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DEPFET Sensors, A Test Case to Study 3D Effects

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DEPFET sensors (comp. [1]) are a well suited example to study algorithms for solving the 3d drift-diffusion equations and to improve the understanding of critical design issues.

Properties of the classical drift-diffusion equations

$$-\nabla \cdot \epsilon \nabla \psi = f - n + p, \tag{1}$$

$$\frac{\partial n}{\partial t} + \nabla \cdot \mu_n n \nabla \phi_n = R, \tag{2}$$

$$\frac{\partial p}{\partial t} - \nabla \cdot \mu_p p \nabla \phi_p = R, \tag{3}$$

discretized on boundary conforming Delaunay simplex grids are discussed. The discretization allows the introduction of 'test functions', related adjoint equations for functionals describing quantities of interest, for instance the contact currents. With some assumptions one can get properties like weak discrete maximum principle for the quasi Fermi potentials and the dissipativity of the discrete equations (see [2]). Using the related discrete adjoint solutions for computing contact currents ($J = J(\psi, n, p)$, with $\psi = \psi^* + \delta\psi$, $n = n^* + \delta n$, $p = p^* + \delta p$, u_i^*, δu_i denote the solution components, sufficiently small errors fulfilling homogeneous boundary conditions, respectively) yields $J(\psi, n, p) = J(\psi^*, n^*, p^*) + O(\delta^2 u_i)$ due to the orthogonality properties of the test functions. The analog of partial integration avoids the use of second differences and replaces these expressions by products of first differences. This reduces rounding, hence it is of interest in case of small other errors. The technique adds almost no effort and should be applied. It is of special value in the study of small effects, differences, and large problems, where minimal numerical noise is crucial (typical relative current balance errors are 10^{-12} or better).

In the DEPFET case one follows typically 1600 electrons generated by some X-ray of specific energy in the depleted sensor bulk. One is interested in a sensor design with low power, large amplification, low noise (goal: max. 2 electrons are lost from the cloud for different starting positions), reasonable readout frequency, and stable operation over years in a astro-physics satellite.

A DEPFET (see Figure 5) collects the generated electrons in an internal gate. The internal potential distribution resulting from applied potentials and the dopant distribution has to guarantee: electrons starting from any point below the upper $2\mu m$ of the device arrive in the internal gate. After a collection time the MOSFET (SOURCE, GATE, DRAIN) above the internal gate is used to compare the present current with the reference current defined by an empty internal gate (computation of a current difference). After this 'read out' process the internal gate is cleared by moving the electrons to the CLEAR contact applying a voltage pulse at CLEAR.

The time scales are given by: a) the creation of the electron-hole cloud (maximum generation rate at $25ps$ in the computations), b) the drift time from bottom to top (roughly $1ns$), c) the drift and diffusion time below the surface (it is strongly influenced by small electric fields, compare Figure 3) and d) the time defined by thermal recombination processes for adding the typical noise level of 2 electrons in the internal gate. Depending on the carrier life times a steady state after the clear process is reached after 1 to $100s$. Hence computing the influence of the electron cloud (with the MOSFET in the on state to check the time evolution of the SOURCE-current), starts at $1fs$ and ends at around $100\mu s$ (the typical measurement time), if the time for reaching the steady state is not checked (Figure 6).

The simulations added more and more features of the device, the grids grew from 120 000 to 150 000 nodes. A 4 CPU SMP allowed the evaluation of a new design within 4 days.

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REFERENCES

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[2] H. Gajewski, K. Gärtner, *On the discretization of van Roosbroeck's equations with magnetic field*, ZAMM **76**, 247 (1996).

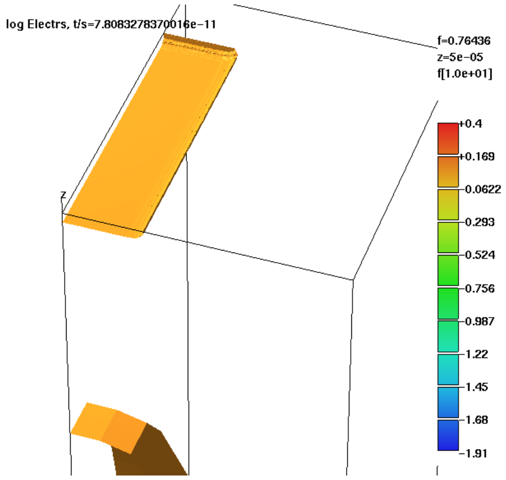

Fig. 1. Electrons start at the lower south west (SW) corner (shown is the position of the $n = 7.6n_i$ iso-surface), time $78ps$

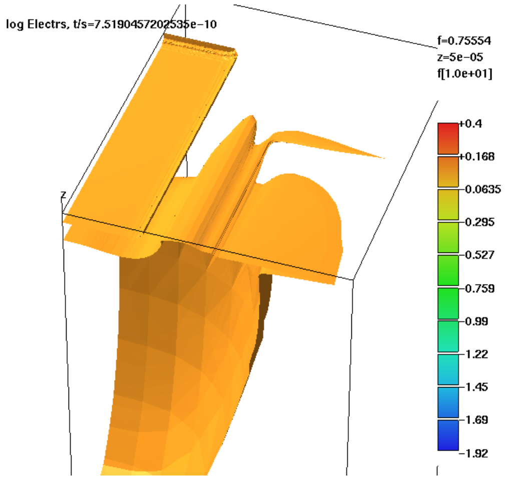

Fig. 2. The first electrons reached the top layer $(0.75ns)$

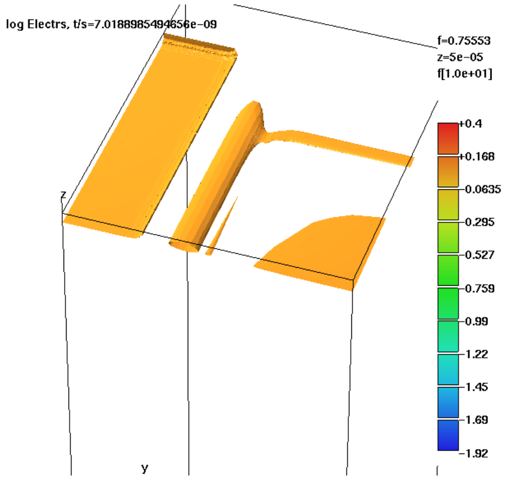

Fig. 3. Slow horizontal movement follows $(7ns)$

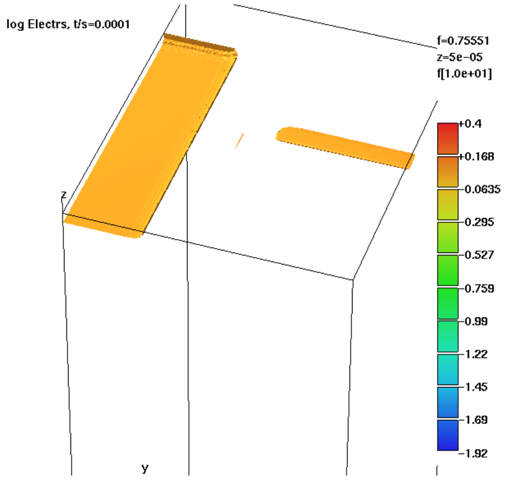

Fig. 4. Finally most electrons arrived in the internal gate $(100\mu s)$

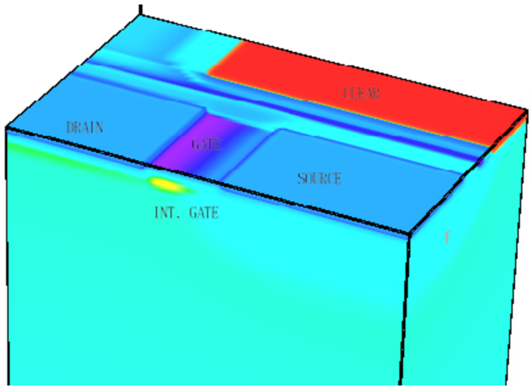

Fig. 5. Essential contacts on top of a $50 \times 22 \times 18\mu m^3$ sensor, the internal gate stores electrons (yellow spot)

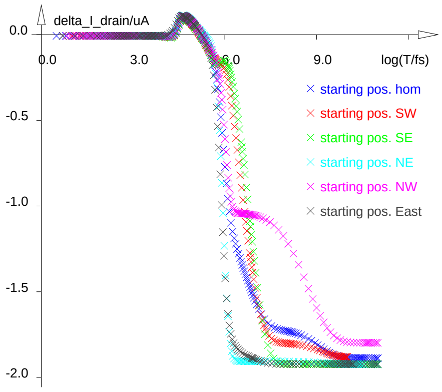

Fig. 6. Typical computed time dependent drain current differences (the reference current is $241.4\mu A$)