Plans for Investigation on Electron-Induced Radiation Damage

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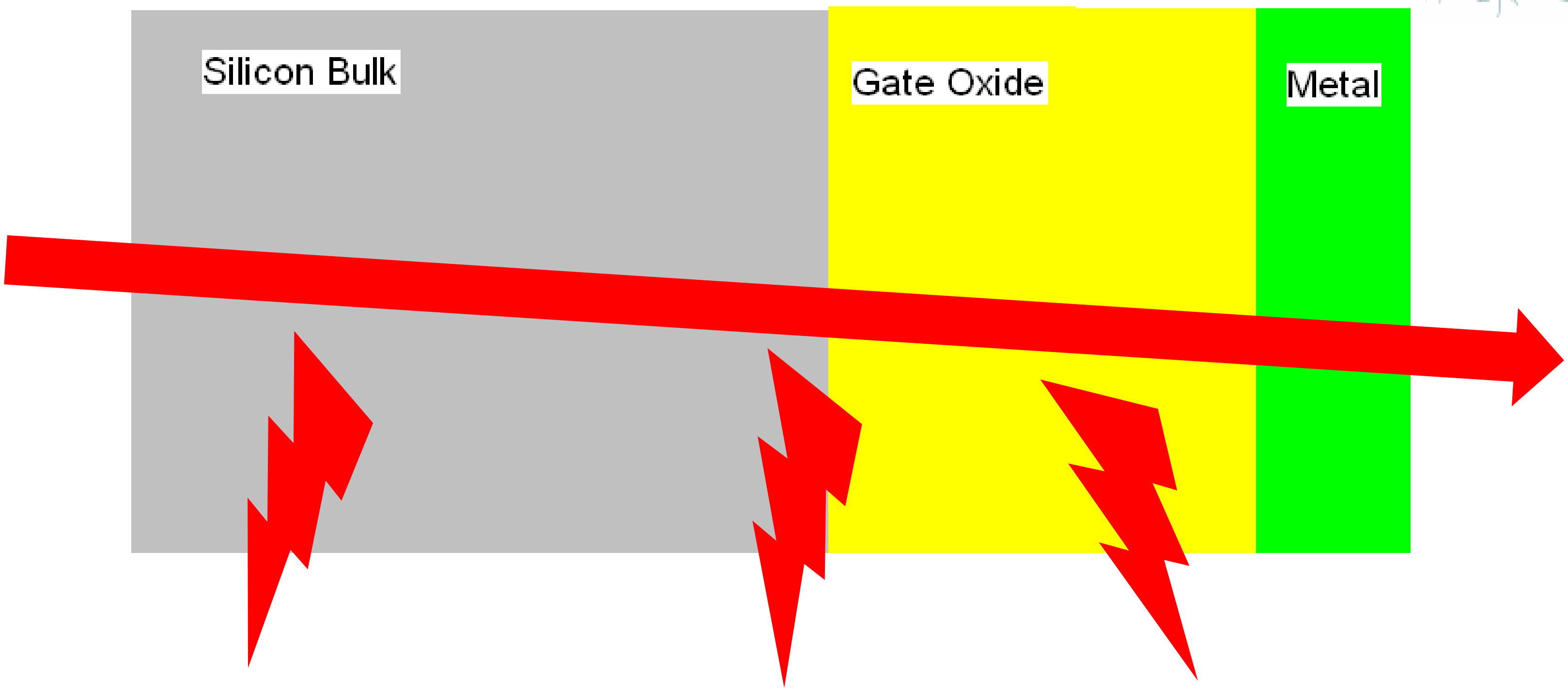
Outline of this Talk

Different Kinds of Radiation Damage



Bulk Damage

Mainly caused by *hadrons* but also by high-energetic *electrons (>255keV)*

Interface Traps

Mainly caused by ionizing radiation like *electrons* or *gammas*

Oxide Charges

Mainly caused by ionizing radiation like *electrons* or *gammas*

Oxide Charges & Interface Traps

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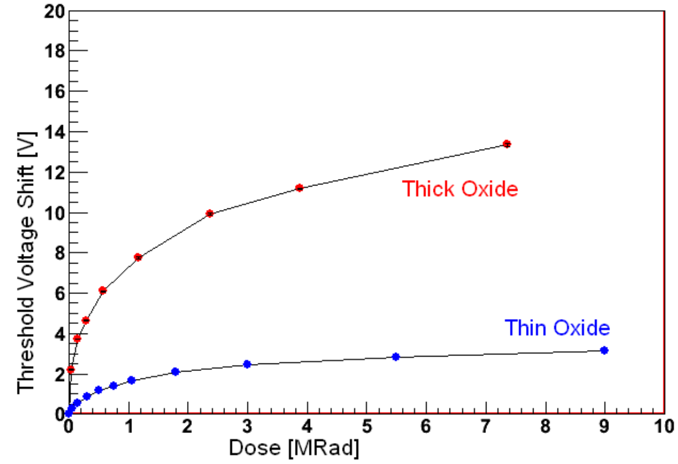
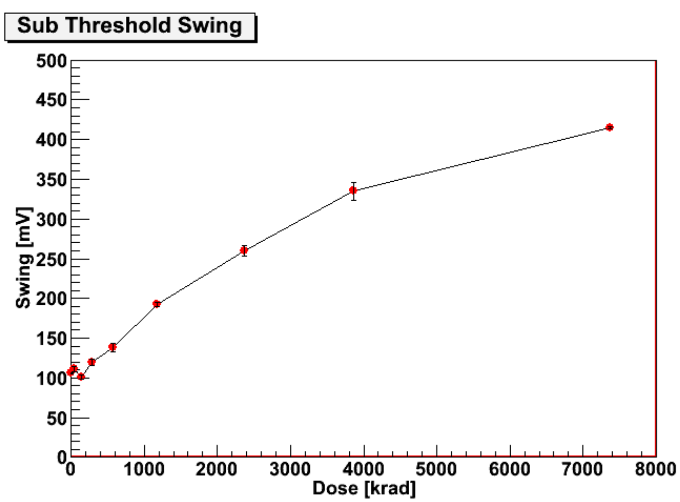
Already investigated with X-Rays at KIT

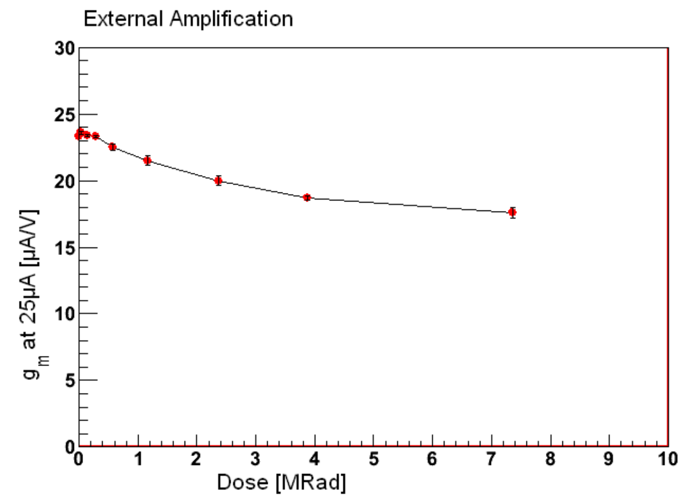
- Threshold Voltage Shift

- Reduced gm => gq

- Increased Sub Threshold Swing

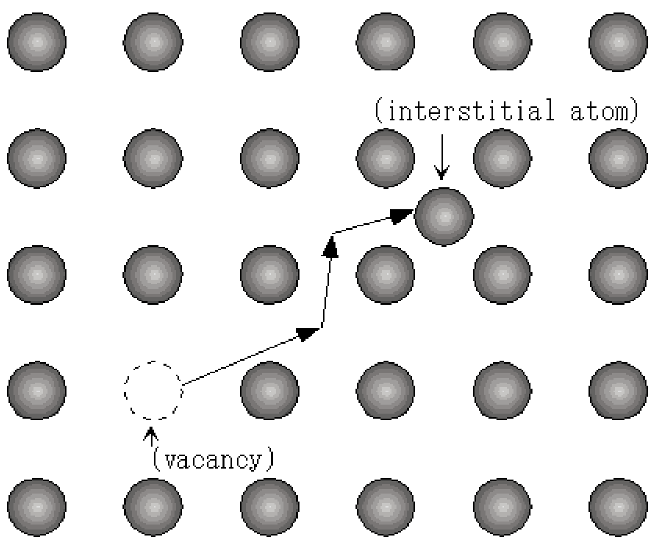


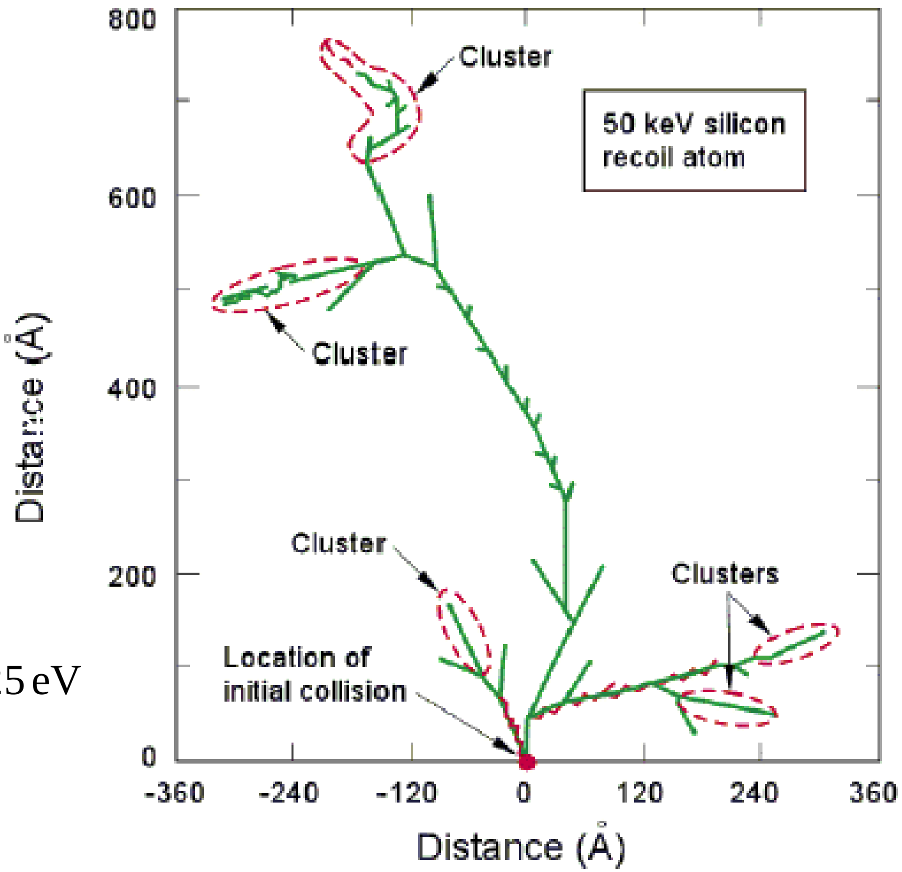




Bulk Damage

Creation of *Frenkel Pairs*





Silicon displacement energy threshold: $E_d(\mathrm{Si}) = 25\,\mathrm{eV}$

Recoil energy displaced to silicon atom:

$$E_{max}(\text{central impact}) = 2\,E_e \frac{(E_e + 2\,m_e c^2)}{(m_{Si} c^2)}$$

Electron Energy creating a Frenkel Pair E > 255 KeV
Electron Energy creating a Cluster E > 8 MeV

NIEL Hypothesis

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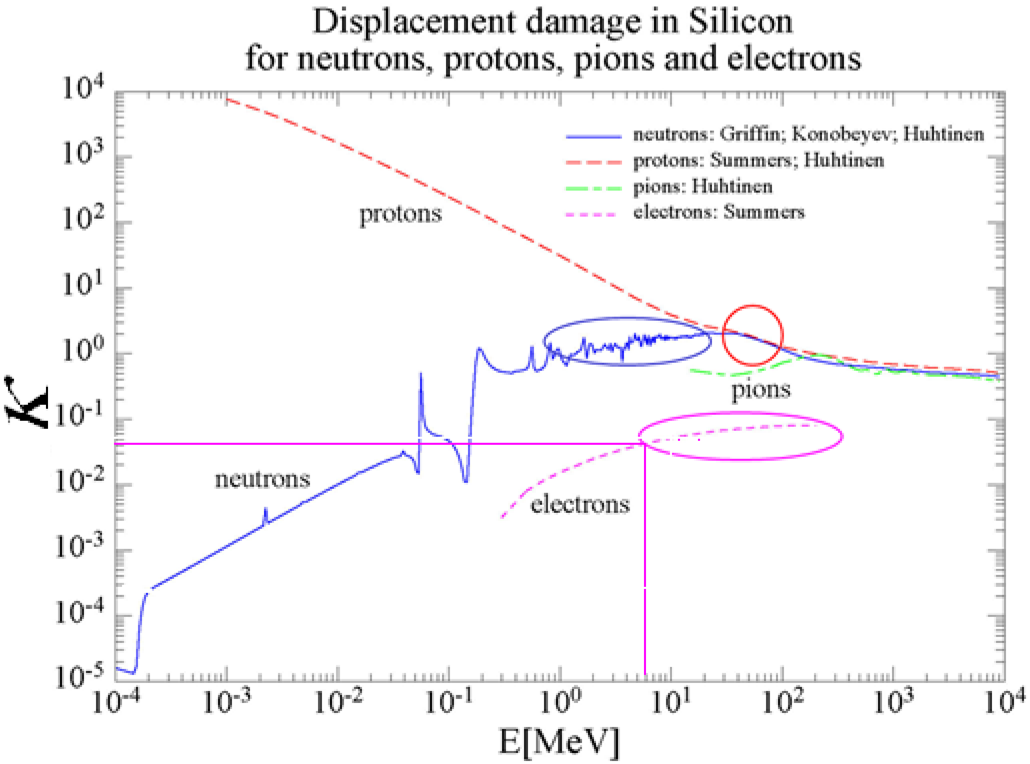


$$\phi_{eq} = \kappa \cdot \phi_{e^\pm}$$

(neutron equivalent)

Hardness Factor

$\kappa = 0.0425$ for 6 MeV e (BelleII)

Estimated electron flux at BelleII

$\phi_{e^\pm} \approx 10^7 s^{-1} cm^{-2}$

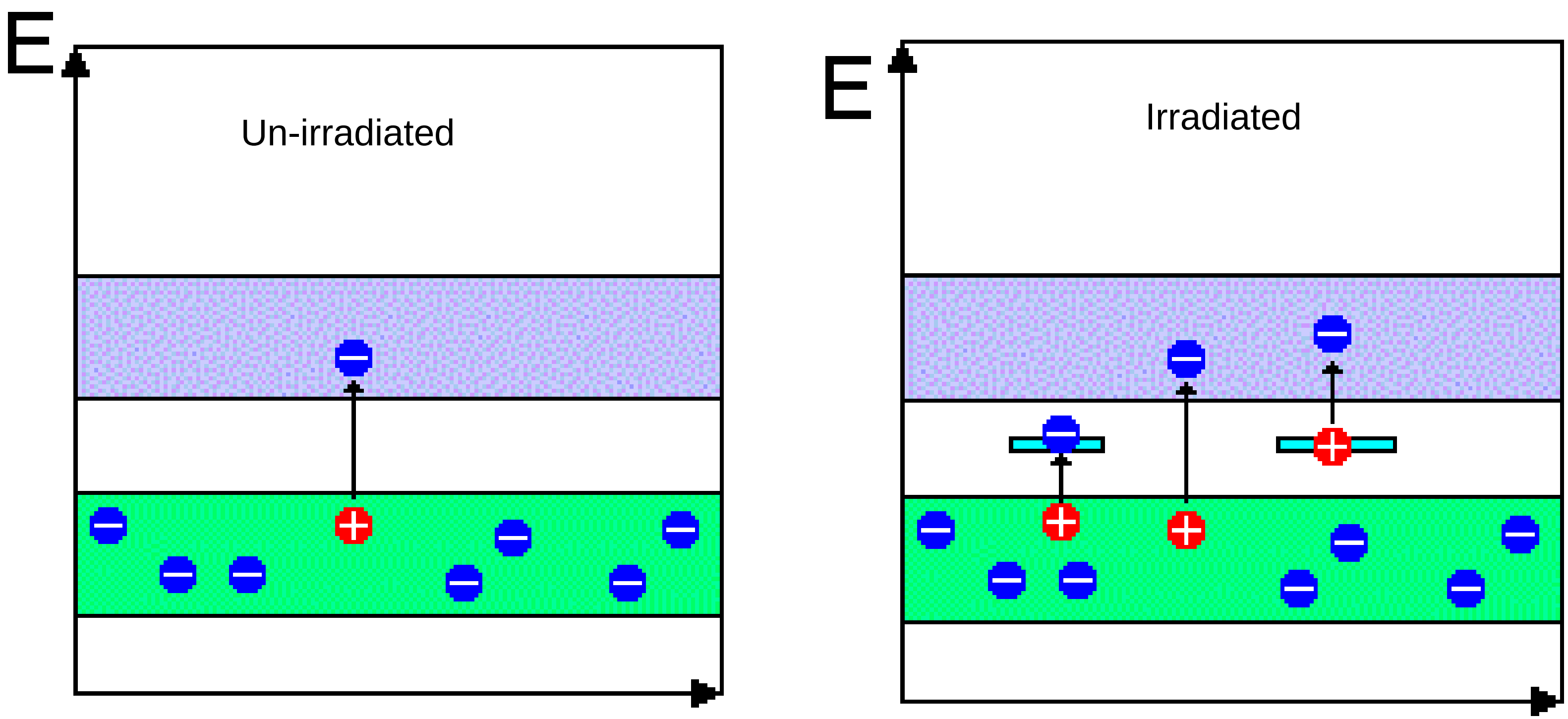
$\Rightarrow \phi_{eq} \approx 4 \cdot 10^5 s^{-1} cm^{-2}$

For 5 years

$\phi_{e^\pm} \approx 5 \cdot 10^{14} cm^{-2}$

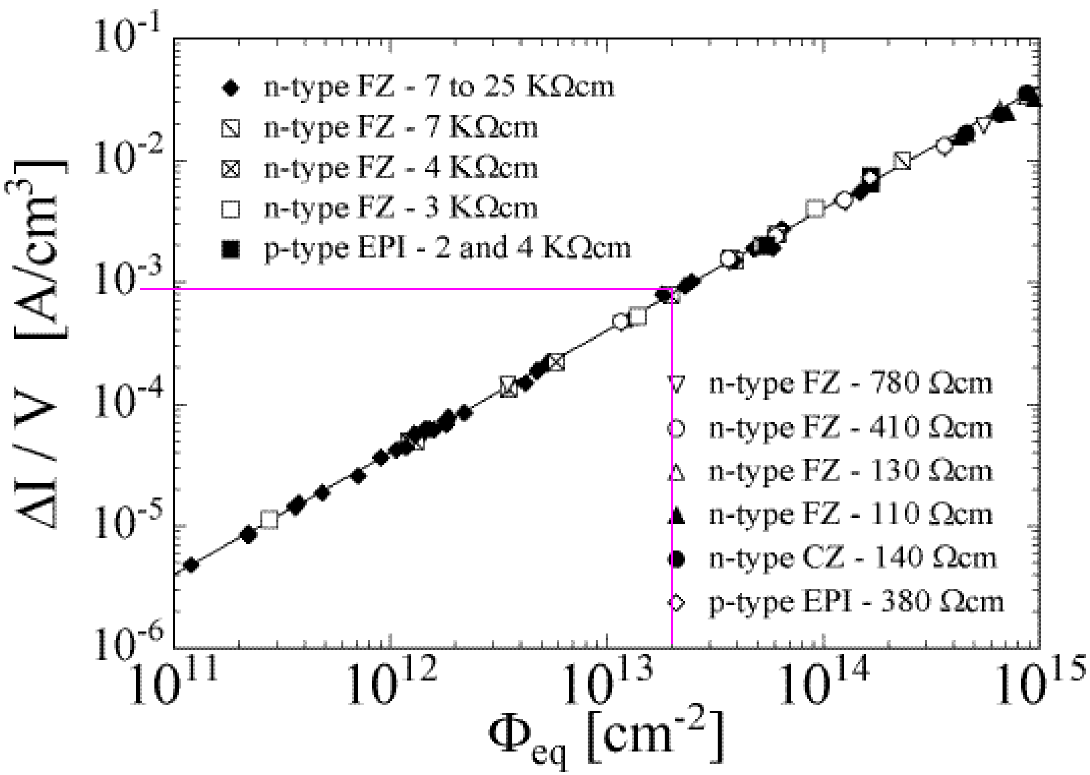
$\Rightarrow \phi_{eq} \approx 2 \cdot 10^{13} cm^{-2}$

New States in the Band Gap



Additional energy states in the bandgap increase the number of thermally generated electron-hole-pairs and thereby the leakage current.

Increased Leakage Current



Estimation:

$\phi_{eq} \approx 2 \cdot 10^{13} cm^{-2}$

$\Rightarrow \Delta I_{leak} \approx 1 \cdot 10^{-3} A / cm^3$

$\Rightarrow \Delta P_{heat} \approx 4 \cdot 10^{-4} W / cm^2$

(assuming 75µm thick bulk and 50V Depletion Voltage)

$\Rightarrow$ No problems with heat!

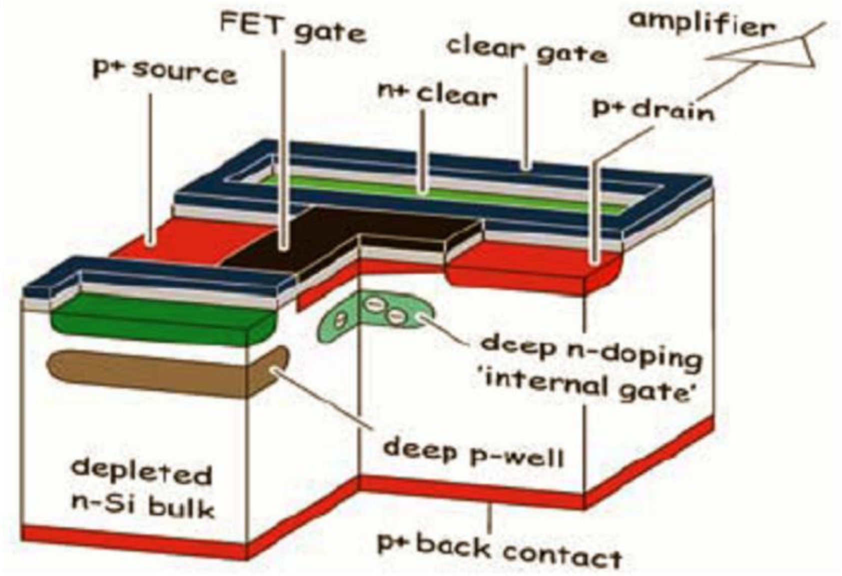
$$\boldsymbol{\Delta I_{leak} = \alpha \phi_{eq} V}$$

α = current related damage constant

ϕ = radiation flux

V = Volume

Increased Noise



More thermally generated charge carriers.

Most of them drift into the *Internal Gate.*

$$\text{Estimation:}$$

$$\phi_{eq} \approx 2 \cdot 10^{13} cm^{-2}$$

$$\Delta I_{leak} \approx 1 \cdot 10^{-3} A / cm^3$$

$$\Rightarrow \Delta C \approx 23000e$$

$$\text{(assuming a 20 } \mu\text{s time}$$

$$\text{and } 50\text{x}50\text{x}75 \, \mu\text{m size)}$$

$$\Rightarrow \text{Increased Noise}$$

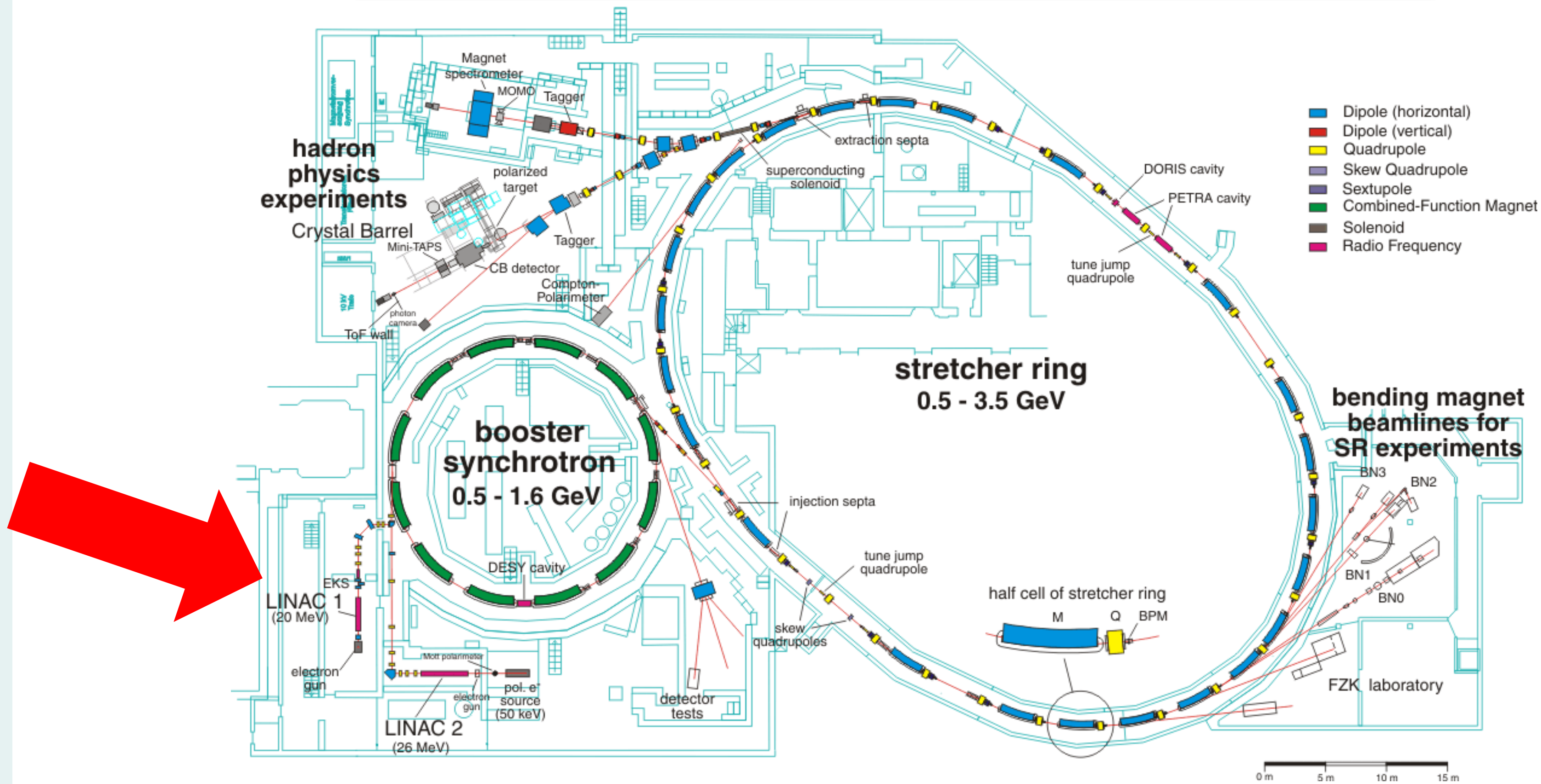
$$\Delta \text{Noise}_{\text{leak}} \approx 150e$$

ELSA

Scheduled irradiation in June 2010 — Pre-Accelerator LINAC 1

10 MeV electrons (hardness factor κ = 0.0516) — Flux/Dosimetry ?

Electron Stretcher Accelerator (ELSA)



Devices Under Test

- DEPFET Minimatrix PXD5 (All effects)

- Diodes (Bulk Damage)

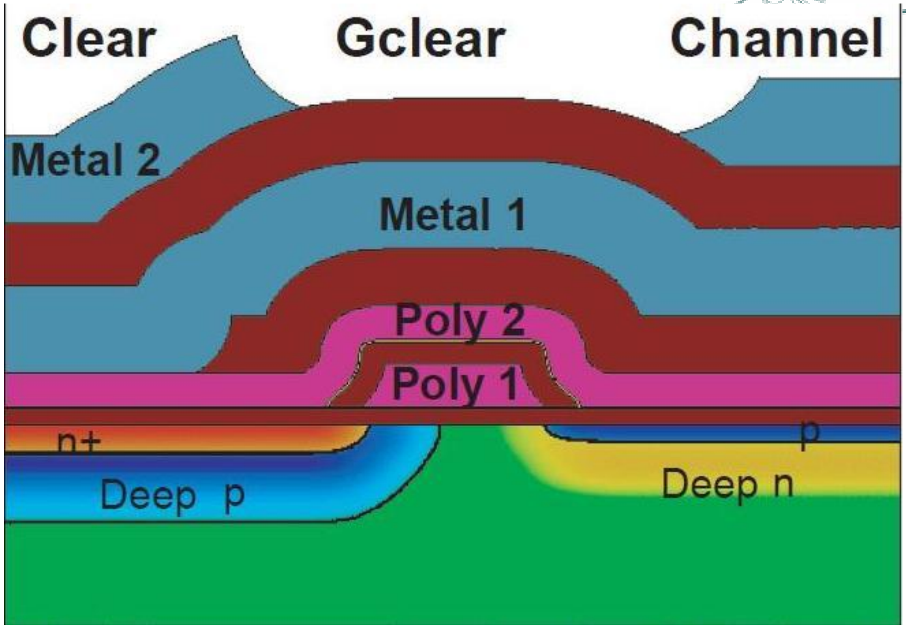
- Gate Controlled Diodes (Surface generated Leakage Current)

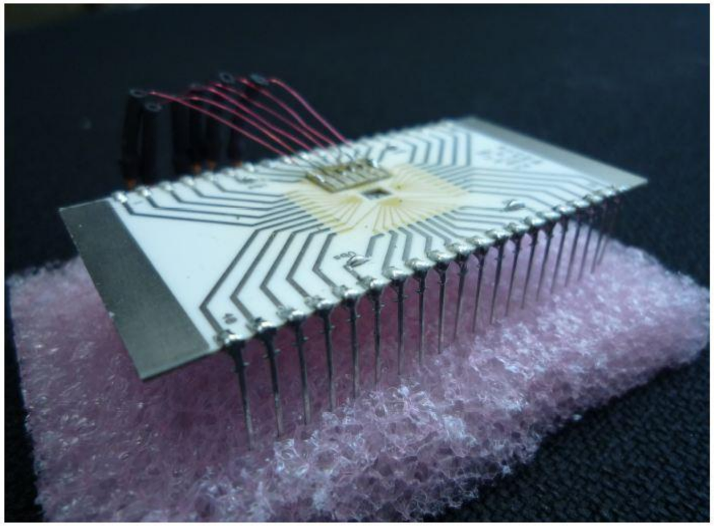
- Capacitors w. thin oxide (Interface Trap Density &Thr. Volt Shift)

ESD Problems

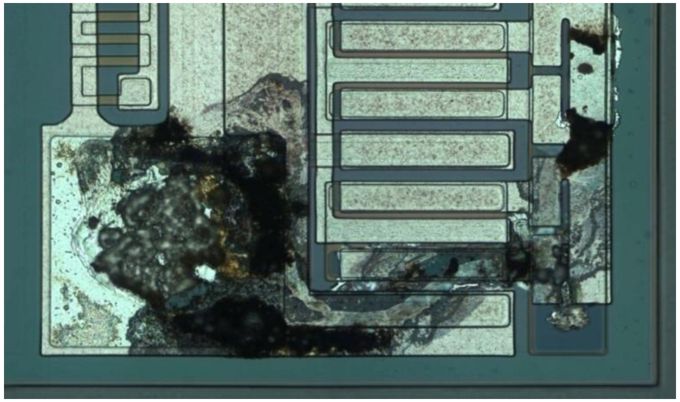
Electro Static Discharge

- Friction can charge your hand up to 30 kV
- Potentially damage of insulator between *Poly1* and *Poly2* at 20 V+
- Problems might occur not instantly but even weeks later



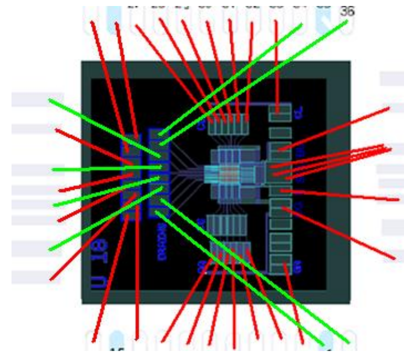


40 pin carrier for minimatrix



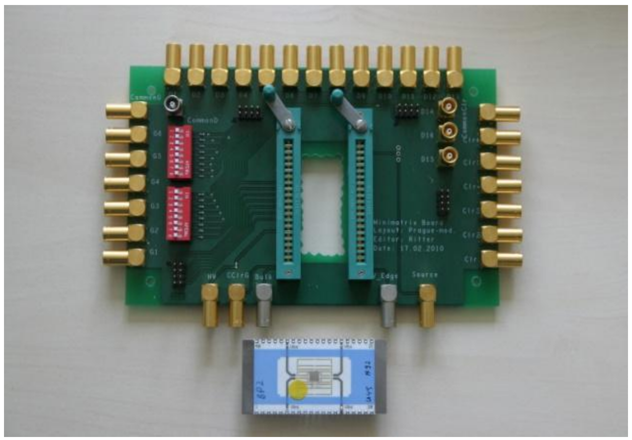
Example of ESD caused damage

Improved PXD5 Minimatrix Setup



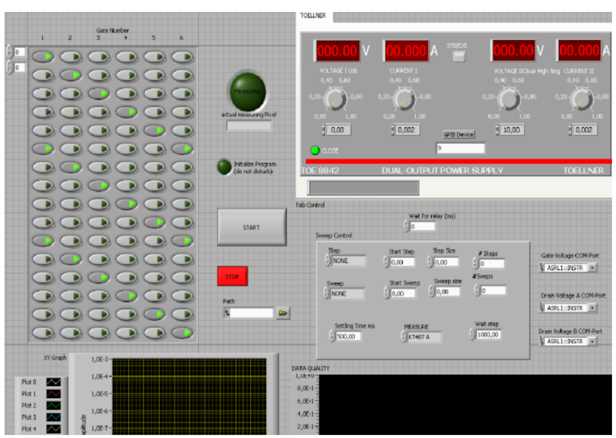
New *Bond-Scheme* :
All 16 *Drains* and 6 *Gates* are bonded.

Compatible with old and new
Irradiation Board
and *Prague-Noise-Setup*



New *Irradiation Readout Board*:
Access to **all** pixels
(before access to only 8 of 96)

Including safety resistors



New *LabView* measurement software.

Measuring any number of pixels without switching cables or changing parameters.

Required time for measuring greater numbers of pixels is reduced significantly.

Summary

- New improved *Irradiation Setup* is ready

- ESD danger reduced significantly

- Electron Irradiation @ ELSA in June 2010

- Measuring *Bulk Damage* cause *by Lattice Displacement*

- Haeting won’t be a problem

- *Noise* will increase a bit

- *Annealing* measurements are planned

Thank you for your attention

Backup Claculation

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$$\textbf{\textit{MonteCarloSimulation}}$$

$$\textbf{\textit{HitRate}}: 10\,\textbf{\textit{MHz}}/\textbf{\textit{cm}}^2$$

$$\phi_{e^\pm} = 10^7\,\textbf{\textit{cm}}^{-2}\textbf{\textit{s}}^{-1}$$

$$\kappa = 0.0425$$

$$\phi_{eq} = \kappa \cdot \phi_{e^\pm} = 4.25 \cdot 10^5\,\textbf{\textit{cm}}^{-2}\textbf{\textit{s}}^{-1}$$

$$1\textbf{\textit{a}} \approx 10^7\,\textbf{\textit{s}}$$

Assuming 5 years

$$\phi_{eq} = 2.1 \cdot 10^{13}\,\textbf{\textit{cm}}^{-2}$$

$$\Delta \mathrm{I}_{\mathrm{leak}} = 10^{-3}\,\textbf{\textit{A}}/\textbf{\textit{cm}}^3$$

Depletion Voltage $\mathrm{U}_{\mathrm{dep}} = 50\textbf{\textit{V}}$

Assuming 75 µm thick bulk

$$\textbf{\textit{P}}_{\textbf{\textit{heat}}} = \textbf{\textit{I}} \cdot \textbf{\textit{U}} \cdot \textbf{\textit{d}} = 3.75 \cdot 10^{-4}\,\textbf{\textit{W}}/\textbf{\textit{cm}}^2$$

$$I = 10^{-3}\,A/cm^3 = 10^{-3}\,C/s\,cm^3$$

$$1C = 6.24 \cdot 10^{18}\,e$$

$$I = 6.24 \cdot 10^{15}\,e/s\,cm^3$$

Pixel Volume

$$50 \cdot 50 \cdot 75\mu m = 1.875 \cdot 10^5\,\mu m^3$$

$$1\mu m^3 = 10^{-12}\,cm^3$$

$$V = 1.875 \cdot 10^{-7}\,cm^3$$

$$I = 6.24 \cdot 10^{15}\,e/s\,cm^3 \cdot 1.875 \cdot 10^{-7}\,cm^3$$

$$I = 1.17 \cdot 10^9\,e/s\ pixel$$

20µs Readout

$$\mathrm{I} = 1.17 \cdot 10^9\,e/s\ pixel \cdot 20 \cdot 10^{-6}\,s = 2.34 \cdot 10^4\,e/\,pixel$$