Effects of ionizing radiation in semiconductor devices: simulation with Geant4

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**Goal of this work**

To analyze and simulate the effects of ionizing radiation on silicon-based integrated circuits.

When ionizing radiations collide with a semiconductor, they create electron-hole pairs:

- α and β particles progressively lose their kinetic energy when crossing the material
- γ rays pass through or are absorbed (photoelectric, Compton effect or e+e- pair production)

- secondary charged particles if absorbed
- neutron particles interact with nuclei either elastically or inelastically

Depending on the nature and energy of the ionizing radiations, their stopping power in matter is different. From least to most penetrating: alpha, beta, gamma and neutron.

**Simulations**

**Aim:** determination of the charge (number of deposited electron-hole pairs) in a block of silicon by ionizing radiations.

**Tool:** software Geant4 (for Geometry and Tracking) developed by CERN

**Our work:** implementation of a block of silicon of variable width (2 x 2 x 3 cm³) inside an air envelope (2 x 2 x 3 cm³).

**Studied parameters**

- block’s thickness
- incident radiations’ properties including:
  - type (α, β, γ),
  - number of particles, and
  - energy.

For integrated circuits fabrication, the silicon is doped. Nevertheless, considering the low concentration of dopants (typically maximum 10²⁸ atoms/cm³ of dopants for approximately 10²⁷ atoms/cm³ in intrinsic crystalline silicon), simulating a block of pure silicon is a good approximation.

**Results**

**Summary:** dose (output of GEANT4) for different types of ionizing radiations as a function of silicon thickness or kinetic energy.

**Validation:** The dose values obtained as well as their variation vs Si thickness are consistent with the way that the ionizing radiations are expected to interact in a solid silicon layer.

- 6 MeV radiation — path in Silicon [2][3]
  - range = 30 μm
  - β range = 1.5 cm
  - γ half-value-layer = 15 cm

**Conclusion and future work**

- neutron radiations: further studies are needed in order to understand the importance of Non-Ionizing Energy Loss events — possible damages in the Si lattice.
- β radiations lead to the highest dose in Si. Computation of the deposited charge (number of e-h pairs) from the passage of 100 000 ionizing β radiations of 6 MeV in a 500 μm thick silicon block:
  - D = 6 μGy — ΔD = 0.6 nC
- Further simulation studies: passage of ionizing radiations in doped Si, pn junctions, circuits to evaluate the intensities of transient currents created by charge deposition.

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**References**