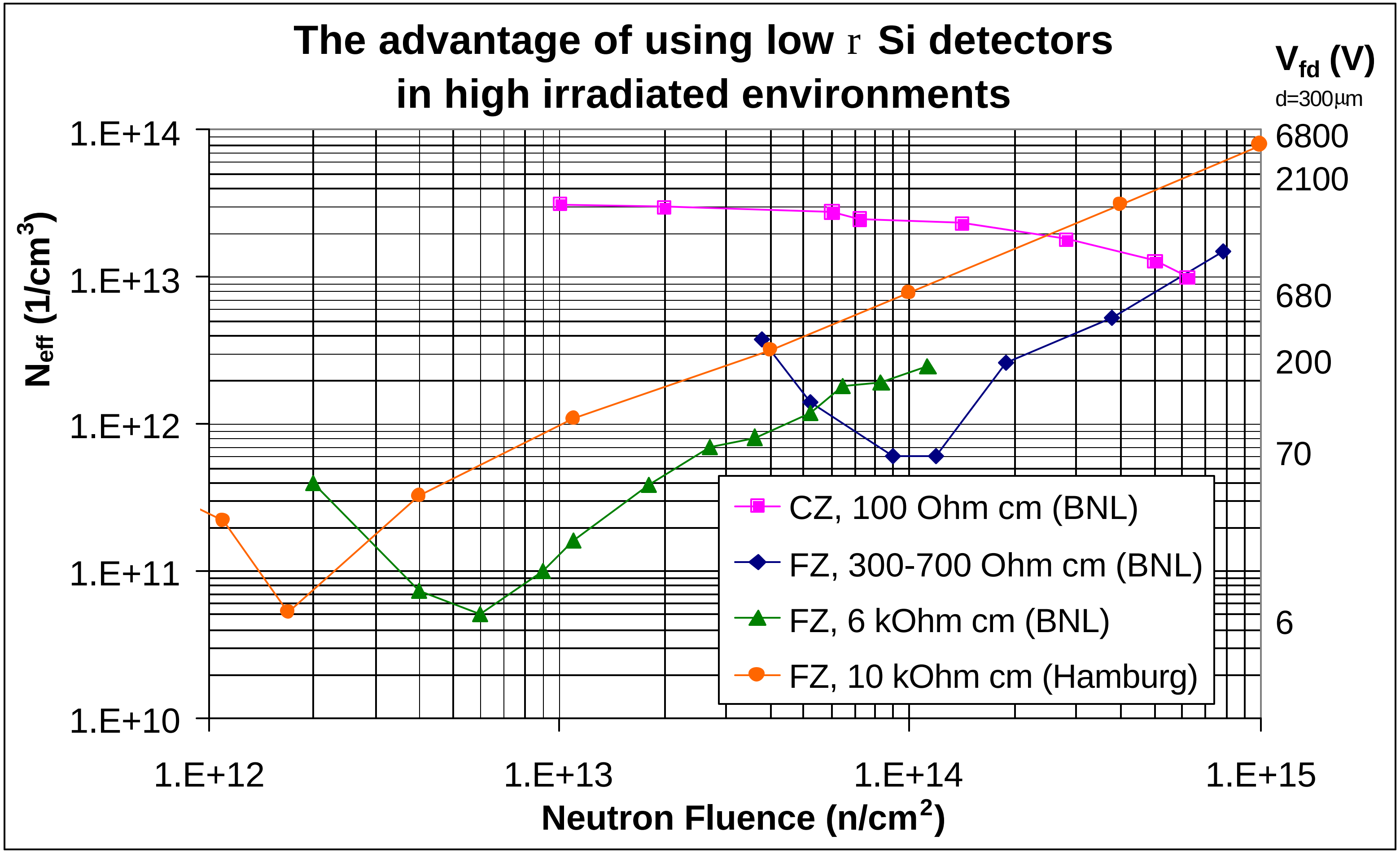
The local [O] is much smaller than [V] within the cluster

Z. Li et al., Nucl. Inst. & Meth., A461 (2001) 126-132

Material/ impurity/defect Engineering (MIDE)

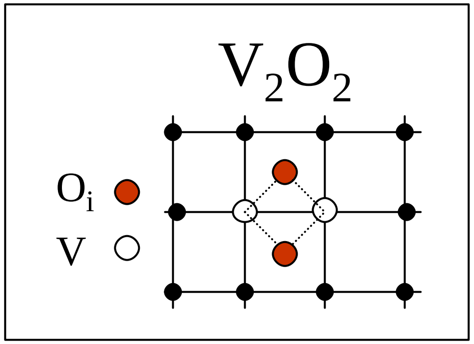
Low resistivity starting Si materials

- **Delayed SCSI**
- **Lower V_{fd} at higher fluences**



Nucl. Inst. Meth. A360 (1995) 445

Oxygen Dimers in Silicon



Oxygen dimer O_{2i} formed during pre-irradiation by Co^{60} g-irradiation at 350°C

$$V + O \rightarrow VO; \qquad V + VO \rightarrow V_2O$$

S. Watts et al., presented at Vertex 2001

$$V + O_2 \rightarrow VO_2; \qquad V + VO_2 \rightarrow V_2O_2 \longrightarrow \textit{neutral ?}$$

Thinner Detectors

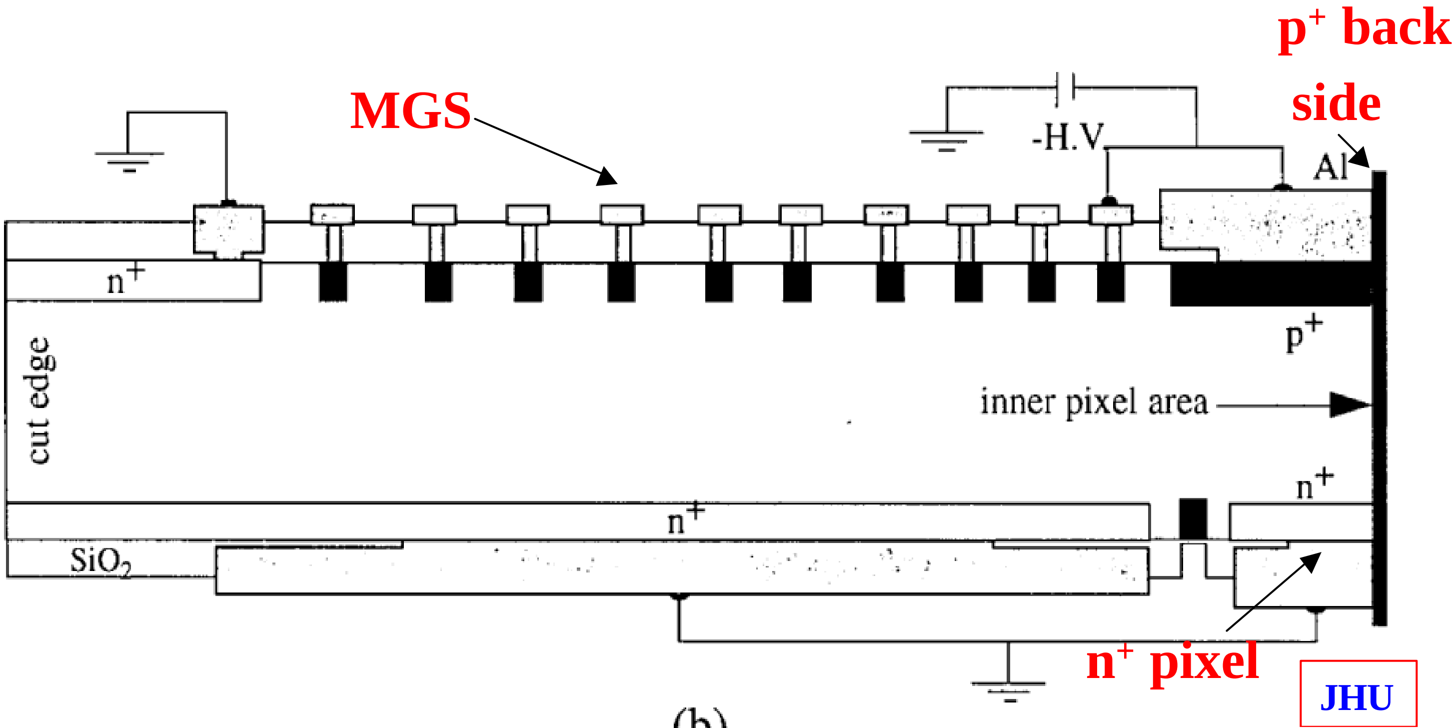
More radiation tolerance:

For d = 50 mm, the detector can be still fully depleted up to a fluence of 2-3x10^{15} n/cm^2 at bias of 200 V:

- **For a low starting resistivity Si (50 W–cm), no SCSI up to 1.5x10^{15} n/cm^2**
- **For high starting resistivity Si (³ 4 kW-cm), still fully depleted up to 3x10^{15} n/cm^2 , even though SCSI taking place at about 1x10^{13} n/cm^2.**

Device Structure Engineering (DSE)

- **Multi-guard-ring system (MGS)**
  - **To increase the detector breakdown voltage**
  - **High operation voltage to achieve more radiation tolerance**
  - **Up to 1000 volts can can be achieved (up to 6x10^{14} n/cm^2 tolerance)**
  - **Both CMS and ATLAS pixel detector systems use MGS**
- **n on n and n on p detectors**
  - **Not sensitive to SCSI**
  - **Both CMS and ATLAS pixel detector systems use n on n**



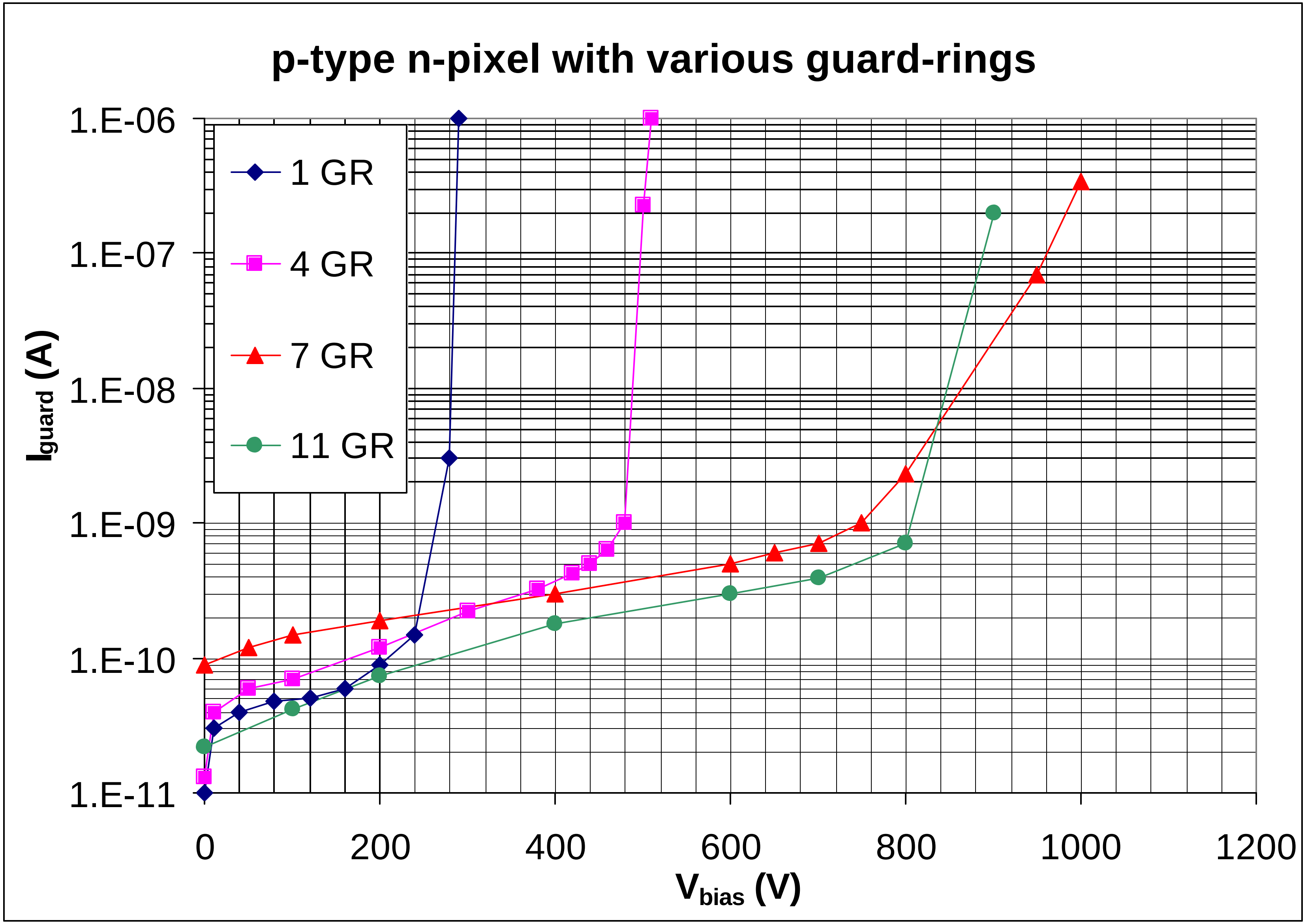
MGS

p^+ back side

n^+ pixel

JHU

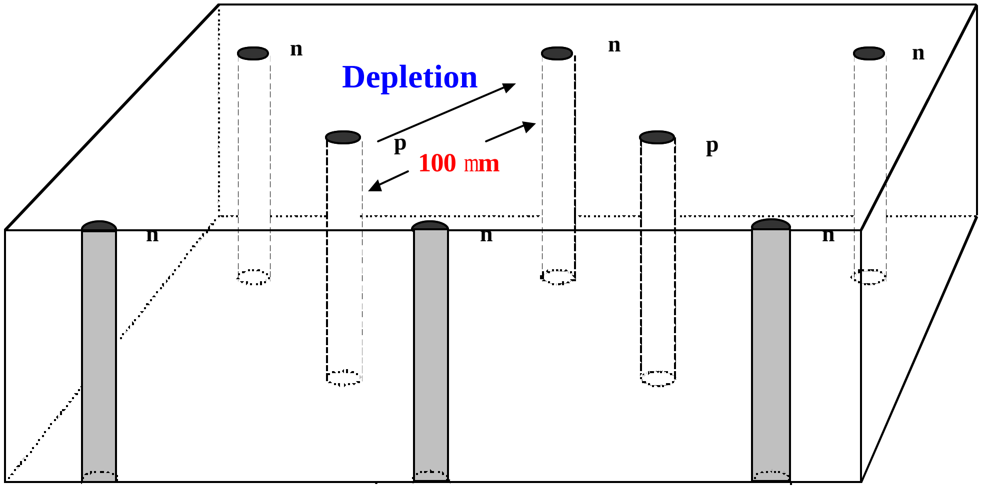
Multi-guard-ring system (MGS)

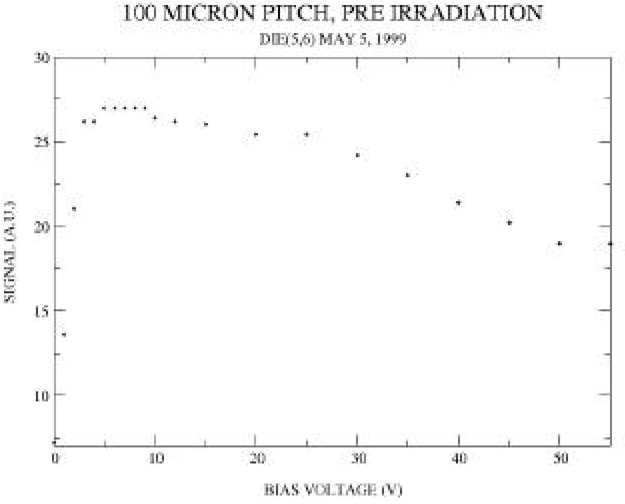


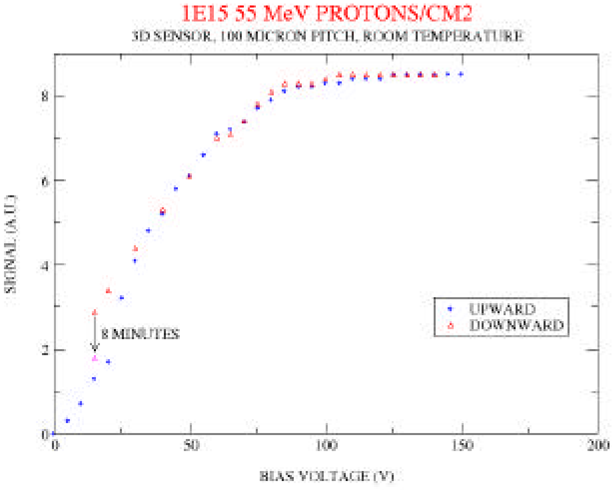
G. Bolla et al., NIM A435 (1999) 178

3-d Detector

- Differ from conventional planar technology, p^+ and n^+ electrodes are diffused in small holes along the detector thickness (“3-d” processing)
- Depletion develops laterally (can be 50 to 100 μm): not sensitive to thickness
- Much less voltage used --- much higher radiation tolerance







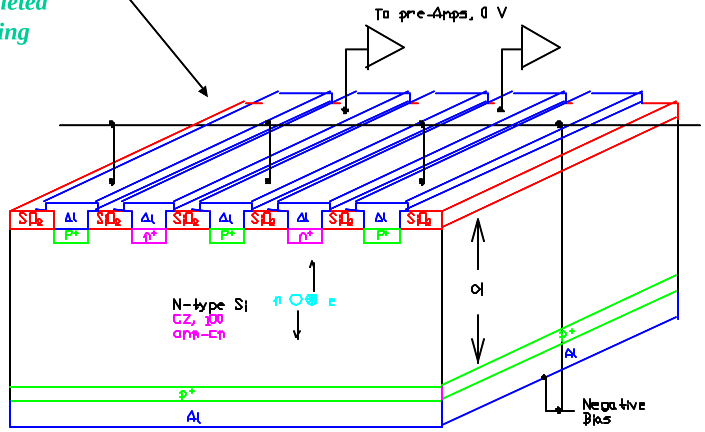
V_{fd} reduced up to a factor of 8-10

Non-planar process

Sherwood I. Parker et al., UH 511-959-00

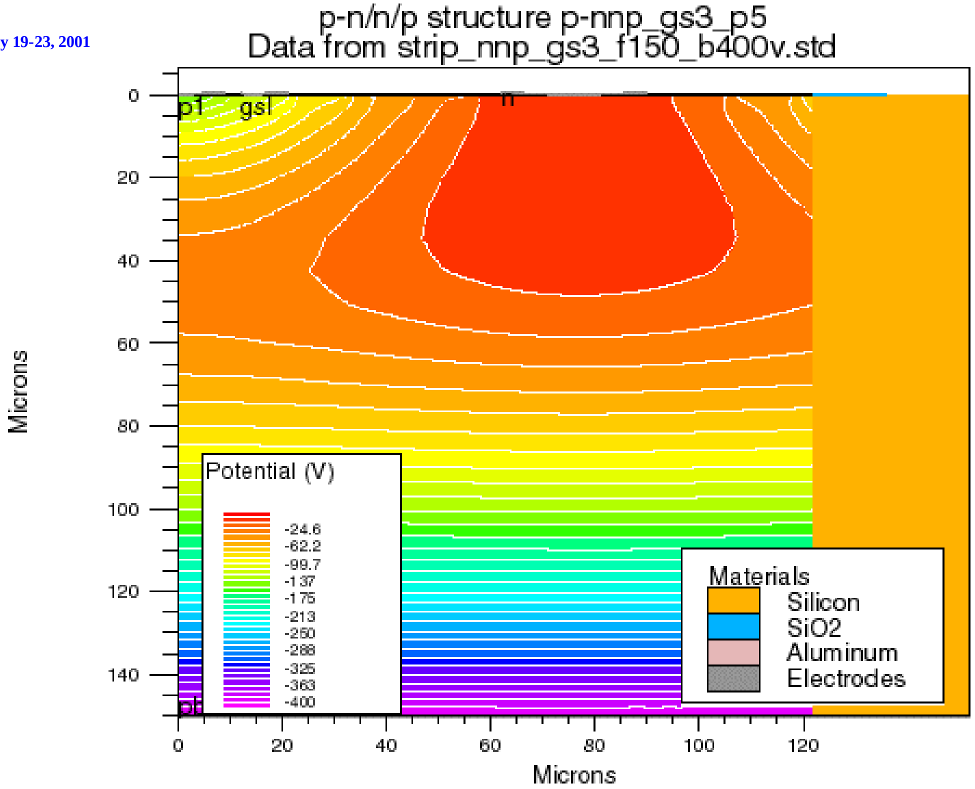
Other Novel Structures

p^+- n^+ /n/p^+ configuration (low resistivity)
2-sided process
Depletion from both sides
Can be fully depleted
from the beginning



Z. Li, 9th Vienna Conference on Instrumentation, Vienna, Austria, February 19-23, 2001

p^+- n^+ /n/p^+ configuration
(low resistivity)

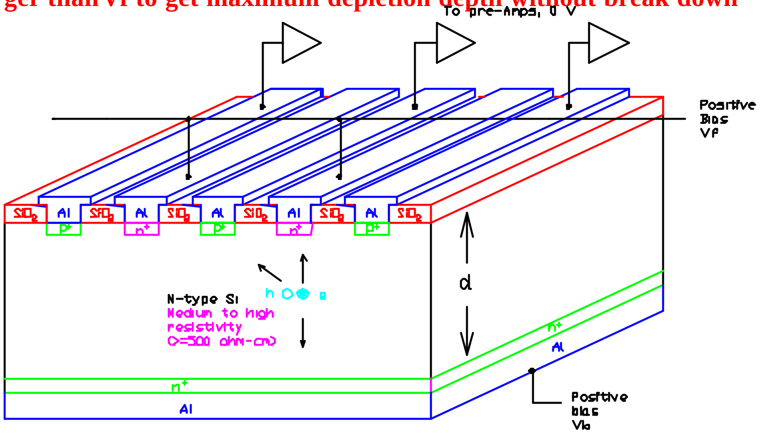


V_{fd} reduced up to a factor of 3-4

Two-sided process

Other Novel Structures

- Low bias at the beginning
- p^+- n^+ /n/n^+ configuration:
  - Depletion from one side before SCSI
  - Depletion from both sides after SCSI
- May work up to 1×10^{15} n/cm^2 rad.
- One sided processing
- Bias Vb may be larger than Vf to get maximum depletion depth without break down



p^+- n^+ /n/n^+ configurati
(Medium resistivity)

Z. Li, 9th Vienna Conference on Instrumentation, Vienna, Austria, February 19-23, 2001

p^+- n^+ /n/n^+ configuration
(Medium to high resistivity)

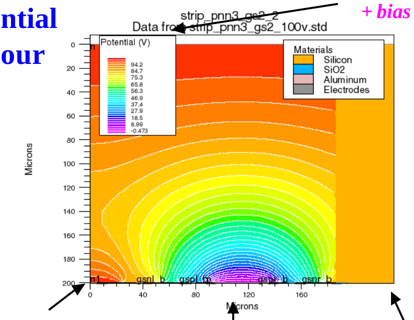
Single-sided process!

V_{fd} reduced up to a factor of 3-4

- **Before radiation, N_{eff}= $+1\times10^{12}$ /cm^3 (4 kW-cm)**
- **Junction on the p^+ contacts**

Simulation, V = 100 volts

Potential contour



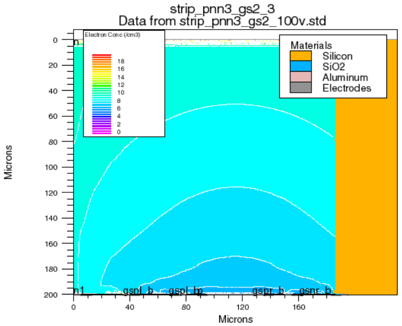
n^+ electrode
+ bias

n^+ electrode
+ bias

p^+ electrode
to pre-amps

n^+ electrode
+ bias

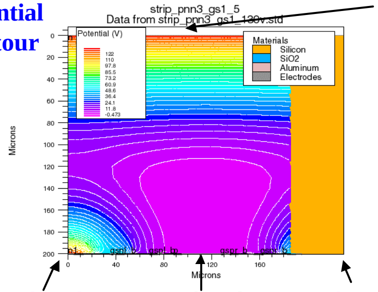
Electron concentration



- **After radiation, N_{eff}= -1×10^{13} /cm^3 (5×10^{14}n/cm^2)**
- **Junction on the n^+ contacts**

Simulation, V = 130 volts (<<370 volts)

Potential contour



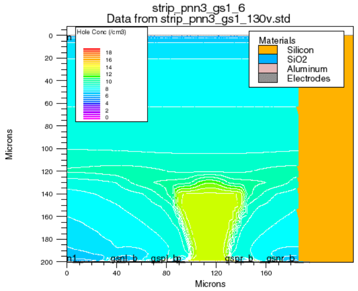
n^+ electrode
+ bias

n^+ electrode
+ bias

p^+ electrode
to pre-amps

n^+ electrode
+ bias

Hole concentration



Z. Li, 9th Vienna Conference on Instrumentation, Vienna, Austria, February 19-23, 2001

New Materials

o**Other semiconductor materials may have to be used for extremely high radiation (>1x10^{16} n/cm^2)**

Diamond, SiC, etc.

Properties of Si as compared to other Semiconductors

	Lattice const. ( )	Density (g/cm^3)	Eg (eV)	Dielec Const.	Disp. threshold E (eV)	e-h creat E (eV)	μ_e (cm/s/V)	μ_h (cm/s/V)	Rad. Length (cm)	e-h/0.3% X_0[e]
C	**3.567**	**3.5**	**5.5**	**5.7**	**80**	**13-17**	**1800**	**1200**	**12**	**7.2k**
SiC	3.086 15.117	3.2	3.3	9.7	30?	9	400-900	20-50	8.1	13k
GaP	5.4512	4.1	2.8	11	10	8	110	75	3.5	5.2k
CdS	5.8320	4.8	2.5	9.1	8	7.6	340	50	2.1	[redacted]
CdTe	6.482	5.9	1.49	10	6.7	5	1050	100	1.5	[redacted]
GaAs	5.653	5.3	1.43	13.1	9	4.8	8500	400	2.3	[redacted]
InP	5.869	4.8	1.34	13	7.5	4.2	4600	150	2.1	[redacted]
Si	5.431	2.3	1.12	11.9	13.5	3.6	1450	450	9.4	24k
Ge	5.646	5.3	0.66	16	15	3	3900	1900	2.3	[redacted]
										[redacted]

SiC is a most promising material for radiation detection. The 3.3eV gap provides very low leakage currents at room temperature and a mip signal of 5100e per 100μm. Epitaxial SiC Schottky barriers have been successfully tested as alpha detectors and showed a 100% CCE after 24GeV/c proton irradiation up to 10^{14} cm^{-2}.

Future RD50 Tasks

o **More studies in the fields of:**

- **MIDE --- O and other impurities: H, Cl, N, oxygen-dimer, etc.**
- **DSE --- Realize 3D and semi-3D detectors, and thin detectors**

  (push rad-hardness/tolerance to a few times of 1x10^{15} n/cm^{2})

o **Make detectors with combined technologies:**

- **Oxygenated detectors with MGS and/or 3D and novel detector structures**
- **Oxygenated low resistivity detectors with MGS and/or 3D and novel detector structures**
- **And so on**

(push rad-hardness/tolerance close to 10^{16} n/cm^{2})

o **Other semiconductor materials for extremely high radiation**

- **SiC, etc.**

(push rad-hardness/tolerance over 1x10^{16} n/cm^{2})

Summary

o Different particles cause different displacement damage in Si material and detectors

o Radiation-induced damages cause detector electrical properties to degrade:

- increase of detector leakage current
- compensation of Si bulk (intrinsic bulk resistivity)
- increase of negative space charge during radiation and annealing
- space charge maybe modified by charge trapping

o To obtain ultra high Radiation hardness/tolerance, newly-formed CERN RD50 Collaboration is poised to carry out various tasks

- Material/impurity/defect engineering
- Device structure engineering
- Detector operation and modeling
- Full detector integration
- Other semiconductor materials for extreme radiation (> 10^{16} n/cm^2)

1st RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders, CERN 2-4 October, 2002
http://rd50.web.cern.ch/rd50/1st-workshop/default.htm