

Article

Influence of Temperature on the Growth of Vertically Aligned ZnO Nanowires in Wet Oxygen Environment

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Abstract: The nanowires (NWs) of zinc oxide (ZnO) are developed effectively on an n-type silicon substrate through a seed zinc (Zn) layer by a wet oxidation technique. The growth is performed at different temperatures, 650, 750, and 850 °C, in a wet and rich oxygen environment under a flow of oxygen in the presence of water vapor at atmospheric pressure with a heating rate of 100 °C in 30 min. At 415 °C, the oxygen gas is introduced for the oxidation process. The Zn seed layer is deposited by the thermal evaporation technique. The structural, morphological, and optical properties are investigated. The temperature effect on NWs of ZnO growth intensity and their direction are explored. The nanowires are grown vertically oriented at a temperature of $T = 750$ °C. The ultraviolet (UV) analysis has been exposed in the visible region ranging from 10 nm to 700 nm at UV to visible intensity ratio of 2.22. In addition, X-ray diffraction analysis (XRD) is employed to research the structural properties of NWs of ZnO, and the characterization is verified by a scanning electron microscope (SEM) to investigate the morphology.

Keywords: wet oxidation; ZnO NWs; n-type silicon substrate; zinc seed layer; oxygen rich environment; water vapor; thermal evaporation



Citation: ElZein, B.; Salah, N.; Barham, A.S.; Elrashidi, A.; Al Khatab, M.; Jabbour, G. Influence of Temperature on the Growth of Vertically Aligned ZnO Nanowires in Wet Oxygen Environment. *Crystals* **2023**, *13*, 876. <https://doi.org/10.3390/cryst13060876>

Academic Editor: Vladimir M. Kaganer

Received: 24 April 2023

Revised: 24 May 2023

Accepted: 25 May 2023

Published: 27 May 2023



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1. Introduction

Recently, the research on the growth methods, properties, and applications of ZnO nano-structures have been increased worldwide due to their electrical and mechanical properties [1–3]. At room temperature, ZnO nanostructure is well characterized by its 3.37 eV band gap and 60 meV excitation energy. Due to their optical functions, the ZnO nanostructures become very important and a potential nanomaterial for several future applications [4–10]. ZnO material can form different 1-D nanostructures such as nanowires (NWs) and nanorods, and zero-dimensional nanostructures (0D) such as nanoparticles, using different growth techniques [11–14]. ZnO NWs can be used in different optical materials, nanoscale electronics, optoelectronics, and photovoltaic applications. ZnO NWs are very reactive nanomaterials having a high surface area [15–17]. Many researchers used chemical and physical vapor deposition techniques and others to synthesize a large range of nanostructures [18–23], and significant review papers on the synthesis of ZnO nanostructures have been published [24,25].

Growth techniques that rely on catalysts include a combination of solids–liquids–solids (SLS), vapor–liquid–solid (VLS), and vapor–solid (VS) processes.

VS is a self-organization technique where nanowires are grown without a metal catalyst by thermally evaporating the source material near its melting temperature and then condensing at a lower temperature. Two peculiar effects are registered: the first effect occurred when the lattice defects at the beginning of growth. The second effect arose when the nanowire growth rate referred to the adsorption by all nanowire facets of molecules, then afterward, diffusion will occur on the principal growth of NWs, as shown in Figure 1. This occurred in catalysts' free evolution processes. At elevated temperatures, source materials evaporated and condensed directly at the substrate surfaces that were prepared in lower temperature conditions of the furnace. By minimizing the surface energy, condensation progression occurs. The condensed molecules obtained from the seed crystals will serve as the nucleation sites to facilitate the directional growth development [26]. Therefore, the VS method can be described as a two-step physical evaporation at high temperatures and a catalyst-free process.

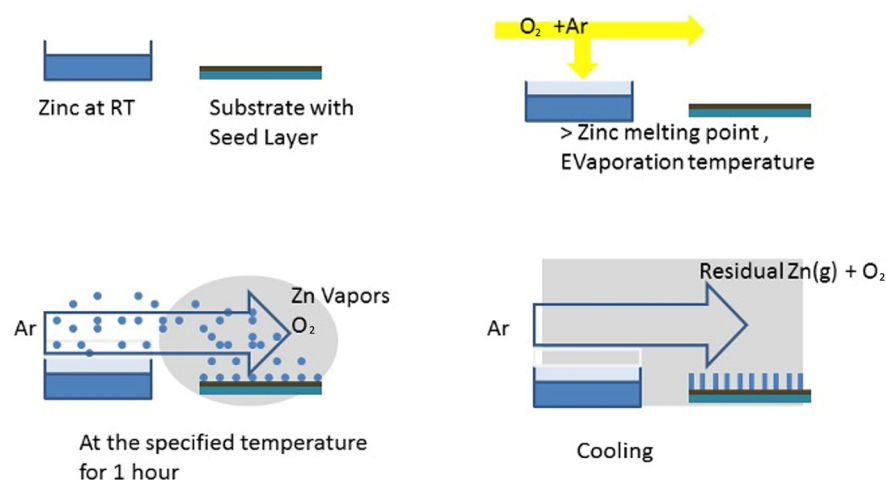


Figure 1. Schematic illustration of the VS process.

The VS process is capable of producing a wide range of nanostructures, for example, nanowires, nano-rods, or belts along with complex nanostructures such as nanohelixed and nanobelts according to Kong et al. [26]. When oxygen flows to the tube furnace, the liquid droplets of evaporated source material solidify quickly by oxidation, this will be followed by the formation of ZnO NWs. Therefore, the diameter of NWs can be controlled by changing some parameters such as vapor pressure, the temperature of condensation, and evaporation, whereas spatial arrangement could not be controlled so far.

The literature reports the evolution of ZnO NWs by vapor deposition; for example, Zn nanowires with a randomized order are prepared in the air at 600 °C for 1 h. The furnace tube used in the experiments is horizontally oriented, and the Zn seed layer developed on several substrates such as glass [27]. Basma et al. [19] have used pulsed laser deposition (PLD) to grow perfect ZnO NWs on different substrates of silicon or glass, without using any catalyst [19]. An intermediate seed layer of ZnO NWs, built in a honeycomb shape of a nanowall network (c-axis oriented) is used to grow NWs that vertically oriented with a self-forming at 400 °C and >5 Torr pressure in an argon atmosphere. Several parameters, including gas pressure, substrate-target distance, and laser intensity, are shown to influence the formation of prepared nanowires [19]. Well-aligned NWs of ZnO is conducted on different substrate materials of gold, titanium, and silicon. By varying deposition time, ZnO seed layers with 5–100 nm thickness are obtained by using a sputtering technique operated in the region of radio frequency (RF). At 400 °C, the deposited material is post-annealed in the air [28]. At atmospheric pressure, vertically aligned ZnO NWs are prepared by the CVD method. In this method, the specifications of the reactor chamber are complex compared to the traditional CVD chambers because the quartz boat used contains (ZnO/C) as a source, and the substrate is positioned in a slightly opened quartz tube and then inserted into the CVD reactor [29].

By using the wet oxidation and RF sputtering method, Farhat et al. [30] have successfully grown ZnO NWs covered on Teflon substrates. The oxidized Zn films sputtered in a horizontal tube furnace under steam at 100 °C for 5 h. Then, Zn films were transformed into ZnO NWs upon the oxidation process [30]. Hierarchical nanorods, thin caps, and nanorod structures are obtained by the synthesis of doped aluminum ZnO nanostructures by CVD using the ZnO seed layer as starting material. The heating temperature, which is changed in two steps during the development process, is believed to be a main parameter for changing in the habit of layered aluminum doped ZnO [31]. Moreover, vertically aligned hierarchical ZnO nanostructures were prepared by a three-step CVD method with nickel as a catalyst. At 380 nm, the emission ultra-violet peak was observed close to the edge emission band of ZnO, whereas at 492 nm, very weak defects in the related peaks are also observed [32].

Xu et al. [33] have deposited Zn on glass by wet oxidation to grow ZnO NWs at 390 °C in an oxygen and nitrogen environment at 1 atm pressure with a flow of gas of 400 mL/min. in dry oxygen, the feather-like nanostructure is observed, whereas nothing was observed in wet oxygen. NWs of 10 µm in length are grown in dry nitrogen and 2 µm length NWs in a wet nitrogen environment [33], whereas Li et al. [34] have used a glass substrate with a zinc seed layer [34]. A wet oxidation technique is employed at 300–600 °C in an Ar, N₂, and O₂ atmospheric environment for 10 h. It is noticed that particles of ZnO aggregated together and shaped in short chains of 50 and 30 nm in an oxygen environment. At 350 °C, NWs of 2 and 6 µm long are observed with a diameter of 150–480 nm. At 420 °C, thin NWs are observed of 20–50 µm in length [34].

Wet oxidation (vapor solid deposition in a wet environment) has produced nanostructures with high quality, plasticity, and good adhesion to substrates at moderately high temperatures of 500–600 °C and low experimental conditions [30,35]. In addition to the solid-state sublimation, thermal evaporation in the presence of water vapor where the starting components (zinc powder with 99.99% purity) are located at the center of the furnace. Hence, the material will be sublimated by increasing the temperature and the resulting vapor phase in the presence of water vapor which results in nanostructures under certain conditions [8].

In the study of Chen et al. [36], the temperature between 380 °C and 450 °C with a flow of oxygen 0.3 min^{−1} by bubbling oxygen in a water container allows oxygen to carry water vapor inside the heater to start the wet oxidation process. Growth lasts for 4 h and results in very long nanowires (>300 nm length). By controlling the type of gas, the growth temperature, the seed layer, and the position of substrates, various nanostructures will be formed. ZnO NWs formation pointed in the z direction and requires several nucleation sites to begin. The water vapor method used to grow ZnO nanowires actually has improved the plasticity of the oxide [37].

In the range of 500–600 °C, Zn oxidation is considered to occur at low temperatures, particularly if using glass substrates. In addition, Zn powders, like other powders, have some weaknesses interacting with supporting substrates like having free-flowing properties and having poor adhesion powder. However, few reports showed how the act of introducing water vapor to the oxidation atmosphere will affect ZnO nanostructure preparations from the oxidation of Zn films.

Based on the defect equilibrium theory [38] and across the oxide scale, the point defect concentrations like zinc interstitials (Zni) and/or O₂ vacancies are O₂ partial pressure dependent. It can be concluded that point defects concentrations of ZnO rise with the lessening of partial pressure of O₂ in the atmospheric surroundings [38]. Therefore, it is expected that ZnO nanorods grow in N₂/O₂ where it is been noticed that their intensity ratio UV/defect is high in O₂. Although the growth temperature has a great impact on the growth of nanorods compared to other growth parameters, it has not been sufficiently investigated in wet oxidation.

In this work, wet oxidation methods are used to synthesize ZnO NWs in the presence of water as an alternative strategy for nanowires growth. This method has the virtue of simplicity, efficiency, and low cost. Therefore, it will play a role in oxygen generation to

be used in ZnO NWs growth. The process is conducted in two steps: preparing the seed layer on different substrates and then being oxidized in a water vapor atmosphere pressure and in the presence of a zinc source. Optical and structural characteristics are illustrated. Taking into consideration that several researchers reported ZnO thin film development and its nanostructures by thermal evaporation, only a few have reported in a water vapor environment and atmospheric pressure in addition to low temperature and in the presence of Ar/N₂. In addition, the wet oxidation technique to grow ZnO NWs on the top of an n-type silicon substrate is used for its advantage in reducing the oxidation temperature which leads to lessening of the required instrument and consequently reduces the cost. Therefore, the wet oxidation is applied at different temperatures in the presence of pure zinc, 99.99%, and under oxygen gas flow.

2. Experimental Procedure

The process is conducted in two steps; the first step is the formation of Zn seed layer deposition, and the second step is the development progress of ZnO NWs by wet oxidation.

2.1. Deposition and Formation of Zn Seed Layer

Zn seed layer deposition by thermal evaporation technique in the vacuum on a silicon substrate n-type (100) (Alpha Nanotech, Research Triangle Park, NC, USA) sliced in 1.5 cm² size. The substrates are cleaned in ethanol ultrasonically for 10 min and then dried by blowing nitrogen gas before being loaded inside the chamber. No gas is introduced in the chamber, and deposition took around 15 min at 750 °C and at a pressure of 1.2×10^{-6} mbar. The zinc powder was placed in a boat at the bottom of the chamber, and the substrate was placed over a distance of 1.5 cm above the boat.

2.2. Growth of Nanowires/Nanorods

A horizontal quartz tube furnace (Syskey, LPCVD, Hsinchu, Taiwan) is used for the experiment. A trial and error method is used to find optimum parameters to grow high-quality ZnO NWs such as tube furnace diameter, pressure, gas flow rates, the temperature of the furnace, and other parameters. The zinc source powder (99.99% purity, Sigma Aldrich, St. Louis, MO, USA) is placed in an alumina container in the center of the furnace hot tube (~8-inch diameter), whereas the substrates with Zn seed layer are located in the downstream transporter gas directions of the horizontal tube furnace at a lower temperature schematic in Figure 2. The Zn source is sublimated by increasing the temperature. Oxygen gas flowed (50 cm³_{STP}/min) in the furnace in addition to oxygen generated by heating the distilled water (20 mL) placed inside the furnace, which results in an oxygen quantity that is not controlled. Gao et al. [37] have introduced humid gas in the furnace by flowing it into a flask containing boiling distilled water. The breakup of H₂O molecules into hydrogen and oxygen is faster than oxygen molecules between 500 °C and 600 °C [38].

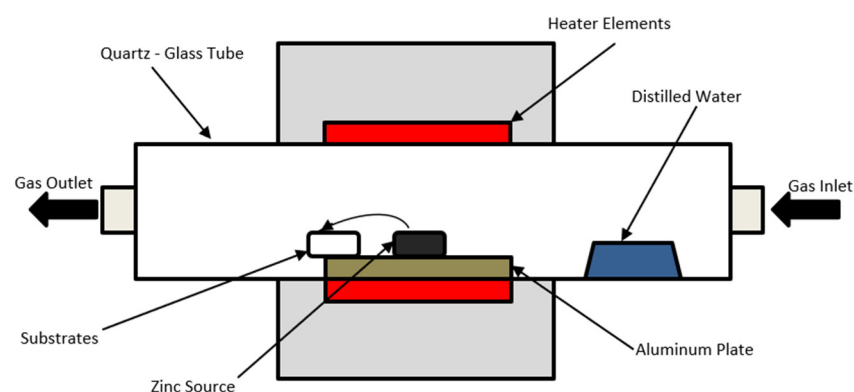


Figure 2. The schematic of the experiment.

Table 1 presents the growth parameters by wet oxidation for the preparation of ZnO NWs.

Table 1. ZnO NWs growth conditions.

Parameter	Nanowire Growth
Substrate	Si (n-type) (100)
Nucleation mater	Zinc
Gas flow	Oxygen
Growth temperature	650 °C, 750 °C, 850 °C
Growth rate	30 °C/min
Growth Pressure	atmospheric

ZnO NWs formation along the c-axis is based on the nucleation sites (locations at which crystals develop) to start. The nucleation sites are being shaped after the formation of small platelet habit above Zn grains based on the Zn seed layer deposited on the substrates. The main reaction arises in the rich oxygen environment according to the reaction below as given in Equation (1):



The condensation can be controlled by controlling the substrate temperature T_s . At higher substrate temperatures, the thermal energy and surface diffusivity of adsorbed molecules increase, and the deposited film will be annealed. Too much heat will desorb the deposited film and evaporate it away. By controlling the type of gas, the growth temperature, seed layer material, and substrate position, different structures will be produced. Examples are summarized in Table 2.

Table 2. Survey of ZnO NWs synthesis by vapor transport in a wet environment.

Precursor Used	Substrate	Carrier Gas	Time	Nanostructure	Ref.
ZnO + Graphite (950 °C)	Si + SiO ₂ + Zn SL	Ar + O ₂	1 h	NWs	[39]
Zn (600 °C)	Si + Au (20 nm)	Ar + O ₂	–	NWs randomly oriented	[40]
ZnO + graphite (975 °C)	Ti, Mo foil + Au	Ar + O ₂	45 min	NWs randomly oriented	[41]
Zn (620–630 °C)	Si(100), Si(111), Glass	Ar + O ₂	40 min	NWs	[42]
ZnO + graphite (930 °C)	SiO ₂ , Au, ZnO, Au/ZnO	Ar	30 min	Nws randomly oriented	[43]
ZnO + graphite (950 °C)	c-Al ₂ O ₃ + Au	Ar	1 h	Nws	[44]
Zn (900 °C)	Si	Ar + O ₂	30 min	Tetrapods	[45]
Zn (900–1050 °C)	Si + Au	N ₂	1 h	NWs randomly oriented	[46]
Zn (650 °C)	Alumina + Zn	Ar + O ₂	30 min	NWs	[47]

Pure Zn (99.99%) is placed at a hot spot in a tube furnace horizontally. The substrates are located in the downstream side of the furnace, and distilled water is at the upper stream of the furnace. The Zn source is evaporated and then transported by humid carrier gas, oxidized, and deposited onto the substrate surface coated with the Zn seed layer. It is expected that by changing the temperature from 650 °C to 850 °C, the morphology and quality of ZnO nanostructures will change. The placement of substrates, Zn source, and distilled water is critical for the proper growth of ZnO nanostructures.

When using a one-zone furnace, it is necessary to identify the degradation of temperature as a function of the furnace's (hot spot) distances from the center. Taking into consideration the furnace size, the temperature at the different zones is measured by a thermocouple. The Zn powder source is located in the furnace's hot spot (point 0), substrates at the zone of the lower temperature of around 450 °C, and the distilled water at the zone of 200 °C and 100 °C. Figure 3 illustrates the temperature drop from the center to the side of the furnace for different temperatures at 850–650 °C.

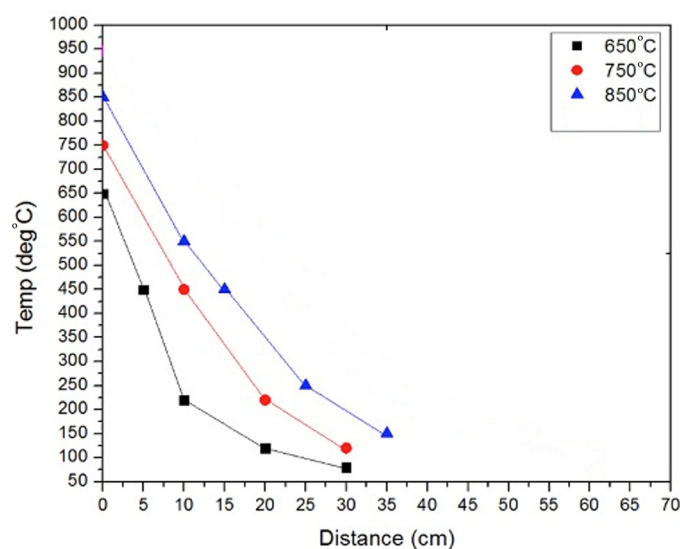


Figure 3. Illustration of horizontal tube furnace and degradation of temperature in function of distance from the hot spot of the furnace.

The Zn powder is heated up to 450 °C, close to the melting point of Zn, 420 °C with a dwell period of 5 min which is enough to introduce the gas inside the chamber. The temperature is then increased to the desired temperature. Once the desired temperature is reached, the system is shut down for cooling to RT, as reflected in Figure 4.

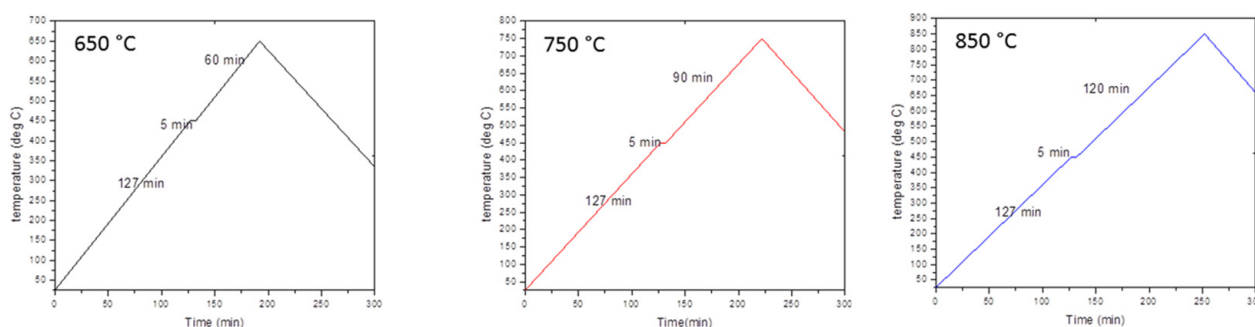


Figure 4. Illustration of deposition evolution. The temperature is set as a function of time.

2.3. Characterization

The structural properties were examined by using a Rigaku X-ray diffractometer (Ultima 4) with CuK α radiation with $\lambda = 0.15406$ nm and a Bruker D8 Discover high-resolution XRD with CuK α and $\lambda = 0.15406$ nm with a scintillation counter point detector and Ventec -1 linear detector. For optical properties, a RF-5301 PC Shimadzu device with a 150 W xenon lamp as the excitation source was used with the wavelength of excitation used of 325 nm, step size = 0.2 nm, and a photomultiplier tube (220–750 nm) as a detector, and aUV-39 as a filter. The morphology is examined by FE-SEM Quanta FEG 450 and FEI Nova NanoSEM 630 FESEM.

3. Results and Discussions

3.1. Structural Properties

XRD patterns of ZnO NWs grown at several sets of temperatures are illustrated in Figure 5 at $T = 650$ °C, 750 °C, and 850 °C. It shows that the nanostructures are polycrystalline, with a high intensity at the plane (002) and other planes like (100), (101), (102), (110), (103), (200), and (112) as presented in Table 3 which reflected the random orientation of the nanowires and different morphologies obtained. In addition, the presence of zinc hydroxide ($\sim 38^\circ$, 64°) will be eliminated by annealing, which might be due to the growth

in a wet environment. Furthermore, at 32.5° , SiO_2 was noticed, whereas the peak at 44.5° is unknown. The average crystal size is found to range between 9 nm and 24 nm and calculated using the Scherrer Equation (2). It is clear that the crystallization of the deposited nanomaterial is affected by the temperature of the substrate.

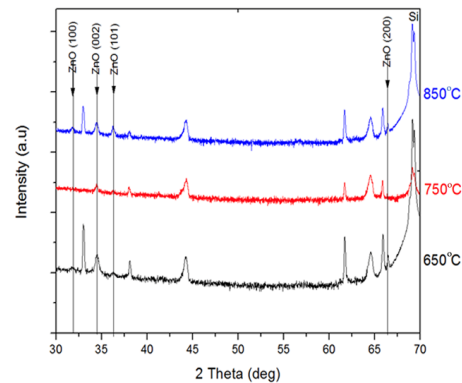


Figure 5. Typical XRD spectrum of as-synthesized ZnO NWs at $T = 650^\circ\text{C}$, 750°C , and 850°C .

Table 3. 2θ shown XRD spectra at $T = 650^\circ\text{C}$, 750°C , and 850°C .

Temperature in $^\circ\text{C}$	Planes							
	100	002	101	102	110	103	200	112
650	31.60°	34.5°	36.33°	-	-	-	66.42°	-
750	31.76°	34.44°	36.25°	47.60°	56.50°	62.80°	-	67.90°
850	31.80°	34.45°	36.27°	-	-	-	66.35°	-

The (002)-near 34° , (100)-near 31.8° , and (200)-near 66° , as indicated in Table 3, are indicators of the hexagonal wurtzite crystalline phase. The slight shift is caused by stress, strain, impurities, and other defects that shift a bit these peaks from the ideal values. The other planes are not necessarily related to wurtzite but could be higher-order diffraction. Usually, the main peaks for these nanowires are at (002), (100), (101), (102), and (110) as they are strong indicators of the wurtzite crystal phase.

$$D = \frac{0.94 \lambda}{\beta \cos \theta} \quad (2)$$

where λ is the wavelength of the used signal ($\lambda = 0.15406 \text{ nm}$), β is the full-width half maximum (FWHM) in rad, and θ is the diffraction angle [35]. The FWHM for each plane is calculated using Figure 5 as the width of the intensity at 0.5 of the peak value. For example, the value of FWHM at $T = 650^\circ\text{C}$ for (002) is almost 0.71, and the peak value is at 34.5° , hence the average crystal size is almost 12.15 nm.

3.2. Optical Properties

ZnO PL spectra contained peaks of ultraviolet (UV) (approximately 380 nm), blue (approximately 470 nm), and green (approximately 510 nm) [29,37]. In our work, as revealed in Figure 6, a strong emission of UV and blue peaks are noticed at RT. Instead, UV emission peak values are at 383 nm, 382 nm, and 384 nm for ZnO NWs fully-fledged at 650°C , 750°C , and 850°C , respectively, as shown in Table 4, whereas the highest intensity ratio is noticed to be grown at 750°C . Furthermore, it has been noticed that by varying the growth temperature, PL ZnO NWs spectra show an improvement in the relative UV intensity ratio emissions towards the blue as temperature increases, but is not reflected at 850°C .

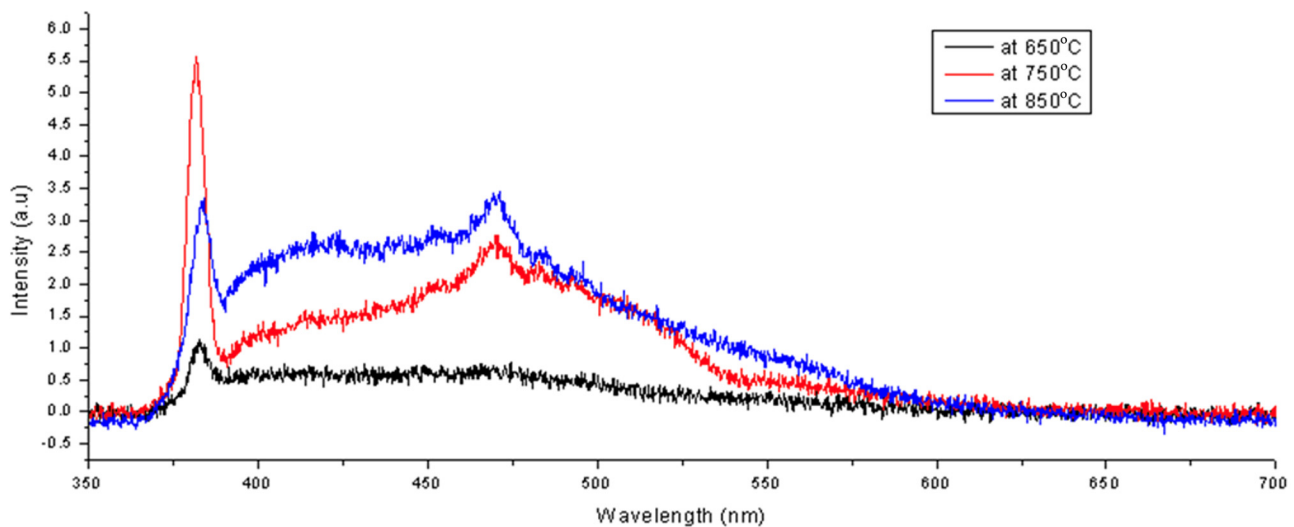


Figure 6. PL ZnO NWs spectra at several temperatures $T = 650\text{ }^{\circ}\text{C}$, $750\text{ }^{\circ}\text{C}$, and $850\text{ }^{\circ}\text{C}$.

Table 4. UV, visible emissions peak values and intensity ratio at $T = 650\text{ }^{\circ}\text{C}$, $750\text{ }^{\circ}\text{C}$, and $850\text{ }^{\circ}\text{C}$.

	$T = 650\text{ }^{\circ}\text{C}$	$T = 750\text{ }^{\circ}\text{C}$	$T = 850\text{ }^{\circ}\text{C}$
UV emission peak values (nm)	382.43	381.6	384
Visible emission peak values (nm)	471	471	471
UV/Visible intensity ratio	2.176	2.22	0.955

Upon using the wet oxidation method, the prepared ZnO NWs lack any visible light emission between 510 nm and 700 nm. This is attributed to deeper-level defects such as O_2 vacancies and Zn [37]. Visible light emission absence is considered to be caused by using water vapor that is reported by Munoz-Rojas et al. [38] that water-assisted oxidation can improve the crystalline structure of the oxide product [38].

The narrow single band emission in the deep-level region at 470 nm (2.64 eV) corresponds to rare blue emission, which might be due to the influence of the degree of the crystallization and the stoichiometry of ZnO films. It might also contribute to the transition from Zn_i to VB , considering that Zn_i lies $\sim 0.41\text{ eV}$ deeper to the CB edge [48].

3.3. Morphology

Nanowires /nanorods are grown on silicon n-type substrate at different temperatures $650\text{ }^{\circ}\text{C}$, $750\text{ }^{\circ}\text{C}$, and $850\text{ }^{\circ}\text{C}$.

Figure 7a,b illustrate the top and side view of short, high-density, randomly oriented ZnO nanowires grown at $650\text{ }^{\circ}\text{C}$. This might contribute to the flow of water vapor through the oxidation tube. Nanowires' growth of 363 nm length and diameter of 20 nm, similar to [36,40], where the working temperature of [36] was $750\text{ }^{\circ}\text{C}$ and the one of [40] was $600\text{ }^{\circ}\text{C}$. This technique is highly affected by the tube furnace, placement of the substrates and the source, as well as the oxygen source in our case (distilled water inside the chamber).

Figure 8a demonstrates the top view that is tilted at 33° , and Figure 8b shows a cross-section view of ZnO NWs grown at $750\text{ }^{\circ}\text{C}$. A grass form is shown and the average length of nanorods is $1.5\text{ }\mu\text{m}$. The diameter ranges from 50 nm to 130 nm. It is clear that the deposited grains have aggregated to form uniformly distributed, randomly oriented ZnO nanorods, similar to nanostructures obtained in the literature [42,46,47].

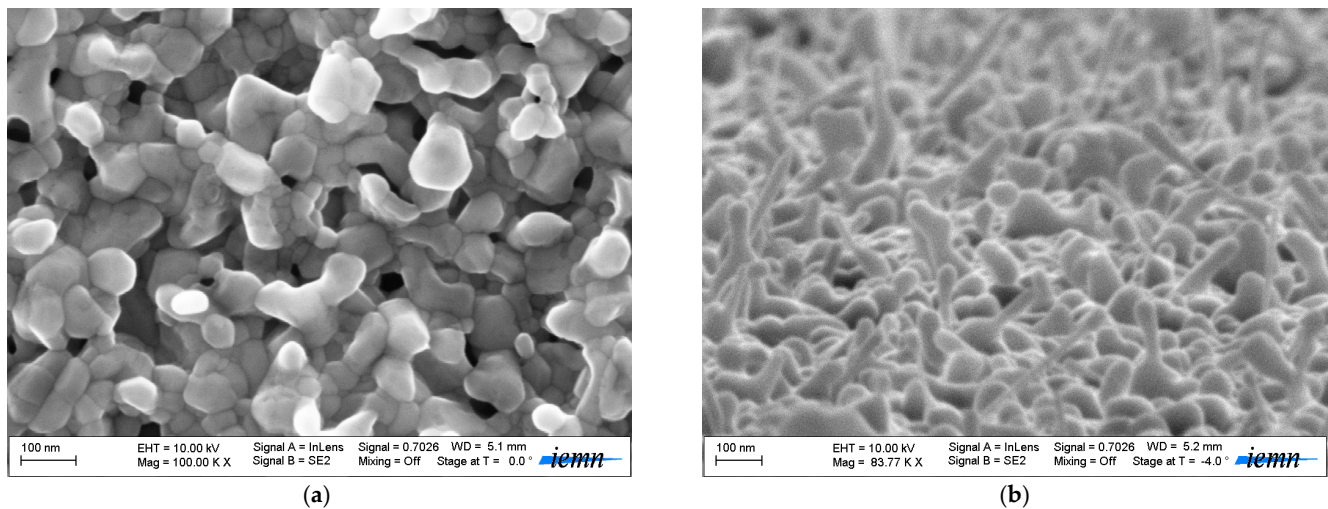


Figure 7. SEM of ZnO NWs grown at $T = 650\text{ }^{\circ}\text{C}$: (a) top view and (b) cross-section.

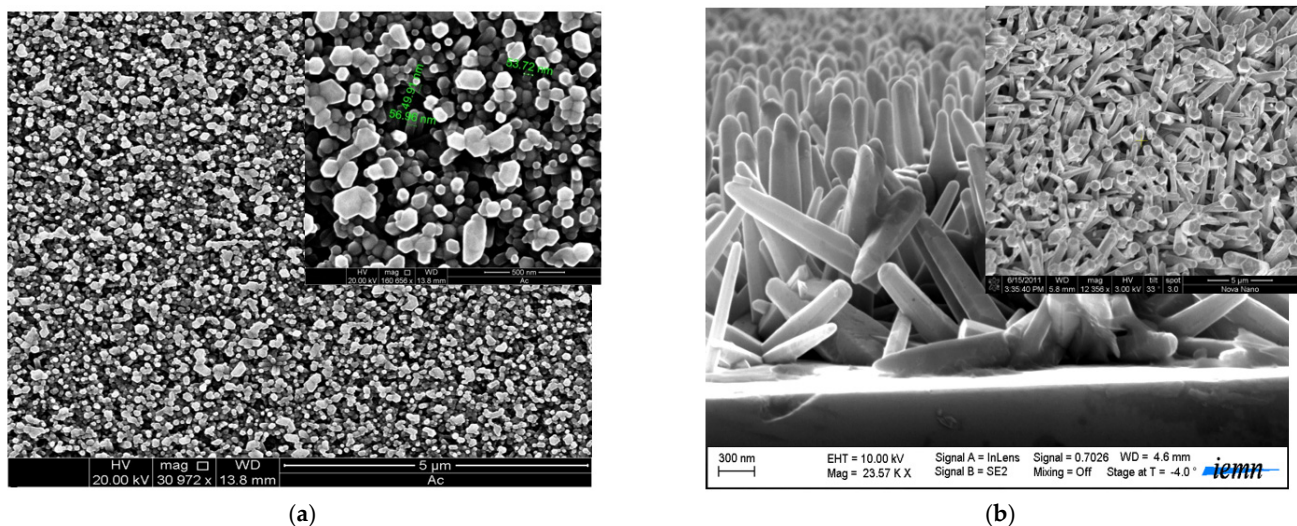


Figure 8. SEM of ZnO NWs grown at $T = 750\text{ }^{\circ}\text{C}$: (a) top view and (b) cross-section view.

In Figure 9a, the top view of ZnO NWs grown at $850\text{ }^{\circ}\text{C}$ is illustrated, and a cross-section view is shown in Figure 9b, which shows a feather-like morphology, and grown NWs are randomly grown on the surface and have a length of $1\text{ }\mu\text{m}$ and a diameter of 50 nm .

The grown feather-like nanostructures obtained are similar to what has been grown in [33], but at $390\text{ }^{\circ}\text{C}$ in a dry environment.

Different morphologies have been identified at different temperatures, reflecting the high influence of temperature on the growth of ZnO nanowires.

Oxidation kinetics can be accelerated by the quicker absorption with a faster disintegration of water vapor enabling the surface of the Zn structure to transform into nucleation sites for ZnO NWs.

At a low temperature of $450\text{ }^{\circ}\text{C}$, the zinc vapor does not have sufficient energy. Zn atoms are placed exactly where they land. This has caused the formation of non-uniform rough films in nuclei clusters. The nuclei clusters have resulted in several ZnO nanowires assembled in the development process.

In each nuclei cluster, and at a higher temperature of $650\text{ }^{\circ}\text{C}$, fewer assembled nuclei are formed. The closed nuclei together consumed each other to form a bigger size grain in the main growth stage, resulting in the growth of NWs of larger diameter.

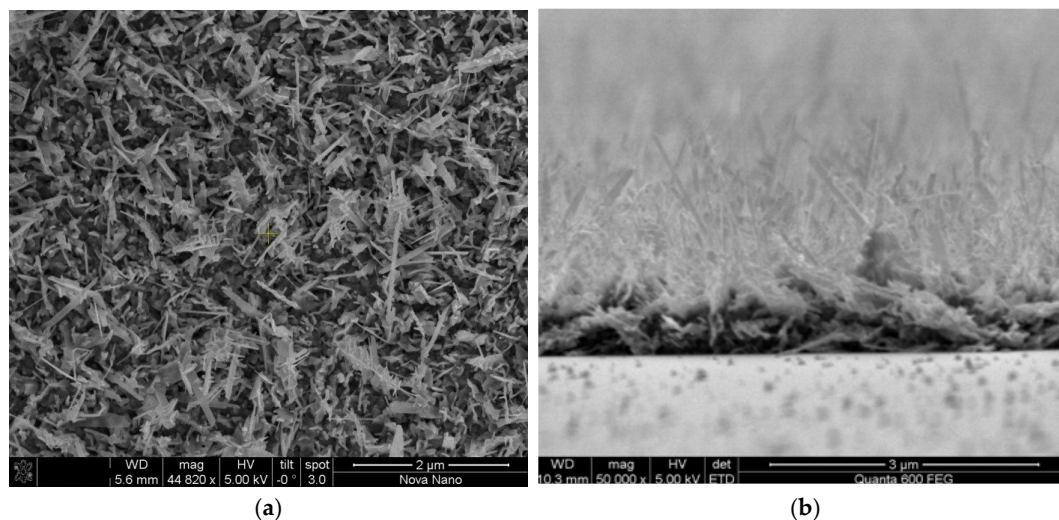


Figure 9. SEM of ZnO nanowires grown with wet oxidation at $T = 850\text{ }^{\circ}\text{C}$: (a) top view and (b) cross-section view.

Surfaces have formed after the nucleation sites on substrates, and the Zn atoms' surface diffuses and reacts with water vapor that will dominate the growth process of ZnO NWs, which will be stopped when NW becomes longer for Zn atoms to be diffused above the surfaces of the tip or the process is stopped at a specific temperature. At $420\text{ }^{\circ}\text{C}$, the melting point of Zn, the Zn evaporates then oxidizes in the O_2 and H_2O environment to prepare ZnO in the gaseous phase and condense on substrate's surfaces to form different ZnO NWs. Moreover, Zn is oxidized before evaporation, which may result in several morphological habits of ZnO obtained at different temperatures.

4. Conclusions

ZnO NWs were successfully grown at $750\text{ }^{\circ}\text{C}$, whereas at $650\text{ }^{\circ}\text{C}$ and $850\text{ }^{\circ}\text{C}$, random nanowires on silicon n-type substrate with a zinc seed layer, in a humid environment at atmospheric pressure were formed. Intensity and FWHM of as-synthesized ZnO NWs at different temperatures, $750\text{ }^{\circ}\text{C}$, $650\text{ }^{\circ}\text{C}$, and $850\text{ }^{\circ}\text{C}$, were measured using the XRD spectrum then the crystal average size was calculated between 9 nm and 24 nm. In addition, peaks are obtained at planes (100), (002), and (101) at $T = 750\text{ }^{\circ}\text{C}$, $650\text{ }^{\circ}\text{C}$, and $850\text{ }^{\circ}\text{C}$; however, the peaks were only noticed at $T = 750\text{ }^{\circ}\text{C}$ for planes (102), (110), (103), and (200). The UV emission peak values of the ZnO NWs are 383 nm, 382 nm, and 384 nm at $650\text{ }^{\circ}\text{C}$, $750\text{ }^{\circ}\text{C}$, and $850\text{ }^{\circ}\text{C}$, respectively, and the visible emission peak values are 471 nm at any temperature which gives the highest UV/visible intensity ratio at $750\text{ }^{\circ}\text{C}$, and the value is 2.22. Furthermore, the SEM image of ZnO NWs grown at $T = 650\text{ }^{\circ}\text{C}$ shows that the grown nanowires have an average length of 363 nm and diameter of 20 nm, whereas the average length of NWs is $1.5\text{ }\mu\text{m}$, and the diameter ranges from 50 nm to 130 nm at $T = 750\text{ }^{\circ}\text{C}$. Finally, the obtained average length of the NWs is $1\text{ }\mu\text{m}$, and the average diameter is 50 nm at $T = 850\text{ }^{\circ}\text{C}$.

Author Contributions: Conceptualization, B.E. and N.S.; methodology, B.E., M.A.K. and N.S.; validation, G.J. and A.S.B.; formal analysis, B.E., A.S.B. and M.A.K.; investigation, A.S.B. and G.J.; resources, N.S.; Analysis, B.E., A.S.B. and A.E.; writing—original draft preparation, B.E.; writing—review and editing, A.E., B.E. and A.S.B.; visualization, B.E. and A.E.; supervision, B.E., N.S. and G.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: All data are included in this work.

Acknowledgments: We thank Ali Marashdeh (a.marashdeh@bau.edu.jo) from the Department of Chemistry at Al-Balqa Applied University, Salt, Jordan, for his kind assistance during the course of this work. Special thanks also go to Elhadj Dogheche for his help in facilitating the conduction of some SEM characterization at the IEMN Lab-France.

Conflicts of Interest: The authors declare no conflict of interest.

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