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Compact Model for Schottky-Barrier CNT-FETs

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Abstract

Carbon nanotube field-effect transistors (CNT-FETs) are being the subject of very intense research as promising devices for future electronic applications. This research is motivated by the technical and economic difficulties in further miniaturizing silicon-based transistors with the current fabrication technologies.

At present, an important issue is to dispose of compact models describing the interplay between the observed phenomenology in CNT-FETs. These models are intended to serve as guidelines for understanding the experimental work at this early stage of development, and for design and projection purposes. In this work we develop a physics-based compact model for the current-voltage (I-V) characteristics of Schottky-barrier CNT-FETs (Fig. 1). The model captures a number of features exhibited by Schottky barrier CNT-FETs: (a) thermionic and tunnel emission [1]; (b) ambipolar conduction [2]; (c) ballistic transport [3]; (d) multimode propagation [4]; and (e) electrostatics dominated by the nanotube capacitance [5].

In the proposed model, the spatial band diagram along the nanotube consists of three distinctive regions: two injecting barriers at the ends of the nanotube and an intermediate region where ballistic transport occurs (Fig. 2). This latter region is approximated by a flat band structure, its energetic level being essentially determined by the nanotube capacitance, which is supposed to dominate over the insulator capacitance (operating conditions close to the quantum capacitance limit). The energetic diagram at the two injecting barriers can be analytically calculated solving Laplace's equation along the transport direction. A coaxial gate geometry is considered. The current is calculated by means of the Landauer formula for one-dimensional systems contacted with infinite reservoirs. The key information to compute the current is the transmission probability for all energies, which is calculated using the WKB formalism.

We have taken into account that multiple reflections can arise between both Schottky barriers at the interfaces, in the same way as a Fabry-Pérot resonator [6]. The proposed model is compared with accurate self-consistent quantum mechanical simulations based on the Non-Equilibrium Green's Functions (NEGF) [7]. Specifically, the test consist in the comparison of the I-V characteristics showing the effect of power supply voltage scaling (Fig. 3), nanotube diameter scaling (Fig. 4), and barrier height (Fig. 5). Notice the good agreement between our model and NEGF's simulations. The compact model is valid as long as the CNT-FET operates at the quantum capacitance limit (see Fig. 6).

Acknowledgement

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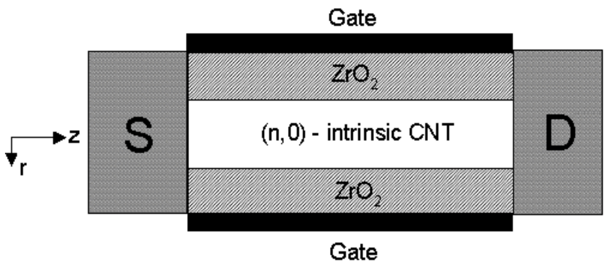

Fig. 1. CNT-FET cross-section. The electrodes are assumed to be metallic and the body is an intrinsic (n,0) semiconductor nanotube.

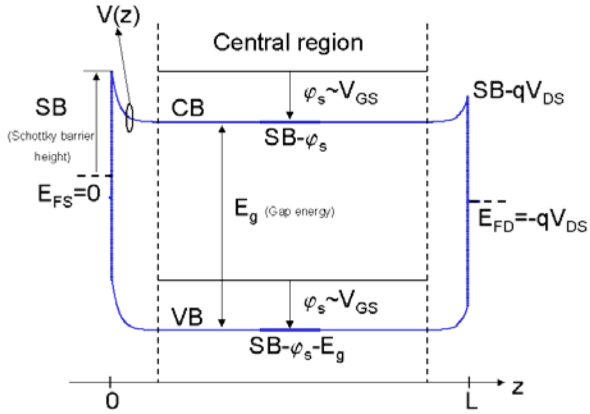

Fig. 2. Spatial band diagram scheme (along the transport direction).

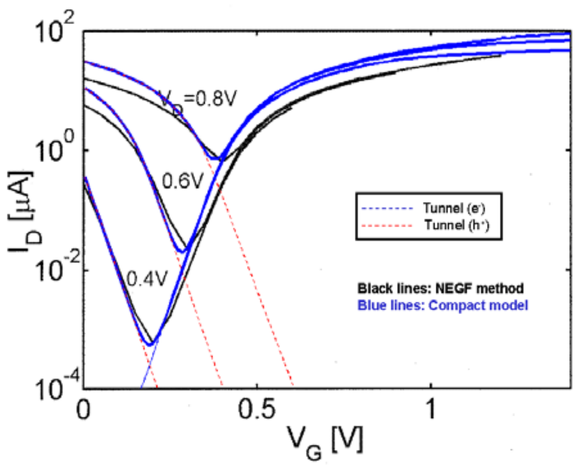

Fig. 3. Transfer characteristics: effect of the power supply voltage scaling.

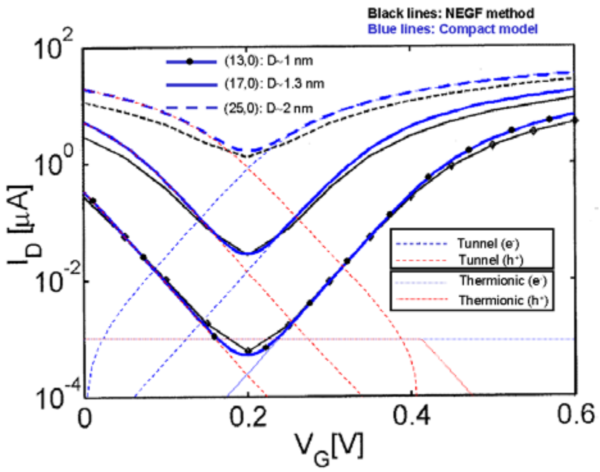

Fig. 4. Transfer characteristics: effect of the nanotube diameter scaling.

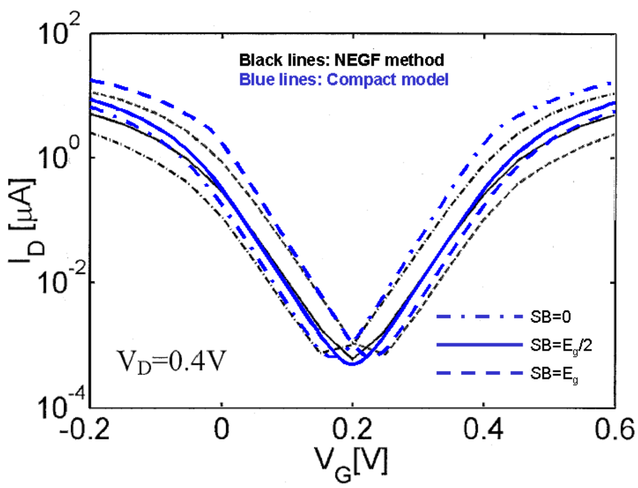

Fig. 5. Transfer characteristics: effect of the barrier height.

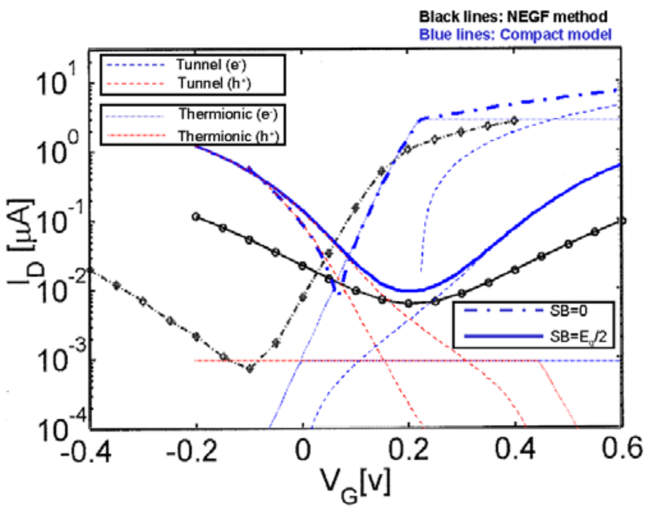

Fig. 6. Transfer characteristics for a thick oxide thickness (40 nm) CNT-FET, not working at the quantum capacitance limit.