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ORIGINAL PAPER

A highly selective and sensitive dopamine and uric acid biosensor fabricated with functionalized ordered mesoporous carbon and hydrophobic ionic liquid

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Abstract An ordered mesoporous carbon material functionalized with carboxylic acid groups was synthesized. It was characterized by powder X-ray diffraction, transmission electron microscopy, Fourier transform IR spectroscopy and N_2 adsorption/desorption. Furthermore, this material was used to modify an electrode surface combined with a hydrophobic ionic liquid. The functionalized ordered mesoporous carbon/ionic liquid gel modified electrode shows excellent electrocatalytic performances for the oxidation of dopamine, uric acid and ascorbic acid. The presence of the ionic liquid promotes the electron transfer. Linear responses for dopamine and uric acid were obtained in the ranges of 0.1 to 500 μM and from 0.1 to 100 μM with detection limits of 4.1 and 2.5 nM (signal-to-noise ratio of 3), respectively, under optimum conditions. A quick and sensitive biosensor based on functionalized ordered mesoporous carbon and an ionic liquid has been developed for the first time for the detection of dopamine and uric acid in the presence of a large amount of ascorbic acid.

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Introduction

Highly ordered mesoporous carbon (OMC) has become a hot subject since it was synthesized in 1999 [1]. OMC exhibits an extremely high surface area, a well-ordered pore structure and chemical inertness, which make it suitable for applications in catalysis, adsorption, energy storage and sensing [2–5]. Similar to another well-known and widely used carbon-based material, i.e., carbon nanotubes (CNTs), OMC possesses the advantages of carbon nanomaterials, making it a novel electrode material in electrochemical sensors [6–11]. For example, the simultaneous determination of catechol and hydroquinone has been achieved at a mesoporous carbon modified electrode [12]. OMC was adopted as protein immobilization material to study the direct electrochemistry of haemoglobin [13]. A lot of research was conducted by Guo's group on an OMC-modified electrode. Different electrodes based on OMC were constructed for the detection of electroactive species, including hydrogen peroxide [14], hydroquinone [15], NADH [16], glutathione and cysteine [17], epinephrine [18], L-cysteine [19], ascorbic acid (AA) [20] and Sudan I [21]. Zhou et al. [22] compared the responses at an OMC-modified glassy carbon electrode and a CNT-modified glassy carbon electrode for the electrocatalysis of eight kinds of electroactive compounds, and the findings suggested that the OMC-modified glassy carbon electrode has more favourable electron transfer kinetics than the CNT-modified glassy carbon electrode.

Dopamine (DA) is one of the important catecholamine neurotransmitters in the mammalian central nervous system, and plays a significant role in several diseases, such as

schizophrenia and Parkinsonism [23]. Therefore, its determination by electrochemical techniques has attracted much attention [24–26]. Uric acid (UA) is the primary end product of purine metabolism. Abnormal levels of UA are symptoms of several diseases, such as hyperuricaemia, gout and Lesch–Nyhan disease [27], so it is desirable to seek a simple and direct method for monitoring the concentration of UA. The determination of UA has been reported by some researchers [28–30]. However, the oxidation potentials of the coexisting DA, UA and AA in body fluids are rather similar and always interfere with each other at conventional electrodes. Considerable efforts have been devoted to solving this problem. CNTs show high electrocatalytic activity towards the oxidation of DA, UA and AA and provide satisfactory results for determination of the three components. Yogeswaran and Chen [31] synthesized a composite film containing functionalized multiwalled CNTs with poly(neutral red) on glassy carbon electrodes by a potentiostatic method. Well-separated voltammetric peaks were obtained at the composite film modified electrode for AA, DA and UA ,with a peak separation of 0.17 V between AA and DA and 0.15 V between DA and UA. In addition, multilayer films composed of negatively charged single-walled CNTs (SWCNTs) and positively charged cetylpyridinium bromide (CPB) have been deposited on a glassy carbon electrode by Zhang et al. [32]. DA, UA and AA could be well separated at this SWCNT/CPB multilayer film modified electrode. The peak-to-peak potential separation obtained by differential pulse voltammetry (DPV) was 0.123, 0.179 and 0.302 V for DA–UA, DA–AA, and UA–AA. Furthermore, DA, AA and UA could be detected simultaneously at a glassy carbon modified electrode containing multiwalled CNTs and ionic liquid (IL) gel [33].

OMC material, as a new class of carbon nanomaterials, has been exploited in the detection of DA, UA and AA. Jia et al. [6] reported the electrochemical properties of OMC and its electroanalytical application for selective determination of DA in the presence of AA. The oxidation of UA and AA was investigated by Ndamanisha et al. [20, 34] at an OMC functionalized with ferrocenecarboxylic acid modified electrode. Recently, the simultaneous detection of DA, UA and AA was achieved at an OMC/Nafion composite film coated glassy carbon electrode by Ye et al. [35].

In this study, an ionic liquid was first introduced into a functionalized OMC (f-OMC)-modified electrode for simultaneous detection of DA, UA and AA. ILs are widely employed in electrochemistry because of their high chemical stabilities, relatively high ionic conductivity and wide electrochemical windows. It was reported that the electrochemistry of a CNT-modified electrode could be improved by introducing an IL [36, 37], where the IL was used as a binder in a carbon paste electrode or formed a gel with CNTs by grinding. Similarly, the gel could also be formed by grinding OMC and the IL together. The OMC/IL gel modified electrode was finally fabricated by the rubbing method. The sensor thus constructed exhibited outstanding catalytic activities towards the oxidation of DA, UA and AA. The simultaneous determination of DA, UA and AA could be achieved at a f-OMC/IL gel modified electrode.

Experimental

Reagents and apparatus

Pluronic123 (non-ionic triblock copolymer, $EO_{20}PO_{70}EO_{20}$) and DA were from Aldrich. 1-Butyl-3-methylimidazolium hexafluorophosphate ($BMIMPF_6$) was synthesized as described elsewhere [38]. UA, AA, tetraethylorthosilicate, sulfuric acid and sucrose were purchased from Sinopharm Chemical Reagent Co. (Shanghai, China) and were used as received. The other chemicals used were of analytical grade and all solutions were prepared with doubly distilled water. All electrochemistry experiments were performed using 0.20 M phosphate buffer (pH 7.0) as the supporting electrolyte at room temperature (18±2 °C).

Small-angle X-ray diffraction (XRD) patterns were determined with a Rigaku D\MAX-2550 using Cu Kα radiation. Transmission electron microscopy was performed with a JEOL 2011 instrument. Fourier transform IR spectra were obtained using a Nicolet 370 Fourier transform IR spectrometer. N_2 adsorption/desorption isotherms were measured using a Micromeritics ASAP 2010. The specific surface area and the pore size distribution were calculated by the Brunauer–Emmett–Teller and Barrett–Joyner–Halanda methods, respectively, using the desorption branch of the isotherms. Electrochemical measurements were carried out with a CHI-660C electrochemical workstation (Chenhua, Shanghai, China) with a three-electrode system: a glassy carbon electrode as the working electrode, a platinum wire as the auxiliary electrode and a saturated calomel electrode as the reference electrode.

Synthesis of materials

The synthesis of OMC was performed using SBA-15 silica as the template and sucrose as the carbon source. Briefly, 1.0 g of SBA-15 was added to a solution containing 1.25 g of sucrose and 0.14 g of H_2SO_4 in 5 ml of water under stirring. The mixture was placed in a drying oven for 6 h at 100 °C, and then kept for 6 h at 160 °C. The sample turned dark brown during the treatment in the oven. This process was repeated. The carbon–silica composite was obtained after heating to 800 °C under nitrogen flow. Finally, the dark-brown product was etched with 5% HF solution to remove the silica framework and dried at 120 °C to get the OMC. To obtain a more hydrophilic surface for electro-

chemical applications, the OMC was functionalized with carboxylic groups via acid treatment: the OMC was treated with H_2SO_4 for 3 h at 80 °C according to the procedure in the literature [39]. The IR spectrum of the acid-treated OMC showed two new bands at 1,746 and 1,557 cm^{-1}, typical of the carboxylic acid group (–COOH) and the carboxylate group ($–COO^-$) [32, 40].

Preparation of the modified electrode

The glassy carbon electrode (2 mm in diameter) was polished to a mirrorlike surface with 0.5- and 0.02-μm alumina slurry and successively sonicated in 1:1 nitric acid, acetone and doubly distilled water. Fifteen milligrams of f-OMC was mixed with 0.2 ml hydrophobic IL ($BMIMPF_6$) by grinding in an agate mortar to form a black gel. The f-OMC/IL gel modified electrode was fabricated by the rubbing method as follows [41]. The pretreated glassy carbon electrode was rubbed over the gel placed on a smooth glass slide, and the gel was mechanically attached to the electrode surface. Then the gel was smoothed with a spatula to leave a thin gel film on the glassy carbon electrode surface.

Results and discussion

Structural characteristics of OMC

The OMC gives rise to the well-resolved XRD peaks shown in Fig. 1, which are assigned to (100), (110) and (200) diffractions of the hexagonal space group. Furthermore, the presence of two small XRD peaks (d_{110} and d_{200}) demonstrates that the carbon materials synthesized are interconnected into a highly ordered hexagonal array by the carbon spacers, which is the inverse replica of mesoporous silica of SBA-15.

Figure 2 shows the transmission electron microscopy image for the OMC structure. The characteristic hexagonal arrangement is clearly visible, which is exactly an inverse replica of SBA-15.

As shown in Fig. 3, the N_2 adsorption/desorption isotherms of OMC (isotherm b) and SBA-15 (isotherm a) both exhibit capillary condensation at higher relative pressures and narrow mesoporous size distributions (Fig. 3, inset). The Brunauer–Emmett–Teller specific surface area, pore volume and predominant pore size of OMC are 810 m^2/g, 0.589 cm^3/g and 4.3 nm, respectively.

Electrochemistry of f-OMC-modified electrodes in an IL

The electrochemical responses of differently fabricated types of OMC-modified electrodes were evaluated in 0.20 M phosphate buffer solution (pH 7.0). As seen in Fig. 4a, the f-OMC-modified electrode exhibits an excellent electrochemical response in an IL. A pair of well-defined reversible redox peaks is observed with oxidation at -0.148 V and reduction at -0.216 V at the f-OMC/IL- gel modified electrode (cyclic voltammogram c). This is owing to the oxygen-containing functional groups on the surface of mesoporous carbon (carboxylic acid or carboxylate groups), which is similar to the case of CNTs [40]. Moreover a weaker peak current could be observed at the pristine OMC/IL gel modified electrode (cyclic voltammogram b) when OMC was not further treated by acid. In the absence of IL, the voltammetric response of the f-OMC-modified electrode (cyclic voltammogram a) was very weak in spite of the smaller background current. This indicates that the presence of an IL could improve the electrochemical response of an OMC-modified electrode.

The influence of scan rates was also studied at the f-OMC/IL gel modified electrode in phosphate buffer solution as seen

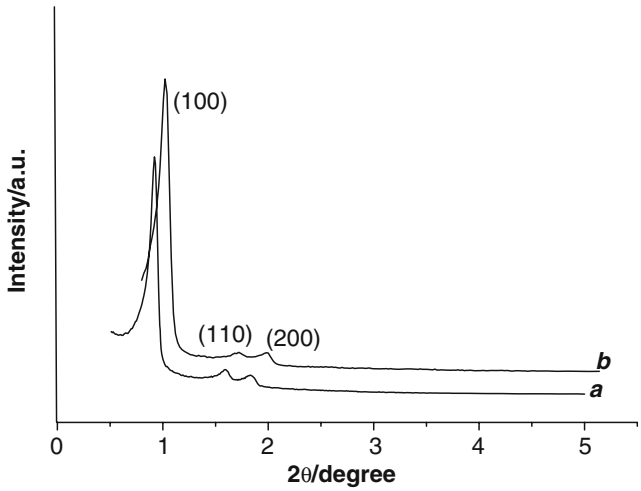

Fig. 1 X-ray diffraction patterns of SBA-15 (***a***) and ordered mesoporous carbon (***b***)

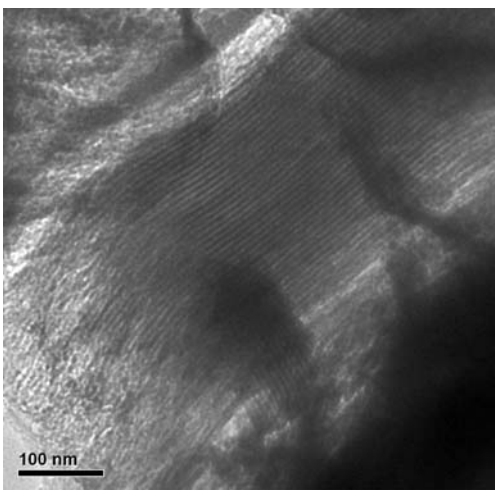

Fig. 2 Transmission electron microscopy images of ordered mesoporous carbon (OMC)

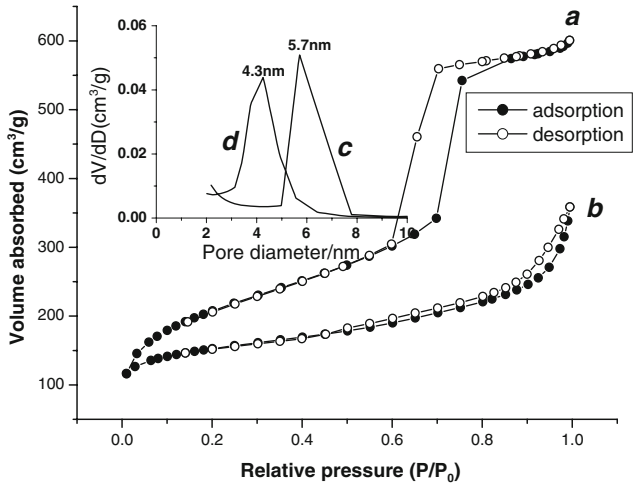

Fig. 3 N_2 adsorption/desorption isotherms of SBA-15 (***a***) and (OMC) (***b***). The *inset* shows the pore size distribution of SBA-15 (***c***) and OMC (***d***)

in Fig. 4b. At increasing scan rates the redox peak currents increase. The peak separation remains almost unchanged (approximately 70 mV) and the value of the ratio i_{pa}/i_{pc} is about 1 in the scan rate range from 0.01 to 0.4 V/s. Both anodic and cathodic peak currents are linearly proportional to the scan rates, suggesting a typical surface-controlled process. Additionally the redox peak potentials shift linearly in the negative direction with increasing pH, indicating the reaction of functional groups on the surface of mesoporous carbon is a proton-involved redox process.

Electrochemistry of biomolecules at the f-OMC/IL gel modified electrode

Electrochemical oxidation of DA

Figure 5 shows the cyclic voltammograms of 0.05 mM DA in 0.20 M phosphate buffer solution (pH 7.0) at the bare electrode (cyclic voltammogram a), the f-OMC-modified electrode (cyclic voltammogram b), the OMC/IL gel modified electrode (cyclic voltammogram c) and the f-OMC/IL gel modified electrode (cyclic voltammogram d). A pair of well-defined reversible redox peaks is observed at the f-OMC/IL- gel modified electrode with an anodic peak at 0.146 V and a cathodic peak at 0.112 V. The OMC/IL gel modified electrode exhibits smaller peak currents and weaker reversibility compared with the f-OMC/IL gel modified electrode. This is probably due to the more active carboxylic acid on the surface of functionalized mesoporous carbon. These active groups are favourable to the electro-oxidation of DA. It is noteworthy that the response of DA is dramatically improved when an IL is introduced into the modified electrode. The f-OMC with negatively charged carboxylate groups could interact with the IL cations. At the interface of the OMC/IL electrode the response of DA is enhanced, and larger capacitive currents were observed.

To further understand the role of the IL in the electrode reaction process, the electron transfer rate constant (k_s) was evaluated. From the dependence of the peak separation (ΔE_p) on the scan rate, the dynamic parameters can be calculated according to the Laviron equation for a diffusionless electrode reactant [42]. The number of electrons transferred (n), the electron transfer coefficient (α) and the heterogeneous electron transfer rate constant (k_s) of DA are listed in Table 1. In the case of the f-OMC/IL gel modified electrode, k_s is 2.5 s^{-1} for DA oxidation. It is relatively larger than the value of 0.97 s^{-1} at a f-OMC-modified electrode in the absence of the IL. This indicates that the presence of the IL facilitates the electron transfer between the biomolecules and the electrode surface; thus, anodic and cathodic currents are dramatically enhanced. Additionally,

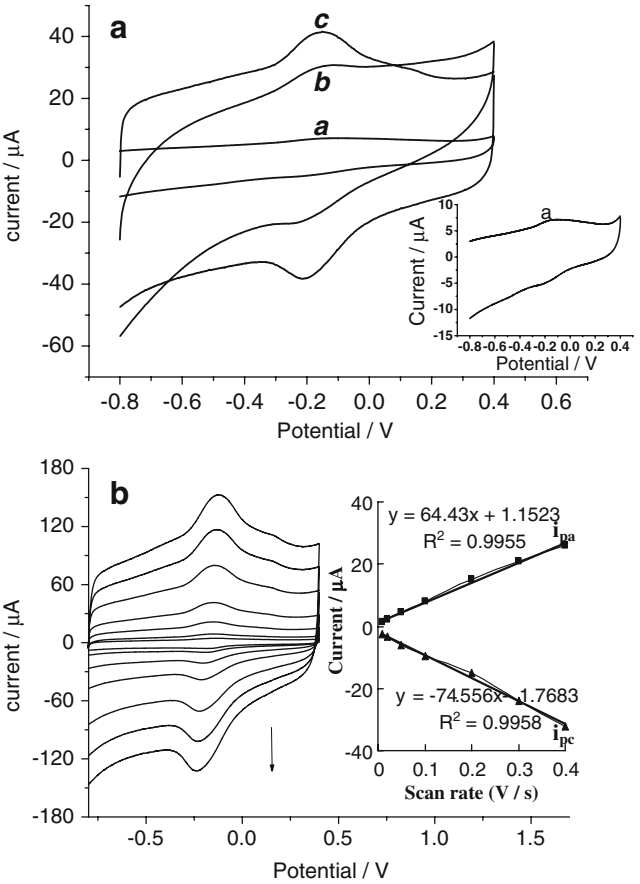

Fig. 4 **a** Cyclic voltammograms of the functionalized OMC (f-OMC)-modified electrode (***a***), the OMC/ionic liquid (IL) gel modified electrode (***b***) and f-OMC/IL gel modified electrode (***c***) in 0.20 M phosphate buffer (pH 7.0) at 0.1 V/s. The *inset* shows a magnification of the cyclic voltammogram of the f-OMC modified electrode. **b** Cyclic voltammograms of the f-OMC/IL gel modified electrode in 0.20 M phosphate buffer (pH 7.0) at various scan rates: 0.01, 0.02, 0.05, 0.1, 0.2, 0.3 and 0.4 V/s (from *top* to *bottom*). The *inset* shows the variation of I_p with scan rate

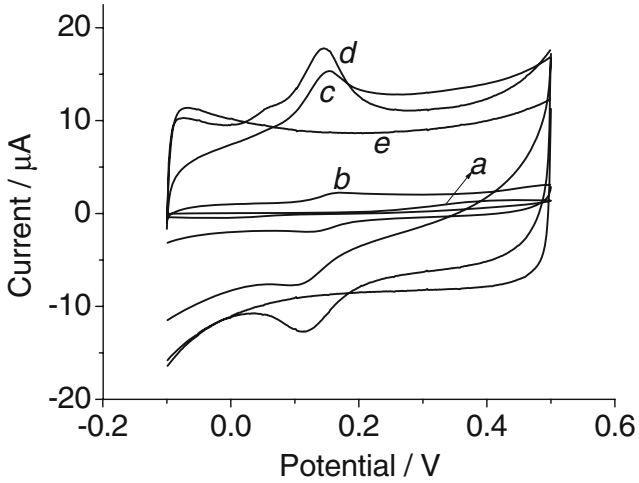

Fig. 5 Cyclic voltammograms of 0.05 mM dopamine (DA) at a bare glassy carbon electrode (***a***), the f-OMC-modified electrode (***b***), the OMC/IL gel modified electrode (***c***), the f-OMC/IL gel modified electrode (***d***) and of a blank solution at the f-OMC/IL gel modified electrode (***e***) in pH 7.0 phosphate buffer solution at 0.1 V/s

an interesting result is found that the oxidation of DA at the f-OMC/IL gel modified electrode is a one-electron transfer in the rate-determining step, which is different from the two-electron oxidation process as generally thought.

The effect of scan rate was investigated at the f-OMC/IL gel modified electrode, the OMC/IL gel modified electrode and the f-OMC-modified electrode, respectively. The results indicate that the electrode reaction of DA is a typical adsorption-controlled process at the f-OMC electrode whether IL is added or not. This is different from the pristine OMC/IL gel modified electrode, which has a diffusion-controlled process. This implies the functionalization of OMC has a certain effect on the electrode process of DA. The negatively charged OMC could weakly adsorb the positively charged DA; thus, adsorption process becomes dominant.

Voltammetric responses of the f-OMC/IL gel modified electrode to UA and AA

The f-OMC/IL gel modified electrode also demonstrates outstanding electrocatalytic performance towards UA. Cyclic voltammograms were recorded at the bare electrode (Fig. 6a, cyclic voltammogram a), the f-OMC-modified electrode (Fig. 6a, cyclic voltammogram b) and the f-OMC/IL gel modified electrode (Fig. 6a, cyclic voltammogram c) in 0.05 mM UA buffer solution (PH 7.0). Only a broad and weak oxidation peak was observed at about 0.40 V at the bare electrode, whereas it shifted negatively to 0.313 V and an obvious reduction peak appeared at 0.266 V at the f-OMC/IL gel modified electrode. Moreover, the peak currents also significantly increased in the presence of the IL. Some works have been reported on the electrocatalytic oxidation of UA [43, 44], but the reduction of UA is seldom discussed owing to its cathodic product being unstable. Recently, this cathodic peak has been observed by Ndamanisha and Guo [34] at an OMC/ferrocenecarboxylic acid modified electrode where ferrocene was used as a mediator [34].

Since AA is the major interference in the electrochemical measurement of DA and UA, its voltammetric behaviour at the f-OMC/IL gel modified electrode was also studied. A larger and sharper anodic peak was observed at -0.108 V at the f-OMC/IL gel modified electrode (Fig. 6b, cyclic

Table 1 The dynamic parameters for electrode reaction of dopamine (DA)

Electrode	*n*	α	k_s (s^{-1})
f-OMC-modified electrode	2	0.60	0.97
f-OMC/IL gel modified electrode	1	0.55	2.5

f-OMC functionalized ordered mesoporous carbon, *IL* ionic liquid

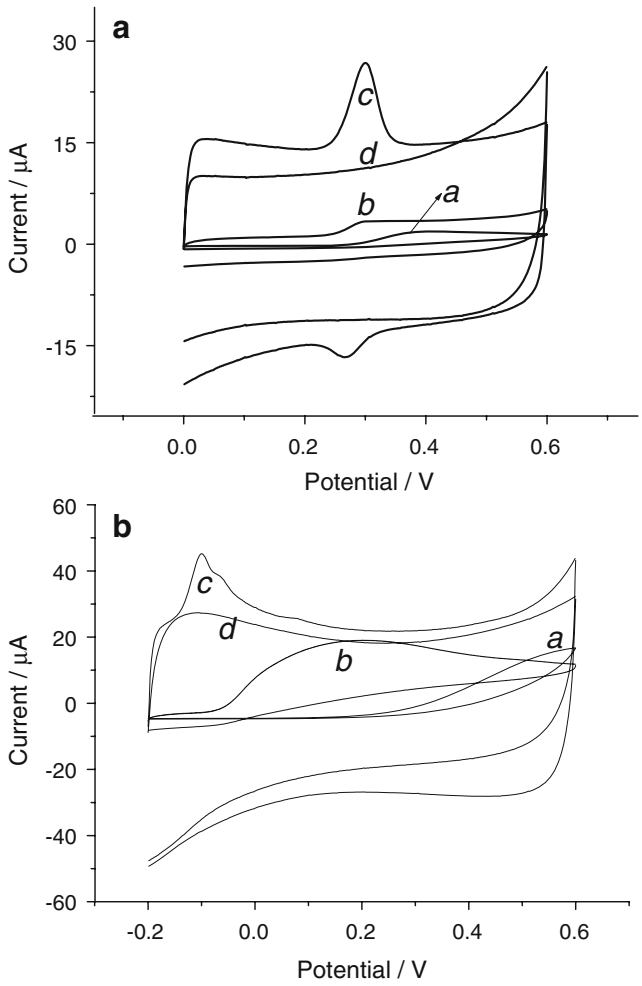

Fig. 6 Cyclic voltammograms of 0.05 mM uric acid (UA) (**a**) and 5 mM ascorbic acid (AA) (**b**) at a bare glassy carbon electrode (***a***), the f-OMC-modified electrode (***b***), the f-OMC/IL gel modified electrode (***c***) and of a blank solution at the f-OMC/IL-gel modified electrode (***d***) in pH 7.0 phosphate buffer solution at 0.1 V/s

voltammogram c). The f-OMC-modified electrode (Fig. 6b, cyclic voltammogram b) exhibits a broad anodic peak at 0.112 V and the peak current is much smaller owing to the lack of IL. At the bare electrode (Fig. 6b, cyclic voltammogram a) only a very weak voltammetric response can be seen at about 0.6 V.

It is concluded from these results that in the absence of the mediator the excellent electrocatalytic activity of the f-OMC/IL gel modified electrode originates from the synergistic effect of the IL and carboxylate groups on the OMC.

Effect of pH

The effect of pH was investigated at the f-OMC/IL gel modified electrode in the pH range from 3.0 to 9.0. The oxidation peak potentials of DA and UA shift with pH as E_{pa} (DA)=-0.047 pH+0.5649 (r=0.9907) and E_{pa} (UA)= -0.058pH+0.7806 (r=0.9997). The oxidation potentials for DA and UA shift linearly in the negative direction with increasing pH with slopes of -47 and -58 mV/pH, respectively, at 20°C. This indicates that two electrons and two protons are involved in the overall oxidation process.

Amperometric response of the biosensor

The amperometric responses of the f-OMC/IL gel modified electrode to DA at an applied potential of 0.21 V and to UA at an applied potential of 0.30 V are illustrated in Fig. 7a and b, respectively. After successive addition of 5.0 mM DA (or UA) solution with different volumes to 25 ml phosphate buffer solution, a stepwise growth of the oxidation current is observed. The modified electrode achieves 95% of the steady-state current in 5 s for DA and in 3 s for UA, indicating that the biosensor response is very fast.

Calibration curve and electrode stability

Owing to the significant background currents in the presence of the IL, the DPV technique is used to alleviate this. The linear correlation between the anodic peak current (i_{pa}) and the concentration is obtained in the range 0.1–500 μM for DA with the regression equation i_{pa} (μA)=0.3055 c (μM)+ 3.9374, r=0.9954, and in the range 0.1–100 μM for UA with the regression equation i_{pa} (μA)=0.4980 c (μM)+0.2544, r= 0.9995. The detection limits are estimated to be 4.1 and 2.5 nM (signal-to-noise ratio of 3), respectively. The calibration curve parameters for determination of DA and UA are listed in Table 2.

Table 3 compares the response characteristics for determination of DA and UA at various modified electrodes reported in previous works. It is found that the f-OMC/IL gel modified electrode has very good response characteristics in comparison with the electrodes reported previously.

The stability of the f-OMC/IL gel modified electrode was tested in 0.05 mM DA solution. Five electrodes prepared in the same manner gave a relative standard deviation of 6.4%. Furthermore, the modified electrode was stored in air for 1 week, the electrochemical activity of DA could be well maintained and only 2.1% decay of the initial current was observed.

Simultaneous determination of DA and UA in the presence of AA

The simultaneous determination of the three components was carried out at the f-OMC/IL gel modified electrode using the DPV technique. Figure 8 records the DPV curves of various concentrations of DA and UA in the presence of AA. The peak potentials of UA, DA and AA are 0.252, 0.116 and -0.096 V, respectively, in pH 7.0 phosphate buffer solution. The potential differences are large enough to allow simultaneous detection of DA, UA and AA. From Fig. 8a it can be seen that the peak current of DA increases with the DA concentration, whereas the peak heights of AA and UA do not change. Likewise, the peak current of UA is positively proportional to its concentration, as shown in Fig. 7b, whereas the peak currents of the other two components remain constant. Clearly DA and UA could

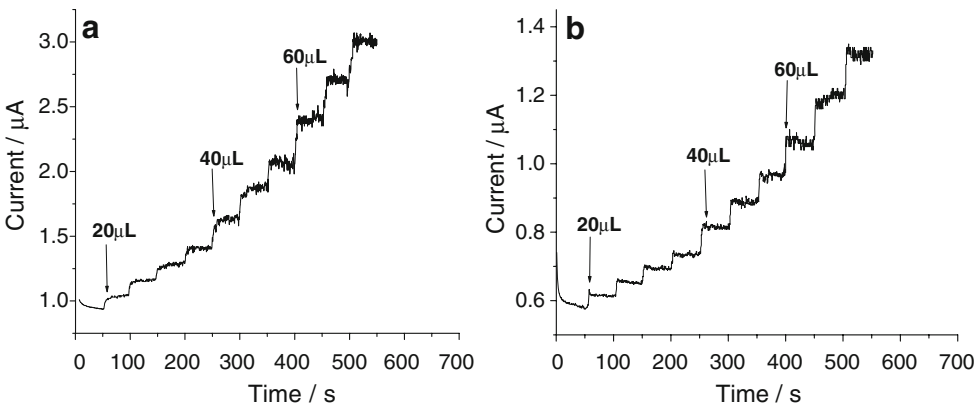

Fig. 7 Amperometric responses of the f-OMC/IL gel modified electrode upon successive additions of 20, 40 and 60 μL of 5.0 mM DA (**a**) and 5.0 mM UA (**b**) to 25 ml phosphate buffer solution (pH 7.0) under stirring at an applied potential of 0.21 V and 0.30 V, respectively

Table 2 Calibration curve parameters for the determination of DA and uric acid (*UA*)

Biomolecule	Concentration range (μM)	Regression equation i_{pa} vs. c ($\mu A \mu M^{-1}$)	r	Detection limit (nM)
DA	0.1–500	$i_{pa}=0.3055c + 3.9374$	0.9954	4.1
UA	0.1–100	$i_{pa}=0.4980c + 0.2544$	0.9995	2.5

be simultaneously determined in the presence of a higher concentration of AA (4,000-fold higher for DA, 5,000-fold higher for UA) at the f-OMC/IL gel modified electrode.

Conclusions

In this work, an OMC/IL gel modified electrode was functionalized with carboxylic acid. The f-OMC-modified electrode shows outstanding electrocatalytic behaviours for DA, UA and AA in an IL. A marked enhancement in the current and an obvious decrease in the peak separation were observed. The carboxylate groups on the surface of functionalized mesoporous carbon are favourable for the electrooxidation of DA, UA and AA. The f-OMC with negatively charged carboxylate groups could interact with the IL cations. At the interface of the OMC/IL electrode the responses of biomolecules are enhanced. Linear responses for DA and UA were obtained in the range from 0.1 to 500 μM and from 0.1 to 100 μM with detection limits of 4.1 and 2.5 nM (signal-to-noise ratio of 3), respectively, under optimum conditions. Moreover, simultaneous detec-

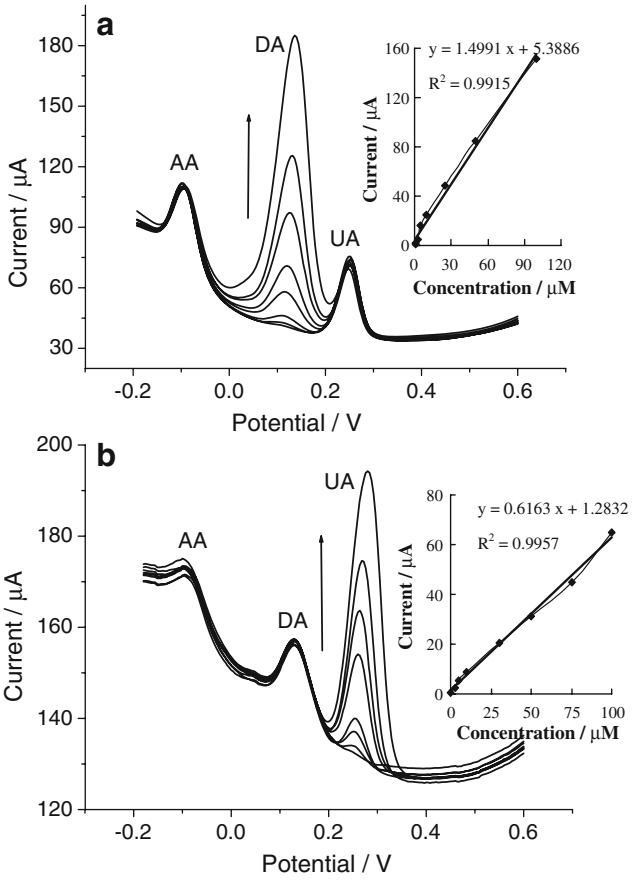

Fig. 8 Differential pulse voltammetry curves recorded at the f-OMC/IL gel modified electrode in pH 7.0 phosphate buffer solution containing 2 mM AA, 20 μM UA and different concentrations of DA (from *bottom* to *top* 0.5, 1, 2.5, 5, 10, 25, 50 and 100 μM) (**a**) and 1 mM AA, 15 μM DA and different concentrations of UA (from *bottom* to *top* 0.2, 3, 5, 10, 30, 50, 75 and 100 μM) (**b**)

Table 3 Response characteristics for determination of DA and UA at various modified electrodes

Type of electrode	Technique	Linear range (μM)		Detection limit (μM)		Reference
		DA	UA	DA	UA	
OMC-modified electrode	CV	40–1000	–	–	–	[6]
OMC/Nafion/GC electrode	DPV	1–90	5–80	0.5	4.0	[35]
OMC–Fc GC electrode	I-T	–	60–390	–	1.8	[34]
MWNT/IL gel/GC electrode	DPV	1–100	–	0.1	–	[33]
Nafion/SWNT/P3MT/GC electrode	DPV	0.02–0.1	–	0.005	–	[24]
RuO_2/MWNT electrode	*I–T*	0.6–3600	–	0.06	–	[26]
Functionalized-SWNT-modified electrode	CV	1–200	–	–	–	[40]
Gold-nanoparticle-modified GC electrode	DPV	–	0.6–850	–	0.1	[32]
DNA/poly(*p*-aminobenzensulfonic acid) composite bilayer/GC electrode	DPV	0.19–13	0.4–23	0.088	0.19	[43]
Functionalized-SWNT-modified electrode	DPV	4–120	2–90	0.6	7	[32]
LaHCF-modified electrode	DPV	–	0.2–100	–	0.1	[45]
f-OMC/IL gel modified electrode	DPV	0.1–500	0.1–100	0.0041	0.0025	This work

OMC ordered mesoporous carbon, *GC* glassy carbon, *Fc* ferrocene, *MWNT* mulltiwalled carbon nanotube, *SWNT* single-walled carbon nanotube, *P3MT* poly(3-methylthiophene), *CV* cyclic voltammetry, *DPV* differential pulse voltammetry

tion of DA, UA and AA could be achieved at the f-OMC/IL gel modified electrode by the DPV method. In conclusion, the sensor constructed in this study exhibits a wide linear range, a very low detection limit and good stability, so it will become a promising candidate for a DA and UA electrochemical biosensor.

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