

## Research Article

# Nonenzymatic Glucose Biosensors Based on Silver Nanoparticles Deposited on TiO<sub>2</sub> Nanotubes

Zheng Li,<sup>1,2,3</sup> Yong Zhang,<sup>4</sup> Jiaye Ye,<sup>1</sup> Meiqing Guo,<sup>1,3</sup> Jing Chen,<sup>1</sup> and Weiyi Chen<sup>2,3</sup>

<sup>1</sup>College of Mechanics, Taiyuan University of Technology, Taiyuan 030024, China

<sup>2</sup>Institute of Applied Mechanics and Biomedical Engineering, Taiyuan University of Technology, Taiyuan 030024, China

<sup>3</sup>Shanxi Key Laboratory of Material Strength and Structural Impact, Taiyuan University of Technology, Taiyuan 030024, China

<sup>4</sup>Academic Affairs Office, Taiyuan University of Technology, Taiyuan 030024, China

Correspondence should be addressed to Meiqing Guo; [gmgg82@sina.com](mailto:gmgg82@sina.com) and Jing Chen; [1165059779@qq.com](mailto:1165059779@qq.com)

Received 17 September 2015; Revised 7 December 2015; Accepted 13 December 2015

Academic Editor: Thomas Thundat

Copyright © 2016 Zheng Li et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

In the present research, a nonenzymatic glucose biosensor was fabricated by depositing Ag nanoparticles (Ag-NPs) using in situ chemical reduction method on TiO<sub>2</sub> nanotubes which were synthesized by anodic oxidation process. The structure, morphology, and mechanical behaviors of electrode were examined by scanning electron microscopy and nanoindentation. It was found that Ag-NPs remained both inside and outside of TiO<sub>2</sub> nanotubes whose length and diameter were about 1.2 μm and 120 nm. The composition was constructed as an electrode of nonenzymatic biosensor for glucose oxidation. The electrocatalytic properties of the prepared electrodes for glucose oxidation were investigated by cyclic voltammetry (CVs) and differential pulse voltammetry (DPV). Compared with bare TiO<sub>2</sub> and Ag-fresh TiO<sub>2</sub> nanotube, Ag-TiO<sub>2</sub>/(500°C) nanotube exhibited the best electrochemical properties from cyclic voltammetry (CVs) results. Differential pulse voltammetry (DPV) results showed that, at +0.03 V, the sensitivity of the electrode to glucose oxidation was 3.69 mA · cm<sup>-2</sup> · mM<sup>-1</sup> with a linear range from 20 mM to 190 mM and detection limit of 24 μM (signal-to-noise ratio of 3). In addition the nonenzymatic glucose sensors exhibited excellent selectivity, stability, and repeatability.

## 1. Introduction

The blood glucose detection is of great significance in the application of food process, clinical medicine, and biology [1–3]. In particular accurate glucose determination for diabetics can be very effective to the detection and treatment of diabetes mellitus [4]. The glucose oxidase (GOD) analytical method is the first and most commonly used way for glucose detection in clinical trials [5, 6]. However, the entity of GOD is enzyme which is easily inactive and denatured, resulting in poor stability and repeatability of enzymatic electrodes [7, 8].

Nonenzymatic glucose biosensors can avoid that problem because of direct catalyzed oxidation to glucose on the surface of electrode [9–11]. In order to increase specific surface areas and enhance mass transport ability, these electrodes could use nanomaterials as substrates like carbon nanotubes (CNTs) [12], nanowires [13], mesoporous structure [14], and so forth and decorate with metal nanoparticles such as Pt [15], Ni [16], Ag [17], and Cu [18].

TiO<sub>2</sub> nanotube has been paid more and more attention in chemical reactions and biosensor fields because of their well-aligned nanostructure, large surface area property, thermal stability, chemical inertness, and nontoxicity [19, 20]. Recently, silver doped TiO<sub>2</sub> nanocomposite structures have attracted much attention not only because TiO<sub>2</sub> is a promising material with desirable electronic, but also because Ag displays some unique activities in chemical and biological sensing compared with the other noble metals such as Ru and Pt [19]. However, the electrocatalytic activity of Ag doped TiO<sub>2</sub> nanotubes has not been subjected to intensive report.

Many approaches were developed to fabricate different sizes of Ag doped TiO<sub>2</sub> nanotubes such as sol-gel, “wet” chemical, and ceramic methods. However, drying, heating, or annealing at high temperatures is revolved in the preparation process [21, 22]. In order to modify the TiO<sub>2</sub> nanotubes by Ag nanoparticles, a polyol method at low temperature has been developed. The polyol process was that using polyol such as diethylene glycol [23] and glycerol [24] both as

solvent and reducing agent during reaction which can be conducive to the formation of nanostructures. The  $\text{Ag}^+$  ions from silver nitrate ( $\text{AgNO}_3$ ) can be reduced to metallic Ag. The Ag nanoparticles were deposited successfully on the surface of  $\text{TiO}_2$ . Moreover the specific surface area will be hugely increased by silver nanoparticles deposited on  $\text{TiO}_2$  nanotubes. So  $\text{TiO}_2$  nanotubes decorated with silver nanoparticles possess distinct advantages for nonenzymatic glucose sensors.

In this work, the Ag nanoparticles were deposited successfully on the surface of  $\text{TiO}_2$  by polyol process. Scanning electron microscope (SEM) and nanoindentation were used for characterization. Furthermore, the electrocatalytic activity of the Ag- $\text{TiO}_2$  electrode was also evaluated by cyclic voltammetry (CVs) and differential pulse voltammetry (DPV).

## 2. Experimental

**2.1. Reagents.** Titanium sheet (15 mm \* 10 mm \* 1 mm) was provided by Tianjin Pengbo Company, China. All of the other chemicals, including glycerol, ammonium fluoride ( $\text{NH}_4\text{F}$ ), sodium borohydride ( $\text{NaBH}_4$ ), silver nitrate ( $\text{AgNO}_3$ ),  $\text{Na}_2\text{HPO}_4$ ,  $\text{NaH}_2\text{PO}_4$ ,  $\text{H}_3\text{PO}_4$ , poly(vinylpyrrolidone) (PVP), and KCl, were of analytical grade and used as received. A 0.1 M phosphate buffer solution (PBS) prepared using  $\text{Na}_2\text{HPO}_4$  and  $\text{NaH}_2\text{PO}_4$  was employed as supporting electrolyte. The desired pH of solution was adjusted with 0.1 M NaOH or 0.1 M  $\text{H}_3\text{PO}_4$ . All aqueous solution was prepared with reagent grade chemicals and double distilled water.

**2.2. Apparatus.** All the electrochemical measurements were performed on a CH instrument 660E electrochemical workstation (ChenHua Instruments Co. Ltd., Shanghai, China). Scanning electron microscope (FE-SEM, Hitachi S-4800) was used to determine the morphology and composition of the samples. Nanoindentation (NanoIndenter G200, USA) was used to determine the mechanical properties. All measurements were conducted at room temperature.

**2.3. Synthesis of  $\text{TiO}_2$  Nanotube Arrays on Ti Substrate.** Before use, the titanium foils were polished with abrasive paper of 400#, 600#, and 800# until the surfaces were smooth and remained with no scratch and then ultrasonically cleaned in alcohol and double distilled water for 10 min, respectively, and dried in air eventually. Then, titanium sheets were used as the substrate electrode with Pt electrodes as cathode. Samples were anodized in water/glycerol (1:1 Vol.%) mixtures containing 0.3 M  $\text{NH}_4\text{F}$  at a potential of 30 V for 3 h. Finally, the as-prepared  $\text{TiO}_2$  nanotube electrode was annealed at 500°C (10°C/min) under nitrogen atmosphere for 2 h.

**2.4. Preparation of Ag Nanoparticles on  $\text{TiO}_2$  Nanotubes.** Ag nanoparticles on  $\text{TiO}_2$  nanotubes were prepared by the following process. Firstly, 1 mL  $\text{AgNO}_3$  (0.04 M) was mixed with 10 mL PVP (0.01 M) and stirred with ice-bath after adding 50 mL water to the solution. Then, 1 mL  $\text{NaBH}_4$  (0.06 M) was dropped quickly into the solution with colour turning brown,

by stirring for 10 min. At last, the above-prepared  $\text{TiO}_2$  nanotubes (500°C) were entirely immersed in this electrolyte under static conditions for 7 h and subsequently rinsed with double distilled water and air-dried and then Ag- $\text{TiO}_2$ /(500°C) was obtained.

**2.5. Characterization of Electrocatalytic Properties of Ag- $\text{TiO}_2$  Nanotube Electrode.** The electrochemical measurements were carried out with a conventional three-electrode system. The prepared electrode ( $\text{TiO}_2$ , Ag- $\text{TiO}_2$  and Ag- $\text{TiO}_2$ /(500°C)) was used as a working electrode with a platinum electrode as an auxiliary electrode and a saturated calomel electrode (SCE) as a reference electrode in all cases.

## 3. Results and Discussions

**3.1. Morphology, Composition, and Structure Analysis.** The morphologies of the as-formed  $\text{TiO}_2$  nanotubes, Ag-fresh  $\text{TiO}_2$ , and Ag- $\text{TiO}_2$ /(500°C) were depicted in Figure 1. Figure 1(a) showed clearly the prepared vertically aligned  $\text{TiO}_2$  nanotubes arrays with diameter of 120 nm and length of 1.2  $\mu\text{m}$ . It is apparent from Figure 1(b) that the ordered and evenly distributed Ag nanoparticles with average diameter of 20 nm are formed preferentially on the exterior mouth of the amorphous  $\text{TiO}_2$  nanotubes. After the nanotubes were annealed at 500°C, the Ag nanoparticles were deposited on them under the same method (see Figure 1(c)). Some Ag nanoparticles were dispersed on the pore openings and showed a distribution that is more dense than that in Figure 1(b), while some were deposited into the nanotubes, as indicated by the arrow. It can be presumed that the nanotubes annealed at 500°C facilitate the Ag formation on the tube surface, and the electrocatalytic properties were also improved as discussed later.

**3.2. Nanoindentation Properties.** In recent years nanoindentation technology has been widely used to measure the hardness and elasticity modulus of medical materials, especially in implants devices [25]. The description of the samples' ( $\text{TiO}_2$ , Ag-fresh  $\text{TiO}_2$  and Ag- $\text{TiO}_2$ /(500°C) nanotube) nanomechanical characterization was provided. As observed in Figure 2, the displacement of Ag- $\text{TiO}_2$ /(500°C) nanotubes was the shortest and  $\text{TiO}_2$  nanotubes were the longest when load was selected the same. It was easy to figure out Ag- $\text{TiO}_2$ /(500°C) nanotubes were the hardest and the reason could be ascribed to two aspects. Compared with nonannealed sample, the higher hardness observed for Ag- $\text{TiO}_2$ /(500°C) nanotubes can be due to the higher hardness of anatase and rutile phases for annealed samples at 500°C. The hardness results obtained for nonannealed sample and annealed sample were similar to those stated in earlier studies [26]. In addition, it may be ascribed to the deposition of Ag nanoparticles. Both inside and outside of nanotubes were attached with Ag-NPs which densified empty space, resulting in fixed enhancement of hardness.

**3.3. Electrocatalytic Oxidation of Glucose on the Prepared Electrodes.** CVs were used to investigate the catalytic activities of the Ag- $\text{TiO}_2$ /(500°C) electrode. Figure 3 showed CVs of

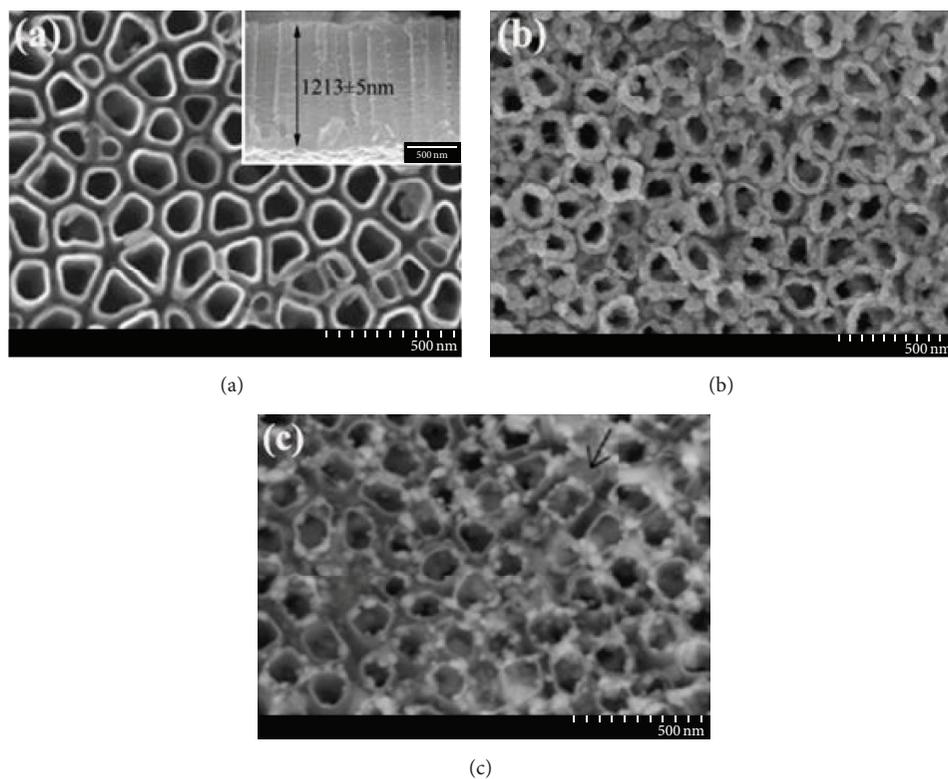


FIGURE 1: SEM images of TiO<sub>2</sub> (a), Ag-TiO<sub>2</sub>(b), and Ag-TiO<sub>2</sub>(500°C) (c) nanotube. Inset: the sectional view of TiO<sub>2</sub>.

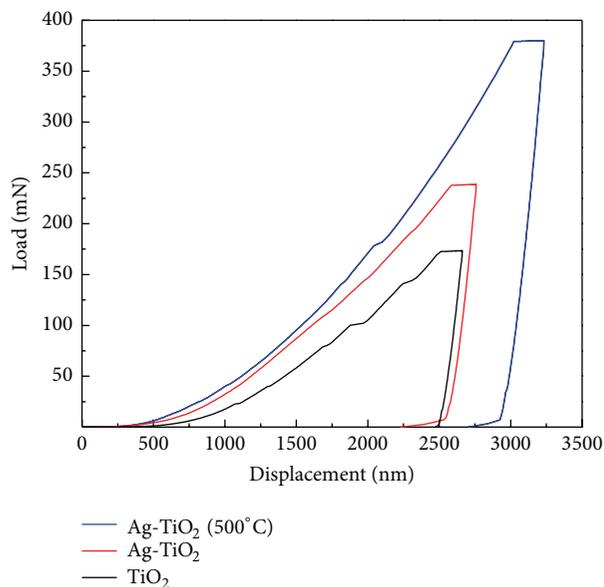


FIGURE 2: Characteristic load versus nanoindentation depth for TiO<sub>2</sub>, Ag-TiO<sub>2</sub>, and Ag-TiO<sub>2</sub>(500°C) nanotube.

the as-formed TiO<sub>2</sub> nanotube, Ag-fresh TiO<sub>2</sub> nanotube, and Ag-TiO<sub>2</sub>/(500°C) nanotube electrode in the presence and absence of 0.5 M glucose supported by 0.1 M neutral PBS, respectively. Almost no current increase of TiO<sub>2</sub> and Ag-TiO<sub>2</sub> nanotubes with glucose addition from Figures 3(a) and 3(b)

was observed, which demonstrated that the TiO<sub>2</sub> nanotubes and Ag-TiO<sub>2</sub> nanotubes electrode exhibited no electrocatalytic oxidation activity to glucose while Ag-TiO<sub>2</sub>/(500°C) electrode displayed a pair of redox peaks with the anodic and cathodic peak potential positioned at +0.03 V and -0.3 V from Figure 3(c), which can be ascribed to the oxidation of glucose, indicating that the Ag-TiO<sub>2</sub>/(500°C) electrode possessed strong catalytic activity towards glucose. There were two possible explanations for this result. The first possibility was relatively weak adherence of Ag nanoparticles onto the nonannealed nanotubular surfaces. The other possibility was that a small amount of silver titanates were obtained by depositing Ag nanoparticles on the TiO<sub>2</sub>/500°C nanotubes, which indicated that the Ag can not only be deposited but also be doped in the TiO<sub>2</sub> nanotubes. The crystal structure distortion increased state density of Ag-TiO<sub>2</sub>/500°C coating, facilitating the migration of charge carriers, and enhanced catalytic activity [19].

Figure 4 showed CVs of Ag-TiO<sub>2</sub>/(500°C) nanotube electrode in 0.5 M glucose supported by 0.1 M neutral PBS, 0.1 M H<sub>2</sub>SO<sub>4</sub>, and 0.1 M NaOH. As observed in Figure 4, compared with CVs in 0.1 M H<sub>2</sub>SO<sub>4</sub> and 0.1 M NaOH, CVs of Ag-TiO<sub>2</sub>/(500°C) nanotube electrode in PBS exhibited two oxidation peaks related to the oxidation of glucose, which indicated excellent electrochemical behavior.

Figure 5 showed CVs of the Ag-TiO<sub>2</sub>/(500°C) nanotube electrode in blank solution and 0.5 M glucose with the presence of 0.12 M NaCl and without the presence of 0.12 M NaCl supported by 0.1 M neutral PBS. Cl ion was the

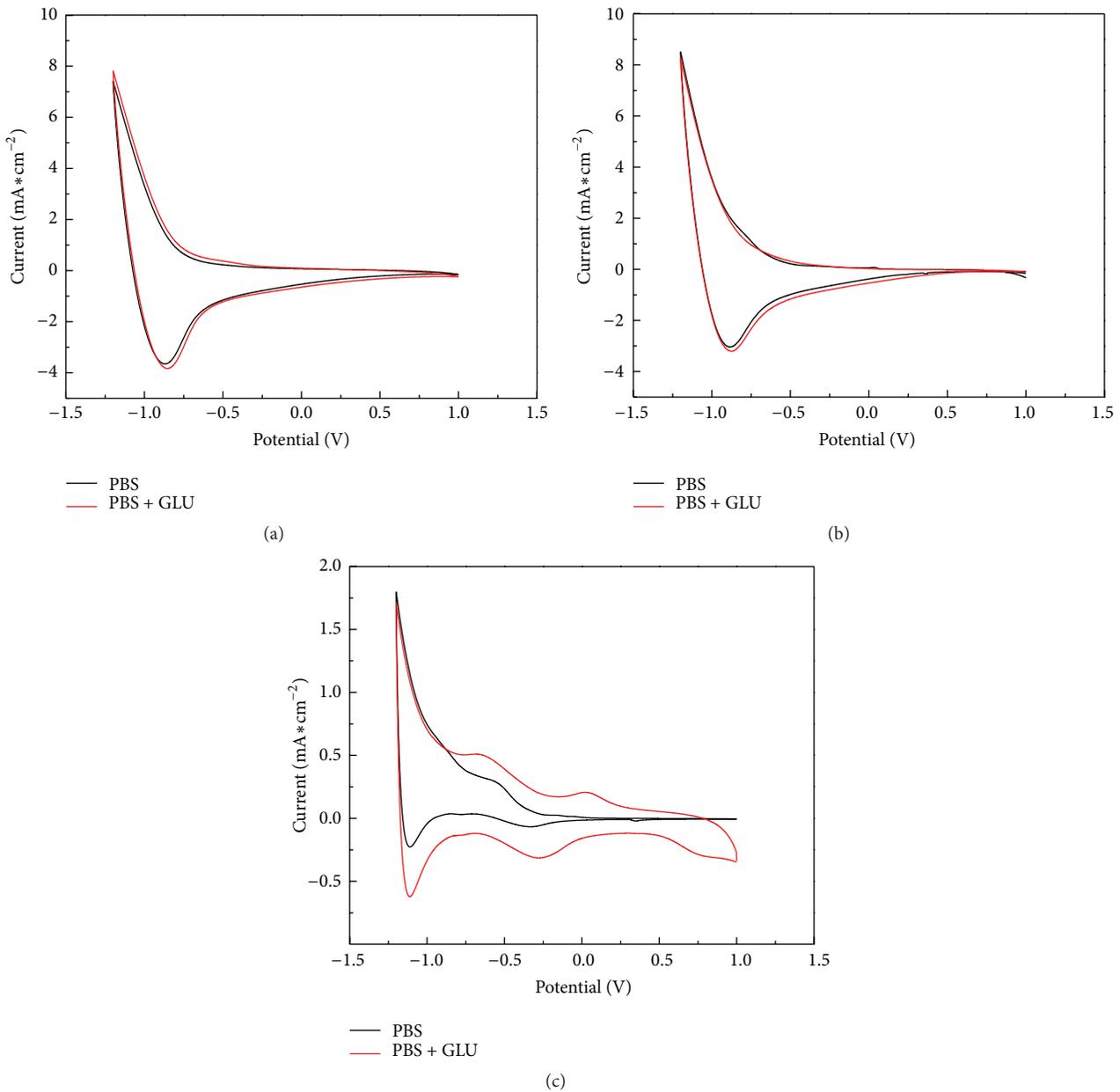


FIGURE 3: CVs of TiO<sub>2</sub> (a), Ag-TiO<sub>2</sub> (b), and Ag-TiO<sub>2</sub>(500°C) (c) electrode in 0.1 M neutral PBS with (red line) or without (black line) 0.2 M glucose.

usual interfering ion which was preferentially adsorbed on the surface of electrodes, resulting in toxicosis and losing electrocatalytic property. As observed in Figure 5, in the blank PBS solution, CVs were characterized by hydrogen adsorption/desorption peaks at negative potentials and a flat double layer region at positive potentials. After 0.5 M glucose was added, an obvious redox peak appeared from -0.3 V to +0.03 V, proving excellent electrocatalytic oxidation ability, whereas in the presence of chloride ions, when Cl<sup>-</sup> ions were dropped into the solution, the redox peak vanished and the oxidation of glucose was suppressed, which could be attributed to the adsorbing of Cl<sup>-</sup> preferentially compared with glucose.

According to the adsorption theory proposed by Wang et al. [27], it could be deduced that when there were no Cl<sup>-</sup> ions in the solution, glucose molecules would adsorb on the surface of Ag-TiO<sub>2</sub>(500°C) nanotube electrode in the first place, forming glucose intermediates. During the potential scanned from -0.3 V to +0.03 V gradually, the intermediates were oxidized leading to current increasing. When potential was over +0.03 V, the oxidized intermediates were adsorbed on the surface, covering the active sites of electrode and decreasing current. When large amounts of chloride ions were present, the poisoning Ag-TiO<sub>2</sub>(500°C) nanotube electrode showed no electrocatalytic properties.

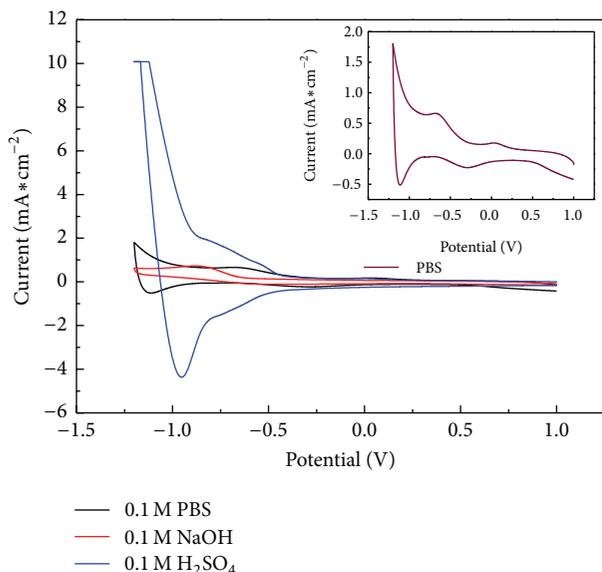


FIGURE 4: CVs of Ag-TiO<sub>2</sub>(500°C) nanotube electrode in 0.5 M glucose supported by 0.1 M neutral PBS, 0.1 M H<sub>2</sub>SO<sub>4</sub>, and 0.1 M NaOH.

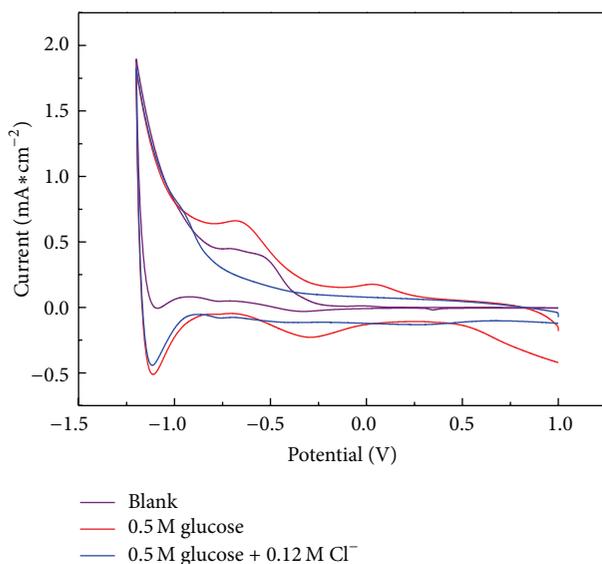


FIGURE 5: CVs of Ag-TiO<sub>2</sub>(500°C) nanotube electrode in blank solution, 0.5 M glucose with the presence of 0.12 M NaCl and 0.5 M glucose without the presence of 0.12 M NaCl supported by 0.1 M neutral PBS.

**3.4. Amperometric Performance of Ag-TiO<sub>2</sub>(500°C) Nanotube Electrode to Glucose Oxidation.** Differential pulse voltammetry (DPV) was used to determine the sensor outputs at different glucose concentrations. Figure 6 presented the relationship between currents and variation concentrations of glucose. The prepared electrode exhibited linearity for glucose sensing that ranged from 20 mM to 190 mM with a correlation coefficient of 0.9993. The electrode sensitivity calculated from the slope of the calibration curve was 3.69 mA \* cm<sup>-2</sup> \* mM<sup>-1</sup> with the detection limit of 24 μM.

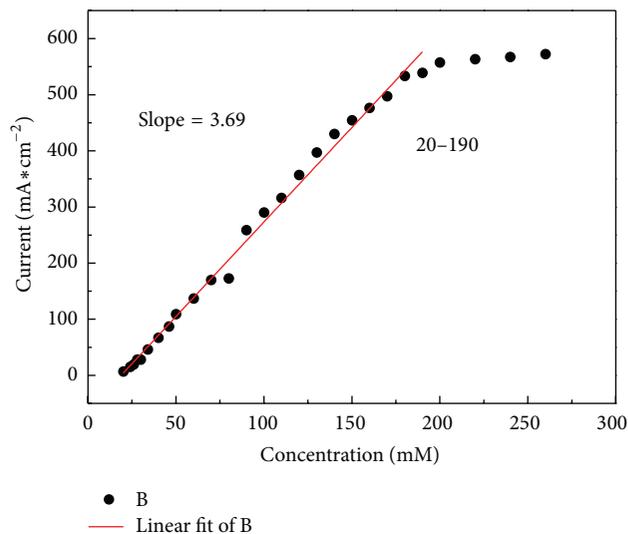


FIGURE 6: Calibration curve for the amperometric responses of the Ag-TiO<sub>2</sub>(500°C) nanotube electrode to glucose.

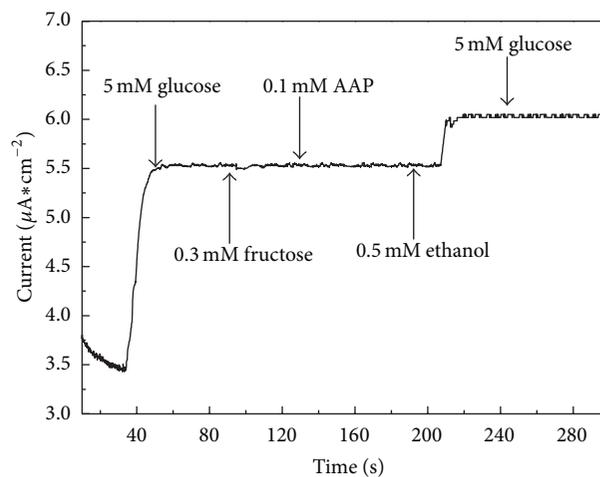


FIGURE 7: The influence of electroactive compounds (ethanol, fructose, and AAP) on the response of 5.0 mM glucose.

Ascorbic acid (AA), uric acid (UA), sucrose, fructose, dopamine, ethanol, and acetaminophen (AAP) were the commonly interfering biomolecules which coexist with glucose in the human blood. To evaluate the selectivity of the Ag-TiO<sub>2</sub>(500°C) nanotube electrode, the current responses to ethanol, fructose, and AAP were examined. As shown in Figure 7, it was observed that the response signals of ethanol, fructose, and AAP were negligible for glucose determination. The good selectivity of the nonenzymatic sensor was related to the proper working potential used.

The reproducibility and stability of response current of the Ag-TiO<sub>2</sub>(500°C) nanotube electrode were studied. The amperometric response of 10 different Ag-TiO<sub>2</sub>(500°C) nanotube electrodes to 1.0 mM glucose was tested independently. As shown in Figure 8, the relative standard deviation (RSD) was 1.5% for 10 successive measurements, revealing that the

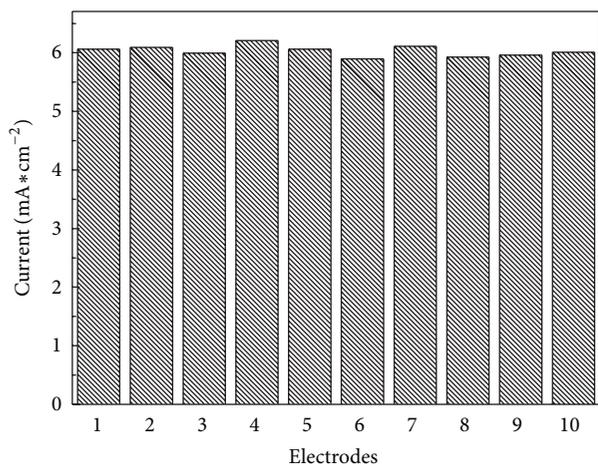


FIGURE 8: Current response of 10 different Ag-TiO<sub>2</sub>(500°C) nanotube electrodes to 1.0 mM glucose in PBS (7.0).

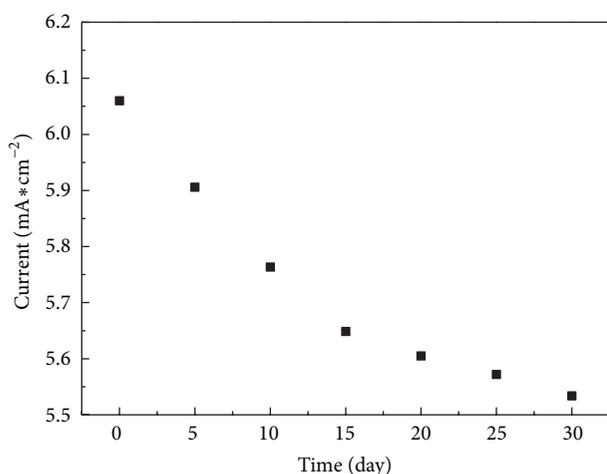


FIGURE 9: Current response of the Ag-TiO<sub>2</sub>(500°C) nanotube electrode to 10 mM glucose after storing for different days.

preparation method was acceptably reproducible. The long-term stability was explored by measuring a glucose solution, and the electrode was stored at room temperature. Figure 9 showed that the response current maintained about 92% of the initial value after 30 days, demonstrating the good stability of the Ag-TiO<sub>2</sub>(500°C) nanotube electrode based nonenzymatic glucose biosensor.

#### 4. Conclusions

In this work, a simple and effective way to prepare Ag nanoparticles deposited on the surface of TiO<sub>2</sub> nanotube was developed. The Ag deposited and annealing processes made TiO<sub>2</sub> nanotube harder which was conducive to the application of tough condition. The electrochemical results demonstrated that the prepared Ag-TiO<sub>2</sub>(500°C) nanotube electrode possessed excellent electrocatalytic performance. The constructed nonenzymatic glucose biosensor exhibited good selectivity, stability, and reproducibility. Because of the

simple preparation method and good catalytic performance, such material has potential application in catalysis and sensor areas.

#### Competing Interests

The authors declare that they have no competing interests.

#### Acknowledgments

The authors gratefully acknowledge the financial support from the Natural Science Foundation of China (Grant nos. 51301117 and 31271005) and the Natural Science Foundation for Young Scientists of Shanxi Province, China (Grant nos. 2013021003-1 and 2013021013-5).

#### References

- [1] Y. Ding, Y. Wang, L. Su, H. Zhang, and Y. Lei, "Preparation and characterization of NiO-Ag nanofibers, NiO nanofibers, and porous Ag: towards the development of a highly sensitive and selective non-enzymatic glucose sensor," *Journal of Materials Chemistry*, vol. 20, no. 44, pp. 9918–9926, 2010.
- [2] V. Poitout, D. Moatti-Sirat, G. Reach et al., "A glucose monitoring system for on line estimation in man of blood glucose concentration using a miniaturized glucose sensor implanted in the subcutaneous tissue and a wearable control unit," *Diabetologia*, vol. 36, no. 7, pp. 658–663, 1993.
- [3] X. Cao, N. Wang, S. Jia, and Y. Shao, "Detection of glucose based on bimetallic PtCu nanochains modified electrodes," *Analytical Chemistry*, vol. 85, no. 10, pp. 5040–5046, 2013.
- [4] E. Reitz, W. Jia, M. Gentile, Y. Wang, and Y. Lei, "CuO nanospheres based nonenzymatic glucose sensor," *Electroanalysis*, vol. 20, no. 22, pp. 2482–2486, 2008.
- [5] L. C. Clark Jr. and J. C. Lyons, "Electrode systems for continuous monitoring in cardiovascular surgery," *Annals of the New York Academy of Sciences*, vol. 102, pp. 29–45, 1962.
- [6] A. Riklin, E. Katz, I. Willner, A. Stocker, and A. F. Buckmann, "Improving enzyme-electrode contacts by redox modification of cofactors," *Nature*, vol. 376, no. 6542, pp. 672–675, 1995.
- [7] Y. B. Vassilyev, O. A. Khazova, and N. N. Nikolaeva, "Kinetics and mechanism of glucose electrooxidation on different electrode-catalysts. Part I. Adsorption and oxidation on platinum," *Journal of Electroanalytical Chemistry*, vol. 196, no. 1, pp. 105–125, 1985.
- [8] B. Beden, F. Largeaud, K. B. Kokoh, and C. Lamy, "Fourier transform infrared reflectance spectroscopic investigation of the electrocatalytic oxidation of D-glucose: identification of reactive intermediates and reaction products," *Electrochimica Acta*, vol. 41, no. 5, pp. 701–709, 1996.
- [9] L. M. Lu, L. Zhang, F. L. Qu et al., "A nano-Ni based ultrasensitive nonenzymatic electrochemical sensor for glucose: enhancing sensitivity through a nanowire array strategy," *Biosensors and Bioelectronics*, vol. 25, no. 1, pp. 218–223, 2009.
- [10] L. Meng, J. Jin, G. X. Yang, T. H. Lu, H. Zhang, and C. X. Cai, "Nonenzymatic electrochemical detection of glucose based on palladium-single-walled carbon nanotube hybrid nanostructures," *Analytical Chemistry*, vol. 81, no. 17, pp. 7271–7280, 2009.
- [11] F. Xiao, F. Q. Zhao, D. P. Mei, Z. R. Mo, and B. Z. Zeng, "Nonenzymatic glucose sensor based on ultrasonic-electrodeposition

- of bimetallic PtM (M = Ru, Pd and Au) nanoparticles on carbon nanotubes-ionic liquid composite film,” *Biosensors and Bioelectronics*, vol. 24, no. 12, pp. 3481–3486, 2009.
- [12] J.-S. Ye, Y. Wen, W. D. Zhang, L. M. Gan, G. Q. Xu, and F.-S. Sheu, “Nonenzymatic glucose detection using multi-walled carbon nanotube electrodes,” *Electrochemistry Communications*, vol. 6, no. 1, pp. 66–70, 2004.
- [13] C. Y. Guo, H. H. Huo, X. Han, C. L. Xu, and H. L. Li, “Ni/CdS bifunctional Ti@TiO<sub>2</sub> core-shell nanowire electrode for high-performance nonenzymatic glucose sensing,” *Analytical Chemistry*, vol. 86, no. 1, pp. 876–883, 2014.
- [14] H.-K. Seo, D.-J. Park, and J.-Y. Park, “Fabrication and characterization of platinum black and mesoporous platinum electrodes for in-vivo and continuously monitoring electrochemical sensor applications,” *Thin Solid Films*, vol. 516, no. 16, pp. 5227–5230, 2008.
- [15] D. Rathod, C. Dickinson, D. Egan, and E. Dempsey, “Platinum nanoparticle decoration of carbon materials with applications in non-enzymatic glucose sensing,” *Sensors and Actuators, B: Chemical*, vol. 143, no. 2, pp. 547–554, 2010.
- [16] J. H. Zhu, J. Jiang, J. P. Liu et al., “CNT-network modified Ni nanostructured arrays for high performance non-enzymatic glucose sensors,” *RSC Advances*, vol. 1, no. 6, pp. 1020–1025, 2011.
- [17] A. Baciú, A. Pop, A. Remes, F. Manea, and G. Burtica, “Nonenzymatic electrochemical determination of glucose on silver-doped zeolite-CNT composite electrode,” *Advanced Science, Engineering and Medicine*, vol. 3, no. 1-2, pp. 13–19, 2011.
- [18] L.-M. Lu, X.-B. Zhang, G.-L. Shen, and R.-Q. Yu, “Seed-mediated synthesis of copper nanoparticles on carbon nanotubes and their application in nonenzymatic glucose biosensors,” *Analytica Chimica Acta*, vol. 715, pp. 99–104, 2012.
- [19] Y. Q. Liang, Z. D. Cui, S. L. Zhu, Y. Liu, and X. J. Yang, “Silver nanoparticles supported on TiO<sub>2</sub> nanotubes as active catalysts for ethanol oxidation,” *Journal of Catalysis*, vol. 278, no. 2, pp. 276–287, 2011.
- [20] Y. Q. Liang, Z. D. Cui, S. L. Zhu, and X. J. Yang, “Formation and characterization of iron oxide nanoparticles loaded on self-organized TiO<sub>2</sub> nanotubes,” *Electrochimica Acta*, vol. 55, no. 18, pp. 5245–5252, 2010.
- [21] J. Joo, S. G. Kwon, T. Yu et al., “Large-scale synthesis of TiO<sub>2</sub> nanorods via nonhydrolytic sol-gel ester elimination reaction and their application to photocatalytic inactivation of *E. coli*,” *Journal of Physical Chemistry B*, vol. 109, no. 32, pp. 15297–15302, 2005.
- [22] S. Yoo, S. A. Akbar, and K. H. Sandhage, “Nanocarving of bulk titania crystals into oriented arrays of single-crystal nanofibers via reaction with hydrogen-bearing gas,” *Advanced Materials*, vol. 16, no. 3, pp. 260–264, 2004.
- [23] Y. Yu, L.-L. Ma, W.-Y. Huang, J.-L. Li, P.-K. Wong, and J. C. Yu, “Coating MWNTs with Cu<sub>2</sub>O of different morphology by a polyol process,” *Journal of Solid State Chemistry*, vol. 178, no. 5, pp. 1488–1494, 2005.
- [24] P. V. Suneesh, V. S. Vargis, T. Ramachandran, B. G. Nair, and T. G. Sathesh Babu, “Co–Cu alloy nanoparticles decorated TiO<sub>2</sub> nanotube arrays for highly sensitive and selective nonenzymatic sensing of glucose,” *Sensors and Actuators B: Chemical*, vol. 215, pp. 337–344, 2015.
- [25] S. A. Catledge, J. Borham, Y. K. Vohra, W. R. Laceyfield, and J. E. Lemons, “Nanoindentation hardness and adhesion investigations of vapor deposited nanostructured diamond films,” *Journal of Applied Physics*, vol. 91, no. 8, pp. 5347–5352, 2002.
- [26] E. Zalnezhad, A. M. S. Hamouda, G. Faraji, and S. Shamshirband, “TiO<sub>2</sub> nanotube coating on stainless steel 304 for biomedical applications,” *Ceramics International*, vol. 41, no. 2, pp. 2785–2793, 2015.
- [27] J. P. Wang, D. F. Thomas, and A. C. Chen, “Nonenzymatic electrochemical glucose sensor based on nanoporous PtPb networks,” *Analytical Chemistry*, vol. 80, no. 4, pp. 997–1004, 2008.



**Hindawi**

Submit your manuscripts at  
<http://www.hindawi.com>

