Indian Journal of Data Analysis and Information Systems
Volume 12 • Number 2 • December 2020

# A facile fabrication and sensing characteristics of gas sensor based on ZnO-RGO composite activated by UV-irradiation

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**ABSTRACT**

The gas sensor based on zinc oxide-reduced graphene oxide (ZnO-RGO) nanocomposite has been fabricated and studied in this work. The ZnO-RGO composite was characterized by X-ray diffraction (XRD) and scanning electron microscopy (SEM). The response of device based on ZnO-RGO nanocomposite under UV irradiation is nearly two times higher than its counterpart based on ZnO nanowires with 3 bias voltage. It was also demonstrated that the gas sensor based on ZnO-RGO showed great responses while varying concentration of O2 or different gas under ultraviolet (UV) irradiation. The results demonstrate that the gas sensor based on ZnO-RGO structure may have a potential application in gas sensing fields.

***Keywords:*** Semiconductor, Zinc oxide, Nanocomposite, Sensor

## 1. INTRODUCTION

Among the various semiconductor metal oxide, one-dimensional Zinc oxide (ZnO) nanostructures have attracted much attention due to large surface to volume ratio, persistent photoconductivity, excellent optoelectronic properties and so on. ZnO materials have been widely used in many fields such as laser diodes, UV optical detectors, solar cells, etc [1-5]. As one kind of important gas sensing materials, they are sensitive to many sorts of gases and have satisfactory stability. In spite of some advantages of one-dimensional ZnO nanomaterials made as gas sensors, they have the demerit of operating a high operating temperature normally between 400 and 500 $^{o}$C. Up to now, there have been great efforts to decrease the operating temperature of sensors based on ZnO nanomaterials [6-10] such as doping with noble metals, surface decoration, adding the electrostatic field and operating UV-irradiation technique, wherein taking advantage of UV irradiation technique is one of the most promising approaches to achieve low working temperature for ZnO gas sensors.

Graphene, a unique two-dimensional structure consisting of $sp^2$ bonded carbon atoms in a hexagonal lattice, has aroused much attention due to its unique properties, excellent thermal conductivity, specific surface area, excellent mobility of charge carriers at room temperature, etc[11–13]. The combination of graphene and ZnO can exhibit excellent optoelectronic properties by improving the carrier transport and collection efficiency[14–16]. There have been some reports about gas sensing properties of sensors based on ZnO nanomaterial [17,18]. However, the fabrication and investigation of gas sensor based on ZnO-rGO compostie under UV irradiation are very limited. In this study, we reported a facile gas sensor based on ZnO-RGO composite. The photoelectric response of sensor based on ZnO-RGO with a low bias voltage was investigated under UV irradiation. The response curves of sensors were measured when it was exposed to oxygen or alcohol gas detection in darkness and under UV illumination. We found that the developed ZnO-RGO sensor exhibited excellent responses toward different gases, which may have a great potential for the ZnO application in the gas sensing field.

## 2. EXPERIMENTAL

The ZnO nanowires (NWs) were prepared through CVD and the RGO sample was synthesized by the Hummers method in our previous reports [19,20]. The 0.2 μL ZnO-RGO suspension was extracted and deposited onto the interdigital electrode gap by a microsyringe. The networks of ZnO-RGO sample can be bridged on electrode and the sensor would be constructed. The morphology of the sample was also observed by field emission scanning electron microscopy (FE-SEM, Carl Ultra 55). The crystal structure of the sample was tested using an advanced X-ray diffractometer (D8 ADVANCE, Bruker, Germany). In our experiments, oxygen or alcohol was carrier gas and nitrogen was used as diluting gas and background gas. In order to acquire different concentrations of oxygen or alcohol, which can be controlled adding the nitrogen gas by mass flow controllers. The concentration of 1sccm carrier gas would be diluted to approximately 15ppm after adding 1sccm $N_2$ gas. The response characteristics of the gas sensors were monitored both in the dark and UV illumination using Agilent 4156C at room temperature.

## 3. RESULTS AND DISCUSSION

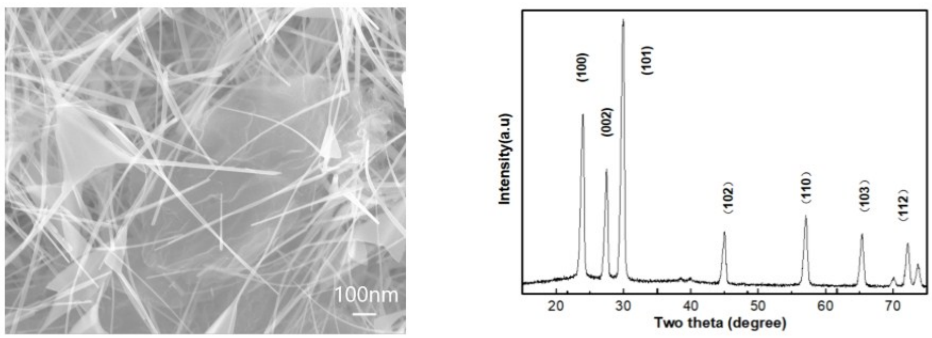


Fig. 1. (a) The SEM image of ZnO-RGO sample. (b) X-ray difraction pattern of ZnO-RGO sample.

Fig. 1 (a) shows a typical scanning electron microscope (SEM) image of ZnO-RGO hybrid structure. It is obvious that the ZnO structure had the wire-like shape and mixed well with reduced graphene oxide. Fig. 1 (b) illustrates the typical diffraction pattern for the sample. There are a series of diffraction peaks corresponding to planes of crystalline ZnO such as (100), (002), (101) and (102), which demonstrate a hexagonal wurtzite structure for ZnO nanowires.

Fig. 2 (a) shows the response of the sensing test based on ZnO NWs exposed to $O_2$ gas with various flow rate at room temperature. Compared the sensor in dark, the sensing device exposed to pure $O_2$ gas exhibits a markedly enhanced photocurrent under UV illumination. The photocurrent of sensor based on ZnO has the same figure for the same bias voltage at different flat rates, which means the gas mass flow could not change the current value at different bias voltages. Fig. 2 (b) shows the current of sensor based on ZnO-RGO nanocomposite is more than twice as large as the counterpart based on ZnO NWs at 3 bias voltage under UV irradiation, which is also nearly two orders of magnitude higher than the current in dark. It means that the photoinduced electrons and holes for ZnO/RGO composite under UV illumination are efficiently separated and the current value can be greatly improved.

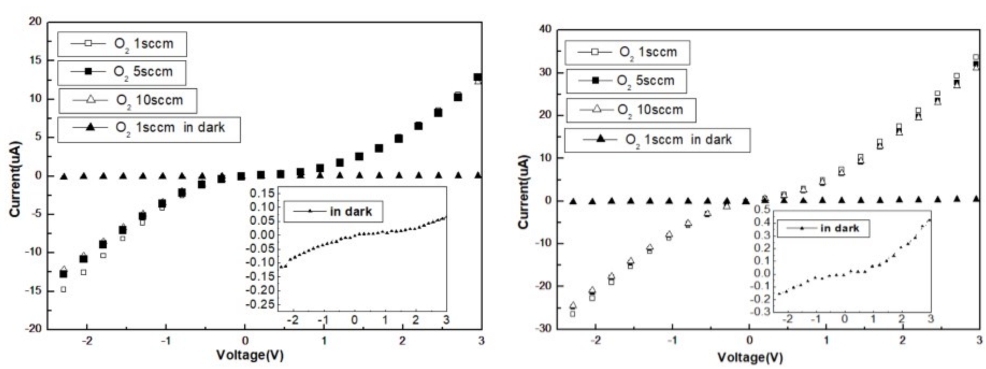


Fig. 2. I-V characteristics of gas sensing test at room temperature (a) the sensor based on ZnO NWs with exposed to $O_2$ with different flow rate under UV irradiation . Lower inset: the amplified characteristic of ZnO sensor exposed to $O_2$ in dark. (b) the sensor based on ZnO-RGO exposed to $O_2$ with different flow rate under UV irradiation. Lower inset: the amplified characteristic of ZnO-RGO sensor exposed to $O_2$ in dark.

As can been seen from Fig. 3 (a), compared with the ZnO-RGO sensor exposed to pure $O_2$ gas under UV irradiation, the current of the ZnO-RGO sensor is greatly increased when exposed to a mixer gas of 1sccm $O_2$ and 1sccm $N_2$. The photocurrent of device based on ZnO-RGO nanocomposite under UV irradiation is nearly three times as large as its current at 3 basing voltage under UV irradiation. The figure of the ZnO-RGO gas sensor exposed to a mixer gas is dramatically increased, which suggests the response of ZnO-RGO sensor under UV irradiation is related to the concentration of $O_2$ gas.

Fig. 3 (b) reveals the response for the ZnO-RGO sensor exposed to a mixer gas of 1sccm $O_2$ and 1sccm $N_2$ during two cycles when switching on and off the UV illumination. After several cycles, the response ability can be repeated and remained, which suggests that the ZnO-RGO may be used as excellent sensing material and have potential application in the sensing areas.

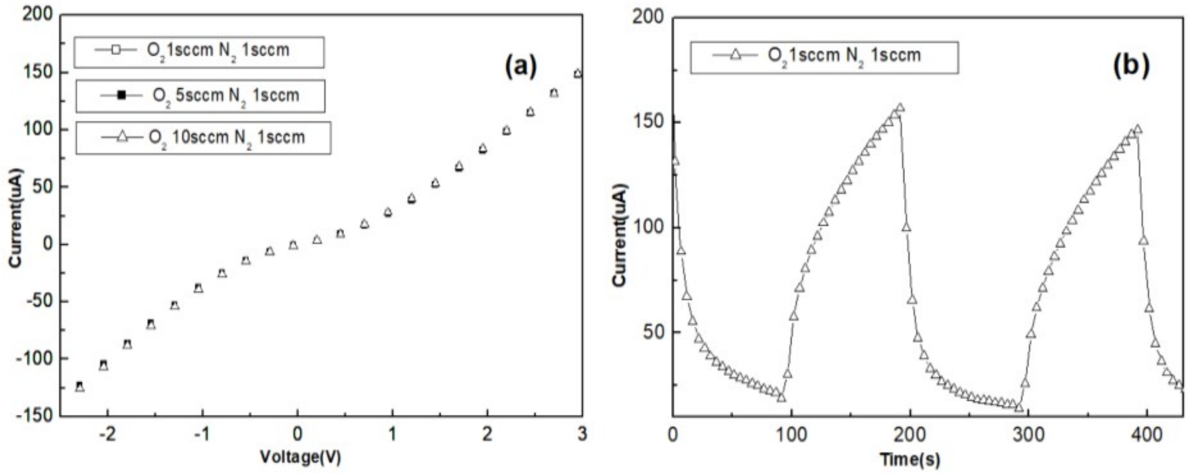


Fig. 3. (a) I-V characteristics of ZnO-RGO sensor exposed to a mixer of $O_2$ and $N_2$ gas with different flow rate under UV irradiation at room temperature. (b) Dynamic variation of the response of ZnO-RGO sensor under UV excitation that exposed to a mixer gas of $O_2$ and $N_2$ at room temperature.

Fig. 4 shows the response of the sensing device based on ZnO-RGO exposed to different gases and its schematic diagram of sensing setup at room temperature. It is obvious that the current of device based on ZnO-RGO nanocomposite exposed to a mixer of alcohol and $N_2$ gas is much higher than exposed to $O_2$ gas or a mixer of $N_2$ and $O_2$ gas at 1 basing voltage under UV irradiation, which indicates alcohol gas can facilitate to increase the current of the ZnO-RGO sensor. The above phenomena can be explained as follows. Nitrogen will not participate in chemical reactions with ZnO-RGO materials. When ZnO-RGO sensor is exposed to the diluted $O_2$ gas, an oxygen molecule can not enough adsorb on the surface of the ZnO-RGO and then affect to form an $O_2$ ion which leads to a decrease of oxygen ions concentration. Compared with ZnO-RGO gas sensor exposed to the pure $O_2$ gas. the trapped electrons will be back to the conduction band of the ZnO, resulting in an increased current.

When the ZnO-RGO sensor is exposed to a reductive gas just as ethanol gas under UV illumination, the reductive gas reacts with oxygen species adsorbed on the semiconductor surface and release electrons to the conduction band. This will also result in a decrease in the amount of surface $O^{2"}$, $O^{"}$ ions etc, which will lead to an increase in concentration of electrons in the conduction band and increase the conductivity of the sensor based on ZnO-RGO material. In addtion, the ZnO-RGO naomaterial has the diameter of nanoscale in our experiment, the more the effective surface area, the higher the sensitivity of this kind of sensors. The combination of RGO and ZnO under UV irradiation can facilitate to efficiently separate electrons and holes and make a contribution to produce a larger current. It is expected that the sensing device based on ZnO/RGO composite will exhibit an excellent good response to various gases, which may hold a great promise for practical application of ZnO gas senors.

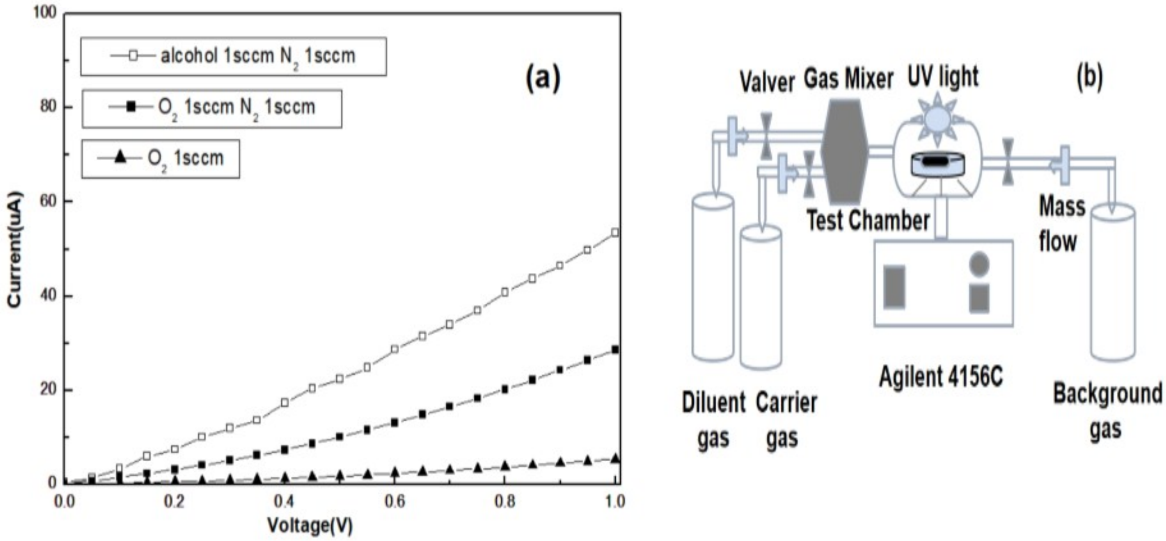


Fig. 4. (a) I-V characteristics of ZnO-RGO sensor exposed to a mixer of alcohol and $N_2$ gas under UV irradiation at room temperature (b) Schematic diagram of gas sensing setup at room temperature.

## 4. CONCLUSION

In this work, the gas sensor based on ZnO-RGO nanocomposite was fabricated and investigated to study its gas sensing properties. The result shows excellent sensitivity to different gases such as oxygen or alcohol gas under UV irradiation at room temperature. The ZnO-RGO sensor exhibited nearly 3 times response higher than the sensor based on ZnO sensor while exposed to $O_2$ atmosphere. The gas mass flow could not change the current value at different bias voltages. The device showed increased response when the concentration of $O_2$ was diluted by $N_2$ gas. Moreover, alcohol gas can also enhance the photocurrent of the ZnO-RGO sensor under UV illumination at room temperature. The findings may indicate the potential application of the ZnO-RGO sensor in gas sensing fields.

### Acknowledgements

The authors gratefully acknowledge Shanghai Funds for young college teachers (ZZSDJ15009). Scientific Research Foundation of Shanghai DianJi University (No. 14QD38).

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