Silicon Strip Sensor Simulations

MSSD capacities

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Silicon Strip Sensor Simulations
Phase II Meeting, 8.6.2012

HELMHOLTZ | ASSOCIATION

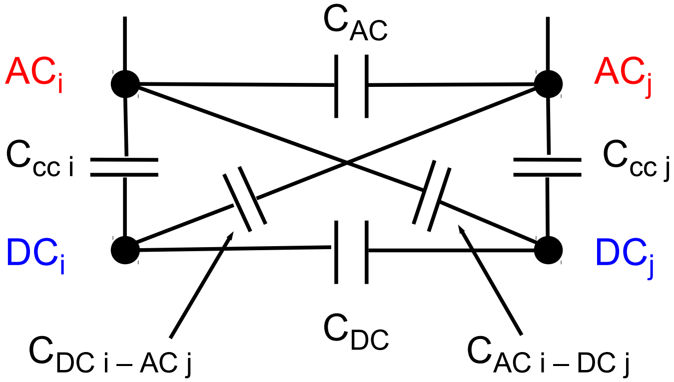
DESY

Status update

- Previous interstrip capacitance simulation anomalies fixed?
  - Improved geometry, performed parameter space scan for one MSSD sensor (#3)
  - Use gained information to re-run simulations for all MSSDs → in progress
  - Simulated C_{int} now corresponds to measurements
  - But: 'additional' capacitance network still required:

    $C_{int} \sim C_{AC} + C_{DC} + C_{DCi\text{-}ACj} + C_{ACi\text{-}DCj}$

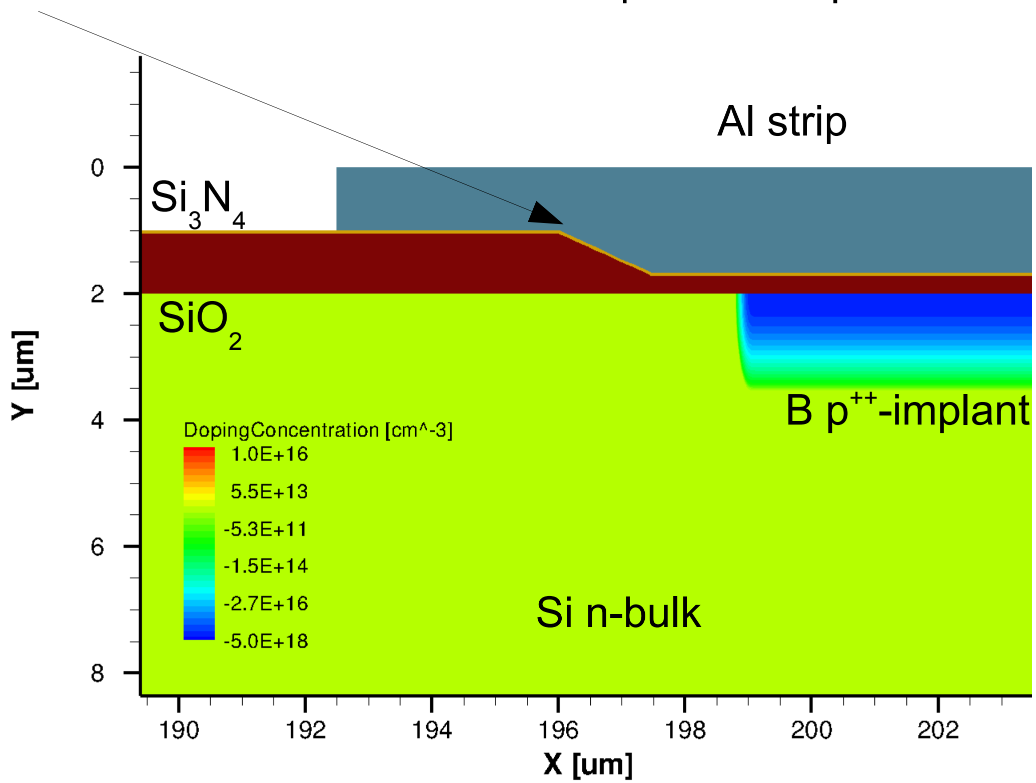
    - Method described by *S. Chatterji et al.* in *Solid-State Electronics 47 (2003) 1491 – 1499* and by *K. Yamamoto et al.* in *NIMA 326 (1993) 222 – 227*
  - Individual capacities C_{AC}, C_{DC}, $C_{DC\text{-}AC}$ are ~ 0.3 pF / cm



- Unknown HPK sensor properties could be extracted from simulations
  - Compare simulations with measurements → info from fitting parameters?

Improved geometry I

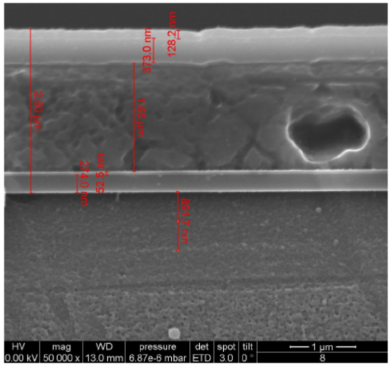
- Aluminum strips now have diagonal element to closer follow actual production process
- Nitride layer (Si_3N_4) included
- Intensive parameter scan over most geometrical sizes:
  - Mesh spacing
  - Al overhangs/form
  - Nitride width
- Future parameters to be checked:
  - Oxide charges (wider scan range)
  - Material properties (esp. Si, SiO_2)
  - Up to now: only n-type simulated, p/y-type sensors to follow



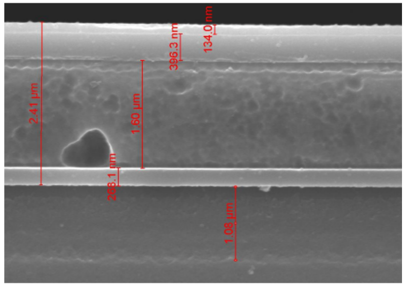
Improved geometry II

- Fixed parameters:
  - Sensor sizes given by original HPK specs: overall thickness, Al strip top width, implant width, pitch
  - Y-axis distances taken from Vienna measurements: Al, SiO2, Si3N4 and implant depths
  - Bulk (3 – 4.5 e12 cm^{-3}) and strip doping (1e18 cm^{-3}) from Karlsruhe simulations which were fitted to their data

- First conclusions from parameter scan for MSSD #3:
  - Pitch 80µm, Al width 23µm, implant width 10µm, FZ320N
  - Small mesh size is critical, but increases simulation time
  - Al overhang of 2µm, x-diagonal 1.5µm, Si_3N_4 overhang 5µm yield highest C_{int}
  - Al overhang esp. critical (up to 15% effect)



Strip cross section of FZ-320-Y W6



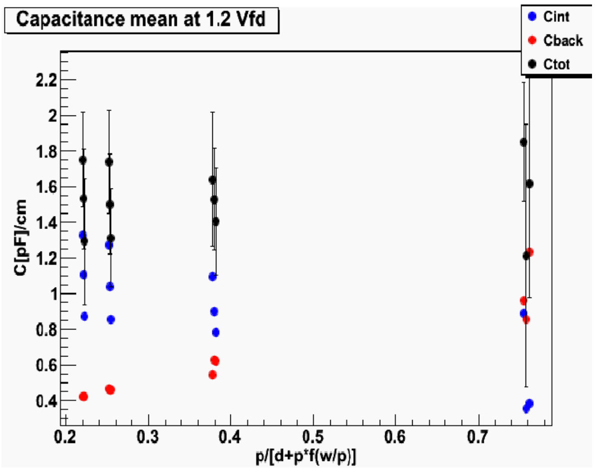
Strip cross section of FZ-320-P W4

W. Treberspurg, HEPHY Vienna

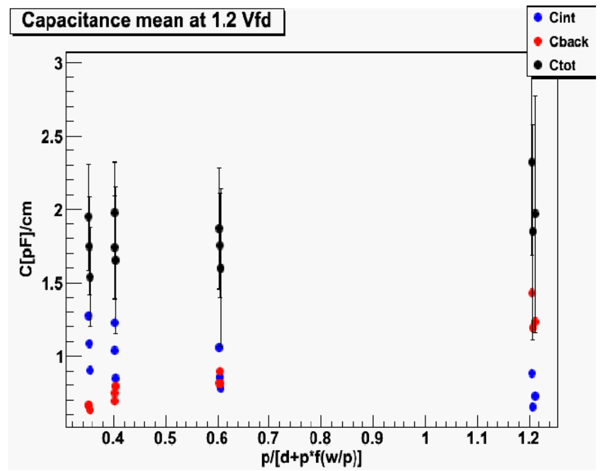
Experimental capacitance measurements

- Plots from G. Auzinger (CERN):

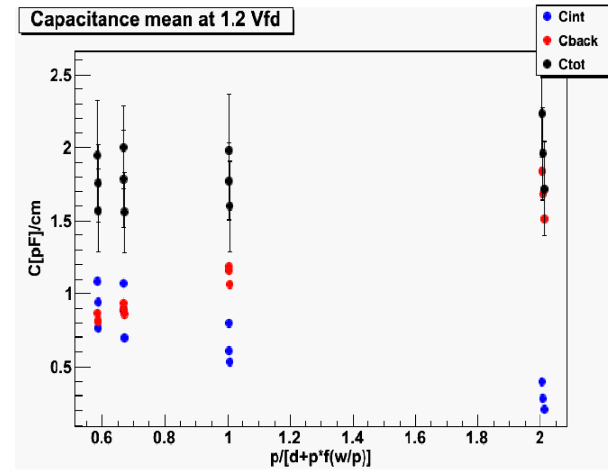
FZ 320 N



FZ 200 N



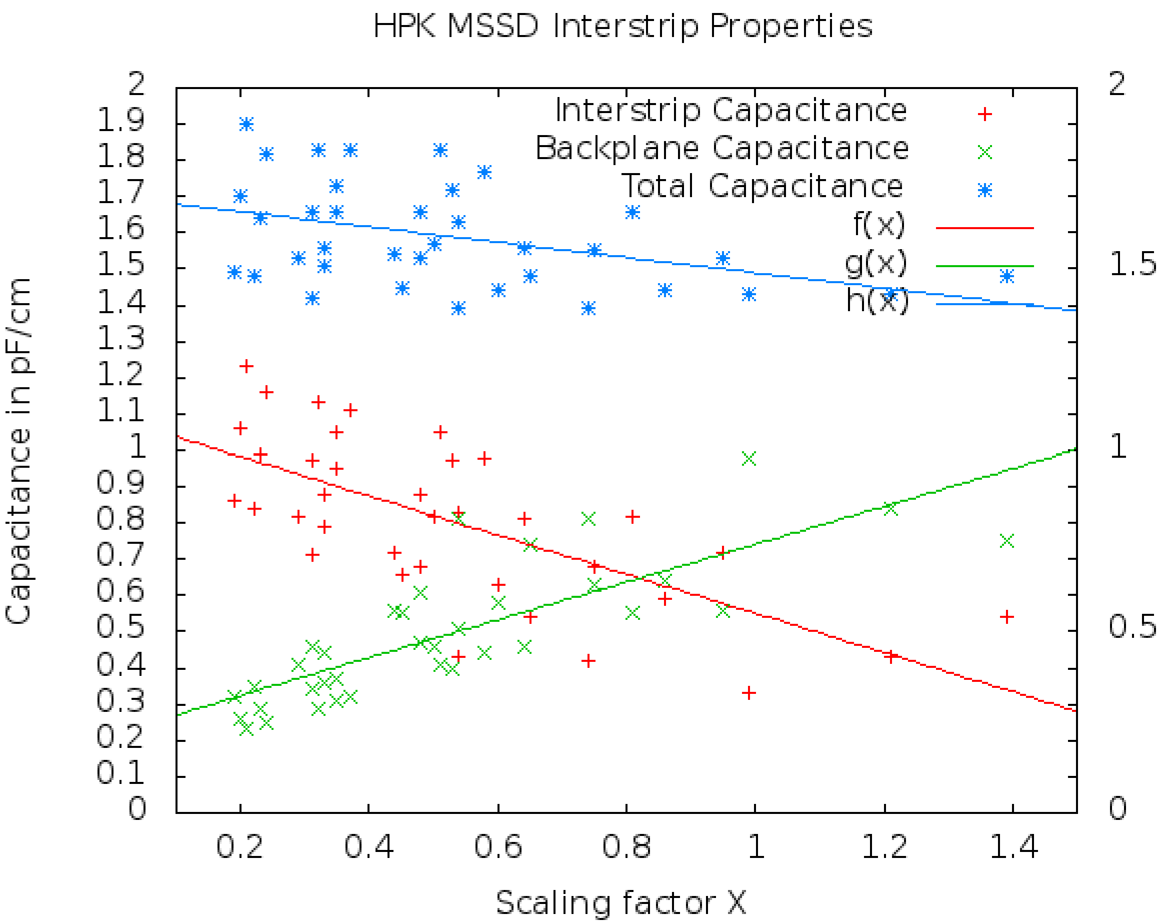
FZ 120 N



- Data shows C_{tot} as approx. constant, with C_{int} decreasing, C_{back} increasing over x
- $x = p / \{ d + p * [-0{,}00111(w/p)^{-2} + 0{,}0586(w/p)^{-1} + 0{,}24 - 0{,}651(w/p) + 0{,}355(w/p)^2] \}$
  - Explained in *NIMA 485 (2002) 343–361* → x(w/p) gives linear C

- Caveat: larger binning in x shown here

Simulated capacities



- Simulated C_{int} (and C_{back} / C_{tot}) now in the correct magnitude, but C_{tot} still decreasing
- Geometry for many x-values still has to be checked:
  - E.g.: Is a change in strip width reflected in the overhang?
- Data taken @ 1.2 V_{fd}, simulated capacities extracted at fixed voltage → V_{fd} method needs to be implemented

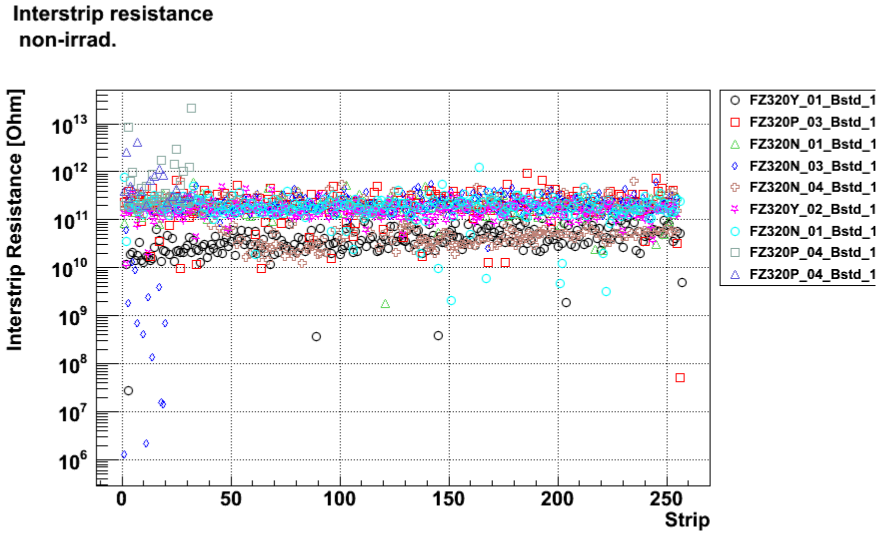
Summary / outlook

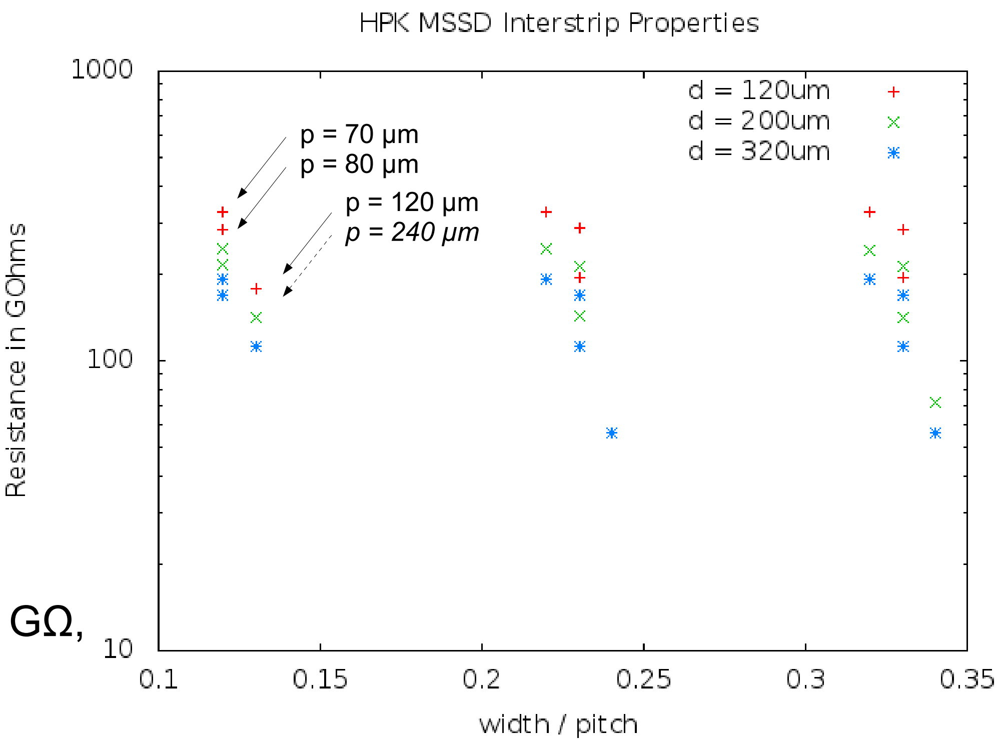
- With information gained from adjusting one MSSD geometry:
  - Simulated capacities in correct magnitude (pF/cm)
  - Parameter scans for all MSSDs will be done (with wider scan range)
    → further improve results
  - For C_{int}: additional capacities (DC-DC and AC-DC) still required
- p/y-type sensors to be simulated too → geometry already implemented, isolation dose is possibly an additional parameter to be scanned
- Material properties can be changed → are defaults ok?
- Interstrip resistance R_{int} also simulated and has correct magnitude, but some effects not yet understood
- Features still to be included: automatic V_{fd} extraction, output into non-proprietary format (ROOT)

Backup

Interstrip resistance

- Measurements by R. Eber (KIT):





- Expected R_{int} is in the order of 10 – 100 GΩ, Robert acknowleges low precision

- Simulations can confirm order of magnitude
  - R_{int} independent of w/p ratio, but: R_{int} smaller for larger pitch?
  - sensor pitch and thickness distinguishable
- Missing data points due to failing simulation convergence → will be checked

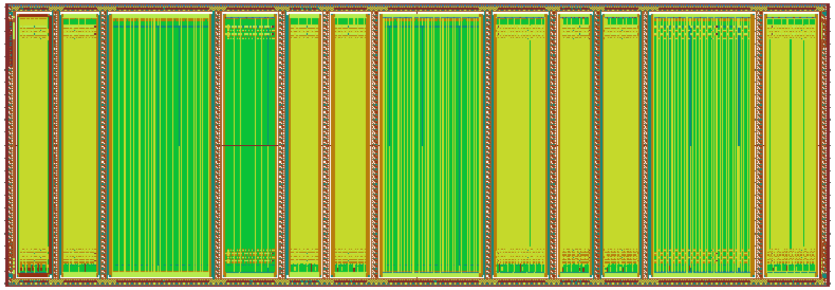
Simulation software

- Synopsys TCAD
  - Comercial package for semiconductor simulations
  - Framework:
    - Create 2D or 3D structure (materials, doping, etc) and generate a mesh
    - Select physical models to be used in simulation: temperature, field generation, carrier recombination, trapping (→ radiation damage), carrier lifetime, etc.
    - Include external effects: electric circuit (SPICE), laser illumination, traversing particle...
    - Specify what kind of simulation: simple I-V, capacitive, or time-dependant
    - Run simulation: at each mesh-point solve poisson's equation $\frac{d^2V(x)}{dx^2} = -\frac{\rho(x)}{\epsilon_r \epsilon_0}$ and carrier continuity equations: $$\nabla \cdot \vec{J}_n = q\left(R_{\text{eff}} + \frac{\partial n}{\partial t}\right)$$ $$-\nabla \cdot \vec{J}_p = q\left(R_{\text{eff}} + \frac{\partial p}{\partial t}\right)$$
    - Derive physical properties: electric field, current flows, charge distributions, etc.

Simulation group within CMS sensor upgrade WG

- 4 other institutes: Delhi, Helsinki, Karlsruhe, Pisa
- Task list with simulation activities:
  - Device design
    - MSSD, MPix, diodes, p-stop/p-spray, deep diffusion, biasing schemes, etc.
  - Charge collection and read-out
    - Capacitance, 3D-coupling, lorentz angle, etc.
  - Radiation damage
    - Full defect list, trap models, cluster defects, IV/CV/transient simulations, CCE, E-Fields, double junction, etc.
  - General
    - Comparison of simulation tools and packages
- First selected task: device design, MSSD capacities

MSSD properties



- 12 strip sensor regions with different pitch and width → interstip capacitance C_{int} should vary
- Scaling factor X for comparison:

  $X = p / [d + p*f(w/p)]$ with

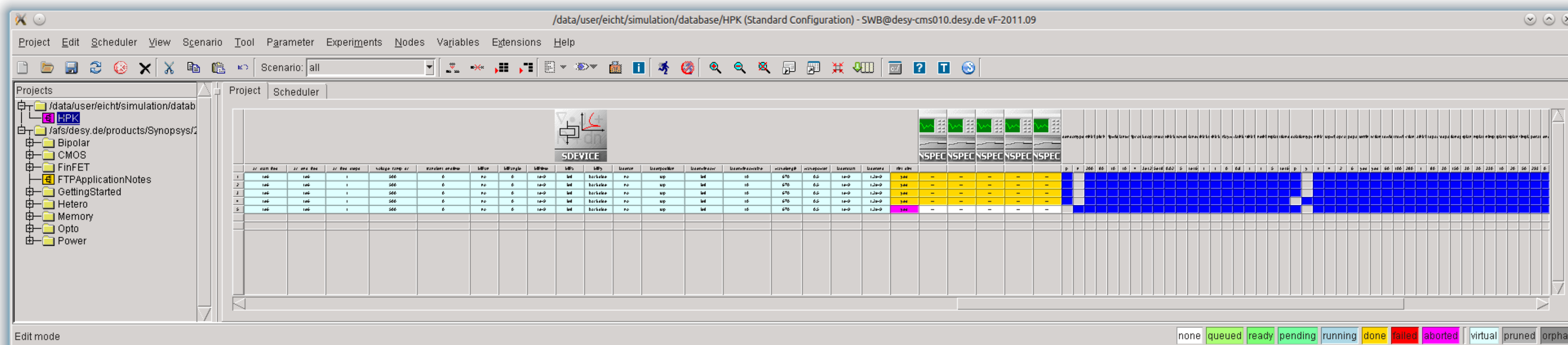
  $f(w/p) = -0{,}00111(w/p)^{-2} + 0{,}0586(w/p)^{-1} + 0{,}24 - 0{,}651(w/p) + 0{,}355(w/p)^2$

- Measurements: total sensor capacity $C_{tot} = C_{int} + C_{back}$ is constant for all X
  → try to reproduce in simulations

Sensor	Pitch [µm]	Implant width [µm]	Alu width [µm]	w/p	X
1	120	16	29	0,133	0,31
2	240	34	47	0,142	0,54
3	80	10	23	0,125	0,22
4	70	8,5	21,5	0,121	0,19
5	120	28	41	0,233	0,33
6	240	58	71	0,242	0,6
7	80	18	31	0,225	0,23
8	70	15,5	28,5	0,221	0,2
9	120	40	53	0,333	0,35
10	240	82	95	0,342	0,64
11	80	26	39	0,325	0,24
12	70	22,5	35,5	0,321	0,21

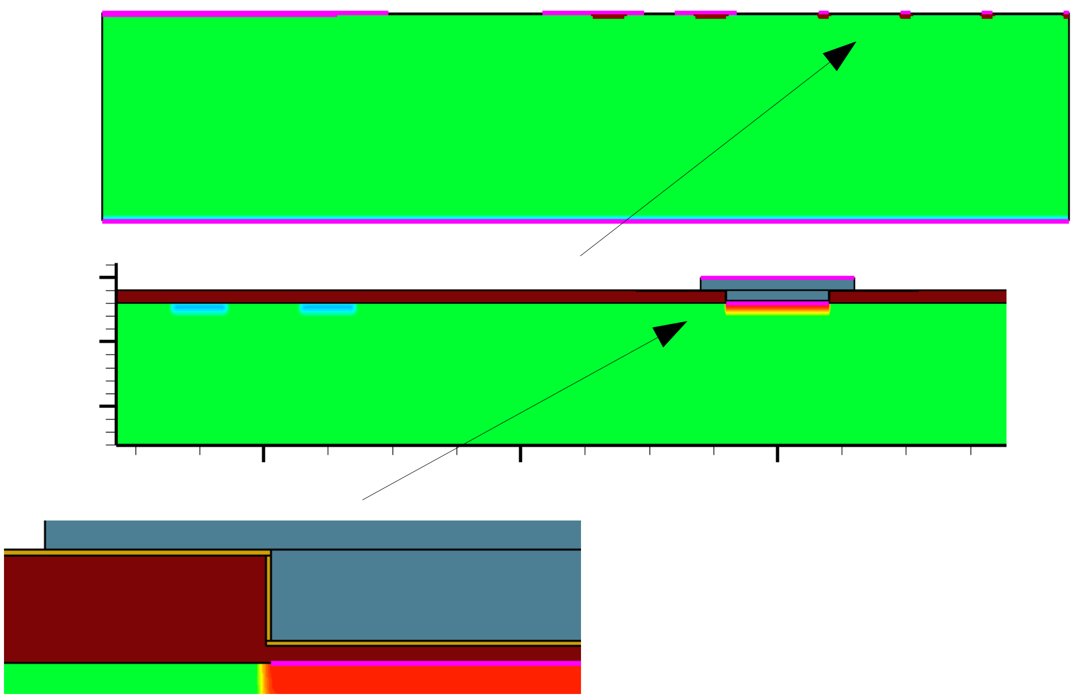
TCAD Workbench I

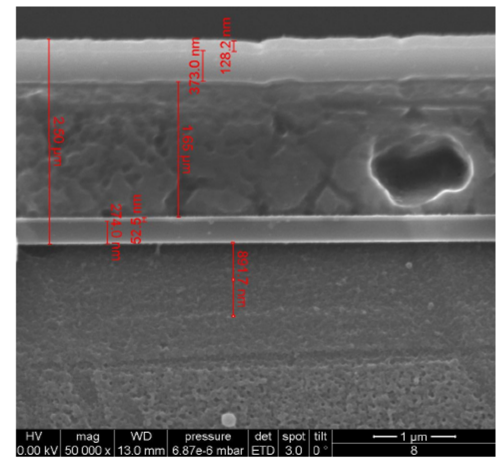
- To recheck geometry and make multiple simulations easier: usage of the workbench package:
  - Script and parameterize the entire simulation process instead of using command files
  - Corrections, new features, models, parameters can be added to all simulations at once
  - Has been shared with the other simulation groups → everyone can use same geometry (future: same simulation steps/models/etc.) → comparability of results
  - No user interaction needed when simulating multiple devices/setups



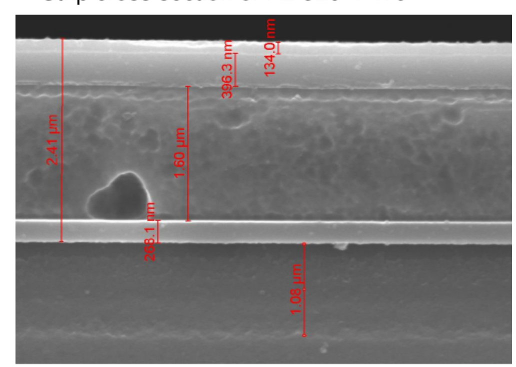
TCAD Workbench II

- Scripted and parameterized geometrical features:
  - All strip sensor distances: thickness, pitch, implant size, strip count, etc.
  - Sensor type: p- or n-type with correct doping, p-spray or p-stop(s)
  - HPK feature: 50nm Si_3N_4 over implants
  - Optional outer ring structure: protection- guard- and bias ring





Strip cross section of FZ-320-Y W6



Strip cross section of FZ-320-P W4

W. Treberspurng, HEPHY Vienna

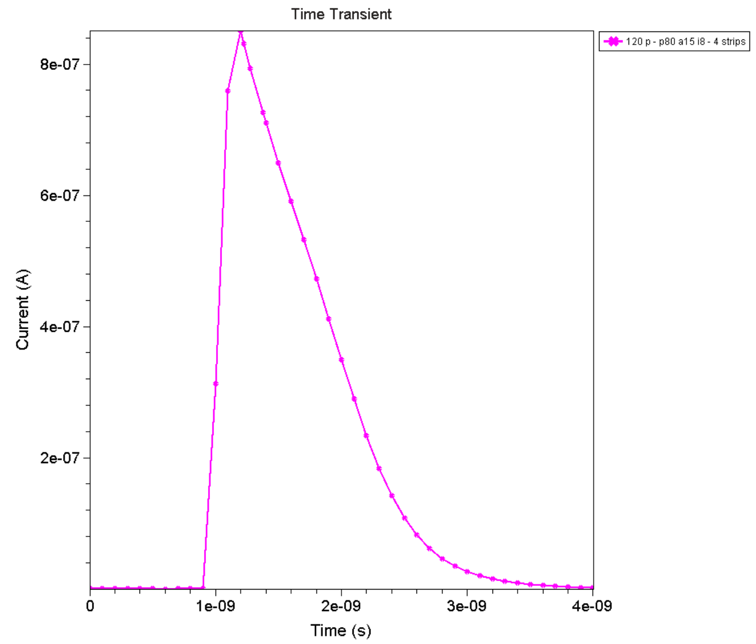
TCAD Workbench III

- Scripted and parameterized simulation steps:
  - Biasing/grounding, bias resistors, floating guardring
  - Physical parameters (temperature, fluence, etc.)
  - Voltage ramp → IV curve production and plot
  - Time transient with laser/mip (angle, duration, intensity, etc.)
  - Interstrip resistance measurement
  - Capacitance simulation → CV and C_{int}
  - Automatic plot generation under construction
  - Extraction of 'interesting' values planned

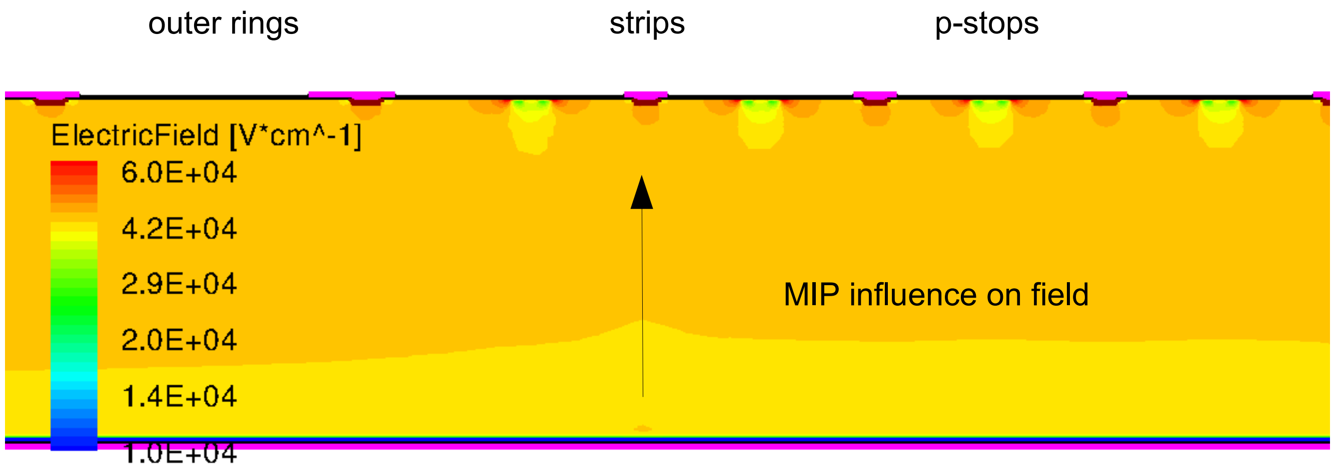
- The following results are only based on a few test simulations

Crosscheck of scripting - simulation results I

- Time transient of traversing MIP
  - 20°C, 500V, p-type, MIP: 0° angle, hits on strip 1
  - Current height and shape as expected
  - Simulation takes too long: ~ 1h on desy-cms010 → numerical issue?



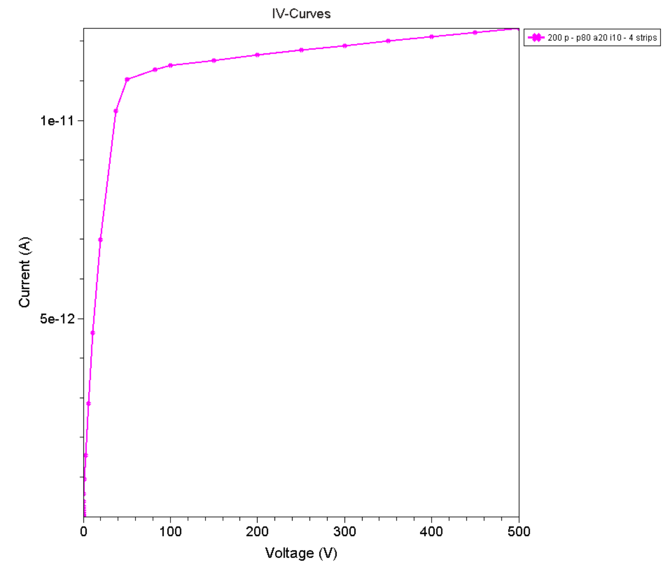
  - Electric field: influence of p-stops, MIP and outer rings visible

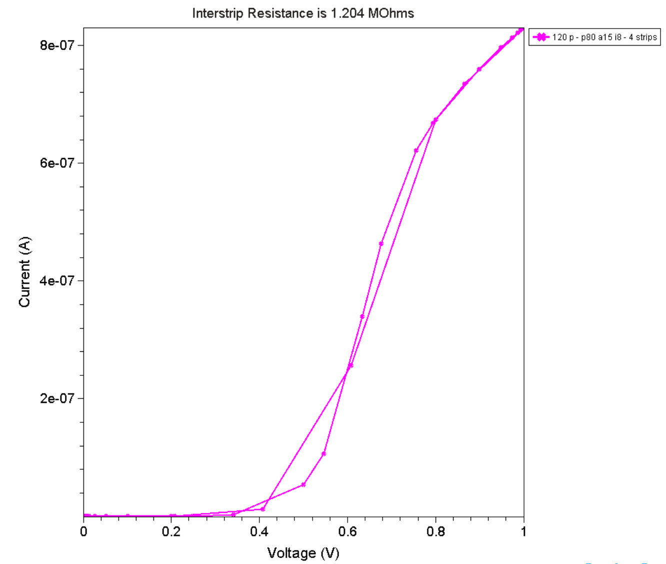


Crosscheck of scripting - simulation results II

- IV-curves
  - Shape correct, absolute values will be corrected for actual sensor size (3D) to be comparable to data

- R_{int} simulation
  - First problems: expected Rint ~ 100-300 GΩ independent of type/isolation
  - Simulation: n-type has 234 GΩ → good fit, but p-type has an Rint of only 1.2 MΩ → needs to be investigated





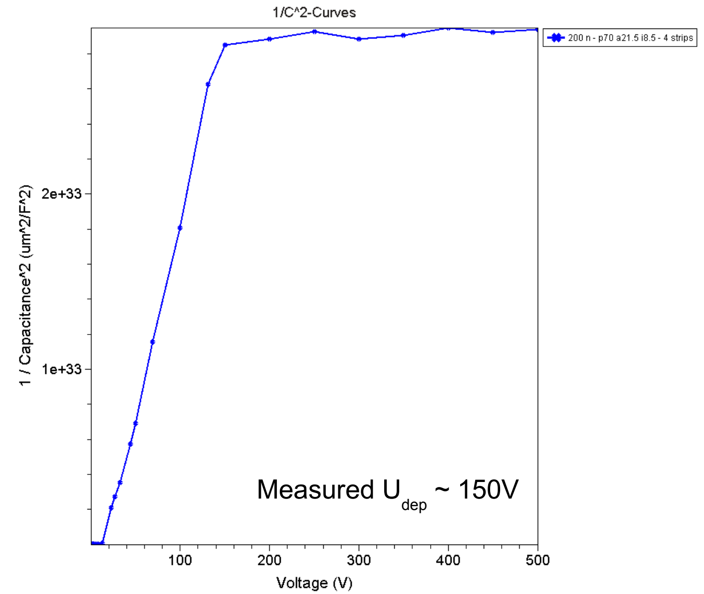
Crosscheck of scripting - simulation results III

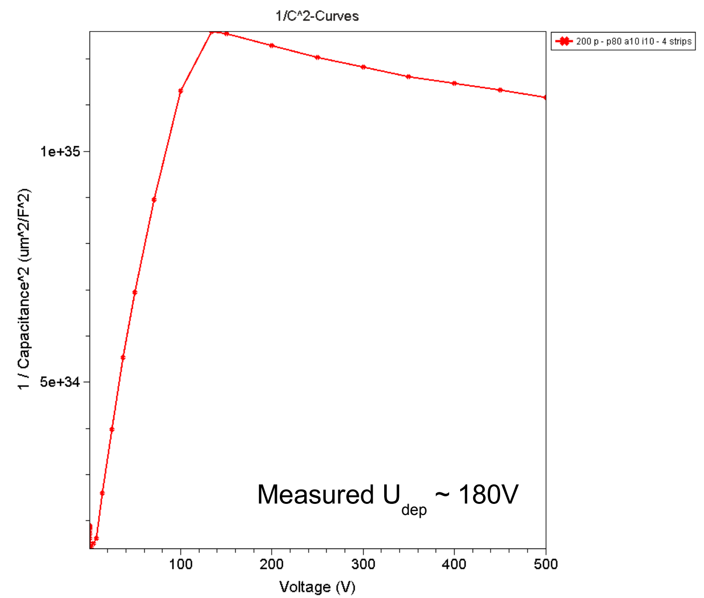
- Capacitance simulations
  - CV: extractable depletion voltage agrees with measurements. Y-axis has to be scaled to actual geometry
  - P-type has strange shape, U_{dep} not as good
  - C_{int}: with no additional capacities, C_{int} in n-type is only one magnitude off (0.2pF/cm)
  - In p-type still a factor of ~ 1000 too low

→ n-type shows that direct AC-contact simulation can work

→ 'Tiny' R_{int} in p-type may correspond to low C_{int}

→ Recheck isolation, possibly a more exact geometry can improve results





Summary

- Simulation group
  - Delhi and Karlsruhe are checking radiation damage models – will be implemented into the workbench script when ready
  - Workbench script made public to group → comparability of results

- TCAD workbench
  - 'mass production' of simulations possible, allows more structured approach
  - Now running on workgroup server with local access → speed, disk space
  - Still to be done:
    - Improve plot generation, parameter extraction
    - Possibly transform simulation output into a non-proprietary format

- Simulations
  - Improved geometry to model HPK sensors more accurately → more input needed
  - Oxide and oxide/silicon interface seems to be critical to R_{int} and C_{int}

    → recheck mechanism of oxide traps and charges