TCAD 2D SIMULATIONS FOR PHASE II CMS PIXEL SENSOR DESIGN

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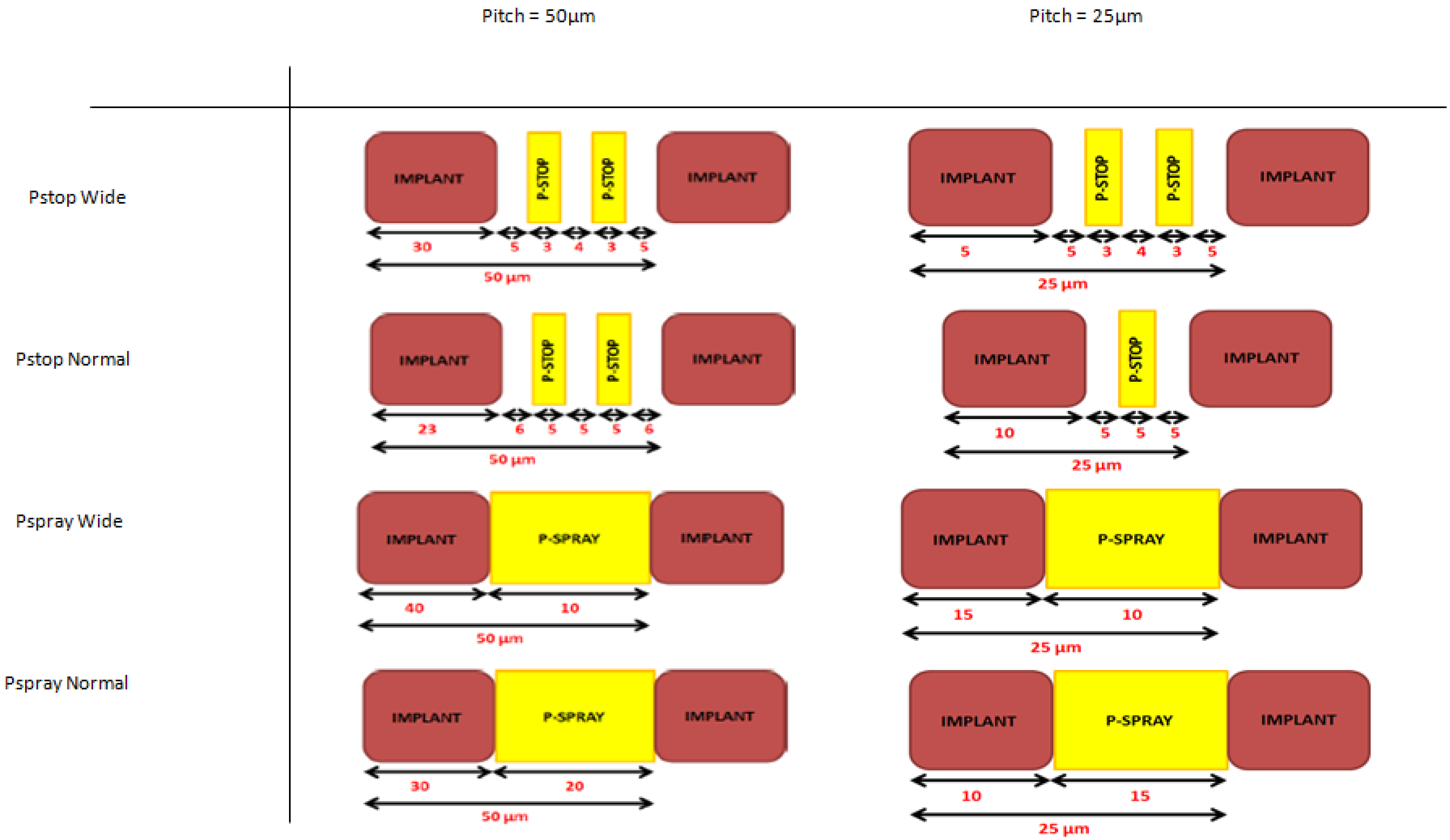
Outline

1. Pixel geometries & their parameters
2. Radiation damage model
3. Design optimization through electric field plots
4. Charge collection efficiency
5. Initiation of 3D Simulation!
6. Summary

8 Pixel Designs !

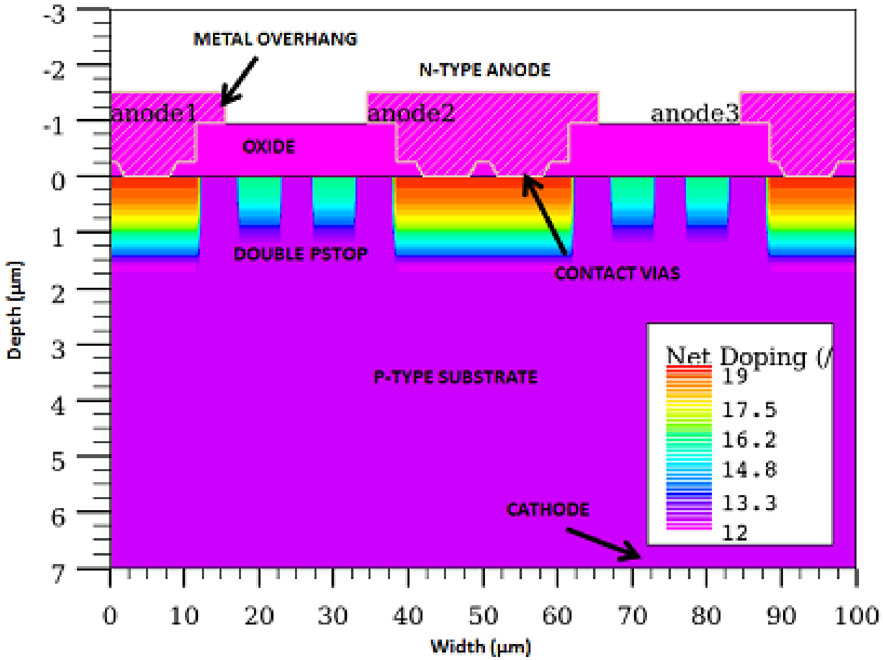


8 Pixel Designs !

	Structure	Pitch p (um)	Im Width w (um)	Ratio w/p
	1	25	10	0.4
PSPRAY	2	25	15	0.6
	3	50	30	0.6
	4	50	40	0.8
	5	25	5	0.2
PSTOP	6	25	10	0.4
	7	50	23	0.46
	8	50	30	0.6

Pixel Structure & Parameters

2D Net Doping Profile: Structure 7, MO=4µm, Npst=1e16cm^{-3}, dpst=1µm, d=200µm



Parameters from the Pixel Upgrade Group

- N-in-P type
- Al thickness = 0.55 µm, DC contact through Vias
- Gate SiO$_2$ thickness = 0.25 µm, Field SiO$_2$ thickness = 0.70 µm
- Bulk doping concentration **N_b = 3e12 cm^{-3}**
- Implant doping : conc. N_{im} = 1e19 cm^{-3}, depth D_{im} = 1.5 µm, type = gaussian, lateral expansion = 0.5 µm
- Temperature = **293 K (non-irr), 253 K (irr)**
- Qf = 1e11 for non-irr, 12e11 for 5e14 n_{eq}/cm^2, 2e12 for all fluence >1e15 n_{eq}/cm^2
- **All plots @ external bias of 500 V, unless specified**
- Horizontal cutline @ 0.9 µm for non-irr & irr structures.

Radiation Damage Model - I

 # Non-Irradiated = QF + 2 N_{it} traps **# Irradiated = 2 bulk traps + QF + 2 N_{it} traps**

Bulk Traps

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}

QF

Irradiation Fluence, ϕ (n_{eq}.cm^{-2})	QF Range (cm^{-2})
0	5.0 x 10^{10} to 5.0 x 10^{11}
1.0 x 10^{14}	1.0 x 10^{11} to 8.0 x 10^{11}
5.0 x 10^{14}	5.0 x 10^{11} to 12.0 x 10^{11}
10.0 x 10^{14}	8.0 x 10^{11} to 20.0 x 10^{11}

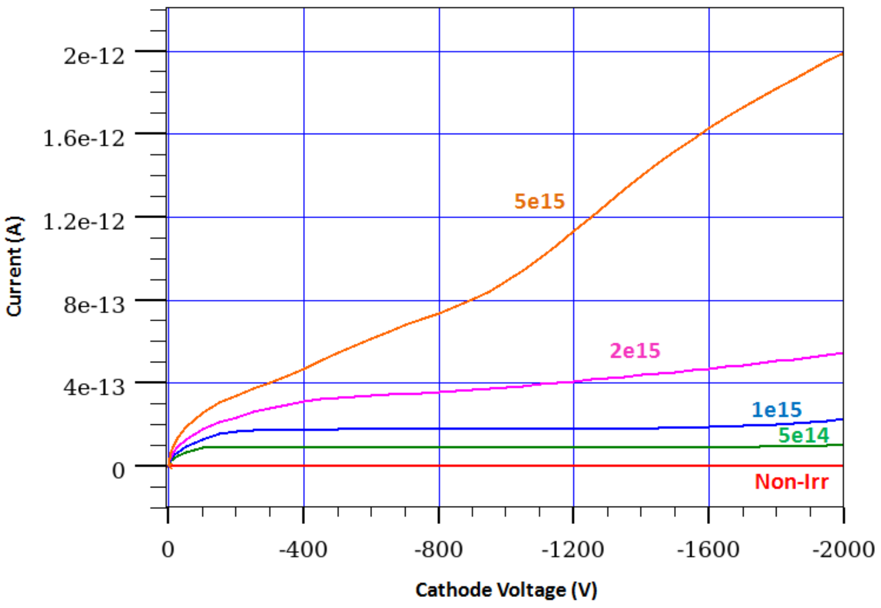
Interface Traps

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}

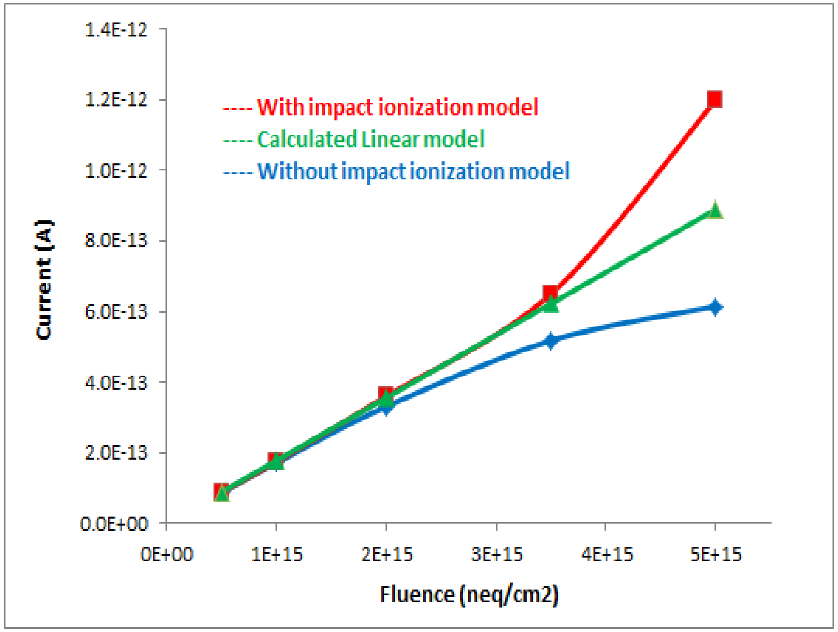
* R. Dalal et al., Simulation of Irradiated Si Detectors, proceedings of The 23rd International Workshop on Vertex Detectors, PoS(Vertex2014)030 (2014)

Radiation Damage Model - II

IV Characteristics: 1X1X200 μm^3 Pad Diode @ 253 K



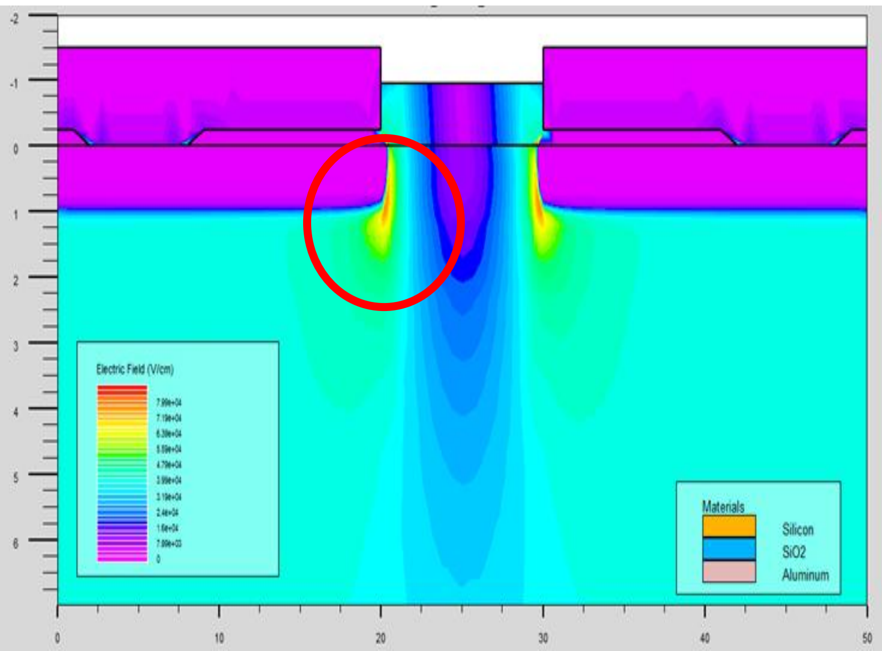
Simulated & Calculated Comparison



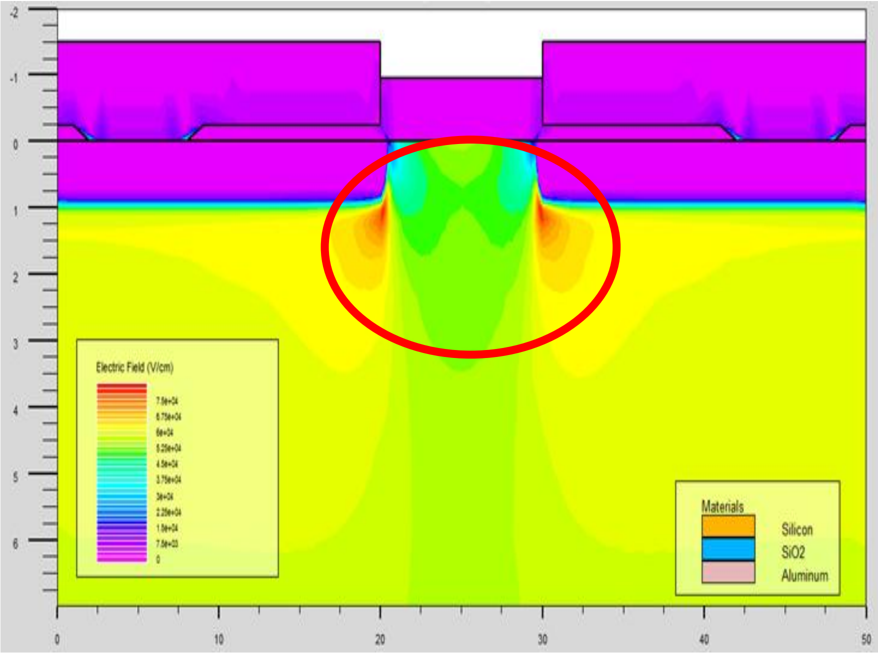
- ☐ The model is well verified upto 2e15 neq/cm^2 fluence and gives correct values of current, full depletion voltage & charge collection efficiency in comparison to the measurements!
- ☐ However, measurements are required to further verify the model for higher fluence range.

2D Electric Field Profiles @ 500V

Fluence=0 neq/cm2



Fluence=1e15 neq/cm2



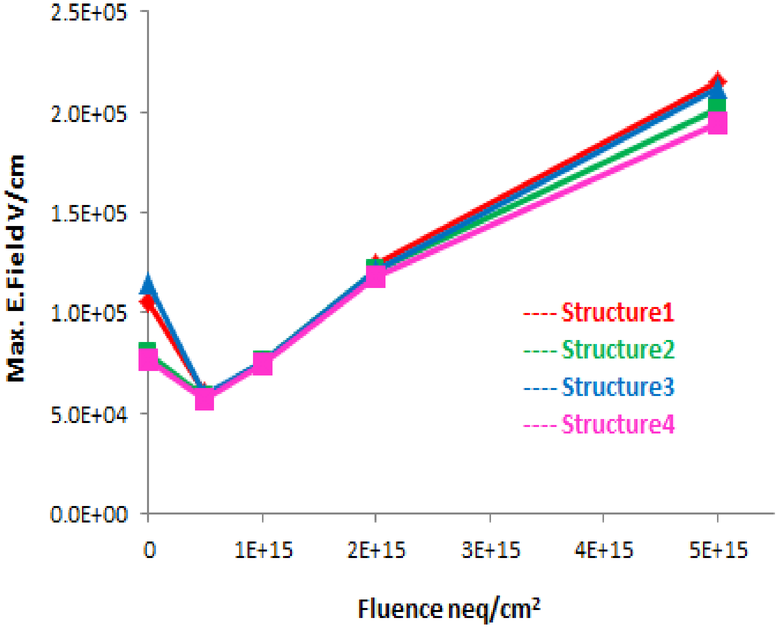
❑ Max E.Field is at a cutline of 0.9 µm, at the implant curvature.

❑ For irradiated pixels, E.Field is not concentrated, but has a spread, unlike non-irradiated pixel!

* Structure4, MO=0µm, Npsp=1e15cm^{-3}, dpsp=1µm, d=150µm, fluence=1e15 neq/cm2

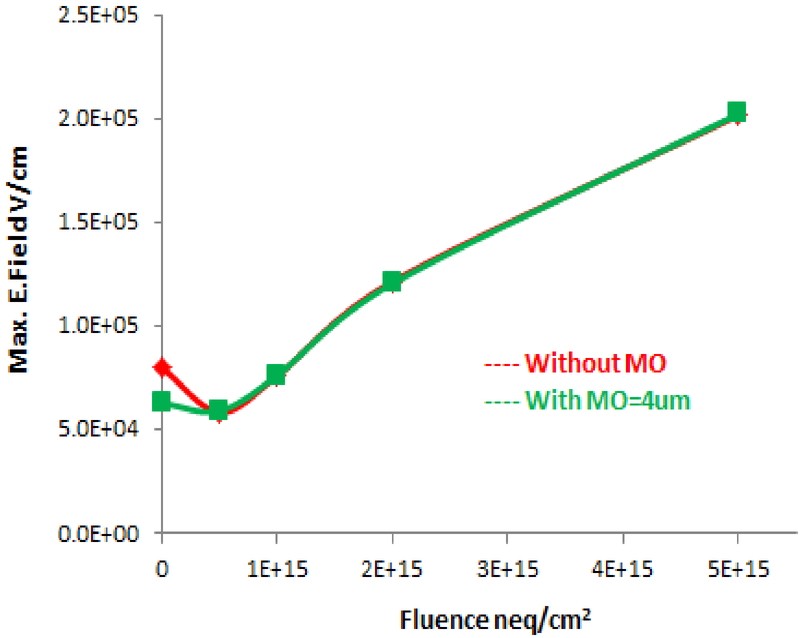
Max. E.Field VS Fluence @ 500V

Pspray Geometries: MO=0µm, N_{psp}=1e15cm^{-3}, dpsp=1µm, d=150µm



- ❑ Structure 4 shows the least rise in the critical Efield, among all the geometries.

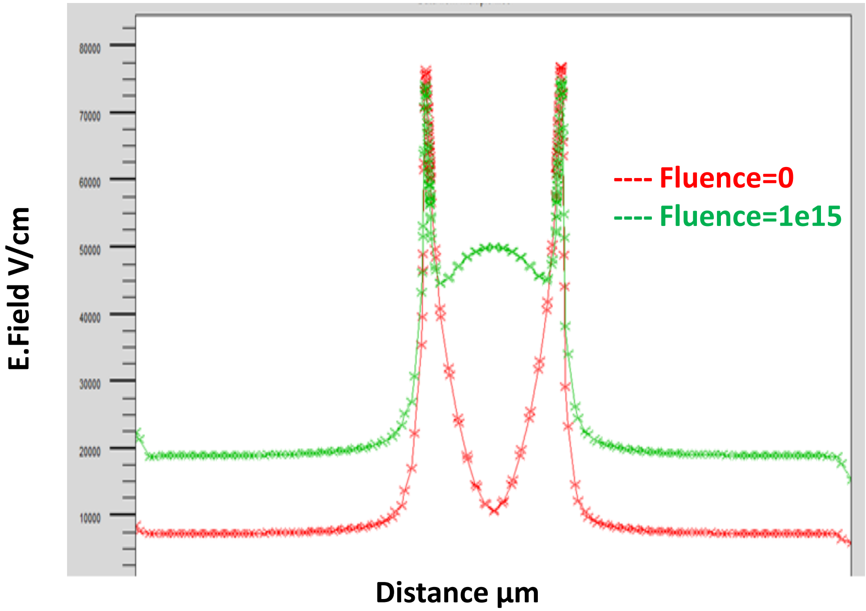
MO Effect: Structure 2, Npsp=1e15cm^{-3}, dpsp=1µm, d=150µm



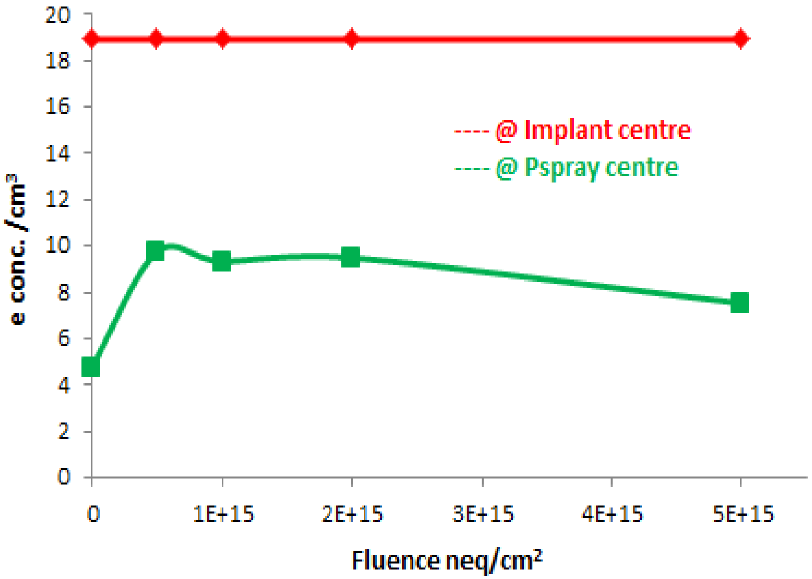
- ❑ Metal Overhang is effective in reducing the peak electric field in the case of non-irradiated pixel only where the E.field is shifted towards the metal overhangs.

1D E.Field & Electron Conc. @ 500V

1D E.Field Profile: Structure 4, MO=0µm, Npsp=1e15cm^{-3}, dpsp=1µm, d=150µm, Cutline=0.9µm



e concentration @ implant & @ pspray: Structure 4, MO=0µm, Npsp=1e15cm^{-3}, dpsp=1µm, d=150µm, Cutline=0.1µm

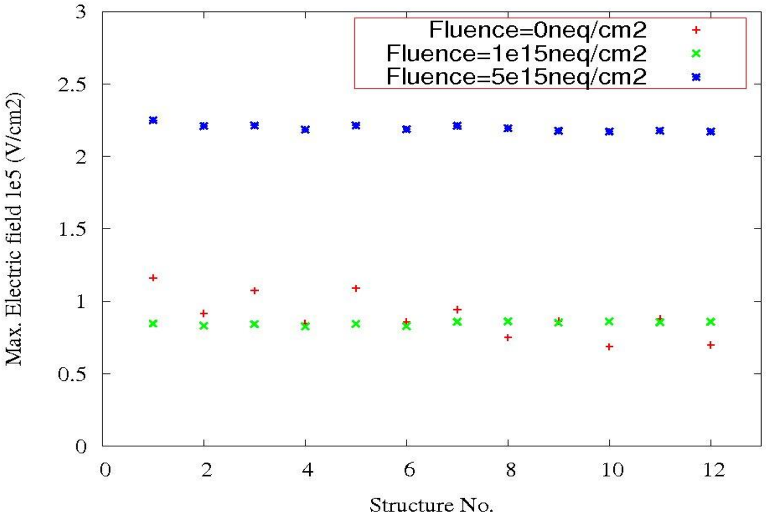


❑ Peak E.field for 1e15 n_{eq}/cm^2 irradiated pixel is lower than non-irradiated pixel bcz of compensation by increase in field by the pspray.

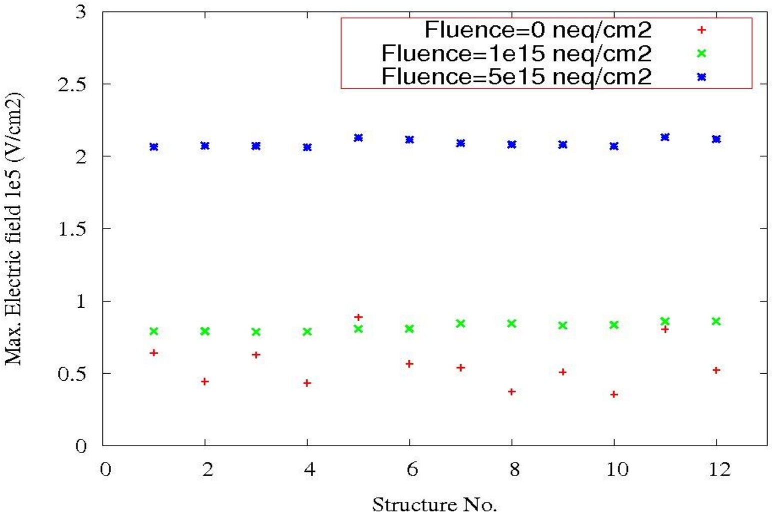
❑ Isolation is provided through pspray!

Design Optimization

Best Pstop Geometry: Structure 6



Best Pspray Geometry: Structure 4

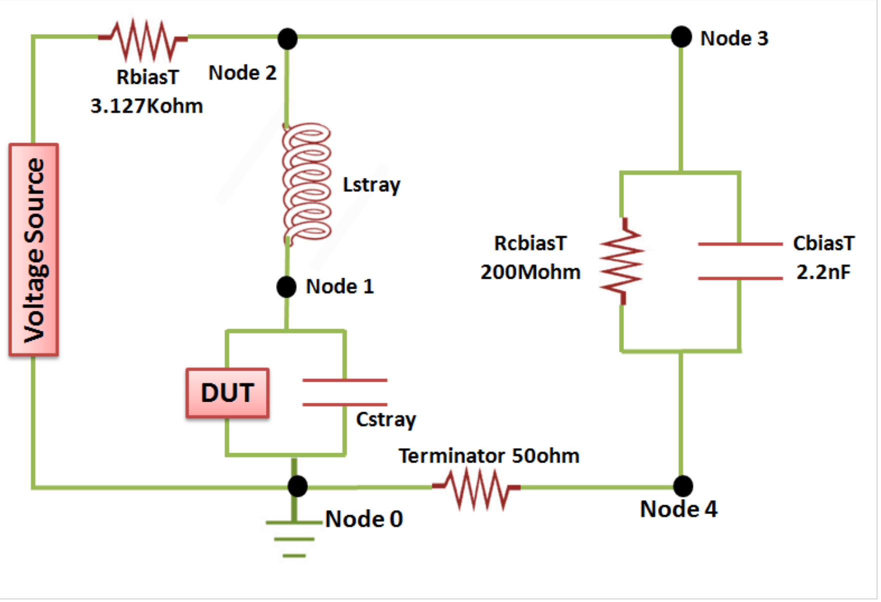


Structure No.	**Npst/npsp - dpsp/dpst - mo - d**
1	1e16/1e15 - 1/1 - 0 - 150
2	1e16/1e15 - 1/1 - 4 - 150
3	1e16/1e15 - 0.5/0.5 - 0 - 150
4	1e16/1e15 - 0.5/0.5 - 4 – 150
5	5e15/5e15 – 1/1 – 0 – 150
6	5e15/5e15 – 1/1 – 4 – 150
7	1e16/1e15 – 1/1 – 0 – 200
8	1e16/1e15 – 1/1 – 4 – 200
9	1e16/1e15 - 0.5/0.5 – 0 – 200
10	1e16/1e15 - 0.5/0.5 – 4 – 200
11	5e15/5e15 – 1/1 – 0 – 200
12	5e15/5e15 – 1 – 4 – 200

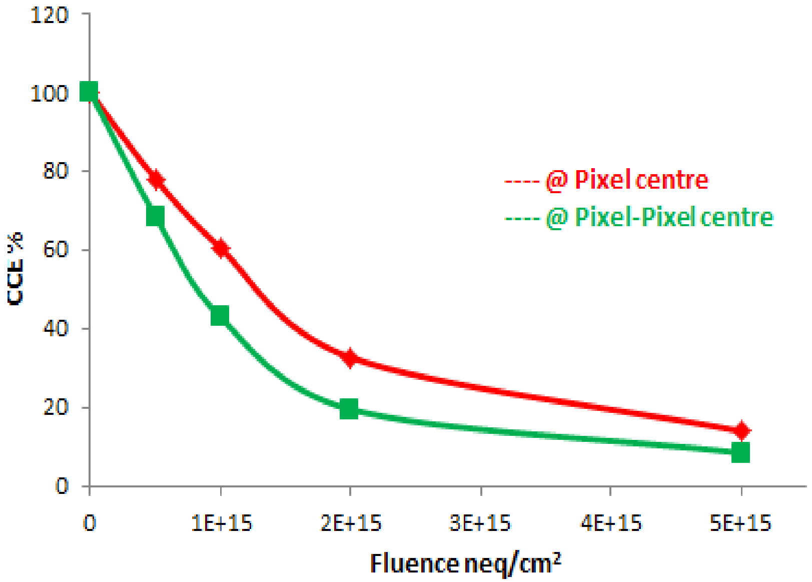
- ❑ Significant reduction in E.field with use of MO for non-irradiated pixels.
- ❑ Not much difference in the critical E.field rise for different parameters variation (specified above) for irradiated pixel structures!

Charge Collection Efficiency

DU TCT Circuit: Simulation parameters



CCE for IR fired at 2 positions: Structure6, MO=0µm, Npst=1e16cm^{-3}, dpst=1µm, d=200µm, @ 200V

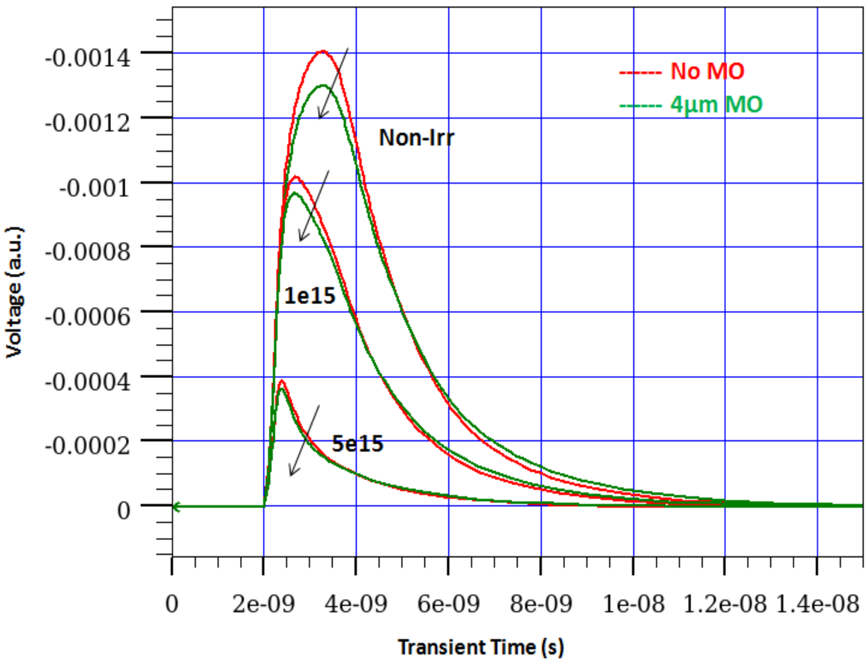


- ☐ Have not used Lstray and Cstray in the present simulations!

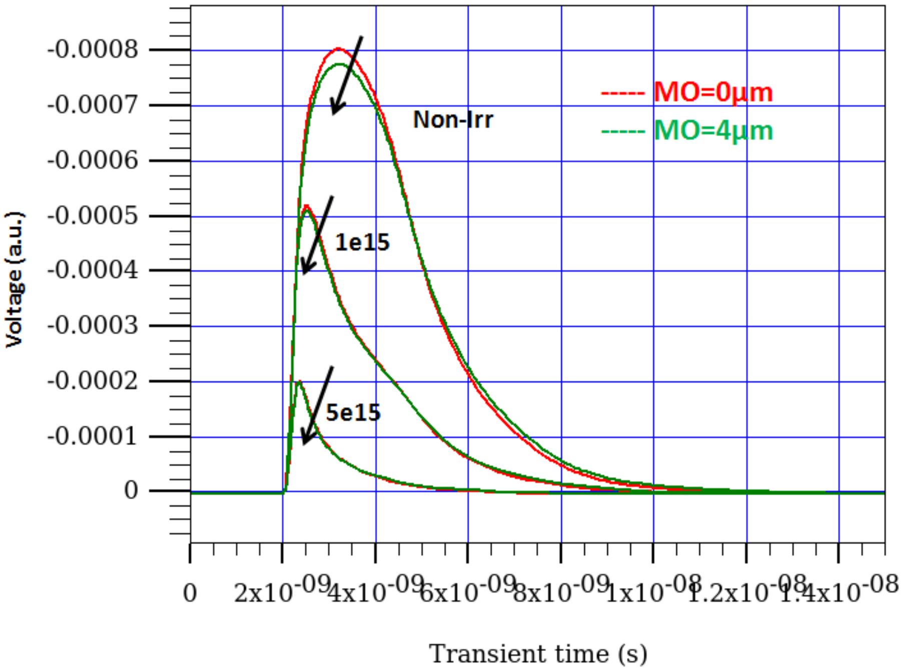
- ☐ CC at pixel-pixel / inter-pixel centre is less than that at pixel centre as expected.

MO Effect on CCE @ 200V

@ Pixel Centre



@ Inter-Pixel Centre

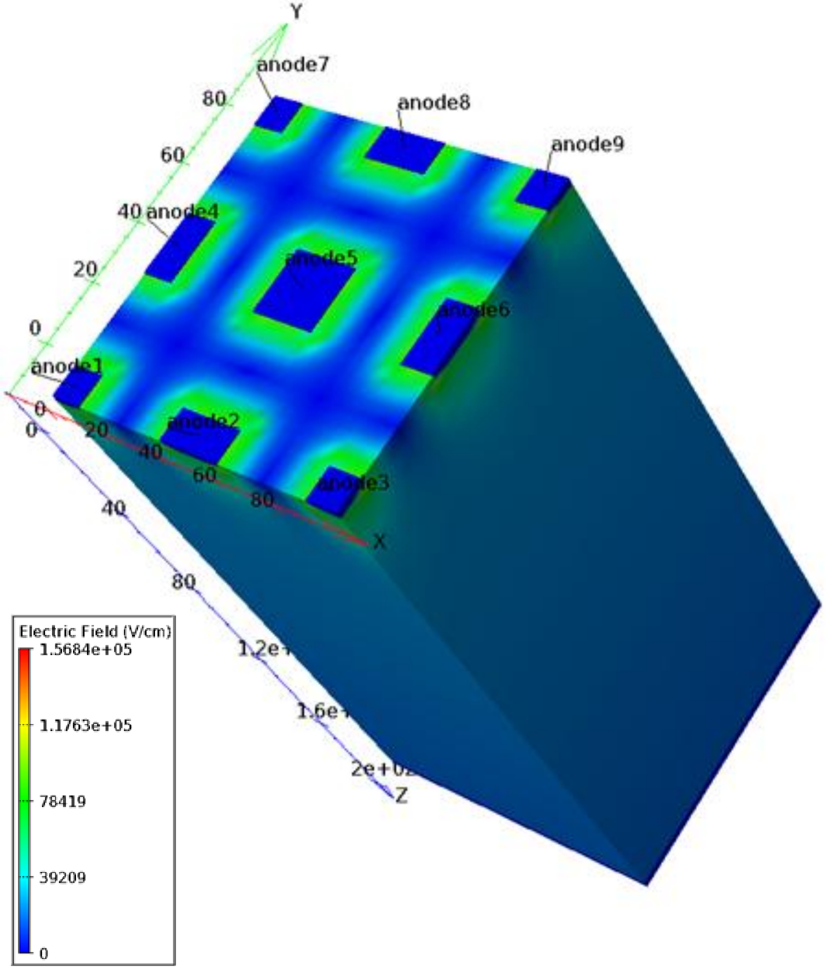


❑ Small effect of MO on CCE of irradiated pixel.

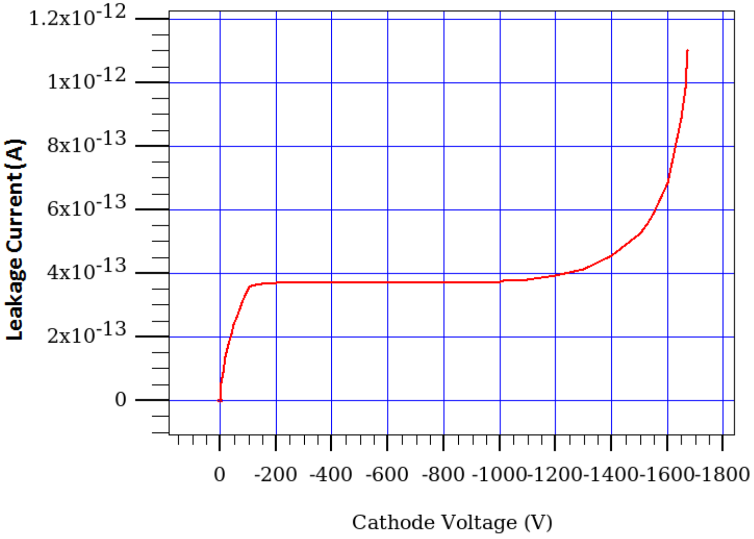
❑ No effect at all of MO on CCE!

3D Simulations (Pixel Structure)

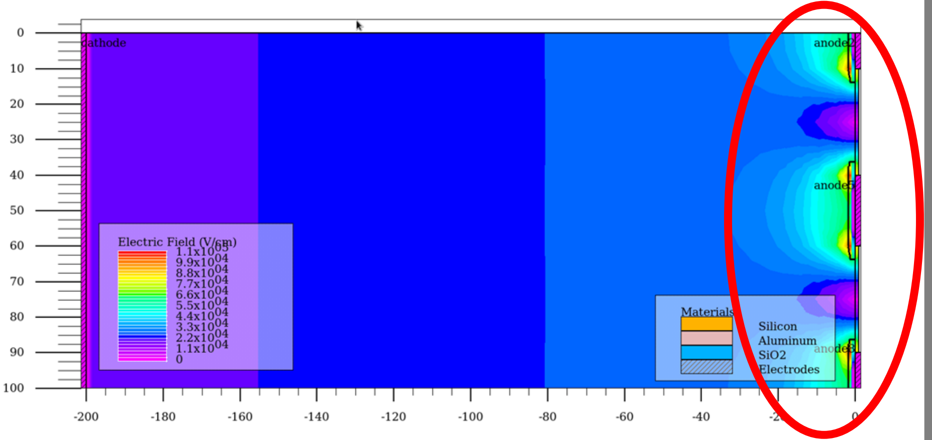
Structure: Structure 4, MO=0µm, Npst=1e16cm^{-3}, dpst=1µm, d=200µm



Leakage current characteristics



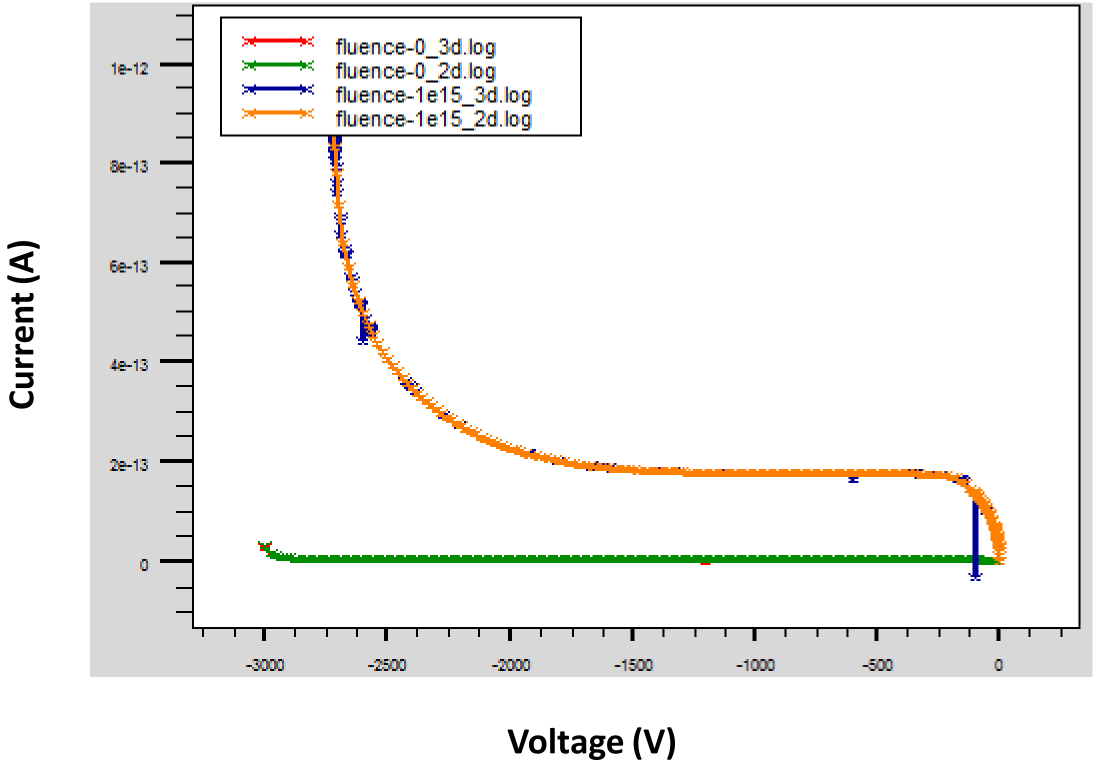
Cutplane along middle of YZ plane



2D VS 3D : IV Characteristics For a Pad Diode

2D Structure: 1X200 μm^3 Pad Diode, with WIDTH = 1 μm

3D Structure: 1X1X200 μm^3 Pad Diode



Summary

Electric Field Behaviour

- Maximum electric field lies at implant curvature, at 0.9 µm cutline below the oxide.
- It is compensated by the isolation structure with irradiation to some extent.
- However, for very high irradiation, the electric field at the implant curvature rises faster!
- Structure 4 and Structure 6 are the best geometries for pspray and pstop respectively, of the other geometries.
- A metal overhang of even 4 µm does not seem to redistribute the electric field.

Charge Collection Efficiency

- A slightly higher value of the isolation structures should provide very good isolation between the pixels.
- CCE is lesser at the pixel-pixel centre than at the pixel centre, as expected.

3D Simulations

- Initiated 3D simulations.

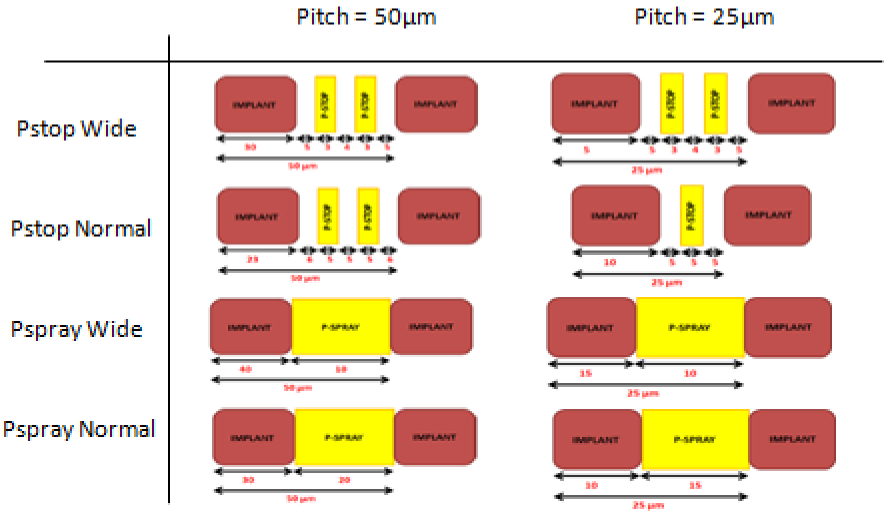
Future Plans

- Experimental results (CVIV, CCE) required for tuning the radiation model for higher irradiation.
- CCE at higher voltages and for different parameters of structure 4 & 6.
- 3D simulations of critical parameters.

Backup - I

	Design No.	Pitch (p) (µm)	Im Width (w) (µm)	Metal Width (µm)	Ratio w/p	Iso Width (µm)	Iso1-Iso2 Separation (µm)	Im-Iso Separation (µm)
	1	25	10	10, 14	0.4	15	0	0
PSPRAY	2	25	15	15, 19	0.6	10	0	0
	3	50	30	30, 34	0.6	20	0	0
	4	50	40	40, 44	0.8	10	0	0
	5	25	5	5, 9	0.2	3	4	5
PSTOP	6	25	10	10, 14	0.4	5	0	0
	7	50	23	23, 27	0.46	5	5	6
	8	50	30	30, 34	0.6	3	4	5

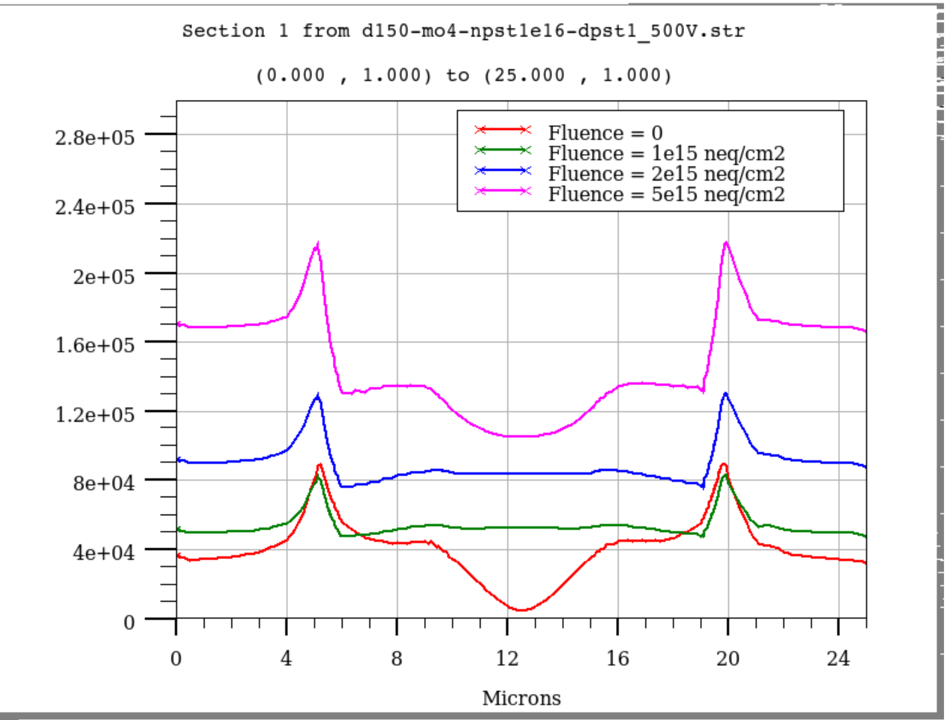
* Im=implant
* Iso=Isolation structure (pstop/pspray)



Backup - II

Pstop Structure 6

MO = 4 µm



MO = 0 µm