Capacitance-Voltage and Current-Voltage Characteristic for Multi-Walled Carbon Nanotubes Grown in Oxygen Atmosphere

Izzat M. Al-Essa, Ghazala Y. Hermiz, Ghusson .H. M

Department of Physics, College of Science, University of Baghdad, Jadiriya, Baghdad, Iraq

Abstract

Carbon nanotubes were prepared by an arc-discharge method, under different values of pressure of oxygen gas. The structure of multi-walled carbon nanotubes powders has been characterized by low-angle X-ray diffraction .The morphology of carbon nanotube powder was examined by transmission electron microscope. The capacitance-voltage and current- voltage (dark and illumination current) characterization were measured under different values of pressure (10^{-3}, 10^{-4}, 10^{-5}) mbar of oxygen gas.

Keywords

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خصائص المتسعة – الفوالتية و التيار – الفولتية لانابيب الكاربون النانومترية المتعددة الجدران المنماة في محيط من غاز الاوكسجين

عزت محمود العيسى، غزالة يلدا هرمز وغصون حميد

قسم الفيزياء - كلية العلوم - جامعة بغداد – الجادرية – بغداد - العراق

الخلاصة

نميت انابيب نانومترية من الكربون بطريقة التفريغ القوسي وتحت ضغوط مختلفة من غاز الاوكسجين. تم فحص تركيب انابيب الكربون النانومترية بواسطة الزاوية الصغرى لحيود الاشعة السينية. ولقد تم وصف شكل السطح لمسحوق انابيب الكربون النانومترية باستخدام المجهر الالكترونيالنفاذ .قيست خصائص سعة -فولتية وتيار – فولتية في الظلام وتحت تاثير الاضاءة وبضغوط مختلفة mbar(10^{-3},10^{-4},10^{-5})من غاز الاوكسجين .

Introduction

Nanotechnology attracts scientist to miniaturize the electronic, actuating, sensing, and optical devices and their components. Nanotechnology offers new design, characterization, production, and application of systems, devices and materials at the nanometeric scale. Over the past ten years, carbon nanotubes came forth as a very important new class of electronic materials [1].

In 1991, Iijima of the NEC Laboratory in Japan reported the first observation of multi-walled carbon nanotubes (MWNT) in carbon-soot made by arc discharge [2]. About two years later, he made the observation of Single-Walled NanoTubes (SWNTs) [3]. The past decade witnessed significant research efforts in efficient and high-yield nanotube growth methods. The success in nanotube growth has led to the wide availability of nanotube materials, and is a main catalyst behind the recent progress in basis physics studies and applications of nanotubes.

Nearly ten years after their discovery, carbon nanotubes (CNs) are still attracting much interest for their potential applications, which largely derives from their unusual structural and electronic properties. Since all these properties are directly related to the atomic structure of the tube.

Carbon nanotubes. in the past 10 years witnessed significant progress in both carbon nanotube synthesis and investigations on their electrical, mechanical, and chemical properties[4]

Carbon nanotubes (CNT) are carbon nanostructures of a small diameter on the nanometer scale with one or more walls, and a length large in comparison to the diameter result in large ratio , generally, of about 1ooo, so they can be considered as nearly one-dimensional structure.Therefore carbon nanotubes have interesting properties due to their one-dimensional structure and giant molecular nature[5] extensive studies on its structure have been reported .They have mechanically and chemically stable carbon shells which can be opened, filled and closed again without losing their stability.

A SWNT can behave as a well defined metallic, semiconducting or semi-metallic wire depending on two key structural parameters, chirality and diameter [6].

In this paper carbon nanotube thin films are prepared over glass and p- type Si substrates in oxygen gas as atmosphere under different values of pressure (10^{-3},10^{-4},10^{-5}) mbar using the arc discharge method. The powder of carbon nanotube are collected from the chamber after the preparation method and examined by x-ray diffraction technique using low-angle diffraction. The morphology of the powder is examined by transmission electron microscope. Capacitance-voltage and current-voltage characterization were measured for the thin films under different values of pressure.

1. Hetrrojunction Theory

A heterojunction is a junction formed between two dissimilar semiconductors [7], which have different values of energy gap, dielectric constant, electron affinity and work function as well as a difference in lattice constant and this is called lattice mismatch. The heterojunction can be classified according to the type of the conductivity presents on either side of the junction ,when the two semiconductors have the same type of conduction the junction is called isotype (p–p) or (n–n) , but when the conductivity type differs, the junction is called anisotype heterojunction (p–n) or (n–p). Also the heterojunction can be classified into abrupt or graded junction according to the distance during which the transition of charge from one material to the other is completed near the interface [8]

The electrical properties which characterize a heterojunction are current-voltage and the capacitance-voltage characteristics. In fact, these properties which do not only yield information the band structure of a heterojunction (i.e. type of heterojunction and built-injunction potential) but also enable one to determine its device usefulness. Since these properties of a heterojunction depend strongly on the method of formation and the doping levels of the two semiconductors forming it.

2. Capaeitance-Voltage Characteristics

The powerful experimental technique for the analysis of the depletion region potential and the charge distribution in a heterojunction is measured the junction capacitance (C=dQ/dV) as a function of reverse bias.The expression for the junction capacitance per unit area of an abrupt anisotype heterojunction can be written as [9,10]:

$$\frac{C}{A}=\left[\frac{q\varepsilon_n\varepsilon_p N_n N_p}{2(\varepsilon_n N_n+\varepsilon_p N_p)}\right]^{1/2}(V_D-V)^{-1/2} \quad ....(1)$$

Where N_n and N_p are the donor and acceptor concentrations respectively, and ε_n and ε_p are the dielectric constant of n and p-type semiconductor respectively, V_D is the built-in junction potential, V is the applied voltage, and A is the area of the junction.

The width of the depletion region (w)can be calculated by [10,11]:

$$w = \varepsilon_s / c_\circ \quad \text{---------(2)}$$

Where $c_\circ$ is the capacitance at zero biasing voltage, and

$$\varepsilon_s = (\varepsilon_n \varepsilon_p)/(\varepsilon_n + \varepsilon_p) \quad \text{-------- (3)}$$

Where ε_s is the semiconductor permittivity for the two semiconductors materials.

3. Current-Voltage Characteristics

The current-voltage characteristics are studied to explain the electrical, and are used to determine the built-in junction potential and energy discontinuities in the conduction. Depending on the polarity of the applied voltage these characteristics can be classified as for ward or reverse bias. The forward bias characteristics as one in The reverse bias characteristics of these heterojunctions show a linear at low reverse voltage.which the voltage is of such a polarity that it reduces the built-in junction potential .The reverse bias characteristics of these heterojunctions show a linear at low reverse voltage.

Experimental Method

The multi-wall carbon nanotubs (MWNTs) were synthesized by the DC arc discharge method in oxygen gas as the atmosphere under the various pressure (10^{-3},10^{-4},10^{-5}) mbar which is monitored by using penning gauges . Two graphite rods of purity 99.999% and diameters of 3cm and 7cm are used as an anode and cathode electrodes , respectively. Theses two electrodes was installed in the center of the chamber vacuum coated unit end to end separated by approximately 1mm .DC current of approximately (50-100) ampere with voltage of 25 volt was applied between the two electrodes. The current density of cathode was significantly smaller than that of the anode; hence there was a notable temperature gradient between the anode and the cathode. After the arc was carried out, carbon anions arrived at the cathode, they were deposited there and formed several forms of carbon which include nanotubes and the powder of carbon nanotube are collected from the chamber after the preparation method and examined their morphology using transmission electron microscope.

The X-Ray Diffraction (XRD) patterns of the crystal nature of the powder was studied using Cu Kα radiation source with wavelength 1.54056Å in the scanning 0^0-50^0 (2θ).

The capacitance – voltage characteristics of heterojunction at different reverse bias voltage at range (0-2) volt was measured to determined the type of heterojunction (abrupt or graded)

The current – voltage measurement of CNT /p-Si heterojunction with different values of oxygen pressure are done using Keithly Digital Electrometer 616 and DC power supply.

Result and discussion

1. X-Ray Diffraction

Under various pressure of oxygen gas (10^{-3},10^{-4} and 10^{-5}) , as shown in Fig.(1) , no signification of structural transformation was observed in the x-ray diffraction patterns until 10^{-5} mbar .The peaks related to interlayer length corresponding to indices of graphite (002) and (110) exhibited shift toward higher angles with increasing pressure this is agreement with Hitoshi Yusa and Tetsu Watanuki [13]. The full width at half maximum (FWHM) of (002) and (110) peaks are insensitive to the pressure i.e. keeps a constant.

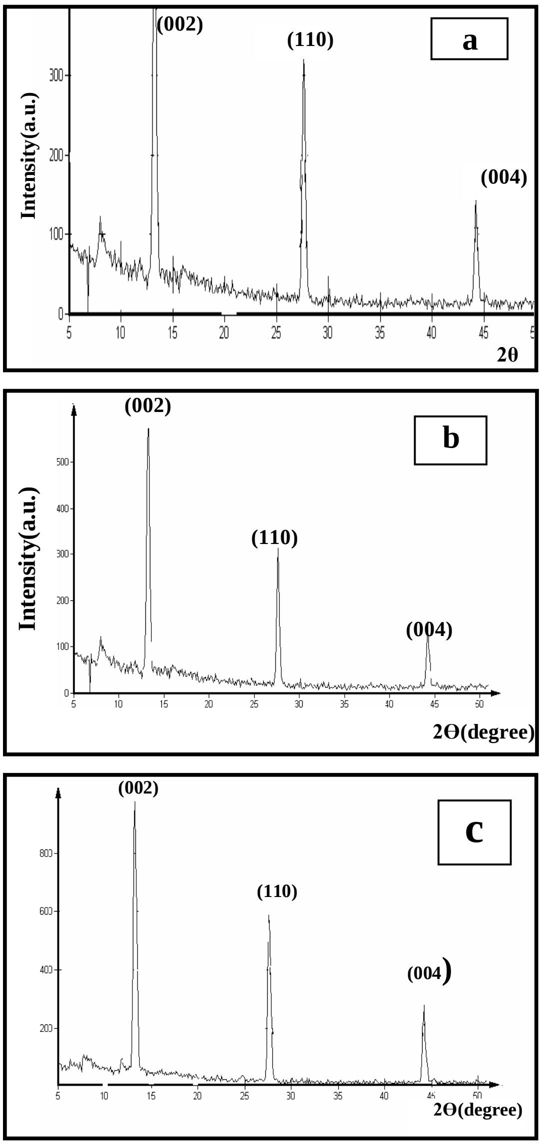


Fig.(1) Powder X-ray diffraction patters of MWNT under various pressure of oxygen gas.a-10^{-3}mbar,b-10^{-4}mbar,c-10^{-5}mbar

2. <u>The Morphology Structure</u>

Fig.(2) shows the morphology structure of carbon nanotube powder under various pressure of oxygen gas using transmission electron microscopy.

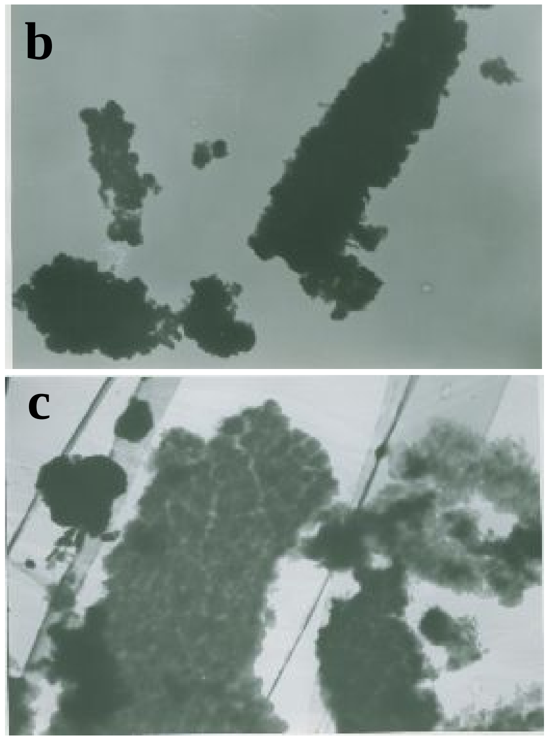
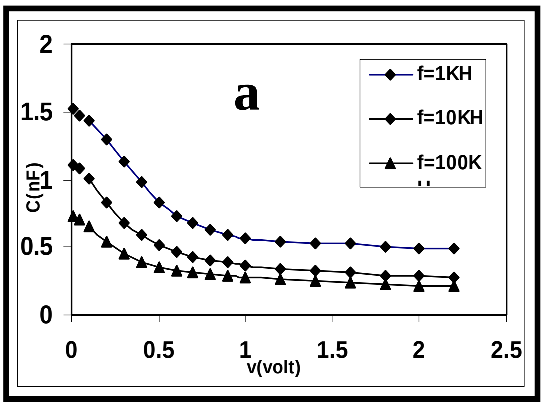
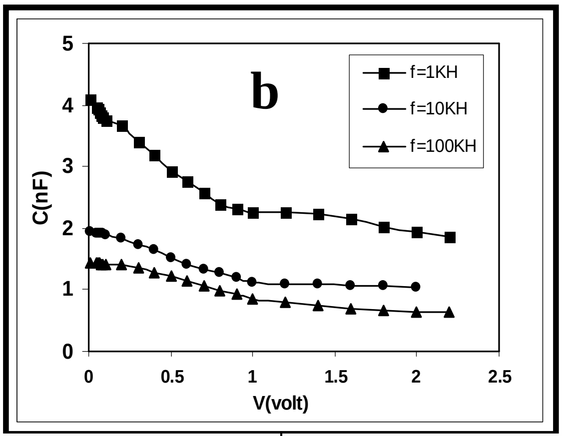


Fig.(2) the Transmission electron microscopy for carbon nanotube powder prepared under various pressure :a-10^{-3} mbar, b-10^{-4} mbar c=10^{-5}mbar

3. <u>Capacitance-Voltage Measurements</u>

The capacitance-voltage characteristics have been studied. The variation of capacitance as a function of reverse bias voltage (0-2.4) volt for CNT/Si hetero-junction at different values of oxygen pressure (10^{-3},10^{-4},and 10^{-5}) mbar are shown in Fig.(3) . It is observed that the capacitance decreases with increasing the reverse bias, and this is in agreement with equation (1). The reduction was not linear , the reason attributed to an increment of the depletion region width which causes an increasing of built in voltage





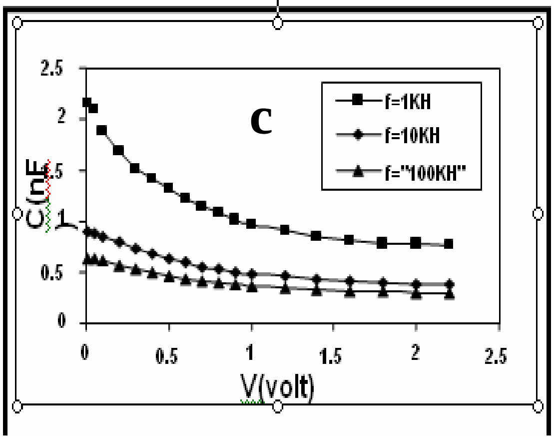
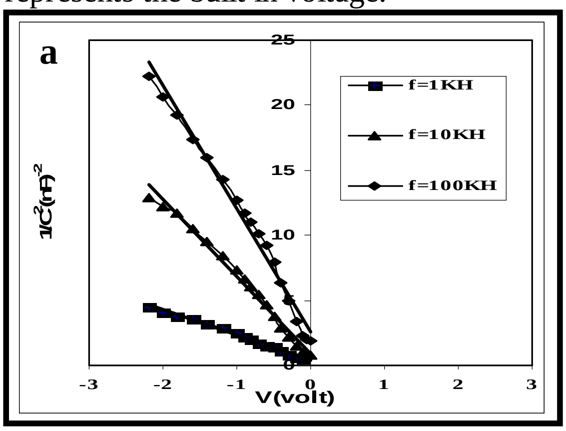
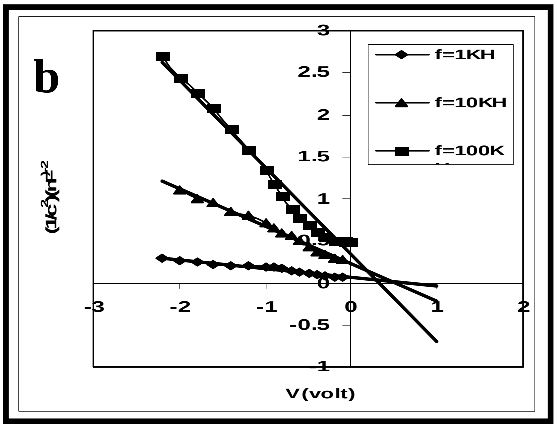


Fig.(3) shows the variation of capacitance as a function of reverse bias voltage forCNT/Si heterojunction under various pressure of oxygen gas
a-10-3 mbar , b-10-4mbae ,c-10-5mbar

The inverse capacitance square was plotted against applied reverse voltage for CNT/Si heterojunction at different pressure of oxygen gas (10^{-3}, 10^{-4}, and 10^{-5}) mbar .The plots reveal a straight line relationship which means that the junction was an abrupt type .The intersection (1/c2=0) of the straight line with the voltage bias axis represents the built in voltage.





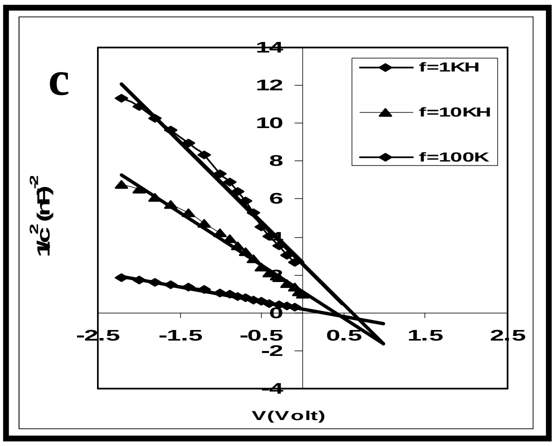


Fig.(3) shows the variation of inverse capacitance square as a function of reverse bias voltage for CNT/Si heterojunction under various pressure of oxygen gas :a-10-3 mbar , b-10-4mbae ,c-10-5mbar

4. <u>Current-Voltage Measurements</u>

The current(I)-voltage(V) characteristic in the heterojunction is an important tool for analyzing the different conduction process .Fig.(5) shows I-V characteristic for CNT/Si heterojunction at forward and reverse bias voltage for different pressure of oxygen gas with dark and illumination current. From this figure, it was been observed that the curve exhibit a highly non- linear feature. The non-linearity of the I-V characteristic indicates that the prevalent conduction mechanism is non-ohmic contact. in nature.

In general the forward dark current is generated due to the flow of majority carriers and the applied voltage injected majority carriers which leads to decrease the width of the depletion layer. The majority and minority carrier concentration is higher than the intrinsic carrier concentration $ni^2 < np$ which leads to generate recombination current at low voltage region .While the tunneling current is represented at high voltage region .After that there is a fast exponential increase in the current magnitude with increasing voltage and this is called the diffusion current ,which is dominated.

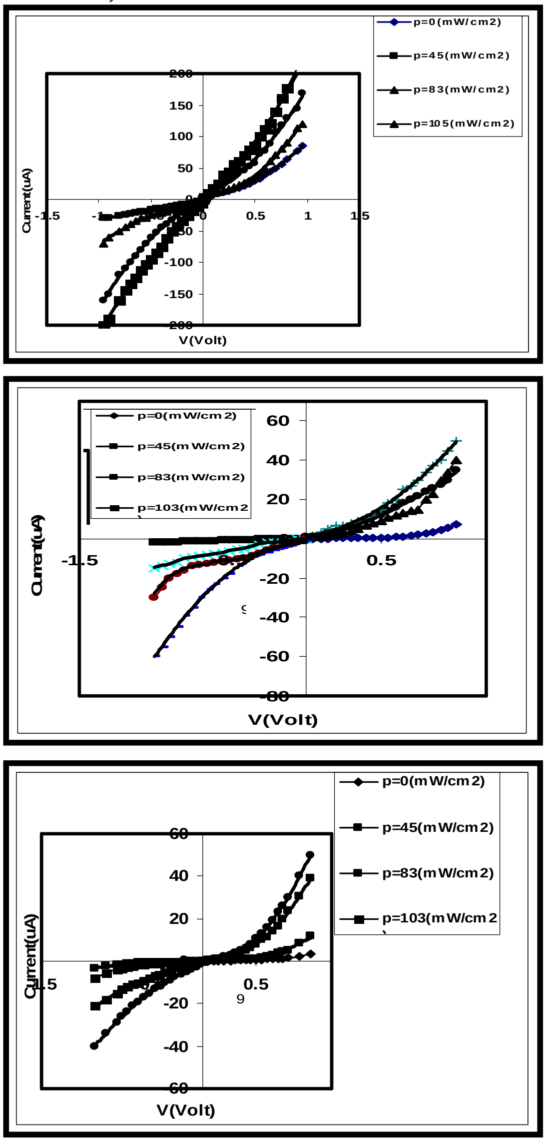


Fig.(5) Show I-V Characteristic of CNT/Si hetrojunction at different value of oxygen pressure a=10^{-3}mbar, b-10^{-4} mbar and c-10^{-5}mbar.

Conclusion

Multi wall of carbon nanotube was grown by arc discharge technique under various pressure of oxygen gas (10-3,10-4 and 10-5) mbar. The structure of carbon nanotube powder of low angle X-Ray diffraction showed that the crystallites are preferentially oriented with (002) reflection plane and the peaks exhibited large shifting toward higher angles with increasing pressure The full width at half maximum (FWHM) of (002) and (110) peaks are insensitive to the pressure i.e keeps constant .

C-v and I-V characteristic (under illumination) were measured.

Reference

[1] Rao. C. N R, Satishkumar B. C., Govindaraj A. and Nath M., 2001 Chem. Phys. Chem,. 2 ,78.
[2] S. Iijima, Nature 354, 56–58 (1991) 29
[3] Erlangung des Doktorgrades, Carbon Nanotube Composite – Mechanical, Electrical, and Optical Properties, Thesis Rheinischen Friedrich-Wilhelms-Universit,t Bonn 2006
[4] Daenen, M., De Fouw, R.D., Hamers, B., Janssen, P.G.A., Schouteden, K., Veld, M.A.J., 2003, The Wondrous World of Carbon Nanotubes, Eindhoven University of Technology.
[5] S. Iijima, T. Ichihashi, Nature 363, 603–605 (1993) 29
[6] Haddon R C (ed.) Acc. Chem. Res. 35 (2002)997 (special issue on carbon nanotubes).
[7] S.M.Sze "Physics of Semiconductor Devices" John Wiley and Sons,(1981).
[8] L.Sharma and R.K.Purohit ,"Semiconductor Heterojunctions", Pergamon Press, Oxford, New York (1974).
[9] B.L.Sharma, R.K.Purohit and S.N.Mukerjee "Infrared Physics", Vol.10, , Pergamon Press, printed in Great Britain, (1970) pp.225-231.
[10] M.J.Adams and A.Nussbaum, "Solid State Electron", Vol.22, (1997) pp.783-791.
[11] Morgan and K.Board, "An Introduction to Semiconductors Microtechnology", John Wiley and Sons, Inc., New York (1991).
[12] Hitoshi Yusa and Tetsu Watanuki 2005, X-ray diffraction of multiwalled carbon nanotube under high pressure: Structural durability on static compression, Carbon, 43 (2005) 519–523.