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Carbon Nanotubes - A Potential Material for Affinity Biosensors

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1. Introduction

The detection of bacteria, virus and toxins in food, clinical and environmental samples is an important area of research. Normally, the identification of pathogens is based on immunological and DNA based methods. In case of immunological methods, the interaction between an antigen and antibody was exploited. Techniques such as agglutination, ELISA are based on this principle. Another method is based on attraction between complementary sequences of DNA. PCR method is a very popular method used to detect DNA. All these techniques either have poor sensitivity or need qualified man power. During the past two decades, efforts were made to develop biosensors which are faster and more sensitive than traditional techniques. The development of biosensors need materials which should be biocompatible and has good electrochemical properties. Nanomaterials such as metal oxides, carbon nanotubes and quantum dots were found to be promising materials. Carbon nanotubes have several important properties such as biocompatibility, good electrochemical and electrical properties. They are amenable for immobilization of biomolecules. This chapter highlights on the recent developments and improvements in the field of affinity based biosensors by using CNTs.

2. Biosensor: An introduction

Biosensor is an analytical device consisting of a sensing element which is in close contact with a transducer and an electronic circuit for display of results. The sensing element may be a biological material (enzyme, antibody), biologically derived material (recombinant antibodies, proteins, and aptamers) or biomimic (synthetic catalysts, imprinted polymer, conducting polymer). The transducer will convert any physicochemical changes taking place in its proximity into electrical signals. Various types of transducers have been used in realizing biosensor. These are based on electrochemical, optical, mass-sensitive, thermal and electronics principles. Based on the biological recognition elements, biosensor can be catalytic or an affinity based device. The catalytic biosensors are made by using enzymes which utilize their catalytic efficiency towards an analyte. While affinity based biosensors utilize the complexing forming ability of antigen and antibody. And also they utilize the attraction between complimentary sequences in DNA. The carbon nanotubes are mainly used in electrochemical biosensors and Field effect transistor (FET) based biosensors.

2.1 Electrochemical biosensor

The electrochemical biosensors can be further subdivided into amperometric, potentiometric, impedometric and conductometric sensors. The electrochemical biosensors are cheap and require simple instrumentation. An amperometric biosensor contains a three electrode system consisting of sensing electrodes, reference electrode and auxiliary electrode. All these electrodes are to be immersed in a suitable electrolyte. And a constant potential on the sensing electrode is applied and the resulting current is related to the concentration of analyte. Some electrochemical sensors utilize voltammetric techniques such as cyclic voltammetry, differential pulse voltammetry or square wave voltammetry. In potentiometric experiments the potential developed between two electrodes is measured by a high impedance voltmeter. The biological element is attached to the sensing electrode and the other electrode serves as reference electrode. In the impedometric sensors, a three electrode system is used and the impedance plots were made in presence of a redox compound such as ferrocyanide. In a conductometric sensor the conductivity of the sensor is measured. CNTs are mainly used in amperometric and impedometric sensor and voltammetry based biosensors.

2.2 FET based biosensor

Typically a field effect transistor device (FET) will have a source and a drain. A current passes from source to drain. The FET also contains a gate, whose properties will be able to control the current passing between the source and drain. The gate material will generate an electrical field and controls the current flow. Ion sensitive field effect transistors (ISFET) are found to be suitable for pH sensing. Another form of FET utilizes a nano wire between two conducting materials. The nanowire has its atoms concentrated on its surface. Thus, any small changes in the charges present on the nanowire will cause a change in the flow of current. The electrical properties of one dimensional material such as Silicon nanowire, conducting polymer based nanowires, metal oxide nanowires and carbon nanotubes are sensitive to the recognizing element attached to them. This is because the high surface to volume ratio associated the one dimensional materials. The single walled carbon nanotubes (SWCNT) have a band gap varying from 0 eV to 2 eVs. Hence, SWCNT can behave as metallic or as semiconductor. Hence, they are suitable for FET devices.

3. Nanotechnology

Nanotechnology refers to materials and structures having dimensions less than 100 nm. These nanomaterials and nanostructures offer newer methods of sensing. The nanomaterials possess special properties due to quantum confinement effect, high surface area and high aspect ratio. In addition, the electrochemical devices have high sensitivity with transducers using nano materials because of edge diffusion phenomena. Nanomaterials such as precious metal nanoparticles, metal oxides, nano-structured conducting polymers and carbon nanotubes have recently attracted much interest owing to their application in nano-scaled devices, sensors and detectors. Nanotechnology also offer new devices such as interdigitated electrodes, nano gap electrodes, cantilevers and FETs. These devices have high sensitivity.

3.1 Properties of CNTs

The development of biosensors need novel material with suitable properties. Depending on the type of transducer, the material property requirements varies. For example, electrochemical immunosensors require materials having good electrochemical and good electrical conducting properties. While the electrical sensors such as FETs require nano

wires having semiconductor properties. Besides these properties, the materials should have good biocompatibility and amenable for immobilization of biomolecules.
The carbon nanotubes have several desirable properties such as good electronic, mechanical and optical properties. Their remarkable mechanical strength stems from covalent sp^2 bonds between individual carbon atoms [Bockrath et al., 1997]. Thus they have good thermal stability. Depending on their structure, carbon nanotubes can be metallic or semiconducting in nature and hence some nanotubes have conductivities higher than that of copper, while others behave more like silicon. And this characteristic opens the way for carbon nanotubes applications in electronic devices including field effect transistor, single-electron transistors and rectifying diodes [Popov et al., 2004]. Carbon nanotubes have large surface area due to their nanometer diameter range. In case of semiconducting nanotubes, transport measurement depicts that a nanotube is connected to two metal electrodes and hence characteristic of field effect transistor. By applying potential to a gate electrode, nanotubes can be switched from a conducting to an insulating state. This type of system was shown to be operative even at room temperatures thus meeting the requirement for potential practical application [Robertson et al., 1992]. The FET operation was explained by semiclassical band-bending model. Carbon nanotubes (CNTs) have been widely discussed as materials with enormous potential for various applications. Due to superior electronic and mechanical properties along with nanoscale dimensions, a lot of attention has been drawn toward CNTs for bio-applications ranging from drug delivery to highly sensitive biosensors. CNT-based immunosensors and applications are still in the nascent stage, and there are many challenges to be overcome for the successful commercialization of the concepts. This chapter highlights on the recent developments and the improvement in the sensitivity of immunosensors by using CNTs.

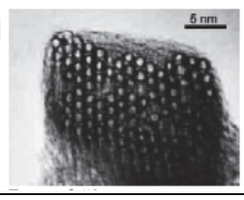
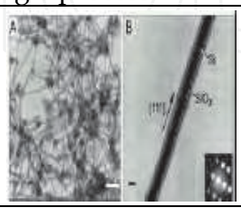
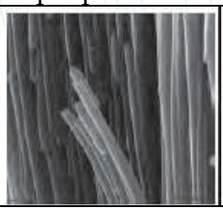
	CNTs	SiNWs	CPNWs
Materials	Carbon	Silicon	Metal alloy/oxide, conduct. polymers
Deposition technique	Arch discharged Laser assisted CVD	Laser assisted Super critical fluid solution VLS method	Electrochemical methods
Manufacturability	Difficult	Difficult	Easy
Surface modification	Limited	Well known	Well known
Functionality	Single process	Single process	Multiple process
			

Table. 1. State-of-the Art Nanosensor Materials

4. Methods of immobilization of biomolecules on CNTs

For realizing a biosensor, it is essential to fix biomolecules on to the transducer. Carbon nanotubes can be a part of transducer. In general, several classes of immobilization methods

have been used, such as physical adsorption, microencapsulation, entrapment, covalent attachment and cross-linking. The CNTs offer newer opportunities and special abilities than the existing materials. Physical adsorption is the simplest method of immobilization in which biomolecules are mechanically attached on to the surface with the help of van der Waals forces. And in this method no conformational change occurs. This method also has a disadvantage that biomolecules may leak from the surface during experiments due to weak binding force between biomolecules and the surface. It is very easy to adopt physical adsorption methods because it involves dropping of a buffer solution containing the biological molecule on to the electrode. Carbon nanotubes are in the range of nanometer size, so it has large surface area. Also they are hydrophobic in nature. Hence, the biomolecules can get adsorbed easily. The CNTs were used in various forms for development of immunosensors. They are used in making or modifying screen printed electrodes. They are also used in modifying the glassy carbon electrode. Normally, a binder such as nafion or chitosan has been used for this purpose [Tsai et al., 2005, 2007; Liaw et al., 2006]. The CNT paste electrodes were prepared by mixing CNTs with mineral oil. It was found that CNT paste has lot of crevices and voids, which help in holding the antibodies. Below is the SEM Image of CNTs which shows the crevices and voids on the surface of a MWCNT paste electrode [Fig. 1]. By spectroscopic experiments it was proved that the MWCNT paste can adsorb more quantity of antibody than graphite paste electrode [Suresh et al., 2010]. Similar property was also reported for nano porous zinc oxide.

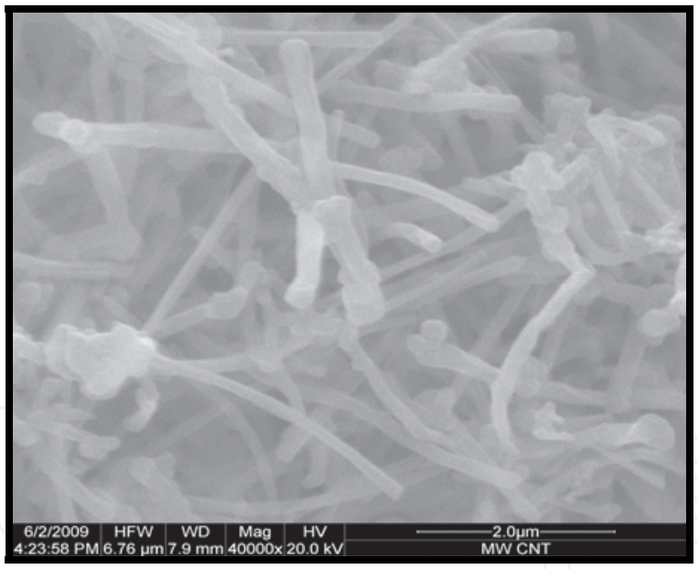
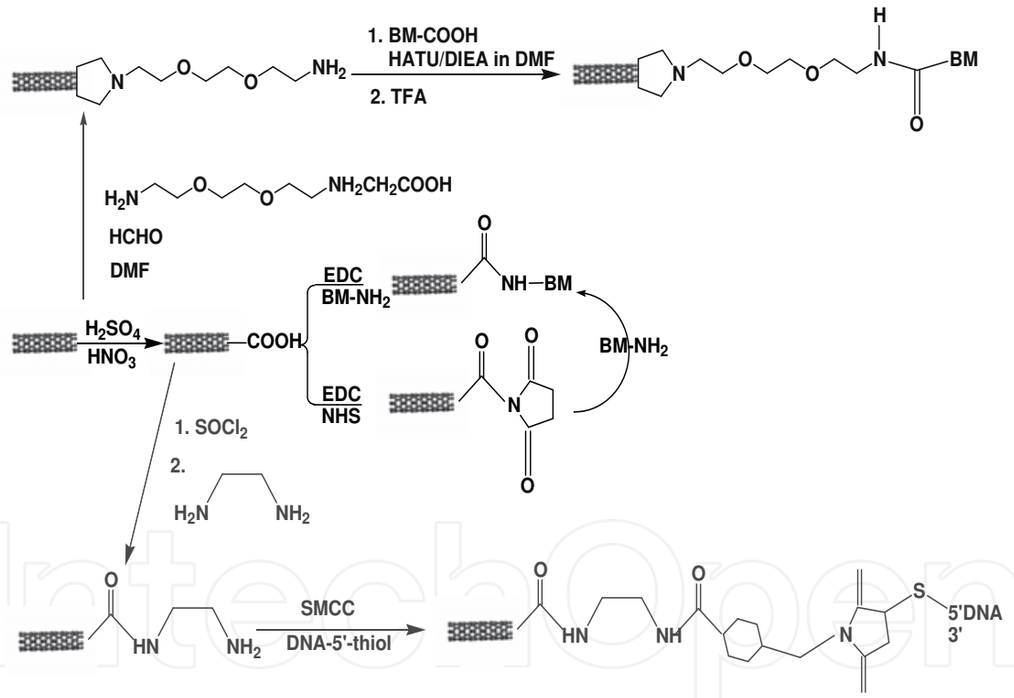


Fig. 1. SEM image of MWCNT. Reprinted with permission from Talanta, 81, 703 (2010).

In microencapsulation, biomolecules are trapped between membranes. In the entrapment method, biomolecule is trapped in a matrix of a gel, paste or polymer and it is the very popular method. In covalent attachment, there is a formation of covalent chemical bonds between biomolecules and transducer. The CNTs are a part of transducer. The best stability, accessibility and selectivity can be achieved through covalent bonding. Covalent bonding has the capability to control the location of the biomolecules; therefore, it improves the stability, accessibility and selectivity. For the covalent bonding of molecules to the

nanotubes, it is essential to form functional groups on the carbon nanotubes [Scheme 1]. The carboxylic acid group is often the best choice because it can undergo a variety of reactions and is easily formed on carbon nanotubes via oxidizing treatments, e.g. sonication in sulphuric and nitric acid, refluxing in nitric acid and air oxidization. The control of reactants and/or reaction conditions may control the locations and density of the carboxylic groups on the nanotubes which can be used for controlled attachment of biomolecules. One of the universal methods for connecting biomolecules to other materials is diimide-activated amidation, by direct coupling of carboxylic acid to proteins using N-ethyl-N′-(3-dimethylaminopropyl) carbodiimide hydrochloride (EDAC) or N,N′ dicyclohexyl carbodiimide (DCC) as a coupling agent. However, this process leads to undesirable side reactions of intermolecular conjugation of proteins, because most proteins are rich in both amine groups and carboxylic acid groups on their surface. This intermolecular connection can be avoided by using a two-step process: carboxylic acid groups are first converted to active esters via diimide-activation, and then the active esters are reacted with the amine groups on proteins without the presence of diimide. Thus, the process can guarantee homogenous attachment of proteins onto carbon nanotubes.



Scheme 1. Covalent functionalization with biomolecules

Kuiyang et al. reported the covalent immobilization of the protein molecules on carbon nanotubes via a two-step process of diimide-activated amidation. Here, ferritin and bovine serum albumin (BSA) proteins are chemically bonded to nitrogen-doped multi-walled carbon nanotubes (CNx MWNTs) through a two-step process of diimide-activated amidation. This two-step process avoids the intermolecular conjugation of proteins, and guarantees the uniform attachment of proteins on carbon nanotubes. This approach provides an efficient method to attach biomolecules to carbon nanotubes at ambient conditions (Kuiyang et al., 2004).

Biofunctionalization and manipulating of carbon nanotubes (CNTs) is important for biomedical research and application. Cy5 labeled goat anti-rabbit IgG (anti-IgG-Cy5) is chemically bonded to CNTs via a two-step process of diimide-activated amidation. This process can avoid the intermolecular connection of proteins (Xu et al., 2008).

The phage display to identify peptides with selective affinity for CNTs has been explored (Wang et al., 2003). Binding specificity has been confirmed by demonstrating direct attachment of nanotubes to phage and free peptides immobilized on microspheres. Consensus binding sequences show a motif rich in histidine and tryptophan at specific locations. The analysis of peptide conformations shows that the binding sequence is flexible and folds into a structure matching the geometry of carbon nanotubes. The hydrophobic structure of the peptide chains suggests that they act as symmetric detergents. An IgG monoclonal antibody against the fullerene C_{60} (Braden et al., 2000) was also studied to show binding to CNTs with some selectivity (Erlanger et al., 2001). The combination of multiwalled carbon nanotubes (MWCNT) as a transducer with polysulfone (PS) polymer enables easy incorporation of biological moieties (hormones or antibodies). It provides three dimensional composites with high electrochemical response to corresponding analytes. For biomedical purposes, human chorionic gonadotropin (hCG) hormone was tested by competitive immunoassay. The detection limit was determined to be 14.6 mIU/mL with a linear range up to 600 mIU/mL (Sanchez et al. 2008).

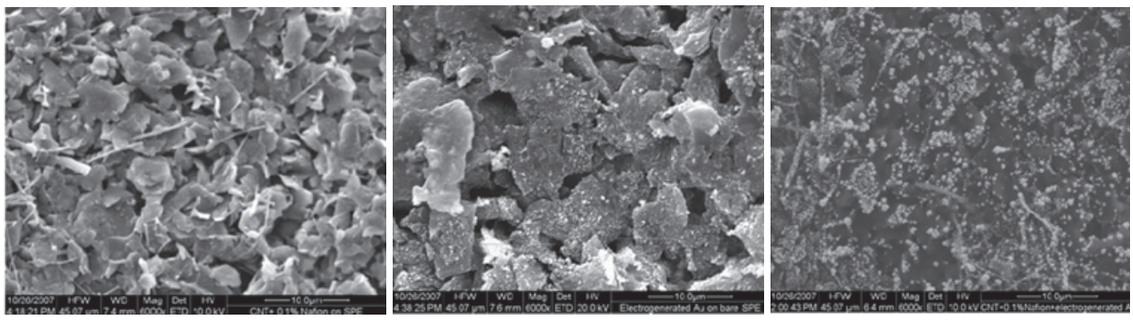
The nanotechnology applied in biosensing must have relevant methods to immobilize biomolecules, whose activity may be preserved for long periods of time. The most used methods for this purpose are the electrostatic layer-by-layer (LbL) (Decher et al.,1992) and the Langmuir–Blodgett techniques (LB technique)(Blodgett, 1934), which are complementary to each other in terms of the types of material that can be employed. The LbL method utilizes alternating layers of positive and negatively charged materials soluble in water, which is suitable for proteins. The LbL films are obtained via transfer of insoluble films from the air/water interface onto solid supports. Traditional materials forming stable monolayers are fatty acids, phospholipids, sterols, and substances with a long alkyl chain and a hydrophilic moiety. Soluble substances with affinity to the air–water interface (proteins and nucleic acids) can also be incorporated into the monolayers by adsorption from the aqueous subphase. Therefore, a variety of materials may be immobilized on solid matrices through the LB method, opening the way to fabricate hybrid systems. In particular, LbL technique is promising for silicon-based sensors as this method allows a control of film architecture and thickness, in addition to the synergy between properties of distinct materials, including carbon nanotubes [Lee et al., 2009], proteins [Lvov et al.,1995], antigen-antibody pairs [Zucolotto et al., 2007], DNA [Elbakry et al., 2009] and nanoparticles [Crespilho et al., 2006].

The most widely used advanced technique is patterning of biological macromolecules onto solid surfaces in the form of microarrays and/or chips. The target-capture process is performed on the substrates (e.g., silicon wafer, glass slide) via biological recognition. A signal probe (fluorescent dye molecules are used usually) is utilized to signal such biological interactions. Sensitivity is a central factor for bioanalytical technique. To achieve a high sensitivity, a large amount of research has focused on signal amplification by utilizing various nanomaterials (e.g., quantum dots, metal nanoparticles) as strong and photostable signal probes [Cao et al.,, 2002; Maxwel et al., 2002; Li et al., 2002]. Although these approaches have made condsiderable progress in biomolecular detection, they still have several drawbacks: (1) these techniques involve a complex procedure for immobilization of

the biomolecules on the flat substrate; (2) since the target-catching procedure is carried out on the flat surface of microarray or titer plate, such heterogeneous procedure increases assay time and decreases the sensitivity due to the slow target-binding kinetics; (3) some nanomaterials (e.g., nanoparticles of Ag, CdS, CdSe) used for signal amplification are sensitive to air, which causes reduced reproducibility. In cross-linking method, a bifunctional agent is used to bond chemically the transducer to the biomolecules. There are a number of advantage of immobilizing biomolecules to the surface- (i) single batch of biomolecules can be used multiple times (ii) reaction can be stop rapidly by removing the biomolecule from the reaction solution (iii) there is less chance of contamination of product with biomolecules (iv) immobilization provide long life to the biomolecules.

5. CNTs and metal nanoparticles composites

There are many reports on the application of CNTs with metal nanoparticle such as gold, platinum, copper, silver etc. [Lin et al., 2009; Wen et al., 2009; Valentini et al., 2007; Lin et al., 2009] . Below are the SEM images of MWCNTs/SPE, nano-gold/SPE and MWCNTs/nano gold/SPE (screen printed electrode).



(a) (b) (c)

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Fig. 2. (a) MWCNTs/SPE, (b) nano-Au/SPE, (c) MWCNTs/nano-Au/SPE

In these figures, figure 2(a) shows the nanotube like structure on the electrode surface, figure 2(b) shows the nanoparticle like structure of gold which are electro-generated on the surface of bare screen printed electrode and figure 2(c) shows the nanohybride structure of MWCNTs and gold [Sharma et al., 2008]. The electrocatalytic efficiency of SPE modified electrode towards oxidation of naphthol was found to be very high. The 1-naphthol is produced by hydrolysis of 1-naphthyl phosphate by the enzyme alkaline phosphatase. Hence, these electrodes were suited in the detection of malaria by sandwich ELISA system, in which alkaline phosphatase is used as an enzyme tagged to revealing antibody.

Preparation of nanocomposite materials from carbon nanotubes (CNTs) and metal or metal oxide nanoparticles has important implications to the development of advanced catalytic and sensory materials. Molecularly mediated assembly of monolayer-capped nanoparticles on multiwalled CNTs via a combination of hydrophobic and hydrogen-bonding interactions between the capping/mediating shell and the CNT surface have advantage that it does not require tedious surface modification of CNTs. It shows simplicity and effectiveness for assembling alkanethiolate-capped gold nanoparticles of 2-5 nm core sizes onto CNTs with

controllable coverage and spatially isolated character. The loading and distribution of the nanoparticles on CNTs depend on the relative concentrations of gold nanoparticles, CNTs, and mediating or linking agents. The composite nanomaterials can be dispersed in organic solvent, and the capping/linking shells can be removed by thermal treatment to produce controllable nanocrystals on the CNT surfaces.

6. CNTs and affinity biosensors

There are two types of affinity based biosensors. These are called immunosensors and DNA sensors. The immunosensors exploit the property of complex formation between an antigen and its antibody. And the other utilizes attraction between the complimentary sequences of the DNA strands. Mainly CNTs were utilized in developing electrochemical, optical and electronic sensors.

6.1 Immunosensors

The immunosensors utilizes the affinity between the antigen and its antibody to form a complex. The ELISA methods were well established techniques and have variety of formats. Since, the formation of the complex can not be determined directly by earlier methods, an enzyme tagged antibody is used to reveal the formation of the complex between the antigen and antibody [Suresh et al., 2010; Sharma et al., 2008]. The enzyme tagged antibody will provide an optical or electrochemical signal based on the substrate used. Carbon nanotubes are used both in label less methods and labeled methods. The enzymes used for conjugation with antibodies are HRP or alkaline phosphatase. The CNTs are mainly used because of their good electrochemical properties and binding properties towards biomolecules. In the case of electrochemical immunosensors CNTs were used in various forms. They are mixed with a binder to modify glassy carbon electrodes or screen printed electrodes (SPE). The electrochemical properties of these are enhanced due to modifications. The main reason for using SPEs is disposability and cost effectiveness. The binder materials normally used are nafion, chitosan or sodium alginate. These three are known to be biocompatible. In some publications the MWCNTs modified electrodes were further modified by electrodeposition of gold nano particles [Sharma et al., 2008]. In some reports the CNTs were initially modified with gold nano particles and then used to modify the GC electrodes using a binder. Various electrochemical techniques such as amperometry, square wave voltammetry and impedance were used in these immunosensors. Even pure carbon nanotubes were used. Highly aligned multiwalled carbon nanotubes were grown on a Fe/Al2O3/SiO2/Si substrate by chemical evaporation. An elaborate procedure is used to expose the ends on the CNTs . These are oxidized at their tips electrochemically to functionalize. The resulting carboxylic acid is attached to the antibodies. This is a label less sensor working on the principle of impedance.

Carcinoembryonic (CEA) antigen is present in serum samples and other biofluids in patients suffering from cancer. Viswanathan et al. developed a disposable electrochemical immunosensor by attaching monoclonal anti carcinoembryonic antibodies (α-CEA) covalently on polyethyleneimine wrapped multi walled carbon nanotubes modified SPE by sandwich immunoassay. A sandwich immunoassay with CEA & α-CEA was tagged to ferrocene carboxylic acid encapsulated liposomes. Square wave voltammentric technique (SWV) was used to detect the antigen in the range of $5X10^{-12}$ to $5X10^{-7}gmL^{-1}$ and the detection limit of $1x10^{-12}$ gmL^{-1} [Viswanathan et al., 2009].

Alpha Fetoprotein (AFP) is known as an important tumor marker and has an average concentration of about 25 ng/mL in healthy human serum [Zhu et al., 2000]. An elevated level of AFP concentration in serum can be determined and the disease cancer can be diaginised earlier. Jiang et al. also reported on α-fetoprotein sensor based on MWCNTs / Prussian blue / nanogold modified GC electrode and found the linear range 0.01-300ng/mL with detection limit of 3pg/mL [Jiang et al.,2010]. In this study Jiang et al. deposited Prussian blue (PB) and gold nanoparticles electrochemically on MWCNT modified GC electrode. The leakage of PB was prevented due to sequential deposition of PB and Gold on the modified electrode. This GNP film also helps to prevent shedding of MWCNT/PB composite film to electrode surface. The electron transfer between the PB and electrode gets affected due to antigen-antibody interaction. It results in decrement in cyclic voltammetric response. This decrement is related to antigen concentration. This is a lablel less immunosensor. Lin et al. also reported amperometric immunosensor for detection of alpha fetoprotein by using GNP/CNT/Chitosan modified GC electrode, formed by one step synthesis through direct redox reaction. For this immuno detection they used sample AFP, immobilized AFP and alkaline phosphatase tagged antibodies. The linear range of AFP was found from 1-55ng/mL with a detection limit of 0.6ng/mL [Lin et al, 2009].

Tang et al. reported enzyme free electrochemical immunoassay for AFP detection by using carbon nanotube enriched Au nanoparticles as a nanocatalyst on anti-AFP/glutaraldehyde/thionine-modified GCEs with a wide linear range of 8.0×10^{-7}–2.0×10^{2} ng/mL and detection limit (LOD) of 0.8 fg/mL of AFP which was lower 6 orders than that of commercially available ELISA. This high sensitivity was possible due to redox cycling of p-aminophenol and p-quinone imine and that was resulted in continuously increasing of signaling. In this process, initially the p-nitrophenol molecules were reduced to p-aminophenol by the catalysis of the AuNP labels on the CNT-AuNPs with the help of $NaBH_4$, then the generated p-aminophenol molecules were oxidized to p-quinone imine by an electron mediator of thionine, and then the oxidized QI molecules were reduced back to APs by $NaBH_4$ [Tang et al., 2011].

Zhao et al. reported on the disposable Shigella flexneri immunosensor based on MWCNT/sodium alignate (SA) composite SPE [Zhao et al., 2011]. They used HRP labeled antibodies to S. flexneri and immoblised these antibodies on MWCNT/sodium alignate composite screen printed electrode by physical adsorption. Shigella is major causes of human infectious diseases and is responsible for millions of cases of diarrhea [Li et al., 2006]. Alginate is a copolymer of β-D-mannuronic acid and α-L-guluronic acid linked together by 1–4 linkages [Rehm et al., 1997]. It is a natural and biocompatible polymer that can provide microenvironments to improve the biomolecules stability and maintain their bioactivity [Liu et al., 2009]. Here sodium alignate biocomposite acts as a matrix to adsorb and immobilize antibodies. Linear range was found to be 10^{4}cfu/mL to 10^{11} cfu/mL and detection limit was $3.1x10^{3}$ cfu/mL. There is noncovalent association of MWCNTs with SA chains and has proved to be preferable for electrochemical immunosensing due to the unique structural and electronic properties of MWCNTs [Zhao et al., 2009]. In this system, MWCNTs provide a signal transduction, whereas SA works as a biocompatible and chemically modifiable scaffold for biomolecule immobilization. SA can effectively improve the solubility of MWCNTs, providing a useful way for preparing MWCNT–binder composite modified electrode for a wide range of sensing applications [Zhao et al., 2009].

Zhu et al. studied the amperometric immunosensor for the detection of neomycin by using GNP decorated electrode. Neomycin performs activity against both gram negative bacteria as well as gram positive bacteria and this behaviour of neomycin is similar to other aminoglycosides. In this study Zhu et al., used poly-[2,5-di-(2-thienyl)-1H-pyrrole-1-(p-benzoic acid)] (pDPB). It is a conducting polymer and behaves as a sensor probe to detect neomycin in sandwitch manner in which secondary antibody was attached to GNP decorated MWCNTs labeled with hydrazine (Hyd–MWCNT(AuNP)–Ab2). Hydrazine works as catalyst for the reduction of H_2O_2. The linear range was found to be 10ng/mL-250ng/mL with a detection limit of 6.76±0.17ng/mL [Zhu et al., 2010]. In this study Zhu et al., immobilized neomycin antibody on conducting polymer covalently and this type of immobilization of biomolecules on conduction polymer has attracted wide attention due to great compatibility of polymer with biomolecule in neutral solution [Lee and Shim, 2001; Abdelwahab et al., 2010; García-Aljaro et al.,2010].

Sanchez et al., reported immunosensor for rabbit IgG (RIgG) by using MWCNTs/polysulfone/RIgG modified SPE and based on competitive immunoassay between free and labelled anti-RIgG. Labeling of antibody was done by horseradish peroxidase (HRP) and hydroquinone was used as mediator. This resulting immunosensor have high sensitivity as well as double roughness in comparison to graphite/polysulfone/RIgG immunosensor. Incorporation of RIgG in MWCNTs/polysulfone was resulted from phase inversion. MWCNTs/polysulfone works both as reservoir of immunological material and transducer while offering high surface area, high toughness and mechanical flexibility. Linear range of anti RIgG was found to be 2-5μg/mL with Detection limit of 1.66μg/mL and C_{50} value at 3.56μg/mL. The polysulfone have high resistance in extreme pH conditions, good adhesion and susceptibility to incorporate biological molecules and good thermal stability, while MWCNT has good conductivity. Hence the composite made by using polysulfone and MWCNT will be ideal for use in immunosensors. [Sanchez et al., 2007]. In order to immobilize antibodies in polysulfone matrix by phase inversion technique Mulder et al. modify the chemical nature of the polysulfone matrix [Mulder et al., 2000]. There has been little research also done on the basis of adsorption of antibody for example Yu et al. and O'Connor et al. reported immunosensor by immobilizing antibody on SWCNTs, oriented perpendicularly [Yu et al.,2004; O'Connor et al.,2005].

Recently, He et al. reported on label free electrochemical immunosensor for rapid determination of clenbuterol by using CNTs. In this study, Clenbuterol and to MWCNTs was linked covalently in a two-step process using 1-(3-(dimethylamino)-propyl)-3-ethylcarbodiimide and N-hydroxysulfo-succinimide as crosslinkers after that casted on GC electrode and found the detection limit of 0.32ng/mL [He et al., 2009]. There are two strategies which were applied to immobilize immunological molecules in literatures (1) antibody immobilised on the electrode was directly applied to determine the antigen in solution by observing the response change of ferrocyanide redox marker on the electrode [Lei et al., 2003; Zhang et al., 2006; Zhou et al., 2005]. (2) Antigen immobilised on the electrode was used to compete with free antigen in solution for a specific antibody [Chen et al., 2005]. But the above method suited for protein, virus, and cell factor detection mostly and also this type of direct cross-linking of immunological molecules might lose their activities, and then regeneration of the sensor required complete removal of all immobilized materials from the electrode surface.

Recently, Cao et al. studied electrochemical immunosensor for casein based on GNP/Poly (L-arginine)/MWCNTs modified GC electrode and observed linear range was $1x10^{-7}$ - $1x10^{-5}$

gmL^{-1} with detection limit of $5x10^{-8}$ [Cao et al., 2011]. Cui et al. reported on human IgG detection based GNPs/CNTs hybrid modified GC electrode. Linear range was observed between 0.125 and 80 ng/mL with a detection limit of 40pg/mL. This high sensitivity was possible due to using of bioconjugates featuring HRP labels and secondary antibodies linked to GNPs at high HRP/Ab2 molar ratio [Cui et al., 2008]. Bourigua et al. studied label free impedemetric biosensor for the detection of deep venous thrombosis biomarker by using SWCNT-COOH modified gold microelectrodes and found the linear range in between of 0.1pg/mL-2µg/mL with detection limit of 0.1pg/mL and response time of 10min [Bourigua et al., 2010]. Deep venous thrombosis is named due to formation of blood clot in deep vein [Firkin and Nandurkar, 2009]. Panini et al 2008 reported that Integrated microfluidic systems with an immunosensor for detection of prostate specific antigen (PSA) in human serum samples by using MWCNTs modified GC electrodes with observed detection limit of 0.08 μgL^{-1} which was very high than the observed detection limit by ELISA. Hetero-geneous enzyme immunoassays, coupled with flow injection system and electrochemical detection, represent a powerful analytical tool for the determination of low levels of many analytes such as antibodies, hormones, drugs, tumour markers, and viruses [Gubitz and Shellum, 1993; Wu et al., 2006]. Okuno et al., 2007, studied Label-free immunosensor for prostate-specific antigen based on single-walled carbon nanotube array-modified microelectrodes and found the detection of 0.25ng/mL. Li et al., 2010 reported reagentless amperometric immunosensor for the detection of cancer antigen 15-3 based on enzyme-mediated direct electrochemistry and found the linear range in between of 0.1-160U/mL with detection limit of 0.04U/mL. Recently, Piao et al., 2011 reported sensitive and high-fidelity electrochemical immunoassay for the detection of human IgG by using CNT coated with enzymes and magnetic nanoparticles. In this report, Piao et al. used tyrosinase as enzyme. In this immunosensor firstly enzyme and magnetic nanoparticle were immobilized covalently on the surface of CNT then cross-linked via glutaraldehyde to form multilayered cross-linked tyrosinase-magnetic nanoparticles composite that was further conjugated with primary antibody against human IgG. Secondary antibody was conjugated with alkaline phosphatase and used in sandwich immunoassay pattern. Detection limit was found to be 0.19ng/mL. Zhao et al., 2011, reported on determination of lutiolin in peanut hulls by using MWCNT modified GC. Linear range was found to be $2x10^{-10}$ – $3x10^{-9}$ with detection limit of $6x10^{-11}$. Luteolin is member of flavonoid and it is actually 3′,4′, 5, 7-tetrahydroxyflavone and has a wide range of biochemical and pharmacological effects and also have anti-oxidation, anti-bacteria, anti-virus, anti-inflammatory, anti-carcinogenic and other beneficial properties [Jian & Xiao, 1986; Merken & Beecher, 2000; Robards & Antolovich, 1997]. Highly precise and sensitive electrochemical immunosensor for the detection of carcinoembryonic antigen (CEA) in saliva and serum was reported [Vishwanathan et al., 2009]. Monoclonal anti-CEA antibodies (anti-CEA) were covalently immobilized on polyethyleneimine wrapped multiwalled carbon nanotubes screen-printed electrode. A sandwich immunoassay was performed with CEA and anti-CEA tagged ferrocene carboxylic acid encapsulated liposomes (anti-CEA-FCL). The squarewave voltammetry (SWV) was employed to analyze faradic redox responses of the released ferrocene carboxylic acid from the immunoconjugated liposomes on the electrode surface. The calibration curve for CEA concentration was in the range of 5×10^{-12} to 5×10^{-7} gmL^{-1} with a detection limit of 1×10^{-12} gmL^{-1} (S/N = 3). Sharma et al. have reported sensitive immunosensor for the detection of *Plasmodium falciparum* histidine- rich protein 2 (PfHRP-2) in the sera of humans with *P. falciparum* malaria based on modified SPEs. For this purpose, disposable SPEs were

modified with multiwall carbon nanotubes (MWCNTs) and Au nanoparticles. The immunosensing experiments were performed on bare SPEs, MWCNT-modified SPEs, and Au nanoparticle and MWCNT-modified SPEs (Nano-Au/MWCNT/SPEs) for the amperometric detection of PfHRP-2. Nano-Au/MWCNT/SPEs yielded the highest-level immunosensing performance among the electrodes, with a detection limit of 8ng/ml. The analytical results of immunosensing experiments with human serum samples were compared with the results of a commercial Paracheck Pf test, as well as the results of microscopy. The Paracheck Pf kit exhibited a sensitivity of 79% and a specificity of 81%, whereas the amperometric immunosensor showed a sensitivity of 96% and a specificity of 94%.

Carboxylated multiwalled carbon nanotubes (MWCNT-COOH) were used to modify the working electrode surface of different SPEs. The effect of this modification on the electrodic characteristics (double layer capacitance, electroactive area and heterogeneous rate constants for the electron transfer) was evaluated and optimized for the cyclic voltammetric determination of *p*-aminophenol. The enzymatic hydrolysis of *p*-aminophenylphosphate was employed for the quantification of alkaline phosphatase, one of the most important label enzymes in immunoassays. Finally, ELISA assays were carried out to quantify pneumolysin using this enzymatic system. Results obtained indicated that low superficial densities of MWCNT-COOH (0.03–0.06 μg mm^{-2}) yielded the same electrodic improvements but with better analytical properties [Lamas et al., 2008].

Vishwanathan et al described a sensitive method for the detection of cholera toxin using an electrochemical immunosensor with liposomic magnification followed by adsorptive square-wave stripping voltammetry is described [Vishwanathan et al., 2006]. In this immunodetection potassium ferrocyanide-encapsulated and ganglioside (GM1)-functionalized liposomes act as highly specific recognition labels for the amplified detection of cholera toxin. The sensing interface consists of monoclonal antibody against the B subunit of CT that is linked to poly (3,4-ethylenedioxythiophene) coated on nafion-supported MWCNTs caste film on a GC electrode. The CT is detected by a "sandwich-type" assay on the electronic transducers, where the toxin is first bound to the anti-CT antibody and then to the GM1-functionalized liposome. The potassium ferrocyanide molecules are released from the bounded liposomes on the electrode by lyses with methanolic solution of Triton X-100. The released electroactive marker is measured by adsorptive square-wave stripping voltammetry. The sandwich assay provides the amplification route for the detection of the CT present in ultratrace levels. The calibration curve for CT had a linear range of 10^{-14}–10^{-7}g mL^{-1}. The detection limit of this immunosensor was 10^{-16} g of cholera toxin (equivalent to 100 μL of 10^{-15} g mL^{-1}).

Typically, a field-effect transistor (FET) device will have a nanowire in contact with a source and drain along with a gate. Typically a nanowire such as silicon, metal oxide or carbon nanotubes was used. In case of single walled carbon nanotube, all the carbons will be on its surface. The conductivity of this can be greatly influenced by any molecules attached to it. Since, various methods are available for immobilization of biomolecules on CNTs. The CNTs possesses good electrical properties and are ideal for FET based Biosensors also. Dekker's group reported the first carbon nanotube-FET (CNTFET) [Tans et al., 1997]. CNTFETs have been proved suitable system for biosensing applications due to its properties to combining the principles of molecular recognition through the recognition layer with the transduction capabilities of the carbon nanotubes. CNTFETs have been used to detect DNA [Gui et al., 2007; Star et al., 2006; So et al, 2006,], proteins like thrombin and IgE and IgG by

means of antibodies and aptamers as molecular receptors [Cid et al., 2008; Maehashi et al., 2007; So et al., 2005], viruses by means of peptide nucleic acids [Dastagir et al., 2007] and bacteria [Villamizar et al., 2008; So et al., 2008].

Recently, Villamizar et al., 2009 reported CNTFET based detection of candida albicans. CNTFET have a network of SWCNTs which works as the conductor channel. This CNTFET based biosensor was able to detect atleast 50 cfu/mL within 1h and remained stable for more than 10 days. This CNTFET was also tested with potential competing yeasts like Cryptococcus albidus and Saccharomyces cerevisiae for C. albicans to evaluate the selectivity of FET devices. Kim et al., 2008, reported a method for ultrasensitive CNT-FET based biosensors by using antibody binding fragment. In this study, CNTFETs were functionalized with antibody binding fragment as a receptor, and the binding event of target IgG onto the fragments was detected by observing gating effect caused by charges of target IgG. And it was observed that CNTFET biosensors based on small antibody fragments (Fab fragments) have very high sensitivity (detection limit 1pg/mL) in comparison to those CNTFET biosensors based on whole antibody segment (detection limit 1000 ng/mL).

6.2 DNA sensors

DNA sensor is an affinity based biosensor and considered a promising tool in pre-diagnostics as well as in the prevention and control of infectious diseases in real-time and on site analysis [Drummond et al., 2003]. DNA sensors have several potential applications including the diagnosis of genetic diseases, detection of infectious agents and environmental cases [Malhotra et al., 2005; Wang et al., 2002]. Methods used for DNA sequence detection reported are based on radiochemical, enzymatic, fluorescent, electrochemical, optical, and acoustic wave techniques [Kara and Meric, 2004]. Optical DNA sensors gave promising results but some disadvantages are also there including the requirement of a separate labeling process and an equipment to stimulate the transducer of high cost [Pearson et al., 2000]. Electrochemical methods for hybridization detection present a good alternative in comparison fluorescent detection due to having considerable advantages ascribed to their potential for obtaining specific information in a faster, simpler, and less expensive way and huge progress has been made towards the development of the electrochemical DNA sensors. These sensors rely on the conventional hybridization signal of the DNA sequences into useful electrical signal.

DNA is potentially a building block for the assembly of nanoscale electronic devices and has all the basic properties necessary for it with their application in decentralized clinical testing, food safety and environmental monitoring. The DNA nanoscale device construction will be a predominant technique of new molectron with attention paying benefits like high efficiency, low power requirement, miniaturization and low heat generation [Guo et al., 2004].

DNA immobilization considered as a fundamental methodology for construction of DNA biosensor, requires intimate connection between nucleic acid and electronic transducer. High sensitivity, long life-span as well as short response time depends mainly on attachment of DNA sequence on the surface of the sensor. So it is necessary that the binding chemistry should be stable during subsequent assay steps.There are various methods like chemical adsorption, covalent binding, electrostatic attraction, co-polymerization and avidin-biotin affinity system for DNA immobilization [Cai et al., 2003]. Besides DNA biosensor, some other approaches have been studied like DNA mineralization, the use of DNA to nanopaticles/nanotubes assembly, and larger colloidal particles. There are various

methods to the DNA strands immobilization on the sensor surface and several groups have reported using the covalent binding of the CNTs to immobilize the DNA sequences. Such as the covalent attachment on the functionalized support [Gabl et al., 2004], physical adsorption [Komarova et al., 2005] and monolayer self-assembling [Saoudi et al., 1997; Huang et al., 2001; Peelen & Smith, 2005]. The most ideal approach for DNA immobilization in CNTs is covalent binding on a solid surface via a single point attachment. Among these methods, immobilization by means of covalent attachment has advantages such as simplicity, efficiency, ordered binding, and low cost. In covalent attachment, various mediators can be used to attach the DNA sequences on the sensor surface such as carbon nanotubes (CNTs), Aminopropyltriethoxy silane (APTES), Alkanethiols etc.. Covalent immobilization of the CNTs is usually performed by amino-terminated DNA reaction with the carboxylic acid groups of the CNTs, or directly reacting with the amino group of the oxidized CNTs. Jung et al., 2004 demonstrated that the DNA strands can be covalently attached to immobilized SWNT multilayer films. These multilayer films were constructed via consecutive condensation reactions and resulted into stacks of functionalized SWCNTs layers linked together by 4,4-oxydianiline. Singh et al., 2006 reported that aminated- or carboxylated- DNA strands were covalently immobilized to the carboxylated or aminated SWNT multilayer films respectively through formation of amide bond by help of using 1-ethyl-3-(3-dimethylaminopropyl) carbodiimide hydrochloride. Baker et al., 2002 reported a multistep route for the formation of covalently linked adducts of SWNT and DNA sequence. Most of the applications of immobilized oligonucleotide are based on the hybridization between immobilized oligonucleotide and its complementary DNA sequence in the sample [Lee et al., 2003]. Singh et al. studied the synthesis of functionally engineered SWCNTs–peptide nucleic acid conjugates for nanoelectronic applications [Singh et al., 2006].Wang et al., 2004 reported that the strong accumulation of phenolic products of alkaline phosphatase onto CNT-modified electrodes allow the detection of extremely low levels of the target DNA. Enhanced voltammetric response of phenolic compounds at CNT modified GC electrode was measured in connection with enzyme-based electrochemical detection of DNA hybridization. The detailed mechanism behind the dissolution of nanotubes in DNA is not clear at present. Nakashima et al., 2003 suggested that the π-π interactions between the nanotube sidewalls and the nucleic acid bases may be responsible. There may also be some weak interaction between the major and minor grooves of the DNA and the nanotubes. Cai et al.,2003 reported the application of CNTs to the fabrication of an electrochemical DNA biosensor for the specific DNA sequence detection. Moghaddam et al., 2004 firstly reported the azide photolysis for the functionalization of CNTs. They used the azide-photochemistry to functionalize the sidewalls and tips of CNTs in a solid-state reaction and the subsequent synthesis of a DNA oligonucleotide from the reactive group on each photo-adduct. Lu et al., 2005 investigated a system consisting of B-DNA and an array of carbon nanotubes periodically arranged to fit into major grooves of the DNA. They discussed in detail about the system used as an electronic switch or as a sensor device for ultra fast DNA sequencing. A novel sensitive electrochemical biosensor based on magnetite nanoparticle for monitoring DNA hybridization by using MWCNT – COOH/ppy – modified GC electrode was described by Cheng et al., 2005. CNTs can amplify DNA, protein recognition and transduction events. This property was used for the ultrasensitive method for the electrical biosensing of DNA or proteins. An effective DNA sensing system to detect specific nucleic acid sequences is playing an important role in many areas such as clinical diagnosis, medicine, epidermic prevention, environmental protection and bioengineering.

The delivery of gold nanoparticles to CNTs using the self assembly properties of DNA represents an advance towards building higher order nanostructures with rational control. The controlled self-assembly of CNTs was recently achieved by interphasing the CNTs with biomolecules. This approach has considerable potentials for driving self-assembly of CNT-based devices in the light of the immense richness of biological recognition. The approach involves two steps. In the first step, a self-assembled nanolayer of single stranded DNA is adsorbed onto Au contacts by reaction with thiol terminated oligonucleotides and in the next step, the oxidized CNTs modified with oligonucleotides of the complementary sequence are allowed to hybridize with the DNA located on the Au contacts. Hazani et al., 2004 used a long DNA molecule featuring Rec A proteins as a scaffold, onto which streptavidin-functionalized SWCNTs were assembled utilizing anti-ReeA primary antibodies and biotinylated secondary antibodies. Wang et al., 2004 reported a novel DNA immobilization strategy, in which the DNA probes are adsorbed on self-assembled multiwalled nanotubes. Their results showed that this immobilization strategy based on self assembled MWCNTs yields higher hybridization efficiency than that adsorbed on random MWCNTs. Li et al., 2005 demonstrated that a wide range of multicomponent structures of CNTs can be constructed by DNA directed self-assembling of CNTs and gold nanoparticles. Wang et al., 2004 developed DNA biosensors based on the self-assembly of CNTs. They assayed the hybridization by the changes in the voltammetric peak of the indicator methylene blue and the results showed that the DNA biosensors based on the self-assembled MWCNTs have higher hybridization efficiency than that based on random MWCNTs.

Recently, Tam et al., 2009, reported label free DNA sensor for detection of Influenza virus (type A) by using CNTs and found the detection limit of 0.5M with a response time of 4 min. DNA was attached to sensor surface By means of covalent bonding between amine and phosphate group of DNA sequence.

Recently, Weber et al., 2011 reported on electrochemical impedance based DNA sensor for detection of Salmonella enterica serovar *Typhimurium* by using SWCNTs modified electrode. In this study, Weber et al., reported on the use of SWCNTs with a diameter range of 20–30 nm for DNA attachment, and its subsequent hybridization. SWCNTs covalently bonded via N-Ethyl-N′-(3-dimethylaminopropyl) carbodiimide hydrochloride (EDAC) to oligonucleotide probes having amino groups on the 3' end. After achieving hybridization, the capacitance change and charge transfer resistance of the electrode to the redox-active compound $Fe(CN)6^{-3/-4}$ were measured by electrochemical impedance spectroscopy (EIS). In this study, Weber et al. used Salmonella specific probes. This method of genosensing is a quick, facile approach to detecting DNA without the use of additional labels. By this impedance method, detection was found to be at 1x10-9 $molL^{-1}$. Wang et al., 2011 reported on label free DNA biosensor for detection of short DNA species by using MWCNTs/Chitosan nanocomposite modified GC electrode with glutaraldehyde as an arm linker and found the linear range between $1x10^{-13}$ - $5x10^{-10}$ M with detection limit of $8.5x10^{-14}$.

Carboxylic group-functionalized SWNTs were assembled vertically on the electrode using ethylenediamine as linking agent to fabricate an aligned electrode (SWNTE). Single-stranded DNA (ssDNA) wrapped around the SWNTs to form ssDNA-wrapped SWNTE structures based on the interaction between ssDNA and SWNT. A sensitive differential pulse voltammetric (DPV) response was obtained at the ssDNA-wrapped SWNTE owing to the electro-oxidation of guanine bases. Double-stranded DNA (dsDNA) was formed when

ssDNA on the ssDNA-wrapped SWNTE was hybridized with complementary ssDNA (cDNA). The dsDNA was removed from the SWNTs by undergoing a process of preconditioning at −0.6 V. Consequentially, the DPV response of guanine bases decreased. The used SWNTE could be renewed easily via ultrasonically rinsing. On the basis of this mechanism, a label-free and readily reusable electrochemical DNA hybridization biosensor was designed by directly monitoring the current change of guanine bases. Under optimum conditions, the plot of the measurement signal of guanine bases versus the cDNA concentrations was a good straight line in the range of 40−110 nM with a detection limit of 20 nM (3*s*). The biosensor can be switched to detect different target DNAs easily.

CNTs modified electrodes have been used for biochemical detection [Wang et al., 2004] and recently have been used as transducers for more sensitive DNA hybridization detection electrically [Wang et al., 2003]. CNTs can play an important role in selective and sensitive recognition of DNA in electrical DNA biosensing due to its ability to amplify DNA recognition and transduction events. For this selective and sensitive recognition, single strands DNA can be grafted chemically on to aligned CNT-electrodes. Successful integration of CNTs in sensors needed controlled deposition at well defined location. Interphasing of CNTs with biological molecule provide controlled self assembly of CNTs and this approach has considerable potential for self assembly of CNTs based devices with intense recognition of biological molecule. Due to charge transfer characteristics of CNTs while approaching the size of biomolecules, CNTs utilities will be beneficial in electrochemical biosensing. CNTs are helpful in amplifying enzyme based bioaffinity and hence can be used in electrical sensing of DNA [Wang et al., 2004].

Recently, DNA attracted several attentions in connection with CNTs and through sequence-specific pairing interaction DNA chains have been used to create various functional structures and devices. Also the principle based on DNA based biomolecular recognition has been applied to construct CNT-DNA electrochemical sensors [Daniel et al., 2007]. Guo et al., 2004 described the electrochemical characteristics of DNA functionalization of CNTs holds interesting prospects in various fields including solubilization in aqueous media, nucleic acid sensing, gene-therapy and controlled deposition on conducting or semiconducting substrates. DNA molecules can increase the CNT solubility and also be used to distinguish metallic CNT from semiconducting CNTs. The DNA attachment occurs predominantly at or near the nanotube ends. The rare attachment of DNA to other regions of CNTs indicates that it is the result of sequence specific polynucleic acid–DNA base pairing rather than nonspecific interactions [William et al., 2002]. The individual CNTs can be functionalized with special selectivity and can be used to differentiate between the two DNA sequences. The concept of using DNA to direct the assembly of nanotubes into nanoscale devices is attracting attention because of its potential to assemble a multicomponent system in one step by using different base sequence for each component. The reactive sites on the CNTs were created by the acid treatment to introduce the carboxyl groups on their tips. DNA molecules with functional linkers are then coupled to the carboxyl groups on the CNTs. Chen et al., 2005 developed a multistep method to covalently functionalize multiwall carbon nanotubes with DNA and oligonucleotides. Thus, the bioconjugates of carbon nanomaterials and DNA will have potential uses in many areas due to the combination of unusual structure of carbon nanomaterials and bioactivity of DNA [Yan et al., 2005]. Hazani et al., 2003 reported the confocal fluorescence imaging of SWCNT–DNA adducts obtained by carbodiimide assisted coupling of amine functionalized oligonucleotides to oxidized SWCNTs. CNTs have been recently used as transducers for

enhanced electrical detection of DNA hybridization . The DNA sensing application requires high sensitivity through amplified transduction of the oligonucleotide interaction. The wrapping of CNTs in DNA results in some interesting effects. The DNA nanotube species are highly soluble in water removing the requirement for surfactants. Also the negative charges on the phosphate group of DNA results in the charging of DNA nanotube species. The bifunctional chemical structure of CNTs would facilitate the selective attachment of multiple DNA sequences using two distinct DNA–CNT linking strategies. In one strategy, by accessing the free carboxyl groups of CNTs, single stranded, amine terminated DNA oligonucleotides are attached to the CNT array using amide coupling chemistry in aqueous/organic solvent mixtures. The second strategy involves the attachment of oligonucleotides to the sidewalls of the CNTs through hydrophobic interactions. Taft et al., 2004 reported the immobilization of DNA through the interaction of the hydrophobic pyrene group with the graphite-based sidewalls of the CNTs, which was highly specific and DNA-dependent process.

The unique property of the specific molecular recognition of DNA coupling with SWCNTs and hybridizing these macromolecular wires will provide a versatile means of incorporating SWCNTs into larger electronic devices by recognition-based assembly and using SWCNTs as probes in biological systems by sequence-specific attachment [William et al., 2002]. Buzaneva et al., 2002 developed the DNA nanotechnology for the formation of the multifunctional CNT cells using theoretical predictions of chemical activity changing of SWCNT under its localization into the biopolymer surrounding and electronic/optical properties of these cells that are determined by SWCNT–biopolymer heterostructure properties.

7. Conclusions

Applications of nanomaterials in the field of affinity biosensors have become advanced greatly. For example, nanomaterials-based biosensors, which represent the integration of material science, molecular engineering, chemistry and biotechnology, can markedly improve the sensitivity and specificity of biomolecule detection, hold the capability of detecting or manipulating atoms and molecules, and have great potential in applications such as biomolecular recognition, pathogenic diagnosis and environment monitoring.

CNTs have unique properties. Unique properties lead to fabrication of different devices. Improvements of current synthesis of CNTs needed to make available commercial products. The totally new nanoelectronic architecture may be constructed on CNTs. There is a little knowledge about growth mechanism, structural defects and their influence on practical properties of CNTs. There are many attractive phenomena hidden within the tiny, mysterious world that exists inside the CNTs.

CNTs have several interesting properties suitable for developing affinity based biosensors. They have good electrical properties, electrochemical properties and amenable for immobilisation of biomolecules by various methods. They are stable and biocompatible. They are already exploited for detection of several pathogens and biomarkers for various diseases. Their properties can be enhanced by incorporation of nano gold and platinum. Since they are having one dimensional structure and semiconducting properties they are being studied as potential materials for FET based biosensor. Since they are nano materials, it is possible to make array of sensors on a single platform so that it is possible to develop multianalyte systems. The results of affinity based sensors using CNTs indicate high

sensitivity. The practical use of sensors will depend on the shelf life and ease of use. Research work in this direction will be beneficial.

CNT based nanobiosensors may also be used to detect DNA sequences in the body. These instruments detect a very specific piece of DNA that may be related to a particular disease. Therefore, these sensors can possibly diagnose patients as having specific sequences related to a cancer gene. The use of CNT-based sensors will avoid problems associated with the current much-larger implantable sensors, which can cause inflammation, and eliminate the need to draw and test blood samples.

In time, nanodiagnostics may become very cost-effective, as is currently the case with nanotubes arrays. This should allow better clinical diagnostic services. These nanodiagnostics can also be applied to point-of-care testing and lab-on-a-chip technologies. Whether nanodiagnostics will replace current diagnostic methods remains to be seen. Many aspects of these nanodiagnostics techniques need to be evaluated further, especially the safety issues. However, the advantages that these new technologies offer are too good to ignore.

8. References

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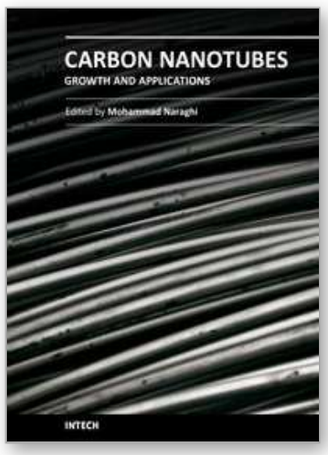

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Carbon Nanotubes are among the strongest, toughest, and most stiff materials found on earth. Moreover, they have remarkable electrical and thermal properties, which make them suitable for many applications including nanocomposites, electronics, and chemical detection devices. This book is the effort of many scientists and researchers all over the world to bring an anthology of recent developments in the field of nanotechnology and more specifically CNTs. In this book you will find:
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