EFFECT OF HEAT AND LIGHT ON ELECTRICAL PROPERTIES OF SI-CNT JUNCTION

Anwar M. Ezzat[1a], Bassam M. Mustafa[2a] and Mohammad M. Uonis[3a*]

[a]Department of Physics, College of Science, Mosul University, Mosul, IRAQ. E-mail: anwarezzat2000@yahoo.com[1]; bassam_alemam@yahoo.com[2]; mohmahnua@gmail.com[3]
Corresponding author: anwarezzat2000@yahoo.com
Received: 19th Sep 2019 Accepted: 30th Jun 2020 Published: 31st Oct 2020
DOI: https://doi.org/10.22452/mjs.vol39no3.5

ABSTRACT Plasma sputtering was used to deposit carbon layer from pure graphite with thicknesses (20, 54, 63 nm) on a p-type silicon wafer substrate for the preparation of a Si-CNT (Silicon – Carbon Nano Tubes) junction without any catalyst. The I-V characteristics of the junction were found to be similar to that of the diode, which confirm that the carbon layer or, in other words, that the carbon nanotubes are acting as an n-type semiconductor. The effect of heat and light illumination on the I-V characteristics is studied. At temperatures (32, 40, 50 and 60 ^{o}C), the I-V characteristics shows increase in conductivity with increasing the temperature for a certain thickness. The effect of light on I-V characteristics has also been studied showing an increase in current flow, the effect of both heat and light illumination is more pronounced at low values of the thickness of the CNT layer due to their low resistivity.

Funding information : This project is granted by College of Science - University of Mosul.

Keywords : Si-CNT junction, semiconductor, plasma sputtering, graphite.

1. INTRODUCTION

Carbon atoms are characterized by a strong tendency to bind with each other or with the atoms of other chemical elements (Pierson, 1993). This behavior gives rise to a variety of structural forms, including crystallized carbon, such as diamonds, graphite, fullerene, carbines, non-crystalline carbon and nanoparticles, including nanotubes (Mahtani, 2010). Each of these forms has different physical and chemical characteristics (Saito, 1998).

For the preparation of carbon layers with a nanoscale thickness in which carbon nanotubes are formed, there are different chemical and physical methods. One of those methods is the plasma sputtering (Seshan, 2002).The physical basis of this method is the transfer of kinetic energy and momentum of the bombarding atoms to the surface of the target material. Sputtering can occur irrespective of the particle charge or type. The bombarding particles can be atoms, electrons, ions or even molecules (Seshan, 2002; Uonis et. al, 2014).

In this study the Si-CNT junction was prepared using the plasma sputtering method with different thicknesses of the carbon nano tube layers (20, 54, 63 nm) without using catalyst (Uonis et. al, 2014). Scanning electron microscope (SEM), atomic force microscope AFM and Raman spectroscopy are used to ensure the existence of the CNT and to study samples structures (Aksak et. al, 2009; Zhang, 2009). The main aim of the present work is to examine the effect of light and heat on the electrical properties of the Si-CNT junction prepared by plasma sputtering without catalyst.

2. EXPERIMENT

Silicon wafers were used as substrates to prepare the nanotube layer for the Si-CNT junction. A glass cutter was used to cut the silicon wafers into square pieces of area (▲1×1 cm^2). The process of cleaning silicon wafers includes several steps: washing with distilled water, drying with alcohol and methanol, using ultrasound waves to remove the dirt from the Si wafers surface, washing again with distilled water, and drying. Finally removing the silicone dioxide layer from the surfaces of the wafers by fluoric acid, then washing another time with distilled water (Seshan, 2002).

To fabricate the Si-CNT junction, a highly purred graphite rods were used as a source of carbon in plasma sputtering device to deposit a layer of carbon nano tubes with different thicknesses using a plasma sputtering method with a helium as ambient gas and a precipitation current of 70 A from pure carbon rods without catalyst. Thickness of carbon nano layer was controlled by application of the current on the graphite rods for different times lapses (Seshan, 2002).

Figure 1 shows the Si-CNT junction (right), and the mask (left) used in deposition of the upper gold contact points, the lower part of the junction is the back gold contact, the layer above the back contact (blue) is the silicon wafer, and the upper layer is the carbon nano tube layer. Figure 2 shows the electrical circuit used for measuring I-V characteristics, while light and heat is applied to the sample.

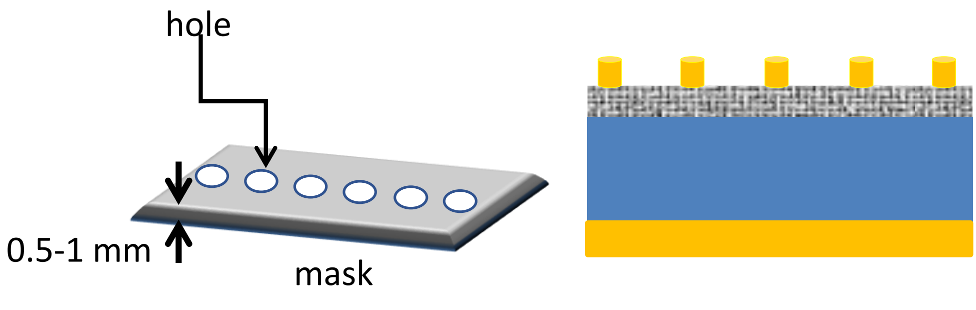

Figure 1. The Si-CNT junction (right), and the mask (left) used in deposition of the upper gold contacts seen on the top of the right figure, below them is the CNT layer, then Si layer and the gold back contact layer.

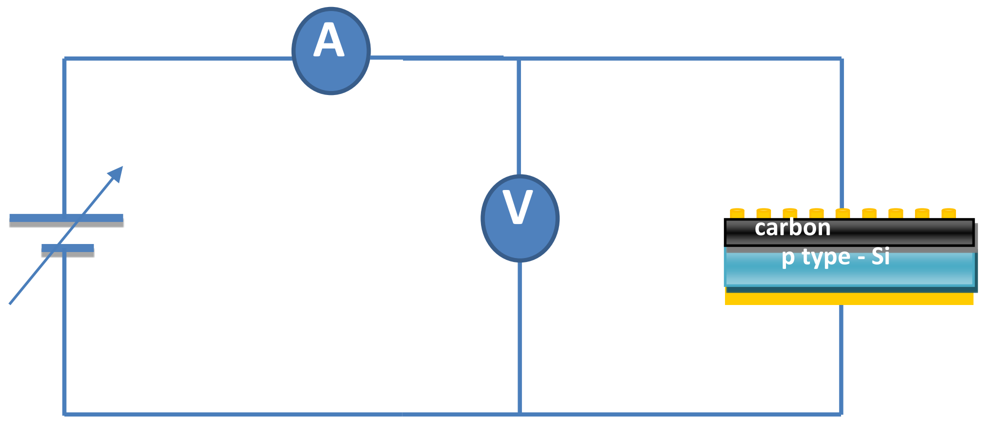

Figure 2. The electrical circuit used to measure the I-V characteristics.

After preparation of the samples with different thicknesses of the CNT layer, each sample was connected to the circuit shown in Figure 2 to measure the I-V characteristics, which were initially measured with light applied at the top surface of the junction. Then, the I-V characteristics was measured without light, to compare between the two cases as shown in Figure 6. The same procedure was repeated and the I-V characteristics were measured again, but now for studying the heat effect. By heating the sample of different thicknesses of the CNT layer, and at different temperatures 32, 40, 50 and 60 ^{o}C the effect of heating the samples is shown in Figure 8.

Structural properties are important in the understanding of the nature of nanomaterials (Aksak et. al, 2009; Zhang, 2009; Costa et.al, 2008). So, scanning electron microscope SEM (Aksak et. al, 2009) and atomic force microscope images AFM (Zhang, 2009) were taken, for our samples as in figures 3 and 4. In Figure 5, Raman spectra of Carbon layers with thicknesses (a-20, b-40 and c- 60 nm) using 70 A sputtering current and different time periods, are shown which give clear evidence of formation of the CNT tubes because the appearance of the D band 1357 cm^{-1} and G 1588 cm^{-1} proves the existence of CNT (Costa et.al,2008).

3. RESULTS AND DISCUSSIONS

Figure 3 shows SEM images of Carbon layers with thicknesses (20, 40 and 60 nm) using 70 A sputtering current and different time periods (Uonis et. al, 2014; Aksak et. al, 2009).Insight study of the samples shows clear evidence of increase of diameter of nano tubes of the CNT layer with increasing thickness of the CNT layer, because more carbon layers are added to the nano tubes, which increases the multiwall nano tubes diameter and length (Aksak et. al, 2009). The increase in diameter and length of multiwall nano tubes increases resistivity. This result also proved experimentally in Figure 7. This leads to the result that, current decreases, with increasing CNT layer thickness.

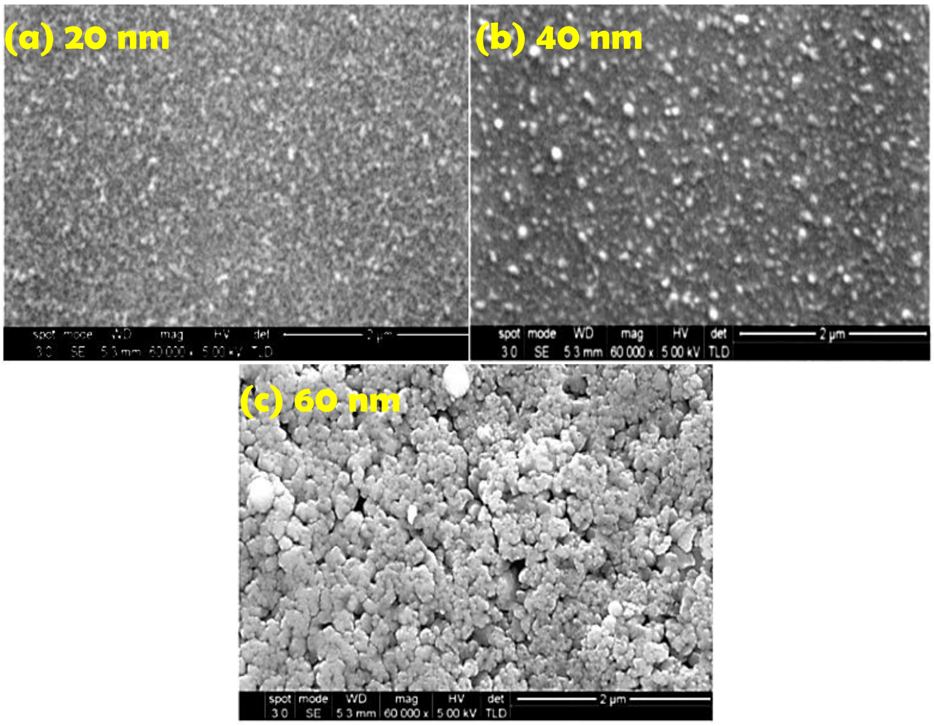

Figure 3. SEM images of Carbon layers with thicknesses (20, 40 and 60 nm) using 70 A sputtering current and different time periods (Uonis et. al, 2014; Aksak et. al, 2009).

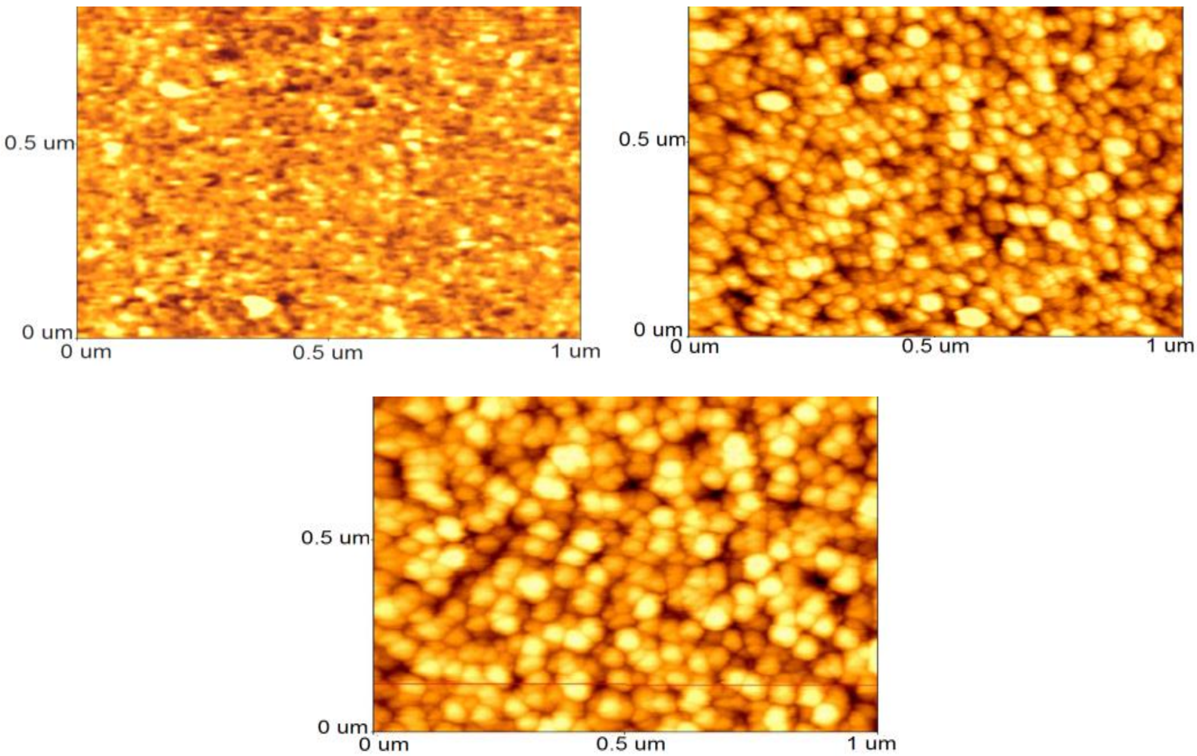

Figure 4. AFM images of Carbon layers with thicknesses (20, 40 and 60 nm) and 70 sputtering current (Uonis et. al, 2014; Zhang, 2009).

Figure 4 shows AFM images of CNT layers with thicknesses (20, 40 and 60 nm) and 70 A sputtering current (Uonis et. al, 2014; Zhang, 2009). Insight study of these images reinforce our former conclusion from SEM images that the increase in diameter and length of multiwall nano tubes increases the thickness of the CNT layer. Here increase of diameter and length of CNT is more pronounced, which gives another powerful prove to our conclusion that, the increase in diameter and length of multiwall nano tubes increase resistivity, this leads to decrease of current with increasing thickness (Zhang, 2009) .

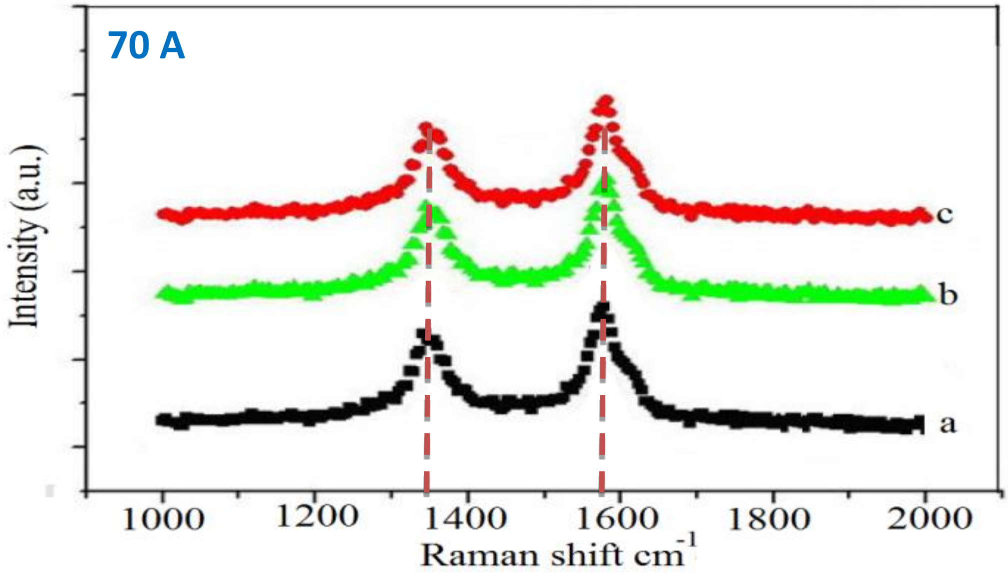

Figure 5. Raman spectrum of carbon layers with thicknesses (a) 20nm, (b) 40nm and (c) 60 nm and 70 A sputtering current, the D band 1357 cm^{-1} and G 1588 cm^{-1} proves the existence of CNT (Costa et.al, 2008).

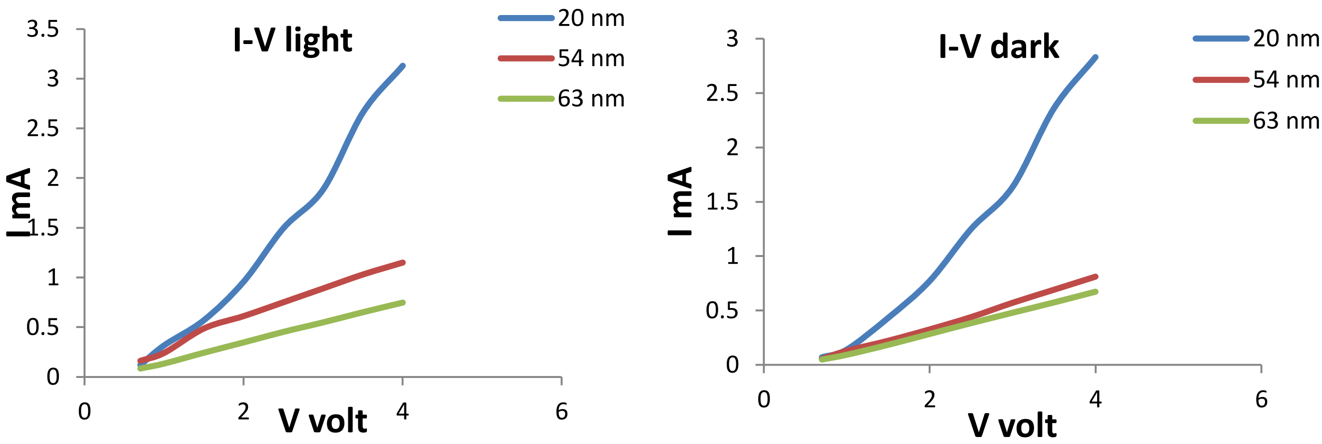

Figure 6. The I-V characteristics for Si-CNT junction for different carbon thicknesses (20, 54 and 63 nm) in light and dark.

Figure 6 shows the I-V characteristics when light is on and off respectively. In general, the shape of I-V characteristics is comparable to the general shape of I-V characteristics of the diode (Fedawy et. al 201; Uchino et.al 2013). This gives an indication that the carbon CNT layer have n-type semiconductor behavior due to the production of a multi-wall nanotubes (MWCNT), as SEM and AFM images in Figure 3 and Figure 4 shows. These results also agree with conclusions of references (Fedawy et. al 2012; Uchino et.al 2013). The current increases with voltages for all samples, but the variation in current values with a change in the carbon nano layer thickness have inverse dependence. This inverse dependence can be explained as it is due to the increase of diameter and length of nano tubes of the CNT layer with increasing thickness of the CNT layer, because more carbon layers are added to the multiwall nano tubes, (Costa et. al,2008; Fedawy et. al 2012; Uchino et.al 2013). By studying resistivity characteristics of these layers as shown in Figure 7 it is clear that, the increase in resistivity with increasing thickness which explains that the small thicknesses have higher currents in comparison with greater thicknesses due to its low resistivity (Pierson, 1993).

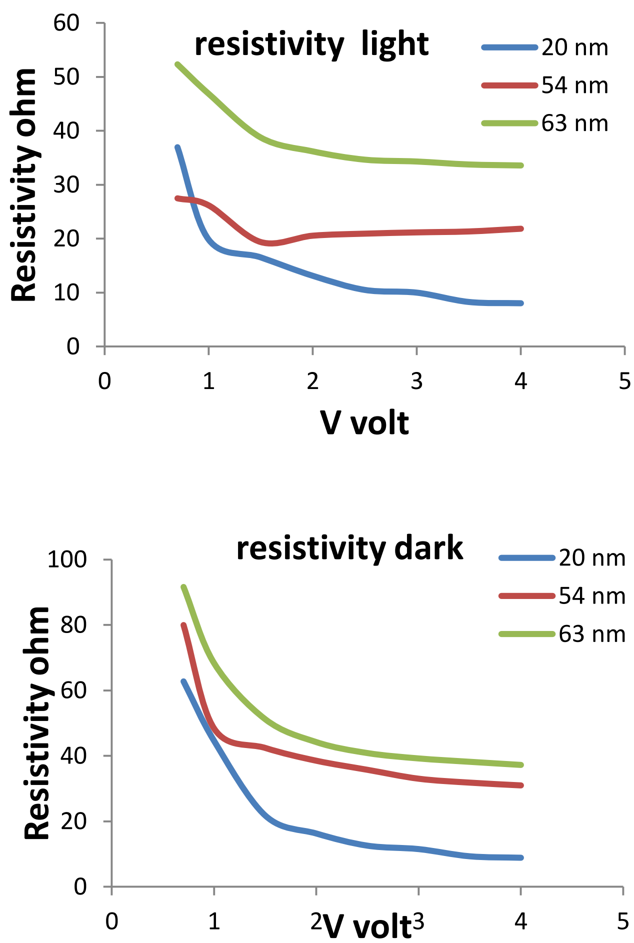

Figure 7. The resistivity of Si-CNT junction for different carbon thicknesses (20, 54 and 63 nm) in light and dark.

The effect of the variation in temperature on the Si-CNT characteristics appears in the Figure 8 (a, b). In Figure 8(a) and for CNT layer thickness of (63 nm) the currents increases with increasing temperature proportional and this agrees with the typical behavior of semiconductor diodes due to generation of carriers, but here the mechanism of this increase in the CNT is unknown and we register it as an experimental fact**.**

Figure 8(b) shows the effect of temperature on the I-V characteristics for different thicknesses. We notice that the intensity of the current increases with the decrease in the CNT layer thickness at any value of the voltage. The sample of thickness 20 nm shows great increase of current about two times that of 60 and 54 nm thickness this also is good experimental fact and can be due to low diameter of the nano tubes with low resistivity and so, have higher current.

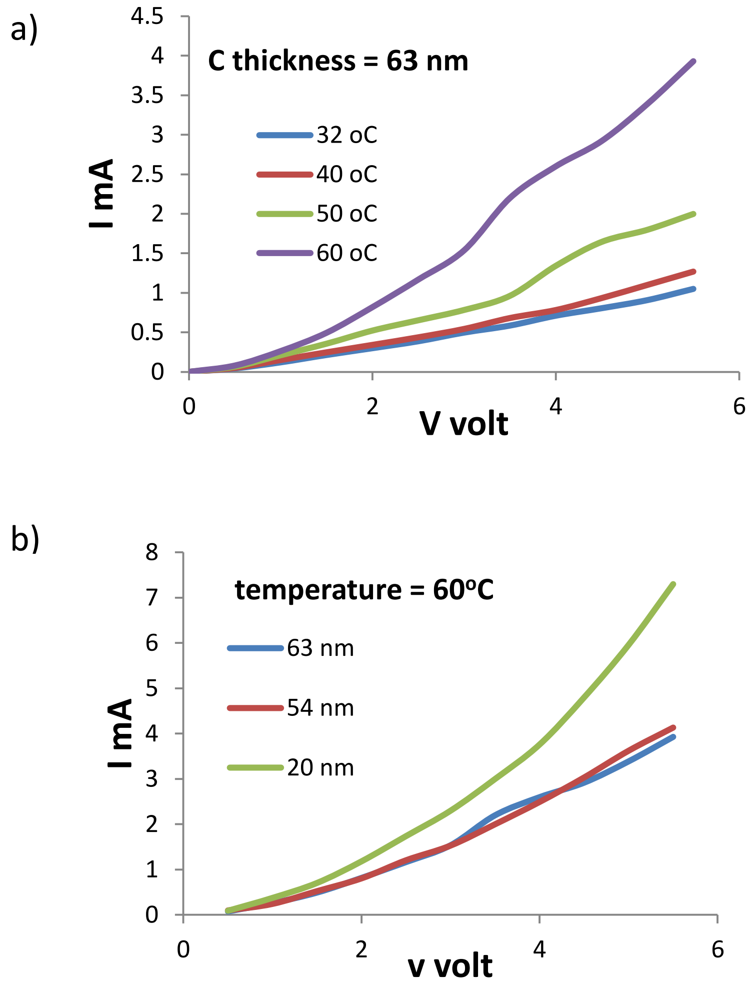

Figure 8. The I-V characteristics for Si-CNT junction a) different operating temperature; b) different thicknesses (20, 54 and 63 nm) at temperature 60 °C

4. CONCLUSIONS

Finally, Si-CNT junction prepared by plasma sputtering of Carbon without catalyst leads to the following conclusions:

1. Iluminating Si-CNT junction by light increasing generated current flowing in the Junction.
2. Heating of Si-CNT junction increasing current flowing in the junction and heat are more effective than light in increasing generated current.
3. Low diameter carbon nano tubes are more sensitive to light and heat due to low resistivity of them in comparison with higher diameter ones.
4. The current is inversely proportional with carbon layer thickness because of the increase in nano tube thickness, as a result of addition of more carbon layers, this increases resistivity, and explains the inverse proportionality of current with thickness.

5. ACKNOWLEDGEMENTS

For endorsing and funding this project, the authors want to thank the University of Mosul – College of Science.

6. REFERENCES

Aksak, M. Kir,s. and Selamet, y. (2009) "Effect of the growth temperature on carbon nanotubes grown by thermal chemical vapor deposition method", Journal of optoelectronics and advanced materials - symposia, Vol. 1, No. 3, p. 281 – 284.

Costa S., E. Borowiak-palen, M. Kruszyńska, A. Bachmatiuk, R. and Kalenczuk, J. (2008) "Characterization of carbon nanotubes by Raman spectroscopy", Materials Science-Poland, Vol. 26, No. 2, pp 433-441.

Fedawy, Mostafa Fikry, Wael Alhenawy, Adel and Hazem Hassan (2012) "I-V characteristics model for ballistic Single Wall Carbon Nanotube Field Effect Transistors (SW-CNTFET)", IEEE International Conference on Electronic Devices, Systems and Applications (ICEDSA).

Mahtani, Pratish (2010) "Optical and Structural Characterization of Amorphous Carbons Films", MSc. thesis, Department of Electrical and Computer Engineering University of Toronto.

Pierson, Hugh O. (1993) "Handbook of Carbon, Graphite, Diamond and Fullerenes", Park Ridge, New Jersey, U.S.A.

Saito R., (1998) "Physical Properties of Carbon Nanotubes", Imperial College Press, 203 Electrical Engineering Building, Imperial College, London SW7 2BT.

Seshan, Krishna (2002) "Handbook of thin-film deposition processes and techniques", second edition, William Andrew Publishing Norwich, New York, U.S.A., www.williamandrew.com, www.knovel.com.

Uchino, T. Shimpo, F. Kawashima, T. Ayre, G. N. Smith, D. C. de Groot, C. H. and Ashburn, P. (2013) "Electrical transport properties of isolated carbon nanotube/Si heterojunction Schottky diodes "APPLIED PHYSICS LETTERS 103, 193111

Uonis, Mohammad M. Mustafa, Bassam M. Ezzat, Anwar M. "The Role of Sputtering Current on the Optical and Electrical Properties of Si-C Junction", World Journal of Nano Science and Engineering, 2014, 4, 90-96.

Zhang, Jin Zhng (2009) "Optical properties and spectroscopy of nanomaterials", World Scientific Publishing Co. Pte. Ltd.5 Toh Tuck Link, Singapore 596224.