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Facile synthesis and enhanced gas sensing properties of grain size-adjustable In_2O_3 micro/nanotubes

Lihuan Wang [a,b], Jing Cao [a,*], Xiaoming Qian [b], Haiming Zhang [a,*]

[a] School of Science, Tianjin Polytechnic University, Tianjin 300387, People's Republic of China
[b] School of Textiles, Tianjin Polytechnic University, Tianjin 300387, People's Republic of China

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ABSTRACT

Without accurately controlling the ratio of reactants, indium oxide (In_2O_3) micro/nanotubes are successfully fabricated by a facile coaxial electrospinning route and a subsequent annealing treatment. The micro/nanotubes consist of In_2O_3 nanocrystals with primary grain sizes of 10-23 nm and present rough surfaces. The grain sizes of In_2O_3 micro/nanotubes can be adjusted by the calcination temperature. The In_2O_3 micro/nanotubes present grain size-dependent gas sensing properties. The sensors based on In_2O_3 micro/nanotubes calcined at 400 °C (NT400) show better HCHO gas sensing performances in comparison with the sensors based on In_2O_3 micro/nanotubes calcined at 600 °C (NT600) and 800 °C (NT800). The facile fabrication method and excellent gas sensing performances make as-prepared In_2O_3 micro/nanotubes developed for HCHO gas detection in practice.

1. Introduction

With increasing concerns of air pollution on human health and public safety, the need for high performance gas sensors have been highlighted [1]. In order to effectively detect combustible and toxic gas, significant effects have been made in the design and engineering of novel gas sensing materials, which can be employed for highly sensitive gas sensors [2,3]. Among them, one-dimensional nanostructures have received considerable attention due to their large surface area and efficient transforming of surface chemical species into electrical signals by surface depletion layers [4–6]. In_2O_3, as an important n-type wide band gas semiconductor, has been acknowledged as a promising candidate for the application in gas sensors [7–9]. Up to now, various micro/nanostructured In_2O_3 has been prepared by different routes. In general, these approaches usually demand stringent experiment conditions or the use of catalysts/templates, which possibly limit the potential applications. In contrast, the facile coaxial electrospinning approach becomes a promising choice to solve the above problems.

In this work, In_2O_3 micro/nanotubes with different grain sizes have been successfully fabricated via a facile coaxial electrospinning technique and the subsequent annealing treatment. The as-obtained In_2O_3 micro/nanotubes are developed for HCHO gas detection and their sensing properties have been investigated in detail. The gas sensing results indicate that In_2O_3 micro/nanotubes with small nanograins present better HCHO sensing performances in comparison with In_2O_3 micro/nanotubes with large nanograins and solid In_2O_3 micro/nanofibers.

2. Experiments

All the reagents (analytical-grade purity) were used as purchased without further purification. 0.5 g PVP was dissolved in the mixed solution of 0.3 mL DMF, 4.7 mL C_2H_5OH and 2.5 ml CH_3COOH under vigorous stirring for 1 h. And then, 0.4 g $In(NO_3)_3 \cdot 4.5H_2O$ was added into the above mixture and stirred for 4 h to form uniform and clear precursor solution. The obtained precursor solution was then loaded into the syringe as outer fluid, the inner fluid was paraffins. Coaxial electrospinning installation was shown in our previous report [10]. To obtain In_2O_3 nanotubes, the PVP/$In(NO_3)_3 \cdot 4.5H_2O$ composite micro/nanofibers prepared by coaxial electrospinning were calcined in air (no inert gas protection) at 400 °C, 600 °C, or 800 °C for 3 h. These samples were named as "NT400", "NT600", "NT800" according to calcination temperature, respectively. Micro/nanofibers (NF600) fabricated by electrospinning (calcined at 600 °C) were synthesized as a reference material.

The morphology and crystal structure of the In_2O_3 micro/nanotubes were characterized by the transmission electron microscope (JEOL JEM-2200FS) and the X-ray diffraction (Rigaku D/max-Ra). The details of the sensor fabrication were similar to our previous report [10]. Briefly, 0.01 g In_2O_3 nanomaterials were mixed

* Corresponding authors.
E-mail addresses: caojing@tjpu.edu.cn (J. Cao), zhmtjwl@163.com (H. Zhang).

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with 0.1 mL deionized water to form a paste. The paste was printed on a ceramic tube. A pair of gold electrodes was previously printed on the ceramic tube to transfer electrical signal, and a Ni-Cr heating wire was inserted into the tube to form a side-heated gas sensor. The sensors were dried at 100 °C for 3 h and then welded on a socket. The work temperature of the sensor was controlled by work electrical current. The gas sensing properties were measured by a CGS-8 intelligent gas sensing analysis system.

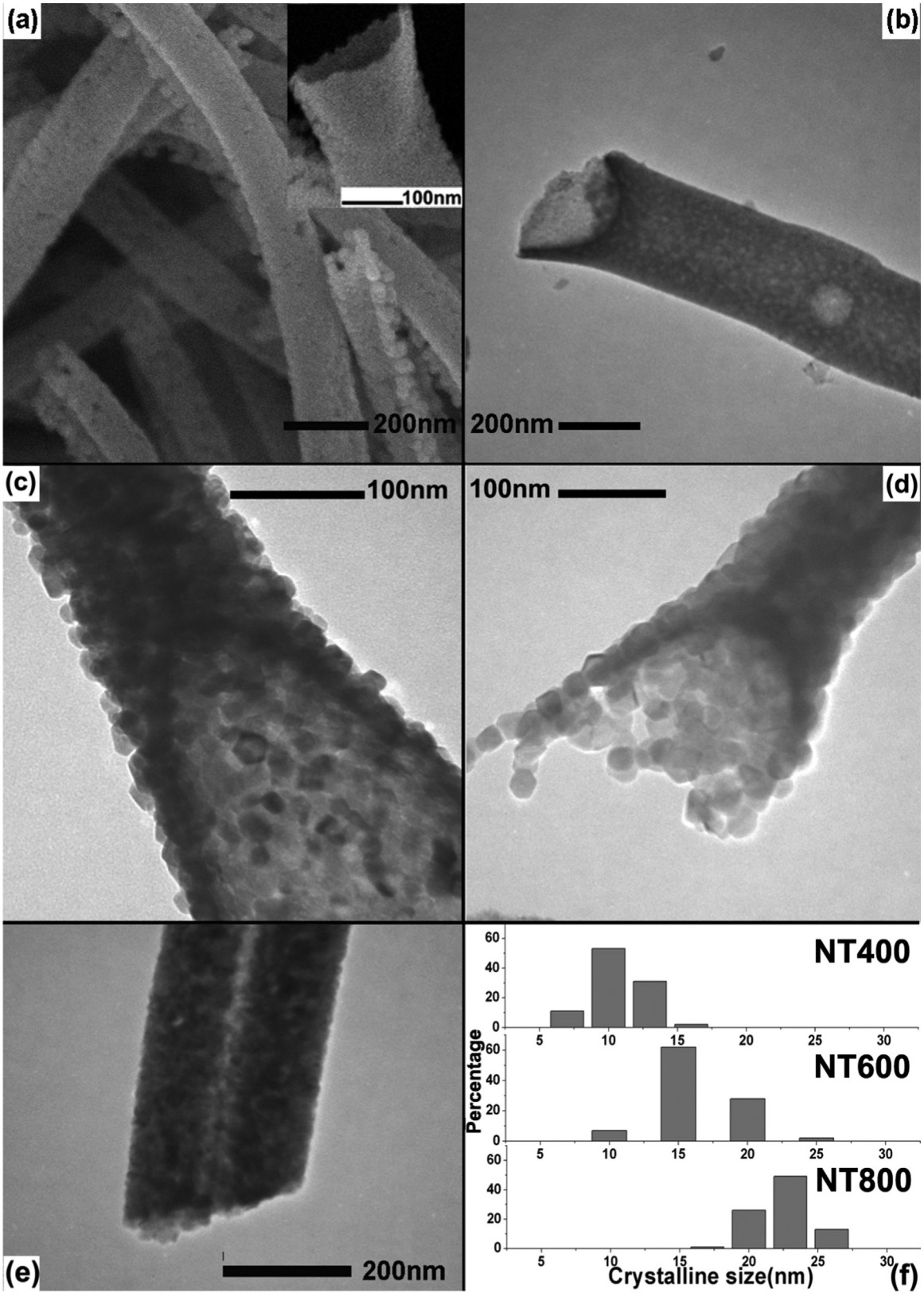

Fig. 1. (a) The SEM image of In_2O_3 NT400, (b)–(d) TEM images of In_2O_3 NT400, NT600 and NT800, respectively, (e) the TEM image of In_2O_3 NF600, (f) grain size distributions of NT400, NT600, NT800. The inset is the enlarged image.