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Investigation of Non-Equilibrium Carrier Transport in Sub-0.1μm MOSFET's Based on Monte Carlo Analysis

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Device simulation based on Monte Carlo method can treat the non-equilibrium carrier transport more precisely compared with the conventional hydrodynamic model simulation. Moreover, by tracing the carrier with time, the motion of the carriers inside the device can be analyzed more clearly. In this time, we have concentrated on carrier tracing of the conducting electron along the channel and holes generated by impact ionization phenomena, and analyzed the non-equilibrium carrier transport of the sub-0.1μm MOSFET in detail.

1 Introduction

The device size of MOSFETs has been dramatically reduced for the last decade to improve the performance and packing density of LSIs. Such effort to reduce the device size has been still continued toward the scaling limit. As a result, several small size MOSFETs with the physical gate length of 0.1μm or sub-0.1μm have been reported for these two or three years. In such small size devices, a non-equilibrium carrier transport becomes significantly important[1]-[3]. The computer simulation with accurate physical model is very useful for analyzing the carrier transport in such small size devices. However, we can not accurately analyze such non-equilibrium carrier transport using the hydrodynamic model which has been widely used so far. Then, we have developed a new Monte Carlo simulator to investigate the non-equilibrium carrier transport in sub-0.1μm MOS devices.

2 Simulation Algorithms

The flowchart for Monte Carlo simulation is shown in Fig.1. In the former part of the flowchart, the electric field distribution is calculated by solving Poisson equation. Taking into account this electric field distribution, the motion of particle during the free flight is calculated by solving Newton equation in the latter part of the flow chart. After calculating the particle motion, the simulation flow returns to the calculation of the electric field distribution using the redistributed particle data. As for the scattering mechanism after the free flight, the acoustic phonon scattering, the optical phonon scattering and the impact ionization scattering are included. Moreover, the hole-electron pairs are generated when the impact ionization scattering occurs and the holes generated can be traced with time in this simulator.

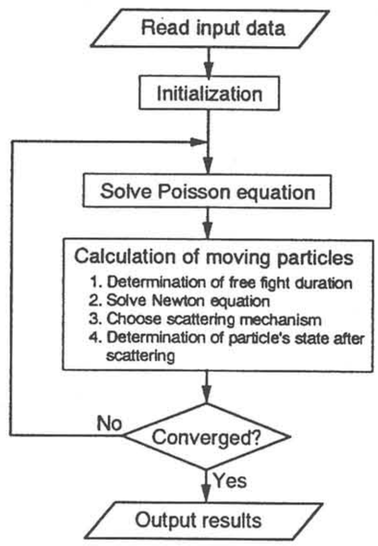


Fig.1 Flowchart of Monte Carlo simulation.

3 Simulation Results

LDD MOSFET with the device structure and device parameters as shown in Fig.2 is used in this simulation. The gate length is 0.06μm. Figure 3 shows the two-dimensional carrier distribution and the potential contour map in such device. The bias condition is V_G=0.8V and V_D=2.0V. It is clearly seen in the figure that the electrons

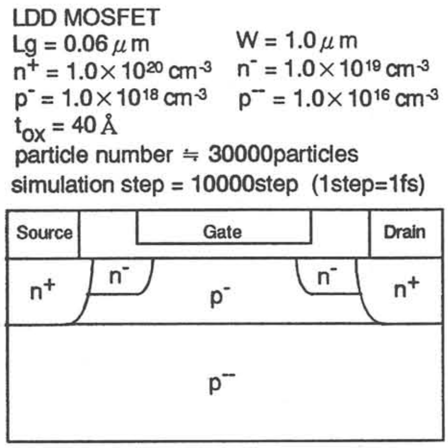


Fig.2 Device structure and parameters.

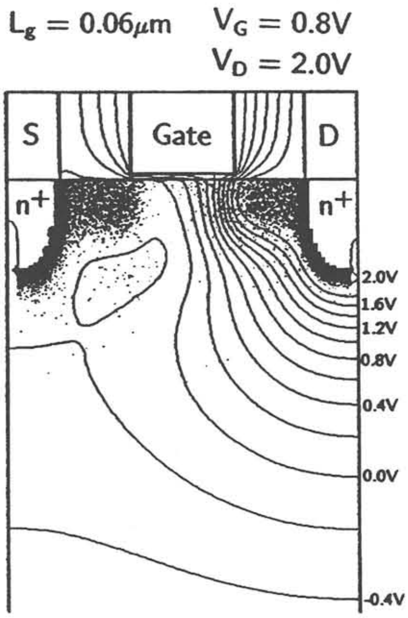


Fig.3 Two-dimensional carrier distribution and potential contour maps.

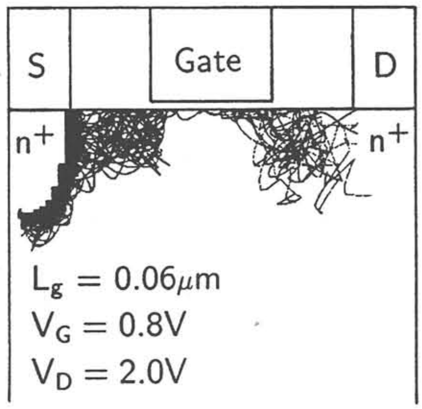


Fig.4 Trajectory of electrons emitted from the source.

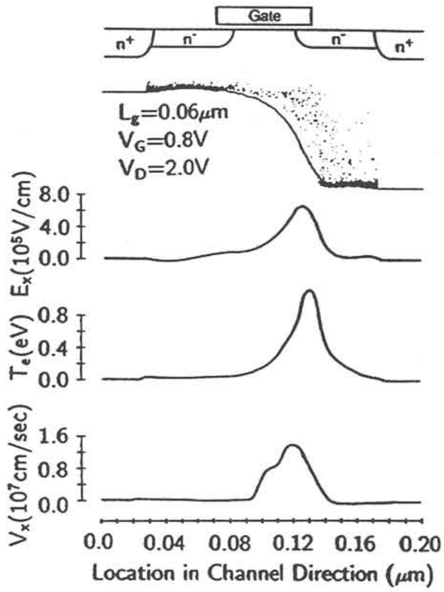
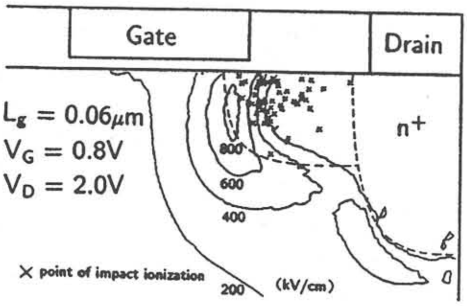


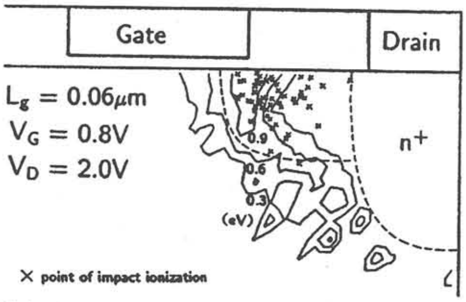
Fig.5 Distributions of electron energy in conduction band, electric field, electron temperature and electron drift velocity along the channel.

flow from the source to the drain according to the potential distribution although only a part of electrons are plotted inside the source and the drain. The trajectory of electrons emitted from the source is illustrated in Fig.4. It is obvious from the figure that the electrons with high energy are more pronouncedly scattered near the drain. Figure 5 shows the distributions of the electron energy in the conduction band, the electric field, the electron temperature and the electron drift velocity in the channel direction. It is clear from the electron energy distribution that there exist a considerably large number of electrons with high energy which escape from the scattering and hence represent the ballistic conduction in the n^- drain region although these electrons lose their energies near the n^+ drain region. It is also obvious in the figure that the average electron drift velocity exceeds the saturation velocity in the channel region and the n^- drain region and hence the velocity overshoot effect occurs in this device.

The non-equilibrium impact ionization phenomenon has been also investigated in detail using our new Monte Carlo simulator. The contour maps of the electric field and the electron temperature near the drain are plotted in Fig.6 in which the location where the impact ionization events occur is indicated by "x" mark. As is obvious from the figure, the peak position in the electron temperature distribution is more shifted to the



(a) electric field distribution.



(b) electron temperature distribution.

Fig.6 **Two-dimensional electric field distribution and electron temperature distribution with the location where the impact ionization occurs.**

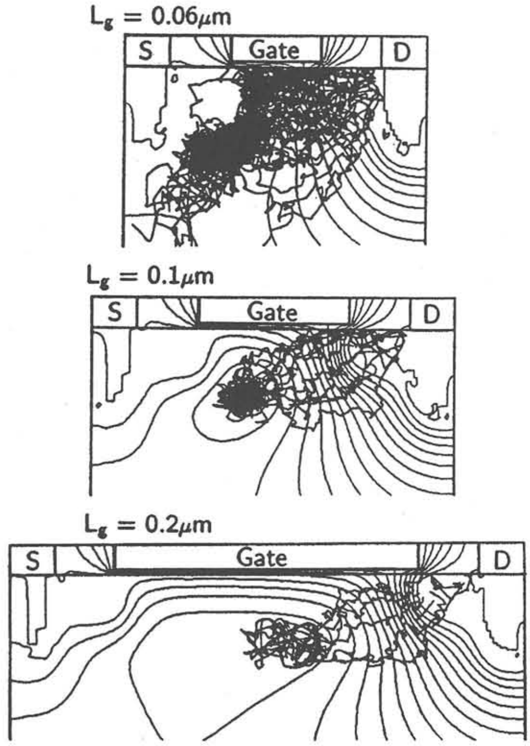


Fig.7 **Trajectory of the holes generated by impact ionization (V_G = 0.8V, V_D = 2.0V, time = 10ps).**

drain side compared with that of the electric field distribution. This is because the electrons must travel for some distance through the peak position of the electric field distribution to gain the sufficient energy from the electric field. In addition, it is also obvious in the figure that the location for the impact ionization is far more shifted to the drain side compared with two peaks of the electric field distribution and the electron temperature distribution. This means that the electrons with high energy which cause the impact ionization exist in the n^- drain region closer to the n^+ drain region where the electron temperature is lower than the peak value. Still many electrons with high energy can exist in this region although the electron temperature is relatively low there because the electrons with low energy which initially exist are taken into consideration to calculate the electron temperature which is the average electron energy. The trajectory of the holes generated by the impact ionization is plotted for three kinds of devices with different gate length in Fig.7. It is clear from the figure that the generated holes move closer to the channel and the Si-SiO_2 interface in the device with smaller gate length. This means that MOSFET's with shorter channel length more easily suffer from the device characteristic degradation by the hot carrier injection.

4 Conclusion

We have developed a new Monte Carlo simulator which can trace the carrier motion with time and hence simulate the non-equilibrium phenomena in sub-0.1μm MOSFET's. By using this Monte Carlo simulator, it was shown that the velocity overshoot effect can not be neglected in 0.06μm MOSFET and the electrons with high energy in the n^- drain region closer to the n^+ drain region cause the significant impact ionization although the electron temperature is relatively low in this region. In addition, it was revealed that the device characteristic degradation is caused more seriously in sub-0.1μm MOSFET's by the hot holes which move closer to the channel and the Si-SiO_2 interface.

References

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[3] M. Koyanagi, SEMICON Korea 95(1995) p37.