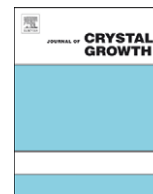




ELSEVIER

Contents lists available at ScienceDirect

Journal of Crystal Growth

journal homepage: [www.elsevier.com/locate/jcrysgr](http://www.elsevier.com/locate/jcrysgr)

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

Oleg Lupan<sup>\*,1</sup>, Thierry Pauporté<sup>\*</sup>

Laboratoire d'Electrochimie, Chimie des Interfaces et Modélisation pour l'Energie (LECIME), UMR 7575 CNRS, Chimie ParisTech, 11 rue P. et M. Curie, 75231 Paris cedex 05, France

## 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.

© 2010 Elsevier B.V. All rights reserved.

## 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

<sup>\*</sup> Corresponding authors. Tel.: +331 5542 6383; fax: +331 5542 6379.

E-mail addresses: [lupanoleg@yahoo.com](mailto:lupanoleg@yahoo.com) (O. Lupan), [thierry-pauporte@chimie-paristech.fr](mailto:thierry-pauporte@chimie-paristech.fr) (Th. Pauporté).

<sup>1</sup> On leave from: Department of Microelectronics and Semiconductor Devices, Technical University of Moldova, 168 Stefan cel Mare Blvd., FCIM, MD-2004, Chisinau, Republic of Moldova.