Journal of Crystal Growth 312 (2010) 2454–2458

Contents lists available at ScienceDirect

Journal of Crystal Growth

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

Hydrothermal treatment for the marked structural and optical quality improvement of ZnO nanowire arrays deposited on lightweight flexible substrates

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ARTICLE INFO

Article history:
Received 15 November 2009
Received in revised form
11 May 2010
Accepted 14 May 2010
Communicated by D.W. Shaw
Available online 24 May 2010

Keywords:
A1. Nanostructures
A1. Photoluminescence
A2. Growth from solutions
A3. Electrodeposition
B1. Oxides
B2. ZnO nanowire arrays

ABSTRACT

ZnO nanowire arrays (NWs) have attracted great interest as the building blocks for emerging applications in new flexible and elastic electronic and optoelectronic devices (e.g. smart cards, light emitting diodes (LEDs), displays, etc.) with higher functionality. Since flexible plastic substrates (FPS) are important, soft post-growth treatments compatible with FPS must be found to significantly improve the properties of NWs deposited on it. We present an innovative low-temperature hydrothermal treatment in an autoclave to improve the structural and optical properties of ZnO NWs grown by electrochemical deposition at low temperature (80 °C) on transparent flexible polymer-based indium-tin-oxide (ITO) coated substrates. The layer characterizations by scanning electron microscopy (SEM) and X-ray diffraction (XRD) showed the improvement of the wire surface smoothness and of their structural quality. The observed higher excitonic photoluminescence at 381 nm and the stronger optical phonon modes in the Raman spectra demonstrated the superior performance of the post-growth hydrothermal treatment compared to a conventional annealing at the same temperature. The presented results pave the way for the realization of new highly efficient ZnO-based optoelectronic devices on flexible plastic substrates or elastic foils.

1. Introduction

One-dimensional (1-D) nanostructures of semiconductors have attracted great interest during the last decade for advanced functional applications due to additional and improved properties compared to bulk films related to high surface to volume ratio, inherent anisotropy, and quantum confinement of charge carriers [1–4]. They are the building blocks for interesting emerging applications such as transparent UV protection films, dye-sensitized solar cells (DSSCs), room-temperature lasers, light-emitting-diodes (LEDs), flexible transparent field-effect-transistors (FETs), spintronic devices, smart cards, displays, ultraviolet (UV), and gas sensors [1–15]. Many papers have reported the growth of ZnO nanorod (NR) and nanowire (NW) arrays on inorganic rigid substrates. In most cases vapor phase growth methods were used. Alternatively, electrodeposition is a low-temperature wet-deposition technique that allows the fine control of the nanowire array morphology [3,16–18]. Due to softness of the electrodeposition process, it is well suited for deposition of nanomaterials on a large variety of substrates such as plastic ones. Flexible plastic substrates (FPS) are considered as very useful due to their cost-efficiency, lightweight, and robustness in future flexible and elastic electronic and optoelectronic devices (e.g. smart cards and displays, etc.) with higher functionality [19,20]. They have attracted much attention because they are suitable for roll-to-roll mass production. However, typical FPS cannot withstand a thermal processing above 180–200 °C.

Typically indirect procedures are used to prepare nanostructures on FPS. One starts from pre-grown nanostructures that are connected by low-temperature techniques such as electrophoretic deposition, film transfer, hydrothermal or mechanical pressing to form a film [21–23]. The literature on the direct synthesis of ZnO nanorod/nanowires arrays on FPS by electrochemical deposition is very scarce [19,20]. Nadarajah et al. [19] have shown a fast, simple, and safe electrochemical method for the growth of ZnO nanowires on flexible polymer-based indium-tin-oxide-coated substrates. Flexible nanowire LEDs based on such arrangement were prepared, but the emission of ZnO covered most of visible region (instead of UV) due to the nanomaterial properties. The development of efficient electronic and optoelectronic flexible devices based on ZnO-NR and NW arrays requires the

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doi:10.1016/j.jcrysgro.2010.05.022