Materials Letters 153 (2015) 85–88

Contents lists available at ScienceDirect

Materials Letters

journal homepage: www.elsevier.com/locate/matlet

Effects of Ag doping amount on structural properties of zinc oxide nanostructures

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ARTICLE INFO

Article history:
Received 20 January 2015
Accepted 4 April 2015
Available online 13 April 2015

Keywords:
ZnO
Ag
Flower-like bundles
Nanorods
Disks

ABSTRACT

We investigated the structural properties of zinc oxide (ZnO) nanostructures grown on the glass substrates using the chemical solution deposition while being doped with Ag in different amounts. The undoped ZnO nanostructures were composed of flower-like bundles consisting of nanorods with a length of ~2.3 μm and hexagonal disks with a diameter of ~2.2 μm and thickness of ~350 nm. In these flower-like bundles, the diameter and density of the nanorods at the center were smaller and higher, respectively, than those of the nanorods at the edge. With addition of Ag in the ZnO, the Ag nanoparticles were formed on the substrate, which led to suppress the growth of the flower-like bundles and decrease the thickness of the disks. The intensities of the diffraction peaks corresponding to the ZnO and Ag phases decreased and increased, respectively, with an increase in the amount of Ag added. It was found that the Ag-doped ZnO nanostructures contained Ag particles, which formed a continuous thin film, resulting in low sheet resistance (~1 Ω/sq).

1. Introduction

Recently, zinc oxide (ZnO) nanostructures have received significant attention owing to their outstanding potential for use in various nano-scaled electronic and optoelectronic devices [1–5]. It was reported that the nanodisk ZnO exhibited excellent gas-sensing performances by Zhao et al. [6]. Tang and coworkers reported outstanding photoluminescence properties of the nano-6flower-shaped ZnO [7,8].

In our previous study, we had investigated the properties of Li-doped and Cu-doped ZnO nanorods and had compared them to those of undoped ZnO nanorods grown on ZnO seed layers formed on fluorine-doped tin oxide (FTO)-coated glass substrates [9]. When ZnO was doped with Li, long and well-aligned nanorods could be grown. On the other hand, the use of Cu as a dopant triggered a morphological change in the ZnO. Under the same growth conditions, the addition of dopants resulted in the synthesized ZnO nanorods exhibiting a different growth behavior [9–11]. In addition, we found that the substrate materials used also played an important role in determining the characteristics of the grown ZnO nanorods [12]. When compared to the ZnO nanorods grown on FTO and silicon substrates, those grown on glass substrates exhibited poorer crystal quality, owing to the poor adhesion between the nanorods and the glass substrates.

In this study, we investigated the effects of the Ag doping amount on the structural properties of ZnO nanostructures grown on glass substrates using a solution deposition method.

2. Experimental

The ZnO seed layer was prepared using an aqueous solution of zinc acetate dihydrate ($Zn(CH_3COO)_2 \cdot 2H_2O$, 0.25 M). 20 μL of the solution was dropped on a glass substrate (Eagle XG, 2×2 cm^2) and spin-coated at a speed of 2000 rpm for 30 s. It was then dried at 250 °C for 5 min and subsequently annealed at 350 °C for 30 min in air.

The ZnO nanostructures were fabricated by the chemical solution deposition using an aqueous solution of zinc nitrate hexahydrate ($Zn(NO_3)_2 \cdot 6H_2O$, 0.01 M) and HMT ($C_6H_{12}N_4$, 0.01 M). The pH value of the solution was 7.1. To grow Ag-doped ZnO (AZO) nanostructures, silver nitrate was added to the above-mentioned solution in different amounts: 0.1 mM (pH 7.0, labeled as AZO1), 0.5 mM (pH 7.0, labeled as AZO2), and 3 mM (pH 6.9, labeled as AZO3). The substrates with the ZnO seed layers were immersed vertically in the aqueous solution at 90 °C for 6 h. The samples were then washed with deionized water and dried at 120 °C for 10 min.

The crystal structures and orientations of the various ZnO nanostructures were observed using X-ray diffraction (XRD, Bruker, D8ADVANCE) analyses. Their surface morphologies were examined

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http://dx.doi.org/10.1016/j.matlet.2015.04.022
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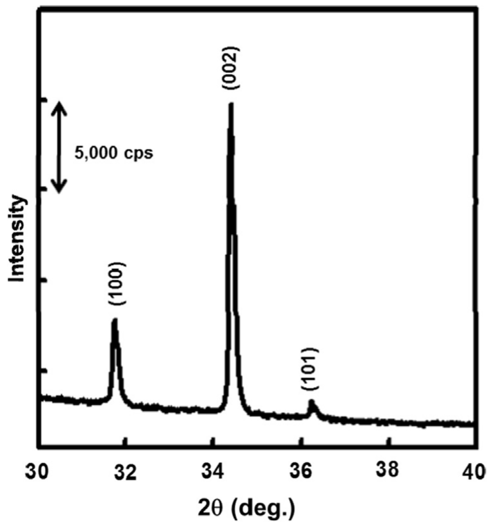

Fig. 1. XRD pattern of the ZnO nanostructures grown on the glass substrate.

using a field emission scanning electron microscopy (FESEM, JSM-6701F) system to which an energy dispersive X-ray spectrometry (EDX) detector was attached. The electrical property of the ZnO nanostructures was characterized using a four-point probe.

3. Results and discussion

Fig. 1 shows the XRD pattern of undoped ZnO nanostructures grown on a glass substrate. The diffraction peaks at 31.7°, 34.4°, and 36.2° correspond to the (1 0 0), (0 0 2), and (1 0 1) planes, confirming that the ZnO is the hexagonal wurtzite structure (JCPDS card no. 36-1451) (see Table S1 in the Supporting information).

Fig. 2(a and b) show the top-view and cross-sectional FESEM images of the undoped ZnO nanostructures. It can be seen from the top-view image (Fig. 2(a)) that the nanostructures consisted of flower-like bundles of nanorods and hexagonal disks were distributed randomly on the surface of the glass substrate. Further, it can be seen from the cross-sectional image (Fig. 2(b)) that the nanorods with a length of ~2.3 μm grew radially on the surface of

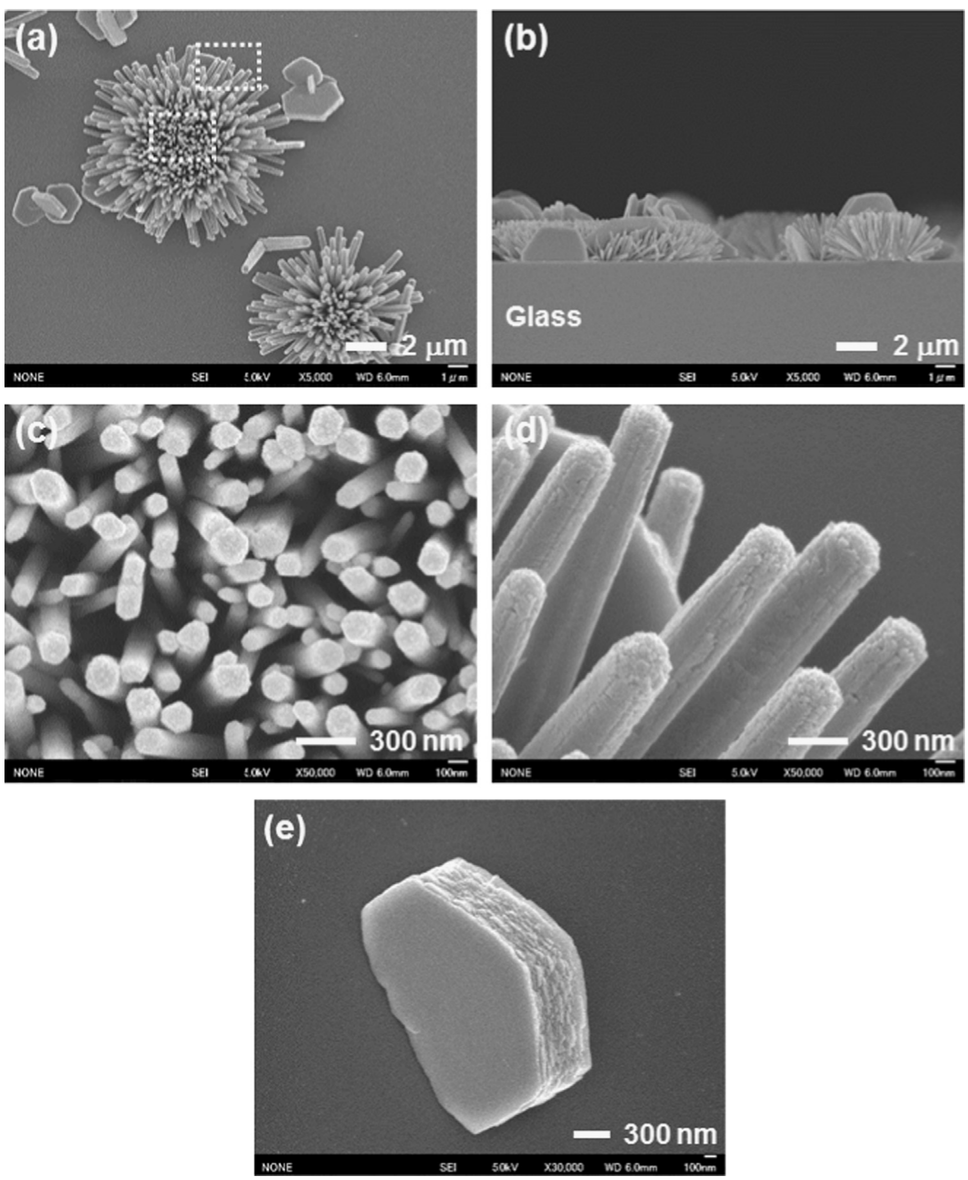

Fig. 2. FESEM images of the ZnO nanostructures; (a) top-view image, (b) cross-sectional image, (c and d) high-magnification images of the areas marked by dotted squares at center and edge regions in (a), and (e) high-magnification image of a hexagonal disk.