Perturbative vs Non-Perturbative Impurity Scattering in a Thin Si Gate-All-Around Nanowire transistor: A NEGF study

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Nanowires are strong candidates as potential replacements for Bulk MOSFET architectures due to their better electrostatic integrity and performance. Impurity scattering is the source of series resistance that degrades the performance of small, doped nanowire transistors. In this work we have used a silicon nanowire transistor to investigate the inclusion of series resistance in quantum transport simulations. We analyse a non-perturbative approach as well as a perturbative one in the framework of the Non-Equilibrium Green Function (NEGF) formalism [1]. A very narrow nanowire with 2.2×2.2nm² cross-section, with a channel length of 6nm has been used in the simulation. The source/drain doping is 10¹⁰ cm⁻² and the channel is undoped.

First we have simulated the impurity scattering through a non-perturbative approach, i.e. we have introduced the impurity scattering through discrete dopants which are distributed randomly throughout the source/drain (s/d) extension regions as shown in Fig. 1. Thirty different nanowire transistors, which differ in the realisations of disorder through different dopant positions, have been simulated at a low drain bias (1mV) in order to keep the device operation in the linear response region. Fig. 2 shows the $I_D$-$V_G$ characteristics of the simulated transistors, and the corresponding average characteristic. At high gate bias the effective resistance of the s/d extensions have been extracted by using the ballistic $I_D$-$V_G$ device characteristic. This resistance is 1.68×10⁴Ω.

A perturbative approach [2], including density of state broadening and decoherence, has also been used to study the effect of the impurity scattering. Here scattering is introduced through self-energies within a 4nm region of the s/d. The $I_D$-$V_G$ characteristics of the transistor with incoherent scattering are shown in Fig. 3 as well as the curves for the atomistic average and the purely ballistic transistor. The $I_D$-$V_G$ of the transistor with incoherent scattering (short s/d) gives similar results to the atomistic average $I_D$-$V_G$ for devices with random dopants in the same 4nm region. We have also calculated the $I_D$-$V_G$ characteristics for a device that includes scattering in a 10 nm region of the source and drain (long s/d). The on-current for this device drops to 40% of that in the short s/d simulations (see Fig. 3), which matches the expected value given a linear dependence of the resistance as function of the wire length.

![Schematic illustration of the nanowire simulated here.](image1)

![Atomistic $I_D$-$V_G$ curves. Dashed line shows the average curve.](image2)

![$I_D$-$V_G$ curves of perturbative and non-perturbative approaches.](image3)
