

4-Aminobenzoic acid covalently modified glassy carbon electrode for sensing paracetamol at different temperatures

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Received: 27 May 2011 / Revised: 2 August 2011 / Accepted: 8 August 2011 / Published online: 26 August 2011
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Abstract 4-Aminobenzoic acid (4-ABA) was covalently grafted on a glassy carbon electrode (GCE) during an electrochemical oxidation process in 0.1 M KCl aqueous solution. The modified electrode was applied to sense paracetamol (PCT) at serials of simulated physiologic conditions, compared to the bare electrode. The results showed that the modified electrode possessed better stability, reusability, and longevity than the bare GCE at room to physiologic temperatures. This indicated that 4-ABA/GCE can be used as the electrochemical sensing platform of PCT at the physiologic condition.

Keywords Covalently modified electrode · 4-Aminobenzoic acid · Paracetamol · Temperature influence

Introduction

Drug determination possesses a very important position in pharmaceutical and medical applications. Traditionally, spectrophotometry, titrimetry, fluorimetry, capillary electrophoresis, high-performance liquid chromatography, etc.

were widely employed to determine drug [1–4]. These methods need a tedious extraction process prior to detection; therefore, they are unsuitable for routine analysis. Recently, the use of electrochemical technique has greatly attracted attention to sense drug molecule owing to its direct rapid response, simple operation, and high sensitivity [5–8].

The electrochemical determinations of drug molecule such as nortriptyline hydrochloride, paracetamol (PCT), amiloride, dipyrone, thalidomide, and so on were studied on various electrodes [9–13]. A primary conclusion obtained is that the bare electrodes were not a good choice to sense drug molecule because their surfaces need to be revitalized before each usage. Currently, chemically modified electrodes are frequently used as an electrochemical sensing platform since the structures and electrochemical functions of the electrode surfaces can be designed and tailored according to expectations. Organic small molecules, polymer, metal nanoparticles, carbon nanotubes, and graphene were often used as modifiers to fabricate the modified electrodes sensing drug molecule [14–17]. Among them, the organic small molecule covalently modified electrodes showed a better effect than the others due to its excellent stability, reusability, and longevity. For example, glassy carbon electrode (GCE) is very easily repetitive to be covalently modified with L-cysteine monolayer film that significantly improved the redox peak current and consequently remarkably improves the sensitivity of the determination of PCT [18].

Although the drug molecule on the bare and modified electrodes was widely determined, the measurements were finished mainly at room temperature [14–18]. No report focusing on temperature influence on sensing drug molecule on the bare and modified electrodes was published up

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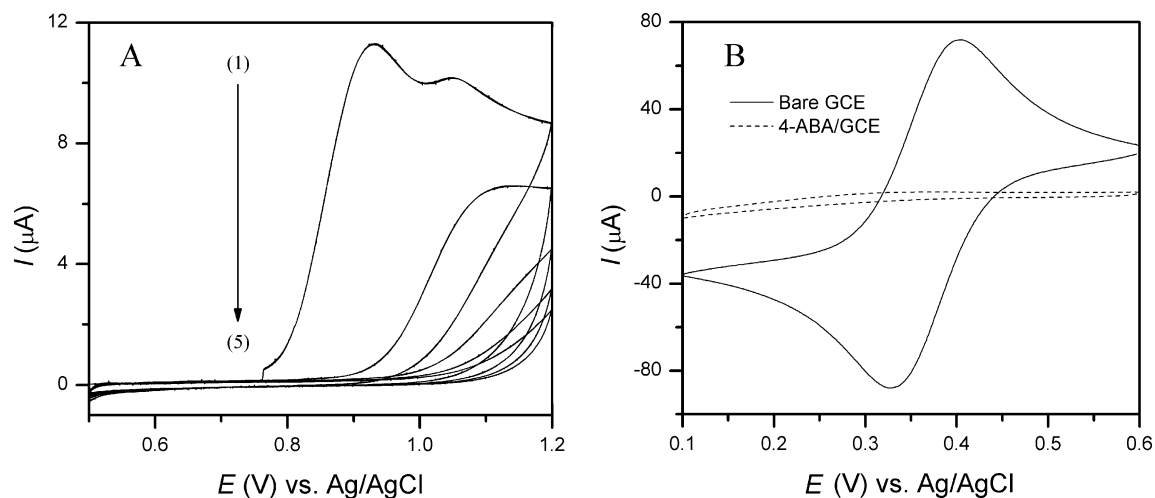


Fig. 1 **a** Cyclic voltammograms on GCE in 0.1 M KCl aqueous solution with 1 mM 4-ABA for different cycles: (1)–(5) corresponding to first, second, third, fourth, and fifth cycles at 10 mV s^{-1} . **b** Cyclic

voltammograms on the bare (*solid line*) and 4-ABA monolayer modified (*dashed line*) GCEs in 0.1 M KCl aqueous solution containing $5 \text{ mM Fe(CN)}_6^{3-}$ at 100 mV s^{-1}

to now. In this paper, PCT was selected as a drug model, its cyclic and linear sweep voltammetric determinations on the bare and 4-aminobenzoic acid (4-ABA) covalently modified GCEs were carefully researched at different temperatures. The results showed that the electrochemical sensitivity of PCT on 4-ABA/GCE was gradually changed with increasing system temperature, but there is no linear relationship between the temperature and the oxidation peak current.

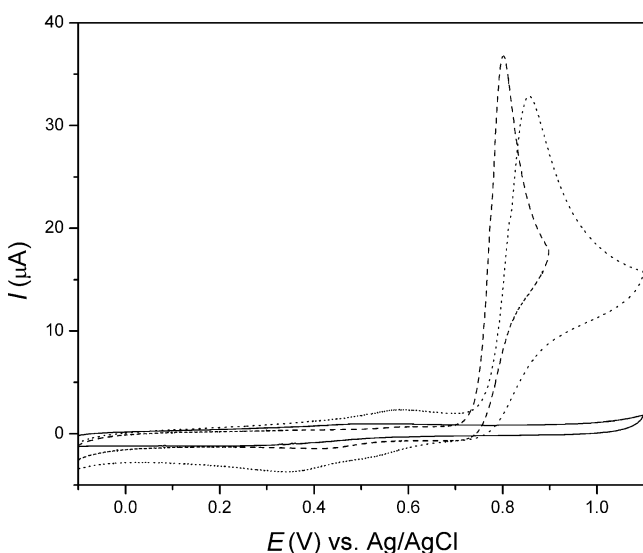


Fig. 2 Cyclic voltammograms on 4-ABA/GCE without PCT (*solid line*), on the bare (*dashed line*), and 4-ABA monolayer modified (*dotted line*) GCEs in buffer solution of pH 1.02 with 10 mM PCT at 50 mV s^{-1}

Experimental

Reagents

4-ABA and PCT were purchased from Aldrich and Johnson Matthey Company, respectively. All the other chemicals were of analytical grade and used as received. The buffer solution was prepared from $0.1 \text{ M H}_2\text{SO}_4 + \text{K}_2\text{SO}_4$ (pH < 3), $0.1 \text{ M HAc} + \text{NaAc}$ (pH 3–6), and $0.1 \text{ M NaH}_2\text{PO}_4 + \text{Na}_2\text{HPO}_4$ (pH 6–8). Water was purified using Millipore Mili-Q purification system.

Apparatus

All electrochemical measurements were carried out with a CS350 electrochemical workstation (Wuhan Corrtest Instrument Co., Ltd., China) in a self-prepared three-electrode cell using GCE or 4-ABA/GCE as the working electrode, the twisted platinum wire as the counter electrode, and Ag/AgCl (KCl saturated) as the reference electrode. The temperature of the electrochemical cell was controlled by a super thermostat with a temperature fluctuation of $\pm 0.05 \text{ }^\circ\text{C}$ (Shanghai Cany Precision Instrument Co., Ltd, China).

Electrode modification

GCE was polished with 1.0-, 0.3- and $0.05\text{-}\mu\text{m}$ $\alpha\text{-Al}_2\text{O}_3$ powders successively and sonicated in water for 2 min after each polishing step. Finally, GCE was sonicated in water and ethanol, washed with ethanol, and dried with high-purity nitrogen stream immediately

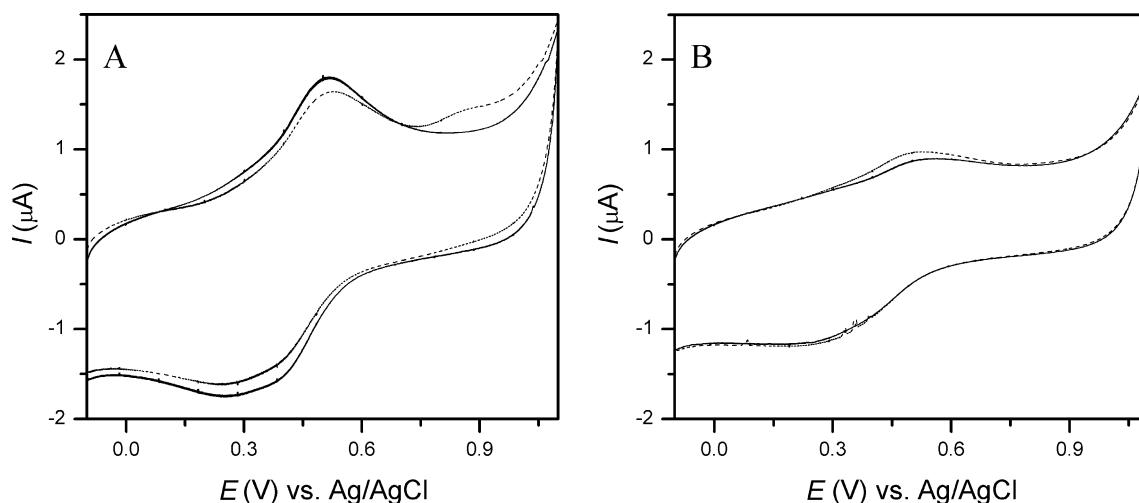


Fig. 3 Cyclic voltammograms on the bare (a) and 4-ABA monolayer modified (b) GCEs before (solid line) and after (dashed line) measuring PCT in a buffer solution of pH 1.02 at 50 mV s^{-1}

before use. The electrochemical modification of a GCE is according to our previous work [19]. It was performed in 0.1 M KCl aqueous solution containing 1 mM 4-ABA by potential scanning between 0.5 and 1.2 V. Then, the monolayer film was rinsed with ultrapure water and sonicated for a while in water to remove the physically adsorbed species. $\text{K}_3\text{Fe}(\text{CN})_6$ (5 mM) dissolved in 0.1 M KCl aqueous solution was used as a redox probe to measure GCE and 4-ABA/GCE by cyclic voltammetry between 0.1 and 0.6 V.

Procedure for the determination of PCT

The bare and 4-ABA monolayer covalently modified GCEs were employed to sense PCT comparatively. A total of 15 mL sulphuric buffer solution (pH 1.02) containing a specific amount of PCT was added to an electrochemical cell. The cyclic or linear sweep voltammograms were recorded in the potential range of -0.1 – 1.1 V at a scan rate of 0.05 V/s after 4-s quiet time.

Results and discussion

Preparation of 4-ABA monolayer on GCE

Figure 1a shows the cyclic voltammograms of GCE in 0.1 M KCl aqueous solution containing 1 mM 4-ABA with different numbers of scan cycle; the peak currents of oxidation gradually diminish to background alongside increasing scan cycles, indicating the formation of 4-ABA monolayer on GCE surface [19]. The cyclic voltammograms of $\text{Fe}(\text{CN})_6^{3-}$ on the bare GCE (solid line) and 4-ABA/GCE (dashed line) shown in Fig. 1b also indicates the formation of 4-ABA monolayer on GCE surface, which blocks completely the electron transfer of the $\text{Fe}(\text{CN})_6^{3-}$.

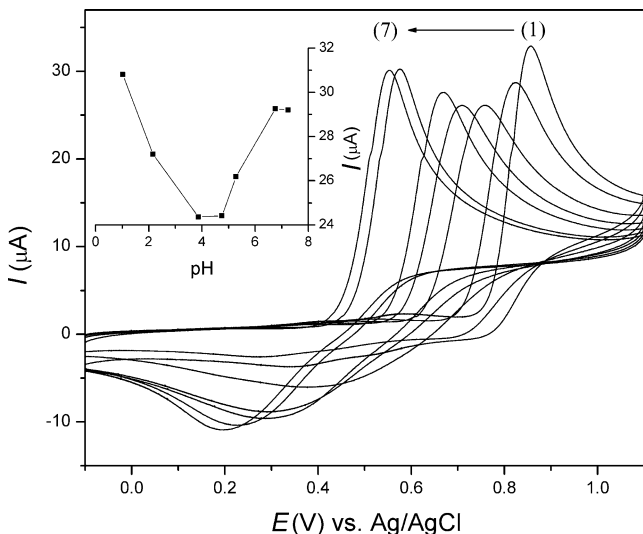


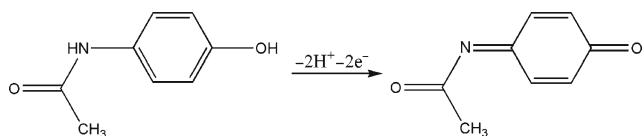
Fig. 4 Cyclic voltammograms on 4-ABA/GCE in buffer solution containing 10 mM PCT at different pH values: (1)–(7) corresponding to 1.02, 2.16, 3.86, 4.75, 5.28, 6.76, and 7.23 at $36.8 \text{ }^\circ\text{C}$ at a scan rate of 50 mV s^{-1} ; the inset corresponds to the relationship between the oxidation peak current and pH

Electrochemical behavior of PCT

Cyclic voltammetry was used to investigate the electrochemical behavior of PCT on GCEs before and after the modifications in buffer solution of pH 1.02. As shown in Fig. 2, it can be seen that there was no peak observed on the

bare and 4-ABA monolayer modified GCEs in empty buffer solution of pH 1.02.

After addition of 10 mM PCT, sensitive irreversible oxidation peaks appear on both electrodes, but the oxidation peak potential and current of PCT on the bare GCE are different from those on 4-ABA/GCE. The oxidation peak potential of PCT on the bare GCE (~ 0.80 V) is lower than that on 4-ABA/GCE (~ 0.85 V), indicating that the oxidation reaction of PCT happening on the bare GCE is easier than that on 4-ABA/GCE. The oxidation peak current of PCT on the bare GCE is higher than that on 4-ABA/GCE, indicating that the bare GCE possesses better sensitivity to PCT than 4-ABA/GCE. The irreversible oxidation process of PCT on the electrodes is shown as follows [20].



We also checked whether the PCT will remain on the GCE surface after measuring PCT by cyclic voltammetry. As shown in Fig. 3a, the bare GCE measured PCT still displays the oxidation peak of PCT (~ 0.80 V) in buffer solution of pH 1.02 at 50 mV s^{-1} ; this indicated that PCT remains on the bare GCE during measurement. The results do not happen on 4-ABA/GCE, which points that PCT does not remain on 4-ABA/GCE surface during measurement (Fig. 3b). According to this case, 4-ABA/GCE is a better electrochemical platform that can be repeatedly used in the long period, although the bare GCE possesses good sensitivity to PCT.

pH influence

The pH influence on the redox peak potential of PCT on the bare and 4-ABA monolayer modified GCEs is researched. As shown in Fig. 4, the electrochemical reaction transits from irreversible to quasi-reversible, and the oxidation peak potential of PCT gradually shifts to more negative with increasing pH at 36.8°C . A linear relationship between the oxidation peak potential and solution pH could be described as follows: $E_{\text{pa}} = -0.0504 \text{ pH} + 0.9292$ ($R=0.98$). Similar results were also observed at the other temperature (figures not shown here).

Temperature influence

Figure 5 shows the influence curves of ambient temperature on the electrochemical sensing of PCT (10 mM) on the bare (a) and 4-ABA monolayer modified GCEs (b) in buffer solution of pH 1.02 at different temperatures. From Fig. 5, it can be seen that the voltammetric curves obtained from the bare GCE almost overlap together. The oxidation peak currents of PCT on 4-ABA/GCE increase randomly with the same PCT concentrations, although the voltammetric curves do not overlap together, and no linear relationship between the temperature and the oxidation peak current was observed. This indicates that temperature influence on electrochemical sensing PCT on both electrodes is complex. Further results need to be gained.

The linear sweep voltammetry on the bare and 4-ABA monolayer modified GCEs in buffer solution of pH 1.02 with different PCT concentrations at different temperatures was carefully investigated. The results showed that no good relationship between the temperature and the oxidation peak current can be obtained from the bare GCE sensing PCT

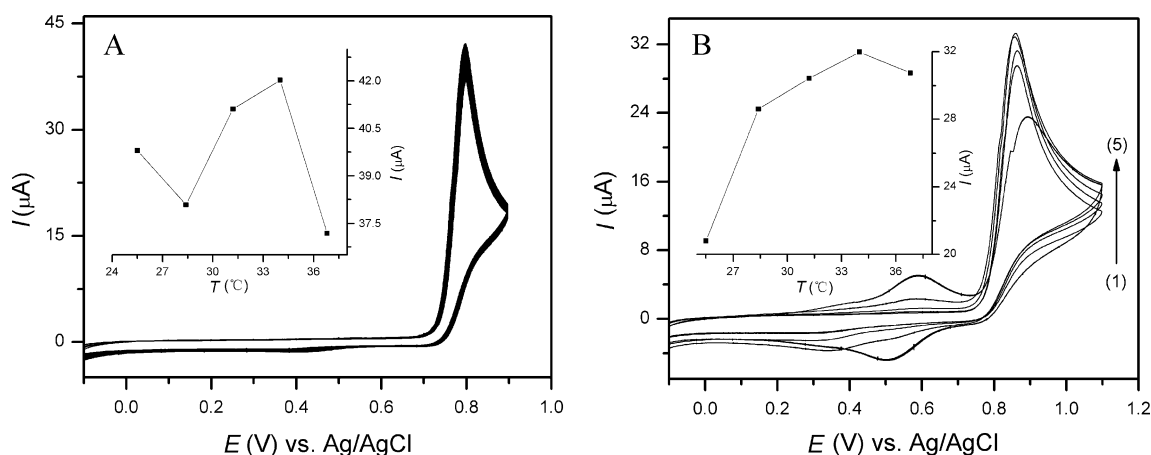


Fig. 5 Cyclic voltammograms on the bare (a) and 4-ABA monolayer modified (b) GCEs in buffer solution of pH 1.02 containing 10 mM PCT at different temperatures: (1)–(5) corresponding to 25.5, 28.4, 31.2, 34.0, and 36.8°C at a scan rate of 50 mV s^{-1}

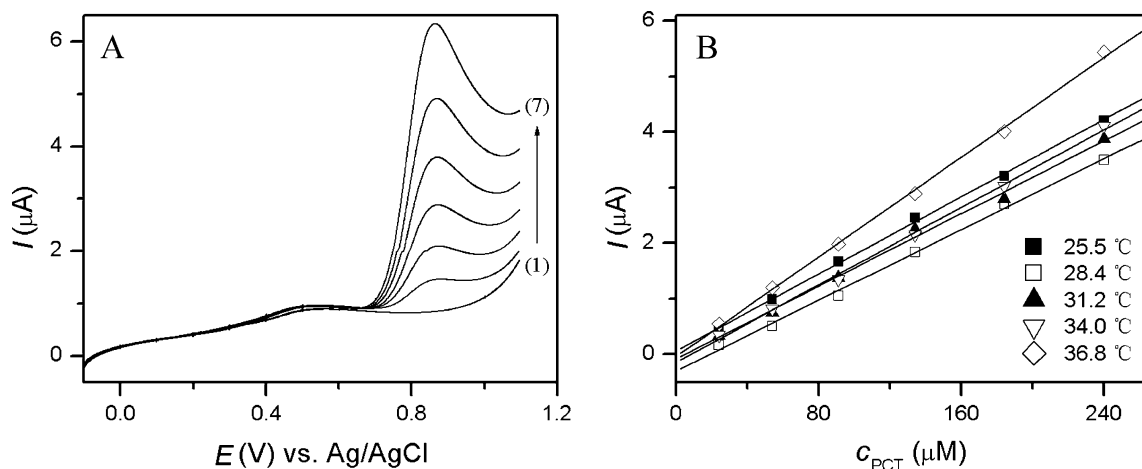


Fig. 6 a Linear sweep voltammograms on 4-ABA/GCE in buffer solution of pH 1.02 with different concentrations of PCT: (1)–(7) corresponding to 0, 24, 54, 91, 134, 184, and 240 µM at 36.8 °C. **b**

The calibration curves on 4-ABA/GCE in buffer solution of pH 1.02 with different concentrations of PCT at different temperatures

(figure not shown) because the surface activity of the bare GCE is gradually changed at different temperatures. The 4-ABA monolayer modified GCEs always exhibit very stable electrochemical sensing properties to PCT at different temperatures. Here, the linear sweep voltammograms on 4-ABA/GCE in buffer solution of pH 1.02 with different concentrations of PCT at 36.8 °C are provided as a sample as shown in Fig. 6a (figures taken at other temperatures are not shown here).

Figure 6b displays the calibration curves on 4-ABA/GCE in buffer solution of pH 1.02 with different concentrations of PCT at different temperatures. Under optimal conditions, the calibration plots were obtained. The oxidation peak current was linearly related to the concentration of PCT in the range of 24 and 240 µM. The linear regression equation could be expressed as follows: $I (\mu A) = kc (\mu M) + b$; the corresponding parameters are summarized in Table 1.

From Table 1, it can be seen that the slopes of the linear regression equations firstly decrease then increase with increasing system temperature. As known, the resistance of the pure electronic conductor and the activity of a solute that is PCT in this work will increase with increase in temperature; the resistance of the ionic conductor will decrease with increase in temperature [21]. The 4-ABA monolayer modified GCE reveals the negative electro-

chemical sensing property with increasing resistance. The increase of the PCT activity and the decrease of the solute resistance will promote the electrochemical sensing properties; among them, we think that the PCT activity plays a dominant role. So, the electrochemical sensitivity of PCT on the 4-ABA monolayer modified GCE is related to the resultant of the positive and negative effects. The temperature changes from 25.5 to 28.4 °C and the corresponding slopes of the linear regression equations change from 0.0174 to 0.0159, indicating that the increase of 4-ABA/GCE resistance is in control even though the PCT activity increases. However, the increase of the PCT activity gradually commands the electrochemical sensitivity of PCT on 4-ABA/GCE with temperature increase from 28.4 to 36.8 °C so that the maximum value of the slope, which is 0.0224, was obtained at 36.8 °C, indicating that 4-ABA/GCE possesses better electrochemical sensing properties to PCT at physiological temperature.

Conclusion

The 4-ABA monolayer modified GCE was used to sense PCT at different temperatures and compared to the bare GCE. The results show that 4-ABA/GCE possessed better stability, reusability, and longevity than the bare GCE at room to physiological temperatures. The increases of the PCT activity in the solutions gradually overcome that of the 4-ABA/GCE resistance, resulting in the slope increase of the linear regression equations gradually; namely, the electrochemical sensitivity of PCT on 4-ABA/GCE is gradually increased with temperature increase. In short, the 4-ABA monolayer modified GCE is fully usable at physiological conditions.

Table 1 The parameter of the linear regression equations

T (°C)	k (µA/µM)	b	R
25.5	0.0174	0.0613	0.999
28.4	0.0159	-0.3000	0.998
31.2	0.0163	-0.0800	0.998
34.0	0.0174	-0.1425	0.998
36.8	0.0224	-0.0371	0.999

Acknowledgments This work was supported by the National Science Foundation of China (No. 21005008).

References

1. Romos ML, Tyson JF, Curran DJ (1998) *Anal Chim Acta* 364:107–116
2. Palgarin JAM, Bermejo LFG (1996) *Anal Chim Acta* 333:59–69
3. Knochen M, Giglio J, Reis BF (2003) *J Pharm Biomed Anal* 33:191–197
4. Zhao SL, Bai WL, Yuan HY, Xiao D (2006) *J Anal Chim Acta* 559:195–199
5. Zhang Y, Luo LQ, Ding YP, Liu X, Qian ZY (2010) *J Microchim Acta* 171:133–138
6. Zhang L, Lin XQ (2005) *Anal Bioanal Chem* 382:1669–1677
7. Wang CY, Liu QX, Shao XQ, Hu XY (2007) *Anal Lett* 40:689–704
8. Jain R, Dwivedi A, Mishra R (2009) *Langmuir* 25:10364–10369
9. Razmi H, Habibi E (2010) *Electrochim Acta* 55:8731–8737
10. Hammam E (2004) *J Pharmaceut Biomed Anal* 34:1109–1116
11. Muralidharan B, Gopu G, Vedhi C, Manisankar P (2009) *J Appl Electrochem* 39:1177–1184
12. Shahrokhian S, Asadian E (2010) *Electrochim Acta* 55:666–672
13. Goyal RN, Gupta VK, Oyama M, Bachheti N (2005) *Electrochim Commun* 7:803–807
14. Li MQ, Jing LH (2007) *Electrochim Acta* 52:3250–3257
15. Alothmana ZA, Bukharia N, Wabaidura SM, Haider S (2010) *Sens Actuators B: Chem* 146:314–320
16. Doi T, Takeda K, Fukutsuka T, Iriyama Y, Abe T, Ogumi Z (2005) *Carbon* 43:2352–2357
17. Kang XH, Wang J, Wu H, Liu J, Aksay IA, Lin YH (2010) *Talanta* 81:754–759
18. Wang CH, Li CY, Wang F, Wang CF (2006) *Microchim Acta* 155:365–371
19. Yang GC, Shen Y, Wang MK, Chen HJ, Liu BF, Dong SJ (2006) *Talanta* 68:741–747
20. Nematollahi D, Shayani-Jam H, Alimoradi M, Niroomand S (2009) *Electrochimica Acta* 54:7407–7415
21. Hudson JL, Hall T, Tsotsis TT (1994) *Chem Eng Sci* 49:1493–1572