

# Electrical, Optical and Structural Studies of Some Transparent Conducting Films Prepared by Pulsed Laser Deposition

#### A Thesis

Submitted For The Degree of M.sc. in Science As a Partial Fulfillments For the Requirements of the Master Degree in Science

to

physics Department, Faculty of Science, Ain Shams University

BY

Ahmed Mohamed Abd El-Karim Ahmed



### Electrical, Optical and Structural Studies of Some Transparent Conducting Films Prepared by Pulsed Laser Deposition

#### **A THESIS**

Submitted For The Degree of M.Sc. in Science As a Partial Fulfillments

For the Requirements of the Degree in Science

to

Physics Department, Faculty of Science,

Ain Shams University

#### BY

# Ahmed Mohamed Abd El-Karim Ahmed B.Sc. (2008)

### Supervised by

Prof. Dr. Mohamed Hassan Talaat
Physics Department
Faculty of Science
Ain Shams University

Prof. Dr. Ali Ali Shabaka Spectroscopy Department Physics Division National Research Center

Assist. Prof. Dr. Monazah Kafaghi Spectroscopy Department Physics Division National Research Center

Electrical, Optical and Structural Studies of Some Transparent Conduc Prepared by Pulsed Laser Deposition	eting Filn
Written by : Ahmed Mohamed Abd El-Karim Ahmed	
Has been approved for Physics Department, Ain Shams	
University	
	——————————————————————————————————————
	Dat
	Dat Dat
	Dat
	Dat
	Dat Dat
e final copy of this thesis has been examined by the signatories, and worth the content and form meet acceptable presentation standards of	Dat  Dat

degree of master of Science own investigation.	e (Physics) to Ain Shams University, is the result of my
	Candidate (Ahmed Mohamed Abd El-Karim)
	Supervisor (Prof. Dr. Mohamed Hassan Talaat)
	Supervisor (Prof. Dr. Ali Ali Sabaka)
	Supervisor (Assist. Prof. Dr. Monazah Kafaghi)
	ork embodied in this thesis has not already accepted in and is not currently being submitted for any other
	Candidate (Ahmed Mohamed Abd El-Karim)



Physics Department

#### Approval Sheet

Student Name: Ahmed Mohamed Abd El-Karim Ahmed

Thesis Title: Electrical, Optical and Structural Studies of Some Transparent Conducting Films Prepared by Pulsed Laser Deposition

Submitted in the partial Fulfillment for M.Sc. Degree in Physics

Supervisors Committee:	Signatu	
Prof. Dr. M. Hassan Talaat Physics Department Faculty of Science Ain Shams University	(	)
Prof. Dr. Ali. Ali. Shabaka Spectroscopy Department		,
Physics Division National Research Centre	(	)
Assist. Prof. Dr Monazah Kafaghi Spectroscopy Department Physics Division National Research Centre	(	)
Date of research: / /		
Post Graduate Studies Department Approval Stamp Faculty Council Approval Date: / /	Approval Date: / / University Council Approv	val

#### Acknowledgment

First and foremost, with a deep sense of gratitude, I want to thank Allah for allowing me to perform this thesis smoothly even though I face some obstacles throughout my work and peace be upon Prophet Mohammed.

This thesis is the result of the work whereby I have been accompanied and supported by many people. It is a pleasant opportunity for me to express my gratitude for all of them.

I am pleased to express my deep appreciation to my advisors for accepting me as a Master Student for this challenging thesis, their advices were crucial for my research and learning experience. Prof. Dr. M. Hassan Talaat, Professor of Experimental physics, Faculty of Science, Ain shams University, his continuous encouragement, helpful suggestions, invaluable advices and support.

I would like gratefully to express my profound gratitude and deep thanks to Prof. Dr. Ali A. Shabaka, Professor of Experimental Physics, Spectroscopy Department, Physics Division, National Research Center (NRC), for his technical and professional guidance continuous encouragement, helpful suggestion, valuable supervision, support and invaluable advices for me, who always gave me good advice with my synthesis problems and the first who introduced me and others to the promising area of semiconductor nanocrystals research. It is difficult not to take these things for granted under his tutelage. He has allowed me to develop the confidence in myself which I am convinced will carry me through the rough spots. I will inevitably encounter in my professional future.

I am highly indebted to Assist. Prof. Dr. Monazah G. Kafaghi, Assist, Professor of Physics, Spectroscopy Department, Physics Division, National Research Center (NRC), She gave me freedom to learn on my own, lending advice when it was appropriate. She allowed me to set my own goals and to achieve them.

I sincerely express my deepest gratitude to Dr. Wael M. H. El-Din, Doctor of Physics, Spectroscopy Department, Physics Division, National Research Center (NRC), for his valuable suggestions on Personal and thesis work, Making all the facilities available to me for my research work, He leaved me to set what I should or should not do, And if some discussion weren't going on my way.

.

I am highly indebted to Prof. Dr. Roshdi Seoudi, Spectroscopy Department, Physics Division, National Research Center (NRC), He welcomed me into his laboratory and, by his outstanding leadership, paved the inroads on which I could develop the skills and knowledge requisite of a scientist.

Also, I sincerely express my special appreciations to my friend Dr. Emad.M. El-Menyawy, Doctor of Solid State Physics, Physics Division, National Research Center (NRC), for his assistance to me on the Personal and the Thesis work either in synthesis or discussions of my thesis.

I would like gratefully to express my profound gratitude and deep thanks to **Dr. Safa Saied, Spectroscopy Department, Physics Division, National Research Center (NRC),** for her personal and technical guidance, Thanks for her to welcome me in her laboratory and in the spectroscopy department.

I am highly grateful to Prof. Dr. M. Boshta and Prof. Dr. F. M. Abd El-Hamied, Solid State Department, Physics Division, National Research Center (NRC) for making there facilities available in my research work.

My special appreciations go to my friend **Dr. Sherif El-Khodary** for his valuable suggestions and making the facilities available to me in my research work

My heartfelt thanks to all my friends and colleagues in Spectroscopy Department, Physics Division, National Research Center, and my colleagues in the Faculty of Engineering, Misr University For Science and Technology for them untiring and continued support during my thesis work. Those timely help, constant encouragement and friendship shall always be remembered.

Finally, this thesis could not have been completed without the endless love and blessings from my family. I wish to thank my parents, who taught me the value of hard work and rendered me enormous support during the whole tenure of my research work. I would like to thank them, for their patience to go through this endeavor hand-in-hand with me. Without their dearly accompaniment, both physically and spiritually, there would be no such an achievement.

# **CONTENTS**

	Page
<u>ABSTRACT</u>	
<b>CHAPTER (I): INTRODUCTION AND LITERATURE</b>	
REVIEW	
<ul> <li>1.1. Transparent Conducting Oxide</li> <li>1.2. Indium Tin Oxide (ITO)</li> <li>1.3. Physical Structure and Properties of ITO</li> <li>1.4. Thin film Deposition Techniques</li> <li>1.4.1. Chemical Vapor Deposition (CVD)</li> <li>1.4.2. Sputtering</li> <li>1.4.3. Thermal Evaporation</li> <li>1.4.4. Spray Pyrolysis</li> <li>1.4.5. Serson Printing Technique</li> </ul>	1 2 3 4 5 6 6 7
<ul> <li>1.4.5. Screen Printing Technique</li> <li>1.4.6. Pulsed Laser Deposition (PLD)</li> <li>1.5. Why Grow Compound Semiconductors by PLD?</li> <li>1.6. Application of TCO</li> <li>1.7. Literature Review</li> <li>1.8. Aims and Objectives</li> </ul>	7 8 11 12 13 23
CHAPTER (II): THEORETICAL CONCEPTS	
<ul> <li>2.1. Ultrafast Femtosecond Laser</li> <li>2.1.1. Chirped Pulse Amplification (CPA)</li> <li>2.1.1.1. The Seed Laser (Femtosecond Oscillators)</li> <li>2.1.1.2. Stretcher Stage</li> <li>2.1.1.3. Laser Amplification Stage</li> <li>2.1.1.4. Compressor Stage</li> <li>2.2. Pulsed Laser Deposition Technique (PLD)</li> </ul>	24 24 26 27 28 29 29
2.2.1. Mechanism of PLD  2.3. X-Ray Diffraction (XRD)  2.3.1. Fundamental Principles of X-ray Diffraction  2.3.2. The Bragg Equation  2.3.3. Determination of Unit Cell Dimension a <sub>o</sub>	30 33 33 33 34

2.3.4. Crystallite Size Determination from Line	34
2.4. Origin of Absorption Spectra	34
2.4.1. Ultraviolet and Visible Spectroscopy	36
2.4.1.1. Optical Absorption Coefficient	37
2.4.1.2. Burstein–Moss effect	39
2.5. Semiconductors from Bulk Materials to Quantum	40
Confinement	
2.5.1. Energy Band Theory	40
2.5.2. Bulk Semiconductor	42
2.5.3. Quantum Confinement Effect	43
2.6. Electron Microscopy	46
2.6.1. Transmission Electron Microscope (TEM)	46
2.6.1.1. Imaging and Diffraction in Transmission	47
Electron Microscope	
2.6.2 Scanning Electron Microscope (SEM)	49
2.7. Four-Point Probe (4-point probe)	51
CHAPTER (III): EXPERIMENTAL TECHNIQUES AND	
INSTRUMENTATION	
3.1. Samples Preparation	53
3.1.1. Substrates Preparation	53
3.1.2. Preparation of ITO thin films	53
3.2. Characterization Techniques	55
3.2.1. X-ray Diffraction (XRD)	55
3.2.2. Ultraviolet Visible Spectrophotometer (UV-Vis)	56
3.2.3. Four-Point Probe Manual (4-point probe)	57
3.2.4. Transmission Electron Microscope (TEM)	58
3.2.5. Scanning Electron Microscope (SEM)	59
3.2.6. Stylus Profile	60
<u>CHAPTER (IV):</u> RESULTS AND DISCUSSION	
4.1 ECC + CD - ' E	(2
4.1. Effect of Deposition Temperature	62
4.1.1. X-ray Diffraction Analysis	63
4.1.2. Optical properties	68
4.1.3. Electrical properties	78
4.2. Effect of Vacuum Annealing	80

4.2.1. X-ray Diffraction Analysis	80
4.2.2. Optical properties	83
4.2.3. Electrical properties	86
4.3. Effect of Oxygen Environment during Deposition	88
4.3.1. X-ray Diffraction Analysis	89
4.3.2. Optical properties	91
4.3.3. Electrical properties	94
4.4. Deposition under medium vacuum 10 <sup>-4</sup> torr	97
4.4.1. X-ray Diffraction Analysis	97
4.4.2. Optical properties	99
4.4.3. Electrical properties	102
4.5. Transmission Electron Microscope (TEM)	103
4.6. Scanning Electron Microscope (SEM)	108

## Conclusion

## Reference

## **Arabic Summary**

# **LIST OF TABLES**

No	Title	Page
4.1	Grain Size and Lattice Parameter of ITO thin films prepared under different deposition temperatures (24 - 400 °C)	67
4.2	Thickness, Average, and Max transmission of ITO thin films prepared at different deposition temperatures under vacuum base pressure 10 <sup>-6</sup> torr	71
4.3	Grain size of different deposition temperatures under vacuum base pressure 10 <sup>-6</sup> torr before and after the annealing process	83
4.4	Sheet resistance of the prepared films at different deposition temperatures before and after the vacuum annealing process	88
4.5	Grain size of ITO film prepared under two different oxygen pressures at deposition temperature 400 °C	90
4.6	Sheet resistance of the prepared thin films under different oxygen pressure and vacuum base pressure 10 <sup>-6</sup> torr at deposition temperature 400 °C.	96
4.7	Grain size of ITO thin film prepared under vacuum base pressure 10 <sup>-4</sup> torr at deposition temperature 400 °C	98
4.8	Sheet resistance of the prepared thin films under vacuum base pressure 10 <sup>-4</sup> torr at deposition temperature 400 °C	103

# **LIST OF FIGURES**

No	Title	Page
1.1	Assumed parabolic band structure of undoped $In_2O_3$ and the effect of tin doping	4
2.1	Schematic diagram showing the chirped pulse amplification technique	25
2.2	Schematic layout of a grating-based stretcher, in this case, $L < f$ , which leads to a positive dispersion	28
2.3	Schematic layout of a grating-based compressor with negative dispersion	29
2.4	Schematic represents the laser target interaction processes	33
2.5	Schematic diagram illustrating direct and indirect transition from the valence to conduction band	38
2.6	Schematic diagram showing the moss–shift effect	40
2.7	Schematic diagram showing band gaps and luminescence properties of materials (a) Band diagram for conductors, semiconductors and insulators (b) Semiconductor photoluminescence: excitation of electron from VB to CB, formation of carrier charges, emission of photon	41
2.8	The effective mass approximation of the valence band and the conduction band	43
2.9	Density of states of materials (a) Macroscopic crystal (b) Quantum dots (QDs).	45
2.10	Density of states functions plotted against energy for bulk (3-D), quantum well (2-D), quantum wire (1-D) and quantum Dot (0-D)	46
2.11	Schematic diagram showing the Transmission Electron Microscope (TEM)	49
2.12	Schematic diagram showing the Scanning Electron Microscope (SEM)	51
2.13	Schematic of 4-point probe configuration	52
3.1	Schematic diagram of the Pulsed Laser Deposition Technique	54
3.2	Ultrafast Femtosecond Laser System	54
3.3	Ultrahigh Vacuum system	55
3.4	Panalytical – Empyrean, X-ray Diffractometer	56
3.5	V-570 UV/VIS/NIR Jasco Spectrophotometer	57

No	Title	Page
3.6	4-point probe, Model 1906 Computing Multimeter, Thurlby Thander	58
3.7	Transmission Electron Microscope (TEM) Jeol - JEM- 1011	59
3.8	Scanning Electron Microscope (SEM) Inspects FEI Philipes Company, Netherlands	60
3.9	Schematic diagram illustrating the determination of thin film thickness with Stylus Profiler	61
4.1	X-ray spectra of ITO thin films prepared at different deposition temperatures under vacuum base pressure 10 <sup>-6</sup> torr.	65
4.2	UV-Vis-NIR transmission spectra of ITO thin films prepared at different deposition temperatures under vacuum base pressure 10 <sup>-6</sup> torr	69
4.3	UV-Vis-NIR reflection spectra of ITO thin films prepared at different deposition temperatures under vacuum base pressure10 <sup>-6</sup> torr	70
4.4	Relation between absorption coefficient and wavelength for ITO thin films prepared at different deposition temperature under vacuum base pressure 10 <sup>-6</sup> torr	72
4.5	Schematic shows the grain boundary scattering for two different grain sizes	73
4.6	Variation of (αhυ) <sup>2</sup> with hυ for ITO thin films prepared at deposition temperature 200 °C under vacuum base pressure 10 <sup>-6</sup> torr	75
4.7	Variation of (αhυ) <sup>2</sup> with hυ for ITO thin films prepared at deposition temperature 300 °C under vacuum base pressure 10 <sup>-6</sup> torr	76
4.8	Variation of $(\alpha h \upsilon)^2$ with $h \upsilon$ for ITO thin films prepared at deposition temperature 400 °C under vacuum base pressure $10^{-6}$ torr	76
4.9	Schematic illustrates the conduction band filling due to heavily doped n-type doping	77
4.10	Sheet resistance of ITO thin films prepared under vacuum base pressure 10 <sup>-6</sup> torr at different deposition temperatures	79
4.11	X-ray spectra of ITO thin films prepared under vacuum base pressure 10 <sup>-6</sup> torr at deposition temperature 24 °C	81

No	Title	Page
4.12	X-ray spectra of ITO thin films after the annealing process for samples prepared under vacuum base pressure 10 <sup>-6</sup> torr under deposition temperatures (24, 100 and 400 °C)	82
4.13	UV-VIS-NIR transmission spectra of ITO thin films prepared under vacuum base pressure 10 <sup>-6</sup> torr at different deposition temperatures after the annealing process	84
4.14	Average transmission spectra of ITO thin films at the optical range (400-800) nm for the as-deposited and annealed thin films	85
4.15	Sheet resistance of ITO thin films prepared under vacuum base pressure10 <sup>-6</sup> torr at different deposition temperatures before and after the annealing process	87
4.16	X-ray spectra of ITO thin films prepared at deposition temperature 400 °C and oxygen pressure 1mtorr	90
4.17	X-ray spectra of ITO thin films prepared at deposition temperature 400 °C and oxygen pressure 10 mtorr	90
4.18	UV-VIS-NIR transmission spectra of ITO thin films prepared under different oxygen pressure at deposition temperature 400 °C	92
4.19	UV-VIS-NIR reflection spectra of ITO thin films prepared under different oxygen pressure at deposition temperature 400 °C	93
4.20	Variation of (αhυ) <sup>2</sup> with hυ for ITO thin films prepared under oxygen pressure 1 mtorr at deposition temperature 400 °C	94
4.21	Variation of (αhυ) <sup>2</sup> with hυ for ITO thin films prepared under oxygen pressure 10 mtorr at deposition temperature 400 °C	94
4.22	X-ray spectra of ITO thin films prepared under vacuum base pressure 10 <sup>-4</sup> torr at deposition temperature 400 °C	98
4.23	UV-VIS-NIR transmission spectrum of ITO thin film prepared under vacuum base pressure 10 <sup>-4</sup> torr at deposition temperature 400 °C	100
4.24	UV-VIS-NIR reflection spectrum of ITO thin film prepared under vacuum base pressure 10 <sup>-4</sup> torr at deposition temperature 400 °C	101
4.25	Variation of $(\alpha h \nu)^2$ with hv for ITO thin films prepared under vacuum base pressure $10^{-4}$ torr at deposition	102

No	Title	Page
	temperature 400 °C	
4.26	TEM image of ITO nanoparticle prepared at deposition temperature 200 °C under vacuum base pressure 10 <sup>-6</sup> torr	105
4.27	TEM image of ITO nanoparticle prepared at deposition temperature 300 °C under vacuum base pressure10 <sup>-6</sup> torr	106
4.28	TEM image of ITO nanoparticle prepared at deposition temperature 400 °C under vacuum base pressure10 <sup>-6</sup> torr	106
4.29	TEM image of ITO nanoparticle prepared at deposition temperature 400 °C and oxygen pressure 1mtorr	107
4.30	TEM image of ITO nanoparticle prepared at deposition temperature 400 °C and oxygen pressure 10 mtorr	107
4.31	TEM image of ITO nanoparticle prepared at deposition temperature 400 °C under vacuum base pressure 10 <sup>-4</sup> torr	108
4.32	SEM image of ITO thin film prepared at deposition temperature 24 °C and vacuum base pressure 10 <sup>-6</sup> torr	109
4.33	SEM image of ITO thin film prepared at deposition temperature 400 °C and vacuum base pressure 10 <sup>-6</sup> torr	109
4.34	SEM image of ITO thin film prepared at deposition temperature 24 °C after the annealing process	110
4.35	SEM image of ITO thin film prepared at deposition temperature 400 °C with oxygen pressure 1 mtorr	111
4.36	SEM image of ITO thin film prepared at deposition temperature 400 °C under vacuum base pressure 10 <sup>-4</sup> torr	111