Carbon Nanotube Devices for GHz to THz Applications

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In this talk I will present an overview of the high-frequency applications of carbon nanotubes, one realization of nano-electronic devices, and where the challenges and opportunities lie in this new field. The study of the ac properties of nano-electronic systems is still in its infancy. Concepts such as the quantum capacitance of 1d quantum systems have been discussed theoretically for many years, but there is currently very little data on which to base realistic high-frequency device models for nano-scale devices where the transport is often ballistic.

The first step towards understanding the high-frequency electronic properties of carbon nanotubes is to understand the passive, ac impedance of a 1d quantum system. We have recently proposed an effective circuit model, currently being tested in our lab, for the ac impedance of a capacitively contacted nanotube, and a dc contacted nanotube[1]. The effective circuit diagram is summarized in the figure below, and includes the spin-degeneracy as well as the band-structure degeneracy for graphite. In the figure, L_K is the kinetic inductance per unit length, C_Q is the quantum capacitance per unit length, and C_{ES} is the electrostatic capacitance per unit length. Numerically, L_K is approximately 10 nH/μm, which is much larger than the magnetic inductance. This inductance can in principle be used as part of a tank circuit for on-chip, GHz passive signal processing components, currently under development[2].

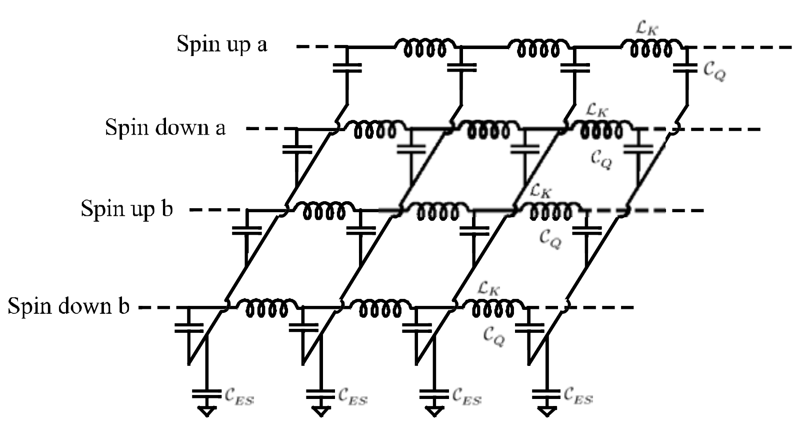

Figure 1: Proposed RF circuit model for a carbon nanotube.

A second application of nanotubes in high frequency electronics is in the *active* mode of operation, i.e. nanotube *transistors*. Generally speaking, the maximum frequency at which current gain can be achieved is given by the transconductance g_m divided by the gate-source capacitance C_{gs}, i.e.

$$f_T = \frac{g_m}{2\pi C_{gs}} \quad \textbf{(1)}$$

At present there are no detailed theoretical models for the high frequency properties of carbon nanotube transistors, but equation 1 can be used to give an estimate of device performance. In order to predict f_T, we use the largest transconductance measured to date[3] of 20 μS; similar transconductances have been measured by other groups[4]. (Note that up to 60 μS was recently predicted[5,6] by the Purdue simulation group, which would mean an even higher f_T). We plot in figure 2 our predictions for f_T vs. gate length for a nanotube transistor, and compare to other technologies[7,8]. The predictions are very promising, suggesting that a nanotube transistor with THz cutoff frequencies should be possible.

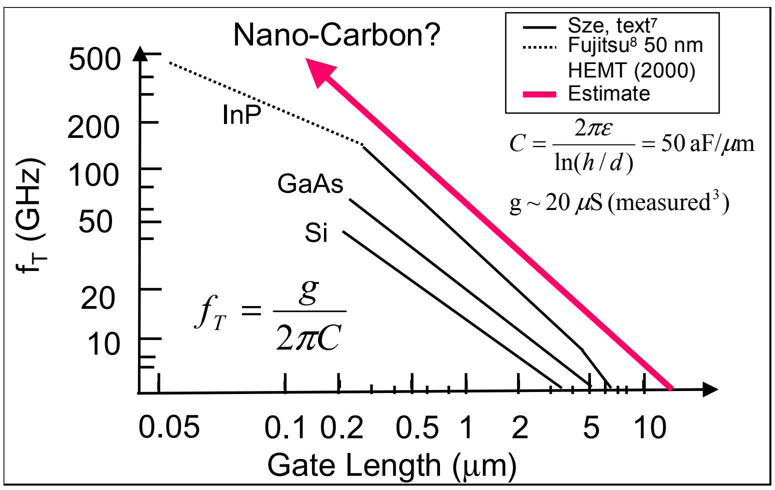

Figure 2: Speculative prediction of f_T vs. gate length for nanotube transistors.

This work lays the foundation for future work on *ballistic* gated devices, an unexplored but technologically increasingly important regime of device operation for both carbon and silicon based nano-scale transistor devices.

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