SANDIA REPORT
SAND2013-7592
Unlimited Release
Printed September 2013

Temperature Dependence of the Electronic and Optoelectronic Properties of Carbon Nanotube Devices

François Léonard, John Goldsmith, Alexander Kane, Alexandra Ford

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Approved for public release; further dissemination unlimited.

Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represent that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof, or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof, or any of their contractors.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865) 576-8401
Facsimile: (865) 576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: http://www.osti.gov/bridge

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd.
Springfield, VA 22161

Telephone: (800) 553-6847
Facsimile: (703) 605-6900
E-Mail: orders@ntis.fedworld.gov
Online order: http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online

SAND2013-7592
Unlimited Release
Printed September 2013

Temperature Dependence of the Electronic and Optoelectronic Properties of Carbon Nanotube Devices

Contact : François Léonard
Materials Physics Department
Sandia National Laboratories
Livermore, California 94551-MS9161

Abstract

This report details the progress made in measuring the temperature dependence of the electronic and optoelectronic of devices made with individual carbon nanotubes.

CONTENTS

1. Introduction 6

2. Measuring the temperature dependence of CNT electronic devices 7
   2.1 Results 7

3. Conclusions 9

Distribution 10

FIGURES

Figure 1. Measured temperature dependence of the current in a CNT FET device. 8
Figure 2: Gating of CNT device at room temperature in ambient and in vacuum. 8

NOMENCLATURE

DOE	Department of Energy
SNL	Sandia National Laboratories
CNT	Carbon Nanotube
FET	Field-Effect Transistor

1. INTRODUCTION

The detection of low levels of light in the infrared region of the electromagnetic spectrum is central to many applications across the Sandia Missions. Existing approaches for infrared detection use exotic semiconductor materials (e.g. HgCdTe), which raises issues with reliability, performance, and cost. Novel approaches for optical detection that would use different materials, in particular ones compatible with existing CMOS fabrication infrastructure, would be valuable. The advent of nanotechnology brings novel materials with unique properties for infrared detection; carbon nanotubes are particularly attractive, but much research and development is needed to establish firmly their electronic and optoelectronic properties.

In order to realize the promise of nanotubes for infrared detection, it is important to understand the fundamental electronic and optoelectronic processes that govern their properties so that the best IR pixels can be designed. To reach this goal, it is important to measure the temperature dependence of the electronic and optoelectronic properties. Measurements of the temperature dependence allow us to differentiate between different electronic and optoelectronic mechanisms. For example, rectifiers are essential for photodetection, but often suffer from soft breakdown at reverse bias due to carrier multiplication, tunneling, or generation. It is usually difficult to distinguish between these cases by doing measurements at a single temperature; however, the temperature dependence of these processes are all different, and thus the dominating phenomenon can be identified based on the temperature dependence. Identifying the electronic and optoelectronic processes is important to assess the promise of carbon nanotubes for IR detectors, and to design pixels that take full advantage of these properties.

2. MEASURING THE TEMPERATURE DEPENDENCE OF CNT ELECTRONIC DEVICES

The temperature dependence of field-effect transistors with individual carbon nanotubes as the channel material was measured using a variable-temperature and variable-pressure probe station. CNT FETs were fabricated by depositing CNTs from solution onto a SiO_2 wafer, and electrical contacts were patterned using conventional photolithography.

2.1 Results

Figure 1 shows an AFM image of a nanotube device obtained by deposition of nanotubes from solution onto a SiO_2 substrate.Several such devices were fabricated and tested.

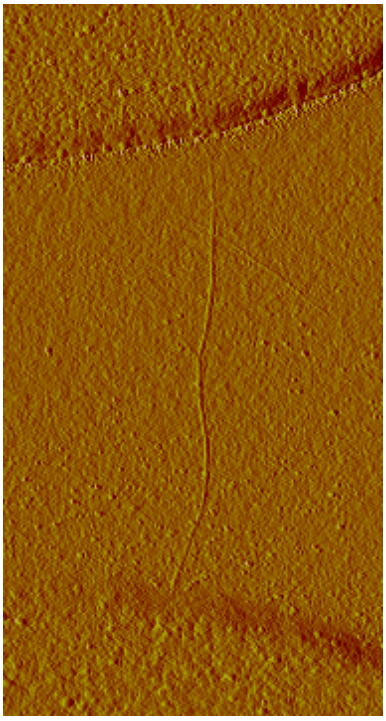

Figure 1: AFM of a nanotube device. The nanotube is visible as the vertical line bridging the upper and lowerelectrodes.

Figure 2 shows the measured current in a CNT FET when applying a source-drain voltage. The device shows a slightly asymmetric behavior which can be ascribed to slightly different properties of the two contacts. Measurements we performed at different temperatures and clearly show that the current increases with increasing temperature. This implies that thermally activated processes play an important role in these devices.

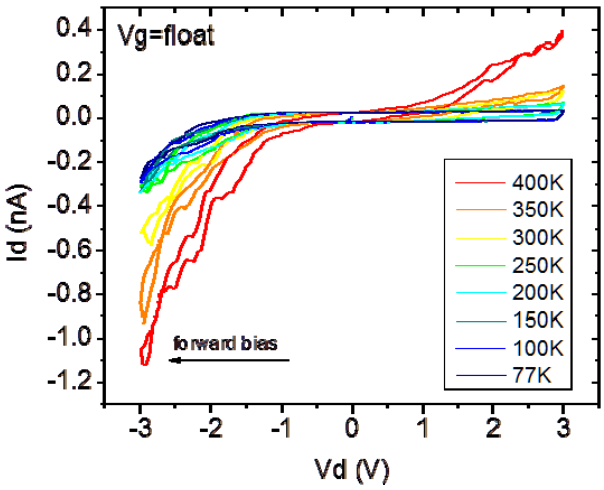

Figure 2. Measured temperature dependence of the current in a CNT FET device.

We also measured the gate dependence of the I-V curves as shown in Fig. 2. The results show that the current can be modulated for both voltage polarities, with a negative gate bias leading to higher currents. This is consistent with a p-type behavior of the devices. We also compared these same measurements in vacuum (Fig. 2 left panel) and in ambient (Fig. 2 right panel) and found that vacuum invariably leads to a decrease in the amount of current. This behavior could originate from desorption of molecules from the nanotube or from the substrate; additional experiments would be necessary to further explore this point.

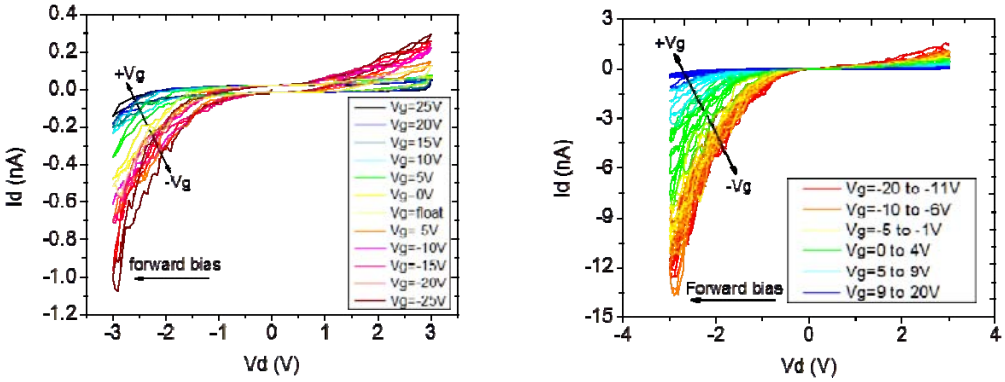

Figure 3: Gating of CNT device at room temperature in ambient and in vacuum.

3. CONCLUSIONS

This work has demonstrated the ability to measure the temperature dependence of the electronic transport properties of carbon nanotube devices made with individual nanotubes. The results show that thermally activated processes play an important role in these devices, and also indicate that the environment can influence device properties.

DISTRIBUTION

1	MS0899	Technical Library	9536 (electronic copy)
1	MS0359	D. Chavez, LDRD Office	1911

Sandia National Laboratories