Sensitivity Analysis for Random Dopant Fluctuation in DG MOSFET using Regression Model

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Abstract

Random dopant fluctuation has been constantly noticed in double gate metal-oxide-semiconductor field effect transistor. It causes several problems in the device such as threshold voltage shift and drive current variation. In this paper, a regression model is proposed to provide sensitivity of drive current. For the regression model, the numerical model is built and compared the results with a commercial TCAD simulated results for the verification.

Keywords: Random dopant Fluctuation (RDF), double gate (DG) MOSFET, Sensitivity.

1. Introduction

Over the past decades, technology for shrinking the device has been steadily developed. However, with improving the performance, several problems have taken place. The one of example about the problems is random dopant fluctuation (RDF). It brings threshold voltage shift and variation of drive current ($I_{DS}$) representatively [1]. Since double gate (DG) metal-oxide-semiconductor (MOSFET) cannot also avoid the phenomenon, by using impedance field method, previous researches has focused threshold voltage shift caused by RDF [2].

On the other hand, in this paper, we propose other way to analyze RDF through a regression model with respect to randomly doped body doping concentration ($N_A$). Unlike previous researches, regression model can directly shows relationship between $I_{DS}$ and doping profile in DG MOSFET. For the regression model, a numerical model is realized using Poisson’s equation and continuity equation. All of the results are verified by comparing a commercial numerical device simulator.

2. Modeling Scheme

For the simulation, DG MOSFET is simplified as the two dimensional schematic structure shown in Fig 1.

FIG. 1. Schematic structure of two dimensional symmetric DG MOSFET.

where $x$ and $y$ are the orthogonal coordinate, $L$ is the 100nm channel length, $t_{ox}$ is the 1nm oxide thickness, $t_{si}$ is the 10nm silicon body thickness, source and drain are heavily n-type doped $N_D=10^{20} cm^{-3}$, $S_1$ to $S_9$ are virtual 9 sections divided with the same area in order to roughly represent random dopant in DG MOSFET. By numerically solving Poisson’s equation and continuity equation in steady state as the following equation (1) and (2), $I_{DS}$ is calculated.

$$\nabla^2 V = -\frac{q}{\varepsilon}(p - n + N_D^+ - N_A^-) \quad (1)$$

$$\nabla \cdot J = 0 \quad (2)$$

where $V$ is the potential, $q$ is the elementary charge, $\varepsilon$ is the dielectric constant, $n$ and $p$ are the electron and hole density, $N_D^+$ and $N_A^-$ are the ionized donor and acceptor concentration, $J$ is the current density.

To build the regression model for RDF in DG MOSFET, the device is virtually divided with the same area. Each section from $S_1$ to $S_9$ has different $N_A$, which is generated by Latin hypercube sampling. Based on $N_A=5\times10^{18} cm^{-3}$, total 100 doping profiles randomly...
generated and simulated using the numerical model. From the results, the regression model can be defined as a linear $I_{DS}$ function according to $N_d$ of each section:

$$I_{DS} = a_0 + \sum_{i=1}^{9} a_i N_i$$  \hspace{1cm} (3)$$

where $a_i$'s are the model coefficients, $N_i$'s are the doping concentrations of section $S_i$. Since the coefficients can be regarded with sensitivity about doping concentration, it provides how the position of random dopants affects the performance of DG MOSFET.

3. Result and Discussion

First of all, the numerical model is verified with the simulation results of the commercial 2-D ATLAS numerical device simulator of Silvaco, Inc [3]. In this study, in order to only focus on investigation about the dopants fluctuation, normalized $I_{DS}$ based on $V_{DS}=0.1\text{V}$, $V_{GS}=1\text{V}$ and $N_i=10^{17}\text{cm}^{-3}$ are used. The following Fig. 2 shows comparison of the numerical model and the simulation results according to uniform $N_d$. Considering all results, we can analyze the effect of random dopants in DG MOSFET.

![Comparison of the numerical model and the simulation results at $V_{DS}=0.1\text{V}$.](image1)

FIG. 2. Comparison of the numerical model and the simulation results at $V_{DS}=0.1\text{V}$.

Next, from the verified numerical model, 100 sets of $I_{DS}$ are calculated for the regression model. Since $I_{DS}$ is normalized, random doping profiles are also normalized by using maximum and minimum $N_d$. The Fig. 3 represents the coefficients of the regression model. In the Fig. 3, the $I_{DS}$ tendency about $N_d$ variations is represented. Since the symmetric structure is used, coefficients are almost the same along center of y axis. However, the coefficients of drain side are higher than that of source side indicating that the $I_{DS}$ variation is more vulnerable to $N_d$ variations of drain side. It reflects the phenomenon of channel length modulation, which includes that the inversion charge density of drain side is more sensitive with respect to $N_d$ [4].

![Coefficients of the regression model at $V_{DS}=0.1\text{V}$ and $V_{GS}=1\text{V}$.](image2)

FIG. 3. Coefficients of regression model at $V_{DS}=0.1\text{V}$ and $V_{GS}=1\text{V}$.

4. Conclusion

In this study, we proposed to analyze the effects of RDF in DG MOSFET using regression model. In order to support the regression model, although the virtually divided nine sections cannot exactly explain the random dopants, it can allow us to know how the position of RDF can impact on the variability of DG MOSFET performance through the coefficients of the model.

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