Abstract:
In order to overcome the size and speed limitations of our existing carbon nanotube-based field effect transistor (CNT-FET) devices, we have fabricated short-channel single-nanotube devices from a pre-sorted high bandgap (E_g > 1 eV) CNT stock. High bandgap and short-channel (L ≤ 100 nm) semiconductor nanotube transistors are expected to favor ballistic transport within the nanotube.

Summary:
We have fabricated CNT-FETs using semiconductor nanotubes sorted by bandgap [1]. Aqueous fractions of nanotubes enriched in semiconductor (6,5) were deposited onto silica wafers. This (6,5) chirality has a bandgap of 1.28eV with an average tube length of ~300 nm after enrichment. In our initial devices, an electrode array with a source-drain electrode separation of 250-400 nm was photolithographically patterned on the deposited carbon nanotube “mat.” Ti/Au evaporation and lift-off were then performed to create percolation network CNT-FETs. A number of unknowns in the device structure and physics made it difficult to evaluate and compare device performance.

In order to improve performance and yield a more uniform test-bed, single carbon nanotube FETs were then fabricated. In these devices a gold localization grid was first patterned by electron beam lithography. This grid consisted of a 10 x 10 matrix of 1 x 1 µm squares spaced 5 µm apart center to center in each direction. A (6,5) enriched carbon-nanotube solution was then deposited in the grid areas. This deposition was optimized to yield a population density of nanotubes small enough to prevent multiple tubes bridging an electrode gap, but large enough to facilitate localization.

Precise coordinates for 30 individual CNT’s were then computed from AFM images of the grid areas using tube position relative to grid squares. These coordinates were used to prepare 20 individual electrode masks for five different electrode arrays. Each pair of electrodes was formed, first, by a 1 µm wide source and drain separated by 100 nm. This was then connected by lateral extensions to the second layer of electrodes which terminated in 500 x 500 µm contact pads. The first layer of electrodes was patterned by e-beam lithography and made of 5/15 nm Ti/Au. The second was patterned by stepper lithography and made of 15/45 nm Ti/Au.

References:
Single Carbon Nanotube-Based FETs

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- Figure 1, top right: 3D-AFM phase image of one pair of Ti/Au electrodes bridged by several carbon nanotubes. One electrode acts as a source while the second is a drain. Source, drain, bottom-gate (silicon wafer), and semiconductor (nanotubes), constitute a typical CNT-FET.

- Figure 2, below left: Optical micrograph of a single-carbon nanotube FET array. (1) First e-beam layer: reference grid consisting of 100 gold squares. (2) 2nd e-beam layer: customized electrodes and their respective lateral extensions for contact to individual nanotubes. (3) Third photolithographic layer: contact pads.

- Figure 3, below right: AFM phase image of single-tube CNT-FET. A single carbon nanotube bridges a 100 nm gap between source & drain electrodes 1 µm wide.