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Sputtered ZnO Rods/Film Structure on Different Substrates

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ABSTRACT

The wide investigation of zinc oxide (ZnO) nanorods is primarily driven by their exceptional utility in several industries, such as solar cells, sensors, photodetectors, photocatalysts, microchip technology, and piezoelectric transducers. There has been a growing focus in environmental defense applications on the use of ZnO nanorods as photocatalysts. This investigation discusses the growth of ZnO rods on ZnO films using the radio-frequency magnetron sputtering method at a temperature of 400 °C. The growth was performed on several substrates including Si (100), Si (111), and SiO_2 substrates. A careful examination was conducted to examine the influence of the substrate on the structure and surface morphology of ZnO rods/film. Based on the X-ray diffraction patterns, it was seen that both the films and rods exhibited a high degree of crystallinity and exhibited a wurtzite structure. Furthermore, there was a preferred orientation along the (002) direction, which was perpendicular to the substrate. Scanning electron microscopy images demonstrated the significant effect of substrates on both the thickness of ZnO films and the length of rods. The findings indicated that these structures were well-suited for several applications, including thermionic/field emission, solar cells, UV detectors, and gas sensors.

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1. Introduction

Zinc oxide (ZnO) has been extensively utilized in a wide range of everyday applications during the course of the previous century. The applications encompass piezoelectric transducers, pigments, antimicrobial uses, cosmetics for UV screening, and catalysts [1]. Zinc oxide (ZnO) nanostructures have gained significant attention in recent decades due to their diverse range of possible nanostructures that can be customized in terms of shape and characteristics. This has happened in spite of the scientific community's substantial focus on the creation and applications of semiconductor nanostructures [2].

Zinc oxide (ZnO) is a semiconductor oxide that belongs to the II-VI group of elements. Its electrical properties are well-known due to its distinct chemical bonding qualities. Furthermore, ZnO possesses a broad direct band gap of 3.37 eV, excellent thermal conductivity, a high refractive index of 2.0041, a moderately substantial excitation binding energy of 60 meV, and a considerable surface area [3]. At high pressures, ZnO undergoes a change in its initial wurtzite crystalline structure. The wurtzite structure contains a hexagonal unit cell with two lattice parameters (a and c), and a c/a ratio ranging from 1.5393 to 1.6035. This transformation results in a metastable rock salt structure [4], [5]. Zinc oxide (ZnO) has been regarded as an option to gallium nitride (GaN) in the advancement of short-wavelength optoelectronic devices such as light-emitting diodes, ultraviolet (UV) lasers, and UV detectors [6]. This is due to its broad and direct bandgap, as well as its elevated exciton binding energy. Furthermore, there has been a recent surge of interest in utilizing ZnO rods with semiconducting characteristics as extremely appealing choices for film structure. A wide range of nanostructures, such as nanoparticles, nanotubes, nanorods, and thin films, have undergone substantial research [7]. Therefore, these attributes make it a highly efficient substance in numerous domains [8]-[14].

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This work discusses the use of RF-magnetron sputtering for growing ZnO rods on film structures on a variety of substrates, such as Si (100), Si (111), and SiO_2. The work was mainly supposed to assess the effect of various substrates on the crystal structure and morphology of ZnO rods in film structures.

2. Materials and Methods

The Si(100) and Si(111) substrates were rinsed in the following solutions: deionized water (DI), isopropyl alcohol (IPA), 5% sulfuric acid (H2SO4), and 20% hydrofluoric acid (HF). The SiO_2 substrates were exposed to a 2-minute sonication process using acetone and 2-propanol, and then immersed in a heated methanol bath at a temperature of 60 °C. Ultimately, they were dried using nitrogen gas blows. The substrates underwent a vacuum-baking process at a temperature of 325 °C for a duration of 15 minutes. This process effectively removed all remaining contaminants and water vapor from the surfaces of the substrates, with the vacuum pressure maintained at 7.5×10^{-6} Torr. RF-magnetron sputtering was used to create ZnO rods on film structures. The substrates utilized for deposition consisted of Si (100), Si (111), and SiO_2 substrates. The growth temperature was maintained at 400 °C and a fixed RF power of 100 W was employed. The argon to oxygen gas flow rate ratio was 9 : 1.The X-ray diffraction (XRD) method was employed to analyze the crystal structures of ZnO rods and films. The surface morphology of ZnO rods on film structures was analyzed using SEM scanning.

3. Results and Discussions

The influence of the substrates on the morphology of ZnO rods on film structures was examined using scanning electron microscopy. According to the cross-sectional scanning electron microscope (SEM) photographs, the film structures displayed two distinct sections of ZnO rods (see Figure 1). Initially, thick ZnO films were grown onto three distinct substrates. The film thicknesses measured on Si(100), Si(111), and SiO_2 substrates were 679 nm, 779 nm, and 743 nm, respectively. The slight variation in thickness among the three samples can be attributed to the minimal mismatch in lattice structure between the substrates and the ZnO materials [15]. The Si atoms on the textured Si (111) substrate exhibited a hexagonal morphology, but on the Si (100) substrate, they were arranged in a square pattern. Hence, the surface roughness of Si (111) has a structure that matches the ZnO lattice structure [16], making it more conducive for the growth of ZnO films compared to the other substrates.

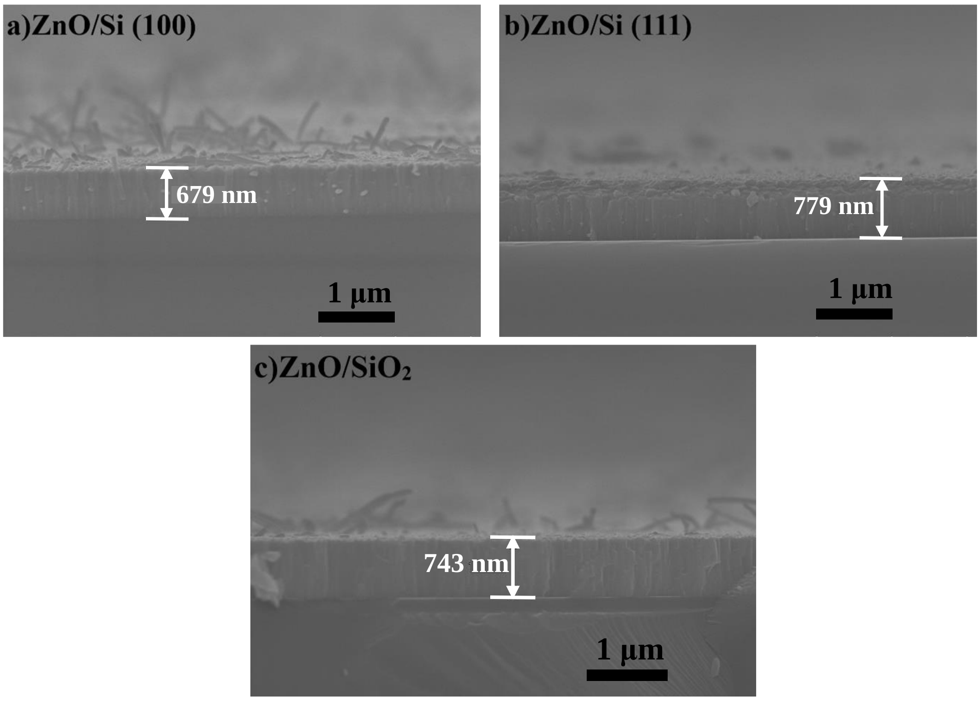

Figure 1. *The cross sectional SEM scan of ZnO nanorods grown on various susbtrates a) Si(100), (b) Si(111), and (c) SiO_2.*

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Table 1. *Morphology analysis of the SEM scans for ZnO/Si(100), ZnO/Si(111), and ZnO/SiO_2 samples.*

Samples	Length of rods (nm)	Diameter of rods (nm)	Thickness (nm)
ZnO/Si(100)	186.09 ± 14.71	43.49 ± 3.65	679
ZnO/Si(111)	173.33 ± 10.04	122.69 ± 11.27	779
ZnO/SiO_2	205.44 ± 12.46	37.94 ± 2.37	743

Some locations on ZnO surfaces have the ability to help with the thermodynamic growth of ZnO rods. The top view of ZnO rod SEM images on film constructions is displayed in Fig. 2. The ZnO/Si(100) sample was large rods measuring 186.09 ± 14.71 nm in length and 43.49 ± 3.65 nm in diameter (see Figure 2a). Specifically, the ZnO/Si(111) sample exhibited a formation of shaped like a protrusions, also known as hillocks (see Figure 2b). The ZnO nanorods were observed as pyramids composed of four crystal planes (111). The ZnO rods grown on SiO_2 had the largest length, measuring 205.44 ± 12.46 nm, when compared to those grown on Si(100) and Si(111) substrates (see to Figure. 2c). The heat transport of Si(100) and Si(111) substrates was higher than that of thermally insulating SiO_2 substrates [17], [19]. Hence, Si(100) and Si(111) substrates have the ability to create a greater number of nuclei for the growth of ZnO rods [18]. The ZnO nanorods on Si(100) and Si(111) substrates exhibited reduced length compared to those on SiO_2, which could be attributed to this phenomenon. Table 1 presents a summary of the data acquired from the SEM scan of three different substrates of ZnO samples.

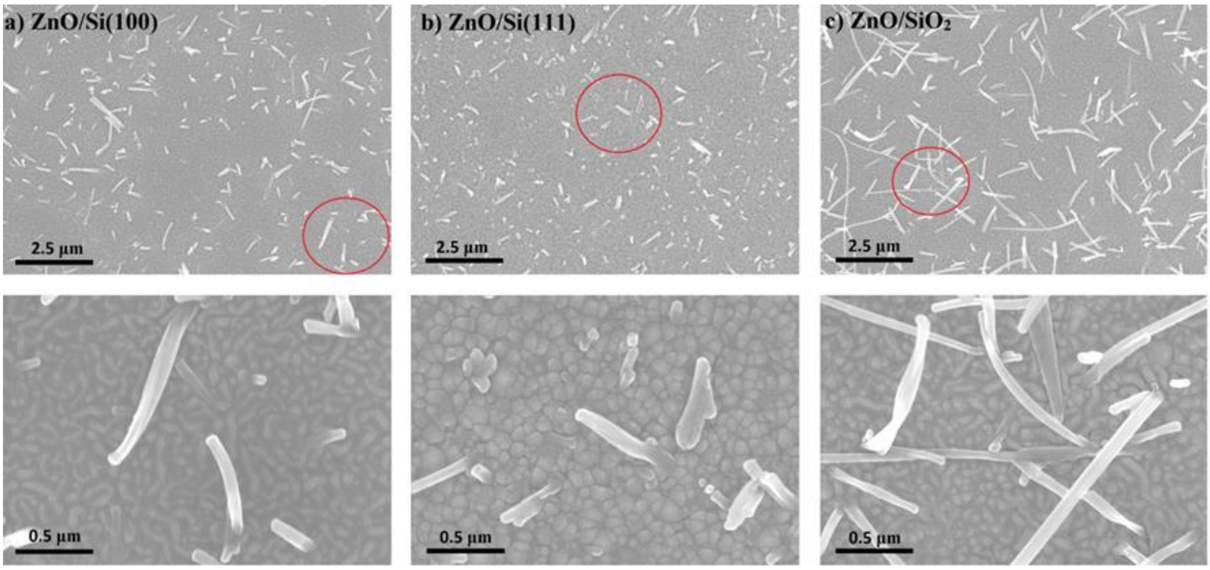

Figure 2. *The SEM images of ZnO rods on film structures on different substrates: a) Si(100), b) Si(111), and c) SiO_2. The SEM images below are magnified images of the locations marked with red circles.*

After the morphology characterization, the structural properties of ZnO nanorods were investigated by using XRD. Fig. 3 displayed XRD patterns of ZnO/Si(100), ZnO/Si(111), and ZnO/SiO_2 samples, respectively.

The ZnO/Si(100), ZnO/Si(111), and ZiO/SiO_2 samples displayed different diffraction peaks, including ZnO (001), ZnO (002), ZnO (103), and ZnO (004). The peaks observed in the film structures of ZnO rods were consistent with the hexagonal wurtzite phase [20], [21]. The full width at half maximum (FWHM) values of the diffraction peaks for the (002) plane were 0.262°, 0.231°, and 0.283° for the ZnO/Si(100), ZnO/Si(111), and ZnO/SiO_2 samples, respectively (Table 2). The ZnO/Si (111) sample with the shortest full width at FWHM exhibited the highest quality crystallinity of ZnO films and rods compared to the other two substrates, which is consistent with previous research [22].

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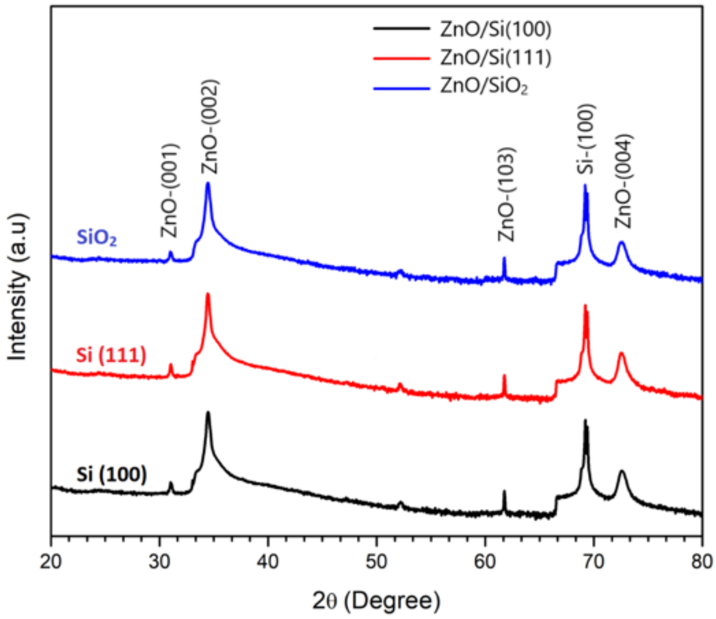

Figure 3. *XRD spectra of ZnO/Si(100), ZnO/Si(111), and ZnO/SiO_2 samples.*

Table 2. *Crystal structural properties obtained from the XRD spectra.*

Samples	(h k l)	2*θ* (°)		FWHM (°)	*d*-spacing (Å)
		Our data	Bulk		
ZnO/Si(100)	(0 0 2)	34.55	34.4	0.262	2.594
ZnO/Si(111)	(0 0 2)	34.47	34.4	0.231	2.599
ZnO/SiO_2	(0 0 2)	34.39	34.4	0.283	2.606

4. Conclusions

In conclusion, we obtained ZnO rods on film structures (nanorods/films) on Si (100), Si (111), and SiO_2 substrates using the use of the RF-magnetron sputtering technique. An investigation was conducted to examine the influence of the substrate on the microstructure and morphology of ZnO formations. The ZnO nanorods exhibited the greatest length when grown on the SiO_2 substrate, compared to the Si (100) and Si (111) samples, due to the substrate's poor ability for transferring heat. The XRD results for three samples revealed a hexagonal wurtzite phase structure that was highly aligned in the *c*-planes. Our results suggested that these ZnO hydrid structures can be helpful in future studies on cold emission cathodes and gas sensors.

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Author contributions

Van Tri Le and Phan Tan Sang Ho contributed equally to the design, performed the experiments, analyzed the data, and wrote the manuscript under the guidance of Thi Kim Hang Pham. All authors participated in the discussion of the results and contributed to the writing of the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

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