CHEMICAL VAPOR DEPOSITION GROWN SINGLE-WALLED CARBON NANOTUBE JUNCTIONS FOR NANO-ELECTRONICS AND SENSORS

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ABSTRACT

Using an Fe-containing diblock copolymer as the catalyst, single walled carbon nanotubes (SWNTs) have been grown on Si/SiO2 substrate by chemical vapor deposition technique. Atomic force microscopic image of the grown samples exhibit interesting junction architectures in the form of T, Y, and X of small-diameter (~2nm) SWNT bundles.

SUMMARY

Single walled carbon nanotubes (SWNT) are potential candidates for interconnects and active device elements in nanoelectronics.[1] However, the challenge lies in the controlled growth of clean, uniform SWNTs. Often, the growth process leads to amorphous carbon buildup, leftover catalyst material, and unevenly dispersed nanotubes over the substrate surface.[2] We report the growth of such SWNTs via chemical vapor deposition (CVD), where methane is used as the carbon source.[2] Our approach allows for the clean growth of small diameter SWNT bundles with lengths averaging 10 µm. An iron containing block copolymer, poly(styrene-*b*-ethylmethylferrocenylsilane) was used as the catalyst. The polymer was spin cast over highly doped silicon substrates with a thermally grown oxide layer. The thickness of the polymer film was about 25 nm. The iron containing block of the polymer forms spherical domains in the polystyrene matrix, allowing uniform iron nanoparticles to form on the surface at temperatures above 500ºC. The benefit of this growth method is that the nanotube density can be controlled and the tubes are uniformly dispersed over the surface. Here, we report the growth of nanotube junctions for the construction of nanodevices and sensors.

Figures 1 and 2 show the atomic force microscopic (AFM) images of different SWNT samples. The X (Fig 1a), T (Fig 1b), and Y (Fig. 1b) junctions can be clearly seen in the two images among long, straight SWNT bundles. The average diameter of the bundles is ~2 nm. Since this process generally yields SWNTs of about 0.8 nm,[2] we estimate the bundles to consist of four to six individual tubes.

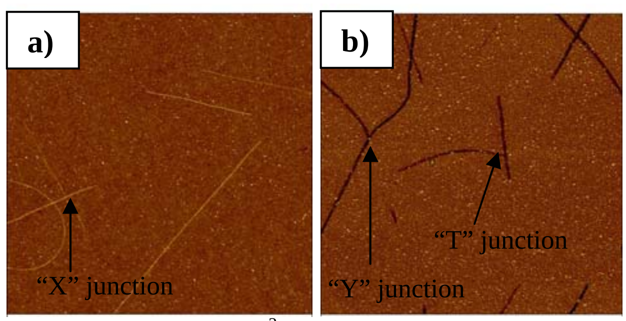

Figure 1. (a) $10x10\mu m^2$ AFM height image of SWNT bundles (~2 nm in diameter) grown on highly doped silicon/silica surface. "X" junction is clearly seen on the left side as indicated by the arrow; (b) $10x10\mu m^2$ AFM phase image of SWNT bundles forming "Y" and "T" junctions as shown by arrows.

These junctions offer excellent architecture for exploring all-SWNT electronic device applications. Here, we report the first step towards achieving such nanodevice designs. After the nanotubes are grown, long

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metal contacts stretching the length of the 1”x1” substrates are deposited via photolithography. Unlike other methods, the nanotube surface coverage density was manipulated via the polymer film thickness to create approximately three to six tubes per 100 µm^2. This allows for the direct deposition of metal electrodes onto the silica/nanotube surface without tedious positioning of the nanotubes between the metal contacts as an additional processing step. Thus, over 100 working nanodevices can be constructed on a single 1”x1” wafer with this simple three step process: 1) spin casting catalytic polymer film; 2) CVD; 3) metal electrode deposition.

Figure 2 shows a two point probe measurement carried out after nanotubes were determined to be bridging between the gold contacts, as identified in Figure 3. The high current observed in these I-V curves may be the result of a large number of nanotubes bridging a single gap. During AFM imaging, bridging nanotubes were readily found without difficulty (on average, there was at least one bridging bundle every 20 µm along the length of the gap). Their high surface coverage allows for a high yield of nanotubes bridging any two gold contact pads. The high current could also in part be caused by a small number of metallic tubes. The devices showed current anywhere from hundreds of µA’s to a few mA’s, most likely depending on the number of and size of SWNT bundle electrical channels; however, further analysis is required. The SWNTs gave linear I-V curves in these two terminal measurements, leading to the conclusion that this CVD method allows for the growth of at least a percentage of metallic tubes. It should be noted that only a few metallic tubes must exist between these contacts to overpower any semiconducting behavior of other SWNTs. The experiments toward fabricating diode and transistor structures using the SWNT junctions are underway at ARL.

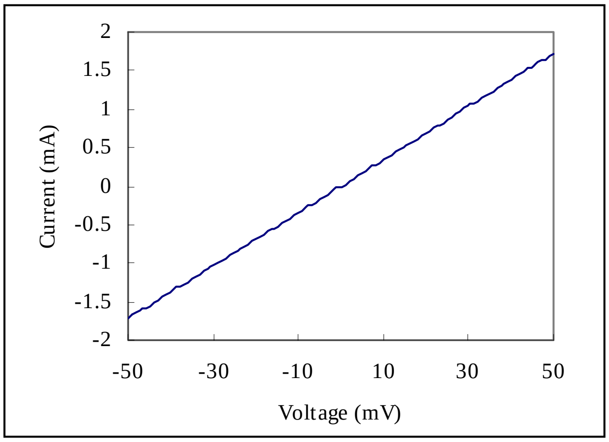

Figure 2. Two point probe measurement showing conductance between two gold contacts with an electrically connected by SWNT bundles.

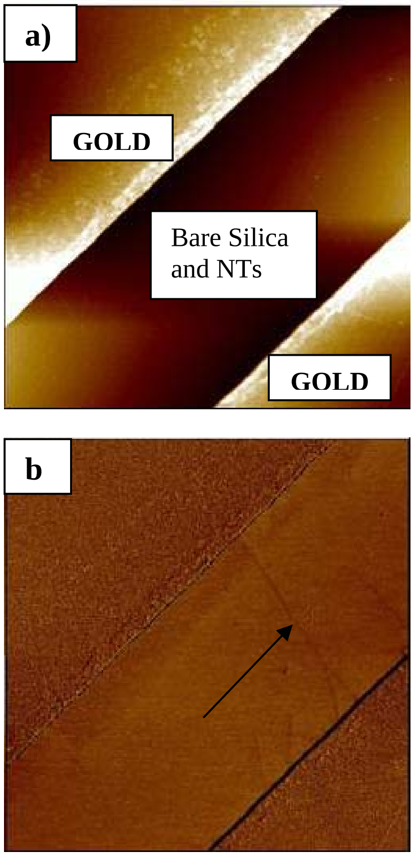

Figure 3. (a) 15x15 µm^2 AFM height image of two gold pads separated by a 7.2 µm gap. (b) AFM phase image of (a) where a SWNT is seen bridging between the two electrodes (indicated by arrow).

REFERENCES

1. P. Avouris, “Carbon nanotube electronics,” *Chem. Phys*, **281**, pp. 429-445 (2002).
2. S. Lastella, Y. J. Jung, R. Vajtai, H. Yang, C. Ryu, P. Ajayan, D. Rider and I. Manners, “Density control of single-walled carbon nanotubes using patterned iron nanoparticle catalysts derived from phase separated thin films of a polyferrocene block copolymer,” *J. Mat. Chem.* **14**, pp. 1791-1794 (2004).