Random doping fluctuations of small-signal parameters in nanoscale semiconductor devices

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Random doping fluctuations affect negatively the functionality and yield of many analog and mixed signal circuits that are based on pairs of nearly identical elements and whose performance depends on the matching properties of their components (e.g. differential amplifiers, A/D converters, etc). Most of the existing approaches to the analysis of random doping fluctuations in semiconductor devices focus on the analysis of fluctuations of threshold voltages while fluctuations of small-signal parameters, such as transconductance, gate capacitance, and admittance matrix parameters have received very little attention.

The only existing work on fluctuations of small-signal parameters is presented in Ref. [1]. This approach is based on the linearization of transport equations and has the advantage that it is computationally very efficient. It yields information on the sensitivity of fluctuations of small-signal parameters to the locations of doping fluctuations, and, as a result, it can be used in the design of fluctuation resistant structures of semiconductor devices. However, its numerical implementation is cumbersome because it requires the computation of the second-order derivatives of the discretized transport equations with respect to the state variables (electrostatic potential, electron and hole concentrations, quasi-Fermi potentials) and doping concentration. For this reason, the approach presented in [1] is difficult to implement in commercial device simulators such as DESSIS, PISCES, etc. In this article we present a method that avoids the numerical implementation of second-order derivatives of transport equations by using only the Jacobian matrix of transport equations (that are first-order derivatives). The Jacobian matrix is usually readily available in device simulators, which makes our method easy to implement.

Figure 1 presents the "sensitivity coefficients" of admittance matrix parameters for a 25 nm channel length *n*MOSFET device, with $t_{ox} = 2$ nm. The "sensitivity coefficients" show how sensitive the y-parameters are to the locations of doping fluctuations. The channel extends between 30 nm and 55 nm, while the drain and the source regions correspond to $x > 55$ nm and $x < 30$ nm, respectively. The acceptor dopant concentration of both devices decreases from D = 5x10^{18} cm^{-3} at y = 20 nm from the oxide/semiconductor interface, to D = 5x10^{16} cm^{-3} at the interface. For y>20 nm, the doping concentration is constant and equal to its value at y = 20 nm. The bias point is given by $V_S = V_B = 0$ V, $V_G =$ 0.9 V, and $V_D =$ 1.2 V, while the operating frequency is 10 GHz. One can see that the fluctuations of the doping concentration at different locations inside the semiconductor device contribute differently to the fluctuations of admittance matrix parameters. In most cases, the most sensitive regions are located in the conduction channel and in the direct proximity of the oxide-semiconductor interface.

Figure 2 presents the dependence of transconductance $g_m = y_{DG}\left(\omega = 0\right)$ and of the standard deviation of transconductance on the average doping concentration in the channel and on the oxide thickness.

[1] P. Andrei and I. Mayergoyz, J. Appl. Phys., vol. 93, pp. 4646-4652, 2003.

A full journal publication of this work will be published in the Journal of Computational Electronics.

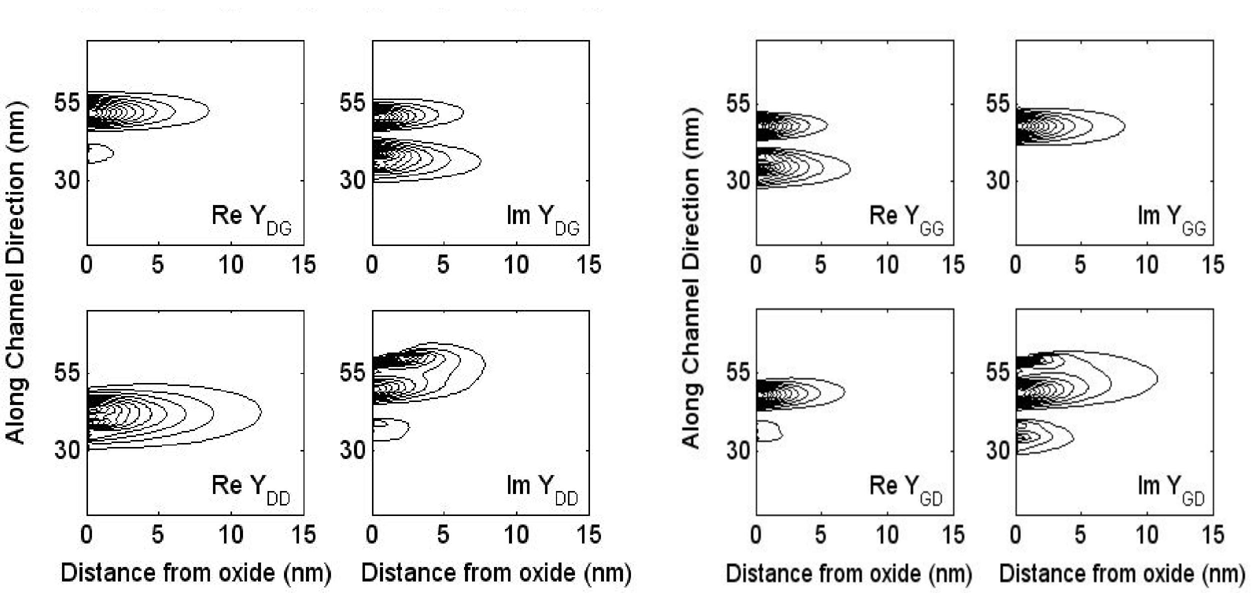

Figure 1: Contour plot representation of sensitivity coefficients for admittance matrix parameters for a 25 nm channel length *n*MOSFET device. The dark areas represent regions that are particularly sensitive to fluctuations of the doping concentration.

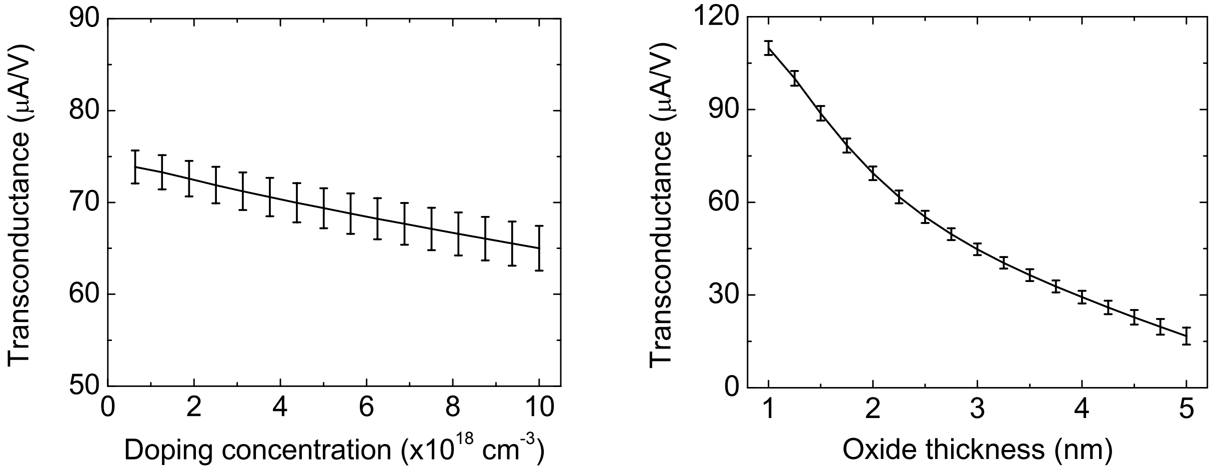

Figure 2: Transconductance (continuous line) and standard deviation of the transconductance (vertical bars) as functions of the average doping concentration in the channel and of the oxide thickness. The doping concentration indicated on the abscissa corresponds to the doping concentration at y = 20 nm from the oxide/semiconductor interface.

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