SIMULATION OF IMPACT IONIZATION PROCESS IN DEEP SUBMICRON N-CHANNEL MOSFETS

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Abstract – The ensemble Monte Carlo simulation of deep submicron silicon MOSFET with 50 nm channel length is performed. The effective threshold energy of impact ionization process in the MOSFET is calculated in the framework of Keldysh model.

I. Introduction

It is known that in numerical simulations of integrated circuit elements with the reduction of their dimensions, particularly deep submicron MOSFETs, an account of impact ionization process is essential. The latter is caused by the fact that the rate of impact ionization in such elements can be comparable or even greater than the rates of other considered scattering processes as a result of the presence of high electric field strengths [1, 2]. The main purpose of this study is the estimation of effective threshold energy in deep submicron silicon n-channel MOSFET with 50 nm channel length in the framework of Keldysh impact ionization model.

II. Simulation model and results

The considered MOSFET structure is presented in Fig. 1. The MOSFET dimensions are denoted in the same figure. Other parameters used in the simulation are the following: gate oxide thickness is 10 nm, acceptor doping levels of the channel and substrate are equal to $5 \cdot 10^{23}$ m^{-3} and 10^{24} m^{-3}, donor doping level of the source and drain regions is equal to 10^{25} m^{-3}. The calculations are performed for the temperature T = 300 K.

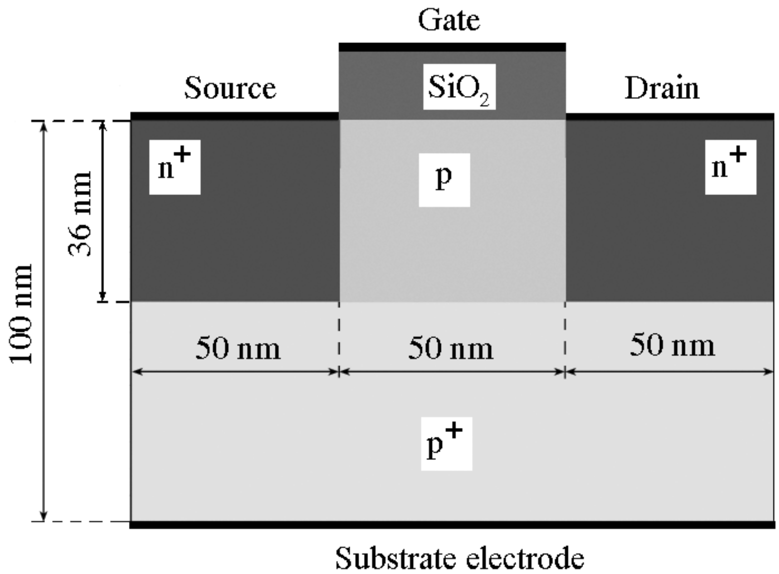

Figure 1 – The cross-section of the simulated silicon n-channel MOSFET

Electron transport simulation in silicon conduction band is performed in the framework of the effective mass approximation and includes X and L valleys with account of nonparabolicity of the dispersion relation. Electron scattering processes are intravalley and intervalley phonon scattering, ionized impurity scattering, plasmon scattering and impact ionization process [1–4]. Hole transport in valence band is simulated in the effective mass approximation in heavy, light and split-off bands. Scattering mechanisms for holes are phonon and ionized impurity scatterings. Nonparabolicity and anisotropy are taken into account [5–7]. The electrostatic potential and electric field strength are found via the solution of a corresponding two-dimensional Poisson equation which is self-consistently incorporated into the Monte Carlo transport simulation. Source, drain and substrate electrodes are modeled as ideal ohmic contacts and metal gate is supposed to be aluminum.

To calculate the effective threshold energy of impact ionization process in the n-channel MOSFET the process was included into Monte-Carlo simulation as additional scattering mechanism. In the framework of Keldysh impact ionization model its scattering rate $W_{II}(E)$ is expressed by so-called Keldysh formula with given threshold energy E_{th} [8]

$$W_{II}(E) = AW_{ph}(E_{th})\left(\frac{E - E_{th}}{E_{th}}\right)^2, \qquad (1)$$

where E is electron energy, A is a fitting parameter, $W_{ph}(E_{th})$ is the total electron-phonon scattering rate at the energy equal to E_{th}. Thus the model has two fitting parameters A and E_{th} with E_{th} = 1.2 eV for "soft" and E_{th}= 1.8 eV for "hard" thresholds.

The effect of impact ionization process on some characteristics of a deep submicron MOSFET for both "soft" and "hard" threshold models was studied, particularly, in [9] but holes were treated in quasi-equilibrium approximation. In present simulation we used a "soft" threshold model with A = 0.38 [10].

The dependence of the effective threshold energy E_{theff} versus the drain voltage V_D for several gate biases V_G for the simulated MOSFET are presented in Fig. 2. As it can be seen, it is possible to conclude that the effective threshold voltage has nearly linear dependence on the drain voltage for gate biases in the range from 1 to 1,4 V. The dependence can be approximated as

$$E_{theff} = 0,22V_D + 0,98 \quad [\text{eV}]. \qquad (2)$$

At rather high drain biases (V_D > 3 V) when high electric field (> $5{\cdot}10^7$ V/m) exists in the transistor channel, the effective threshold energy for "soft" threshold model saturates at approximately 1,7 eV [9]. The obtained results are in a reasonable agreement with the results of [11] where the effective threshold energy was calculated in bulk silicon for uniform electric field with the strength of $5{\cdot}10^7$ V/m.

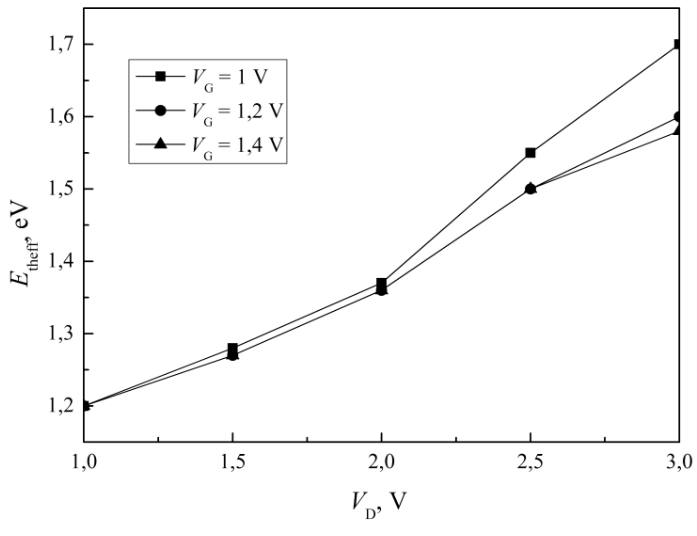

Figure 2 – The effective threshold energy in the channel of the MOSFET

III. CONCLUSION

In this paper the effective threshold energy of impact ionization process in deep submicron n-channel MOSFET was calculated in the framework of Keldysh "soft" threshold model. The results of the simulation show the possibility of the use of one fitting parameter *A* in the description of impact ionization process. Threshold energy is *a priory* known and can be approximated by linear dependence versus the drain voltage.

References

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