Chapter V

Simultaneous determination of adenine and guanine using \( \text{Fe}_3\text{O}_4-\text{Gnp} \) modified aluminium electrode

Research in the production of composite coatings by electrolytic codeposition of fine particles with metal oxides from plating baths has been investigated by numerous investigators. Interest in electrodeposited composites has increased substantially during the past two decades due mainly to the fact that composite coatings can give various properties, corrosion resistance, oxidation resistance and self-lubrication, to a plated surface. Research attention on electrodeposition of composite coatings has been directed towards the determination of optimum conditions for their production, i.e., current density, temperature, particle concentration and bath composition. Nanocomposite coatings offer novel properties, such as increased toughness, high temperature inertness, chemical and biological compatibility, magnetism, piezoelectricity and photochromatism [1-3].

Magnetite (\( \text{Fe}_3\text{O}_4 \)) is a material having currently both industrial and scientific interest. This material reveals the strongest saturation magnetization of any natural iron oxide [4], and is used mainly in printing ink, and recently for biomedical applications because of their biocompatibility and low toxicity in the human body [5]. Because of these applications, importance in magnetite nanoparticles has lately grown. It has been reported that nanoparticles exhibit electrical, chemical, magnetic and optical properties different from those presented in bulk size [6, 7].

Iron nanoparticles have many potential to bio application such as drug delivery system, hyperthermia treatments, magnetic resonance imaging contrast enhancement, etc [8-10]. The carbon-encapsulated metal nanoparticles were first synthesized as LaC nanoparticles in 1993 by Ruoff et al. [11]. So far, these particles have been commonly produced by conventional arc discharge [12], modified arc
discharge [13], chemical vapor deposition (CVD), combustion, laser synthesis, ion beam sputtering [14], and annealing microporous carbon or diamond with metal nanoparticles [15]. Carbon coating of the magnetic nanoparticles can leave the toxicity out without detracting their magnetic properties. Moreover, the carbon coating not only stabilize the nanoparticles but can also be used for further functionalization, such as addition of the therapeutic agent, targeting agent or fluorophore, depending on the purposes.

Electrodeposition is one method used to prepare metal/metal oxide-matrix nanocomposite coatings. In this process, the nanoparticles (or whiskers) are suspended in an electrolyte and embedded in the growing metal/metal oxide layer [16]. Nano-sized particles dispersed into a metal matrix can stimulate the homogeneity of the composites and develop the potential applications for metal/metal oxide matrix nanocomposite coatings.

In the present chapter, a composite made of Fe₃O₄ nanoparticles immobilized on graphite nanoparticles modified aluminium electrode (Gnp) was fabricated by electrochemical deposition. The modified electrode was characterized by SEM, XRD, and cyclic voltammetry (CV). The modified electrode eliminates the disadvantage of the irreversible adsorption of purine bases on the electrode surface. The outcomes presented here are more evident that Fe₃O₄-Gnp/Al modified electrode could bring new capabilities for the electrochemical devices by combining the advantages of graphite nanoparticles and magnetite nanoparticles, and can be readily used for simultaneous determination of the applicable bases as well as ultra-high sensitive detection of DNA.
5.1. Characterization of Fe$_3$O$_4$-Gnp/Al electrode

5.1.1 SEM images of Fe$_3$O$_4$-Gnp/Al electrode

![SEM images of Fe$_3$O$_4$-Gnp/Al electrode](image)

**Fig. 5.1.** SEM image of bare Al electrode (a), and Fe$_3$O$_4$-Gnp/Al electrode (b)

FE-SEM images of bare Al electrode and Fe$_3$O$_4$-Gnp/Al are showed in fig. 5.1. From the figure, it can be seen that the surface of bare aluminium is quite even and the indiscernible. After electrodeposition, the Al electrode is covered by Fe$_3$O$_4$-
Gnp/Al composite. As shown in figure 5.1. (b) the surface of Fe₃O₄-Gnp/Al is rough and spherically shaped particles are presented. This rough and spherically shaped surface could easily adsorb the analyte in the buffer solution and act as better electrochemical sensor for adenine and guanine.

5.1.2. XRD pattern of Fe₃O₄-Gnp/Al

![XRD Pattern](image)

Fig 5.2 XRD patterns of as-obtained Fe₃O₄-Gnp composite coating on aluminium electrode

Fig. 5.2 shows the XRD pattern indicates the crystal nature of magnetic nanocomposite. XRD pattern of Gnp exhibit a single carbon peak at 2θ with a value of 26.7° which corresponds to the graphitic layered structure. XRD pattern of Fe₃O₄-Gnp nanocomposites exhibit the peak of magnetite at 2θ values of 30.5°, 36.4°, 43.5° and 62.5° along with graphitic carbon peak at 26.7°. These peaks correspond to the
face centered cubic structure of magnetite nanoparticles (JCPDS No. 65-3107). Thus XRD pattern of nanocomposite suggests the formation of two phases, one is cubic magnetite nanoparticles and the other is graphite structure of Gnp. That is to say that the XRD patterns conform the formation of Fe₃O₄-Gnp composite material, and there are no diffraction peaks for impurities, implying the controllable process in this reaction system.

5.2 Electrocatalytic behaviour of modified electrode

5.2.1 Electrochemical oxidation of guanine

The influences of graphite and Fe₃O₄ on the aluminium electrode for guanine oxidation was investigated based on cyclic voltammetric measurements (Fig. 5.3). No redox peak was observed in the range from +0.0 to +1.2 V at bare aluminium modified electrode (Fig.5.3 (a)), indicating that graphite, and Fe₃O₄ on the aluminium electrode are electroinactive in the scanned potential window. In the presence of 10 μM guanine, the Gnp/Al electrode (Fig. 5.3 (b)) showed a small oxidation peak. While the Fe₃O₄/Al electrode (Fig. 5.3 (c)) exhibits an excellent amplification of the guanine oxidation response, with peak current value of -0.63 μA. The highest oxidation peak current (-0.965 μA) of guanine was observed at Fe₃O₄-Gnp/Al electrode (fig. 5.3(d)), which indicates that the modified electrode possesses the highest electrocatalytic activity. The direct electrochemistry of adenine oxidation was also carried out for comparison and similar results were obtained. From those results, it can be seen that, substantial reduction in the overpotentials and notable enhancement in the peak currents were observed in the CVs for both compounds on Fe₃O₄/Al and Fe₃O₄-Gnp/Al, electrodes indicating the catalytic role of graphite in the electrooxidation of guanine and adenine bases.
Fig. 5.3. The cyclic voltammograms of Fe₃O₄-Gnp/Al (a) in absence of 10 μM guanine, and Gnp/Al (b), Fe₃O₄-Gnp/Al (c) and Fe₃O₄-Gnp/Al (d) in presence of 10 μM guanine in 0.1 M PBS (pH = 7).

We know that, in general, the smaller the size of nanoparticles, higher the catalytic activity they will possess. This phenomenon may be due to the smaller nanoparticles having a greater surface-to-volume ratio to interact with the substrates. Therefore, we can infer that the graphite used here as mimics have a relatively high catalytic property. Previous reports showed that a chemical bond (Fe-O-C) [17] is formed between graphite and magnetite networks. Moreover, Fe₃O₄-Gnp/Al composite may possess high conductivity, good antifouling property and fast electron transfer rate.
5.2.2 Electrochemical oxidation of adenine

Fig. 5.4. exhibits the cyclic voltammograms of various modified electrodes in the presence and absence of 10 μM adenine. No peak is observed at Fe₃O₄-Gnp/Al modified electrode (curve a) and a small oxidation peak is observed at +0.928 V for Gnp/Al electrode and a large peak current is observed at +0.951 V (Vs SCE) at the Fe₃O₄/Al (curve c). Electrochemical responses are in excellent agreement with independent literature reports [18]. Attention was turned to explore the electrochemical oxidation of adenine utilizing the Fe₃O₄-Gnp/Al electrode. Fig. 5.4 (d) depicts a typical voltammetric profile for the Fe₃O₄-Gnp composite modified aluminium electrode. In comparison to the Fe₃O₄/Al and Gnp/Al electrodes, a shift to higher oxidation potential is observed for the Fe₃O₄-Gnp/Al electrode at +0.971 V while no oxidation peak is observed at Fe₃O₄-Gnp/Al in the absence of adenine. As shown in Fig. 5.4 the increase in current response on introducing the graphite in Fe₃O₄ is evident compared to Fe₃O₄/Al and only and Gnp/Al electrode only. It is known that the electrochemical oxidation of adenine is highly dependent on the density of edge plane like sites in graphite [18] and therefore a response at higher oxidation potentials is observed at Fe₃O₄-Gnp/Al compared to Fe₃O₄/Al electrode. This is due to the density of edge plane sites in graphite upon the electrode surface greatly influenced the electrochemical response of adenine [18]. From these observations, it can be concluded that Fe₃O₄-Gnp/Al modified electrode is suitable electrochemical sensor compared to other electrodes.
Fig. 5.4. The cyclic voltammograms of Fe$_3$O$_4$-Gnp/Al (a) in absence of 10 μM adenine, Gnp/Al (b), Fe$_3$O$_4$-Gnp/Al (c) and Fe$_3$O$_4$-Gnp/Al (d) in presence of 10 μM adenine in 0.1 M PBS (pH = 7).

5.2.3 Simultaneous determination of adenine and guanine

Determination of coexistence of 10 μM adenine and 10 μM guanine in pH 7.0 phosphate buffer was investigated using CV and the results are shown in Fig. 5.5. In the absence of guanine and adenine, no redox peak is observed in the range from +0.0 to +1.2 V at all modified electrodes, indicating that graphite, Fe$_3$O$_4$ on the aluminium electrode is electroinactive in the scanned potential window. Guanine and adenine show just a small hump peak with the potentials around 0.693 V and 0.933 V respectively at Gnp/Al electrode. The graphite modified aluminium electrode was included for comparison purpose (curve b).
Fig. 5.5. The cyclic voltammogram resulting from electrochemical oxidation of 10 μM guanine and 10 μM adenine in pH 7 of PBS (b) Gnp/Al (c) Fe₃O₄/Al (d) Fe₃O₄-Gnp/Al. (a) CV of Fe₃O₄-Gnp/Al electrode in the absence of 10 μM guanine in pH 7 of 0.1 M PBS solution.

However, examination of Fe₃O₄/Al modified electrode (curve c) exhibits that the anodic peaks of guanine and adenine at approximately 0.665 V and 0.954 V respectively. A negative shift of oxidation potential and enhanced response to guanine and adenine are clearly seen. The cyclic voltammogram changes indicate that the modified electrode has good catalytic activity toward guanine and adenine, and Fe₃O₄ nanoparticles are dominating participator in the electrocatalytic reaction. In contrast to the case of Fe₃O₄ nanoparticles modified electrode, the Fe₃O₄-Gnp/Al modified electrode significantly increase the effective surface area, and the interaction between Fe₃O₄ nanoparticles and guanine or adenine may the increase
the catalytic activity. So the highest oxidation peak current of guanine and adenine is observed for Fe₃O₄-Gnp/Al at 0.686 V and 0.977 V (curve d), which illustrated that the Fe₃O₄-Gnp/Al modified electrode possesses the highest electrocatalytic activity. From these results, it can be inferred that, substantial reduction in the overpotentials and notable enhancement in the peak currents were observed in the CVS for both compounds on both Fe₃O₄/Al and Fe₃O₄-Gnp/Al electrodes indicating the catalytic role of graphite nanoparticles and Fe₃O₄ in the electrooxidation of guanine and adenine bases. The modified electrodes show a peak-to-peak separation of 290 mV in the cyclic voltammogram response of guanine and adenine.

5.2.4 Effect of graphite concentration in Fe₃O₄-Gnp/Al

It is well known that the amount and dispersion of co-deposited nanoparticles play vital role in the properties of the nanocomposite coatings. Adequate incorporation percentage and more uniform distribution of nanoparticles in the nanocomposite coatings lead to improvement of the mechanical, tribological, anti-corrosion, and anti-oxidation properties of the coatings [19]. Thus, much attention has been focused to study the influence of the incorporated nanoparticle content in the nanocomposite coatings. The amount of graphite nanoparticles was varied between 5 and 20 g/l and their peak current response to guanine and adenine oxidation was measured in phosphate buffer solution. Fig. 5.6. shows the effect of concentration of graphite nanoparticles on peak current in the presence of guanine and adenine. From the fig 5.6, it can be observed that the peak current is increases with increase in graphite concentration upto 16 g/l in electrodeposition bath (fig 5.6). Further increase of graphite nanoparticles in composite coatings the peak current of guanine and adenine were almost constant. This can be attributed to the
effective saturation particle concentration. In high concentrations, because of the agglomerations of particles in the bath, the effective graphite particles is constant, thus resulting in constant peak current for adenine and guanine.

![Graph showing the effect of concentration on peak current](image)

Fig. 5.6. Effect of concentration of graphite nanoparticles on peak current in the presence of guanine and adenine

5.2.5. Effect of pH

Fig. 5.7 and Fig. 5.8 shows the effect of pH on peak current and peak potential of guanine and adenine oxidation at Fe₃O₄-Gnp/Al electrode. In order to achieve the optimum pH and evaluate the ratio of electrons and protons involved in the anodic oxidation of guanine and adenine on the surface of the modified electrode, the electrochemical behaviours of these compounds were investigated in various buffered solutions with pH range of 3-8. As can be seen in Fig. 5.7 and fig.
5.8, the anodic peak potentials shift negatively on increasing the solution pH, suggesting the participation of H$^+$ in the oxidation processes.

![Graph showing the effect of pH on peak current and peak potentials at Fe$_3$O$_4$-Gnp/Al in presence of 10 µM Guanine](image)

**Fig. 5.7.** Effect of pH on peak current and peak potentials at Fe$_3$O$_4$-Gnp/Al in presence of 10 µM Guanine.

The obtained slope values of 54.91 mV and 58.7 mV per pH unit (Fig. 5.7) for guanine and adenine respectively, indicate that equal numbers of electrons and protons are involved in the electro-oxidation of both compounds on the surface of the Fe$_3$O$_4$-Gnp/Al. From the results of pH investigation as shown in Fig. 5.7 and Fig. 5.8, maximum anodic peak currents for both guanine and adenine occur at pH 7.0, which is well-matched for their determinations in physiological conditions.
Fig. 5.8. Effect of pH on peak current and peak potentials at Fe₃O₄-Gnp/Al in presence of 10 μM Adenine

2.2.6 Effect of accumulation time

It is important to fix the potential and time in many accumulation steps when adsorption studies are undertaken. Both conditions could affect the amount of analyte adsorption at the electrode, and then influence the subsequent CV responses of adenine and guanine. To improve the sensitivity of the electrode, the effects of the accumulation potential and accumulation time on peak current response were studied by cyclic voltammetry. The effect of accumulation time on the oxidation peak current of adenine and guanine is shown in Figure 5.9. The oxidation peak current increased rapidly with increasing accumulation time for the first 180s, revealing rapid and effective adsorption of adenine and guanine on the surface of the modified electrode. The plot nearly leveled off after 180s, which indicates the saturation of active sites of electrode surface by adsorption of adenine and guanine
molecules. As too long accumulation time might reduce the stability of the film, 180 s was chosen as the accumulation time.

Fig. 5.9. Effect of accumulation time on peak current of adenine and guanine at Fe₃O₄-Gnp/Al electrode in 0.1 M phosphate buffer solution

5.2.7 Effect of scan rate

Cyclic voltammetry responses of Fe₃O₄-Gnp/Al electrode at different potential scan rates for 0.1 μM guanine and adenine in 0.1 M PBS of pH 7.0 are shown in fig 5.10 & 5.11. The peak current (Iₚ) for oxidation of guanine and adenine is proportional to the square root of the scan rate (fig. 5.10 (b) & 5.11 (b)), suggesting that the process is controlled by diffusion of analyte as expected for a catalytic system. It can also be noted in fig 5.10 (a) & 5.11 (a) that by increasing the sweep rate, the peak potential for the catalytic oxidation of guanine and adenine shifts to more positive values and the plots (Fig. 5.10 b & 5.11 b) of peak current vs square root of scan rate deviates from linearity in higher scan rates, suggesting a
kinetic limitation in the reaction between the redox sites of the Fe₃O₄ nanostructures and guanine and adenine. Also the plots of peak current, (Iₚ/μA) versus square root of scan rates, v¹/₂ (mVs⁻¹), for guanine and adenine are linear (Fig.5.10 & 5.11 (b)). This behaviour can be related to the adsorption of these species at the modified electrode surface and their diffusion through the porous Fe₃O₄/Gnp composite. The relationship between the oxidation peak potentials, Eₚ/V, and logarithm of the scan rates, log v (mVs⁻¹), is also linear as shown in Fig. 5.10 & 5.11 (c) with the corresponding Eqs. (1) and (2); indicates the irreversible nature of the electrochemical processes for both oxidation of guanine and adenine.

\[
E_{p,\text{guanine}} = 38.1\log(v) + 588.8, \ R^2 = 0.9994
\]

\[
E_{p,\text{adenine}} = 51.5\log(v) + 829.9, \ R^2 = 0.9991
\]

Assimilating the results with those obtained in pH investigation, one can conclude that the electrochemical oxidation of guanine and adenine on Fe₃O₄-Gnp/Al electrode are two-electron and two proton transfer processes. The plausible reaction mechanisms for electrochemical oxidation of guanine and adenine are given below.
Fig. 5.10. (a) Cyclic voltammograms of the Fe$_3$O$_4$-Gnp/Al electrode in buffer solution (pH 7) containing 1 µM guanine at scan rates of 10-100 mVs$^{-1}$. (b) Plot of peak current vs. square root of scan rate. (c) Plot of peak potential vs log v.
Fig. 5.11. (a) Cyclic voltammograms of the Fe$_3$O$_4$-Gnp/Al electrode in buffer solution (pH 7) containing 1 µM adenine at scan rates of 10-100 mV/s$^{-1}$. (b) Plot of peak current vs. square root of scan rate. (c) Plot of peak potential vs log $v$. 
5.3. Simultaneous determination of adenine and guanine by DPV

Fig. 5.12. (a) DPV of various concentrations of guanine (0.01-10 µM) in the presence of 1 µM adenine

Since differential pulse voltammetry (DPV) has higher sensitivity and better resolution than cyclic voltammetry, DPV was used for simultaneous determination of guanine and adenine. Probable common interferences due to adenine-guanine interactions were investigated by changing the concentration of one species at a constant concentration of the other species. Fig.5.12 shows the DPVs of various concentrations of guanine in the presence of a fixed concentration of adenine (1 µM) in 0.1 M PBS (pH 7.0) at Fe₃O₄-Gnp/Al electrode. As can be seen, the peak currents, Ip/µA of adenine are almost constant, but those of guanine increase with increasing its concentration in the mixture. The calibration curve for guanine shows a linear
range of 0.01-10 μM with regression equation of $I_p/\mu A = 0.321C_{\text{Guanine}/\mu M} + 1.436$ ($R^2 = 0.995$) and detection limit of 1 nM (Fig. 5.13).

![Graph](image)

**Fig. 5.13.** Calibration plot for guanine obtained from above DPV voltammogram

Similarly, fig. 5.14 shows DPVs of solutions containing a constant concentration of guanine (1 μM) and various concentrations of adenine. In this case, the peak currents are proportional to the concentration of adenine in the range of 0.05-8 μM with regression equation of $I_p/\mu A = 0.3823C_{\text{Adenine}/\mu M} + 2.145$ ($R^2 = 0.993$) and detection limit of 5 nM (Fig. 5.15).
Fig. 5.14. DPV of various concentrations of adenine (0.01–10 µM) in the presence of 1 µM guanine

The peak current of guanine are almost constant. The results indicate that, due to relatively large peak potential separation of ~290 mV, the electrochemical signals of adenine and guanine at the modified electrode are independent of each other.
Fig. 5.15. Calibration plot for guanine obtained from above DPV voltammogram

For further evaluation of the feasibility of the Fe₃O₄-Gnp/Al electrode for simultaneous determinations, the fabricated electrode was applied to the determination of guanine and adenine by simultaneously changing their concentrations (Fig. 5.16). As can be seen in Fig. 5.16, the results indicated that the analytical characteristics of the electrode including response equations and detection limits did not change significantly in solutions containing various concentrations of both guanine and adenine.
Fig. 5.16. (a) DPV for the simultaneous determination of guanine and adenine in 0.1 M PBS at Fe₃O₄-Gnp/Al with guanine and adenine concentration (0.01 to 10 µM); (b) calibration graphs for guanine (0.01–10 µM) and adenine (0.05–6 µM).
5.4 Repeatability, Reproducibility and stability of the modified electrode

The repeatability of the modified electrode was investigated by repetitive recording its response at guanine and adenine concentrations of 1 and 10 μM. The relative standard deviation of the peak currents for five replicate DPV determinations of 1 and 10 μM of guanine are 1.6% and 1.55%, respectively, and the corresponding values for adenine were 2.61% and 2.64%, respectively. The reproducibility of the Fe₃O₄-Gnp/Al modified electrode was observed in phosphate buffer (pH 7.0), and the cyclic voltammograms were changed slightly after 50 consecutive cyclic voltammetric scans indicating that the electrode possessed excellent reproducibility. The results indicate that the modified electrode has high reproducibility and excellent repeatability in both the preparation procedure and the voltammetric determinations.

The stability of the Fe₃O₄-Gnp composite coating on aluminium and its electrocatalytic activity in the adenine and guanine solutions were also examined. The results showed that the stability and current response of the electrode in the analyte did not change significantly for several uses. On using the Fe₃O₄-Gnp/Al electrode daily while storing under ambient conditions, the electrode retained 95.3% of its initial peak current response to 10 μM each of guanine and adenine after a period of one month, indicating long-term stability of the modifier film on the Al surface.

5.5 Interference study

In the present work, the interference effects of 1 mM ascorbic acid (AA), 0.1 mM uric acid (UA), 10 μM dopamine (DP) and 1 mM glucose (Glu) were tested on the voltammetric response of 10 μM guanine and adenine (Fig. 10. No changes in
response currents of guanine and adenine were observed in the presence of AA, UA, DP, Glu solutions or the mixtures of all. In the mixture of all these compounds by using the modified electrode, five well-defined waves with a very good resolution are resulted. Among these interferences, glucose has no response but AA, UA, and DP showed oxidation peaks in the selected potential range. Therefore, in this study it was proved that this method can be successfully applied for the simultaneous determination of guanine and adenine in the presence of the other interference compounds in the clinical preparations.

5.6 Analytical applications

The applicability of the modified electrode in analysing biological samples was assessed by measuring adenine and guanine in DNA of calf thymus. Fig. 5.17 (a) shows the DPV of various concentrations of DNA in PBS (pH 7.0). As can be seen, the acid-denatured DNA gives two well-defined peaks due to the oxidation of guanine and adenine residues. Fig. 5.17 b shows the calibration plots of adenine and guanine peak currents versus DNA concentration. There are linear relationships between DNA concentrations in the ranges of 0.04-5 and 0.06-5 \( \mu \text{g mL}^{-1} \) vs. guanine and adenine peak currents, respectively. The experimental detection limit was found to be equal to 3 ng mL\(^{-1}\) DNA. The determination of guanine and adenine concentrations was performed by standard addition method as follows. 20 \( \mu \text{L} \) of denatured DNA was added in a cell containing 10 mL PBS of pH 7.0, and the peak currents of guanine and adenine residues were measured. Then a certain quantity of guanine or adenine solution was added and the corresponding peaks were measured again. From the differences between the peak currents, the concentrations of guanine and adenine in DNA were obtained using the corresponding calibration graphs. The
contents of adenine and guanine in acid-denatured DNA were calculated to be 23.4% and 28.6% (mol %), respectively. Using the proposed method, the value \((\text{G+C})/(\text{A+T})\) of 0.81 was obtained in HCl-denatured calf thymus DNA sample, which is in an acceptable agreement with the standard value of 0.77 [20].

![Graph](image_url)

Fig. 5.17. (a) DPV for various concentrations of DNA (0.05-0.35 µg mL\(^{-1}\)) on Fe\(_3\)O\(_4\)-Gnps/Al in 0.1 M PBS (pH 7), (b) and (c) calibration graphs for guanine and adenine in DNA samples.
5.7. Conclusions

In this work, we used the excellent characteristics of Fe$_3$O$_4$-Gnp nanocomposites to construct a highly sensitive sensor based on the Al modified electrode for simultaneous determination of guanine and adenine.

A Fe$_3$O$_4$ can effectively adsorb guanine and adenine on the electrode surface resulting in an increase in the oxidation currents.

A Electrodeposition of Fe$_3$O$_4$-Gnp composite enables preparation of simple, stable and reproducible modifier films on the Al electrode surface, which leads to a considerable enhancement in repeatability and reproducibility in the voltammetric measurements.

A Significant enhancements in the electron transfer kinetics of guanine and adenine were observed on the surface of the modified electrode, resulting in lowering the anodic overpotentials and considerably increasing sharpness of the waves and anodic peak currents.

A Very wide linear dynamic ranges, very low detection limits, high sensitivity, very good repeatability and reproducibility, and high stability, together with simple procedures for surface modification and determination were presented as the advantages of the prepared sensor.

A The modified electrode can be used for the determination of trace amounts of guanine and adenine in calf thymus DNA.

A So, this simple and reliable strategy based on Fe$_3$O$_4$-Gnp/Al is proposed for the development of an ultrasensitive voltammetric biosensor for simultaneous determination of guanine and adenine in biological systems.
References


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