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Monte Carlo simulation of nanoscale *n-i-n* diode: Influence of the hot-electron in drain region on ballistic transport

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1. Introduction

Recently, Si-MOSFETs are scaled down to the deca-nanoscale or nanoscale size due to progression of the process technologies. In nanoscale MOSFETs, the ballistic or quasi-ballistic transport is expected because the length scale of mean free path of the carrier and the channel length of MOSFETs are comparable [1]. Therefore, understanding the physics of the ballistic or quasi-ballistic transport is quite important now.

In this paper, we present a numerical study of the ballistic nanoscale Si *n-i-n* diode by Monte Carlo simulation. We found that the penetration of rebounded hot-electrons from the drain into the channel region significantly degrades the electron drift velocity near the drain-edge. We conclude that the scattering and the energy relaxation in the drain seriously influences the transport of nanoscale devices, and the analysis focused on channel region alone is sometimes inappropriate.

2. Simulation Method

We have simulated transport of the nanoscale *n-i-n* diode shown in Figure 1 using the self-consistent Monte Carlo method [2,3]. To clarify influence of scattering inside the source and the drain on transport, we have performed two different simulations. In all cases, the channel region is assumed ballistic and the scattering there is ignored artificially. In the first case, the source and the drain also are assumed ballistic (denoted as BCSD diode). Carriers suffer no scattering in the whole region. The long-range electron-electron (e-e) interaction affects the electron motion via the 1-dimensional Poisson's equation. Note that the long-range Coulomb interaction is always present even in th ballistic limit due to its long-range nature. The second is a simulation where carriers suffer from phonon scattering, elastic and inelastic, only inside the source/drain region (denoted as BC diode). The short-range e-e scattering and ionized impurity scattering are ignored to avoid complexity in our MC simulations. We assumed that the lattice temperature is 300K.

3. Results and Dicussions

Figure 2 and 3 show the electrostatic potential, the electron drift velocity and the mean kinetic energy in the BCSD and BC diode, respectively. In the BCSD diode, the peak positions of velocity and kinetic energy distributions are located near the drain–edge. On the other hand, the peak position of the drift velocity in the BC diode shifted to the center of the channel from the drain-edge altough the peak of energy distribution is still in the drain-edge. The peak value of drift velocity and the terminal current are lower than that of the BCSD diode with increasing applied bias (Figure 4).

The fact that the drift velocity decreases with increasing energy toward the end of channel in Figure 3 suggests the presence of the back-scattered electrons within the channel. In the BC diode, the electrons that reached the drain are scattered by phonons and the motion is randomized. A part of the hot-electoron can flow backward toward the channel due to random motion, and penetrates deep into the channel. The length of the penetration is controlled by the kinetic energy (Figure 5). The drift velocity near the drain-edge is degraded and its peak position is shifted toward the center of channel. As we see in Figure 4, the current is not much degraded at small applied biases. But a large bias volage causes the deeper penetration to the source and degrades the current. Figure 6 shows the trajectory of electrons in each diode. We can observe paths of the hot-electron penetrated from the drain to channel only in the BC diode.

We have performed the addional simulation of the BC diode to clarify the role of scattering process in the drain region. Only the elastic scattering is considered and the inelastic scattering is ignored inside the drain region (The current "elastic drain" in Figure 4). Surprisingly, the total current decreased as compared with the normal BC diode in which both of elastic and inelastic scatterng processes are considered. The penetration length of hot-electrons from the drain to the channel region is controled by the kinetic energy (see Figure 5). If the scattering in drain is completely elastic, energy relaxation of hot-electons is forbidden. The rebounded hot-electron can penetrate deep into the channel to the source degrading the current. The results suggest the energy relaxation process of hot-electon in the drain region is quite important on the transport of nanoscale devices.

4. Conclusions

We have investigated the electron transport of the ballistic nanoscale *n-i-n* diode by the semi-classical Monte Carlo simulator. We found that penetration of rebounded hot-electrons from the drain to the channel degrades the drift velocity near the drain-edge and also the total current of the diode. We conclude that the energy relaxation process of hot-electrons in the drain region is important to understand the nanoscale device characteristics because the length scale of penetration depends on the loss of kinetic energy of the hot-electons in the drain region.

Refferences

[1] K. Natori, Journal of Applied Physics, **76**, 8, 1994 (4879)
[2] C. Jacoboni and P. Lugli, *The Monte Carlo Method for Semiconductor Device Simulation*, Springer-Verlag, New York, 1989
[3] K. Tomizawa, *Numerical Simulation of Submicron Semiconductor Devices*, Artech House, Boston, 1993

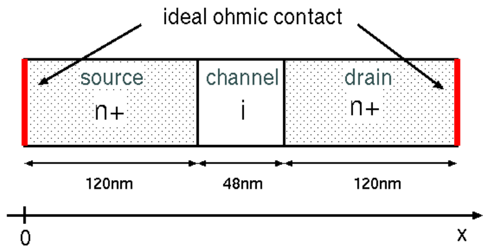

Fig..1 Schematic structure of the Si *n-i-n* diode. The doping concentration of source/drain regions is 10^{18} cm^{-3} and the device area is 120 nm x 120 nm.

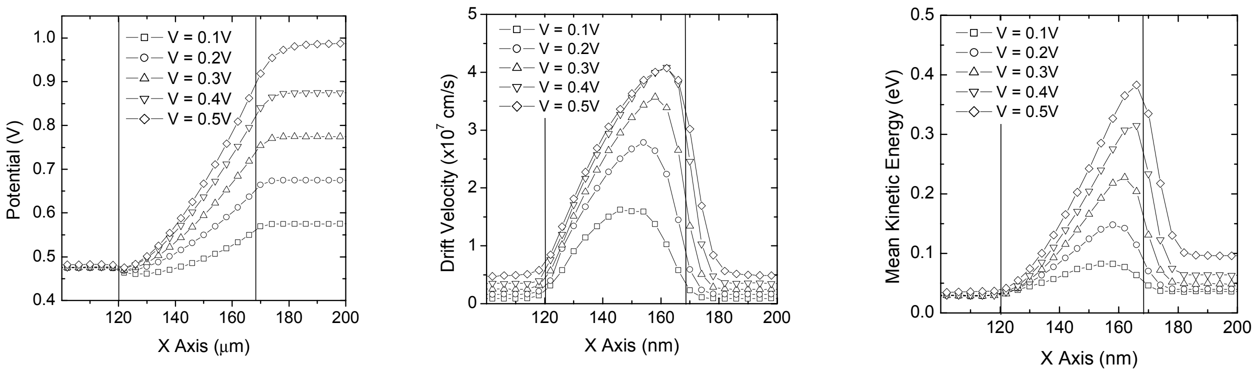

Fig. 2 The electrostatic potential, electron drift velocity, and electron mean kinetic energy in the BCSD nin-diode.

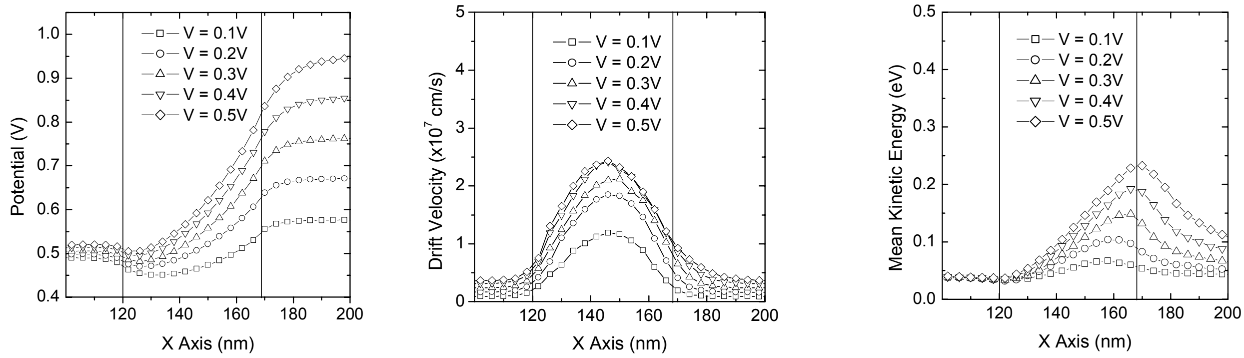

Fig.. 3 The electrostatic potential, electron drift velocity, and electron mean kinetic energy in the BC nin-diode.

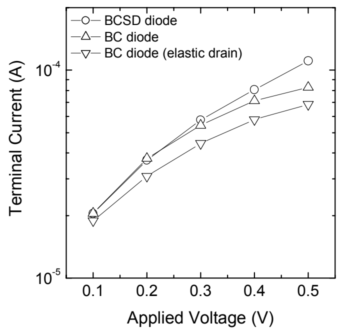

Fig.4 *I-V* characteristics of the *n-i-n* diode.

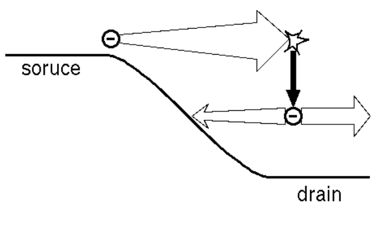

Fig.5 Schematic diagram to show the penetration of hot-electons from drain to the channel region.

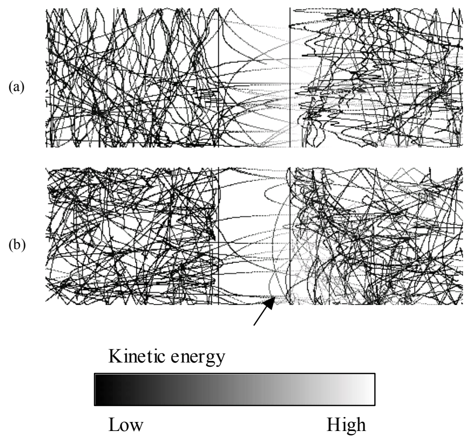

Fig. 6 The electon trajectory in each diode. (a) BCSD diode (b) BC diode.