Measurements and simulations of surface and bulk radiation damage effects in silicon detectors for phase II CMS outer tracker

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on behalf of the CMS Collaboration

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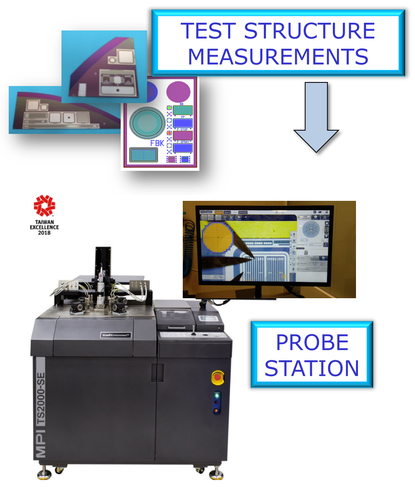
Introduction

- From 2026 the **HL-LHC** will start, with a very high fluence, up to 1×10^{15} 1MeV (2×10^{16}) n_{eq}/cm^2 in the outer (inner) tracker. A new tracker detector will be installed in CMS.
- Two different Hamamatsu Photonics (HPK) sensor technologies have been investigated as support for the final choice: standard **FZ290** and thinned **FZth240**.
- An intense activity on the Si/SiO2 surface and bulk radiation damage effects have been carried out:
  - development of a surface radiation damage effects model based on [1];
  - measurements on the test structures before and after irradiations:
    X-rays
    X-rays and neutrons

Experimental setup



IRRADIATION FACILITIES

Padova -> X-rays
- doses range:
  50 krad - 70 Mrad(SiO_2)

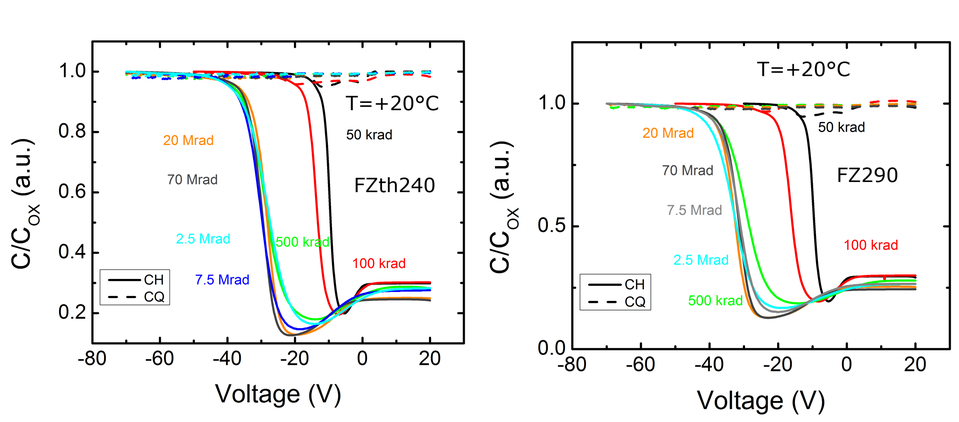
Ljubjana –> neutron (combined to X-rays):
- doses range:
  5 Mrad(SiO_2)+ 1.5×10^{14} (1 MeV n/cm^2)
  10 Mrad(SiO_2)+ 3×10^{14} (1 MeV n/cm^2)
  20 Mrad(SiO_2)+ 6×10^{14} (1 MeV n/cm^2)
  70 Mrad(SiO_2)+ 1×10^{15} (1 MeV n/cm^2)

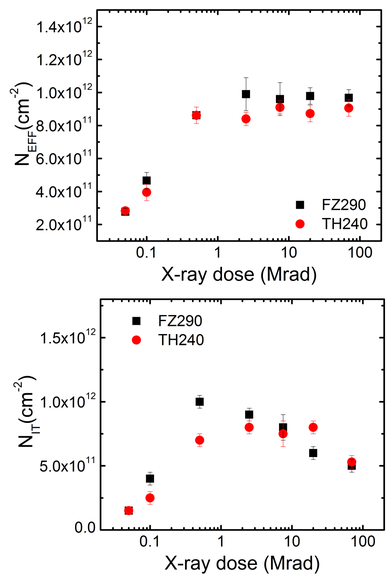
Expected in the outer tracker after 3000fb^{-1}

Surface damages

Measurements after X-rays to validate the surface model

1





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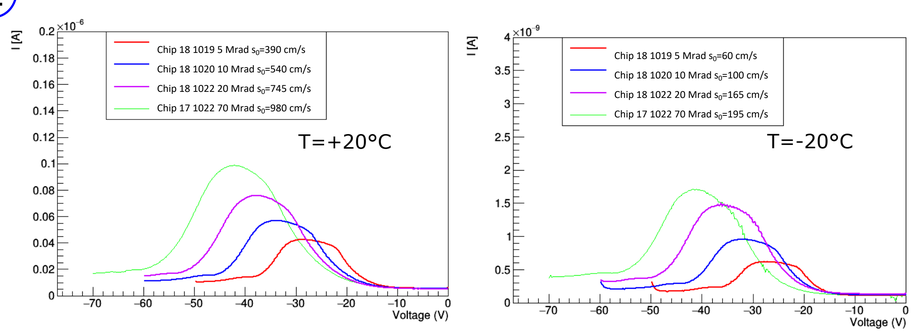

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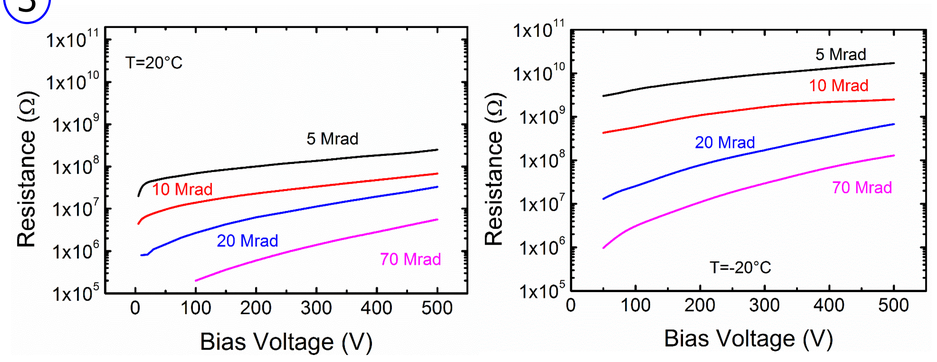
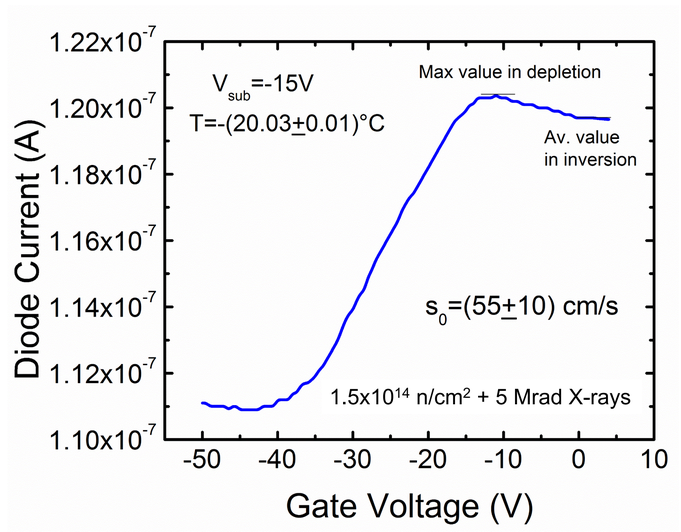


Measurements are performed on both 290 and th240 HPK sensors.

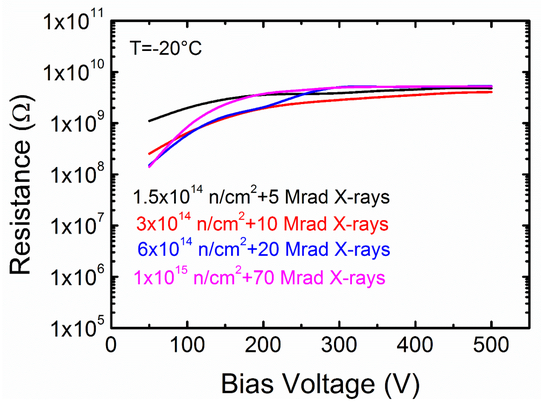
1) From the CV curves the N_{eff} and N_{it} parameters are extracted.
   A saturation of the V_{FB} is observed.
2) IV curves for the irradiated gated diodes show an **increase of the surface generation velocity vs dose**
3) Interstrip resistance curves for different doses show a **strong dependence on temperature**

Combined Bulk and Surface

Measurements after X-rays and neutrons to couple surface and damage effects



IV on the gated diodes irradiated with X-ray + neutrons -> whole characterization on going.



With neutrons and X-rays irradiations the Interstrip resistance saturate at high values.

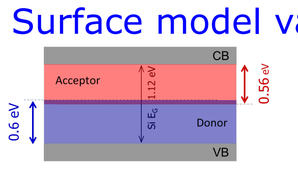
In agreement with [2.]

"New Perugia model"

Modern TCAD simulation tools -> different damage mechanisms interact in a non-trivial way

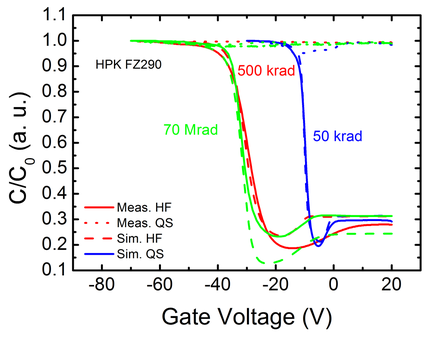
Bulk and **surface** radiation damage taken into account by means of the introduction of deep level radiation induced traps whose parameters are physically meaningful.

Surface model validation

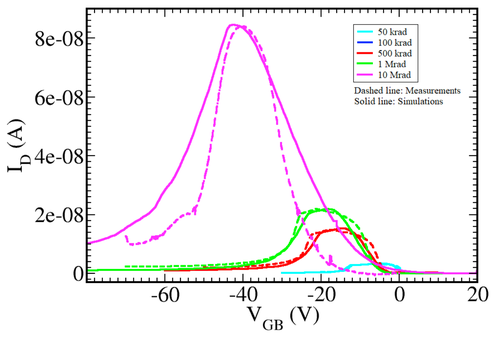


Type	Energy (eV)	Band width (eV)	Conc. (cm^{-2})
Acceptor	$E_C \le E_T \le E_C$-0.56	0.56	$D_{IT} = D_{IT}(\Phi)$
Donor	$E_V \le E_T \le E_V$+0.6	0.60	$D_{IT} = D_{IT}(\Phi)$

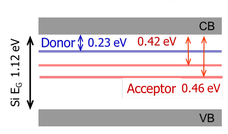
MOS capacitors



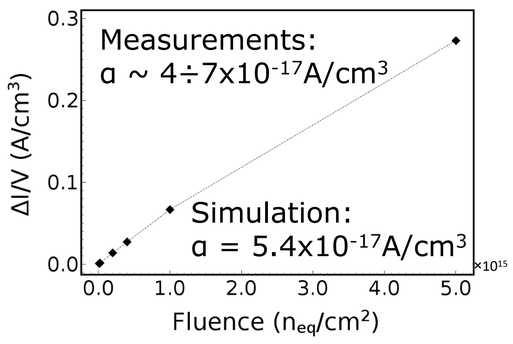
Gated Diodes



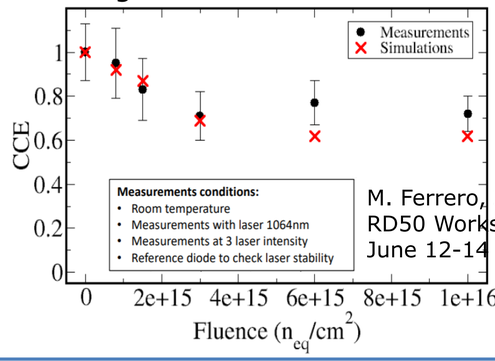
Bulk model validation



Type	Energy (eV)	η (cm^{-1})	σ_n (cm^2)	σ_h (cm^2)
Donor	E_C - 0.23	0.006	2.3×10^{-14}	2.3×10^{-15}
Acceptor	E_C - 0.42	1.6	1×10^{-15}	1×10^{-14}
Acceptor	E_C - 0.46	0.9	7×10^{-14}	7×10^{-13}



Charge Collection for PiN diodes



M. Ferrero, 34th RD50 Workshop, June 12-14 2019

Conclusions

In view of the upcoming OT tracker upgrade for the HL-LHC an intense characterization of irradiated sensor started.

Sensors have been irradiated with X-rays before (50 krad - 70 Mrad(SiO_2)) and neutrons then (1.5e14 – 1e15 (1 MeV n/cm^2)) to study the surface and the combined bulk + surface damage effects.
The new measurements on surface and bulk damages have been presented.
Similar behavior between FZ290 and FZth240.

A model for the bulk and surface damages has been developed "**New Perugia model**" to provide a general radiation damage model. A further [1, 3] comparison between measurements and simulations confirms the validity of the model.

References

1. F. Moscatelli, et al., *Analysis of surface Radiation Damage Effects at HL-LHC Fluences: comparison of different technology options*, Nucl. Instr. Methods Phys. Res. A, 2018.
2. Jan-Ole Gosewisch et al. *Interstrip Isolation of p-type Strip Sensors,* 14th "Trento" Workshop on Advanced Silicon Radiation Detectors
3. F Moscatelli, et al., *Measurements and simulations of surface radiation damage effects on IFX and HPK test structures*, Nucl. Instr. Methods Phys. Res. A, 2019.