Sensitive, real-time and anti-interfering detection of nitro-explosive vapors realized by ZnO/rGO core/shell micro-Schottky junction

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\textbf{A B S T R A C T}

The ZnO/rGO core/shell micro-Schottky junction was successfully prepared via a one-step facile hydrothermal method. It is found that the resulting gas sensor exhibited excellent capability to detect trace vapor of nitro-explosives, typically, the responses towards 9 ppb 2,4,6-trinitrotoluene (TNT) and 4.9 ppt hexogen (RDX) reach to 56.8% and 80%, respectively, and all the response times are less than 5 s. Most importantly, superior anti-interfering property is shown even towards interfering gases of ppm level. Furthermore, it is demonstrated that with the wrapping of rGO, the response values of the pure ZnO-based sensor for TNT and RDX detection were boosted by 5.5 and 3.4 times. The enhanced sensing performance is attributed to the micro-Schottky junction built at the interface of ZnO and rGO. The present work demonstrates that the ZnO/rGO core/shell micro-Schottky junction is an excellent candidate material for explosives detection.

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1. Introduction

Due to the increasing threat of explosion related terrorism attack and the need for homeland security, extensive researches have been carried out for typical nitro-explosives detection [1–3]. To date, most of these sensing devices in the detection of explosive vapors are based on inorganic semiconductors, like bare silicon nanowires (SiNWs) [4], ZnO [5], TiO\textsubscript{2} [6,7] and carbon nanotubes (CNTs) [5], organic materials, like organic nanoribbons [8], or organic-inorganic hybrids, such as oligomer-coated carbon nanotubes [9] and organic groups modified SiNWs [10,11]. However, the sensitive and real-time detection is still a challenge due to the ultralow saturated vapor pressure of nitro-explosives, such as, the saturated vapor pressures of TNT and RDX are only a few ppb (parts-per-billion) and ppt (parts-per-trillion) at room temperature, respectively [12].

Fortunately, recent researches have revealed that gas sensors based on Schottky junctions could realize supersensitive and fast response towards the gas phase analytes [3,13–16]. The basis of the Schottky junction enhanced sensing is that a small change in the SBH (Schottky barrier height) would lead to a huge change in the output electric signal. However, the fabrication processes of Schottky junction based gas sensing devices are complicated and need expensive equipment. If Schottky junctions could be introduced into the traditional chemiresistive gas sensing devices by fabricating micro Schottky junctions, it would be especially beneficial for simplifying the preparation technology and fully taking advantage of high sensitivity resulted by Schottky junction. As is well-known, the work functions of n-type semiconducting zinc oxide (ZnO) and the zero bandgap reduced graphene oxide (rGO) are about 4.1 [17,18] and 4.55 eV [19], respectively. Thus, the Schottky junction fabricated by ZnO and rGO could be a promising material for ultrasensitive detection [5,11,20–23], and this has been verified by the excellent performance of a light sensitive photodetector based on a rGO-coated ZnO quasi-shell-core structure [24]. In this system, the adsorption of analyte molecules could also induce the change in SBH, and thus, compared with the simple rGO@ZnO composite structure [25–27], supersensitive detection of gas phase analyte molecules could be realized. However, up to now, this important structure has been largely ignored and there is no report on nitro-explosive vapors detection based on it.

Herein, we demonstrate a ZnO/rGO core/shell micro-Schottky junction-based gas sensor with high sensitivity, rapid response and recovery process towards nitro-explosive vapors. Typically, the responses for room-temperature saturated vapors of TNT, DNT and RDX are 56.8%, 58.4% and 80%, respectively. And almost all the

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response times and recovery times are less than 5 s, ensuring the real-time detection. Furthermore, superior anti-interfering performance was shown even towards ppm level interfering gases.

2. Experimental

2.1. Preparation of sensing materials

Graphene oxide (GO) was firstly prepared using a modified Hummers’ method [28,29], and then 20 mg of it was uniformly dispersed in 20 mL of Dimethylformamide (DMF) by ultrasonication for 30 min. At the same time, 0.46 g (NO.3) of Zn(CH₃COO)₂ · 2H₂O was dissolved in 100 mL of DMF. For another three ZnO/rGO samples with different ratios, the mass of Zn(CH₃COO)₂ · 2H₂O is 0.115 g (NO.1), 0.23 g (NO.2) and 0.69 g (NO.4), respectively. In this process, GO could disperse well in DMF and in the presence of the salt solution to form a stable solution, which is consistent with the previous reports [30,31]. After that, the GO solution was slowly added into the Zn(CH₃COO)₂ solution under stirring to form a stable precursor. Subsequently, the mixed solution was heated to 95 °C and kept for 5 h. The white-greyish product was obtained by centrifugation, and then washed with ethanol and water for several times. The final product was obtained after drying at 60 °C in oven and an annealing process at 350 °C for 6 h. For the preparation of ZnO nanospheres, all the procedures are the same with that of ZnO/rGO core/shell junction without adding GO in the reaction.

2.2. Materials characterization

X-ray diffraction (XRD) measurement was conducted using powder XRD (Bruker D8 Advance, with Cu Kα radiation operating at 40 kV and 40 mA, scanning from 2θ = 20° to 80°). Field-emission scanning electron microscope (FESEM, ZEISS SUPRA 55VP), transmission electron microscope (TEM, FEI Tecnai G2 F20 S-TWIN, 200 kV) and Raman spectroscopy (LabRAM HR Evolution, 532 nm) were used to characterize the morphology and composition of the samples. The X-ray photoelectron spectroscopy (XPS) measurement was conducted on a Escalab 250Xi spectrometer (Thermo Scientific) using monochromatic Al Kα X-ray source (anode HT = 15 kV) operating at a vacuum higher than 2 × 10⁻⁹ mbar. Metal ion content was analyzed using Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) (VARIAN, USA).

2.3. Gas sensing performance test

Initially, the ZnO/rGO core/shell junction material was mixed with deionized water in a weight ratio of 100:25 and ground in a mortar for 15 min to form a paste [32,33]. The paste was then coated on a ceramic substrate by a thin brush to form a sensing film on which silver interdigitated electrodes with both finger-width and inter-finger spacing of about 200 μm was previously printed. Here, the brush painting method is a traditional and classical method to obtain devices [32,34,35], and the thickness of the film can be easily controlled by adjusting the ratio of water and materials, as well as the brushed cycles. The sample was dried naturally in air overnight. The gas sensing property was measured by a Keithley 2636 B Source Meter gas sensing performance analysis system. Before the test, a series of 250 mL glass chambers with different explosive vapors were prepared ahead of 48 h and sealed by rubber stopper.

Then, the sensor was placed into a same chamber filled with air, when the resistance of the sensor reached a steady value, the sensor was placed into the chamber with explosive vapor and sealed by the rubber stopper. After reaching a new steady value, the sensor was exposed to the chamber with air again (Fig. S1). In the whole test process, the temperature and the relative humidity (RH) are 25 ± 3 °C and 20% ± 2%, respectively. The test was repeated for 10–20 cycles in the same process. In this study, the response of a sensor was defined as the relative change of the electric current of the sensing material in air and in analyte gas: Response = [(Iₐ – Iₓ)/Iₓ], where Iₓ and Iₐ are the electric current values of a sensor in analyte gas and air, respectively. The response time is defined as the period in which the sensor current reaches 90% of the response value upon exposure to the analyte vapor, while the recovery time is defined as the period in which the sensor current changes to 10% of the response value after the analyte vapor is removed.

3. Results and discussion

3.1. Concept of ZnO/rGO core/shell micro-Schottky junction-based gas sensing

ZnO/rGO core/shell structure, in which several ZnO nanospheres were wrapped by a rGO sheet, is prepared by a facile one-step hydrothermal method, as illustrated in Fig. 1a and b. Once these core/shell structures were connected with each other and formed into a thin-film gas sensor (Fig. 1c), conductive paths are built in the continuous ZnO/rGO junctions. As illustrated by Fig. 1d, the energy bands of two adjacent semiconducting ZnO components are connected by the metallic rGO shell, forming a Schottky junction. In this configuration, when an electron deficient gas molecule, such as TNT, is adsorbed, it would trap electrons from the Schottky junction, leading to the increase in SBH. Thus, according to the thermionic emission model of a Schottky device [3], the number of electrons that flow across the Schottky interface would be decreased and a great decrease of the current is expected. In this system, the adsorption of TNT molecules could also trap electrons from ZnO through rGO, which is similar to the traditional chemiresistor, playing a minor role in response value. Therefore, the gas sensor based on the ZnO/rGO core/shell structure should show higher sensitivity towards nitro-explosives than the traditional chemiresistive gas sensors due to the construction of Schottky contact.

3.2. rGO-wrapped ZnO nanospheres as a core/shell unit

The morphology and structure of the ZnO/rGO core/shell junctions were characterized by Field-emission scanning electron microscope (FESEM) and transmission electron microscope (TEM). From the FESEM characterization on a large scale, one can see that most of the ZnO spheres have a diameter of 0.4–1 μm, and a layer of rGO wrapped across the surface of several ZnO spheres (Fig. 2a). From an enlarged SEM view (Fig. 2b), it is obviously observed that several ZnO nanospheres aggregated together and were tightly wrapped by rGO to form a core/shell configuration. This wrapping characteristic was further confirmed by the TEM observation (Fig. 2c). The enlarged area in the high-resolution transmission electron microscope (HRTEM) image shows the hexagonal atomic lattice with uniform contrast (Fig. 2d), indicating the existence of a monolayer rGO sheet [36]. And one can see the lattice fringes with a d-spacing of ~0.26 nm, which corresponds to the (002) plane of ZnO, could still be clearly observed in spite of the wrapping of rGO. Furthermore, 3 batches of ZnO/rGO core/shell junctions were prepared using the same ZnO/rGO precursor ratio, and the morphologies are quite consistent with each other. Besides, the corresponding weight ratios of ZnO in ZnO/rGO obtained by Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) analysis are 90.16%, 90.59% and 88.93%, respectively, proving that the present synthesis procedure is repeatable.

To investigate the crystal phase of the ZnO/rGO core/shell structure, XRD analysis was performed (Fig. 2e). It is clearly shown that all the diffraction peaks are sharp and can be indexed to hexago-
Fig. 1. (a, b) Schematic illustration of the preparation process for ZnO/rGO core/shell structure. (c) Schematic conductive paths in the continuous ZnO/rGO core/shell junction film in TNT vapor. (d) Energy band diagram of the ZnO/rGO junction in TNT vapor (E_C, E_V and E_F are the conduction band, valance band and Fermi energy, respectively).

Fig. 2. (a) SEM, (b) enlarged SEM, (c) TEM, (d) HRTEM images and (e) XRD pattern of the ZnO/rGO core/shell junction. (f) Raman spectra of the ZnO/rGO core/shell junction and GO.
nual wurtzite ZnO (JCPDS, 89-0511), suggesting a good crystallinity of the ZnO spheres. From the Raman spectra (Fig. 2f), the graphitized structures (D band ~1342 cm\(^{-1}\) and G band ~1582 cm\(^{-1}\)) are observed for both the ZnO/rGO structure and graphene oxide (GO). It is observed that there is no shift of peak position between GO and ZnO/rGO, and the intensity ratio of D band over G band (I_d/I_g) increases from 1.04 to 1.07 after the hydrothermal and annealing process, indicating the reduction of GO [37–39]. Here, in the hydrothermal process, numerous functional groups on GO, like carboxyl groups and hydroxyl groups, act as reactive sites for Zn\(^{2+}\) to anchor, and are reduced partially. Then, those remained active functional groups are further reduced by the following annealing treatment [40,41]. To determine the reduction degree of rGO, the oxygen-bound carbon content in rGO was calculated based on the X-ray photoelectron spectroscopy (XPS) results (Fig. S2) with the following equation [42]:

\[
\text{O-bound CD} = \left( \frac{A_C - O + A_{O - C = O}}{A_C + A_{C - O} + A_O - C = O} \right) \times 100\%
\]  

(1)

where \(A_C - O\), \(A_{C - O}\), and \(A_{O - C = O}\) are the peak areas in the XPS spectra for the sp\(^2\)-hybridized (C–C) and O-bound (C–O and O–C=O) carbon, respectively [43]. It is found that after the hydrothermal reaction and annealing treatment, the O-bound C content decreased from the original 46% in GO to 23% in the ZnO/rGO, indicating that the reduction degree of rGO is about 50%.

It is noted that two new peaks at 572 and 1118 cm\(^{-1}\) are observed in the Raman spectrum of the ZnO/rGO junction (Fig. 2f). The first peak (572 cm\(^{-1}\)) corresponds to the finger signal of the characteristic E\(_1\) (LO) mode of ZnO wurtzite structure, and the second one at 1118 cm\(^{-1}\) belongs to the 2LO mode [44]. These results further indicate the successful combination of wurtzite ZnO and rGO.

3.3. Sensitive, real-time and anti-interfering detection of nitro-explosive vapors

The ZnO/rGO core/shell junctions are then constructed into a gas sensor, as shown in Fig. 3a, which shows the schematic diagram of the device for the gas sensing performance evaluation. And the real device structure is shown in Fig. S3. The current-voltage (I-V) characteristics of the sensor, which were measured in air and in TNT vapor at room temperature, were shown in Fig. 3b. The I-V curves showed the non-linear characteristics of the sensor, indicating the formation of Schottky junction between the ZnO core and rGO shell [16,24]. The current measured in TNT saturated vapor is always lower than the value in air due to the adsorption of the electron-deficient TNT molecules at the Schottky junction.
area, indicating the present sensor design could be well employed to detect analyte molecules. Thus, the sensor was used to detect five room-temperature saturated nitro-explosive vapors (TNT, 2,4-dinitrotoluene (DNT), para-nitro toluene (PNT), RDX, picric acid (PA)), which are all of extremely low concentration (Table S1). The recorded current changes of the sensor are almost the same and can recover to the initial value during three successive cycles (Fig. 3c), indicating the good repeatability of the sensor. Furthermore, one can see that for TNT, DNT and RDX, the sensor responses are negative, and for PNT and PA, the sensor responses are positive (Fig. S4). To further confirm the response mechanism, relative electron withdrawing and electron-donating abilities are simulated (Fig. S5). It is obvious that TNT, DNT and RDX show stronger electron withdrawing ability than PNT and PA. When TNT, DNT and RDX molecules adsorb on the Schottky interface, they trap electrons from the Schottky interface, leading to the increase of SBH and the decrease of the current. On the contrary, the current would increase when exposed to PNT and PA vapors.

The response values towards TNT, DNT, PNT, RDX and PA saturated vapors are $-56.8\%$, $-58.4\%$, $20.2\%$, $-80\%$ and $16.3\%$ (Fig. 3e), respectively, which indicate the ultra-sensitivity of the sensor, especially, for 9 ppb TNT, 411 ppb DNT and 4.9 ppb RDX. Furthermore, the sensor shows fast response and recovery characteristics towards all of the explosive vapors (Fig. 3f). Except for the response time of PNT is relatively longer (12.3 s), the response times for all the other four vapors are less than 5 s, ensuring the real-time detection. The recovery ability is also a key factor for a real-time sensor. Fortunately, the recovery times towards the above five vapors are 4, 14.7, 2.7, 5.3 and 2.7 s, respectively, illustrating that the sensor could quickly regenerate after operation. From the above analysis, it can be concluded that the sensor possesses a high sensitivity and real-time characteristic for nitro-explosives detection.

To further confirm the superiority of the present ZnO/rGO core/shell junction-based sensor towards explosive vapors detection, a comparison of the response values and response times with other explosive vapor sensors is listed in Table 1. Generally, for TNT and DNT detection, the response values of the present sensor are equivalent to the best TiO$_2$-B NW-based sensor. However, the response value for RDX vapor is as high as 80%, which is remarkably higher than the response values of the TiO$_2$-B NW and the silicon NW-based sensors (50% [6] and 24% [4]). Furthermore, the corresponding response time of the present sensor to RDX is as short as 3 s, which is comparable to the previous records of 2.35 s and 2.93 s, demonstrating the strong competitiveness of the present ZnO/rGO core/shell junction-based sensor either in sensitivity or in response speed.

The anti-interfering capability of the sensor is evaluated with ETOH (ethyl alcohol), NO$_2$ and NH$_3$ with a concentration of 100, 1 and 1 ppm, respectively, which is much higher than the concentration might be encountered in daily life (Fig. 4a and b). It is shown that the response values towards the above three gases are $-10.1\%$, 6.9% and 0, respectively, which are much smaller than the response values towards nitro-explosive vapors. Considering that the vapor pressures of nitro-explosives are much lower than 100 or 1 ppm, it can be concluded that the common interfering gases in real-world have very limited influence on the sensing performance of the sensor towards nitro-explosives. It is known that humidity would affect the response of the metal oxide-based sensor remarkably. Here, the responses of the sensor towards air with RH of 33% and 54% were evaluated to be 0 and 45%, respectively (Fig. S5). Since the relative humidity was 20 ± 2% during the testing process, the response values towards explosive vapors in the present study are not affected by humidity. Thus, the ZnO/rGO core/shell junction-based sensor is beneficial for sensitive, real-time, and anti-interfering detection of nitro-explosive vapors.

### 3.4. The role of micro-Schottky junction in enhanced sensing

In order to explore the effect of the content of ZnO on the sensing behavior of the ZnO/rGO junction, another three ZnO/rGO samples (NO.1, NO.2 and NO.4) with different mass ratios of ZnO to rGO were prepared. It is observed that when the content of ZnO is low, rGO tends to aggregate into bulk structure (Fig. 5a and b). While a higher ZnO content would induce plenty of the ZnO nanospheres being uncovered (Fig. 5c). Furthermore, the sensing performance of the three ZnO/rGO sample-based sensors towards room-temperature saturated vapors of TNT, DNT, PNT, RDX and PA was evaluated (Fig. S6). It is found that with the increase of the ZnO content, the response firstly increases and then decreases towards a certain explosive (Fig. 5d), and the ZnO/rGO core/shell junction-based sensor shows the largest response value. As a result, the appropriate content of ZnO in ZnO/rGO could lead to the formation of a core/shell structure, and fully take the advantage of ZnO/rGO micro-Schottky junction.

To further illustrate the decisive role of Schottky junction in improving the sensing performance, a pure ZnO nanosphere-based chemiresistive sensor was designed and compared. The morphology and size of the pure ZnO structure are the same with that in the ZnO/rGO core/shell junction (Fig. 6a). Comparing to those of the ZnO/rGO core/shell junction-based sensor, the current change curves of the pure ZnO nanosphere-based sensor show an unstable characteristic, for example, the absolute current change value tends to decrease from one cycle to the other cycle (Figs. S7 and 6b). Besides, the current jumped to a maximum value once the sensor contacts with the analyte vapor, and followed a decrease or stabilizing process. The corresponding response values towards room-temperature saturated vapors of TNT, DNT, PNT, RDX and PA are $-10.4\%$, $-26\%$, $11.7\%$, $-23.2\%$ and 8.4%, respectively (Fig. 6c), which are remarkably smaller than those of the ZnO/rGO core/shell junction-based sensor. Especially, by the intro-
Table 1
Comparison of different gas-phase nitro-explosive sensors.

<table>
<thead>
<tr>
<th>Sensing material</th>
<th>Analytes and concentration</th>
<th>Response value</th>
<th>Response time (s)</th>
<th>Refs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZnO NW</td>
<td>TNT, 60 ppb</td>
<td>20%</td>
<td>–</td>
<td>[5]</td>
</tr>
<tr>
<td>Silicon NWs array</td>
<td>TNT, 9 ppb</td>
<td>28.5%</td>
<td>12.07</td>
<td>[4]</td>
</tr>
<tr>
<td></td>
<td>DNT, 411 ppb</td>
<td>50%</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RDX, 4.9 ppt</td>
<td>24%</td>
<td>2.93</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PA, 0.97 ppb</td>
<td>15.3%</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>rGO/TiO2/SiNWs array</td>
<td>TNT, 9 ppb</td>
<td>6.3%</td>
<td>81</td>
<td>[3]</td>
</tr>
<tr>
<td></td>
<td>DNT, 411 ppb</td>
<td>40%</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RDX, 4.9 ppt</td>
<td>9%</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PA, 0.97 ppb</td>
<td>4%</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>TiO2-(B) NWs</td>
<td>TNT, 9 ppb</td>
<td>57%</td>
<td>1.67</td>
<td>[6]</td>
</tr>
<tr>
<td></td>
<td>DNT, 411 ppb</td>
<td>58%</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RDX, 5 ppt</td>
<td>50%</td>
<td>2.35</td>
<td></td>
</tr>
<tr>
<td>TiO2 decorated GaN NWs</td>
<td>TNT, 100 ppb</td>
<td>10%</td>
<td>30</td>
<td>[45]</td>
</tr>
<tr>
<td></td>
<td>DNT, 100 ppb</td>
<td>2%</td>
<td>60–75</td>
<td></td>
</tr>
<tr>
<td>DNA decorated SWNTs</td>
<td>DNT, 46 ppm</td>
<td>23%</td>
<td>–</td>
<td>[46]</td>
</tr>
<tr>
<td>This work</td>
<td>TNT, 9 ppb</td>
<td>56.8%</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DNT, 411 ppb</td>
<td>58.4%</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RDX, 4.9 ppt</td>
<td>80%</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PA, 0.97 ppb</td>
<td>16.3%</td>
<td>2.3</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: NW: nanowire; NT: nanotube.

Fig. 5. SEM images of the ZnO/rGO samples with different ZnO to rGO ratios: (a) NO.1, (b) NO.2 and (c) NO.4. (d) The comparison of responses of the four ZnO/rGO samples towards room-temperature saturated vapors of TNT, DNT, PNT, RDX and PA.

duction of the ZnO/rGO core/shell junction, an improvement in response values of 5.5 times for TNT, 2.2 times for DNT, and 3.4 times for RDX was achieved (Fig. S8). For the pure ZnO-based sensor, the response is determined by the change of depletion layer depth resulted by the adsorption of the nitro-explosive molecules. Thus, the sensor current linearly depends on the depletion layer depth. While for the ZnO/rGO core/shell junction-based sensor, the response is determined by the change of the SBH led by the adsorption of the nitro-explosive molecules onto the Schottky interface. And SBH has an exponential dependence on the reverse current, thus a small change in the SBH would lead to a huge change in the output electric signal. Due to the ultralow saturated vapor pres-
sures of nitro-explosives, the response values of ZnO-based sensor are smaller than those of the ZnO/rGO core/shell junction-based sensor.

However, the response times and recovery times of the pure ZnO nanosphere-based sensor are less than 4 s and 7 s (Fig. 6d), which are a bit shorter than those of the ZnO/rGO core/shell junction-based sensor. This phenomenon could be attributed to that the diffusion rate of the explosives molecules is faster in ZnO nanosphere-based sensor with the gaps between the spheres than in the ZnO/rGO system where the molecules have to diffuse onto the ZnO/rGO interfaces. Furthermore, it is considered that the strong chemisorption ability of rGO inhibits the ZnO/rGO-based sensor to recover.

Besides, a bare rGO based chemiresistive sensor was also fabricated for direct comparison of the sensing performance (Fig. 7). It is observed that the response of the rGO-based sensor is much smaller than those of the ZnO/rGO-based sensor. Furthermore, the sensing behavior is completely opposite to those of the ZnO/rGO-based sensor. These results clearly demonstrate the advantage of the construction of the core/shell junction and the p-type sensing behavior of rGO.

4. Conclusion

A Schottky junction-based nitro-explosive vapor sensor was designed to considerably improve the response values. The ZnO/rGO core/shell structure was prepared by a facile one-step hydrothermal method to obtain the micro-Schottky junction unit. The resulting sensor shows remarkably high sensitivity towards representative room-temperature saturated vapors, such as, TNT, DNT, PNT, RDX and PA, and the corresponding absolute response values reach 56.8%, 58.4%, 20.2%, 80% and 16.3%, respectively.
Besides the high sensitivity, almost all the response/recovery times are less than 5 s, ensuring the real-time detection. Superior anti-interfering capability was shown even with the testing gases of ppm level. The decisive role of the Schottky junction in improving the sensing performance was proved by comparing with the sensing performance of a pure ZnO nanosphere-based chemiresistive sensor. The present result demonstrates that the Schottky junction-based sensor is an excellent candidate for trace vapor detection.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.snb.2016.07.175.

References


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Xincun Dou obtained his Ph.D. in Materials Physics and Chemistry from Institute of Solid State Physics in Chinese Academy of Sciences in 2009. Following postdoctoral research at Nanyang Technological University in Singapore in Materials Science, he joined the Xinjiang Technical Institute of Physics & Chemistry, Chinese Academy of Sciences in 2011 as a “Hundred Talents Program” professor. His research interests focus on the exploratory design of nanomaterials and nanodevices, with an emphasis on explosive sensing application.