Impact of Discrete Dopants in ultrascale FinFETs and the Effect of XC on Dopant Clustering

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ABSTRACT

Non-equilibrium Green's Function simulations of an ultra-scale FinFET in the ballistic regime have been carried at low/high drain bias. We have calculated variability due to random dopants located in the source/drain regions of the transistor. The channel length of the scaled transistor is under 10 nm and therefore substantial tunneling is expected. We have calculated the tunneling as a function of the gate bias in two dopant configurations with the lowest and highest drain current. We have also computed the threshold voltage, sub-threshold slope and off current variability. We have studied the effect of the exchange correlation on the simulation of a cluster of dopants in the channel of the transistor.

3D Field Effect Transistors (FETs), such as FinFETs, are already being fabricated. The channel length of transistors currently in production is approximately under 20 nm. At the end of the International Technology Roadmap for Semiconductors (ITRS) [1] a further reduction in channel length into the sub-10 nm regime is envisaged. Source to drain tunneling is expected to degrade the transistor on/off ratio at these dimensions. Variability induced by the discrete nature of the dopants is also expected to be detrimental. Semi-classical descriptions of the electron transport lack tunneling and coherence, and from a physical point of view are unsuitable for describing transport at sub-10 nanometer scale. In this work, a Si FinFet of 10.6/4.2 nm high/width and 6nm channel length has been considered. The discrete dopants are distributed in 6nm region in the source and drain extension. 35 devices, which differ in the realization of disorder, have been simulated [2]. The electron concentration of one of the devices is shown in Fig. 1. The Non-equilibrium Green's Function formalism combined with a coupled mode space approach has been deployed. The Hamiltonian is written in the effective mass approximation. The I_D-V_G characteristics for the ensemble of devices at V_D=0.05/0.6 V are shown in Fig. 2. As a comparison, the characteristics of the devices with continuous doping are also shown in the figure. At low gate, the fluctuation in the channel length is due to the location of the dopants, which produce fluctuation in the off current and in the sub-threshold slope. At high gate bias the coherent scattering of dopants decreases the current with respect to the corresponding current of the continuous doping device. Fig. 3 shows the I_D-V_G of the device with maximum and minimum current of the whole ensemble (V_D=50mV). The corresponding tunneling currents are also shown. Fig 4 shows the percentages of tunneling currents showed in Fig. 3. We have also studied the effect of exchange-correlation (XC)[3] on a device with a cluster of dopants in the middle of the channel. The current spectrum is shown in Fig. 5. As the electron concentration in the channel increases with the increasing of the gate bias, the impact of the XC also increases (with the gate bias). This can be seen in Fig. 6, which shows the I_D-V_G of the device with/without XC.

REFERENCES

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[3] L. Hedin et al J. Phys. C: Solid St. Phys. **4**, 2064-83 (1971).

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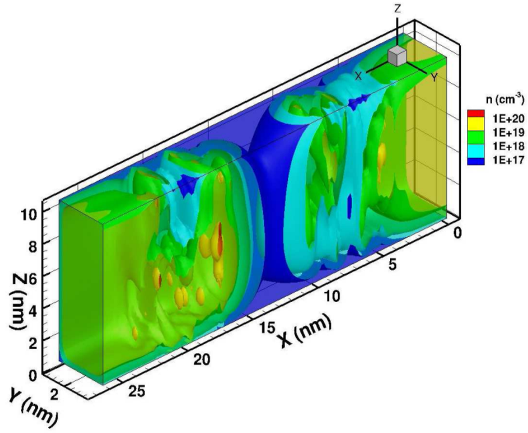

Fig. 1: Electron density of a device with discrete random dopants.

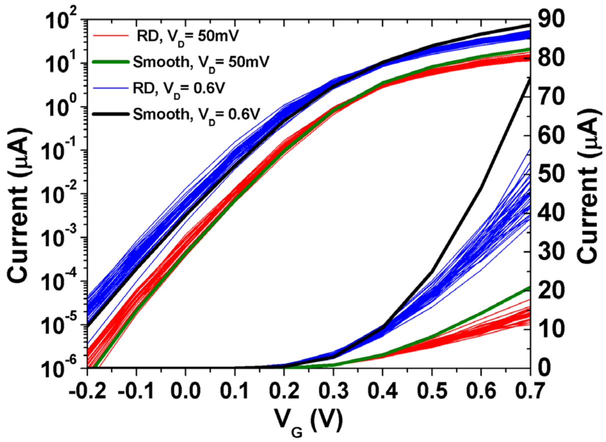

Fig. 2: I_D-V_G characteristics of 35 discrete dopant devices at high and low gate bias.

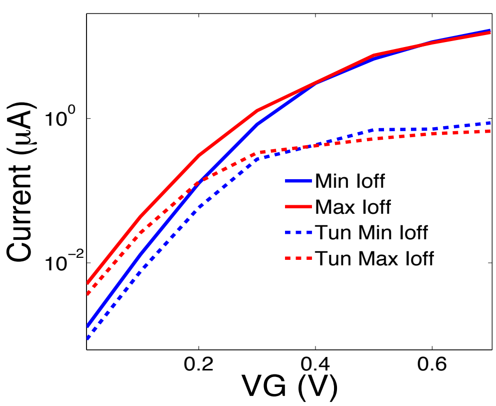

Fig. 3. I_D-V_G characteristics of the devices with maximum and minimum off-current. The corresponding tunneling currents are shown for comparison.

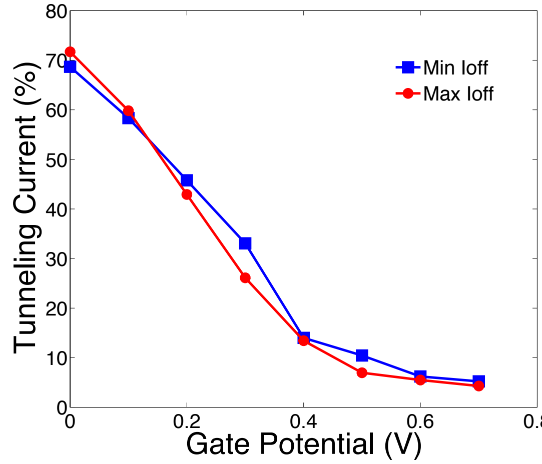

Fig. 4 Percentage of tunneling current as a function of the gate bias.

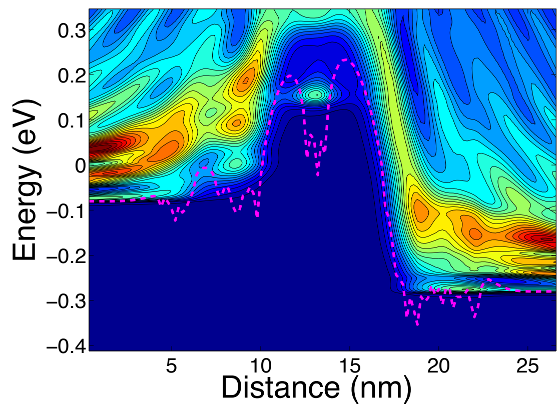

Fig. 5. Energy-resolved current spectrum for the device with discrete random dopants and the cluster of dopants in the middle of the channel (V_D = 0.3 V).

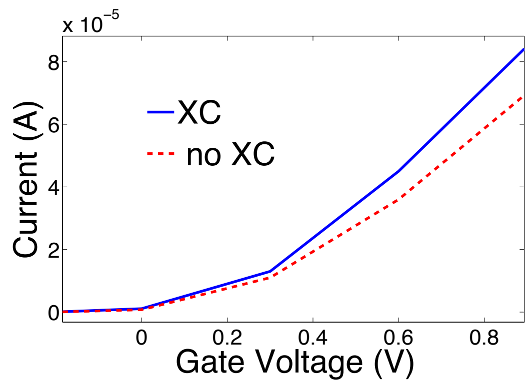

Fig. 6. I_D-V_G characteristics of the device with the cluster of dopants in the channel (V_D = 0.3 V).