MOS Capacitor Displacement Damage Dose (DDD) Dosimeter

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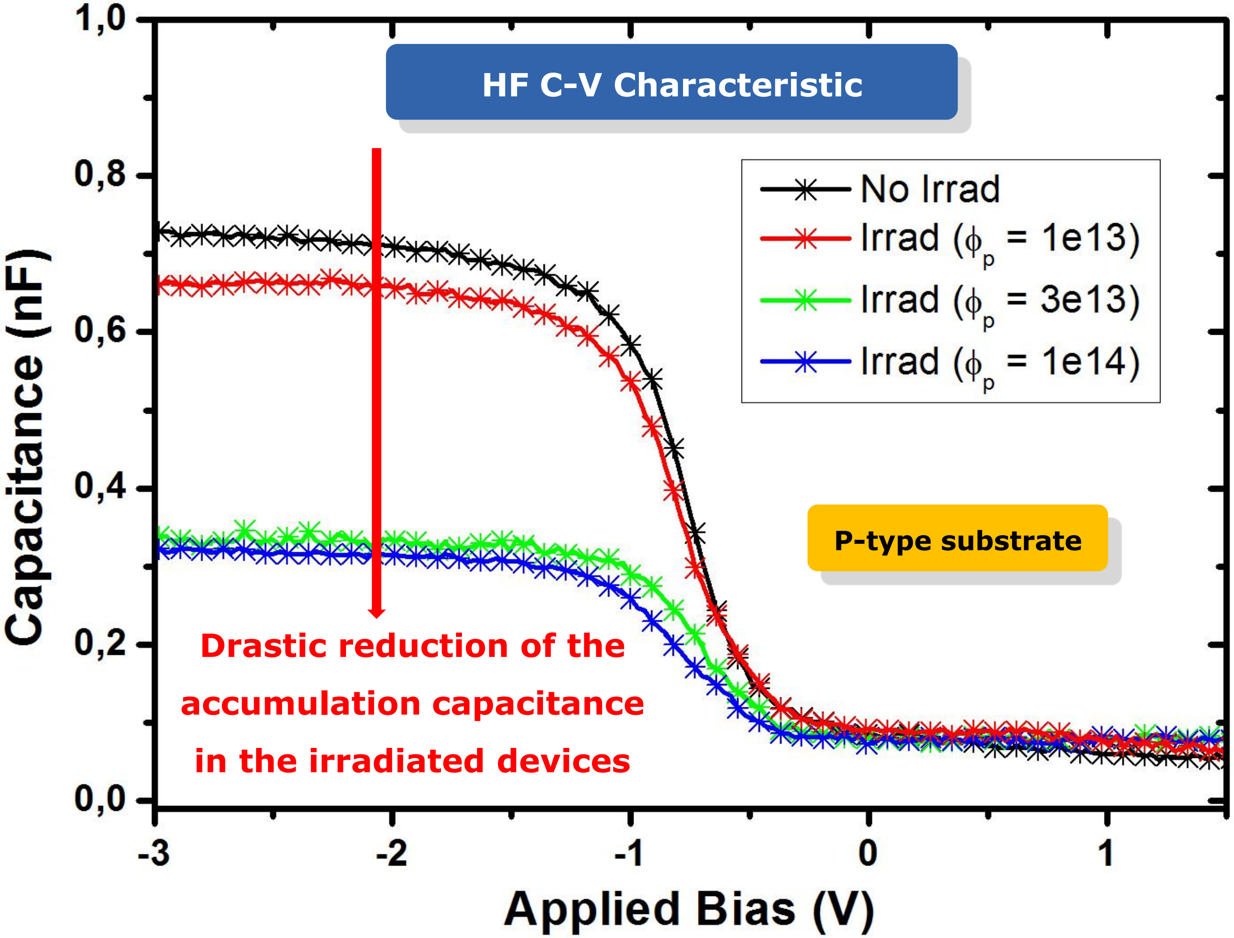
Outline

- ☐ **Proton Irradiation in MOS Capacitors**
- ☐ **HF C-V curves**
- ☐ **Radiation Effects in MOS Capacitors**
- ☐ **Effect of the Substrate Resistivity**
- ☐ **DDD Damage in Sentaurus TCAD**
- ☐ **Conclusions: MOS Capacitor DDD Dosimeter**

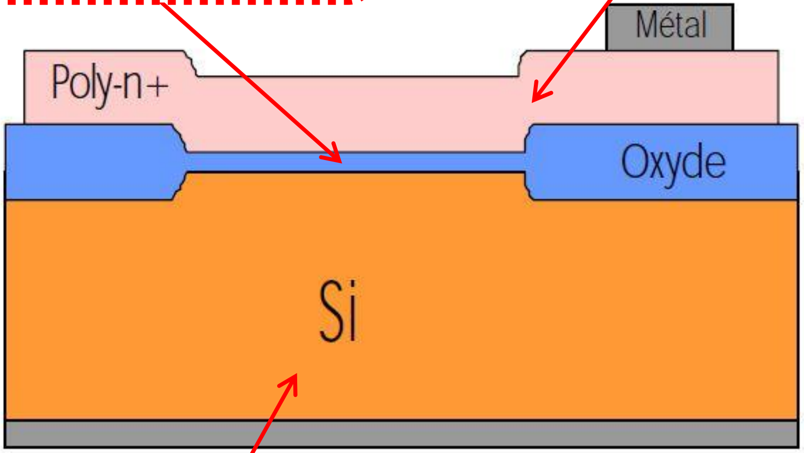
Proton Irradiation on MOS Capacitors

- **MOS capacitors (substrate resistivity 4.48 Ω·cm) fabricated at the IMB-CNM (CSIC) have been irradiated in the PS facility with 24 GeV protons at CERN**



Drastic reduction of the accumulation capacitance in the irradiated devices

Proton Irradiation on MOS Capacitors



Highly doped n-type polysilicon gate electrode

T_{ox} ranges at the nanometric scale (3-10 nm)

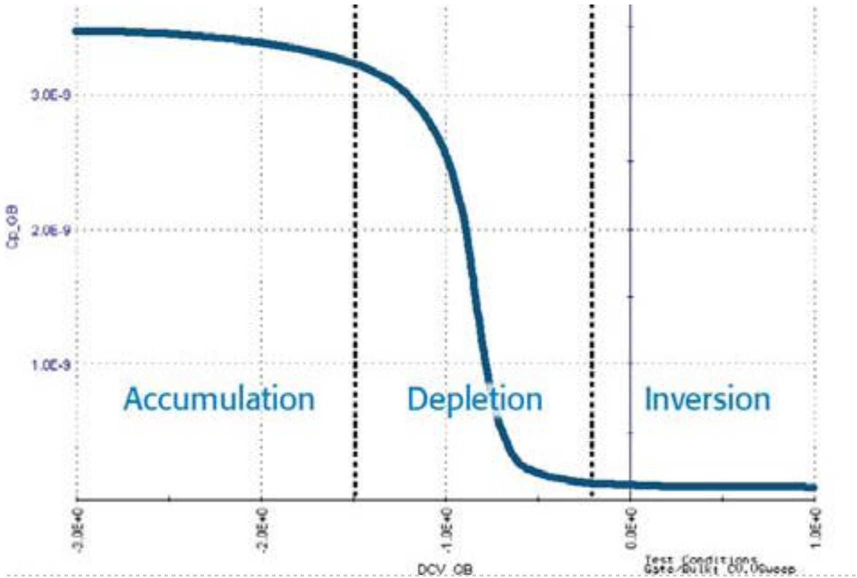
P-type silicon <100> substrate with boron doping concentration = 10^{15} cm^{-3}

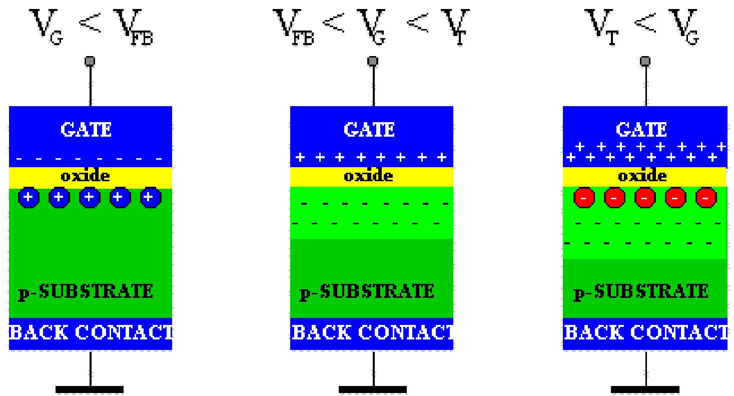
Φ_p [cm^{-3}]	E [GeV]
1×10^{13}	24
3×10^{13}	24
1×10^{14}	24

Low ionising Conditions

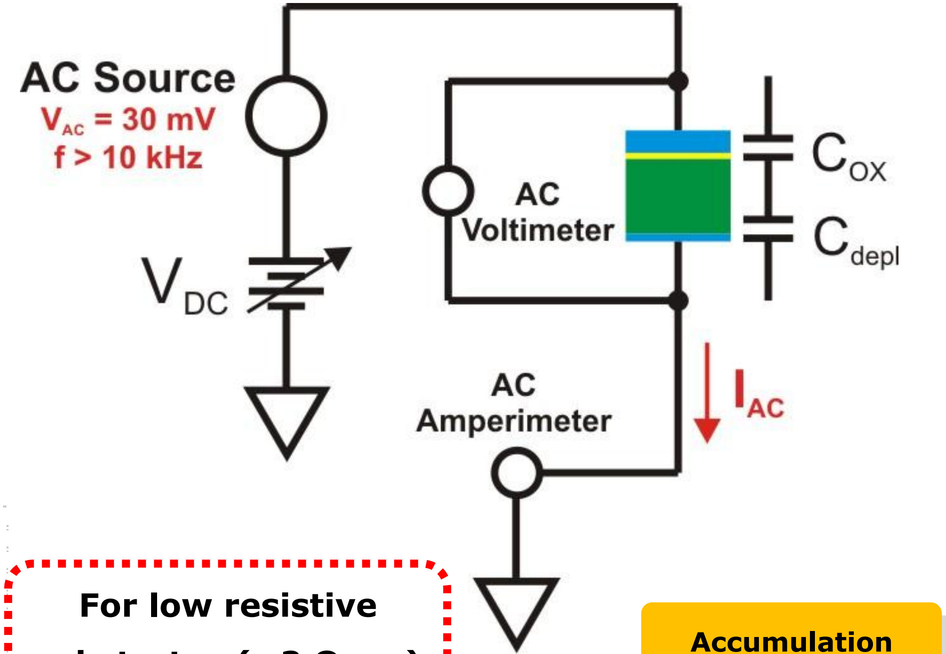
- **24 GeV protons are MIPs with reduced ionising capability**
- **Generated N_{ot} densities drain out the nanometric oxide by tunneling processes**
- **Low N_{it} densities are expected in low-hydrogen containing nm-thin oxides**
- **Interface does not play the most relevant role in MOS capacitor C-V characteristics**

HF C-V curves in MOS Capacitors





HF C-V Measurement Procedure



For low resistive substrates (~2 Ω·cm)

$$C_{AC} = \frac{I_{AC}}{2\pi f V_{AC}}$$

Accumulation

$$C_{AC} \to C_{OX}$$

Inversion

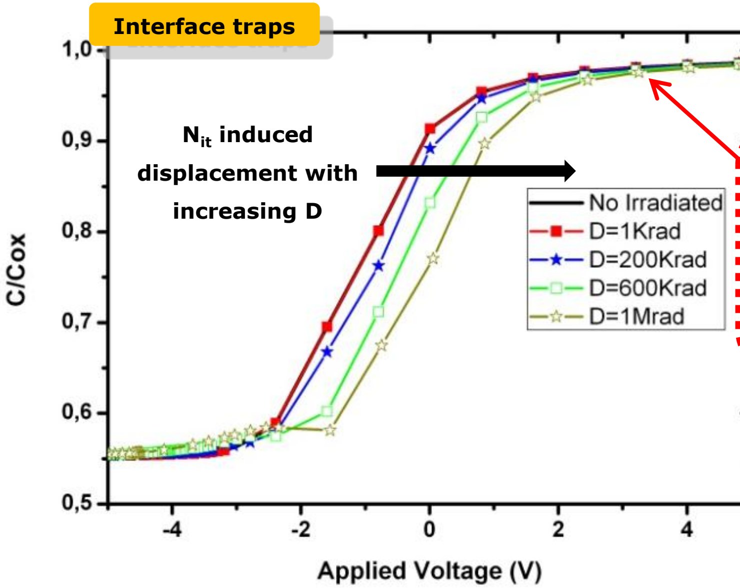
$$C_{AC} \to \frac{C_{OX}\cdot C_{depl}}{C_{OX}+C_{depl}}$$

Radiation Effects in MOS Capacitors

TID effects

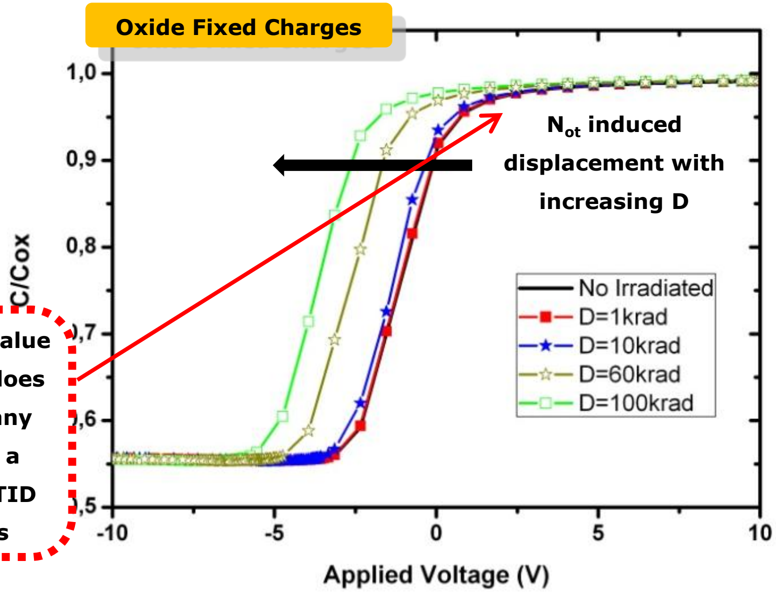
- **Oxide layer makes MOS capacitors sensitive to ionising damage**
- **Total Ionising Dose (TID) induces the formation of oxide fixed charges (N_{ot}) and interface trap (N_{it}) densities.**

C-V characteristics experiences horizontal displacements with increasing D



N_{it} induced displacement with increasing D

The capacitance value in accumulation does not experience any modification as a consequence of TID induced effects



N_{ot} induced displacement with increasing D

TID effects are expressed by the variation on the flat-band voltage values (ΔV_{fb})

8th Spanish Conference on Electronic Devices (CDE'11), Palma de Mallorca, Spain, February 2011
***"Simulation of Total Ionising Dose in MOS Capacitors"* P. Fernández-Martínez**, F.R. Palomo, I. Cortés, S. Hidalgo and D. Flores.

Radiation Effects in MOS Capacitors

DDD effects

- **Silicon substrate is sensitive to displacement damage.**
- **Displacement Damage Dose (DDD) induces the formation of displacement defects within the volume of the substrate.**

M. Moll
"Radiation Damage in Silicon Particle Detectors"
Univerität Hamburg, PhD Dissertation, Chapter 3, 1999

- **Electrically, displacement defects are identified with localised levels within the forbidden energy band gap.**
- **Depending on the charge stored in the defects, the effective substrate doping concentration become modified by the presence of DDD induced defects.**

P-type Substrates

$$N_{eff}(\phi) = -N_A + b_{DA}\phi$$

Reduction of the effective doping concentration with increasing fluence

Increase of the effective substrate resistivity

Effect of the substrate resistivity

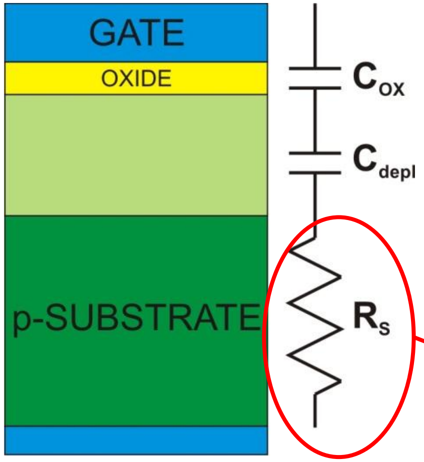
Revista Mexicana de Física S 52(2) p.45-47, 2006
"Modelling the C-V characteristics of MOS capacitor on high resistivity silicon substrate for PIN photodetector applications",
J.A. Luna-López, M. Aceves-Mijares, O. Malik, R. Glaenzer

HF C-V Measurement Procedure

$$C_{AC} = \frac{I_{AC}}{2\pi f V_{AC}}$$

Current measurement

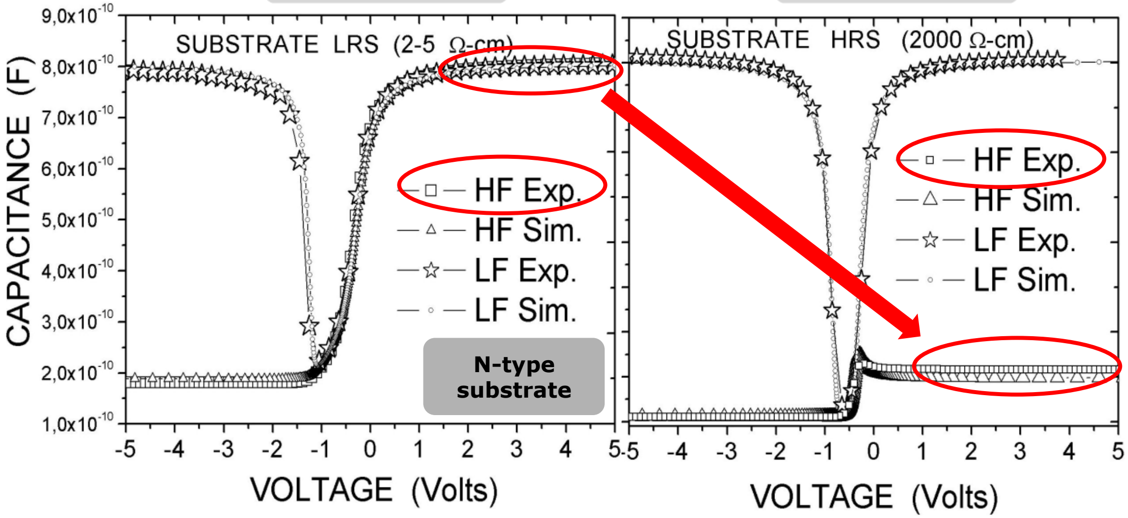
MOS Capacitor complete electric model



Undepleted substrate resistance (R_s) becomes relevant as long as substrate resistivity is increased

Low Resistivity

High Resistivity

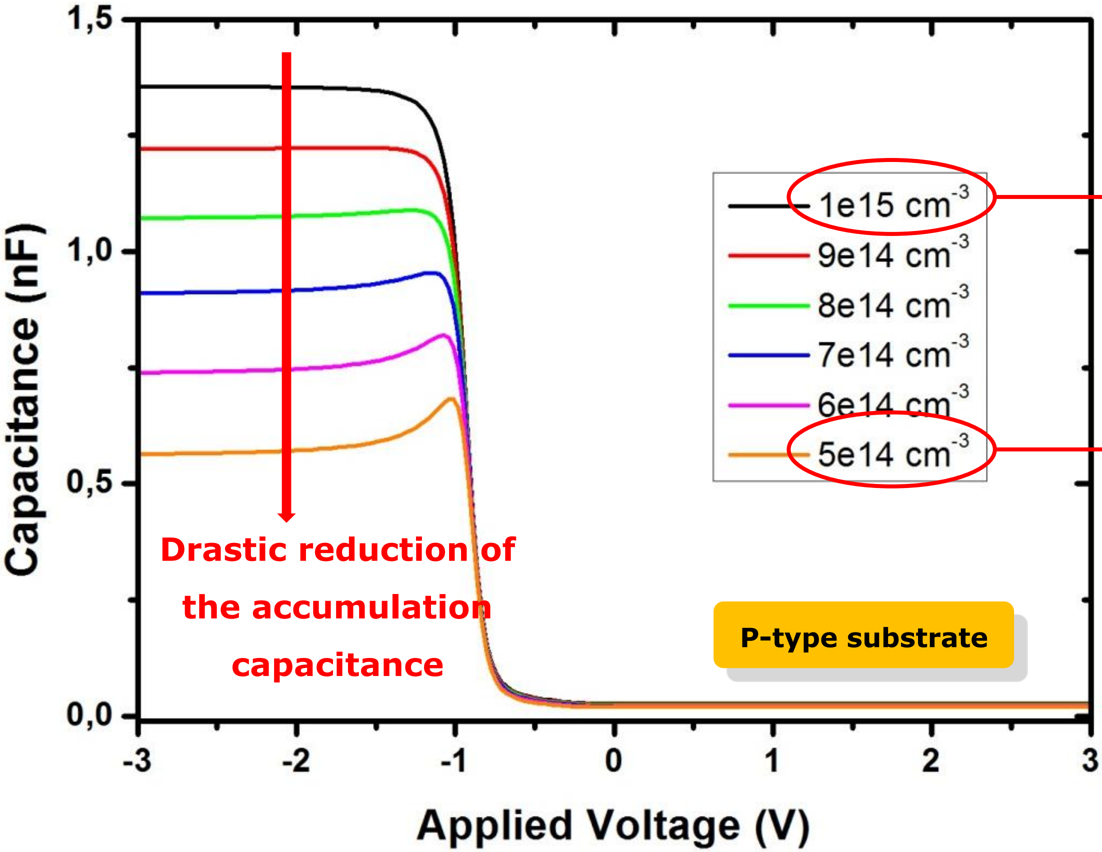


In highly resistive substrates, capacitance value in accumulation is no longer C_{ox}

Effect of the substrate resistivity

Sentaurus TCAD

- **Simulations: increase of the substrate resistivity => decrease in the substrate doping concentration**

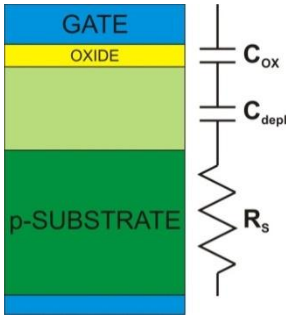


Drastic reduction of the accumulation capacitance

P-type substrate

4.48 Ω·cm

8.79 Ω·cm



Solid-State Electronics 36(4) pp.489-493, 1993
"Recalculation of Irvin's Resistivity curves for diffused layers in Silicon using updated bulk resistivity data",
C. Bulucea

DDD Damage in Sentaurus TCAD

IEEE Trans. Nucl. Sci., vol. 53, pp. 2971–2976, 2006
“Numerical Simulation of Radiation Damage Effects in p-Type and n-Type FZ Silicon Detectors”,
M. Petasecca, F. Moscatelli, D. Passeri, and G. U. Pignatel

University of Perugia trap model

- **DDD defects are emulated by localised traps within the band-gap, with fluence dependent density:**

$$Conc(cm^{-3}) = \Phi_{eq}\eta$$

P-type (FZ)

Type	Energy [eV]	Trap	σ_e [cm^2]	σ_h [cm^2]	η [cm^{-1}]
Acceptor	$E_C - 0.42$	VV	9.5×10^{-15}	9.5×10^{-14}	1.613
Acceptor	$E_C - 0.36$	VVV	5.0×10^{-15}	5.0×10^{-14}	0.9
Donor	$E_C + 0.36$	CiOi	3.23×10^{-13}	3.23×10^{-14}	0.9

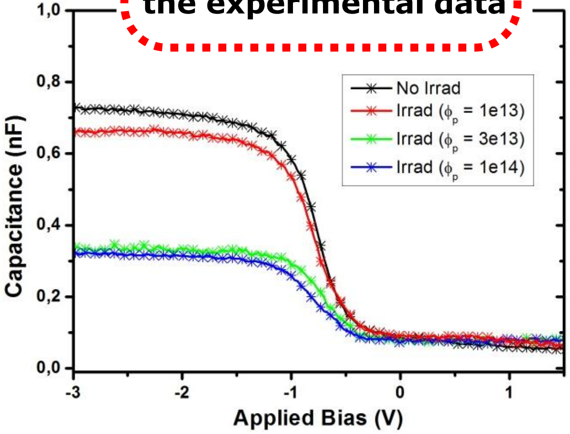
Modified cross sections to match trapping times

10th RD50 Workshop, June 2007, Vilnius, Lithuania
“Simulation results from double-sided and standard 3D detectors”,
D. Pennicard, C. Fleta, C. Parkes, R. Bates, G. Pellegrini, and M. Lozano

Traps model: Simulation

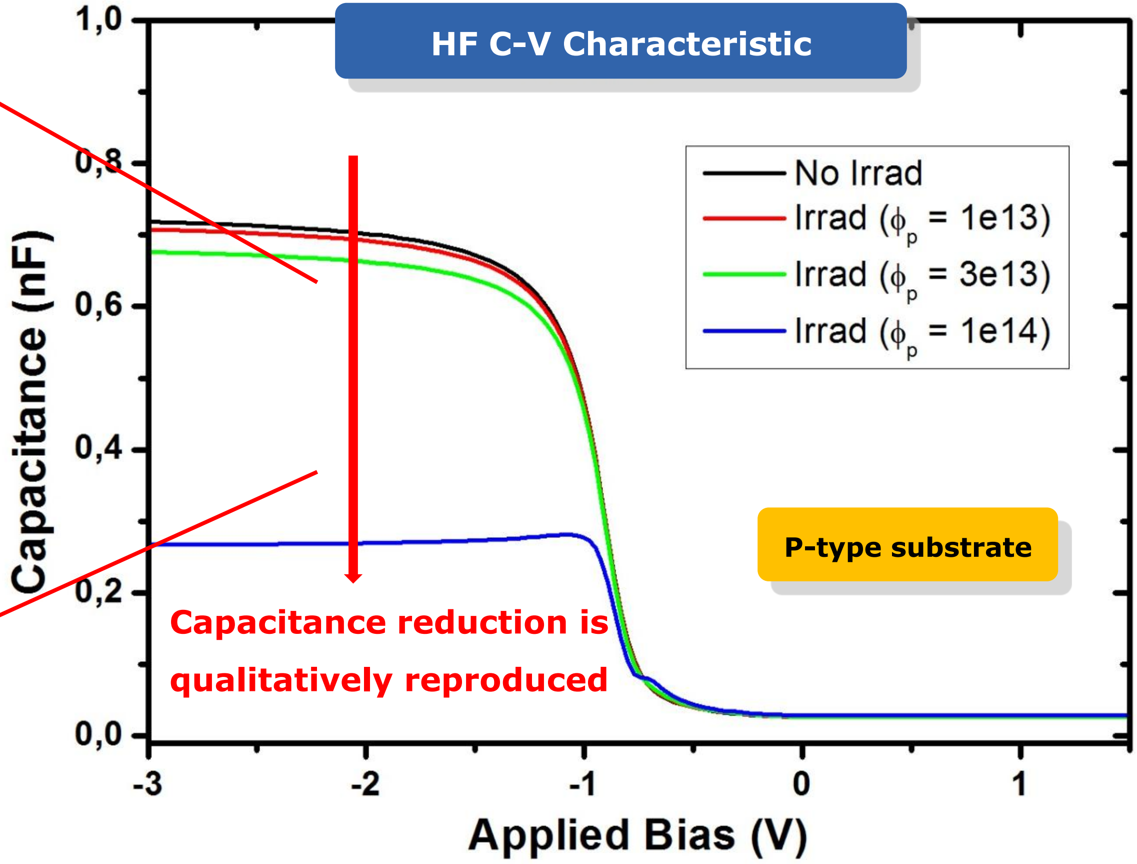
Sentaurus TCAD

Simulation Results with the trap model does not fit exactly the experimental data



With a proper model, simulations could be used to calibrate the capacitance-fluence relation

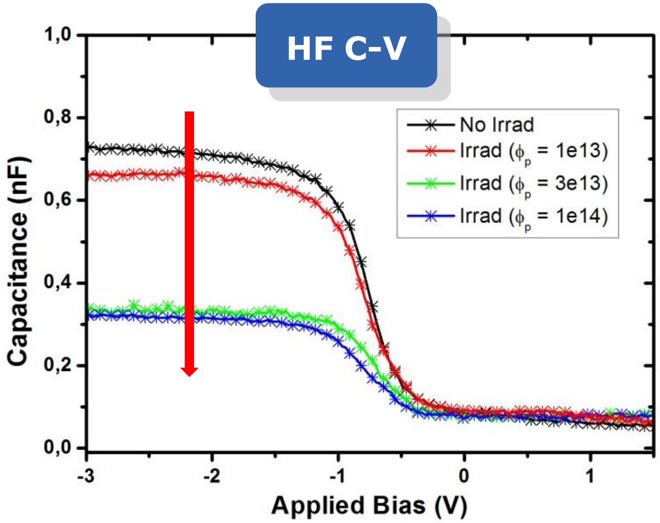
HF C-V Characteristic



Capacitance reduction is qualitatively reproduced

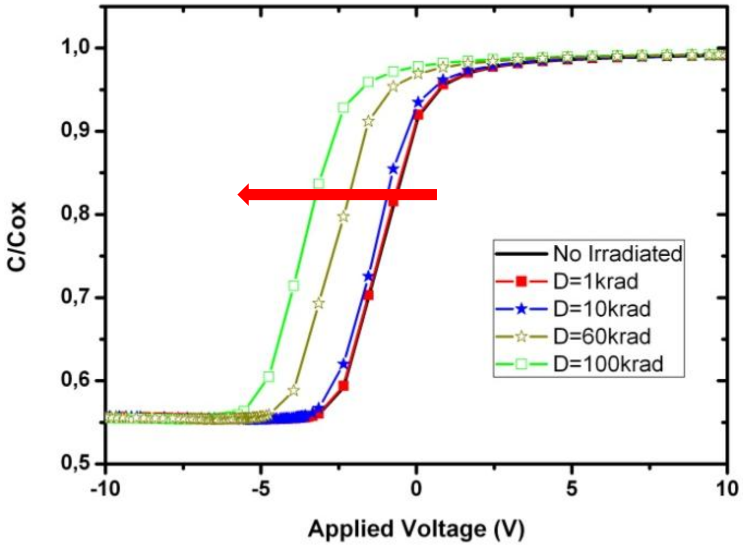
P-type substrate

Conclusions



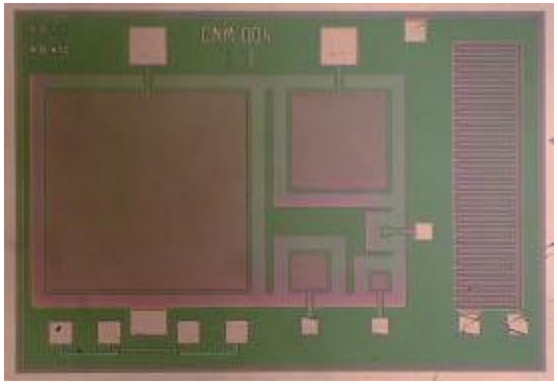
- **Displacement damage effects on MOS capacitors induce a significant reduction of the capacitance value in accumulation.**
- **The capacitance reduction is related with the received Displacement Damage Dose.**

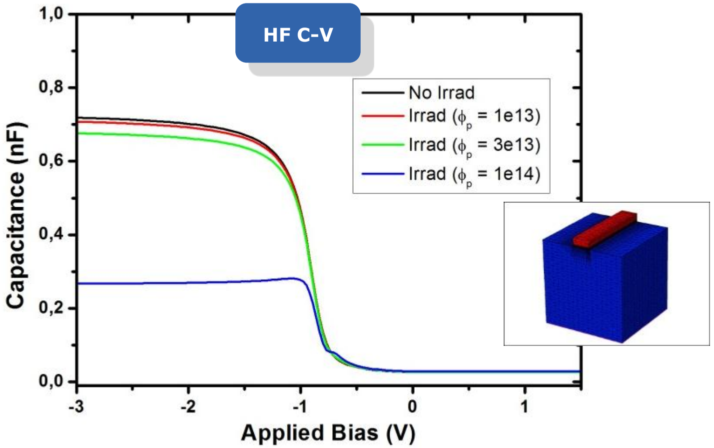
- **DDD effects are clearly distinguishable from TID effects on the HF C-V characteristics.**
- **For MOS capacitors with nm-thick oxides TID effects can be considered negligible**



MOS Capacitor DDD Dosimeter

- **MOS Capacitor can be used as a simple DDD dosimeter**
  - **Both TID and DDD effects are produced on the device**
  - **HF C-V curves differentiated both effects**
    - **TID: Flat-band displacement**
    - **DDD: Reduction of the capacitance value in accumulation**
  - **For nanometric oxide thickness, TID effects are negligible**
  - **It can be monitored during irradiation**
  - **It can be easily integrated together with the technological process**





Thanks for your Attention

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