4-20-2015

# Towards Molecular Modification of Carbon Nanotube Junctions in Thin Film Transistors

Noelia Caloca

A. Nicole Chang

Kari McLaughlin

David Estrada

# Towards Molecular Modification of Carbon Nanotube Junctions in Thin Film Transistors


## Abstract

Carbon nanotube thin film transistors have recently been used on flexible and transparent substrates for applications in integrated circuits and display drivers. Such networks are of interest due to their relatively high carrier mobility and mechanical flexibility. However, the $I_{ON}/I_{OFF}$ ratio of these networks varies inversely with the carrier mobility, and advances in reducing the electrical and thermal resistance of nanotube junctions are needed to improve the device performance and reliability. The objective of this work is create a process to improve CNT TFT device performance by using 0-dimensional molecules to modify the physical properties of the nanotube junctions. Our preliminary data indicate C60 fullerenes deposited on CNT TFTs results in decreased carrier mobility and a reduced $I_{ON}/ I_{OFF}$ ratio. This is likely a result of an n-type doping effect by the C60 molecules on the otherwise p-type CNTs, leading to increased p-n junctions throughout the CNT network. While this effect is detrimental to p-type CNT TFT device performance it highlights the potential of 0-dimensional molecules in tuning the transport properties of CNT networks for applications such as transparent electrodes, chemical sensors, and transistors.



## Keywords

Carbon nanotube thin film transistors (CNT TFT), carrier mobility


## Disciplines

Materials Science and Engineering

# Towards Molecular Modification of Carbon Nanotube Junctions in Thin Film Transistors

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Noelia Caloca, A. Nicole Chang, Kari McLaughlin, David Estrada
Boise State University, Department of Material Science and Engineering

## Background

Carbon nanotube thin film transistors (CNT TFT) have recently been used on flexible and transparent substrates for applications in integrated circuits and display drivers. Such networks are of interest due to their relatively high carrier mobilities and mechanical flexibility. [1] However, the $I_{ON}$ / $I_{OFF}$ ratio of these networks varies inversely with the carrier mobility and advances in reducing the electrical and thermal resistance of nanotube junctions are needed to improve the device performance and reliability. [2,3]

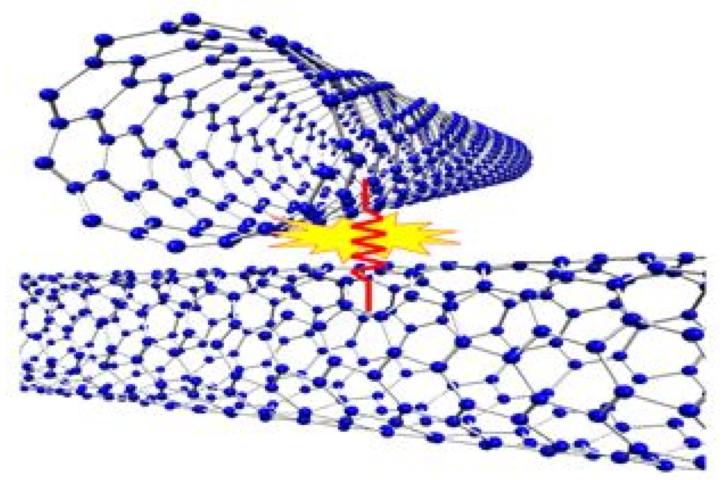

Fig. 1 Schematic of cylindrical nanostructure of a carbon nanotube and nanotube junction

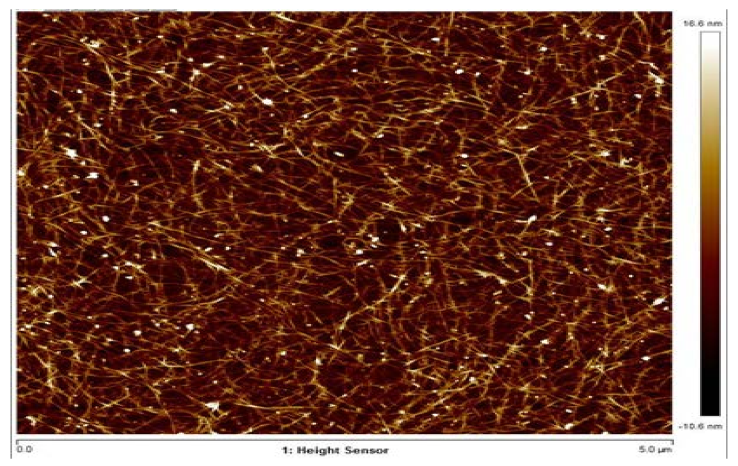

Fig. 2 AFM image of a carbon nanotube network

## Objective

Our objective is to create a process to improve CNT TFT device performance by using zero-dimensional molecules to modify the physical properties of nanotube junctions.

## Methods

1. Contacts and metal pads are placed on the substrate via photolithography, thermal evaporation, and lift off processes
2. Carbon nanotube (CNT) solution is vacuum filtrated
3. A CNT film is then transferred on to the receiving substrate by dissolving the filter via an acetone vapor bath
4. Carbon nanotube network (CNN) channels are patterned via photolithography
5. Devices are characterized by running voltage sweep tests
6. Fullerene solution is deposited on to device
7. Devices are characterized to determine the effect of the fullerenes on device performance

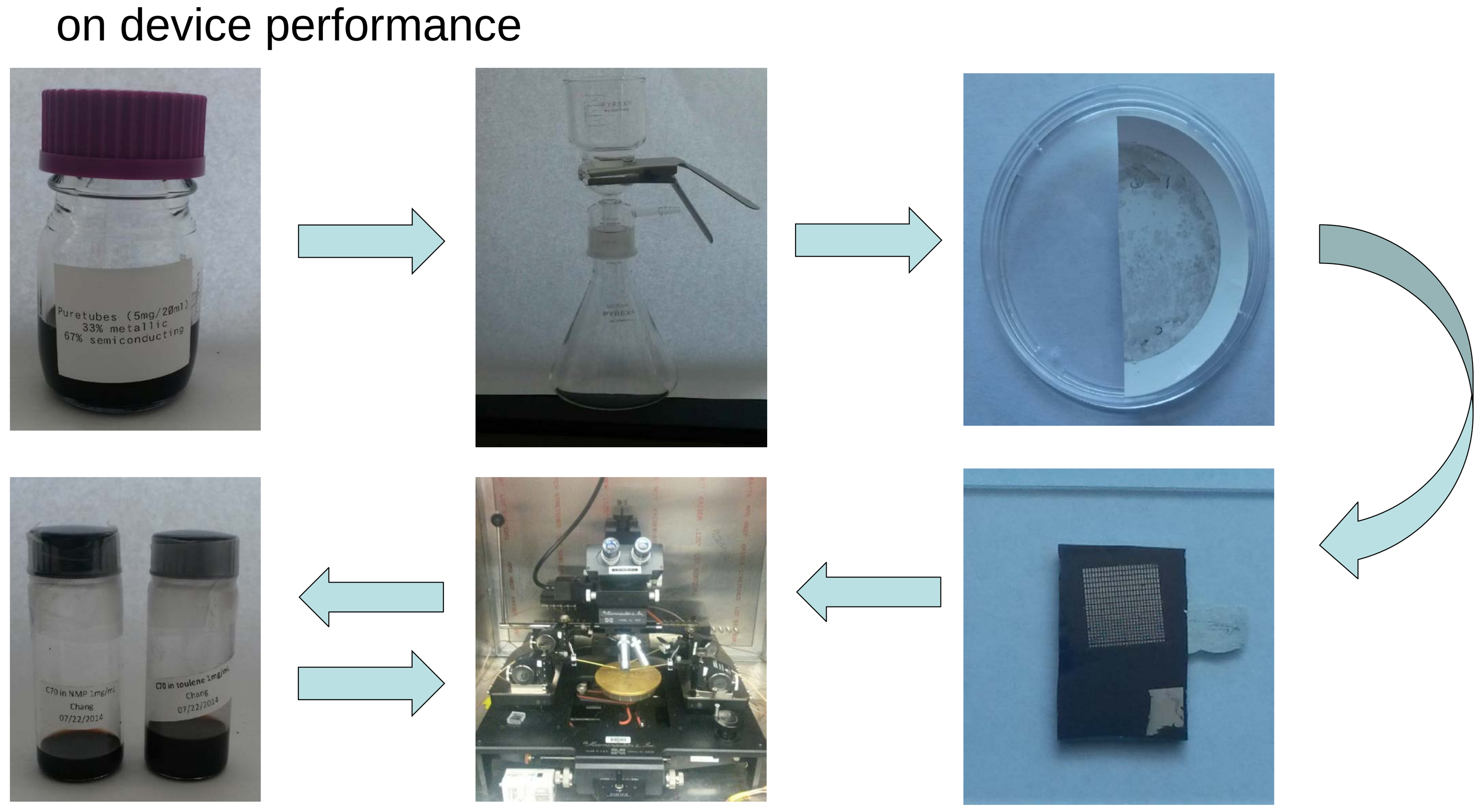

Fig. 3 Carbon nanotube device fabrication procedure

## Device Structure & Experimental Setup

To characterize these devices:

- $V_{GS}$ is swept across the device (-20V to 20V)
- $V_{DS}$ is held constant (0.1 V)
- $I_{DS}$ is obtained for each $V_{GS}$
- $I_{ON}$ / $I_{OFF}$ ratios, device resistance, and carrier mobility can be extracted

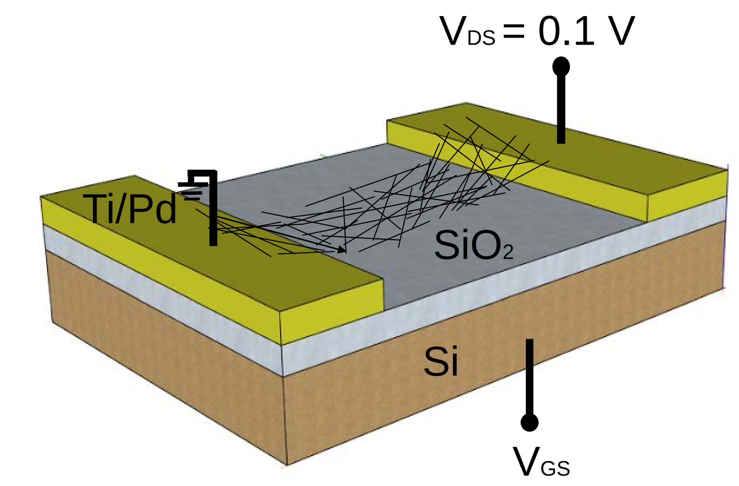


Fig. 4 Thin film transistor device structure utilizing a channel of CNTs

$C_{OX}$: Gate Capacitance per unit area
$V_{DS}$: Drain voltage
$L$: CNN channel length
$W$: CNN channel width
$g_m$: Peak Conductance

**Carrier Mobility, $\mu_{FE}$ :**

$$\mu_{FE} = \frac{L g_m}{W C_{ox} V_{DS}}$$

**$I_{ON}$ / $I_{OFF}$ Ratio:**

$$\frac{I_{ON}}{I_{OFF}} = \frac{I_{max,at\ -20\ V}}{I_{min}}$$

**Device Resistance $R_{ON}$ :**

$$R_{on} = \frac{V_{DS}}{I_{ON}}$$

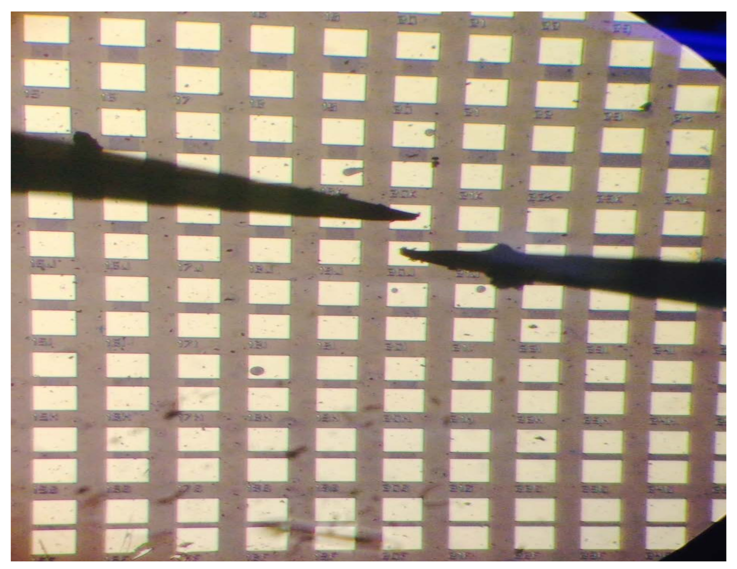

Fig. 5 Devices through microscope lens during characterization

## Results

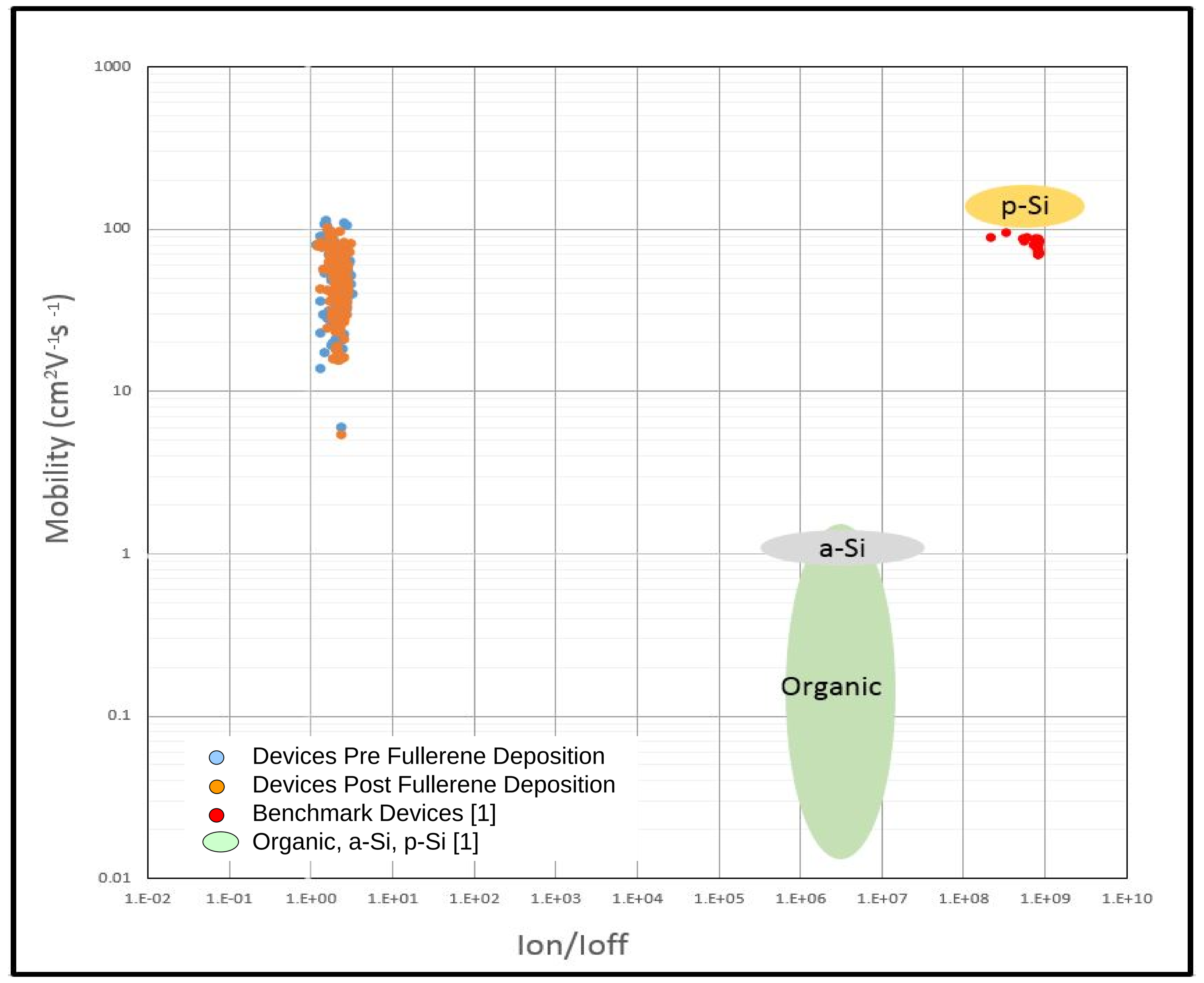


Fig. 6 Plot comparison between current study devices and other devices

## Discussion & Conclusion

It was hypothesized that both carrier mobility and $I_{ON}$/ $I_{OFF}$ ratio would increase with the deposition of fullerenes. When testing was done this was not the case. In fact, both mobility and $I_{ON}$/ $I_{OFF}$ ratio decreased. This is believed to be because the fullerenes dope the devices as n-type, leading to increased p-n junctions in the otherwise p-type network.

Fig. 7 Keithly characterization system used to perform voltage sweep test on devices

The next steps in the project are as follows:

- Use different concentrations of metallic and semiconductor CNT solutions to decrease overall device resistance
  - 99% Semiconducting
  - 99% Metallic
- Deposit C70 via thermal evaporation

Fig. 8 Thermal evaporation station that will be used in future fullerene deposition techniques

## References

[1] D. Sun et al., Nat. Nanotechnol. 6, 156 (2011)
[2] P. Nirmalraj et al., Nano Lett. 9, 3890 (2009)
[3] M. Stadermann et al., Phys. Rev. B: Condens. Matter Mater. Phys. 69, 201402 (2004)

## Acknowledgements

A special thanks to the Nation Science Foundation and Idaho Science Talent Expansion Program and to Dr. Paul Davis and the Boise State University Surface Science Lab for their assistance with AFM imaging.

Funded by:

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING
Department of Materials Science & Engineering

Grant No. NSF 0856815