Supporting Information:

Experimental and Theoretical Studies of Transport through Large Scale, Partially Aligned Arrays of Single Walled Carbon Nanotubes in Thin Film Type Transistors

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1) Determination of Percentage of Metallic and Semiconducting SWNT:

Electrical characterization of SWNT is the best way to figure out the metallic and semiconducting percentage. Therefore we have fabricated back gated field effect transistors using aligned SWNT. Aligned SWNTs were grown on quartz wafers using the same growth process described in the paper and then transferred on highly doped Si wafers (with 100 nm SiO2) using a transfer technique (1). Figure S1 shows the device layout and an SEM image of single tube device. We counted the number of metallic and semiconducting SWNT using electrical burning process, similar to that described before (2). In this procedure, the number of tubes can be counted from the sharp current drops on the IV curve. Figure S2 shows the transfer curves for semiconducting (a,b) and metallic (c,d) SWNT before and after the electrical burning. We measure the transfer curves before and after the burning process. We tested 50 such devices in this manner. From the data, we counted 86 SWNTs, 56 of which showed semiconducting behavior and 30 of which showed metallic behavior. The ratio, then, is ~1.9. The similar results have been reported previously by different groups who used the similar growth technique (2-5).

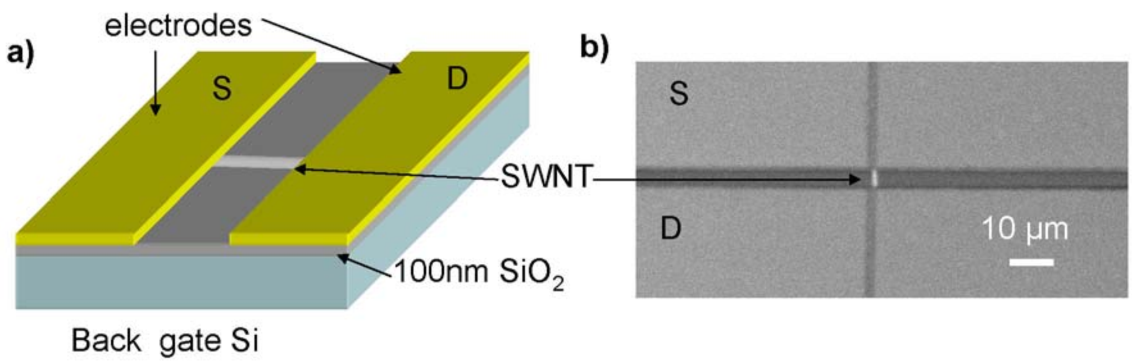


Figure S1: (a) Schematics of back gated SWNT field effect transistor, (b) SEM image of one of tested devices.

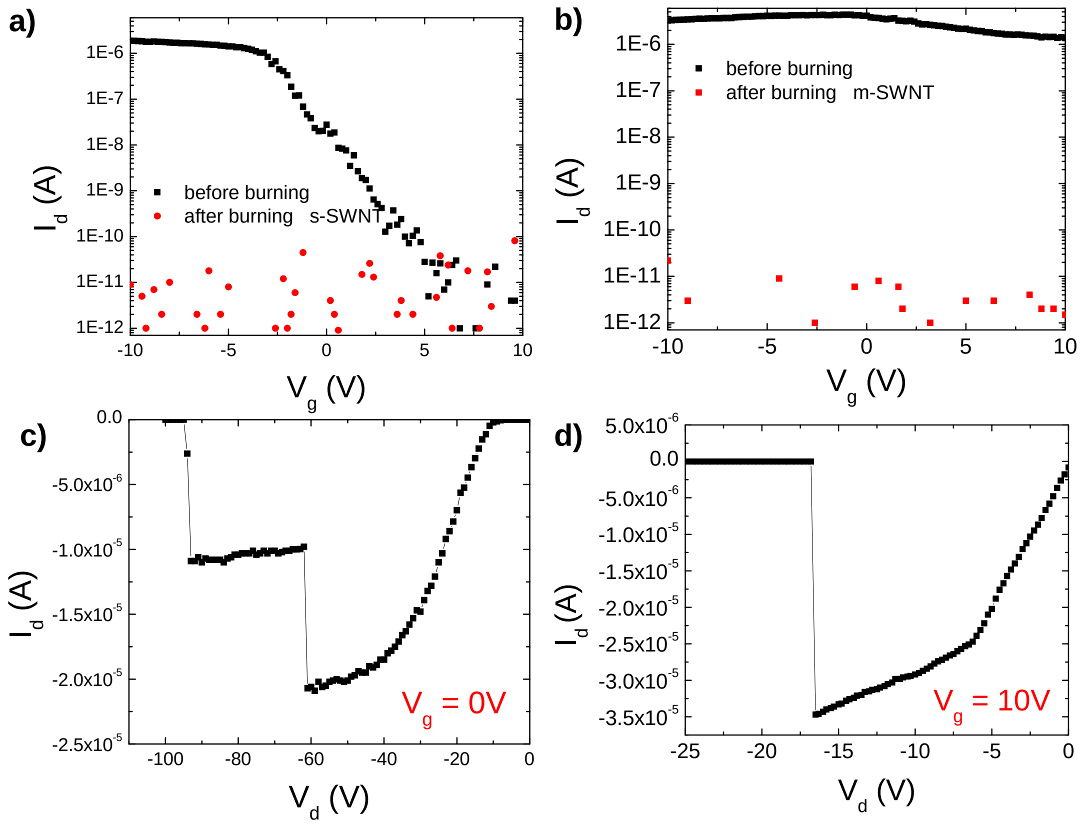


Figure S2: (a,b) Transfer curves for semiconducting and metallic SWNT . (c) electrical burning of two semiconducting and (d) one metallic SWNT. The number of tubes can be counted from the sharp current drops.

2) Derivation of non-dimensional potential along tube:

The equation is derived from Drift-Diffusion Equation

$$J = q\mu\, n\frac{dV}{dx} + qD\ \frac{dn}{dx} \qquad (1)$$

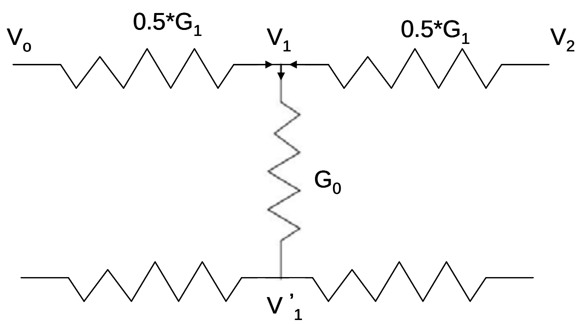
and Carrier Continuity Equation

$$\frac{1}{q}\frac{dJ}{dx} = 0\,. \ (2)$$

For linear voltage-current regime (gate voltage V_g=constant and drain voltage V_{sd} ~ small), the carrier concentration is uniform across the channel, therefore one need not solve the Poisson equation explicitly. Since the channel length is several microns long, contact resistance is unimportant and scattering dominated drift-diffusion theory apply. However, in the linear response regime, the diffusion term is negligible compared to the drift term in Eq. (1), therefore Eqs. (1) and (2) can be combined to obtain

$$q\mu n\frac{d^2V}{dx} = 0 \ \Rightarrow \sigma\frac{d^2V}{dx^2} = 0 \qquad (3)$$

where V is the potential and σ is the conductivity. Eq. (3) applies to transport in isolated tubes. To understand the modification of Eq. (3) for intersecting tubes, consider the following derivation. When two tubes intersect each other, the tube resistance and the contact resistance can be represented by the circuit below.



The respective voltages are shown in the figure above. Using Kirchoff's law, voltage drop-equation can be written as:

$(V_0 - V_1)\times\frac{G_1}{2} + (V_2 - V_1)\times\frac{G_1}{2} = (V_1 - V_1^{'})\times G_0$, which can be rearranged as:

$$\frac{V_0 - 2V_1 + V_2}{2\Delta x^2} = (V_1 - V_1^{'})\times\frac{G_0}{G_1\Delta x^2}$$

$$\Delta x^2\left.\frac{d^2V}{dx^2}\right|_1 = C_{ij}(V_1 - V_1^{'}) \ \text{where } c_{ij} = \frac{G_0}{G_1}$$

Now for two intersecting tubes i and j, the above equation takes following form (Kirchoff's law):

$$\frac{d^2V_i}{dx^2} - c_{ij}(V_i - V_j) = 0 \;\; ; \;\; c_{ij} = \frac{G_0}{G_1}$$

where V_i and V_j are the potentials of the tube i and j at the point of intersection, $G_0(\sim \frac{0.1e^2}{h})$ is the contact-conductance between the tubes and $G_1(\sim qn_{1D}\mu / \Delta x)$ is the conductance of the tube. Here n_{1D} is the carrier density of tubes and $\Delta x(\sim 1e^{-6}cm)$ is the grid spacing. We find c_{ij} ~ 50.0 from the above calculations. Our simulations for nanotubes are reported for this value of c_{ij} . This equation can be written in non-dimensional form as:

$$\frac{d^2\phi_i}{ds^2} - c_{ij}(\phi_i - \phi_j) = 0$$

where s = x / Δx and ϕ is the non-dimensional voltage.

Effect of variation of metallic tube ratio: We used simulations to provide additional evidence that the fractions of metallic and semiconducting CNTs are close to 1/3 and 2/3, respectively. Fig. S3 shows I_{on}, I_{off} and on/off ratio for four different values of f_M. I_{on} is not sensitive to f_M but the simulated I_{off} and on/off ratio match closely to the experimental results (symbols) only for f_M close to 1/3 and 1/4. The simulation results for f_M = 1/2 and 1/9 do not match experiment, suggesting that the fraction of metallic CNTs is close to 1/3. The values of f_M chosen for the simulations here are in the range of measured values by using electrical burning method.

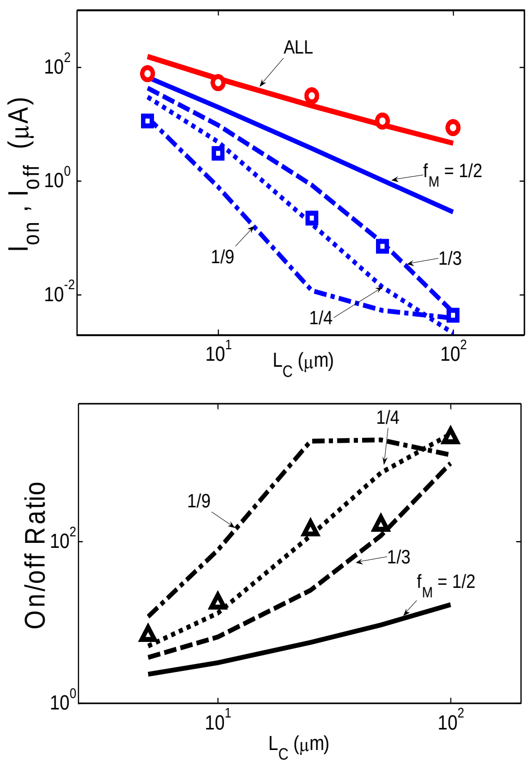


Fig. S3. On current I_{on}, off current I_{off}, and on/off ratio for partially aligned networks corresponding to Fig 3 (b) in the paper, where the symbols show experimental and lines show simulation. The 4 lines correspond to metallic tube fraction of f_M = ½ (solid), 1/3 (dashed), ¼ (dotted) and 1/9 (dash-dot) as indicated. The simulation curves for I_{on} are overlapping.

References:

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