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To cite this article: Y Y Liu et al 2018 Nanotechnology 29 235706

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Facile preparation of surfactant-free Au NPs/RGO/Ni foam for degradation of 4-nitrophenol and detection of hydrogen peroxide

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Abstract

The application of Au nanoparticles (Au NPs) often requires surface modification with chemical surfactants, which dramatically reduce the surface activity and increase the chemical contamination and cost of Au NPs. In this research, we have developed a novel Au NPs/reduced graphene oxide/Ni foam hybrid (Au NPs/RGO/NiF) by in situ reduction through ascorbic acid and replacement reaction. This method is green, facile and efficient. The Au NPs are free of chemical surfactants and are homogeneously distributed on the surface of the RGO/NiF. The as-prepared Au NPs/RGO/NiF hybrid is uniform, stable and exhibits not only a high reduction efficiency for the reduction of 4-nitrophenol with a catalytic kinetic constant of up to 0.46 min−1 (0.15 cm3 catalysis) but also a sensitive and selective detection of H2O2 with a detection limit of ∼1.60 μM.

Keywords: Au nanoparticles/reduced graphene oxide/Ni foam, catalytic properties, 4-nitrophenol, hydrogen peroxide

1. Introduction

Au NPs have been widely applied in the field of catalysis [1–3] and sensing [4–6] due to their excellent optical and electrical properties. However, Au NPs prepared by a chemical method usually require surface modification with chemical surfactants to prevent their agglomeration. The presence of surfactants dramatically reduces the active sites of Au NPs, which greatly limits their performance. Moreover, during the process of application, Au NPs are difficult to use and have a low ratio of recovery. Therefore, it is necessary to find proper carrier materials to evenly disperse Au NPs in the absence of surfactants. Recently, much effort has been devoted to developing hybrid catalysts by immobilizing metal NPs onto various supporting materials, such as carbon nanotubes [7–9], graphene [10–12], Fe3O4 [13], TiO2 [2, 14, 15], and polymer [16–18], which is considered an effective strategy to avoid agglomeration and improve...
catalytic activity. Of particular interest is reduced graphene oxide (RGO), which is a honeycomb-like sheet of carbon with the properties of a large specific surface area, which makes it an ideal carrier of metal NPs such as Cu [19], Ag [20], Au [21, 22], Pt [23], Pd [24], for applications in catalysts and sensors. Such a kind of two-dimensional (2D) graphene sheet carrier could possibly not only improve the dispersion of Au NPs but also produce the synergistic effect to further improve their properties. Unfortunately, like other nanocatalyst hybrids of metal NPs/supported materials, metal NPs/graphene nano-composites have the characteristic of being difficult to rapidly recycle. The highly-dispersed nanocatalysts are hard to separate totally from the system using the commonly used methods, such as magnetic adsorption and fine filtration, when there is a lot of reaction solution. Therefore, it is also important to immobilize the nanocatalyst hybrids onto a macroscopic support. Ni foam has high strength, good conductivity and a large specific surface, which makes it an excellent substrate material for nanocatalyst hybrids. Combining the advantageous properties of Au NPs/RGO and NiF is, therefore, a promising strategy to simultaneously achieve both high activity and efficient reusability by using NiF as the macro-support for Au NPs with RGO as the nano-support.

4-nitrophenol (4-NP) is a pollutant that often exists in industrial and agricultural wastewaters. It is necessary to remove it from the polluted waters to meet increasingly stringent environmental quality standards. The reduction of 4-NP to 4-aminophenol (4-AP) in the presence of a catalyst is the best method for removing the toxic 4-NP.

Diabetes has not been optimally controlled in some people. The positive monitoring and control of blood glucose are the key to curing diabetes clinically. As we know, the glucose level can be indirectly determined by testing for its reaction product, H2O2. Many studies have been carried out when there is a lot of reaction solution. Therefore, it is also important to immobilize the nanocatalyst hybrids onto a macroscopic support. Ni foam has high strength, good conductivity and a large specific surface, which makes it an excellent substrate material for nanocatalyst hybrids. Combining the advantageous properties of Au NPs/RGO and NiF is, therefore, a promising strategy to simultaneously achieve both high activity and efficient reusability by using NiF as the macro-support for Au NPs with RGO as the nano-support.

This preparation method is characterized by easy accessibility, a shorter reaction time and steady product quality. The Au NPs/RGO/NiF hybrid is used both as the catalyst for the reduction of 4-NP to 4-AP and as the nonenzymatic sensor for the detection of H2O2.

2. Experimental section

2.1. Materials and reagents

Ascorbic acid (AA) (C6H8O6, ≥99.70% pure), chloroauric acid (HAuCl4·3H2O, ≥99.99% pure), hydrogen peroxide (H2O2, 30%), 4-nitrophenol (C6H3NO3, ≥99.00% pure), sodium borohydride (NaBH4, ≥96.00% pure), glucose (C6H12O6), dopamine (DA) (C8H11O2N, ≥97.70%), uric acid (UA) (C4H4N4O3), citric acid (C6H8O7·H2O, ≥98.80% pure) and sucrose (C12H22O11, ≥99.99% pure), potassium ferri cyanide (K4[Fe(CN)6], ≥98.00% pure), sodium hydroxide (NaOH), sodium dihydrogen phosphate (NaH2PO4, ≥99.50% pure), disodium hydrogen phosphate (Na2HPO4, ≥98.00% pure) were used in this experiment.

2.2. Preparation of Au NPs/Gr/NiF hybrid

Graphene oxide (GO) was prepared using the modified Hummer’s method. Ni foam (2 cm × 3 cm × 0.15 cm) was orderly washed with the acetone, ethanol and deionized water. Then the Ni foam was dipped into 1 M GO under the condition of ultrasound for full immersion. The Ni foam, evenly coated with GO solution, was taken out and dried at 60 °C. The above process was repeated three times, forming GO/NiF. AA (0.10 g) was dissolved in 30 ml deionized water and heated to 80 °C. GO/NiF was added to the above solution for 30 min. RGO/NiF was then obtained after washing and drying. 25 ml HAuCl4 solution (10 mM) was added to a beaker. RGO/NiF was immersed in it and taken out after only 1 min. Au NPs/Gr/NiF hybrid was prepared, washed and dried.

2.3. Characterizations and measurement

2.3.1. Reduction of 4-NP catalyzed by Au NPs/RGO/NiF hybrid. 0.05 mM 4-NP solution and 0.10 M NaBH4 solution were freshly prepared. Then, 2 ml of 4-NP was mixed with 1 ml of icid NaBH4 in a bottle. The Au NPs/RGO/NiF hybrid (1 × 1 × 0.15 cm3) was immersed in the above mixed solution. At 30 s intervals, the Au NPs/RGO/NiF was removed and the remaining mix solution was transferred to a quartz cuvette for UV–vis measurement. The solution was transferred back to the bottle for sequential reaction for the next 30 s until the reaction finished.

2.3.2. Detection of H2O2 by Au NPs/RGO/NiF hybrid. For the detection of hydrogen peroxide, electrochemical measurements were performed using a CHI660D workstation with a typical three-electrode at room temperature. The Au NPs/RGO/NiF sample was used as
the working electrode, a platinum wire was used as the counter-electrode and Ag/AgCl as the reference electrode. Sodium phosphate buffer solution (PBS, 0.10 M, PH7.4) was inlet with N₂ for 15 min.

Raman spectra were measured by using Thermo Fisher Raman spectrometer equipment in the range of 200~4000 cm⁻¹. Scanning electron microscope (SEM) and energy dispersive x-ray (EDX) spectroscopy measurements were performed using an FEI Quanta 200 SEM with 10 KV acceleration voltage. X-ray diffraction (XRD) spectra were obtained using a D8-Discover x-ray diffractometer (Bruker, Germany) by scanning at angles of 2θ=20°~80°. UV–vis spectra were measured by a UV-2450 (Japan) spectrophotometer with 1 cm × 1 cm × 3 cm quartz cells in the range of 200 ~ 500 nm.

3. Results and discussion

The morphologies of RGO/NiF are examined by SEM (figures 1(a)–(c)). Figure 1(a) shows that the RGO/NiF is a porous structure. To verify the distribution of the elements in the RGO/NiF, EDX element mapping was used to understand the distribution of RGO on the NiF as shown in figure 1(d). The result indicated that C-element homogeneously dispersed on the surface of the entire RGO/NiF. Figure 1(e) shows the EDX spectrum of RGO/NiF hybrid and the weight percentage and the atomic percentage of C are calculated to be ~4.43 and ~18.48, respectively.

Similarly, the microstructures of Au NPs/RGO/NiF are also detected by SEM. Figures 2(a)–(c) show the Au NPs/RGO/NiF hybrids with different magnifications. We can see a mass of Au NPs evenly distribute on the RGO/NiF baseplate. The EDX-mapping shows that the C and Au elements homogeneously dispersed over the entire Au NPs/RGO/NiF (figure 2(d)). Figure 2(e) displays the EDX spectrum of Au NPs/RGO/NiF hybrid and the weight percentage and the atomic percentage of Au are calculated to be ~4.56 and ~1.35, respectively. The particle size distribution is shown in figure 2(f) and the mean diameter of Au NPs is 29.76 nm.

The XRD spectra NiF, RGO/NiF, and Au NPs/RGO/NiF hybrid are shown in figure 3. It is noted that the peaks at 2θ of 44.50°, 51.88°, and 76.43° are assigned to the (111), (200), and (220) planes of the face-centered cubic Ni. The RGO/NiF shows one more diffraction peak at 2θ of 26.50°, than NiF, which is attributed to the (002) reflection of graphitic carbon. In addition, the Au NPs/RGO/NiF presents one more diffraction peak, at 38.18°, than RGO/NiF, indicating the (111) planes of the face-centered cubic Au. The XRD pattern of the Au NPs/RGO/NiF hybrid shows that Au NPs on RGO/NiF have relatively high crystalinity.

Figure 4 exhibits the Raman spectra of NiF, RGO/NiF, Au NPs, and Au NPs/RGO/NiF hybrid. The Raman spectrum of NiF has no sharp peak. The RGO/NiF presents three peaks at ~1350, ~1570 and ~2700 cm⁻¹, indicating the characteristic D, G and 2D bands of graphene, respectively. The Au NPs have two outstanding peaks at ~517 cm⁻¹ and ~1572 cm⁻¹. The Au NPs/RGO/NiF hybrid presents additive peaks of all materials, indicating the successful preparation of Au NPs/RGO/NiF hybrid. In addition, the stronger Raman peaks of Au NPs/RGO/NiF are attributed to many active Au NPs on the surface of Au NPs/RGO/NiF.

The catalytic reduction of 4-NP to 4-AP with an excess amount of NaBH₄ has often been used as a model reaction to evaluate the catalytic performance of metal nanoparticles. A UV–vis spectrometer is used to monitor the reaction process in real time. Figures 5(a)–(c) show the UV–vis absorption spectra of the NiF and RGO/NiF, and Au NPs/RGO/NiF hybrid. Obviously, the UV–vis absorption spectra of the NiF and RGO/NiF almost have no significant changes within 60 min. Furthermore, the absorption peak at 300 nm, which is the product of the catalyst, does not appear in the catalytic reaction. Therefore, the NiF and RGO/NiF have almost no catalytic effect for the catalytic reduction of 4-NP to 4-AP.
Figure 5(d) shows a linear correlation between ln(A) (A is the absorbance at 400 nm) vs reduction time, indicating that the reaction is of pseudo-first-order. Obviously, the rate constant (K) of Au NPs/RGO/NiF (0.46 min⁻¹) determined from the slope is much larger than that of NiF (3.00 × 10⁻⁴ min⁻¹) and of RGO/NiF (2.70 × 10⁻³ min⁻¹). We calculated the ratio (k) of the rate constant K over the macroscopic volume of the Au NPs/RGO/NiF, k = K/V. The activity k is k = 0.46 min⁻¹/(1 × 1 × 0.15 cm³) = 3.06 min⁻¹·(cm³)⁻¹.
The high activity of Au NPs/RGO/NiF can be attributed to the following factors: (1) The surfactant-free Au NPs can be fully exposed at its active sites, providing a number of places for swapping elements. (2) The NiF has good conductivity and stability, speeding up electron transfer.

In the process of catalysis, other environmental factors, such as reacting temperature, the initial concentration, and the pH have an effect on the rate of catalysis. In the above testing process, the reaction was catalyzed at 25 °C in the presence of 0.05 mM 4-NP, with an unadjusted pH value of 8. In order to explore the effect of these factors on the catalytic reaction, a couple of comparisons had been carried out. The experimental results show that the temperature affects the reaction remarkably. As shown in figure 6(a), the reaction rate was significantly increased with the temperature rising and the highest rate constant is up to 32 times higher than the above result (0.46 min⁻¹). The result may be attributed to the following two reasons. (1) The high temperature reduces the reaction kinetics of the barrier. (2) The high temperature speeds up the diffusion and increases the speed of electron transfer and ion exchange in the process of the reaction. The initial concentration of 4-NP has little effect on the rate of reaction and the highest rate constant is no more than 1.5 times the 0.46 min⁻¹ (figure 6(b)). The pH has an important effect on the reaction. It is known that sodium borohydride (NaBH₄) can rapidly decompose and release hydrogen in acidic conditions, which means it is unstable in acidic conditions. However, NaBH₄ can be used in neutral and alkaline conditions. Therefore, the proper pH values are controlled within 8 to 14 and adjusted by NaOH. The result is shown in

Figure 5. (a)–(c) Successive UV–vis absorption spectra of the reduction of 4-NP by NaBH₄ in the presence of NiF, RGO/NiF, and Au NPs/RGO/NiF hybrid. (d) The logarithm of the absorbance at 400 nm vs reduction time of NiF, RGO/NiF, and Au NPs/RGO/NiF hybrid.

Figure 6. Effect of temperature (a), initial 4-NP concentration (b), and pH (c) on the reaction rate of the reduction of 4-NP by NaBH₄ in the presence of Au NPs/RGO/NiF hybrid.
Before detecting the H$_2$O$_2$, the pH-value of the buffer solution was optimized. Figure 7 shows that pH7.4 has the highest sensitivity for the detection of H$_2$O$_2$. In the electrochemical detection method, the pH is one of the factors that control the sensitivity of the electrode [29–32]. Before detecting the H$_2$O$_2$, the pH-value of the buffer solution was optimized. Therefore, pH7.4 was selected as the optimal pH value for the detection of H$_2$O$_2$.

The electrochemical behavior of NiF, RGO/NiF, and Au NPs/RGO/NiF were investigated by using cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS) in phosphate buffer solution (0.1 M, pH7.4) in the presence of 1 mM [Fe(CN)$_6$]$^{3−}$. The CVs were measured in N$_2$-saturated PBS (0.1 M, pH 7.4) in the potential range from 0 to 0.60 V at 100 mV s$^−1$. As shown in figure 8(a), it was observed that, compared with the bare NiF and RGO/NiF, the current response of [Fe(CN)$_6$]$^{3−}$ at the Au NPs/RGO/NiF electrode was greatly enhanced. Thus, the Au NPs/RGO/NiF electrode has more fractions of catalytic active sites on the surface of the electrode. The EIS measurements were performed at a frequency range of 100 kHz to 10 mHz (figure 8(b)). At the high-frequency region, the diameter of the semicircle of the Au NPs/RGO/NiF is smaller than that of both RGO/NiF and NiF, which reveals a lower charge transfer resistance ($R_q$) for the Au NPs/RGO/NiF. In addition, the real axis intercept of the real part ($Z'$) is the internal resistance ($R_s$), and the Au NPs/RGO/NiF reflect a smaller resistance, as can be seen from the inset of figure 8(b).

In order to study the electrochemical behavior in the presence of H$_2$O$_2$, the CV evolutions of the NiF, RGO/NiF, and Au NPs/RGO/NiF were measured in N$_2$-saturated PBS (0.10 M, pH 7.4) in the potential range of ~0.40 to 0.90 V at 50 mV s$^{-1}$, as is shown in figure 9(a) (in the presence of H$_2$O$_2$). Obviously, the CV of the Au NPs/RGO/NiF hybrid electrode showed a pair of redox peaks at 1.63 V and ~3.60 V, respectively. On the contrary, the CVs of NiF and RGO/NiF had no obvious redox peaks (see the inset in figure 9(a)). Furthermore, the Au NPs/RGO/NiF hybrid showed a 30-fold increased range and a 100-fold increased range of current response over NiF and RGO/NiF, respectively. The reason for this is that the introduction of Au NPs increased the electrochemically active surface area and provided conductive layers for the electronic transmission. Figure 9(b) showed the CV behavior of Au NPs/RGO/NiF in the presence of H$_2$O$_2$. When added to 1 mM H$_2$O$_2$, the redox peaks of Au NPs/RGO/NiF increased with the addition of H$_2$O$_2$. Figure 9(c) presented the CV curves of the Au NPs/RGO/NiF hybrid electrode at different scan rates from 10 to 50 mV s$^{-1}$ in the presence of 3 mM H$_2$O$_2$. Clearly, along with the augmentation of scan rate, the range of current response was significantly increasing. This characteristic indicated that the redox reaction of Au NPs on RGO/NiF was rather rapid.
At the same time, the anodic current ($I_{pa}$) and cathodic peak current ($I_{pc}$) were linearly enhanced with the growing scan rate with the correlation coefficients of 0.997 and 0.989, respectively. It was indicated that the redox reaction was a quasi-reversible surface-controlled electrochemical process.

The current response of the sensor was evaluated with the successive addition of H$_2$O$_2$ to a stirred electrolyte solution as a static potential of 0.1 V vs. Ag/AgCl electrode. Figure 10 shows the typical steady-state current-time ($I$-$t$) plot of Au NPs/RGO/NiF hybrid carried out in N$_2$-saturated PBS (pH 7.4). The top right inset is the enlarged figure of $I$-$t$ for low concentration. The amperometric response current decreases linearly with increasing H$_2$O$_2$ concentration from 0.003 to 1.06 mM. As seen in the lower left inset, for every addition of H$_2$O$_2$, the steady state current is reached within 5 s. The linear regression equation of $I = -3.6891 + 0.1558C_{H_2O_2}$ with a correlation coefficient of 0.998. The detection limit is 1.60 μM (at a signal-to-noise ratio of 3) and the sensitivity value is determined to be 156 μA mM$^{-1}$ cm$^{-2}$.

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The selectivity of the Au NPs/RGO/NiF for the detection of H$_2$O$_2$ was also evaluated. As shown in figure 11, the amperometric response of the relevant sensor upon addition of 1 mM H$_2$O$_2$, 0.5 mM glucose, 0.5 mM UA, 0.5 mM DA, 0.5 mM AA, 0.5 mM citric acid, 0.5 mM sucrose and a second injection of 1 mM H$_2$O$_2$. After adding the glucose, UA, DA, AA, citric acid and sucrose, the current response was
trivial. While for the addition of H$_2$O$_2$, the sensor gave a remarkable and repeatable current response. Therefore, the Au NPs/RGO/NiF hybrid-based sensor exhibits a versatile ability to not be influenced by such possible interferences coexisting along with H$_2$O$_2$.

Figure 12 illustrates the process for the preparation of Au NPs/RGO/NiF and the mechanism of the reduction of 4-NP to 4-AP and the detection of H$_2$O$_2$. The detailed processes are in the experimental section. In this method, Ni foam as the support material has two main functions: (1) the NiF was used as a supporting frame for RGO and Au NPs, forming an easily recoverable catalyst; (2) the NiF was employed as a reducing agent to swap out Au NPs by metathesis reaction. In the process of preparation, Au NPs without any other reductants and surfactants were added. Au NPs were obtained by replacement reaction: Ni + Au$^{3+} \rightarrow$ Ni$^{2+} + $ Au. Besides, a small amount of Au$^{3+}$ may be reduced by the residual ascorbic acid in the process of reduction of GO. The as-prepared Au NPs/RGO/NiF was applied to catalyze the reduction of 4-NP in the presence of NaBH$_4$ in an aqueous medium and the enzyme-free detection of H$_2$O$_2$. The catalytic process mainly consists of three parts: (1) -BH$_4^-$ and 4-NP absorb on Au NPs together. (2) Then, -BH$_4^-$ and 4-NP start electron transfer and atomic exchange. In detail, -BH$_4^-$ ions lose their electrons and hydrogen atoms while 4-NP obtain electrons and hydrogen atoms by losing oxygen atoms. Subsequently, the new material of 4-AP generates. (3) The generated 4-AP automatically breaks from Au NPs and spread to the solution. In this process, Au NPs show high catalytic activity for the reaction by providing many reaction sites and reduce the reaction kinetics of the barrier. For the detection of H$_2$O$_2$, the Au NPs show excellent electrocatalytic activity, which provides a conductive layer for the electronic transmission in the redox reaction: H$_2$O$_2$ + 2H$^+$ + 2e$^-$ $\leftrightarrow$ 2H$_2$O.

Table 1. Comparison of rate constant values for the 4-NP reduction to 4-AP and detection limit/response time for the detection of H$_2$O$_2$ by different as-prepared hybrids.

<table>
<thead>
<tr>
<th>Hybrid</th>
<th>Support material</th>
<th>Preparation time</th>
<th>Application</th>
<th>K (min$^{-1}$)</th>
<th>LOD$^a$(μm)/RT$^b$(s)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>G0/CNT-Au</td>
<td>Graphene oxide</td>
<td>&gt;5 h</td>
<td>4-NP catalyst</td>
<td>0.042</td>
<td>—</td>
<td>[33]</td>
</tr>
<tr>
<td>G/PDA-Au</td>
<td>Graphene sheet</td>
<td>&gt;24 h</td>
<td>4-NP catalyst</td>
<td>0.225</td>
<td>—</td>
<td>[34]</td>
</tr>
<tr>
<td>GO/Au</td>
<td>Graphene oxide</td>
<td>&gt;20 h</td>
<td>4-NP catalyst</td>
<td>0.15</td>
<td>—</td>
<td>[35]</td>
</tr>
<tr>
<td>Au/graphene</td>
<td>Graphene hydrogel</td>
<td>&gt;12 h</td>
<td>4-NP catalyst</td>
<td>0.19</td>
<td>—</td>
<td>[22]</td>
</tr>
<tr>
<td>S/GS-N/P-A-H$^c$</td>
<td>Graphene sheet</td>
<td>&gt;1.5 h</td>
<td>H$_2$O$_2$ sensor</td>
<td>—</td>
<td>12/∼3</td>
<td>[36]</td>
</tr>
<tr>
<td>G/N/AZI/Au/GCE$^d$</td>
<td>Graphene sheet</td>
<td>&gt;5.5 h</td>
<td>H$_2$O$_2$ sensor</td>
<td>—</td>
<td>10/∼3</td>
<td>[37]</td>
</tr>
<tr>
<td>Au-M-S$^g$</td>
<td>Graphene sheet</td>
<td>no data</td>
<td>H$_2$O$_2$ sensor</td>
<td>—</td>
<td>2.48/∼1</td>
<td>[38]</td>
</tr>
<tr>
<td>Au NPs/RGO/NiF</td>
<td>Graphene/Ni foam</td>
<td>&lt;1 h</td>
<td>Both</td>
<td>0.459</td>
<td>1.6/∼5</td>
<td>This work</td>
</tr>
</tbody>
</table>

$^a$ Limit of detection.  
$^b$ Response time.  
$^c$ SPCE/GS-Nafion/Fe$_3$O$_4$-Au-HRP.  
$^d$ Graphene/Nafion/AZI/Au NPs/GCE.  
$^e$ Au NPs-MWCNTs-sG.
A linear relation is obtained between the current value and the concentration of H$_2$O$_2$ by electrochemical measurement.

In order to expound the differences between different hybrids, we made a comparison in table 1. By contrast, several advantages of the Au NPs/RGO/NiF hybrid can be found. (1) This novel hybrid uses Ni foam as the supporting material. For application in catalysis, the sturdy structure of Ni foam ensures a long service life and a good recyclability. For the sensor, the continuous mesh structure of Ni foam directly makes the as-prepared Au NPs/RGO/NiF a free-standing monolithic electrode. (2) Ascorbic acid as a green reductant meets the requirements for production technology and environmental protection. (3) Au NPs were prepared without adding any surfactant and were quickly displaced by Ni from gold salt solution. The difficulties of agglomeration and nonuniform dispersion also have been well solved. (4) This preparation method is characterized by easy accessibility, shorter reaction time and steady product quality. It can also be applied to other noble metal nanoparticles composites, such as Pt, Ag, etc. (5) This hybrid is a new type of multifunctional material that has huge potential benefits in catalysts and biosensors.

4. Conclusions

In summary, we developed a novel Au NPs/RGO/NiF hybrid using a facile, green, and efficient method. The Au NPs are free of chemical surfactants and homogeneously distributed on the surface of RGO/NiF. The as-prepared Au NPs/RGO/NiF hybrid is uniform, stable and exhibits not only a high reduction efficiency for the reduction of 4-nitrophenol but also a sensitive and selective detection of H$_2$O$_2$. The novel Au NPs/RGO/NiF hybrid show good potential for application in both catalysts and sensors.

Acknowledgments

The authors are grateful for financial support from the Science and Technology Major Project of Shanxi Province (No. MC2016-06), National Natural Science Foundation of China [21173041], the Opening Project of Jiangsu Key Laboratory of Advanced Metallic Materials and the Fundamental Research Funds for the Central Universities and the Graduate Student Innovation Program for Jiangsu Regular Universities, China [No. KYLX16_0196]. We would also like to thank Mr Drew Cannon from Washington State University, USA, for his help with writing in English.

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