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Research Article

Enhancing Dopamine Detection Using a Glassy Carbon Electrode Modified with Aluminum Oxide, Titanium Dioxide, and Poly(3,4-ethylenedioxythiophene)-poly(4-styrene sulfonate)

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Abstract: Dopamine is an important neurotransmitter involved in signal transmission to the brain. Deficiencies in dopamine are associated with various neurological disorders, such as schizophrenia, attention deficit hyperactivity disorder, and Parkinson's disease. In this study, a novel non-enzymatic electrochemical sensor for dopamine detection was developed using aluminum oxide/titanium dioxide/poly(3,4-ethylenedioxythiophene)-poly(4-styrenesulfonate) (Al_2O_3/TiO_2/PEDOT:PSS) composite modified glassy carbon electrode (GCE). Al_2O_3/TiO_2/PEDOT:PSS composite exhibited enhanced catalytic activity for the oxidation of dopamine due to the increase of the working electrode's surface area. Using the cyclic voltammetry (CV) method, dopamine was detected in the range of 50–1000 µM in 0.1 M phosphate-buffered saline (PBS) solution at pH 7.0, with a determined limit of detection of 6 µM. Since this nanocomposite modification showed low cost, easy process, and high performance, Al_2O_3/TiO_2/PEDOT:PSS modified GCE may be a good candidate for the development of a non-enzymatic dopamine sensor.

Keywords: Conductive polymer; Cyclic voltammetry; Dopamine; Electrochemical biosensor; Nanocomposite

1. Introduction

In 2012, the World Health Organization (WHO) reported that 35.6 million people worldwide were affected by neurological disorders, with projections indicating that this number could double by 2030 and more than triple by 2050 due to accelerated population aging (World Health Organization, 2012). Among neurotransmitters, dopamine is one of the most extensively studied

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because of its critical role in movement and coordination (Latif et al., 2021). In common conditions, the concentration of dopamine in the blood circulation is relatively small, ranging from approximately 0.01 to 0.1 µM, thereby creating difficulties in the detection (Balkourani et al., 2023). Due to its critical role in signal transmission to the brain, the deficiency of dopamine can lead to several neurological conditions, such as Parkinson's disease, schizophrenia, attention deficit, and hyperactivity disorder (Abhilash et al., 2024; Shinde et al., 2024; Aziziyan et al., 2023; Selvam et al., 2023; Whulanza et al., 2014).

Several methods have been developed for the determination of dopamine levels, including spectrophotometry (Moghadam et al., 2011), fluorescence analysis (Wang et al., 2015), capillary electrophoresis (Zhao et al., 2011), mass spectrometry (Vuorensola et al., 2003), flow injection (Van Staden and Van Staden, 2012), high-performance liquid chromatography (Ferry et al., 2014), gas chromatography-mass spectrometry (Naccarato et al., 2014), and electrochemical luminescence (Yuan et al., 2014).

Electrode surface modification is a method that can alter an electrode's electrochemical properties. This method has been widely used in electroanalysis and electrocatalysis, as well as for the conversion and storage of electrochemical energy through adsorption, bonding, and deposition (Alenezi, 2017; Su and Hatton, 2017; Wu et al., 2017). Modified electrodes have certain benefits compared to other electrodes, such as good reproducibility and homogeneity (Putri et al., 2024). Recent studies on polymer conductive electrodes have shown their wide applicability in the electrochemical field due to ease of synthesis, high conductivity, and excellent electroactivity (Dong et al., 2025; Gawali et al., 2024; Lete et al., 2015). Carbon-based nanomaterials, metals, metal oxides, polymers, and enzymes such as laccase, n-acetyl-L-cysteine, and PDA are the most popular methods for modifying electrode surfaces (Bala et al., 2019).

Diverse materials have been investigated for the electrochemical detection of neurochemicals. Metal oxides such as zinc oxide (ZnO), nickel oxide (NiO), and copper oxide (CuO), non-metal oxides including iron (III) oxide (Fe_2O_3), iron (II) molybdate ($FeMoO_4$), and cobalt oxide (Co_3O_4); polymers such as polypyrrole, Nafion™, and poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS), and carbon-based nanomaterials such as carbon nanotubes, graphene, and carbon fibers exhibit excellent physicochemical and electrical properties. These materials have been used in combination to detect neurotransmitters both in vitro and in vivo (Priyanto et al., 2024; Rao et al., 2024; Yang et al., 2024; Sáenz et al., 2018).

Short-term studies may validate the viability of a suggested electrochemical sensor using nanoparticles, while long-term assessments are important to ascertain the stability and toxicity of the nanomaterials in living beings. The integration of in vivo and in vitro assays provided important information about a nanomaterial's capacity to identify neurotransmitters. Diverse electroanalytical methods, including cyclic voltammetry (CV), differential pulse voltammetry, square wave voltammetry, and amperometry, have been used to identify and monitor neurotransmitters in various body fluid types (Ribeiro et al., 2024; Teleanu et al., 2022).

Aluminum oxide (Al_2O_3) is a metal oxide that has desirable properties, such as high mechanical strength. The addition of 2 wt% Al_2O_3 in nanocomposite modification can enhance hardness by 11% (Li et al., 2023), while another study showed a 9% enhancement in flexural strength by incorporating 1 wt% Al_2O_3 (Meena et al., 2023). Nanoparticles combined with Al_2O_3 have several potential uses, particularly in electrochemical and catalytic processes (El-Morsy et al., 2024; Alfarobi et al., 2022; He et al., 2021). The incorporation of nanocomposites combined with Al_2O_3 in urea sensing has the potential to be developed to achieve rapid dopamine detection, as it showed the limit of detection (LOD) of 0.11 µM with a detection range of 3.56 µM to 1 mM (Wahab et al., 2023).

Titanium dioxide (TiO_2) has recently been used in the advancement of diverse areas, including dye-sensitized solar cells, electrochemical sensors, and biomaterials. Nano-TiO_2 possesses many unique physicochemical properties, such as good biocompatibility, solid adsorptive capacity, large surface area, thermal stability, and non-toxicity (Fajarani et al., 2024; Ismail et al., 2024; Kumar and Sinha, 2024; Rao et al., 2024). The addition of TiO_2 into the nanocomposite for glucose detection

showed significant stability and selectivity, yielding a low detection limit of 756.8 µM in a concentration range of 0 to 13 mM and sensitivity of 360.13 µA/mMcm² (Kumar and Sinha, 2024).

Despite Al_2O_3 showing excellent electrochemical responses and mechanical qualities, the large energy band gap of 4.63 to 7.6 eV can hinder its conductivity. However, TiO_2 integrated with Al_2O_3 has a weak oxygen binding ability, which facilitates target molecule adsorption processes since it has a lower band gap of 3.20 eV (Morsi et al., 2024; Arafat et al., 2017).

The combination of Al_2O_3 and TiO_2 has been conducted before, which was synthesized from the Fagonia plant and used to detect acetaminophen, one form of paracetamol. In the concentration range of 0.06 to 65 µM, this modification achieved satisfactory detection with the LOD of 0.017 µM (Akhtar et al., 2024). Another study shows that metal oxide-based materials consisting of TiO_2 and Al_2O_3 exhibit a favorable response to the increase in active surface area from 0.0201 cm² to 0.0539 cm² (Akhtar et al., 2024). To enhance the conductivity and stability of the sensor, particularly in dopamine applications with a narrow concentration range, a combination of materials is required to incorporate each metal oxide.

The organic nature of PEDOT:PSS and the good compatibility with bioorganic molecules, including enzymes, make this compound an attractive bioelectronic material with promising electrochemical and material properties. PEDOT:PSS, consisting of both positively and negatively charged polymers, can be integrated with composites or other materials to enhance electrochemical characteristics in many applications, particularly in biosensors (Baruah et al., 2024, Ariyasajjamongkol et al., 2023).

The drop-casting method is widely used for fabricating recognition layers by applying a droplet of customized materials onto electrodes. This study uses electrodeposition to create a thin layer on the electrode, utilizing an electrical signal to adjust the deposition rate and thickness (Okoye et al., 2023). This method facilitates the formation of more even electrode modifications and improves reproducibility (Roushani and Zalpour, 2021; Kumar et al., 2020).

Various electroanalytical methods, such as cyclic voltammetry (CV), differential pulse voltammetry (DPV), square wave voltammetry (SWV), and other techniques, have been used to detect and track neurotransmitters (Kimmel et al., 2012; Grieshaber et al., 2008). This study uses CV method for electrodeposition and detection. CV is a method commonly used in biosensor applications to identify redox activity on the electrode surface. The method is frequently used since it may determine the reversibility of the reactions by applying potentials in a specific range to facilitate oxidation and reduction processes (Simoska et al., 2023).

Novel composites with favorable electrochemical characteristics can be synthesized by combining PEDOT:PSS with nano-TiO_2 and Al_2O_3. Furthermore, a nanocomposite consisting of Al_2O_3, TiO_2, and PEDOT:PSS was produced by a simple electrodeposition process. This novel investigation on the incorporation of Al_2O_3/TiO_2/PEDOT:PSS nanocomposite onto glassy carbon electrode (GCE) surface has not been conducted, thereby providing an opportunity for the exploration of its structure and electrocatalytic oxidation activity in dopamine detection.

2. Materials and Methods

2.1. Chemicals and Reagents

Dopamine hydrochloride, Al_2O_3, TiO_2, and PEDOT:PSS were purchased from Sigma-Aldrich, St. Louis, USA. Ethanol (99%), sodium dihydrogen phosphate (NaH_2PO_4), and disodium phosphate (Na_2HPO_4) were purchased from Merck, Darmstadt, Germany. Electrode polishing alumina suspension (particle size of 0.05 µm) was obtained from BASi®, West Lafayette, USA. The supporting electrolyte, phosphate-buffered saline (PBS), was prepared using Na_2HPO_4 and NaH_2PO_4 solutions in distilled water. No additional purification was performed on the distilled water solutions, and all chemicals utilized were of analytical grade.

2.2. Apparatus

The open-source Rodeostat potentiostat, purchased from IO Rodeo, California, USA, with SigmaPlot from Systat Software for data processing and charting, was utilized for all electrical measurements. The three-electrode system was used for electrochemical experiments, which consisted of silver-silver chloride (Ag/AgCl) as reference electrode, platinum (Pt) as auxiliary electrode, and GCE as working electrode. All electrodes were purchased from BASi®, West Lafayette, USA, and were used at room temperature.

2.3. Fabrication of Al_2O_3/TiO_2/PEDOT:PSS modified GCE

GCE was polished sequentially with Al_2O_3 slurry to form a mirror-like surface. In addition, it was then rinsed and ultrasonicated for 1 min in a 1:1 water-ethanol mixture before being dried at room temperature. The prepared GCE was electropolymerized with Al_2O_3/TiO_2/PEDOT:PSS by immersing the GCE into the nanocomposite suspension, and the CV method was performed with the potential range of +1.4 to +2.4 V for 10 cycles with a scan rate of 100 mV s^{-1} (Whulanza et al., 2017). The modified electrodes underwent CV with +0.3 to +1.2 V in 0.1 M PBS (pH 7.0) until a stable voltammogram was obtained. These procedures were applied to the other modifications, including PEDOT:PSS, Al_2O_3/PEDOT:PSS, and TiO_2/PEDOT:PSS, to compare each morphological performance.

3. Results and Discussion

3.1. Electropolymerization of Al_2O_3/TiO_2/PEDOT:PSS

Figure 1(a) shows the electropolymerization phenomena of Al_2O_3/TiO_2/PEDOT:PSS in 1 mM PBS (pH 7.0) on GCE. The anodic peak potential during the first cycle obtained at potential 0.275 V, 1.545 V, and the cathodic peak potential at –0.635 V showed that Al_2O_3/TiO_2/PEDOT:PSS nanocomposite was successfully deposited on the GCE surface (Wang and Hui, 2017). As the number of scanning cycles increased, the anodic and cathodic peak currents progressively rose, while the corresponding peak potentials shifted toward more positive and negative values, respectively. These results showed that the electrochemical behaviors of the working electrode improved by producing a uniform conductive layer of nanocomposite on the working electrode surface (Niu et al., 2013). The incorporation of Al_2O_3/TiO_2/PEDOT:PSS nanocomposite on GCE improved the electrode's surface area, allowing for higher dopamine absorption capacity, which may improve the detection process (Bahrami et al., 2021).

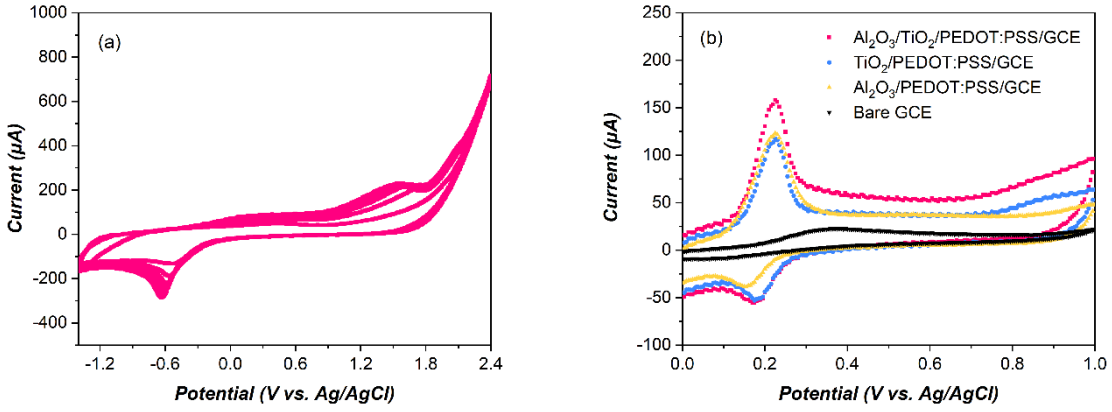

Figure 1 CV curve of (a) the electropolymerization process of Al_2O_3/TiO_2/PEDOT:PSS on GCE in 1 mM PBS (pH 7.0) with the scan rate of 0.1 V/s and (b) each modification of GCE in 1 mmol/L dopamine solution 1 mM in 0.1 M PBS (pH 7.0) with the scan rate of 0.05 V/s

The current responses of each cycle increased as the scans continued, showing continuous growth of the Al_2O_3/TiO_2/PEDOT:PSS film. A rapid increase occurred during the first five cycles, followed by an insignificant increase during the remaining cycles. After 10 scans, a thin black-gray

adhesive film was observed on the electrode's surface, showing the successful deposition of the nanocomposite. Xiao et al. stated that the modified GCE showed optimal electrochemical performance at 10 scans, as the thickness of the conductive layer must be regulated to prevent an increase in resistance around the working electrode and electric double layer caused by excessive nanocomposite layer formation (Yulianti et al., 2024; Xu et al., 2010).

3.2. Structural and morphological characterization of the nanocomposites

The morphologies of PEDOT:PSS, Al_2O_3/PEDOT:PSS, TiO_2/PEDOT:PSS, and Al_2O_3/TiO_2/PEDOT:PSS modifications were studied to verify their surface homogeneity and adhesion on GCE. Scanning Electron Microscopy (SEM) images are presented in Figure 2.

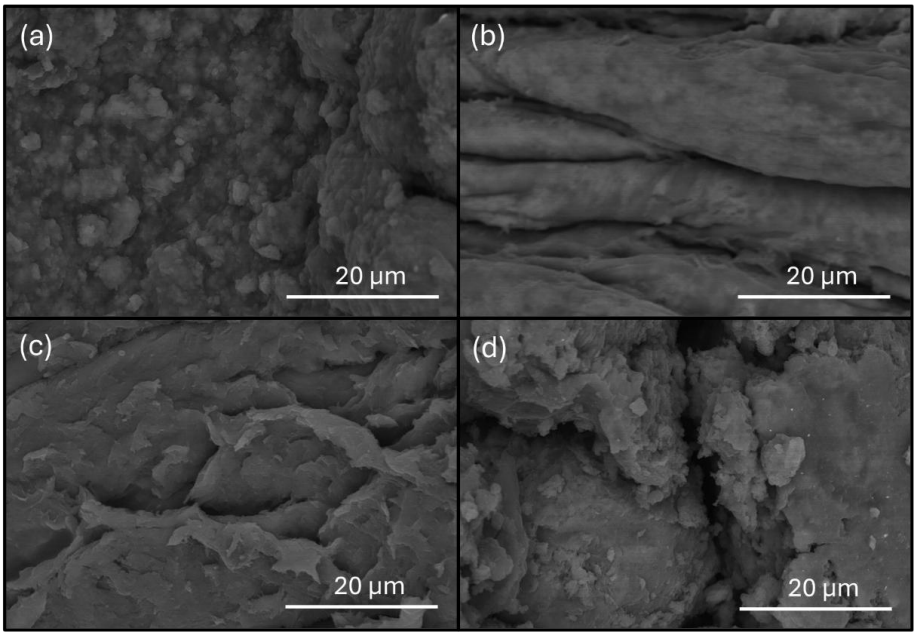

Figure 2 SEM images of (a) PEDOT:PSS, (b) TiO_2/PEDOT:PSS, (c) Al_2O_3/PEDOT:PSS, and (d) Al_2O_3/TiO_2/PEDOT:PSS

In Figure 2, SEM images showed the successful deposition of each modification into GCE by electropolymerization. Figure 2(a) shows SEM image of PEDOT:PSS that displays the aggregates of PEDOT-rich colloidal structures connected by PSS (Medhi et al., 2022; Wang et al., 2021). These aggregates suggest a stable and uniform surface coverage essential for robust electrode performance. SEM images of TiO_2/PEDOT:PSS and Al_2O_3/PEDOT:PSS modified GCE exhibited wrinkled sheets that agglomerated after being exposed to multiple cycles, as shown in Figure 2(b) and Figure 2(c), respectively (Baruah et al., 2024). Figure 2(d) captured the agglomerated clusters of Al_2O_3/TiO_2/PEDOT:PSS nanocomposite, which exhibited a rougher and more porous surface. This increased surface roughness and more porousness are critical features, as they enhance the electrode's electrochemical activity by providing a higher surface area for reaction sites. The high surface area of the composite particles was attributed to the enhancement of the electrochemical activity and the direct electron transfer on the electrode's surface. The wrinkled edges of Al_2O_3/TiO_2/PEDOT:PSS, along with the presence of larger particles resulting from increased nanocomposite surface tension, contribute to an enhanced surface area and the formation of additional active sites for dopamine detection. This improvement is expected to enhance both the sensitivity and overall performance of the sensor (Akhtar et al., 2024).

3.3. Electrochemical responses of Al_2O_3/TiO_2/PEDOT:PSS

CV method was performed with three electrode systems consisting of Ag/AgCl, Pt wire, and GCE-modified nanocomposites, including Al_2O_3/TiO_2/PEDOT:PSS, TiO_2/PEDOT:PSS, or Al_2O_3/PEDOT:PSS. As shown in Figure 1(b), Al_2O_3/TiO_2/PEDOT:PSS nanocomposite-modified

GCE yielded the most attractive results, showing higher electrochemical reversibility and increased current compared to the other nanocomposite modifications. This showed that the structural and surface properties affect the electrochemical activity of dopamine oxidation (Nazari et al., 2018).

The peak current response of Al_2O_3/TiO_2/PEDOT:PSS modified GCE during dopamine oxidation was obtained at 0.22 V and reversibly reduced at 0.17 V. This modification showed the high electrochemical reversibility of the system due to the resulting anodic/cathodic peak current ratio (I_{Pa}/I_{Pc}) of 1.28 that is close to 1 and peak potential separation (ΔE_P) of 0.05 V. The small ΔE_P value showed that the oxidized dopamine was rapidly transferred to the electrode surface (Whulanza et al., 2022b; Gaur, 2020). An investigation was carried out on the effect of Al_2O_3/TiO_2/PEDOT:PSS modified GCE on dopamine response, which confirmed the material's ability to detect dopamine. Electrochemical pretreatment contributed to the improvement of the current response and showed the highest oxidation peak.

TiO_2 is an n-type semiconductor material that has a wide band gap (3.20 eV) and is widely used for biosensor applications (Mohd Roseny et al., 2021). However, the use of TiO_2 is generally incorporated with metal oxide materials that have a wider band gap. To enhance the efficiency of TiO_2 utilization from the UV to the visible region, this incorporation was implemented to generate an electrochemical response to the analyte (Rao et al., 2024). Al_2O_3 is a type of metal oxide that has a wider band gap (8–10 eV) and has been used to enhance the performance of non-enzymatic biosensors by acting as a sensing mediator (Alam et al., 2020).

The interaction between TiO_2 and Al_2O_3 will form a heterojunction that may improve the conductivity and selectivity of the electrode modification toward dopamine. The addition of PEDOT:PSS as a conductive polymer into the matrix will enhance the interaction between TiO_2 and Al_2O_3, allowing more rapid electrochemical responses, as shown in this study (Yang et al., 2024; Sharma et al., 2023). Furthermore, since the formation of oxygen vacancies in this modification requires low energy, the resulting defects develop easily, particularly after deposition onto the GCE surface. This allows the improved current responses of Al_2O_3/TiO_2/PEDOT:PSS modified GCE, resulting in elevated conductivity (Alam et al., 2020).

The combination of TiO_2 and Al_2O_3 has the potential to generate chemisorbed reactive oxygen species on its surface. Oxygen species include O_2^-, O^-, and O^{2-}, which are used as charge transfer mediators in electrochemical oxidation and reduction processes. Subsequently, dopamine, a reducing agent, will be converted to dopamine quinone by these chemisorbed reactive oxygen species, an oxidizing agent, which will also lower the nanocomposite layer's resistance, providing an electrocatalytic reaction as a detection mechanism (Khosravi-Hamoleh et al., 2021; Montazeri and Jamali-Sheini, 2017).

3.4. Effect of temperature

Temperature is a crucial parameter that must be controlled during the detection process to optimize the kinetic reaction of dopamine at the nanocomposite-modified electrode. Lower temperatures can slow the kinetics of dopamine oxidation, resulting in a reduced current response, while higher temperatures may increase signal noise, potentially hindering the detection process (Kabir and Ju, 2023). A significant shift to lower dopamine oxidation potentials was observed with rising solution temperatures. Figure 3(a) shows dopamine current response and peak potential changes with temperatures rising from 20°C to 40°C. The marked jump in sensitivity may be related to the dramatic shift of the dopamine oxidation peak to lower potentials with higher temperatures. Future studies should concentrate on investigating the dopamine electron transfer process.

3.5. Effect of pH

The effect of pH on the anodic current response was studied to optimize the performance of the amperometric dopamine detection in Al_2O_3/TiO_2/PEDOT:PSS modified GCE. This study was performed at pH levels ranging from 6 to 8. Figure 3(b) shows that the highest value is obtained at pH 7 and is selected for subsequent experiments.

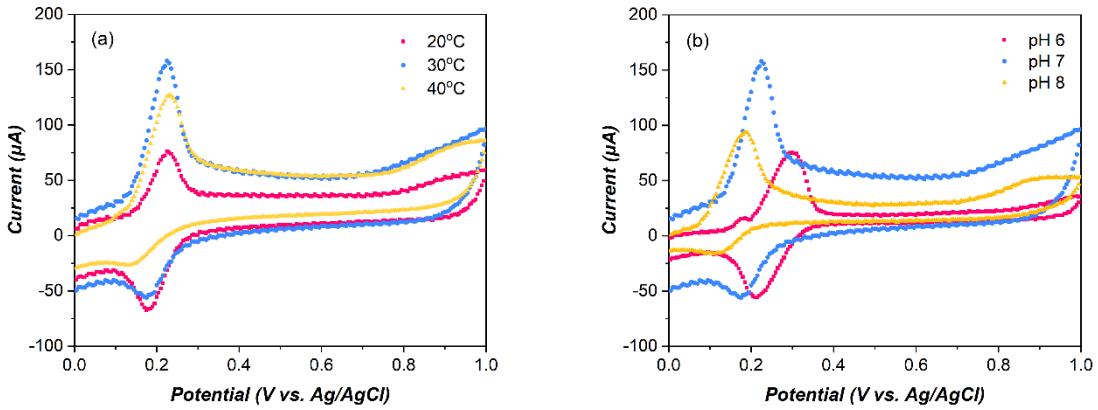

Figure 3 Effects of (a) temperature and (b) pH on the oxidation peak current and peak potential responses of Al_2O_3/TiO_2/PEDOT:PSS modified GCE in 1 mM dopamine

An organic compound's rate of reaction is heavily influenced by its proton concentration. These results led to the study of the connection between pH and the anodic peak potential of dopamine. In Figure 3(b), the peak potential shifted negatively with an increased pH, suggesting that protons were involved in electrode reactions. The peak potential vs. the pH curve exhibited a slope of −0.060 (R^2 = 0.990), which confirmed that the process involved a loss of protons and that the number of protons participating in the electrode reaction was the same as the number of electrons (Chatti et al., 2019). According to the Nernst equation, the slope showed that the oxidation of dopamine was equal to the number of electrons and protons transferred to the electrochemical process (Deng et al., 2013).

3.6. Effect of scan rate

The effect of the scan rate (v) on the CV responses during dopamine detection was studied in order to examine the process of electrochemical oxidation of dopamine with GCE under different operating conditions. Figure 4(a) shows CV curve of Al_2O_3/TiO_2/PEDOT:PSS nanocomposite-modified GCE responses during dopamine detection at scan rates ranging from 0.005 to 0.1 V/s.

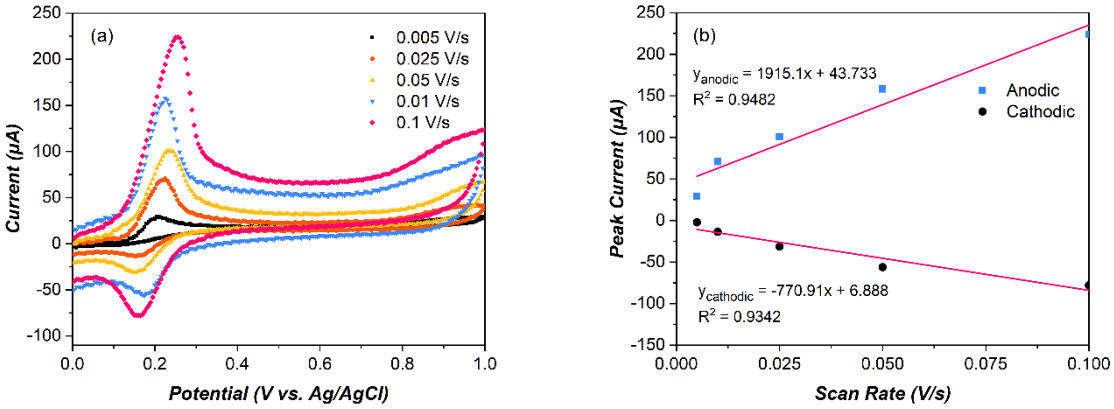

Figure 4 (a) CV curve of Al_2O_3/TiO_2/PEDOT:PSS modified GCE at scan rates ranging from 0.005 to 0.1 V/s and (b) effect of scan rate on anodic and cathodic currents of 1 mM dopamine in 0.1 M PBS (pH 7.0) on Al_2O_3/TiO_2/PEDOT:PSS modified GCE

Scanning at higher rates resulted in higher anodic and cathodic dopamine peak current responses, suggesting that the dopamine oxidation process on Al_2O_3/TiO_2/PEDOT:PSS modified GCE was a completely reversible electron transfer mechanism since the dopamine peak oxidation potential shifted positively over time. According to Figure 4(b), the currents for both oxidation and reduction increased linearly with the scan rate (v). The relation between v and anodic/cathodic peak

current responses can be expressed as linear regression equations of I_{Pa} (μA) = 2078.8 + 26.007 v (V/s) with R^2 = 0.966 and I_{Pc} (μA) = −873.71 + 3.1012 v (V/s) with R^2 = 0.9262, indicating an adsorption-controlled process (Nazari et al., 2018).

3.7. Electrochemical performance of Al_2O_3/TiO_2/PEDOT:PSS during dopamine detection

The effect of dopamine concentration on GCE linearly modified with Al_2O_3/TiO_2/PEDOT:PSS in 0.1 M PBS is shown in Figure 5(a). The results showed that a higher concentration of dopamine was associated with higher peak currents for both oxidation and reduction.

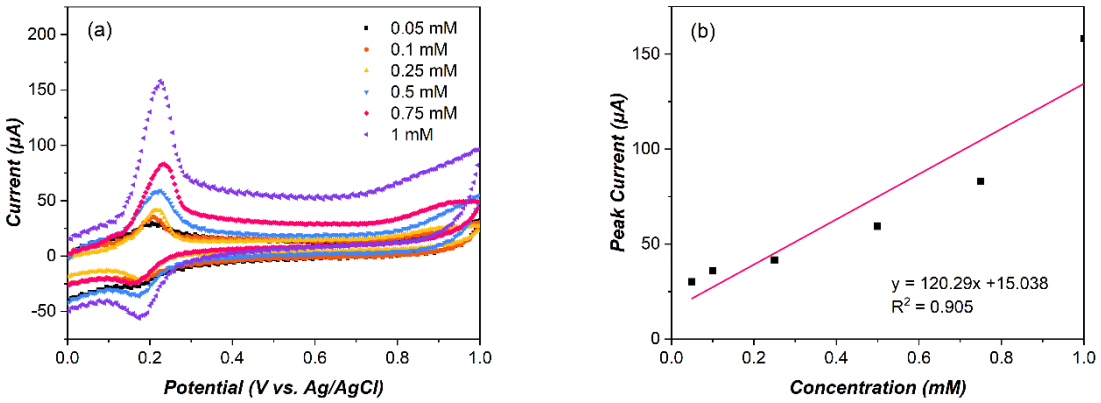

Figure 5 CV curve of (a) Al_2O_3/TiO_2/PEDOT:PSS modified GCE during dopamine detection at different concentrations of 0.05, 0.1, 0.25, 0.5, 0.75, 1 mM and (b) linear calibration curve of electrocatalytic peak current responses as a function of dopamine concentration in the range of 0.05 to 1 mM in 0.1 M PBS (pH 7.0) with the scan rate of 0.05 V/s

Figure 5(b) shows the linear relationship for dopamine concentration in CV responses observed between 0.05 and 1 mM. The linear regression equation was $y = 120.29x + 15.038$ with an R^2 = 0.9047. LOD for dopamine was calculated with the following equation 1 below:

$$LOD = 3\frac{S}{M} \quad (1)$$

Where S is the standard deviation of the peak current response on the blank sample, which was 0.1 M PBS (pH 7.0), and M is the slope of the calibration plot obtained from the linear regression equation (Hegde et al., 2009). LOD was found to be 6 × 10^{-6} (6 μM). In this study, Al_2O_3/TiO_2/PEDOT:PSS modified GCE was used to amplify the current response and achieve good LOD in a wide linear range (50–1000 μM), as compared in Table 2. These findings showed a significant improvement in dopamine detection performance compared to the previous studies, which displayed the relatively low LOD of Al_2O_3/TiO_2/PEDOT:PSS modified GCE.

Table 1 Results comparison of dopamine detection using different composite-modified electrodes with previous studies

Modifications	Method	Linear range	LOD	References
PEDOT/CNT/CPE	DPV	0.1–20 μM	20 nM	(Xu et al., 2013)
AuNPs/PEDOT-ERGO/GCE	DPV	5–200 μM	1 μM	(Chen et al., 2024)
α-MnO_2/rutile TiO_2/GCE	CV	0.012–3.64 μM	3.5 nM	(Song et al., 2023)
TiO_2/CS/MAPTPA/ITO glass	PEC	0.0005–5 mM	0.206 μM	(Shang et al., 2021)
Graphite-SiO_2/Al_2O_3/Nb_2O_5-methylene blue	CV	5–500 μM	1.49 μM	(Giarola et al., 2017)
ZnO/Al_2O_3/GCE	DPV	5–700 μM	2 μM	(Ganjali et al., 2018)
Al_2O_3/TiO_2/PEDOT:PSS/GCE	CV	50–1000 μM	6 μM	This study

CV: cyclic voltammetry; DPV: differential pulse voltammetry; PEC: photoelectrochemical; SWV: squarewave voltammetry

3.8. Selectivity and Stability analysis of Al_2O_3/TiO_2/PEDOT:PSS

CV method was used to explore the influence of ascorbic acid on dopamine detection. Figure 6(a) shows its effect on the dopamine oxidation process on Al_2O_3/TiO_2/PEDOT:PSS modified GCE in the solution containing interference molecules, which was ascorbic acid. According to Figure 6(b), the dopamine peak current response was discovered at a potential of 0.2 V, which has an oxidative peak current from ascorbic acid (Whulanza et al., 2022a). Ascorbic acid shares a similar chemical structure with dopamine, making detection challenging. Therefore, a highly selective detection mechanism is required to distinguish dopamine and prevent cross-reactivity with other molecules. In living organisms, ascorbic acid concentrations are greater than dopamine concentrations, which was implemented in this study and resulted in high selectivity of dopamine detection in Al_2O_3/TiO_2/PEDOT:PSS modified GCE.

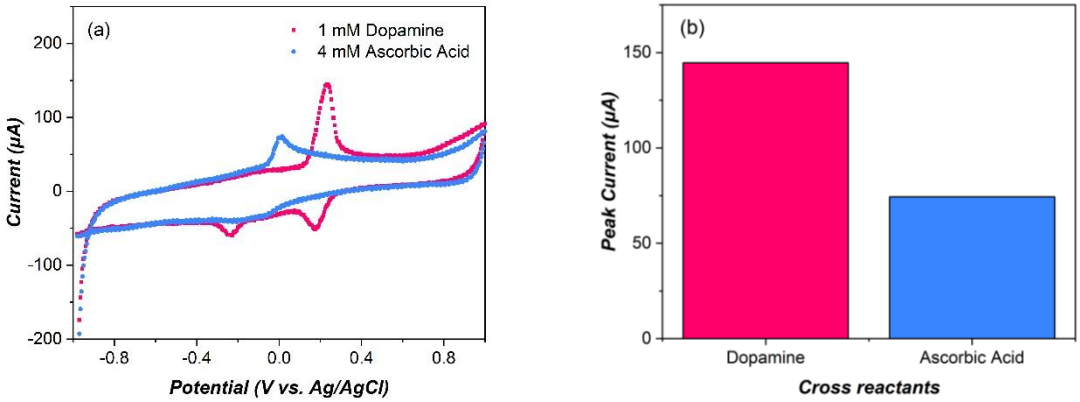

Figure 6 CV curve of Al_2O_3/TiO_2/PEDOT:PSS modified GCE during (a) interference study in a solution containing 1 mM dopamine and 4 mM ascorbic acid in 0.1 M PBS (pH 7.0) and (b) the comparison between peak current responses with the scan rate: 0.05 V/s

Ascorbic acid can reduce the dopamine quinone back to dopamine, thereby enhancing the oxidation current of dopamine on the electrode surface. This interaction explains why the presence of both dopamine and ascorbic acid in the solution significantly amplifies the current signal for dopamine oxidation. Dopamine detection selectivity was enhanced as a result of this action (Adhikari et al., 2018; Li et al., 2018).

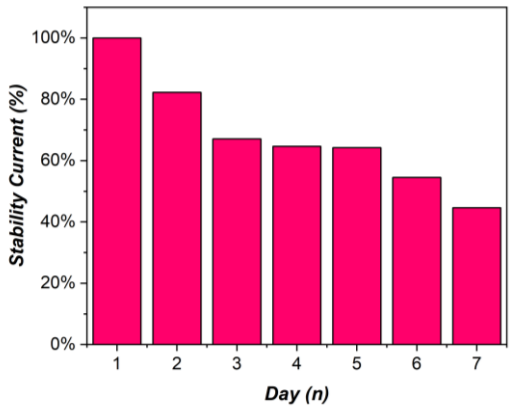

Figure 7 Stability current percentage of Al_2O_3/TiO_2/PEDOT:PSS modified GCE after 7 days

The stability test was conducted to evaluate the durability of Al_2O_3/TiO_2/PEDOT:PSS modified GCE toward the environmental conditions and repeated dopamine detection. Figure 7 presents the stability of the current over 7 consecutive days, showing a decline in current response to 45%. The continuous monitoring of dopamine on Al_2O_3/TiO_2/PEDOT:PSS modified GCE showed a decreasing trend due to the possible composite fallout from the GCE surface during the repeated

measurement and wash. This stability result must be confirmed with a repeatability test where the modified GCE was subjected to multiple successive cycles at a time, and the relative standard deviation of CV responses (Lima et al., 2018).

4. Conclusions

In conclusion, electrocatalytic dopamine oxidation was examined by synthesizing Al_2O_3/TiO_2/PEDOT:PSS composite and studying its behavior and mechanism. The modified electrode based on Al_2O_3/TiO_2/PEDOT:PSS showed excellent dopamine detection at a low limit of 6 µM in the range of 50–1000 µM. The high electroactivity and rapid transfer potential of Al_2O_3/TiO_2/PEDOT:PSS make it a material with potential applications in the electrochemical field, specifically dopamine detection. The development of an electrochemical dopamine detection system is expected to enhance early detection of Alzheimer's disease, which is often challenging to diagnose, while also improving the accessibility of diagnostics across a broader range of regions. This study has the potential to evolve into a point-of-care system, enabling more efficient dopamine detection.

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Conflict of Interest

The authors declare no conflicts of interest.

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