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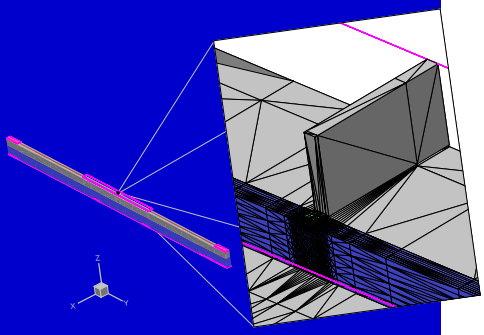
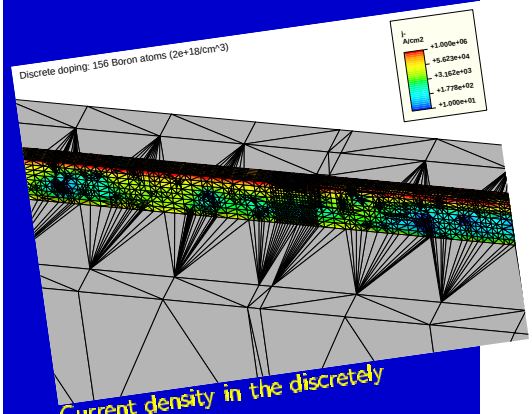
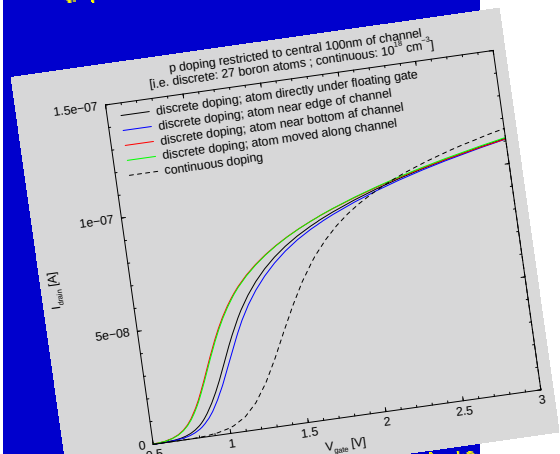


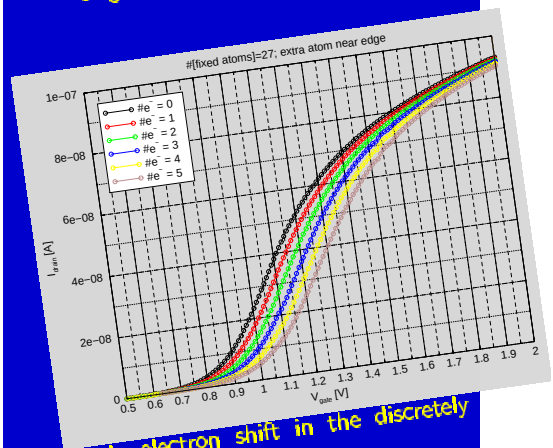
Geometry of the simulated device



Current density in the discretely doped device



Sensitivity of the I–V characteristic to changes in the position of a single dopant atom



Single electron shift in the discretely doped device

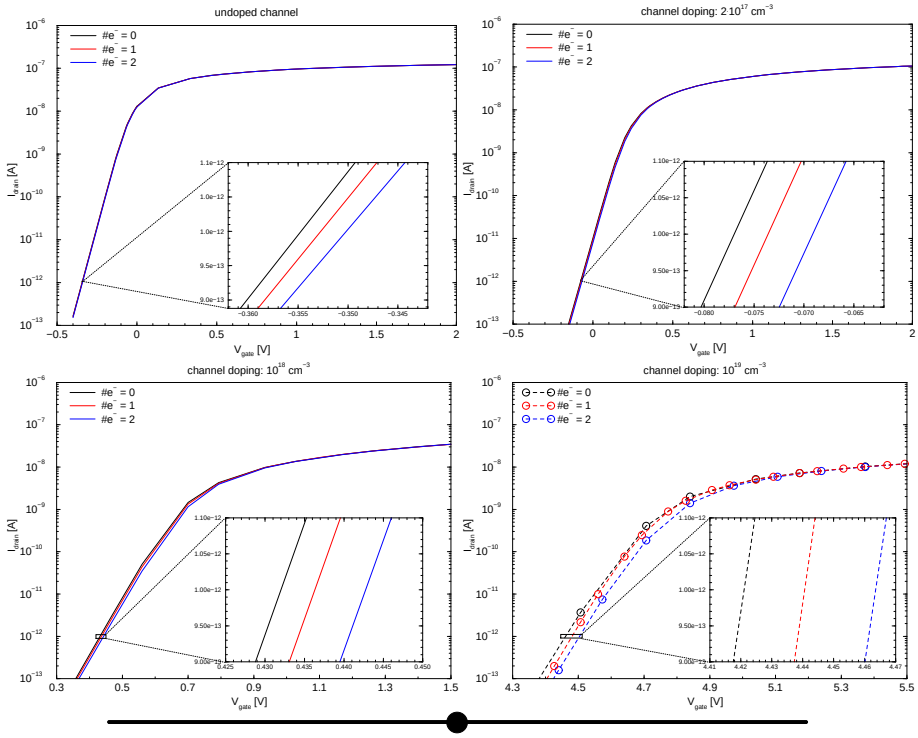
Effects in SOI Floating Gate MOSFETs

F. O. Heinz[a], A. Schenk and W. Fichtner

Keywords: Single Electron Devices, EEPROM, Discrete Doping, Drift–Diffusion, Device Simulation

A series of 3D simulations of an SOI MOSFET with a $7 \times 7 \times 2\ \mathrm{nm}^3$ poly-Si floating gate (cf. [1]) were conducted. Primary focus was put on the variation of the threshold voltage of the FET with the amount of charge stored on the floating gate. The authors of [1] report an increase in threshold voltage V_{th} of 55 mV for each single electron brought onto the floating gate. Since they do not supply doping data for their device, the doping concentration of the channel silicon was treated as a free parameter. Increasing the homogeneous boron concentration inside the channel was found to result in an increase in the threshold voltage shift brought about by a single electron from about 2 mV in an undoped channel to 20 mV at a channel doping of $10^{19}\ \mathrm{cm}^{-3}$ (cf. figure below).

Variation of the I–V characteristic of the transistor with the number of electrons on the floating gate at various (continuous) doping levels:



Due to the small device dimensions the simplifying assumption of a homogeneous doping concentration inside the channel material loses its justification: at a doping concentration of $10^{18}\ \mathrm{cm}^{-3}$ there are on average less then 3 dopant atoms in the channel section underneath the floating gate. Therefore, the simulation model was modified such as to allow for the inclusion of discrete (atomistic) doping effects. The resulting I–V characteristic was found to be very sensitive to the position of the dopant atom closest to the floating gate: displacing this atom resulted in effects as large as 150 mV. The self–consistent current density brought about by the discrete doping distribution is depicted in the second figure from the top in the figure area to the left: doping centres are surrounded by zones of high resistivity (cf. [2]); therefore, at high gate voltages the source–drain current through the discretely doped device is smaller than in the continuous doping case. The onset of conduction, however, takes place at lower gate voltages with discrete doping: since regions far away from the dopant atoms are effectively undoped, a conducting path avoiding the locations of the dopant atoms can form without need for the inversion of p–Si.

From these findings it is clear that doping is unsuited for manufacturing reproducible electronic devices featuring nanometer structures, so that potential barriers have to be formed either electrostatically or as heterojunctions.

The above results were obtained using the semiclassical drift diffusion simulator DESSIS–ISE [3]. In ultra short channel ("ballistic") MOSFETs, however, subthreshold conductivity eventually will be dominated by quantum tunneling across the depleted channel region. Therefore, we are currently adapting the SIMNAD [4] QM simulation software developed at our institute to the computation of such tunneling conductances.

[1] Guo *et al.*; 'A Silicon Single-Electron Transistor Memory Operating at Room Temperature', Science, Vol. 275, pp. 649-651, 1997

[2] Sano, N. *et al.*; 'Statistical Fluctuations in Si–MOSFETs: Jellium vs. Atomistic Dopant Variations', in 'Extended Abstracts of the 2000 International Conference on Solid State Devices', Sendai, 2000, pp. 217–217

[3] ISE AG Zurich, 'ISE TCAD Manuals', Release 6, Vol. 5, 1999

[4] Scholze, A.; 'Simulation of Single-Electron Devices', PhD thesis, ETH Zurich, Diss. Nr. 13526; Hartung-Gorre Verlag, Konstanz; 2000

[a]corresponding author — address: Institut für Integrierte Systeme, Gloriastrasse 35, ETH Zentrum, CH–8092 Zürich, Switzerland; phone: +41 1 632 59 57; e–mail: frederik.heinz@iis.ee.ethz.ch