# Comparison of non-equilibrium Green's function and quantum-corrected Monte Carlo approaches in nano MOS simulation

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With the significant advances in lithography technology, nano MOSFETs with channel length smaller than ten nanometers have been realized in several research laboratories [1]. Since the channel length becomes comparable to de Broglie wave length and scattering length, a quantum mechanical modeling of nano MOSFETs involving carrier's quasi-ballistic behaviors will be indispensable. In the previous workshop (IWCE9), we have reported independently based on the non-equilibrium Green's function (NEGF) [2] and quantum-corrected Monte Carlo (QMC) [3] approaches that a detailed understanding of scattering effects is important and crucial in determining the on-state current of nano MOSFETs. In this paper, we present a joint study on comparison between the NEGF and QMC methods for an ultra-short channel device. We will also discuss a role of impurity and plasmon scatterings on the drain current degradation.

For our comparison, we have adopted the double-gate MOSFET shown in Fig. 1. The channel length, channel thickness and gate oxide thickness are 10 nm, 3 nm and 1.5 nm, respectively. The doping density in the source and drain regions is $10^{20}\,\mathrm{cm}^{-3}$ and no doping inside the channel. In both of the NEGF and QMC methods, the ellipsoidal multi-valleys of silicon conduction band are incorporated, where only the lowest quantized energy levels for each valley are considered in the NEGF method. First of all, we consider only phonon scattering. To elucidate the role of scattering, we calculate the drain current as a function of the right boundary of scattering, $Y_{\mathrm{R\text{-}Scatt}}$, as shown in Fig. 2. Namely, scattering is included from the edge of the source region (-20 nm) to $Y_{\mathrm{R\text{-}Scatt}}$. The solid line and the solid circles represent the results from the NEGF and QMC methods, respectively. The results from the classical Monte Carlo method are also plotted in the open circles. As reported in ref. 2, the phonon scattering is important throughout the device, and not just in the source-end of the channel. The reason why drain-end scattering is so important was well explained in terms of the electrostatic barrier height floating due to the reflected electrons [2]. Here, it should be noted that there is a good agreement between the NEGF and QMC results, while the classical model underestimates the drain current considerably, because an increase in the occupancy of the 2-fold valleys due to the quantum size effect, which leads to a higher mobility, is not taken into account. The above results mean that the NEGF and QMC methods describe the relevant transport physics in a nano MOS transistor.

Next, a role of impurity and plasmon scatterings on the drain current degradation is simulated based on the QMC method as shown in Fig. 3. The solid squares denote the drain current considering the phonon and impurity scatterings, while the solid circles represent the drain current considering the phonon, impurity and plasmon scatterings. Since the donors are doped only in the source and drain regions, a further reduction in drain current due to the impurity scattering is observed in those two regions. Here, it is interesting to notice that the plasmon scattering deteriorates the drain current largely and mainly at the drain-edge of the channel. This is due to the fact that since the plasmon scattering has a strong effect to thermalize high energy electrons, the hot electrons at the drain-edge are most seriously affected by the plasmon scattering. The present results indicate that a detailed modeling of the dominant scattering processes will be required for an accurate and practical nano MOS simulation. At the workshop, we will also discuss the carrier's quasi-ballistic behaviors in nano-scale MOSFETs.

**References** [1] H. Wakabayashi et al., IEDM 03-989. [2] A. Svizhenko et al, IEEE Trans. Electron Devices **50** (2003) 1459. [3] H. Tsuchiya et al, Jpn. J. Appl. Phys. **42** (2003) 7238.

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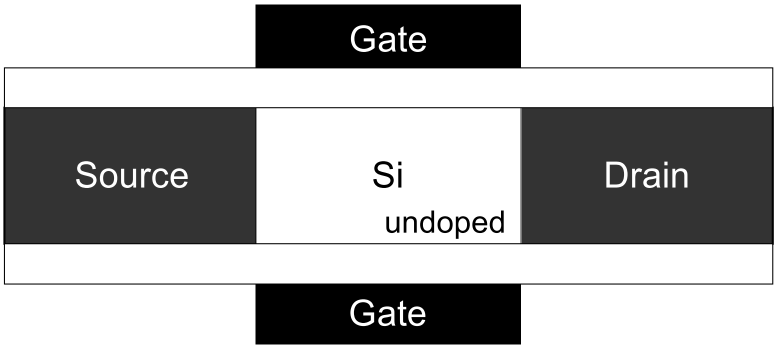


Figure 1: Schematic of a double-gate MOSFET used in the simulation. The channel length, channel thickness and gate oxide thickness are 10 nm, 3 nm and 1.5 nm, respectively. The doping density in the source and drain regions is $10^{20}$ cm$^{-3}$ and no doping inside the channel.

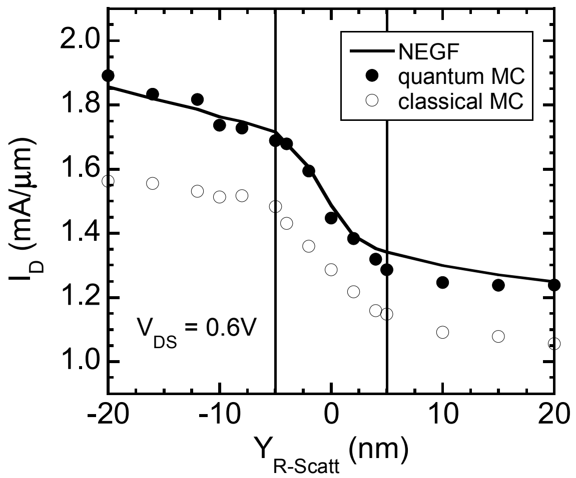


Figure 2: Drain current versus right boundary of scattering $Y_{\text{R-Scatt}}$. Channel extends from –5 nm to 5 nm. Scattering is included from –20 nm to $Y_{\text{R-Scatt}}$. The solid line, solid circles and open circles represent the results from the NEGF, quantum-corrected MC and classical MC methods, respectively. Note that only phonon scattering is considered here. The drain voltage is 0.6 V, while the gate voltage is adjusted so that the total charge density under the gate region becomes identical in the three methods.

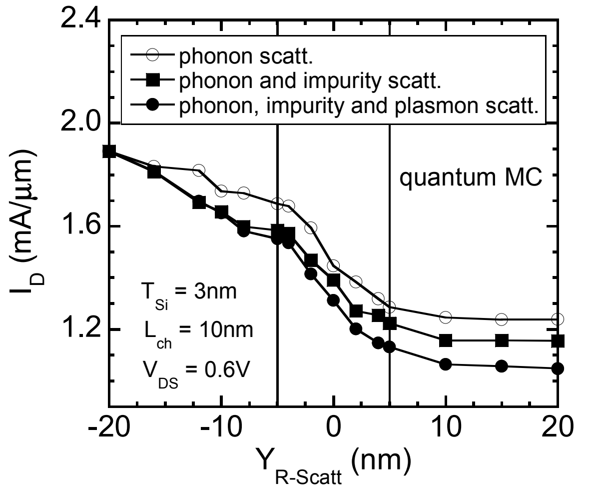


Figure 3: A role of impurity and plasmon scatterings in drain current degradation simulated by using the quantum-corrected MC method. The open circles include only the phonon scattering, the solid squares include the phonon and impurity scatterings and the solid circles include all of the phonon, impurity and plasmon scatterings. The drain voltage is 0.6 V.

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