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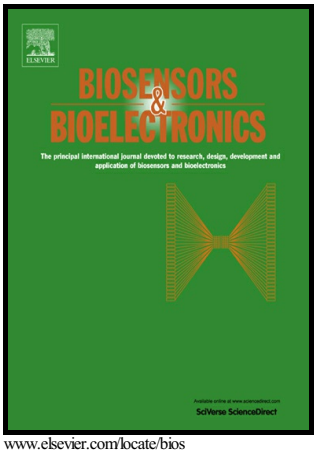

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Recent Uses of Carbon nanotubes & Gold nanoparticles in Electrochemistry with application in Biosensing: A review

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Abstract

The innovation of nanoparticles assumes a critical part of encouraging and giving open doors and conceivable outcomes to the headway of new era devices utilized as a part of biosensing. The focused on the quick and legitimate detecting of specific biomolecules using functionalized gold nanoparticles (Au NPs), and carbon nanotubes (CNTs) has turned into a noteworthy research enthusiasm for the most recent decade. Sensors created with gold nanoparticles or carbon nanotubes or in some cases by utilizing both are relied upon to change the very establishments of detecting and distinguishing various analytes. In this review, we will examine the current utilization of functionalized AuNPs and CNTs with other synthetic mixes for the creation of biosensor prompting to the location of particular analytes with low discovery cutoff and quick reaction.

Keywords: Carbon nanotube; Au nanoparticle; Electrochemistry, Biosensor

1. Introduction

Nanoscale materials and also nanomaterials are known as an arrangement of substances where any measurement is not as much as around 100 nanometers (one millionth of a millimeter). Nanomaterials divulge exciting properties that make them reasonable and appealing too to be exploited as a part of electrochemistry and also in the improvement of the biosensor. Among them, carbon nanotubes (CNTs) and gold nanoparticles (AuNPs) are the most broadly explored nanomaterials because of their exceptional properties, which can be connected in different applications, for example, detecting, distinguishing, and imaging. Still now, the exploration field of advancement of new conventions for getting ready functionalized AuNPs and CNTs with their utilizations for biosensing is a dynamic research territory. The amalgamation systems of these nanoparticles have been persistently developing, prompting to the enhancements in control over their size and shape.

2. Properties of Carbon Nanotubes:

Carbon is a standout amongst the most copious and most entrancing components on earth. It shows up in a few distinctive structures or allotropes with generally extraordinary properties. Among these allotropes are a precious stone, graphite, and amorphous carbon. It shapes likewise a remarkable assortment of novel structures that are being found for a long time these last years. The revelation of novel carbon allotropes or carbon nanostructures (CNSs) has pulled in solemn consideration due to their key and mechanical interests (Dresselhaus et al. 1996). They exhibit inimitable structural and physical properties. Idealize CNTs have all carbons fortified in a

hexagonal cross section aside from at their finishes, though abandons in mass delivered CNTs present pentagons, heptagons, and different flaws in the sidewalls that for the most part corrupt wanted properties. Carbon Nanotubes are gathered into two sorts (single-walled CNTs and multi-walled CNTs) contingent upon their number of walls. Cylinder shaped single-walled CNTs (SWCNT) as little as a nanometer in width can be grown up to 20 cm long (Lin et al. 2004; Zhu et al. 2002). SWCNT is a single molecular nanomaterial forming only a layer that rolls a single sheet of graphene into a seamless molecular cylinder, whereas, the diameter distribution and length range between 0.75–3 nm and l–50 nm respectively. On the other hand, multi-walled carbon nanotube (MWCNT) is constituted of more than two layers of the curly graphene sheet, whereas, the diameter is at the range of 2–30 nm and some even more than l00 nm (Popov 2004). Individual CNT walls can be metallic or semiconducting depending on the alignment of the graphene lattice with respect to the tube axis, which is known as the chirality. Individual SWNTs may have a thermal conductivity of 3500 $Wm^{-1}K^{-1}$ at room temperature, which exceeds the thermal conductivity of diamond (Pop et al. 2006). Furthermore, CNTs possess an extensive specific surface area (SSA), which allows immobilization of a substantial number of practical units at the surface of CNTs, for instance, receptor moieties for biosensing applications. Eventually, the packaging impact, and also the expansion in the number of dividers, debilitates the SSA of CNTs (Valcárcel et al. 2007).

3. Properties of Gold Nanoparticles:

Gold nanoparticles (AuNPs) have mostly been exploited in nanobiotechnology in view of their one of a kind property and numerous surface functionalities. The simplicity of the

functionalization procedure of AuNPs gives an malleable stage to nanobiological gatherings with oligonucleotides (Lv et al. 2017a), antibodies (Hu et al. 2017), and proteins (Lv et al. 2017b). The adaptability of AuNPs has given precious materials to the scope of biomedical applications. AuNPs likewise fill in as commonsense stages for therapeutic agents, with their high surface area permitting an introduction of multifunctional moieties such as medicates and targeting agents (Alexander et al. 2011). Surface plasmon resonance (SPR) and the capacity to extinguish fluorescence are the key physical properties of AuNPs, whereas, spherical AuNPs exhibit a range of colors like brown, orange, red and purple in aqueous solution as the core size increases from 1 to 100 nm, and generally a size relative absorption peak from 500 to 550 nm is shown (Priyadarshini and Pradhan 2017). This absorption band (surface plasmon band) is usually absent in both small nanoparticles ($d < 2$ nm) and the bulk material. Additionally, AuNPs has the capability of going about as the acceptors of an electron to extinguish fluorophores in the photoinduced electron transfer (PET) process (Radousky and Liang 2012). This PET procedure is regulated by charging/releasing the gold core which can be utilized in the fabrication of biosensor.

4. Functionalization of Carbon Nanotubes:

Due to the large inter-tube attraction energy, the structure of CNTs is stable enough which causes their insolubility in various solvents. Furthermore, the solubility of CNTs is the foremost task for the preparation of CNTs in order to develop biosensors (Yang et al. 2015a). Due to the hydrophobicity of CNTs, functionalization with polymers, guest particles or side wall substituents surface is important to enhance the biocompatibility of CNTs (Barsan et al. 2015).

Functionalized CNTs possesses many enhanced attributes like high catalytic efficiency, large edge plane, high surface activity and more functional groups. The biosensors developed with functionalized CNTs possess higher sensitivity, more stability, faster response, and wider detection range by contrasting with the conventional solid-state carbon biosensors.

Functionalization of CNTs can be triumphed by both physical and chemical methods, whereas, physical approaches exploit the mechanical means such as ultrasonic, milling, crushing and friction to activate CNTs surface by changing their surface structure (Fujigaya et al. 2008). Additionally, chemical approach comprises of two methods such as covalent and non-covalent modification, whereas, only non-covalent modification can remain the original structure and properties of CNTs, and does not damage the π system but the structure of covalent modification is more stable (Zhang et al. 2010). For example, Wasik et al described the non-covalent modification of CNTs with heparin in their work where CNT were first treated with 1-Pyrenemethylamine (Pyr-NH_2) by incubating with 10 μL of 6 mM Pyr-NH_2 in DMF for 1 h under high humidity conditions, followed by thoroughly washing with PB. After that, EDC, N-hydroxy succinimide (NHS), and heparin were mixed in 2-morpholinoethane sulphonic acid buffer (pH 5.5) in a separate reaction tube and incubated for 10 min prior to exposure to the formerly modified CNTs for 2 h at room temperature (Wasik et al. 2017).

Covalent modification ensues in tip defects as well as side wall of CNTs followed by introducing functional groups. Loads of functional group**s** can be introduced to the surface of CNTs if they are treated with different acids (Pavlidis et al. 2012) providing a huge number of active site to formulate the functionalized CNTs with better catalytic activity for biomolecules. A larger surface area is possessed by the hollow tube structures of functionalized CNTs and the carboxyl group on the surface of functionalized CNTs helps the protein or enzyme to be immobilized via

covalent binding (Musameh et al. 2012). For example, Li et al presented covalent modification of CNTs in their research work, whereas, 3-aminophenylboronic acid (APBA) was covalently linked with carboxylic CNTs to form APBA-CNTs composite. Briefly, carboxyl-MWCNTs was dispersed into PBS (pH 7.4) containing EDC, APBA and NHS and incubated at room temperature for 6 h to activate the –COOH on the MWCNTs. The prepared APBA-MWCNTs were then centrifuged and washed with PBS for several times to remove free APBA (Li et al. 2017b). Sun et al reported a functionalization mechanism of CNT to fabricate NiO/CNT/PEDOT composite (Fig. 1) , which was used in biosensing of dopamine, seretonine and tryptophan. In this work the functionalization of CNTs was obtained through the oxidation of hydroxilated CNT. The overall reaction to synthesis of NiO/CNT/PEDOT composite is as followed (Sun et al. 2018). The Ni^{2+} ions are first reduced and deposited on the GCE, while CNT-OH continues to migrate toward the GCE under the action of the electric field. The -OH groups on the CNT are oxidized to carboxyl groups (-COOH), and the CNTs that are deposited on the GCE surface with Ni particles act as nucleation sites for the polymerization of EDOT monomers. Polymerization occurs on the surface of the CNTs, forming a coaxial core-shell composite with PEDOT as the shell and the CNT as the core.

Ghrera et al reported a DNA biosensor fabricated through Electrophoretic deposition of carboxyl-modified CNTs (Ghrera et al. 2018). For functionalization, MWCNTs were exfoliated via sonication with TOAB to prepare the stable suspension of MWCNT-TOAB (Fig. 2). The functionalized CNTs facilitated the immobilization of desired biomolecules for sensing application also the functionalization of CNT leaded to biocompatibility and improved

dispersibility in the solution phase of biomolecules. Ma et al described a procedure for functionalization of CNTs for fabricating CNT/AuNPs nanocomposite which was then used to biosensing of mi-RNA (Fig. 3). The carboxylic functional group (COOH) was modified on the surface of MWCNTs during functionalization, which enhanced their dispersion and compatibility (Ma et al. 2018a). The quenching abilities of functionalized MWCNT/AuNPs nanocomposites were much greater than conventionally used MWCNTs.

5. Functionalized Gold Nanoparticles preparation:

Different sorts of methodologies are utilized by the analysts to synthesize AuNPs till now in the research laboratory. Among them, the solution phase synthesis method is being used greatly for preparing AuNPs. They can be prepared in either aqueous or sometimes in the organic phase. More specifically, it was demonstrated that AuNPs with 10–20 nm diameter could be attained by reacting hot chloroauric acid solution with sodium citrate solution, whereas, sodium citrate is used as the reducing and capping agent in this process of synthesis (Li et al. 2017d). AuNPs with size ranging from 2 to 5 nm can be attributed in general by reducing gold salt with sodium borohydride in the presence of alkanethiol molecules (Tang et al. 2016). This method is utilized for the synthesis of stabilized colloidal AuNPs. Also, some green synthesis approaches had been reported recently for the preparation of AuNPs. For example, polysaccharides and biopolymers are used as both stabilizers and reducing agents to synthesize AuNPs (Alex and Tiwari 2015; El-Naggar et al. 2016). However, another technique had been found for synthesizing AuNPs by using laser ablation in the presence of cyclodextrins where the particle size and colloidal stability

could be controlled by adjusting the pH value in the solution (Scaramuzza et al. 2016). Synthesis of highly fluorescent gold nanoparticles by using matrix sputtering method had been described in another work recently (Sumi et al. 2015). The size of the AuNPs obtained through this method varied from around 2–3 nm to approximately 5 nm. Baetson-Young et al. showed the development of a novel unamplified genomic DNA nanobiosensor with AuNPs (Fig. 4), whereas, the AuNPs were functionalized during the synthesis with dextrin (Baetsen-Young et al. 2018). By comparing with other methods this functionalization procedure provided more stability to the biosensor and facilitated in binding ssDNA probes for detecting unamplified pathogenic DNA.

Lee et al. described a functionalization method of AuNPs for the development of biosensor to detect viral DNA (Lee et al. 2018). In this work, functionalized AuNPs were synthesized by using only the reducing agent (without surface stabilizer) and the size of these NPs were not controlled (Fig. 5). As a result, large sizes up to 200 nm could be grown. Usually, organic compound based surface stabilizer was used to control the size of AuNPs during synthesis step; however, that chemical could provoke reduction of electrical conductivity of hybrid material and cause other side effect. Also, that chemical stabilizer could prevent the direct binding of probe DNA on AuNPs.

In table 1, an overview of different ways described for the functionalization of CNTs & AuNPs in biosensor fabrication and their corresponding analytes are listed concisely.

6. Application of Carbon Nanotubes in Biosensing:

Carbon nanotube (CNTs) based biosensors are recognized to be a next generation building block for highly-sensitive biosensing systems because of providing the eminent advantages like greater sensitivity, faster response time, greater stability, lower potential of redox reaction, etc. (Yang et al. 2015a). Carbon nanotubes has been found to be promising among a lot of potential application for the development and advancement of different biosensors like glucose biosensors, H_2O_2 biosensors, metal ion biosensors, immunosensors, choline biosensors, gas sensors, etc. It was also found that the direct electron transfer (DET) from the active site of redox protein or enzymes to the electrode surface was promoted due to the use of CNTs which is the major drawback for the development of biosensor. Also, the use of CNTs of different forms itself or incorporation with other materials enhanced the sensitivity and selectivity and stability of the biosensor when used in.

6.1. Application in Glucose Biosensor

Carbon nanotubes have been used extensively for the development of glucose biosensors for the last years. Partially unzipped carbon nanotube (PUCNTs) was utlized by Hu et al. to fabricate an amperometric glucose biosensor based on direct electron transfer of glucose oxidase (GOx) that was self- assembled on the surface of PUCNTs modified glassy carbon electrode (GCE) (Hu et al. 2015). There the sensitivity and stability of the biosensor was greatly enhanced due to the utilization of CNTs. Singh, B., et al. proposed another efficient approach for glucose biosensor fabrication, whereas, carbon nanochips and carbon nanotubes were used together for the utilization of Pt in the fabrication. The synthesized materials were capable of bulk production

and were adept to stable and robust operation under optimal environmental conditions, where enzyme-based systems fail like bioprocess monitoring (Singh et al. 2014). Ali et al. fabricated a highly-sensitive glucose biosensor which was amenable to ultra-miniaturization by immobilization of glucose oxidase, onto a poly (2, 6-diaminopyridine)/multi-walled carbon nanotube/glassy carbon electrode. A remarkable improvement was observed in the electrocatalytic properties of the developed biosensor by the synergistic effect of the high active surface area of both the conducting polymer and MWCNT (Ali Kamyabi et al. 2016). A simple, solvent-free sensor was proposed by Prashad R and BR Bhat where MWCNTs was used with nickel oxide nanoparticles (NiO-NPs) (Prasad and Bhat 2015). Poly brilliant green (PBG) and poly thionine (PTH) films had been formed by Ghica et al on carbon film electrodes (CFEs) modified with carbon nanotubes by an electro-polymerization method using potential cycling. Glucose oxidase and uricase enzymes were immobilised on top of PBG/CNT/CFE and PTH/CNT/CFE for the biosensing of glucose and uric acid (UA) (Ghica and Brett 2014). Synthesis of zinc oxide nanoparticles incorporated with graphene–carbon nanotubes hybrid (GR–CNT–ZnO) through a simple, one-pot method was described by Kuo-Yuan in 2014, and that composite was used in glucose biosensing by immobilizing glucose oxidase (GOx) (Hwa and Subramani 2014). Qian proposed a sensitive fiber microelectrode very recently for nonenzymatic detection of glucose by incorporating nickel hydroxide nanosheets into highly-aligned carbon nanotube scaffold which possessed remarkable performance in the biosensing of glucose due to the presence of CNTs (Qian et al. 2018). Another very recent use of CNTs in glucose sensor has been proposed by Yan et al. where non-covalently functionalized nanotube was employed for glucose detection (Li et al. 2017g). Sajjadi et al. reported on an amperometric biosensor for

glucose detection by Prussian-blue/CNTs/Ionic liquid modified glassy carbon electrode (Sajjadi et al. 2017)

6.2. Application of in H_2O_2 Biosensor

Balamurugan et al. successfully synthesized a novel 3D nanocomposite of nitrogen doped Co-CNTs over nitrogen doped graphene sheets (3D N-Co-CNT/NG) which offered an excellent conductive network for effective charge transfer and avoided the agglomeration of nitrogen doped graphene matrices. That nanocomposite demonstrated direct responses to the reduction of H_2O_2 at a low potential (Balamurugan et al. 2016). Cobalt (II), dicobalt (III) oxide nanoparticles, were attached to MWCNTs for the first time by microwave decomposition method by Heli et al. (2014), and that nanostructure was then used as the modifier of a carbon paste electrode in enzymeless biosensing of H_2O_2 (Heli and Pishahang 2014). Kong et al. also presented a new, facile and effective method to use carbon nanotubes and used it in the preparation of H_2O_2 biosensor (Kong et al. 2015), whereas, the electrical conductivity and sensitivity was improved. Baghayeri et al., constructed a sensitive amperometric H_2O_2 biosensor based on synergetic catalysis of hemoglobin and porous Pd/Fe_3O_4-MWCNT nanocomposite (Baghayeri and Veisi 2015). Another efficient and simple approach was proposed by Li et al. to fabricate an amperometric H_2O_2 biosensor by Pt nanoparticles-loading MWCNTs, whereas, MWCNTs were first functionalized with an anionic surfactant, sodium dodecyl sulfate (SDS); then the Pt nanoparticles (NPs) were loaded on MWCNTs–SDS by electrodepositing. The fabricated sensor on this work was drastically improved in the amperometric detection of hydrogen peroxide by combining the advantages of MWCNTs and PtNPs (Li et al. 2014b). Zhang et al., reported on an

experimental study of flexible nanocomposite film for electrochemical detection of H_2O_2 based on bacterial cellulose (BC) and MWCNTs in combination with microperoxidase-11(MP-11). MWCNTs were used to functionalize BC which offered a flexible conductive film and BC boosted the biocompatibility of MWCNTs (Zhang et al. 2015). Thandavan proposed a hybrid interface in the same year by combining nano iron oxide and CNTs which offered an improved performance for the detection of H_2O_2. That proposed biosensor was found to be highly reproducible, stable and showed high anti-interference property (Thandavan et al. 2015). Another novel biocompatible sensing strategy had been suggested by Vilian et al. for the biosensing of H_2O_2 based on functionalized MWCNTs, poly-l-histine, and ZnO nanocomposite film by immobilizing hemoglobin (Hb) on it (Vilian et al. 2016). Ni(II)-Based metal-organic framework (Ni(II)-MOFs) was successfully attached on carbon nanotubes (CNTs) through in situ solvothermal method by Wang et al for the first time which revealed admirable electrocatalytic performance including a wide linearity and lower detection limit with very fast response towards non-enzymatic H_2O_2 detection (Wang et al. 2016a). A novel H_2O_2 sensing platform of AgNPs-RGO-MWCNTs composite was synthesized through a simple one-step hydrothermal method by Lorestani et al. Notable expediency of that single-step reaction was employing the reaction without using any toxic solvent or reducing agent by offering a novel green synthetic method to produce the AgNPs-RGO-MWCNTs nanocomposite (Lorestani et al. 2015). Deng et al. developed an H_2O_2 biosensor by using Copper nanoparticles (CuNPs) on the electrode with pyrocatechol violet (PCV) and SWCNTs. That electrodeposited PCV was applied as a chelating agent for copper ions as well as the redox mediator during the electrocatalysis of H_2O_2 (Deng et al. 2015). A new type of flexible and light weight electrode was developed by Sun et al based on highly dense Pt nanoparticles decorated free-standing graphene–CNT hybrid paper

(Pt/graphene–CNT paper) and its practical application as flexible electrochemical biosensor for the real–time tracking of H_2O_2 secretion by live cells was also investigated (Sun et al. 2015). The synthesis of a network of crosslinked CNT/Hb on a thiol-modified Au surface (fig. 6) and its application as the H_2O_2 sensor was proposed by us which revealed high conductivity by expediting the electrical transfer from Hb to the Au electrode and had a high electrocatalytic property for biosensing of H_2O_2 in smaple (Kafi and Crossley 2013). We also studied the application of CNTs in our work very recently by immobilizing Hb with multiporous nanofiber of SnO_2 and CNTs onto GCE, whereas, the composite material with Hb showed high sensitivity and lower detection limit towards the H_2O_2 reduction (Alim et al. 2018). In our other recent works, we discussed the role of CNTs to triumph high electron transfer (fig. 7) from HRP by immobilizing it with CNTs onto thiol modified Au electrode (Kafi et al. 2018b) and immobilizing hemoglobin with carbonyl functionalized SWCNTs onto the Au electrode (Kafi et al. 2018a).

6.3. Application in Nucleic Acid Biosensor

Liu et al., fabricated a DNA biosensor where they reported the preparation and characterization of tungsten disulfide-multi-walled carbon nanotubes (WS_2-MWCNTs) composite through a simple hydrothermal process and demonstrated its application as a biosensing platform for ultrasensitive determination of hepatitis B virus genomic DNA coupled with hybridization chain reaction (HCR) signal amplification (Liu et al. 2016). Another application of carbon nanotube was found in a research by Chen et al where a novel and sensitive electrochemical biosensor was

fabricated to detect specific-sequence target DNA (Chen et al. 2016). In the work of Li et al., MWCNTs have been used for developing a biosensor for detection of miRNA-24 by monitoring the oxidation signal of guanine. The synthetic DNA which were complementary with miRNA-24 were immobilized onto the surface of MWCNT-modified glass carbon electrodes by covalent cross-linking method (Li et al. 2014a). Qiu et al described a carbon nanotube (CNT)-based lateral flow biosensor (LFB) for rapid and sensitive detection of DNA sequence where amine-modified DNA detection probe was covalently immobilized on the condensed multi-walled carbon nanotubes (MWCNTs) through diimide-activated amidation between the carboxyl groups on the CNT surface and amine groups on the detection DNA probes (Qiu et al. 2015). Another label-free DNA biosensor was constructed by Benvidi et al., whereas, MWCNTs were implied in the electrode modification to develop the sensitivity of the biosensor (Benvidi et al. 2015). Functionalized MWCNTs were used very recently by Li and Lee as an additive in electrochemical DNA sensor to curb the electrochemical current depending on the sequence of the target DNA. This DNA detecting framework was straightforwardly generated by blending the constituents in a buffer solution and showed high DNA sequence separation capacity (Li and Lee 2017).

6.4. Application in Heavy Metal and superoxide Biosensor

A biosensor for trace metal ions detection was proposed by Moyo et al., based on horseradish peroxidase (HRP) immobilized on maize tassel multi-walled carbon nanotube (MT-MWCNT) through electrostatic interactions. That biosensor did not necessitate any complex immobilization procedure for the construction, and the metal ions were measured with low detection limits by

that biosensor (Moyo et al. 2014). A simple, signal-on electrochemical biosensor for sensitive detection of Ag^{+} was developed by Yan et al based on the three components of alkanethiol, SWCNTs and silver ion-specific oligonucleotide (SSO) layer-by-layer modified electrode. By comparing with other Ag+ biosensors based on C–Ag+–C interaction that developed biossensing platform might offer several pluses that made it suitable enough (Zhang and Yan 2014). In 2014, Ali and Mohamed developed a biosensor for the first time through a novel derivatized MWCNTs based on Mn(II) carbon paste electrodes. Modified carbon paste electrodes were prepared on that experiment by matrices compositions of potassium tetra kis[p-cholorophenyl] borate (KTpClPB), carbon powder and o-NPOE (Ali and Mohamed 2014). Yao et al. successfully showed use of CNTs by constructing a novel strip biosensor using MWCNTs as a color substrate for rapid and sensitive detection of Hg^{2+}. The mechanism of detection of Hg^{2+} was based on the covalent binding of the amino group with hydroxyl group for the assembly of multi-walled carbon nanotubes/DNA (MWCNT-DNA) (Yao et al. 2016). Recently, we have 3D Enzyme/Carbon Nanotube Conductive Networks to detect superoxide radical (Kafi et al. 2017). Synthesized 3D networks showed promising response to superxide radical as shown figure 8.

7. Application of Gold Nanoparticles in Biosensing:

Gold nanoparticles (AuNPs) offer a stable immobilization of biomolecules (redox protein or enzyme) by maintaining their bioactivity which is a significant benefit for the development and advancement of any biosensors. Moreover, gold nanoparticles also permit direct electron transfer like CNTs between the active site of redox proteins or enzymes and bulk electrode materials, which permits electrochemical biosensing to be performed without any necessity of mediators

for electron transfer. Its recent applications in the development of different biosensing devices were found to be significant in the improvement of sensitivity, selectivity and repeatability.

7.1. Applications in Glucose Biosensor

The general process of the synthesis of AuNP has been described in figure 9. The study of He et al., represented the application of AuNPs by presenting the synthesis and characterization of a novel electrochemical glucose biosensor based on AuNPs/bovine serum albumin/Fe_3O_4 (AuNPs/BSA/Fe_3O_4) composite nanoparticles. In situ immobilization of AuNPs significantly enhanced the electron transfer of glucose oxidase (GOx) enzyme used in this experiment (He et al. 2016). A ternary nanocomposite synthesized by dispersed AuNPs on the surface of RGO was achieved by Xue et al. in 2014 via easy wet-chemical routes by using polypyrrole (PPy) as a linker which exhibited brilliant electrocatalytic property toward O_2 reduction compared with RGO/PPy, RGO, and PPy. The sensor fabricated by these combinations exhibited long range of linearity against glucose concentration (Xue et al. 2014). Very recently by Gao et al., used AuNPs where they coupled this with silver nanoparticles (AgNPs) to assemble a plasmonic sensing platform for colorimetric detection of glucose. On that system, small AuNPs (~4 nm) acted as mimic of glucose oxidase (GOD) enzyme to catalytically oxidize glucose in the presence of oxygen by producing hydrogen peroxide, which dissolved AgNPs to lead the color changes in the solution (Gao et al. 2017). In 2015, a glucose biosensor based on the electrodeposited gold nanoparticle– polyvinyl pyrrolidone–polyaniline (AuNP–PVP–PANI) nanocomposites has been demonstrated by Miao et al. where the nanocomposites were electrodeposited on a glassy carbon electrode (GCE) in a homogeneous three component solution

comprised of aniline, PVP and AuNPs. Glucose oxidase (GOx) was further immobilized on the as-prepared AuNP–PVP–PANI nanocomposites using Nafion as the preventing layer (Miao et al. 2015). Use of Au-nanoparticles was also observed in the study of Thanh et al., where novel gold nanoparticle-anchored nitrogen-doped graphene (AuNP/NG) nanohybrid was synthesized through a seed-assisted growth method, as an effective electrocatalyst for glucose and dopamine detection (Thanh et al. 2016). In the work of Azak et al, a novel approach for constructing different glucose biosensors using conducting polymers of 4-(4H-dithyinol[3,2- b:2′,3′-d]pyroll-4-yl)aniline and 4-(4H-dithyinol[3,2-b:2′,3′-d]pyroll-4-yl)-[1,1′-biphenyl]-4-amine was propositioned where the surface of gold electrode was modified with mercaptoethane sulfonic acid and paminothiophenol functionalized gold nanoparticles and aniline modified GOx which showed very good linearity for glucose sensing (Azak et al. 2016). A novel route for the fabrication of a third generation glucose biosensor based on the immobilization of glucose oxidase on graphene-polyethyleneimine-AuNPs composite (GNS-PEI-AuNPs) was described recently by Rafighi et al. Glutaraldehyde was used in this study as cross-linking reagent (Rafighi et al. 2016). Biopolymer pectin stabilized AuNPs were prepared by Devasenathipathy et al in 2015 at graphene and multiwalled carbon nanotubes (GR-MWNTs/AuNPs) which was employed for the detection of glucose. Enzyme glucose oxidase (GOx) was successfully immobilized on GR-MWNTs/AuNPs film and direct electron transfer of GOx was observed from the experiment (Devasenathipathy et al. 2015). A novel and efficient bioactive surface nanostructuration method was proposed by Sapountzi et al. very recently via using enzyme-based electrospun nanofibers decorated with AuNPs for the fabrication of electrochemical biosensors (Sapountzi et al. 2017) and researcher described that the direct electron transfer was obtained with the increment of sensitivity, long linear range of detection and selectivity due to the utilization of AuNPs. Sabury

et al reported a facile method for immobilization of GOx on the partially reduced graphene–gold nanocomposite (PRGO–AuNPs/GOx) as a novel biosensor for determination of glucose concentration in tested samples (Sabury et al. 2015). Parlak et al. conveyed the fabrication of a novel biosensor with AuNPs very recently based on MoS_2 nanosheets and the effect of nanostructuring of metal particles using a simple, inexpensive and high order two-dimensional biosystem, which was highly sensitive, selective and stable (Parlak et al. 2017a).

7.2. Application in H_2O_2 Biosensor

Zhang et al. reported the electrodeposition of AuNPs onto porous GaN electrode obtained by photoelectrochemical etching planar GaN to fabricate a non-enzymatic hydrogen peroxide (H_2O_2) biosensor. The AuNPs/porous GaN electrode exhibited good electrocatalytic activity toward the nonenzymatic detection of H_2O_2 with enhanced sensitivity. (Zhang et al. 2017a). Another application of AuNPs was observed in the study of Boujakhrout et al where AuNPs modified with 4-mercaptopyridine and 6-mercapto-1-hexanol were utilized as coordination agents to fabricate a novel hybrid nanomaterial with Ag:4,40-bipyridine nanobelts which was employed to modify glassy carbon electrodes and to design an HRP-based mediatorless amperometric biosensor for H_2O_2 and that biosensor was able to detect the analyte at picomolar levels (Boujakhrout et al. 2016). Gong et al., used AuNPs where novel self-assembled dipeptide–AuNPs hybrid microspheres with a hollow structure have been synthesized in aqueous solution by a simple one-step method, and HRP was further immobilized on the dipeptide–AuNPs hybrid spheres to construct an amperometric biosensor for the detection of H_2O_2 (Gong et al. 2015). A

self-referenced cholorimetric optical biosensor was proposed by Rivero et al. very recently, whereas, both AuNPs an AgNPs were used for quantitative determination of H_2O_2 (Rivero et al. 2017) and the synergistic effect of these two nanomaterials showed great performance in enhancing the sensitivity and selectivity of this fabricated biosensor. A facile solvothermal route for synthesizing SnS_2/gold nanoparticle (SnS_2/AuNPs) hybrids was proposed by Yan et al., which was further utilized in biosensing and showed acceptable performance in the detection of H_2O_2 in the sample (Yan et al. 2017).

7.3. Application in Nucleic Acid Biosensor

Esmaeili et al., very recently showed the use AuNPs in the preparation and characterization of a DNA biosensor which was fabricated based on kappa-carrageenan-polypyrrole-gold nanoparticles nano-biocomposite. The biosensor was applied for gender classification of Arowana fish. On that experiment, immobilization of the thiol modified Arowana fish ssDNA probe sequence was successfully carried out through covalent attachment to the gold (Au) on the surface of the nano-biocomposite membrane (Esmaeili et al. 2017). Li et al., designed an ultrasensitive electrochemical DNA biosensor based on the assembly of highly conductive AuNPs on the free terminal of hairpin-structured probe DNA, and the biosensor exhibited robust hybridization selectivity, stability and regeneration ability (Li et al. 2016). Another sensitive electrochemical DNA biosensor was developed by Hajihosseini et al. by using AuNPs for *Helicobacter pylori* detection using differential pulse voltammetry. On that experiment, single-stranded DNA probe was immobilized on GO/AuNPs/GCE (Hajihosseini et al. 2016) and possessed greater hybridization selectivity and stability. Very recently McVey et al., proposed a

pioneering approach is exploiting endonuclease-controlled aggregation of plasmonic AuNPs for label-free and ultrasensitive detection of bacterial DNA where RNA-functionalized AuNPs was utilized which formed DNA-RNA heteroduplex structures through specific hybridization with the target DNA (McVey et al. 2016). In the same year, an electrochemical DNA biosensor was successfully fabricated by Mohammed through using 3-aminopropyl-tri-ethoxysilane (APTES) as a linker molecule coalesced with AuNPs on a thermally oxidized SiO_2 thin film (Mohammed 2016). One more new method was proposed by Sattaramady et al., based on hybridization of gold nanoparticles linked a specific single stranded DNA probe from the non-protein coding region of *Leishmania* major mini circle kinetoplast DNA (Sattarahmady et al. 2016). Sattarahmady et al., reported a nanobiosensor based on AuNPs and oligonucleotide probe for the visual detection of *Brucella spp*. A specific oligonucleotide probe from IS711 gene region was functionalized with AuNPs on that work (Sattarahmady et al. 2015). In 2015, Cai et al reported on a AuNPs decorated graphene field-effect transistor (FET) biosensor for highly sensitive, selective and label-free detection of miRNA. That AuNPs-decorated graphene FET biosensor was constructed by drop-casting the reduced grapheme oxide (RGO) suspension onto the eletrode surface, and consequently decorating AuNPs onto the surface of RGO. After the immobilization of peptide nucleic acid (PNA) probe on the AuNPs surface, PNA–miRNA hybridization technique was implied for miRNA detection (Cai et al. 2015). A one-target-triggered hybridization chain reaction (HCR) strategy was proposed by Wang et al. in the same year for high sensitive electro-generated chemiluminescence (ECL) detection of DNA, whereas, the sensor was constructed by immobilizing a capture probe (CP) on a gold electrode via an Au–S bond (Wang et al. 2015c). An ultrasensitive sandwich-type electrochemical biosensor was developed most recently by Shuai et al. for the detection of microRNA (miRNA) based on

magnesium oxide (MgO) nanoflower and graphene oxide–AuNPs hybrids coupling with electrochemical–chemical–chemical (ECC) detection system. That biosensor exhibited a good dynamic property of selectivity and a low detection limit (Shuai et al. 2017). A novel, enzyme-free and highly sensitive SPR biosensor for miRNA detection using amplification of AuNPs coupling with DNA super sandwich was developed by Wang et al in 2016 (Wang et al. 2016c). Frang et al designed an ultra-sensitive hairpin DNA-based electrochemical DNA biosensor for K-ras gene detection in 2014 where the AuNPs and HRP–streptavidin capped AuNPs (HAS) conjugates were used for signal amplification. The fabricated biosensor was applied to a short single-stranded oligonucleotide model target, and that application to double-stranded genomic DNA had not been demonstrated and the recovery investigation in serum sample provided the possibility to qualitatively and quantitatively detect the K-ras gene in pancreatic cancer (Fang et al. 2014).

7.4. Application in Heavy Metal Biosensing

Taghdisi et al., developed a sensitive, selective and fast colorimetric aptasensor for Pb^{+2} based on polyethylenimine (PEI) and AuNPs. That developed sensor retained a high selectivity & low detection limit with greater sensitivity (Taghdisi et al. 2015). Another researcher proposed a sensitive, selective, and simple fluorescence spectrometric sensor for Hg^{2+} detection in aqueous solution by using thiol-DNA-functionalized AuNPs which was based on the Hg^{2+}-induced conformational change of single-stranded DNA (ssDNA) with an enhanced fluorescence resonance energy transfer (FRET) process between the energy donor (fluorescein, FAM) and the energy acceptor (AuNPs) (Wang et al. 2015a). Nanoporous AuNPs dispersed on the ITO film

coated glass was employed for the first time by Lin et al., to fabricate Hg(II) biosensing platform in differential pulse anodic stripping voltammetry. That integrated features of highly porous nanoparticles and the high affinity of gold nanomaterials to mercury endowed the biosensing platform with high sensitivity and excellent reproducibility (Lin et al. 2015). A well-dispersed AuNPs grown on carbon nanofibers (AuNPs/CNFs) with excellent electroanalytical activity and sensitivity towards the detection of heavy metal ions was synthesized by Zhang et al via electrospinning technology and in situ thermal reduction (Zhang et al. 2016). In the contemporary work, Wang et al., reported on a sensitive, selective and reusable electrochemical biosensor for the determination of mercury ions (Hg^{2+}) based on thymine (T) modified AuNPs/rGO nanocomposites. The proposed biosensor was found to be highly sensitive for the detection of Hg^{2+} (Wang et al. 2016b). Another novel electrochemical sensing system for Pb^{2+} had been developed by Peng et al based on a typical icosahedral AuNPs modification and the improved rolling circle amplification (RCA) (Peng et al. 2014). Another highly sensitive electrochemical DNA based biosensor comprised of polyaniline and AuNPs nanocomposite had been used by Yang for the detection of trace concentration of Ag^{+} which exhibited good selectivity and repeatability (Yang et al. 2015b). Novel electrochemical biosensors for the detection of Ag^{+} based on Ag^{+}-induced DNA hybridization, using Ethyl green (EG) as an electroactive label on the surface of bare carbon paste electrode (CPE) and AuNPs-modified carbon paste electrode were proposed by Ebrahimi et al. That biosensors confirmed good selectivity towards Ag^{+} ions detection in the presence of some metal ions such as Pb^{2+}, Cu^{2+}, Ca^{2+}, Zn^{2+}, Fe^{2+} and Hg^{2+} (Ebrahimi et al. 2015).

7.5. Application in Immunosensor

Application of AuNPs in immunosensor was proposed by Liu et al. where a highly sensitive electrochemiluminescence (ECL) strategy was developed for the protein kinase A (PKA) activity and inhibition assay based on double-quenching of graphene quantum dots (GQDs) ECL by G-quadruplex–hemin DNAzyme and AuNPs (Liu et al. 2015). The experimental work of Miao et al proposed a label-free platform for sensitive cholesterol detection upon the precipitation of cetyltrimethyl ammonium bromide (CTAB) stabilized gold nanoparticles (AuNPs) (Miao et al. 2017). A simple and ultrasensitive electrochemical biosensing technique based on AuNPs/GO for quantification of p53, a tumor suppressor protein, was developed and characterized by Afsharan et al., in 2016. The causes for such ultrahigh and amplified sensitivity could be attributed to the use of GO and streptavidin- modified AuNPs which had not only improved the electron transfer rate but also had increased the amount of captured anti-p53 (Afsharan et al. 2016). Experimental study of Ly et al. employed a quartz crystal microbalance (QCM) technique to detect HIV-1 antigen at a very low concentration by using gold nanoparticles (AuNPs) as a signal enhancer (Ly et al. 2016). Monerris et al described the development of a simple and sensitive electrochemical immunosensor (EI) in 2016 to quantify estrone in water samples where the immunosensor was constructed by the immobilization of the anti-E monoclonal antibody (mAbE) on a glassy carbon electrode (GCE) modified with AuNPs electro-synthesized on a 1-naphtylamine polymer (pNap) film (Monerris et al. 2016). A novel liquid crystal (LC) biosensor based on seedless production of AuNPs had been developed by Li et al for the detection of l-tyrosine (Tyr) where tyrosinase (TR) stimulated the biocatalyzed hydroxylation of Tyr to l-DOPA, which mediated the generation and growth of AuNPs. Results obtained from this study also suggested high anti-interference activity of the fabricated biosensor (Li et al. 2015b). In

2015, Li et al., developed a new method for real-time detection of carcinoembryonic antigen (CEA) in human serum with high sensitivity and selectivity using surface plasmon resonance (SPR) biosensor, whereas, two kinds of antibodies were utilized to identify CEA at different epitopes with high affinity and specificity. Gold nanoparticles (GNPs) modified with streptavidin (SA) were used on that biosensor to further enhance signal specifically through biotin–streptavidin interaction and the biosensor also revealed good selectivity for CEA in the interference study (Li et al. 2015a). Recently Zhang et al., developed a novel peptide self-assembled biosensor based on gold nanoparticles functionalized grapheme oxide (GO) for specific detection of thrombin. By designing sulfhydryl, peptides containing thrombin cleavage sites could self-assemble with the nanocomposites of the graphene material and gold particles bringing the biosensor unique optoelectronic properties and high biological sensitivity to transduce bio-molecular interactions into optical signals (Zhang et al. 2017b). Khalilzadeh et al. developed an ultrasensitive novel electrochemical biosensor for convenient, sensitive and selective detection of caspase-3 activity. Gold nanoparticles functionalized silica-based mesoporous material (MCM-41) modified glassy carbon electrode was synthesized and used for measurement of caspase-3 activity especially in its active form. Thiolated MCM-41 was decorated with gold nanoparticle by using post modification method (Khalilzadeh et al. 2016). Miao et al., presented an ultrasensitive and simple strategy in 2016 for protein tyrosine kinase-7(PTK7) detection based on the recognition-induced structure change of sgc8 aptamer and the signal change of methylene blue (MB) which interacted with sandwiched DNA complex. A homogeneous nano-surface was formed firstly on the surface of glass carbon electrode (GCE) by using negatively charged Nafion (Nf) as the inner layer and positively charged gold nanoparticles ((+)AuNPs) as the outerlayer for fabrication that biosensor. The immobilization of

sgc8 aptamer based on Au–S bond was done after that (Miao et al. 2016). A novel colorimetric assay for myoglobin detection was developed by Wang et al based on hemin/G-quadruplex DNAzyme functionalized gold nanoparticles (AuNPs) where no expensive instruments were required except UV–vis spectrophotometer and that assay exhibited excellent sensitivity because of the AuNPs amplification. Furthermore, this simple and sensitive assay was used for the detection of myoglobin in human serum samples indicating great potentiality in clinical biological analysis, especially in developing countries (Wang et al. 2015b)

8. Future Perspectives:

AuNPs and CNTs have been used extensively in the development of nanomaterial based biosensosing system. But we assume that there are a few research with these nanomaterials are still unconcluded that have the potential in the recent future and demand further modification and advancement in functionalizing of these two nanomaterials for overcoming the challenges of ultrasensitive biosensing. The first demand is to develop multifunctional AuNPs and CNTs with different sizes for the biosensing of different analytes at a time within very short time with higher selectivity and sensitivity. Another necessity is to functionalize these two nanomaterials in such way where different types of other nanomaterials can be attached to them, and the synergic effect in biosensing can be examined. Further advancement of these two novel nanomaterials can be a great scope of research for obtaining more novel characteristics which can be aspiring in the development of nanomaterial based biosensor in the near future.

9. Conclusion

Gold nanoparticles (AuNPs) and Carbon nanotubes (CNTs) represent a magnificent nanoplatform in advancing analytical strategies for biosensing, and many research bunches have shown that they can be utilized for an extensive variety of detecting applications, extending from compound to natural example. The combination of low toxicity, high surface area, rich surface functionalization chemistry and colloidal stability of these two nanomaterials permits to be safely introduced into the system of a biosensor for the detection of different analytes in vitro and in vivo. We believe that in the coming few years, there will be tremendous growth in developing carbon nanotubes and gold nanoparticle based biosensor devices for therapeutic as well as diagnostic applications in different aspects.

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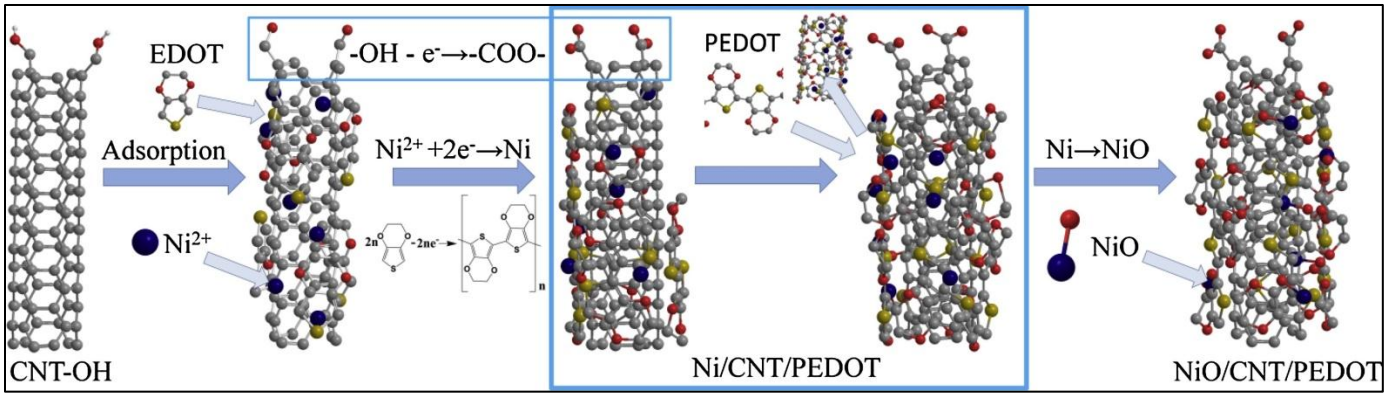

Figure 1. Mechanism for the formation of NiO/CNT/PEDOT on GCE (Sun et al. 2018).

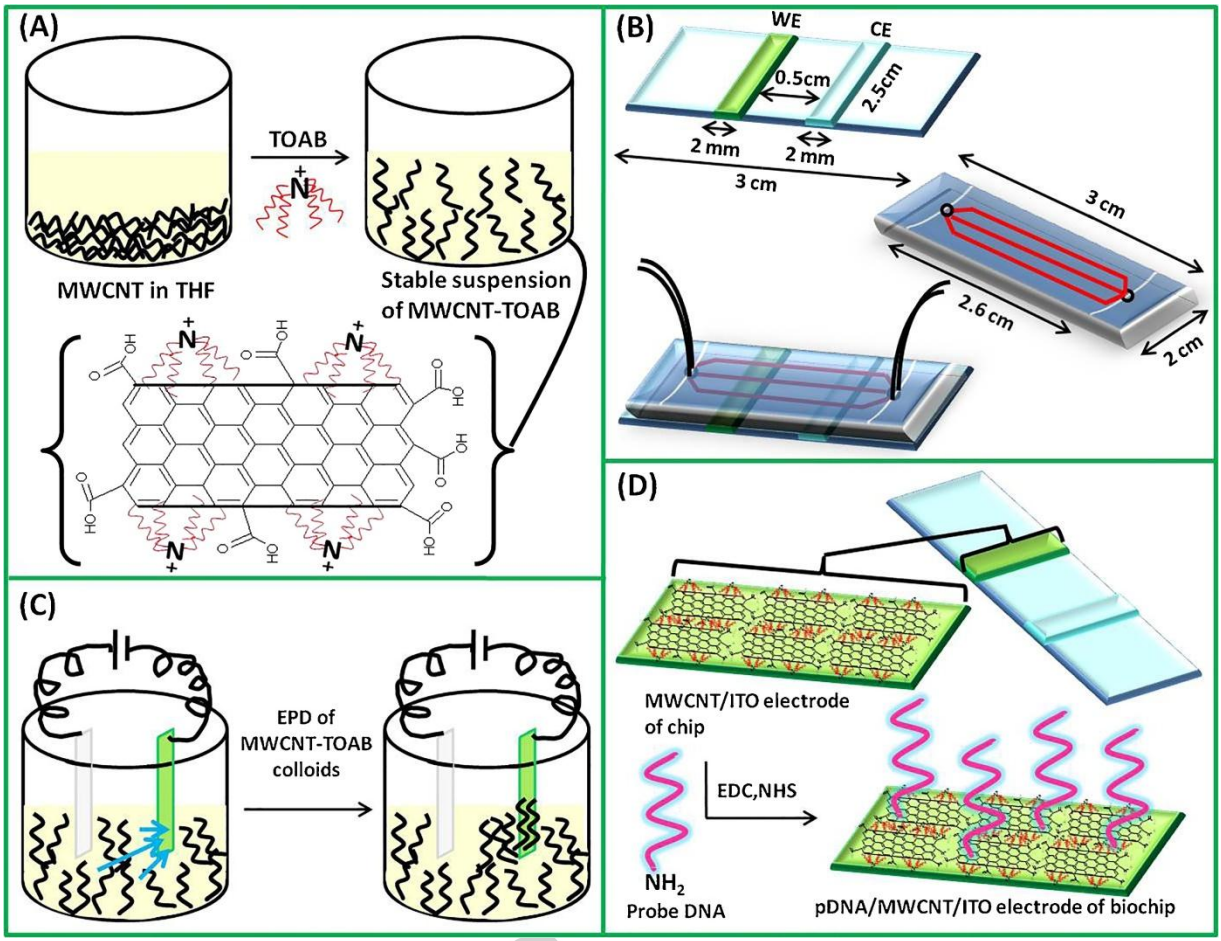

Figure 2. Stepwise illustration of microfluidic biochip fabrication for electrochemical detection of DNA hybridization; (A) Exfoliation of MWCNT via sonication with TOAB, (B) micropatterning of the ITO substrate and fabrication of microchannels, (C) EPD of MWCNT over the working electrode of the chip and (D) immobilization of DNA probe on the surface of MWCNT/ITO chip (Ghrera et al. 2018),

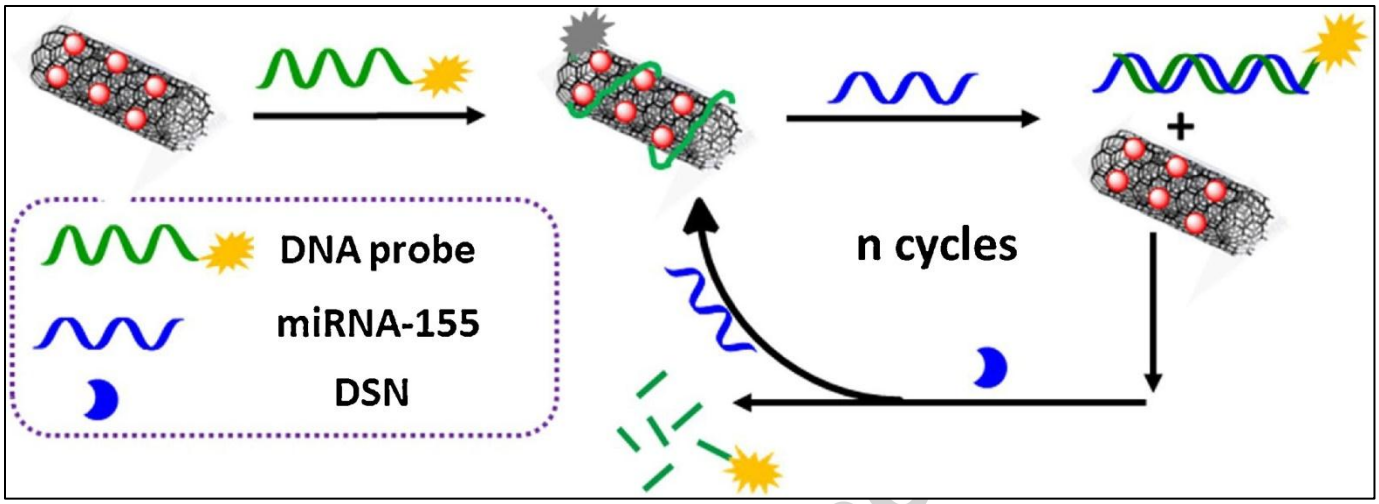

Figure 3. Schematic explanation of the functionalization of CNTs for miRNA-155 assay (Ma et al. 2018a).

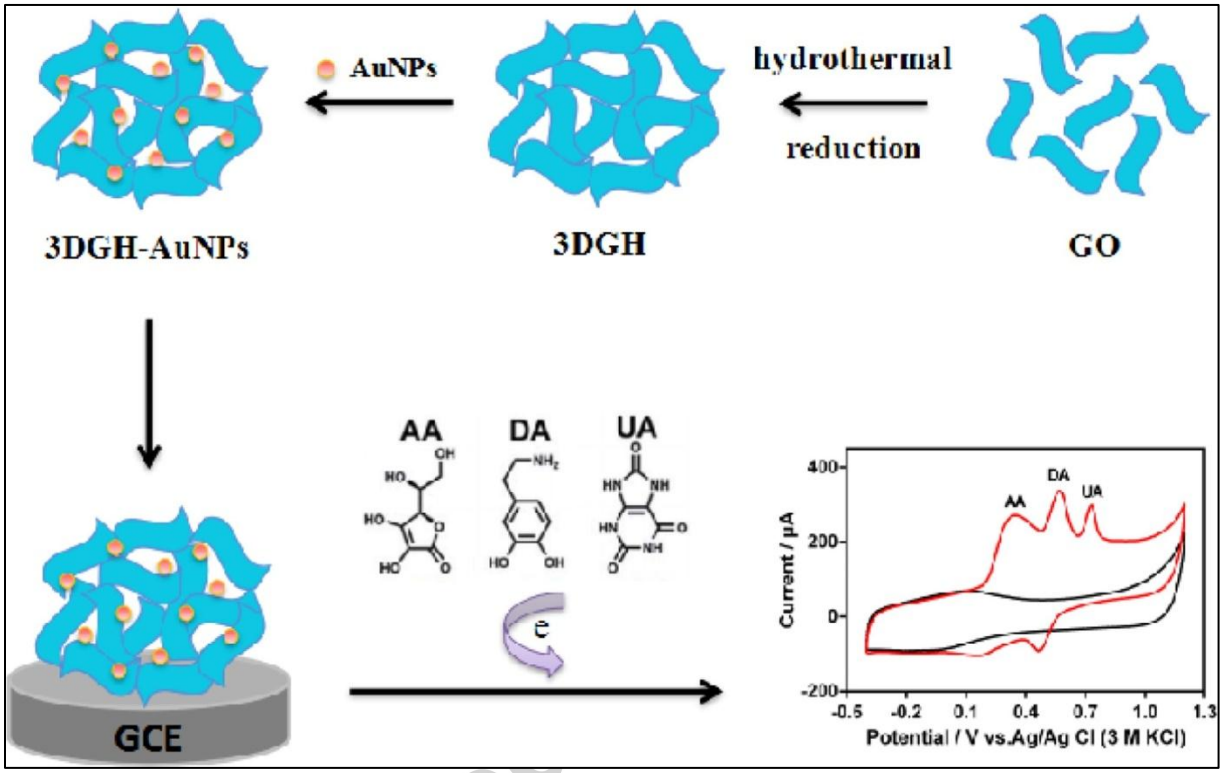

Figure 4. Fabrication and detection process of the electrochemical sensor by using functionalized AuNPs (Baetsen-Young et al. 2018).

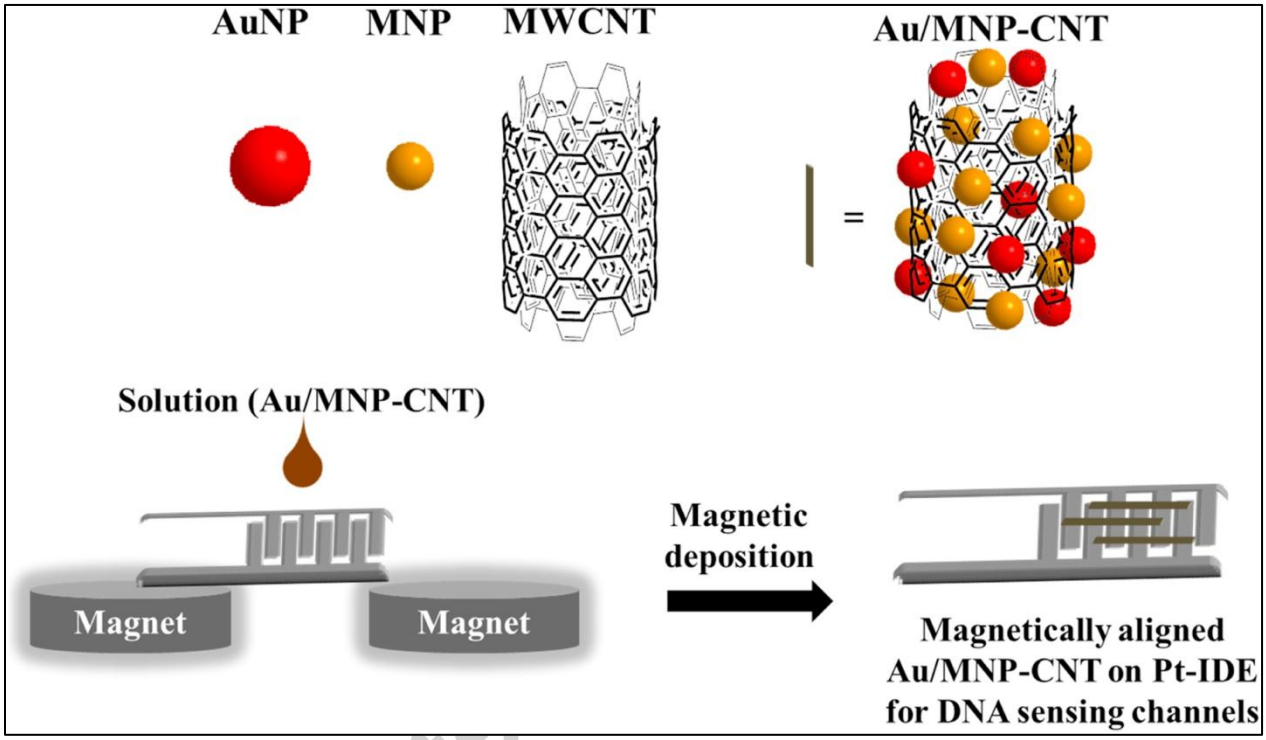

Figure 5. Illustration of the preparation of the magnetically aligned Au/MNP-CNTs on the Pt-IDE for DNA sensing channels (Lee et al. 2018).

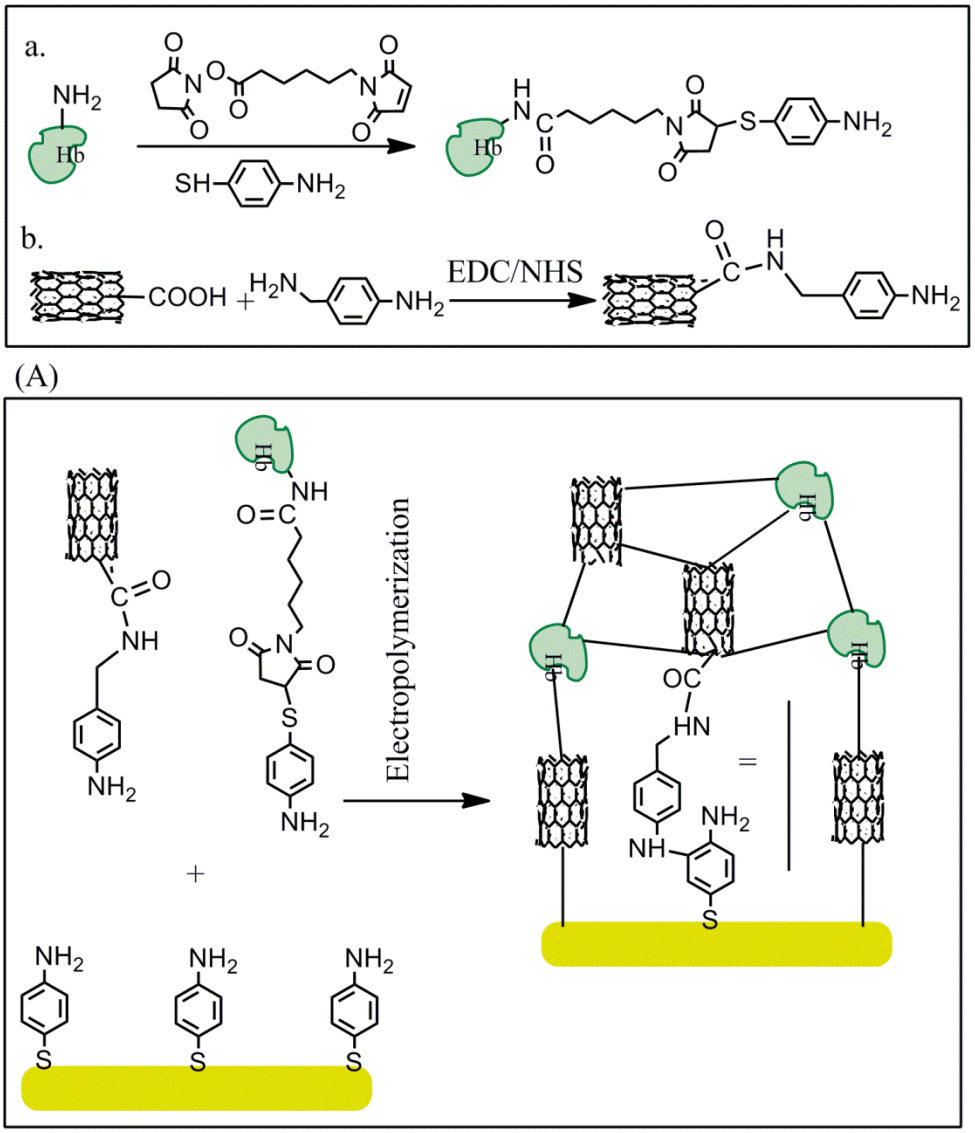

Fig 6 A. (a) Modification of enzyme (Hb) with the polymerizable 4-aminothiophenol functionality. (b) Functionalization of the CNT with the electropolymerizable aniline functionality. **B.** Formation of the three-dimensional (3-D) oligoaniline-cross-linked CNTs/Hb composite by the co-electropolymerization of the thiol-modified Hb and thiol-modified CNT on the thiol-monolayer-functionalized Au electrode. (Reprinted from, Kafi et al., 2013)

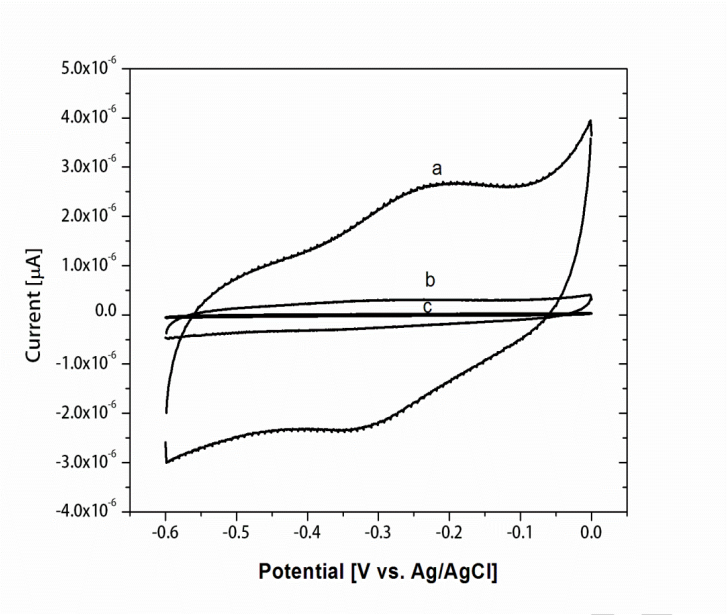

Fig 7. Cyclic voltammamograms response at the Au/SAM/HRP/CNT (a); the Au/SAM/HRP (b) and a bare Au electrode (c) in 0.1 mol l^{-1} PBS with pH 7.0 at a scan rate of 0.1 V/s. (Reprinted from Kafi et al., 2013))

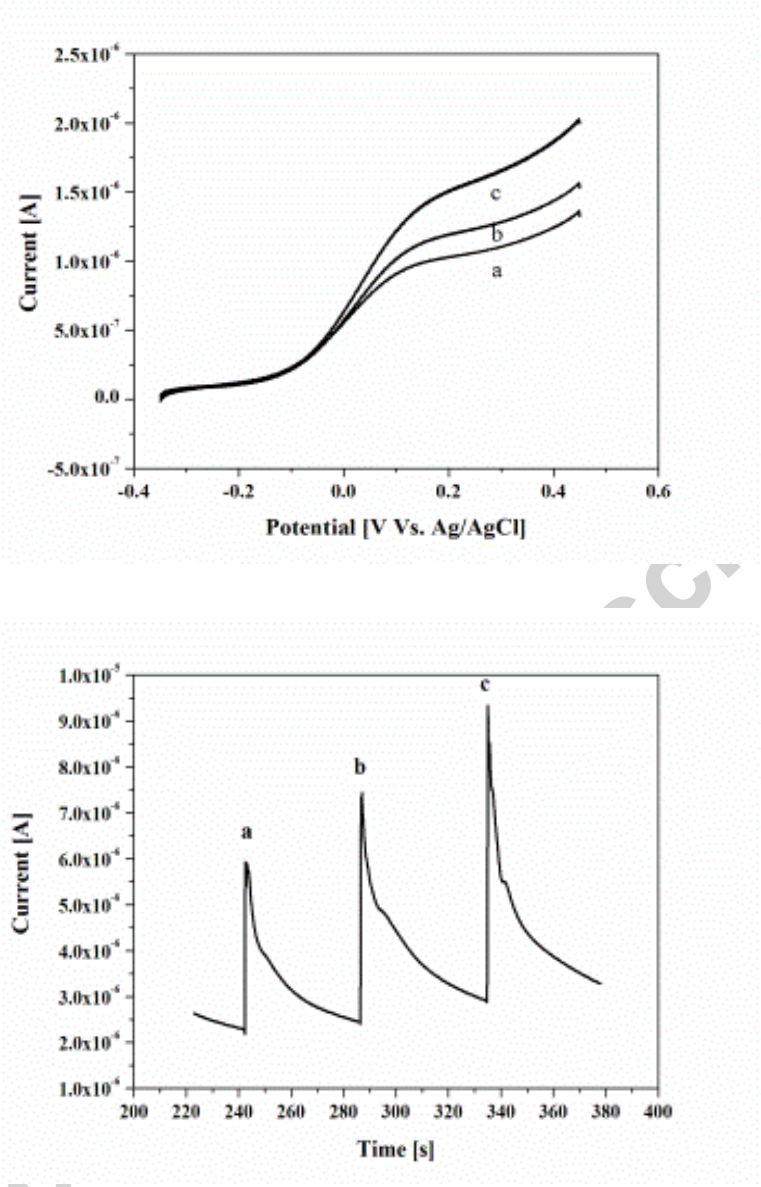

Fig.8 : (A) Linear sweep voltammogram of the Au/SAM/CNT/CytC electrode in the presence and absence of superoxide. (B) Amperometric response of the Au/SAM/CNT/CytC electrode against superoxide. (Reprinted from Kafi et al., 2017)

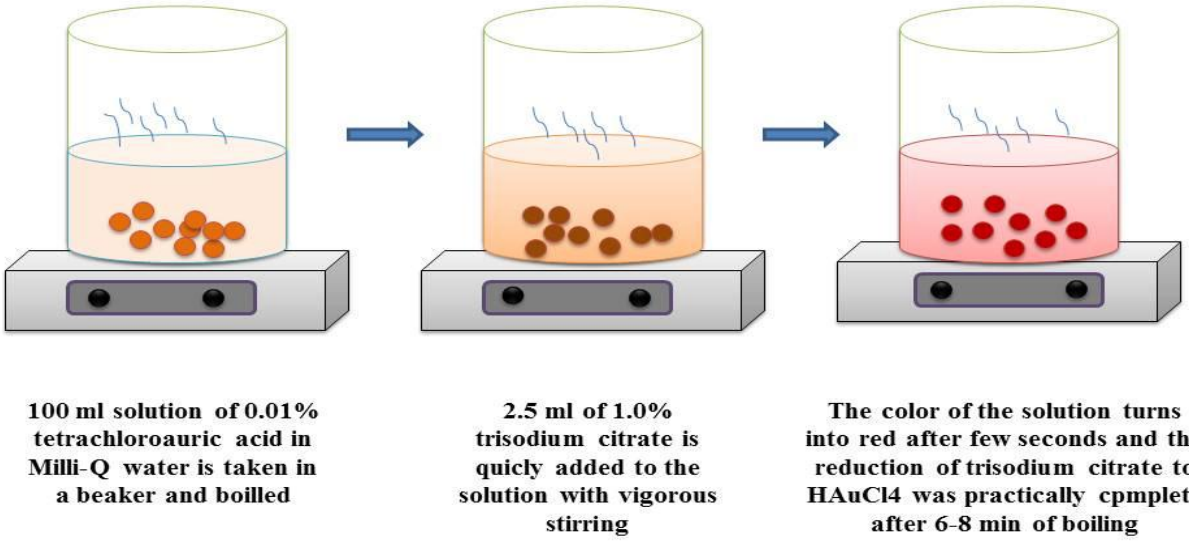

Fig.9 : The AuNPs with particular sizes of 5, 10, 15, and 25 nm is prepared by following the procedures reffered in the literature [109], whereas, the AuNPs with 5 nm is prepared at room temperature by adding 1 mL of a 1% (w/w) sodium citrate solution with 100 mL of a 0.01% (w/w) $HAuCl_4$ aqueous solution through stirring. 1.6 mL of 0.075% (w/w) $NaBH_4$ (dissolved in the 1% (w/w) sodium citrate solution) is added after 1 min. The mixture is stirred vigorously and the 5 nm AuNPs are obtained when the solution color turns into red. For preparing the 10 nm AuNPs, the same procedures are followed as those are used for the 5 nm NPs, except that 1 mL of the $NaBH_4$ solution is added. For the 15 and 25 nm AuNPs, 5 or 4 mL of the 1% (w/w) sodium citrate solution, respectively, is added to 100 mL of a 0.01% (w/w) boiling aqueous $HAuCl_4$ solution with robust stirring. The color is changed from pale to blue and then to burgundy. Boiling is continued for 15 min, and then, the sample is stirred continuously until it is cooled to room temperature.

Table 1. Different ways of CNTs & AuNPs functionalization for the fabrication of biosensor with their LOD and sensitivity towards corresponding analytes.

	Analyte	Way of functionalization for biosensor	LOD	Sensitivity ($\mu A\ \mu M^{-1}\ cm^{-2}$)	References
CNTs	Virus H5N1	DNA-probe sequences non-covalently attached to the sidewalls of N-doped CNTs	0.00002–0.02 μM	-	(Fu et al. 2017)
	Dengue virus	Non-covalent modification with heparin	8.4×10^2 $TCID_{50}$/mL	-	(Wasik et al. 2017)
	Protein C	Dendrimer modified 8-channel screen-printed electrochemical array	0.035 μM	-	(Silva et al. 2015)
	Serotonin	Electrochemical deposition of NiO/CNT/PEDOT	0.063 μM	3.04	(Sun et al. 2018)
	Toxin (Ochratoxin A)	Carboxyfluorescein-modified aptamer adsorbed onto the CNTs surface	0.0172 μM	-	(Lv et al. 2016)
	Myoglobin	Modified with molecularly imprinted polymerized ionic liquid	0.0097 μM	-	(Wang et al. 2017)
	Dopamine	Grapheme foam &	0.00136 μM	12.72	(Huang et

	AuNPs coupled with CNTs			al. 2017a)
Glucose	CNTs coated with carbonized silk fabric by Pt microsphere decoration	50 μM	288.86	(Chen et al. 2018)
DNA/gene	Electrophoretic deposition of carboxyl-modified CNTs	-	-	(Ghrera et al. 2018)
miRNA	Fluorophore labeled DNA probe to CNTs/Au composite	3.34×10^{-8} μM	-	(Ma et al. 2018a)
Choline	CNTs/AuNPs composite with chitosan	0.6 μM	204	(Magar et al. 2017)
Bacteria	Anti-*E. coli* O157:H7 combined with CNT	1 CFU mL^{-1}	-	(Li et al. 2017f)
NADH	CNTs functionalized with 3-aminophenyl boronic acid	0.16 μM	161	(Li et al. 2017b)
Xanthine	CNTs in poly(GMA-co-VFc) copolymer film	0.12 μM	16	(Dervisevic et al. 2015)
Cholesterol	Prusian blue modified CNTs	3 μM	-	(He et al. 2017)
Lactate	Carboxylated MWCNT/ (CuNPs)/polyaniline	0.25 μM	-	(Dagar and Pundir 2017)
Ethanol	Electrodiposition of	10 μM	4.28±0.06	(Wilson et

		Polytyramine onto CNTs			al. 2017)
	Cancer biomarker	Polyethyleneimine modified CNTs	0.35 U/mL	-	(Thapa et al. 2017)
	Bisphenol A	AuNPs attached with carboxylated CNTs	0.004 μM	-	(Messaoud et al. 2017)
	Nitric oxide	Recombinant silk modified CNTs	0.002 μM	-	(Musameh et al. 2018)
	Virus	Sialic Acid-functionalized AuNPs	0.156 vol%	-	(Lee et al. 2017)
	Carbofuran	GO combined with AuNPs	0.72 μM	-	(Jirasirichote et al. 2017)
	Tryptophan	AuNPs/amine-functionalized silica nanoparticle	0.00026 μM	-	(Hashkavayi et al. 2017)
	miRNA-21	AuNPs modified with MoS_2	7.8×10^{-10} μM	-	(Su et al. 2017)
AuNPs	Protein kinase	Ferrocene-labeled peptide-triggered AuNPs	20 mU/mL	-	(Sun et al. 2017)
	Myoglobin	AuNPs/arginine-glycine-aspartic/carboxylated grapheme	26.3 ng mL^{-1}	-	(Li et al. 2017a)
	Dopamine	Ionic liquid functionalized GO supported AuNPs	0.0023 μM		(Li et al. 2017c)
	Glucose	AuNPs modified with 2D-MoS_2	0.042 μM	13.80	(Parlak et al. 2017b)
	DNA/gene	dextrin-capped AuNPs	2.9×10^{-9} μM	-	(Baetsen-Young et al. 2018)

miRNA	Thiol terminated capture probe with AuNPs	0.0001 μM	-	(Mandli et al. 2017)
Acrylamide	AuNPs with FAM-labeled dsDNA	0.5 μM	-	(Asnaashari et al. 2018)
Ascorbic acid	Graphene hydrogel modified AuNPs	0.0028 μM	-	(Zhu et al. 2017)
Bacteria	AuNPs functionalized as SERS nanoprobes	4 cfu/mL	-	(Ma et al. 2018b)
Dibutyl Phthalate	AuNPs with CNTs and antigen	7 ng/mL	-	(Liang et al. 2017)
Xanthine	Polypyrrole functionalized AuNPs	0.25 μM	-	(Dervisevic et al. 2017)
Cholesterol	Silver deposition on AuNPs	3.0 μg/mL	-	(Huang et al. 2017b)
Lactate	Tetradentate ligand-modified AuNPs	2.6 μM	5.1 ± 0.1	(Bravo et al. 2017)
Drug	RGo/polyaniline capped AuNPs	0.00029 μM	-	(Hashemi et al. 2017)
Prostate specific antigen	AuNPs-Dpa-melanin nanosphere	2.7 pg mL^{-1}	-	(Dong et al. 2017)
Influenza virus DNA	AuNPs & Iron oxide nanoparticle modified CNTs	0.0000088 μM	-	(Lee et al. 2018)
Carcinoembryonic antigen	SiO_2 layer combined with AuNPs	37 pg/mL	-	(Li et al. 2017e)

Highlights

- Wide range of and application of carbon nanotube and gold nanoparticles based on electrochemistry has been overviewed
- We have summarized and future outlooks the application of CNT and AuNP in different biosensing applications.
- Wide range of readers will be benefited.