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Studying of Gas Sensing Properties of Titania Nanotubes for Health and Safety Applications †

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Abstract: We studied the preparation and gas sensing performance of a hybrid nanomaterial based on titania nanotubes and graphene derivatives. We fabricated the hybrid structure with tunable chemical sensing properties, achieved by tailoring the structure and composition of graphene oxide and coupling it with titania nanotubes. The parameters of manufactured sensing structures were investigated towards hydrogen and ammonia. Our experimental findings indicate that this research may provide an efficient way to enhance the gas sensing properties of metal oxide nanomaterials for health and security applications.

Keywords: nanomaterials; titania; graphene; chemical sensor; gas sensor

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1. Introduction

Modern gas sensing systems based on nanotechnologies may enable reliable and continuous detection of different gaseous compounds to control atmospheric pollutants and human health [1–5]. Wide bandgap semiconductor nanostructures with their quantum-mechanical properties can affect the characteristics of functional devices [6–8]. Therefore, the application of semiconductor nanomaterials in the development of chemical gas sensors is of great interest [9–11]. Highly ordered transition metal oxide nanostructures have been considered as promising materials for applications in chemical gas sensors due to their good chemical stability and functional properties [12]. In this regard, the well-ordered and highly aligned titania nanotubes with their superior electron transport properties and large surface area are very attractive structures for the fabrication of gas sensing systems [13–16]. Herein, we report the preparation and investigation of sensing properties of titania-based nanotubular structures for their application in gas detection devices. We studied the effect of the additive material on the functionalities of nanotubes to optimize their sensing performance. The morphology, structure and composition of prepared materials were examined. The sensing properties of materials were studied towards hydrogen (H_2) and ammonia (NH_3). We have analyzed the interaction mechanism between the prepared nanotubes and gaseous compounds considering their structural and compositional modifications. The obtained results demonstrate that the fabricated sensing materials have a potential for application in detection systems.

2. Materials and Methods

Titania nanotubes were prepared as follows: The metallic titanium films were deposited on alumina substrates by radio frequency magnetron sputtering. Then, metallic films were anodized in a two-electrode system Teflon cell at room temperature. We reported the detailed information on anodization procedure in our previous reports [16,17]. As-prepared materials were crystallized by thermal treatment in a tubular furnace at 400 °C for 6 h. We reported the crystallization regimes and analysis of the samples in [18]. The morphological analysis of samples was performed by means of LEO 1525 scanning electron microscope (SEM) equipped with field emission gun. In order to fabricate the hybrid material, we prepared an aqueous dispersion of graphene oxide. Then, we drop casted the prepared dispersion on the surface of titania nanotubes. To carry out gas sensing measurements platinum electrodes and a heater were deposited on the surface of sensing structures and on the backside of substrates by RF magnetron sputtering. The gas sensing tests were performed in a test chamber and the measurements were controlled by computer-controlled gas flow system. The sensor based on pure titania is denoted as S1 and the sensor based on composite material is denoted as S2.

3. Results and Discussion

The results of the morphological analysis of samples are shown in Figure 1. The SEM observations confirmed that highly ordered titania nanotubes were prepared. The tube diameter is 30 nm (Figure 1a). Figures 1b) and 1c report the surface morphology of the composite structure. As can be seen, the surface of titania nanotubes is covered by graphene oxide sheets. Figure 2 presents the dynamical response of the fabricated S1 and S2 sensors towards 120, 240 and 480 ppm of H_2 and 10, 20 and 30 ppm of NH_3. The sensing measurements were carried out at 200 °C. The graphene oxide significantly increases the response of titania nanotubes towards H_2. Meanwhile, very small differences were observed between the sensing behavior of S1 and S2 structures towards NH_3. The drastic enhancement in the response of the S2 sensor compare to the S1 can be attributed to the depletion layer formed between the titania nanotubes and graphene oxide. In this case, the presence of more active centers improves the adsorption of H_2 on the surface of hybrid material, which is important for its sensitivity.

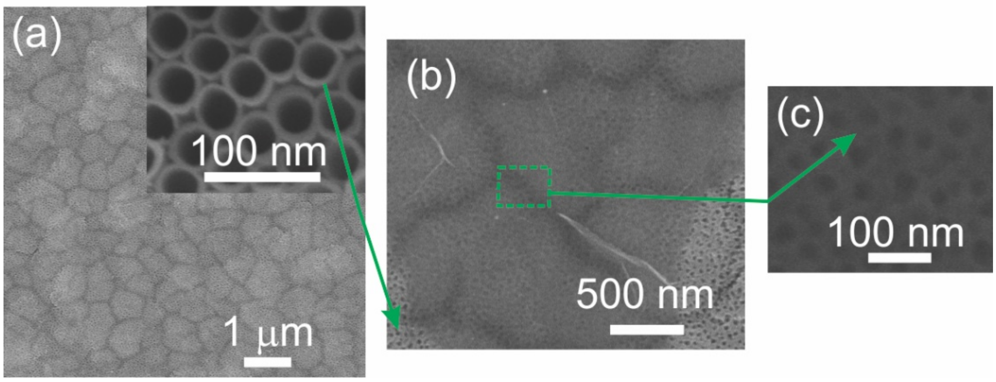

Figure 1. SEM images of the obtained samples. (**a**) The surface morphology of pristine titania nanotubes with different resolutions, (**b**) and (**c**) the morphologies of the fabricated composite material with different resolutions.

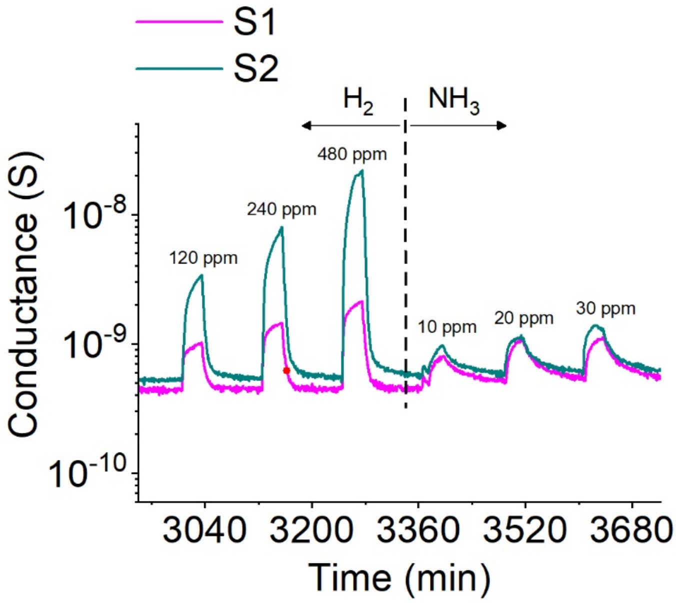

Figure 2. The dynamical response of obtained S1 and S2 sensors towards different concentrations of H_2 and NH_3 at 200 °C.

4. Conclusions

We fabricated a hybrid structure based on titania nanotubes and graphene oxide. Then, we investigated its gas sensing performance towards H_2 and NH_3. Our experimental findings show that the depletion layer formed between two materials plays a crucial role to tune the sensing response of the hybrid structure. The hybrid material exhibited a better sensing response towards H_2 compared to pristine titania nanotubes indicating that this this is an efficient and promising way to enhance the sensing parameters of metal oxide gas sensors.

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