Channel Doping-dependent Thermal and Flicker Noise Compact Model in Double Gate MOSFET under Weak Inversion Region

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Abstract
Channel doping-dependent compact model for thermal and flicker noise in double-gate (DG) metal-oxide-semiconductor (MOSFET) under weak inversion region is presented. Based on the previously proposed analytical model for the charge distribution and drive current, the power spectral density of the thermal and flicker noise is calculated with respect to channel doping variation by substituting of the differential charge and voltage relation. To verify our proposed noise compact model, commercially available 2D numerical simulation is used, and the results from the model show a good agreement with respect to the channel doping variation.

Introduction

Double gate (DG) metal-oxide-semiconductor field-effect transistor (MOSFET) is strong candidate for the future device technology, which has more stable and powerful device performance than that of conventional MOSFET [1, 2].

Therefore, a lot of compact models have been proposed in order to show the electrical characteristics of DG MOSFET [3, 4]. Representatively, in noise analysis, the model of Srabanti et al. [5] and Sudhamsu et al. [6] are analytically represented with thermal and flicker noise. However, because these models ignore consideration of channel doping variation, it cannot be able to obtain any information about channel doping-dependent thermal and flicker noise in DG MOSFET. Since good noise performance critically determines the quality of analog and RF circuits, therefore, it is necessary to be analyzed and modelled for improving reliability of analog/RF applications.

In this work, we propose analytical model for channel doping-dependent thermal and flicker noise in DG MOSFET under weak inversion region. According to results of the previous researches, because of charge screening effect, electrical characteristics such as drive current and charge distribution in strong inversion region are converged regardless of channel doping concentration [3, 4]. Therefore, our proposed model is focused under weak inversion region where the influence of channel doping is significantly distinguishable.

To build model, we basically use the previously proposed analytical model [4] which shows the charge distribution and drive current in DG MOSFET with varying the channel doping concentration. For validation of the proposed noise model, we use the commercially available 2D ATLAS numerical simulation [7].

Compact Model for Noise Analysis

A. Charge distribution and drive current model
For representing the charge distribution and drive current of the DG MOSFET, we adapt the previously proposed potential-based analytical model [4], which can be used for investigation of the effects on channel doping variation. From the model, drive current and charge distribution are calculated.

B. Thermal and Flicker noise model
The drain current noise power spectral density is given by [5],

\[
S_{\text{DS n}} = \frac{1}{I_{\text{DS}}} \int_{V_s}^{V_D} g \left( 1 + \frac{E}{E_c} \right)^2 S_{\delta i} dV,
\]

where \( S_{\delta i} \) is the power spectral density of local current, \( E \) is the electric field along the channel, \( E_c \) is the critical electric field, the factor \( g(1+E/E_c) \) and \( L \) are decided by the same equations in the previously reported research [5].

The power spectral density of local current for the thermal and flicker noise are written as [5]:

\[
S_{\text{DS thermal}} = A \int_{V_s}^{V_D} \frac{Q^2}{Q-B} dV,
\]

\[
S_{\text{DS flicker}} = D \int_{V_s}^{V_D} \frac{Q^2}{Q-B} \left( \frac{q}{Q+F} + G \right) dV,
\]

where \( A, B, D, F, G \) are functions related to drive current \( I_{\text{DS}} \), effective electron mobility \( \mu_{\text{eff}} \), frequency \( f \), and several constant values. \( V \) is the electron quasi-Fermi potential, \( Q \) is the charge distribution, the source and drain voltage are \( V_s \) and \( V_D \), respectively. To calculate Eqs. (2) and (3), the differential charge and voltage relation \( dV \) is newly adapted as the following equation (4) instead of commonly used the function reported by Oana et al. [4, 8].

\[
dV = \frac{t_{\text{Si}} t_{\text{SiO2}} \epsilon_{\text{SiO2}}}{\epsilon_{\text{Si}}} - \frac{V}{c} \frac{dC}{dc}.
\]

where \( N_d \) is the channel doping concentration, \( C \) are the total inversion charge density, \( \epsilon_{\text{Si}} \) and \( \epsilon_{\text{SiO2}} \) are the permittivity of silicon and oxide, respectively. Through substitution Eq. (4) into (2) and (3), the power spectral density can be calculated as...
compact model for thermal and flicker noise with respect to $N_A$ variation.

**Results and Discussion**

In this paper, the structure parameters are used as 100 nm channel length, 10 nm silicon thickness, and 1nm oxide thickness. $N_A$ has a range from $10^{15}$ cm$^{-3}$ to $10^{19}$ cm$^{-3}$ in the results.

Fig. 1 (a) and (b) show the results of the proposed thermal noise model against gate voltage ($V_{GS}$) and $V_{DS}$, respectively. The results of the proposed thermal noise model are well-matched with the results of TCAD simulation. With increasing $V_{GS}$ and $V_{DS}$, the thermal noise spectral density increases and decreases, respectively. It has the same tendency compared to the results of previously reported researches [5, 6]. With $N_A$ increase, more lower noise spectral density is observed due to lower inversion charge.

Fig. 2 (a) and (b) shows the proposed flicker noise model with respect to $N_A$ variation against $V_{GS}$ and $f$. Compared to simulation results, Fig. 2 shows good agreement on calculation of the flicker noise. Through Fig. 2, well-known general characteristics of flicker noise cannot be observed, but also the descent of the spectral density with increasing $N_A$ is represented because of the same reason in the thermal noise case.

**Conclusion**

In this paper, we proposed the thermal and flicker noise compact model with respect to channel doping variation in DG MOSFET under weak inversion region. From all shown results, the proposed model expressed general characteristics of the thermal and flicker noise as well as the effects of channel doping variation. For effectiveness of the proposed model, the results from the proposed noise model were compared with commercially available 2D numerical simulation. Therefore, the compact thermal and flicker noise model can be useful to investigate noise in DG MOSFET with varying channel doping concentration.

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**References**


