

# Optimization of a 3D Micro-Structured Neutron Imaging Sensor Through Combined Simulation Approaches

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## Abstract

Neutron imaging offers additional information compared to X-ray imaging because of the different types of interaction of the two different types of radiation. This technique is particularly valuable in fields such as nuclear engineering and non-destructive industrial diagnostics.

Based on 3D sensor technology, an innovative thermal neutron detection and imaging device has been developed within the INFN HYDE2 project [1]. This device has a 3D microstructure design. It is based on the standard planar n-on-p pixel structure, but the backside is processed with Deep Reactive Ion Etching (DRIE) to create deep ( $\sim 25 \mu\text{m}$ ) and narrow cavities, which are later filled with  ${}^6\text{LiF}$  or  ${}^{10}\text{B}$  converter. The sensor consists of a  $256 \times 256$  pixel array, with a size of  $55 \times 55 \mu\text{m}^2$ , making it compatible with the Timepix readout electronics. A schematic overview of the device is presented in Figure 1.

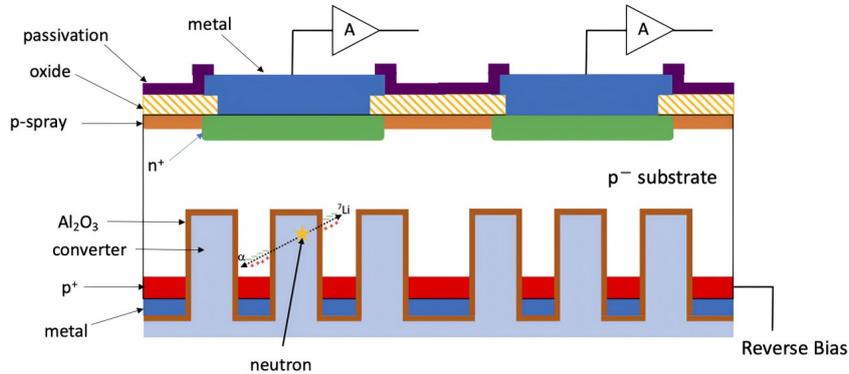


Figure 1: Schematic representation of the HYDE2 device (not to scale).

A key objective of this study is to optimize the geometry of the cavities, specifically their radius and distance, to maximize the neutron detection efficiency. Achieving this requires careful evaluation of neutron capture, detection of the resulting charged particles, and collection of the generated charges. Taking all these aspects into account is not a trivial task.

To address these challenges, the study is structured into multiple steps. First, GEANT4 simulations are used to generate an energy deposition map of charged particles resulting from neutron capture. In this step, the neutron capture probability and the trajectory of the resulting charged particle are taken into account. Next, TCAD Sentaurus static simulations are used to extrapolate the electrical properties of the silicon device, like weighting potential and electric field. This step is essential as a starting point for studying the charge motion inside the device. With TCAD, it is also possible to perform transient simulations to estimate the charge collection efficiency (CCE), but evaluating multiple geometries using this method is computationally demanding.

To overcome this limitation, the Allpix2 simulation framework is used, integrating the results from GEANT4 and TCAD [2, 3]. The Weighting Potential, Electric Field, and Doping Profile extracted

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from TCAD are imported into Allpix2. Charge injection is simulated using the DepositionPointCharge module, following the energy distribution obtained from GEANT4. Furthermore, a modified version of the TransientPropagation module is implemented to account for the specific geometry of the HYDE2 device and accurately model charge transport. The total CCE is computed for different geometries and validated against transient TCAD simulations for selected configurations, ensuring the precision of the Allpix2 results.

Finally, all the partial simulation results are merged to find the optimal geometry to maximize the neutron collection efficiency.

## References

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