

Chirality Engineering of Carbon Nanotubes, Modeling and Photons Density Improvement for Solar cell Applications

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Abstract

Carbon nanotubes and fullerenes offer exceptional mechanical and electrical qualities due to their cylindrical and hollow spherical molecular structures. Their extensive range of applications, which includes field emission displays, impregnated metal composites, battery storage media, and nanoelectronics devices, demonstrates their exceptional adaptability. The combination of simple materials, variable behavior, and simplicity of manufacture makes these materials a focal point of contemporary research. Due to the low bias transmission at a few nanometers, they have a wide range of applications in electronic devices, and finding their potential applications is a complicated process. Due to the fact that the valence and conduction bands are symmetric, they have a straight band gap and can be exploited for optical emission. Three processes, including arc discharge, laser ablation, and chemical vapor deposition, can be used to generate carbon nanotubes (CNTs), although chemical vapor deposition (CVD) is the most used method since it yields CNTs that are more than 98% pure. Multiple chirality of 100% pure MWCNTs results in enhanced optical properties and improved use as a light harvesting material. Using CNT composites and functionalized nanotubes, the dye-sensitized solar cells are constructed. In this brief review, the synthesis of CNT and its application in solar cells are discussed.

Keywords: Carbon nanotubes, conduction, laser ablation, band gap, chemical vapor deposition.

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I. INTRODUCTION

Sumio Iijima discovered carbon nanotubes (CNTs) in 1991; its applications in nanoscience and nanotechnology seem promising [1]. It possesses a high surface-to-volume ratio and a particular carbon atomic configuration. Multiple chiral carbon nanotubes are utilized in the construction of solar cells [2]. Chirality will boost the absorption capacity of CNTs so that the semiconducting nanotube produces the most photocurrent, expanding the solar spectrum's border region. Due to its outstanding and highly desirable thermal, electrical, and mechanical properties, Carbon Nanotubes (CNTs) have attracted a great deal of attention [3]. CNTs combined with other nanomaterials or functionalized with various acidic groups are utilized as gas sensors or biosensors and can also be functionalized for the production of dye-sensitized solar cells [4].

Carbon nanotubes (CNTs) belong to the fullerene family of carbon allotropes [3], which are characterized by cage-like structures formed by the interconnected atoms of the material. Curvy fullerenes are made up of interconnected hexagonal and pentagonal rings in graphene sheets. As a carbon allotrope, graphene consists of a single sheet of hexagonal carbon atoms arranged in two dimensions. It is a semi-metal because its valence and conduction bands coincide, resulting in a bandgap of zero. CNTs are versatile because to their innovative and valuable traits, which include low cost, light weight, high aspect ratios and surface area, distinct optical characteristics, excellent thermal and electrical conductivity, and high mechanical strength that can be reflected in the Potential Impacts of Wireless Power Transfer on the Global Economy, Society, and Environment, threshold Voltage Modeling of Carbon Nanotube Field-Effect Transistor (CNTFET) and analyzing the Operational Parameters of a Single Walled

Carbon Nanotube Field Effect Transistor (SWCNT-FET) [38-42].

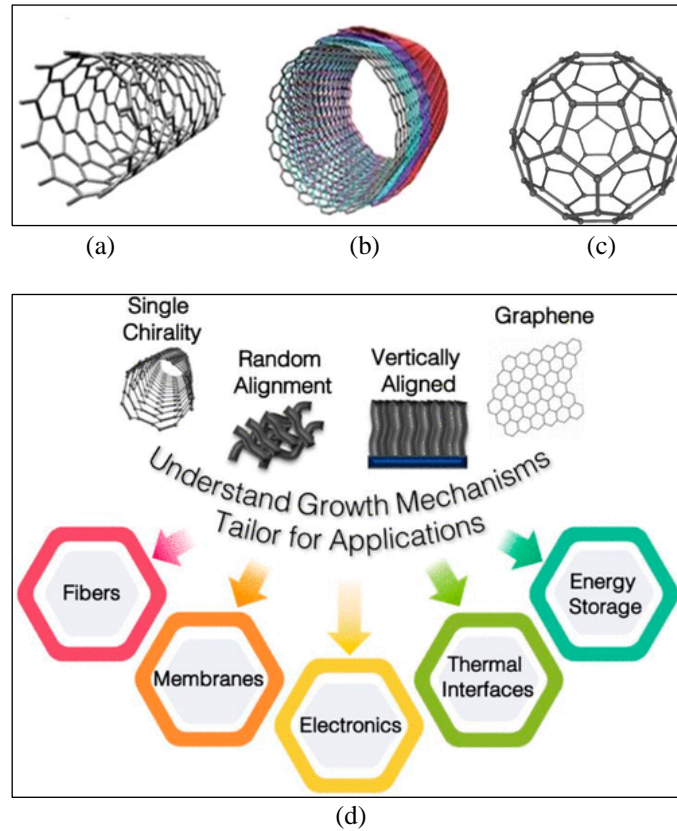


Fig. 1. Idealize Unterminated representation of SWNTs. (a) a metallic conducting armchair tube (10/10), (b) a chiral semiconductor armchair tube (12,7), and (c) a conducting zig-zag tube (15,0). An armchair and zig-zag tubes are both achiral. [3] (d) Carbon nanotubes applications [7]

Numerous approaches have been used to synthesis CNTs, however CVD is the most effective technique for synthesizing nanotubes under controlled conditions [3]. As in the arc discharge technique, catalysts such as nickel and cobalt result in the formation of single-walled carbon nanotubes (SWNT), but the

absence of catalysts results in the formation of multi-walled nanotubes (MWNT) [4]. In the case of CVD, the flow of carrier gases, the temperature, and the composition of the evaporating materials govern the length and diameter [5-7].

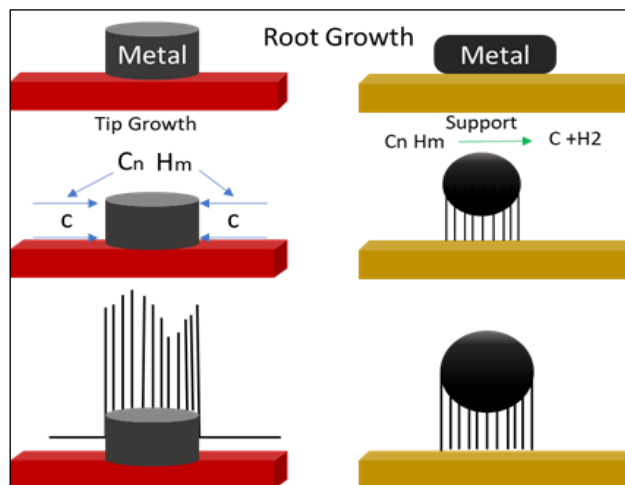


Fig. 2. Growth Mechanism of Carbon Nanotubes

II. PROPERTIES OF CARBON NANOTUBES

Carbon nanotubes are cylindrical structures created by wrapping graphene sheets along the axial direction. CNTs can be classed as single walled nanotubes (SWNT) or multi walled nanotubes (MWNT) based on the rolled graphene sheet [6]. The rolling vector (chiral vector) determines the nanotube's structure, which may be zigzag, armchair, or chiral. The physical, chemical and optical properties of carbon nanotubes are controlled by the synthesis process [5].

Electrical Properties

Graphene's band structure makes it easy to comprehend the electrical properties of carbon nanotubes [8]. By examining the band structure using the zone folding approximation, we determined that the Brillouin zone's permitted k-points are restricted to parallel lines [9]. The band structure of graphene can be used to determine the model of nanotubes and their electronic energies along the permitted lines, as depicted in Fig. 5, exhibit the band structures of graphene, p-type, and n-type nanotubes, respectively.

The (n, m) pair of numbers specifies the length and direction of these lines. Nevertheless, this

approximation also gives us many helpful data regarding the electrical properties of carbon nanotubes, and a small change in the parameters can change CNTs from a metallic to a semi-conductive state [7-9].

Each graphite structure is composed of carbon, which possesses two 1s electrons, one 2p electron, and three sp² electrons [10]. The three sp² electrons form three bonds in the band at the sheet plane of graphene, leaving an unsaturated p-orbital. This p-orbital, which is perpendicular to the graphene and therefore the nanotube surface, generates a delocalized p-network across the nanotube that is responsible for its electrical characteristic [10-11]. The behavior of armchair CNTs should be metallic, with band degeneracy between the highest p valance band and the lowest p conduction band. The point at which these bands meet is known as the Fermi level, and a new type of CNT, namely metallic nanotubes, is generated. The ballistic conduction of metallic CNTs is the least responsive to gate voltage [13]. Small band gap semiconducting nanotubes are beneficial for transistor and sensor applications as shown in Fig. 5.

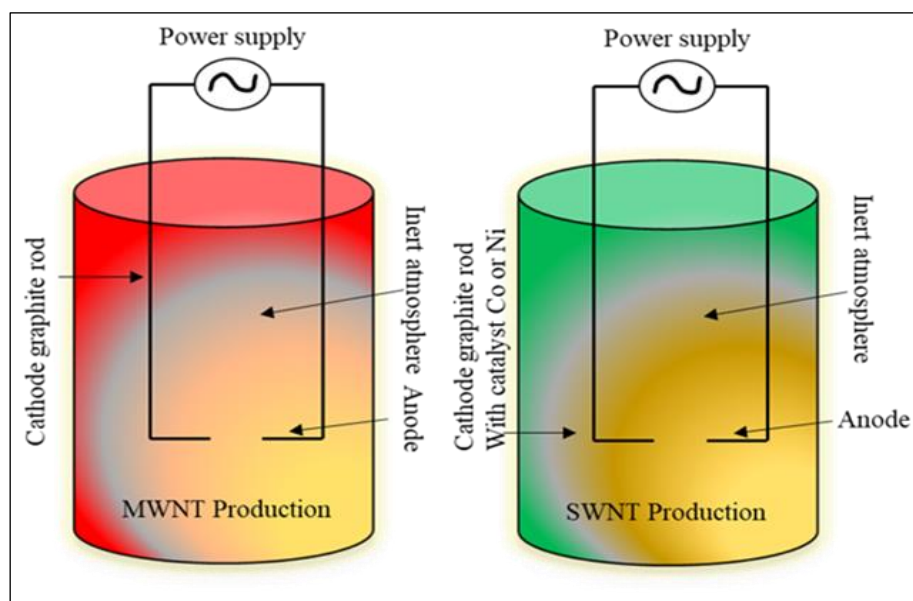


Fig. 3: MWCNT and SWCNT production by using Arc discharge method

Chemical Properties

The pyram-idealization angle H_p of nanotubes is zero because of their sp² hybridization bonds, as predicted by the band structure. According to research by Hamon *et al.*, and Niyogi *et al.*, [12], the angle of pyramidalization of a carbon atom is not zero but rather 11.60, which is near to tetrahedral. However, the nanotube's tubular shape generates strain since the angle of pyramidalization of the sidewalls is only 60. In a nanotube, the strain is caused by a p-orbital mismatch [13]. High reactivity is seen at the end cap [11] due to its high pyramidalization angle, whereas low reactivity is

found at the side walls [14] because of their low pyramidalization angle.

Nanotube defects can be introduced into the synthesis process by the existence of stone wall-like structural defect [14], which creates sp² character on the hexagonal network of tubular nanostructures. When nanotubes are flawed, their reactivity is increased, leading to higher gas adsorption and, in turn, a faster rate of functionalization [15].

III. FUNCTIONALIZATION OF CNTS

Despite their inert surface property, CNTs are typically insoluble in solvent due to the strong Vander Wall contact that bundles them together. Increasing the solubility through a process known as functionalization is useful for a wide variety of other uses [12]. We can classify functionalization strategies into two broad categories:

Inner Functionalization of CNTs/ Endohedral

This is accomplished by utilizing the scenario in which nanotubes are filled with colloidal suspensions or by allowing for spontaneous penetration of nanoparticles of diverse materials [15]. When the nanotubes are filled with certain compounds, the compounds will react at a specific temperature and pressure after a number of conditions, resulting in nanoparticles which are confined inside the nanotube

[16]. This process is followed by the capillary action of the tubes.

Outside Chemical Functionalization of CNTs / Hexahedral

Attachment mechanisms for the various groups or chemicals to the nanotube wall allow for further categorization of this category into three subgroups:

- The nanotubes are encased within the polymer during the non-covalent hexahedral functionalization procedure [16].
- Covalent functionalization in which the functionalization group is connected to the faulty side or tube end [17].
- Sidewall functionalization as a method of covalent functionalization [15].

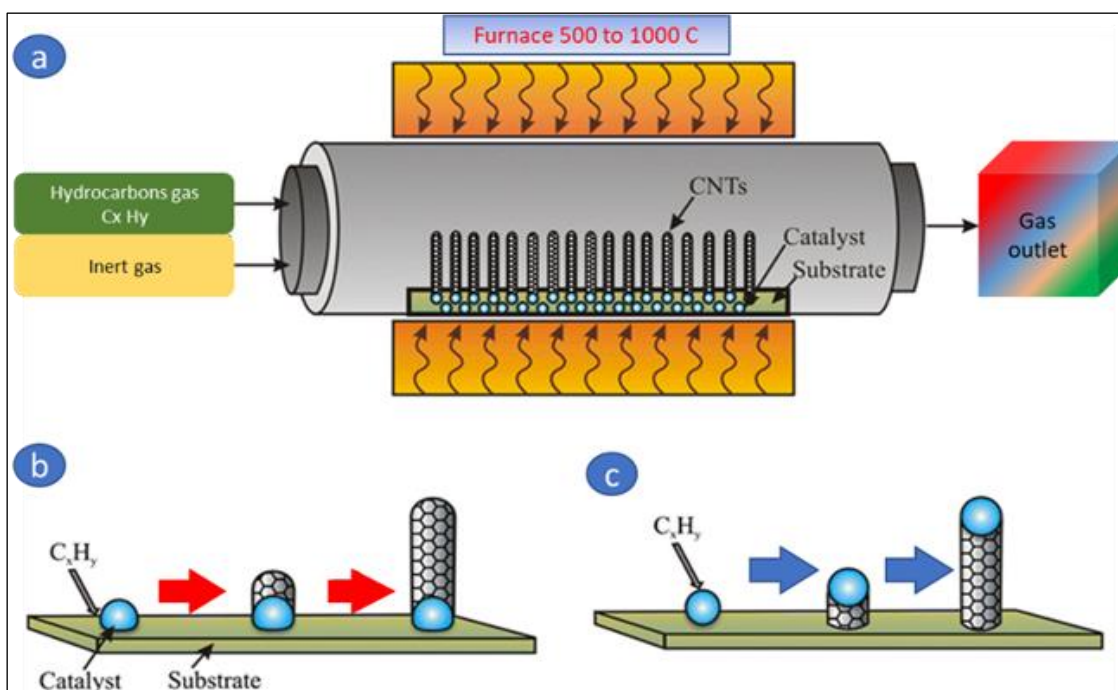


Fig 4. CVD reaction chamber

Table 4 outlines the numerous techniques for functionalizing nanotubes and their applicability in a variety of fields, along with their respective advantages and limitations. The optimal sidewall functionalization for solar cells involves cycle and nucleophilic addition radical reactions [15].

IV. SYNTHESIS OF CARBON NANOTUBES

Carbon nanotubes are manufactured by three basic techniques; arc discharge, laser ablation and chemical vapor deposition. Growth of CNTs by arc discharge and laser involve the addition of carbon dimers (C_2) to the CNT edges. Sometimes CNTs are also generated via flame synthesis using camphor or mesh like structure [18]. In the arc discharge technique the atmosphere of inert gas or some carbon-containing gas

(inert gas) is generated by an arc discharge between two carbon electrodes [19] with or without catalyst. In the laser ablation process, a high intensity laser beam impinges on a volume of carbon containing feedstock gas. Laser ablation generates a limited amount of pure nanotubes, but the arc discharge approach often generates a substantial amount of impure CNTs. CVD results in MWNTs or poor grade SWNTs [19]. CVD produces SWNTs with a wide range of diameters.

Mechanisms Of CNT's Growth

1) Reaction Mechanism

Hydrocarbon molecules can be broken down on the free Ni, Co metal surface to generate carbon atoms while simultaneously evolving molecular hydrogen, a process that can lead to the formation of carbon

nanotubes [20]. The growth of carbon nanotubes and nanofibers is based on the magnetometry breakdown of a supported Ni crystal using methane. Since, high

electrons as carriers are generated at high temperatures, the nucleation point for nanotube growth is created.

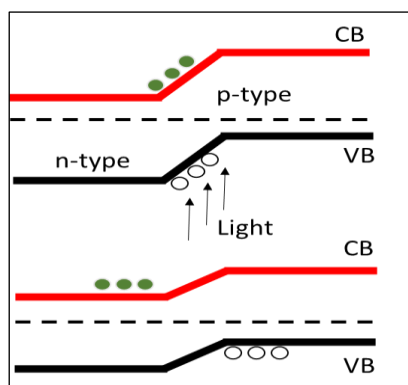


Fig. 5. Band Variation of CNT Based Solar Cell

Carbon atoms are separated from methane gas and deposited on the surface of dissolved Ni particles to generate sub-stoichiometric nickel carbide. This carbide phase then decomposes into metallic nickel particles surrounded by graphite layers. The metal particle is then expelled by a significant pressure increase caused by the creation of a graphite layer on the envelope's inner surface. This is feasible due to the metal's liquid-like property as a result of the dissolution of carbon atoms that remained in the bulk; the fresh surface of the squeezed-out Ni particle will further breakdown methane and continue the formation of carbon nanotubes.

2) Growth Mechanism

The formation of nanotubes begins with the evaporation of gas from the source of carbon; gases are evaporated off a surface by laser pulses, arcs, or solar radioactive fluxes. Each approach has a number of shared characteristics and diverse hypothesized mechanisms for the creation of SWNT.

Such a process consists of three steps: first, the production of a precursor composed of nanoparticles of metal that serve as the nucleation point at high temperatures; second, the dissociation of gas; and third, the formation of a solid. Later, carbon atoms are deposited on the nucleation spot, and development begins in two ways: for root growth, the catalyst is positioned at the bottom of the tubes, and for tip growth, it is placed at the top of the tubes as shown in Fig. 1. Decompose methane and sustain the development of carbon nanotubes [15-20].

Types Of Synthesis of CNTs

1) Arc Discharge Method

In this process, carbon vapor is produced in an inert atmosphere by an arc discharge between two carbon electrodes [8] with or without a catalyst. The arc discharge method, which was initially used to make C_{60} fullerenes [19], is the most prevalent and simplest method for manufacturing carbon nanotubes. However, these methods result in a mixture of components and necessitate the separation of nanotubes.

Table 1: Arc Discharge Production of Carbon Nanotubes Under Different Circumstances

Arc Discharge Method	Conditions	Product	Product properties	Reference
Arc Discharge	Ar atmosphere with KCl/FeS catalyst Packs containing several nanotubes Graphite electrode in hydrogen gas environment	DWCNT (double walled carbon nanotube)	Sizeable at 4-7 nm in both dimensions.	[11]
	An FeS and CoS catalyst was employed in a hydrogen environment.		Large and high quality, diameter 1-3 nm	[12]
	Composition of Co, Ni, and Fe in the presence of a trace amount of S in an Ar environment as a catalyst.		Bundel of high quality CNT	[15]
Plasma Rotating Arc Discharge	Hydrogen atmosphere with pure graphene electrode	CNT	Large scale production	[16]
Liquide Arc Discharge	Deionized water NaCl with liquid atmosphere	MWCNT CNTs capsules	Metal filled inside the tubes High purity	[17]

From the soot and catalytic metals present in the basic product [20].

Arc-vaporization between two carbon rods [21] at a distance of about 1 mm creates nanotubes in a chamber typically filled with inert gas (helium/argon) at low pressure (between 50 and 700 mbar). Recent studies have discovered that liquid nitrogen, deionized water, and NaCl solution can all be used to create carbon nanotubes. High temperature discharge of 2000-3000 C is produced between the electrodes by a direct current of 50-100 A driven by *20 V. The discharge evaporates from one carbon rod and deposits on the second carbon rod. The yield of nanotubes is dependent on the regularity of the plasma arc and the temperature of the carbon electrode's deposit form. Table 1 details the synthesis of CNTs by the discharge method under various conditions [13-19].

The preceding table illustrates how nanotubes were produced by modifying the arc discharge chamber's surroundings and the electrode material. Under a helium environment, Y/N₂ and CaC₂ were utilized for high yield and purity of CNTs, fullerenes, etc. Utilizing the deionized water in liquid arc discharge approach, carbon onions, MWNTs, and CNTs were produced [22].

Nanotubes produced by this method are typically short in length, with diameters ranging from 0.6 to 1.4 nm for single-walled nanotubes and 10 to 14 nm for multi-walled nanotubes. Depending on whether or not the catalyst is contained in a rod, these tubes may have a single wall or several walls. This strategy is simple to adopt and has a 35% success rate. In

comparison to other methods, the nanotubes produced by this procedure have a high impurity level and numerous flaws, and the single walled nanotubes and multi walled nanotubes formed by this approach are determined by the synthesis process, which is followed by the doping of Ni/Co in the anode, which produces the SWNT, and the usage of pure graphite rod without doping, which produces the MWNT shown in Fig. 2. Their lengths are fairly unpredictable.

2) Laser Ablation Method

Laser ablation is often performed in a tube furnace at temperatures between 700 and 1500 K, where a block of graphite is heated along with catalytic metals like Ni, Co, Pt, etc. After aiming a high-powered laser at the graphite cube, argon (Ar) gas is injected in that laser's direction. Carbon nanotubes are produced during laser ablation and are transported by the gas flow into a cooled copper collector.

The method for the development of nanotubes is identical to that of the arc discharge, in which the laser will pierce the target material and carbon vapor will be produced inside the chamber, which will then grow on the cooled copper collector. This procedure may not be simple to conduct, but a high-temperature furnace is necessary for yields of up to 70% [23].

The table 2. below outlines the various lasers, target materials, and environmental conditions used to create nanotubes. Ablation is a phenomenon that results in CNTs of varying diameters and lengths, and it is directly related to the power and intensity of the laser source [24].

Table 2: Laser ablation method with different mechanisms to synthesize the CNTs

Laser Ablation Method	Conditions	Product	Properties	References
KrF excimer	Composite of C/Co, C/Co/Ni in atmosphere O ₂ Ar at room temp	MWCNT, Nano onions	Pure and easy to synthesize	[12]
XeCl excimer	1100 – 1400 °C using catalyst C, Co, Ni in Ar atmosphere	SWCNT bundles Fullerenes	Large and high quality Diameter of 2-6 nm	[17]
O ₂ continuous wave	Laser power 400-950 W At room temperature	Bamboo like structures of SWCNT bundles	Metal filled inside the tubes. Purity is high and diameter is 1-3 nm.	

Table 3: Synthesis of Carbon Nanotube by Chemical Vapor with different gases on various types of substrates

Precursor	Temperature	Flow rate	Gas used in medium	Advantages	Disadvantage	Reference
Si/SiO ₂	750 0C	40 sccm for Ar and 150 sccm	Arg ass and ethylene with H ₂ O vapors	Self cleaning process is done by water vapors and ultra tall vertical bundle of CNTs found.	Defects may be created in tubes sometimes	[11]
Si wafer + Mueller catalyst	940-980 0C	4 sccm for H ₂ and 2 sccm for CH ₄	CH ₄ with H ₂	Low pressure Ultra long CNTs obtained	High temperature required for growth	[27]
Si/SiO ₂ with Fe	900 0C	1000 sccm for gases	CO and H ₂	Good growth Efficient production due to high temperature	Hazardes due to CO Impure CNTs	[29]

Synthesis through Chemical Vapor Deposition (CVD) Method

The substrate is heated to the growth temperature while exposed to one or more volatile precursors in a quartz tube during a conventional CVD process.

Gas containing carbon is being pushed through a quartz tube at a constant pace and temperature. The wafer is then tested for nanotube growth as the furnace is gradually cooled following the growth mechanism [24].

The lowest growth is obtained at 650 C using CO₂, although the gas emitted in this case is quite poisonous, as shown in Table 3 which details the synthesis of CNTs using different substrates in CVD chamber by the change of temperature and carbon containing gases. Since methane gas is readily hydrolysable, it can be employed in this synthesis without fear of the release of harmful gases. These methods were initially applied to the growth of single-walled nanotubes on a silicon substrate [25]. Similarly, the CVD method [23] has been well-liked for the generation of pure SWNT shown in Fig. 4.

Carbon monoxide (CO) [21], methane (CH₄), ethylene (C₂H₄) [23], acetylene (C₂H₂), benzene (C₆H₆), toluene (C₇H₈), ethanol (C₂H₅OH) [26], and methanol (C₂H₆O) are all examples of carbon-containing molecules that have been utilized as precursors (CH₃OH) during our research [7-23].

The varied temperatures at which the various gases breakdown promote nanotube growth. The yield of nanotubes can be increased by increasing the pressure, which controls the rate of dissociation of gases like carbon monoxide. Nanotube size can vary depending on the flow rate, with bigger nanotubes sometimes forming at lower flow rates. Premixed gas in the cylinder can also form undesirable nanotubes when employed as a carbon precursor; thus, a gas filter or cleaning gas is occasionally used in the CVD chamber to produce properly aligned or well-regulated nanotubes [25-30].

V. CNTS IN SOLAR CELL

Presently, fossil fuels supply the majority of the world's energy, but they also produce extremely toxic and poisonous chemicals, such as carbon monoxide, which contaminate the environment every second. In order to produce clean energy, we utilize solar energy,

which is environmentally benign and does not upset the economic equilibrium. For increasing the use of solar energy, it is possible to manufacture solar cells that convert solar energy into electrical energy, which can then be stored in batteries through charging [25]. The operation of a solar cell is dependent on the following variables:

- Light absorption to generate electron-hole pairs.
- Transport of charge carriers.
- Electron and hole segregation.
- The collection of free carriers.

Working Mechanism of Solar Cell

The operation of solar cells is based on the transition of free electrons gaining additional energy when photons strike the surface of the film. Now, after evaluating the band structure of the solar cell, Bu Jong *et al.*, have determined that the cell gains energy from photons and generates free electrons, which recombine and generate some photovoltaic current, indicating that the maximum number of electrons is generated. In order to increase the efficiency of solar cells, a technology based on thin films that absorbs a great amount of light across a broader range of the solar spectrum is employed. The solar cell theory is defined as follows:

Semiconducting materials, such as silicon and germanium, absorb photons from the sun that strike the solar panel. Negatively charged electrons are ejected from their existing molecular/atomic orbitals. Once excited, an electron can either return to its orbital state or move through the cell until it hits an electrode. Current begins to flow through the substance in order to neutralize the potential, and the resulting electricity is caught. Due to the unique composition of solar cells, electrons are restricted to a single direction of motion. A collection of solar cells transforms solar energy into direct current (DC) power [6].

Contribution of this work

Analyzing these solar cells revealed that their efficiency had increased somewhat. As illustrated in Figure 5, hetero-junctions were constructed between silica and SWNT using carbon nanotubes as a p-type semiconductor and silica as an n-type semiconductor to increase the efficiency of solar cells further[4]. Based on Fig. 5, we conclude that CNTs operate as p-type semiconductors and silica-based materials act as n-type

Table 4: Functionalization of CNTs by using various methods

Functionalization	Mechanism	Applications	References
Hexahedral/ Covalent/ Sidewall, Functionalization	Nucleophilic addition radical reaction	LED Bulbs Transistors Solar cells Chemical sensors	[30]
Endohedral functionalization	Wet chemistry	Hydrogen storage materials Drug supplier	[29]

semiconductors, so the transition of electrons and holes begins when a hetero-junction is formed, and a particular band-gap is established between them[6]. After light emerges on such a cell, the holes gather energy and transmit electrons from silica to CNT, so producing photovoltaic current that is stored in the battery. After examining SWNT, it was discovered that replacing SWNT with poly chiral MWNT increased the absorption power. In comparison to all previous solar cells, the MWNT solar cell absorbed a broad frequency spectrum [4].

Solar cells constructed by thin film

Thin film technology minimizes the amount of material needed to create solar cells, and the majority of thin film-based solar cells are produced by sandwiching thin film between two panes of glass to create a module [4,6].

Comparing the unit costs of fossil fuel combustion versus silicon solar cells for electricity generation revealed a significant disparity. The primary constituent of these cells is a thin layer of substance. Compared to silicon wafers, only 1% of material is necessary for the fabrication of these solar cells. This is the primary reason why this technology is somewhat less

expensive. The majority of these cells are composed of amorphous silicon, which lacks a crystalline structure. These are significantly less expensive fabricators, but their efficiency is only about 8% [6-18].

Nanomaterial incorporation into thin-film solar cells increases conversion efficiency at a reduced cost. Numerous nanomaterials are now under investigation for photovoltaic applications. The three benefits of utilizing nano-structured layers in thin-film solar cells are as (a) Due to repeated reflections, the effective optical absorption route grows longer than the actual film thickness, (b) The shorter path followed by light-generated electrons and holes results in a reduction in recombination losses. In conventional thin-film solar cells, the absorber layer thickness is measured in μm , however in nano-structured solar cells, it can be as thin as 150 nm. (c) Nanoparticles of varying sizes are utilized to provide the appropriate design value for the energy band gap of many layers. This gives for greater design flexibility in solar cell absorber and window layers. 'Al' and 'W' are utilized as dopants to improve photovoltaic characteristics. Al-doped titanium dioxide and electrodes increase open-circuit voltage (V_{oc}) while decreasing short circuit current (I_{sc}) [32].

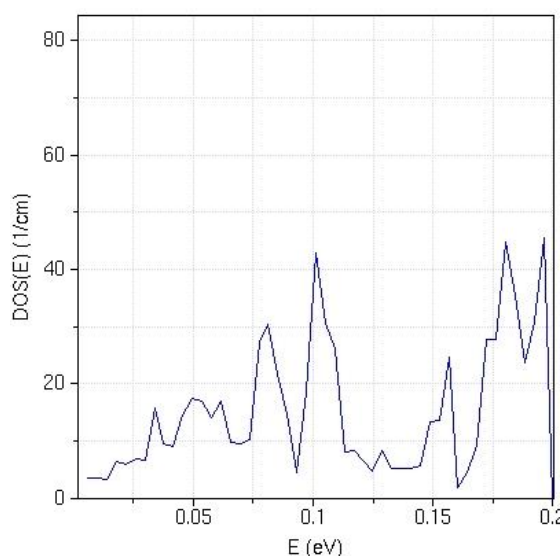


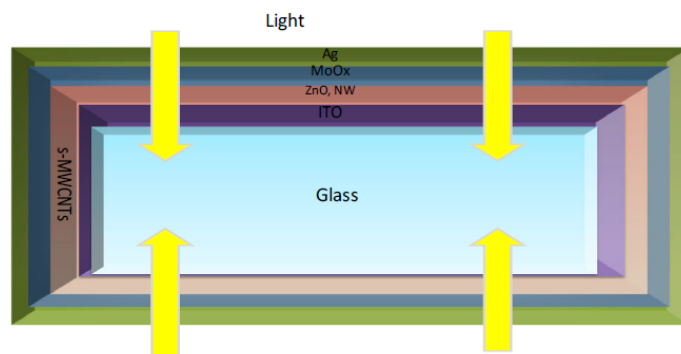
Fig. 5.1. Density of the photons by changing E value by proposed work

Table 5 displays the effectiveness of several solar cell production procedures, together with their merits and downsides. Unlike most three-dimensional substances, graphene has unique properties. A zero-gap semiconductor or a semi-metal, graphene has this property because of its intrinsic nature. Its high conductivity can be attributed to its high electron mobility, which is about twice as high as that of Si. Also, because it creates a straight band gap, it can absorb more light in a smaller area than indirect band gap semiconductors like silicon. Since graphene has unique optical properties, it can be used to create transparent

electrodes and bridge the gap between the two solar cell halves in tandem solar panels. Condensed six-member rings form a carbon sheet just one atom thick. The hexagonal 2D lattice formed by the sp^2 linked carbon atoms. Carriers in perfect graphene move at a rate of around $10^5 \text{ cm}^2/(\text{V}\cdot\text{s})$ at ambient temperature. This suggests that graphene can be utilized as a replacement for Silicon in nano-electronics, as its carrier mobility is one to two orders of magnitude higher than that of Silicon. Not only does it have remarkable electrical qualities, but also very great mechanical durability.

Table V: Construction of CNTs by using different materials

Types of material	Deposition technique	Efficiency approximately	Reference
CdTe	Evaporation	21%	
CZTS/SE	PVD, Sputtering	28%	[9]
CNT	CVD/Electroplating by chirality.	46.5%	[over present work]

**Fig. 6. CNTs Fabrication process in solar cell**

Bandgap tuning is another feature of graphene. That we did by using our model and changed the absorbing ability of the Carbon nanotubes [4].

Graphite is the name given to 3D graphene. It has the highest strength to thickness ratio of any material known, is completely transparent, and is an excellent conductor of electricity. It can be shown that adding carbon nanotubes into a solar cell boosts the efficiency of the cell by changing the chirality. [33,37] Using Carbon nanotubes (CNTs), Bujong *et al.*, created a novel solar cell that is twice as efficient as the previous one at converting sunlight into electricity. Other carbon nanomaterials, such as fullerene and graphene, can also be utilized in the manufacturing of solar cells due to their enhanced photovoltaic characteristics. R.G. Shrestha *et al.*, [32] fabricated one dimensional (1D) single-crystalline fullerene C60 nanorods at ambient temperature utilizing the ultrarapid interfacial creation approach. The nanorods had a hexagonal close-packed crystal structure and measured 11 μm in length and 215 nm in width.

The optical transitions revealed a predominance of charge transfer excitonic transitions with exceptional charge transfer properties. L.K. Shrestha *et al.*, [33] described the surfactant-triggered assembly of fullerene (C60) into 3D flower-like microcrystals at the liquid-liquid interface following crystal development by liquid-liquid interfacial precipitation (LLIP). These microcrystals offer greater potential for use in solar cell-based optoelectronic systems in the future (Fig. 6). In a separate study [34], he created microporous and mesoporous fullerene crystals with bimodal pore topologies using the same (LLIP) approach that can be utilized to fabricate nanodevices, such as organic solar cells as shown in Fig. 6[15].

Consequently, graphene is a promising candidate for use as an electrode material in transparent solar cells as well as in dampers too [35]. A flash of CB, VB, CB n-type p-type Fig. 5, Band structure shifts in a CNT-based solar cell as a function of temperature that is proved in [4,6,15,17].

The principle of operation of solar cells is based on their ability to absorb photons from sunlight and convert them into electron-hole pairs, and thin-film photovoltaic materials are superior to conventional solar-cell materials (such as silicon) due to their lightweight, flexible, and inexpensive fabrication (or excitons). For electricity to flow, an electron and hole must be quickly separated before they can recombine and be reabsorbed by the substance. For optimal light absorption, solar cells require that the exciton swiftly go to a different layer in the device (where the charge separation will occur) [17]. Because of their high absorption of light from the visible to the near-infrared spectrum and their fast-moving charge carriers (electrons and holes), single-walled carbon nanotubes (SWCNTs) are a promising candidate for use in thin-film photovoltaics. While most thin-film cells unfortunately, power-conversion efficiency in devices using SWCNTs have been low so far [33-37].

VI. CONCLUSION

A systematic advancement of carbon nanotubes in terms of production, functionalization, and solar cell application has been studied. Compared to mono-chiral nanotubes, poly-chiral nanotubes absorb a greater range of the solar spectrum and are used in thin-film solar cells. Additionally, solar cells constructed on poly-chiral nanotubes have a very high efficiency. Future research will focus on the development of novel approaches to increase the efficiency of solar cells by examining the chirality and potential composite possibilities for absorption in various spectral bands.

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