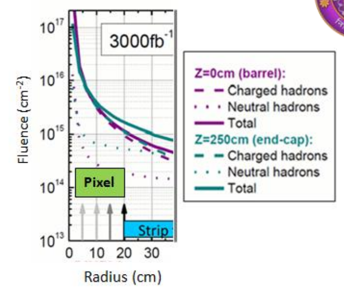
DESIGN OPTIMIZATION OF PIXEL SENSOR USING DEVICE SIMULATIONS FOR PHASE-II CMS TRACKER UPGRADE

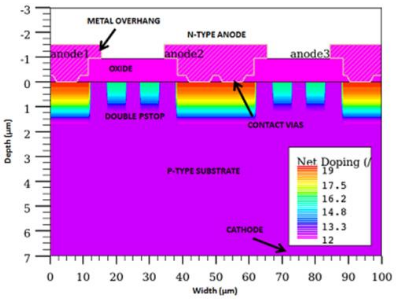
G. Jain on behalf of the CMS tracker collaboration

• During the **high luminosity phase of the LHC** (HL-LHC), all Si tracking detectors (pixels and strips) in the CMS experiment will experience a very harsh environment and will therefore require to undergo an upgrade.

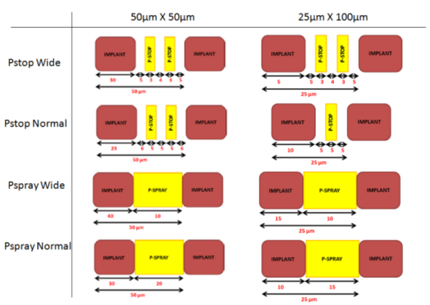


• Therefore, to develop radiation hard pixel sensor, **2D TCAD simulations**, using SILVACO & SYNOPSYS, are being performed on p-type planar pixel sensors, with pitch 25μm & 50μm, in normal & wide configurations for pstop & pspray isolation structures. → **8 DESIGNS!!**

2D Pixel Structure



8 Possible Pixel Geometries



Parameter Details

- Aluminium thickness = 0.55μm
- DC contact through Vias
- Gate SiO_2 thickness = 0.25μm
- Field SiO_2 thickness = 0.70μm
- P-Type bulk doping concentration N_b = 3e12cm^{-3}
- Implant doping : concentration N_{im} = 1e19cm^{-3}, depth D_{im} = 1.5μm, type = gaussian, with a factor of 0.5μm times diffusion in all directions
- Temperature = 253K

Damage Models Used : 2 bulk traps + QF + 2 N_{it}

in quantity as described in figure below.

* QF = fixed positive oxide charge density, N_{it} = Interface traps at Si-SiO2 interface

Bulk Damage

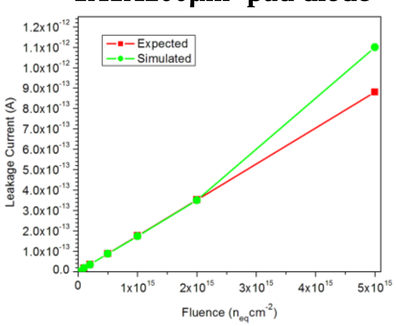
Trap Type	Energy Level (eV)	Density (cm^{-3})	σ_e (cm^{-2})	σ_h (cm^{-2})
Acceptor	E_C - 0.51	4 x ϕ	2.0 x 10^{-14}	2.6 x 10^{-14}
Donor	E_V + 0.48	3 x ϕ	2.0 x 10^{-14}	2.0 x 10^{-14}

Surface Damage

Trap Type	Energy Level (eV)	Density (cm^{-3})	σ_e (cm^{-2})	σ_h (cm^{-2})
Acceptor	E_C - 0.60	0.6 x QF	0.1 x 10^{-14}	0.1 x 10^{-14}
Acceptor	E_C - 0.39	0.4 x QF	0.1 x 10^{-14}	0.1 x 10^{-14}

E_C = Lowest energy level of conduction band, E_V = Highest energy level of valence band, Φ = Fluence, σ_e = Electron cross- section, σ_h = Hole cross- section

* IV Characteristics of 1X1X200μm^3 pad diode



✓ **IV increases linearly with fluence at 253K using: ΔI = αΦV, where V is the volume of the sensor.**

✓ **Calculated & Simulated IV characteristics are in very good agreement for fluence below 2e15cm-^{2}.**

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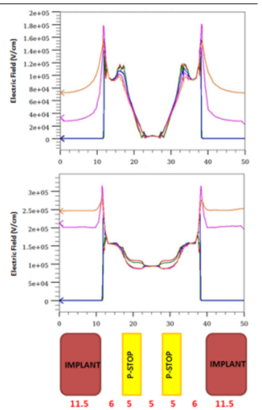
Step-wise Follow-up in Optimizing the Planar Pixel Design through Simulations.

1. Identifying the crucial electric field regions within the device - **Electric Field across the surface of the detector at different cutlines**

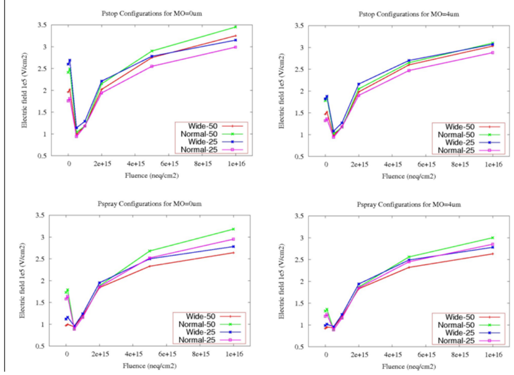
	Fluence	@ 1000V
Pstop Pitch=50µm Conf.=Normal d=200µm N_{pst}=1e16cm^{-3} D_{pst}=1µm MO=4µm	0	
	1e16	



✓ **Critical region @ 0.9µm below the oxide, at strip curvature!**

2. Looking for the best configuration among the 8 possible designs for least electric field increase in the crucial electric field region identified in step 1 - **Maximum electric field as a function of fluence**

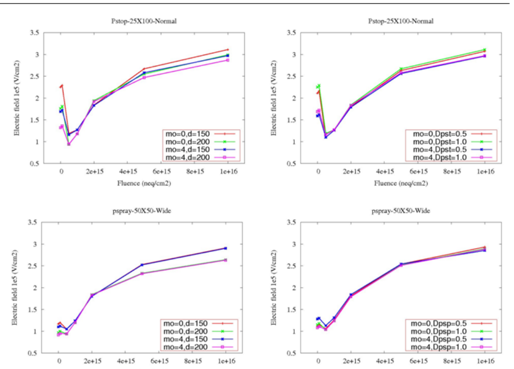
Cutline 0.9µm	MO = 0µm	MO = 4µm
Pstop d=200µm N_{pst}=1e16cm^{-3} D_{pst}=1µm		
Pspray d=200µm N_{psp}=1e15cm^{-3} D_{psp}=1µm		



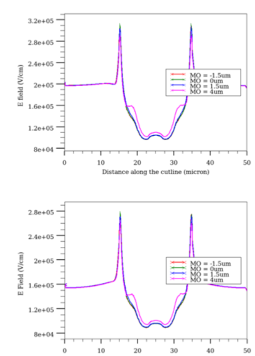
✓ **Pstop-Normal-25 & Pspray-Wide-50 have the least electric field!**

3. Optimizing parameters – **Effect of variation of MO, d, $D_{pst-psp}$, for the best configuration only**

Cutline 0.9µm	d Effect : $D_{pst-psp}$=1µm	$D_{pst-psp}$ Effect : d=150µm
Pstop Pitch=25µm Conf.=Normal N_{pst}=1e16cm^{-3}		
Pspray Pitch=50µm Conf.=Wide N_{psp}=1e15cm^{-3}		



Cutline 0.9µm	Pstop - Pitch 50µm – Wide d=200µm - N_{pst}=1e16cm^{-3} - D_{pst}=1µm
@1000 V	
@ 500 V	



✓ **Electric field reduces for larger detector depth.**
✓ **Small effect of variation of $D_{pst-psp}$ at high fluence.**

✓ **MO is effective in reducing the electric field, though the effect is a small one.**

SUMMARY :

• Of the 8 designs, normal-25µm & wide-50µm configurations of pstop & pspray structures respectively, are the most radiation tolerant.
• The best parameters so far seem to be: d=200µm, $N_{pst-psp}$=1e16-1e15cm^{-3}, $D_{pst-psp}$=1µm, MO=4µm.
• The parameters reported here are optimized looking at the operation stability against breakdown provided by the critical field, however a further study on charge collection efficiency (work on going), is needed to finalize the best device layout parameters

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* Expanded forms of symbols used: $N_{pst-psp}$ = Concentration of pstop - pspray, $D_{pst-psp}$ = Depth of pstop - pspray, d= Detector active depth, MO = Metal overhang