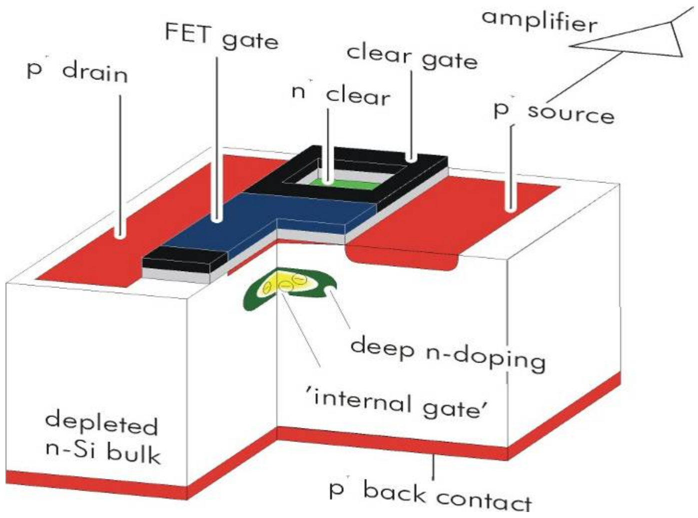
The Active DEPFET Pixel Sensor: Irradiation Effects due to Ionizing Radiation

- Motivation / Radiation Effects
- Devices and Facilities
- Results
- Summary and Conclusion

MPI Semiconductor Laboratory Munich in collaboration with the Universities of Bonn and Mannheim

Motivation

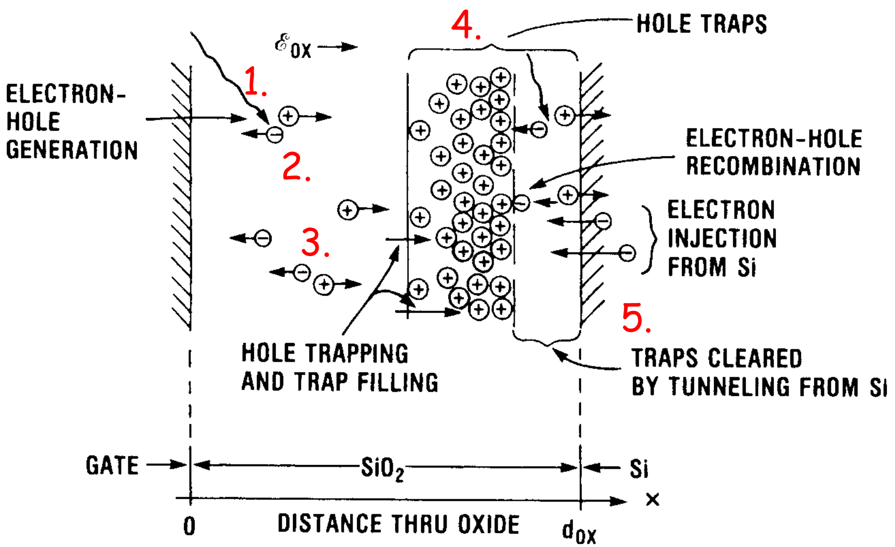


Radiation levels at the ILC VTX (TESLA TDR):

≈10^{10} n_{eq}(1MeV)/cm^2

≈100 krad TID in 5 years

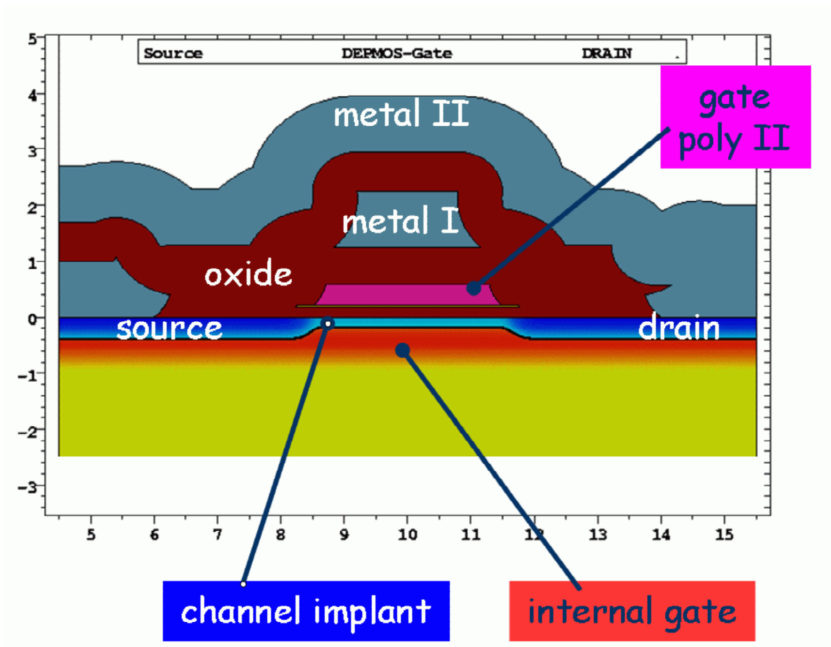
1. e/h pair generation (~17eV/pair in SiO_2)
2. e/h pair recombination ("charge yield")
   - rad. Source
   - field
3. e and h transport
   - e: ~ps…ns
   - h: ~ms…s
4. hole trapping
   - precursor density → technology
5. interface trap formation
   - precursor density → technology

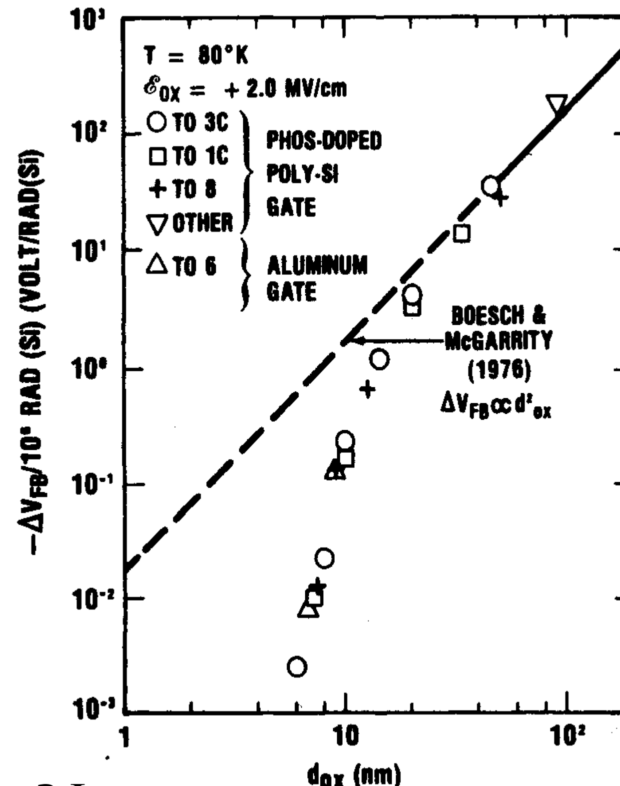


Ladislav Andricek. MPI Semiconductor Lab

Radiation Effects

Gate Dielectrics 180 nm SiO_2 + 30 nm Si_3N_4





$$V_{th} = f(N_B, \Phi_{MS}, Q_f) - \frac{N_{it} \cdot e \cdot 2\Phi_f}{C_{ox}} - \frac{N_{ot} \cdot e}{C_{ox}}$$

1. postive oxide charge and postively charged oxide traps have to be compensated by a more negative gate voltage: negative shift of the theshold voltage

2. increased density of interface traps: higher 1/f noise and reduced mobility (g_m)

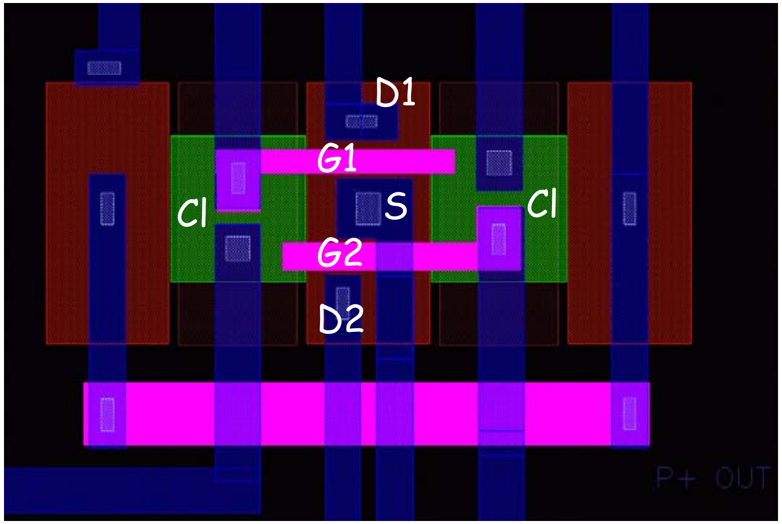
Irradiated Devices - Overview

PXD4-2: L= 6 µm A2-1[1], B2-1[1], D2-1[2]
L= 7 µm A2-2[1], B2-2[1], D2-2[2]

PXD4-2: L=10 µm T10-1[1]
L=20 µm T20-1[1]

PXD4-1: L=60 µm T60-1[3], T60-2[3], T60-3[3]

PXD4-3: L=5 µm T5-1*



Bias during irradiaton:

1: empty int. gate, in „off" state, V_{GS}= 5V, V_{Drain}=-5V → $E_{ox} \approx 0$
2: empty int. gate, in „on" state, V_{GS}=-5V, V_{Drain}=-5V → $E_{ox} \approx$ -250kV/cm
3: all terminals at 0V

NB: only one row active at a time in normal matrix operation!
for a 512x1024 matrix → $T_{off}/T_{on} \approx 1000$!

→ measure threshold voltage (quadratic extrapolation if $I_D(V_G)$ to I_D=0) as a function of TID

all measurements with V_{bulk}=10V..12V, $V_{cleargate}$=5V .. 12V → "empty" internal Gate

Irradiation Facilities

GSF – National Research Center for Environment and Health, Munich

^{60}Co (1.17 MeV and 1.33 MeV)

CaliFa Teststand at MPI HLL

X-Ray tube with Mo target at 30kV

bremsstrahlung with peak at 17.44 keV

Dosimetry

Ionization Chamber, provided and calibrated by GSF staff
(M. Panzer, GSF)
Dose rate: ≈ 20 krad(SiO_2)/h

Integrated Spectrum with known absorption coeff. of SiO_2
(A. Pahlke, HLL)
Dose rate: ≈9 krad(SiO_2)/h

Irradiation Facilities

GSF – National Research Center for
Environment and Health, Munich

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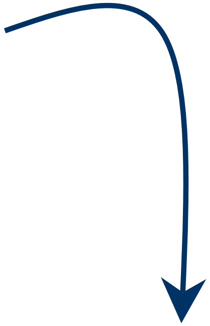
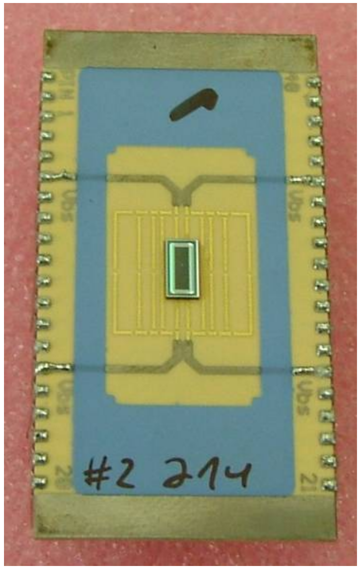
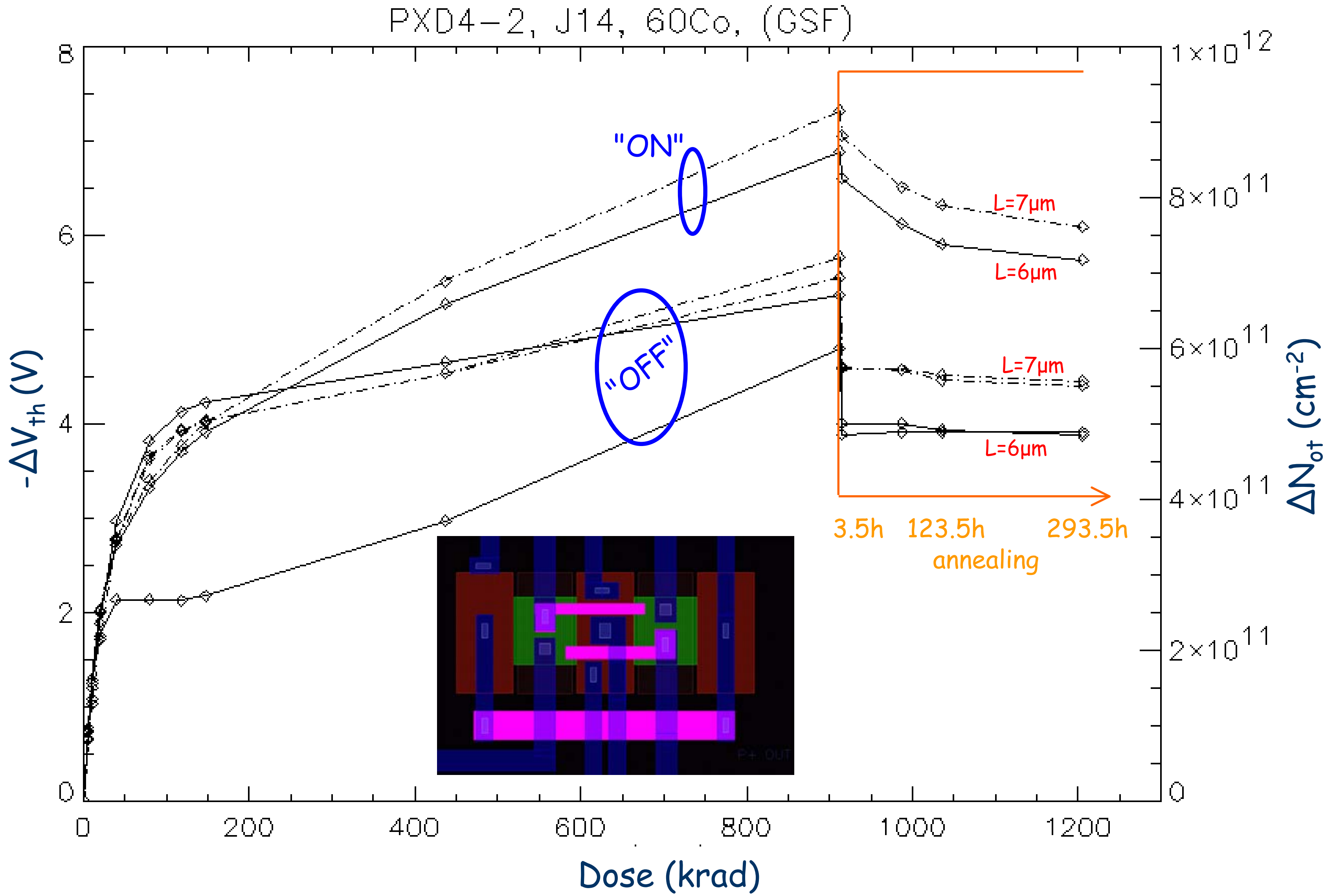




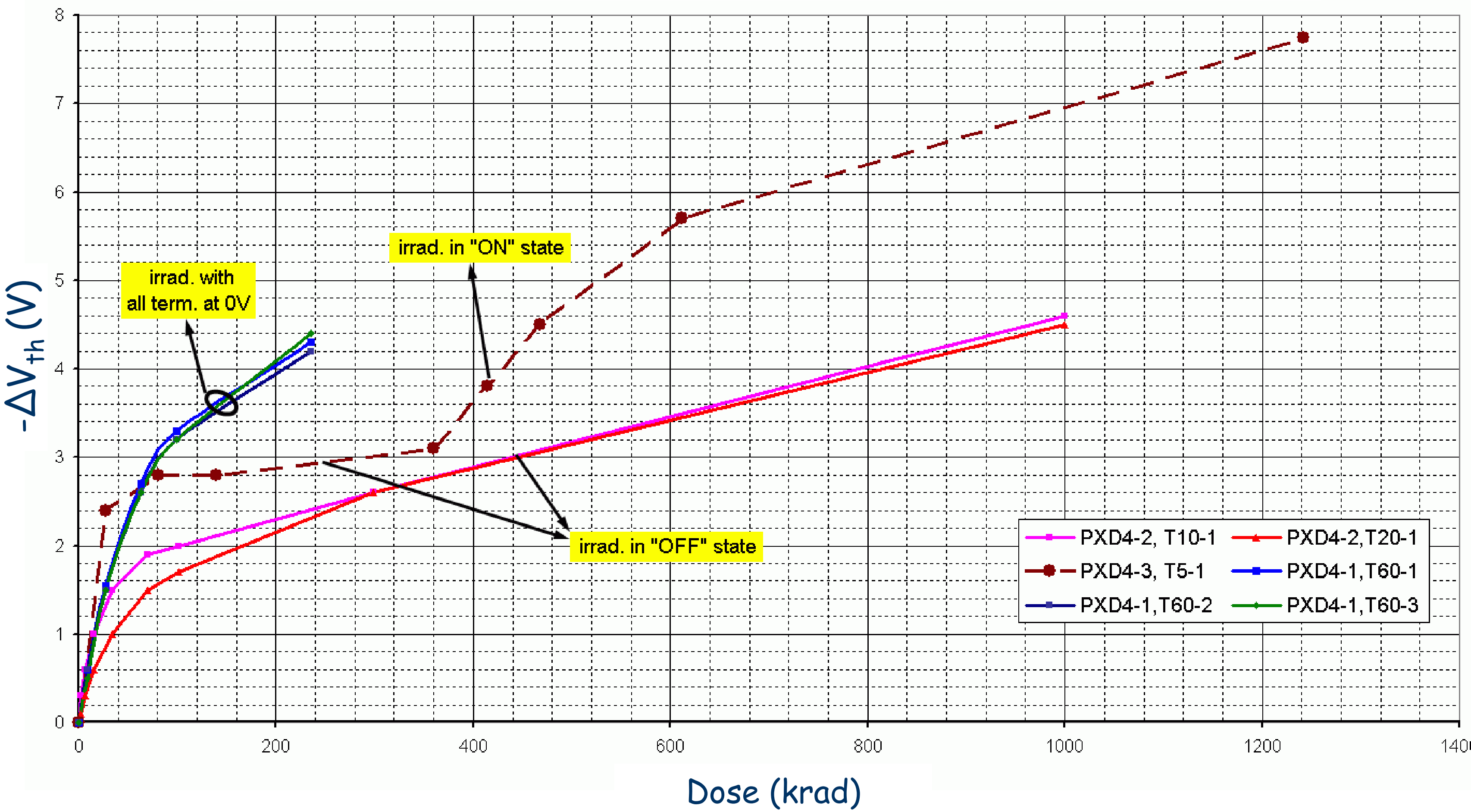
ΔV_{th} : ^{60}Co



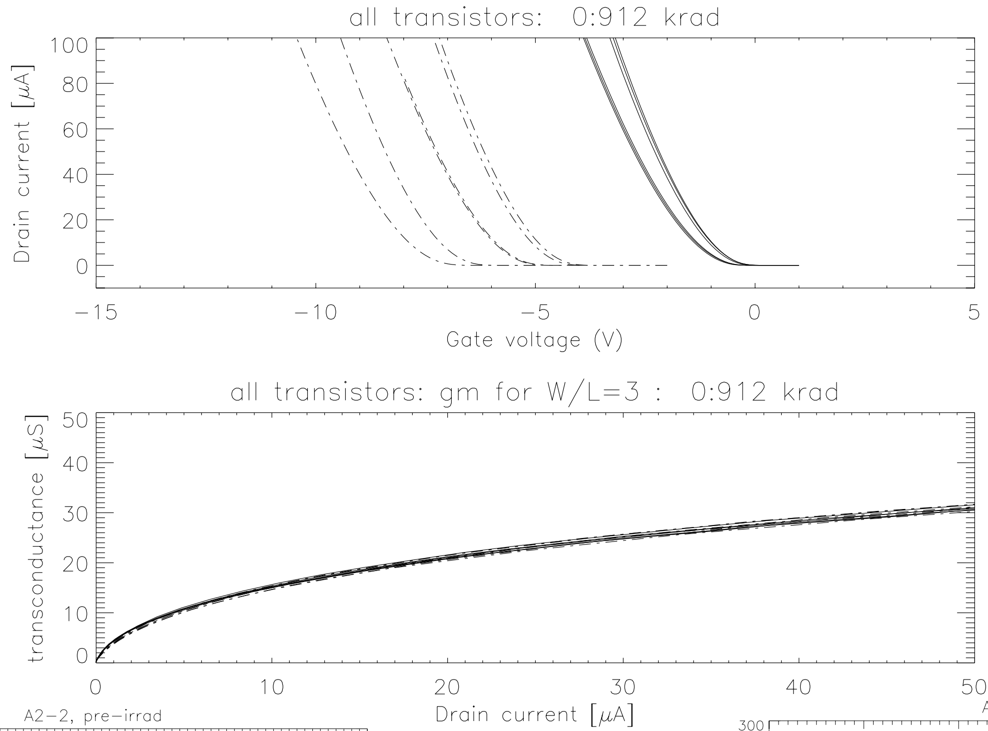
ΔV_{th} : X-ray, Mo target, 30kV

9krad/h, 24 h annealing after each irradiation period

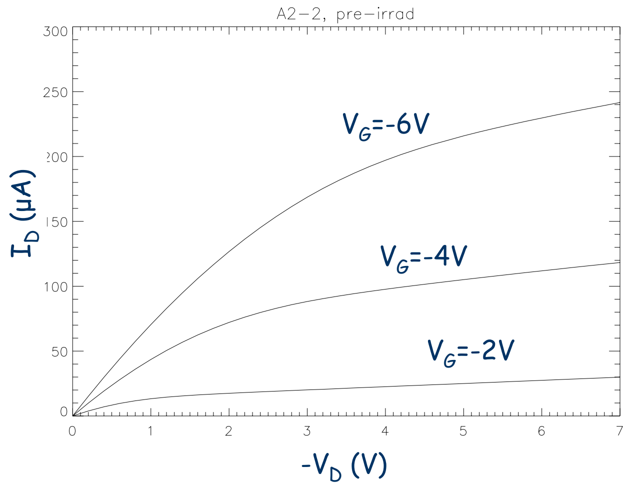
→ ~1 week irradiation

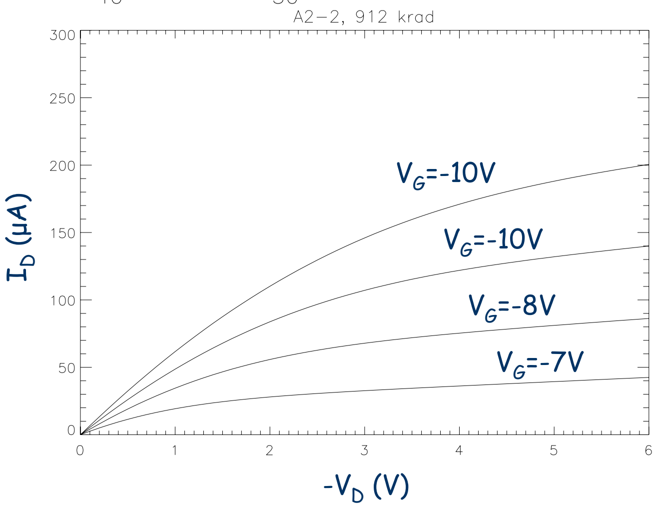


Basic Characteristics - pre and post-irradiation

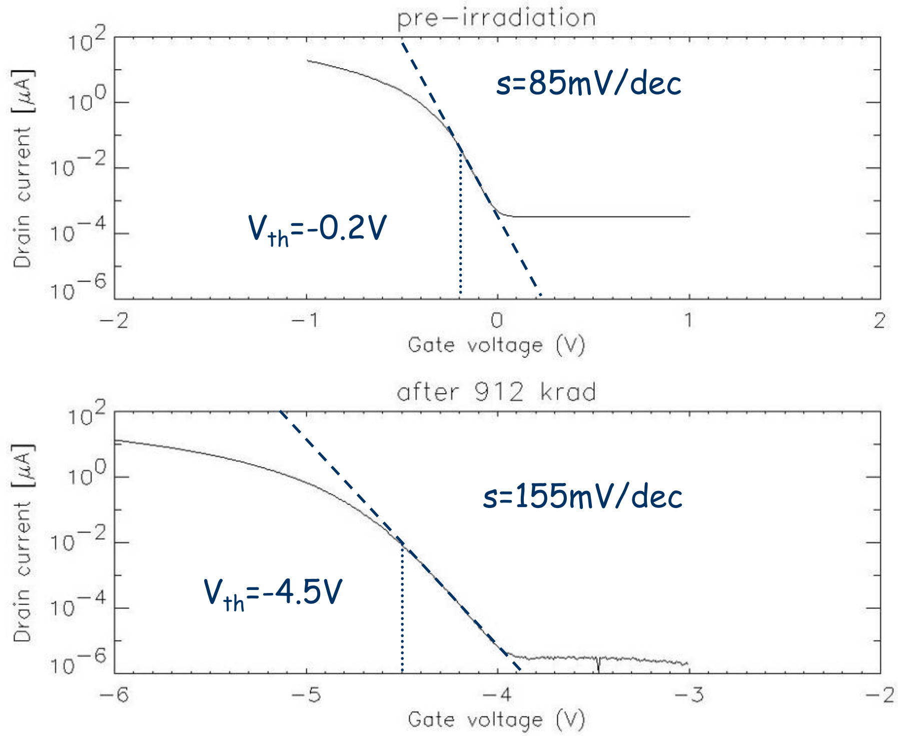


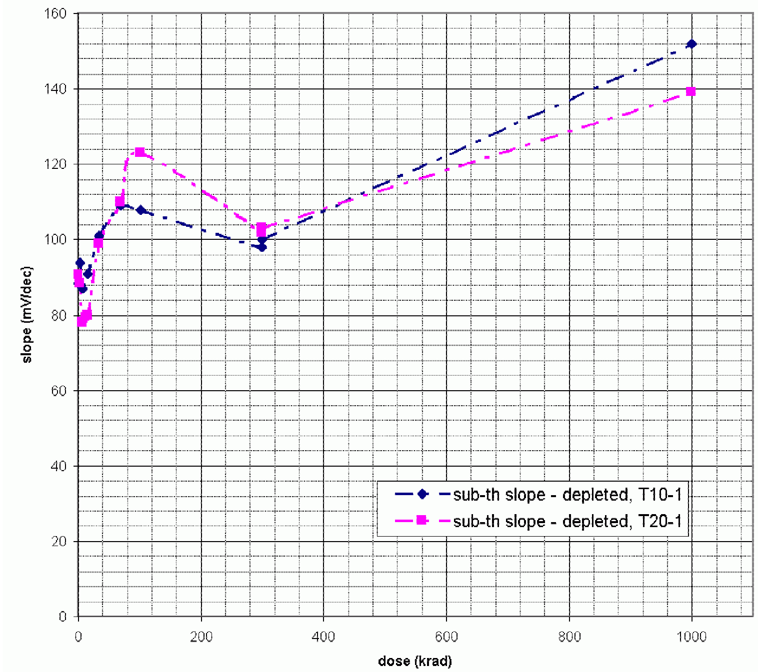
$$g_q = \frac{dI}{dQ} = \frac{g_m}{C_{ox}}$$





Subtreshold slope → interface traps





$$N_{it} = \frac{C_{ox}}{kT} \cdot \ln(10) \cdot \left(s_{D2} - s_{D1}\right)$$

300 krad	:	$N_{it} \approx 2 \cdot 10^{11}\ cm^{-2}$
1 Mrad	:	$N_{it} \approx 7 \cdot 10^{11}\ cm^{-2}$

Literature:
after irradiation (1Mrad) of 200 nm oxide:
$N_{it} \approx 10^{13}\ cm^{-2}$

Summary and Conclusion

- MOS-type DEPFETs have been irradiated under realistic biasing conditions with ^{60}Co gammas and 17.44 keV X-rays up to 1 Mrad(SiO_2) at two different irradiation facilities.
- The threshold voltage shift of about -4 V can easily be compensated by adjustment of the external gate voltage for the read out of the pixel cell.
- There is no change of the transconductance of the external gate after irradiation. The shapes of the input and output characteristics of the DEPFETs are not affected by irradiation.
- The interface trap density is an order of magnitude better than for standard technology with comparable oxide thickness.

→ The DEPFET technology is remarkably tolerant against ionizing radiation!

Next steps

- Source/Laser measurements with irradiated devices, noise evaluation
- irradiate matrix, look for homogeneity of ΔV_{th}
- irradiation with 24 GeV protons at the CERN/PS (2006) → NIEL damage

NEW DEVELOPMENTS IN RADIATION DETECTORS

10th European Symposium on Semiconductor Detectors

Wildbad Kreuth, Germany, June 12 – 16, 2005

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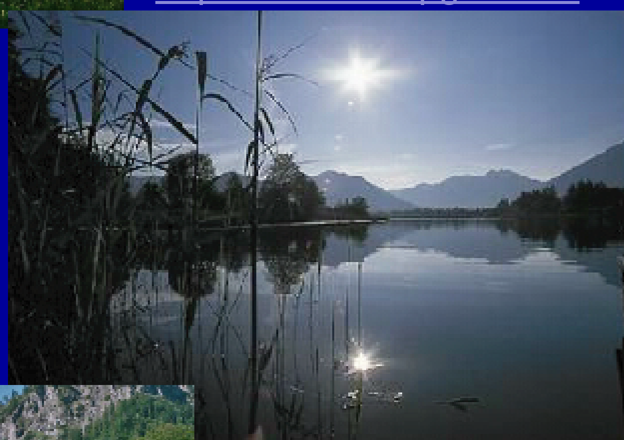
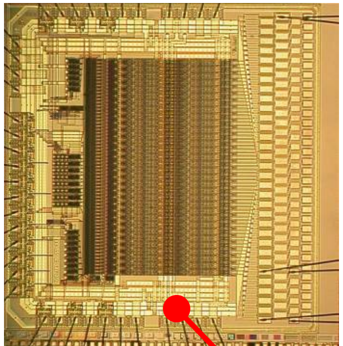


Program Summary
Principles and Properties of Detectors
Readout Electronics
Device Physics
Detector Technology
Semiconductor Material Properties
Defects in Base Material and Devices
New Applications for Detectors

Organizing Committee: L. Andricek, P. Holl, F. Schopper, L. Strüder; *MPI Halbleiterlabor*
S. Masciocchi; *DESY Hamburg* C. Fiorini, C. Guazzoni, A. Longoni; *Politecnico di Milano*

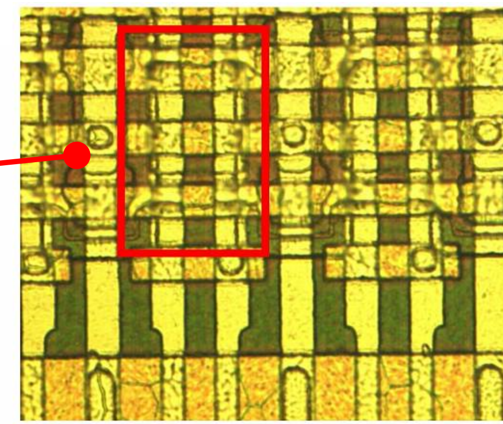
Project Status - in Summary

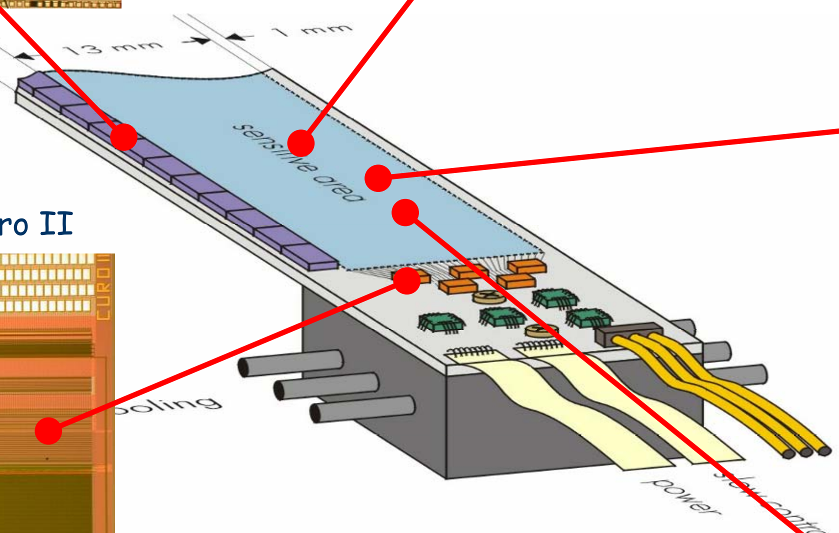
✓ steering chips Switcher II



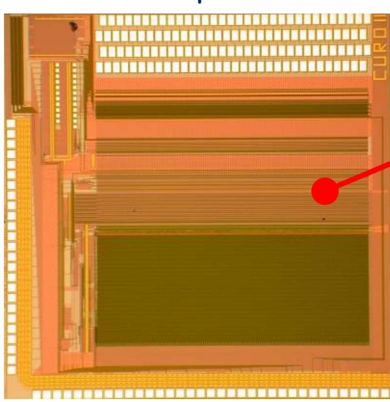
✓ thinning technology

✓ double metal/double poly technology

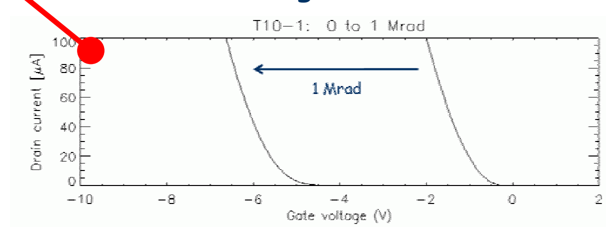




✓ r/o chips Curo II



✓ tolerance against ion. radition

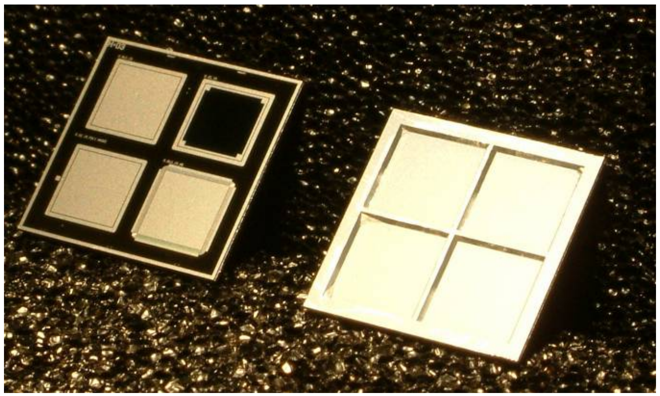


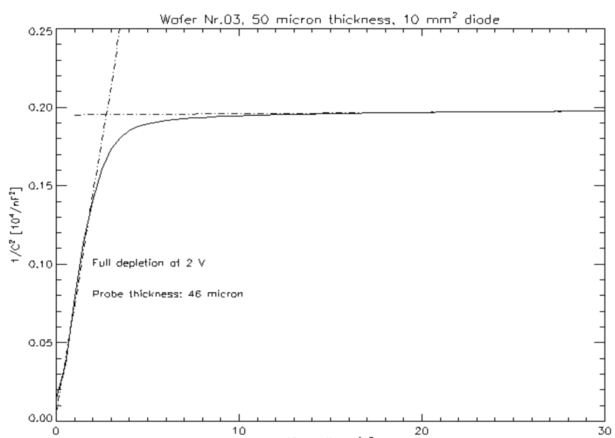
That's all

Proton Irradiation of thin Diodes (50µm)

Irradiated at the CERN PS with 20 GeV protons (E. Fretwurst, Uni Hamburg)

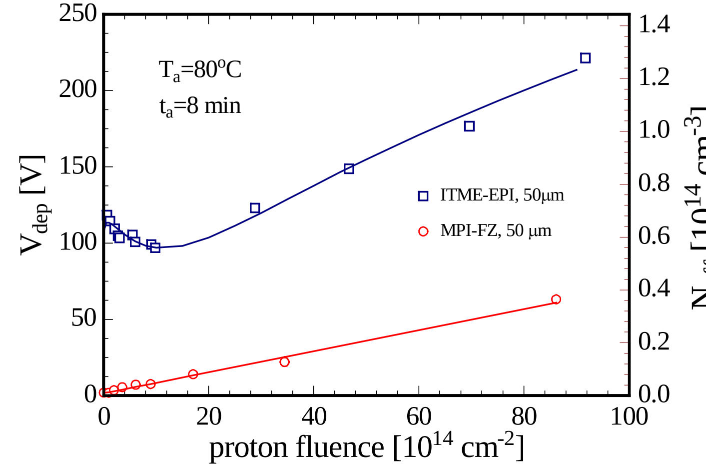
Up to ~$9 \cdot 10^{15}$ p/cm_2 !!

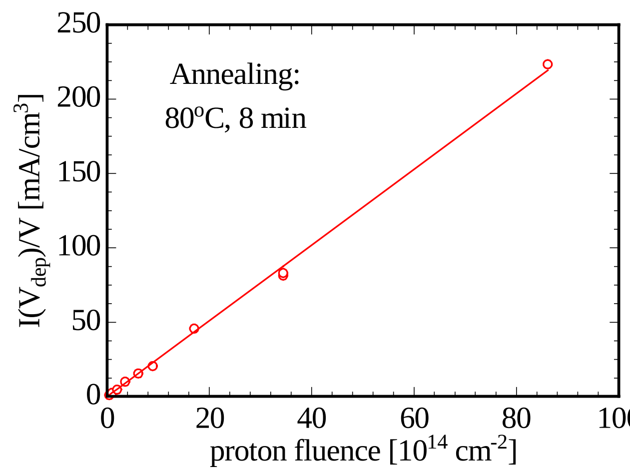




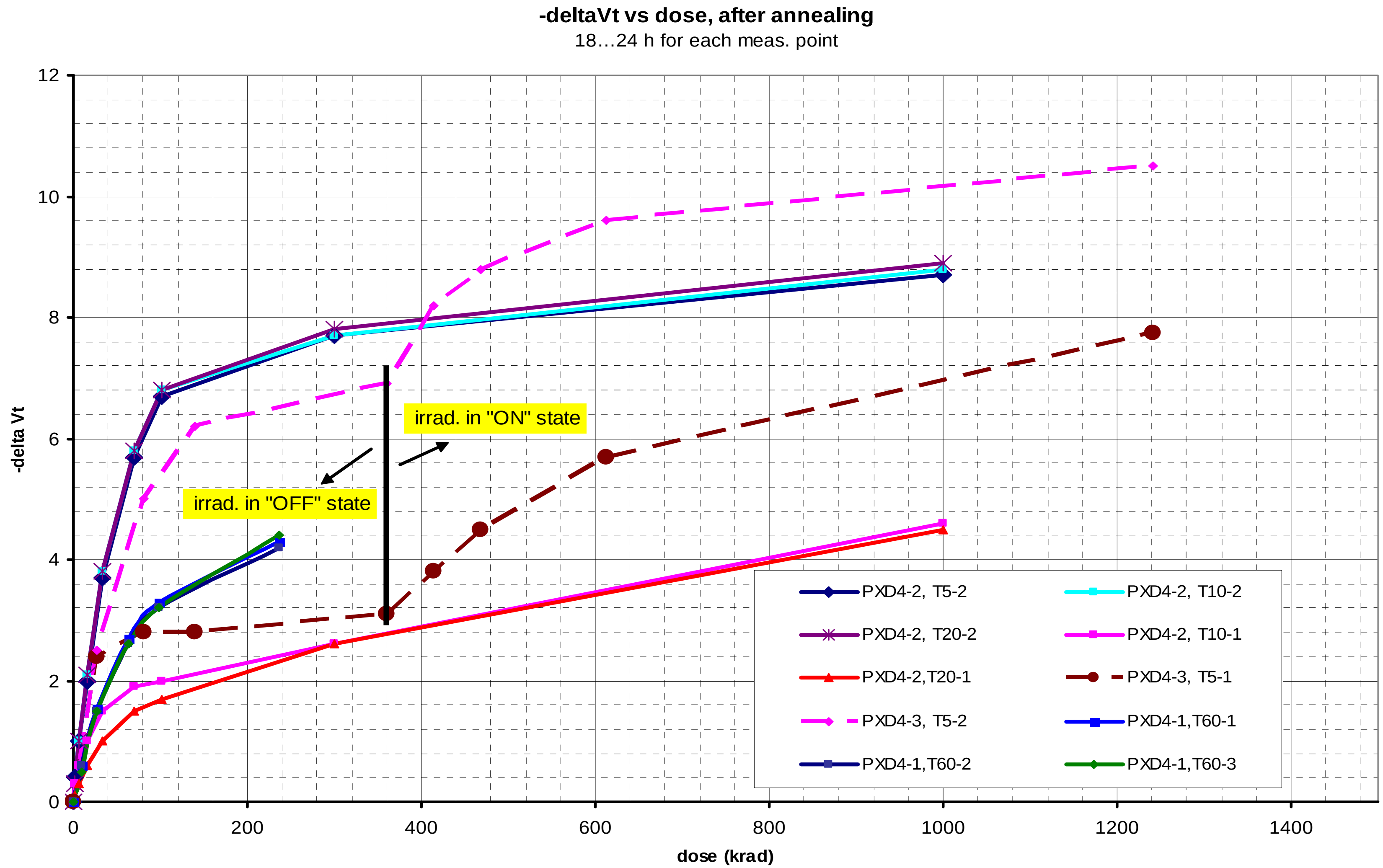
C(30V) → 47 µm

ρ ≈ 4 kΩcm

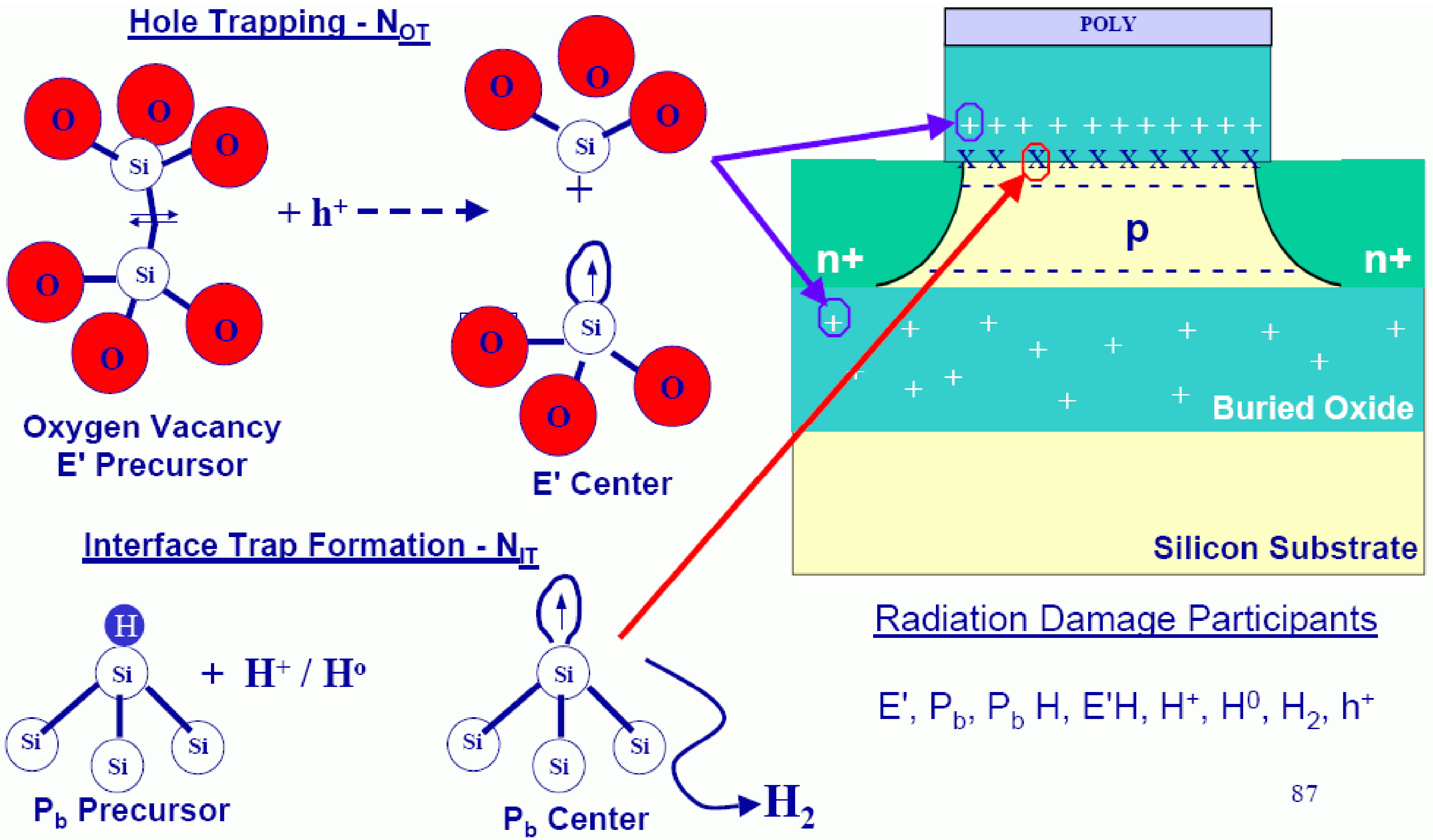




Backup : w/o channel implant



Backup: Radiation Effects in MOS Devices

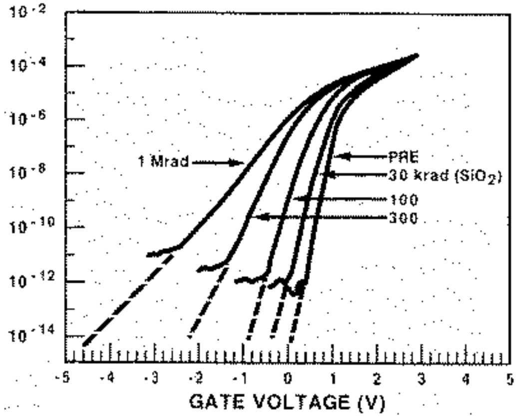


Radiation Damage Participants

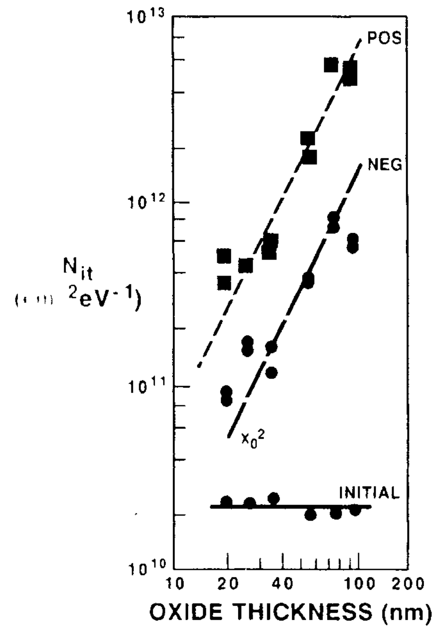
E', P_b, P_b H, E'H, H^+, H^0, H_2, h^+

Backup : interface states, bias dependance

Mc Whorter, Winokur et al, 1984



Viswanathan und Maserjian, 1976



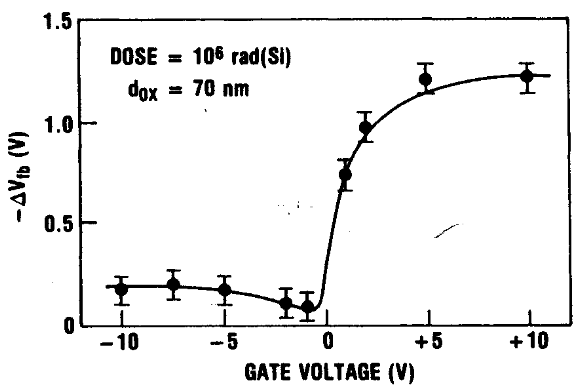


Fig. 3.30 Radiation-induced ΔV_{fb} in an MOS capacitor as a function of gate bias during irradiation. (From Derbenwick and Gregory [134], © 1975 IEEE. Reprinted with permission.)

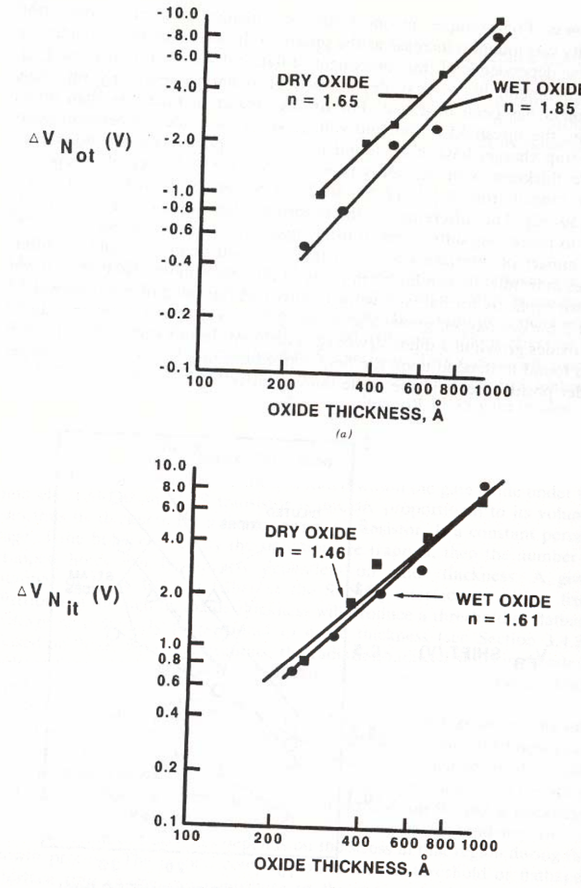


Fig. 6.10 Dependence of radiation-induced charge components on oxide thickness for oxides grown in dry oxygen or steam: (a) dependence of oxide-trapped charge on oxide thickness; (b) dependence of interface-trap charge on oxide thickness. (After Schwank [62].)

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