Prussian blue nanocubes decorated three-dimensional silver nanowires network for high-performance electrochemical biosensing

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Abstract

High sensitivity and selectivity play critical roles in practical applications of glucose biosensors. In this study, we reported a novel glucose biosensor based on three-dimensional (3D) structured biosensing film, which consisted of silver nanowires (AgNWs) network and Prussian blue nanocubes (PBNCs). 3D AgNWs network was successfully built on the electrode surface with assistance of self-assembled monolayers (SAMs), while PBNCs were in situ prepared on the network through aerosol deposition approach and glucose oxidase (GOx) was immobilized onto the surface of PBNCs/AgNWs film with glutaraldehyde cross-linking method. Owing to an enhanced surface area, high conductivity and synergistic electrocatalytic activity of fabricated PBNCs/AgNWs film, an ultrasensitive glucose biosensor with high selectivity was constructed. As a result, the as-prepared biosensor exhibited an ultrahigh sensitivity of 359.0 nA M⁻¹ cm⁻² with a linear range from 0.01 to 0.9 mM, an outstanding anti-interference ability at a low potential of −0.05 V, as well as excellent stability and reproducibility. It is believed that the proposed 3D sensing film would have widespread applications in biological sensing and quantitative biochemical analysis.

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1. Introduction

Due to the rapid development of biotechnology and life science, human is paying more and more attention in disease prevention and health care [1,2]. Recently, numerous biosensors, especially glucose biosensors, which focus on kinds of diseases detection have been rapidly produced and attempted to apply in real medical diagnosis. However, unsatisfactory sensitivity and selectivity have restricted their further development from lab to factory. These key parameters are mainly depended on the properties of adopted sensing materials. Therefore, the development and design of functional materials is generally considered as an effective method to improve the sensing performance of biosensors.

Nanomaterials have attracted considerable attention on the construction of glucose biosensors because of their large surface area, suitable hydrophilicity and good biocompatibility [3–7]. For examples, Xi et al. prepared a PPy/CNT based glucose biosensor, in which a sensitivity of 97.3 nA M⁻¹ cm⁻² was achieved [8]. Tang et al. fabricated a Pt nanoparticle/CNT modified electrode for the detection of glucose, and a sensitivity of 91 nA M⁻¹ cm⁻² was observed [9]. Besides, Zhai et al. presented a Pt nanoparticle/polyaniline hydrogel heterostructure for glucose analysis, in which a sensitivity of 96.1 nA M⁻¹ cm⁻² was obtained [10]. Furthermore, Chen et al. employed a novel PtPd-MWCNTs to construct a sensitive glucose biosensor, which exhibited a sensitivity of 112 nA M⁻¹ cm⁻² [11]. Additionally, Anusha et al. used chitosan nanoparticles as a glucose biosensor with a sensitivity of 156.3 nA M⁻¹ cm⁻² [12]. Particularly, in the recent researches, Lang et al. prepared a nanoporous gold supported cobalt oxide glucose biosensor with high sensitivity and Choi et al. synthesized carbon nanotube–nickel nanocomposites for glucose sensing, which owned an outstanding performance [7,13]. Obviously, the introduction of nanomaterials has significantly enhanced the performance of fabricated biosensors. However, the applied detection potential of proposed biosensors were usually high, which would suffer from severe signal interference arising from common electroactive species, e.g. ascorbic acid (AA) and uric acid (UA), in the detection of glucose [14]. Therefore, it has remained a great challenge to construct desired glucose biosensor with high sensitivity and selectivity through developing novel promising nanomaterials.

As we know, nanowires have promising activities in sensors due to their unique electronic properties [15,16]. Particularly, owing to the superior conductivity, silver nanowires (AgNWs) may facilitate more efficient electron transfer than other metal nanowires in biosensors [17–19]. Nevertheless, its high catalytic
potential may easily lead to a weak selectivity in the real complex system. Accordingly, it is critical and prerequisite to improve the selectivity of AgNWs based biosensors in practical applications. Prussian blue (PB) is regarded as an excellent electron mediator, which possessed an outstanding ability to effectively reduce applied potential in electrochemical systems [20–22]. Therefore, constructing a promising sensing film consisting of AgNWs and PB was expected to harvest both excellent electrocatalysis and anti-interference ability for glucose biosensor.

In this work, we constructed a novel biosensor based on aerobic oxidation of glucose followed by electrochemical detection of hydrogen peroxide by a 3D nanostructured film consisting of AgNWs and PB nanocubes (PBNCs). 3D AgNWs network with enhanced electron transport and increased surface area were uniformly formed on gold substrate, in which self-assembled monolayers (SAMs) were introduced to enhance binding strength between AgNWs and substrate. Furthermore, PBNCs with a diameter of around 200 nm could be produced on AgNWs through an in situ aerosol deposition approach and the 3D structure could be remained, resulting in a large surface area of sensing film, in which nanocubic PB crystals could significantly enhance the electrocatalytic activity of proposed sensing film. Additionally, glutaraldehyde cross-linking method was used to immobilize glucose oxidase (GOx) onto the surface of PBNCs/AgNWs film, which was an effective immobilization method although this technique might lead to the partly loss of enzyme activity. The as-prepared biosensor exhibited an ultrahigh sensitivity in the detection of glucose, as well as an excellent anti-interference ability attributed to a low operation potential.

2. Experimental

2.1. Reagents and apparatus

All chemicals were of analytical purity and used as received. K$_3$[Fe(CN)$_6$], 3H$_2$O, FeCl$_3$, 6H$_2$O, 1,6-hexanediol (EG) and GOx from Aspergillus niger (E.C. 1.1.3.4, 180,200 U g$^{-1}$) were purchased from Sigma-Aldrich. AgNO$_3$ and polyvinylpyrrolidone (PVP) (M$_w$ ≈ 40,000) were purchased from the Shanghai Chemical Reagent Company. 30 wt% H$_2$O$_2$ and glucose were purchased from Sinopharm Chemical Reagent Co., Ltd, China. All solutions were prepared with deionized water.

All electrochemical measurements were performed with an electrochemical workstation (CHI 660C, Shanghai Chenhui, China), which employed Pt and Ag/AgCl (saturated KCl) as the counter and reference electrodes, respectively. Chronoamperometry characterizations were carried out in a stirring PBS solution at the −0.05 V potential. Electrochemical impedance spectroscopy (EIS) measurements were performed in the presence of a stationary 5 mM K$_3$[Fe(CN)$_6$]/K$_4$[Fe(CN)$_6$] (1:1) mixture as a redox probe in 0.1 M KCl solution with the frequency changed from 0.01 Hz to 100 kHz with signal amplitude of 5 mV. All the characterization experiments were performed at the temperature of 25 °C. Field emission scanning electron microscopy (FESEM) (Hitachi-4800, Japan) was operated to investigate the film morphologies. The ultrasonic nebulizer (Shanghai Yu Yue Medical Equipment Co., Ltd, China; size: 240 mm × 130 mm × 200 mm; power: 50 W; frequency: 1.7 MHz) was introduced to produce aerosol of precursor solutions for the fabrication of PBNCs on AgNWs network.

2.2. Pretreatment of gold electrode

In order to satisfy the clean and plane demands to substrate, gold electrode (2 mm diameter) was firstly polished as a mirror with metallographical sand paper. Then the electrode was dipped into a Piranha solution (7:3 mixture of H$_2$SO$_4$ and H$_2$O$_2$, v/v) (Caution: The mixture is strongly oxidizing and may detonate upon contact with organic material) for 30 min and rinsed with water. Finally, it was washed in ultrasonic environment for 30 min. The cleaned gold electrode was immersed into a 5 mM 1,6-hexanediol ethanol solution for 6 h to form the SAMs, and then rinsed by ethanol [23–25].

2.3. Synthesis of AgNWs

AgNWs were synthesized through a two-step-injection polyol method [26]. In a typical synthesis of AgNWs, 0.333 g of PVP was dissolved in 34 ml of EG with moderate stirring and then heated to 160 °C. Once the temperature was stable, 40 μl of 0.2 M NaCl EG solution was added into the reaction flask, which was used to enhance the etching ability of the reaction solution on metallic silver and decrease the total generation rate of silver solids. After 1 min, 6 ml of 0.34 g AgNO$_3$ EG solution was added into the reaction flask by using a syringe pump at a rate of 600 μl min$^{-1}$. Once the reaction solution began to become cloudy, all remaining AgNO$_3$ EG solution was added into the reaction flask immediately. Then the flask was sealed until the solution glistened, indicating the formation of AgNWs. The products were collected by centrifugation.

2.4. Preparation of the sensing film of PBNCs/AgNWs

The ethanol solution containing AgNWs was repeatedly dropped and dried on the gold electrode modified with 1,6-hexanediol SAMs at 60 °C, and then 3D AgNWs network was obtained on electrode surface, as shown in Fig. 1. Moreover, a facile aerosol deposition method was used to fabricate PB [22], in which two aerosol solutions of solution 1: 0.01 M K$_3$[Fe(CN)$_6$] + 0.1 M KCl + 0.1 M HCl, and solution 2: 0.01 M FeCl$_3$ + 0.1 M KCl + 0.1 M HCl were prepared preliminarily. The AgNWs network modified electrode was firstly fixed in the airtight organic glass container. Then, aerosol of solution 1 was continuously injected into the container for 4 h. The average injection rate was 1.5 ml min$^{-1}$ and the temperature was kept at 35 °C. Subsequently, aerosol of solution 2 was continuously injected for 4 h after the former aerosol exhausted. The two steps were denoted as a deposition process of aerosol, and deposition time was the time required for a process of aerosol injection. Finally, the PBNCs/AgNWs film was successfully prepared on the electrode surface, which was cleaned with deionized water and dried at 100 °C for 1 h.

2.5. Enzyme immobilization

Glutaraldehyde cross-linking method was used to immobilize GOx onto the surface of PBNCs/AgNWs film. A mixture was prepared by adding GOx and glutaraldehyde into 0.05 M phosphate buffer solution (PBS, pH 6.5) including 0.1 M KCl. The concentration of GOx and glutaraldehyde was 5 mg ml$^{-1}$ and 0.125% (v/v), respectively.

Subsequently, the mixture of 5 μl was dropped onto the PBNCs/AgNWs film and allowed to dry for 1 h at room temperature. The resulting enzyme electrode was stored at 4 °C when not in use.

2.6. Real blood sample analysis

Human serum was used to confirm the applicability of fabricated glucose biosensor in practical applications. Firstly, human blood collected from a healthy man was centrifuged at 12,000 rpm for 15 min to obtain serum sample, and the glucose concentration of serum sample was determined to be 6.09 mM by
3. Results and discussion

3.1. Influence of AgNO₃ concentrations on AgNWs

As reported, the concentration of AgNO₃ would strongly affect the morphology and distribution of prepared AgNWs. Therefore, several AgNO₃ concentrations of 0.05, 0.1 and 0.15 M were investigated to obtain the optimum parameter for AgNWs formation. Fig. 2(a)–(c) shows FESEM images of AgNWs synthesized with different AgNO₃ concentrations. As shown in Fig. 2a, AgNWs with smaller and uniform diameter were prepared with a lower concentration of AgNO₃. While increasing the concentration of AgNO₃, AgNWs with obviously enlarged diameters were produced, as shown in Fig. 2b and c, which would obviously reduce the effective surface area of obtained 3D AgNWs network. In addition, it could be found that well dispersed AgNWs were stably immobilized on the electrodes modified with 1,6-hexanedi-thiol SAMs. As a comparison, the formed AgNWs network was easily peeled from the electrode surface in the absence of 1,6-hexanedi-thiol SAMs (Fig. 2d), indicating that terminal –SH groups of the

![Fig. 2](image-url)
1,6-hexanediithiol SAMs could effectively address the binding issue between AgNWs and gold electrode.

Besides, different morphologies of prepared 3D AgNWs networks would affect their electrochemical behaviors and the low interfacial resistance will generally produce the better performance [21]. Therefore, EIS technique was applied to investigate the electron transport impedances of AgNWs networks. The semicircle part was probed by high frequencies corresponding to the electron transfer kinetics of redox species at the electrode surface, while the linear part at low frequencies represented the mass transfer of probe species from bulk solution to the interface region. The semicircle diameter equalled the electron-transfer resistance, \( R_\text{ct} \). The charge transfer resistance \( R_\text{ct} \) was obtained by using the Classical Randles circuit (Fig. 3 inset). The fitting values were 784, 2696 and 3484 Ω of the AgNWs networks fabricated with the AgNO₃ concentration of 0.05, 0.1 and 0.15 M, respectively. As shown in Fig. 3, the AgNWs networks fabricated with lower AgNO₃ concentrations owned a lower electronic transfer resistance, which was attributed to that smaller and uniform diameter of proposed AgNWs would significantly enhance the electroactive surface of 3D network.

Besides, in order to investigate the influence of morphologies of prepared 3D AgNWs networks quantificationally, the surface areas of different morphologies were studied. The surface area can be determined with the Randles–Svcek equation [27]:

\[
\frac{I_p}{v^{1/2}} = (2.69 \times 10^4)n^{3/2}D_0^{1/2}C_0^{1/2}A
\]

where \( A \) is the electrode area, \( n \) the number of electrons transferred in the redox event, \( v \) the scan rate, \( D_0 \) the diffusion coefficient of the molecules, \( C_0 \) the concentration of the probe molecules, and \( I_p \) is the peak current of the redox couple. From this equation, the surface area is proportional to \( I_p/v^{1/2} \). Cyclic voltammetry curves (CVs) of AgNWs network were investigated to calculate \( I_p/v^{1/2} \) in 10 mM K₂Fe(CN)₆, containing 3 M KCl under different scan rates. The applied potentials ranged from 0 to 0.6 V, which employed Pt and Ag/AgCl (saturated KCl) as the counter and reference electrodes. As shown in Fig. 4b, the relationship between the peak current and the square root of the scan rate was linear for AgNWs network, and the Randles’ slope was \( I_p/v^{1/2} \). The surface areas of AgNWs networks were calculated from the Randles’ slope and are shown in Table 1. Consequently, the AgNWs networks fabricated with lower AgNO₃ concentrations resulted in high surface area. Additionally, in comparison with the bare Au electrode, the surface area of the AgNWs networks with AgNO₃ concentration of 0.05 M were increased by about 3.2 times. As a result, the AgNO₃ concentration of 0.05 M was selected as the optimal condition for the preparation of 3D AgNWs network.

### 3.2. Growth of PBNCs on 3D AgNWs network

In order to realize the controllable growth of PB crystals on AgNWs network, aerosol deposition approach was introduced in this work. Aerosol is considered as a method based on small molecules reaction, which slows down the driving force for the chemical equilibrium and reduces the formation rate of PB crystals [21]. For aerosol reaction, deposition time was one of the critical factors. Hence, different deposition time of 7, 8, 9 and 10 h was implemented. As shown in Fig. 5a, it was found that aerosol deposition approach was effective in the fabrication of PB on AgNWs network, and the surface of PBNCs was successfully covered by the formed PBNCs when the deposition time of 7 h was adopted. With an increased deposition time to 8 h (Fig. 5b), more PBNCs were produced, which were uniformly distributed on the 3D AgNWs network. In this condition, PBNCs with uniform diameter of around 200 nm were obtained (insert of Fig. 5b). However, while further improving the deposition time to 9 h, more PBNCs with larger dimensions were produced, which was prone to fill the interspace in 3D network (Fig. 5c). Till 10 h, PBNCs with further enhanced diameters have completely covered the surface of

<table>
<thead>
<tr>
<th>Table 1</th>
<th>The surface area of AgNWs networks fabricated with different concentrations of AgNO₃.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified electrodes</td>
<td>Randles’ slope</td>
</tr>
<tr>
<td>Bare Au electrode</td>
<td>0.0694</td>
</tr>
<tr>
<td>AgNWs network (0.05 M)</td>
<td>0.0948</td>
</tr>
<tr>
<td>AgNWs network (0.1 M)</td>
<td>0.0715</td>
</tr>
<tr>
<td>AgNWs network (0.15 M)</td>
<td>0.05997</td>
</tr>
</tbody>
</table>

Fig. 3. EIS results of 3D AgNWs networks fabricated with different concentrations of AgNO₃.

Fig. 4. (a) CVs of AgNWs network with AgNO₃ concentration of 0.05 M in a mixture solution of 10 mM of K₂Fe(CN)₆ and 3 M KCl at scan rates of 50, 100, 150, 200, 250 and 300 mV s⁻¹. (b) Peak currents as a function of scan rate for calculating surface area of AgNWs networks with different concentrations of AgNO₃, and bare Au electrode.
AgNWs network and a relatively compact structure was formed (Fig. 5), which would severely decrease the effective surface area of proposed PBNCs/AgNWs film.

### 3.3. Electrochemical characterization

#### 3.3.1. Electrochemical characterization of H$_2$O$_2$

Fig. 6 shows the CVs of PBNCs/AgNWs film in the absence and presence of 1 mM H$_2$O$_2$ solution. The scan rate was 50 mV s$^{-1}$. With the addition of H$_2$O$_2$ into solution, the reduction peak current of PBNCs/AgNWs film was increased. This demonstrated that the as-prepared PBNCs/AgNWs film electrode showed high electrocatalytic activity towards the reduction of H$_2$O$_2$.

Additionally, H$_2$O$_2$ was selected to evaluate the performance of prepared PBNCs/AgNWs films prepared with different deposition time, which were characterized by chronoamperometry technique. Under a potential of $−0.05$ V, H$_2$O$_2$ was successively injected into a stirring PBS solution at 25 $^{\circ}$C by the same interval. As shown in Fig. 7a, the current step could keep stable and distinct even after injection of 30 times, indicating that the proposed 3D structure of PBNCs/AgNWs possessed a high stability and catalytic activity towards the electrochemical reduction of H$_2$O$_2$. According to above data, a linear dependence of response currents vs. H$_2$O$_2$ concentrations were exhibited in Fig. 7b. The sensitivities were calculated as 2672.3, 2868.6, 2591.5 and 1550.3 mA M$^{-1}$ cm$^{-2}$ for PBNCs prepared with different deposition time of 7, 8, 9 and 10 h, respectively (shown in insert of Fig. 7b). From the results, it was found that the highest sensitivity was obtained with a deposition time of 8 h. Obviously, less coverage of PBNCs prepared with 7 h could not provide enough catalytic sites and lead to the generation of weak response signals. However, with increased deposition time over 9 h, a higher coverage of PBNCs with enhanced dimensions was observed. Besides, the compact surface morphology severely decreased effective area and resulted in an increased electron transfer resistance, which hindered the acquisition and transport of response signals. We compared the performance of our proposed sensor with that of other reported PB or AgNWs based H$_2$O$_2$ sensors, which is shown in Table 2. It could be seen that the sensitivity of the as-prepared sensor was superior to other H$_2$O$_2$ sensors. Definitely, the excellent conductivity, significantly enhanced surface area, and especially the synergistic electrocatalytic activity of fabricated PBNCs/AgNWs film made a great contribution to the ultrahigh sensitivity. As H$_2$O$_2$ is a common product generated from an enzymatic reaction, PBNCs/AgNWs film fabricated with a deposition time of 8 h was selected as a promising candidate for the construction of sensitive glucose biosensor.

#### 3.3.2. Amperometric glucose detection

After the PBNCs/AgNWs film immobilizing with GOx, the glucose sensing performance was evaluated with amperometric measurement by successively injecting 0.1 mM glucose into a stirring PBS solution at 25 $^{\circ}$C at an applied potential of $−0.05$ V (Fig. 8a). The corresponding calibration curve was shown in Fig. 8b, the $\Delta$I of PBNCs/AgNWs film glucose biosensor exhibited a linear correlation to glucose concentration with linearity.
The Fig. 7. (a) Chronoamperometry curves of PBNCs/AgNWs films prepared with different deposition time for the detection of H₂O₂; (b) calibration lines according to the data of (a), inset of (b) showed the dependence of sensitivities on different deposition time.

Table 2
Performance comparisons with literature reported H₂O₂ and glucose biosensors.

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Modified material</th>
<th>Applied potential (V)</th>
<th>Sensitivity (mAM⁻¹ cm⁻²)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O₂</td>
<td>PBNCs/AgNWs</td>
<td>−0.05</td>
<td>2868.6</td>
<td>This work</td>
</tr>
<tr>
<td></td>
<td>PB/aerosol</td>
<td>−0.05</td>
<td>1163</td>
<td>[22]</td>
</tr>
<tr>
<td></td>
<td>PB/mesoporous</td>
<td>−0.05</td>
<td>196.6</td>
<td>[28]</td>
</tr>
<tr>
<td></td>
<td>TiO₂</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Graphene/PB</td>
<td>0.1</td>
<td>1300</td>
<td>[29]</td>
</tr>
<tr>
<td></td>
<td>AgNWs array</td>
<td>−0.2</td>
<td>26.6</td>
<td>[30]</td>
</tr>
<tr>
<td>Glucose</td>
<td>PBNCs/AgNWs</td>
<td>−0.05</td>
<td>359.0</td>
<td>This work</td>
</tr>
<tr>
<td></td>
<td>PVP–AgNWs</td>
<td>−0.63</td>
<td>22.43</td>
<td>[15]</td>
</tr>
<tr>
<td></td>
<td>Au cypress/PB</td>
<td>−0.05</td>
<td>74.3</td>
<td>[31]</td>
</tr>
<tr>
<td></td>
<td>grid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PB/sol–gel</td>
<td>0</td>
<td>26.6</td>
<td>[32]</td>
</tr>
<tr>
<td></td>
<td>PR/GS</td>
<td>0.1</td>
<td>30.63</td>
<td>[33]</td>
</tr>
</tbody>
</table>

3.3.3. Anti-interference, reproducibility and stability tests

Due to the complexity of practical detection system, accuracy is an important parameter for glucose biosensor. High operational potential (in many cases > 0.3 V) often limits its application in physiological media [31]. As shown in Fig. 9, the PBNCs/AgNWs film provided perfect selectivity for glucose detection at the low applied potential of −0.05 V, which eliminated the responses of common interference species such as UA, AA, in physiological levels, as well as other sugars including maltose, lactose, fructose, sucrose and mannose.

Besides, the reproducibility of fabricated biosensor was evaluated with parallel experiments, in which five enzyme modified electrodes were used. The relative standard deviation (RSD) of ca. 5.3% in sensitivity was observed in the detection of glucose, indicating that the proposed biosensor possessed satisfactory reproducibility.

Furthermore, the freshly prepared enzyme modified electrode was firstly stored in the refrigerator at 4 °C for 30 days and then examined after adding the glucose. Results of the experiments showed that the fabricated biosensor retained about 81.4% of its initial sensitivity, indicating an excellent stability was realized on the constructed biosensor.

3.3.4. Application of the biosensor in real samples

In order to evaluate the ability of the PBNCs/AgNWs film in real sample analysis, the biosensor was employed to measure glucose in human blood serum. The rapid and stable amperometric responses were acquired at −0.05 V with the addition of 2.6, 2.0 and 1.3 ml of the blood serum into 40 ml PBS, respectively. Then the corresponding glucose concentrations could be calculated from the calibration curve, and the results are listed in Table 3. As shown in Table 3, good recoveries from 95.0% to 105.0% and RSD from 4.2%

Fig. 8. (a) Chronoamperometry curves and (b) the calibration curves (current density versus glucose concentrations) of PBNCs/AgNWs film and PB film in glucose detection. The insert of (b) was the diagram of fitted Lineweaver–Burk equation.
Table 3
Detection of glucose in real samples.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Added (mM)</th>
<th>Found (mM)</th>
<th>Recovery (%)</th>
<th>RSD (N=5) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.40</td>
<td>0.42</td>
<td>105.0</td>
<td>5.1</td>
</tr>
<tr>
<td>2</td>
<td>0.30</td>
<td>0.31</td>
<td>103.3</td>
<td>4.6</td>
</tr>
<tr>
<td>3</td>
<td>0.20</td>
<td>0.19</td>
<td>95.0</td>
<td>4.2</td>
</tr>
</tbody>
</table>

To 5.1% demonstrated that serum sample had no significant effect on glucose detection and the PBNCS/AgNWs glucose biosensor was feasible for practical analysis.

4. Conclusions

We have developed a 3D PBNCS/AgNWs sensing film to construct an ultrasensitive electrochemical glucose biosensor. 3D AgNWs network was stably fixed on the electrode surface with assistance of SAMs, while PBNCS with diameters of 200 nm were uniformly grown on AgNWs network through an aerosol deposition approach. Due to an excellent conductivity, significantly enhanced surface area, and especially the synergistic electrocatalytic activity of fabricated PBNCS/AgNWs film, an ultrahigh sensitivity of 359.0 mAM−1 cm−2 with a linear range from 0.01 to 9.9 mM, as well as excellent anti-interference ability, reproducibility and stability were observed on proposed glucose biosensor. The biosensor could be employed to measure glucose in real samples. It is believed that the proposed 3D sensing film would have widespread applications in the fields of electrochemical catalysis and biological analysis.

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