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Single Walled Carbon Nanotubes Grown by Chemical Vapour Deposition: Structures and Devices for Transport and Optics

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1. Introduction

The carbon nanotube material system is rapidly developing and is anticipated, because of its unique optical and electronic characteristics [1-3], to one day find practical application in electronic and opto-electronic devices. The leading method of nanotube synthesis is chemical vapour deposition (CVD) [4]. We have been developing a particular variant, cold wall CVD, which has several advantages over common methods [5]. Nanotube-based devices have been made in various ways, including CVD, on a limited basis for a decade. However, it is still challenging to reliably synthesize and fabricate them in particular for opto-electronic applications. Towards this goal, we show the results of very recent work, including individual single walled carbon nanotube (SWNT) field effect transistors (FET's) grown by cold wall CVD and fabricated lithographically, and discuss issues determining device yield.

2. Growth and Fabrication

SWNT's are grown by cold wall CVD [5] with hydrocarbon sources on substrates with either patterned catalyst or uniform catalyst covering the whole surface. The substrates are n-doped silicon covered with a micron of oxide. Catalyst, deposited by electron beam evaporation, consists of a thin layer of iron on top of a thin layer of aluminum, and is exposed to air before CVD growth. Proper preparation of the sample at this stage is very important for a significant yield of nanotubes suitable for transport and optical measurements.

Fig. 1 shows a scanning electron micrograph of SWNT's growing from regions of patterned catalyst.

3. Optics

Fig. 2 shows a photoluminescence spectrum obtained from a single SWNT, estimated to be ~100 microns long, lying over a high density of iron oxide nanoparticles. A HeNe laser was used for excitation with 1.7mW power at 633 nm focused to a ~10 micron diameter spot. Although the SWNT's are not intentionally suspended, the particle density of catalyst is sufficiently high that SWNT's are occasionally draped across the particles and are thus coincidently suspended.

We have also obtained photoluminescence from SWNT's that have been intentionally suspended on patterned substrates.

4. Transport Measurements

Fig. 3 shows a scanning electron micrograph of a typical SWNT device. Molybdenum metal electrodes are patterned in a spiral around the catalyst region prior to CVD. Several nanotubes grow from the catalyst region but only those sufficiently long to bridge the electrodes are probed.

Fig. 4 shows the room temperature transfer characteristics of the single nanotube device shown in Fig. 3. The source-drain voltage, applied between the molybdenum electrodes, is 100mV and the gate voltage, applied to the substrate, is swept in both directions between -20 and +50V. The device exhibits semiconducting p-FET behavior. Other single SWNT devices we have measured exhibit either semiconducting or metallic-like behavior.

In addition to measuring the transport properties of SWNT's lying just on molybdenum electrodes, we have also investigated and compared other electrodes combinations, including Ti/Au, Cr/Au and Pd/Au deposited after growth of the nanotubes on either the oxide or molybdenum electrodes.

5. Conclusions

We describe growth, optical properties and transport characteristics of single SWNT structures and devices. We will describe the key issues for the development of SWNT based opto-electronic devices. The main factors affecting device yield will be discussed.

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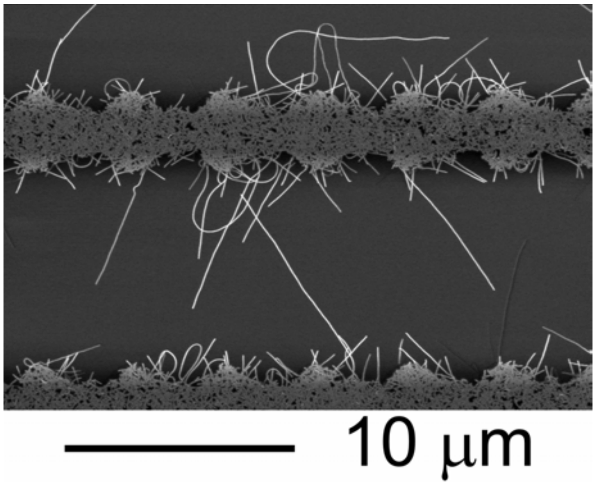

Fig. 1 Scanning electron micrograph of SWNT's grown from lithographically patterned iron-aluminum catalyst.

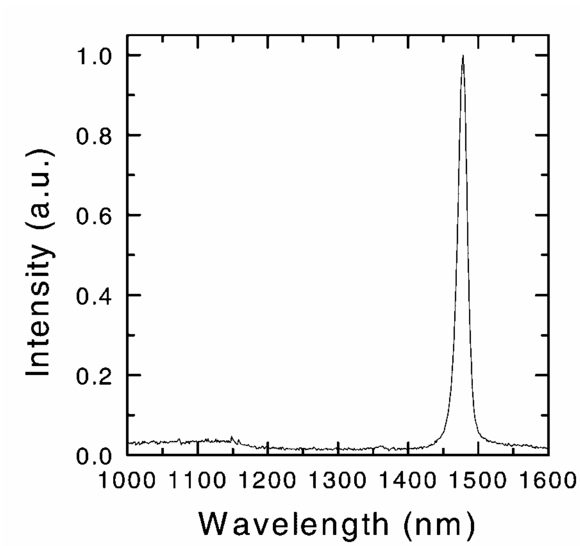

Fig. 2 Photoluminescence spectrum from a single suspended SWNT at room temperature. Note the sharp asymmetric line-shape.

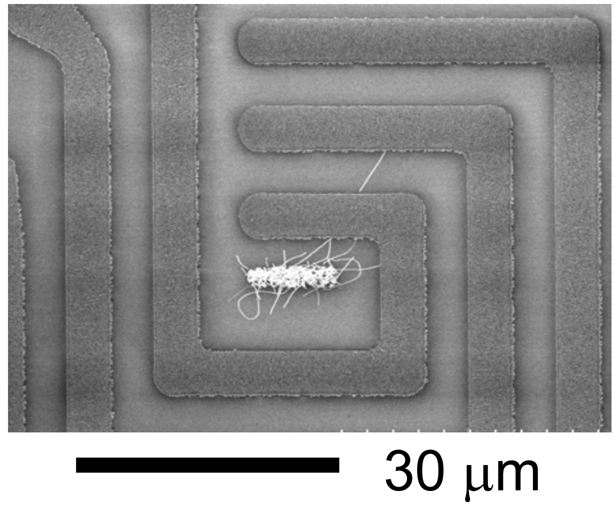

Fig. 3 Scanning electron micrograph of a single SWNT device. Molybdenum metal electrodes were placed around the catalyst region prior to CVD growth. Several nanotubes are visible, but here only one is sufficiently long to bridge two (source and drain) electrodes.

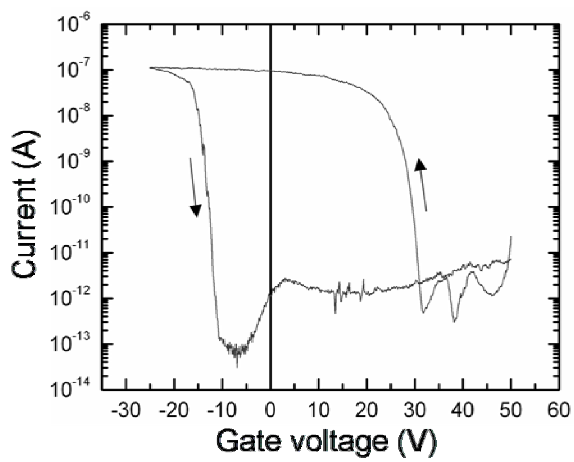

Fig. 4 Room temperature gate sweep for the single semiconducting SWNT device shown in Fig. 3. The source-drain voltage is 100mV and the gate voltage, applied to the substrate, is swept in both directions between -20 and +50V.