small methods

Supporting Information

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Nozzle-Free Printing of CNT Electronics Using Laser-Generated Focused Ultrasound

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To fabricate back-gated CNT-TFT, 99.9% pure semiconducting single-walled carbon nanotube (S-SWCNT) was purchased from NanoIntegris with a length range of 300 nm – 5 μm, as shown by the histogram in Figure S1[1].

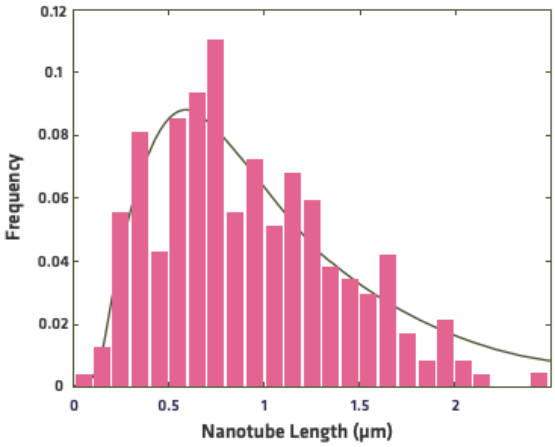


Figure S1. Histogram of CNT length in purchased ink [1]. (Reproduced with permission from NanoIntegris)

To fabricate the bottom gated transistor structure, a positive photoresist was used to define the features, thin titanium and gold for metal deposition. In our photomask design, the shortest channel length is 2 µm and the longest is 300 µm while the channel width remains at 300 µm. The device fabrication process flow, and device layout pattern are depicted in Figure S2(a), and (b), respectively.

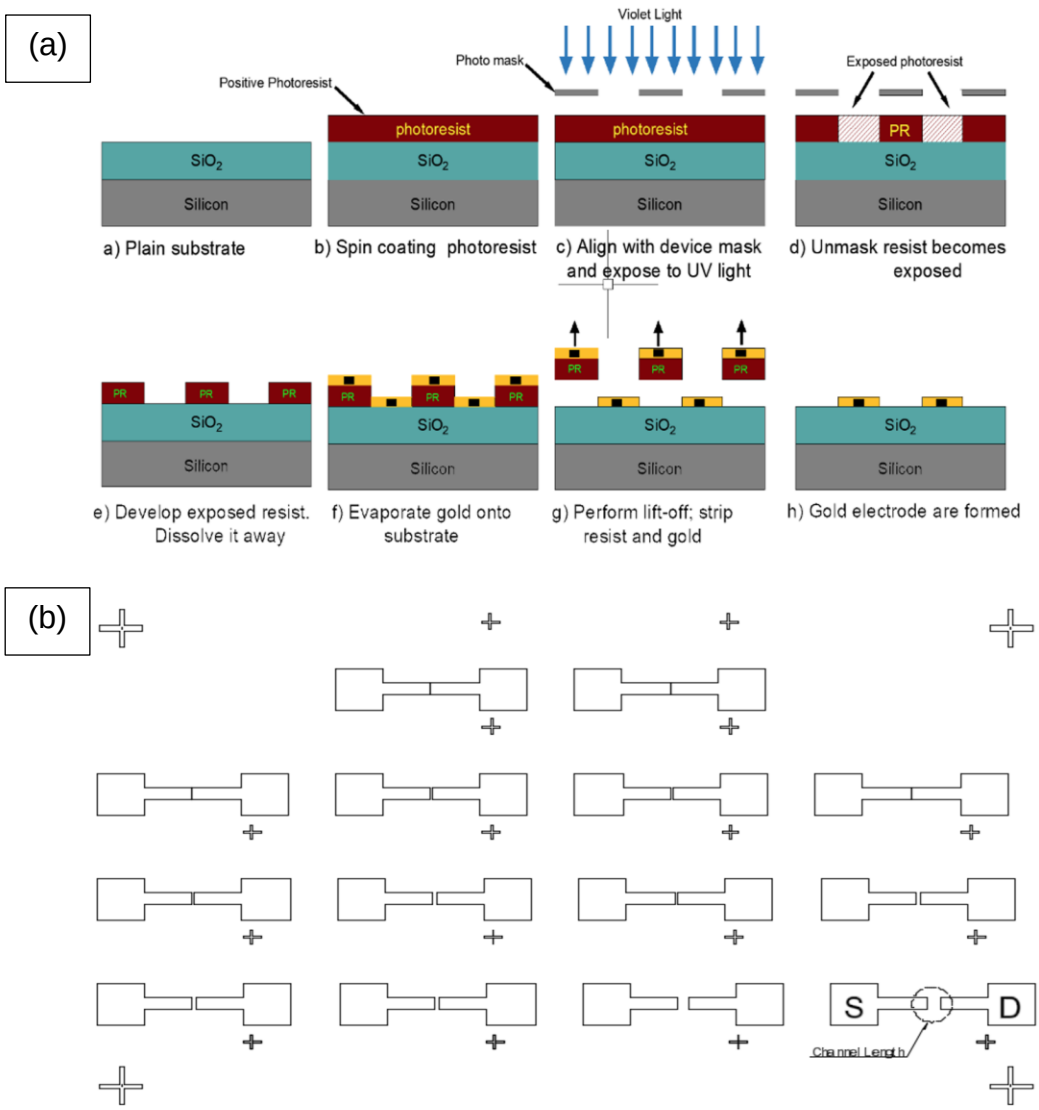


Figure S2. (a) Device fabrication process steps, and (b) Device layout pattern in top-down view.

IJP showed more than 90% surface coverage compared to only 32% for SJP as shown Figure S3.

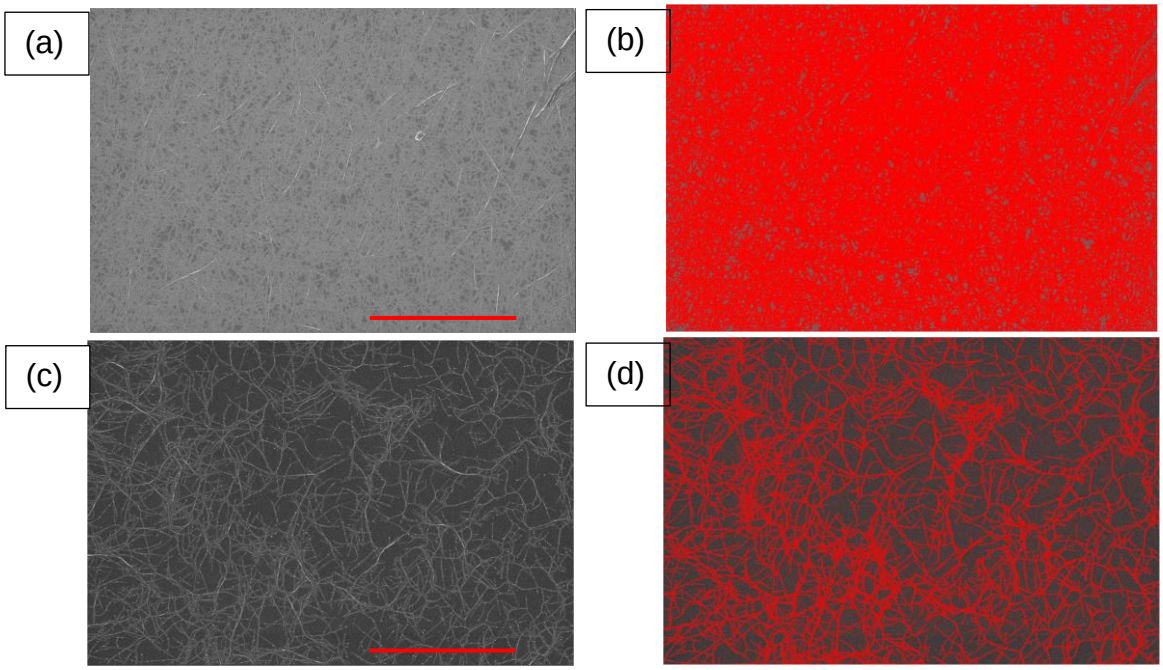


Figure S3. SEM image of CNT printed by (a) IJP (10 print pass) and (c) SJP (1 print pass), here scale bar is 5 μm. Colorized CNT images for both are shown in (b) and (d), respectively, used to extract surface coverage.

Transfer characteristics of the SJP device with maximum mobility and same dimension IJP device is shown in Figure S4.

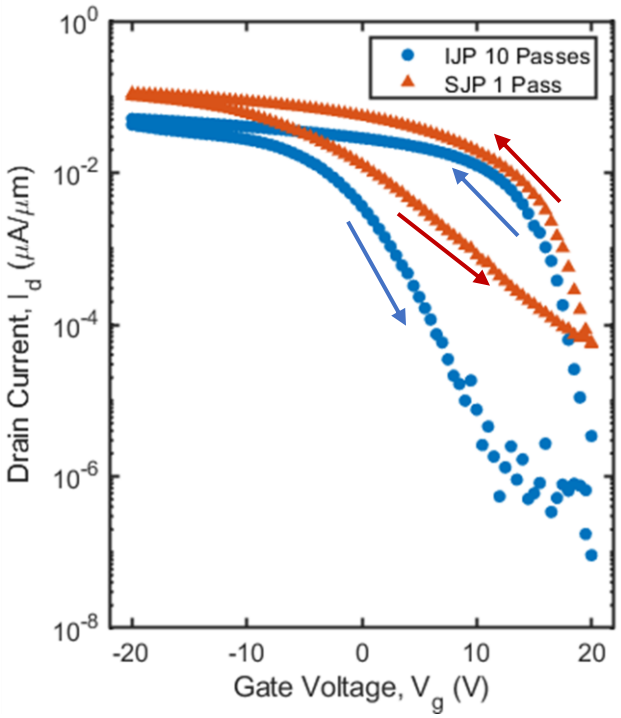


Figure S4. I_d-V_g logarithmic plot for optimally performed devices with L = 300 µm and W = 300 µm, 10 print passes for IJP and 1 print pass for SJP.

Raman characterization also showed similar D-peak [2] for IJP and SJP (shown in Fig S5), confirming no unexpected change in the morphology of SJP printed CNTs.

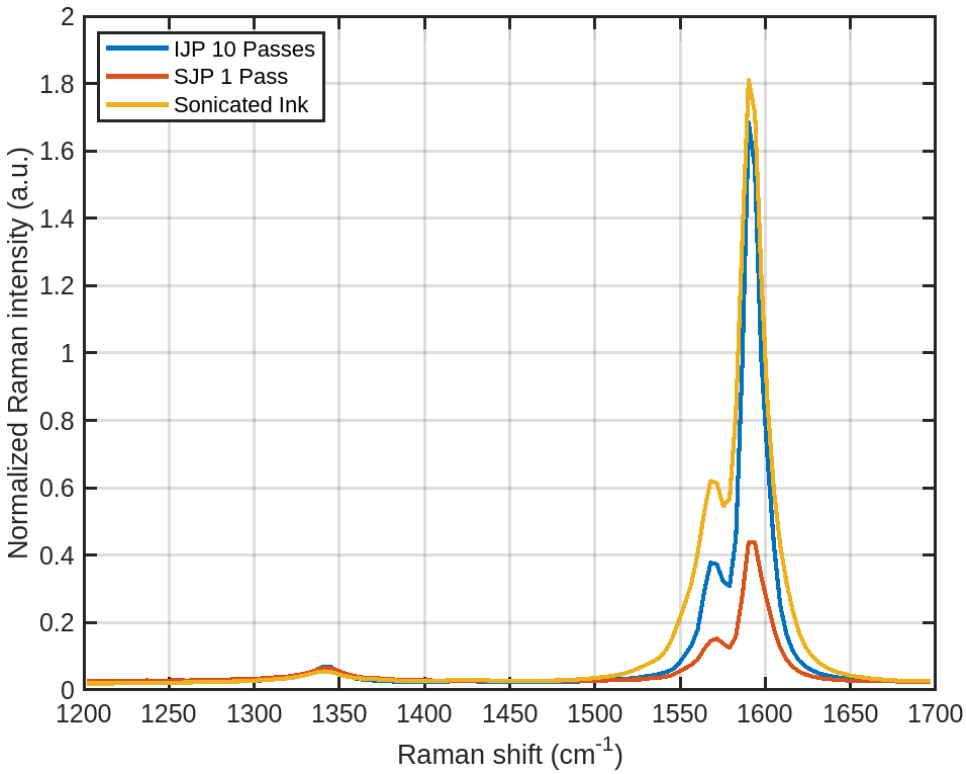


Figure S5. Raman spectra of sonicated drop-casted ink, IJP and SJP printed CNT showing similar D-peak [2] while G peak is higher for IJP, could be originated from thicker CNT film from 10 passes [3,4].

References

1. https://nanointegris.com/our-products/semiconducting-swnts-isonanotubes-s/
2. M. Kalbac, Martin, Y.-P. Hsieh, H. Farhat, L. Kavan, M. Hofmann, J. Kong, M. S. Dresselhaus. Nano letters 2010, 10, 4619.
3. M. S. Dresselhaus, G. Dresselhaus, R. Saito, A. Jorio, Physics reports 2005, 409, 47.
4. B. H. Kumar, H. S. Tan, N. Ramalingam, S. G. Mhaisalkar. Carbon 2008, 47 313.