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Growth of nanostructured ZnO on wearable fabrics for functional garment

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ABSTRACT

ZnO thin films and nanorods were grown via a wet chemical route on various wearable fabrics such as cotton, nylon, and polyester. The seed layer of ZnO was deposited by a dip-pad-cure method, and thermolysis assisted chemical solution method was used to grow well-aligned ZnO nanorods. The growth behaviors were investigated by comparing ZnO nanorods with/without a seed layer and on different fabrics. The seed layer significantly influenced the growth of ZnO nanorods while the types of fabrics did not. Nanostructured ZnO on fabrics showed reduced diffused reflectance near 380 nm by absorbing UV light. Increased electrical conductivity was also observed due to the ZnO nanorods.

1. Introduction

Science and technology are continuously focusing on the miniaturization of electronic machines or devices using nano-fabrication on silicon substrates [1,2]. Efforts to realize soft portable electronic devices such as wearable devices, electronic papers and chip smart cars could revolutionize modern society [3,4]. Fabrics can be good substrates for constructing electronic systems with another functionality, such as protection of the body against harmful environments or collection of the body's status and conditions [5,6]. The use of fabric materials as a substrate for functional systems remains a critical challenge due to issues with developing more robust and cheaper fabrication of inorganic materials on fabrics [6]. The environmental constraint of fabrics such as temperature and pressure is another consideration. Thus solution-based fabrication of inorganic materials on fabric materials can be a better approach than physical vapor deposition or chemical vapor deposition [2].

Among multifunctional inorganic materials, ZnO is an excellent candidate material that can be deposited by solution-based routes such as dip-pad-cure, hydrothermal, and thermolysis assisted chemical solution method. In addition to semiconductor properties including a band gap of 3.37 eV and 60 meV of exciton binding energy [7], ZnO has received much attention because of its good UV blocking properties, from the lower UV wavelength range (UV-A, 100–280 nm) to higher range (UV-C, 320–400 nm) [5,7]. It is also known that the structural properties of ZnO (size, crystallinity, and shape) can easily be altered by parameters in solution-based processes [9]. Recently, fabrics impregnated with ZnO have been used for UV protection, clothing colors, and anti-odor function [6,9–11]. Exploring new properties and advancing fabrication of ZnO for functional garments will demand morphological control of ZnO nanostructures on fabrics. However, little is known about how fabric types and their properties affect ZnO nanostructues. In this report, ZnO nanoparticles and nanorods were grown on various fabrics such as cotton, PET, and nylon by chemical solution process. The growth behavior of ZnO nanostructures on fabrics and their properties were characterized.

2. Experiment methods

Woven cotton (138 ± 2 g/m^2), PET (62 ± 2 g/m^2), and nylon (65 ± 2 g/m^2) with fiber thickness of about 17 μm were used. These fabrics were ultrasonicated in ethanol and water for 5 min. These were then dried at 50 °C overnight and cooled to room temperature prior to ZnO growth. A transparent nanosol of ZnO was synthesized to grow a seed layer. Zinc acetate dehydrate (0.04 M) and sodium hydroxide (0.12 M) were dissolved in ethanol

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for 2 h at 60 °C. Coating ZnO seed layer on fabrics using the ZnO nanosol was performed via a dip-pad-cure method in the ambient conditions. The cleaned pieces of fabrics were immersed in the ZnO nanosol for 5 min. and the piece was then padded with a padder with constant pressure, 10 kg/m^2. The padded fabrics were air dried for 20 min at room temperature and cured at 170 °C for 10 min to remove the organic solvent. ZnO nanorods were grown via a thermolysis assisted chemical solution method. Zinc nitrate hexahydrate (0.01 M) and hexamethylenetetramine (HMT, 0.01 M) were dissolved in 400 ml deionized (DI) water, followed by mixing for 24 h under stirring. The substrates were immersed in the prepared solution and the solution was dipped in a hot water bath for 4 h at 85 °C to grow ZnO nanorods. After 4 h, the substrates were rinsed with DI water.

After depositing the ZnO seed layer on the fabrics, the nanorods were characterized by SEM (scanning electron microscope, JEOL) and XRD (X-ray diffraction, Bruker). The optical and electrical properties of the samples were also characterized using UV–Vis diffuse reflectance spectroscopy (Avantes) and current–voltage (I–V) measurement. Aluminum electrodes with a diameter of 500 μm were deposited on ZnO to measure the current flow.

3. Results and discussion

The SEM images were used to observe the surface morphology of fabric substrates and ZnO nanorods grown on various fabrics. Fig. 1(a)–(c) shows the surface morphology of bare fabrics including cotton, nylon, and PET, respectively. Although weave types show different patterns, similar width of fibers (around 17 μm) was used to compare the growth of ZnO nanostructures. Uniform coverage of ZnO seed layers and nanorods was obtained for three fabric substrates. Fig. 1(d) shows the surface topography of a ZnO seed layer deposited by a dip-pad-cure method on nylon fabric. Irrespective of fabric types, uniform coating of ZnO seed layers was obtained and similar topography of the ZnO was observed in this study. ZnO nanorods were then fabricated on bare fabrics and ZnO seeded fabrics. Fig. 1(e) shows ZnO nanorods grown without a seed layer. The ZnO nanorods were not uniformly grown on fabrics and the nanorods was larger due to lower nucleation density. The ZnO nanorods on seeded fabrics show uniform and dense growth along the vertical direction. But the nanorods' dimensions were slightly different depending on fabric type. The size and length of ZnO nanorods on PET are around 50 nm and 1.5 μm each, which are typical dimensions of the nanorods when similar deposition conditions for ZnO nanorods and seed layers are used on solid substrates [8,12,14]. However, the diameter of ZnO on nylon shows about three times larger than on the cotton and PET, whereas the length of ZnO on the cotton was shorter than one on the nylon and PET. Since the surface topologies of ZnO seed layers on the three fabrics were similar, the slight difference in the ZnO nanorods' dimensions may be attributed to expansion and contraction of fabrics resulting from temperature change and/or possibly solution impregnation during the growth of ZnO nanorods in aqueous solution. Apparently, uniform growth of ZnO nanorods on fabrics requires a seed layer. It

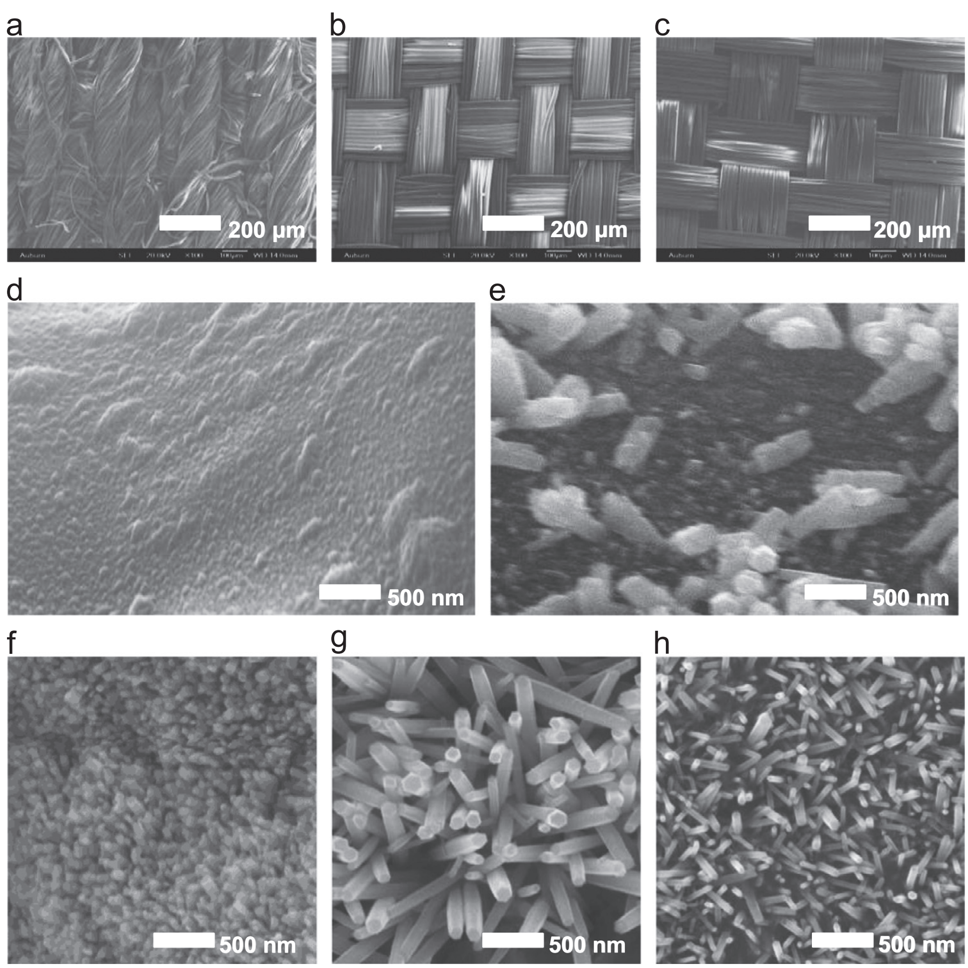

Fig. 1. SEM images of ZnO nanorods and seed layer on fabrics: bare fabrics (a) of cotton, (b) of nylon, and (c) on PET, (d) ZnO seed layer on nylon, ZnO nanorods (e) without seed layer and with seed layer (f) on cotton, (g) on nylon, and (h) on PET.