An Improved Energy Transport Model Suitable for Simulation of Partially Depleted SOI MOSFETs

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Abstract. When applied to partially depleted SOI MOSFETs, the energy transport model predicts anomalous output characteristics. The effect that the drain current reaches a maximum and then decreases is peculiar to the energy transport model. It is not present in drift-diffusion simulations and its occurrence in measurements is questionable. The effect is due to an overestimation of the diffusion of channel hot carriers into the floating body. A modified energy transport model is proposed which describes hot carrier diffusion more realistically and allows for proper simulation of SOI MOSFETs.

Keywords: energy transport, moment equations, Boltzmann equation, device simulation, silicon on insulator

Introduction

With the ongoing down-scaling of modern semiconductor devices simulation results obtained by the widely accepted drift-diffusion (DD) transport model become more and more questionable. In particular the lack of accounting for nonlocal effects such as carrier heating and velocity overshoot makes it desirable to use more sophisticated transport-models. These are obtained typically by considering the first four moments of the Boltzmann equation. However, the resulting energy transport (ET) models, which are nowadays available in most of the device simulation programs, lead to interesting problems when applied to SOI MOSFETs.

Using the ET model for the simulation of partially depleted SOI MOSFETs, an anomalous decrease of the drain current with increasing drain-source voltage can be observed (Gritsch et al. 2001a,b) (Fig. 1). The anomalous effect has been reproduced using two different device simulators, namely MINIMOS-NT (Simlinger et al. 1997) and DESSIS (User’s Manual, Release 6). It is believed that this decrease is a spurious effect because to our knowledge it is neither present in experiments nor can it be observed when using the DD transport model. One exception is given in Egley et al. (2000), where a weak decrease of the drain-current is reported.

Cause of the Effect

A major difference between the ET and the DD transport model is the treatment of the carrier temperature. While in the ET model the carrier temperature can differ from the lattice temperature, in the DD model carriers are assumed to stay at lattice temperature. Since the diffusion of carriers is proportional to their temperature, the diffusion can be significantly higher when predicted by the ET model. Figure 2 clearly shows the enhanced vertical diffusion of electrons near the pinch-off region of a bulk MOSFET, as compared with the DD result in Fig. 3.

When simulating SOI MOSFETs this increased diffusion has a strong impact on the body potential, because the hot electrons of the pinch-off region have
enough energy to overcome the energy barrier towards the floating body region and thus enter into the sea of holes. Some of these electrons in the floating body are collected by the drain-body and source-body junctions, but many recombine. The holes removed by recombination cause the body potential to drop. A steady state is obtained when the body potential reaches a value which biases the junctions enough in reverse direction so that thermal generation of holes in the junctions can compensate this recombination process. The decrease in the output characteristics is directly connected to the drop of the body potential via the body-effect.

The Energy Transport Model

A first attempt to avoid the anomalous current decrease was to tune the empirical weight factors of thermal diffusion and heat flow, as provided by the ET model of DESSIS. However, within this parameter-space only minor improvements in the output characteristics were possible.

In Monte-Carlo (MC) simulations the spreading of hot carriers away from the interface is much less pronounced than in ET simulations. If we assume that the Boltzmann equation does not predict the hot carrier spreading, and if the ET equations derived from the Boltzmann equation do so, the problem must be introduced by the assumptions made in the derivation of the ET model. Assumptions considered important in this regard are the approximation of tensor quantities by scalars and the closure of the hierarchy of moment equations.

In order to capture more realistically the phenomenon of hot carrier diffusion an ET equation set has been derived from the Boltzmann equation, permitting an anisotropic temperature and a non-Maxwellian distribution function. The current density $J_{n,l}$ and the