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An investigation into the effects of applied magnetic field during Zn vacuum thermal evaporation on ZnO nanostructures

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Abstract. ZnO nanostructures were produced with an innovative and simple vacuum thermal evaporation method with evaporating Zn in the presence of strong static electric and magnetic fields perpendicular to each other. These evaporated Zn thin films were oxidized on the furnace to obtain ZnO. In order to investigate the effects of magnetic field on ZnO nanostructures in this method, two different setups with different magnetic field strengths were assembled. Morphology and structure of ZnO thin films in both setups were investigated by micrographs prepared by Field Emission Scanning Electron Microscopy (FESEM) and X-Ray Diffraction (XRD) analysis. Results showed that the grown nano rods of ZnO in both setups were blade-like and match-like. Increase in magnetic field changed the dominant type of nano rods from blade-like in weaker magnetic field to match-like in stronger magnetic field. Also, increasing magnetic field strength caused different crystalline orientation in ZnO nanostructures. The results suggested that morphology and structure of ZnO thin films were affected by applying magnetic fields with different strengths during deposition of Zn in this innovative method.

1. Introduction

Changing conditions of thin films growth and investigating its effects on the structure and morphology of grown thin films is a useful method in order to reveal and find the effective parameters on the grown thin films. By comparing the effects of different conditions, controlling the growth procedure in order to produce desired nanostructures is possible [1,2]. In particular, in thermal evaporation method for producing ZnO nanostructures, conditions such as different substrates [3-5], temperatures of substrate [6], O_2 partial pressure during deposition [7], growth temperatures [8,9], temperatures for annealing Zn thin films to produce ZnO thin films [10], and high magnetic field during oxidizing Zn thin films [11] are effective on the growth mechanism of ZnO nanostructures. Producing ZnO thin films in the presence of static electric and magnetic fields in vacuum by thermal evaporation is an innovative method [12,13]. In this research work, the effects of different applied magnetic fields on the morphology and structure of Zn thin films evaporated in the presence of electric field, which is then oxidized to achieve ZnO nanostructures, in this particular method are investigated.

2. Material and methods

Zn thin films were grown in the presence of static electric and magnetic fields in vacuum of 10^{-5} mbar

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utilizing thermal evaporation method without injection of gas. Zn granules with 99/99% purity (Merck) were placed in a tungsten basket for evaporation. Zn thin films were deposited on soda lime glass substrates. Two different setups were assembled during coating of Zn; in both setups, a strong electric field was applied in the distance between evaporation source and substrate in order to ionize and polarize evaporated Zn atoms and clusters. To produce this strong electric field, an aluminium sheet was used as anode. This sheet was set above the substrate and connected to a DC voltage of 700 Volts. The diameter and thickness of the aluminium sheet were 150 mm and 1 mm, respectively. Also, a circular aluminium mesh was used as the cathode. The diameter of the mesh was 158 mm and the diameter of the wires and the area of each square opening in this mesh were 0.125 mm and 1.5 mm^2, respectively. This mesh was connected to zero voltage of the supplier. The distance between the mesh and the sheet was 7 cm, which corresponded to an electric field of 10,000 V/m. A variable high-voltage source (Griffin 5 Kv EHT supply) was used as supplier. Applied electric field during the deposition was simulated using CST (Computer Simulation Technology) software of which the result is shown in Figure 1.

In the first setup, besides the electric field, a magnetic field produced by one flat neodymium magnet (a permanent magnet made from an alloy of neodymium, iron, and boron) was applied during the deposition. The dimensions of this magnet were $100 \times 30 \times 10$ mm for length, width, and height, respectively. This magnet was set on the aluminium sheet (anode) when the substrate was set under the aluminium sheet. Figure 2(a) shows the simulated magnetic field applied

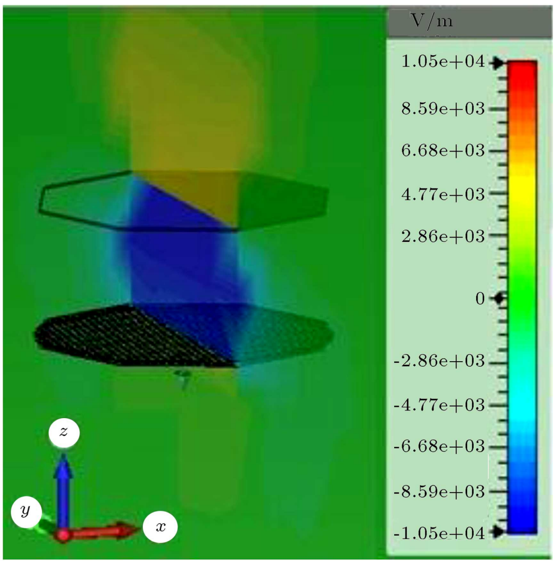


Figure 1. Simulated applied E-field between aluminium mesh and aluminium sheet as cathode and anode, respectively, during depositing Zn thin films.

in the first setup. In the second setup, two flat magnets were used in order to produce stronger B-field while depositing Zn in the presence of the same applied electric field as that in the first setup. Simulated magnetic field in this setup is shown in Figure 2(b). Simulation of applied magnetic fields was done with CST software.

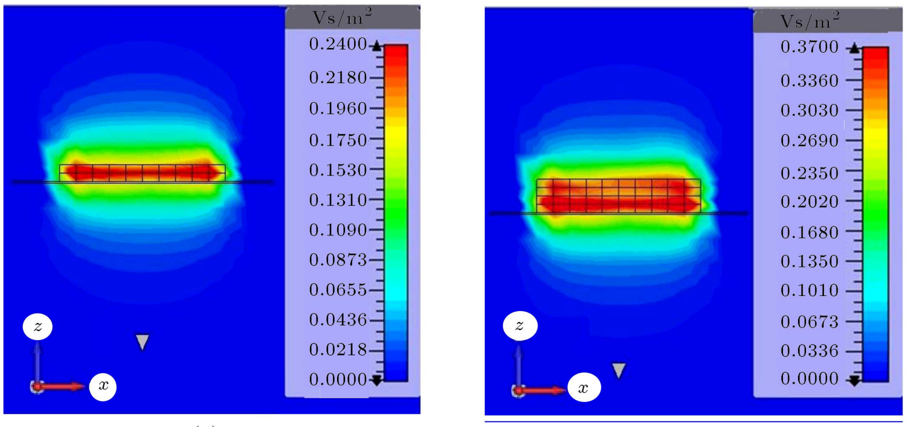
The deposited Zn thin films in both setups were oxidized in the furnace for 4 hours in 500°C in air ambient. Then, the oxidized Zinc thin films were studied using FESEM images and XRD patterns. The FESEM micrographs showed the ZnO grew in nanostructure forms in both conditions.

3. Results and discussion

Figure 3 shows FESEM images of ZnO thin films produced in presence of electric field without applying magnetic field [13] and ZnO thin films in both setups as well as their relevant Zn nanostructures in the right upside of each picture. Edges of Zn nano packs and sheets in the first setup were rough, while, in the second setup, the edges became jagged [13]. In both setups, growth of blade-like and match-like nano rods could be seen. Blade-like nano rods had different diameters in top and bottom, while match-like nano rods had constant diameter in top and bottom. In the first setup, growth of blade-like nano rods was dominant, while, in the second setup, nano rods were dominantly match-like. Careful observation showed growth of some trunks with growth of shorter nano rods on them in the second setup.

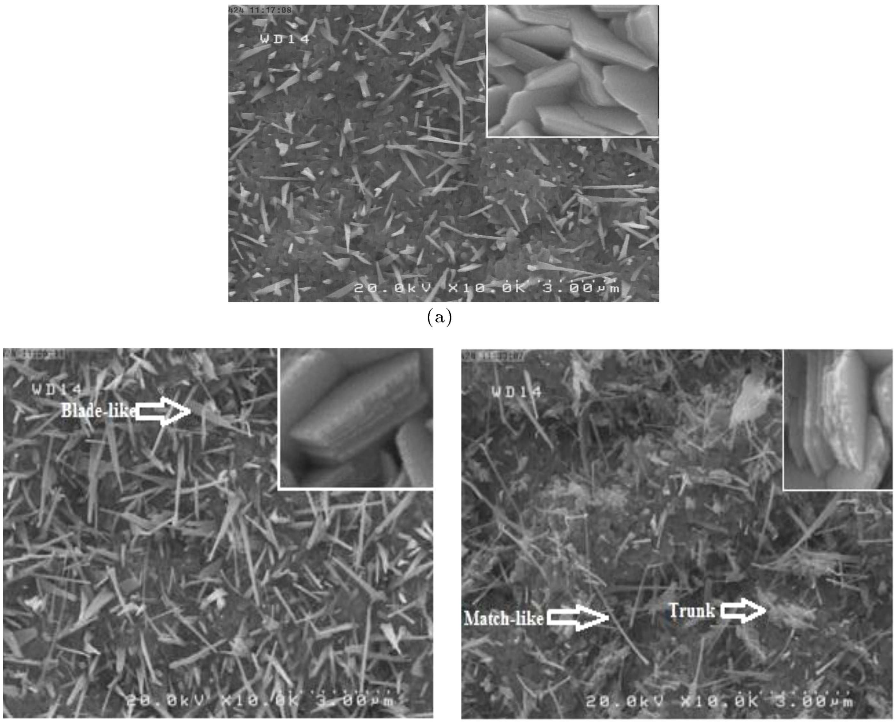
Figure 4 shows mean diameters of match-like and blade-like nano rods in both setups. It is seen in this figure that increasing magnetic field caused decrease in mean diameters of both types of nano rods. Also, mean length of nano rods decreased from 1345 nm to 1290 nm for match-like nano rods and from 1562 to 1549 for blade-like nano rods. Further, by increasing B-field magnitude, aspect ratio of match-like nano rods increased.

Figure 5 shows schematics of blade-like nano rods growing in match-like types based on mean diameters and lengths of nano rods obtained by analyzing FESEM images in the first and second setups. Without an applied magnetic field, nano sheets and nano packs were well hexagonal in shape, and edges of these sheets and packs were sharp and clean (Figure 3(a)). When the evaporated clusters passed from evaporation source to substrate, they were influenced by electric field in two setups. These clusters were ionized or polarized when they touched or passed the aluminum mesh, respectively. By applying magnetic field, ionized and polarized clusters faced a circular motion perpendicular to z-axis due to Lorentz force. This motion was the reason for jagged Zn nano sheets. Clusters with circular



(a) (b)

Figure 2. Simulated applied B-field during depositing Zn thin films: (a) In the first setup with an applied magnetic field produced by one flat magnet, and (b) in the second setup with an applied magnetic field produced by two flat magnets.



(a) (b) (c)

Figure 3. FESEM images of Zn (in right upper corner of each figure) and ZnO thin films produced in (a) presence of only electric field, (b) the first setup (in presence of electric field and magnetic field during zinc deposition), and (c) the second setup (in presence of electric field and stronger magnetic field during zinc deposition).

motion crashed the edge of sheets and packs, which were previously coated and grown on the substrate, and made them flawed.

The roughness of the edge of the Zn sheets and the packs in second setup increased and became jagged in comparison with the first setup due to larger applied magnetic field. This difference led to increasing interaction between oxygen and these structures during oxidizing in furnace in the second setup [7,13]. Therefore, domination of match-like nano rods in the second setup could be expected. Figure 6 shows schematic model for the process of growing ZnO nano rods during oxidizing of Zn thin films.

Figure 7 shows the X-ray diffraction analysis of ZnO thin films in both setups. XRD patterns reveal that ZnO thin films in both setups had hexagonal wurtzite structure. The differences between (101) and (002) planes in the first and second setups implies the formation of different crystalline orientations by utilizing different magnetic field strengths.

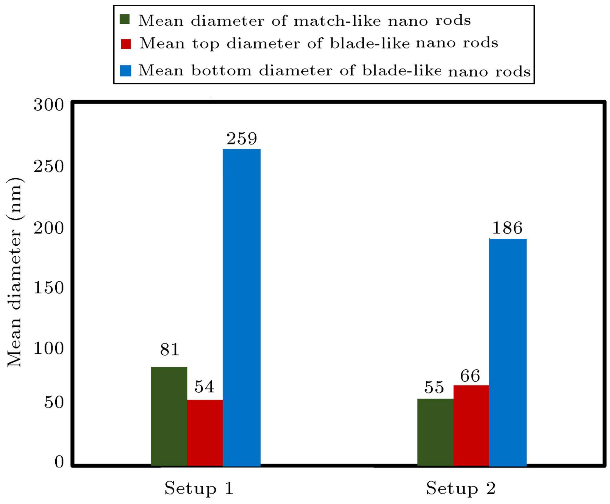


Figure 4. Mean diameters of nano rods in both setups.

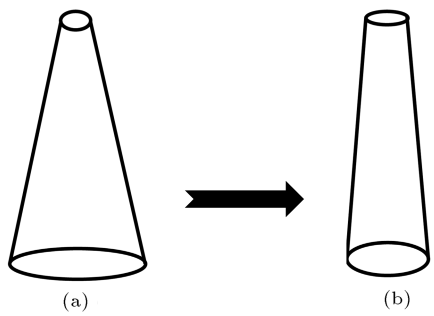


Figure 5. Schematic change of blade-like nano rods from: (a) The first setup, and (b) the second setup.

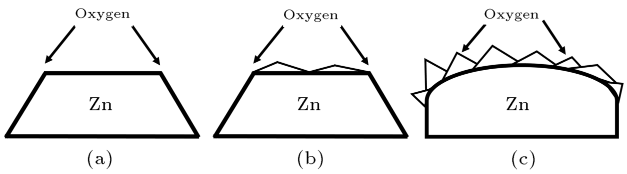


Figure 6. Simplified model for the process of growing ZnO nano rods while oxidizing Zn thin films with (a) E-field, (b) E and B-field, and (c) Electric field and larger B-field.

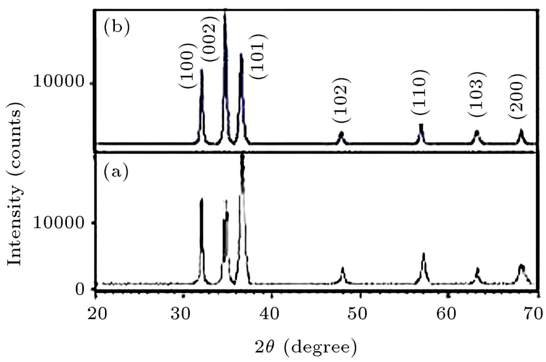


Figure 7. XRD patterns of ZnO thin films produced in (a) the first setup, and (b) the second setup.

4. Conclusions

Based on an innovative method, which suggested vacuum thermal evaporation depositing of Zn thin films in the presence of strong static electric and magnetic fields, two different depositing conditions were applied. In both setups, the applied electric fields and vacuums were similar. In the second setup, the applied magnetic field during deposition increased by doubling the magnets. In both setups, growth of ZnO nano rods in match-like and blade-like was observed. Increase in magnetic field caused decrease in mean diameter of nano rods and caused dominant growth of match-like nano rods in the second setup, while, in the first setup, the blade-like nano rods were dominant. Further, increasing magnetic field increased XRD intensity of (002) pick and decreased intensity of (101) pick in comparison with the first setup.

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Biographies

Zahra Sadat Jahanshah Rad received her BSc degree in Physics (ranked first) and MSc degree in Physics with specialty in Solid State Physics from K. N. Toosi University of Technology in 2010 and 2013, respectively. Her master thesis was entitled: "Coating of nano structural ZnO thin films in presence of magnetic and electric fields and studies on electrical and gas sensing properties of it". Her research interests include synthesis, characterization, and applications of semiconductor nanostructures and simulating the growth mechanism.

Reza Afzalzadeh was born in 1960 in Ahvaz. He received his BSc and MSc degrees from University of Delhi, and his PhD from University of Poona-India. In 1991, he joined K. N. Toosi University of Technology and, presently, he is Associate Professor in Physics. He is interested in research on thin films, gas sensors, ultrasonics, magnetic water, and synthesis of nanostructures like ZnO, ZnS, ZrO_2, Graphene, etc. Also, he is involved with manufacture of ultrasonic homogenizer and other laboratory equipment.