Current Applied Physics 14 (2014) 1696–1702

Contents lists available at ScienceDirect

Current Applied Physics

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

Influence of growth temperature and post-annealing on an n-ZnO/p-GaN heterojunction diode

Sanjeev K. Sharma*, Sungeun Heo, Byoungho Lee, Hwangho Lee, Changmin Kim, Deuk Young Kim*

Semiconductor Materials and Device Laboratory, Department of Semiconductor Science, Dongguk University-Seoul, Jung-gu, Seoul 100-715, Republic of Korea

ARTICLE INFO

Article history:
Received 3 January 2014
Received in revised form
22 August 2014
Accepted 23 September 2014
Available online 30 September 2014

Keywords:
n-ZnO/p-GaN heterojunction
Growth temperature
Microstructural properties
Diode characteristics

ABSTRACT

We report on an n-ZnO/p-GaN heterojunction diode fabricated from zinc oxide (ZnO) films at various growth temperatures (450, 500, 550, and 600 °C) by RF sputtering. The films were subsequently annealed at 700 °C in N_2 ambient. To investigate the influence of the growth temperature of n-ZnO films, the microstructural, optical, and electrical properties were measured using scanning electron microscopy (SEM), X-ray diffraction (XRD), photoluminescence (PL), and Hall measurements. The XRD pattern showed the preferred orientation along the *c*-axis (002) regardless of growth temperature. The PL spectra showed a dominant sharp near-band-edge (NBE) emission. Current–voltage (I–V) curves showed excellent rectification behavior. The turn-on voltage of the diode was observed to be 3.2 V for the films produced at 500 °C. The ideality factor of ZnO film was observed to be 1.37, which showed the best performance of the diode.

1. Introduction

Among the wide band-gap semiconductors, zinc oxide (ZnO) has emerged as the most promising semiconductor for future applications in electronic, optoelectronic, and power devices because of its characteristic features, such as its large exciton binding energy of 60 meV and strong cohesive energy of 1.89 eV [1–3]. However, the fabrication of high-quality p-type ZnO remains a great challenge because of instability [4]. Since ZnO and GaN have similar crystal structures (wurtzite hexagonal) with a small in-plane lattice mismatch (1.8%), p-GaN can be substituted for p-ZnO [1]. Many studies have reported on n-ZnO/p-GaN heterojunction LEDs operated at forward bias [5–8].

To improve the emission of n-ZnO-based heterojunction LEDs, double and triple heterojunction LEDs have been fabricated [9–11]. Different device architectures based on the n-ZnO/p-GaN heterojunction have been proposed to obtain different kinds of emission spectra using simple and low-cost devices [6,12–14]. Characteristics of ZnO thin films with respect to various growth temperatures on p-GaN have rarely been studied in order to optimize diodes. However, with a view to improving diode characteristics using n-ZnO/p-GaN-based heterojunctions, understanding the temperature-dependent growth of heterojunctions and testing their current–voltage (I–V) characteristics are vital for the optimization of ZnO thin films.

The objective of this research work was to grow nanocrystalline n-ZnO thin films, at various growth temperatures, using RF sputtering on p-GaN/sapphire substrates. Efforts were made to achieve the optimal parameters of the n-ZnO/p-GaN heterojunction diode to reduce heat output and improve performance.

2. Experimental details

Nanostructured n-ZnO thin films were grown on p-GaN/sapphire substrates, using RF sputtering. A p-GaN epitaxial film, deposited on sapphire (0001) substrate by metal-organic chemical vapor deposition (MOCVD), was purchased commercially. The ZnO film growth temperatures were 450, 500, 550, and 600 °C. The pressure in the chamber was maintained at 30 mTorr, with the flow rates of Ar and O_2 gases at 15 and 30 sccm, respectively.

Surface microstructures were taken using field emission–scanning electron microscopy (FE-SEM). The thickness of ZnO films was measured by cross-sectional images and was approximately 328 nm on average. The crystallographic structures were analyzed by X-ray diffraction (XRD). The photoluminescence (PL) spectra of

* Corresponding authors.
E-mail addresses: sksharma@dongguk.edu (S.K. Sharma), dykim@dongguk.edu (D.Y. Kim).

http://dx.doi.org/10.1016/j.cap.2014.09.019
1567-1739/

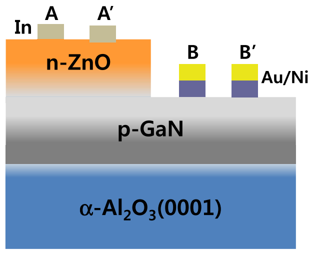

Fig. 1. Schematic illustration of In/n-ZnO/p-GaN/Ni–Au heterojunction diode.

as-grown and annealed ZnO films was performed at room temperature (RT) by a spectrometer using a nanosecond pulsed laser (He–Cd CW Laser: 325 nm). To evaluate the annealing effect on the microstructural, optical, and electrical properties, all samples were annealed at 700 °C in N_2 ambient for 3 min, using the rapid thermal annealing (RTA) technique.

To estimate the Hall coefficients of n-ZnO grown on p-GaN substrate, the modified Hall Effect equation was used, which was manipulated for bilayer or multilayer films [15–17]. The carrier concentration and mobility were measured by the Hall measurement. Indium was used as the top contact with a soldering iron. Since p-GaN has a high work function, metal contacts such as Au/Ni were evaporated by a thermal evaporator in a complex scheme to

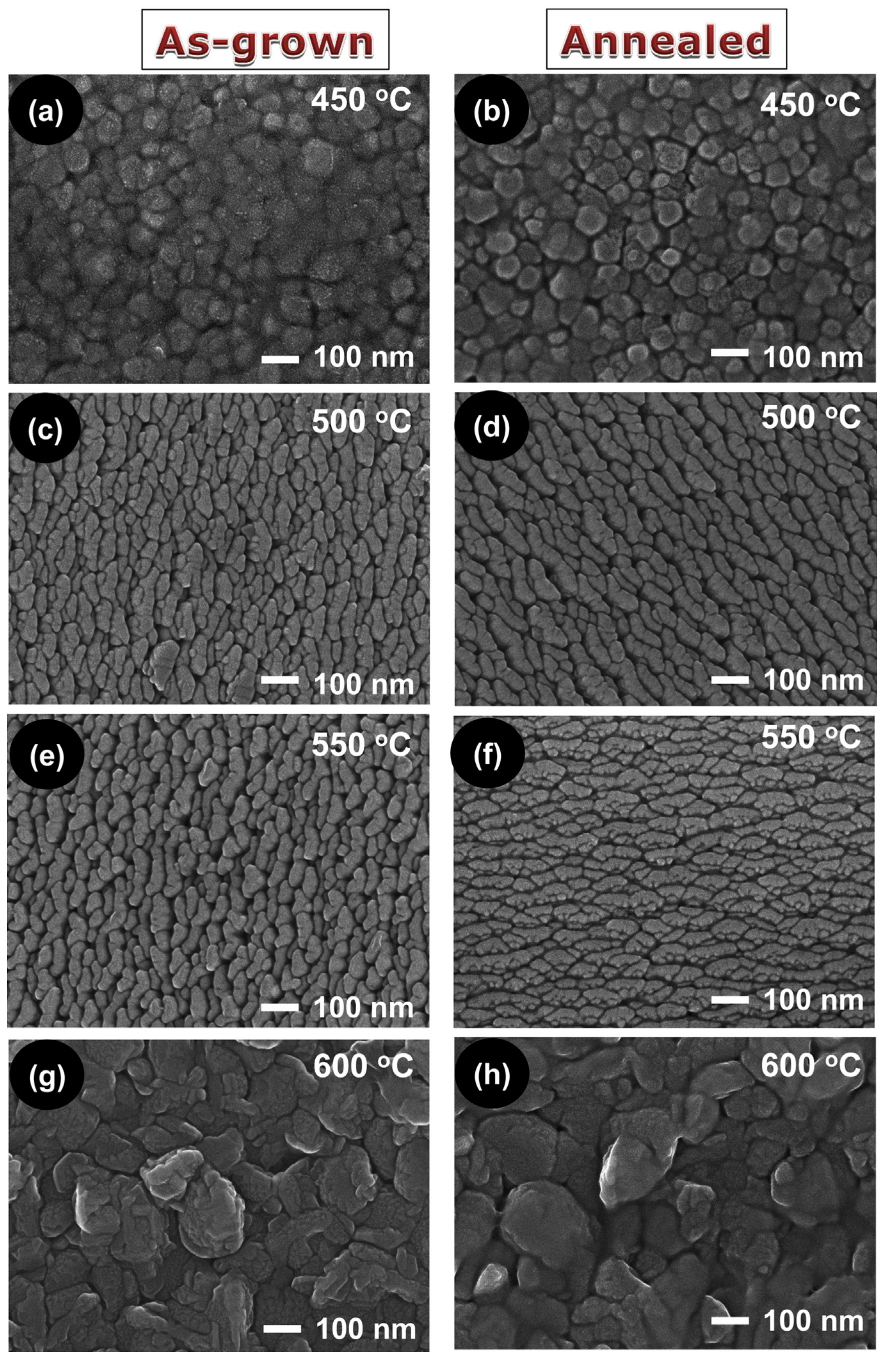

Fig. 2. Surface microstructure images (FE-SEM) of as-grown ZnO thin films grown on p-GaN substrates by DC sputtering and subsequently annealed at 700 °C in N_2 ambient. The samples were grown at various growth temperatures (a) & (b) 450 °C, (c) & (d) 500 °C, (e) & (f) 550 °C, and (g) & (h) 600 °C.