EFFECT OF SOURCE, SURFACTANT, AND DEPOSITION PROCESS ON ELECTRONIC PROPERTIES OF NANOTUBE ARRAYS

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ABSTRACT

Carbon nanotubes are currently being sought as a potential candidate in the device research area. However, a scalable manufacturing technology for nanotube devices with appropriate yield, reproducibility, and performance in various metrics (mobility, on/off ratio, cost, chemical sensitivity, sensor specificity, etc.) is currently lacking. This is, in part, due to the variety of synthesis and deposition techniques and challenges due to the inherent differences in nanotube physical properties. All known synthesis methods for single walled carbon nanotubes result in a mixture of chiralities and diameters, resulting in heterogeneous electrical properties, particularly a mixture of semiconducting and metallic nanotubes. The chemistry community has lead a successful effort aimed at sorting and purifying nanotubes in solution post-synthesis[1]. In solution, as produced single walled carbon nanotubes exist as bundles. In order to de-bundle and sort the nanotubes, various surfactants are typically used. At present, it is not known how these surfactants affect the electronic properties of nanotube arrays and films made from depositing nanotubes using various techniques. While a complete understanding of the physical processes involved in these complex manufacturing steps is still lacking, in this work we have made an attempt to make a comprehensive study and report a raw set of empirical guidelines to guide future technology development in this area.

Keywords: Carbon nanotubes, surfactants.

We obtained carbon nanotubes from several different sources differing in manufacturing process used with a variety of average properties such as length, diameter, and chirality. We then used several common surfactants to disperse each of these nanotubes and then deposited them on Si wafers from their aqueous solutions using dielectrophoresis[2]. While most studies of purified nanotubes use spectroscopic techniques to determine nanotube purity and composition, these studies are useless for the electronics industry unless they can be directly correlated with transport measurements. Thus, in this study, transport measurements were performed to compare and determine the effect of different surfactants, deposition processes, and synthesis processes on nanotubes nanotubes synthesized using CVD, CoMoCAT, laser ablation, and HiPCO.

From our experiments, we found when a gap width close to the average nanotube length was used, it was possible to deposit enough well aligned nanotubes from all sources to have dc resistance values lower than 100 W for a width of 100 mm. For the effective dispersion of nanotubes, sodium cholate (SC) was most suitable among others despite of source (or synthetic process) of nanotubes. An average 2 hours of sonication in 1% surfactant solution

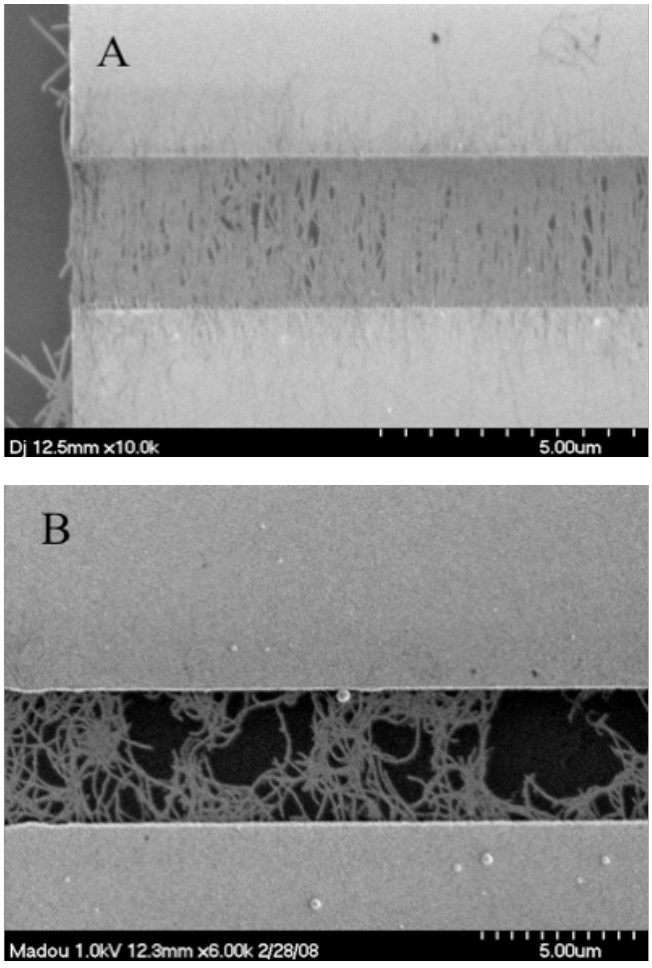

Figure 1. Nanotubes deposited on Si wafers using different frequencies for electric field direct alignment (dielectrophoresis). A) 25 MHz, yielding well-aligned arrays and B) 2 MHz, yielding poorly aligned arrays. Statistical properties of devices yielded reasonably low scatter in the electronic properties from device to device.

(w/v in DI water) in an ultrasonic bath @ 40 watts, followed by repeated centrifugation for up to 6 hours yielded fairly clean nanotubes solutions to be used for device fabrication. DEP parameters such as frequency and field strength play an important role for effective deposition of nanotubes on wafers. Using a dilute solution and giving more time for the deposition or using a comparatively concentrated solution with less time yielded devices with similar properties. Also using any amplitude above 3 V did not make much difference on device characteristics. In our observations, we also found the frequency used for DEP to be the most important factor having a direct effect on device properties. As shown in Figure 1, using a frequency higher than 10 MHz resulted in far better alignment of nanotubes deposited on a wafer. In fact using 25 MHz resulted devices with well-aligned nanotubes between the electrodes despite the source of the nanotubes used. Also Figure 2 shows the dependence of device resistance on electrode gap length. These studies lay important groundwork for useful application of nanotube electronics using purified, mono-disperse nanotubes in solution as the starting material for a diverse array of heterogeneously integrated systems.

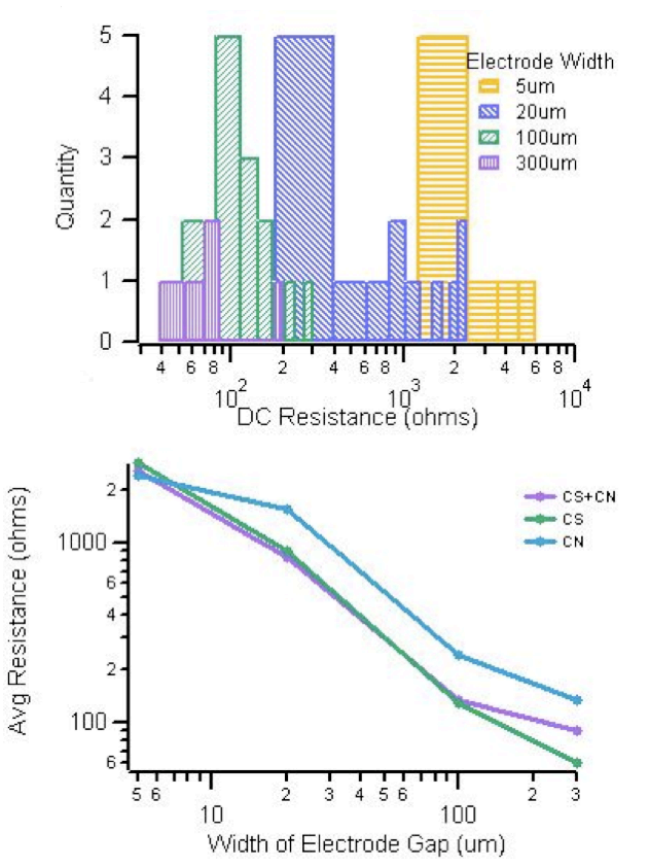

Figure 2. The results of deposition from two different manufacturers (Carbon Solutions CS, and Carbon Nanotechnologies, CN), gave similar results for the resistance at different electrode widths. D)

TABLE 1
SUMMARY OF RESULTS

SWNT Sources	Electrode spacing	Avg. length after deposition (in SEM)	DC resistance (1000's of SWNTs in parallel)	On/off ratio
Cheap Tubes	3 µm	> 3 µm	< 50 Ω	2-8%
SWeNT	1 µm	< 1 µm	50-100 Ω	2-6%
CSI	1 µm	<1.5 µm	100-200 Ω	<1%
CNI/Unidym	1 µm	<1 µm	100-500 Ω	<1%
Las Alamos	1 µm	<1.5 µm	120-150 Ω	<1%
Nanointegris (semi-enriched, 90%)	1 µm	<1.5 µm	150-180 Ω	<1%

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