Nonstationary Carrier Dynamics in Quarter-micron Si MOSFETs

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ABSTRACT

An application of full Monte Carlo modeling to quarter-micron Si MOSFETs is given. Nonstationary carrier transport is shown to dominate in 0.4 μm or less channel devices, with peak velocities exceeding 1 x 10^7 cm/sec. The calculated results agree well with experimental values for a device with 0.15 μm channel length and 2.5 nm gate oxide thickness.

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A full Monte Carlo particle model has been successfully applied to quarter-micron Si MOSFETs. It is clarified that nonstationary carrier dynamics play an important role in 0.4 μm or less channel devices.

The present particle model involves the use of phonon, impurity, and surface roughness scatterings. The latter scattering model utilizes a partial diffusive scattering[1]. The electric field is determined two-dimensionally in a self-consistent manner with variable grid sizes. Under inhomogeneous electric fields, free flight and scattering events for each particle are calculated every adjusting time step.

To estimate the influence of the nonstationary carrier transport, drain currents from the present model are compared with those from a relaxation time model based on Fukuma's formulae[2] and from a conventional static model based on drift and diffusion. The drain currents are calculated for various channel lengths ranging from 0.1 to 0.8 μm, as indicated in Fig.1. The figure shows that the drain currents of the two nonstatic models (particle and relaxation time models which describe nonstationary carrier dynamics) are larger in comparison with those of the static model for channel lengths of 0.4 μm or less. These features suggest that nonstationary carrier dynamics become dominant for such small devices.

By using these two nonstatic approaches, the spatial distributions of the carrier velocity v and energy ε in the 0.4 μm channel length device are calculated as shown in Fig.2. It is found that values of v higher than the maximum static value (1×10^7 cm/sec) are obtained for both models under the gate near the drain where a large electric field is observed. This phenomenon is caused by velocity-overshoot due to the difference between momentum and energy relaxation time. Notice that v is almost the same (over 1×10^7 cm/sec) for both nonstatic models, whereas ε for the relaxation time model is larger than that for the particle model. The reason is considered as follows; Although the energy relaxation time is defined on the basis of the energy transition from the thermal equilibrium energy ε_0, the energy preceding to the transition under the gate is no longer equal to ε_0. Therefore, ε for the relaxation time model is overestimated. Accordingly, the hot electron phenomena such as the electron injection to gate oxide can not be simulated accurately with a relaxation time model.

For devices with a very thin gate oxide (2.5 nm), transconductance values for various channel lengths are calculated using the present particle model as shown in Fig.3. In a 0.15 μm channel length device, transconductance values of 620 and 925 mS/mm are obtained at 300 and 77 K, respectively. These results well agree with the intrinsic transconductance values derived from experimentation[3].

The obtained results serve as a good physical basis for carrier dynamics in quarter-micron Si MOSFETs. Therefore, a full Monte Carlo simulation becomes an indispensable tool for investigating nonstationary carrier dynamics and hot electron phenomena in deeper-submicron Si MOSFETs.

References

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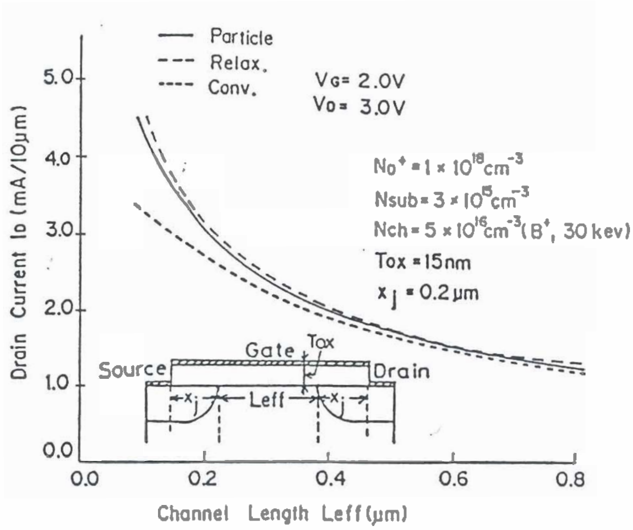

Fig. 1 Drain current versus channel length for various models. Solid line: with particle model; broken line: relaxation time; dotted line: conventional.

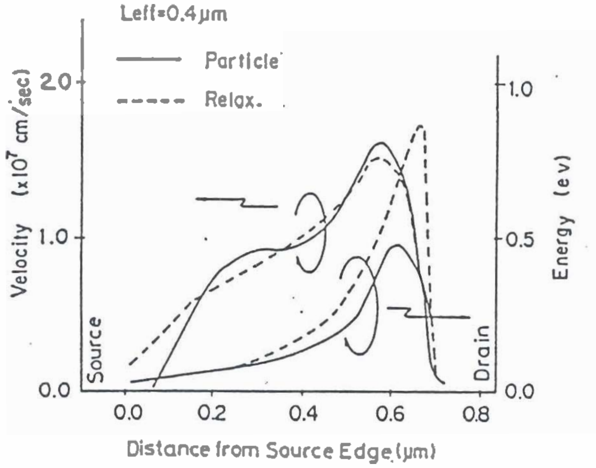

Fig. 2 Average electron energy and velocity in a channel of 0.4 μm effective channel length device. Solid line: particle model; broken line: relaxation time model.

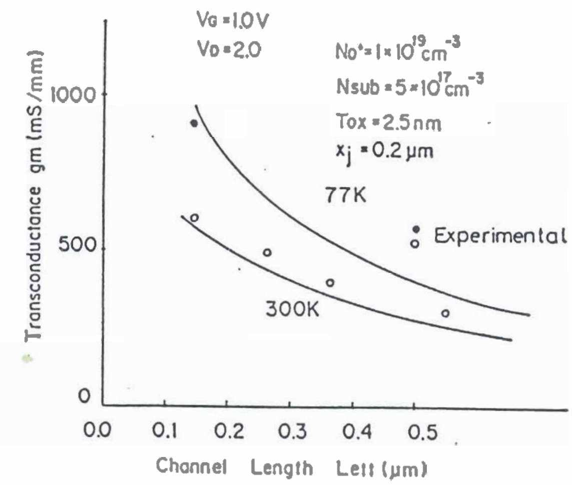

Fig. 3 Transconductance versus channel length for 2.5 nm gate oxide Si MOSFETs using particle model.