HIGH-FREQUENCY FIGURES-OF-MERIT OF CARBON NANOTUBE FIELD-EFFECT TRANSISTORS

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During the last few years, carbon nanotube field-effect transistors (CNFETs) have established themselves as leading candidates for high-performance transistors of the near future [1]. While there is little expectation for them to supplant their silicon counterparts in production cost, they may be well suited to niche applications by overcoming fundamental limitations of silicon-based devices.

The DC characteristics of CNFETs are reasonably well understood, although optimization of devices is still being actively pursued, notwithstanding difficulties in large-scale fabrication. Although the subject of promising experiments [2,3], the frequency-dependent performance has yet to be studied thoroughly in theory, and this work takes a step in that direction. We seek to describe a small-signal method and give preliminary estimates of valuable figures-of-merit in transistor design, the unity current-gain and unity power-gain frequencies (f_T and f_{max}).

We derive a general equivalent circuit model under the small-signal, quasi-static approximation, including relevant transcapacitances, transconductances, and contact series resistances. The intrinsic circuit components are justified in the device physics, while the extrinsic resistances are parameterized in order to accommodate the possibly large parasitic components of actual experiments. The intrinsic parameters are computed numerically with a self-consistent Schrödinger-Poisson model, adapted from that in Ref. [4]. We study CNFETs with coaxial, wraparound gates, as these are sought for yielding idealized electrostatics and an upper limit on performance figures. We assume ballistic transport, as appropriate for short-channel devices, and employ the effective-mass approximation, with a value determined by the tight-binding method. Negative-Schottky barrier CNFETs operate via the modulation, by the gate electrode, of the channel barrier, and such devices herein are scaled so as to operate near the so-called "quantum capacitance limit" that renders this modulation highly efficient [5].

Preliminary results indicate that both f_T and f_{max} are expected to approach the THz regime. Fig.1 shows the figures-of-merit for a device with: a nanotube of radius 0.6 nm and bandgap 0.62 eV; a channel length of 20 nm; an insulator thickness of 2.5 nm; a gate to end-contact gap of 4 nm; and source, drain and gate parasitic resistances of 1 kΩ. We observe unusual characteristics in relation to gate voltage variations, suggestive of resonance behaviour, owing to charge quantization in the channel and the formation of quasi-bound states. These may prove to be a challenge for circuit designers, or a benefit if conveniently exploited. We will further illustrate the dependencies on structure dimensions, nanotube bandgap, parasitic resistances, and temperature.

References:

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Figures:

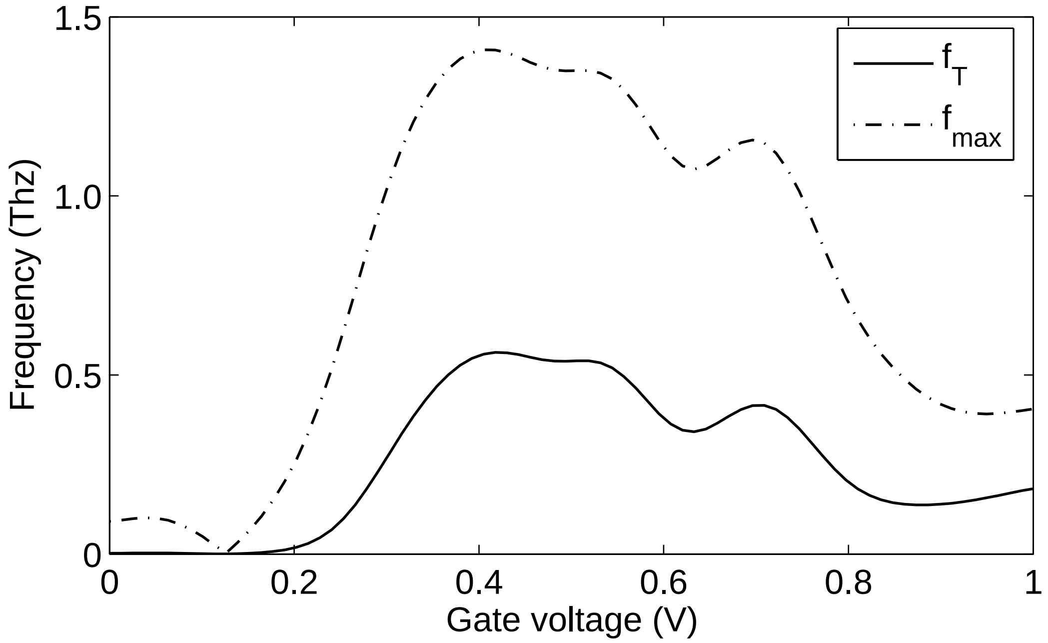

Figure 1: Unity current-gain and unity power-gain frequencies with R_{series}=1kΩ for all contacts