# Scaling in Carbon Electronics

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Carbon nanotubes and graphene have been considered to be promising channel materials for field-effect transistors due to their ultra-thin bodies for aggressive channel length scaling and excellent intrinsic transport properties. Understanding their scaling behaviors is extremely important for proper device designs in order to gain the maximum benefits for scaling and performance improvement.

In the first part of my talk, I will show the most scaled carbon nanotube FETs (CNFETs) fabricated up to date. A novel local bottom gate geometry is implemented to achieve good electrostatics in these 1-D devices. Excellent on-state currents and subthresdhold slopes have been obtained in CNFETs down to 15nm channel lengths. Owing to the long phonon scattering mean free path of nanotubes and aggressively scaled channel lengths, CNFET devices shorter than 45nm show ballistic transport with resistances closer to the quantum limit than have ever been reported [1].

While scaling nanotube devices has achieved substantial progress over these years, exploration of the scalability of graphene devices has been very limited. We measured mobility vs. channel length for back-gated graphene FETs. When employing diffusive transport equations to determine mobilities, different from conventional materials which have constant mobilities a rather peculiar mobility versus channel length dependence is revealed. We argue that the linear dependence of the mobility on the channel length is evidence that ballistic or partial ballistic transport has been reached in our devices. We have also identified the existence of a series resistance in the vicinity of the graphene contact area. Using both, the device characteristics and channel length dependent mobility data, we were able to extract the mean free path of the graphene channel for graphene FETs fabricated on $SiO_2$ substrates [2]. While the Dirac point has been considered to be the indicator for impurity or phonon scattering from the substrate or doping level in graphene, for the first time, we observe a shift of Dirac point in graphene devices as a consequence of gate length scaling. This shift has been identified as one of the signatures of short channel effects in graphene [3].

Reference:
[1] **Can carbon nanotube transistors be scaled without performance degradation?**
Aaron D. Franklin, George Tulevski, James B. Hannon, and Zhihong Chen
*IEEE IEDM Technical Digest, p. 561-564 (2009)*
[2] **Mobility extraction and quantum capacitance impact in high performance graphene field-effect transistor devices**
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*IEEE IEDM Technical Digest, p. 509-512 (2008)*
[3] **Study of Channel Length Scaling in Large-Scale Graphene FETs**
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