Solid state electron multiplier

EP R&D WP1.1 Hybrid silicon detectors, 22.03.2021

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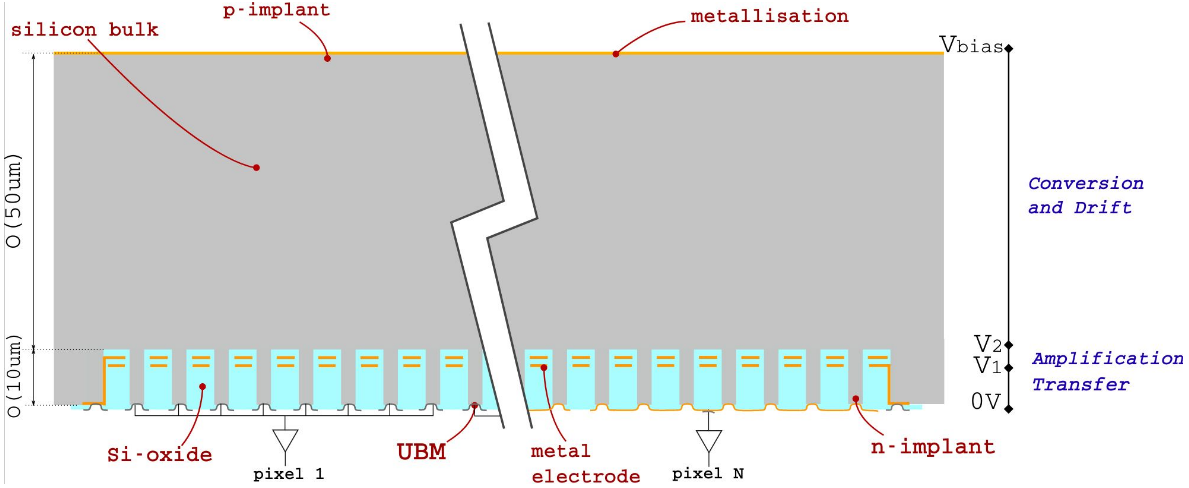
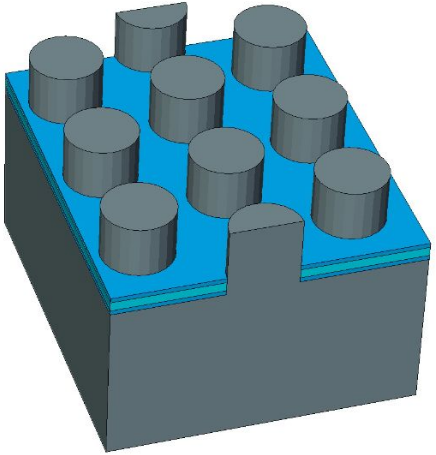
Main objectives of the solid state electron multiplier

- Target <50ps time resolution
  - increase signal-to-noise and slope-to-noise by signal amplification
- Target down to ~10um pitch (and larger)
- Hope to achieve gain independently of radiation level
  - avoid use of dopants to promote gain
  - taylor electric field by electrodes in the substrate, ala GEM with silicon instead of gas

First presentation of SSEM, Victor Coco:



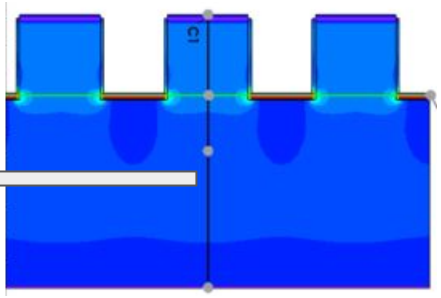
Discussion with Olivier Girard from LETI, CEA on the production aspects

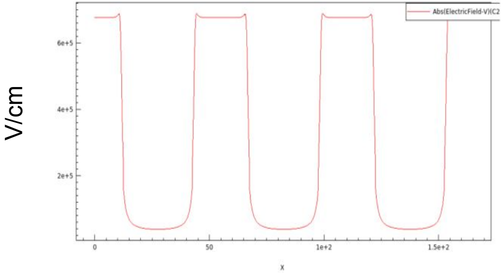


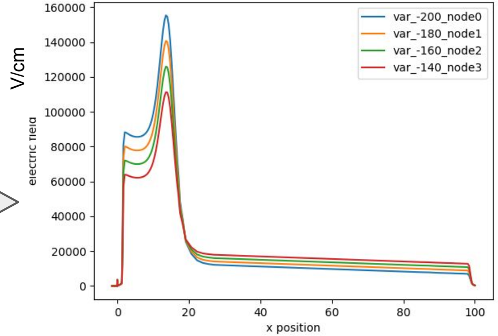
Recap from last presentation

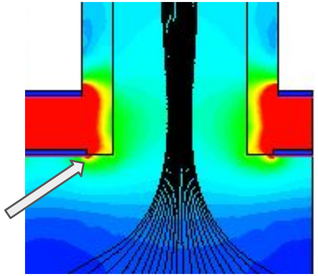
[Last meeting](#)

- **Electric field drops quickly** outside multiplication electrodes.
- **Narrower pillars** makes it easier to **connect field lines** to further strengthen the field in the pillar center.
- Field at the **pillar edge** impacts the **breakdown**
- Field in **pillar center** is important for **gain**
- Bottom electrode should be separated from the silicon bulk to reduce high fields due to edge effects



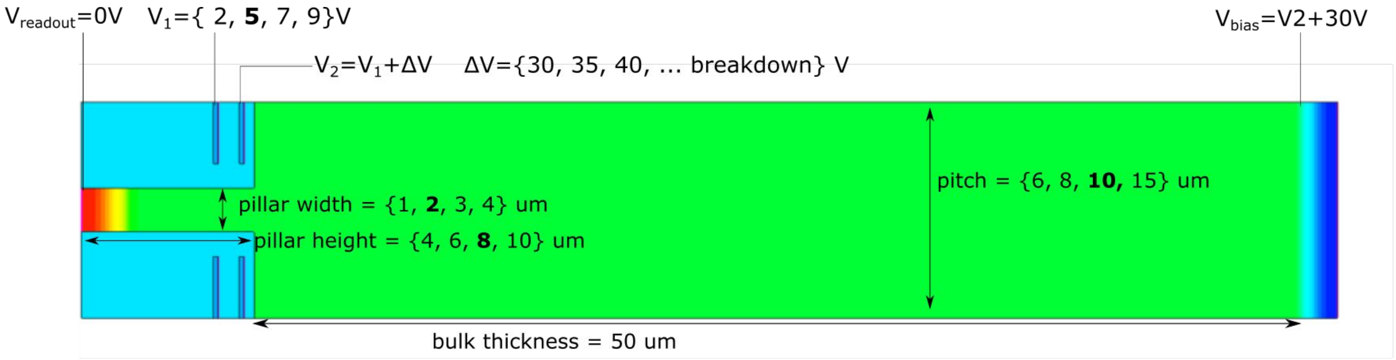


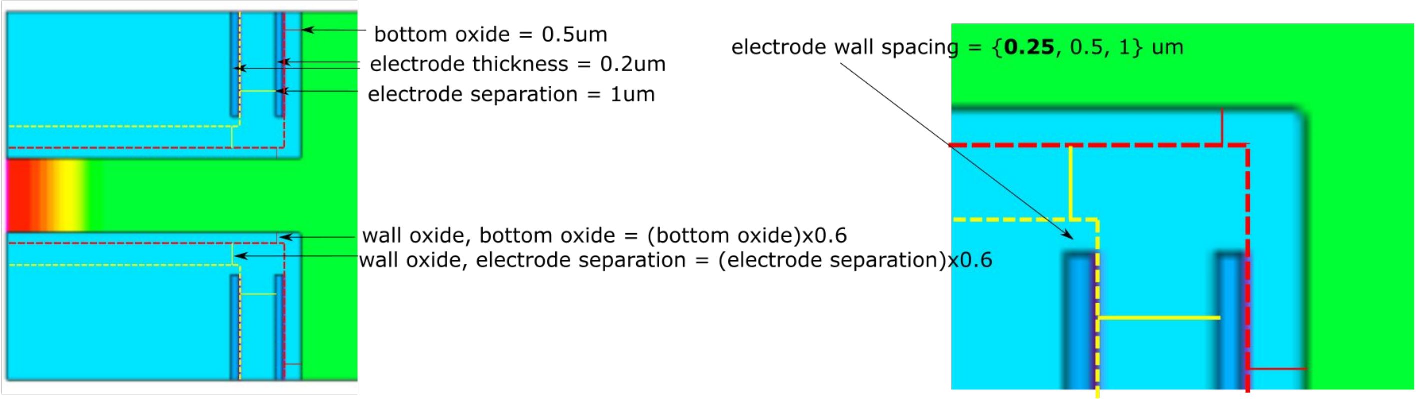




Updated geometry and parameter space of single wafer SSEM

Bold values represent default configuration.



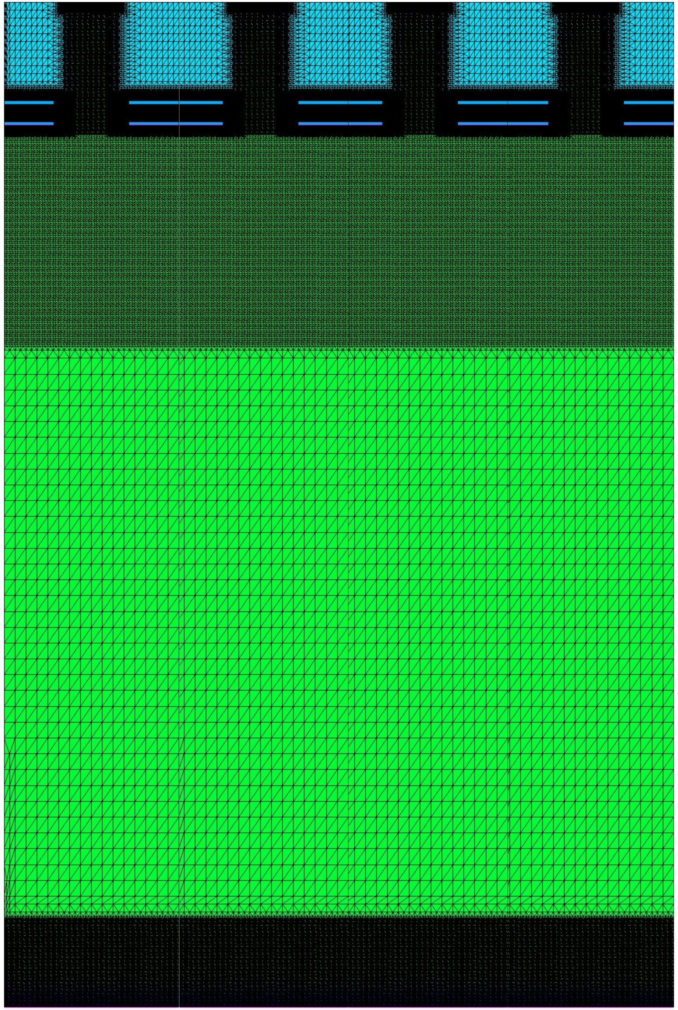


Properties to evaluate

- Electric field
    - target 30V/um in pillar center -> significant probability of charge multiplication
- Leakage current, noise
    - achieve gain while noise is kept small
- Time structure of signal
    - in GEMs only the charges in transfer regions are seen by the readout electrode
- Technological constraints
    - some of the optimal configurations could be hard to make.
- Operation
    - investigate stability of geometry

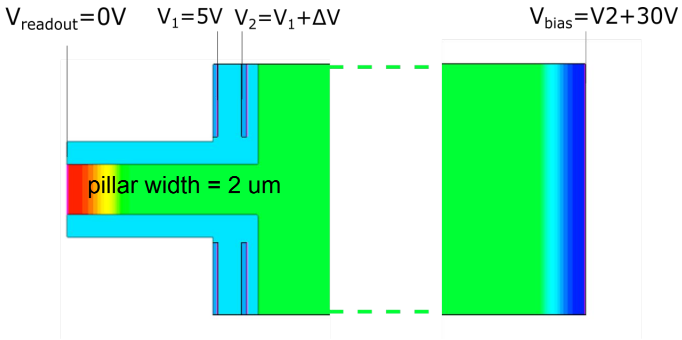
Simulation software

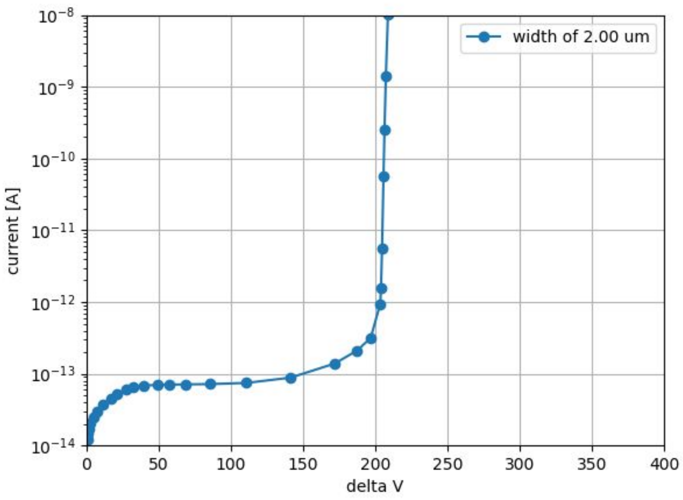
- Synopsys TCAD
  - Version Q-2019.12
- Impact Ionization model: vanOverstraeten
- Mobility model: Canali
- Recombination: Shockley-Read-Hall
- Transient model: HeavyIon
- Band gap model: Slotboom

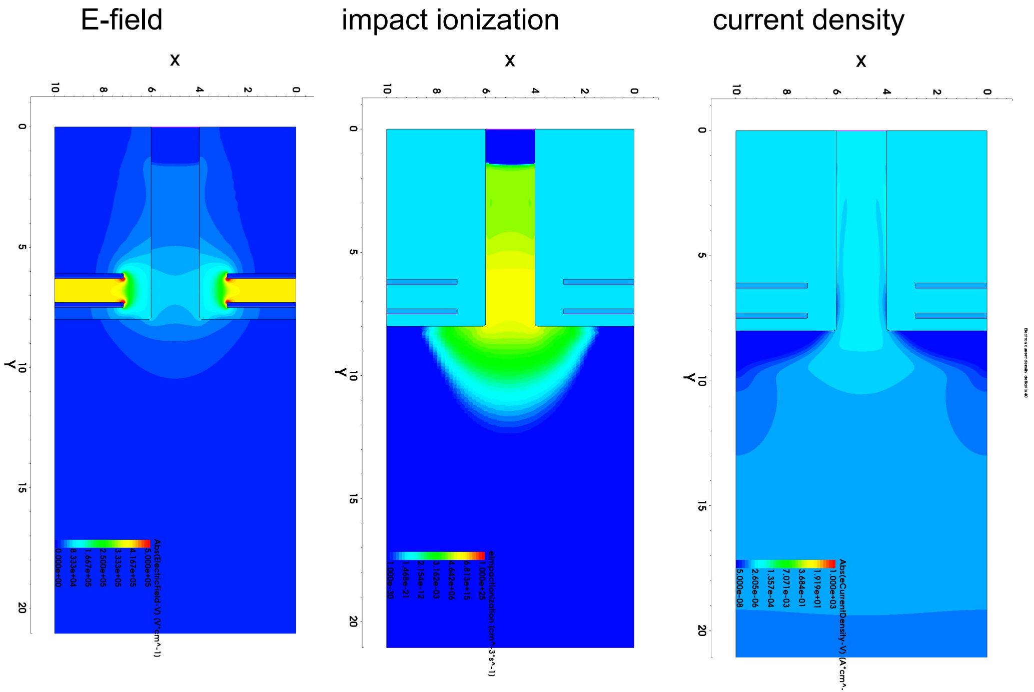


Voltage scan

- Scan ΔV
- Field, impact ionization and current density are evaluated

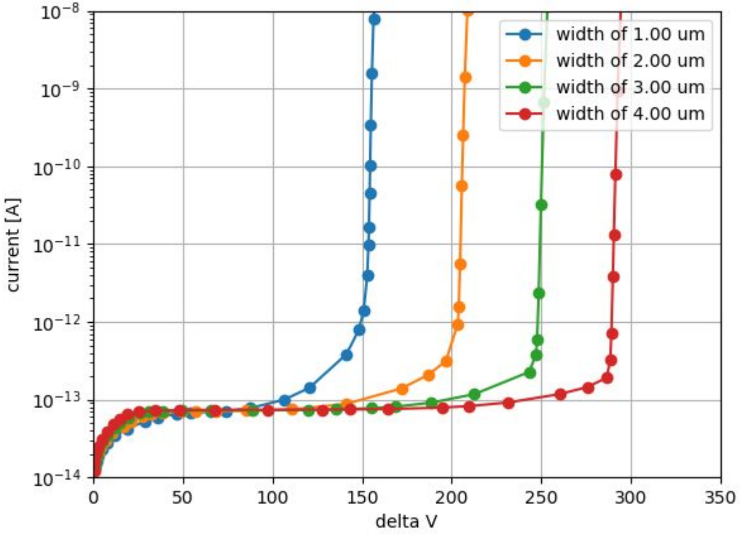




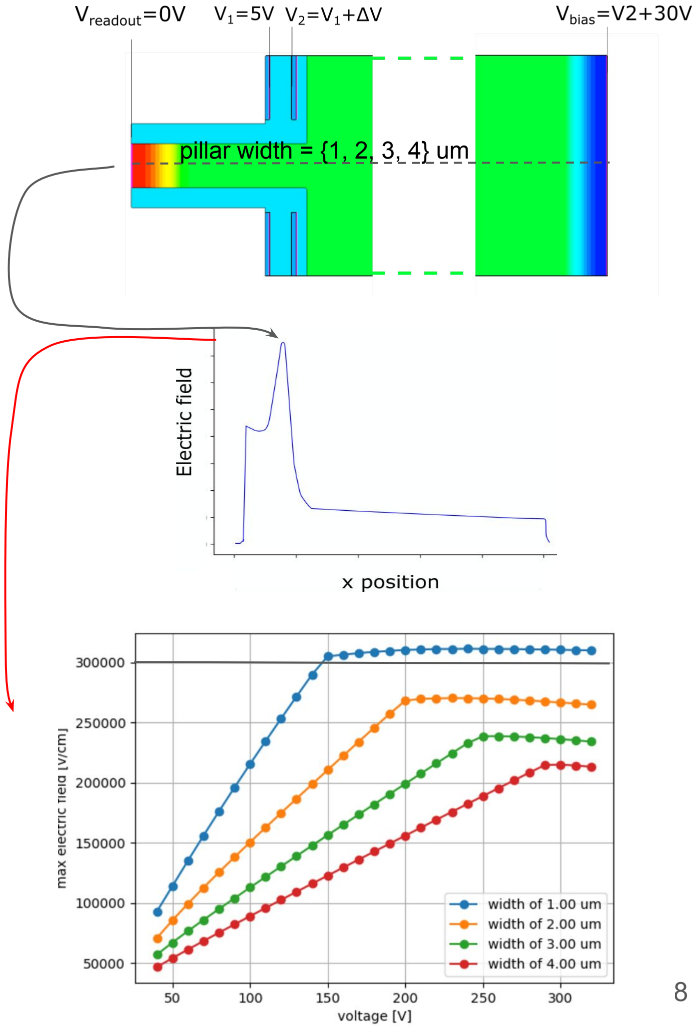


Pillar width scan

- Wide pillars reach breakdown later
- Already seen that narrow pillars are desirable
- Electric field in pillar center decreases with the width



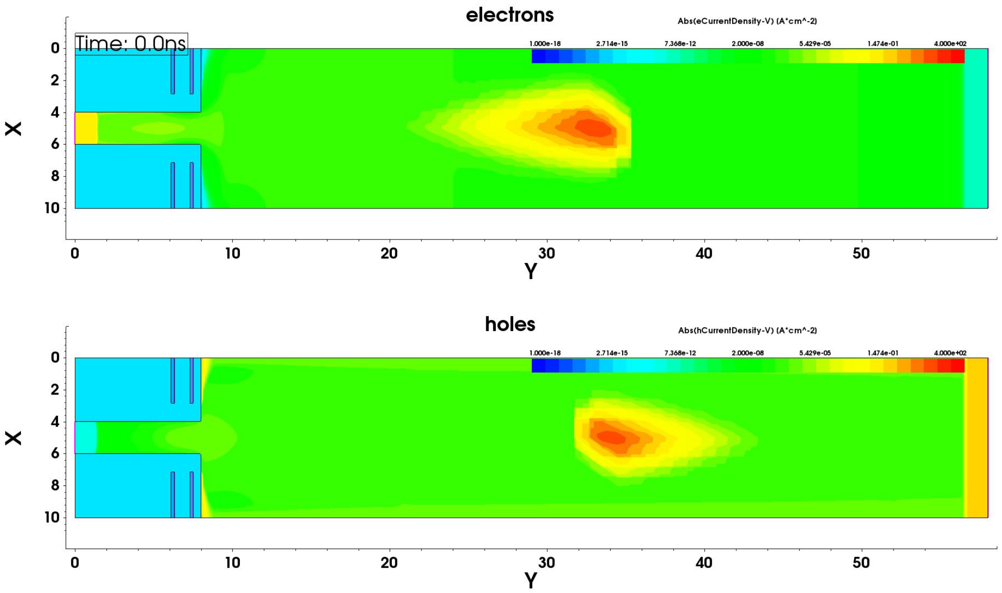
[V]



Transient simulations

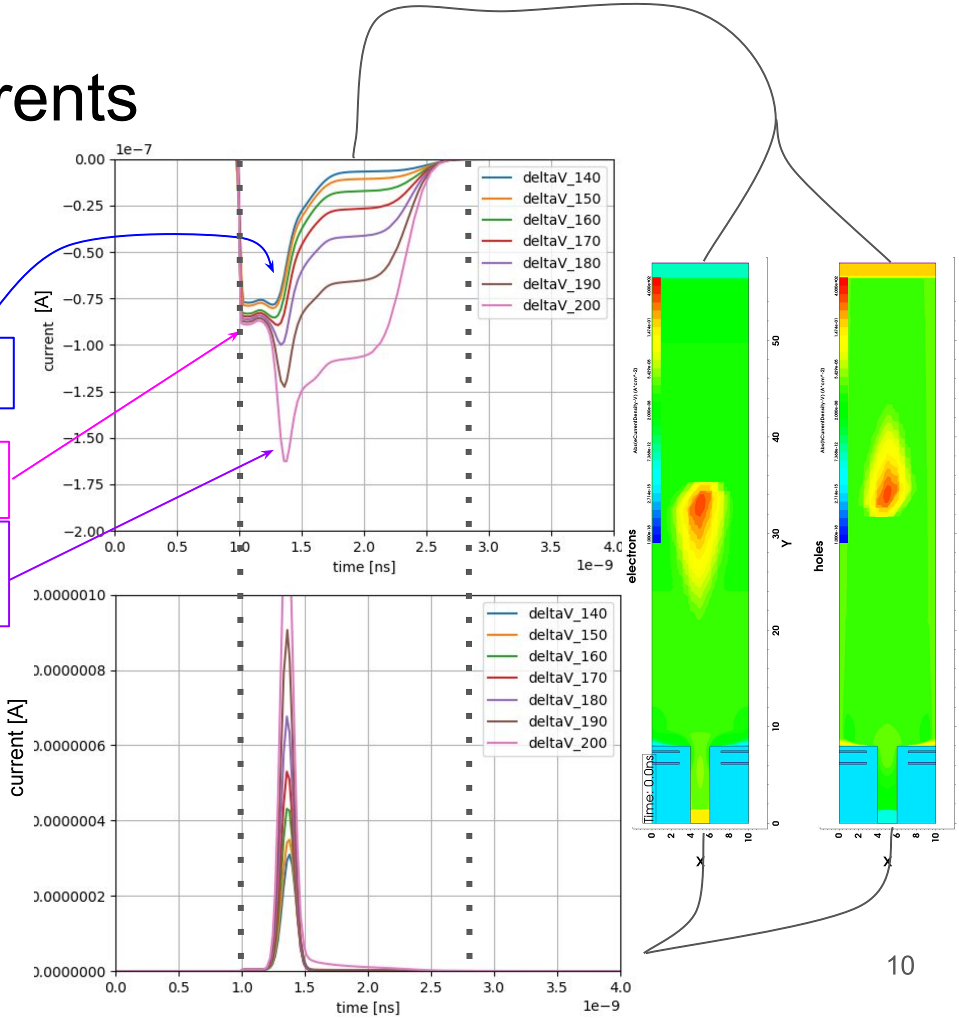
- Study propagation of charges
- Charge cloud is deposited in the bulk center.
  - track length: 2.0um, position: bulk center, direction: **y**, standard deviation of spread: 0.1um, charge deposition: 80 eh-pairs/um
- Charge transport characteristics.
  - primary holes drift towards the backplane
  - electrons drift towards the read-out electrode
  - multiplied holes drift to the backplane

current density of transient, deltaV=180V



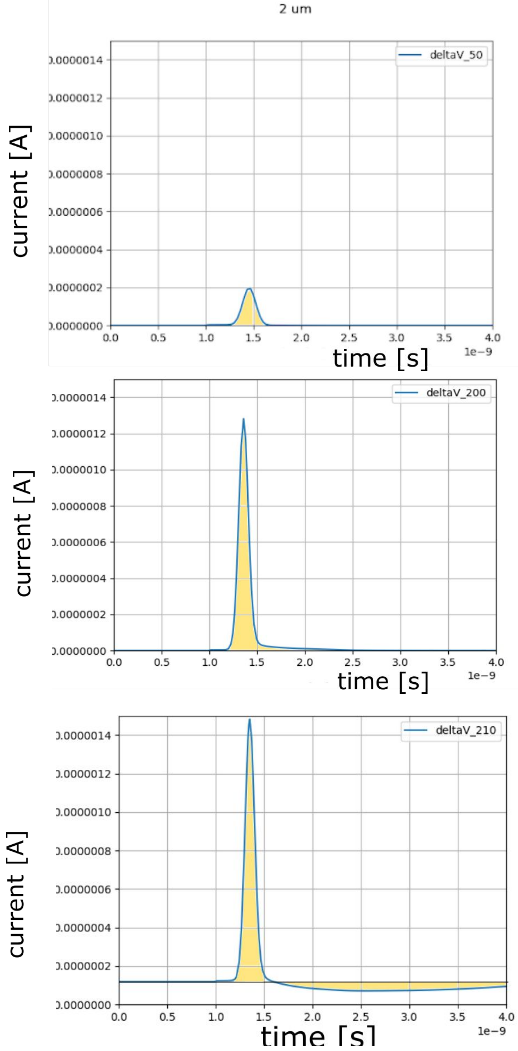
Time structure of induced currents

- weighting field of backside electrode is more “pad-like”
  - with very little charge multiplication:
    - rather constant current until charge is collected, then the signal is attenuated
  - with charge multiplication
    - signal is at first dominated by moving primary charges.
    - when the charge cloud reaches the multiplication region, multiplied holes dominate the signal
- The read-out electrode only sees the charges moving inside the pillar.
  - signal width scales with the length of the deposited charge cloud
  - charge multiplication gives more moving charges which gives a larger current



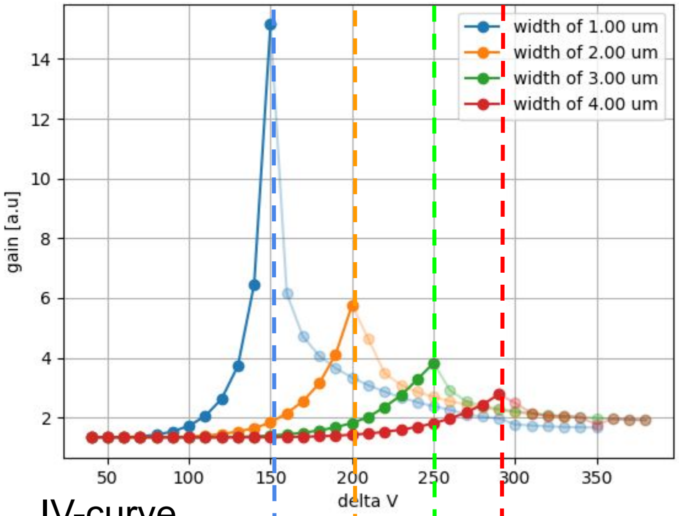
Evaluation of gain

- Gain is evaluated as input charge relative collected charge.
    - $G=Q_{collected}/Q_{input}$
    - Leakage current correction is performed

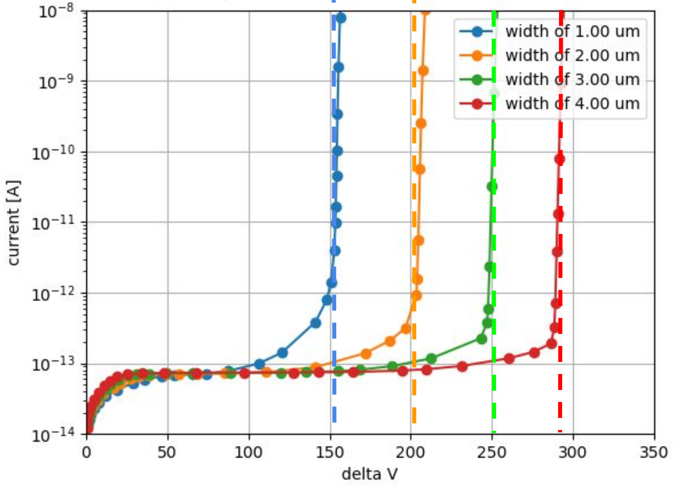


Gain

- Narrower pillars give earlier breakdown but higher gain
  - less attenuation of electric field
- Breakdown after peak
- Sensors with wider pillars are less sensitive to voltage variations



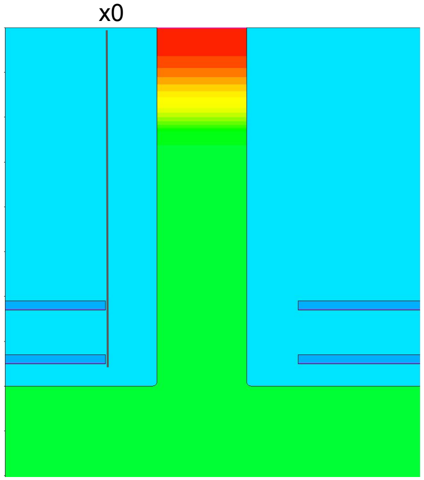
IV-curve



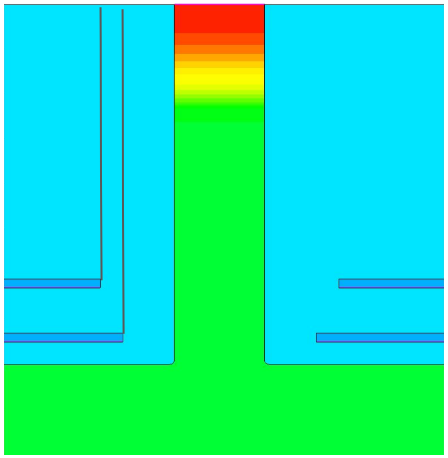
Electrodde geometry

- study impact of electrode geometry

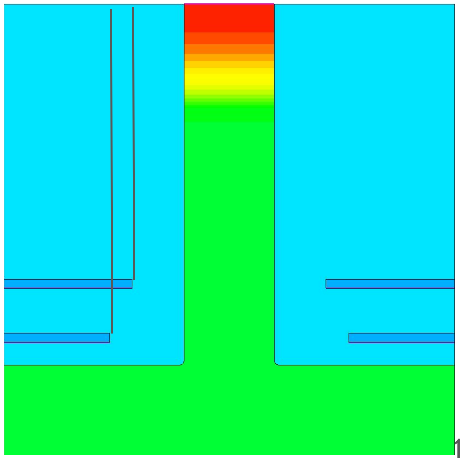
upper electrode= x0
lower electrode= x0



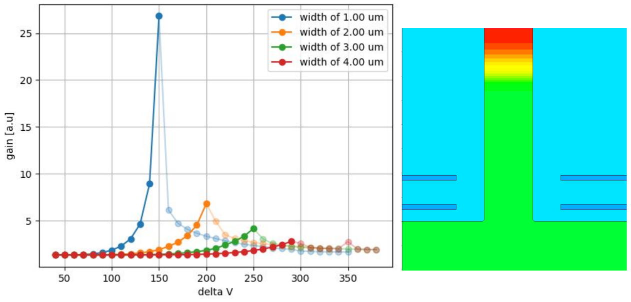
upper electrode= x0-0.5um
lower electrode= x0

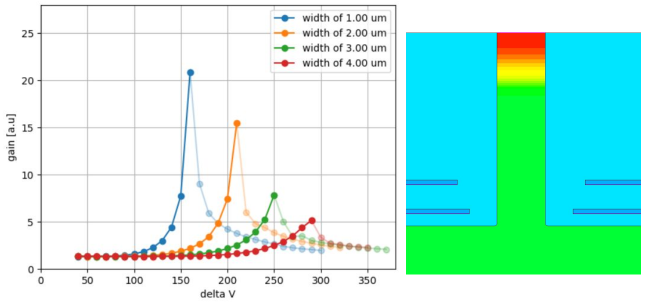


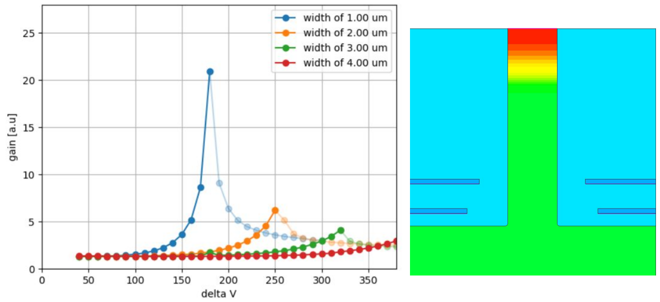
upper electrode= x0
lower electrode= x0-0.5um

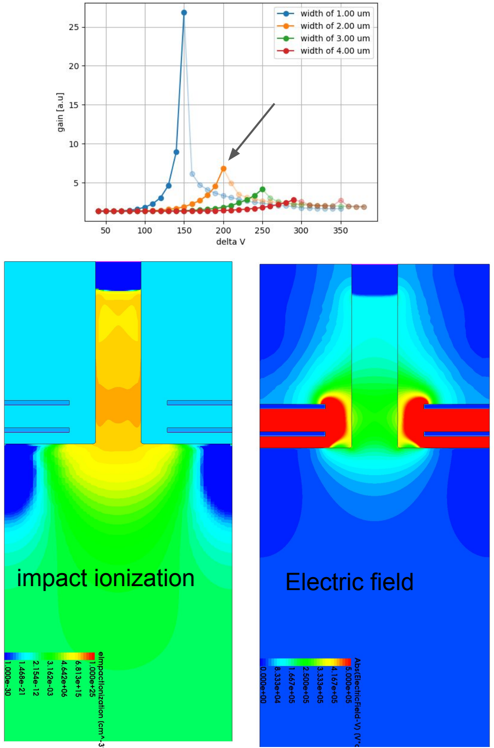


- Two features seen:
    - one retracted electrode weakens the electric field → later breakdown
- Retracted upper electrode gives higher gain

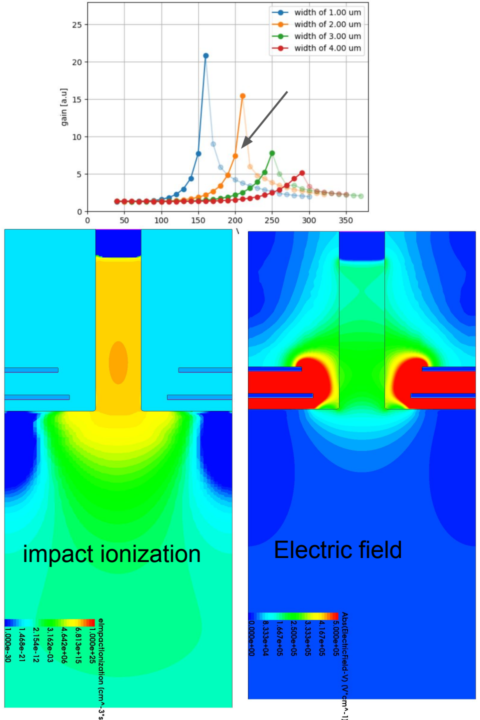




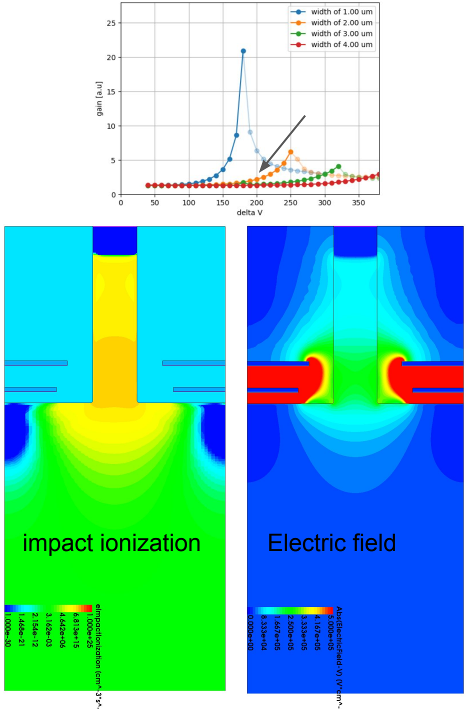




a wider lower electrode pushes field towards read-out electrode.



wider upper electrode shields field from the lower electrode



Summary and outline

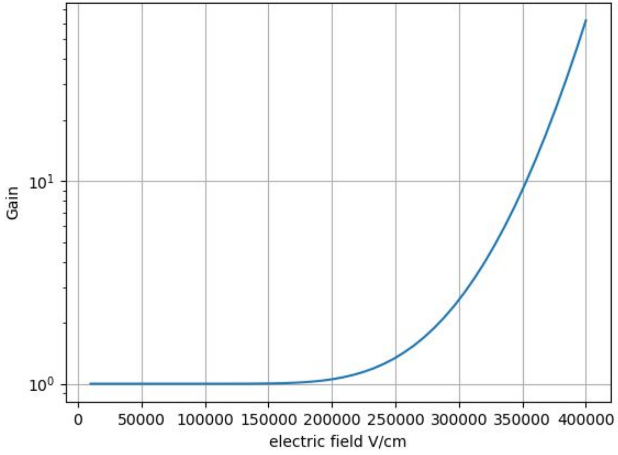
- With narrow pillars, gain can be achieved
- Narrower pillars promote more gain
- Geometry of multiplication electrodes impacts sensor performance.

Outline

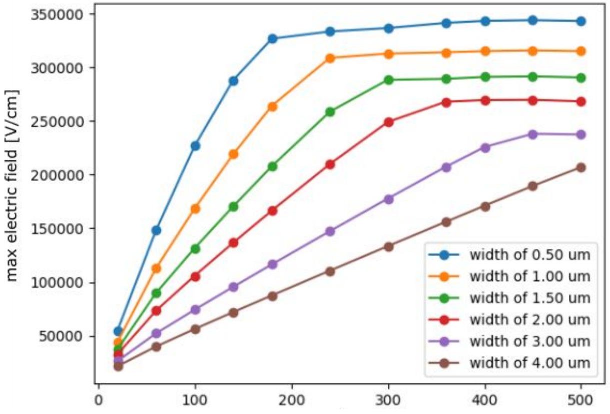
- Simulate different pitches
- Simulate different pillar heights
- Study weighting field
- Investigate deeper the electrode geometry
- Evaluate capacitance
- Move towards 3D simulations

Thanks for your attention

Backup



Gain
10^1
10^0
0
50000
100000
150000
200000
250000
300000
350000
400000
electric field V/cm



max electric field [V/cm]
350000
300000
250000
200000
150000
100000
50000
0
100
200
300
400
500
width of 0.50 um
width of 1.00 um
width of 1.50 um
width of 2.00 um
width of 3.00 um
width of 4.00 um