The Effective Conduction-Band Edge Method of Quantum Correction to the Monte Carlo Device Simulation

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A self-consistent Monte Carlo (MC) simulation is used to simulate the ultra-thin double gate MOSFET. To include quantum effects, a quantum correction is made to the semi-classical MC simulation by the effective conduction-band edge (ECBE) method [1]. The quantum corrected potential energy V^* can be calculated from the classical potential energy V by the ECBE equation, and the classical force $\vec{F} = -\nabla V(\vec{r})$ is replaced by the quantum mechanical force $\vec{F}^Q = -\nabla V^*(\vec{r})$.

Under the non-equilibrium condition, carriers have a different temperature from the lattice. In the Schrödinger-corrected MC (SCMC) simulation [2], the authors used a "transverse" temperature T_t which is related to the energy component acting on the plane transverse to the channel. Similarly, for the simulation of a D-G MOSFET, we can replace $k_B T$ in the ECBE equation with $U = \overline{U}_{yy}$, the average value of the stress tensor $\overline{U}_{yy} = \overline{< v_y \hbar k_y >}$ along each transverse line, to account for the variation of the electron's "temperature" along the longitudinal direction. For convenience, let us call this ECBE method, which utilizes U, the ECBE-U method.

The same device structure presented in [1] is studied here. Figure 1 shows a smoother electron density in the gate to source and gate to drain transition regions compared to previous study [1]. This is because the quantum correction is performed on all the vertical lines from the source to the drain contacts rather than only in the region between the gates. The drain current is plotted against the gate voltage in Fig. 2. In Fig. 3, U is plotted along the y direction at different x positions. Figure 4 compares U with $\overline{U}_{xx} \equiv \overline{< v_x \hbar k_x >}$ and $\overline{W} = \overline{< \hat{a} >}$ averaged over the y direction, at bias $V_{gs1} = V_{gs2} = 0.213V$ and $V_{DS} = 0.1V$. U increases between the gates because the electrons gain more energy in the channel when transported in the x direction and part of this energy is transferred to the transverse component due to scatterings and the nonuniformity of the electric field. The values of U are larger than $k_B T$ everywhere along the x direction. Because a larger U is equivalent to a higher "temperature", at which the ECBE approaches the classical limit [3][4], the electron density curve which results from the ECBE-U method is now double peaked accordingly (see Fig. 5). However, the quantization region is broadened near the interfaces compared to the result obtained by the ECBE method, resulting in a higher electron density at the center of the channel. Consequently, V and thus V^* (Fig. 6) in the middle of the channel, obtained from Poisson's equation by the ECBE-U method, is larger than that obtained by the ECBE method. Because the electrons now see a higher barrier from the source to the drain in the ECBE-U simulation, the resulting drain current is smaller than that obtained from the ECBE method.

Compared to the SCMC method, the ECBE-U method does not need to impose the condition that the quantum correction potential vanishes at the mid-points of the channel, which may not be correct for ultra-thin double gate MOSFETs. The MC simulation using the ECBE-U method does not need a reference potential for V^* and the quantum correction is determined self-consistently along each transverse line in the channel.

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[2] B. Winstead and U. Ravoioli, IEEE tranns. ED, vol. 50, pp.440-446, 2003.
[3] T. Tang and B. Wu, Semicond. Sci. and Tech., vol. 19, pp.54-60, 2004.
[4] T. Tang, T. O'Regan and B. Wu, J. Appl. Phys. Vol. 95, pp.7990-7997, 2004.

A full journal publication of this work will be published in the Journal of Computational Electronics.

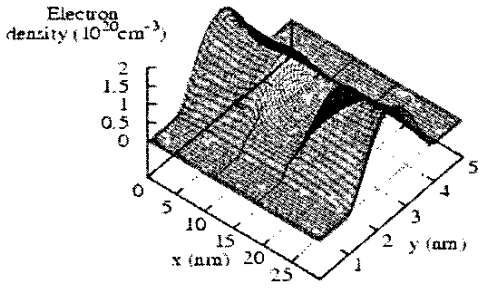

Figure 1 Electron density for V_{GS}=0.213V and V_{DS}=0.1V obtained by using the ECBE method. The quantum correction is performed on all the vertical lines.

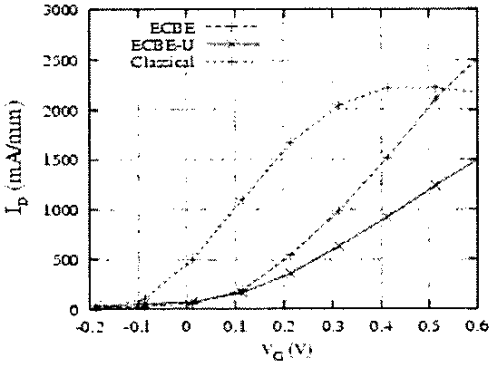

Figure 2 I_D vs. V_{GS} for V_{DS}=0.1V when the quantum correction are made by ECBE and ECBE-U method together with the classical result.

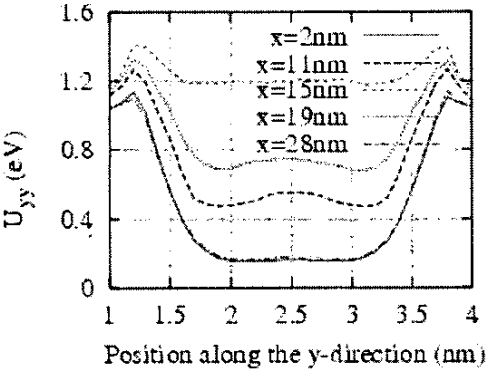

Figure 3 U_{yy} along the y-direction at different x positions.

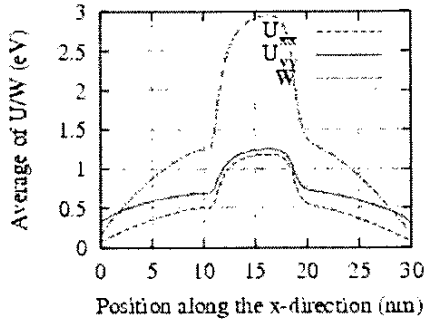

Figure 4 $\overline{U}_{xx}$, $\overline{U}_{yy}$ and $\overline{W}$ along the x-direction at the bias V_{gs1}=V_{gs2}=0.213 V and V_{ds}=0.1V

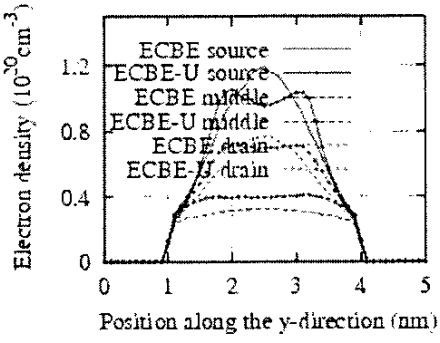

Figure 5 Electron density along the y-direction near the source (x=11nm), at the center (x=15nm) and near the drain (x=19nm).

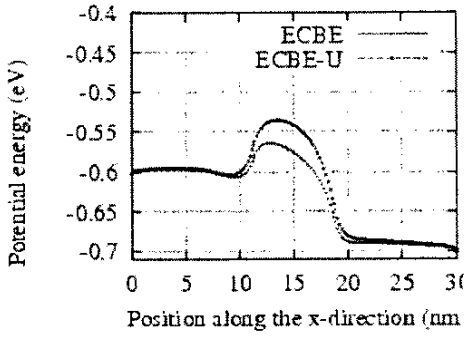

Figure 6 Comparison of V^* along the x-direction obtained by ECBE and ECBE-U methods.