The Silicon Electron Multiplier Sensor

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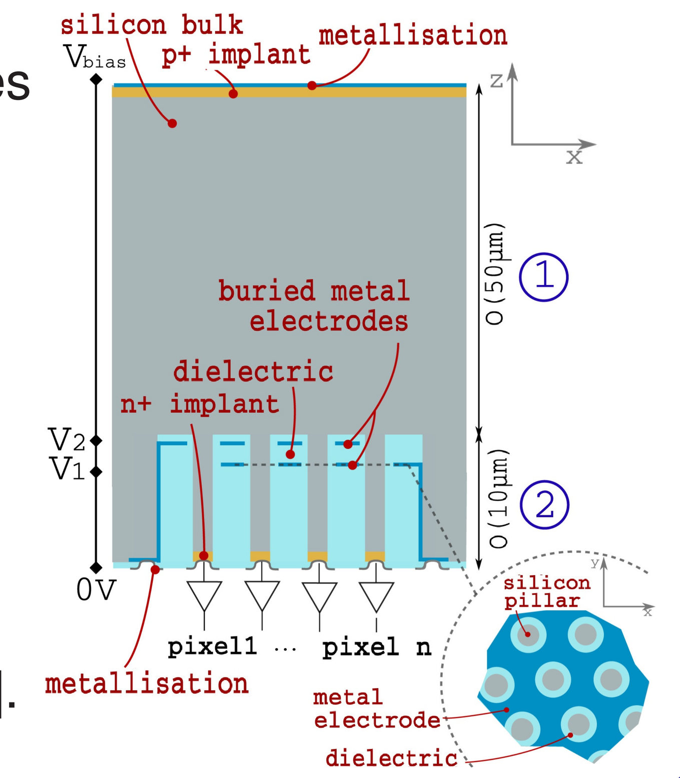
1. Introduction

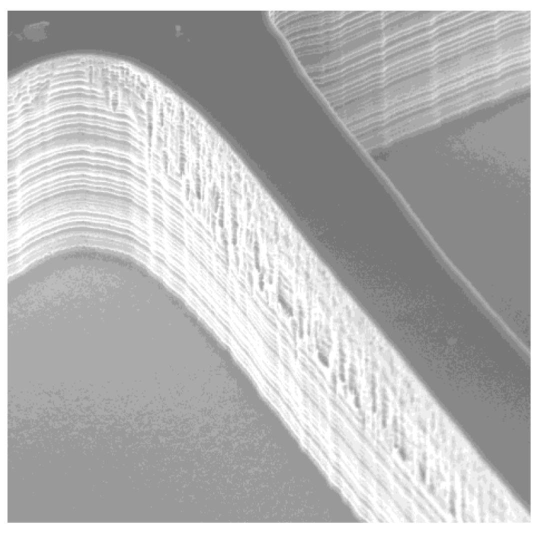
The detector upgrades foreseen for the HL-LHC and FCC will require unprecedented radiation hardness (expected fluence ranges from $5 \cdot 10^{16}$ neq/cm^2 to 10^{17} neq/cm^2 [1]), with excellent spatial and temporal resolution down to 10 ps per track.

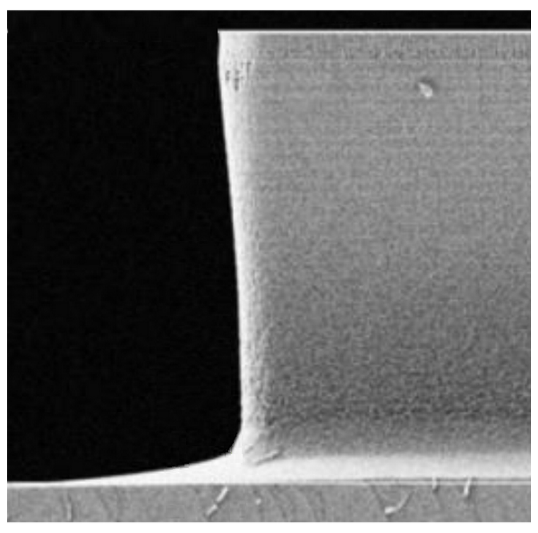
The Silicon Electron Multiplier (SiEM) sensor aims to achieve **internal gain**, **fine pitch**, and **excellent radiation hardness**.

- The electrons generated by the impinging particle in the drift region (1) travel toward the gain region (2).
- A silicon pillar is etched in the region (2), and metal electrodes are deposited at the bottom.
- A voltage applied to the electrodes allows a high electric field to be generated at the pillar base.
- Electrons are multiplied by impact ionization and collected by the readout electrode through the silicon pillar.
- **No gain deactivation** expected since gain mechanism is based on electrodes voltage difference (aiming to 10^{16} **neq/cm^2**).
- Initial TCAD simulations show gain greater than 10 and time resolution of tens of picoseconds depending on the geometry [2].



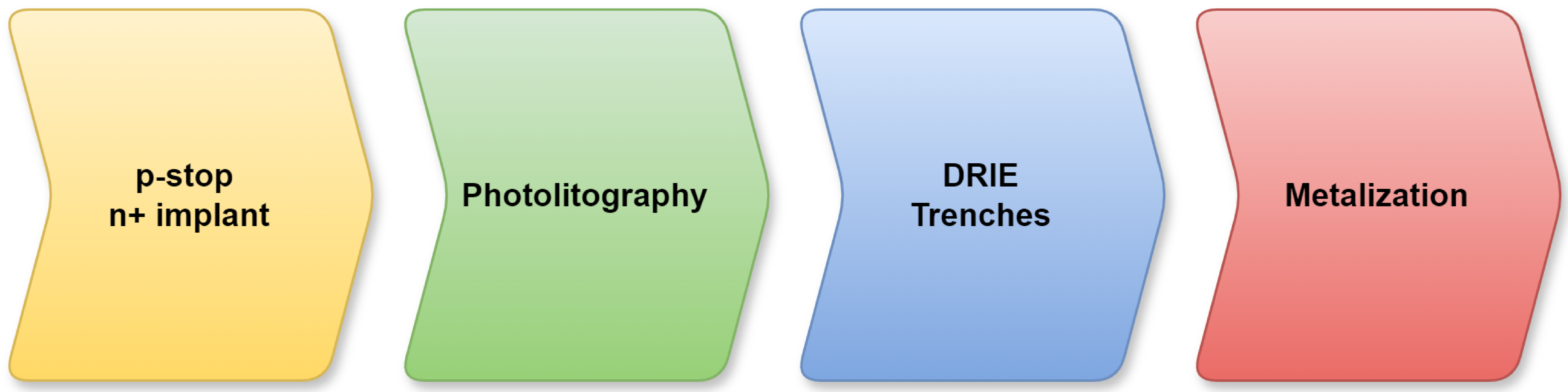
2. Demonstrator Production

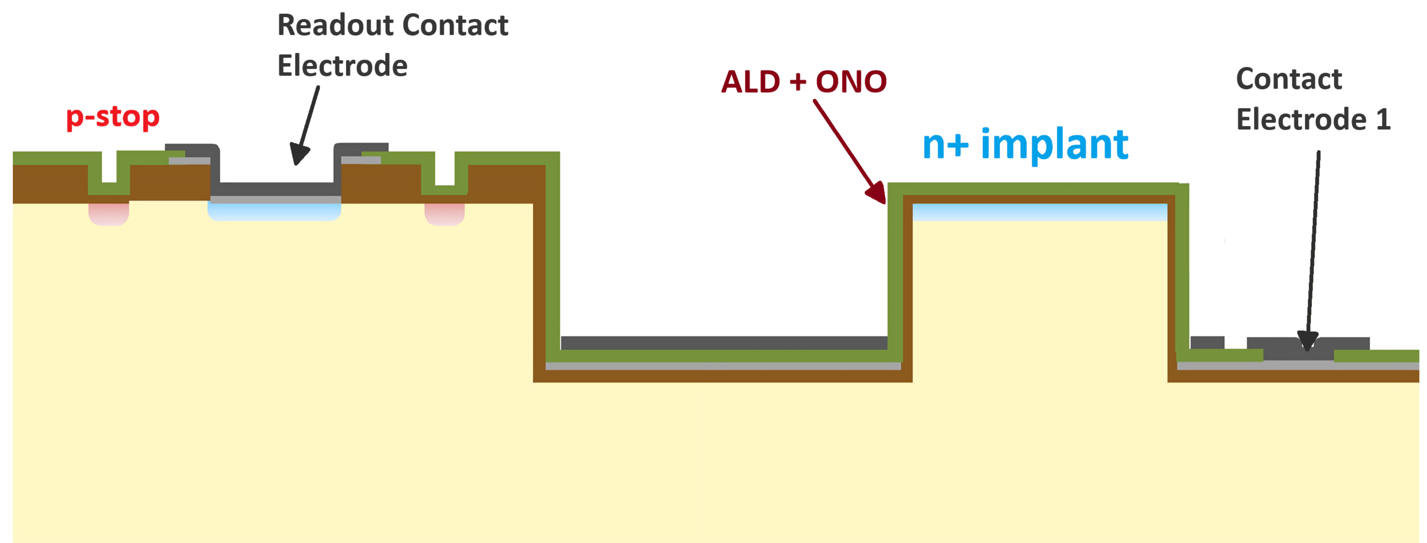




A silicon **strip demonstrator** is being manufactured in collaboration with CNM using the DRIE technique. This proof-of-concept will have **two gain electrodes** and a **pyramidal pillar shape**.

- The width of the pillar base is expected to be 1 or 2 um to maximize the electric field.
- The width of the pillar on top is expected to be 2, 3 and 4 um to investigate different shapes.
- The silicon trenches are etched with the Deep Reactive Ion Etching (DRIE) technique.
- The first gain electrode is deposited in the trench on top of an Atomic Layer Deposition (ALD) of HfO_2.
- The second gain electrode is deposited into the trench and insulated by the first one using SiO_2.
- The electrodes are deposited using an evaporative Aluminum process.

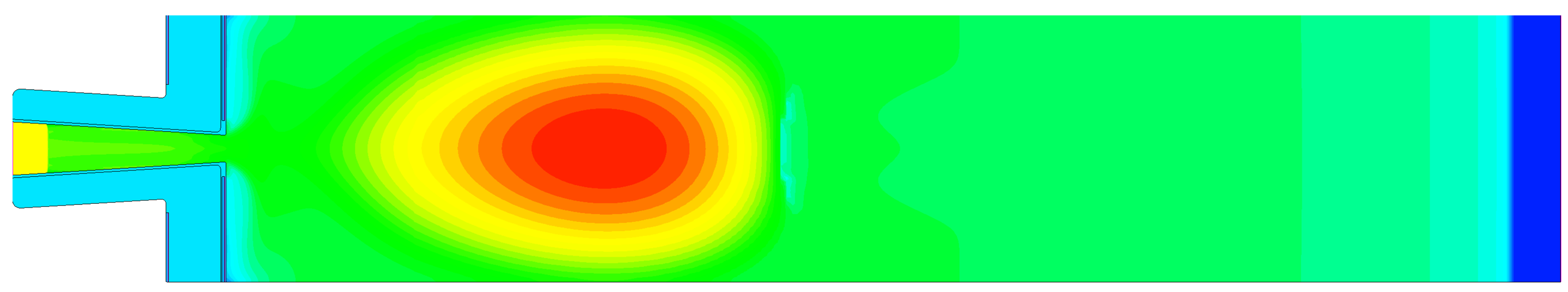


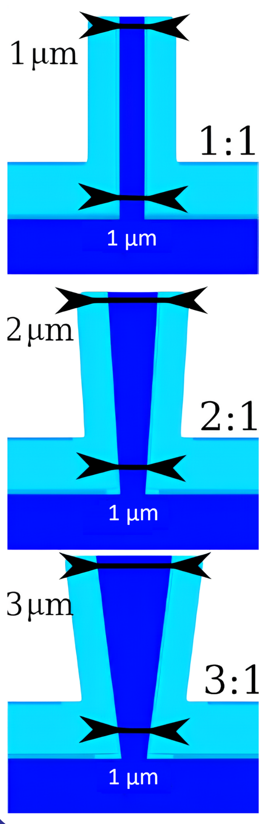


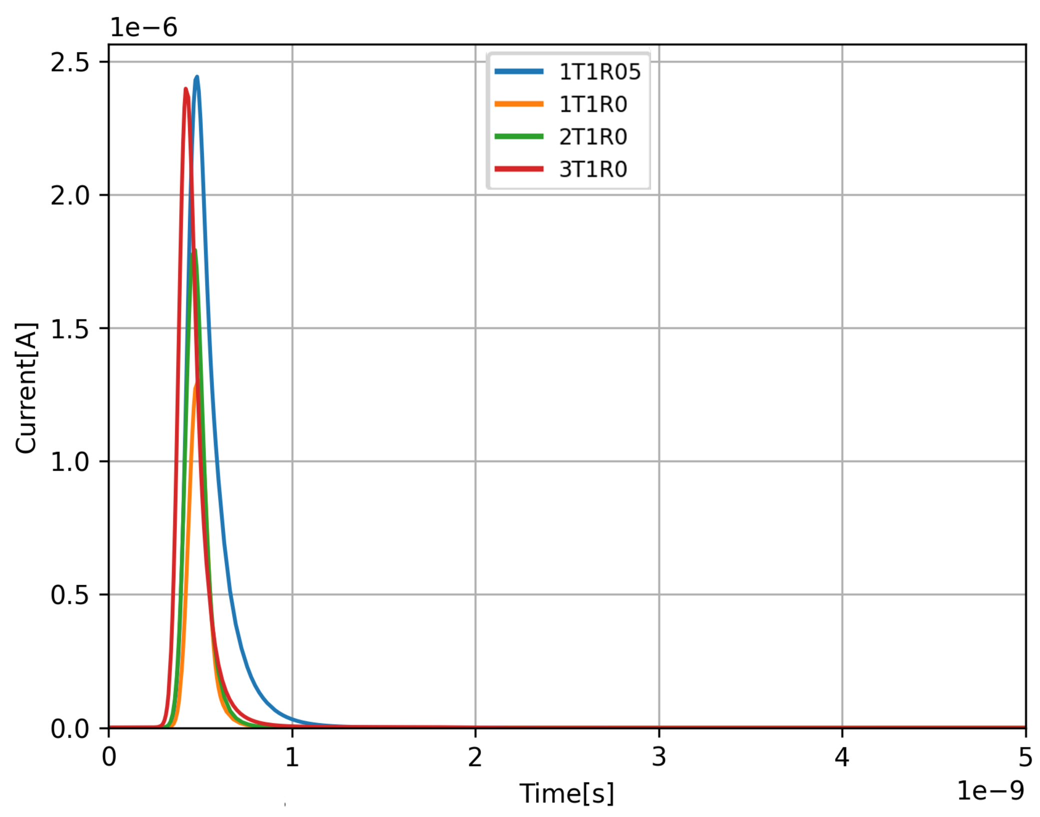
3. TCAD Simulations

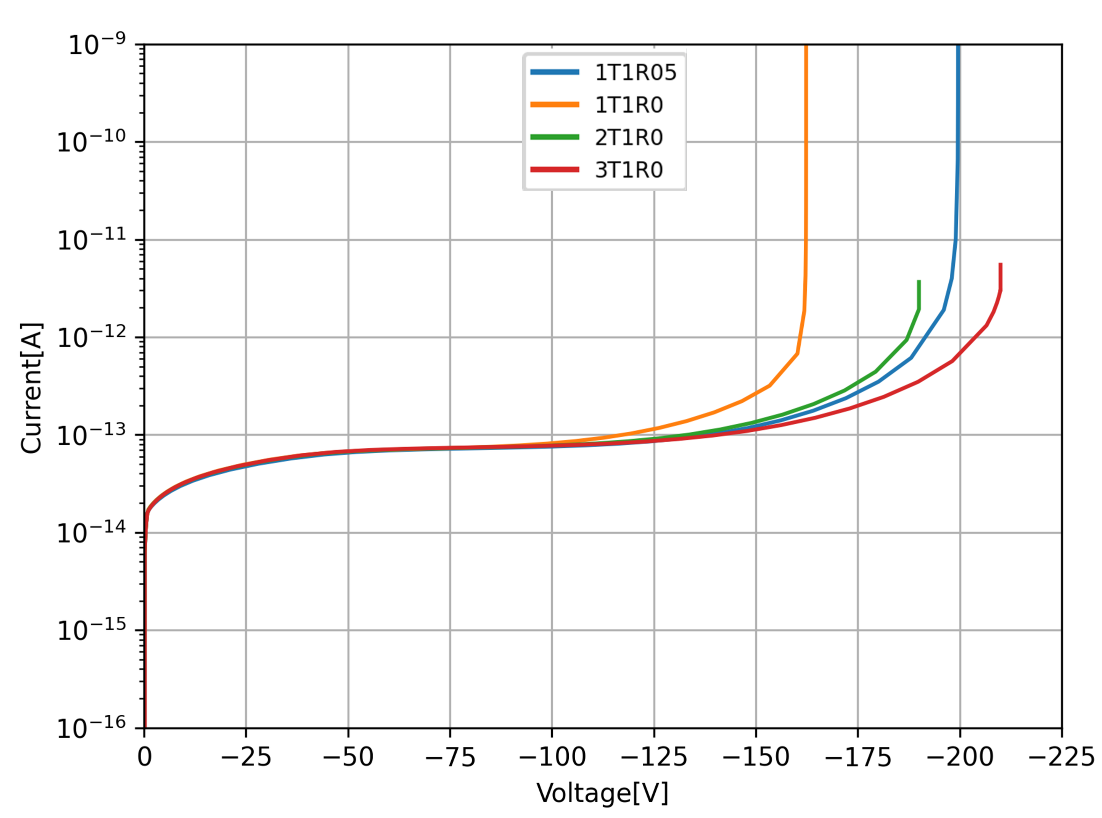
Several geometries have been investigated using TCAD:

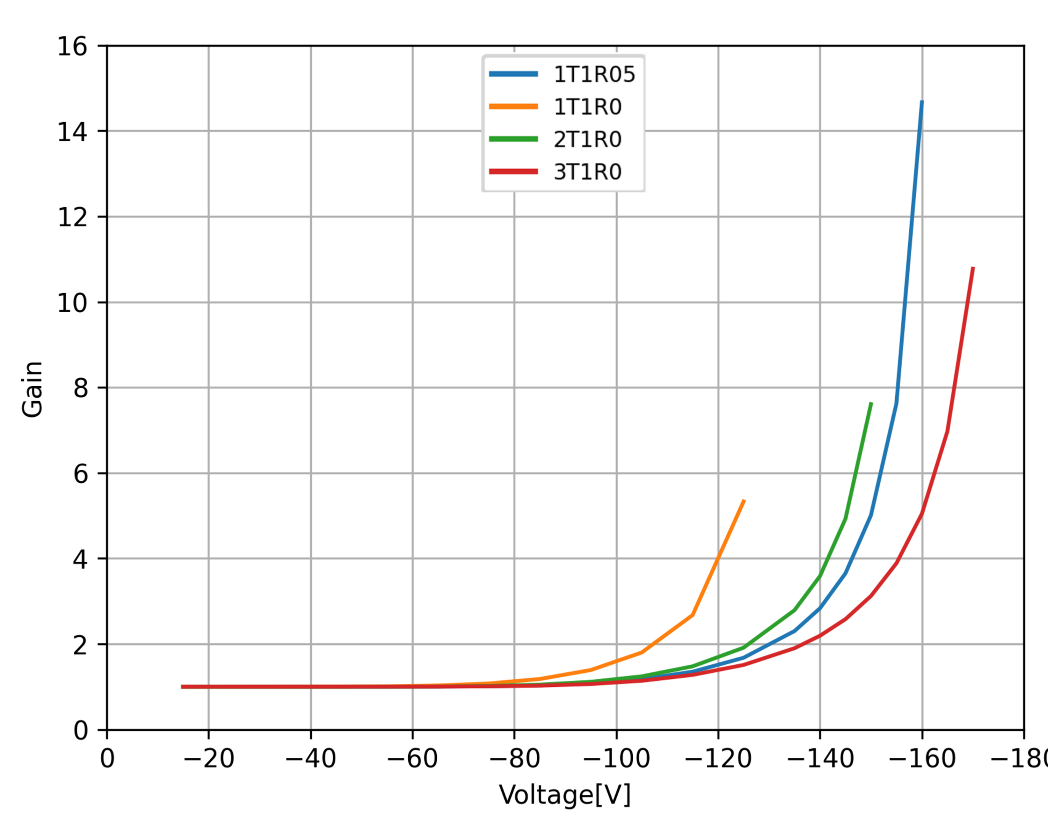
- The pillar width and the electrode distance from the pillar are studied.
- Quasistationary simulations are performed to study the electric field.
- Transient simulations are performed to study the MIP response.
- The time to collect electrons is around 600ps, and the **centroid is ~40ps**.
- A **gain > 10** can be achieved.











4. Conclusions

- The Silicon Electron Multiplier is a novel approach for MIP detection in silicon sensors, targeting detector applications with challenging requirements in terms of spatial and time resolution and radiation hardness.
- Simulations of different structure shapes show a gain > 10 and timing of ~40ps.
- Demonstrators are being manufactured with the DRIE technique at CNM.
- A test campaign with laser and test beam will investigate the gain and time performance.
- A production process based on MacEtch has been investigated as an alternative.

References

[1] "Strategic R&D Programme on Technologies for Future Experiments". In: *CERN-OPEN-2018-006* Detectors and Experimental Techniques (2018). DOI: 10.17181/CERN.5PQI.KDL2.

[2] "The Silicon Electron Multiplier sensor". In: *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 1041 (2022), p. 167325. ISSN: 0168-9002. DOI: 10.1016/j.nima.2022.167325.