A Parametric Study of Electrophoretic Deposition of Single Wall Nanotubes In Nanoscale Windows

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We have previously reported on electrophoretic deposition [EPD] of single wall carbon nanotubes (SWNTs) on metal through 100nm diameter windows in silicon nitride [1]. There are several parameters that influence EPD. A well understood EPD process that leads to uniform and repeatable deposition could open the door to commercialization of novel vertical SWNT devices. As an example, we have developed a nanoscale probe that is capable of performing electrical measurements of biological cells including those that are too small for traditional patch-clamping [2]. We have also developed a novel process which utilizes EPD of nanotubes to fabricate a vertical field effect transistor (vFET) [3]. Previously, we relied on high pressure carbon monoxide (HIPCO) nanotubes, which contained a mixture of metallic and semiconducting SWNTs and were subject to bundling in suspension [1]. In this study we are now utilizing presorted commercial SWNTs from NanoIntegris that are either 95% metallic or semiconducting and are better protected from bundling. Here we present results of the effects of deposition parameters on the distribution of these SWNTs after EPD. In particular by varying the time of deposition we have achieved a degree of control over the number of SWNTs deposited in nanoscale windows in both isolated and dense patterns while preventing nanotube bridges from forming between windows.

The experimental set-up for EPD (Figure 1a) and the nanoscale features (Figure 1b and 1c) are shown below. We varied the deposition time from 10 minutes to 0.5 seconds for two kinds of patterns using both metallic and semiconductor nanotubes. The pattern density ranged from isolated windows (6μm spacing from center to center) to dense arrays (200nm spacing from center to center) with diameters of the windows being approximately 30–80nm. We found that in order to prevent networks of nanotubes from forming (which could short together individual devices), the duration of the deposition should be between 0.6 and 1 second for both dense and isolated patterns. Dense patterns were found to have a tighter constraint on the deposition time. Isolated patterns formed networks with times greater than 1 sec, whereas the dense patterns formed networks with times larger than 0.8 seconds. In addition, we found that the length of nanotubes plays an important role as well. Longer nanotubes were more likely to form networks. The ideal length is inferred to be less than 200 nm. These results (Figure 2) are consistent with a theoretical model we are developing, which will be reported elsewhere. Implications for wafer scale processing and commercialization of novel vertical nanotube devices will be discussed.

[1] A. Goyal, S. Liu, Z. Iqbal, L. A. Fetter and R. C. Farrow, "Directed self-assembly of individual vertically aligned carbon nanotubes", Journal of Vacuum Science and Technology (2008) **26**, 2524.

[2] A. Kanwal, S. Lakshmanan, A. Bendiganavale, C. T. Bot, A. Patlolla, R. Raj, C. Prodan, Z. Iqbal, G. A. Thomas, and R. C. Farrow, "Scalable Nano-Bio Probes with Sub Cellular Resolution", to be published

[3]. R. C. Farrow and A. Goyal, "Method of Forming Carbon Nanotube Vertical Field Effect Transistor", US Patent #7,736,979 (2010)

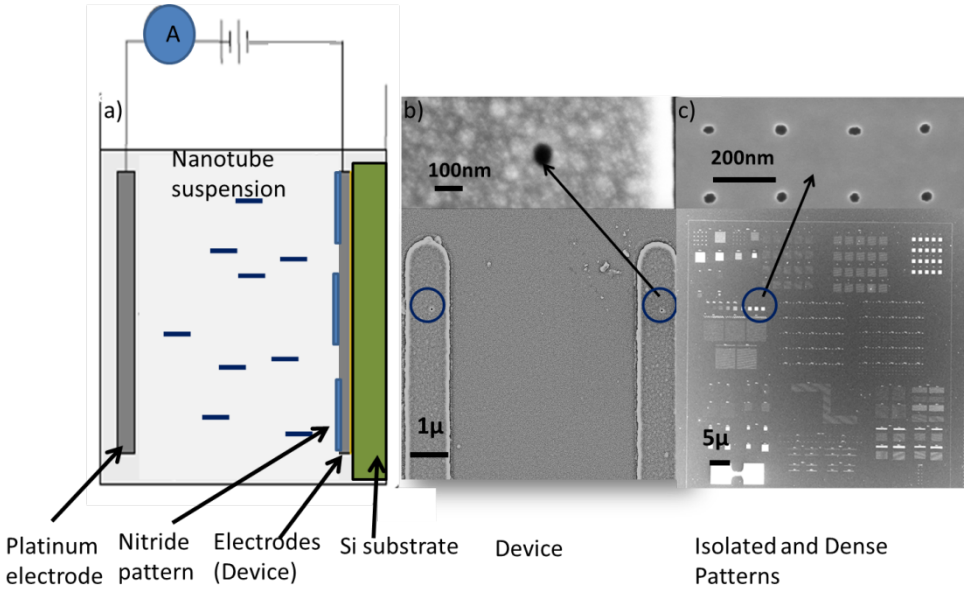

Figure 1. a) Schematic of EPD set-up. b) Devices with isolated windows (~30nm diameter separated by 6 µm spacing) c) ~40nm windows magnified out of a region containing various features (both dense and isolated).

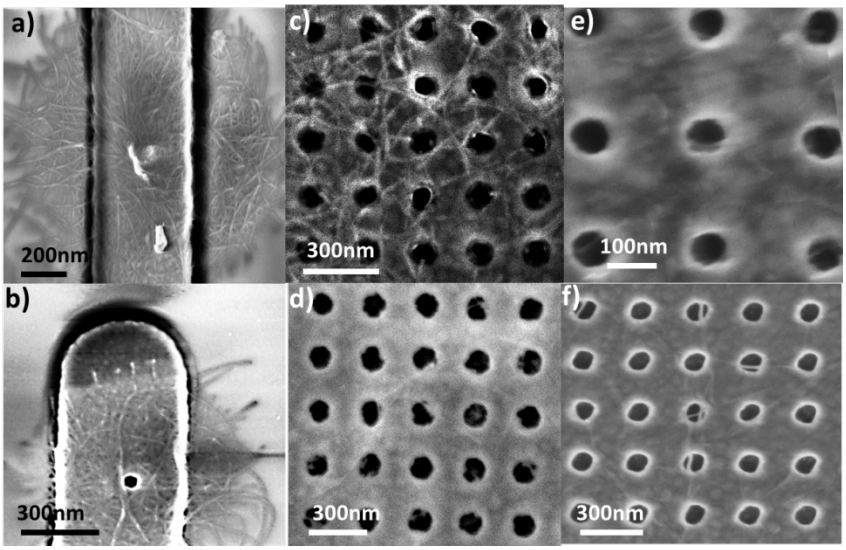

Figure 2. a)-b) Metallic nanotubes deposited inside the isolated windows (30-50nm) for 5 seconds and 2 seconds respectively. c)-d) Metallic nanotubes deposited inside dense windows (47-80nm holes) for 2 seconds and 0.5 second respectively. e)-f) Semiconducting nanotubes deposited inside the dense windows (50-80nm holes) for 1 minute and 2 seconds respectively.