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LDRD Final Report: Chromophore-Functionalized Aligned Carbon Nanotube Arrays

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Abstract

The goal of this project was to expand upon previously demonstrated single carbon nanotube devices by preparing a more practical, multi-SWNT device. As a late-start, proof-of-concept project, the work focused on the fabrication and testing of chromophore-functionalized aligned SWNT field effect transistors (SWNT-FET). Such devices have not yet been demonstrated. The advantages of fabricating aligned SWNT devices include increased device cross-section to improve sensitivity to light, elimination of increased electrical resistance at nanotube junctions in random mat devices, and the ability to model device responses. The project did not achieve the goal of fabricating and testing chromophore-modified SWNT arrays, but a new SWNT growth capability was established that will benefit future projects.

Acknowledgments

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Nomenclature

FET	field effect transistor
SWNT	single-walled carbon nanotube

1. Introduction

We recently demonstrated the effectiveness of tuning the low intensity, visible light response of single-walled carbon nanotube field effect transistors (SWNT-FETs) through non-covalent attachment of light-isomerizable chromophores.¹ These single SWNT devices (i.e. there was one nanotube in each device) served as excellent model systems and generated data that could be supported by theory; however, more practical devices will be based on carbon nanotube films or arrays. This project was intended to expand the utility of chromophore-functionalized SWNT devices by building devices with aligned SWNTs that fully span the interelectrode spacing (i.e. the transistor's channel). Such an arrangement would eliminate issues of resistance at SWNT junctions that would be expected in randomly oriented SWNT films² while increasing the area of the detector. Examples of aligned SWNTs have been demonstrated,^{3,4} but these were not utilized to examine the response of the devices to low intensity visible light. Aligned SWNT devices are a very recent advance in the area of carbon nanotubes, and their potential uses are only now beginning to be explored. LDRD funding supported basic research into a proof of concept application of SWNT devices.

2. Results and Discussion

The project was originally divided into two parts with initial work focused on the growth of horizontally aligned SWNTs. Once these were prepared, devices would be fabricated and tested with chromophores. SWNT growth was found to be more challenging than anticipated so the project was did not proceed beyond efforts to optimize SWNT growth conditions.

A growth furnace was set up with flow controllers for argon, hydrogen and methane (Figure 1). Variables that were adjusted to attempt to optimize SWNT growth conditions included gas flow rates, catalyst deposition methods, and growth substrates.⁵⁻¹⁰ Interesting results were obtained with e-beam evaporated iron catalyst on 1000 Å SiO₂ on <100> Si substrate. Aligned arrays of SWNTs were not obtained, but a very long SWNT was observed in



Figure 1. SWNT growth furnace

SEM images. Tracking the SWNT and assembling the images showed a microns-long nanotube was produced (Fig. 2).

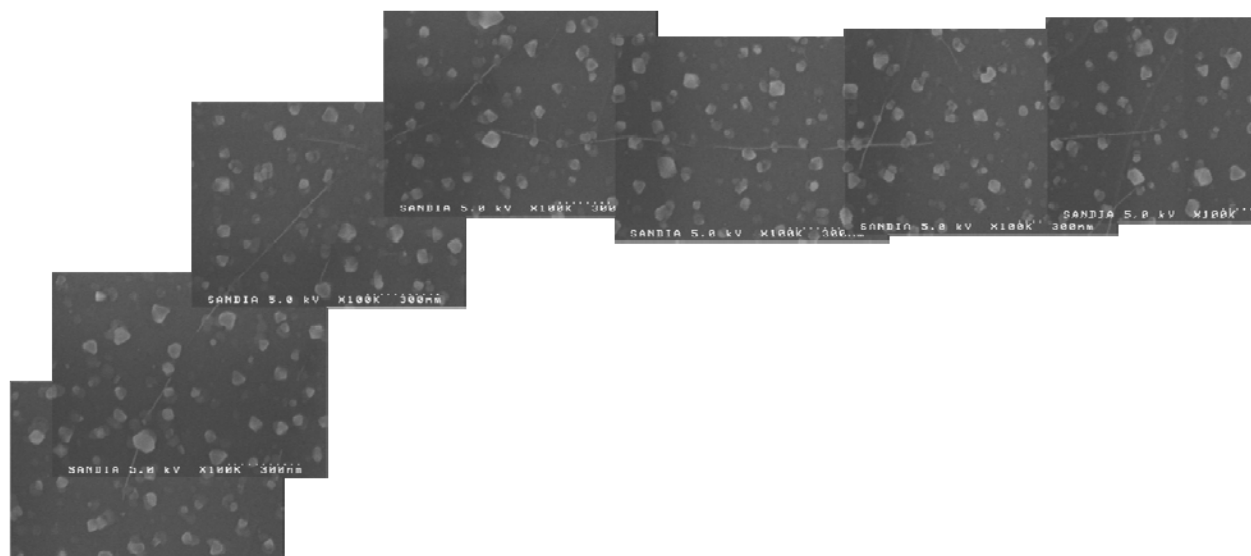


Figure 2. Assembled SEM images showing long SWNT

Another approach utilized drop-cast iron chloride that was subsequently annealed to form iron nanoparticle catalysts. This method produced sparse, but fairly long (~5 μm) SWNTs; however, aligned arrays were not found. Figure 3 shows one of these SWNTs.

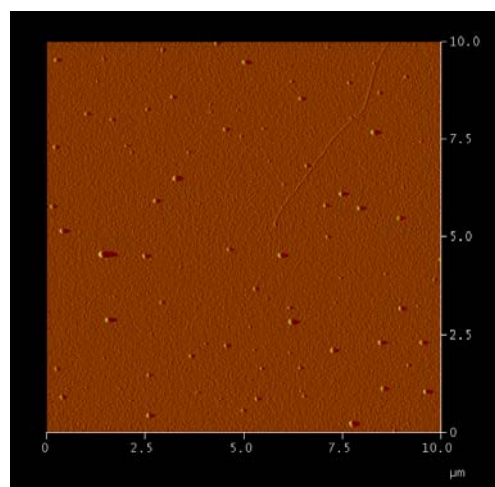


Figure 3. SWNT from annealed iron catalyst nanoparticles

3. Conclusions

Although the ultimate goal of fabricating and testing chromophore-modified SWNT arrays was not achieved, the work did lead to a new carbon nanotube growth capability at Sandia/CA. The synthesis of dense arrays of horizontally aligned SWNTs is a developing area of research with significant potential for new discoveries. In particular, the ability to prepare arrays of carbon nanotubes of specific electronic types (metallic or semiconducting) could yield new classes of nanoscale devices.

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Appendix: Experimental Details

Examples of SWNT Synthesis

E-Beam evaporated iron: 5 Å thick iron film was e-beam evaporated on a 1000 Å SiO₂ on <100> Si substrate. The thin film was annealed in air at 550°C for 10 minutes. Argon was flowed in at 100 SCCM for 10 minutes. Argon flow was stopped then hydrogen was introduced at 100 SCCM and the furnace/quartz tube were heated to 900°C then held for 20 minutes. The temperature was increased to 970°C and hydrogen flow decreased to 4 SCCM and held for 3 minutes. Methane was introduced at 2 SCCM to start SWNT growth. After 30 minutes, hydrogen and methane were turned off, argon was introduced at 10 SCCM and the system was allowed to cool to room temperature.

Drop-cast iron: An ethanol solution of iron(III)chloride was drop cast onto a silicon wafer. After drying, the iron chloride was oxidized at 700°C in air for five minutes. The temperature was increased to 900°C with 100 SCCM argon flow. Argon was turned off when 900°C was reached, and the nanoparticles were reduced under a 200 SCCM hydrogen flow for 5 minutes. Methane was introduced at 800 SCCM while hydrogen was maintained at 200 SCCM. After 15 minutes, the hydrogen and methane were turned off and the sample cooled to room temperature under 10 SCCM flow of argon.

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