11th International Workshop on Computational Electronics
TU Wien, 25-27 May 2006

"Real-Performance" Modeling of Carbon Nanotube FETs

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Introduction

The first phase of modeling carbon nanotube field-effect transistors (CNFETs) can be considered to be over: simplifying assumptions about the geometry (coaxial), transport (ballistic), the potential distribution (azimuthally invariant), and the gate-metal thickness (zero), have allowed "ultimate-performance" predictions to be made for both DC and AC operation. Researchers are now examining these assumptions to determine whether they are appropriate for models intended to predict, and analyze, the performance of more realistic devices. In this work we focus on the azimuthal potential distribution and on the gate-metal thickness in non-coaxial structures. We self-consistently solve the equations of Poisson and Schrödinger: the latter gives the local density of states from a p_z-tight-binding Hamiltonian using a Non-Equilibrium Green's Function formalism, within which the self-energies for the semi-infinite leads are computed by solving a quadratic matrix equation [1]. We consider two structures: the semicylindrical-gate geometry shown in Fig. 1, which may be a realizable tri-gate-like structure, and an asymmetrical, double-gate geometry shown in Fig. 2, which has recently been used to study doped-contact CNFETs [2].

Azimuthal Potential Distribution

Equilibrium results for the azimuthal potential at mid-tube for our two structures are shown in Fig. 3. The variation in potential can be appreciable. The effects of this on the electrical characteristics of the CNFETs are under investigation; results will be presented in the full paper.

Gate-metal Thickness

In Schottky-barrier CNFETs the gate and end-contact electrodes are inevitably close together, resulting in large, gate-thickness-dependent parasitic capacitances that significantly affect the AC performance [3]. In doped-contact CNFETs the electrode separations may be larger, but the gate-metal thickness T_G will still influence the electrostatics. The latter devices are of particular interest because of the suppression of ambipolar effects [4], and the possibility of exceptional sub-threshold slopes [5]. Solutions to Poisson's Equation for our two structures, using null-Neumann boundary conditions to define the length L_{SD} of semi-infinite, doped lead within the simulation space [6], are shown in Figs. 4 and 5. For a self-consistent solution the potential must become flat well before the imposition of the null-Neumann boundary condition. For the case of $L_{SD} = 20\,\text{nm}$ considered here, it is clear that this does not happen even for T_G as small as 2 nm in the semicylindrical-gate case, but does happen up to $T_G \approx 10\,\text{nm}$ in the double-gate case. The implications of this for the electrical characteristics will be discussed in the full paper.

References

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ISBN 3-901578-16-1

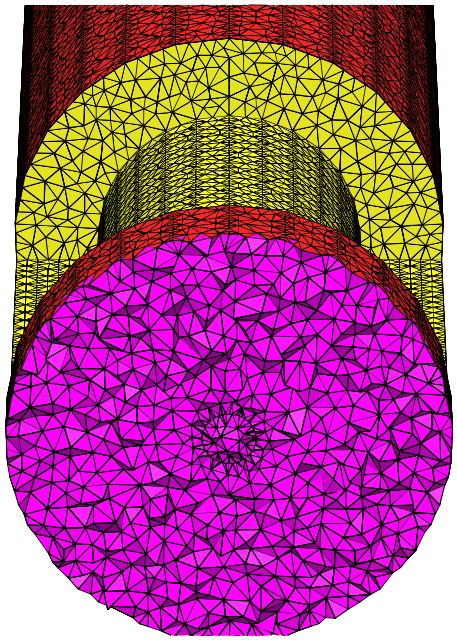

Fig. 1. Mesh for the semicylindrical-gate structure. The yellow facets are the gate surface. The results to follow are for an (11,0) tube, with an intrinsic, gated length of 7 nm and doped leads of 20 nm.

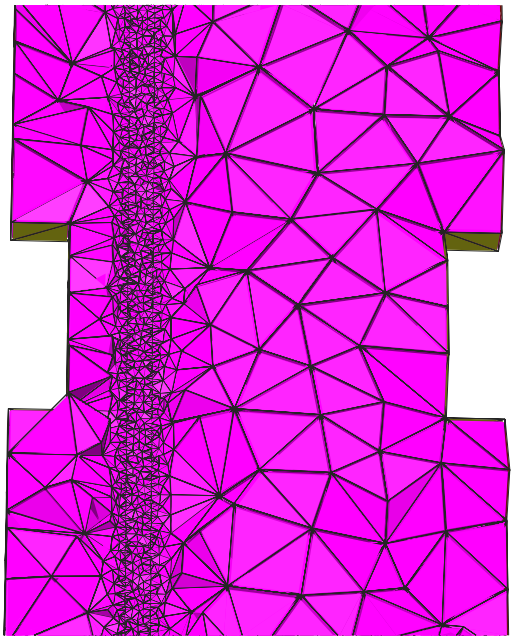

Fig. 2. Mesh for the planar, asymmetrical, double-gate structure. The gates are the cut-out regions. The results to follow are for an (11,0) tube, with an intrinsic, gated length of 7 nm, doped leads of 20 nm, oxide thicknesses of 2 nm (left) and 10 nm (right).

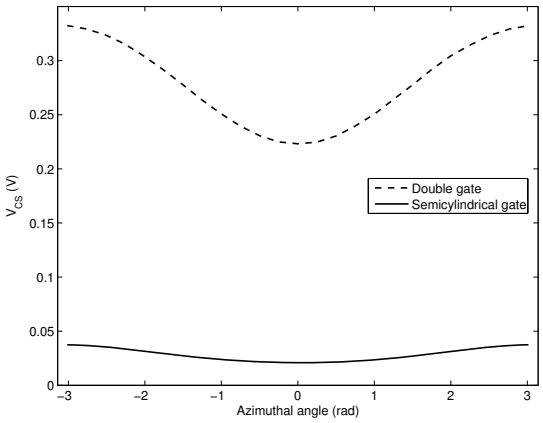

Fig. 3. Azimuthal variation of surface potential at mid-length of the nanotube for both structures.