A Model for Nano-manufactured Electrodes utilizing Vertical Carbon Nanotubes

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We have recently demonstrated a cell detection device using precisely placed vertical single walled carbon nanotubes (SWNTs) (*1*). The key innovation that made the precise placement of the nanotubes possible is the application of a nanoscopic lens (*2*). The nanotubes are deposited in 30-40 nm windows in a 75 nm thick silicon nitride layer and make contact to metal leads. The resulting geometry is unique in that it consists of a 30-40 nm diameter window with a 1.2 nm diameter nanotube standing through it, as shown in Figure 1 with part of the nitride pealed back. This raises the question of how conduction occurs, whether it's from the exposed metal at the bottom the hole, or from the nanotube, or even from a combination of the two. Understanding the physics is important to allow for both better-optimized devices and to help lead a path to commercialization.

To help understand the physics we fabricated devices spaced 2 microns apart as shown in Figure 2a. We submerged devices with and without nanotubes in a conductive media (phosphate buffer), applied external voltages between devices and measured the resulting currents using a HP 4140B picoammeter. Figure 2b shows the resulting current vs. voltage (IV) data. The current measured with nanotubes is 3 orders of magnitude higher than without them. This suggests that the nanotubes play a crucial role for conduction. To help understand that role and to determine if the metal at the bottom contributes any current, we performed finite element analysis on the geometry with and without deposited nanotubes, using COMSOL. The model confirms the effect and predicts that the geometry of the nanoscale windows plays a key role in nanomanufactured devices of this type where conductive paths in liquids contribute to their performance.

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1. A. Kanwal *et al.*, Scalable Nano-Bioprobes with Sub-Cellular Resolution for Cell Detection. *Biosensors and Bioelectronics* **45**, 267–273 (2013).
2. A. Goyal, S. Liu, Z. Iqbal, L. A. Fetter, R. C. Farrow, Directed self-assembly of individual vertically aligned carbon nanotubes. *Journal of Vacuum Science and Technology B* **26**, 2524 (2008).

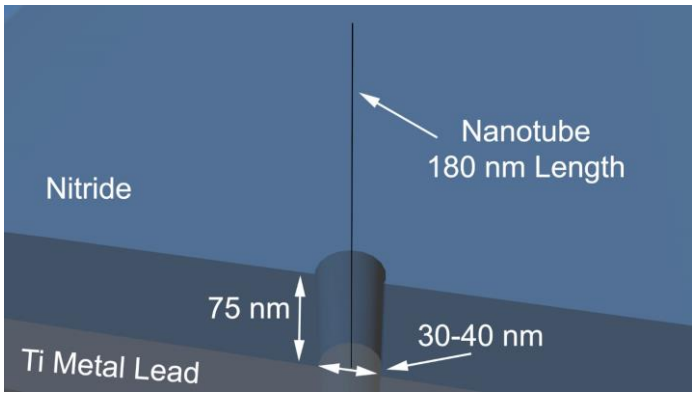

Figure 1 – Schematic showing a vertical SWNT inside a 30-40nm hole that is 75 nm deep.

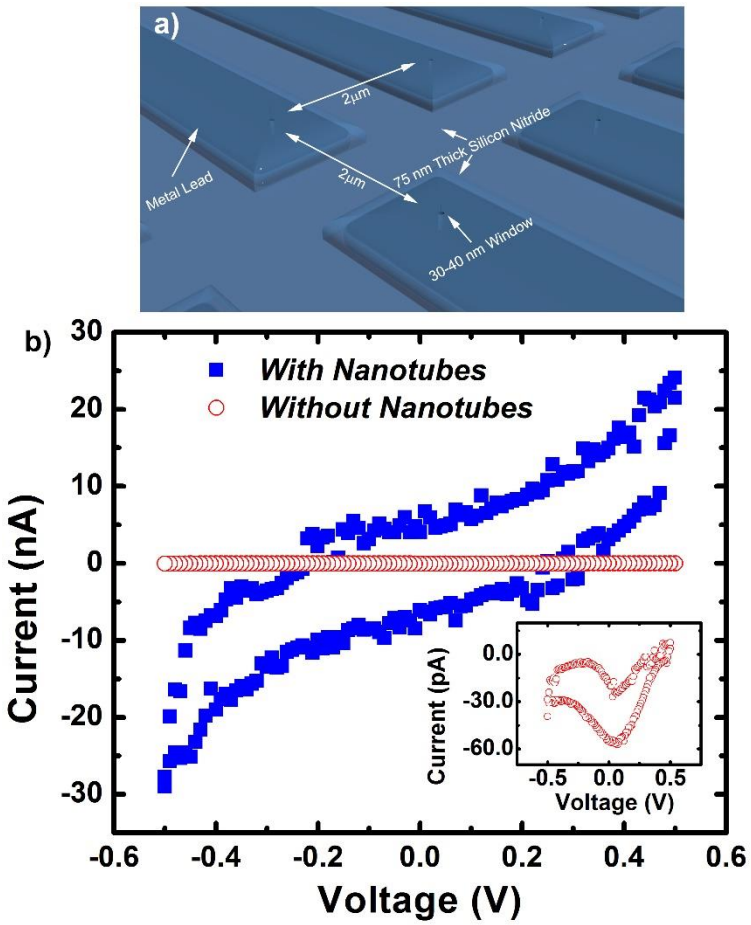

Figure 2 - – (a) Schematic showing the geometry of a nanoelectrode, consisting of a single walled carbon nanotube inside a 30-40nm wide window in 75 nm thick silicon nitride. (b) Current vs. voltage data for electrodes immersed in a phosphate buffer with nanotubes (blue squares) and without (red circles).