SIMULATION OF SEMICONDUCTOR DEVICES AND PROCESSES Vol. 3
Edited by G. Baccarani, M. Rudan - Bologna (Italy) September 26-28, 1988 - Tecnoprint

TWO DIMENSIONAL PARTICLE SIMULATION OF LDD MOSFET

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ABSTRACT

The numerical modelling of submicrometer gate LDD MOS device using Monto Carlo method is implemented in this paper. To cut down the computation time, a particle window approach is proposed. The calculation result indicates that the carrier velocity overshoot effect is of little significance for 0.4 μm LDD MOSFET.

INTRODUCTION

Along with the rapid progress of VLSI fabrication technology, the device size are scaled down to micrometer and submicrometer. Due to the significant improvement in device performance, the submicrometer gate Lightly Doped Drain-Source (LDD) device has been used as one of the building elements of VLSI. To predict the behavior of LDD MOSFET, several numerical techniques have been proposed to simulate the device, which are based on Poisson's equation and current continuity equation using a static relation of velocity versus electric field. However, there is no reasonable excuse to assure that the static v/E relation can be used to analyze submicrometer gate LDD MOSFET without producing significant error. In this paper, the Monto Carlo particle method is employed in simulation of 0.4 μm gate LDD MOS device. The numerical result shows that the velocity overshoot effect can be neglected in this case.

SIMULATION

A two dimensional configuration of 0.4 μm gate LDD MOS device is given in fig.1, where the lattice temperature is 300 K, the impurity density in N^+ region is 10^{19} cm^{-3}, N^- region $2X10^{17}$ cm^{-3}, P substrate region $5X10^{16}$ cm^{-3}, gate oxide thickness is 20nm, N^+ and N^- junction depth are 0.1 and 0.25 μm, respectively.

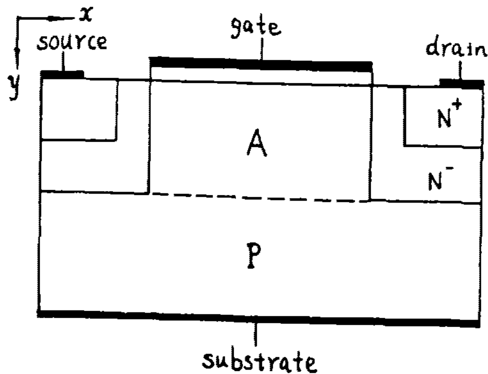

Fig.1 Structure of simulated
0.4μm gate LDD MOS device

In particle simulation, two types of boundary conditions for Poisson's equation are imposed. At the insulating boundary, the electric field normal to the boundary is zero. At the ohmic boundary, the electric potential is a constant given by applied bias plusing diffusion voltage. Poisson's equation is solved using the SIP iteration approach.[1] The charge distribution is obtained using the nearest grid point assignment scheme. To reduce the simulation time, a particle window method is presented. As shown in region A of fig.1, the window is limited to region where carrier density is high enough and it is much smaller than the solution region of Poisson's equation. Corresponding to zero current density and heavily doped boundary, the edges of window can be regarded as *reflecting* and absorbing walls for particles, respectively. In the absorbing wall, a constant charge density is also assumed, which can easily be implemented by keeping the number of particle in a row of cells immediately adjacent to the contact constant. In addition, an initial guess *of solution* is *made*, *in which the carrier* is *uniformly* existed in the device and the velocity follows Maxwell distribution.

Considering the computer memory capacity can not meet the need of simulating all electrons in the device. A limited number of super particles are introduced and each of them stands for a cloud of electrons, the numerical modelling procedure is same as that for real particle. Considering that the intravalley scattering process occures mainly through acoustic phonons, the transition probability of electron by intravalley scattering can be represented as

$$P_a = D_a^2 k_B T \ (m_n^*)^2 \ v / (\pi \hbar^4 \rho s) \tag{1}$$

where k_B is Boltzmann constant, D_a is the deformation potential (9eV), m_n^* is the effective mass of electron ($0.295m_0$), ρ is the density of silicon ($2.33 g/cm^3$), s is the sound velocity (5.22×10^5 cm/sec.), v is the electron velocity. The intervalley inelastic scattering and surface roughness scattering are also taken into account.[2] At the interface of Si-SiO_2, the silicon surface roughness scattering is treated in a particle manner, that is

$$k_x = k_x + \alpha r |k| \tag{2}$$

$$k_y = -(k^2 - k_x^2)^{1/2} \tag{3}$$

$$k_z = k_z \tag{4}$$

where k is the wave number of carrier, r is a normalized Gaussian random number, α is a fitting parameter ($10^{-4} \sim 10^{-1}$).

To accelerate the rate of convergency, the number of particles entering and leaving the device are equal. The steady state is reached at time when the accumulative count of particles absorbed by drain terminal begin as a linear function of timesteps[3](see fig.2).

In simulation, the propagation of truncation and roundoff errors should be suppressed to avoid an unstable solution of discrete equation. For this reason, a smoothing technique for charge density and average velocity, as expressed below, is adopted

$$Q_j(i,j) = CQ_{j-1}(i,j) + (1-C)Q(i,j) \tag{5}$$

where C=0.9 will lead to a satisfactory result, Q_j is charge density (or average velocity) in the jth timestep, Q is the initial charge (or average velocity).

Once the electron distribution function has been obtained, the physical observables, such as the drift velocity etc., can in principle be calculated by numerical integration. However, a fine histogram mesh has to be used to achieve desired accuracy. In order to save computation resources, these quantities are simulated directely from the initial and final k-components of each free flight, eg., the drift velocity of electron can be calculated as below

$$V_d = \frac{1}{K} \sum \int_{k_i}^{k_f} \frac{1}{\hbar} \frac{\partial E}{\partial k_x} dk_x = \frac{1}{\hbar K} \sum (E_f - E_i) \tag{6}$$

where k_i and k_f are the initial and final value of k_x for a particular flight, K is the total length of the k space trajectory. The summation in (6) is over all electron free-flights. E_i and E_f are the initial and final energies for the flight.

RESULTS AND DISCUSSIONS

The simulation of LDD MOS device takes about 15 CPU hours in DPS-8/49 computer. Fig.2 illustrates the curve of accumulative count of particles absorbed by drain terminal versus time. Fig.3 gives the lateral electric field distribution along the channel of LDD MOSFET, where V_{GS} =1.5V, V_{DS} =3V, V_{BS} =-0.5V. The electric field peak is found in the N^- region closest to the N^+ region and is lower than that of conventional device under the same bias condition.

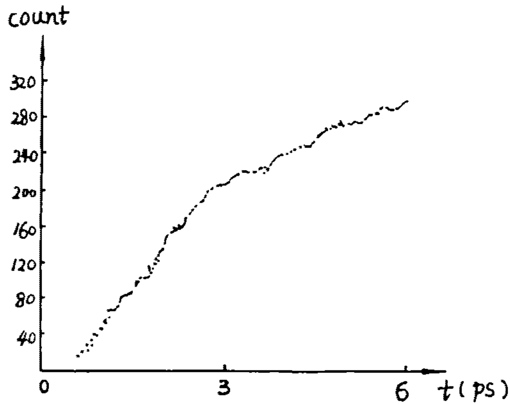

Fig.2 Accumulative count of particles absorbed by drain terminal versus time

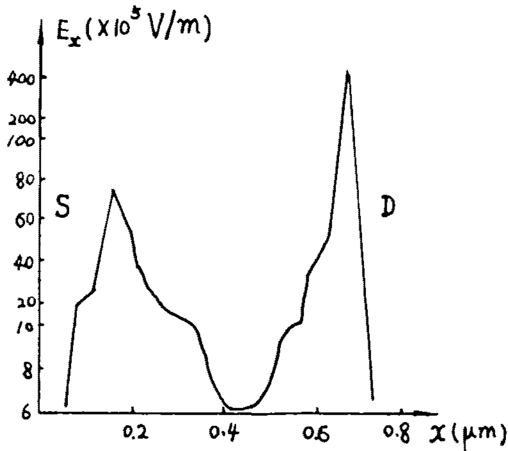

Fig.3 Lateral electric field distribution along the channel

Fig.4 shows the distribution of average drift velocity V_d in the channel of LDD MOSFET and it is in reasonable agreement with the result predicted by the conventional device modelling. Thus we can come to the conclusion that the carrier velocity overshoot effect is weak and the drift-diffusion transport model is still available for 0.4μm LDD MOS device.

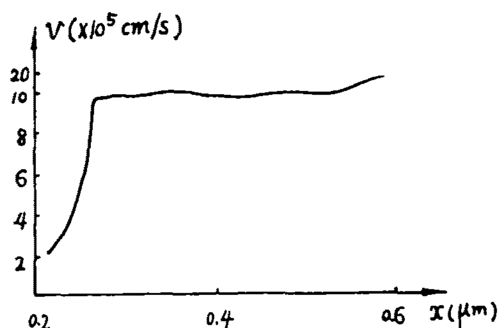

Fig.4 Average drift velocity in the channel of LDD MOSFET

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