Unveiling the importance of controllable growth of *c*-axis oriented Sn-doped ZnO nanorod arrays: Towards humidity sensing applications

A.S. Ismail [a,*], M.H. Mamat [b], R. Mohamed [c], Z. Embong [d], S. Kossar [e]

[a] Faculty of Manufacturing and Mechatronic Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, 26600, Pekan, Pahang, Malaysia
[b] NANO-ElecTronic Centre (NET), Faculty of Electrical Engineering, Universiti Teknologi MARA (UiTM), 40450, Shah Alam, Selangor, Malaysia
[c] NANO-SciTech Centre (NST), Institute of Science (IOS), Universiti Teknologi MARA (UiTM), 40450, Shah Alam, Selangor, Malaysia
[d] Department of Physics and Chemistry, Universiti Tun Hussein Onn Malaysia, 84600, Pagoh, Johor, Malaysia
[e] School of Natural Sciences, GNA University, Phaghwara, Punjab, 144401, India

ARTICLE INFO

ABSTRACT

In this study, tin (Sn)-doped zinc oxide (ZnO) nanorod arrays (SZO) were prepared using a sonication assisted sol-gel immersion method, with the growth of the nanorod arrays controlled by varying the immersion time in the precursor material. Morphology images taken using a Field Emission Scanning Electron Microscope (FESEM) demonstrated an enlargement of the average diameter of the nanorod arrays from 55 nm at 5 min immersion to 122 nm at 200 min immersion. The cross-sectional and surface elemental analysis showed that the sample immersed for 60 min has the highest detection of Sn, with a bulk concentration of 1.8 at.% and surface concentration of 1 at.%. Interestingly, we noticed that Sn is not exist on the surface of 200 min immersion, indicating the depletion of the Sn precursor due to the prolongation of the immersion time. From the current voltage (I-V) analysis, 60 min immersion sample generated the lowest thin film resistivity, which engendered the best humidity sensitivity of 4.05. This study demonstrated the significant importance of optimizing the immersion or growth time for doped 1-D nanostructures to obtain the best humidity sensing performance.

1. Introduction

Zinc oxide (ZnO) is an n-type semiconductor widely used in many applications, including capacitors, transistors, sensors, and solar cells [1–4]. These versatile applications are due to the material's excellent properties, such as being non-toxic, having a wide bandgap, ease of fabrication, and the ability to be modulated using different materials. In the development of ZnO-based sensors, structures with high surface-to-volume ratios are extremely important to enhance the sensing capabilities of the devices. To date, there have been many reports regarding the synthesis of ZnO nanostructures using various techniques, including solution-based methods, chemical vapor deposition, physical vapor deposition, screen printing, and electrolysis [5–8]. Among these methods, solution-based techniques are more favorable due to their simple process and ability to produce high crystalline quality thin films.

One-dimensional (1-D) ZnO nanostructures like nanorods or nanowires have been reported to exhibit excellent properties in enhancing device performances due to their high surface area and provide a direct path for electron charge transport [9,10]. Despite having great advantages over their structures, the 1-D ZnO nanostructures still require further modifications to improve their intrinsic structure such as by doping approach. This doping approach is necessary to alter the intrinsic properties of the ZnO nanostructures such as improving the conductivity, modifying the energy bandgaps, reducing the size of the nanostructures, enhancing the surface sensitivity, and to modulate the crystal defects in the thin film [11–14]. For instance, Kasapoglu et al. studied on the effects of different concentrations of antimony (Sb) doping to the hydrogen gas sensing performance of ZnO nanorod films [15]. Based on their study, the introduction of Sb into the ZnO crystal had increased the crystallite size and improved the hydrogen gas sensitivity up to 23-fold as compared to intrinsic ZnO. Choudary et al. reported the synthesis of ZnO nanorods at different concentrations of praseodymium (Pr) [16]. The Pr-doped ZnO nanorods exhibited smaller crystal strain, excellent optical absorbance, and better photocatalytic properties than undoped ZnO nanorods. Batra et al. investigated on the barium (Ba) doped ZnO nanorod-based piezoelectric nanogenerators [17]. Their study showed that the presence of Ba had induced the ferroelectricity inside the nanorods, which did not occur in the pure ZnO