Design Optimization of Pixel Sensors using Device Simulations for Phase-II CMS Tracker Upgrade

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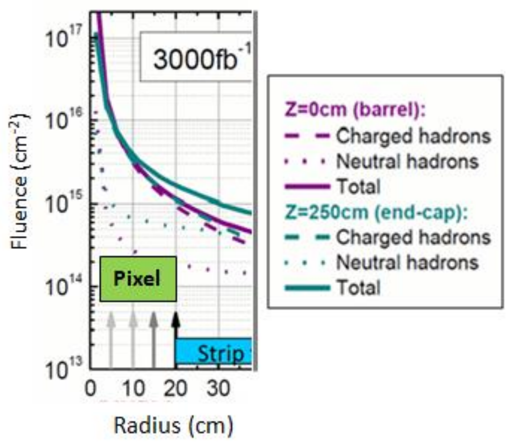
Introduction

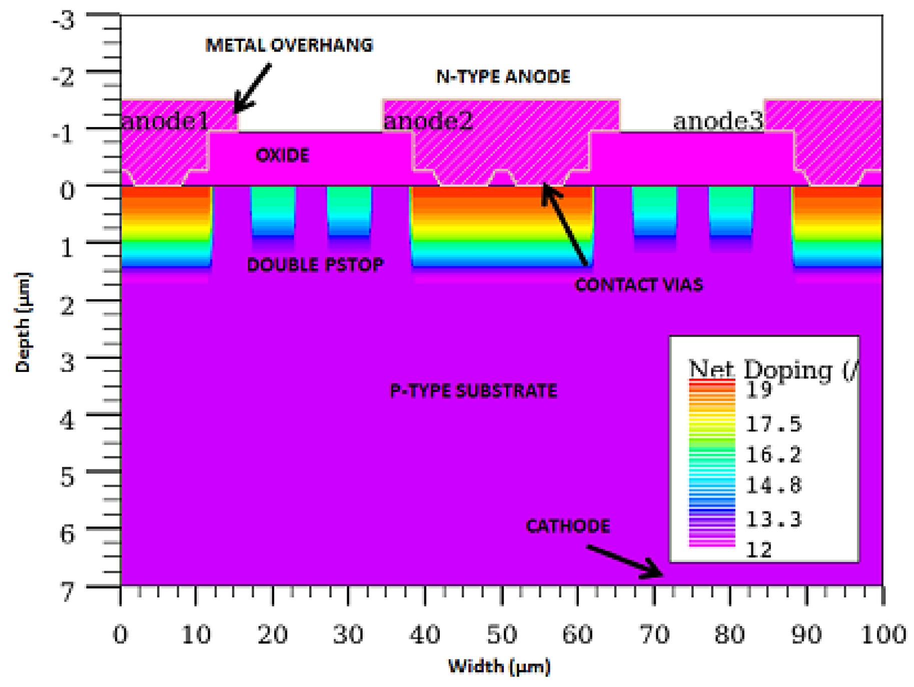
• Si sensors - high precision tracking devices.
• Presently installed in CMS tracker - pixel & strip detectors.

• HL-LHC upgrade :
Luminosity ~ $5\times10^{34}cm^{-2}s^{-1}$
Integrated luminosity ~ $3000fb^{-1}$
→For inner layer pixel - fluence (n_{eq}) > $1\times10^{16}cm^{-2}$
→ Harsh radiation environment!



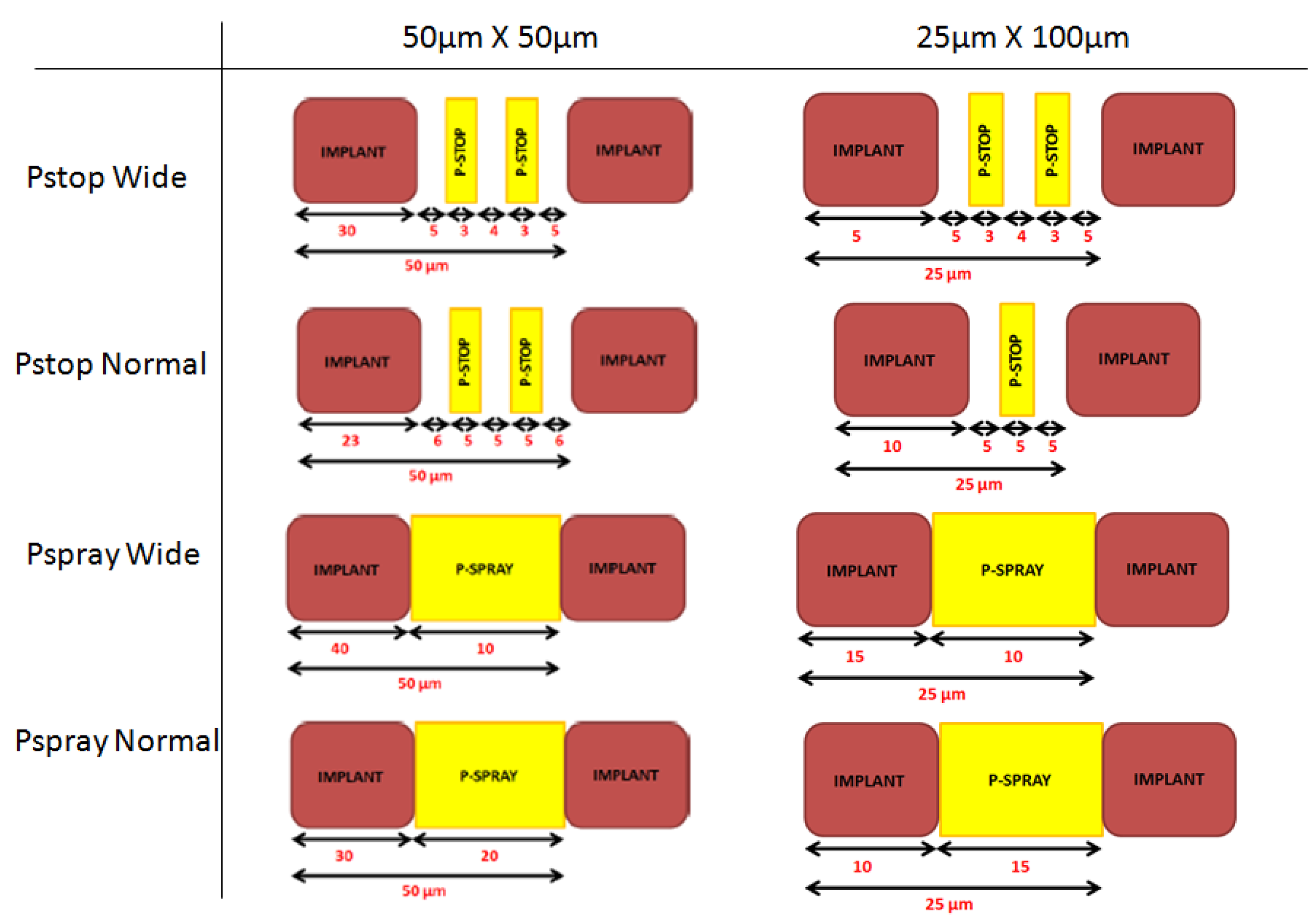
• Need to optimize the pixel detector design to make it withstand such high radiation levels!!

2D Pixel Structure



• Aluminium thickness = 0.55µm
• DC contact through Vias
• Gate SiO_2 thickness = 0.25µm
• Field SiO_2 thickness = 0.70µm

8 Possible Pixel Geometries



Parameter Details

• 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

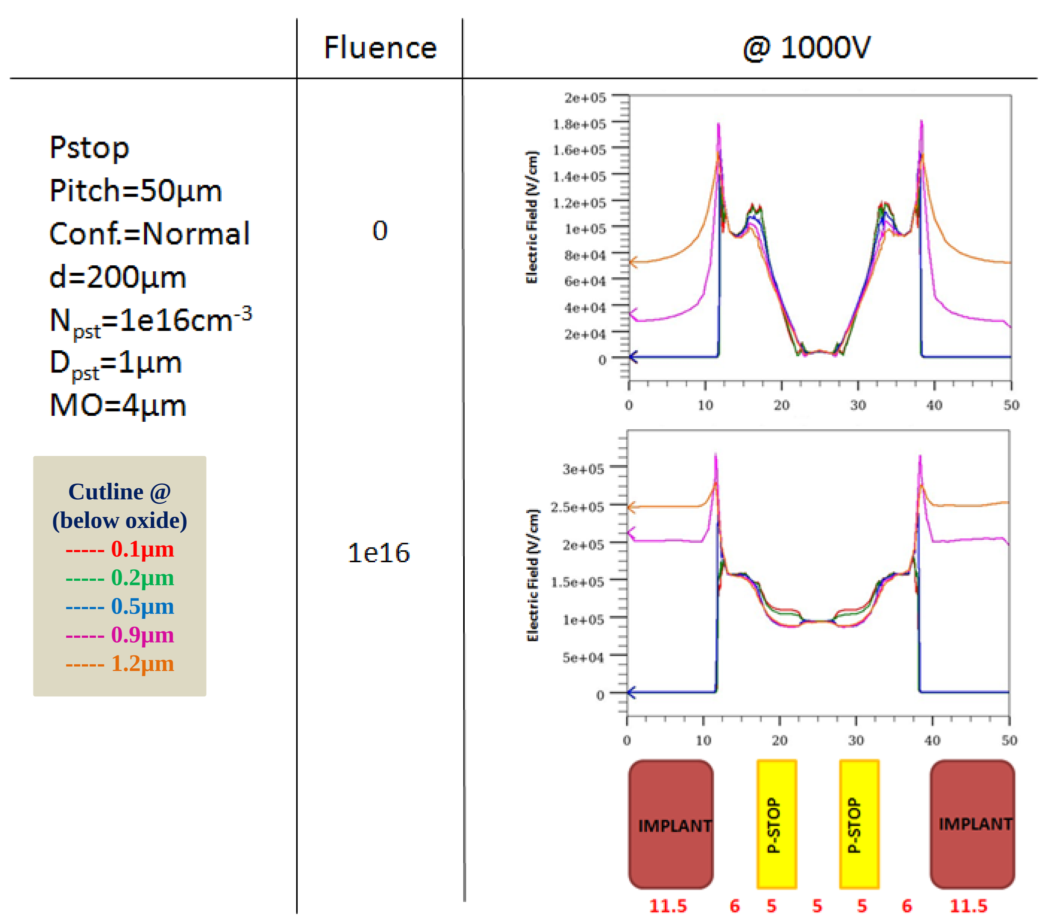
Trap Type	Energy Level (eV)	Density (cm⁻³)	σ_e (cm⁻²)	σ_h (cm⁻²)
Acceptor	E_C - 0.51	4 x Φ	2.0 x 10^{-14}	2.6 x 10^{-14}
Donor	E_V + 0.48	3 x Φ	2.0 x 10^{-14}	2.0 x 10^{-14}

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}

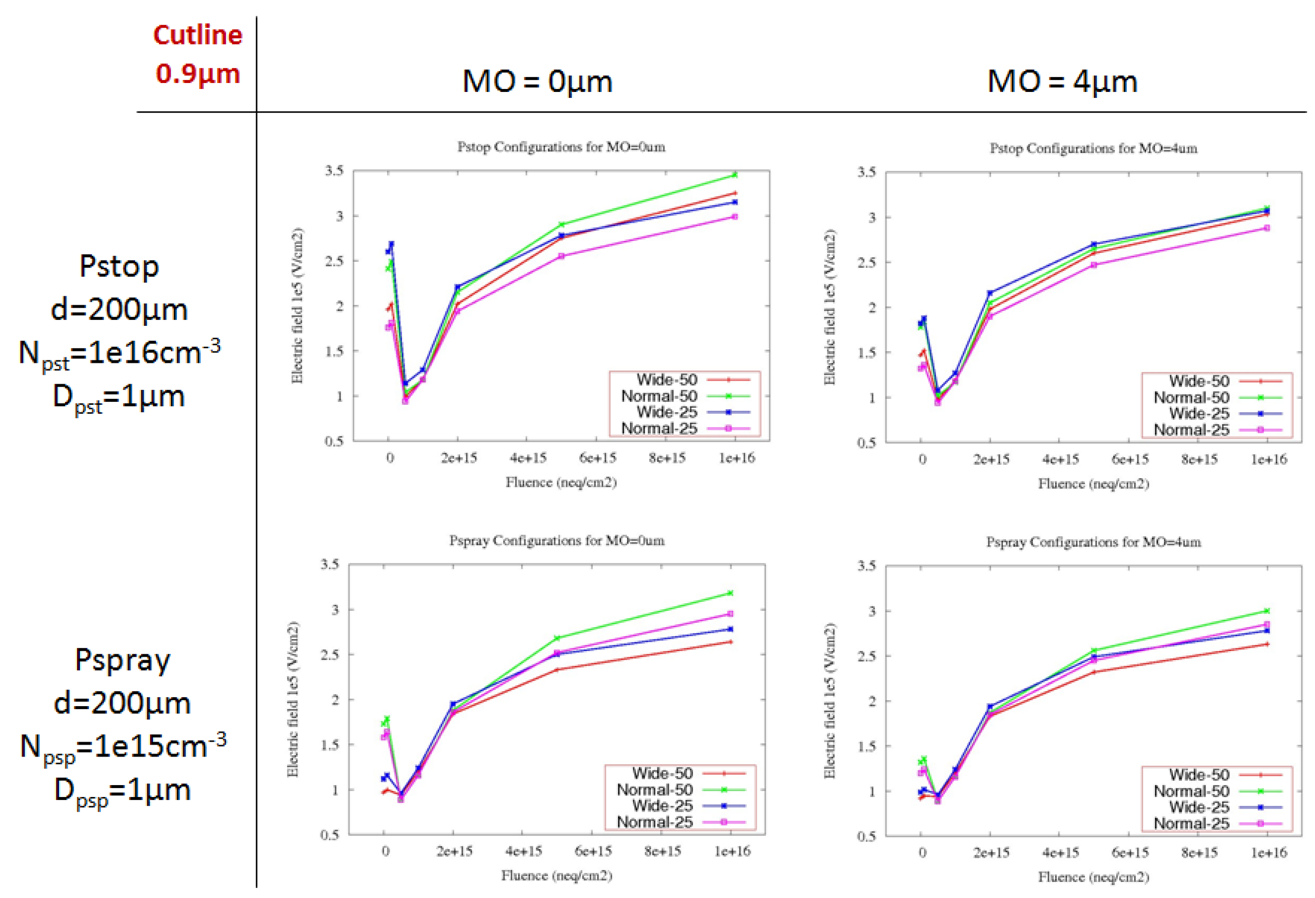
E_C = Lowest energy level of conduction band, E_V = Highest energy level of valence band, Φ = Fluence, σ_e = Electron cross-section, σ_h = Hole cross-section

1. Identify crucial electric field regions in device – Electric field across the sensor surface at different cutlines.



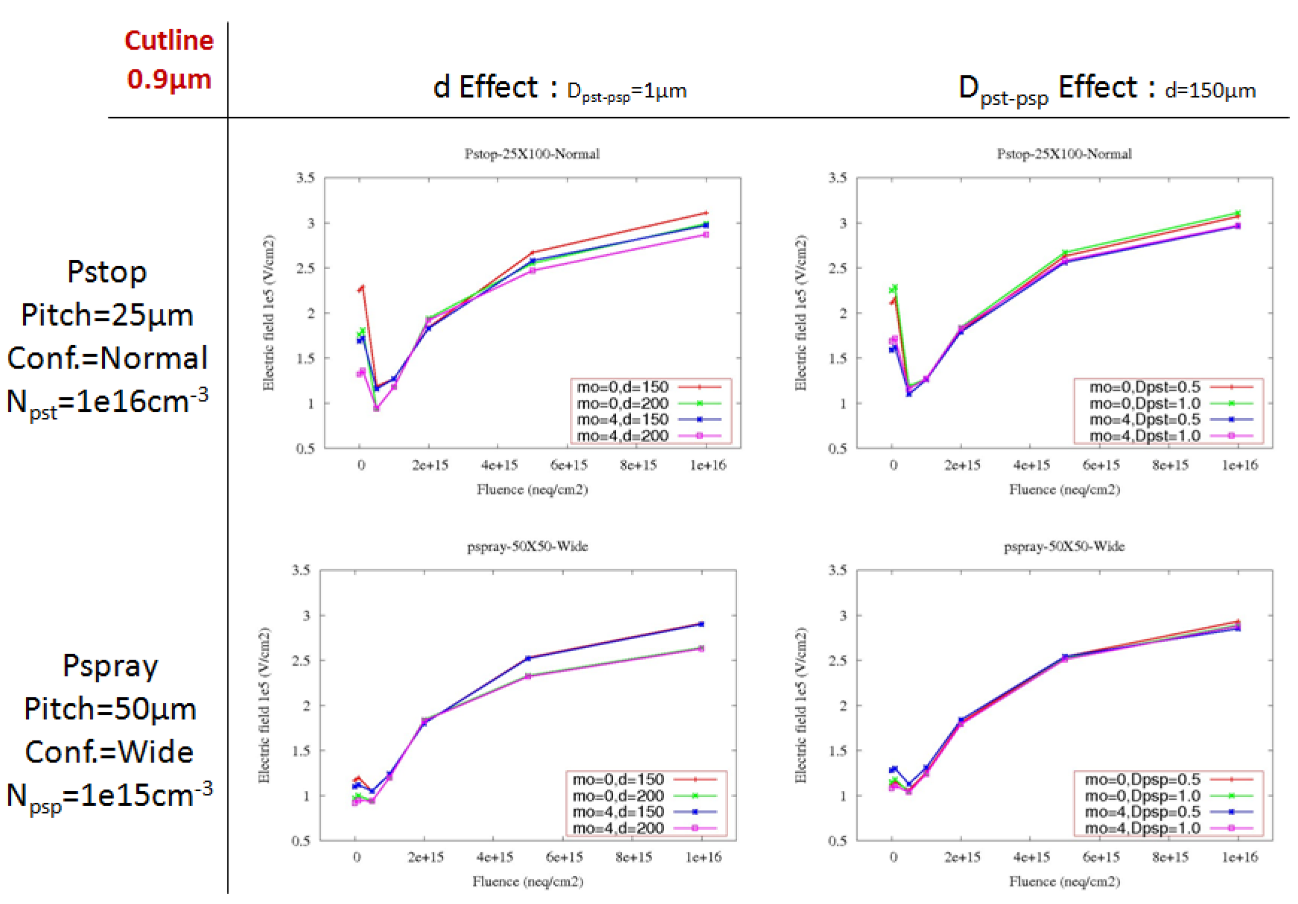
✓ Maximum electric field is at cutline of 0.9µm below the oxide, at strip curvature!!

2. Identifying best geometry from the 8 pixel configurations @ 1000V – Maximum electric field vs fluence.



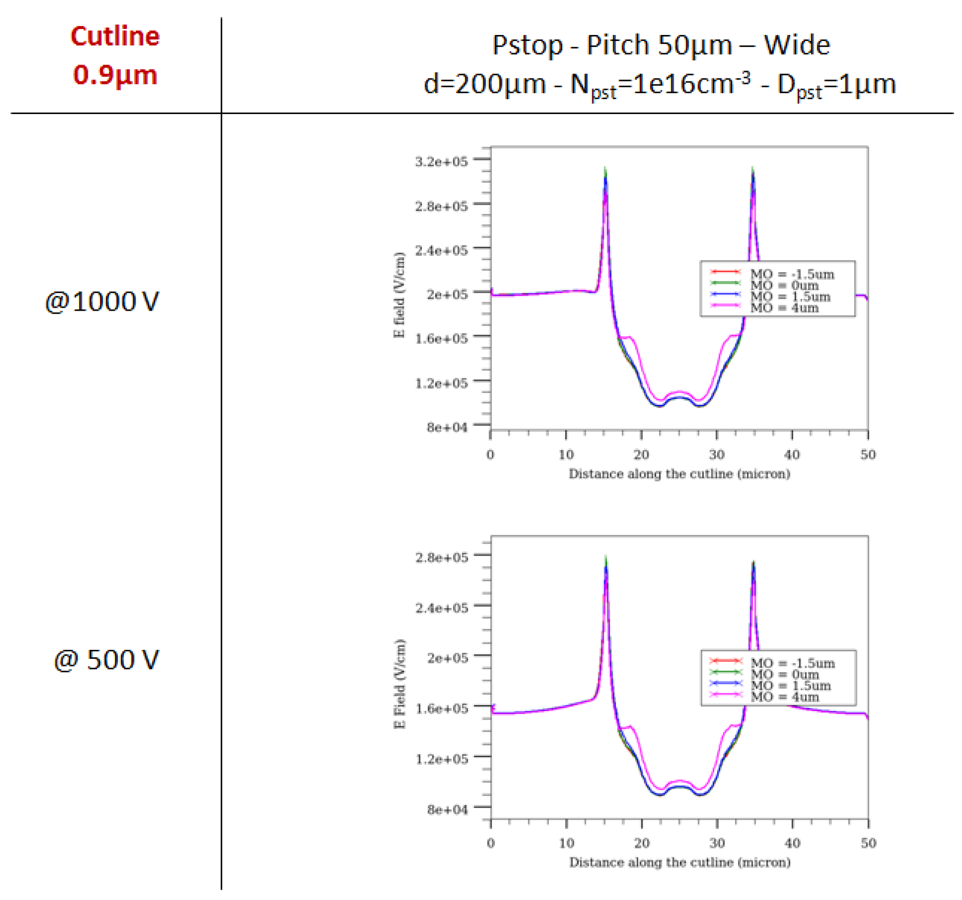
✓ Pstop-Normal-25 & Pspray-Wide-50 have the least electric field!

3a. Effect of variation of d and $D_{pst-psp}$ on the crucial electric field @ 1000V – Maximum electric field vs fluence.



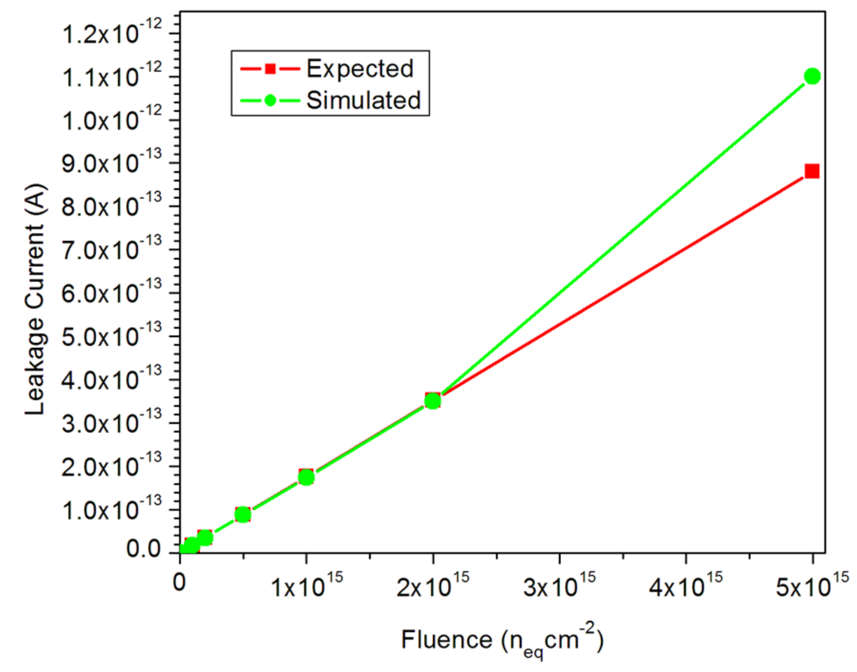
✓ Electric field reduces for larger detector depth.
✓ Small effect of variation of $D_{pst-psp}$ at high fluence.

3b. Effect of variation of MO on the crucial electric field @ 1e16cm^{-2} fluence – Electric field across the sensor surface.



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

* Leakage Current for a Pad Diode 1X 1X200µm^3 – Expected & Simulated current as a function of fluence.



✓ Current increases linearly with fluence at 253K using: ΔI = αΦV, where V is the volume of sensor.
✓ Calculated and Simulated IV characteristics are in very good agreement for fluence below 2e15cm^{-2}.

* 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

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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