Current Estimation in Backward Monte Carlo Simulations

H. Kosina, M. Kampl
Institute for Microelectronics, TU Wien, Austria
kosina@iue.tuwien.ac.at

The theoretical foundations of the backward Monte Carlo (BMC) method for the solution of the semiconductor Boltzmann equation have been laid out three decades ago [1][2]. A modified version of the BMC algorithm that guarantees numerical stability has been developed recently and implemented in a full-band MC device simulator [3].

We have studied the electrical characteristics of a 65nm n-channel MOSFET. The BMC method allows one to calculate the drain current in the entire sub-threshold region including the leakage current in the off-state. Compuation times are on the order of 10 seconds for frozen-field simulations (Fig 1).

The current through a plane is calculated by means of MC integration of the current density. For this integration a distribution of the sampling points has to be assumed which, in the present case, represent the initial states of the backward trajectories. In this work we discuss the properties of the current estimators obtained from different choices of that distribution. Typical choices are Maxwellian and velocity-weighted Maxwellian distributions. Fig. 2 shows the output characteristics and the relative standard deviation of the current for different estimators. A symmetric current estimator produces less statistical error than the non-symmetric ones [3]. This improvement is achieved for all operating conditions, and is particularly large when thermal equilibrium is approached.

By assuming a Maxwellian distribution at elevated temperature the method generates more sampling points at higher energies. This method of statistical enhancement reduces the statistical error of quantities that depend on the high-energy tail of the distribution function. Fig. 3 shows that the estimated current is independent from the injection temperature, whereas the statistical error shows a clear minimum where the injection distribution most closely resembles the actual distribution (Fig. 4).

[1] C. Jacoboni, P. Poli, L. Rota, A new Monte Carlo technique for the solution of the Boltzmann transport equation, Solid-State Electronics 31 (3/4), 523 (1988)

[2] M. Nedjalkov, P. Vitanov, Iteration approach for solving the Boltzmann equation with the Monte Carlo method, Solid-State Electronics 32 (10), 893 (1988)

[3] M. Kampl, H. Kosina, The Backward Monte Carlo Method for Semiconductor Device Simulation, Journal of Computational Electronics 17, 1492 (2018)

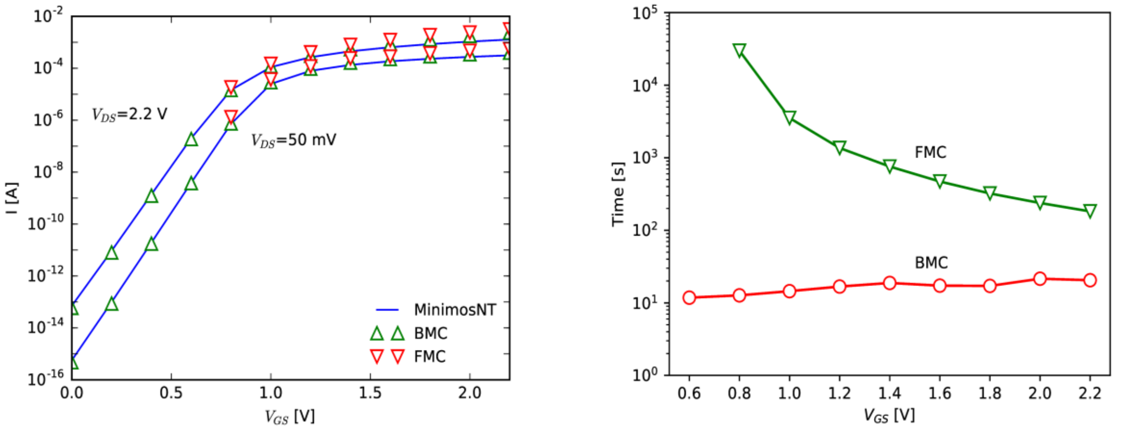

Fig.1: Left: Transfer characteristics of a 65nm n-channel MOSFET simulated using Minimos-NT, the backward and the forward MC methods. Right: Computation times on a single core of an Intel i7 processor for a relative standard deviation of 0.01. VDS=2.2V.

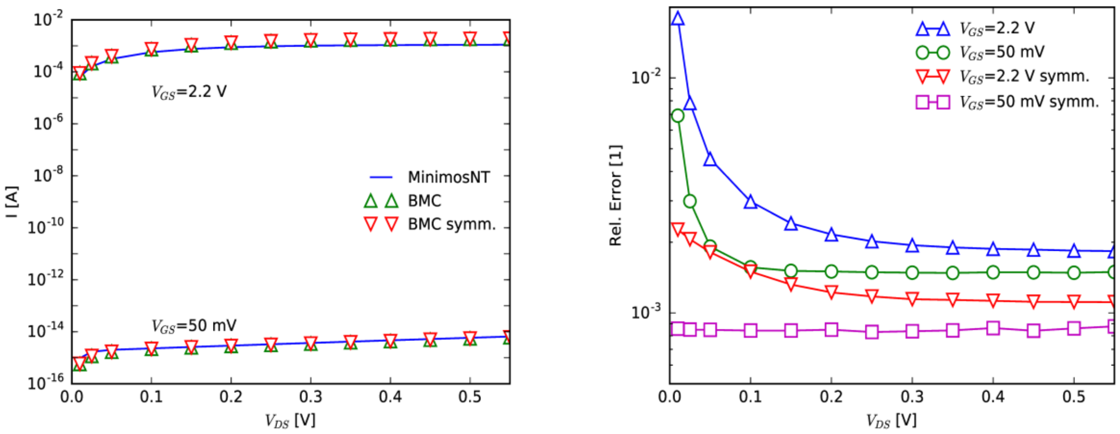

Fig.2: Left: Output characteristics of the MOSFET for two gate voltages, simulated using MinimosNT, the forward and the backward MC methods. Right: Relative standard deviation of the drain current. The non-symmetric and the symmetric estimator based on the velocity-weighted Maxwellian are compared. For each bias point 1e6 backward trajectories are calculated.

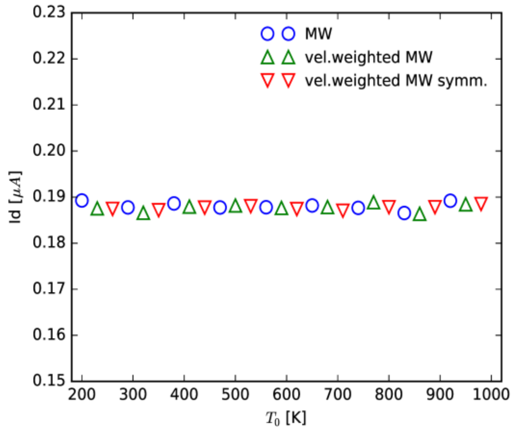

Fig.3: The drain current is independent from the injection temperature and the estimator used. VGS=0.6V, VDS=2.2V.

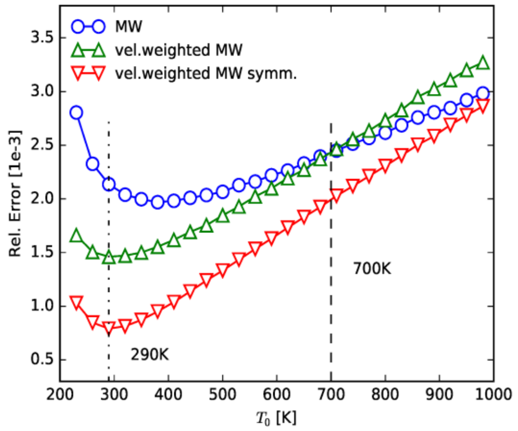

Fig.4: Relative standard deviation of the current for different estimators versus injection temperature. VGS=0.6V, VDS=2.2V.