3D Monte Carlo Analysis of Discrete Dopant Effects on Electron Noise in Si Devices

P. Dollfus, J.E. Velázquez[1], A. Bournel, and S. Galdin-Retailleau
Institut d'Electronique Fondamentale, CNRS, Université Paris-Sud, 91405, Orsay, France
[1]Departamento de Física Aplicada, Universidad de Salamanca, 37008 Salamanca, Spain
E-mail address: philippe.dollfus@ief.u-psud

MOSFETs production has reached sub-100-nm dimensions in 2001 with Intel shipping 60-nm transistors in the 130-nm technology node. At present, the industry is progressively shifting the production to the 90-nm node which involves even shorter gate lengths. As gate length is reduced electron noise appears as a severe limit for both analog and digital applications. Thermal noise, generated by carrier velocity fluctuations in the channel, is still considered as the most important noise source in FET amplifiers operating at RF and microwave frequencies. Thermal noise is generated by carrier velocity fluctuations inside the transistors and can be fully and easily described using Monte Carlo device simulators [1]. Additionally, the noise modelling in deep-submicron MOSFET has necessarily to be studied by taking into consideration that it is coupled to the random distribution of the dopants in the transistors which induces strong device mismatches across the wafer hindering balanced designs in analog circuits. The reduced number of doping impurities and the inescapable in their distribution in the active region of FET devices makes this question specially important. Its physical analysis requires an accurate transport model suitable for the treatment of discrete dopants together with a 3D description of the transport.

This paper reports for the first time a simulation study of thermal noise in a simple test bed structure (three nanometric Si resistors, Table I) using an atomistic model and a continuum one. The 3D Monte Carlo atomistic approach that describes the electron-impurity interaction in the presence of discrete impurities was presented in [2]. This model has been successfully used to compute the electron mobility in Si resistors as a function of average doping concentration (Figure 1) and to study the effect of impurity position in the channel of 50-nm MOSFETs [3]. Figures 2 to 4 shows the self-correlation functions of velocity fluctuations for three concentrations in the doping range for both atomistic (discrete) and continuum models of the carrier-ionized impurity scattering. In the full range noticeable discrepancies between both models are found. Only the atomistic model leads to a smooth decay of the self-correlation function. This behaviour clearly supports the need for atomistic models in the simulation of short structures. As a results of the above, the spectral density of the velocity fluctuations will exhibit large differences between the two models (Figure 5). The *plateau* in Figure 5 corresponds to the white thermal noise in the resistor at the nominal frequency of operation as fluctuations of the carrier number are absent. From Figure 5, it directly follows that for very short and small structures noise is enhanced by the discrete nature of the dopants and to accurately evaluate and optimise the noise behaviour in deep-submicron structures the discrete nature of the dopants can not be ignored. At the Conference a detailed explanation of the complete simulation procedure, its impact on the modelling of noise un ultra-short FET transistors and the scope of the work will be presented.

[1] M. J. Martín, D. Pardo and J. E. Velázquez, Physica B, 272 (1999) 263.
[2] S. Barraud, P. Dollfus, S. Galdin, P. Hesto, Solid-State Electron. 46 (2002) 1061.
[3] P. Dollfus, A. Bournel, S. Galdin-Retailleau, S. Barraud, P. Hesto, IEEE Trans. Electron. Dev. 51 (2004), 749-756.
[4] G. Masetti, M. Severi, S. Solmi, IEEE Trans. Electron. Dev. 30 (1983) 764-769.

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

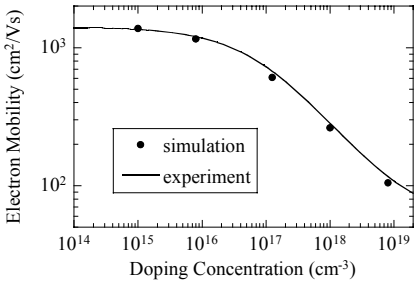

Figure 1. Electron mobility as a function of discrete dopant concentration in N-type Si resistors. Comparison with experiment [4]

	Resistor 1	Resistor 2	Resistor 3
Doping(cm^{-3})	8 10^{15}	1.25 10^{17}	1 10^{18}
Length (nm)	250	100	50
Section (nm^2)	22500.	3600.	900.

Table 1. Description of the devices under study.

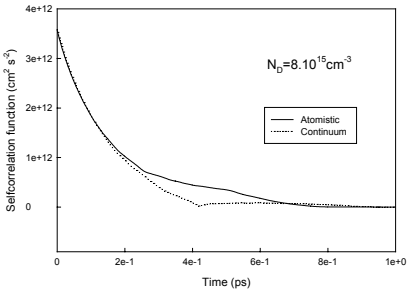

Figure 2. Self-correlation functions in Si resistor 1.

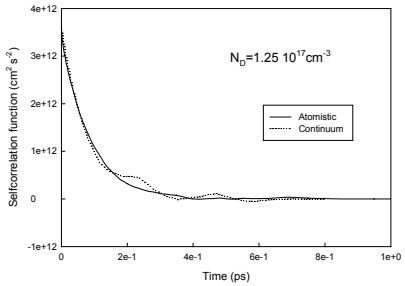

Figure 3. Self-correlation functions in Si resistor 2.

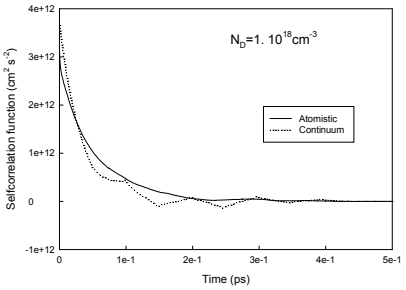

Figure 4. Self-correlation functions in Si resistor 3.

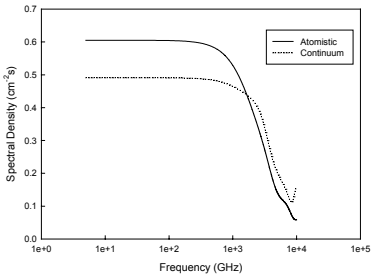

Figure 5. Spectral density in Si resistor 3.

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