Silver-Doped Titania Modified Carbon Electrode for Electrochemical Studies of Furantril

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An electrochemical method for the determination of an antrallinic acid derivative based on nanoparticles modified electrode was studied through cyclic and differential pulse voltammetry. Modification of electrode with silver-doped titania nanoparticles enhanced the peak current for the electro-oxidation of Furantril. The silver-doped titania nanoparticles were prepared by simple wet chemical methods and characterized by scanning electron microscopy (SEM), transmission electron microscopy (TEM), energy dispersive X-ray spectroscopy (EDX), X-ray diffractometer (XRD). Silver-doped TiO2 voltamograms suggested that pH 5.0 was suitable for electrochemical investigation of furantril. Rate constant, diffusion coefficient, electrode process and number of electrons involved were calculated. Based on these investigations a feasible mechanism for electrode reaction was presented. Limit of detection and quantification were found to be 1.98 nM and 6.6 nM respectively. © The Author(s) 2018. Published by ECS. This is an open access article distributed under the terms of the Creative Commons Attribution 4.0 License (CC BY, http://creativecommons.org/licenses/by/4.0/), which permits unrestricted reuse of the work in any medium, provided the original work is properly cited. [DOI: 10.1149/2.0321807jss]

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Wide bind gap and unique properties of oxide semiconductors such as like ZnO,1 In2O3,2 SnO2 and TiO2,7 have attracted researchers more and enforced more usage of these materials for different applications. TiO2 nanoparticles due to their extraordinary properties such as stability, low toxicity, high surface area, and enhanced catalytic activity as attracted a lot.7 TiO2 nanoparticles possess exceptional photo-catalytic property and are used as coating material in optical thin film due to its chemical stability.6,7 However, the short life of electron hole-pairs with poor adsorption capacity has restricted the applicability of TiO2 in many fields.9 Doping of TiO2 nanoparticles with different metals would allow overcoming with these deficiencies and increasing the catalytic activity of TiO2 nanoparticles. The dopants added work by trapping electrons on the surface of semiconductor and reducing the electron hole pair combination. By altering the chemical and physical properties with a metal ion dopant the applicability of TiO2 nanoparticles for new devices can be increased. In past reports, it has been observed that metals like Au, Pt, Rh, Ag, Ru, and Pd10−12 are employed for TiO2 doping. In addition, photo induced separation of electrons and hole can be enhanced by incorporating low cost transition metals like Ni, Fe, and Cr.11 The recombination of electron–hole pair remains very high when TiO2 doped with p-block elements. This restricts the redox capacity of materials surface.12 To hinder the recombination process and increase the catalytic effect it’s suitable to use transition metal such as Ag, Pd, or Pt. Further, with their unique properties Au, Pt and Rh doped TiO2 have also gained a lot of interest.13,14 Since use of Pt, Pd, Rh and Au is commercially viable for large scale production, Ag-doped TiO2 nanoparticles (STNP) has gained a large practical value.15

In addition, Ag shows inimitable sensing properties in chemical and biological field as compared to that of other noble metals.16 Doping TiO2 with Ag enables higher electron-hole pair separation by forming Schottky barrier, which enhances photocatalytic activity of TiO2.17 STNP has also shown greater water splitting activity than TiO2.18 It is been also reported that through density function theory (DFT) calculations Ag can modify TiO2 anatase surface to rutile.19 Introduction of Ag on the lattice creates oxygen vacancies closer to TiO2, which provides a separate channel for electron transport.20 Silver is a well-known noble metal that can trap the electrons leading to easy electron hole pair separation for enhanced catalytic activity of TiO2 nanoparticles.21 Silver can also assist in the electronic excitation by producing a localized electric field.22 Further, silver doping can increase the anatase to rutile conversion, which enhances the surface area and catalytic activity. It is observed that noble metal such as silver and gold in the nano-size exhibits useful application, such as catalytic, electrical, and optical properties. In addition, TiO2 nanoparticles undergo equilibrium in Fermi level enhancing the catalytic behavior. Thus, STNP nanoparticles studies have gained a large practical value as sensor. Preparation technique greatly affects the physical and chemical properties.

Furantril is a commonly used diuretic. It is administered either orally or by intravenous to treat edema linked to renal impairment,23 nephrotic syndrome, hypertension, heart failure24 hepatic cirrhosis.

In the present work, we report the usage of STNP to construct an electrode which has greater sensitivity compared to that of TiO2 nanoparticles. The synthesized nano-particles were used to develop a sensor for the electrochemical determination of furantril. The synthesized nanoparticles were characterized by SEM, TEM, XRD and EDX. Further, the developed method was applied for the analysis of furantril in pharmaceuticals and spiked human urine samples. The electrode prepared was checked for the electrochemical activity toward furantril using cyclic voltammetric method. In addition, the analytical application of electrode was studied using differential pulse voltammetric method and applied for human urine sample and pharmaceutical dose form. The recovery from these samples obtained, economically low cost as to the other methods, easiness in the fabrication and higher sensitivity allows an alternate method for furantril determination.

Experimental

Synthesis of STNP nanoradicles.—In 500 ml Pyrex beaker, 500 mg of TiO2 and 200 ml of double-distilled water was added. (molar ratio) silver nitrate solution was added to the TiO2, and water mixture to carry out doping process. The resulting suspensions was settled at room temperature for a night after thoroughly mixing by vigorous stirring. Moisture contents remained was removed by drying the mixture at 100°C for 12 hours in an oven. Further, calcined at below 500°C for 3 hours in muffe furnace to get STNP nanoparticles.
Preparation of STNP modified carbon paste electrode.—Prior to the modification, CPE was prepared by mixing graphite powder (1.0 gm) with paraffin oil (0.5 ml) using a mortar to obtain homogeneous paste. The paste was filled in the cavity of polytetrafluoro ethylene tube (PTFE) to get a smooth surface. The surface activation was carried at pH 5.0, by cycling it in the potential range 0.6–1.4 V and keeping scan rate at 50 mVs⁻¹.²⁵ For the modification of the electrode, STNP were finely homogenized with carbon paste and filled in the cavity of PTFE tube. Amount of STNP was optimized by using different weight % of STNP nanoparticles. The voltammograms acquired using cyclic voltammetric technique had two anodic peaks and it was observed for both the peaks that, maximum peak current for oxidation of 0.1 mM furantril was for 1% STNP. Hence, the ratio was opted for further investigations.

Material characterization and electrochemical investigations.—Identification of phase and crystal structure JEOL, JSM-6360 was used to obtain surface morphology. TEM images were obtained from JEOL, JEM-2010. X-ray diffractometer AXS D5005 was used for the characterization of nano-particles. To perform the electrochemical experiments, D630 analyzer from CHI Company was connected to three-electrode system. Carbon paste electrode (CPE) modified with STNP nanoparticles (working electrode), Ag/AgCl (reference electrode) and platinum electrode (counter electrode). pH meter (Elico Ltd., India) was used to optimize the pH of buffer solutions.

Reagents and chemicals.—Furantril stock solution was prepared by transferring apposite weight into 25 ml volumetric flask and then dissolving it with ethanol to the mark. Supporting electrolyte, phosphate buffer solution was used to investigate the effect of pH in a range 3.0–11.2 pH (I = 0.2 M). KH₂PO₄, Na₂HPO₄, H₃PO₄, and Na₃PO₄ purchased from Sigma Aldrich were used to prepare the buffer solutions according to the literature.²⁷ For all the studies, double distilled water and analytical grade reagents were utilized.
of agglomeration was obtained by transmission electron microscopy (TEM). Silver doping on TiO₂ nanoparticles were presumed to appear as black spots in TEM images.

Elemental composition of nanoparticles was obtained from EDX analysis. The elemental composition of prepared nanoparticles confirmed the presence of Ti and O with small amount of silver.

The Specific Surface area of STNP obtained from BET surface area measurement was 82.62 m²/g. The Tauc plot of Kubelka-Munk function obtained from UV-Vis diffused reflectance spectra was used to determine the bandgap. The bandgap of STNP was 3.1 eV (Figure 2).

**Cyclic voltammetric behavior of furantril.**—Voltammetric behavior studies were carried out using cyclic voltammetric method (Figure 3). The voltammogram recorded shows the presence of two anodic peaks at 0.950 V and 1.12 V with anodic current of 12.43 μA and 23.36 μA respectively for STNP modified carbon paste electrode. Reversing the scan rate, peaks were absent suggesting the irreversible electrode process. The oxidation current for CPE and Ag-TiO₂/CPE was compared and was observed that the oxidation current for Ag-TiO₂/CPE was enhanced about 4–5 times. Enhancement of the peak current may be attributed to better catalytic effect of silver doping and larger interaction of the analyte with the electrode surface. The bare electrode and TiO₂ nanoparticles modified electrode shows sluggish electron transfer and hence, the peak current corresponding to them was less intense and broader. Therefore, presumed that these electrodes are not suitable for the electrochemical studies of furantril. Further, electron hole pair separation is also affecting the peak current. Since, TiO₂ nanoparticles have a drawback of wide energy band and short life of electron hole pairs with poor adsorption capacity its catalytic activity is reduced. In Figure 4, a working setup is shown.

![Figure 2. Kubelka munk plot for STPN.](image)

![Figure 3. Cyclic voltammogram of 0.1 mM furantril in phosphate buffer solution, pH 5.0 (I = 0.2 M) at scan rate 50 mVs⁻¹; A) Voltammogram recorded at; a) Ag-TiO₂ / CPE (Blank); b) CPE (for 0.1 mM FUR); c) TiO₂ / CPE (for 0.1 mM FUR); d) Ag-TiO₂ / CPE (for 0.1 mM FUR) B) Inserted plot: Comparision of peak current for different electrodes.](image)

![Figure 4. Experimental setup of working.](image)
Effect of variation of pH.—Alonso et al.\textsuperscript{32} used glassy carbon electrode for the determination of furantril in BR buffer solution. Medeiros et al.\textsuperscript{33} proposed a electrochemical method for determination of furantril on Basal-Plane Pyrolytic Graphite, Boron-Doped Diamond, and Amorphous Carbon Nitride Electrodes in 0.10 mol L\(^{-1}\) sulfuric acid, 0.040 mol L\(^{-1}\) BR buffer of pH 4.5, and 0.10 mol L\(^{-1}\) potassium nitrate. It was observed that the investigations were lagging in analysis in PBS. Voltamograms were recorded in PBS in the range 3.0–11.2 pH (Figure 5) and compared with past reported methods. Voltamograms shows two peaks for all the pH in the range 3.0–9.0 pH. As the pH increased above 9.0, the intensity of the peak current decreased. The above obtained results were as similar to the past reported method the oxidation behavior of furantril was frail above pH 5.0. As the pH was increased above 9.0 pH the second peak diminished.

Plot for pH versus peak current shows that the peak current was maximum at pH 5.0. Therefore, pH 5.0 was opted as optimum for the investigations. In addition, as the pH increased the peak potential shifted to a value that is more negative suggested that there is involvement of protons in the electrode reaction. The regression equation for the plot of peak potential versus pH in the range 3.0–9.0 pH was: \(E_p(V) = 1.3266 - 0.046 \text{pH}\); \(R^2 = 0.9989\) and \(E_p(V) = 1.0475 - 0.024 \text{pH}\); \(R^2 = 0.993\). The slope of 46.0 mV/pH closer to the nerstian value of 59.0 mV/pH suggests equal number of electrons and protons are involved in the electrode reaction.

Effect of variation of scan rate.—Effect of variation in scan rate on the peak current for oxidation of furantril was investigated using cyclic voltammetric method (Figure 6A). As the scan rate increases, \(I_p\) also increased with \(E_p\) shifting toward a higher positive value. The shift indicates that the electrode reactions are irreversible. The process was found to be diffusion controlled from the observed linear plot for \(I_p\) versus \(\nu\); with equation, \(I_{p1} = 42.68 \nu - 3.87\); \(R^2 = 0.970\) and \(I_{p2} = 94.18 \nu - 5.81\); \(R^2 = 0.991\) (Figure 6B). Diffusion controlled process was affirmed from the plot \(\log I_p\) versus \(\log \nu\) with a slope closer to 1.

The voltammetric behavior was compared with past reported methods and was observed that the furantril oxidation in our investigations was recorded at lower potential as compared to other electrode material.\textsuperscript{32,33}

Figure 5. Effect of variation of pH on anodic peak current for oxidation of furantril at pH (a) 3.0 (b) 4.0 (c) 5.0 (d) 6.0 (e) 7.0 (f) 8.0 (g) 9.2 (h) 10.4 pH.

Figure 6. A) Cyclic voltammogram recorded for the oxidation of furantril at different scan rates (pH = 5.0); (a) 10; (b) 50; (c) 150; (d) 200; (e) 250; (f) 400; (g) 550; (h) 700; (i) 900 mVs\(^{-1}\). B) Plot for peak current versus scan rate; C) Plot for logarithm of peak current versus logarithm of scan rate; D) plot for peak potential versus logarithm of scan rate.
of Ep versus as 2. Further, from equation, E0 can be calculated from intercept

\[ E_0 = E^0 + \frac{2.303RT}{\alpha nF} \log \left( \frac{nF}{\alpha} \right) \]

From slope, Ep versus log, ‘an’ was calculated to be 0.909 and 0.732 for peak 1 and 2 respectively. Bard and Faulkner equation can be used for calculation of \( \alpha \):

\[ \alpha = \frac{47.7}{E_0 - E_{p/2}} \]

We got \( \alpha \) as 0.65 from the above equation and electrons transferred as 2. Further, from equation, E0 can be calculated from intercept of Ep versus log curve by extrapolating to the vertical axis at \( \nu = \frac{303RT}{\alpha} \) k value was calculated to be \( 5.2 \times 10^3 \) s\(^{-1}\) and \( 4.98 \times 10^3 \) s\(^{-1}\) respectively.

Variation of furantril concentration.—To investigate the response of peak current toward the concentration of furantril DPV was recorded in PBS pH 5.0 at Ag-TiO\(_2\)/CPE (Figure 7A). In the linear range, \( 1.0 \times 10^{-7} \) M to \( 1.2 \times 10^{-5} \) M a calibration plot was obtained (Figure 7B). The equation is as follows; Ip 1 = 6.638 C + 2.227; R\(^2\) = 0.9918 and Ip 2 = 4.352 C + 1.641; R\(^2\) = 0.99. The LOD (\( = 3\sigma / \mu \)) and LOQ (\( = 10\sigma / \mu \)) was 1.98 nM and 6.6 nM, respectively. Table I reviews the LOD reported at different electrodes in past years.

Table I. Comparison of LOD with past reported methods.

| Electrodes | LOD(nM) | Ref. |
|------------|---------|------|
| a          | 150.0   | 32   |
| b          | 70.0    | 39   |
| c          | 7.0     | 40   |
| d          | 550.0   | 41   |
| e          | 2800.0  | 42   |
| f          | 1.98    | Present work |

was studied\(^{47,48}\). Except other than oxalic acid, none interfered with the oxidation signals of furantril.

Detection of furantril in urine samples.—Spiked human urine samples, from healthy volunteers was used to investigate the applicability of proposed method for real sample analysis. Differential pulse voltammetric method was used to investigate the recovery from the samples. The recoveries for different sample were between 99–102\% with R.S.D 1.2\%. Good recoveries suggested that these methods are well applicable for analysis in biological fluid (Table II).

Table II. Application of DPV for the determination of in spiked human urine samples.

| Urine sample | Spiked (\(10^{-4} \) M) | Detected (\(10^{-4} \) M) | Recovery (%) | RSD (%) |
|--------------|------------------------|-------------------------|--------------|---------|
| 1            | 1.0                    | 0.495                  | 99           | 1.19    |
| 2            | 1.0                    | 1.02                   | 102          | 1.16    |
| 3            | 1.5                    | 1.492                  | 99.4         | 1.18    |
| 4            | 2.0                    | 1.995                  | 99.8         | 1.18    |
| 5            | 2.5                    | 2.489                  | 99.5         | 1.18    |

Conclusions

In this work, an electrochemical investigation of furantril was demonstrated based on silver-doped TiO\(_2\) nanoparticles. The electrochemical method adopted had advantages such as speed of detection, easy sample preparation and a low detection limit as compared to past reported methods. The practical applicability of the proposed method was successfully demonstrated in analysis of real sample such pharmaceutical dosage form and human urine samples. In addition, it was observed that the presence of excipients except oxalic acid had no influence on electrochemical behavior of furantril. In conclusion, based on the facts the proposed electrochemical method offers a selective, sensitive, low cost and simple approach for determination of furantril without any complex pre-treatment of samples in real samples.

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