

## ABSTRACT

The growth mechanism, morphology, structure and optical properties of the ZnO nanostructures grown on bare and gold-coated silicon substrates using carbothermal reaction at atmospheric pressure were investigated under different growth conditions. The ZnO nanostructures formed were studied as a function of substrate location, furnace temperature, Ar gas flow rate, deposition time and ZnO powder to carbon powder mass ratio. The morphology and structure of the samples were characterized using the field-emission scanning electron microscopy (FESEM), energy dispersive x-ray spectroscopy (EDX) spectrum, x-ray diffraction (XRD) and high resolution transmission electron microscopy (HRTEM). It was found that in both silicon and gold-coated silicon substrates, the morphology of the ZnO nanostructures was strongly dependent on the location of the substrate from the Zn source and to the furnace temperature. On the other hand, deposition time, gas flow rate and the different ratios of reactant materials played an important role in changing the size of ZnO nanostructures. The density of the ZnO nanostructures grown with Au catalyst was much higher than that of ZnO nanostructures without catalyst. XRD result shows that the ZnO nanostructures grown without catalyst have a better preferential orientation along the [002] orientation than that grown with gold catalyst. The ZnO nanostructures grown with and without Au catalyst can be attributed to the vapor-liquid-solid (VLS) model and self-catalytic (VLS) processes, respectively.

PL spectrum of ZnO nanostructures grown with Au catalyst exhibited a strong defect-related deep-level emission. It demonstrated that the ZnO nanostructures grown with Au catalyst were more defective than grown on bare silicon substrate. It has been found that there is a strong relationship between the furnace temperature and the emission peak. PL study shows that the green emission band peak, which is mainly due to defects in ZnO, can be lowered by increasing the furnace temperature and the best temperature for the removing defects in ZnO nanostructures was found to be 1200°C. Moreover, the post annealed of grown sample at the air atmosphere was also found to reduce the green emission, hence low growth defects. ZnO nanostructures doped with phosphorus have been successfully synthesized. It was found that P incorporation has caused more defects in the ZnO nanostructures, which was confirmed by XRD and PL analysis. While, FESEM results showed that the doping process caused structural change in the ZnO shape from nanowires to nanoballs.

**To**  
*My Father's Soul*

## ACKNOWLEDGEMENTS

*"In the name of Allah, The most merciful and the most beneficial"*

First of all, all thanks and praises for Allah “Subhanahu Wa Ta’ala” who guided me and helped me to complete this thesis.

I would like to express my gratitude to all those who made it possible for me to complete this study. I am deeply indebted to my supervisors, Assoc. Professor. Dr Roslan Md Nor and Professor Dr Yusoff Mohd Amin. I thank them greatly with regards for their patience and unlimited encouragement that carried me on through difficult times, and for their insights and suggestions that helped to shape my research skills. I wish to express my warm and sincere thanks to His Majesty Sultan Qaboos bin Said Sultan of Oman who gave me the opportunity to study inside and outside the country. My thanks go to Mr Azman and Ms Zurina Marzuki for their technical assistance. Many thanks also go to University Malaya for giving me the chance to continue my higher education. I owe sincere thanks to Ministry of Education in Sultanate of Oman for giving me a leave to continue my further study. There are many people who assisted me but have not been mentioned here. I am grateful for their contribution.

A deep hearted gratitude goes to my mother, my wife and my children; Aryam, Yaseen, Anfaal and Taha for their full support, love, care and inspiration.

## TABLE OF CONTENTS

CONTENTS	PAGE
ABSTRACT	i
DEDICATIONS	iii
ACKNOWLEDGMENTS	iv
TABLE OF CONTENTS	v
LIST OF FIGURES	x
LIST OF TABLES	xxi
<b>Chapter 1 Introduction</b>	<b>1</b>
1.1. Introduction	1
1.2. Objectives of the thesis	2
1.3. Organization of the thesis	3
<b>Chapter 2 Literature review of ZnO nanostructures</b>	<b>4</b>
2.1. Introduction	4
2.2. Nanotechnology	5
2.3. Nanomaterials	8
2.4. Classification of nanomaterials	10
2.5. Nano-electromechanical systems	11
2.6. Zinc oxide	14
2.6.1. Crystal structure of zinc oxide	15

2.6.2. Physical properties of zinc oxide	17
2.6.2.1. Mechanical properties	19
2.6.2.2. Electrical properties	20
2.6.2.3. Optical properties	21
2.6.3. Doping of zinc oxide	23
2.6.3.1. N-type doping	24
2.6.3.2. P-type doping	25
2.6.5. Some applications of zinc oxide	26
2.7. Fabrication of nano-sized zinc oxide	28
2.7.1. Ball milling	28
2.7.2. Solution-based chemistry	29
2.7.2.1. Sol-gel synthesis	29
2.7.2.2. Hydrothermal synthesis	30
2.7.3. Vapor phase transport synthesis	31
2.7.3.1. Thermal evaporation	31
2.7.3.2. Sputtering	32
2.8.2.2.3. Laser ablation deposition	33
2.7.4. Chemical vapor transport and condensation	35
2.7.5. Templates assisted processes	37
2.8. Effects of growth parameters on the ZnO nanostructures formation	38
2.8.1. Source material temperature effect	38
2.8.2. Substrate temperature effect	39
2.8.3. Gas flow rate effect	40

2.8.4. Pressure effect	41
2.8.5. Substrate material effect	43
2.8.6. Catalyst effect	44
2.8.7. Deposition time effect	46
2.8.8. Mass ratio of ZnO:C effect	47
2.9. Growth mechanism of ZnO nanostructures	48
2.9.1. Vapor-liquid-solid (VLS)	48
2.9.2. Self catalytic vapor-liquid-solid	51
2.9.3. Vapor-solid (VS)	52
2.9.4. Vapor-solid-solid (VSS)	55
2.10. Characterization techniques	56
2.10.1. Field emission scanning electron microscopy (FESEM)	57
2.10.2. Transmission electron microscopy (TEM)	61
2.10.3. X-ray diffraction (XRD)	63
2.10.3.1. Generation of x-ray	64
2.10.3.2. Bragg's law	65
2.10.4. Photoluminescence (PL) measurements	66
2.10.4.1. Radiative recombination mechanisms observed in PL	67
2.10.4.2. Micro- photoluminescence spectroscopy	69
2.10.4.3. Experimental setup of PL	69
<b>Chapter 3 Experiment Setup</b>	<b>71</b>
3.1. Introduction	71
3.2. Substrate preparation	72

3.3. Zinc oxide Nanostructures Growth Procedure	72
3.4. Doping of ZnO nanostructures	75
3.5. Characterization of ZnO nanostructures	76
3.5.1. Field emission scanning electron microscopy ( FESEM)	76
3.5.2. X-ray diffraction (XRD)	78
3.5.3. High resolution transmission electron microscopy (HRTEM)	79
3.5.4. Photoluminescence (PL)	80
<b>Chapter 4. Result and Discussion</b>	<b>81</b>
4.1. Introduction	81
4.2. Parametric study of ZnO nanostructures grown without catalyst	82
4.2.1. Effect of the location of the silicon substrates	82
4.2.2. Effect of the source temperatures	87
4.2.3. Effect of the Argon flow rate	91
4.2.4. Effect of the deposition time	93
4.2.5. Effect of ZnO:C mass ratio	96
4.2.6. Summary of mechanism growth of ZnO nanostructures	100
4.3. Parametric study of ZnO nanostructures grown with gold as catalyst	107
4.3.1. Effect of gold-coated silicon substrate treatment	108
4.3.2. Effect of the location of the gold-coated silicon substrates	112
4.3.3. Effect of the source temperature	117
4.3.4. Effect of the Ar flow rate	121
4.3.5. Effect of the deposition time	125
4.3.6. Effect of ZnO:C mass ratio	129

4.3.7. Mechanism of ZnO nanostructures growth	132
4.4. Comparative study between ZnO nanostructures grown without and with catalyst	136
4.5. Optical properties of ZnO nanostructures	140
4.6. Different forms of zinc oxide nanostructures	144
4.6.1. Flower-like structure	144
4.6.2. Nano-bottle structure	144
4.6.3. Nanocomb-like structure	146
4.6.4. Cages and Shells structures	148
4.6.5. Nanowires/nanorods structures	149
4.6.6. Nanoneedles-like structure	151
4.6.7. Possible growth mechanism of grown ZnO nanostructures	153
4.6.7.1. Nano-bottle structure	154
4.6.7.2. Nanocomb-like structure	154
4.6.7.3. Shell and cage-like structures	155
4.7. Doping of ZnO nanostructures with Phosphorous	157
<b>Chapter 5. Conclusions</b>	<b>166</b>
List of References	<b>170</b>
List of publication	<b>178</b>

## LIST OF FIGURES

### Chapter 2 Zinc oxide nanostructures.

FIGURE	PAGE
2.1. Pictures of:-	
(a) An 18th century Chinese vase, demonstrating use of red glaze pigments.	
(b) A medieval stained glass window illustrating the use of nanopowders in art glass processing.	
(c) A magnetotactic bacteria, with internal magnetic nanoparticles clearly visible.	
d) A to-scaled computer model of the polio virus.	7
2.2. Vials containing varying sizes of CdSe quantum dots, growing larger from left to right and showing different optical emissions.	9
2.3. Computer generated structures of single-wall carbon nanotubes with different chiral angles between $0^\circ$ and $30^\circ$ .	10
2.4. SEM images demonstrating nanomaterial classifications.	11
2.5. A graph of the exponential growth of IC transistors according to Moore's Law from 1971 to 2000.	13
2.6. Zinc oxide powder.	14
2.7. Different crystal structures of ZnO (a) wurzite, (b) zinc blende and (c) rock salt.	15
2.8. A schematic diagram of a wurtzitic ZnO structure.	16
2.9. PL spectra of 6 nm and 200 nm wide ZnO nanobelts showing a blue shift of the emission peak.	22
2.10. A schematic diagram of the design and structure of the nanogenerator based on ZnO nanowires.	27

2.11.	A schematic diagram of pulsed laser deposition (PLD) technique used on ZnO nanofabrication.	34
2.12.	A schematic diagram showing chemical vapor transport and condensation (CVTC) experiment setup.	36
2.13.	SEM images of (a) AAO membrane surface and (b) AAO membrane used a template to make ZnO nanowires by electroplating.	37
2.14.	A summarized map of the predominant ZnO nanostructures under certain processing temperatures and oxygen contents.	40
2.15.	SEM images of different ZnO nanostructures morphologies obtained at different deposition pressure.	42
2.16.	TEM image of a ZnO nanowire with an alloy droplet on the tip.	45
2.17.	SEM images of different ZnO nanostructures morphologies obtained by controlling the growth time from a few seconds to several hours.	46
2.18.	A schematic diagram illustrating the steps of VLS process.	49
2.19.	Pseudobinary phases of gold when a gold droplet absorbs semiconductor material at a constant temperature.	50
2.20.	A schematic diagram illustrating the growth of a ZnO nanowire by self-catalytic VLS process.	52
2.21.	A schematic diagram illustrating the forming of metal oxide nanostructures directly by the vapor solid mechanism on substrate.	53
2.22.	A schematic diagram illustrating of a proposed growth mechanism for ZnO nanobelts through a VS process.	54
2.23.	A schematic diagram illustrates that the formation of metal oxide nanowires via vapor-solid- solid mechanism.	56
2.24.	A schematic diagram illustrating the function principle of FESEM.	58
2.25.	A schematic diagram implying some of the signals, which used in FESEM.	59

2.26.	A schematic diagram illustrating the operational principle of TEM.	61
2.27.	A schematic diagram showing three different imaging modes on TEM,	
	(a) bright field mode with transmitted plus diffracted beam with little contrast,	
	(b) field mode with only transmitted beam with better contrast since the diffracted beam is blocked, and	
	(c) dark field mode where only the diffracted beam is used.	63
2.28.	A plot of the x-ray spectrum with the bremsstrahlung background and electrons excitations lines.	65
2.29.	A schematic diagram showing Bragg's diffraction condition.	66
2.30.	A schematic diagram illustrating of the recombination processes.	68
2.31.	A schematic diagram illustrating the photoluminescence system.	69

### **Chapter 3 Experiment setup.**

3.1.	A schematic diagram of experiment setup used in the growth process.	74
3.2	The positions of silicon substrates downstream the source material inside the tube furnace (upper graph) and the uniformity curve temperature zone inside the tube furnace.	74
3.3.	FESEM image of ZnO nanostructures after growth process.	76
3.4.	EDX spectrum of ZnO nanostructures grown on silicon substrate.	77
3.5.	XRD pattern of ZnO nanostructures grown on gold-coated silicon substrate.	78
3.6.	HRTEM image of ZnO nanowire.	79

3.7.	PL spectrum of ZnO nanowires obtained on silicon substrate.	80
------	---	----

#### **Chapter 4 Results and Discussion.**

4.1.	FESEM images of ZnO nanostructures grown on silicon substrates located at (a) 6 cm, (b) 11 cm, (c) 15 cm and (d) 19 cm from the source. The furnace temperature was 1200°C. Ar gas flow rate was 40 sccm. The deposition time was 30 min. The mass ratio of ZnO:C was 1:1.	83
4.2.	Fig. 4.2. EDX spectra of ZnO nanostructures grown on silicon substrates located at (a) 6 cm, (b) 11cm, (c) 15 cm and (d) 19 cm away from the source material. The furnace temperature was 1200°C. Ar gas flow rate was 40 sccm. The deposition time was 30 min. The mass ratio of ZnO:C was 1:1.	83
4.3.	XRD patterns of ZnO nanostructures deposited on the Si(100) substrates at different locations from the source. The furnace temperature was 1200°C. Ar gas flow rate was 40 sccm. The deposition time was 30 min. The mass ratio of ZnO:C was 1:1.	86
4.4.	FESEM images ZnO nanostructures formed on Si substrates at (a) 1200°C, (b) 1100°C, (c) 1000°C and (d) 950°C furnace temperatures. The Si substrates were kept at 11 cm from the source. Ar gas flow rate was 40 sccm. The deposition time was 30 min. The mass ratio of ZnO:C was 1:1.	88
4.5.	EDX spectra of ZnO nanostructures grown on Si substrates at (a) 1100°C and (b) 1000°C furnace temperatures. The Si substrates were kept at 11 cm from the source. Ar gas flow rate was 40 sccm. The deposition time was 30 min. The mass ratio of ZnO:C was 1:1.	89
4.6.	XRD patterns of the deposited ZnO products on silicon substrates at different furnace temperatures. The Si substrates	90

- were kept at 11 cm from the source. Ar gas flow rate was 40 sccm. The deposition time was 30 min. The mass ratio of ZnO:C was 1:1.
- 4.7. FESEM images of ZnO nanostructures formed at (a) 10 sccm, (b) 30 sccm, (c) 50 sccm and (d) 70 sccm Ar flow rates. The silicon substrates were located at 11 cm away from the source which is ZnO:C (1:1) heated at 1100°C furnace temperature for 15 min. 91
  - 4.8. XRD patterns of the different ZnO nanostructures grown at different Ar gas flow rates. The silicon substrates were located at 11 cm away from the source, which is ZnO:C (1:1) heated at 1100°C for 15 min. 93
  - 4.9. FESEM images of ZnO nanostructures deposited for (a) 15 min, (b) 30 min, (c) 45 min, and (d) 60 min. The silicon substrates were located at 11 cm away from the source, which is ZnO:C (1:1) heated at 1100°C under 40 sccm Ar flow rate. 94
  - 4.10. EDX spectra of ZnO nanostructures grown with (a) 15 min and (b) 60 min growth time. The silicon substrates were located at 11 cm away from the source, which is ZnO:C (1:1) heated at 1100°C under 40 sccm Ar flow rate. 94
  - 4.11. XRD patterns of as-synthesized ZnO nanostructures obtained at different deposition times. The silicon substrates were located at 11 cm away from the source, which is ZnO:C (1:1) heated at 1100°C under 40 sccm Ar flow rate. 96
  - 4.12. FESEM images of ZnO nanostructures obtained from the ZnO:C source ratios of (a) (2:1), (b) (1:2), (c) (3:1) and (d) (1:3). The Si substrates were located at 11 cm away from the source under 30 sccm Ar flow rate. The source was heated at 1100°C for 15 min. 97
  - 4.13. EDX spectra of ZnO nanostructures synthesized by using (a) (2:1), (b) (1:2), (c) (3:1) and (d) (1:3) ZnO:C mass ratios. The Si substrates were located at 11 cm away from the source. Ar 99

- flow rate was 30 sccm. The source was heated at 1100°C for 15 min.
- 4.14. XRD spectra of ZnO grown using different ZnO:C mass ratios. The Si substrates were located at 11 cm away from the source. Ar flow rate was 30 sccm. The source was heated at 1100°C for 15 min. 100
- 4.15. A schematic diagram illustrated the steps for nucleation and growth of ZnO nanostructures from carbothermal reaction according to self-catalytic (VLS) process. 103
- 4.16. TEM image showing that no tip particle was observed at the end of ZnO nanostructures. 104
- 4.17. TEM image showing that a wide base at the bottom of nanostructures was observed. 105
- 4.18. FESEM image of ZnO nanostructures grown on silicon substrates via self catalytic VLS growth mechanism. 106
- 4.19. EDX spectra showing that the different components between the root and the stem of ZnO nanostructure grown upon bare silicon substrate. 107
- 4.20. FESEM and EDX of ZnO nanostructures grown on (a) non pre-annealed (b) pre-annealed Si/Au substrates (Growth temperature was 1200°C, Ar flow rate was 20 sccm, ZnO:C mass ratio was 1:1 and growth time was 60 min). 109
- 4.21. FESEM image of the distribution of gold droplets on silicon substrate after annealing process at 700 °C for 30 min under 40 sccm Ar gas at atmospheric pressure. 111
- 4.22. EDX spectrum of gold droplets on silicon substrate after annealing process. 111
- 4.23. FESEM images of ZnO nanostructures grown on gold-coated silicon substrates placed at (a) 6 cm, (b) 11 cm, (c) 15 cm and (d) 19 cm downstream of the source. The furnace temperature was 1200°C. Ar gas flow rate was 40 sccm. The deposition time was 30 min. The mass ratio of ZnO:C was (1:1). 112

- 4.24. EDX spectra of ZnO nanostructures grown on Si/Au substrates placed at (a) 6 cm, (b) 11 cm, (c) 15 cm, (d) 19 cm away from the source. The furnace temperature was 1200°C. Ar gas flow rate was 40 sccm. The deposition time was 30 min. The mass ratio of ZnO:C was (1:1). 114
- 4.25. XRD patterns of ZnO grown on the gold-coated silicon substrate at different locations from the source. The furnace temperature was 1200°C. Ar gas flow rate was 40 sccm. The deposition time was 30 min. The mass ratio of ZnO:C was (1:1). 115
- 4.26. FESEM images of ZnO nanostructures formed on gold-coated silicon substrates at (a) 1200°C, (b) 1100°C, (c) 1000°C and (d) 950°C furnace temperatures. The substrates were kept at 11 cm far from the source. Ar flow rate was 40 sccm. The deposition time was 30 min and the mass ratio of ZnO:C was 1:1. 117
- 4.27. EDX spectra of ZnO nanostructures formed on gold-coated silicon substrates at (a) 1200°C, (b) 1100°C, (c) 1000°C and (d) 950°C furnace temperatures. The substrates were kept at 11 cm far from the source. Ar flow rate was 40 sccm. The deposition time was 30 min and the mass ratio of ZnO:C was 1:1. 118
- 4.28. XRD patterns of the deposited ZnO products formed on gold-coated silicon substrates at different furnace temperatures. The substrates were kept at 11 cm far from the source. Ar flow rate was 40 sccm. The deposition time was 30 min and the mass ratio of ZnO:C was 1:1. 120
- 4.29. FESEM images of ZnO nanostructures formed at on gold-coated silicon substrates at (a) 10 sccm (b) 30 sccm, (c) 50 sccm and (d) 70 sccm Ar flow rates. The substrates were located at 11 cm away from the source, which is ZnO:C (1:1) heated at 1100°C furnace temperature for 15 min. 121

- 4.30. EDX spectra of ZnO nanostructures formed on gold-coated silicon substrates at (a) 10 sccm, (b) 30 sccm, (c) 50 sccm and (d) 70 sccm Ar flow rates. The substrates were located at 11 cm away from the source, which is ZnO:C (1:1) heated at 1100°C furnace temperature for 15 min. 122
- 4.31. XRD patterns of the different ZnO nanostructures formed on gold-coated silicon substrates at different Ar gas flow rates. The substrates were located at 11 cm away from the source, which is ZnO:C (1:1) heated at 1100°C furnace temperature for 15 min. 124
- 4.32. FESEM images of ZnO nanostructures formed on gold-coated Si substrates with different (a) 15 min, (b) 30 min, (c) 45 min and (d) 60 min deposition times. The substrates were located at 11 cm away from the source, which is ZnO:C (1:1) heated at 1100°C under 40 sccm Ar flow rate. 125
- 4.33. EDX spectra of ZnO nanostructures formed on gold-coated Si substrates with different (a) 15 min, (b) 30 min, (c) 45 min and (d) 60 min deposition times. The substrates were located at 11 cm away from the source, which is ZnO:C (1:1) heated at 1100°C under 40 sccm Ar flow rate. 126
- 4.34. XRD patterns of ZnO nanostructures grown with different deposition times on the gold-coated silicon substrates. The substrates were located at 11 cm away from the source, which is ZnO:C (1:1) heated at 1100°C under 40 sccm Ar flow rate. 128
- 4.35. FESEM images of ZnO nanostructures obtained from the ZnO:C source ratios of (a) (2:1), (b) (3:1), (c) (1:2) and (d) (1:3). The gold-coated silicon substrates were located at 11 cm away from the source under 30 sccm Ar flow rate. The source was heated at 1100°C for 15 min. 129
- 4.36. EDX spectra of ZnO nanostructures formed by using (a) (2:1), (b) (3:1), (c) (1:2) and (d) (1:3) ZnO:C mass ratios. The gold-coated silicon substrates were located at 11 cm away from the 130

- source under 30 sccm Ar flow rate. The source was heated at 1100°C for 15 min.
- 4.37. XRD patterns of ZnO nanostructures formed at different ZnO:C mass ratios. The gold-coated silicon substrates were located at 11 cm away from the source under 30 sccm Ar flow rate. The source was heated at 1100°C for 15 min. 131
- 4.38. A schematic diagram illustrated the steps of the nucleation and the growth of ZnO nanostructures using gold as catalyst according VLS process. 133
- 4.39. FESEM and EDX results that prove the growth of ZnO nanostructures is triggered and guided via the gold catalyst. The gold-coated silicon substrates were located at 11 cm away from the source under 20 sccm Ar flow rate. The source ZnO:C was (1:1) and heated at 1200°C for (a) 5 min and (b) 15 min. 135
- 4.40. FESEM images of ZnO nanowires with varying diameters during the growth process. The gold-coated silicon substrates were located at 11 cm away from the source under 10 sccm Ar flow rate. The source of ZnO:C was (1:1) and was heated at 1100°C for 15 min. 136
- 4.41. FESEM images of ZnO nanowires grown on (a) bare and (b) gold-coated silicon substrates at same conditions The growth temperature was 1200°C, the substrate location was 11 cm, Ar flow rate was 40sccm, growth time was 30 min and ZnO:C mass ratio was 1:1). 137
- 4.42. XRD spectra of (a) pure ZnO powder and ZnO nanowires grown on (b) catalyst-free and (c) with Au catalyst silicon substrates at same conditions The growth temperature was 1200°C, the substrate location was 11 cm, Ar flow rate was 40sccm, growth time was 30 min and ZnO:C mass ratio was 1:1. 139

4.43.	PL spectra of the deposited ZnO nanostructures at different furnace temperatures on bare silicon substrates. The Si substrates were kept at 11 cm from the source. Ar gas flow rate was 40 sccm. The deposition time was 30 min. The mass ratio of ZnO:C was 1:1.	140
4.44	PL spectra of ZnO nanostructures at room temperature: before and after heat treatment at 1000 °C in the air for 1 h.	142
4.45.	PL spectra of grown ZnO nanostructures on gold-coated silicon and bare silicon substrates.	143
4.46.	FESEM images of flower-like ZnO nanostructures grown on (a) bare and (b) gold-coated silicon substrates.	144
4.47.	EDX spectra of flower-like obtained on (a) bare and (b) gold coated Si substrates	146
4.48.	FESEM image of ZnO nano-bottle structure.	146
4.49.	EDX spectra of (a) the middle and (b) the tip cap of fabricated ZnO nano-bottle, correspondingly.	147
4.50.	Low magnification and high magnification FESEM images of ZnO nanocombs-like structures at gold-coated substrate located at 15 cm far from source material source ZnO:C (1:1) heated at 1200°C for 30 min under 40 sccm Ar gas flow rate.	148
4.51.	EDX spectrum for ZnO nanocomb-like structure.	149
4.52.	FESEM image of the as-synthesized ZnO cages and shells distributed on the substrate surface.	150
4.53.	EDX spectrum of the as-synthesized ZnO cages and shells.	150
4.54.	FESEM images of (a) aligned, (b) randomly oriented and (c) and intermix nanowires.	151
4.55.	XRD patterns of the aligned and randomly oriented nanowires.	152
4.56.	FESEM picture of ZnO nanoneedle-like.	153
4.57.	(a), (b) and (c) are illustrated the growth process of ZnO nano-bottle proceeds via VLS mechanism.	155

4.58.	Schematic diagram showing the possible growth mechanisms of ZnO nanocomb and nanosheet structures.	156
4.59.	FESEM image of ZnO nanosheet structure formed as filled-up process between branches.	157
4.60.	FESEM of P-doped ZnO nanostructures at (a) low magnification and (b) high magnification.	159
4.61.	EDX spectrum of synthesized P- doped ZnO nanoballs.	160
4.62.	FESEM image of the synthesized undoped ZnO nanowires.	161
4.63.	FESEM images (a) low magnification without grown nanostructures surface and (b) cracked flower like microstructures.	162
4.64.	EDX spectrum of flower like microstructures.	163
4.65.	XRD spectra of both doped and undoped ZnO nanostructures.	164
4.66.	XRD spectrum of remain powder after doping ZnO nanostructures.	164
4.67.	PL spectra of undoped and P-doped ZnO nanostructures	165

## LIST OF TABLES

### Chapter 2 Zinc oxide nanostructures.

TABLE	PAGE
2.1. Physical properties of wurtzite ZnO.	18
2.2. Group I and V acceptor properties in ZnO.	26
2.3. Lattice parameters of several epitaxiy substrates.	43

### Chapter 3 Zinc oxide nanostructures.

3.1 The growth parameters used in this work.	75
--	----