

SUPPORTING INFORMATION

Effect of Atomic Interconnects on Percolation in Single-Walled Carbon Nanotube Thin Film Networks

*Xiaojuan Tian,^{†,§} Matthew L. Moser,^{‡,§} Aron Pekker,^{‡,§} Santanu Sarkar,^{‡,§} Jason Ramirez,^{†,§}
Elena Bekyarova,^{‡,§} Mikhail E. Itkis,^{‡,§} and Robert C Haddon,^{†,‡,§,¶*}*

[†]Department of Chemical Engineering, University of California, Riverside, California 92521,
United States

[‡]Department of Chemistry, University of California, Riverside, California 92521, United States

[§]Center for Nanoscale Science and Engineering, University of California, Riverside, California
92521, United States

[¶]Department of Physics, King Abdulaziz University, Jeddah 21589, Saudi Arabia

*Corresponding author: haddon@ucr.edu

Methods

Preparation of SWNTs films

Our experiments were based on separated electric arc SWNTs of diameter 1.2 - 1.7 nm and length 300 nm - 2 μm . Aqueous dispersions of semiconducting (SC) and metallic SWNTs (MT) (IsoNanotubes (99%)) were obtained from NanoIntegris Inc. For the metal deposition and conductivity measurements, SWNT films of predetermined effective thickness were prepared on alumina membranes by filtration; the requisite amount of 0.01 mg/ml SWNT dispersions were diluted with 50 mL of water, and the resulting mixture filtered through the alumina membrane (Anodisc 47, 0.02 μm , 47 mm diameter) and washed with DI water and ethanol to remove surfactants from the SWNTs. The effective film thickness was estimated using a SWNT density of 1.2 g/cm³. The SWNT films on the alumina membranes were diced into 4 mm \times 3 mm substrates and positioned on glass slides with pre-patterned gold electrodes. The finished devices were annealed at 300 ⁰C for 3 h at a vacuum of 10⁻⁷ Torr to remove solvents.

For the spectroscopic studies (near-IR [NIR], Raman and photoelectron spectroscopy) the SWNT films were prepared by filtration as described above using a nitrocellulose membrane (Millipore, 0.1 μm VCWP) and then transferred to the desired substrates. For the transfer a diced piece of the membrane with the SWNT film was placed on the substrate of choice (thin round glass slide for Raman and NIR; Au or HOPG for X-ray photoemission spectroscopy [XPS] and ultraviolet photoemission spectroscopy [UPS]). The substrates with the SWNT film on the membrane were held in an acetone bath for 1 hour to remove the cellulose membrane and then exposed to isopropanol vapors for 30 min.

Metal deposition

The Li, Cr, Au and Al deposition sources were obtained from Kurt Lesker. A customized cryo-pumped Temescal BJD 1800 e-beam evaporator operating at a base pressure of 10^{-6} Torr was used for the metal deposition experiments which were conducted at an evaporation rate of 0.01 nm/s.

In order to protect the metal-SWNT films from the atmosphere for the Raman and NIR microspectroscopy, the evaporation of Cr and Li was followed by the deposition of an additional 50 nm thick Al layer.

Measurements

The electrical measurements as a function of metal deposition were conducted with a custom-built feed-through assembly mounted in the ebeam chamber which was interfaced to a multiplexed Keithley 2700 data acquisition system that allowed the simultaneous collection of six channels of resistance data thereby providing a direct comparison of the transport properties of films of different thickness.

The SEM study was conducted with a Nova NanoSEM 450 instrument (FEI Company) with an acceleration voltage of 12 kV.

The Raman spectra were collected on a Nicolet Almega XS Raman spectrometer with 532nm laser excitation. For the near infrared spectroscopy a Jobin-Yvon iHR 320 spectrometer was used in combination with a Bruker Hyperion 1000 microscope with MCT and Si detectors. To perform the measurements the sample substrate, protected with an Al layer (see above), was inverted and the spectra were measured through the glass slide (see Fig. 6a,b), so in the optical absorption measurements the near-infrared radiation passed through the SWNT layer twice by reflection from the protective aluminum layer. An additional SWNT sample coated with an identical 50 nm Al layer was prepared as a reference for the spectroscopic measurements.

The X-ray photoelectron spectroscopy (XPS) was performed using a Kratos AXIS ULTRADLD XPS system equipped with an Al K α monochromated X-ray source, He UV source, and a 165-mm electron energy hemispherical analyzer. The vacuum pressure was kept below 3×10^{-9} torr and a charge neutralizer was applied during the data acquisition. The slot size for the XPS is 300×700 μm and the UPS aperture has a diameter of 110 μm .

The survey XPS spectra were recorded at 270 kW with a step of 0.5 eV, dwell time of 100 ms and 80 pass energy. The high resolution scans were conducted at 300 kW with a step of 0.05 eV, dwell time 200 ms and pass energy (PE) of 20.

For the XPS and UPS measurements the SWNT films (1 nm, 4 nm and 50 nm thickness on Au and HOPG substrates, 1 cm x 1 cm), were annealed at 400°C in a vacuum of 10^{-7} Torr for 4 hours. Cr deposition was performed by e-beam as described above and the samples quickly transferred to the XPS chamber to minimize the exposure to air.

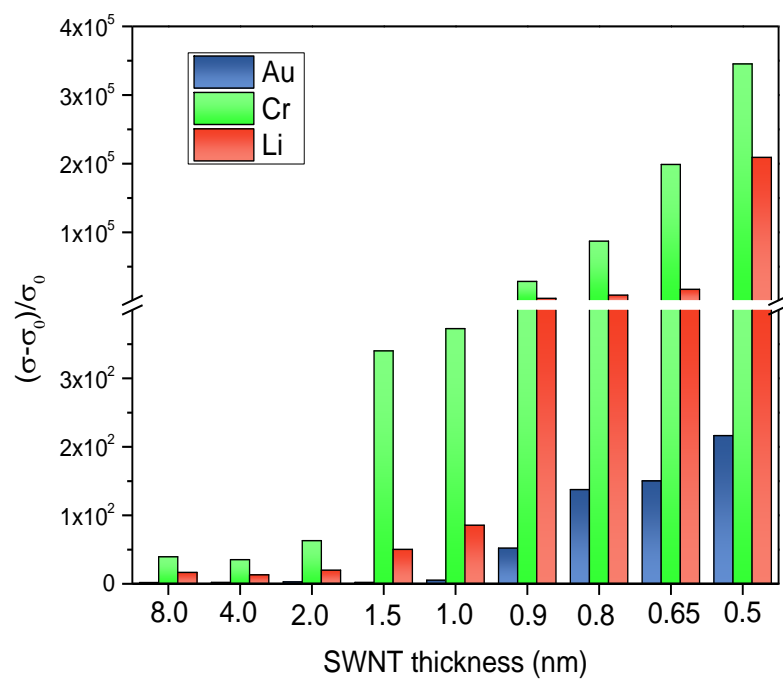


Figure S1. Conductivity enhancements on metal deposition (0.1ML), for an extended set of semiconducting SWNT films.

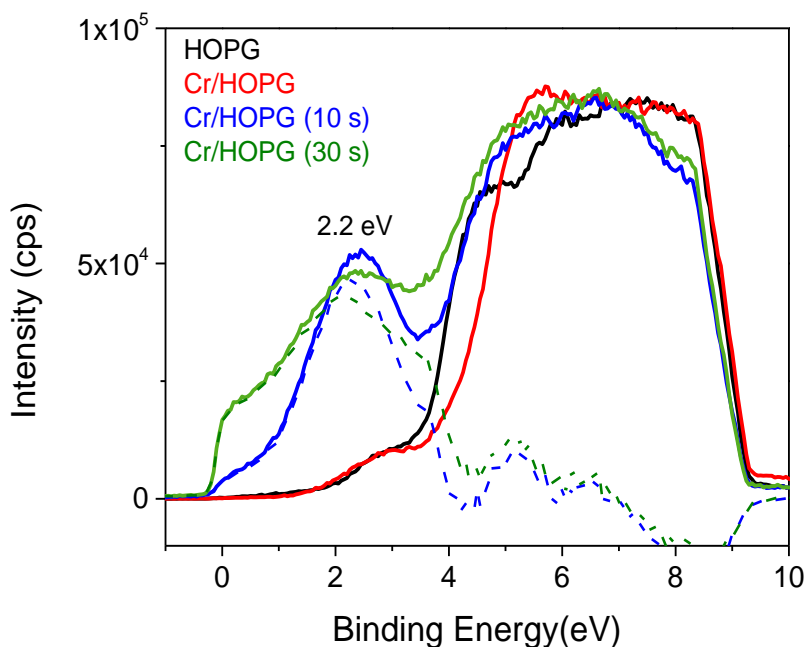


Figure S2. Ultraviolet photoemission spectra (UPS, He I) of HOPG before and after e-beam deposition of 1 nm Cr; the spectra are normalized to the 2p- σ transitions at ~ 7 eV. HOPG (black line) shows a band at around 3 eV assigned to the 2p- π states and broad overlapping bands at ~ 5 eV and 8 eV associated with 2p- σ states. Cr/HOPG (red line) exhibits similar spectrum to HOPG due to the oxidation of chromium during exposure to air. The sample was sputtered with Ar^+ to remove the top oxide layer and the evolution of UPS spectra after 10 s sputtering (blue line) and 30 s sputtering (green line) is illustrated. Dashed lines show the difference spectra obtained by subtracting the spectrum of HOPG.