Parameter Modeling for Higher-Order Transport Models in UTB SOI MOSFETs

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INTRODUCTION

The accurate description of carrier transport in emerging devices based on Boltzmann's equation (BTE) is of fundamental importance. The BTE is conventionally solved by applying the Monte-Carlo (MC) technique, which is very accurate but time consuming [1, 2]. A more efficient way to find approximate solutions is the method of moments. For an accurate description of carrier transport it is important to model several transport parameters, like the carrier mobility in the drift-diffusion model, with as few simplifying assumptions as possible. A good choice is the calculation of parameter tables extracted from MC simulations for a parameter interpolation within a device simulator [3]. So far only bulk MC data has been taken into account. The application of this data to MOSFET devices is problematic due to the importance of surface scattering and quantization in the channel [4]. In [5] the influence of surface roughness scattering on the carrier mobility has been considered using the semiempirical Matthiesen rule. However, the impact of quantization effects and surface roughness scattering on higher-order parameters like the energy relaxation time or the energy mobility has not been described satisfactorily yet. We extract this data from a subband MC (SMC) simulator self-consistently to a Schrödinger Poisson solver [6] where quantization effects and surface roughness scattering are automatically considered.

METHOD

The methodology we use is shown in Fig. 1. In the SMC simulator we consider quantization effects, non-parabolic bands based on Kane's model, phonon induced scattering as well as surface roughness scattering[7]. The extracted mobilities and the velocities as a function of the effective field and the lateral field are plotted in Fig. 2 and Fig. 3.

RESULTS

A UTB fully depleted SOI MOSFET with a Si film thickness of $5\,\mathrm{nm}$ and a donor doping concentration of $10^{20}\,\mathrm{cm}^{-3}$ in the source and the drain regions as well as an acceptor doping in the channel of $10^{12}\,\mathrm{cm}^{-3}$ has been investigated. The spatial distribution energy relaxation time for different bias point conditions is shown in Fig. 4. As shown, the energy relaxation time has a minimum in the middle of the channel in the bulk as well as in the subband case but are otherwise distinctly different. In Fig. 5, we compare the carrier temperatures of bulk table based data with SMC table data. The carrier temperatures based on bulk parameters are considerably overestimated because of the missing consideration of surface roughness scattering and the impact of the inversion layer. The transfer characteristics of the SOI MOSFET obtained with bulk MC and SMC transport parameter data are compared for both the drift-diffusion and hydrodynamic model, respectively, in Fig. 6. Due to the overestimation of the mobilities in the bulk MC case, the appropriate currents are also too large.

CONCLUSION

We show the influence of quantization effects as well as surface roughness scattering for higher-order transport parameters. To confirm this impact of the parameters on the predicted device characteristics, we compare bulk MC data, where no quantization effects are considered with SMC data.

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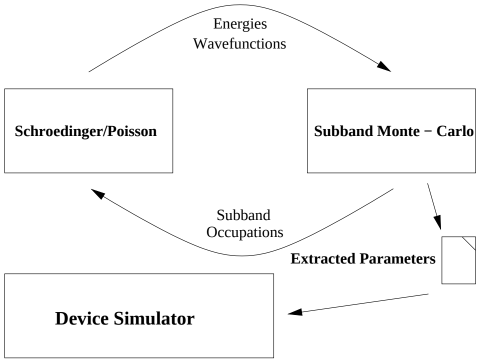

Fig. 1. The Schrödinger/Poisson solver together with the SMC simulator describe the transport of a 2D electron gas in an inversion layer. The device simulator utilizes the extracted parameters to characterize the transport in a device.

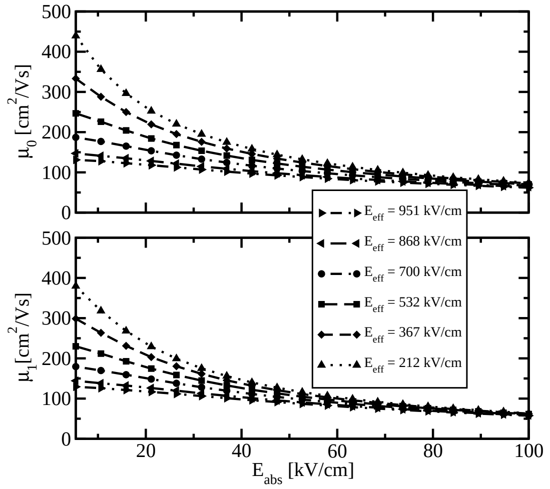

Fig. 2. The extracted carrier mobility as well as the energy mobility as a function of the lateral field for different effective fields are shown. The device simulator interpolates between these values.

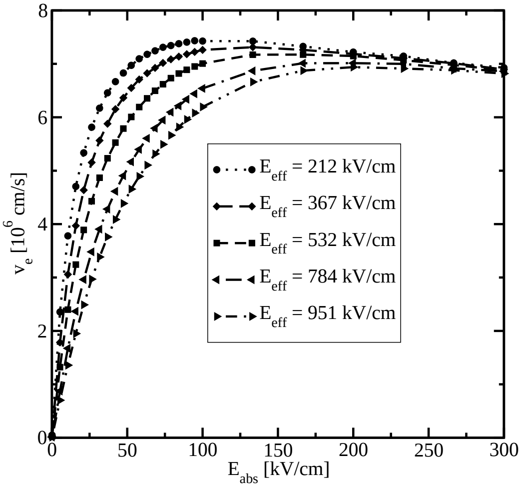

Fig. 3. The extracted velocity of the electrons as a function of the lateral field for different effective fields is plotted. Due to surface roughness scattering the saturation velocity is smaller than in the bulk ($10^7 \mathrm{cm/s}$).

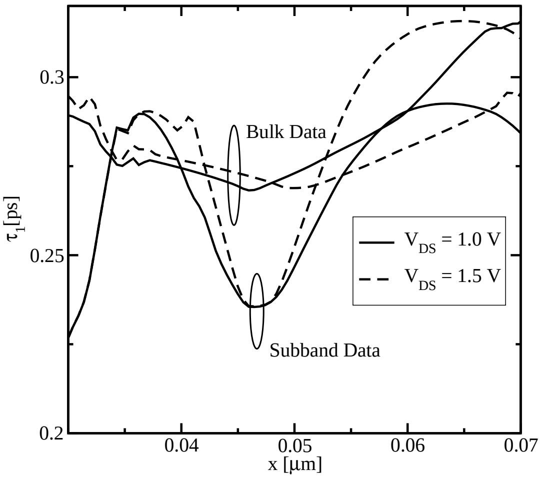

Fig. 4. A comparison of the energy relaxation time profiles of the bulk MC data and SMC data. The relaxation time is plotted over a $45\mathrm{nm}$ long channel. A gate voltage of $0.8\mathrm{V}$ is applied.

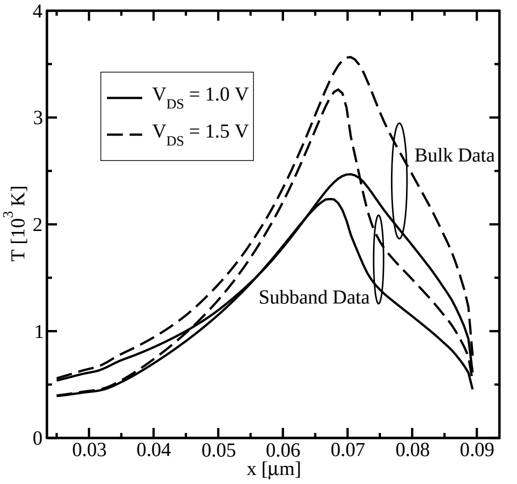

Fig. 5. A comparison of table based bulk MC data with SMC data for different bias points. The maximum peak of the temperature is at the end of the channel. The difference of the curves is due to different mobility tables.

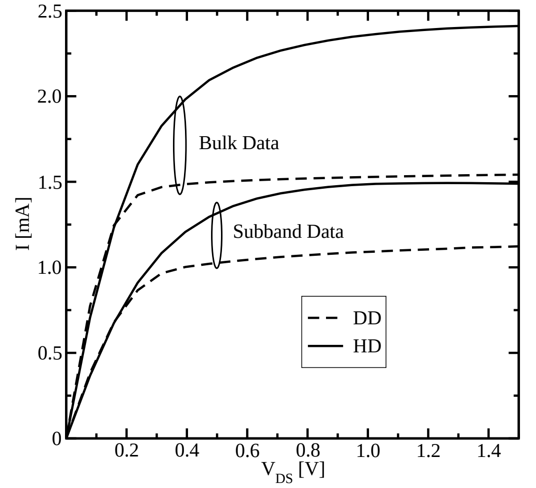

Fig. 6. The transfer characteristic of our device with 2D SMC tabulated data for drift diffusion and hydrodynamic transport in comparison with their counterpart of bulk data.