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Recent Advances In Carbon Nanotubes Based Enzymatic Electrochemical Glucose Biosensors

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ABSTRACT

Biosensors can be defined as devices with a thin layer that acts as a support to immobilized biomolecule that contains bio recognition sites.Enzyme-based electrochemical biosensors have been used widely in health care, food safety and environmental monitoring. Carbon nanotubes (CNTs) are one of the most common materials used because of their unique electronic, chemical, and mechanical properties.CNTs is one of suitable candidate for fabrication of electrochemical biosensors because of their unique strength and remarkable physical & chemical properties,high electrical and thermal conductivity, high mechanical strength, high specific surface area, unique tubular nanostructure with unusually large length to diameter ratios, which may be as high as 132,000,000:1.CNTs are also associated with excellent conductivity, high sensitivity, good biocompatibility and outstanding chemical stability. The features of enhanced electrochemical reactivity of hydrogen peroxide and NADH, and easy detection ofbiomolecules (viz. cells, enzymes and other small molecules) also makes CNTs a preferable nanomaterialfor fabricating biosensors. This review has revealed about the recent advances in the application of CNT for electrochemical bio sensing applications.

KEYWORDS: Carbon Nanotubes (CNTS), Enzyme Biosensors, Glucose Sensors, Glucose oxidase.

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1. INTRODUCTION

Nano biosensors is of critical importance only in medical applications, such as glucose monitoring in diabetics, in environmental monitoring, water remediation, molecular imaging, gas sensing, and other applications. Diabetes is a group of metabolic diseases affecting about 150 million people worldwide, and is one of the leading causes of death and disability, such as blindness, nerve degeneration and kidney failure. The diagnosis and management of diabetic patients require precise monitoring and control of the glucose level in the body. Therefore, frequent testing of the physiological glucose level is critical to confirm treatment efficiency, prevent complications such as hypoglycaemia.This review focuses on the use of carbon nano materials in biosensors. Nanotubes are should be considered as a new material with unique physicochemical properties showing good promise for a wide range of applications. Carbon might be the most widely-used material in electro catalysis and electro analysis for sensing. Carbon-based nanomaterials, especially CNTs and graphene, are extremely attractive material in the bio analytical area for electrode design as they can combine properties of the high surface area, acceptable biocompatibility, chemical and electrochemical stability and good electrical conductivity. Carbon nanotubes (CNT) can find applications in a great number of areas such as additives to polymers and catalysts, in auto electron emission for cathode rays of lighting components, flat displays, gas discharge tubes in telecommunication networks, absorption and screening of electromagnetic waves, energy conversion, lithium battery anodes, hydrogen storage, composite materials (fillers or coatings), nano probes, sensors, super capacitors etc. The great variety of the new unconventional mechanical, electrical and magnetic propertiesof nanotubes can become important in nano electronics.Finally, we outline the current trends and future applications of carbon nanomaterials in the sensor field.

2. BIOSENSOR

A biosensor is a sensing device that transfers a biological event to a measurable signal. It usually comprises of a biological recognition element and a transducer to translate the biological information to the measurable signal. To be specific, the biological recognition element in a biosensor must be selective to a certain biomolecule, biology process, or chemical reaction. Depending on the types of the recognition elements, the biosensors are able to detect a wide range of biological elements, such as nucleic acids, antibodies, enzymes, bacteria, and viruses . The biological recognition elements often are immobilized onto the surface of transducer with high bioactive for targeting. The attachment methods include adsorption, encapsulation, entrapment, covalent binding, and cross-linking .The interaction between the recognition element and the target will then be monitored and further converted to a measurable signal like current which is proportional to the amount of the target molecule. The electrochemical, optical, piezoelectric, and magnetic are the most

common transducing methods included. Among them, electrochemical, electrical, and optical techniques are very famous due to their fast response in detecting bio recognition elements

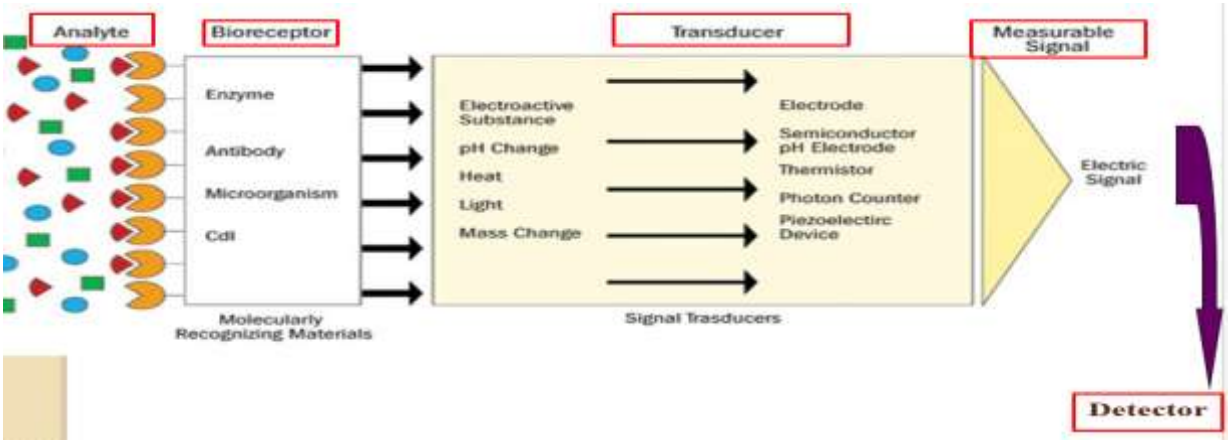

Figure 1: Components of biosensor

3. CARBON NANOTUBES

3.1. Structure of carbon nanotubes

CNTs belong to the fullerene family of carbon allotropes. They are cylindrical molecules consisting of a hexagonal arrangement of sp^2-hybridized carbon atoms (C-C distance of 1.4 Å).CNTs are classified into two types namely, singlewalledcarbon nanotubes (SWCNT) and multi-walled carbon nanotubes (MWCNT) as seen in Figure 2. Rolling a graphene sheet into a cylinder results in SWCNT, on the other hand arrangement of concentric graphene cylinders with an interlayer space of 0.34 nm leads to formation of MWCNTs. The properties of CNTs would vary based on their structure. SWCNTs may be zigzag, arm chair or chiral in their structure (Figure. 2).SWCNTs can be either metallic or semiconducting, a property determined by the atomic arrangement (chirality) and nanotube diameter . The roll-up vectors (n, m) of the cylinder describe the electrical properties of SWCNTs . Metallic SWCNTs have roll-up vectors like n-m=3q, while semiconducting SWCNTs have n-m ≠ 3q (here q is any integer/zero). If m=0, the nanotubes are called zigzag. If n=m, the nanotubes are called armchair and the rest are called chiral. Single-walled carbon nanotubes (SWCNTs) show excellent chemical stability, good mechanical strength and a range of electrical conductivity properties. MWCNTs show metallic electronic properties similar to metallic SWCNTs. Both types of CNTs contain one-dimensional structure and exhibit excellent properties viz. good electrical conductivity, strong adsorptive ability and excellent biocompatibility.

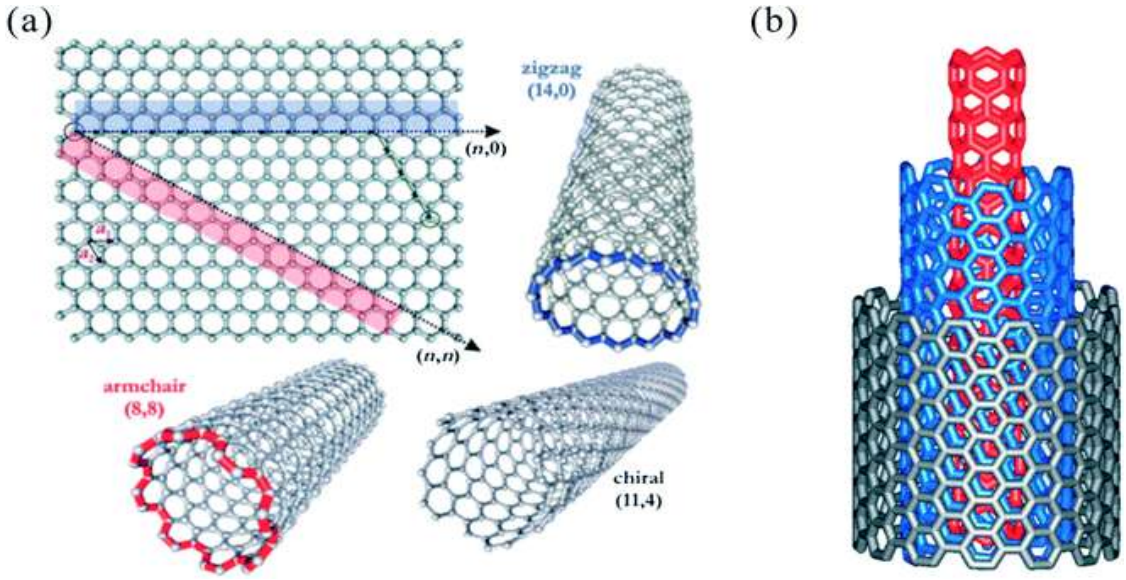

Figure. 2:Structure of (a) single walled carbon nanotubes (b) multi walled carbon nanotubes

3.1.2. Synthesis of carbon nanotubes

Carbon nanotubes are generally produced by three maintechniques, arc discharge, laser ablation and chemical vapor deposition. In arc discharge method, a vapor is created by an arc discharge between two carbon electrodes with or without catalyst.MWCNTs synthesis by the arc discharge technique is straightforward if two graphite electrodes are introduced, however, a great amount of side products, like fullerenes, amorphous carbon and graphite sheets, are simultaneously formed, which cause difficulty and increase cost as post-deposition purification is required. In the laser ablation technique, a high-powerlaser beam impinges on a volume of carbon containing feed stock gas (methane or carbon monoxide). At the moment, laser ablation produces a small amount of clean nanotubes, whereas arc discharge methods generallyproduce large quantities of impure material. In general, chemical vapor deposition (CVD) results in MWNTs orPoor quality SWNTs[12]. CVD synthesis is a better technique for high yield and high purity production of CNT arrays at moderate temperature. The CVD method was firstly used to produce MWCNTs, and involves the decomposition of gaseous carbon sources. Carbon has a low solubility in these metals at high temperature and CNTs with excellent alignment can be grown perpendicular to the substrate. There are two main types of CVD: thermal CVD and plasma enhanced CVD (PECVD). The carbon nanotubes growth by PECVD have also been studied using some new technologies, like hot filament assisted PECVD, microwave PECVD, dc glow discharge PECVD, inductively coupled plasma PECVD and RF PECVD. There are great concerns about the impurities in SWCNTs synthesized by the above methods. These impurities are typically removed by acid treatments. However, these acid treatments in turn can introduce other types of impurities, which degrade the nanotube length and perfection, and also increase nanotube costs.

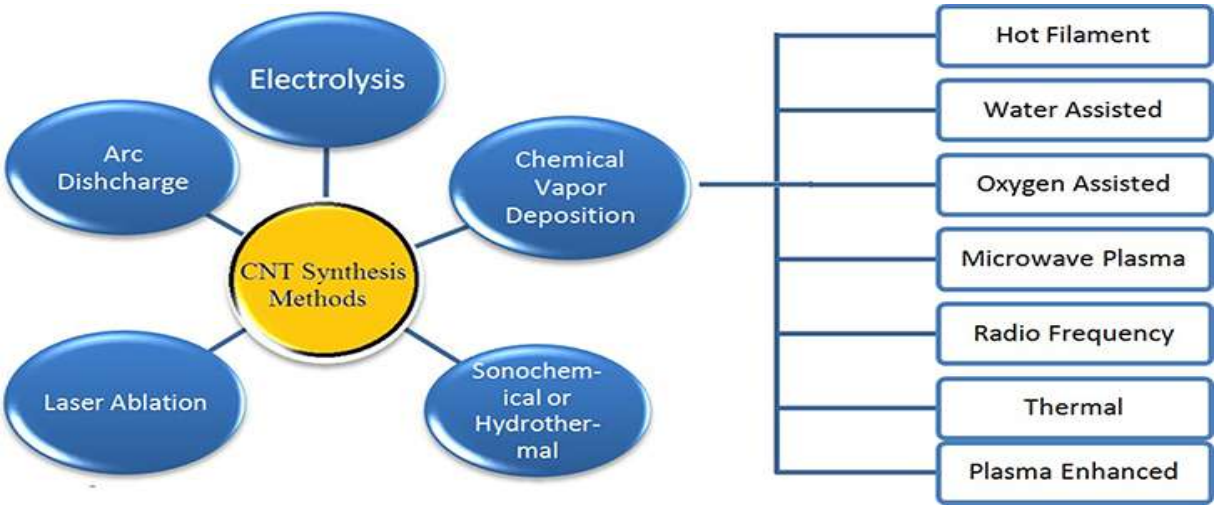

Figure 3: Methods of Synthesis of Carbon Nanotubes

3.1.3. Functionalization of carbon nanotubes (CNT_S)

Pristine CNTs are insoluble in aqueous solutions, polymer resins, and most solvents as they have hydrophobic surfaces. Functionalization is a process in which certain molecules or functional groups are physically or chemically attached to the smooth sidewalls of CNTs without downgrading their desirable properties. Functionalized CNTs are more easily dispersible in liquids, have better biocompatibility and low toxicity . Functionalization of CNTs can be done by covalent or non-covalent approaches. Covalent functionalization is done by forming bonds with nanotube sidewalls, whereas non covalent functionalization occurs through interaction between the hydrophobic domain of an amphiphilic molecule and the CNT surface. The functionalized CNTs can effectively cross biological barriers and penetrate individual cells . This feature andthe mechanism of internalization and release of CNTs from the cells are of major interest for bio sensing applications.

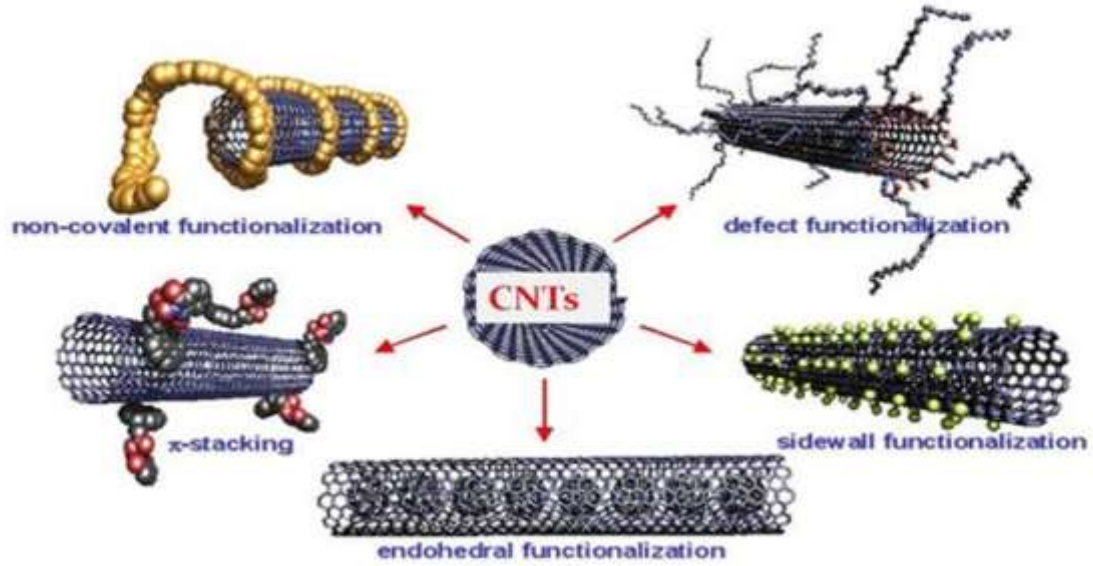

Figure 4: Methods of functionalization of carbon nanotubes

4. CNT-BASED ELECTROCHEMICAL BIOSENSORS

Electrochemical biosensor is a two- or three-electrodeselectrochemical cell, which can transfer a biological eventto electrochemical signal. They often contain a biological recognition element on the electrode which reacts with theanalyte and then produce electrochemical signal .CNT-based electrochemical biosensors play an importantrole in CNT-based biosensors because of their advantages such as high sensitivity, fast response, easy operation, and favorable portability. Based on the method of the recognition process, CNT-based electrochemical biosensors can be divided into bio catalytic sensors and bio affinity sensors. Bio catalytic sensors use the biological recognition element (e.g., enzyme) that can produce electro active species, while bioaffinity sensors monitor a binding event between the biological recognition element and the analyte [16].

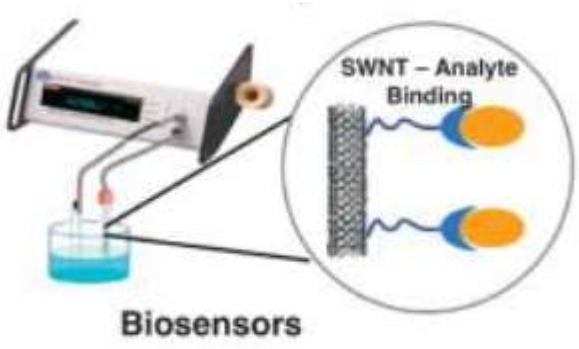

Figure. 5: Systemic Diagram of Biosensor

4.1. Enzymatic electrochemical biosensors based on carbon nanotubes

Electrochemical biosensors are popular due to their low-cost, relatively fast response times, ease of use, and small size. Enzymatic biosensors that combine electrochemical technology with specificity of enzyme have provided great opportunities for strategies in the early diagnosis. The direct electron transfer between the redox-active center of enzyme and the electrode without mediators is critical to the development of enzymatic biosensor. However, because the active centers of enzymes are surrounded by a thick protein layer and located deeply in hydrophobic cavity of molecules, the direct electrochemistry of enzyme is very difficult [17, 18]. Therefore, the use of an electrical connector is required to enhance the transportation of electrons. CNTs, with their small size, extraordinary electrochemical properties, and high specific surface area, have been widely used to promote electron transfer between the electrode and theredox center of enzyme. During the past few years, CNT-based enzymatic biosensor for the detection of clinically important analytes through the electrochemical reactions catalyzed by various enzymes such as glucose oxidase (GOx), horse radish peroxidase (HRP), lactate oxide, malate dehydrogenase (MDH) has been reported.

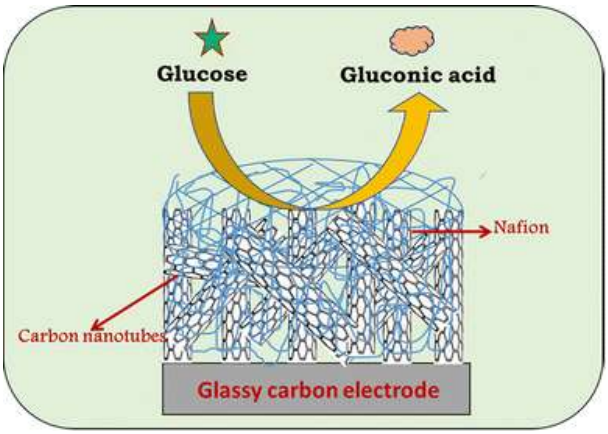

Figure 6: CNT-based enzymatic biosensor for the detection of glucose oxidase (GOx)

4.2. Adaptability of CNTs in the fabrication of biosensors

CNTs were used for fabrication of biosensors because of their superior strength and remarkable physical chemical properties, as a result of their unique tubular nanostructure with unusually large length to diameter ratios, which may be as high as 132,000,000:1 [19]. Further, CNTs are also associated with excellent conductivity, high sensitivity, good biocompatibility and outstanding chemical stability . Moreover, CNTs end and sidewalls can be easily modified by attaching almost any desired chemical species. CNTs due to their significant sensitivity can be excellent transducers in sensors. From the review it is known that CNTs can enhance the electrochemical reactivity of biomolecules, and mediate fast electron transfer kinetics for a wide range of electro activespecies . The features of enhanced electrochemical reactivity of hydrogen peroxide and NADH, and easy detection of biomolecules (viz. cells, enzymes and other small molecules) as shown in (see figure 7) make CNTs make a preferable nanomaterial for fabricating electrochemical biosensors.

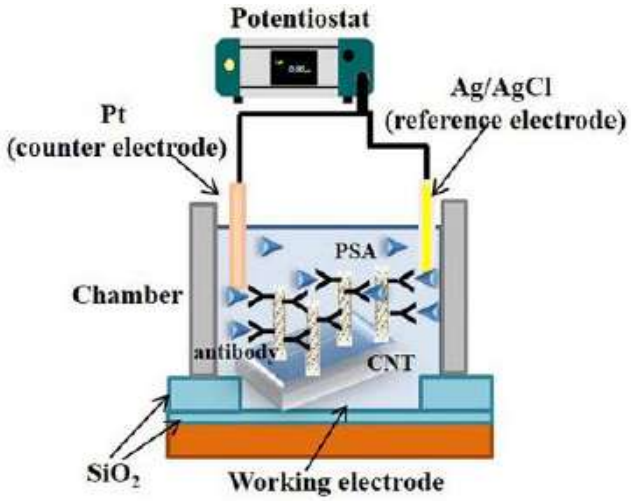

Figure 7: Enzymatic Electrochemical Biosensor for the detection of glucose oxidase (GOx)

4.3. Enzyme immobilization in carbon nanotubes based biosensors

Immobilization of enzymes is the process of confinement or localization of an enzyme to a certaindefined position (or support) with the retention of catalytic activities, leading to their repeateduse [22]. Sufficient enzyme loading and optimal activity is required quality for a good biosensor. There is a need to treat enzymes softly, as they may lose their activity upon harsh chemical treatment or exposure to high temperature. CNTs have small size and excellent electrochemical and electrical properties (approximately 100 times greater ability to conduct electricity than copper wires), CNTs are well suited for transduction of electric signals generated upon recognition of a target, and they plays an important role in development of enzyme-based biosensors .Immobilization of enzymes on the surface of CNTs provides a platform for fabricating biosensors utilizing their unique electronic and optical properties for signal transduction.In enzyme biosensor, electrons can directly transfer from the redox center of the enzyme to the underlying electrode. The importance of physical adsorption or covalent immobilization of large biomolecules onto the surface of immobilized CNTs may provide efficient way through which direct electrical communication between electrodes and the active site of redox-active enzymes can be introduced.

4.4. Role of glucose oxidase in biosensors

4.4.1. Glucose oxidase

The basic concept of the glucose biosensor is based on the fact that the immobilized GOx catalyzesthe oxidation of β-D-glucose by molecular oxygen producing gluconic acid and hydrogen peroxide . In order to work as a catalyst, GOx requires the redox cofactor flavin adenine dinucleotide (FAD). FAD works as the initial electron acceptor and is reduced to $FADH_2$.

$$\textbf{Glucose + GOx- FAD+ } \rightarrow \textbf{Glucolactone + GOx-FADH}_2$$

The cofactor is regenerated by reacting with oxygen, and forming hydrogen peroxide.

$$\textbf{GOx-FADH}_2\textbf{+ O}_2 \rightarrow \textbf{GOx-FAD+ H}_2\textbf{O}_2$$

Hydrogen peroxide is oxidized at a catalytic, classical platinum (Pt) anode. The electrode easily recognizes the number of electron transfers, and this electron flow is proportional to the number of glucose molecules present in blood .

$$\textbf{H}_2\textbf{O}_2 \rightarrow \textbf{2H+ + O}_2\textbf{+ 2e}^-$$

4.4.2. Glucose monitoring in enzyme biosensor

Three general strategies are employed for the electrochemical sensing of glucose: (i) by measuringoxygen consumption, (ii) by measuring the amount of hydrogen peroxide produced by the enzyme reaction or (iii) by using a diffusible or immobilized mediator to transfer the electrons from GOx to the electrode. The quantification of glucose can be achieved by electrochemical detection of the enzymatically liberated H_2O_2.

5. CYCLIC VOLTAMMETRIC BIOSENSORS FOR DETECTION OF GLUCOSE

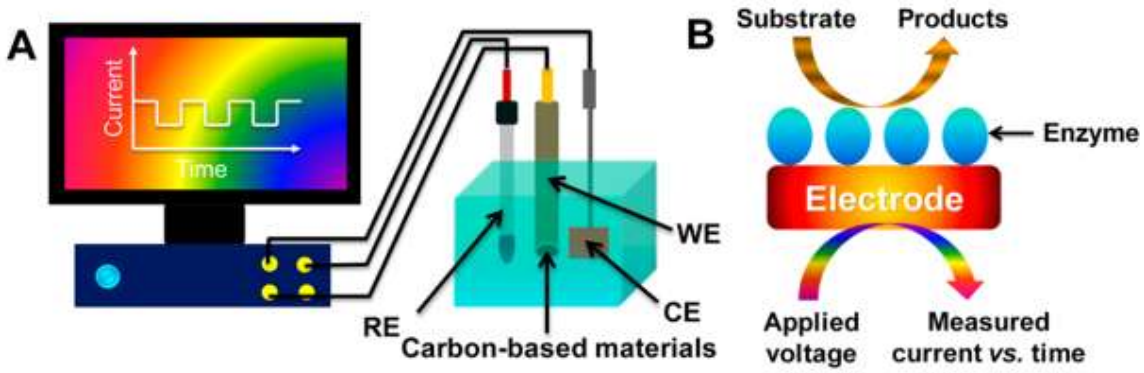

Fig.8:(A) Schematic of a typical carbon nanomaterial voltammetric biosensor made up of a reference electrode (RE), carbon-based working electrode (WE), and counter electrode (CE). (B) Basic principle of a voltammetric biosensor.

Volta metric biosensors are based on electro analytical chemistry techniques in which quantitative analyte sensing is made by varying the potential and measuring the resulting current as an analyte reacts electrochemically with the working electrodes surface (see Figure8). There are multiple techniques whereby the potential can be varied in a voltammetric sensing technique, such as linear sweep, differentialStair case, normal pulse, reverse pulse, and differential pulse. The most commonly applied technique for determination of redox potential and electrochemical reaction rates of analyte solutions is linear sweep cyclic voltammetry (CV).The general shape of a CV is determined by a number of factors such as analyte reduction potential, sweep rate, electrolyte, analyte isomerization, electrode surface, stability of reduced/oxidized analyte, electrochemical reversibility of the analyte, etc. The advantages of the CV approach are (i) high sensitivities and low detection limits, (ii) quantitative analysis of processes, and (iii) fast and clear characterization of the processes that take place on the surface of the sensing electrode .

6. GLUCOSE OXIDASE−CARBON-NANOTUBE-BASED SENSORS

S.G.Wang et al., described the bio-electrochemical characteristics of a novel multi-walled carbon nanotube (MWNT)-based biosensor for glucose detection and are compared with those of glassy carbon (GC)-based biosensor. The MWNT-based biosensor exhibits a strong glucose response at both applied potentials of +0.65 and +0.45V versus Ag/AgCl. It is also shows a high stability of 86.7% of the initial activity after four-month storage, much longer than that of GC-based glucose biosensor. The opening ends of a large number of MWNTs allow the enzyme to enter in hollow cavity, resulting in high sensitivity of the MWNT based biosensor. Meanwhile, a large amount of

enzyme immobilized within nanotubes, along with carboxylic acid groups presented on the nanotube surfaces, greatly enhanced the stability of the biosensor .

Yanli Yao et al.,described the electron-transfer properties of different carbon nanotube materials, and their usage in glucose biosensors. Different types of carbon nanotube material (single-walled carbon nanotubes (SWCNTs) and multiwalled carbon nanotubes (MWCNTs) of different internal diameter) have been used for preparation of CNT-modified glassy-carbon electrodes. Redox reactions involving ferricyanide and hydrogen peroxide were examined at the CNT modified electrodes. Electrodes modified with SWCNTs usually had better electron-transfer properties than MWCNT-modified electrodes. Glucose biosensors were prepared with electro-polymerized polyphenylenediamine films, CNT materials, and glucose oxidase and Amperometric behavior in glucose was determined. SWCNT-modified glucose biosensors usually had a wider dynamic range (from 0.1 to 5.5 mmol L^{-1}) and greater sensitivity in glucose determination. The detection limit was estimated to be 0.05 mmol L^{-1}. The experimental results indicated that SWCNT and MWCNT materials of smaller diameter had better electron-transfer properties and excellent electro-catalytic activity toward hydrogen peroxide and glucose.

Guodong Liu et al., described a flow injection amperometric glucose biosensor based on electrostatic self-assembling glucose oxidase (GOx) on a carbon nanotube (CNT) – modified glassy carbon transducer. GOx is immobilized on the negatively charged CNT surface by alternatively assembling a cationic poly-diallyl dimethyl ammonium chloride (PDDA) layer and a GOx layer. The unique sandwich-like layer structure (PDDA/GOx/PDDA/CNT) formed by self-assembling provides a favorable microenvironment to keep the bioactivity of GOx and to prevent enzyme molecule leakage. The excellent electro-catalytic activity toward H_2O_2 of the fabricated PDDA/GOx/PDDA/CNT electrode indicated that the polyelectrolyte-protein multilayer does not affect the electro-catalytic properties of CNT, enabling sensitive determination of glucose. Flow injection amperometric detection of glucose is carried out at 100 mV (vs. Ag/AgCl) in 0.05 M phosphate buffer solution (pH 7.4) with a wide linear response range of 15μM to 6 mM and a detection limit of 7μM. The PDDA/GOx/PDDA/CNT/GC biosensor showed excellent properties for the sensitive determination of glucose with good reproducibility, remarkable stability, and freedom of interference from other co-existing electroactive species. The biosensor fabrication method demonstrated in this work is readily applicable to the fabrication of other biosensors based on oxidases, such as biosensors for cholesterol, alcohol, lactate, acetylcholine, hypoxanthine, and xanthine. The concept could be extended to assemble other biological molecules, such as antibodies, antigens, and DNA, to the CNT surface for wide bioassay applications .

Ying Liu et al., described the entrapment of glucose oxidase (GOD) in the composite of carbon nanotubes/chitosan and direct electron transfer reaction between GOD and electrode. The electron transfer rate of GOD is greatly enhanced to 7.73 s^{-1} in the system, which is more than one-fold higher than that of flavin adenine dinucleotide adsorbed on the carbon nanotubes (3.1 s^{-1}). This is due to the conformational change of GOD in the microenvironment enabling the accessibility of active site for GOD to the electrode. The GOD/CNTs/CS/GC electrode demonstrates better ability to keep the bioactivity of GOD. So it can be used as an amperometric biosensor for glucose detection taking FMCA as the mediator. It displays higher sensitivity of 0.52μA/mM and better stability. The avenue is promising for the development of biosensors, biofuel cells and other bio-electrochemical devices [33].

Hongtao Zhao et al., described the formation of bilayer of the polyelectrolytes poly (dimethyl diallyl ammonium chloride) (PDDA) and poly (sodium 4-styrenesulfonate) (PSS) on a 3-mercapto-1-propanesulfonic-acid-modified Au electrode. Subsequently, a uniform and stable multilayer membrane of MWCNTs and enzyme can be prepared. This membrane shows a porous structure and the assembled MWCNTs show an electro-catalytic activity to the reduction of dissolved oxygen. Based on the competition between the electrochemical reduction of dissolved oxygen and the oxidation of glucose by dissolved oxygen catalyzed with immobilized GOx, the electro-catalytic response can be used for the detection of glucose at a relatively low applied potential, at which the interference of ascorbic acid and uric acid can be excluded. This modification technology extends the application of CNTs in enzyme amperometric biosensors .

Xiliang Luo et al., described the direct electrochemistry of glucose oxidase (GOD) on carbon nanotube (CNT)-modified glassy carbon electrode, where the enzyme was immobilized with a chitosan film containing gold nanoparticles. The immobilized GOD displays a pair of redox peaks in pH 7.4 phosphate buffer solutions (PBS) with the formal potential of about 455mV (vs. Ag/AgCl) and shows a surface-controlled electrode process. Bioactivity remains good, along with effective catalysis of the reduction of oxygen. In the presence of dissolved oxygen, the reduction peak current decreased gradually with the addition of glucose, which could be used for reagent less detection of glucose with a linear range from 0.04 to 1.0mM. The proposed glucose biosensor exhibited high sensitivity, good stability and reproducibility, and are insensitive to common interferences such as ascorbic and uric acid. The excellent performance of the reagent less biosensor is attributed to the effective enhancement of electron transfer between enzyme and electrode surface by CNTs, and the biocompatibility and immobilization of GOD is due to the presence of chitosan .

Jian-Ding Qiu et al., described a simple and controllable electro-deposition method to fabricate a homogeneous porous chitosan/single-walled carbon nanotubes (CHIT/SWNTs) nanocomposite

film. Glucose oxidase (GOx) served as a model enzyme to demonstrate the potential application of the macro-porous structured films in fabrication of amperometric glucose sensor with negligible mass transport limitation. The glucose biosensor was constructed by entrapping GOx molecules to the porous SWCNTs/CHIT nanocomposite film using glutaraldehyde as a cross-linker. The fabricated biosensor with three-dimension porous structures can provide a biocompatible microenvironment for maintaining the bioactivity of the immobilized enzyme, enhance mass transport of glucose substrate, and increase enzyme loading. Therefore, the biosensor exhibits a rapid response (<5 sec), a wide linear range (10μM to 35μM) and a low detection limit of 2.5μM. The synthesized porous SWNTs/CHIT nanocomposite is highly useful for the fabrication of bioelectronics, biosensors and biofuel cells .

Ram et al have shown that the sensitivity and LOD of a glassy carbon electrode (GCE) toward glucose can be improved by modifying the GCE with SWNTs dispersed in a polymer matrix (polyethylenimine, polyethylene glycol, or polypyrrole) and then a layer of GOx. These polymer layers are beneficial to the enzyme as they provide not only binding places but alsostability. Importantly, the authors showed that the high purity and large surface area of the SWNTs was of critical importance to the response of the electrode. The use of high-purity SWNTs resulted in a high conductivity, enzyme stability, and fast electron transfer rate. The response time of the electrodes was shown to be less than 5 s with a LOD of 0.2633 μM. It has been reported that N-doped carbon nanofibers (NCNF) prepared from electro spun polyacrylonitrile fibers have a large electro catalytic activity toward the oxygen reduction reaction (ORR) .This activity is believed to be due to the presence of abundant defective sites and high pyrrolic-N content in the NCNF. These NCNF films coated with GOx and Nafion showed high sensitivity (LOD of 0.6 mM), stability, and selectivity toward glucose. Additionally, this GOx/NCNF/GCE electrode exhibited successful detection of glucose in the presence of commonly existing interfering species such as ascorbic acid (AA), uric acid (UA), and dopamine (1 mM). This work shows that the doping of SWNTs and other carbon nanomaterials with N can be beneficial in increasing the selectivity and sensitivity of glucose biosensors.

Kwon et al. immobilized GOx on CNTs (GOx/ CNT) to sense glucose, with the authors showing that a larger CNT content contributes to an improved amperometric response. This modified sensor shows increased sensitivity (53.5 μA mM−1 cm−2), glucose activity (86% activity maintained after 2 weeks), and large electron transfer rate constant (1.14 s−1). Interestingly, the Wei group has confirmed an earlier study that CNTs simultaneously modified with GOx and its cofactor, flavine adenine dinucleotide (FAD) show electron transfer kinetics similar to those observed in isolated FAD.This implies that the FAD is directly wired to the CNT, and as such, electron transfer is

unimpeded between the cofactor and support structure, allowing for increased sensitivity. Importantly, as the FAD is itself embedded in the GOx, this in turn allows rapid electron transfer.

Vilian et. al reported a simple and fast approach for the construction of a novel glucose biosensor based on the electropolymerization of a poly-L-arginine film (P-L-Arg) onto functionalized multiwalled carbon nanotubes (f-MWCNTs)/glassy carbon electrode (GCE) via electrostatic attraction with glycoprotein glucose oxidase (GOx).(See Fig. 9)

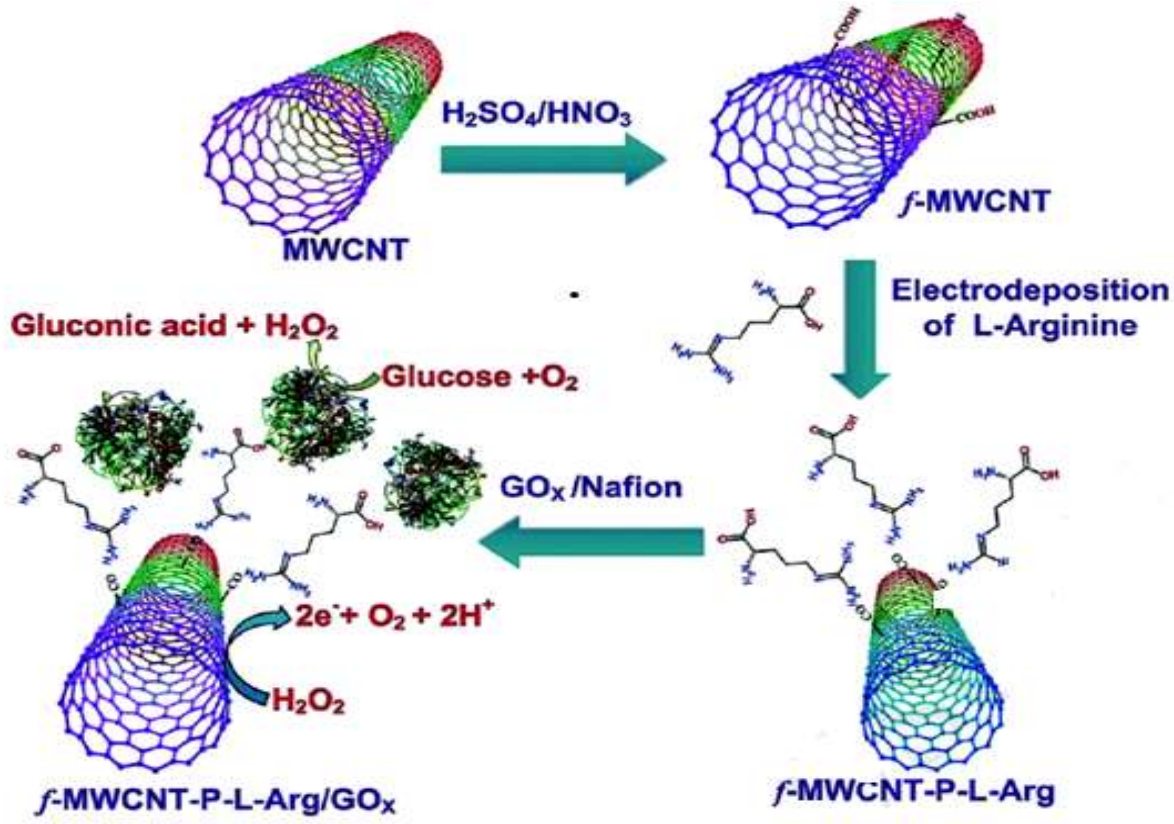

Fig. 9:Construction of glucose biosensor based on the electro polymerization of a poly-L-arginine film (P-L-Arg) onto functionalized multiwalled carbon nanotubes (*f*-MWCNTs)/glassy carbon electrode (GCE) *via* electrostatic attraction with glycoprotein glucose oxidase (GOx).Reproduced with permission of The Royal Society of Chemistry.

Table I: comparison of different CNT based glucose biosensors

Electrode	Sensitivity ($\mu amm^{-1} Cm^{-2}$)	Linear Range (mm)	Electrochemical Technique used	Ks (s^{-1})	References
PPMH/GC-electrode		Upto 2	Amperometry	1.32	39
GOx-PVA-MWCNT	8.67	0.1-20	Cyclic Voltametry	1.58	40
CNT/GOx	2.40	0.04-1	Cyclic Voltametry	1.08	41
MWCNT/Au/GOx	2.52	0.1-10	Amperometry	-	42
Pt nanoparticles on the LD-ACNTs	3.8	Upto 3	Cyclic Voltammetry and chronoamperometry	-	43
CNT/Colloidal Au/PDDA/GOx	2.50	0.5-5.2	Amperometry	1.01	44
CNT/Polypyrrole/GOx	0.095	0.25-4	Amperometry	-	45
MWCNT/ZnO/GOx	4.18	0.2-27.2	Amperometry	1.66	46
CNx-MWCNT/Gox	13	0.02-1.02	Amperometry	4.6	47
Gelatin -MWCNT/GOx	2.47	6.3-20.09	Amperometry	1.08	48
ERGOMWCNT/ GOx/Nf		0.01-6.5	Amperometry	3.02	49

7. CONCLUSION

This review has addressed the recent advances in the applicationof CNT for electrochemical biosensing .The electrochemical properties of CNTs have providedthe platforms for the construction of a wide range of electrochemical biosensors. Electro catalytic activity of CNT based electrodes towards hydrogen peroxide and NADH permits effective low-potential amperometric bio sensing of numerous important substrates. CNTs-modified electrodes have many advantages over other forms of carbon electrodes due to their small size, high electrical and thermal conductivity, high chemical stability, high mechanical strength, and high specific surface area. Due to its faster electron transfer over other carbon based materials, CNTs showexcellent electro catalytic activity in redox behavior of different compounds.CNTs-modified electrodes results in low detection limits, high sensitivities, reduction of over potentials,and resistance to surface fouling.CNTs can cause health risks due to their toxicity and harmful effects in the lung, where they can agglomerate leading to suffocation.More efforts could yield new generations of CNT-based biosensors for a wide range of applications.

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