Impact of stray charges on the characteristics of nano-DGMOSFETs in the ballistic regime: A NEGF Simulation study

A. Martinez1, A. Svizhenko2, M. P. Anantram2, J. R. Barker1, A. R. Brown1, B. Biegel2 and A. Asenov1

1Device Modelling Group, Dept of Electronics & Electrical Engineering, University of Glasgow
Glasgow G12 8LT, UK
2Nasa Ames Research Center, MS:229-1, Moffett Field
California 94035-1000, US

The quest for speed and complexity drives the miniaturisation of CMOS transistors down to the nanometre scale. At these dimensions quantum effects play an important role, introducing confinement effects and tunnelling. At the same time intrinsic fluctuations in device characteristics, for example due to discrete dopants, do not average out [1, 2]. In novel, thin body double gate (DG) MOSFETs, which do not require channel doping [3], unintentional doping can be introduced during the wafer or device fabrication process. Although low in probability such stray doping, which could introduce significant change in the device characteristics [4,5], becomes increasingly important bearing in mind the huge count of transistors per chip. Electrons or holes trapped on defect states at the interface or in the gate oxide could have similar effect. Such defect states could also be created by radiation in space applications and could affect the reliability of circuits for space missions.

The aim of this work is the study of the effect of random stray charges in the channel of nano DG MOSFETs using a Non-Equilibrium Green’s Function (NEGF) technique [6], which correctly captures the quantum aspects of operation in nano devices. If the electron moves coherently through the channel in a ballistic regime it can tunnel, depending on its energy, through the potential barrier created by the stray charge. This tunnelling current can produce differences in current-voltage behaviour when compared to other semi classical transport approaches [7].

The proper treatment of quantum effects associated with localised charges in the channel of nano-MOSFETs requires full scale 3D quantum transport simulations. In this work a self-consistent 2D real space NEGF formalism has been used to model a double gate (DG) transistor and study the effect of an unintentional single charge placed in the channel or at the channel-oxide interface. Compared to the 3D case, which can properly handle individual dopants and trapped carriers, the 2D simulations represent the effect of charged wires running in direction perpendicular to the channel cross section. Still they capture the effect of tunnelling through the sharp potential introduced by the wires and could be very instructive in understanding some of the quantum effects associated with the simulation of discrete charges. The channel length of the simulated transistor, illustrated in Fig. 1, is 10 nm, which justifies the use a ballistic approach. The channel thickness is 3nm, the doping in the source and drain regions, \(N_{Drx}\), is \(10^{20}\) cm\(^{-3}\), and the background channel doping, \(N_s\), is \(10^{14}\) cm\(^{-3}\). The threshold voltage and the shape of the \(I_D-V_G\) characteristics are strongly affected by the position of the charge in the channel. Tunnelling through the single charge potential has also been studied. A comparison between devices with and without the single charge has been carried out.

In general, the location of the single stray charge in the device is completely random. However, in the case of our 2-dimensional simulations we consider six different key cases of charge location illustrated in Fig. 2. The resulting \(I_D-V_G\) characteristics are shown in Fig. 3. At \(V_G = 1.5V\) and \(V_D = 0.6V\) the largest change in threshold voltage (relative to the control device) is produced by a charge placed in the middle of the channel at the source. The 2D potential profile for the case of a centrally located charge is shown in Fig. 4, for \(V_G = 1.5V\) and \(V_D = 0.6V\). This plot illustrates the 2D potential surface create by the charge. The potential profile (for four cases) along the centre line of the transistor, midway between the two gates is shown in Fig. 5. Fig. 6 shows the density for one electron with energy of 0.7eV coming from the source showing the penetration through the potential from the fixed charge. Figs. 7 & 8 show the density of states along the centre line of the transistor, midway between the two gates for a gate potential of 1.0 eV without and with the fixed charge present, respectively.

Fig. 1. Structure of the double gate MOSFET

Fig. 2. Location of charges investigated

Fig. 3. $I_D$-$V_G$ curves showing the effect of a fixed charge at different points within the channel. $V_D = 0.6$ V.

Fig. 4. 2D potential distribution with a charge in the centre of the channel. $V_G = 1.5$ V and $V_D = 0.6$ V.

Fig. 5. Potential profile through the middle of the channel with different configurations of fixed charge.

Fig. 6. Density for one electron with energy of 0.7 eV coming from the source.

Fig. 7. Density of states through the middle of the channel at $V_G=1$ V without stray charge

Fig. 8. Same as Fig. 7 but with stray charge placed at the centre of the channel