Supporting information

Transparent Electronics Based on Transfer Printed Aligned Carbon Nanotubes on Rigid and Flexible Substrates

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1. Multiple transfer of aligned carbon nanotubes

Our transfer can be repeated to transfer multiple layers of aligned nanotubes to obtain sophisticated nanotube networks or "textures" as shown in the schematic diagram of Figure S1. For example, the second layer of aligned nanotubes can be placed orthogonal to the first layer, as shown in Figure S1I. Placing the second layer parallel to the first layer would result in increasing the density of carbon nanotubes as shown in Figure S1II.

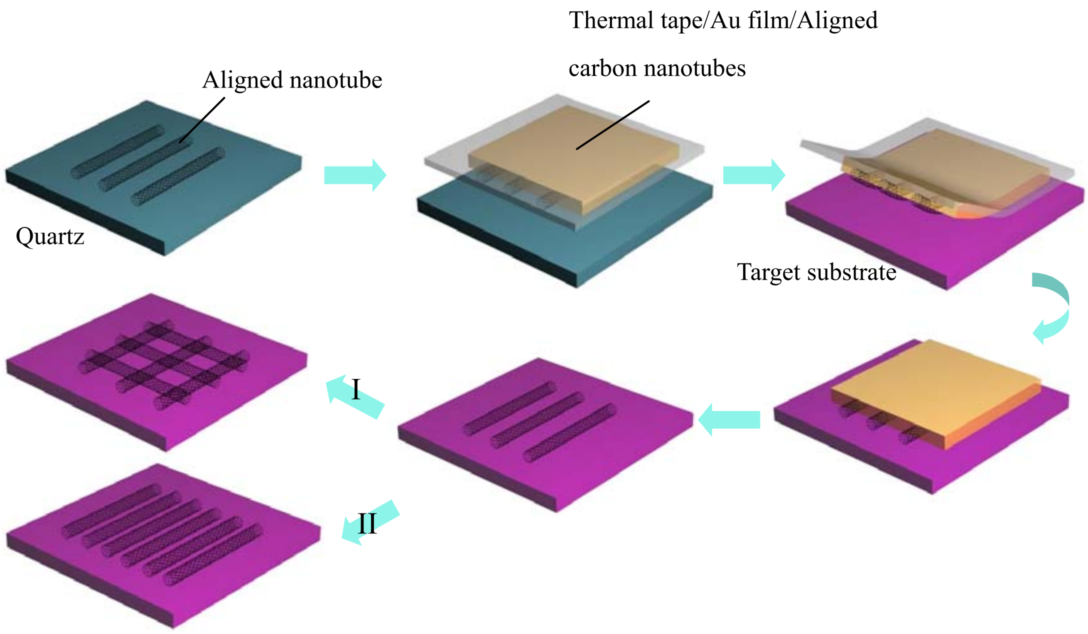

Figure S1. Schematic diagram of multiple transfer. I) second layer of aligned nanotubes is placed orthogonal to the first layer. II) second layer is placed parallel to the first layer.

Figures S2a shows the actual SEM images at different magnifications of a nanotube network with the second layer of nanotubes transferred orthogonal to the first layer as described in Figure S1I, while Figure S2b shows SEM images of nanotubes transferred with 60˚ angle angular alignment. Furthermore, by transferring multiple layers of nanotubes in parallel orientation, we can increase the density of aligned nanotubes dramatically as described in Figure S1II. Figure S2c and d display the SEM images of aligned nanotubes with two-step and three-step transfer, respectively, and the nanotube density exhibited a linear increase from 7 to 25 nanotubes, as shown in Figure S2e. One can further imagine an exponential increase in nanotube density by starting with nanotube samples with a density of *n* nanotubes per micron, performing one round of transfer to obtain multiple samples with 2n nanotubes per micron, and then performing another step of transfer to obtain samples with 4n nanotubes per micron.

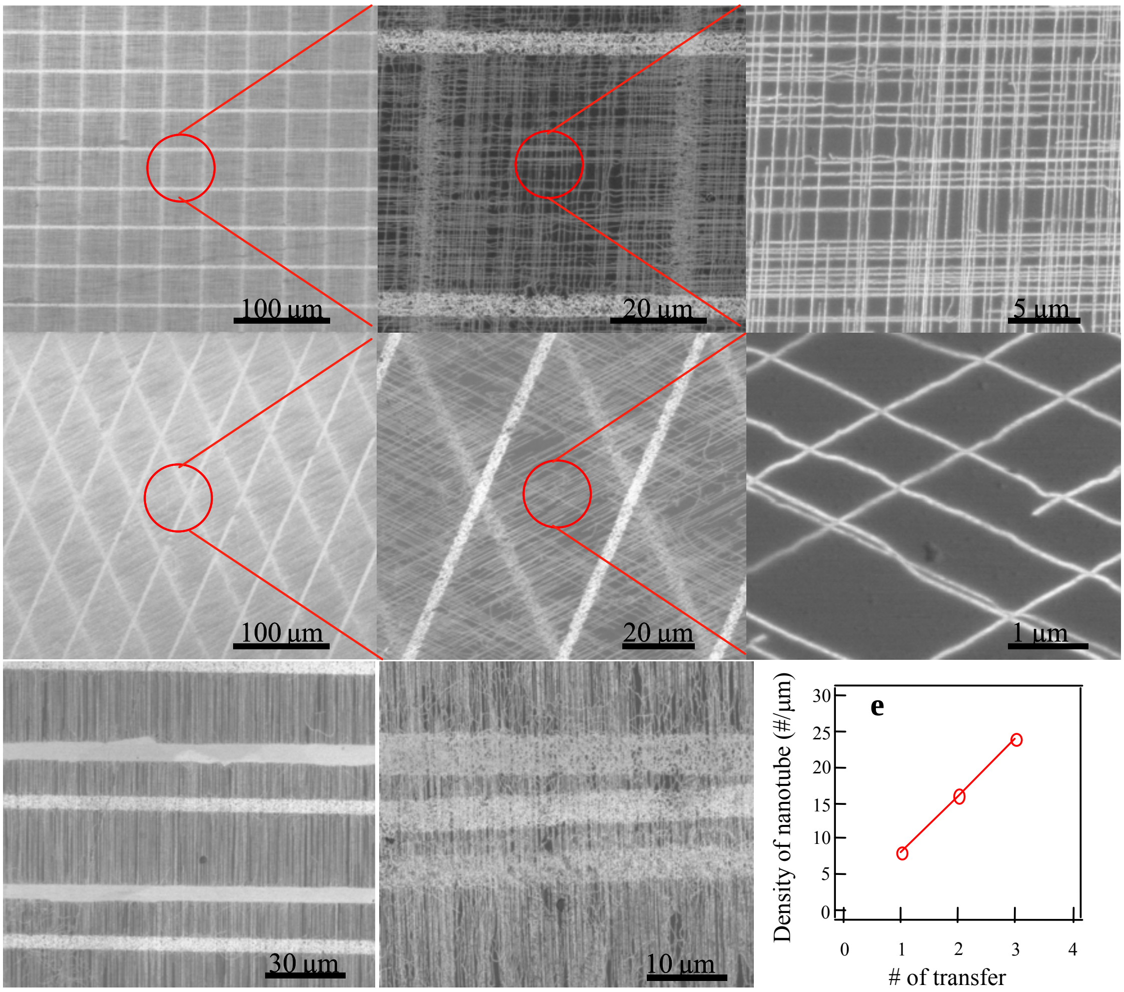

Figure S2. a) SEM images of aligned nanotubes where the second layer was placed perpendicular to the first layer. b) SEM images of aligned nanotubes where the second layer was placed with 60˚ angle to the first layer. c) SEM image of aligned nanotubes after second parallel transfer. d) SEM image of aligned nanotubes after third parallel transfer. e) Density of nanotubes (# of SWNT/µm) versus number of parallel transfer.

2. Histogram of the on/off ratio before and after electrical breakdown

We have performed the electrical breakdown process over large number of samples to confirm the reproducibility of the process. Figure S3 shows the histogram of the on/off ratio of devices before/after the breakdown, confirming the reproducibility of the process. Devices before electrical breakdown exhibited on/off ratio between 1 to 10. In contrast, after breakdown, most devices showed on/off ratios above 10^2.

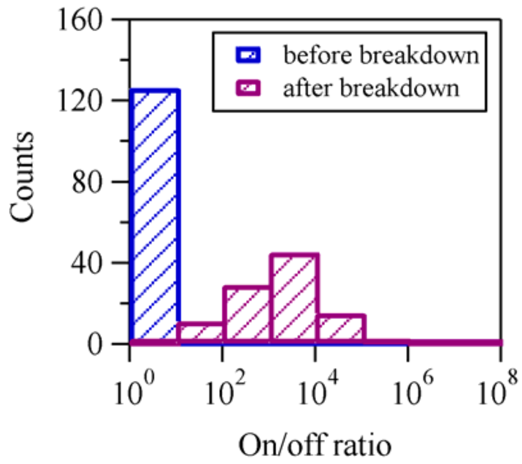

Figure S3. Histogram of on/off ratio of devices before/after the electrical breakdown.

3. Analysis of square resistance and contact resistance

We have estimated the square resistance and contact resistance of devices with Au/ITO contacts at on state (V_g = -20 V) by making a linear fit between the device resistance and channel length according to the following equation.

$$R_{device} = R_{contact} + R_{square} \cdot \frac{L}{W}$$

where R_{device} is the resistance of the device (V_{ds}/I_{ds}), $R_{contact}$ is the contact resistance, and R_{square} is the square resistance. Figure S4 shows the plot of R_{device} versus channel length and the linear fit. Devices used here had channel width of 100 μm, and channel length of 4, 20, 50, and 100 μm. The linear fit gave $R_{contact}$ of 1.73 kΩ and R_{square} of 6.95 kΩ/□.

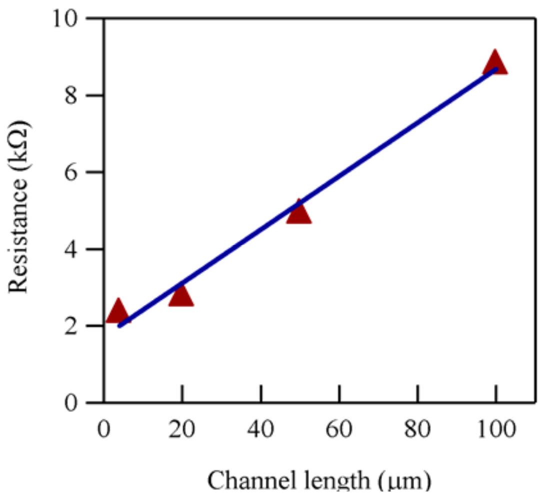

Figure S4. Device resistance versus channel length. The blue line is a linear fit using the equation mentioned above.

4. Transparent N type transistor by PEI coating

N-type transistors were obtained by coating the nanotubes with PEI to dope the devices with electrons to enhance n-conduction of the devices.[1] Figure S4a shows the transmittance of the devices on glass after PEI coating, showing that PEI coating does not hurt the transparency of the devices. Shown in Figure 5a are the I_{ds}-V_g curves under different gate voltage with a step of 0.5 V, showing increasing conductance with increasing V_g, which is indicative of n-type transport. Inset of figure 5b shows the I_{ds}-V_g characteristics of the device after PEI coating, showing ambipolar transport, and the n-branch regime was used to obtain the data in figure 5b (V_g from 2 to 4 V).

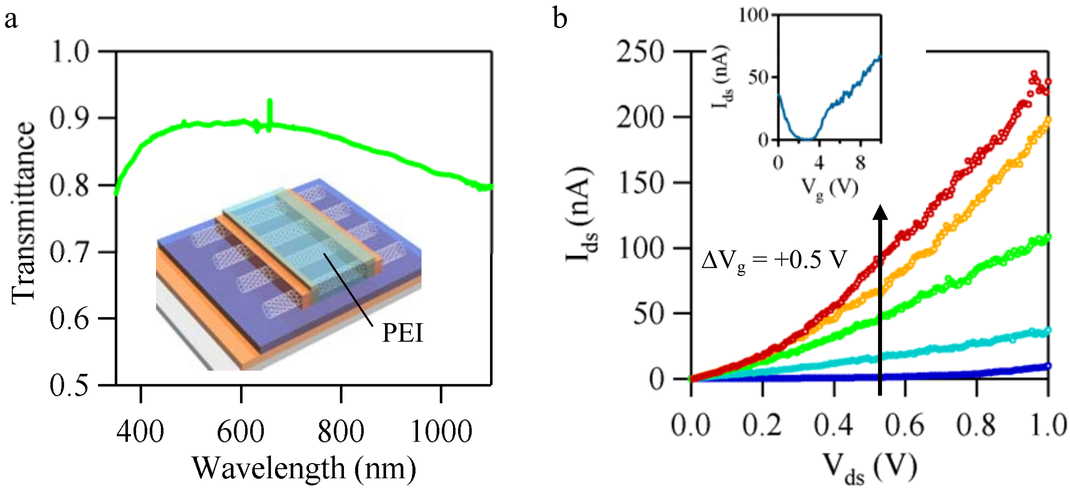

Figure S5. a) Transmittance of the devices on glass after PEI coating. b) I_{ds}-V_g curves under different gate voltage with a step of 0.5 V. Inset of figure 1b shows the I_{ds}-V_g characteristics of the device after PEI coating.

Reference

1. Shim, M.; Javey, A.; Kam, N. W. S.; Dai, H. J., Polymer Functionalization for Air-Stable n-type Carbon Nanotube Field-Effect Transistors. *J. Am. Chem. Soc.* 2001, 123, 11512-11513.