

PREPARING CARBON NANOTUBES (CNTS) FOR OPTICAL SYSTEM APPLICATIONS

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ABSTRACT

In recent years, significant progress in understanding of the physics of carbon nanotube electronics devices and identifying potential application has occurred. In a nanotube low bias (160m V – 200m V) can be nearly ballistic across distances of several hundred nanometers. In this study we have taken carbon nanotubes (17, 0), (12, 5), (10, 10), (16, 2), (15, 0), and (11, 11) they have diameters (1.33, 1.185, 1.35627, 1.338, 1.175, and 1.356) nanometer (nm) respectively. The study and analysis of the optical proprieties through Katuara plot explains the behavior as semiconducting or as metal, Carbon nanotubes are supporting in optical system applications. The electronic proprieties are governed by a single parameter named the chiral vector, and there are three parameters affecting the performance of carbon nanotubes diameter, chirality, and number of walls. The carbon nanotube supports optical proprieties by three main parameters very important to develop work with optical system application such as Electronic structure of carbon nanotubes, Saturable absorption, and third order Nonlinearity. Depending on the chiral vector carbon nanotubes behave as semiconductor or metal. But here focus on semiconducting carbon nanotubes to improve optical integrated circuit. The optical absorption of carbon nanotube determines their electronic energy gap and broadband operation is resulted of a large distribution of (1 -1.5 nm) diameters. Third order susceptibility is responsible for processes such as third harmonic generation (THG). Materials with a high nonlinearity combined with fast response time are desired for roles such as optical to support photonic devices for communication and information technology.

KEYWORDS: OCDMA, SWNTs, CNTs, Optical Systems

INTRODUCTION

Carbon Nanotubes (CNTs) were discovered by Sumio Iijima in NEC in Japan in the early 90s [1]. Carbon is the most important element of the periodic classification for human being. The six electrons with two of them fill the first orbit as shown figure 1 (a). The remaining four electrons fill the second orbit as Diamond (Sp^3) and Graphite (Sp^2) as well as Sp hybrid orbital, responsible for bonding structure of diamond, graphite, nanotubes, and fullerenes [3]. It has since become a prominent material for an amazing breath of scientific and technological displines of ranging from structural and material science to chemistry, biology, and electronics [2]. Carbon nanotubes are one of most commonly mentioned building blocks of nanotechnology, with one hundred times the tensile strength of steel, thermal conductivity better than all but the purest diamond and electrical conductivity similar to copper but with the ability to carry much higher currents, they seem to be a wonder material, thin cylinders of graphite. Graphite (Sp^2) is made up layers of carbon atoms arranged in a hexagonal lattice like chicken wire. Though the chicken wire structure itself is very strong [4]. But let's look at some of the different types of nanotubes and nanotube pretenders such as One of major classification of carbon nanotubes is into Single – walled varieties (SWNTs), which have a single cylindrical wall, and Multi-walled varieties (MWNTs), which have cylinders within cylinders as shown in figure1 (a) which illustrates all stages fabricated for carbon nanotubes (CNTs). There are three parameters very important in carbon nanotubes (CNTs) as diameter, chirality angle, and number of walls,

and also has unique physical and chemical properties. There are two types for fabrication first, chemical (chemical vapor deposition (CVD)) and second, other physical methods (Arc discharge, Laser ablation). Carbon nanotube belongs to polymer electronic Nano system. It is a tube – shaped material, made of carbon, having a diameter measuring on the nanometer scale that means one- billionth of a meter or about one ten – thousand of the thickness of a human hair. The graphite layer appears somewhat like a rolled up chicken wire with a continuous unbroken hexagonal mesh and carbon molecules at the apexes of the hexagons [5]. They have two conduction bands c_1 and c_2 and two valence bands v_1 and v_2 , these are called Van Hove Singularities observed in their electronic density of state (DOS) of these carbon nanotubes (CNTs). The direct electronic band gap proportional to diameter for semiconducting carbon nanotubes, while the direct band gap equal zero for metal carbon nanotubes so, they use in high electrical current. It has typically have diameters range (1-2) nm for single walled nanotubes and (2-25) nm for multi-walled nanotubes as well as the length of nanotubes may be (0.2 - 5) μm or some centimeters, and the spacing distance between walls is 0.36nm. Here, a single wall nanotube is prepared for optical proprieties applicable with optical system [6]. The potential applications of carbon nanotubes have been attracting increasing attention from the photonics research community [7]. It exhibits an exceptionally high third order optical nonlinearity and nonlinear saturable absorption with ultrafast recovery time and broad bandwidth operation. Thus, carbon nanotubes are becoming a key component towards the development of fiber lasers and nonlinear photonic devices. They are making a more significant contribution towards the development of next generation devises both from an academic and a commercial point of view. The electronic properties of single wall carbon nanotubes are governed by a single parameter named the chiral vector (C_n), which indicates the orientation of the tube axes with respect to the orientation of the honeycomb. Depending on this parameter, single-walled carbon nanotubes may behave as semiconductor or as metal [6]. General rules have desired the topology of the termination as a function of the Hamada indices (n, m). Carbon nanotubes can also be opened ended, according to the integer n and m so, they may behave either semiconducting or metallic. Carbon nanotubes are structures from the fullerene (C_{60}) family consisting of a honeycomb sheet of bonded carbon atoms rolled seamless into itself to cylinder as figure 1. [3] - [7].

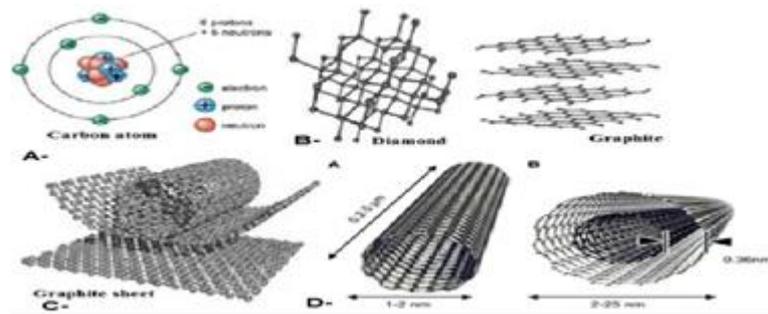


Figure 1(a): Illustrates All Stages Fabricated for Carbon Nanotubes (CNTs) from Carbon Atoms, Graphite Sheet, and Rolled as Form Tube

This strong dependence of the electronic structure on geometrics observed in fullerenes should be generally the case in nanostructured carbon materials including carbon nanotubes since the interaction between valence electrons and the lattice should be much stronger in stiff C-C covalent – bond materials bond. The one dimension (1D) electronic energy band structure for carbon nanotube is related to the energy band structure calculated for two dimensions (2D) graphite honeycomb sheet used to form the nanotube. These calculations electronic structure for carbon nanotube shows about 1/3 of carbon nanotube is metallic and 2/3 is semiconducting, depending on the nanotube diameter (d_t) and chiral angle (θ). Another classification for carbon nanotubes depending on chiral vectors (C_n), they are Zigzag nanotube, armchair

nanotube, and chiral nanotube as shown in figure 1 (b). All these carbon nanotubes have relationship between electronic density of state and energy band gap [3]-[8], [9]. There are three parameters to develop carbon nanotubes optical proprieties to work in optical system, Electronic structure of carbon nanotubes, Saturable Absorption of carbon nanotubes, and Third order nonlinear for carbon nanotubes. The high pressure carbon mono-oxide (HiPCO) has been one of the fabrication methods for the mass production of carbon nanotubes. They are often seen as straight or elastic bending structures individually or in ropes, by transmission electron microscopy (TEM), scanning electron microscopy (SEM), atomic force microscopy (AFM), and scanning tunneling microscopy (STM). It can be great potentials towards the nano - scale photonic devices which can be utilized for optical filtering or nanofiltering, waveguide, switching, and wavelength multiplexing but it expresses nanoscale devices. It offers the concepts of carbon nanotubes sensor networks (CNSN). [35], [36], [37].

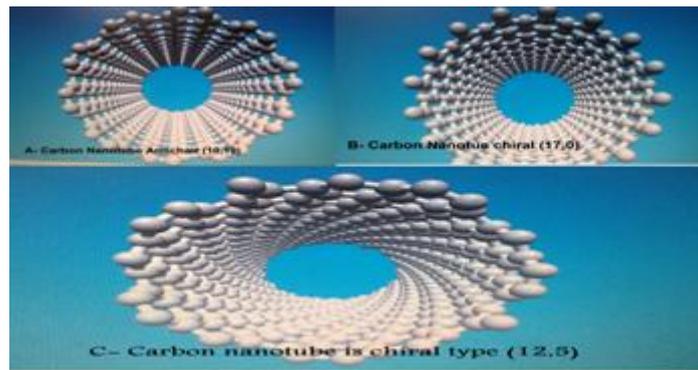


Figure 1(b): Illustrates All Stages Fabricated for Carbon Nanotubes (CNTs) from Carbon Atoms, Graphite Sheets, and Rolled as Form Tube as (10, 10), (17, 0), and (12, 5)

ASSUMPTION SYSTEM AND SIMULATIONS

A single wall carbon nanotube (SWTN) can be described as a single layer of graphite crystal that is rolled up into a seamless cylinder, one atom thick usually with a small number (perhaps 20 - 40) of atoms along the circumference and along length (micron) along the cylinder axis [11]. This nanotube is specified by the chiral vector (C_h).

$$C_h = n * a_1 + m * a_2 \tag{1}$$

Where n and m are two integers indices called Hamada integers, which often described by the pair of indices (n, m) that denote the number of unit vectors $n * a_1$ and $m * a_2$ in the hexagonal honeycomb lattice contained in this vector a_1 and a_2 where $|a| = |a_1| = |a_2| = \sqrt{3} * a_{c-c} = 0.246\text{nm}$, where $a_{c-c} = 0.142\text{nm}$ the c-c bond length a_1 and a_2 are graphite lattice vector, which two vectors real space vectors[2], [3],[8],[11]. The chiral vector makes an angle (θ) called the chiral angle with the zigzag or direction.as figure 2. The vector connects two crystallographic ally equivalent sites O and A on a two – dimensional (2D) graphene sheet where a carbon atom is located at each vertex of the honeycomb structure [8]. The axis of the zigzag nanotube corresponds to $\theta = 0$, while the armchair nanotube axis corresponds to $\theta = 30$, and the chiral nanotube axis corresponds to $0 \leq \theta \leq 30$. The seamless cylinder joint of the nanotube is made by joining the line AB to the parallel line OB in figure 2, in terms of the integer (n, m), the nanotube diameter (d_t) is given by equation (2).

$$d_t = \frac{|a| * \sqrt{n^2 + n * m * \cos(120^\circ) + m^2}}{\pi} \tag{2}$$

The nearest – neighbor C-C distance 1.421 or 0.142 in graphite, C_h is the length of the chiral vector and the chiral angle (θ) is given by equation (3)

$$\theta = \tan^{-1}\left(\frac{\sqrt{3}+m}{2n+m}\right) \quad (3)$$

Thus, a nanotube can be specified by either its (n, m) indices or equivalent by d_T and θ .

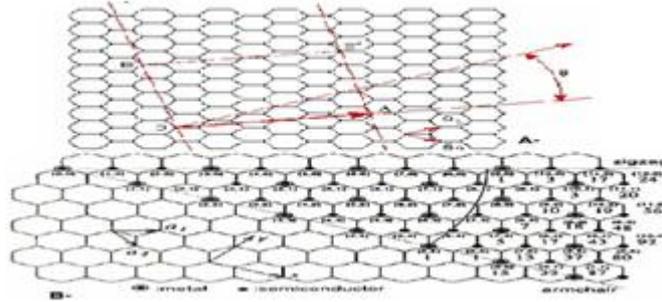


Figure 2: Explanation of Synthesis of Carbon Nanotubes from Graphite Sheet

Next, defined the unit cell OBBA of the 1D nanotube in terms of the unit cell of the 2D honeycomb lattice defined by vectors a_1 and a_2 as shown figure 3 a) the unit cell and b) the brillouin zone of two – dimensional graphite as adopted rhombus and shaded hexagon, respectively, where a_1 and a_2 are basis vector in real space, b_1 and b_2 are reciprocal lattice basis vectors. In the (x, y) coordinates in figure 3, the real space basis vector a_1 and a_2 are expressed as equations (4) and (5).

$$a_1 = \left(\frac{\sqrt{3}}{2} * a, \frac{a}{2}\right), a_2 = \left(\frac{\sqrt{3}}{2} * a, -\frac{a}{2}\right) \quad (4)$$

And

$$b_1 = \left(\frac{2\pi}{\sqrt{3}+a}, \frac{2\pi}{a}\right), b_2 = \left(\frac{2\pi}{\sqrt{3}-a}, -\frac{2\pi}{a}\right) \quad (5)$$

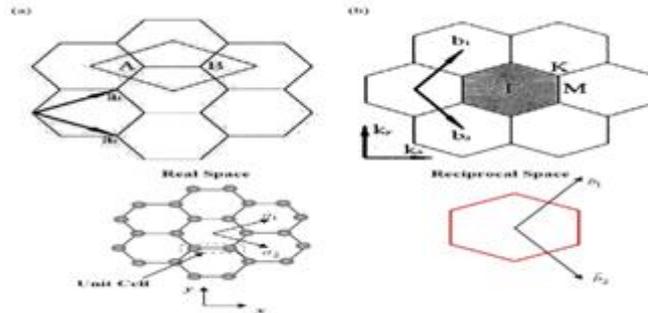


Figure 3: Characteristics of Structure the Unit Cell Real and Reciprocal

where $a = |a_1| = |a_2| = 0.246\text{nm A}$ is the lattice constant of two – dimensional graphite, correspondingly the basis vectors b_1 and b_2 of the reciprocal lattice. Corresponding to a lattice constant of $\frac{4\pi}{\sqrt{3}+a}$ in reciprocal space, the direction of the basis vectors b_1 and b_2 of the reciprocal ($b=2.949\text{nm A}$) hexagonal lattice are rotated by 30 from the basis vectors a_1 and a_2 of the hexagonal lattice in real space, by selecting the first brilluoin zone as the shaded figure 3, the highest symmetry points, Γ , K, and M as the center, the corner, and the center of the edge respectively. The energy dispersion relations are calculated for the triangle ΓMK shown by the dotted lines in figure 3. To define the unit cell for the 1D nanotube, defined OB as figure 2 as the shortest repeat distance along the nanotube axis, there by defining the translation vector (T)

$$T = t_1 * a_1 + t_2 * a_2 \quad (6)$$

Where the coefficient t_1 and t_2 are related to (n, m) by equation (7)

$$t_1 = \frac{(2n+m)}{dR} \quad \text{and} \quad t_2 = \frac{-(2n+m)}{dR} \quad (7)$$

Where dR is the greatest common divisor of (2n+m, 2m+n) and given by equation (8)

$$dR = \begin{cases} d, & \text{if } n - m \text{ is not a multiple of } 3d \\ 3d, & \text{if } n - m \text{ is a multiple of } 3d \end{cases} \quad (8)$$

In which d is the greatest common divisor of (n, m). The magnitude of the translation vector $T = |T|$

$$|T| = \frac{\sqrt{3} \cdot L}{dR} \quad (9)$$

Where L is length of the chiral vector C_h and d_t is the nanotube diameter. The unit cell of the nanotube is defined as the area delineated by the vector T and C_h . The number of hexagons, N contained within the 1D unit cell of a nanotube is determine by the integers (n,m) and given by (10)

$$N = \frac{2(n^2 + n \cdot m + m^2)}{dR} \quad (10)$$

The addition of single hexagon to the honeycomb structure figure 1 corresponds to the addition of two carbon atoms. Assuming a value $a_{c-c} = 0.142 \text{ nm}$ on a carbon nanotube, we selected here (17,0), (12,5),(10,10),(16,2),(15,0), and (11,11) nanotubes. Since the real space unit cell is much larger than that for 2D grapheme sheet, the 1D Brillouin zone (BZ) for the nanotube is much smaller than the BZ for single two grapheme 2D unit cell. Because the local crystal structure of the nanotube is so close to that of a grapheme sheet and because the Brillouin Zone is small, Brillouin Zone – folding techniques have been commonly used to obtain approximate electron and phonon dispersion relations for carbon nanotubes (n, m) with specific symmetry – whereas the lattice vector T, given by equation (6), and the chiral vector C_h , given by equation (1), both the unit cell of the carbon nanotube in real space, the corresponding vectors in reciprocal space are the reciprocal lattice vectors (k_2) along the nanotube axis and (k_1) in the circumferential direction, which gives discrete k values in the direction of the chiral vector C_h . The vectors k_1 and k_2 are obtained from the relation

$R_i * K_j = 2\pi * \delta_{ij}$, where R_i and K_j are the lattice vectors in real and reciprocal space respectively. Form k_1 and k_2 can be written as

$$k_1 = \frac{1}{N}(-t_2 * b_1 + t_1 * b_2) \quad \text{and} \quad k_2 = \frac{1}{N}(m * b_1 - n * b_2) \quad (11)$$

Where b_1 and b_2 are the reciprocal lattice vectors of a two – dimensional grapheme sheet given by equation (5). The N wave vectors μk_1 ($\mu = 0, \dots, N - 1$) give rise to N discrete k vectors in the circumferential direction. For each of μ discrete values of the circumferences wave vectors a one – dimensional electronic energy band appears, whereas each μ gives rise to 6 branches in the phonon dispersion relations [8]. A nanotube (n,m) is formed by rolling a graphite sheet along the chiral vector C_h on the graphite sheet rolled. The nanotube can also be characterized by the diameter (d_t) and the chiral angle θ is with respect to zigzag axis $\theta = 0$. A Single Wall Nanotube (SWNT) can be visualized as a hollow cylinder, formed by rolling over a graphite sheet. It can be uniquely characterized by a vector C_h in terms of a set of two integers (n, m) corresponding to graphite vectors a_1 and a_2 . By rolling a graphite sheet in different directions, two typical nanotubes can be obtained: zigzag (n, 0), armchair (n, m), $n = m$, and chiral (n, m), where $n > m > 0$, they are (17, 0), (15, 0), (12, 5), (16, 2), (10, 10), and (11, 11). The lattice constant and intertube spacing are required to generate a SWNT bundle, and MWNT, the most experimental measurements and theoretical calculations, agree that on average the C-C bond length and intertube ($d_{tt} = 0.34 \text{ nm}$) [11]. Thus, equations (1) and (2) can be used to model various tube structures and interpret

experimental observation. They now consider the energetics or stability of nanotubes; strain energy caused forming a SWNT from a graphite sheet is proportional to $\frac{1}{d_t}$ per tube or $\frac{1}{d_t^2}$ per atom [3]. Typical experimentally observed SWNT diameter is between (0.6 nm – 2.0 nm) while smaller (0.4nm) or larger (3.0nm). In simplest model [3], the electronic properties of a nanotube derived from the dispersion relation of a graphite sheet with the wave vectors (k_x, k_y) , [3], [7].

$$E(k_x, k_y) = \pm \gamma_0 \sqrt{1 + 4 \cos\left(\frac{\sqrt{3} \cdot k_x \cdot a}{2}\right) \cos\left(\frac{k_y \cdot a}{2}\right) + 4 \cos^2\left(\frac{k_y \cdot a}{2}\right)} \quad (12)$$

Where γ_0 is the nearest neighbor – hopping parameter and a lattice constant ($\gamma_0 = 2.5\text{eV}- 3.0\text{eV}$) from different sources and $a=0.246\text{nm}$. When the graphite is rolled over to form a nanotube, a periodic boundary condition is imposed along the tube circumference or the C directions. This condition quantizes the two – dimensional wave vector $k = (k_x, k_y)$ along this direction. The k satisfies $k \cdot c = 2\pi q$ are allowed where q is an integer. This leads to the following condition at which metallic conductance occurs as equation (13)

$$(n - m) = q \text{ metallic or } (2n + m) = 3q \quad (13)$$

Semiconducting.

The top half of the energy curve corresponds to the conduction π^* energy band while the bottom half corresponds to the valence π energy band. The conduction and valence band come into contact at the six corners (high symmetry points k) in the Brillouin zone, implying that 2D graphite is a zero – gap semiconductor, when $s=0$, the valence and conduction band become symmetric a ball $E=E_{sp}$ this is given by equation (12) and $\gamma_0 = 2.9 \text{ eV}$. The positive sign is for the conduction band and the negative one for the valence band. In contrast to Si, which is an indirect band gap semiconductor and asymmetric band structures for electron and holes, graphene has symmetric conduction and valence bands. The energy valleys are located at the corners of the Brillouin zones, which are usually referred as the Fermi points. The basis vectors in the reciprocal lattices b_j . The periodic boundary condition imposed along the circumference direction restricted the wave vectors to

$$k \cdot c = 2\pi q \quad (14)$$

where k is an allowed wave vector and q is integer which is the quantum number [13] – [21]. The conductance for SWNT, a SWNT rope, or MWNT given by equation (15)

$$G = G_0 * M = \left(\frac{2e^2}{h}\right) * M \quad (15)$$

Where $G_0 = \left(\frac{2e^2}{h}\right) = (12.9\text{kohm})^{-1}$ is quantized conductance, M is a apparent number of conducting channels including electron - electron coupling and intertube coupling effects in addition to intrinsic channel, $M=2$ for a perfect SWNT $G = (6.5\text{kohm})^{-1}$ that means resistance for nanotube $R = 6.5 * 10^3 \text{ ohm}$ [24]. The combined STM/STS studies [7] are consistent with 1) about 2/3 of the nanotubes being semiconducting and 1/3 being metallic; 2) the density of states exhibiting van hove singularities, characteristic of the expectations for 1D system; 3) energy gaps for the semiconducting nanotubes that proportional to $1/d_t$ [5]. The physical origin of kinetic inductance (E_k) is the excess kinetic energy associated with current flow [25], [26], [27], which shows ballistic electrons flowing between the source and drain for field effect transistors Fermi energy where μ is the equilibrium Fermi energy. Thus an appropriate choice of diameter is convenient. At 300K temperature, standard values of bandgap are: - (1.12 eV) for silicon, (0.67eV) for germanium and (1.43eV) for GaAs [7]. The unit measurements for electronic density of states (DOS), μ is (unit) equilibrium Fermi energy

in unit nanotube length, and a is (arability) the number of electron – phonon pair in the unit nanotube length this is random.

The expression for average number of electron – phonon pairs have the density of states divided by two because only the right moving carriers are present in the bias window.

RESULTS AND DISCUSSIONS

Electronic Structure of Carbon Nanotubes (CNTs)

The electronic properties of a CNT are determined by its chiral vector C_h from (1). This vector describes how the graphene sheet is rolled when forming the nanotube. Here, we take many carbon nanotubes as (17, 0), (12, 5), (10, 10), (16, 2), (15, 0), and (11, 11). They consist of (17, 0), (15, 0) which is called zigzag nanotube that means the integer (n, m) as $n=17$, and $m=0$, the chiral angle ($\theta = 0$) this nanotube is used either as metal or semiconductor depending to prepare carbon nanotube open fabricated process. Here, we focus on semiconductor chiral nanotubes (12, 5), (16, 2) wherein of $n=12$ and $m=5$ and the chiral angle ($0 \leq \theta \leq 30$), further armchair nanotubes (10, 10), (11, 11) wherein of $n=m=10$, the chiral angle ($\theta = 30$), behaving as metal as expressed by equation (3). In the simulation we have got the diameters of nanotubes as (1.33nm, 1.185nm, 1.35627nm, 1.338nm, 1.175nm, and 1.356nm) respectively. We get the result between the electronic density of states (DOS) (unit measurement - arbitrary, unit), to Fermi energy in unit cell of the atoms of carbon nanotubes and energy band gap in semiconductor nanotube focused on semiconducting nanotubes, wherein band gap is given by equation (16)

$$E_g = \frac{2 \cdot a_{c-c} \cdot \gamma_0}{d_t} = \frac{0.8 \text{ eV}}{d_t} \tag{16}$$

where E_g the energy band gap for semiconductor which has two conduction bands and two valence bands as shown in figure 4 which illustrates how to work with two van hove singularities , with Fermi energy $\gamma_0 = 2.9 \text{ eV}$. If $(2n+m) = 3q \neq 0$, the carbon nanotubes would be 2/3 semiconductor from equation (13). The Kinetic energy (E_k) form the lowest subband is determine by the minimum value given by equation (18)

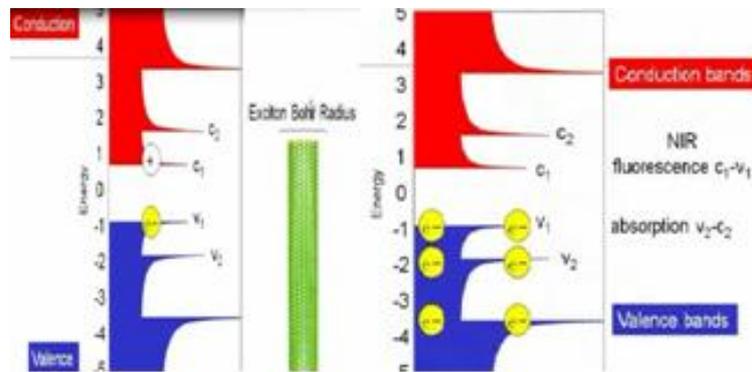


Figure 4: Illustrates Two Van Hove Singularities in Semiconductor Carbon Nanotubes

$$K_{c,q} = \frac{2}{3d_t} \tag{17}$$

Where d_t is the diameter of the carbon nanotube the energy output for CNTs are given by equations (18)

$$E(K_t) = \pm \frac{3 \cdot a_{c-c} \cdot \gamma_0}{2} * \sqrt{k_t^2 + (\frac{2}{3d_t})^2} \tag{18}$$

And

$$E_o = \pm \frac{3 \cdot a_{c-c} \cdot \gamma_0}{2} \tag{19}$$

Where E_o is energy gap with normal temperature for graphite. Subsequently from equations (18) and (19) we get equation (20) for E_{out} , the output energy band gap.

$$E_{out} = \frac{E(k_t)}{E_o} \tag{20}$$

The output energy band gap for carbon nanotubes depends on doping the electron density of states in during fabrication and expressed by equation (21).

$$D(E_k) = \frac{8}{3 \cdot \pi \cdot a_{c-c} \cdot \gamma_o} * \frac{E(k_t)}{\sqrt{E(k_t) - (E_g/2)}} \tag{21}$$

From the equations 18, 19, 20, 21 has got results as shown in figure 5 a and b has been obtained which calculated is nanotubes the energy band gap has positive as well as negative values, that is the carbon nanotubes show very high symmetry in (a) and (b) of figure 5 which illustrate (17, 0), (12, 5), (15, 0), and (16, 2) for energy gap has two van hove two conduction bands (c_1 , and c_2) and two valence bands (v_1 and v_2) symmetries in both side positive and negative in energy gap depend upon doping in electronic density of states (DOS) as in case of semiconductor carbon nanotubes, while (10,10), and (11,11) these have one conduction band and valence band these behave metallic carbon nanotubes because band gap is zero as shown figure 5 a and b.

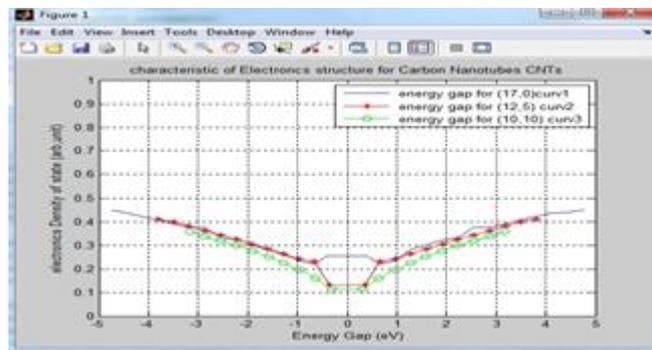


Figure 5 (a): The Results for Some Carbon Nanotubes (17, 0), (12, 5), and (10, 10) to Get Energy Gap with Relation DOS in this System

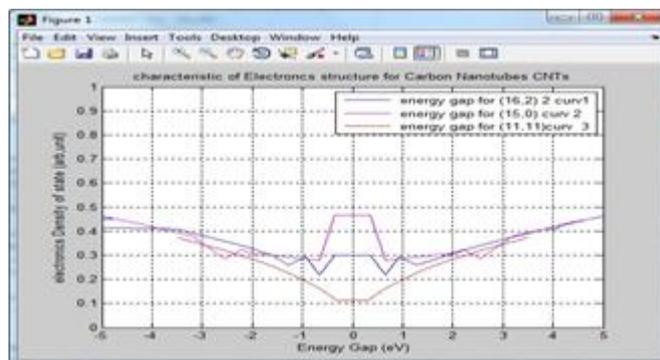


Figure 5 (b): The Results for Some Carbon Nanotubes (16, 2), (15, 0), and (11, 11) to Get Energy Gap with Relation DOS in this System

In metal carbon nanotubes the band gap between one conduction band and one valence band is zero while in semiconductor carbon nanotubes have band gap between two conduction bands and two valence bands. The incident light (photon) is observed by valence band (v_2) to excite electron to conduction band (c_2) leave a hole in v_2 and move electron

from valence band (v_1) to v_2 and then leave hole in v_1 and move electron from c_2 to conduction band (c_1) to move to v_1 causing the flow of electric current is called van hove singularities as in figure 4 where energy gap is very symmetrical and low consumption optical power along life time as shown in figure 5 a and b. The energy corresponding to the symmetric transition $p=q$ for Semiconducting (S) and Metallic tubes (M) follows the relations with one p – orbit approximation equation (22) and (23). [3] - [23].

$$E_{pp}^S = \frac{2 \cdot p \cdot a_{c-c} \cdot \gamma_0}{d_t} \tag{22}$$

For semiconductance carbon nanotube,

$$E_{pp}^M = \frac{6 \cdot p \cdot a_{c-c} \cdot \gamma_0}{d_t} \tag{23}$$

for metallic carbon nanotube, as shown figure 5 part (c).

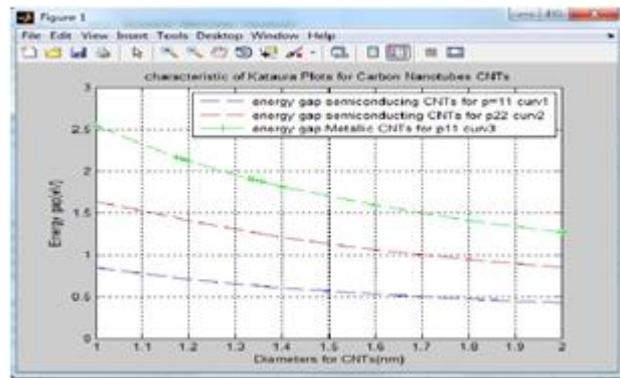


Figure 5 (c): The Results for Kataura Plot for Some Carbon Nanotubes Behavior Either as Semiconducting or as Metallic Energy Gap is Relation to Carbon Nanotube Diameters in the System Metallic Energy Gap with Relation Carbon Nanotube Diameters in this System

Wherein the number p ($p=1, 2, \dots$) is used to denote the order of the valence and conduction bands symmetrically located with respect to the Fermi energy as shown figure 5 c . The good diameter distribution has been chosen from 1nm to 1.5nm, and we select 1.33nm diameter for (17, 0), and 1.185nm diameter for (12, 5) carbon nanotubes respectively. This relation is between diameters (nm) for carbon nanotubes from (1nm – 2nm) for single walled carbon nanotubes (SWNTs) and energy gap. The metallic carbon nanotube has high energy because band gap is zero but for the semiconducting carbon nanotube the energy here the band gap exists and depends on p where $p=1$ or $p=2$ and this results from the equations (22) and (23). [3], [13], [23].

Saturable Absorption of Carbon Nanotubes (CNTs)

The optical absorption of CNTs is of saturable, intensity-dependent nature, it is a suitable material to employ for passively mode-locked laser operation. Passive mode locking is achieved by incorporating an intensity-dependent component into the optical system. The typical absorption of a suspension of CNT fabricated by the high pressure carbon monoxide method (HiPCO) and measured by a spectrometer. This is generally a saturable absorber which absorbs the light which is incoming linearly up to a given threshold intensity, after which is saturates and becomes transparent optical power intensity for output with losses 5% from input incident optical power intensity. Such saturable absorbers discriminate in favor of pulse formation over continuous wave lasing. This is one of the key advantages of carbon nanotube – based devices as has been achieved passive in mode – locked operation not only in the C (1530nm – 1565nm) and L (1565nm – 1625nm) bands but covering also the wavelength (λ) range from ($1\mu\text{m} - 2\mu\text{m}$) using single wall carbon nanotube saturable

absorber [7], [28], [29]. The three parameters the non-linear saturable losses ($\alpha_{ns} = 0.445$), the modulation depth or the linear saturable losses ($\alpha_o = 0.05$), and saturable intensity ($I_{sat} = 7.89 \text{ MW/cm}^2$), together response time ($\tau = 1.85 \text{ ps}$) give us the location of the applicability of carbon nanotubes for passive mode locking applications.

$$\alpha(I) = \frac{\alpha_o}{1 + \frac{I}{I_{sat}}} + \alpha_{ns} \quad (24)$$

The equation (24) gives the relates between the various parameters where $\alpha(I)$ is optical intensity for carbon nanotubes and comprises of information. We selected for simulation only two carbon nanotube diameters 1.33nm and 1.185nm carbon nanotubes to get optical intensity relationship with wavelength (λ) from (500nm – 3000nm). We see increasing optical intensity with increasing wavelength because the absorption is decreasing also as shown in figure 6 (a). Another relationship between the energy gap with the wavelength is as per equation (25)

$$E_g = \frac{h \cdot c}{\lambda} \quad (25)$$

Where h is Planck's constant is equal ($6.626 \cdot 10^{-34} \text{ J}\cdot\text{s}$) and c is speed of light ($3 \cdot 10^8 \text{ m/s}$), resistance also equals ($R = 6.5 \cdot 10^3$) ohm, the half width short pulse for this simulation ($\tau = 1.85 \cdot 10^{-12} \text{ s}$) or is femtosecond ($1 \cdot 10^{-15} \text{ s}$).

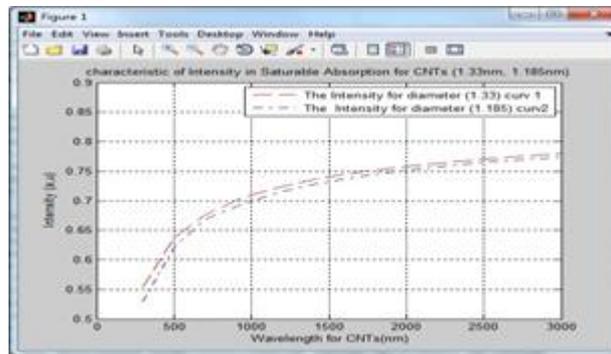


Figure 6 (a): Illustrates the Results for Optical Intensity (a, u) in Saturable Absorption for Carbon Nanotubes (1.33nm, 1.185nm)

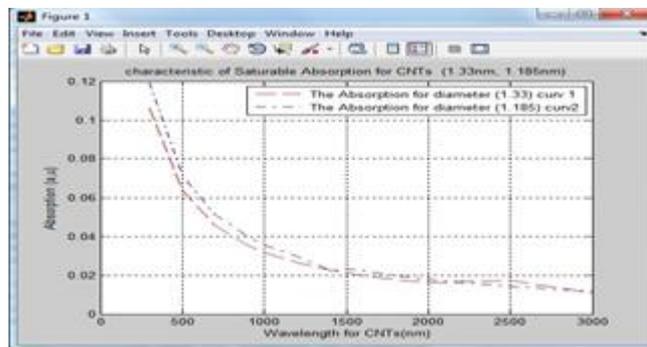


Figure 6 (b): Illustrates the Results for Optical Absorption (a, u) in Saturable Absorption for Carbon Nanotubes (1.33nm, 1.185nm)

The saturable absorption in carbon nanotube is achieved from the relationship of wavelength and absorption that means when the wavelength increases in this system the absorption decreases. Specifically of the wavelength center (1550nm), the third window in optical frequency, the absorption is approximately (0.02 d B/km) from equation (26) as also as shown in figure 6 (b). [7], [30], [31].

$$A = \log_{10} \left(\frac{1}{T} \right) \tag{26}$$

Where T is transmittance optical intensity and can be derived from equation (27)

$$T = 1 - \frac{\alpha_0}{1 + \frac{I}{I_{sat}}} + \alpha_{ns} \tag{27}$$

The transmittance results in figure 6 (c) which illustrates reverse proportion with absorption it means the absorption is decreasing when the wavelength is increasing but the transmittance is observed to be increasing as shown in figure 6 (c).

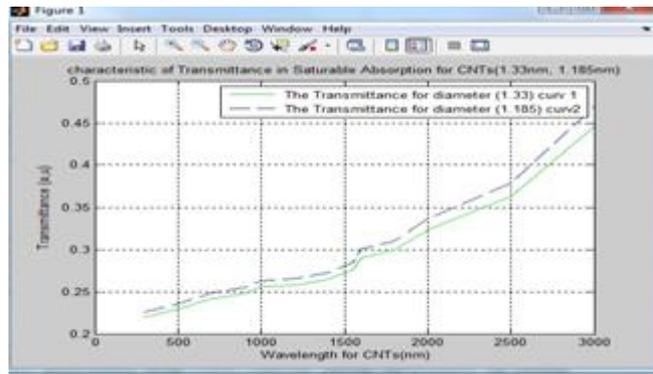


Figure 6 (c): Illustrates the Results for Optical Transmittance (eV) in Satuarble Absorption for Carbon Nanotubes (1.33nm, 1.185nm)

This needs less consumption of power so it is used in bio-electronic applications. The field of the optical signal can be expressed by the equation (28).

$$E_{out} = \frac{E_0}{2} \{ \cos [2 * \pi * f_o * \tau + \alpha_{ns} * \cos (4 * \pi * f_{op} * \tau + \theta)] + \cos [2 * \pi * f_o * \tau + \alpha_{ns} * \cos (4 * \pi * f_{op} * \tau) + \phi] \} \tag{28}$$

Where $f_o = 193 * 10^{14}$ Hz (center wavelength 1550nm) and f_{op} is optical frequency in this system covering wavelength range between (1520nm – 1580nm). This is shown to figure 7 we have maximum optical power intensity at (-10 dBm) at the wavelength center (1550nm) decreasing optical power in both sides ($f_o + f_{op}$) nm and ($f_o - f_{op}$) nm. Similarly, optical power intensity for the same system in saturable absorption for the same band of wavelength as shown in figure 8.

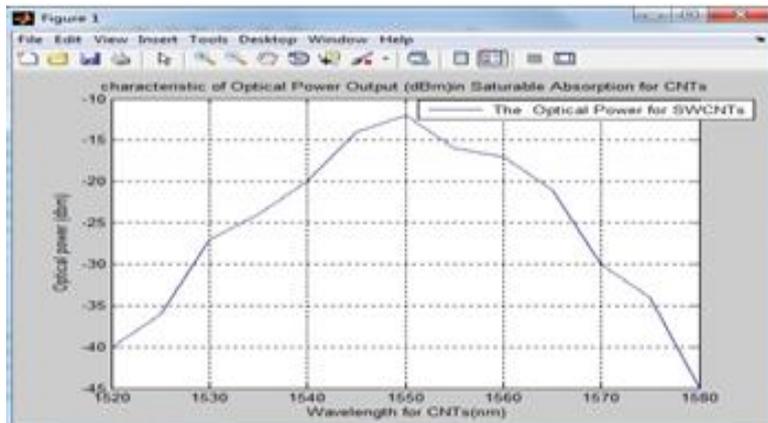


Figure 7: The Results for Optical Power Output (d B m) in Saturable Absorption for Carbon Nanotubes (CNTs)

This also supports optical system application and can be used with Erbium Doped Fiber Amplifier (EDFA) for pumping optical power intensity of the transmitting signal so that it can be used with Wavelength Division Multiplexing (WDM) and Optical Code Division Multiple Access (OCDMA) to bring in improvement performance of optical system applications with increasing data rates..

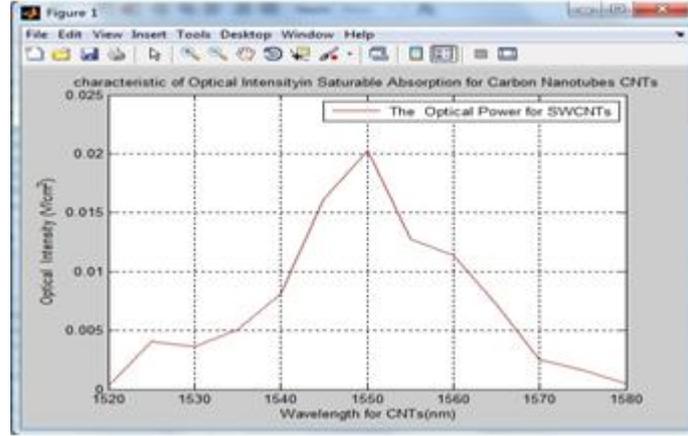


Figure 8: The Results for Optical Intensity in Saturable Absorption for Carbon Nanotubes (CNTs)

Third Order Nonlinearity of Carbon Nanotubes

The third order nonlinear material can be considered for optical switching, routing and wavelength conversion. Optical nonlinearity is due to optical intensity dependent nonlinear response of dielectric material. When the optical intensity of the propagating light is dielectric material is low, stimulated polarization is linearly proportional to optical intensity. However, at high optical intensity, the simulated polarization (P) exhibits a nonlinear response to the optical electric field (E), as described by equation (29).

$$P = \epsilon_0 (X^{(1)} \cdot E + X^{(2)} \cdot E + X^{(3)} \cdot E) \quad (29)$$

Where $X^{(1)}$, $X^{(2)}$, and $X^{(3)}$ correspond to the linear, the second order nonlinear, and third order nonlinearity susceptibility respectively. It has been reported that some types of carbon nanotubes present a high $X^{(2)}$, however, there is not much active research on exploiting this property. On the other hand, the high values of $X^{(3)}$ calculated theoretically and experimentally are of great interest. There refractive index in carbon nanotubes can be described by equation (30). [10] - [30].

$$n_2 = \frac{3}{8n} * ReX_{xxx}^{(3)} \quad (30)$$

Where Re stands for the real part the optical field is assumed to polarized so that only is components $X_{xxx}^{(3)}$, ($n=n_0 = 1$) is refractive index in free space (air). We have another equation to get refractive index to get n_2 from simple equation (31)

$$n_2 = \frac{c}{v} \quad (31)$$

Where v is the optical frequency if we take wavelength (1550 nm) that means ($n_2 = 1.5 * 10^{-8} m^2/W$) is high. The third order susceptibility of carbon single walled nanotube from Z-Scan spectroscopy was estimated for the same n_2 . $X_{xxx}^{(3)}$ can be expressed by equation (32)

$$X_{xxx}^{(3)} = \sqrt{(ReX^3)^2 + (ImX^3)^2} \quad (32)$$

Where $ReX^3 = \frac{4}{3\pi} * n_o * c * \epsilon_o * \alpha_{ns}$ is real part of $X^{(3)}$; ($\epsilon_o = 8.85 * 10^{-12}$), and $Im X^{(3)} = \frac{1}{3\pi} * n_o * c * \epsilon_o * \alpha_{ns} * \lambda$ is the imaginary part of $X^{(3)}$. The values of real and imaginary part of $X^{(3)}$ are being of the carbon single wall nanotubes, the vacuum permittivity (ϵ_o). The nonlinear relationship between the average electrical fields inside materials (D) and the incoming optical (E) field, nonlinear effects is defined the tensor of optical susceptibility x, which is the transformation matrix of the incoming E vector to get the result polarization (P) vector inside materials given by equation (33)

$$P = \epsilon_o [X^{(1)} * E * \cos(wt) + X^{(2)} * E^2 * \cos^2(wt) + X^{(3)} * E^3 * \cos^3(wt)] \quad (33)$$

We get another expression given by equation (34).

$$P = [\frac{1}{2} * \epsilon_o * X^{(2)} * E^2 + (\epsilon_o * X^{(1)} * E + \frac{3}{4} * \epsilon_o * X^{(3)} * E^3) \cos wt + \frac{1}{2} * \epsilon_o * E * \cos wt + \frac{1}{2} * \epsilon_o * X^3 * E^3 * \cos wt] \quad (34)$$

According equation (33) and (34) we can get new equation (35)

$$P_x = \alpha * E + \alpha_{ns} * E^2 + n_2 * E^3 \quad (35)$$

We can get results for optical polarization intensity in third order nonlinearity for carbon nanotubes the maximum optical intensity between wavelengths (1540nm – 1550nm) for single wall nanotube by equation (35) as shown in figure 9 (a).

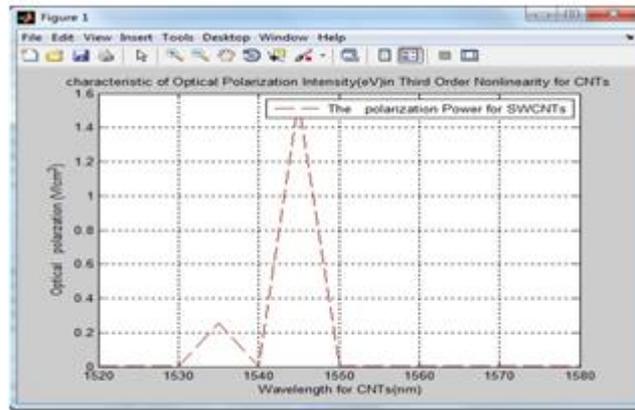


Figure 9 (a): Explains Optical Polarization Intensity in Third Order Nonlinearity for Carbon Nanotubes (CNTs) Also Single Wall Nanotubes (SWNTs)

The optical intensity in third order nonlinearity we get maximum in wavelength center at (1550 nm), the third window in optical systems and covers large bandwidth to support optical integrated electronic circuit to work in optical frequencies to improve performance for optical system application as shown figure 9 part (b). The relationship between the potential V (E) and the electrical field (E) will be symmetrical given by equation (36)

$$V(E) = -[\left(\frac{1}{2}\right) * \alpha * E^2 + \left(\frac{1}{3}\right) * n_2 * E^3 + \left(\frac{1}{4}\right) * n_2 * E^4] \quad (36)$$

The symmetrical potential of the material under the influence of an incoming signal optical E field implies that the material is contrast electrical that electron polarization in positive and negative direction as shown figure 9 part (C). The optical potential in third order nonlinearity the ultrafast optical switches to get approximately (1.85 ps) or few femtosecond ($f_s = 10^{-15}$), fast relaxation process in the order of 100s of femtoseconds combined with an extremely high nonlinear

coefficient can be observed in real carbon nanotubes devices in fabricated optical integrated circuit in ultra large scale integrated circuits (ULSI). It is also very high third nonlinear and ultrafast response times [7], [33], [34].

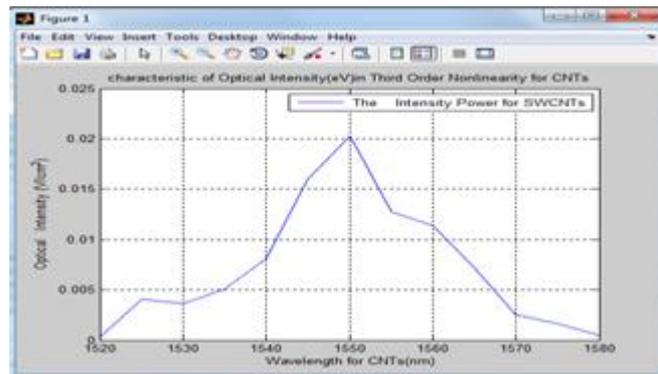


Figure 9 (b): Explains Optical Power Intensity in Third Order Nonlinearity for Carbon Nanotubes (CNTs) Also Single Wall Nanotubes (SWNTs)

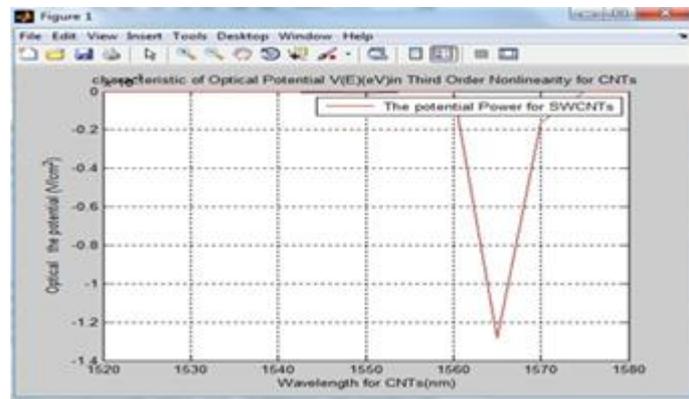


Figure 9 (c): Explains Optical Potential in Third Order Nonlinearity for Carbon Nanotubes (CNTs) Also Single Wall Nanotubes (SWNTs)

CONCLUSIONS

The carbon nanotube used in this work is single walled nanotubes whose electronic structure is semiconducting. Optical integrated circuit has many advantages elastic in direction optical incident and the move almost of optical power intensity and low consumption power, it needs low voltage like (160mV – 200mV) and input power in microwatt or milliwatt . This performs in bio-electronic application. It has saturable absorption to efficient saturable absorbers optical power incident to get output with losses 5% this is very best for work in passive optical network applications. This is one of the key advantages of carbon nanotube – based devices in passive mode locking operation. It continues to work even in high temperature environments without affecting in its performance in the system. The Absorption in carbon nanotube is very low 0.02 dB/km that means very accurate in transfer the optical signal, their devices offer a very high nonlinear coefficient and fast response time to reach 100s of femtosecond, ultrafast work optical switches used in many in communication system applications, information technology, and sensors system. It has two methods to support work in nonlinear optical switching by polarization rotation and four wave mixing (FWM) to develop Wavelength Division Multiplexing (WDM) and Optical Code Division Multiple Access (OCDMA) to increase high data rates to support increasing transferring a lot of data information in communication system applications. Carbon nanotubes have the long life time, so it uses in bio-electronic devices in medical sets. It is used in passive optical devices because of enhanced

nonlinearity applications and ultrafast optical switching where the carbon nanotubes use third order nonlinearity available it uses in space laser in satellite the very fast velocity of satellite and larger distance communication , Gas discharge in telecommunication networks, energy storage, nanoprobes and sensors. It can be great potentials towards the nano - scale photonic devices which can be utilized for optical filtering or nanofiltering, waveguide, switching, and wavelength multiplexing a new next generation electronic technologies.

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