TU Vienna
Institute for Microelectronics
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Simulation of a "Well Tempered" SOI MOSFET using an Enhanced Hydrodynamic Transport Model

M. Gritsch, H. Kosina, T. Grasser, and S. Selberherr

Anomalous Output Characteristics

- Anomalous output characteristics are observed in hydrodynamic simulations of partially depleted SOI MOSFETs (Fig. 1).
- The current drop is not observed in drift-diffusion simulations and its occurrence in measurements is questionable.
- The drop in the drain current has been reproduced using the two different device simulators namely MINIMOS-NT and DESSIS.
- The applicability of the hydrodynamic model to the ever down-scaled devices is nevertheless desirable, because in contrast to the drift-diffusion model it takes non-local effects into account.
- Empirical measures provided by DESSIS, such as weighting heat flow and thermal diffusion, have only little influence on the current drop.
- The drop can be explained by an enhanced diffusion of channel hot carriers into the floating body.

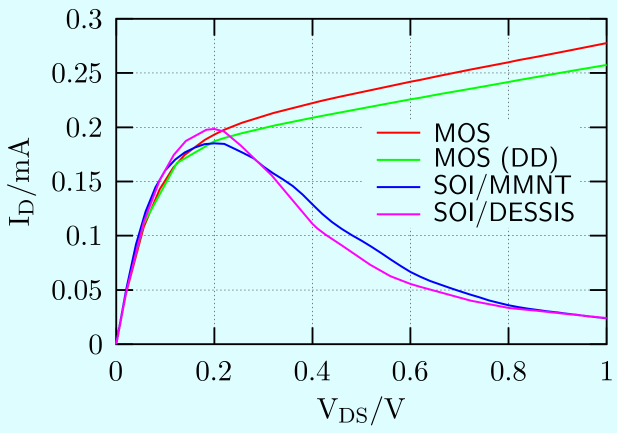

Fig. 1: Output characteristics obtained by standard DD and HD simulations.

Cause of the Effect

- The electron diffusion is significantly higher with the HD transport model due to the increased carrier temperature (Fig. 2 and Fig. 3).
- This increased diffusion has a strong impact on the body potential, because the hot electrons of the pinch-off region enter the floating body where they recombine.
- The holes removed by recombination cause the body potential to drop.
- The decrease in the output characteristics is directly connected to the drop of the body potential via the body-effect.

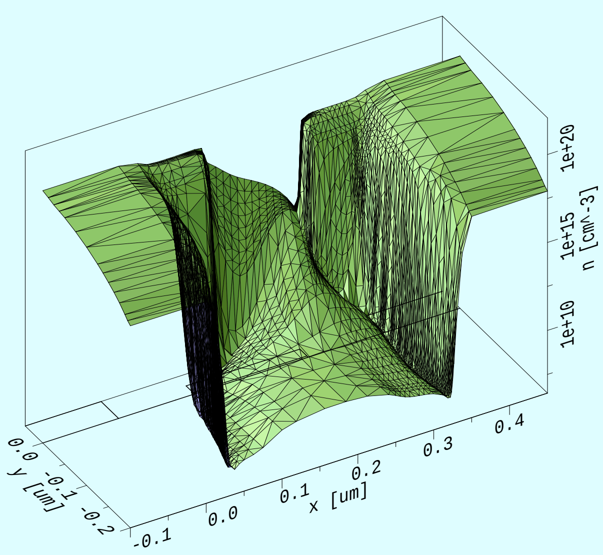

Fig. 2: Electron concentration in a MOSFET obtained by a hydrodynamic simulation.

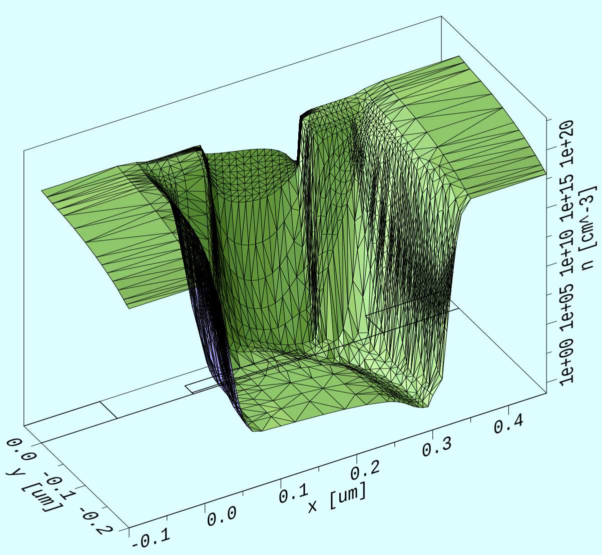

Fig. 3: Electron concentration in a MOSFET obtained by a drift-diffusion simulation.

Monte Carlo Investigations

- Monte Carlo simulations of a $90\,\mathrm{nm}$ and a $180\,\mathrm{nm}$ MOSFET have been performed.
- The simulations showed that the spreading of hot carriers away from the interface is much less pronounced than in hydrodynamic simulations which indicates an anisotropic carrier temperature (Fig. 4).
- In most parts of the channel the high energy tail is less populated than that of a MAXWELLian distribution, which gives a kurtosis $\beta_n < 1$ (Fig. 5).

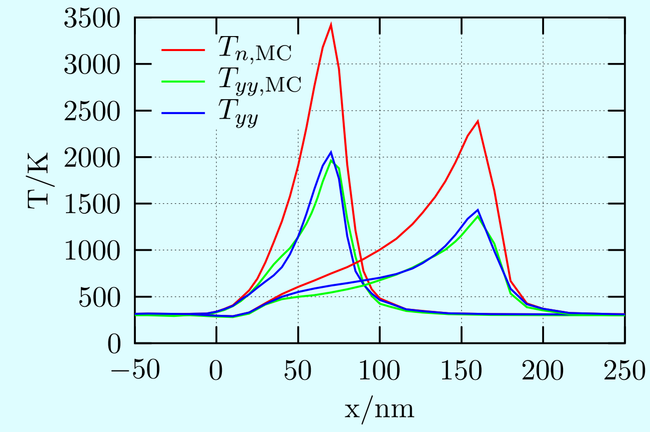

Fig. 4: MC simulation of two MOSFETs showing the y-component of the temperature and the temperature $T_{n,\mathrm{MC}}$ from the mean energy.

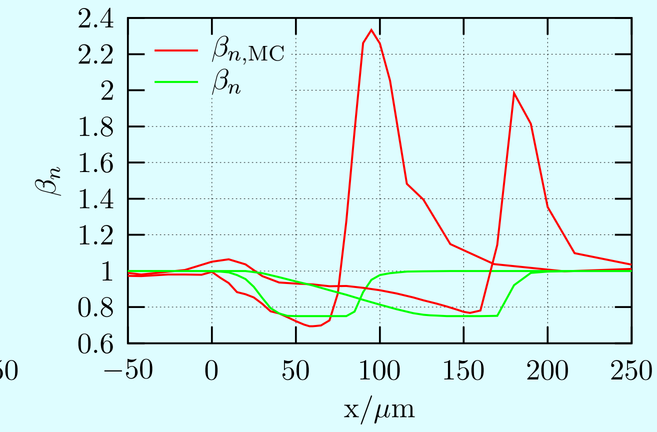

Fig. 5: MC simulation of two MOSFET showing the normalized moment of fourth order $\beta_{n,\mathrm{MC}}$ compared to the analytical β_n.

Modified Transport Model

- By combining the modifications for an anisotropic temperature and a non-MAXWELLian closure relation the artificial current decrease gets eliminated (Fig. 6).
- Parameter values estimated from MC simulations can be used, e.g. $\gamma_{0y} = 0.75$ and $\beta_0 = 0.75$.
- In the parameter range where the current drop is eliminated the output characteristics are found to be rather insensitive to the exact parameter values.

$$J_{n,\xi} = \mu_n \left(\mathrm{k_B} \frac{\partial}{\partial \xi} \left(n\, T_{\xi\xi} \right) + \mathrm{q}\, E_\xi\, n \right) ,$$

$$S_{n,\xi} = -\frac{5}{2} \frac{\mathrm{k_B}}{\mathrm{q}} \mu_S \left(\mathrm{k_B} \frac{\partial}{\partial \xi} \left(n\, \beta_n\, T_{\xi\xi}\, \Theta \right) + \right.$$
$$\left. + \mathrm{q}\, E_\xi\, n\, \Theta \right) , \qquad \Theta = \frac{3\, T_n + 2\, T_{\xi\xi}}{5} ,$$

$$T_{\xi\xi} = T_{xx} \cos^2 \varphi + T_{yy} \sin^2 \varphi , \qquad T_{\nu\nu} = \gamma_\nu\, T_n ,$$

$$\gamma_\nu(T_n) = \gamma_{0\nu} + \left(1 - \gamma_{0\nu}\right) \exp\left(-\left(\frac{T_n - T_L}{\mathrm{T_{ref,\gamma}}} \right)^2 \right) ,$$
$$\nu = x, y ,$$

$$\beta_n(T_n) = \beta_0 + \left(1 - \beta_0\right) \exp\left(-\left(\frac{T_n - T_L}{\mathrm{T_{ref,\beta}}} \right)^2 \right)$$

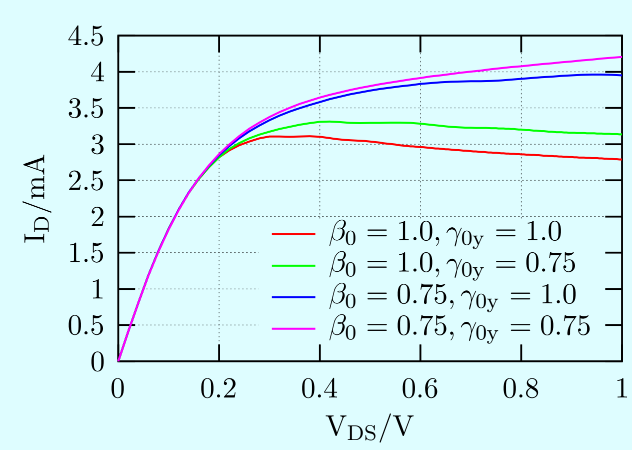

Fig. 6: Output characteristics of the "Well-Tempered" SOI at $V_{GS} = 1\,V$. The spurious decrease got eliminated.