Army Research Laboratory

Improving Microbolometric Response using Carbon Nanotubes

by Nichelle Perera and Priyalal Wijewarnasuriya

ARL-TN-0523 January 2013

NOTICES

Disclaimers

Army Research Laboratory
Adelphi, MD 20783-1197

ARL-TN-0523 **January 2013**

Improving Microbolometric Response using Carbon Nanotubes

Nichelle Perera and Priyalal Wijewarnasuriya
Sensors and Electron Devices Directorate, ARL

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* January 2013	**2. REPORT TYPE** Final	**3. DATES COVERED (From - To)** August 20, 2012
4. TITLE AND SUBTITLE Improving Microbolometric Response using Carbon Nanotubes		**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Nichelle Perera and Priyalal Wijewarnasuriya		**5d. PROJECT NUMBER** SEAP 2012 **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: RDRL-SEE-I 2800 Powder Mill Road Adelphi, MD 20783-1197		**8. PERFORMING ORGANIZATION REPORT NUMBER** ARL-TN-0523
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Single-walled carbon nanotubes (CNTs) provide a semiconductor material with high sensitivity, detectivity, and a high temperature coefficient of resistance (TCR), in comparison to previously used vanadium oxide microbolometers, to detect infrared radiation. The fabrication of the microbolometer uses photolithography and metal deposition processes to create electrical contact pads on the nanotubes, and mounting and wire bonding to a leadless chip carrier. Once fabricated, an experimental dewar is used to test the device at varying temperatures, ranging from 78 K to room temperature. The results indicate that using a semiconductor material with a higher TCR provides a wider range of electrical resistance, and improves the sensitivity and response of infrared imaging technology.

15. SUBJECT TERMS
CNT

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Priyalal Wijewarnasuriya
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified	UU	14	**19b. TELEPHONE NUMBER** (*Include area code*) (301) 394-0963

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

List of Tables

1. Introduction/Background

The ability to detect and interpret the incoming infrared radiation of a scene or object that is not visible (to the naked eye) is essential for the Army to maintain the upper hand. To be better aware of the surroundings, infrared detectors, which can remotely measure the temperature of an object or a scene, require microbolometers with high sensitivity, high detectivity, and a large bolometric response (*6*). Such microbolometers will produce inexpensive, uncooled infrared detectors. To improve the bolometric response of infrared sensors, single-walled carbon nanotubes (SWCNT) can be used as the semiconductor material to absorb the radiation. In addition to detecting radiation, these CNT-based sensors have potential for different applications, such as detecting agents other than radiation. For example, CNT-based sensors can also detect chemical and biological agents, and thus, has potential use in other areas (*6*). For these sensors, individual CNTs showed promise as they can detect non-visible light.

As a solution, a uniform system of nanotubes provides an easily mass-producible material. Figure 1 shows a system of SWCNT deposited onto a sapphire substrate. In comparison to more commonly used vanadium oxide (VO_x) microbolometers, CNT-based bolometers provide better resistivity, as well as higher sensitivity and detectivity. Incoming infrared radiation is absorbed by the SWCNT, raising its temperature. The thermal response is associated with the electrical response, i.e., the temperature change leads to a change in resistance. The measured change in resistance, which results from the change in temperature, corresponds to temperature values, which are represented in the resulting infrared image (*3*, *4*). CNTs provide a wider range of resistance values, dependent on the temperature. A larger variation provides greater clarity in the infrared image by increasing the temperature resolution.

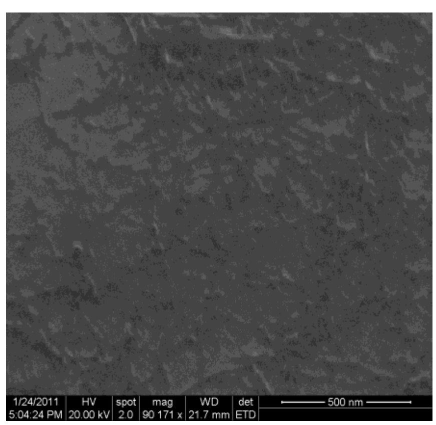

Figure 1. Scanning electron microscopy (SEM) picture of spray-deposited CNT on sapphire substrate.

CNT-based microbolometers offer multiple advantages over previously used VO_x microbolometers. CNTs can provide temperature coefficient of resistance (TCR) values as high as those obtained from VO_x, but CNT films are more easily reproduced. There is experimentation being done to obtain TCR values even higher than VO_x, when certain conditions are modified to increase sensitivity. For other factors, such as detectivity, CNT-based experiments result in values comparable or better than those obtained from VO_x microbolometers, as shown by table 1 (*6*).

Table 1. Comparisons of performance metrics between VO_x and CNT-based microbolometers.

Performance Metrics	**Current VO_x Film Based Technology**	**Expected From the Proposed CNT Technology**
Frame rates	30–60 Hz	100–1000 Hz
Sensitivity (TCR)	0.02 to 0.025/K	≥ (0.01–0.025/K)
Pixel size	25 µm	<25 µm
Detectivity, D*	~(4–7) x 10^9 cm Hz ^{½} W^{-1}	~(4–7) x 10^9 cm Hz ^{½} W^{-1}
Compatible with printed electronics requirements	No	Yes

SWCNTs have a higher TCR, as well, which leads to higher sensitivity (*5*, *6*).

TCR is defined as the change in resistance per Kelvin, divided by the resistance measured at room temperature (*5*):

$$TCR = \frac{1}{R_e}\frac{dR_e}{dT} \qquad (1)$$

2. Experiment/Calculations

To create the system of SWCNTs, the chemical vapor deposition (CVD) method was used. A carrier gas, consisting of argon and hydrogen, acted as the carbon source. The chips were heated to decompose the gases into the SWCNT network. Once the SWCNTs were situated on top of silica oxide, which sits upon the sapphire substrate, photolithography was performed on the samples to define the contact regions. First, resist was spun onto the samples at 3500 rpm and then baked at 75 °C. The samples were then exposed for 4 s and post-expose baked. Once the samples were flood exposed and developed, the areas for the metal to be deposited were defined within the remaining resist. Figure 2 provides a schematic of the SWCNT fabrication process.

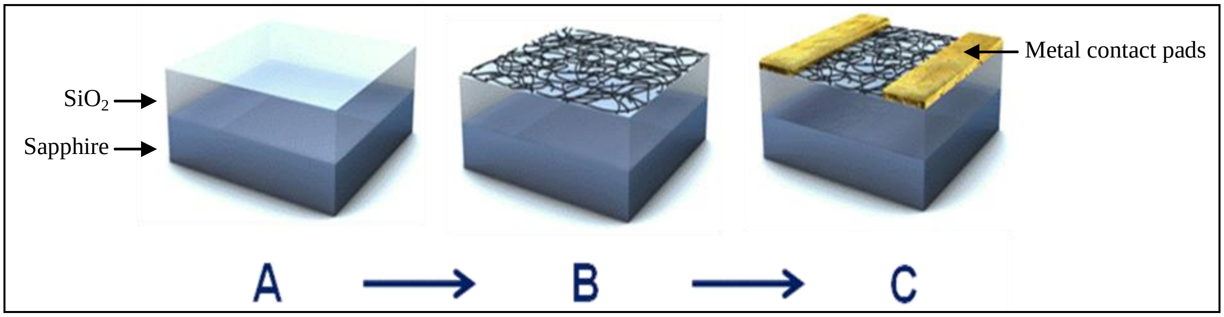

Figure 2. A schematic of the SWCNT fabrication process; (a) substrate template (sapphire/SiO_2), (b) addition of SWCNTs, and (c) deposition of metal contact pads.

Two metals, titanium and gold, were evaporated and deposited onto the samples. First, the pressure was pumped down to 1.9 x 10^{-6} Torr. Then, 0.15 nm of titanium was deposited, followed by 2.5 nm of gold. Once deposited, acetone was used to lift off the remaining resist. The removal of the resist also removed the excess metal surrounding the contact pads. Once complete, the samples were left with metal contact pads sitting atop the system of SWCNTs.

After fabricating the samples, they were wire bonded onto a 68-pin leadless chip carrier (figure 3). Once bonded, the device was measured for current and resistance versus voltage at temperatures ranging from 78 to 300 K. Liquid nitrogen, which flows to the dewar, was used to cool the chip. A parameter analyzer, 4156C, took current-voltage (I-V) measurements at varying temperatures. The range of voltages tested was from –2.0 to 2.0 V.

Using Ohm's law, resistance was calculated for each device at each temperature.

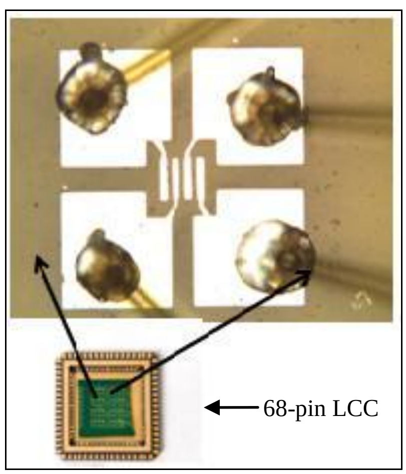

Figure 3. The 68-pin leadless chip carrier: wire-bonded metal contact pads on CNT network

3. Results and Discussion

As mentioned, I-V measurements were taken at temperatures ranging from 78 to 300 K, at a voltage range of –2 to 2 V. Figure 4 shows the I-V measurements for a device at 78, 105, and 300 K. The current is seen to increase as the temperature increases, as expected.

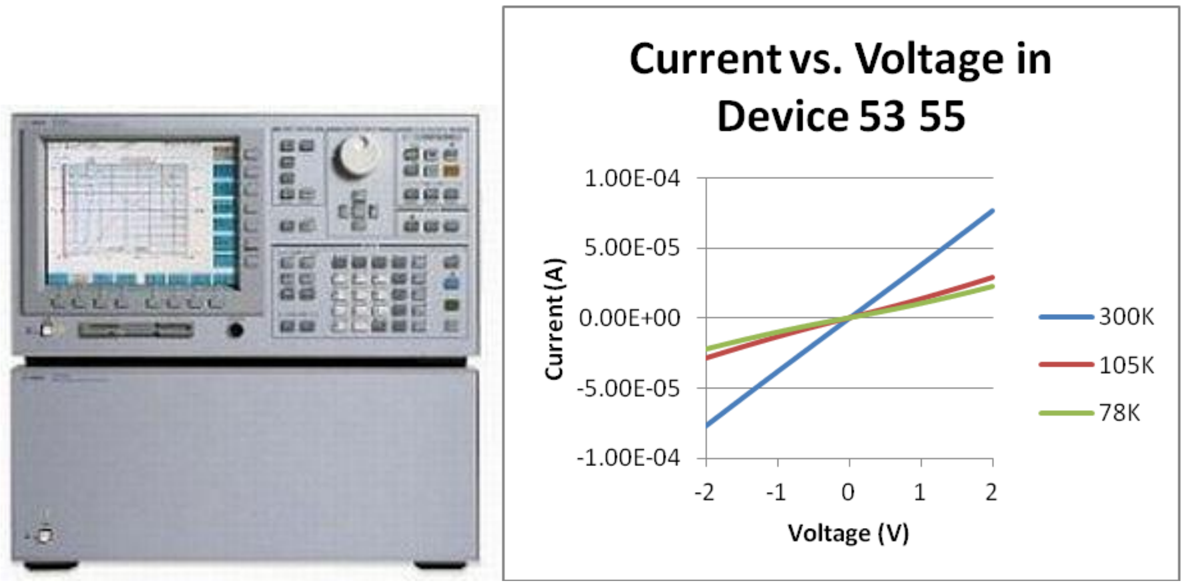

Figure 4. (a) (left) Parameter analyzer 4156C and (b) (right) measured current-voltage vs. temperature using 4156C.

Figure 5 shows that as temperature increases from 78 to 300 K, the resistance decreases. Using the aforementioned equation, the TCR is calculated to be ~3.12% at 300 K.

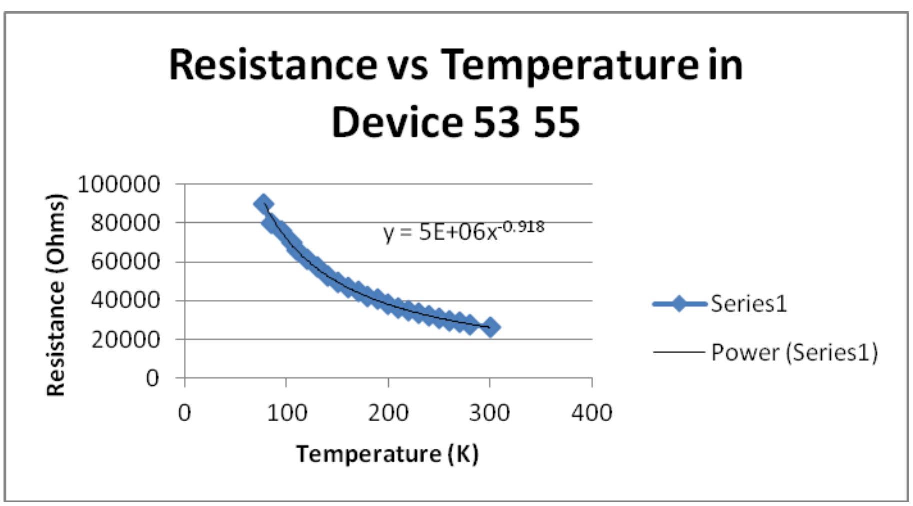

Figure 5. Resistance vs. temperature graph: As temperature decreases, resistance increases, providing a TCR of ~3.12% at 300 K

4. Conclusions

The fabrication of a microbolometer using SWCNTs, which includes the processes of chemical vapor deposition, photolithography, metal deposition, and wire bonding, creates a microbolometer with a better ability to detect incoming infrared radiation. The SWCNT device exhibits a high TCR of 3.12% when exposed to temperatures varying from 78–300 K. This TCR is comparable to that calculated from VO_x microbolometers. Further experiments should be conducted using SWCNTs to measure the response to incoming infrared radiation with respect to frequency. Overall detectivity, D*, could also be examined in CNT-based sensors. By further experimenting and using SWCNT networks in microbolometers, infrared detectors could be improved such that they can be used for an even wider variety of applications in a greater number of situations.

5. References

1. Eminoglu, S. Uncooled Infrared Focal Plane Arrays with Integrated Readout Circuitry Using MEMS and Standard CMOS Technologies. Doctoral thesis. The Middle Eastern Technical University, 2003.

2. Hecht, J. Photonic Frontiers: Room-Temperature IR Imaging: Microbolometer Arrays Enable Uncooled Infrared Camera. *Laser Focus World*. April 2012. http://www.laserfocusworld.com/articles/print/volume-48/issue-04/features/microbolometer-arrays-enable-uncooled-infrared-camera.html (accessed 7 August 2012).

3. Liger, M. Uncooled Carbon Microbolometer Imager. Doctoral thesis. California Institute of Technology. *CaltechTHESIS*. http://thesis.library.caltech.edu/3841/ (accessed 7 August 2012).

4. Maine, S.; Koechlin, C.; Fleurier, R.; Haidar, R.; Bardou, N.; Dupuis, C.; Attal-Trétout, B.; Mérel, P.; Deschamps, J.; Loiseau, A.; Pelouard, J.-L. Mid-infrared Detectors Based on Carbon Nanotube Films. *Phys. Status Solidi C* **2010**, *7*, 2743–2746. http://dx.doi.org/10.1002/pssc.200983827.

5. Ashok K.; Sood, E.; Egerton, J.; Puri, Y. R.; Fernandes, G.; Kim, J. H.; Xu, J.; Goldsman, N.; Dhar, N. K.; Wijewarnasuriya, P. S.; Lineberry, B. I. Carbon Nanotube Based Microbolometer, Development for IR Imager and Sensor Applications. *Proc. SPIE* **2011**, *8155*, 815513. http://dx.doi.org/10.1117/12.895277.

6. Cech, J.; Swaminathan, V.; Wijewarnasuriya, P.; Currano, L. J.; Kovalskiy, A.; Jain, H. Fabrication of Freestanding SWCNT Networks for Fast Microbolometric Focal Plane Array Sensor. *Proc. SPIE* **2010**, *7679*, 76792N. http://dx.doi.org/10.1117/12.855589.

List of Symbols, Abbreviations, and Acronyms

CNT	carbon nanotubes
CVD	chemical vapor deposition
I-V	current-voltage
SEM	scanning electron
SWCNT	single-walled carbon nanotubes
TCR	temperature coefficient of resistance
VO_x	vanadium oxide

1 (PDF only)	DEFENSE TECHNICAL INFORMATION CTR DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FORT BELVOIR VA 22060-6218
1 HC	DIRECTOR US ARMY RESEARCH LAB IMAL HRA 2800 POWDER MILL RD ADELPHI MD 20783-1197
1 HC	DIRECTOR US ARMY RESEARCH LAB RDRL CIO LL 2800 POWDER MILL RD ADELPHI MD 20783-1197
5 HCs 5 PDFs	US Army Research Lab ATTN RDRL SEE G WOOD ATTN RDRL SEE L L BLISS ATTN RDRL SEE I P WIJEWARNASURIYA (5 HCS) ATTN RDRL SEE I Y CHEN ATTN RDRL SEE I JAMES PATTISON ATTN RDRL SEE I ERIC DECUIR ADELPHI MD 20783-1197